PDR

EG&G Idaho, Inc.

(LTR) Report No. 10-2 Rev. C

Date: December 3, 1980

RELEASED BY LOFT CDCS

Report No. RE-I-80-004

USNRC-P394

NRC Research and Technical Assistance Report

INTERNAL TECHNICAL REPORT

Title: HYBRID COMPUTER SIMULATION OF THE LOFT PLANT

Organization: Simulation and Controls Analysis Section
Control Systems Design and Analysis Branch

NRC Research and Technical Assistance Report

Author: F. K. Hyer/C. D. Clayton

Checked By: J. W. Sielinsky

Approved By: G. R. Burdick

THIS REVISION COMPLETELY SUPERSEDES ALL PREVIOUS ISSUES TO LTR 10-2

~~THIS DOCUMENT HAS NOT RECEIVED PATENT CLEARANCE AND IS NOT TO BE TRANSMITTED TO THE PUBLIC DOMAIN~~

EG&G Idaho Inc

FORM EG&G-229 (Rev. 01-80)

LOFT TECHNICAL REPORT

Title HYBRID COMPUTER SIMULATION OF THE LOFT PLANT	LTR No. 10-2-Rev.
Author F. K. Hyer, C. D. Clayton	Released By LOFT CDCS
Performing Organization Control Systems Design and Analysis Branch	Date December 3, 1980
LOFT Review and Approval E. C. Anderson ...	Project System Engineer D. G. Satterwhite 11/28/80

RSB Mgr. PSB Mgr. ...CSB Mgr.

See incorporated DRR-L-4661

SUMMARY

A real-time hybrid computer simulation of the LOFT Facility has been developed to predict dynamic plant response to both normal and abnormal operating conditions. This report contains a detailed description of the analytical basis for the LOFT plant simulation. The current simulation contains the following plant components: reactor core, vessel, primary coolant loop, pressurizer, PPS, high pressure injection, steam generator, air-cooled condenser, condensate receiver, feedwater subcooler, steam generator water level control system and air-cooled condenser pressure control system.

DISPOSITION OF RECOMMENDATIONS

No disposition required.

NRC Research and Technical Assistance Report

THIS REVISION COMPLETELY SUPERSEDES ALL PREVIOUS ISSUES OF LTR 10-2.

TABLE OF CONTENTS

TABLE OF CONTENTS

NRC Research and Technical Assistance Report

FIGURES AND TABLES

NRC Research and Technical
Assistance Report

APPENDICES

1.0 INTRODUCTION

A hybrid computer simulation of the LOFT plant has been developed to analyze dynamic plant performance under both normal and abnormal operating conditions. The present simulation includes the major components of the primary system, secondary system and their associated control systems. Figure 1-1 is a schematic of the current simulation.

1.1 Reactor Core Model

The reactor core model simulates the heat generated within the boundaries of the core and the associated heat transfer from the fuel to the clad surface. Provisions are made for a percentage of the heat to be deposited directly into the coolant. No direct structural heating is simulated.

The power generated within the core is made up of neutron power and fission product decay power. The neutron power production is calculated using the standard point neutron kinetics equations with six delay groups. The reactivity effects of the moderator density, fuel doppler, boron concentration, and rod bank position are computed. The power generated by decay heat as a function of time is an input to the reactor core model.

The core heat transfer is modeled with a single fuel node and a single clad node separated by a variable width gas gap to obtain the basic transitory distribution of heat in the core material. The conductivity of fuel, gap, and clad are combined and used to calculate the heat transfer from the fuel to the clad. The heat transfer from the clad to the water flowing through the core is calculated by the loop flow model using the Dittus-Boelter forced-convection heat transfer correlation.

1.2 Primary Coolant Loop Model

The loop model performs the following functions:

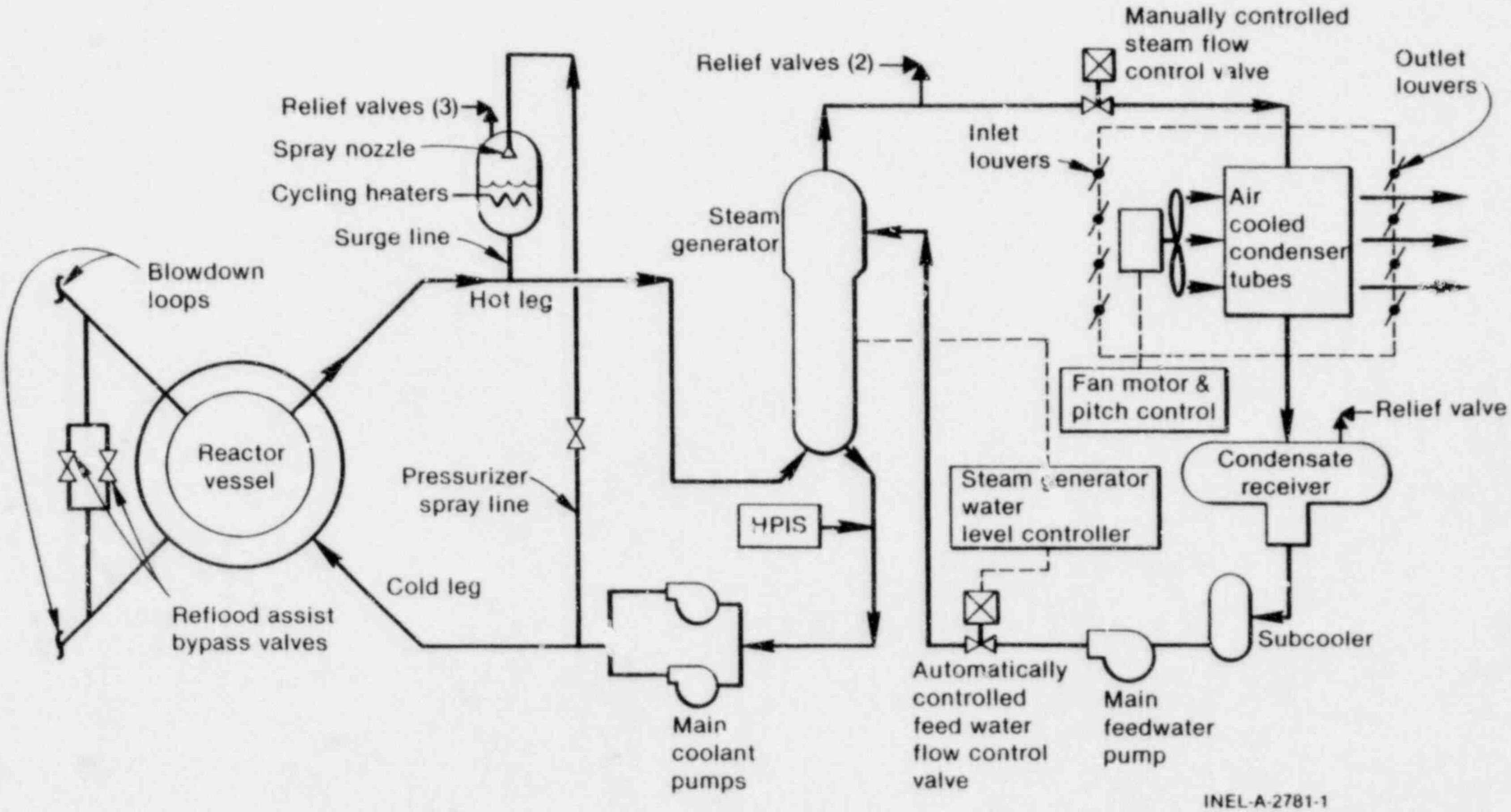


FIGURE 1-1

LOFT REACTOR PLANT SCHEMATIC DIAGRAM

1. Transpo ion of water around the primary loop at the flow rate speci d.

2. mputation of heat transfer to and from the primary water and computation of the corresponding change in water temperature.

3. Computation of the primary system surge rates based on the average water density change as well as computation of the enthalpy of the pressurizer insurge and spray.

Fifty-one control volumes are used in the loop flow model to simulate the actual primary system volume. The transportation of water around the loop is accomplished by moving a slug of water from one control volume, then mixing it with the next downstream volume. The size of the water slug moved is proportional to the system flow rate.

The heat transferred from clad surface to coolant and from primary coolant to the steam generator secondary is computed by the loop flow model. Also, the heat ansferred to or from the pipe and plenum walls is computed. The exterior surface of these walls is assumed to be perfectly insulated. Turbulent convective heat transfer is assumed. The heat transfer coefficient is computed as a function of primary coolant flow rate.

The surge flow to and from the pressurizer is obtained by computing the density change of the water contained in the primary system. The enthalpy of the pressurizer surge and spray is computed as a function of the water temperature at the appropriate locations in the loop.

1.3 Pressurizer Model

The pressurizer model simulates the pressurizing system of the primary loop. Simulation of the pressurizer is based on a computation of the thermodynamic conditions within the pressurizer. The steam can be either saturated or superheated. The water can be either saturated or subcooled.

The pressurizer control systems include the spray, the heaters, the power-operated relief valve, and the code relief valves. The response times of these systems is assumed to be negligible compared to the pressure rate of change.

1.4 Plant Protection System Model

The reactor plant protection system model compares power, temperature, flow and pressure measurements against corresponding scram setpoint values and initiates protective action if a setpoint is exceeded. The model of the PPS includes the time response of the associated instrumentation. By associating a time constant with a particular protective system, the model is capable of computing an "indicated" parameter value (as opposed to the actual value of this parameter). The indicated value is then used to actuate the PPS, thereby simulating actual plant operation.

1.5 Steam Generator and Associated Controller Models

The steam generator model simulates the secondary side of the steam generator. Energy, mass, and volume balances are computed to satisfy the saturation conditions assumed to exist in the homogeneous steam and water mixture inside the shroud. The subcooled condition of the water in the downcomer is also taken into account.

The water level control system which regulates the feedwater flow is simulated. This controller has steam flow, feedwater valve position and steam generator level as the controller inputs.

The steam flow control valve is simulated as a manually controlled valve except under certain conditions. The steam valve is automatically closed if the pressure is below a low-pressure setpoint in coincidence with a reactor trip. The steam valve is automatically opened if the pressure is above a high-pressure setpoint. Control system logic can be disabled to allow analysis of system response in the event of control logic or equipment failure.

1.6 Air-Cooled Condenser Simulation

The air-cooled condenser simulation includes the fluid flow and heat transfer processes occurring in the three air-cooled condenser bays. The water in the air-cooled condenser tubes is assumed to be saturated. The heat transfer is based on an empirical heat transfer correlation. A mass

PDP TAPE AND DISK

ID (tape only)	RAD 50 format. First 3 words contain file name and type (e.g. FILENMDAT).
TITLE	512 bytes of ASCII format. (1-72) Title, (452-455) Number of samples.
HEADINGS / HEADINGS / SUB HEADINGS / SUB HEADINGS	64-8 byte ASCII words in each record. Heading and subheading for 128 data channels (e.g., 'PCS PRES', 'PSIA').
DATA / …	128 floating point, 4 byte, numbers in each record. Each record contains 128 data channels corresponding to one time frame.
INPUT ARRAY / INPUT ARRAY	Same format as data records.
STATUS ARRAY	33 integer, 2 byte, words.

CDC TAPE FILE

ID	First word - file name and type. Second word - number of samples +3. Next 8 words - title.
HEADINGS AND SUB HEADINGS	256 ASCII words. Same order as on PDP tape.
TITLE	52 ASCII words. Same format as on PDP tape.
DATA / … / INPUT ARRAY / INPUT ARRAY	Copied in floating point format from PDP tape record for record.
STATUS ARRAY	50 integer words

FIGURE 1-2
DATA FILE FORMATS

balance is performed to determine the condensate in the tubes. A heat balance is performed between the air-side and the condensate side of the tubes. The air-side heat transfer coefficient is a function of the airflow across the finned tubes. Fan blade angle is used to determine the airflow. The fan blade pitch is adjusted to control condensate receiver pressure.

1.7 Condensate Receiver Simulation

The mass in the condensate receiver is separated into two phases, the liquid phase which can be subcooled or saturated and the gas phase which is either superheated or saturated. Separate mass and energy balances are computed for each phase. The pressure difference between the air-cooled condenser and condensate receiver is neglected.

1.8 Feedwater System Model

The feedwater system is divided into two nodes. The first node includes water from the condensate receiver to the subcooler outlet. The subcooler heat transfer coefficient is selected such that $10^{o}F$ subcooling is achieved during normal full power operations. The second node includes the feedwater pump, control valve and piping to return the water to the steam generator downcomer.

1.9 Program Documentation

A complete set of the analog wiring diagrams are included in Appendix H. Appendix K is a table of the Analog/Digital Interface and Appendix L contains a complete listing of the digital program used for the simulation. Appendix M lists all the parameters in the input array with their nominal values. Data generated by the simulation consists of the 128 data channels listed in Appendix O. The data is stored on PDP-11 disk or tape and can be converted to a CDC 7600 tape file for further use by the customer. Both these file structures are shown in Figure 1-2.

2.0 REACTOR CORE MODEL

The reactor core model simulates power generated by the reactor and is subdivided into four separate categories:

1. Reactor kinetics
2. Reactivity calculations
3. Decay heat generation
4. Core thermal model

The dynamic and steady-state behavior of the LOFT core is modeled using the point neutron kinetics equations with reactivity feedback from fuel temperature, moderator density, boron concentration, and control rod assembly position. Decay heat generation following reactor scram is included in the simulation.

2.1 Reactor Kinetics

Equations:

$$\frac{dP}{dt} = \frac{(\rho - \beta)}{\ell} P + \sum_{1}^{6} \lambda_i C_i \qquad (2\text{-}1)$$

$$\frac{dC_i}{dt} = \frac{\beta_i}{\ell} P - \lambda_i C_i \; ; \quad i = 1, 2, \ldots 6 \qquad (2\text{-}2)$$

Where:

t = Time (seconds)
P = Reactor power
C_i = Concentration of the i-th group of delayed neutrons
β = Effective fraction of delayed neutrons
β_i = Delayed fraction of the i-th group of neutrons
ρ = Reactivity
λ_i = Decay constant for the i-th neutron group (sec^{-1})
ℓ = Prompt neutron generation time (seconds)

Let

$$f_i = \frac{\beta_i}{\beta}, \quad r = \frac{\rho}{\beta}, \quad \psi_i = \frac{\ell}{\beta} C_i$$

Then equations 2-1 and 2-2 are expressed as:

$$\frac{dP}{dt} = (\beta/\ell)\left\{(r-1)\,P + \sum_{1}^{6} \lambda_i \psi_i\right\} \qquad (2\text{-}3)$$

$$\frac{d\psi_i}{dt} = f_i P - \lambda_i\,\psi_i;\ i = 1, 2, \ldots 6 \qquad (2\text{-}4)$$

The analog circuitry shown in Appendix H, Figure H-1, is used to solve equations 2-3 and 2-4. Reactivity, in dollars, is transmitted to the analog console by two digital/analog channels to maintain adequate resolution during steady-state and transient conditions. The values of the parameters used in the kinetics circuitry are listed in Table 2-1.

The circuit is initialized by the initialization subroutine (INIT), which sets ψ_i equal to $(f_i/\lambda_i)P$ for each delayed neutron group. Hand-set potentiometer P149 is provided to balance out small accumulated errors. The circuit integrators are held at the initial condition values until logic switch 011 is returned to its mid position.

For simulations where no change in reactor power is desired, potentiometer P140 and switch 051 are provided to supply a constant power signal to the core thermal circuitry.

The down position of logic switch 011 is used to reset amplifier 053 if an overload condition should arise during initialization.

Table 2-1

Reactor Kinetics Parameters

Neutron Generation Time ℓ 21.9×10^{-6} sec. (note 1)

Delayed Neutron Fraction β .007259 (reference 1)

Delayed Neutron Group	Fraction β_i/β (reference 2)	Decay Constant λ_i (sec^{-1}) (reference 2)
1	.038	.0127
2	.213	.0317
3	.188	.115
4	.407	.311
5	.128	1.40
6	.026	3.87

Note 1. The value for ℓ given in Reference 1 is 19.52×10^{-6}. The value listed in this table is given because the hybrid simulation uses a .03 μf capacitor to simulate $\ell/\beta \times 10$.

2.2 Reactivity Calculations

The simulation computes the total reactivity in dollars as a sum of the following:

2.2.1 Moderator Reactivity

$$\rho_m = \alpha_t \cdot \begin{pmatrix} \text{average density} \\ \text{of core water} \\ \text{(nodes 1-4)} \end{pmatrix}$$

α_t is specified in the input array in units of $\$/(lbm/ft^3)$

2.2.2 Doppler Reactivity

$$\rho_f = \alpha_f \cdot \begin{pmatrix} \text{fuel} \\ \text{temperature} \end{pmatrix}$$

α_f is specified in the input array in units of $\$/^{o}F$.

2.2.3 Boron Reactivity

$$\rho_B = \alpha_B \cdot \begin{pmatrix} \text{Average core} \\ \text{boron concentration} \\ \text{(nodes 1-4)} \end{pmatrix}$$

α_B is specified in the input array in units of \$/ppm.

2.2.4 Control Rod Reactivity

Control rods in the LOFT plant simulation are modeled as an integral worth rod bank. Three methods of rod motion are provided:

2.2.4.1 Control rod shims can be made from the analog control panel. Reactivity is added or subtracted at a rate of .01\$/sec. No change is made to the rod height.

2.2.4.2 A control rod ramp can be simulated by specifying the total change of reactivity and the total time interval for this reactivity change as input parameters. The ramp is automatically stopped when rod motion caused by a reactor scram is initiated. The indicated rod height remains constant until the scram occurs so that the scram is always initiated from 54 inches.

2.2.4.3 Reactor scrams are simulated by a subroutine which performs a table look up of control rod position and reactivity versus time. Reactivity versus time is specified in the input array. Indicated control rod height versus time after scram is given in Table 2-2. This table is based on calculated rod drop times not plant data.

Table 2-2

Control Rod Height Versus Time After Scram

Time (seconds)	CRDM Position (inches)
0.000	54.0
0.075	53.9
0.160	52.8
0.245	51.4
0.331	49.5
0.417	47.2
0.503	43.6
0.589	39.3
0.672	34.6
0.753	29.2
0.830	23.7
0.905	19.7
0.977	16.2
1.050	13.5
1.127	11.1
1.211	9.0
1.265	8.0
1.336	7.0
1.403	5.9
1.514	4.1
1.590	3.0
1.910	0.0

2.3 Decay Heat Generation

The simulation uses the simplified method given in section 3.6 of Reference 3 for determining an upper bound on the decay heat fraction. The model assumes an infinite constant power history and neglects the effect of fission product neutron capture.

Equation:

$$P_d(t)/P_{max} = 1.02\ F(t,\infty)/Q \qquad (2-5)$$

Where:

$P_d(t)$ = Total decay heat power at time t seconds after shutdown.

P_{max} = Initial steady state power.

$F(t,\infty)$ = Decay heat per fission t seconds after shutdown. These values are given in Table 4 of Reference 3.

Q = Total recoverable energy associated with one fission of U^{235}. Equals 199.9 MeV (Reference 4).

Table 2-3 lists the values of P_d/P_{max} which are used by the simulation. Decay heat values are obtained by interpolating the logarithm of the time after shutdown into this table. Total reactor power is found by summing the neutron power and decay heat power. (See Appendix H, Figure H-1.)

Table 2-3

Decay Heat Power

Time (seconds)	log (t)	$F(t,\infty)$	P_d/P_{max}
.1	-1	13.18*	.06725
1	0	12.31	.06281
10	1	9.494	.04844
100	2	6.198	.03163
[illegible]	3	3.796	.01937

*Calculated using Reference 3, Table 7, for t = 0.

$$F(0,\infty) = \sum_{1}^{23} \alpha_i/\lambda_i$$

2.4 Core Thermal Model

The transfer of energy between the fuel and the cladding is modeled by the following equations which assume a uniform distribution of power and temperature and constant heat capacities.

$$(MC_p)_f \frac{dT_f}{dt} = f \cdot P - K_{fc} (T_f - T_c) \qquad (2\text{-}6)$$

$$(MC_p)_c \frac{dT_c}{dt} = K_{fc}(T_f - T_c) - \dot{Q}_{cp} \qquad (2\text{-}7)$$

Where:

T_f = average fuel temperature (^oF)

T_c = average cladding temperature (^oF)

P = Total reactor power (Btu/sec)

f = Fraction of the power generated in the fuel

$(MC_p)_f$ = Heat capacity of the fuel (BTU/^oF)

K_{fc} = Overall fuel to cladding heat transfer coefficient (Btu/sec-^oF)

$\dot{Q}_{cp}$ = Heat transferred from the cladding to the primary coolant (Btu/sec)

$(MC_p)_c$ = Heat capacity of the cladding (Btu/^oF)

The overall heat transfer coefficient, K_{fc}, is a combination of the conductance of the fuel, gap and clad.

$$\frac{1}{K_{fc}} = \frac{1}{K_f\,(T_f)} + \frac{1}{K_{gap}(T_f, T_c)} + \frac{1}{K_c(T_c)} \qquad (2\text{-}8)$$

The value of $K_{fc}(T_f, T_c)$ is approximated by the following family of straight lines:

$$K_{fc} = K_o(T_f) + S_1(T_f) * T_c \qquad (2\text{-}9)$$

Tables 2-4 and 2-5 list the values of the coefficients used by the simulation model. These coefficients are based on values obtained from Reference 14. Appendix H, Figure H-2, shows the analog circuitry used to solve equations 2-6 and 2-7.

Table 2-4

Core Thermal Coefficients

Parameter	Source	Value	Reference
f	$1 - \begin{pmatrix}\text{core direct}\\ \text{heat}\\ .0187\end{pmatrix} - \begin{pmatrix}\text{core bypass}\\ \text{direct heat}\\ .0303\end{pmatrix} =$	.9510	16 (Table III)
M_f	(2.505 lbm/rod) x (1300 rods) =	3256.6 lbm	5 (page II-2-27)
M_c	(0.514 lbm/rod) x (1300 rods) x $\frac{\text{66" active length}}{\text{69.1875 clad length}}$	637.4 lbm	6 (Table V)
$(C_p)_f$	Representative value for fuel temperatures between $800^{o}F$ and $1600^{o}F$	.07646 Btu/lbm ^{o}F	6 (Figure 75)
$(C_p)_c$	Representative for clad wall temperatures less than $1500^{o}F$	.07671 Btu/lbm ^{o}F	6 (Table V)

Table 2-5

Core Heat Transfer Coefficients

$$K_{fc} = K_o(T_f) + S_1(T_f) * T_c$$

T_f (°F)	K_o	S_1
450	50.510	.007525
750	52.171	.005607
1050	53.097	.004100
1350	53.707	.002879
1650	54.339	.001782
1950	55.286	.000732
2250	56.869	-.000429
2550	59.474	-.001889

3.0 PRIMARY COOLANT LOOP SIMULATION

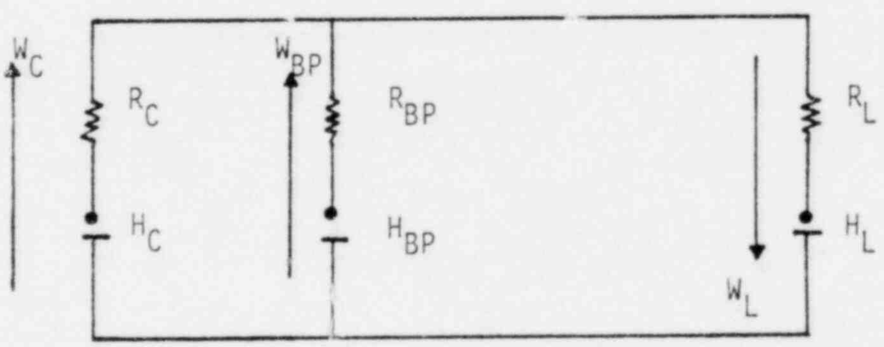
The loop flow model simulates the heat transfer process in a single closed loop. A block diagram of the primary loop model and its interconnections with the other plant systems is shown in Figure 3-1. Primary coolant values of temperature, pressure, and flow are updated once each time step.

3.1 Primary Coolant Flow

Primary coolant flow is calculated in units of cubic feet per second. It is a combination of forced flow from the primary coolant pumps and natural circulation. The initial total flow value is specified in the input array in units of lbm/hr. The flows in various regions of the primary system are related as shown in Table 3-2.

For simulating loss of flow accidents, such as pump coastdowns and reflood assist bypass valve openings, a forced flow versus time curve is entered in the input array. These flow curves are obtained from the SICLOPS program (Reference 8) and from actual plant data. The time function of forced flow can be activated automatically at the start of the transient or it can be controlled manually using logic switch 010.

3.1.1 Natural circulation is calculated using the following model:



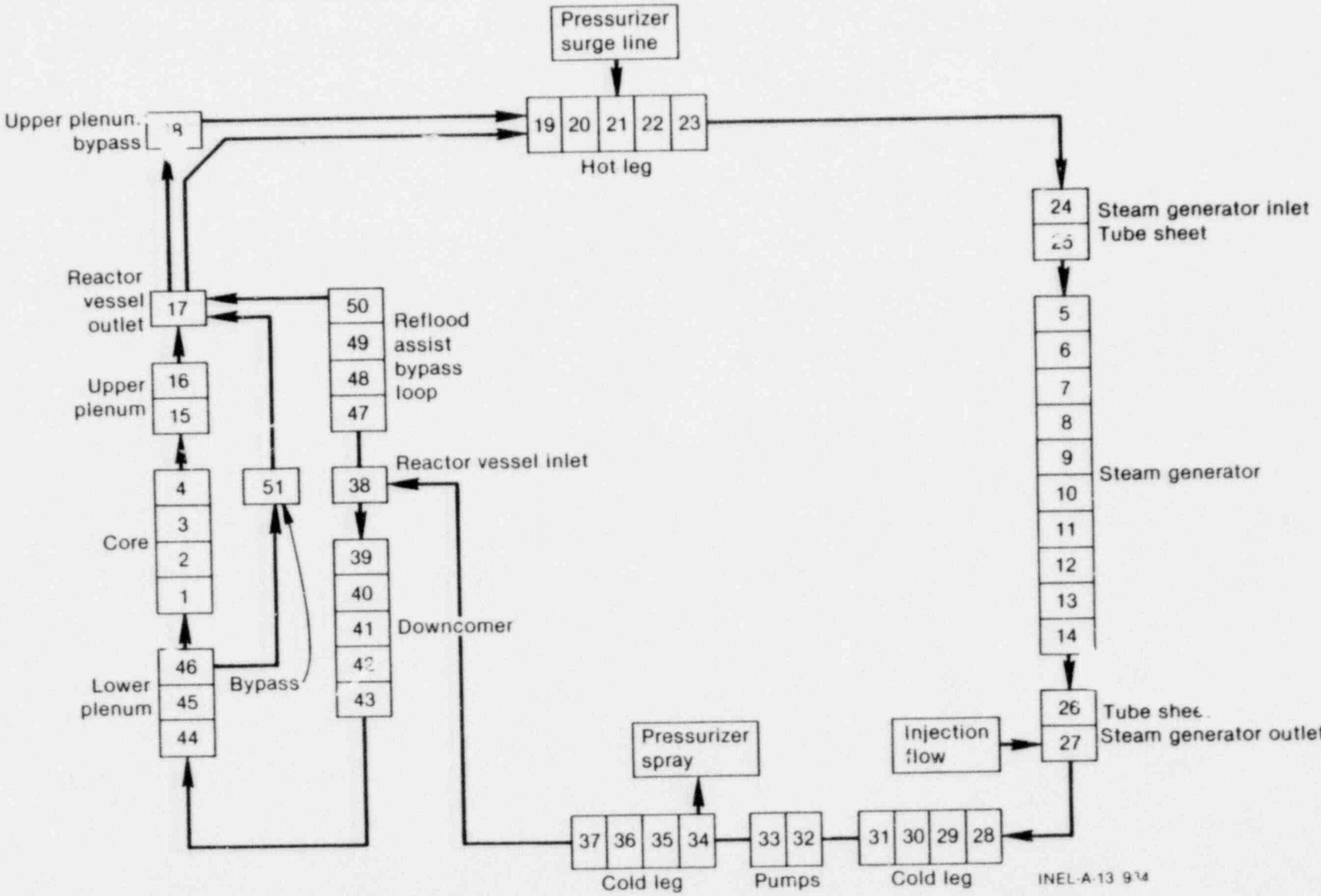


FIGURE 3-1

PRIMARY LOOP MODEL

TABLE 3-2

PRIMARY COOLANT FLOW RELATIONSHIPS

Location	Nodes	Value
Core	1-4, 15, 16	95% of vessel forced flow plus core natural circulation flow
Core bypass	51	5% of vessel forced flow plus bypass natural circulation flow
Vessel	39-46	Variable forced flow plus core and bypass natural circulation flows
Loop	5-14, 17, 19-38	Sum of vessel and reflood flows
Upper plenum bypass	18	20% of vessel forced flow
Reflood assist bypass	47-50	Variable with time

where:

W = flow rate (cu ft/sec)

R = flow resistance

H = gravity head (psid)

and subscripts

C = core

BP = core bypass

L = loop

During normal operation the forced flow is much greater than the natural circulation flow. Under these conditions the natural circulation is added to the forced flow using a perturbation technique. That is:

$$W_{TOTAL} = W_{FORCE} + W_{NC}; \quad W_{NC} = \frac{dW}{dH} H \tag{3-1}$$

From the head-flow relationship, $H = kW^2$,

$$\frac{dW}{dH} = \frac{1}{2kW} \tag{3-2}$$

k is the flow resistance constant calculated in Appendix A.2 and given in Table 3-3.

W is approximated as follows:

$$W = W_o F(t) \tag{3-3}$$

W_o = nominal flow rate given in Table 3-3

F(t) = forced flow fraction, normalized to the initial value of the forced component of flow

By combining equations 3-1, 3-2, and 3-3, the natural circulation contribution to the flow is:

$$W_{NC} = \frac{1}{R} H \tag{3-4}$$

$$R = 2kW_o F(t) \tag{3-5}$$

When forced flow is reduced such that the perturbation method is no longer applicable, natural circulation flow is assumed to be a linear function of the gravity head. The total flow is formed as the sum of the forced and natural circulation flow components.

$$W_{NC} = \frac{1}{R_o} H \tag{3-6}$$

$$R_o = 2kW_o f_o \tag{3-7}$$

The value of k is the same as was used in equation 3-5. The f_o factor is specified in the input array. In order to maintain continuity during a loss of flow transient, the transition between the perturbation method and the linear head loss method is made when $F(t) = f_o$.

The solution of the flow network given above is obtained by using either equation 3-4 or 3-6 to determine the head loss terms.

$$H_L - H_C - W_C R_C - W_L R_L = 0 \tag{3-8}$$

$$H_{BP} - H_C - W_C R_C + W_{BP} R_{BP} = 0 \tag{3-9}$$

$$W_L = W_C + W_{BP} \tag{3-10}$$

The simultaneous solution of these equations for W_C, W_L and W_{BP} is given in Appendix A.

Natural circulation gravity heads are computed by summing the products of the density and the heights of each vertical node in each flow loop. The node heights are shown in Figure 3-4 and listed in Table 3-5.

TABLE 3-3

FLOW CONSTANTS

Symbol	Parameter	Value
k_C	Core flow resistance	.05483 psi/(ft^3/sec)^2
k_{BP}	Core bypass flow resistance	19.7935 psi/(ft^3/sec)^2
k_L	Primary loop flow resistance	.08852 psi/(ft^3/sec)^2
W_o	Nominal flow rate	
	Core	19 ft^3/sec
	Core bypass	1 ft^3/sec
	Primary loop	20 ft^3/sec

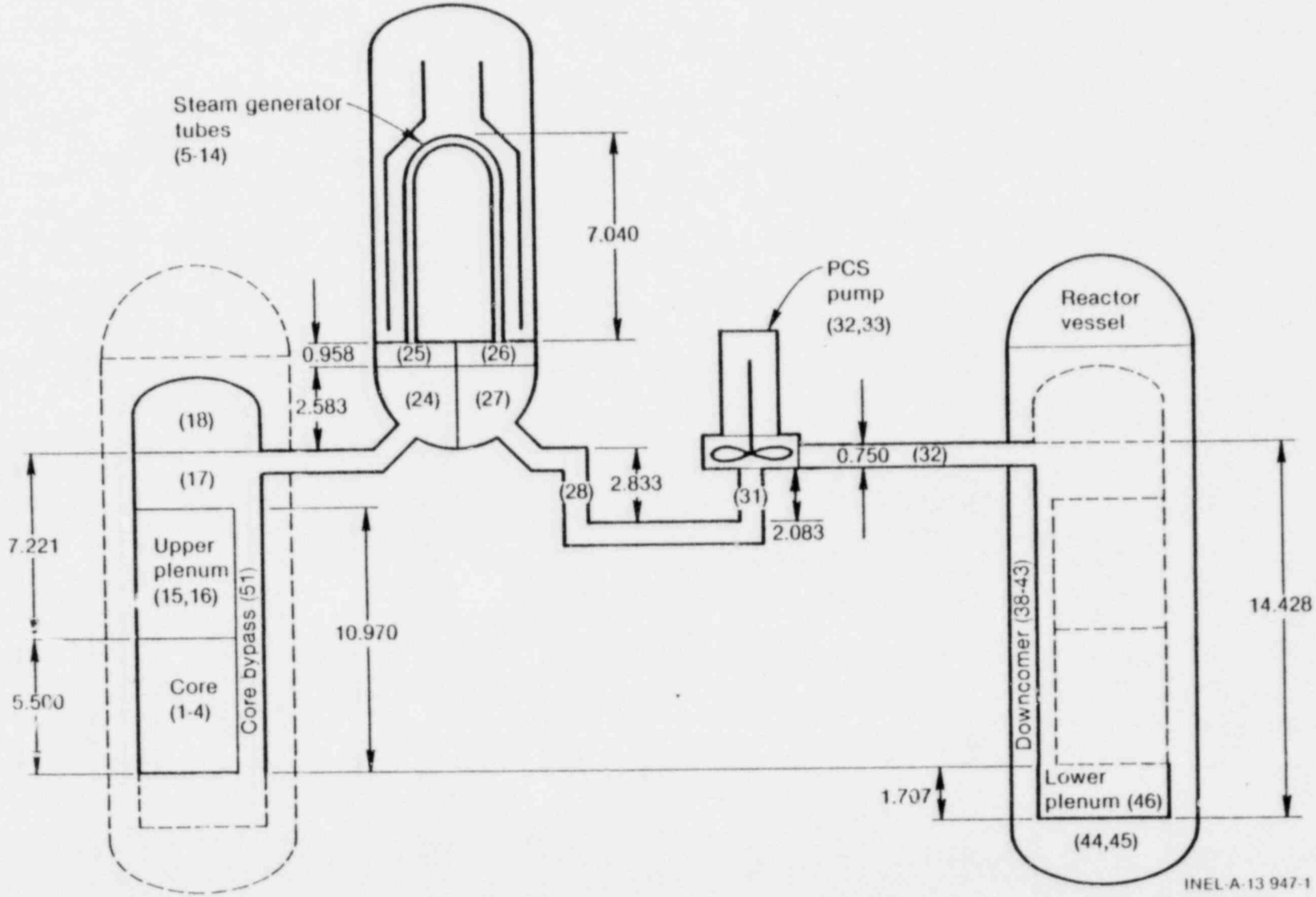


FIGURE 3-4

NATURAL CIRCULATION NODE HEIGHTS

3.2 Primary Coolant Density

The density in each node is computed with the following empirical equation:

$$\rho = 41.58 + .0890337\ T - 1.44741 \times 10^{-4}\ T^2$$

$$+ (P - 2200)(.00025 + 3.89 \times 10^{-7} \exp(.01287\ T_{ave})) \qquad (3\text{-}11)$$

Where T is the node temperature in $^{\circ}F$, T_{ave} is the average temperature of nodes 25 and 26, and P is loop pressure in psia.

See Appendix B for a derivation of this equation. The operating range for this approximation is 400 to 650°F, and 1400 to 3000 psia.

3.3 Primary Coolant Heat Transfer

The heat transfer model assumes forced convection, with turbulent flow and subcooled water. The heat transferred into each node is determined by the following equation:

$$\dot{Q} = UA\ (T_{WALL} - T_{NODE}) + \dot{Q}_{DIR} \qquad (3\text{-}12)$$

The overall heat transfer coefficient, UA, is formed by combining the heat transfer coefficient of the film, h_{DB}, and the conductivity of the wall surface, K, as given in the following equation:

$$\frac{1}{UA} = \frac{1}{K} + \frac{1}{H_{DB}}\ ; \quad H_{DB} = h_{DB}A \qquad (3\text{-}13)$$

H_{DB} is the Dittus-Boelter film coefficient which is dependent on the fluid velocity as follows:

$$H_{DB} = H_{ref}\left(\frac{\dot{V}}{\dot{V}_{ref}}\right)^{.8} \text{ (Reference 7, Section 6.114)} \qquad (3\text{-}14)$$

$$\dot{V}_{ref} = 30.764\ ft^3/sec$$

The values of H_{ref} and K for each node are listed in Table 3-5.

In the reactor core, T_{WALL} is the cladding temperature which is calculated in the analog core thermal model.

For the steam generator nodes, T_{WALL} is the secondary saturation temperature and the thermal conductivity, k, includes a boiling heat transfer coefficient for the secondary side of the tubes. The effect of tube dry-out is modeled by reducing the overall heat transfer coefficient when the steam quality surrounding the tubes is less than X_{DNB} according to the following equation:

$$UA' = \text{[illegible]} \qquad (3\text{-}15)$$

X_{DNB} is specified in the input array. The dryout factor, f, is discussed in section 6.1.6.

$\dot{Q}_{DIR}$ is the heat deposited by radiation directly into the core and core bypass nodes. See Table 2-4 for the fraction of reactor power that is included in $\dot{Q}_{DIR}$.

3.4 Primary Coolant Temperature

Primary coolant temperatures are updated using the following equations:

$$T_{NEW} = T_{OLD} + \dot{Q}\, \Delta t / mc_p \qquad (3\text{-}16)$$

$$T_{NODE} = T_{NEW} + \frac{\dot{V}\, \Delta t}{V} (T_{IN} - T_{NEW}) \qquad (3\text{-}17)$$

T_{NEW} = node temperature resulting from heat transfer

T_{OLD} = node temperature from previous time step

$\dot{Q}\Delta t$ = total heat transferred into the node during the step. $\dot{Q}$ for the core and core bypass nodes includes direct heat.

mc_p = heat capacity of fluid and structure (see Table 3-5)

T_{NODE} = updated node temperature resulting from the ideal mixing of T_{NEW} and T_{IN}

$\dot{V}$ = fluid volumetric flow in the node (ft^3/sec)

Δt = time step duration specified in the input array

V = node volume (see Table 3-5)

T_{IN} = T_{NEW} of the upstream node as shown in Figure 3-1. Reverse flow is only modeled for the core bypass node (51).

3.5 Primary Coolant Piping Wall Temperature

The wall temperature of each node, except the core and steam generator nodes, is updated as follows:

$$T_{WALL} = T'_{WALL} - \dot{Q}\Delta T/mc_p \qquad (3\text{-}18)$$

T'_{WALL} = wall temperature during the previous time step

$\dot{Q}\Delta t$ = total heat transferred into the node during the time step

mc_p = heat capacity of the wall (see Table 3-5)

3.6 Primary Coolant Makeup and Drain

Injection and let down from the primary coolant system is controlled from the analog console. When Logic Switch 110 is UP injection occurs. When Logic Switch 111 is UP primary coolant is drained from the loop. Injection and drain rates are specified in the input array in gpm. The program assumes a density of 62.38 lbm/ft^3 (60^oF) for both drain and makeup. This allows a feed and bleed with no net mass change to be simulated by specifying the same gpm value for both rates.

Injection flow is added to node 27 which simulates injection via the purification system. A temperature difference of 100^oF is used to update the node temperature.

3.7 Primary Coolant Boron Concentration

Primary coolant boron concentration in each node is maintained using the following ideal mixing equation:

$$C = C_{OLD} + \frac{\dot{V}\Delta t}{V} (C_{IN} - C_{OLD}) \qquad (3\text{-}19)$$

C_{OLD} = Boron concentration during previous time step

$\dot{V}\Delta t$ = total volume of fluid entering node during the time step

C_{IN} = boron concentration of fluid entering the node

In addition to boron mixing with upstream nodes, mixing due to injection flow and pressurizer surge flow is also included. Reverse flow in the core bypass node (51) is accounted for.

The initial loop and pressurizer boron concentrations are specified in the input array. Pressurizer boron concentration can be set equal to the loop concentration (node 21) by selecting DAP switch 10 to the ON position.

The boron concentration of the injection flow is controlled by DAP switch 2. In the OFF position the injection concentration is zero (demineralized water). With the switch in the ON position the injection concentration is as specified in the input array.

TABLE 3-5

PRIMARY COOLANT PARAMETER SUMMARY

NODE	LOCATION	1 WATER VOLUME (FT^3)	2 HEAT CAPACITY (Btu/^{0}F)	3 HEAT CAPC. WALL (Btu/^{0}F)	4 FILM HEAT TRANSFER (Btu/Sec ^{0}F)	5 STRUCTURE HEAT TRANS (Btu/Sec ^{0}F)	6 HEIGHT (FT)
1-4	Core	2.54	151.00	NA	342.55	Note 6	1.375
5-14	SG Tubes	2.43	144.59	NA	588.64	Note 6	±1.408
15-16	Upper PLN.	6.87	536.25	61.65	10.80	4.37	2.735
17	UP PLN. Out	7.40	526.41	62.49	11.29	4.57	-1.751
18	UP PLN. ..P.	12.30	1333.94	237.75	63.15	2.45	NA
19-23	Hot Leg	2.76	168.93	83.28	23.84	1.56	0
24	SG Inlet	11.84	725.62	143.66	20.64	1.14	-2.583
25	SG Tube SH	1.56	95.57	242.92	378.15	49.31	-0.958
26	SG Tube SH	1.56	91.30	242.92	384.81	49.31	0.958
27	SG Outlet	11.84	693.21	143.66	21.00	1.14	2.583
28-31	Cold Leg	3.00	175.6[illegible]	90.00	25.90	1.68	2.833,0, 0,-2.083
32-33	Pumps	3.50	204.84	124.46	40.99	3.11	-0.75, 0
34-37	Cold Leg	2.86	167.59	94.14	31.14	1.74	0
38	RV Inlet	9.65	564.85	1588.40	165.89	17.51	1.858
39-43	DWNCMR	5.07	296.99	1057.87	131.75	12.06	2.514
44-46	Lower PLN	7.91	462.76	115.68	3.15	1.19	0, 0, -1.707
47	RABV	3.28	195.21	101.03	29.74	1.87	NA
48		7.64	455.10	207.29	137.94	7.83	NA
49		6.69	398.59	181.13	120.81	6.85	NA
50		3.28	195.21	101.03	29.74	1.87	NA
51	Core Bypass	0.49	29.18	1185.56	11657.53	48.77	10.97

NOTES

1. See Appendix C for calculation details of the listed values.

2.

Column Number	Program Array Names
1	V
2	HC
3	HCWAL
4	HREF
5	CK
6	Z

3. The heat capacity, column 2, is computed as: $(\rho V c_p)_{water} + (\rho V c_p)_{structure}$.

Nodes	c_p (Btu/lbm^{0}F)	ρ lbm/ft^3	Assumed Conditions
26-46	1.2577	46.5333	2250 psia, 555^{0}F
1-14, 47-51	1.3191	45.1467	2250 psia, 575^{0}F
15-25	1.4058	43.5777	2250 psia, 595^{0}F
structure	0.11	495	stainless steel

4. The film heat transfer, column 4, equals the film heat transfer coefficient, h_{DB}, times the surface area. The h_{DB} calculation uses a flow rate of 30.7640 ft^3/sec.

5. The structure heat transfer, column 5, in general is calculated using the formula kA/L. Where k is the conductivity coefficient, A is the surface area and L is 1/4 the thickness of the slab.

6. The structure heat transfer coefficients in the core and steam generator (nodes 1-14) are specified in the input array. This allows for adjustments to establish fuel temperature and steam generator pressure at the desired initial conditions.

4.0 PRESSURIZER MODEL

The pressurizer model is divided into two separate thermodynamic systems corresponding to the steam and water regions. Simulation of the pressurizer response is based upon mass and energy balances in both regions.

4.1 Pressurizer Pressure and Level

The pressure existing in the pressurizer is computed from a volume balance performed by the analog circuit shown in Appendix H, Figure H-4. This circuit performs a continuous iteration on the following equation:

$$V = M_W \nu_W(h_W, P) + M_G \nu_G(h_G, P) \tag{4-1}$$

Where V = Total volume of the pressurizer 34.76 cu ft

M_W = mass in water region

h_W = average specific enthalpy of the water region

M_G = mass in steam region

h_G = average specific enthalpy of the steam region

P = pressurizer pressure

$\nu(h,P)$ = average specific volume of the water or steam regions. These are computed as functions of specific enthalpy and pressure in the AD-10. See figures and tables in Appendix D.

At each time step the mass and energy terms are updated as follows:

$$M_W = M_W' - \Delta M_{SUR} + \Delta M_{SPR} - \Delta M_{BOIL/COND} \tag{4-2}$$

$$H_W = H_W' - \Delta H_{BOIL/COND} + \Delta H_{HTR} + h_f \Delta M_{SPR} - h_{SUR} \Delta M_{SUR} - \Delta H_{AMB} + J V_W \Delta P \tag{4-3}$$

$$M_G = M_G' - \Delta M_{RV} + \Delta M_{BOIL/COND} \tag{4-4}$$

$$H_G = H_G' - h_g \Delta M_{RV} - (h_f - h_{SPR}) \Delta M_{SPR} - \Delta H_{AMB} + \Delta H_{BOIL/COND} + JV_G \Delta P \tag{4-5}$$

$$h_W = H_W/M_W \quad (4\text{-}6)$$

$$h_G = H_G/M_G \quad (4\text{-}7)$$

Where

M_W, H_W, M_G, H_G = mass and enthalpy in the water and steam regions. Primes indicate values from the previous time step.

h_W, h_G = specific enthalpy of the water and steam regions

ΔM_{SUR} = amount of mass leaving the water region via the surge line

ΔM_{SPR} = amount of mass added as spray

$\Delta M_{BOIL/COND}$ = amount of mass transferred between the water and steam regions as boil off or condensation

$\Delta H_{BOIL/COND}$ = amount of energy transferred between the water and steam regions by boiling or condensation

ΔH_{HTR} = energy added to the water by the heaters

h_f = specific enthalpy of water at saturation

h_{SUR} = specific enthalpy of the surge line fluid

ΔH_{AMB} = ambient heat loss term

J = conversion factor = 0.1851 Btu/(cu ft psi)

ΔM_{RV} = mass lost via the relief valves

ΔP = change in pressurizer pressure during previous time step

h_{SPR} = specific enthalpy of the spray fluid

V_W, V_G = volume of water and steam regions

Pressurizer level is computed from the following equation:

$$\underset{(\text{in})}{\text{Level}} = \underset{(\text{cu ft})}{V_W} \times \underset{(\text{in/ cu ft})}{2.02} \qquad (4\text{-}8)$$

where V_W is the volume of the water region obtained from ADC 100.

Pressurizer initialization is accomplished by specifying the desired pressure and liquid level in the input array. The INIT subroutine computes values for the mass and enthalpy of the steam and water regions and initializes the analog circuitry. Handset pot P150 is provided to allow fine adjustment of the pressure.

Loop pressure is computed using the following equation:

$$P_L = P_p - K \dot{V} |\dot{V}| \qquad (4\text{-}9)$$

Where

P_L = Loop pressure

P_p = Pressurizer pressure

$\dot{V}$ = Surge line volumetric flow rate from the pressurizer to the loop (cu ft/sec)

K = surge line resistance, specified as an input parameter

4.2 Surge Flow

The mass flow in the surge line is generated by thermal expansion or compression of the primary loop coolant, and makeup, drain, and spray flows.

The primary loop thermal expansion/compression term is computed by comparing the total loop mass (sum of the volume of each node times density) with the mass from the previous time step. This mass difference is added or subtracted from the surge flow. Due to the incremental nature of the numerical procedure a small but finite amount of "noise" exists in the computation of loop density. In order to eliminate cooldown of the pressurizer water caused by these small density changes, a threshold value is specified in the input array. If the mass difference is smaller than the threshold value, it is not used in the current step but is included with the mass difference of the next time step.

The spray flow term is added to the surge flow to account for the spray mass which is lost from the primary loop mass and is made up by pressurizer outsurge.

Makeup and drain flows are explained in Section 3.6.

The enthalpy and specific volume of the surge line fluid depends upon the direction of the flow. For outsurges they equal the values of the pressurizer water. For insurges the specific volume equals the inverse of the hot leg density, node 21, and the enthalpy is approximated using the following equation:

$$h = 1.25\,T - 140 \qquad (4\text{-}10)$$

where T is the temperature (^{o}F) of node 21. See Appendix D, Figure D-13 for a comparison of this approximation and steam table data.

4.3 Spray

Automatic spray flow is initiated whenever pressurizer pressure increases to the spray setpoint (specified in the input array). The spray reset point is 25 psi below the setpoint. Automatic spray can be inhibited using analog DAP switch 15. Spray can be manually initiated using switch 13.

Spray flow is calculated using the following formula:

$$\Delta M_{SP} = W_o\left(\frac{\dot{V}}{22}\right) \times \rho_{34} \times \Delta t \qquad (4\text{-}11)$$

Where

ΔM_{SP} = Mass transfer via the sprayline in one time step

$\frac{\dot{V}}{22}$ = Loop flow rate ratio - accounts for spray flow changes caused by PCS pump speed

ρ_{34} = Density of cold leg node 34

Δt = Duration of the time step

W_o = Nominal spray flow when automatic spray is on, otherwise the continuous spray flow. Both flow values are specified in the input array.

Spray flow enthalpy is approximated using equation 4-10, where T is the temperature of node 34. The spray is assumed to absorb enough energy from the steam that it enters the water at saturation temperature. The energy difference between the spray enthalpy and saturated water enthalpy is subtracted from the steam region. Because the spray flow is included in the surge flow, the net effect of spray on the water region is no change to the mass and an energy addition equal to $(h_f - h_W) \cdot \Delta M_{SPR}$. Equation 4-13 is used to approximate saturation enthalpy.

4.4 Pressurizer Heaters

Two banks of heaters are simulated. Separate pressure setpoints are specified for each bank in the input array. The reset dead bands are 30 psi for the cycling heaters and 15 psi for the backup heaters. Each bank supplies 24 KW to the water region when activated. DAP switch 1 can be used to override the heater logic.

As an aid in establishing plant conditions, additional energy can be added to the pressurizer. When DAP switch 6 is in the down position, a variable amount of power, specified in the input array in Btu/sec, is added to the pressurizer.

4.5 Relief Valves

The operation of the pressurizer steam relief valves are simulated by subtracting mass and energy from the steam region. The mass flow rate of the power-operated valve is 7200 lbm/hr and the combined flow from both safety relief valves is 45,232 lbm/hr (reference 6, Table XII). The setpoints and reset dead bands are specified in the input array with both safety relief valves sharing the same setpoints.

The power-operated relief valve can be controlled at the console using DAP switch 14 to open the valve and switch 15 to override the automatic operation.

4.6 Pressurizer Ambient Losses

Ambient losses in the pressurizer are divided equally between the steam and water regions. The heat transfer coefficient UA, is specified in the input array. The total heat lost is calculated as follows:

$$\Delta H_{AMB} = UA\,(T_{PZR} - T_{AMB}) \qquad (4\text{-}12)$$

where

T_{PRZ} = Pressurizer Temperature (approximated by h_f)

T_{AMB} = Ambient Temperature $100^{o}F$.

4.7 Pressurizer Boil-Off and Condensation

In addition to calculating the pressurizer pressure, the analog circuitry shown in Appendix H, Figure H-4, also determines the steam quality in the water and steam regions. If the quality of the steam region is less than 1, condensation occurs and $M_G(1-X_G)$ pounds of steam are transferred to the water at fluid saturation enthalpy. Boil-off occurs whenever water region quality exceeds 0. In this case, $M_W X_W$ pounds of water are transferred to the steam region at gas saturation enthalpy.

The approximations used to calculate h_f and h_g are plotted in Appendix D and are as follows:

$$h_f = 438.1 + 0.117 \times \text{pressure (Figure D-10)} \qquad (4\text{-}13)$$

$$h_g = 1320.x - 0.09 \times \text{pressure (Figure D-11)} \qquad (4\text{-}14)$$

The tables used to determine the quality of the steam and water are also shown and plotted in Appendix D.

5.0 PLANT PROTECTION SYSTEM

The plant protection system (PPS) provides for automatic control rod scram and/or emergency core cooling (ECC) when any of the monitored parameters equal or exceed their setpoint. Table 5-1 summarizes the simulated PPS system.

5.1 Time Constants

Instrument channel time constants are modeled as a first order system described by the following equation:

$$\tau \frac{dX_M}{dt} + X_M = X_A \qquad (5\text{-}1)$$

where

τ = time constant

X_M = measured output signal

X_A = actual value of the parameter being measured

The solution of differential equation 5-1 is approximated by the Euler one-step numerical method. Setpoints and time constants are specified in the input array. Scram signals can be inhibited using console DAP switch 4.

5.2 Time Delays

After a scram condition is detected a time delay is used to simulate the actual PPS and control rod circuitry response. The duration of the time delay is specified in the input array. When the scram delay time has expired, the control rod scram is initiated (see section [illegible].2.4.3).

5.3 ECCS

Upon receipt of an ECCS signal, high pressure injection is initiated at a specified flow rate and boron concentration (see sections 3.6 and 3.7).

TABLE 5-1

PPS SIMULATION

Parameter	Instrument Channel Time Constant	Trip Condition	Notes
RSS			
average reactor power	yes	high power	peak power trip not simulated
hot leg temperature	yes	high temperature (node 20)	
loop pressure	yes	high or low loop pressure	
PCS flow	yes	low mass flow (node 23)	
RABV	included in setpoint	high RABV volumetric flow	actual plant trip is based on RABV valve position
loss of pump generator field current	included in setpoint	simulated by a timed trip	
manual scram	no	console DAP switch 11	
ECCS			
loop pressure	yes	low pressure	

6.0 STEAM GENERATOR AND ASSOCIATED CONTROLLERS

6.1 Steam Generator Secondary Side

The secondary side of the steam generator is modeled as two nodes:

(1) Downcomer liquid region

(2) Steam generator saturated liquid/steam mixture including steam dome and piping to the Main Steam Valve.

The relationship of the two nodes is shown in Figure 6-1.

6.1.1 The downcomer node is assumed to consist of subcooled incompressable liquid. The mass and energy equations are as follows:

$$\frac{dM_D}{dt} = W_{FW} + W_{RECIR} - W_D \qquad (6\text{-}1)$$

$$\frac{dh_D}{dt} = W_{FW} \cdot (h_{FW} - h_D) + W_{RECIR} \cdot (h_f - h_D) + J v_D \frac{dP}{dt}$$

M_D = downcomer mass

h_D = downcomer specific enthalpy

h_{FW} = feedwater specific enthalpy

h_f = steam generator saturated liquid specific enthalpy

W_D = downcomer flow

W_{RECIR} = recirculation flow

W_{FW} = feedwater flow

v_D = downcomer specific volume, approximated by saturated liquid specific volume

P = steam generator pressure

J = conversion factor 0.1851 Btu/(cu ft psi)

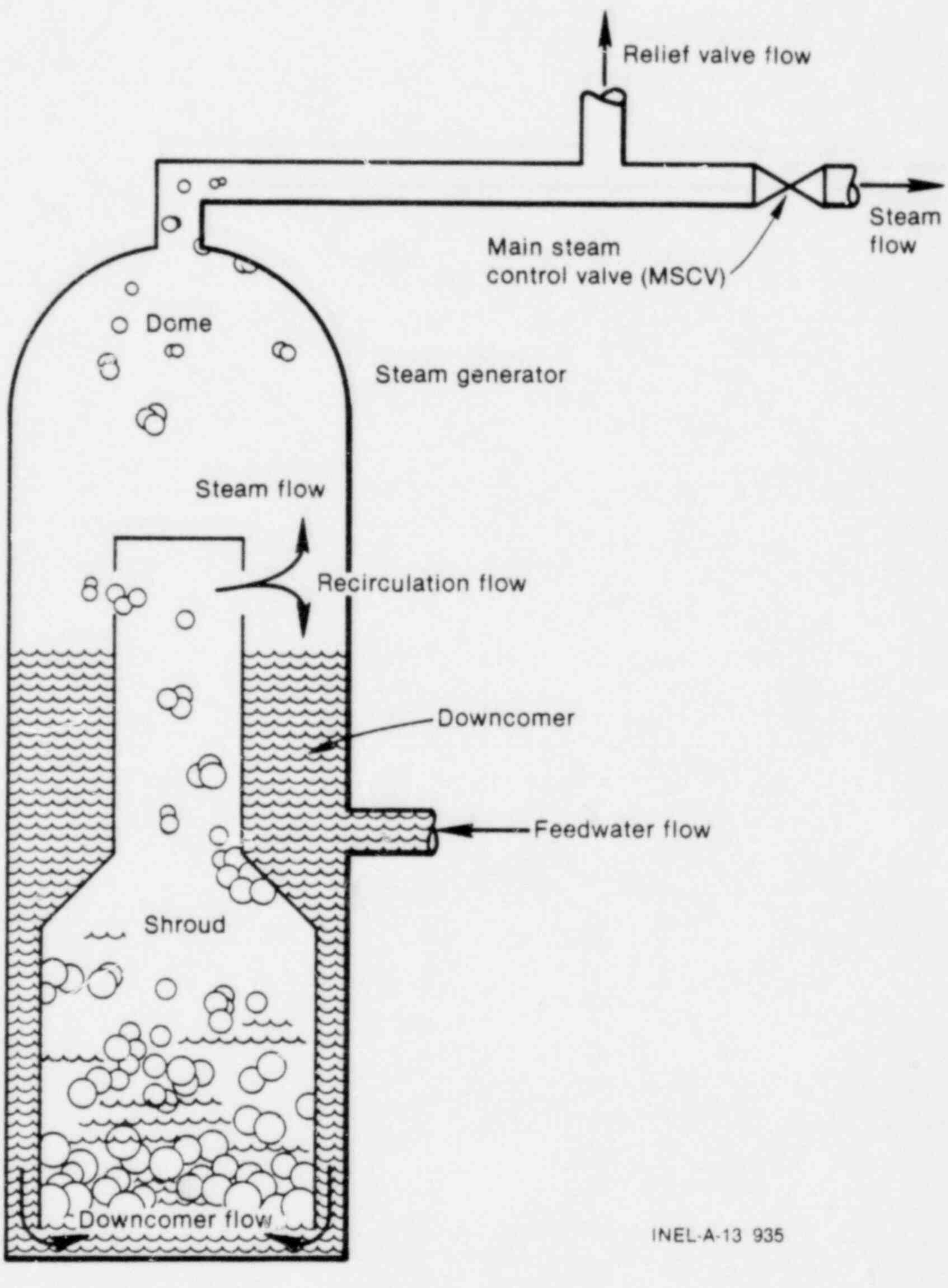


FIGURE 6-1

STEAM GENERATOR

6.1.2 The mass and energy equations for the saturated portion of the steam generator are as follows:

$$\frac{dM_{SG}}{dt} = W_D - W_{RECIR} - W_{STM} \qquad (6\text{-}3)$$

$$\frac{dh_{SG}}{dt} = W_D \cdot (h_D - h_{SG}) - W_{RECIR}(h_f - h_{SG})$$

$$- W_{STM} \cdot (h_g - h_{SG}) + \dot{Q}_{SG} + J\nu_{SG} \frac{dp}{dt} \qquad (6\text{-}4)$$

M_{SG} = steam generator mass
h_{SG} = steam generator specific enthalpy
h_g = saturated steam specific enthalpy
$\dot{Q}_{SG}$ = rate of heat input from the primary coolant
ν_{SG} = steam generator specific volume
W_{ST} = steam flow, including relief valve flow

If the downcomer flow, W_D, is negative its associated enthalpy term is added to h_D instead of h_{SG}.

6.1.3 The recirculation flow rate, W_{RECIR}, is determined by assuming that the steam quality in the shroud riser is proportional to the average shroud steam quality.

$$X_{riser} = \beta \overline{X}_{shroud} = \frac{W_{STM}}{W_{STM} + W_{RECIR}} \qquad (6\text{-}5)$$

β is emperically determined in Appendix F-2 to be a function of power as follows:

$$\beta = 2.8523 + \frac{21974}{\dot{Q}_{SG}} \qquad (6\text{-}6)$$

The following additional relationships are used to determine W_{RECIR}:

$$\overline{X}_{shroud} = (\nu_{shroud} - \nu_f)/(\nu_g - \nu_f) \qquad (6\text{-}7)$$

$$\nu_{shroud} = \frac{V_{shroud}}{M_{shroud}} \qquad (6\text{-}8)$$

$$M_{shroud} = M_{SG} - M_{dome} \qquad (6\text{-}9)$$

$$M_{dome} = \frac{(V_{TOT} - V_{shroud} - \nu_f M_D)}{\nu_g} \qquad (6\text{-}10)$$

$\overline{X}_{shroud}$ = steam quality in the shroud

$X_{ri^{\cdot}}$ = steam flow quality in shroud riser

β = proportionality factor

ν_{shroud}, ν_f, ν_g = specific volumes of the shroud, downcomer, saturated fluid, and saturated gas

V_{shroud} = shroud volume, 88.8 cu ft

M_{shroud} = mass in the shroud

M_{dome} = mass in the dome and steam piping up to the main steam valve

V_{TOT} = total steam generator and steam piping volume, 235 + 41 = 276 cu ft (reference 6, Table XXXIV, page 260)

6.1.4 Downcomer flow is determined by solving the following natural circulation equation:

$$(\rho_D L_D - \rho_{riser} L_{riser} - \rho_{drum} L_{drum})/1728$$

$$= k_1(\nu_D W_D)^2 + k_2(\nu_f W_{RECIR} + \nu_g W_{STM})^2 \qquad (6\text{-}11)$$

L_D = downcomer level (inches)

L_{riser} = height of the riser section of the shroud, 64.44 inches

L_{drum} = height of the drum section of the shroud, 97.31 inches

ρ_D = downcomer density

ρ_{riser} = density in the riser section

ρ_{drum} = density in the drum section

k_1 = downcomer flow loss coefficient
2.2028×10^{-2} psi/(cu ft/sec)^2 (Appendix F-2)

k_2 = shroud flow loss coefficient,
7.8888×10^{-4} psi/(cu ft/sec)^2 (Appendix F-2)

For very small gravity head differences equation 6-11 becomes numerically unstable. This is corrected by substituting $10W_{DL}$ for $W_D{}^2$ whenever W_D is less than 10 cu ft/second. W_{DL} is the laminar downcomer flow and is a linear function of the driving head.

Appendix E contains steam generator dimensions, volume calculations, and the following downcomer level relationship.

$$V_D = M_D \nu_f$$

$$L_D = \begin{cases} 4.8098\ V_D & \text{for } V_D \le 19.41 \text{ cu ft} \\ 0.9241\ V_D + 75.43 & \text{for } V_D > 19.41 \text{ cu ft} \end{cases} \qquad (6\text{-}12)$$

The riser and drum densities are calculated as follows:

$$\rho_{riser} = \frac{1}{\nu_f + X_{riser}\ \nu_{fg}} \qquad (6\text{-}13)$$

$$\rho_{drum} = \frac{M_{shroud} - \rho_{riser} \cdot V_{riser}}{V_{DRUM}} \qquad (6\text{-}14)$$

$$V_{riser} = 17.13 \text{ ft}^3$$

$$V_{drum} = 71.67 \text{ ft}^3$$

6.1.5 Steam generator pressure is determined by a two-dimensional table lookup. The table inputs are h_{SG} and log (ν_{SG})(see Figure 6-2). Table values are interpolated logarithmically for specific volume and linearly for specific enthalpy. The variable log (ν_{sg}) is used to provide a more uniform configuration of the table. Appendix G shows the method used to generate the table.

6.1.6 The steam generator dryout factor, f, discussed in Section 3.3 accounts for the fraction of the secondary heat transfer area in which departure from nuclear boiling (DNB) has occurred. f is calculated by assuming that the steam quality in the drum is linearly distributed with height.

$$f = \frac{L_{DNB}}{L_{DRUM}} \qquad .01 \leq f \leq 1.0 \tag{6-15}$$

L_{DNB} is the height where the steam quality equals X_{DNB}. The method used to compute L_{DNB} is given in Appendix F-3. The resulting equations yield the following:

$$f = \begin{cases} 1 - (X_{RISER} - X_{DNB})\, 2X_{DRUM}/X^2_{RISER} & \text{for } 2X_{DRUM} \leq X_{RISER} \quad (6\text{-}16) \\ 1 - (X_{RISER} - X_{DNB})/2(X_{RISER} - X_{DRUM}) & \text{for } 2X_{DRUM} > X_{RISER} \quad (6\text{-}17) \end{cases}$$

$$.01 \leq f \leq 1.0$$

6.1.7 Two relief valves are included in the steam generator model. When their respective high-pressure setpoints are exceeded they relieve 25 lbm/second of steam each (Reference 15), with a one-second response time constant. The reset deadbands are 55 and 56 psi, respectively, and the setpoints are specified in the input array.

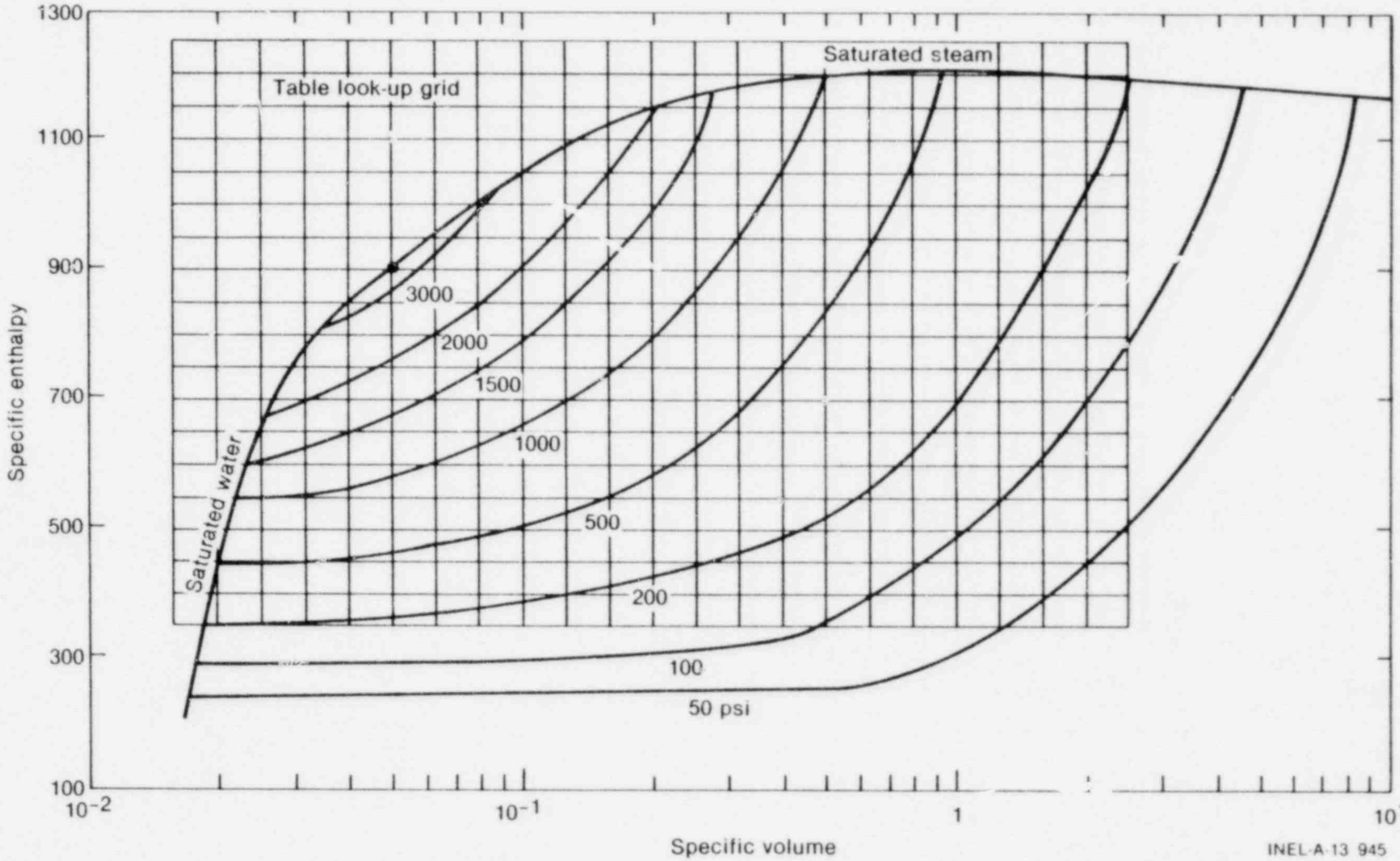


FIGURE 6-2

PRESSURE VS. VOLUME AND ENTHALPY

6.1.8 Saturation values of temperature, specific volume and enthalpy are determined as a function of pressure using a table lookup. The tables extend from 100 to 1600 psia in 100 psia increments.

6.2 Main Steam Control Valve

The Main Steam Control Valve (MSCV) stem position is controlled with an automatic and manual controller. The valve is manually controlled from the console using logic switch 112 to open or shut the valve. In the manual mode valve ramp rate can be multiplied by a factor of 0.1 using DAP switch 5.

The automatic controller uses the following logic:

(a) The valve is demanded to open when the steam generator pressure exceeds the high pressure set point.

(b) The valve is demanded to shut when the steam generator pressure is less than the low pressure set point and a PPS scram condition has been detected.

(c) Automatic operation overrides manual control.

The ramp rate, response time constant, pressure set points, and deadband are specified in the input array.

Steam flow in lbm/sec is calculated using the following formulas:

$$W_S = C_V \sqrt{\overline{P} \cdot \Delta P} \qquad (6\text{-}18)$$

$$\overline{P} = \frac{P_{SG} + P_{CR}}{2} \qquad (6\text{-}19)$$

$$\Delta P = P_{SG} - P_{CR} \qquad (6\text{-}20)$$

where,

W_S = steam flow (lbm/sec)

P_{SG} = steam generator pressure (psia)

P_{CR} = condensate receiver pressure (psia)

C_V = valve flow characteristic (see Table 6-3)

Steam valve leakage can be simulated by specifying the fraction of 50 MW assumed to be leaking past the MSCV when it indicates shut. The INIT program calculates a minimum steam flow, W_{MIN}, and steam flow equals W_S from the valve C_V or W_{MIN}, whichever is greater.

$$W_{MIN} = \begin{pmatrix} \text{leakage} \\ \text{fraction} \end{pmatrix} \times 50\ M_W \times \left. \frac{W_S}{\text{power}} \right|_{\text{initial values}} \qquad (6\text{-}18)$$

6.3 Steam Generator Water Level Controller

The steam generator water level control circuitry uses inputs of steam flow and steam generator water level to determine the proper feed valve position. Figure 6-4 schematically shows the control circuitry. The feed valve is positioned to the control signal with a one-second time constant.

Upon receipt of a PPS scram signal the model initiates a delay then overrides the water level controller and shuts the feed valve. The delay time and valve ramp rate are specified in the input array.

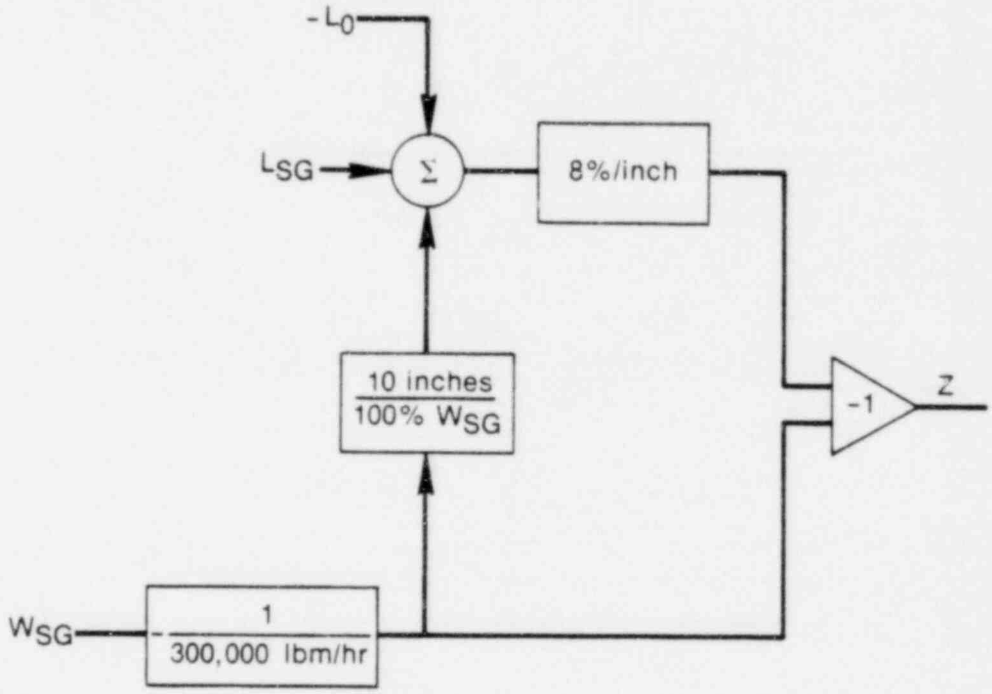
TABLE 6-3

MAIN STEAM VALVE C_v VERSUS STEM POSITION

Stem Position (%)	C_v (lbm/sec/psi)
0	0
10	.0223
20	.0289
30	.0388
40	.0520
50	.0685
60	.0907
70	.1196
80	.1592
90	.2170
100	.2805

See reference 6, Figure 154, where

$$C_v = \frac{(2.1)\sqrt{2}}{3600} \times \text{(the } C_v \text{ listed in engineering units)}$$



L_0 = Level set point (specified as an input parameter)

L_{SG} = Indicated level signal (1 sec time constant)

W_{SG} = Steam generator steam flow

Z = Feed valve control signal

INEL-A-13 937

FIGURE 6-4

STEAM GENERATOR WATER LEVEL CONTROL SCHEMATIC

7.0 AIR-COOLED CONDENSER

Steam from the main steam control valve is condensed in the air-cooled condenser. The condenser is divided into three bays. Each bay has 230 tubes and two adjustable blade air fans. The LOFT simulation models each bay separately. Pressure in the condenser is assumed to be uniform and equal to the receiver pressure.

7.1 Air-Cooled Condenser Air Flow

Air flow through the air-cooled condenser (ACC) is adjusted by changing the blade angle on the fans (total of six). The blade angle controller (shown in Figure 7-1) is used to maintain a constant pressure at the ACC inlet. The positioner setpoint is determined by the INIT subroutine and depends upon the initial condenser pressure specified in the input array.

ACC air flow in cfm ($\dot{V}_{fan}$) is a function of the blade angle and is determined by a table lookup of plant data as shown in Table 7-2. The mass flow rate per bay is calculated as follows:

$$W_{air} = 2\dot{V}_{fan} \times \left(\frac{1 \text{ min}}{60 \text{ sec}}\right) \times \rho_{air} \qquad (7\text{-}1)$$

$$\rho_{air} \cong \frac{33.72}{T}, \text{ T in } ^{o}\text{R, 25.45" Hg} \qquad (7\text{-}2)$$

(See Reference 9, page 1946)

The simulation uses the average air temperature of bay 1 to compute the density.

The ACC model can be operated with air flow to bay 2 and/or 3 secured by selecting BAYSW(2) and/or (3) in the input array to zero. The normal value for these variables is one. Transient air flow conditions are simulated by reducing the air flow from its initial value to a preset minimum at a constant rate. The minimum values for each bay and the flow reduction rate are specified in the input array. Only the bays selected by setting AIRSW(1), (2), and/or (3) in the input array to one are affected by the transient. The normal values in the AIRSW array are zero.

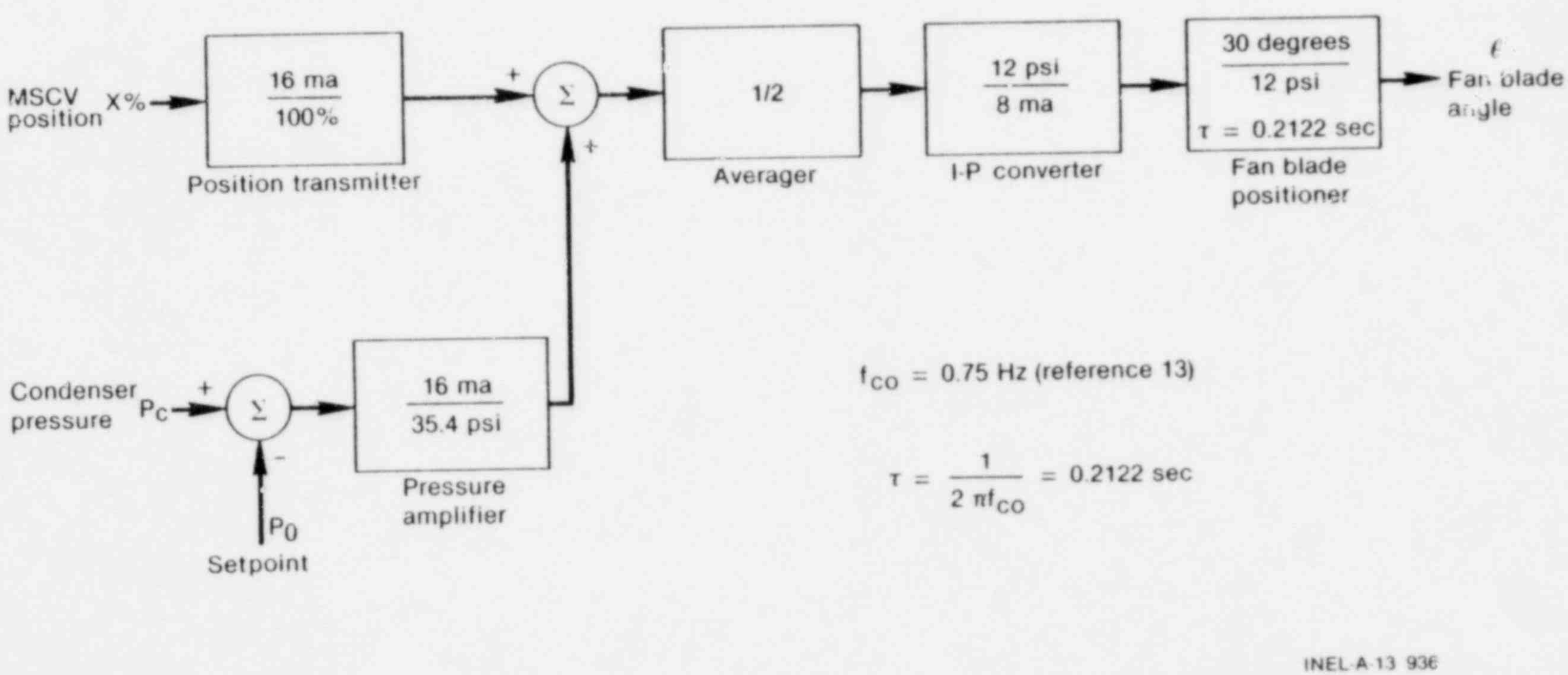


FIGURE 7-1

AIR-COOLED CONDENSER FAN BLADE POSITIONER

TABLE 7-2

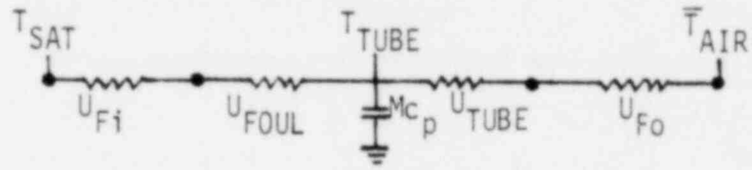
AIR FLOW VS FAN PITCH ANGLE

Pitch Angle (degrees)	Air Flow 1000 cu ft/min/fan
0	0
2	65
4	84
6	100
8	114
10	126
12	137
14	148
16	156
18	164
20	170
22	174

Reference 11, Figure 4, page 11, louvers 100% open.

7.2 Air-Cooled Condenser Heat Transfer

The heat transfer through the condenser tubes is modeled as follows:



T_{SAT} = saturation temperature of the condensate obtained from the condensate receiver pressure by a table lookup

T_{TUBE} = tube temperature

$\overline{T}_{AIR}$ = log mean air temperature

U_{Fi} = heat conduction across the inside film

U_{FOUL} = heat conduction across tube deposits

U_{TUBE} = heat conduction across the tube

U_{Fo} = heat conduction across the outside film

Mc_p = heat capacity of tubes

The heat conduction correlations are from reference 10, modified as follows:

$\underline{U_{Fi}}$: (page 7)

$$\frac{1}{h_i} = 1.29 \times 10^{-5} W_{STM}^{1/3} \quad \frac{hr.\ ft^2\ ^oF}{Btu} \qquad (7\text{-}3)$$

$$h_i = \frac{10^5}{1.29} W_{STM}^{-1/3} \times (2)^{1/3} \times (3600)^{-1/3} \times \frac{hr}{3600\ sec} \qquad (7\text{-}4)$$

$(2)^{1/3}$: converts the length term from per fan to per bay

$(3600)^{-1/3}$: converts W from lbm/hr to lbm/sec

$$U_{Fi} = h_i = 1.77\ W_{STM}^{-1/3} \quad \frac{Btu}{sec\ ft^2\ ^oF}\ ;\ W_{STM} = W_{COND}\,lbm/sec \qquad (7\text{-}5)$$

$\underline{U_{FOUL}}$: (page 3)

$$r_i = .001 \frac{hr\ ft^2\ {}^oF}{BTU} \qquad (7\text{-}6)$$

$$U_{FOUL} = \frac{1}{r_i}\left(\frac{1}{3600}\right) = .2778 \frac{Btu}{sec\ ft^2\ {}^oF} \qquad (7\text{-}7)$$

$\underline{U_{TUBE}}$: (page 6)

$$r_w = .0184 \frac{hr\ ft^2\ {}^oF}{Btu} \qquad (7\text{-}8)$$

$$U_{TUBE} = \frac{1}{r_w}\left(\frac{1}{3600}\right) = .0151 \frac{Btu}{sec\ ft^2\ {}^oF} \qquad (7\text{-}9)$$

$\underline{U_{FO}}$: (page 9)

$$\frac{1}{h_o} = 1620\ W_{air}^{-.72} \frac{hr\ ft^2\ {}^oF}{Btu} \qquad (7\text{-}10)$$

$$h_o = \frac{1}{1620}\ W_{air}^{.72} \times \frac{1}{2}^{.72} \times (3600)^{.72} \times \left(\frac{hr}{3600\ sec}\right) \qquad (7\text{-}11)$$

$\frac{1}{2}$: converts W_{air} from fan flow to bay flow

(3600): converts W from lbm/hr to lbm/sec

$$U_{Fo} = h_o = 3.784 \cdot 10^{-5}\ W_{air}^{.72} \frac{Btu}{sec\ ft^2\ {}^oF} \qquad (7\text{-}12)$$

The heat transfer equations used from the tube to the air are derived as follows:

$$\dot{Q}_{air} = W_{air} c_p (T_{out} - T_{amb}) = UA \cdot \overline{\Delta T} \qquad (7\text{-}13)$$

W_{air} = air flow per bay (lbm/sec)

$\dot{Q}_{air}$ = heat rejected to air (Btu/sec)

c_p = heat capacity of air (from reference 9, page 1909, at 100°F) = 0.242 Btu/lbm°F

T_{out} = air temperature at outlet of bay

T_{amb} = ambient air temperature. Specif ed in the input array.

U = heat transfer coefficient $= \left(\frac{1}{U_{Fo}} + \frac{1}{U_{TUBE}}\right)^{-1}$

A = external area per bay. From reference 6, page 258, Table XXXIII, = 168,383 $ft^2/3$ = 56,128 ft^2

$\overline{\Delta T}$ = mean log temperature difference

$$= (T_{out} - T_{amb})/\ln \frac{T_{TUBE} - T_{AMB}}{T_{TUBE} - T_{OUT}} \qquad (7\text{-}14)$$

From equations ,-13 and 7-14:

$$\Delta T_{air} = T_{OUT} - T_{AMB} = (T_{TUBE} - T_{AMB})\cdot\left(1-e^{-\frac{UA}{W_{air}cp}}\right) \qquad (7\text{-}15)$$

and

$$\dot{Q}_{air} = WC_p \cdot \Delta T_{air}$$

The average bay air temperature is computed as $T_{AMB} + 1/2\Delta T_{air}$.

The heat transfer from the steam to the tube is computed by:

$$\dot{Q}_{cond} = UA\,(T_{SAT} - T_{TUBE}) \qquad (7\text{-}16)$$

$$U = \left(\frac{1}{U_{Fi}} + \frac{1}{U_{FOUL}}\right)^{-1}$$

A = inside surface area. From reference 10, page 6, D = 1 - 2 (.083) = .834 inches.

$A = (230)(44\ ft)\left(\frac{\pi\ .834}{12}\right) = 2210\ ft^2$

The tube temperatures are updated as follows:

$$(Mc_p)\frac{d}{dt}T_{TUBE} = \dot{Q}_{COND} - \dot{Q}_{air} \qquad (7\text{-}17)$$

$$C_p = .12\ BTU/lbm^oF$$

$$M = (490\ lbm/ft^3)\cdot\frac{\pi}{4}(1^2 - .83^2)\ in^2\left(\frac{ft^2}{144\ in^2}\right)\cdot$$

$$(44\ ft/tube)\cdot(230\ tubes)$$

$$= 8414\ lbm$$

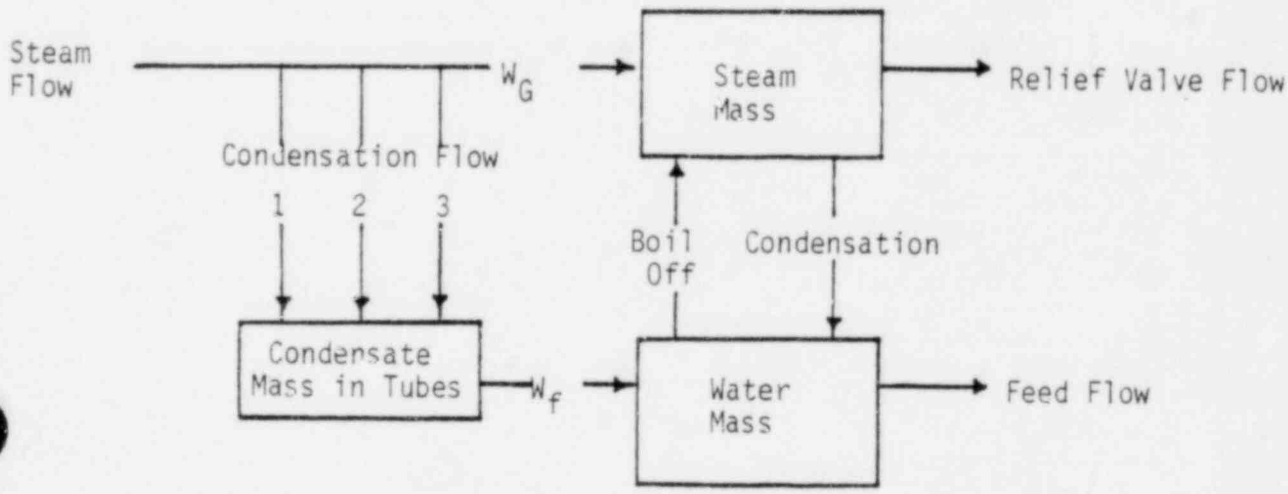
$$Mc_p = 1009.68\ BTU/^oF$$

(tube dimensions from reference 6, page 258, Table XXXIII)

8.0 CONDENSATE RECEIVER MODEL

8.1 Condensate Receiver Mass Transport

The mass transport in the condenser and receiver is modeled as follows:



$$W_{cond} = \dot{Q}_{cond} \Big/ \left(h_{g_{SG}} - h_{f_{CR}} \right) \qquad (8\text{-}1)$$

h_g and h_f are determined by a table lookup of pressure in the steam generator and condensate receiver, respectively.

$$W_G = W_{STM} - \Sigma W_{cond} \qquad (8\text{-}2)$$

$$W_f = M_{cond} \cdot v_{cond} / \overline{L}_{TUBE} \qquad (8\text{-}3)$$

v_{cond} = velocity of condensate traveling down the tube = 1 ft/sec (Appendix I)

$\overline{L}_{TUBE}$ = average length of tube traversed by the condensate = 44 ft/2 = 22 ft

W_{relief} = relief valve flow, activated on high condensate receiver pressure. Values for flow, pressure setpoint, and deadband are specified in the input array.

8.2 Condensate Receiver Mass and Energy Balances

The mass and energy equations for the condensate receiver are as follows:

$$\frac{d\,M_{cond}}{dt} = W_{cond} - W_f \tag{8-4}$$

$$\frac{d\,M_W}{dt} = W_f - W_{FW} - \frac{\overline{\Delta M}_{B/C}}{\Delta t} \tag{8-5}$$

$$\frac{d\,M_{STM}}{dt} = W_G + \frac{\overline{\Delta M}_{B/C}}{\Delta t} - W_{relief} \tag{8-6}$$

$$\frac{d\,H_W}{dt} = h_f\,W_{cond} - \bar{h}_W\,W_{FW} - \frac{\overline{\Delta H}_{B/C}}{\Delta t} + JV_W\,\Delta P \tag{8-7}$$

$$\frac{d\,H_{STM}}{dt} = h_{g_{SG}}\,W_G + \frac{\overline{\Delta H}_{B/C}}{\Delta t} - \bar{h}_{STM}\,W_{relief} + JV_{STM}\,\Delta P \tag{8-8}$$

M_{cond} = mass of the condensate in the ACC tubes

M_W = mass of water in the CR

M_{STM} = mass of steam in the CR and ACC

H_W = enthalpy of water in the CR

H_{STM} = enthalpy of steam in the CR and ACC

$\overline{\Delta M}_{B/C}$ = net mass exchange resulting from boiloff and condensation during the time step Δt.

$$= M_W X_W - M_{STM} (1-X_{STM})$$

X_W and X_{STM} = steam quality in water and steam regions

$\overline{\Delta H}_{B/C}$ = net enthalpy exchange resulting from boiloff and condensation during the time step Δt.

$$= M_W X_W h_g - M_{STM} (1-X_{STM}) h_f$$

h_g = specific enthalpy of saturated steam at P_{CR}

h_F = specific enthalpy of saturated liquid at P_{CR}

$h_{g_{SG}}$ = specific enthalpy of saturated steam at P_{SG}

$\bar{h}_W$ = H_W/M_W

$\bar{h}_{STM}$ = H_{STM}/M_{STM}

J = conversion factor = 0.1851 Btu/(cu ft psi)

ΔP = net change in P_{CR} during time step Δt.

P_{CR} = condensate receiver pressure

P_{SG} = steam generator pressure

V_W = volume of water in condensate receiver

V_{STM} = volume of steam in condensate receiver

8.3 Condensate Receiver Pressure

The Condensate Receiver Pressure is determined by iterating the pressure until the calculated volume ($\tilde{V}$) equals the actual volume (V_{CR}). If $\tilde{V} > V_{CR}$ the pressure is increased. If $\tilde{V}$ is less than V_{CR} the pressure is decreased.

$$\tilde{V} = (M_{cond}\, \nu_f) + M_W \left(\nu_f + \frac{d\nu}{dh} (\bar{h}_W - h_f)\right) \qquad (8\text{-}9)$$

$$+ M_{STM} \left(\nu_f + \frac{d\nu}{dh} (\bar{h}_{STM} - h_f)\right)$$

V_{CR} = 126.02 MSCV to ACC
135.30 ACC
72.31 ACC to CR
412.23 CR (Reference 6, page 260, Table XXXIV)
745.86 ft^3

ν_f = specific volume of saturated water at P_{CR}

For subcooled water,

$$\frac{d\nu}{dh} = 13.828 \times 10^{-6} \text{ (see Figure 8-1)} \qquad (8\text{-}10)$$

For saturated water, steam and superheated steam,

$$\frac{d\nu}{dh} = 2.28 \times 10^{-4} + .496124/P_{CR} \qquad (8\text{-}11)$$

(see Figures 8-2 and 8-3)

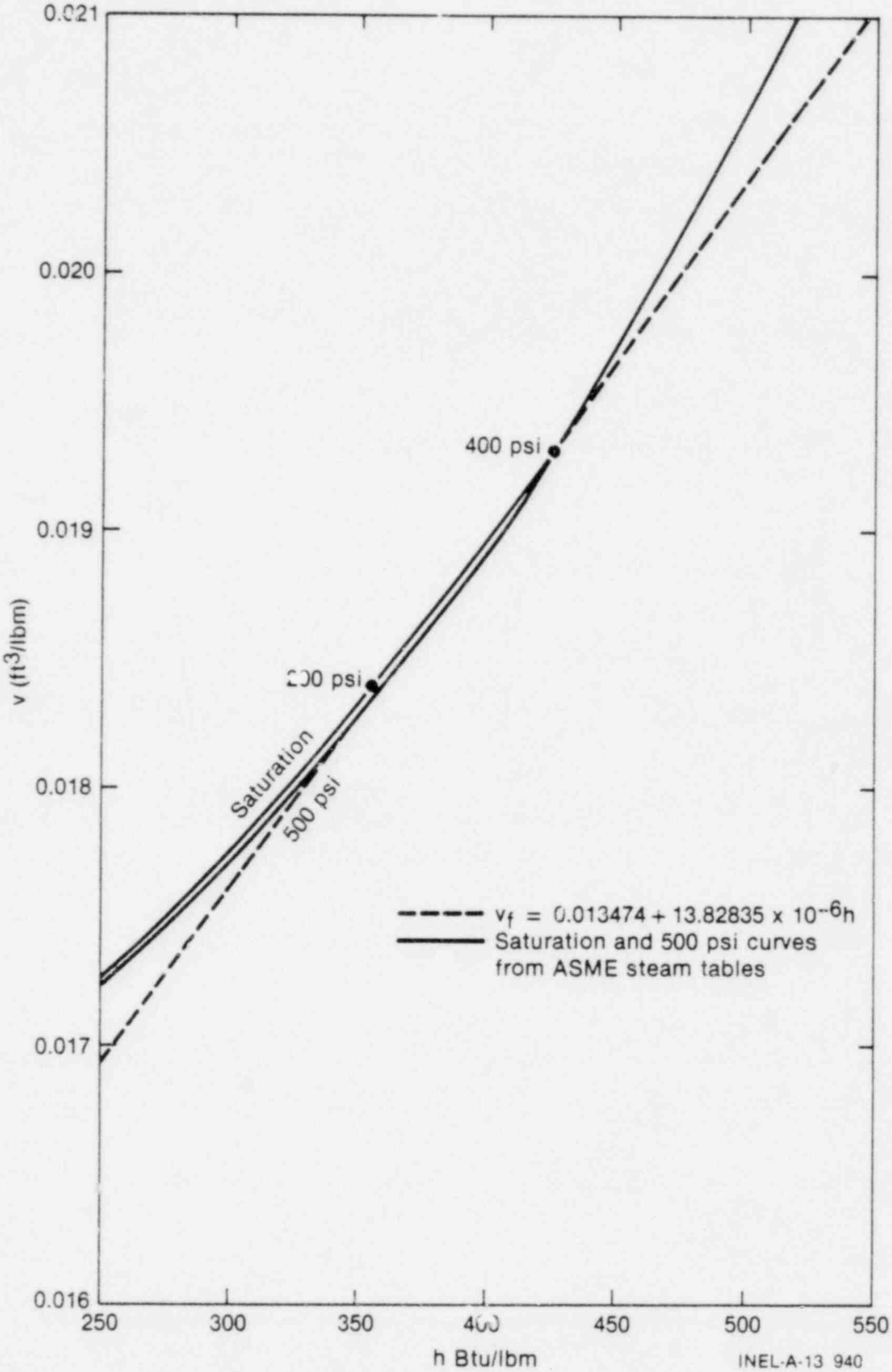


FIGURE 8-1

SPECIFIC VOLUME VS. ENTHALPY-SUBCOOLED WATER

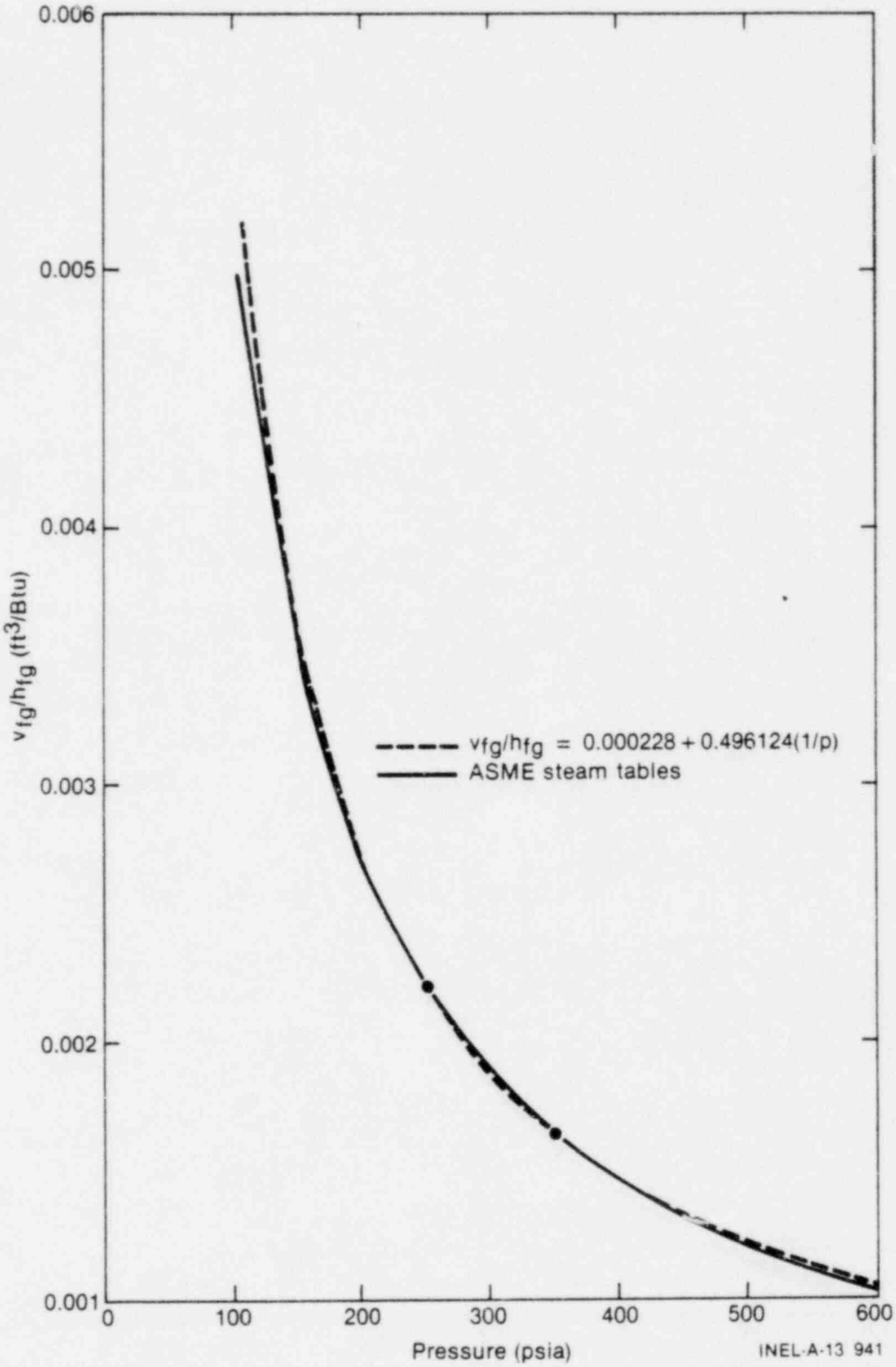


FIGURE 8-2

dv/dh - SATURATED WATER

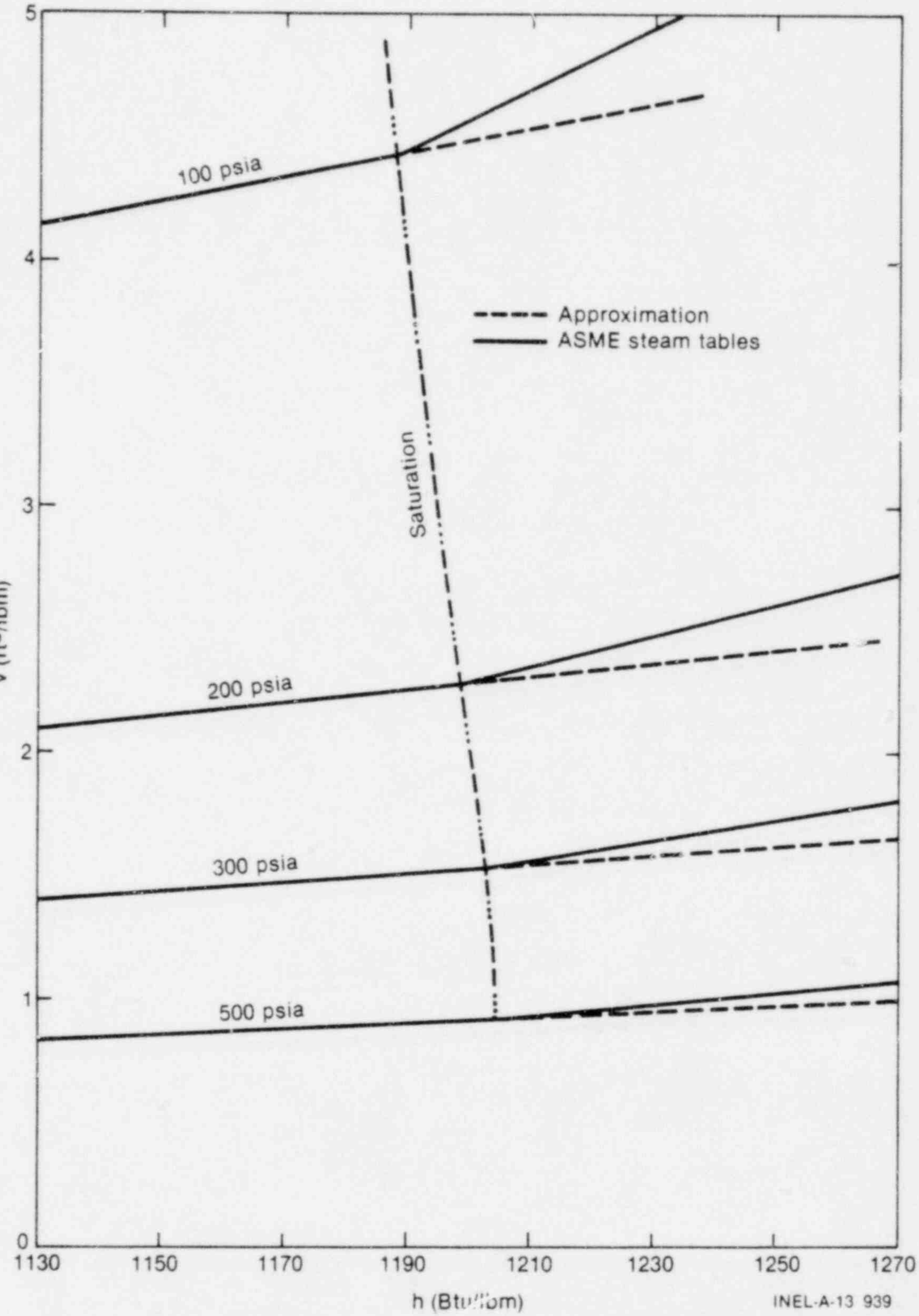


FIGURE 8-3
SPECIFIC VOLUME VS. ENTHALPY - SUPERHEATED STEAM

9.0 FEEDWATER SYSTEM

Feedwater leaving the condensate receiver passes through the subcooler, main feed pump, and feed regulating valve before returning to the steam generator.

9.1 Subcooler

The equations used for the subcooler region are as follows:

$$M_{sc} \frac{dh_{sc}}{dt} = W_{FW} (h_{W_{CR}} - h_{sc}) - \dot{Q}_{sc} \tag{9-1}$$

$$\dot{Q}_{sc} = UA (T_{sc} - T_{amb}) = \frac{UA}{C_p} (h_{sc} - h_{amb}) \tag{9-2}$$

M_{sc} = mass of water in subcooler region

from reference 6, page 260, Table XXXIV

7.62	CR to SC
.50	subcooler
8.12	cu ft

ρ @ 300 psi sat = 52.94 lbm/cu ft

M_{sc} = 430 lbm

$\frac{UA}{C_p}$ = 2.3 lbm/sec (Appendix J)

h_{amb} = 100 BTU/lbm

h_{sc} = specific enthalpy of water in the subcooler region

W_{FW} = feedwater flow

$h_{W_{CR}}$ = specific enthalpy of water in the condensate receiver

9.2 Feedwater Piping

The equations used in the feedwater piping are:

$$M_{FW} \frac{dh_{FW}}{dt} = W_{FW} (h_{sc} - h_{FW}) \tag{9-3}$$

M_{FW} = mass of feedwater (from reference 6, page 260, Table XXXIV)

4.72	SC to feed pump
1.20	feed pump
7.02	feed pump to control valve
18.27	control valve to steam generator
31.21	cu ft

ρ @ 300 psi 10^{o}F subcooled = 53.36 lbm/cu ft

M_{FW} = 1665 lbm

h_{FW} = specific enthalpy of feedwater

9.3 Feed Flow

Feed flow is determined as follows:

$$W_{FW} = C_v \sqrt{\rho(P_p - P_{SG})} \tag{9-4}$$

W_{FW} = feedwater mass flow rate (lbm/sec)

C_v = valve characteristic (from reference 12, figure 2)

C_v = 1.0725 X $\qquad 0<X\leq.75$

C_v = 1.0725 (2 X -.75) $\qquad .75<X\leq1.0$

See figure 9-1 for a comparison of the C_v curve and power range testing data.

ρ = feedwater density = 53.36 lbm/ft^3 at 300 psi, 10^oF subcooled

P_p = feed pump discharge pressure (psi) = $P_{CR} + P_o - RW_{FW}^2$ (9-5)

P_o = shutoff head discharge pressure. Specified in the input array.

R = pump internal resistance factor = .02330 $psi/(lbm/sec)^2$ (see Appendix J).

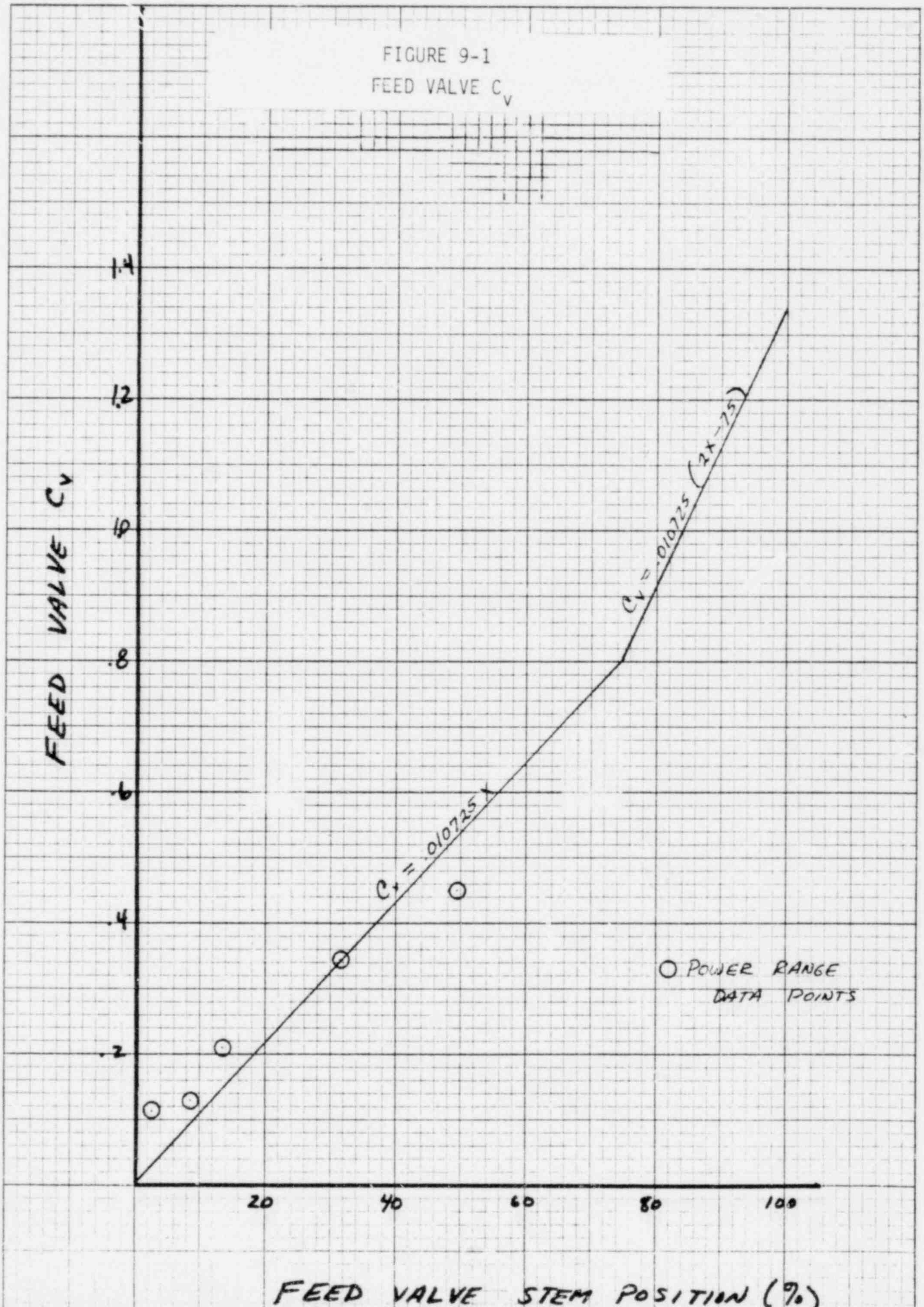
P_{SG} = steam generator pressure (psi)

P_{CR} = condensate receiver pressure (psi)

Solving equations 9-4 and 9-5 explicitly for W_{FW} yields:

$$W_{FW} = C_v \sqrt{\frac{\rho(P_{CR} + P_o - P_{SG})}{1 + C_v^2 \rho R}} \qquad (9\text{-}6)$$

FIGURE 9-1
FEED VALVE C_V



10.0 PROGRAM OPERATION AND CONTROL

The simulation is run on a PDP-11 with an Applied Dynamics, AD-5, analog console and an AD-10 function generator. The operating system is RSX-11M, version 3.2.

10.1 Analog Initialization

The values of the analog potentiometers are preset using an Interactive Hybrid Interpretor (IHI) program called COFSETØ. This program sets the pots to a tolerance of ±.015% of the total range. The source program listing is in Appendix H, Figure H-7.

The AD-10 function generator is loaded with the values given in Appendix H, Figures H-8 through H-12 by an AD-10 program called F12V.

Both of these programs are activated from the operating terminal by a command file named HYSETUP.

10.2 Program Execution

The simulation computer program is named PLAN14. Table 10-1 lists the commands used to control the program.

10.3 Digital Program Initialization

The INIT14 subroutine initializes the program to precomputed steady state values. This is accomplished by using the same modeling equations used for the dynamic solutions except that the time derivatives are set to zero. Because this computation is performed by a separate subroutine which is independent of the dynamic solution, INIT14 serves as a check of the main program implementation.

The steady state temperatures in the primary coolant loop are determined by using a recursive solution which is given in Appendix N.

Iterative solutions are used to determine the initial steam generator shroud mass and air-cooled condenser mass flow rate.

Input parameters used for initialization are:

1. Reactor Power (MW)
2. Hot Leg Temperature (^{O}F)
3. Pressurizer Pressure (PSIA)
4. Pressurizer Level (inches)
5. Condensate Receiver Pressure (PSIA)
6. Steam Generator Level Setpoint (inches)
7. PCS Loop Boron Concentration (ppm)

10.4 Main Operating Program

The main operating program is contained in the MAIN14 subroutine. This subroutine cycles once each frame time as specified in the input array. Figure 10-2 is a block diagram of the logic flow paths. Appendix H, Figure H-2, shows the analog clock and data counter display used by this subroutine.

TABLE 10-1

PLAN14 OPERATING COMMANDS

Digital Commands	Name	Action
PR	Parameters	1. Checks that the previous data file is closed.
		2. Requests the name of the data file to be accessed.
		3. Reads the title, input array, and status array from the specified file into memory.
		4. Decodes run time and scram time from the status array.
TO	Title/Open	1. Checks that the previous data file is closed.
		2. Requests file name, title, and maximum number of samples.
		3. Opens a data file.
		4. Initializes QIO parameters.
OP	Open	1. Same as TO except, file name, title, and maximum number of samples is taken from memory.
CH	Change	1. Changes values in the input array by requesting index number and new values. Values can be inserted from the card reader or from the terminal.
LI	List	1. Lists on the printer the input array, status array, and, if a scram has occurred, run time, scram time, and scram type.

TABLE 10-1 (continued)

Digital Commands	Name	Action
TR	Transient	1. Requests the transient type as follows: 1 - flow transient 2 - not assigned 3 - reactivity transient 4 - feed valve transient 2. Initializes the transient logic variables.
IC	Initial Condition	1. Initializes the hybrid interface and analog console. 2. Initializes the sample counter display. 3. Pre computes steady state from inputted plant conditions. This provides for initialization and self check of the dynamic solution. 4. Sets pots on analog console. 5. Initializes the transient logic variables. 6. Checks that a new data file is open.
RN	Run	1. Activates the main cycling program.
DM	Dump	1. Prints selected plant parameters.
FD	Full Dump	1. Same as DM plus printout of blank common is included.

TABLE 10-1 (continued)

Digital Commands	Name	Action
SA	Save	1. Encodes run time and scram time. 2. Writesinput and status arrays on the data file. 3. Copies reader file onto the data file. 4. Closes the data file.
DS	Description/ Save	1. Same as SA, except program requests a description block which it adds to the title record.
DE	Delete	1. Deletes the data file from the disc.
MC	MCR	1. Issues a PAUSE command which allows operation of other system commands from the terminal. 2. Execution of PLAN14 resumes when RES is entered on the terminal.
EX	Exit	1. Program execution is stopped.

Analog Controls

DAP Switches	Variable Name	Action
1	KNOHTR	1. Inhibits pressurizer heater logic.
2	ICONC	1. Selects the boron concentration of the HPIS fluid: ON - borated water OFF - demineralized water

TABLE 10-1 (continued)

Analog Controls

DAP Switches	Variable Name	Action
3	IZDP	1. Adds reactivity at 1¢/ second.
4	ISCBP	1. Inhibits scram logic.
5	ISVRMP	1. Reduces steam valve ramp rate by 90%.
6	KHTR	1. Activates pressurizer start-up heaters.
7	ISMP	1. Initiates data recording and starts timer at zero.
		2. Activates transient logic.
		3. Enables scram logic.
8	ISMTD	1. Activates fast sample rate.
9	IZDM	1. Subtracts reactivity at 1¢/second.
10	ICPBP	1. Sets pressurizer boron concentration equal to the node 21 concentration.
11	KSCMN	1. Initiates a manual scram.
12	ID	1. Stops the cycling program and data recording.
13	KSPRA	1. Activates pressurizer spray.
14	KPOR	1. Activates power operated relief valve.
15	KNSPPR	1. Inhibits pressurizer spray and power operated relief logic.

TABLE 10-1 (continued)

Logic Switches	Variable Name	Action
010 UP	IFLMN	1. Initiates manual flow transient.
011 UP	IDLZER	1. Holds analog integrators for the reactor kinetics and core thermal circuits in the 1C mode.
		2. Holds clad and steam generator temperatures at their pre-calculated steady state values.
		3. Holds reactivity at zero.
011 DOWN	none	1. Resets the reactor kinetics circuitry.
110 UP	JINJ	1. Activates injection flow.
111 UP	JDRAIN	1. Activates drain flow.
112 UP	IOPMSV	1. Opens steam valve.
112 DOWN	ICLMSV	1. Closes steam valve.

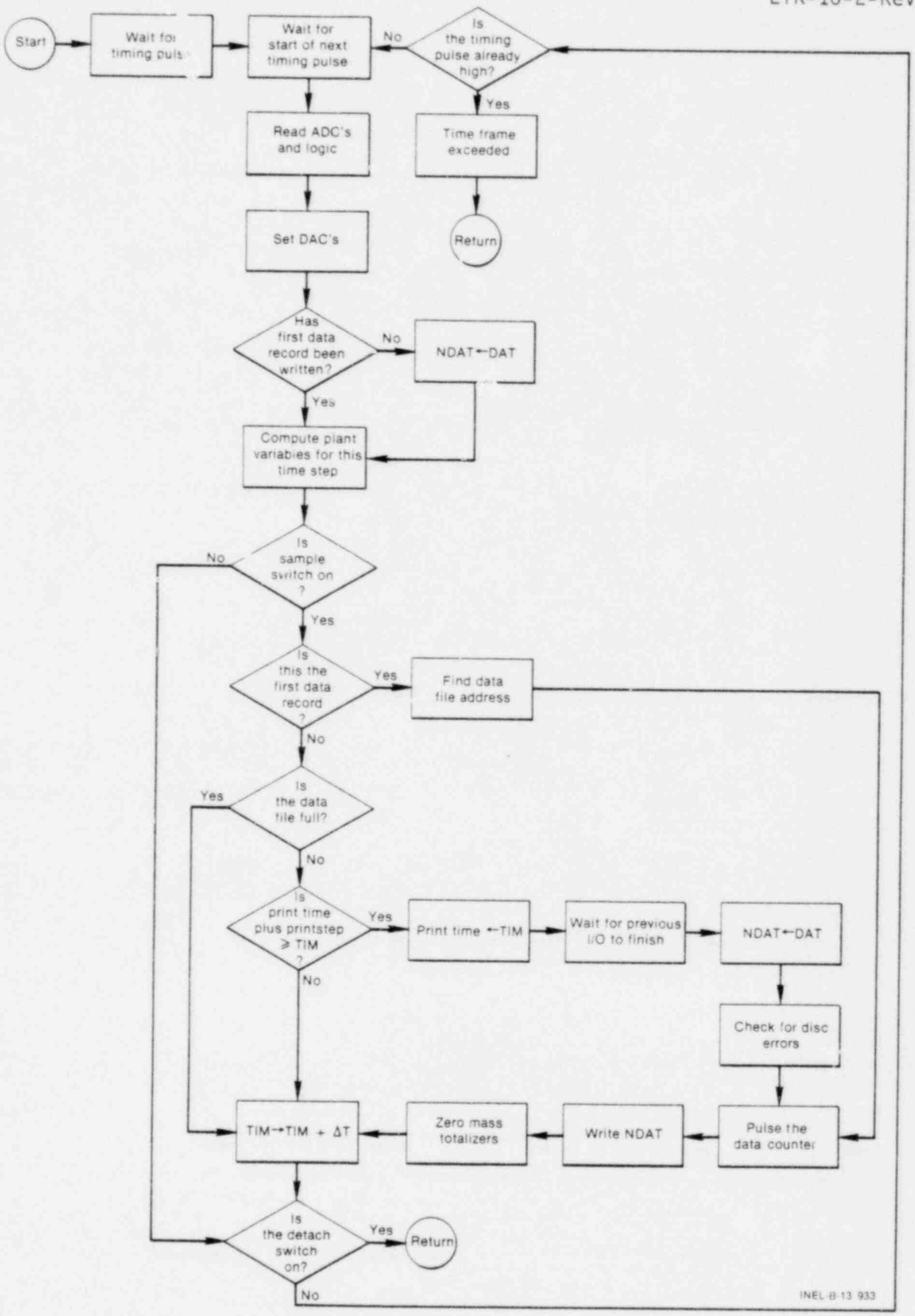


FIGURE 10-2

MAIN14 BLOCK DIAGRAM

REFERENCES

1. B. L. Ruston, "LOFT Core I, Computation of Parameters for the Reactor Kinetics Equations," LTR 111-53 (September 21, 1973).

2. Aerojet Nuclear Company, "RELAP4/MOD5: A Computer Program for Transient Thermal-Hydraulic Analysis of Nuclear Reactors and Related Systems, User's Manual," ANCR-NUREG-1335 (September 1976), Table III.

3. Proposed ANS 5.1 Standard, "Decay Energy Release Rates Following Shutdown of Uranium-Fueled Thermal Reactors," Revised June 1978.

4. K. Tasaka, "Fission Energy of U^{235}, U^{238}, and Pu^{239} for LOFT Analysis," TAS-1-79 (January 12, 1979).

5. Aerojet Nuclear Company, "LOFT Integral Test System Design Basis Report, Final Draft," (January 1974).

6. TREE-1208, "LOFT System and Test Description (5.5 ft Nuclear Core 1 LOCEs)," NUREG/CR-0247 (July 1978).

7. S. Glasstone and A. Sesonske, "Nuclear Reactor Engineering," D. Van Nostrand Company, Inc., Princeton, New Jersey, (August 1962).

8. J. J. Feeley, "A Digital Simulation of the LOFT Reactor Coolant Loop Pumping System (SICLOPS)," LTR 1142-16 (August 24, 1977).

9. Lionel S. Marks, "Mechanical Engineers' Handbook," McGraw-Hill Book Company, Inc., New York, NY, 1949.

10. MPR Associates, Inc., letter to J. J. Feeley, "LOFT Project - Air Cooled Condenser Calculations," (July 10, 1974).

11. J. J. Feeley, "LOFT Air-Cooled Condenser Air Flow Test," LTR 115-25 (June 1977).

12. W. C. Townsend, "LOFT SCS Control Valve Characteristics," WCT-8-76 (November 2, 1976).

13. Moore Products Co., Dwg FRD-011, 5-12-66.

14. C. J. Hocevar and T. W. Wineinger, THETA1-B, A Computer Code for Nuclear Reactor Core Thermal Analysis, IN-1445 (February 1971).

15. D. H. Stevenson and D. J. Hanson, "LOFT Overpressure Protection Report," LTR 1144-11 (May 16, 1972).

16. T. E. Young, "Energy Deposition in the LOFT Reactor at 54.71 MW". LTR 111-58, August 6, 1974.

17. "Design Information Report" (Unpublished GFE steam generator information notes).

APPENDIX A

PCS FLOW CALCULATIONS

A.1 Solution of the Flow Network Equations

1. Given (Section 3.1.1)

$$H_L - H_C - W_C R_C - W_L R_L = 0$$

$$H_{BP} - H_C - W_C R_C + W_{BP} R_{BP} = 0$$

$$W_L = W_C + W_{BP}$$

2. Solve for W_C, W_{BP}, and W_L.

3. In matrix form the equations are:

$$\begin{bmatrix} R_C & 0 & -R_L \\ R_C & -R_{BP} & 0 \\ 1 & 1 & 1 \end{bmatrix} \begin{bmatrix} W_C \\ W_{BP} \\ (-W_L) \end{bmatrix} = \begin{bmatrix} H_L - H_C \\ H_{BP} - H_C \\ 0 \end{bmatrix}$$

($-W_L$ was used so that the flow network would be symmetrical.)

4. Determine the inverse of the R matrix

$$R^{-1} = \frac{\text{adj } R}{|R|}$$

$$R = \begin{vmatrix} R_C & 0 & -R_L \\ R_C & -R_{BP} & 0 \\ 1 & 1 & 1 \end{vmatrix} = -(R_C R_{BP} + R_L R_C + R_L R_{BP})$$

5. $$\text{adj } R = \begin{bmatrix} -R_{BP} & -R_C & (R_C + R_{BP}) \\ -R_L & (R_C + R_L) & -R_C \\ -R_L R_{BP} & -R_C R_L & -R_C R_{BP} \end{bmatrix}^T = - \begin{bmatrix} R_{BP} & R_L & R_L R_{BP} \\ R_C & -(R_C + R_L) & R_C R_L \\ -(R_C + R_{BP}) & R_C & R_C R_{BP} \end{bmatrix}$$

6. $$\begin{bmatrix} H_L - H_C \\ H_{BP} - H_C \\ 0 \end{bmatrix} = \begin{bmatrix} -1 & 0 & 1 \\ -1 & 1 & 0 \\ 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} H_C \\ H_{BP} \\ H_L \end{bmatrix}$$

7. $$\begin{bmatrix} W_C \\ W_{BP} \\ (-W_L) \end{bmatrix} = \frac{-1}{|R|} \begin{bmatrix} R_{BP} & R_L & R_L R_{BP} \\ R_C & -(R_C + R_L) & R_C R_L \\ -(R_C + R_{BP}) & R_C & R_C R_{BP} \end{bmatrix} \begin{bmatrix} -1 & 0 & 1 \\ -1 & 1 & 0 \\ 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} H_C \\ H_{BP} \\ H_L \end{bmatrix}$$

$$\begin{bmatrix} W_C \\ W_{BP} \\ (-W_L) \end{bmatrix} = \frac{-1}{|R|} \begin{bmatrix} -(R_{BP} + R_L) & R_L & R_{BP} \\ R_L & -(R_C + R_L) & R_C \\ R_{BP} & R_C & -(R_C + R_{BP}) \end{bmatrix} \begin{bmatrix} H_C \\ H_{BP} \\ H_L \end{bmatrix}$$

(note symmetry as a check of correctness)

8. $$W_C = \frac{-(R_{BP} + R_L)\, H_C + R_L\, H_{BP} + R_{BP}\, H_L}{R_C R_{BP} + R_L R_C + R_L R_{BP}}$$

$$W_{BP} = \frac{R_L H_C - (R_C + R_L)\, H_{BP} + R_C H_L}{R_C R_{BP} + R_L R_C + R_L R_{BP}}$$

$$W_L = \frac{-R_{BP}H_C - R_C H_{BP} + (R_C + R_{BP})\, H_L}{R_C R_{BP} + R_L R_C + R_L\, R_{BP}}$$

A.2 Derivation of the PCS Flow Resistances

1. $H = kW^2$

2. LOFT Plant Data recorded during Power Range Testing, IP-01.07 Step 6.7.17, Att 8, Step 6.1, Natural Circulation Test 30 percent.

   PLD 263:10:04:06 September 20, 1977

PDT-P139-030	Vessel ΔP	= 24.6148 psid
PDE-PC-001	Pump ΔP	= 68.6457 psid
FT-P139-27-1	PCS Flow	= 3.79162 MLBM/HR
TT-P139-32	Hot Leg Temp	= 544.182°F
PT-P139-002	Hot Leg Pres	= 2235.93 psig

3. Specific volume at 544.182°F and 2235.93 psig = .021176 ft^3/lbm

4. $W = 3.79162 \times 10^6 \frac{lbm}{hr} \times .021176 \frac{ft^3}{lbm} \times \frac{hr}{3600\ sec}$

   $= 22.3032\ ft^3/sec$

5. Assume core flow is 95 percent of total.

   $W_C = (.95)\ (22.3032) = 21.1880\ ft^3/sec$

6. k_C = 24.6148 psid/$(21.1880)^2$ $(ft^3/sec)^2$ = .05483 psi/$(ft^3/sec)^2$

7. Assume core bypass flow is 5 percent of total.

   W_{BP} = (.05) (22.3032) = 1.11516 ft^3/sec

8. k_{BP} = 24.6148/$(1.11516)^2$ = 19.79347 psi/$(ft^3/sec)^2$

9. k_L = (68.6457 - 24.6148)/$(22.3032)^2$
   = .08852 psi/$(ft^3/sec)^2$

10. 2 k_C W_o = (2) (.05483) (19) = 2.0835

11. 2 k_{BP} W_o = (2) (19.79347) (1) = 39.5869

12. 2 k_L W_o = (2) (.08852) (20) = 3.5408

APPENDIX B

PCS DENSITY APPROXIMATION

1. Density was calculated from the ASME Steam Table specific volume values at 2200 psia for each 20°F incr..nent from 400°F to 640°F. See the data plotted on Figure B-1.

2. A second order least squares fit gave the following polynomial which is also plotted on Figure B-1.

$$\rho = 41.58 + 0.0890337T - 1.44741 \times 10^{-4} T^2$$

3. To find the dependence of the density on pressure $\frac{\Delta\rho}{\Delta P}$ was tabulated over a pressure range of 1400 to 3000 psi at the following temperatures:

T	$\frac{\Delta\rho}{\Delta P}$	
400	.000319	
440	.000363	
480	.000438	
520	.000563	
560	.000744	
600	.001084	(pressure range 1800 - 3000 psi)
640	.001863	(pressure range 2200 - 3000 psi)

4. By inspection of the data (see Figure B-2) it was decided to use a least squares fit of the form:

$$\frac{\Delta\rho}{\Delta P} = 250 \times 10^{-6} + a e^{bx}$$

5. Evaluation of the coefficients yielded:

$$\frac{\Delta\rho}{\Delta P} = (250 + .389\ e^{.01287T}) \times 10^{-6}$$

6. Combining the least squares temperature polynomial and the pressure correction formula gives:

$$\rho = 41.58 + 0.0890337T - 1.44741 \times 10^{-4}\ T^2$$
$$+ (P - 2200)\ (250 + .389\ e^{.01287T}) \times 10^{-6}$$

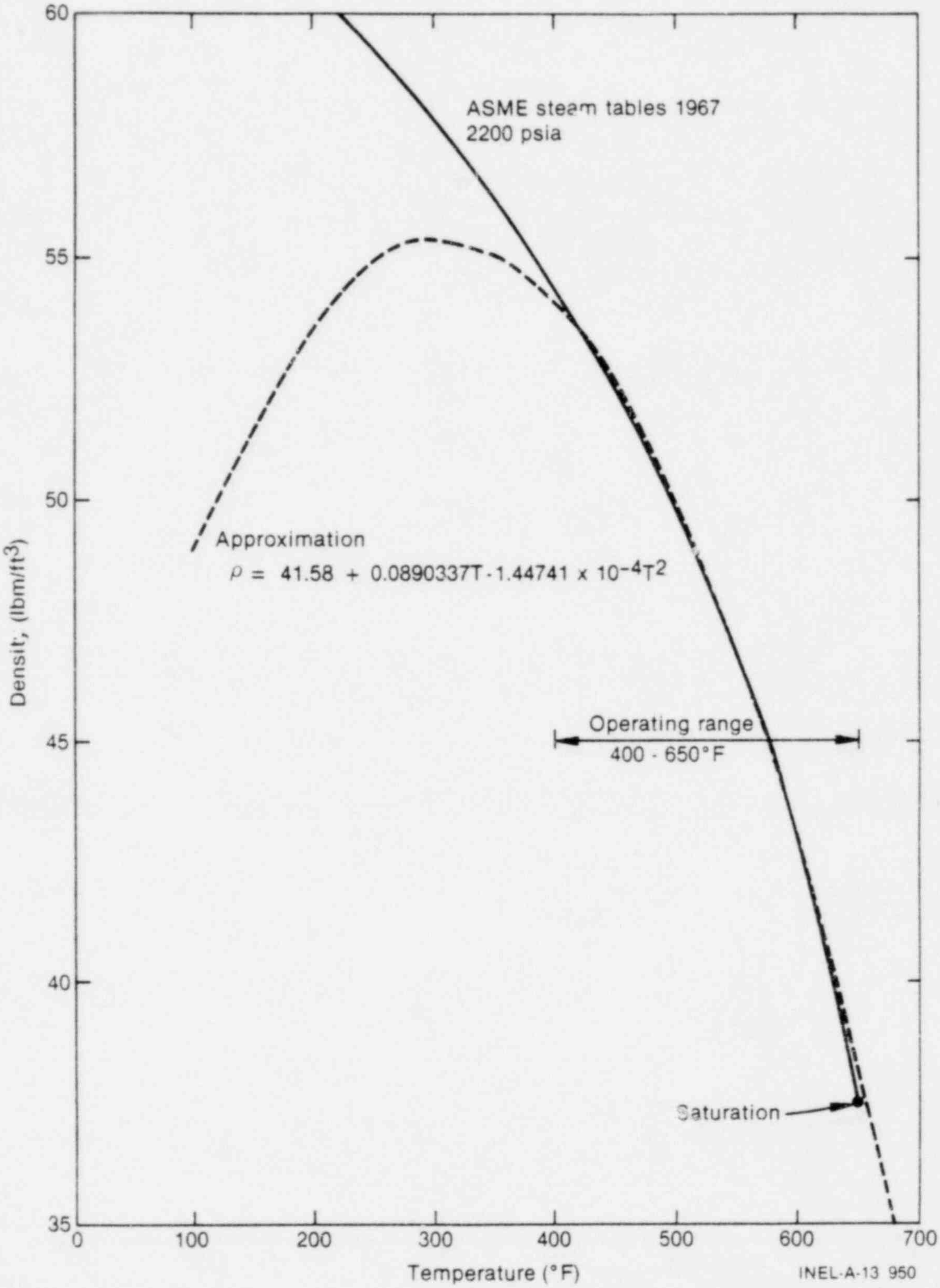


FIGURE B-1

DENSITY AS A FUNCTION OF TEMPERATURE

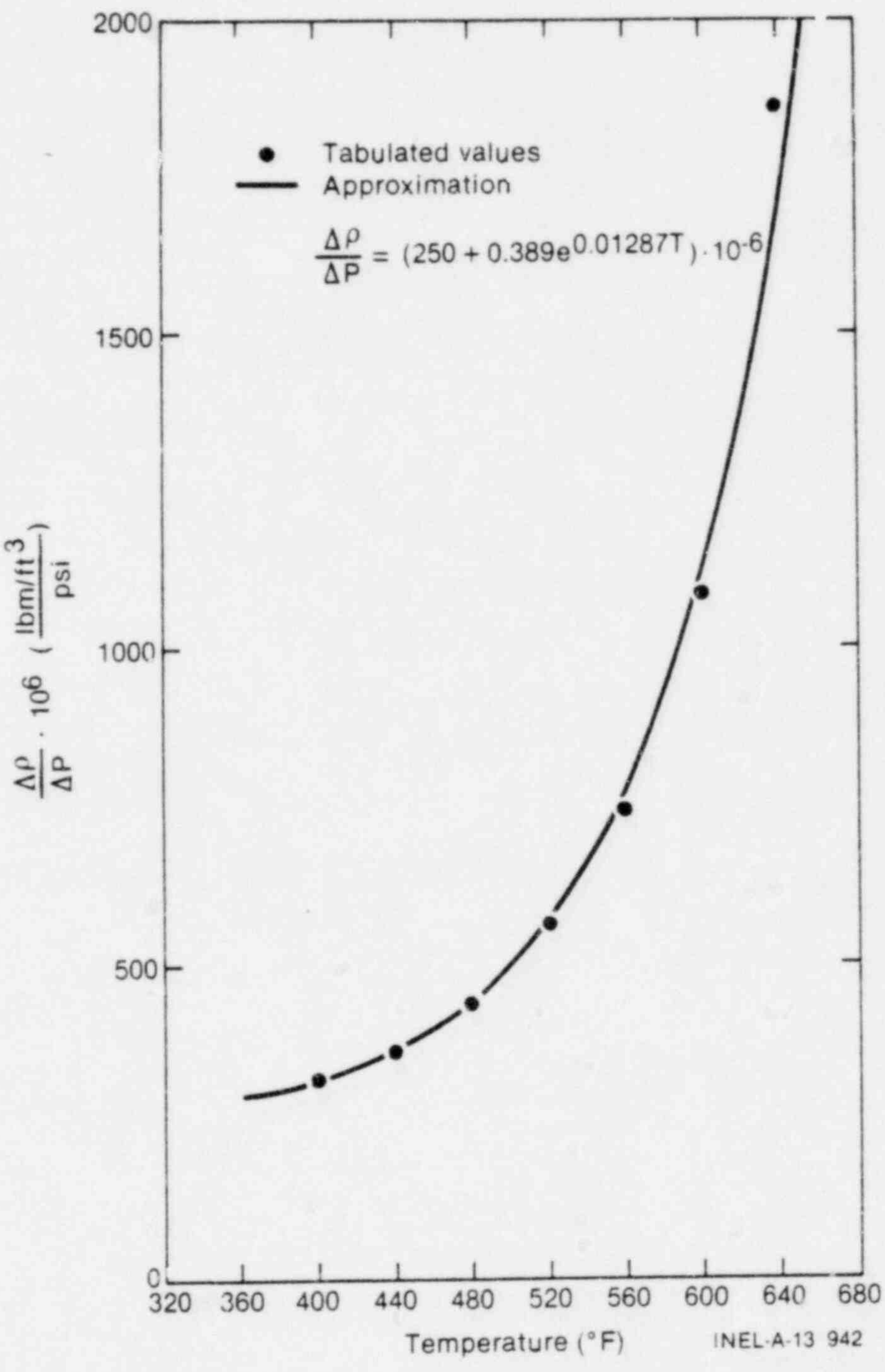


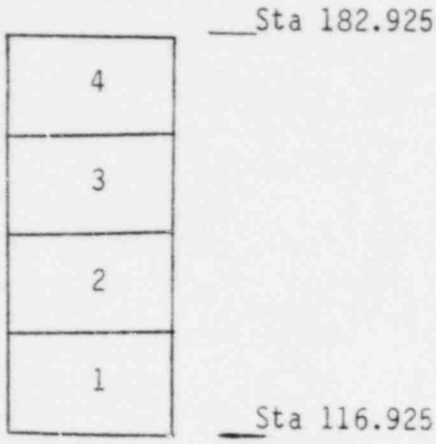
FIGURE B-2

DERIVATIVE OF DENSITY WITH RESPECT TO PRESSURE
AS A FUNCTION OF TEMPERATURE

APPENDIX C

PRIMARY COOLANT NODE DESCRIPTIONS

Core Nodes (1-4)



1. Volume

R. L. Drexler's LOFT Volume Notes 4-17-79 give the volume for the 3 RELAP core nodes (53, 54, and 55) as:

53	3.3653
54	3.3843
55	3.3923
Total	10.1419 ft^3

Water volume per LOFT node = 2.5355 ft^3

2. Heat Capacity

$$C_p = c_p \rho V$$

$$= (1.3191)\ (45.1467)\ (2.5355)$$

$$= 151.00\ \text{Btu}/^{o}\text{F}$$

3. Wall Heat Capacity

The heat capacity of the core cladding is accounted for by the core thermal model, Section 2.4.

4. Heat Transfer Surface Area

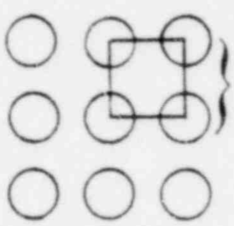
$A = 789.93\ ft^2$ (Reference 6, Table V)

Area per node = $197.48\ ft^2$

5. Heat Transfer Across Film

$$h_{DB} = 0.023\frac{k}{D_H}\ R_e^{0.8}\ P_r^{0.4}$$ (Reference 7 Section 6.115)

D_H - hydraulic diameter = $4\ \frac{\text{flow area}}{\text{wetted perimeter}}$ (Reference 7)



fuel pin pitch = 0.563 inches (Reference 6 Table III)

flow area = $0.563^2 - \frac{\pi}{4}\ (0.422^2) = 0.1771\ \text{inches}^2$

perimeter = $\pi(0.422) = 1.3258$ inches

D_H = 0.5343 inches = 0.04453 ft

Reynolds Number

$$Re = \frac{\rho v\ D_H}{\mu} = \frac{\rho\ \dot{V}\ D_H}{A\mu}$$

$\dot{V}$ = reference flow = $30.7640\ ft^3/sec$

R. L. Drexler's Notes 4-17-79 give the following flow cross sections for the 3 RELAP core nodes (53, 54, and 55):

53	1.8460 ft^2
54	1.8356 Ft^2
55	1.8504 ft^2
Average A =	1.8440 ft^2

Water properties from ASME 1967 Steam tables
2250 psia and 575°F

$\rho = 45.1467\ lbm/ft^3$

$$\mu = 19.0875 \times 10^{-7}\ \frac{lbf \times sec}{ft^2} \times 32.17\ ft^2/sec = 6.1404 \times 10^{-5} lbm/ft$$

$k = 0.3201$ Btu/hr.ft.°F = 88.9167×10^{-6} Btu/sec.ft.°F

$P_r = 0.9292$

$$Re = (45.1467)\left(\frac{30.7640}{1.8440}\right)(.04453)\left(\frac{1}{6.1404 \times 10^{-5}}\right) = 546{,}215$$

$$h_{DB} = (0.023)\frac{(88.9167 \times 10^{-6})}{(0.04453)}(546{,}215)^{0.8}(0.9292)^{0.4}$$

$$= 1.7346 \text{ Btu/sec} \cdot \text{ft}^2 \cdot {}^{\circ}\text{F}$$

$H_{DB} = (1.7346)(197.48) = 342.55$ Btu/sec°F per node

6. Structure Heat Transfer

Thermal conductivity

$$k = 7.51 + 2.09 \times 10^{-2}\, T - 1.45 \times 10^{-5}\, T^2 + 7.67 \times 10^{-9}\, T^3$$

k in W/m °K and T in °K

assume $T_{clad} = 655°F$: $\frac{655-32}{1.8} + 273.18 = 619.29°K$

$k = 16.7138$ W/m°K = 9.6571 Btu/hr ft°F

Diameter = 0.422 inches (Reference 6, Table III)

Thickness = 0.0243 inches

$$r_1 = 0.211 - \frac{0.0243}{2} = 0.19885$$

$$K = \frac{2\pi\, k\, h}{\ln \frac{r_2}{r_1}} N = \frac{(2\pi)(9.6571)\left(\frac{1}{3600}\right)(5.5)}{\ln \frac{0.211}{0.19885}}(1300)$$

K = 2031.99 Btu/sec °F

= 508.00 Btu/sec °F per node

(The simulation uses the value specified in the input array for this coefficient.)

7. Height

182.925 - 116.925 = 66"

= 5.5 ft

= 1.3750 ft per node

Steam Generator Tube Nodes (5-14)

1. Volume

Dimensions from Reference 6 Table XII
Average tube length = 14.93 ft
Tube outside diameter = 0.50 inches
Nominal wall thickness = 0.049 inches
Number of Tubes = 1845

$$V = \frac{\pi}{4} D^2 LN = \frac{\pi}{4} (0.50 - 2x0.049)^2 / 12^2 \times (14.93) \times (1845)$$

$$= 24.2793 \text{ ft}^3$$

$$= 2.4279 \text{ ft}^3 \text{ per node}$$

2. Heat Capacity

$$C_p = \rho V c_p = (45.1467)(2.4279)(1.3191)$$

$$= 144.59 \text{ Btu/}^oF$$

3. Wall Heat Capacity

The heat capacity of the steam generator secondary is accounted for in the steam generator model, Section 6.1.

4. Heat Transfer Surface Area

$$A = \pi DLN = \pi (0.402)/12 \times (14.93) \times (1845)$$

$$= 2899.0 \text{ ft}^2$$

$$= 289.90 \text{ ft}^2 \text{ per node}$$

5. Heat Transfer Across Film

Reynolds Number

$$Re = \frac{\rho \dot{V} D_H}{A \mu} = \frac{\rho \dot{V}_{ref} D}{A \mu} = \frac{\rho \dot{V}_{ref}}{\frac{\pi}{4} D \mu}$$

$$Re = \frac{4(45.1467 \text{ lbm/ft}^3)(30.7640 \text{ ft}^3\text{/sec})}{\pi (0.0335 \text{ ft})(1845)(6.1404 \times 10^{-5} \text{lbm/ft-sec})}$$

$$= 465,985$$

Dittus Boelter Heat Transfer Correlation

$$h_{DB} = .023 \frac{k}{D_H} Re^{0.8} Pr^{0.4}$$

$$= (.023) \frac{(88.9167 \times 10^{-6})}{0.0335} (465,985)^{0.8} (0.9292)^{0.4} = 2.0305 \text{ Btu/sec ft}^2 \,^oF$$

H_{DB} = (2.0305) (289.90) = 588.64 Btu/sec °F

6. Structure Heat Transfer

Heat transfer across tube for cylindrical geometry = $\frac{2\pi \; k \; L \; N}{\ln \; (r_o/r_i)}$

k for Inconel 600 = 10.8 Btu/hr·ft·°F

= 0.003 Btu/sec·ft·°F Reference 6 Table XII

$$K = \frac{2\pi \; (0.003) \; (14.93) \; (1845)}{\ln \frac{0.500}{0.402}} = 2380.1 \text{ Btu/sec}^oF$$

Assume the heat transfer coefficient across the secondary film

= 6000 Btu/hr·ft²·°F (See Reference 17)

Tube Area - Secondary Side

$$A = \pi \; D \; L \; N = \pi \; (\frac{.5}{12}) \; (14.93)(1845)$$

$$= 3605.7 \text{ ft}^2$$

$$\text{Total heat conductivity} = \left(\frac{1}{K} + \frac{1}{H_{Boil}} \right)^{-1}$$

$$= \left(\frac{1}{2380.1} + \frac{1}{\frac{6000}{3600} \times 3605.7} \right)^{-1} = 1704.9 \text{ Btu/sec}^oF$$

$$= 170.49 \text{ Btu/sec}^oF\text{/node}$$

(The simulation use the value specified in the input array for this coefficient.)

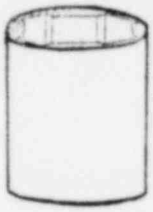
7. Height

Max height	107.5"		(Reference. 6 Table XV)
Min height	84.5"		
	192"	÷ 2	= 96" - 11.5" (height of tube sheet)

= 84.5" = 7.0417 ft

= 1.4083 ft/node

Upper Plenum Nodes 15 and 16



— STA 248.580

— STA 235.393 (transition from intermediate to upper flow skirt)

— STA 182.925

1. Volume

Drexler's upper plenum volume notes 2-21-79 starting on pg 747

Intermediate flow skirt area = 473.050 in^2

Upper flow skirt area = 473.481 in^2

(neglect bypass channels)

Total Volume = (235.393-182.925) 473.05 + (248.580-235.393) 473.481 = 31064 in^3 = 17.9769 ft^3

Page 807

Total displacement from 182.925 to 258.406 = 8408 in^3

To adjust these displacement for our smaller volume

$$8408 \frac{248.580 - 182.925}{258.406 - 182.925} = 7313.5 \text{ in}^3 = 4.2323 \text{ ft}^3$$

Water volume = 17.9769
−4.2323

13.7449 ft^3 = 6.8725 ft^3 per node

Internal Structure Volume

4.2323 ft^3 = 2.1162 ft^3 per node

2. Heat Capacity

C_p = (43.5777) (6.8725) (1.4058) + (495) (2.1162) (0.11)

= 536.25 Btu/°F

3. Wall Heat Capacity

Height = 248.58 - 182.925 = 65.655 in = 5.4713 ft

Average cross section area = $\frac{17.9769}{5.4713}$ = 3.2857

equiv dia D = $2\sqrt{\frac{2.3857}{\pi}}$ = 2.0454 ft

assume core filler is 0.75" thick - adds 1.5" to dia = 0.1250 ft

$V = \frac{\pi}{4}(2.1704^2 - 2.0454^2)\ 5.4713 = 2.2645\ ft^3$

$= 1.1323\ ft^3$ per node

$C_p = (1.1323)\ (495)\ (0.11) = 61.6537\ Btu/^oF$

4. Heat Transfer Surface Area

$A = \pi\ D\ h = \pi\ (2.0454)\ (5.4713)$

$= 35.1576\ ft^2$

$= 17.5788\ ft^2$ per node

5. Heat Transfer Across Film

Reference 7 Section 6.117

$h_{DB} = 0.148\ (1 + 10^{-2}T - 10^{-5}T^2)\ \frac{v^{0.8}}{D^{0.2}}$, v in ft/hr and D in ft

$h_{DB} = (0.5046)\ \frac{v^{0.8}}{D^{0.2}}$ for $T = 595^oF$

flow area (RLD's summary sheet) = $2.5956\ ft^2$

$v = \frac{\dot{V}_{ref} \times 3600}{\text{flow area}} = \frac{30.7640 \times 3600}{2.5956} = 42{,}669$ ft/hr

$h_{DB} = (0.5046)\ \frac{(42{,}669)^{0.8}}{(2.0454)^{0.2}} = 2212.5\ Btu/hr\ ft^2\ ^oF$

$= 0.6146\ Btu/sec\ ft^2\ ^oF$

$H_{DB} = (0.6146)\ (17.5788) = 10.8039\ Btu/sec\ ^oF$

6. Structure Heat Transfer

k for stainless steel = 14 Btu/hr ft °F

= 0.003889 Btu/sec ft °F

let L = 1/4 the thickness of the slab

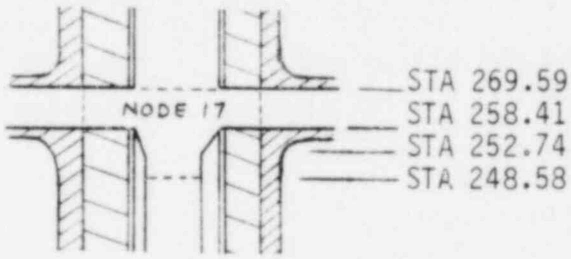
$$= 1/4 \frac{0.75}{12} = 0.01563 \text{ ft}$$

$$K = \frac{k\ A}{L} = \frac{(0.003889)\ (17.5788)}{0.01563} = 4.3739 \text{ Btu/sec } ^{o}F$$

7. Height

5.4713 ft = 2.735 ft per node

Upper Plenum Outlet Region - Node 17



1. Volume

R. L. Drexler's reactor vessel volume notes

From 248.58 to 252.74
cross section area = 479.91 inches^2 (pg 754)
volume = (479.91) (252.74 - 248.58) = 1996.4 in^3 = 1.1553 ft^3

From 252.74 to 258.41 (transition area) (pg 806)

volumes 628.0 in^3
645.0 in^3
1260.0 in^3
609.9 in^3

3142.9 in^3 = 1.8188 ft^3

From 258.41 to 269.59 (zone 2) (pg 803)

volume = 9967.9 in^3 = 5.7685 ft^3

Total volume = 8.7426 ft^3

zone 2 displacement = 1234 in^3 = 0.7141 ft^3 (pg 803)

zone 1 displacement which was not included in nodes 15 and 16

= 8408.0-7313.5 = 1094.5 in^3 = 0.6334 ft^3

Total displacement = 1.3475 ft^3

Water volume = 7.3951 ft^3

2. Heat Capacity

C_p = (43.5777) (7.3951) (1.4058) + (495) (1.3475) (0.11) = 526.41 Btu/^{o}F

3. Heat Transfer Surface Area

The node is approximated by 3 cylinders

Volume of nozzles = 3075.4 in^3 (includes both nozzles) (pg 802)

= 1.7797 ft^3

Length of nozzles = 1/2 (57.615-28.007)

= 14.8040 in

Nozzle diameter = 11.5"

Surface area of each nozzle = πDL

= π (14.8040) (11.5) = 534.84 in^2

= 3.7142 ft^2

volume of node	8.7426
less volume of nozzles	1.7797
Volume of barrel	6.9629 ft^2

Height = 21.01" = 1.7508 ft
ave barrel cross section = 3.9770 ft^2

equiv dia = $2\sqrt{\frac{A}{\pi}}$ = 2.2503 ft

barrel surface area = πDh = 12.3773 ft^2

less area of nozzle = $\frac{\pi}{4} D^2 \times 2$ = 1.4426 ft^2

10.9347 ft^2

Total surface area 10.9347
3.7142
3.7142

18.3631 ft^2

4. Wall Heat Capacity

Assume surface is a slab 0.75" thick

$V = 18.3631\ ft^2 \times \frac{0.75}{12}\ ft = 1.1477\ ft^3$

C_p = (1.1477) (495) (0.11) = 62.4923 Btu/sec°F

5. Heat Transfer Across Film

h_{DB} (same as nodes 15 and 16) = 0.6146 Btu/sec ft^2 ^oF
H_{DB} = (0.6146) (18.3631) = 11.2860 Btu/sec ^oF

6. Structure Heat Transfer

L = 0.01563 ft (same as nodes 15 and 16)
A = 18.3631 ft^2
k = .003889 Btu/sec ft^2 ^oF

$\frac{kA}{L}$ = 4.5690 Btu/sec ^oF

7. Height

21.01" = 1.7508 ft

Upper Plenum Bypass - Node 18

Node extends from the top of the nozzles (STA 269.59) to the top of the CRDM's.

1. Volume

R. L. Drexler's notes

Water Volume = 12.30 ft^3 (page 821)

Displacements	32,224 in^3		= 18.6481 ft^3 (pg 785)
less spacers	4635 in^3 (pg 785)		
and fillers	6614 in^3		
	2555 in^3		
	13,804 in^3		= 7.9884 ft^3
Internal structure volume			10.6597 ft^3

2. Heat Capacity

$$C_p = (43.5777)(12.30)(1.4058) + (495)(10.6597)(0.11) = 1333.94 \text{ Btu/}^\circ\text{F}$$

3. Heat Transfer Surface Area

Assume a cylinder which extends from 269.59 to 300.00.

Height = 30.41" = 2.5342 ft

Active Volume = Envelope - Spacers

= 37336 - 13804 (pg 821)

= 23532 in^3 = 13.6181 ft^3

$$\text{Equiv dia} = 2\sqrt{\frac{V}{\pi h}} = 2\sqrt{\frac{13.6181}{\pi\ 2.5342}} = 2.6157 \text{ ft}$$

$$\text{Surface area} = \pi dh + \frac{\pi}{4} d^2 = 26.1983 \text{ ft}^2$$

4. Wall Heat Capacity

Assume 2" slab

$$V = 26.1983 \text{ ft}^2 \times \frac{2}{12} \text{ ft} = 4.3664 \text{ ft}^3$$

$C_p = (495)\ (4.3664)\ (0.11) = 237.75$ Btu/°F

5. Heat Transfer Across Film

Assume flow channel equals half of available free space.

$$\frac{\text{Structure vol}}{\text{Active vol}} = \frac{10.6597}{13.6181} = 78.28 \text{ percent of the volume is blocked.}$$

$$\text{Flow channel area} = (1-.7828) \times 1/2 \times \text{cross section} = \frac{0.2172}{2} \times \frac{\pi}{4} \times 2.6157^2$$

$$= 0.5836 \text{ ft}^2$$

$$D = 2\sqrt{\frac{0.58326}{\pi}} = 0.8620 \text{ ft}$$

$$h_{DB} = (0.5046)\frac{v^{0.8}}{D^{0.2}}, \quad v = \frac{30.7640 \times 3600}{0.5836}$$

$h_{DB} = 8678.2$ Btu/hr ft^2 °F $= 2.4106$ Btu/sec ft^2 °F

$H_{DB} = (2.4106)\ (26.1983) = 63.1536$ Btu/sec °F

6. Surface Heat Transfer

assume 2" slab

$$L = \frac{1}{4}\ \frac{2}{12} = 0.04167$$

$A = 26.1983$

$k = 0.003889$ Btu/sec ft °F

$\frac{kA}{L} = 2.4450$ Btu/sec °F

Hot Leg Nodes 19-23

1. Volume

These nodes correspond to RELAP Nodes 3, 4, 5, and 6.
From R. L. Drexler's loop volumes notes:

Node	Vol	÷	Flow Area	=	Length
3	2.92940		0.6827		4.2909
4	6.03149		0.6827		8.8348
5	3.27072		0.6827		4.7909
6	1.55642		0.8953		1.7384
	$13.78803\ ft^3$				19.6550 ft

$$\text{vol/node} = 2.7576\ ft^3$$

$$\text{eqv. dia} = 2\sqrt{\frac{V}{\pi L}} = 0.9451\ ft$$

2. Heat Capacity

$$C_p = (43.5777)\ (2.7576)\ (1.4058) = 168.93\ Btu/^oF$$

3. Wall Heat Capacity

14" Sch 160 pipe thickness 1.4" = 0.1167 ft outside dia = 1.1784 ft

$$V = \frac{\pi}{4}\ (1.1784^2 - 0.9451^2)\ (19.6550) = 7.6477\ ft^3$$

$$\text{vol/node} = 1.5295\ ft^3$$

$$C_p = (1.5295)\ (495)\ (0.11) = 83.2813\ Btu/^oF$$

4. Heat Transfer Area

$$\pi DL = 58.3580\ ft^2$$

$$\text{area/node} = 11.6716\ ft^2$$

5. Heat Transfer Across Film

$$h_{DB} = \frac{0.5046}{D^{0.2}}\ v^{0.8};\ v = \frac{30.7640 \times 3600}{\frac{\pi}{4}\ (0.9451)^2},\ \ D = 0.9451$$

$h = 7353.5$ Btu/hr ft^2 ^oF = 2.0426 Btu/sec ft^2 ^oF

$H_{DB} = (2.0426)\ (11.6716) = 23.8404$ Btu/sec ^oF

6. Heat Transfer Across Surface

$$\frac{kA}{L} = \frac{(0.003889)\ (11.6716)}{\frac{1}{4}\ \left(\frac{1.4}{12}\right)} = 1.5563 \text{ Btu/sec } ^oF$$

Steam Generator Inlet and Outlet Plenums - Nodes 24 and 27

1. Volume

   11.8447 ft^3 (Reference 6 Table XV)

2. Heat Capacity

   Hot leg
   C_p = (43.5777) (11.8447) (1.4058) = 725.62 Btu/°F

   Cold leg
   C_p = (46.5333) (11.8447) (1.2577) = 693.21 Btu/°F

3. Heat Transfer Surface Area

   Assume S/G plenums are sections of a sphere.

   eqv. dia:

   $$1/4\left(\frac{4}{3}\pi r^3\right) = 11.8447$$

   r = 2.2447 ft

   1/4 area of sphere = $1/4\ \pi D^2 = \pi r^2$ = 15.8295 ft^2
   (Tube sheet surface is included in next node.)

   Assume partition surface and piping opening areas cancel.

4. Wall Heat Capacity

   Assume 2" slab

   15.8295 $ft^2 \times \frac{2}{12}$ ft = 2.6383 ft^3 (Use C_p for stainless steel neglect Inconel clad.)

   C_p = (2.6383) (495) (0.11) = 143.66 Btu/°F

5. Heat Transfer Across Film

   Hot leg
   $$h_{DB} = \frac{0.5046}{D^{0.2}} v^{0.8}$$

   use average v and D

   $$v \text{ in tubes} = \frac{30.7640 \times 3600}{\frac{.127}{144} \times 1845} = 68,062 \text{ ft/hr}$$

   (.127 ← Reference 6 Table XV)

$$v_{inlet\ pipe} = \frac{30.7640 \times 3600}{.8955} = 123,674 \text{ ft/hr}$$

16" sch 160 pipe

v_{ave} = 95,868 ft/hr

$$95,868 = \frac{30.7640 \times 3600}{\frac{\pi}{4} D^2}$$

D = 1.2128 ft

$$h_{DB} = \frac{0.5046}{(1.2128)^{0.2}} (95868)^{0.8} = 4693.8 \text{ Btu/hr ft}^2 \, ^oF$$

$$= 1.3038 \text{ Btu/sec ft}^2 \, ^oF$$

H_{DB} = (1.3038) (15.8295) = 20.6385 Btu/sec^{o}F

Cold leg

$$h_{DB} = 0.148 \left(1 + \frac{T}{10^2} - \frac{T^2}{10^5}\right) \frac{v^{0.8}}{D^{0.2}}$$

$$h_{DB} = 0.5135 \frac{v^{0.8}}{D^{0.2}} \text{ for } T = 555^oF$$

$$v = \frac{V_{ref}}{\frac{\pi}{4} D^2}$$

$$\frac{v^{0.8}}{D^{0.2}} = \left(\frac{4V_{ref}}{\pi}\right)^{0.8} \frac{1}{D^{1.8}}$$

$$h_{DB} = 0.5135 \left(\frac{4}{\pi} 30.7640 \times 3600\right)^{0.8} \frac{1}{D^{1.8}}$$

$$h_{DB} = \frac{6760.0}{D^{1.8}} \text{ Btu/hr ft}^2 \, ^oF = \frac{1.8778}{D^{1.8}} \text{ Btu/sec ft}^2 \text{ F}$$

for D = 1.2128 ft

h_{DB} = 1.3269 Btu/sec ft^2 ^{o}F

H_{DB} = (1.3269) (15.8295) = 21.0042 Btu/sec^{o}F

6. Structure Heat Transfer

k for Inconel = 0.003 Btu/sec ft °F

$L = 1/4 \frac{2}{12} = .04167$ ft

$\frac{kA}{L} = 1.1396$ Btu/sec °F

7. Height

2'7" (Ref. 6, Fig. 87 Section AA) = 2.5833 ft

Steam Generator Tube Sheet Nodes 25 and 26

1. Volume

$3.12\ ft^3$ (Reference 6 Table XV)

Volume per node = $1.56\ ft^3$

2. Heat Capacity

Hot leg

$C_p = (43.5777)\ (1.56)\ (1.4058) = 95.5680\ Btu/^oF$

Cold leg

$C_p = (46.5333)\ (1.56)\ (1.2577) = 91.2939\ Btu/^oF$

3. Heat Transfer Surface Area

(Dimensions from Reference 6, Table XV)

Tube OD	0.50"
Thickness	0.049"
Number of tubes	1845
Thickness of tube Sheet	11.5"

tube ID = (.500 - 2 x 0.049) = 0.402"

$$A = \pi DhN = \frac{\pi\ (0.402)\ (11.5)\ (1845)}{144} = 186.08\ ft^2$$

4. Wall Heat Capacity

Tube bundle dia 48" (Reference 6 Table XV)

$$V = 1/2\ (\frac{\pi}{4}\ D^2 h\ ) - V_{Tubes} = 1/2 \left[\frac{\pi}{4}\ (\frac{48}{12})^2\ \frac{11.5}{12}\right] - 1.5600$$

$$= 4.4614\ ft^3$$

$C_p = (495)\ (4.4614)\ (0.11) = 242.92\ Btu/^oF$

5. Heat Transfer Across Film

Hot Leg

$$h_{DB} = (.5046)\ \frac{V^{0.8}}{D^{0.2}}$$

v in tubes from node 24 calculations = 68,062 ft/hr

$D = \frac{0.402"}{12} = 0.03350$ ft

h_{DB} = 7315.8 Btu/hr ft^2 ^{o}F = 2.0322 Btu/sec ft^2 ^{o}F

H_{DB} = (2.0322) (186.08) = 378.15 Btu/sec^{o}F

Cold Leg

$$h_{DB} = \frac{(0.5135)}{3600} \frac{v^{0.8}}{D^{0.2}} = 2.0680 \text{ Btu/sec ft}^2 \ ^oF$$

H_{DB} = (2.0680) (186.08) = 384.81 Btu/sec^{o}F

6. Structure Heat Transfer

Area of tube sheet on inlet side $= 1/2 \ \frac{\pi}{4} \ D^2$

$$= \frac{\pi}{8} \left(\frac{48}{12}\right)^2 = 2\pi = 6.2832 \text{ ft}^2$$

Equivalent area surrounding each tube $= \frac{6.2832}{1845}$

$= 0.003406$ ft^2 $= 0.4905$ in^2

Equivalent diameter $= 2\sqrt{\frac{0.4905}{\pi}} = 0.7903$ in

k for Inconel = 0.003 Btu/sec ft ^{o}F

$$K = \frac{2\pi k h N}{\ln \frac{d_2}{d_1}} = \frac{2\pi (0.003) \frac{11.5}{12} N}{\ln \frac{0.7903}{0.402}} = 49.3052 \text{ Btu/sec } ^oF$$

7. Height

11.5" = .9583 ft

Cold Leg Nodes 28-31

1. Volume

These nodes correspond to RELAP nodes 12, 13, and 14. R. L. Drexler's loop volume notes.

Node	Vol	÷	Flow Area	=	Length
12	2.021910		0.895285		2.2584
13	3.947661		0.682704		5.7824
14	6.035087		0.682704		8.8400
	12.004658				16.8808

vol/node = 3.0012 ft^3

2. Heat Capacity

$C_p = (46.5333)\ (3.0012)\ (1.2577) = 175.65$ Btu/°F

3. Heat Transfer Surface Area

eqv. dia $= 2\sqrt{\frac{V}{\pi L}} = 0.9516$ ft

$A = \pi dL = 50.4658\ ft^2$

$= 12.6165\ ft^2$ per node

4. Wall Heat Capacity

14" sch 160 pipe thickness = 0.1167 ft
outside diameter = 0.95156 + 2(0.1167) = 1.1850 ft

$V = \frac{\pi}{4}\ (1.1850^2 - 0.9516^2)\ (16.8808) = 6.6116\ ft^3$

$= 1.6529\ ft^3$ per node

$C_p = (495)\ (1.6529)\ (0.11) = 90.0004$ Btu/°F

5. Heat Transfer Across Film

$h_{DB} = \frac{1.8778}{D^{1.8}} = 2.0532$ Btu/sec ft^2 °F

$H_{DB} = (2.0532)\ (12.6165) = 25.9042$ Btu/sec°F

6. Structure Heat Transfer

$$\frac{kA}{L} = \frac{(0.003889)\ (12.6165)}{\frac{1}{4}\ (\frac{1.4}{12})} = 1.6822 \text{ Btu/sec } ^{o}F$$

7. Height

Reference 6, Figure 83 and Table XIII

drop =	1' 2" 1' 8" 2' 10"	= 2.8333 ft	node 28
rise	1' 1" 1' 0" 2' 1"	= 2.0833 ft	node 31

Primary Coolant Pumps Nodes 32 and 33

These nodes are not connected in parallel as are the actual PCP's. The properties of the pumps are lumped together and then split into two equal nodes in series.

1. Volume

$3.5\ ft^3$ per node (Reference 6 Table XVII)

2. Heat Capacity

C_p = (46.5333) (3.5) (1.2577) = 204.8373 Btu/°F

3. Heat Transfer Surface Area

Assume the volume is contained in a 10" pipe

of inside diameter = 0.7 ft
and outside diameter = 0.9 ft

$$A = \pi DL; \quad L = \frac{V}{\frac{\pi}{4} D^2} = 9.0946 \text{ ft}$$

$$A = 4 \frac{\pi DV}{\pi D^2} = 4 \frac{V}{D} = 4 \frac{3.5}{0.7} = 20.0000 \text{ ft}^2$$

4. Wall Heat Capacity

$$V = \frac{\pi}{4} (0.9^2 - 0.7^2) (9.0946) = 2.2857 \text{ ft}^3$$

C_p = (495) (2.2857) (0.11) = 124.46 Btu/°F

5. Heat Transfer Across Film

$$h_{DB} = \frac{1.8778}{D^{1.8}} \times (0.5)^{0.8} = 2.0495$$

($(0.5)^{0.8}$) accounts for the flow split

H_{DB} = (2.0495) (20.0000) = 40.9900 Btu/sec °F

6. Structure Heat Transfer

$$\frac{kA}{L} = \frac{(0.003889)\ (20.0000)}{\frac{1}{4}\ 0.1} = 3.1112\ \text{Btu/sec}\ ^{o}F$$

7. Height

Assume 9" rise (0.75 ft). This accounts for the difference in the cold leg piping so that the net elevation change equals zero.

Cold Leg Nodes 34-37

1. Volume

These nodes correspond to RELAP nodes 17 thru 21.

R. L. Drexler's Loop Volume Notes

Node	Vol	÷	Flow Area	=	Length
17	1.553076		0.394063		3.9412
18	0.515827		0.394063		1.3090
19	6.463449		0.682704		9.4674
20	1.348992		0.682704		1.9760
21	1.572665		0.682704		2.3036
	11.454009				18.9972

vol/node = 2.8635 ft^3

2. Heat Capacity

C_p = (46.5333) (2.8635) (1.2577) = 167.59 Btu/°F

3. Heat Transfer Surface Area

$$\text{eqv. dia} = 2\sqrt{\frac{V}{\pi L}} = 0.8762$$

$$A = \pi DL = 52.2929 \text{ ft}^2$$

$$= 13.0732 \text{ ft}^2 \text{ per node}$$

4. Wall Heat Capacity

14" sch 160 pipe thickness = 0.1167 ft
outside dia = 0.8762 + 2 (0.1167) = 1.1096 ft

$$V = \frac{\pi}{4} (1.1096^2 - 0.8762^2) (18.9972)$$

$$= 6.9154 \text{ ft}^3$$

vol/node = 1.7289 ft^3

C_p = (495) (1.7289) (0.11) = 94.1386 Btu/°F

5. Heat Transfer Across Film

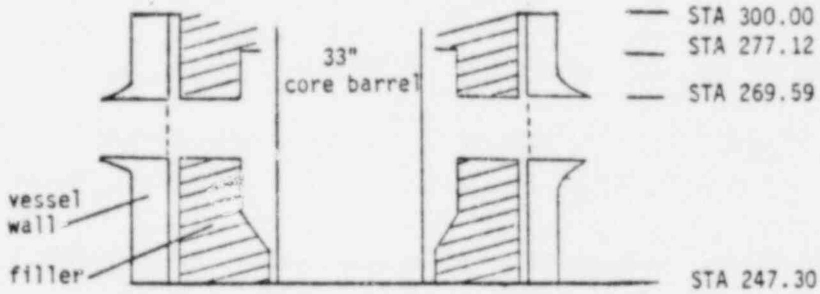
$$h_{DB} = \frac{1.8778}{D^{1.8}} = 2.3821 \text{ Btu/sec ft}^2\ {}^oF$$

$$H_{DB} = (2.3821)\ (13.0732) = 31.1417 \text{ Btu/sec } {}^oF$$

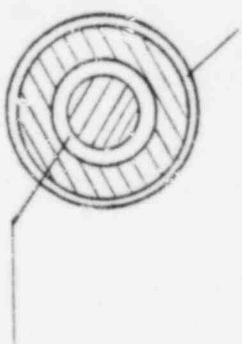
6. Structure Heat Transfer

$$\frac{kA}{L} = \frac{(.003889)\ 13.0732}{\frac{1}{4}\ 0.1167} = 1.7426 \text{ Btu/sec } {}^oF$$

Reactor Vessel Flow Distributor Node 38



This node is modeled as two concentric annuluses and corresponds to RELAP nodes 22 and 25.



Annulus between vessel ID and filler

From R. L. Drexlers notes:

flow area = 0.31334 ft^2
height = 52.70" = 4.3917 ft
ave. dia = (57.2 + 57.7)/2
= 57.45" = 4.7875 ft
vol = (0.31334)(4.3917)
= 1.3761 ft^3

Distributor ring

Height = (277.12 - 247.30) = 29.82" = 2.4850 ft

ID = 33" = 2.7500 ft

Define OD such that vol = 9.6515 - 1.3761 = 8.2754 ft^3

$$V = \frac{\pi}{4} (OD^2 - ID^2) h$$

$$OD = \sqrt{\frac{4V}{\pi h} + ID^2} = \sqrt{\frac{4\ (8.2754)}{\pi\ 2.4850} + 2.7500} = 3.4355 \text{ ft}$$

$$\text{flow area} = \frac{V}{h} = \frac{8.2754}{2.4850} = 3.3301 \text{ ft}^2$$

1. Volume

R. L. Drexler's notes 4-17-79 give the volume as 9.6515 ft^3

2. Heat Capacity

C_p = (46.5333) (9.6515) (1.2577) = 564.85 Btu/°F

3. Heat Transfer Surface Area

Outer Annulus

$$A = 2\pi Dh = 2\pi (4.7875)(4.3917) = 132.11\ ft^2$$

Distributor Ring

$$A = \pi (OD) h + \pi (ID) h$$

$$A = \pi (3.4355)(2.4850) + \pi (2.7500)(2.4850)$$

$$A = 26.8205 + 21.4689 = 48.2894\ ft^2$$

4. Wall Heat Capacity

Assume 2" slab except for core barrel which is only 1.5" thick.

$$\left(\frac{2}{12}\right)(132.11 + 26.8205) + \left(\frac{1.5}{12}\right)(21.4689) = 29.1720\ ft^3$$

C_p = (29.1720) (495) (0.11) = 1588.4 Btu/°F

5. Heat Transfer Across Film

$$v = \frac{\dot{V}_{ref} \times 3600}{0.31334 + 3.3301} = 3(,397\ ft/hr$$

Outer Annulus

$$D_H = 4\frac{area}{perim} = 4\frac{0.31334}{2\pi\, 4.7875} = 0.04167\ ft$$

$$h_{DB} = \frac{0.5135}{3600}\ \frac{v^{0.8}}{D_H^{0.2}} = 1.0388\ Btu/sec\ ft^2\ °F$$

Distributor ring

$$D_H = 4 \frac{3.3301}{\pi (2.7500 + 3.4355)} = 0.6855 \text{ ft}$$

$$h_{DB} = \frac{0.5135}{3600} \frac{v^{0.8}}{D^{0.2}} = 0.5933 \text{ Btu/sec ft}^3 \, ^oF$$

$$H_{DB} = (132.11)(1.0388) + (48.2894)(0.5933) = 165.89 \text{ Btu/sec } ^oF$$

6. Structure Heat Transfer

$$\frac{kA}{L} = \frac{(0.003889)}{\left(\frac{1}{4}\right)\left(\frac{1}{12}\right)} \left(\frac{158.93}{2} + \frac{21.4689}{1.5}\right) = 17.5057 \text{ Btu/sec}^o \text{ F}$$

7. Height

269.59" - 247.30" = 22.29" = 1.8575 ft

Downcomer Nodes 39-43

These nodes include the downcomer and outer annulus between station 247.30 and 96.437. These correspond to RELAP4 nodes 23, 24, 26, and 27. See Reference 6, Figure 78 for geometry.

1. Volume

From R. L. Drexler's Reactor Vessel Volume notes.

2 x 5.8104	(nodes 23 and 26)
+ 2 x 6.8762	(nodes 24 and 27)
25.3732 ft^3	

vol/node = 5.07?6 ft^3

2. Heat Capacity

C_p = (46.5333) (5.0746) (1.2577) = 296.99 Btu/°F

3. Heat Transfer Surface Area

These nodes are modeled similar to Node 38.

Outer Annulus	height	=	150.863" = 12.5719 ft
	vol	=	(0.31334) (12.5719) = 3.9393 ft^3
	area	=	2π (4.7875) (12.5719) = 378.17 ft^2
Downcomer	Vol	=	25.3732 - 3.9393 = 21.4339 ft
	OD	=	$\sqrt{\frac{4V}{\pi h} + ID^2}$ = 3.1198 ft
	A	=	π (3.1198) (12.5719) + π (2.7500) (12.5719)
		=	123.22 + 108.61 = 231.83 ft^2

4. Wall Heat Capacity

Assume 2" slab except for core barrel which is only 1.5" thick.

$$\left(\frac{2}{12}\right) (378.17 + 123.22) + \frac{1.5}{12} (108.61) = 97.1413 \ ft^3$$

C_p = (495) (97.1413) (0.11)/5 = 1057.87 Btu/°F

5. Heat Transfer Across Film

h_{DB} in annulus same as node 38 = 1.0388 Btu/sec ft^2 ^oF

Downcomer

flow area = $\frac{V}{h}$ = 1.7049 ft^2

$$v = (30397)\ \frac{3.3301}{1.7049} = 59373 \text{ ft/hr}$$

$$D_H = 4\ \frac{1.7049}{\pi\ (2.7500 + 3.1198)} = 0.3698$$

$$h_{DB} = \frac{0.5135}{3600}\ \frac{v^{0.8}}{D^{0.2}} = 1.1469 \text{ Btu/sec ft}^2\ {}^oF$$

$$H_{DB} = \left[(378.17)\ (1.0388) + (231.83)\ (1.1469)\right] /5 = 131.75 \text{ Btu/sec } {}^oF$$

6. Structure Heat Transfer

$$\frac{kA}{L} = \frac{0.003889}{\left(\frac{1}{4}\right)\left(\frac{1}{12}\right)} \left[\frac{501.39}{2} + \frac{108.61}{1.5}\right] = 60.3140 \text{ Btu/sec } {}^oF$$

12.0628 Btu/sec ^oF per node

7. Height

12.5719 / 5 = 2.5144 ft

Lower Plenum Nodes 44-46

These nodes are modeled as a cylinder of diameter 37". They correspond to RELAP volumes 28 and 29.

1. Volume

From R. L. Drexler's Reactor Vessel Volume notes

28	18.96
29	4.7609
Total Vol.	23.7209 ft^3
	= 7.9070 ft^3 per node

2. Heat Capacity

C_p = (46.5333) (7.9070) (1.2577) = 462.76 Btu/°F

3. Heat Transfer Surface Area

$$\text{Cross section area} = \frac{\pi}{4} D^2 = 7.4667 \text{ ft}^2$$

$$\text{Eqv height} = \frac{V}{A} = \frac{23.7209}{7.4667} = 3.1769 \text{ ft}$$

$$\text{Wall area} = \pi Dh = 30.7733 \text{ ft}^2$$

$$\text{Total area} = 38.2400 \text{ ft}^2$$

$$= 12.7467 \text{ ft}^2 \text{ per node}$$

4. Wall Heat Capacity

Assume 2" slab

$$V = 12.7467 \times \frac{2}{12} = 2.1245 \text{ ft}^3$$

$$C_p = (2.1245)\ (495)\ (0.11) = 115.68 \text{ Btu/}^\circ\text{F}$$

5. Heat Transfer Across Film

$$h_{DB} = \frac{1.8778}{D^{1.8}} = 0.2474 \text{ Btu/sec ft}^2 \, {}^oF$$

$$H_{DB} = (0.2474)\ (12.7467) = 3.1535 \text{ Btu/sec}{}^oF$$

6. Structure Heat Transfer

$$\frac{kA}{L} = \frac{(0.003889)\ (12.7467)}{\frac{1}{4}\left(\frac{2}{12}\right)} = 1.1897 \text{ Btu/sec } {}^oF$$

7. Height

$$\begin{array}{r} 116.925 \\ \underline{-96.437} \\ 20.488" \end{array} = 1.7073 \text{ ft lumped into node 46}$$

RABV Nodes 47 and 50

Each of these nodes includes the volume from the reactor vessel nozzle to the 14x14x10 tee.

1. Volume

Volume of reactor vessel nozzle and 45 elbow	1.8284 ft^3	(R. L. Drexler's notes)
Volume of tee	1.4495 ft^3	(R. L. Drexler's notes)
Total Volume each node	3.2779 ft^3	

2. Heat Capacity

$$C_p = (45.1467)\ (3.2779)\ (1.3191) = 195.21\ \text{Btu}/^{o}\text{F}$$

3. Heat Transfer Surface Area

for 14" Sch. 160 — OD 14.000" = 1.1667 ft; ID 11.188" = 0.9323 ft

$$\text{area} = 4\ \frac{V}{D} = 4\ \frac{3.2779}{0.9323} = 14.0637\ ft^2$$

4. Wall Heat Capacity

$$V = \frac{\pi}{4}\ (1.1667^2 - 0.9323^2)\ \frac{14.0637}{\pi\ 0.9323}$$

$$C_p = (495)\ (1.8555)\ (0.11) = 101.03\ \text{Btu}/^{o}\text{F}$$

5. Heat Transfer Across Film

$$h_{DB} = 0.148\ \left(1 + \frac{T}{10^2} - \frac{T^2}{10^5}\right)\ \frac{v^{0.8}}{D^{0.2}}$$

$$v = \frac{\dot{V}_{ref}}{\frac{\pi}{4} D^2}\ ; \qquad \frac{v^{0.8}}{D^{0.2}} = \left(\frac{4\ \dot{V}_{ref}}{\pi}\right)^{0.8} \frac{1}{D^{1.8}}$$

for: $T = 575\ ^oF$ and $\dot{V}_{ref} = 30.7640 \times 3600$

$$h_{DB} = (0.5097)\ (\frac{4}{\pi}\ 30.7640 \times 3600)^{0.8}\ D^{-1.8}$$

$$h_{DB} = 6709.9\ D^{-1.8}\ \text{Btu/hr ft}^2\ {}^oF$$

$$= 1.8639\ D^{-1.8}\ \text{Btu/sec ft}^2\ {}^oF$$

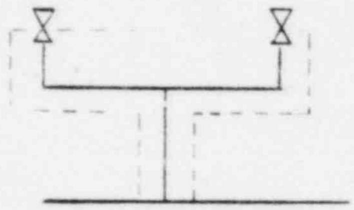
$$h_{DB} = 2.1146\ \text{Btu/sec ft}^2\ {}^oF$$

$$H_{DB} = (2.1146)\ (14.0637) = 29.7391\ \text{Btu/sec}\ {}^oF$$

6. Structure Heat Transfer

$$\frac{kA}{L} = \frac{(0.003889)\ (14.0637)}{\frac{1}{4}\quad \frac{1.406}{12}} = 1.8672\ \text{Btu/sec}\ {}^oF$$

RABV Node 48



For 10" Sch. 140 pipe

OD	10.75"	= 0.8958 ft
ID	8.75"	= 0.7292 ft

1. Volume

From Reference 6 Table XVIV

Location	Volume(ft^3)	Length
40	0.820	23.56
41	0.155	4.45
42	2.340	67.22
43	0.887	17.00
		8.50
44	0.524	15.06
45	0.276	7.94
46	0.820	23.56
46	0.820	23.56
	6.642	190.85 = 15.9042 ft

Add 0.5 ft^3 volume and 1 ft length for each valve.

total volume = 7.6420 ft^3

2. Heat Capacity

C_p = (45.1467) (7.6420) (1.3191) = 455.10 Btu/°F

3. Heat Transfer Surface Area

$$A = 4\frac{V}{D} = 4\frac{7.6420}{0.7292} = 41.9199 \text{ ft}^2$$

4. Wall Heat Capacity

$$V = \frac{\pi}{4}\left[0.8958^2 - 0.7292^2\right] \times 17.9042 = 3.8069 \text{ ft}^3$$

$$C_p = (495)\ (3.8069)\ (0.11) = 207.29 \text{ Btu/}^oF$$

5. Heat Transfer Across Film

$$h_{DB} = 1.8638\ D^{-1.8} = (1.8638)\ (0.7292)^{-1.8}$$

$$= 3.2906 \text{ Btu/sec ft}^2\ {}^oF$$

$$H_{DB} = (3.2906)\ (41.9199) = 137.94 \text{ Btu/sec}^oF$$

6. Structure Heat Transfer

$$\frac{kA}{L} = \frac{(0.003889)\ (41.9199)}{\frac{1}{4} \qquad \frac{1}{12}} = 7.8253 \text{ Btu/sec }^oF$$

RABV Node 49

This volume includes the volume from the RABV's to the tee on the blowdown loop hot leg.

For 10" Sch. 140 pipe

OD	10.75"	=	0.8958 ft
ID	8.75"	=	0.7292 ft

1. Volume

From Reference 6 Table XXIV

Location	Volume(ft^3)	Length
49	0.820	23.56
50	0.820	23.56
51	0.348	10.00
52	0.452	13.00
53	0.887	17.00
54	0.820	8.50
55	1.490	23.56
56	0.056	42.94
	5.693	1.62
		163.74 = 13.6450 ft

Add 0.5 ft^3 volume and 1 ft length for each valve.

total volume = 6.6930

2. Heat Capacity

C_p = (45.1467) (6.6930) (1.3191) = 398.59 Btu/°F

3. Heat Transfer Surface Area

$$A = 4 \frac{V}{D} = 4 \frac{6.6930}{0.7292} = 36.7142 \text{ ft}^2$$

4. Wall Heat Capacity

$$V = \frac{\pi}{4} (0.8958^2 - 0.7292^2) \times 15.6450 = 3.3265 \text{ ft}^3$$

$C_p = (495)\ (3.3265)\ (0.11) = 181.13\ Btu/^oF$

5. Heat Transfer Across Film

(same as node 48) $h_{DB} = 3.2906\ Btu/sec\ ft^2\ ^oF$

$H_{DB} = (3.2906)\ (36.7142) = 120.81\ Btu/sec^oF$

6. Structure Heat Transfer

$$\frac{kA}{L} = \frac{(0.003889)\ (36.7142)}{\frac{1}{4} \qquad \frac{1}{12}} = 6.8535\ Btu/sec\ ^oF$$

Core Bypass Node 51

1. Volume

Bypass cross section area 6.430 in^2 (R. L. Drexler's notes on pg 749).
$= 0.04465 \ ft^2$

Assume length of bypass extends from station 116.925 to 248.58

$= 131.655" = 10.9713 \ ft$

volume $= 0.4899 \ ft^3$

2. Heat Capacity

$C_p = (45.1467)\ (0.4899)\ (1.3191) = 29.1750 \ Btu/^oF$

3. Heat Transfer Surface Area

This node is modeled as several annuluses with a gap width of 0.045" = 0.003750 ft, and diameter of 28". (R. L. Drexler's notes pg. 749)

$$A = 2 \times \frac{V}{w} = 2\,\frac{0.4899}{0.003750} = 261.28 \ ft^2$$

4. Wall Heat Capacity

Assume 1" slab $\frac{1}{12}\,(261.28) = 21.7733 \ ft^3$

$C_p = (495)\ (21.7733)\ (0.11) = 1185.56 \ Btu/^oF$

5. Heat Transfer Across Film

$$h_{DB} = \frac{0.5097}{3600}\ \frac{v^{0.8}}{D_H^{0.2}}\ ; \quad v = \frac{30.7640 \times 3600}{0.04465} = 2.4804 \times 10^6 \ ft/hr$$

$$D_H = 4\,\frac{0.04465}{2\,\pi\,\frac{28}{12}} = 0.01218$$

$h_{DB} = 44.6170 \ Btu/sec\ ft^2\ ^oF$

$H_{DB} = (44.6170)\ (261.28) = 11657.53 \ Btu/sec\ ^oF$

6. Structure Heat Transfer

$$\frac{kA}{L} = \frac{(0.003889)\ (261.28)}{\frac{1}{4} \qquad \frac{1}{12}} = 48.7737 \text{ Btu/sec } ^{o}F$$

7. Height

To account for round off, the height of the bypass node equals the combined height of nodes 1-4, 16 and 17.

4 (1.375) + 2 (2.735) = 10.9700 ft

APPENDIX D

THERMODYNAMIC PROPERTIES USED IN THE PRESSURIZER MODEL

Figure D-1	Specific Volume Versus Specific Enthalpy for Various Pressures - Water Region. (The specific volume of subcooled water is approximated by the saturation curve.)
Figure D-2	Steam Quality Versus Specific Enthalpy for Various Pressures - Water Region.
Figure D-3	Specific Volume Versus Specific Enthalpy for Various Pressures - Steam Region.
Figure D-4	Steam Quality Versus Specific Enthalpy for Various Pressures - Steam Region.
Tables D-5 through D-9	Input values for AD-10 Function Generator.
Figure D-10	Linear Approximation of Specific Enthalpy Versus Pressure at Saturation Conditions - Fluid Region.
Figure D-11	Linear Approximation of Specific Enthalpy Versus Pressure at Saturation Conditions - Steam Region.
Table D-12	Table of Specific Volume of Saturated Steam Versus Pressure.
Figure D-13	Linear Approximation of Specific Enthalpy Versus Temperature for Subcooled Water.
Figure D-14	Linear Approximation of Specific Volume Versus Specific Enthalpy - Fluid Region.

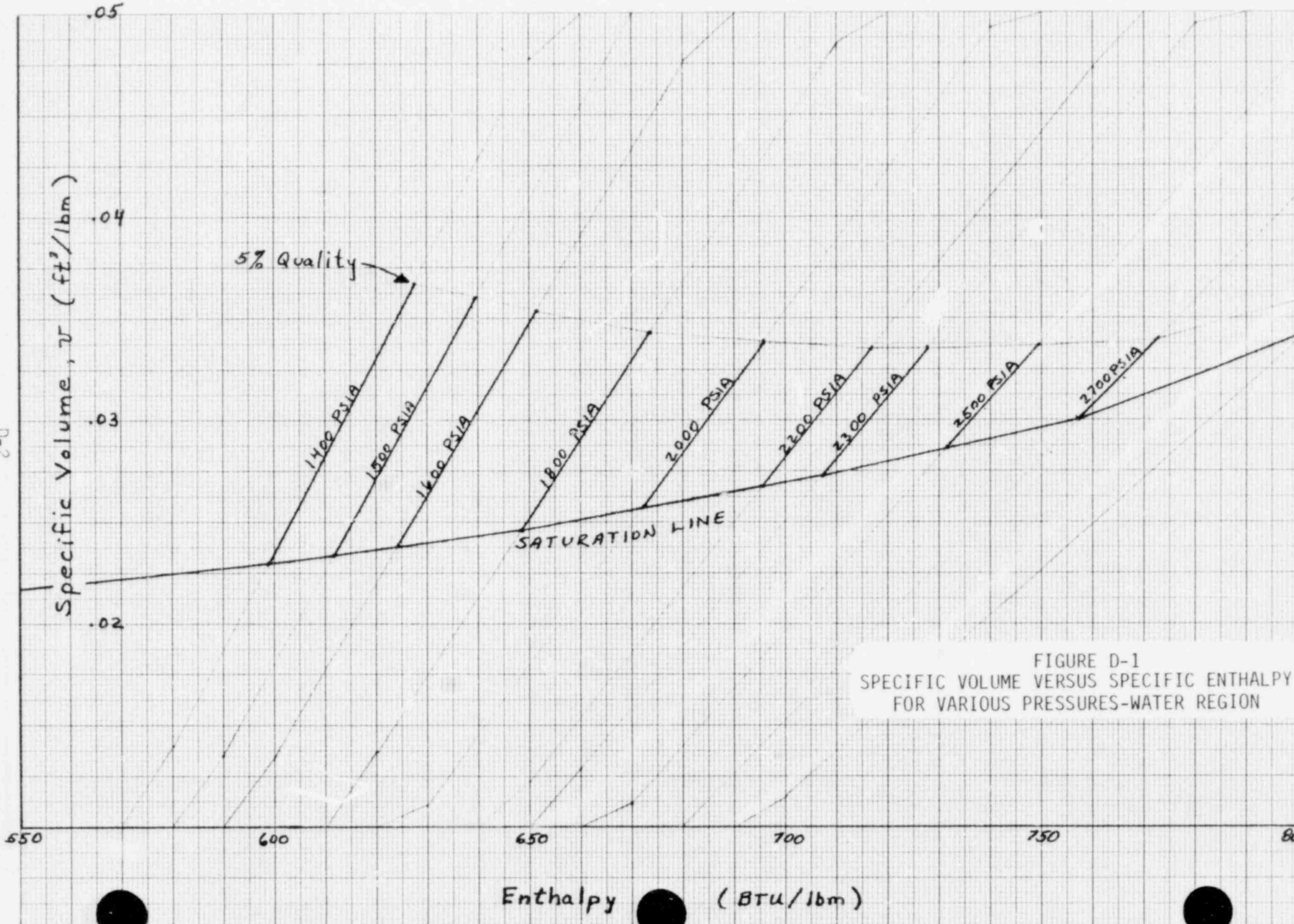


FIGURE D-1
SPECIFIC VOLUME VERSUS SPECIFIC ENTHALPY
FOR VARIOUS PRESSURES-WATER REGION

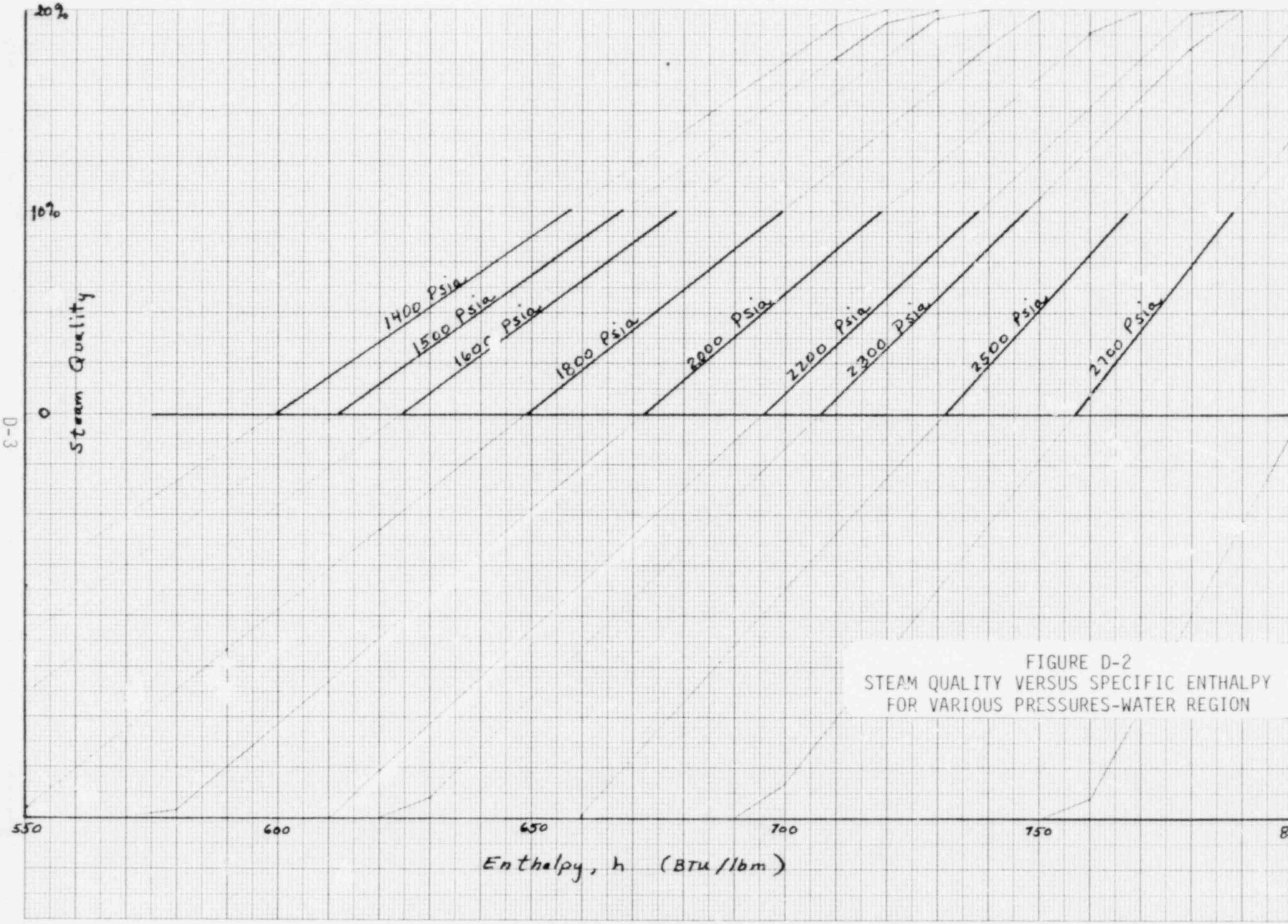


FIGURE D-2
STEAM QUALITY VERSUS SPECIFIC ENTHALPY
FOR VARIOUS PRESSURES-WATER REGION

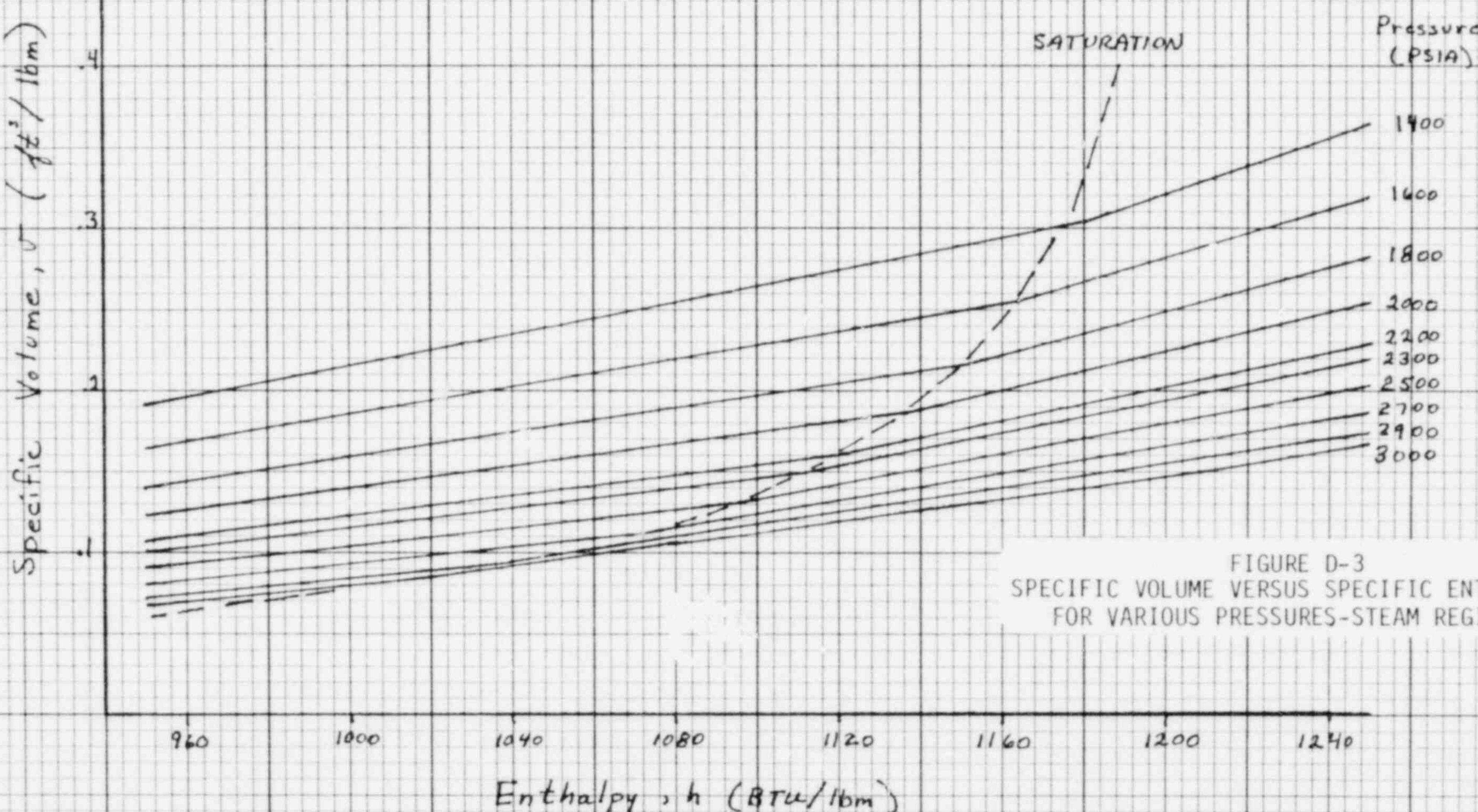


FIGURE D-3
SPECIFIC VOLUME VERSUS SPECIFIC ENTHALPY
FOR VARIOUS PRESSURES-STEAM REGION

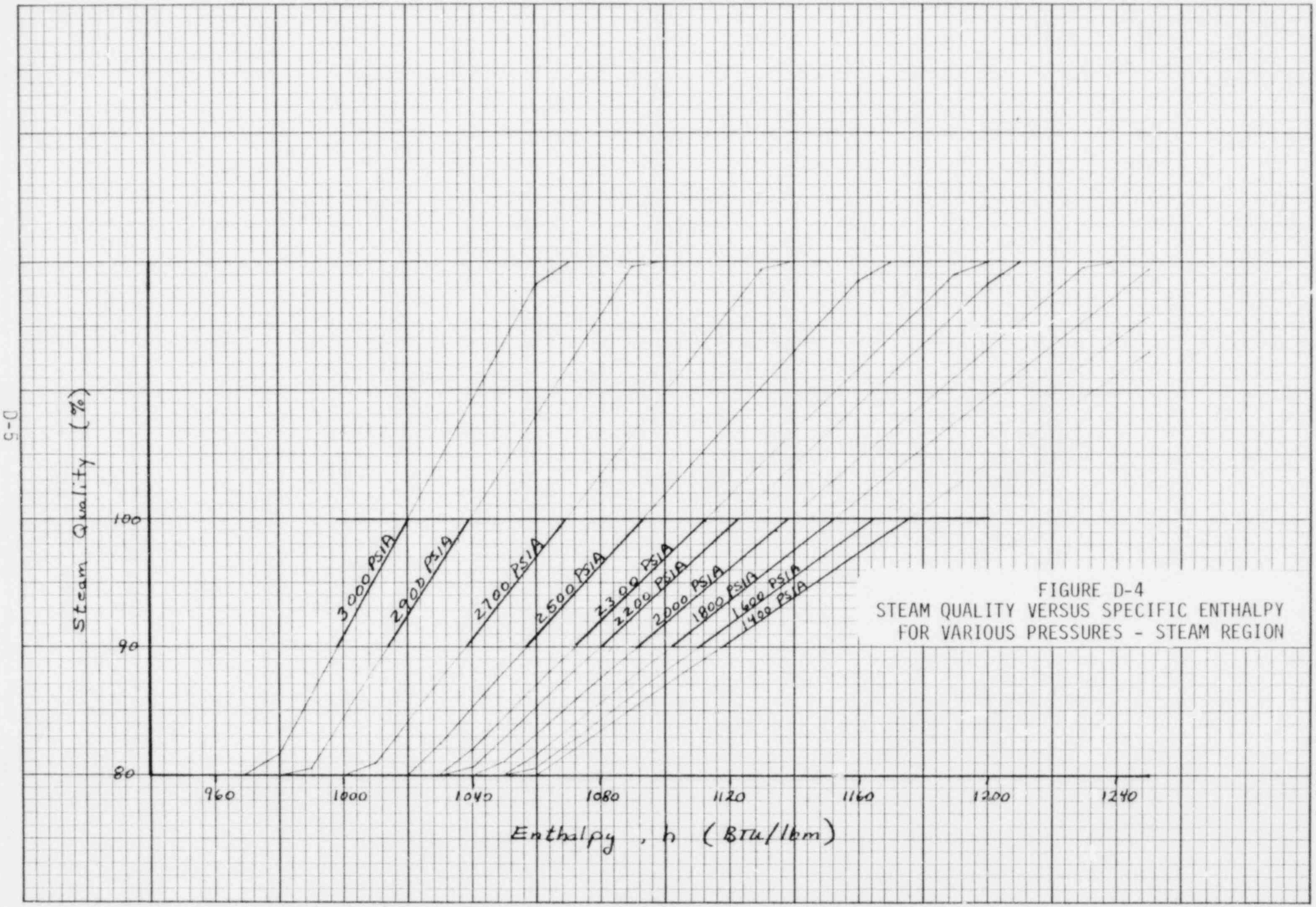


FIGURE D-4
STEAM QUALITY VERSUS SPECIFIC ENTHALPY
FOR VARIOUS PRESSURES - STEAM REGION

TABLE D-5

AD-10 VALUES OF SPECIFIC VOLUME (CU FT/LBM) AS A FUNCTION OF ENTHALPY AND PRESSURE - WATER REGION

PRESSURE (PSIA)

H (BTU/LBM)	1400	1500	1600	1800	2000	2200	2300	2500	2700	3000
550.00										
560.00										
570.00										
580.00	.0140									
590.00	.0188	.0136								
600.00	.0236	.0181	.0135							
610.00	.0285	.0227	.0178							
620.00	.0333	.0272	.0221	.0138						
630.00	.0381	.0318	.0264	.0176	.0110					
640.00	.0430	.0363	.0306	.0215	.0144					
650.00	.0478	.0409	.0349	.0253	.0179	.0122				
660.00		.0454	.0392	.0291	.0214	.0154	.0129			
670.00		.0500	.0435	.0330	.0249	.0186	.0159	.0112		
680.00			.0478	.0368	.0284	.0218	.0190	.0140	.0101	
690.00				.0407	.0319	.0249	.0220	.0168	.0127	
700.00				.0445	.0354	.0281	.0251	.0196	.0153	.0106
710.00				.0484	.0389	.0313	.0281	.0225	.0179	.0130
720.00					.0424	.0345	.0312	.0253	.0205	.0153
730.00					.0458	.0377	.0342	.0281	.0231	.0176
740.00					.0493	.0409	.0373	.0309	.0258	.0199
750.00						.0441	.0404	.0338	.0284	.0222
760.00						.0473	.0434	.0366	.0310	.0246
770.00							.0465	.0394	.0336	.0269
780.00							.0495	.0422	.0362	.0292
790.00								.0451	.0388	.0315
800.00								.0479	.0414	.0339

Sub-cooled region - values above the saturation line are necessary for accurate interpolation.

Saturation Region

Range .01 to .05 cu ft/lbm.
Data is plotted on Figure D-1.
Scaled values are listed in Table H-8.

Saturation Line

TABLE D-7

AD-10 VALUES OF SPECIFIC VOLUME (CU FT/LBM) AS A FUNCTION OF ENTHALPY AND PRESSURE - STEAM REGION

H (BTU/LBM)	PRESSURE (PSIA) 1400	1600	1800	2000	2200	2300	2500	2700	2900	3000
950.00	.1929	.1635	.1407	.1226	.1078	.1014	.0902	.0806	.0725	.0687
960.00	.1977	.1678	.1446	.1261	.1110	.1045	.0931	.0832	.0749	.0710
970.00	.2025	.1721	.1484	.1296	.1142	.1076	.0959	.0859	.0773	.0733
980.00	.2074	.1764	.1523	.1331	.1174	.1106	.0987	.0885	.0797	.0756
990.00	.2122	.1807	.1561	.1366	.1206	.1137	.1015	.0911	.0822	.0780
1000.00	.2170	.1850	.1600	.1400	.1238	.1167	.1044	.0937	.0846	.0803
1010.00	.2219	.1893	.1638	.1435	.1269	.1198	.1072	.0963	.0870	.0826
1020.00	.2267	.1936	.1677	.1470	.1301	.1228	.1100	.0989	.0894	.0849
1030.00	.2315	.1978	.1715	.1505	.1333	.1259	.1128	.1015	.0918	.0882
1040.00	.2364	.2021	.1754	.1540	.1365	.1289	.1156	.1041	.0943	.0915
1050.00	.2412	.2064	.1792	.1575	.1397	.1320	.1185	.1068	.0978	.0948
1060.00	.2461	.2107	.1831	.1610	.1429	.1350	.1213	.1094	.1013	.0980
1070.00	.2509	.2150	.1869	.1645	.1461	.1381	.1241	.1120	.1049	.1015
1080.00	.2557	.2193	.1908	.1680	.1493	.1412	.1269	.1160	.1084	.1050
1090.00	.2606	.2236	.1946	.1714	.1524	.1442	.1298	.1200	.1119	.1084
1100.00	.2654	.2278	.1985	.1749	.1556	.1473	.1335	.1239	.1156	.1119
1110.00	.2702	.2321	.2023	.1784	.1588	.1503	.1380	.1279	.1194	.1154
1120.00	.2751	.2364	.2062	.1819	.1620	.1546	.1424	.1320	.1231	.1191
1130.00	.2799	.2407	.2100	.1854	.1667	.1594	.1468	.1361	.1269	.1228
1140.00	.2847	.2450	.2139	.1893	.1719	.1644	.1513	.1403	.1307	.1264
1150.00	.2896	.2493	.2177	.1950	.1770	.1694	.1559	.1444	.1346	.1301
1160.00	.2944	.2536	.2235	.2008	.1823	.1744	.1604	.1486	.1385	.1338
1170.00	.2992	.2595	.2300	.2066	.1877	.1795	.1650	.1528	.1424	.1377
1180.00	.3057	.2668	.2365	.2125	.1930	.1846	.1696	.1571	.1463	.1415
1190.00	.3141	.2741	.2431	.2184	.1983	.1897	.1743	.1614	.1503	.1453
1200.00	.3226	.2815	.2497	.2243	.2037	.1948	.1790	.1657	.1543	.1492
1210.00	.3311	.2890	.2563	.2303	.2091	.1999	.1837	.1701	.1583	.1531
1220.00	.3396	.2964	.2629	.2363	.2145	.2051	.1885	.1745	.1624	.1570
1230.00	.3482	.3039	.2696	.2422	.2199	.2103	.1933	.1789	.1665	.1610
1240.00	.3568	.3115	.2762	.2483	.2254	.2155	.1981	.1833	.1707	.1649
1250.00	.3655	.3191	.2830	.2543	.2309	.2207	.2029	.1878	.1749	.1689

Saturation Line

Range ± .4000 cu ft/lbm. Data is plotted on Figure D-3. Scaled values are listed in Table H-10.

TABLE D-6

AD-10 VALUES OF STEAM QUALITY AS A FUNCTION OF ENTHALPY AND PRESSURE - WATER REGION

H (BTU/LBM)	PRESSURE (PSIA) 1400	1500	1600	1800	2000	2200	2300	2500	2700	3000
550.00	-.0847	-.1105	-.1373	-.1955						
560.00	-.0674	-.0926	-.1188	-.1756						
570.00	-.0500	-.0747	-.1003	-.1558						
580.00	-.0327	-.0568	-.0818	-.1359	-.1976					
590.00	-.0153	-.0389	-.0633	-.1161	-.1761					
600.00	.0020	-.0210	-.0448	-.0962	-.1547					
610.00	.0194	-.0030	-.0263	-.0764	-.1332					
620.00	.0367	.0149	-.0078	-.05[illegible]	-.1118	-.1768				
630.00	.0541	.0328	.0107	-.0367	-.0903	-.1534	-.1901			
640.00	.0714	.0507	.0292	-.0169	-.0689	-.1300	-.1655			
650.00	.0888	.0686	.0478	.0030	-.0474	-.1065	-.1408			
660.00	.1061	.0865	.0663	.0228	-.0260	-.0831	-.1162	-.1983		
670.00	.1235	.1044	.0848	.0427	-.0045	-.0597	-.0916	-.1707		
680.00	.1408	.1223	.1033	.0625	.0169	-.0362	-.0669	-.1430		
690.00	.1582	.1402	.1218	.0824	.0384	-.0128	-.0423	-.1154		
700.00	.1755	.1581	.1403	.1022	.0598	.0106	-.0177	-.0877	-.1836	
710.00	.1928	.1760	.1588	.1221	.0813	.0341	.0069	-.0600	-.1516	
720.00		.1939	.1773	.1419	.1027	.0575	.0316	-.0324	-.1195	
730.00			.1958	.1618	.1242	.0809	.0562	-.0047	-.0875	
740.00				.1816	.1456	.1044	.0808	.0229	-.0555	
750.00					.1671	.1278	.1055	.0506	-.0235	
760.00					.1885	.1512	.1301	.0782	.0085	-.1915
770.00						.1747	.1547	.1059	.0405	-.1457
780.00						.1981	.1794	.1335	.0725	-.1000
790.00								.1612	.1046	-.0542
800.00								.1889	.1366	-.0084

Sub-cooled region - values above the saturation line are necessary for accurate interpolation.

Saturation Region

Range ±20%.
Data is plotted on Figure D-2.
Scaled values are listed in Table H-9.

[illegible]ration Line

TABLE D-8

AD-10 VALUES OF STEAM QUALITY AS A FUNCTION OF ENTHALPY AND PRESSURE - STEAM REGION

Saturation Region

H (BTU/LBM)	PRESSURE (PSIA) 1400	1600	1800	2000	2200	2300	2500	2700	2900	3000
950.00										
960.00										
970.00										
980.00										.8155
990.00									.8045	.8613
1000.00									.8437	.9071
1010.00								.8089	.8830	.9529
1020.00								.8409	.9223	.9986
1030.00							.8249	.8729	.9615	1.0444
1040.00					.8074	.8197	.8526	.9049	1.0008	1.0902
1050.00				.8106	.8308	.8443	.8803	.9369	1.0401	1.1360
1060.00	.8000	.8066	.8168	.8320	.8542	.8690	.9079	.9689	1.0793	1.1817
1070.00	.8173	.8251	.8366	.8535	.8777	.8936	.9356	1.0010	1.1186	
1080.00	.8347	.8436	.8565	.8749	.9011	.9182	.9632	1.0330	1.1579	
1090.00	.8520	.8621	.8763	.8964	.9245	.9429	.9909	1.0650	1.1971	
1100.00	.8694	.8806	.8962	.9178	.9480	.9675	1.0185	1.0970		
1110.00	.8867	.8991	.9160	.9393	.9714	.9921	1.0462	1.1290		
1120.00	.9041	.9176	.9359	.9607	.9948	1.0167	1.0738	1.1610		
1130.00	.9214	.9361	.9557	.9822	1.0183	1.0414	1.1015	1.1930		
1140.00	.9388	.9547	.9756	1.0036	1.0417	1.0660	1.1292			
1150.00	.9561	.9732	.9954	1.0251	1.0651	1.0906	1.1568			
1160.00	.9735	.9917	1.0153	1.0465	1.0886	1.1153	1.1845			
1170.00	.9908	1.0102	1.0351	1.0680	1.1120	1.1399				
1180.00	1.0082	1.0287	1.0550	1.0894	1.1354	1.1645				
1190.00	1.0255	1.0472	1.0748	1.1109	1.1589	1.1892				
1200.00	1.0428	1.0657	1.0947	1.1323	1.1823					
1210.00	1.0602	1.0842	1.1145	1.1538						
1220.00	1.0775	1.1027	1.1344	1.1753						
1230.00	1.0949	1.1212	1.1542	1.1967						
1240.00	1.1122	1.1397	1.1741							
1250.00	1.1296	1.1582	1.1939							

Saturation Line

Super heat region - values below the saturation line are necessary for accurate interpolation.

Range 80 - 120%.
Data is plotted on Figure D-4.
Scaled values are listed in Table H-11.

TABLE D-9

AD-10 VALUES OF SPECIFIC VOLUME AS A FUNCTION OF ENTHALPY - SATURATION CONDITIONS

H (BTU/LBM)	V (CU FT/LBM)
550.0	.0218
598.8	.0231
611.7	.0235
624.2	.0239
648.5	.0247
672.1	.0257
695.5	.0267
707.2	.0273
731.7	.0286
757.3	.0303
800.0	.0341

Data is plotted on Figure D-1.

Scaled values are listed in Table H-12.

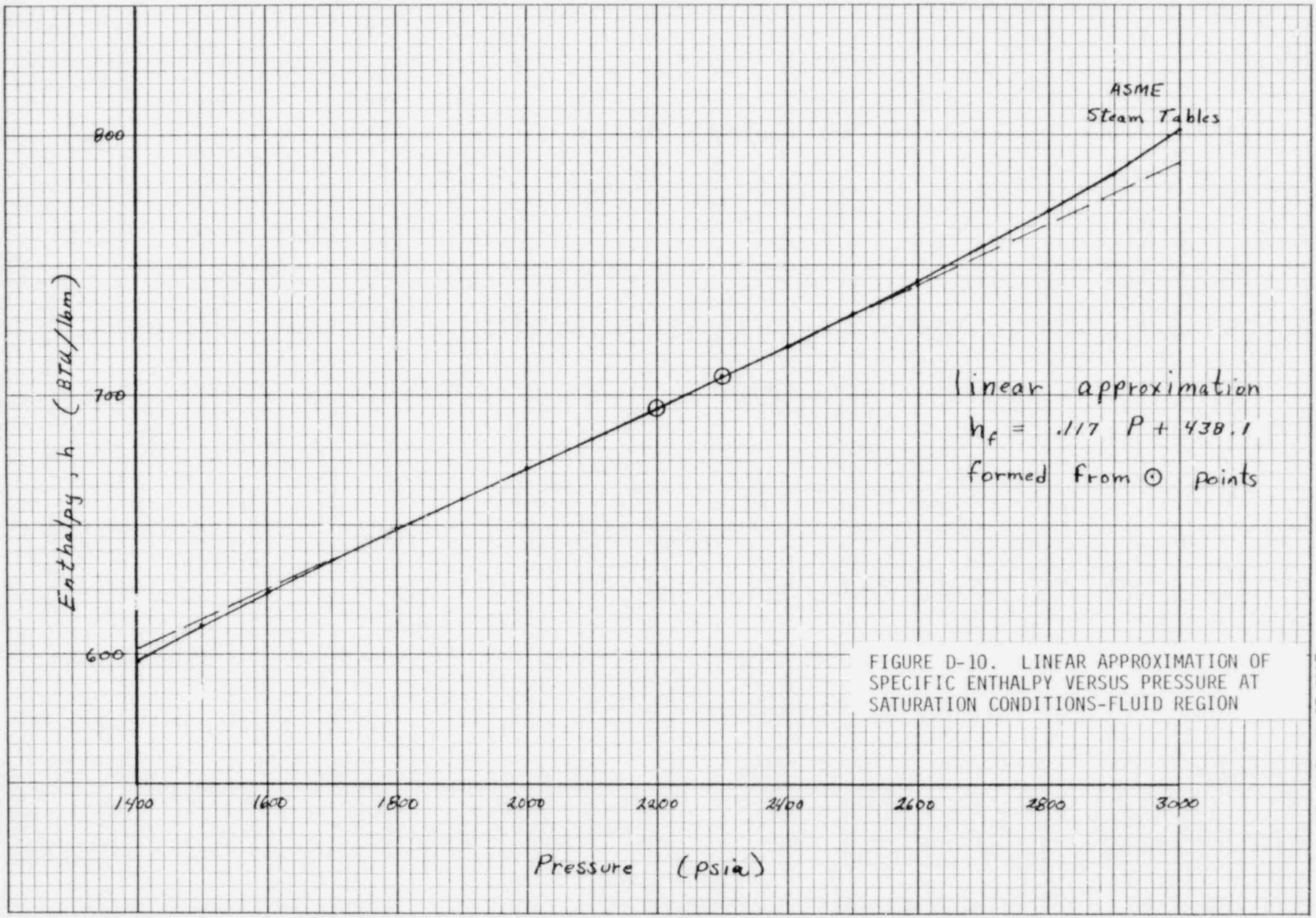


FIGURE D-10. LINEAR APPROXIMATION OF SPECIFIC ENTHALPY VERSUS PRESSURE AT SATURATION CONDITIONS-FLUID REGION

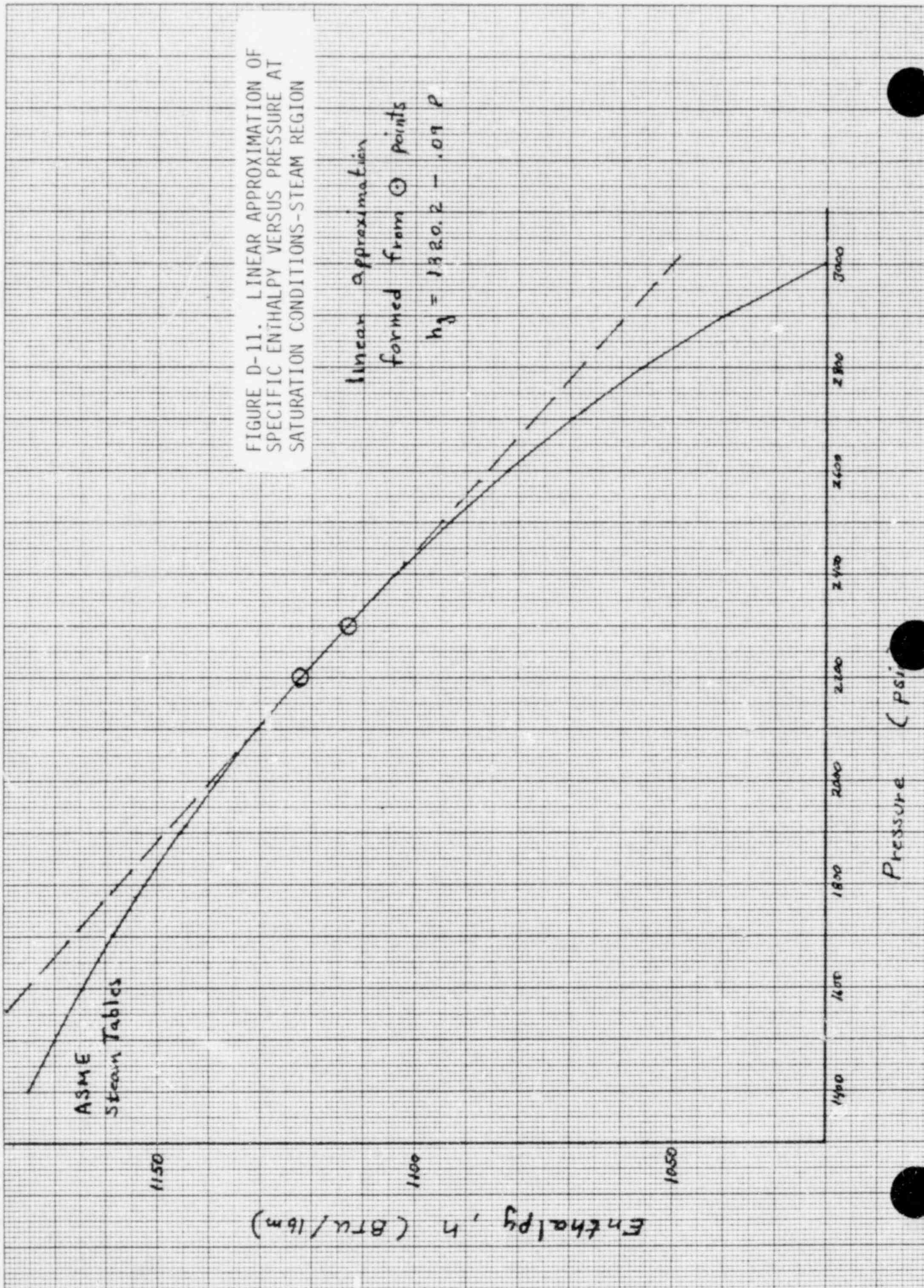


FIGURE D-11. LINEAR APPROXIMATION OF SPECIFIC ENTHALPY VERSUS PRESSURE AT SATURATION CONDITIONS-STEAM REGION

TABLE D-12

SPECIFIC VOLUME OF SATURATED STEAM VERSUS PRESSURE

Pressure PSIA	Specific Volume ft^3/lbm
2000	.1883
2100	.1750
2200	.1625
2300	.1513
2400	.1408

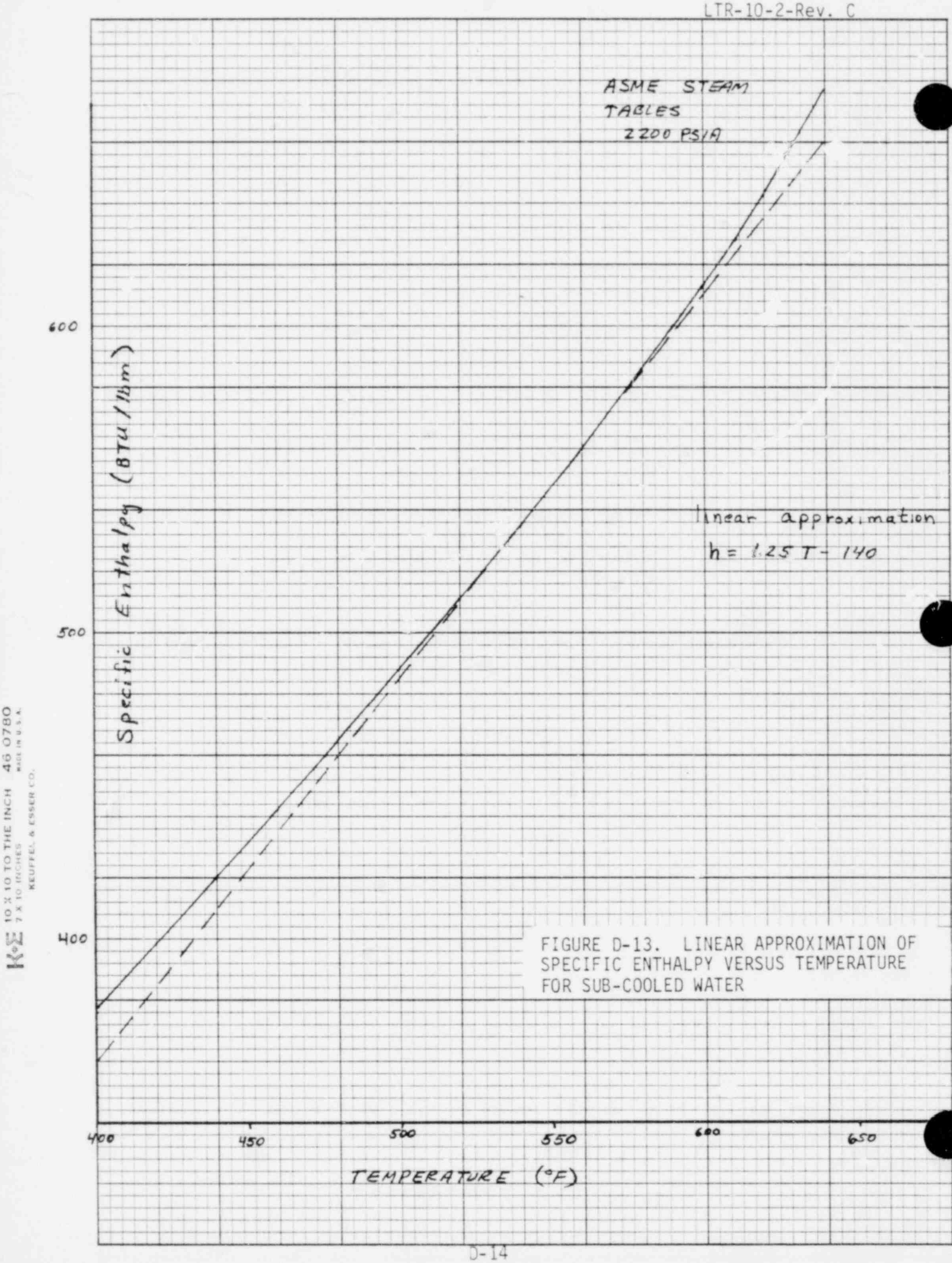


FIGURE D-13. LINEAR APPROXIMATION OF SPECIFIC ENTHALPY VERSUS TEMPERATURE FOR SUB-COOLED WATER

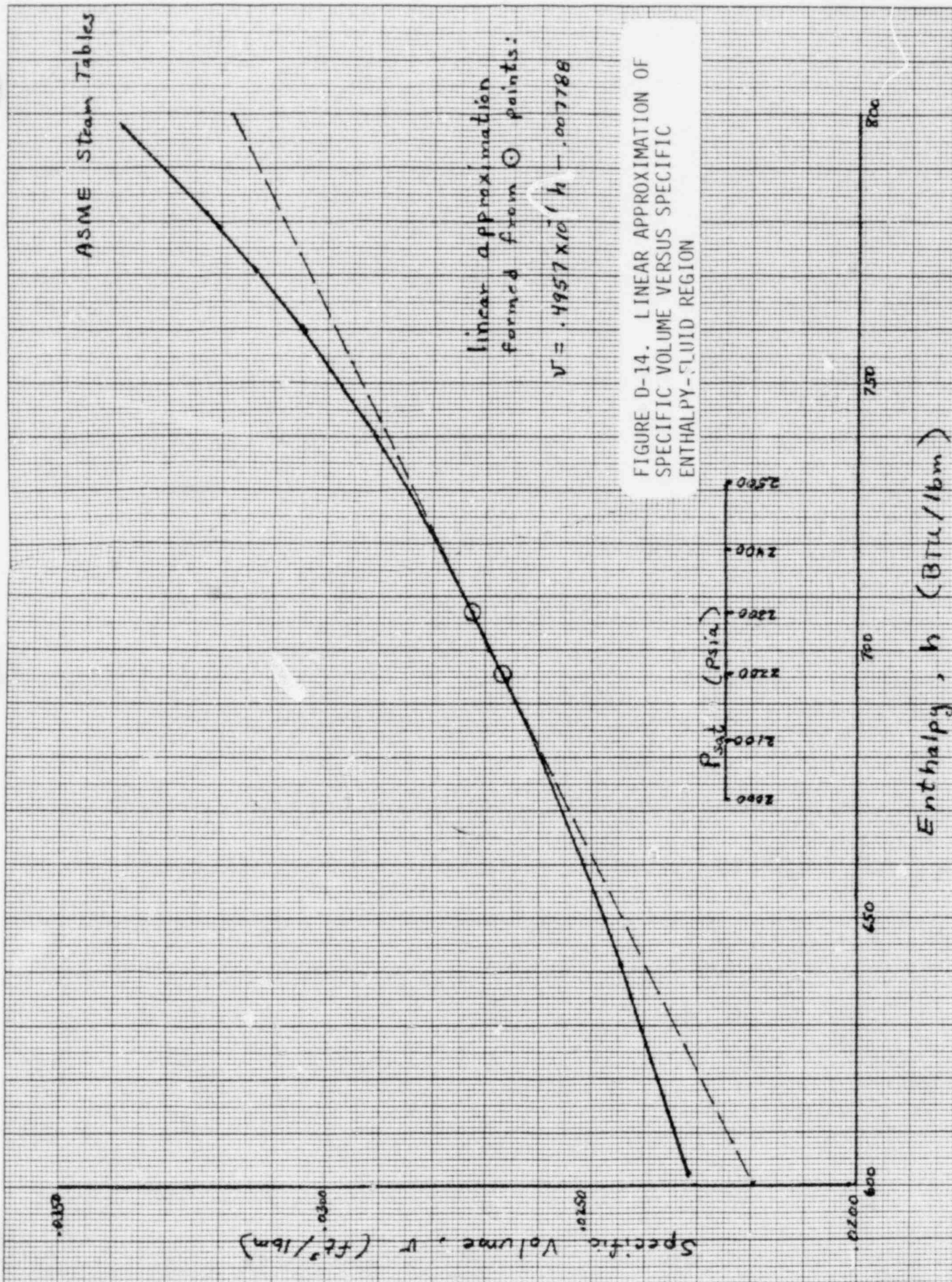


FIGURE D-14. LINEAR APPROXIMATION OF SPECIFIC VOLUME VERSUS SPECIFIC ENTHALPY-FLUID REGION

APPENDIX E

STEAM GENERATOR VOLUME VS LEVEL CALCULATIONS

1. References: LOFT Drawings 206161 through 206169

2. Dimensions:

Dimensions:	Shell	ID	56"
	Shroud	ID	50.75"
		OD	51.75"
	Riser	ID	24"
		OD	24.75"
	Tubes	OD	0.5"
		number	1845
	Frustum base	ID	49.9375"

Heights (referenced to top of the tube sheet):

tube bend line	72.5"
bottom of frustum section	88.125"
max tube height	97.5"
bottom of riser/top of frustum	101.21875"
bottom of separator duct	144.625"
top of riser	161.750"

3. Cross sectional areas:

Shell inside $\frac{\pi}{4} \left(\frac{56}{12}\right)^2 = 17.1042 \text{ ft}^2$

Shroud outside $\frac{\pi}{4}\left(\frac{51.75}{12}\right)^2 = 14.6066 \text{ ft}^2$

Shroud inside $\frac{\pi}{4}\left(\frac{50.75}{12}\right)^2 = 14.0475 \text{ ft}^2$

Riser outside $\frac{\pi}{4}\left(\frac{24.75}{12}\right)^2 = 3.3410 \text{ ft}^2$

Riser inside $\frac{\pi}{4}\left(\frac{24}{12}\right)^2 = 3.1416 \text{ ft}^2$

Tube outside - straight section

$$2 \times 1845 \times \frac{\pi}{4}\left(\frac{0.5}{12}\right)^2 = 5.0315 \text{ ft}^2$$

4. Inside Shroud Volume

4.1 From the top of the tube sheet to the tube bend line.

Height = 72.5"

Cross Sectional Area = 14.0475 - 5.0315 = 9.0160 ft^2

Volume = (9.0160) 72.5/12 = 54.4717 ft^3

Displacements:

Tie Rods - 10 rods, 1/2" diameter, 5'10-3/4" long.

Volume = $10\ \pi/4\ (0.5)^2\ 70.75 = 138.92 \text{ in}^3$

Support Plates - 4 plates, 1/2" thick, 24-7/8" radius with 2 1/4" overlap strip. Assume volume of each plate is equal. Use type "A" as typical.

Area of semi circle = $(1/2)\ \pi\ (24.875)^2 = 971.95 \text{ in}^2$

Area of overlap strip = $(2.25)\ (2 \times 24.875) = 111.94 \text{ in}^2$

Area of holes

1961	17/32" holes for tubes	=	434.68 in^2
6	17/32" holes for tie rods	=	1.33 in^2
3556	3/16" holes for flow	=	98.19 in^2

Total Support Plate Area = 549.69 in^2

Volume (4) (0.5) (549.69) = 1099.38 in^3

Bottom Blowdown Pipe - 1-1/2" sch 40 pipe, 3'9" long with a 1 1/2" elbow.

Volume = $\pi/4\ (1.9)^2\ (45 + \pi/2\ 1.5) = 134.27\ in^3$

Net volume = 54.4717 - (138.92 + 1099.38 + 134.27)/1728 = 53.6774 ft^3

4.2 From the tube bend line to the bottom of the frustum section.

Height = 15.625"

Area inside shroud = 14.0475 ft^2

The displacement of the upper tube support structure is neglected because of its small volume and irregular geometry.

From an analysis of the steam generator tube displacement by C. D. Clayton, 1-24-80:

Height Above bend line (in.)	Displacement of tubes ($in.^3$)	(ft^3)
5.0	3765.00	2.1788
10.0	7268.00	4.2060
15.5	10377.14	6.0053
16.0	10606.46	6.1380

Interpolate to find volume at 15.625" = 6.0385 ft^3

Height Above tube sheet (in.)	Volume inside shroud (ft^3)	Net Volume above tube bend line (ft^3)	Total Volume (ft^3)
77.500	5.8531	3.6743	57.3517
82.500	11.7063	7.5003	61.1777
88.125	18.2910	12.2525	65.9299

4.3 From the bottom of the frustum section (88.125") to the maximum tube height (97.500").

From an analysis of the steam generator tube displacement by C. D. Clayton, 1-24-80.

Height above bend line (in)	Displacement of tubes (in^3)	(ft^3)	Net Displacement above 88.125" (ft^3)
17.0	11035.98	6.3866	0.3481
19.0	11765.17	6.8085	0.7700
21.0	12304.09	7.1204	1.0819
23.0	12634.77	7.3118	1.2733
25.0	12728.98	7.3663	1.3278

Volume of frustum:

$$V = \frac{\pi}{4} \int_0^h D^2 \, dh = \frac{\pi}{4} h \, (1.4431 - 0.05725h + 0.7569 \times 10^{-3} h^2)$$

V in ft^3, h in inches, D = (49.9375 - 1.9809h)/12.

Height above bend line (in.)	Height above tube sheet (in.)	Height above 88.125" (in.)	Volume inside frust. (ft^3)	Net Volume above 88.125" (ft^3)	Total volume (ft^3)
17.0	89.5	1.375	1.4750	1.1269	67.0568
19.0	91.5	3.375	3.3359	2.5659	68.4958
21.0	93.5	5.375	4.8853	3.8034	69.7333
23.0	95.5	7.375	6.1517	4.8784	70.8083
25.0	97.5	9.375	7.1636	5.[illegible]358	71.7657

4.4 From the top of the tubes (97.500") to the bottom of the riser (101.219").

Volume of frustum = $\pi h/3 \, (r_1^2 + r_1 r_2 + r_2^2)$

$h = 101.219 - 88.125 = 13.0940"$

$r_1 = 49.9375/2 = 24.9688"$

$r_2 = 24/2 = 12.000"$

$V = 8.4674 \; ft^3$

Net Volume = 8.4674 - 7.1636 = 1.3038 ft^3

Total Volume = 71.7657 + 1.3038 = 73.0695 ft^3

4.5 From the bottom of the riser (101.219") to the bottom of the separator duct (144.625").

Height = 43.406"

Area = 3.1416 ft^2

Volume = 11.3637 ft^3

Total Volume = 84.4332 ft^3

4.6 From 144.625" to 161.75".

For analytical purposes the volume of the riser is considered to extend vertically to 161.75."

Height = 17.125"

Area = 3.1416 ft^2

Volume = 4.4833 ft^3

Displacements:

Level Control Cup - 6" diameter, 6-1/4" height.

Volume = 0.1023 ft^3

Level Control Piping - 2 pieces, 1-1/2" sch 40 pipe, approximately 19" long.

volume = $2\ \pi/4\ (0.840)^2\ (19)/\ 1728 = 0.0122\ ft^3$

Net Volume = 4.3688 ft^3

Total Volume = 88.8020 ft^3

5. Downcomer Volume

5.1 Lower Section - from the top of the tube sheet to the bottom of the frustum section.

Height = 88.125"

Cross Sectional Area = 17.1042 - 14.6066 = 2.4976 ft^2

Volume = (2.4976) (88.125)/12 = 18.3418 ft^3

Displacements:

Spacer lugs - 8 lugs 2-7/8" x 4" x 3/8"

Volume = 34.5000 in^3 = 0.0200 ft^3

Net Volume = 18.3218 ft^3

5.2 Frustum Section - 88.125" to 101.395".

Height = 13.270"

Volume inside the shell = (17.1042) (13.270)/12 = 18.9144 ft^3

Volume of frustum = $\pi/4 \int_0^h D^2 dh$

Diameter of base = 49.9375 + $\sqrt{2}$ = 51.3517"

D = (51.3517 - 2.0046h)/12

$V = \pi/4\ h\ (1.5260 - 0.05957h + 0.7752 \times 10^{-3}h^2)$

V in ft^3, h in inches.

Displacements:

Shroud Upper lip and weld - Ring 51" diameter, approximate cross section 3/8" x 1/2", located around bottom of frustum

Volume = (0.375) (0.5) π (51)/1728 = 0.0174 ft^3

Level control piping - 2 pieces of 1/2" sch 40 pipe, 17-1/4" long each.

Volume = 2 $\pi/4\ (0.840)^2$ (17.25)/1728 = 0.0111 ft^3

Emergency cooldown pipe bosses - 6 each, 2" diameter, 2-5/8" long, cut at 45^0 angle, located at the top of the frustum.

Volume = 6 $\pi/4\ (2)^2$ (0.6250 + 1/2 (2))/1728 = 0.0177 ft^3

Height Above tube sheet (in.)	Height Above 88.125" (in.)	Volume of Frustrum (ft^3)	Volume of displacement (ft^3)	Net Volume above 88.125" (ft^3)	Total Volume (ft^3)
90.125	2.000	2.2148	0.0191	0.6168	18.9386
92.125	4.000	4.0845	0.0207	1.5962	19.9180
94.125	6.000	5.6383	0.0224	2.8914	21.2132
96.125	8.000	6.9056	0.0241	4.4731	22.7949
98.125	10.000	7.9154	0.0258	6.3123	24.6341
101.395	13.270	9.0883	0.0462	9.7799	28.1017

5.3 Riser Section - 101.395" to 144.625".

Cross sectional Area = 17.1042 - 3.3410 = 13.7632 ft^2

Displacements:

Level control piping - 2 pieces of 1/2" sch 40 pipe.

Area = 2 $\pi/4\ (0.840)^2/144 = 0.007697\ ft^2$

Mist extractor drain piping - 4 pieces of 1/2" sch 40 pipe.

Assume pipe fills as level increases.

Area = 4 $\pi/4\ (0.840^2 - 0.622^2)/144 =$ $0.006953\ ft^2$

Emergency cooldown pipe - 6 pieces of 1" sch 40 pipe, 29-1/2" long, approximately 4-1/2" extends into bosses.

Volume = 6 $\pi/4\ (1.315)^2\ (25)/1728 = 0.1179\ ft^3$

Feed ring - 24" radius, 3" sch 40 pipe, located at 105.0". Assume this pipe is full regardless of the level.

Volume $\frac{\pi}{4}\ (3.5)^2\ 2\pi\ (24)\ /1728 = 0.8396\ ft^3$

Feed ring supports - 4 - 5 3/4" x 2-1/2" x 1/2"

Volume = $0.01664\ ft^3$

Surface blowdown ring - 23" radius, 1-1/2" sch 40 pipe, located at 109.5". The inside of this pipe is assumed to fill up as the level increases.

Volume = $\pi/4 \left[1.9^2 - 1.61^2\right] 2\pi\ (23)/1728 =$
$0.06686\ ft^3$

Surface blowdown ring supports - 4 - 6-1/4" x 2-1/2" x 1/2"

Volume = $0.01808\ ft^3$

Emergency cooldown ring - radius varies from 23" to 24", 1-1/2" sch 40 pipe, located at 120.5".

Volume = $\pi/4\ (1.9)^2\ 2\pi\ (23.5)/1728 = 0.2423\ ft^3$

Cooldown ring supports - 4 - 3-3/8" x 2-1/2" x 1/2"

Volume = $0.009766\ ft^3$

Eject pipes - 8 each - 3" sch 40 pipe with 5" sch 40 6-1/2" high cup. Bottom of cup is at approximately 129.5" and extends to the mist extractors. Assume the cups are full.

Volume of cups = $8\ \frac{\pi}{4}\ (5.563)^2\ (6.5)/1728 = 0.7314\ ft^3$

Area of pipes = $8\ \pi/4\ (3.5)^2/144 = 0.5345\ ft^2$

Gage glass internal piping - 1" sch 40 pipe, starts at 137.5" and extends to top of riser.

Area = $\pi/4\ (1.315)^2/144 = 0.009431\ ft^2$

Net Cross Sectional Area

$$13.7632 - 0.007697 - 0.006953 = 13.7486 \text{ ft}^2$$

Displacements below 122"

0.1179
0.8396
0.0166
0.0669
0.0181
0.2423
0.0098
1.3112 ft^3

Volume at 122"

$$(13.7486)(122.0 - 101.395)/12 - 1.3112 =$$
$$22.2963 \text{ ft}^3$$
$$\text{Total volume} = 28.1017 + 22.2963 = 50.3980 \text{ ft}^3$$

Volume at 129.5"

$$(13.7486)(129.5 - 122.0)/12 = 8.5929 \text{ ft}^3$$
$$\text{Total volume} = 50.3980 + 8.5929 = 58.9909$$

Volume at 144.625

$$(13.7486)(144.625 - 129.5)/12 - 0.7314$$
$$- (0.5345)(144.625 - 136.0)/12$$
$$- (0.009431)(144.625 - 137.5)/12 =$$
$$16.2078 \text{ ft}^3$$

$$\text{Total volume} = 58.9909 + 16.2078 = 75.1987 \text{ ft}^3$$

5.4 From 144.625" to 161.75"

For analytical purpo..s the volume of the downcomer is considered to extend to 161.75". The displacement of the moisture separators is neglected.

Height = 17.125"

Volume = (13.7632 - 0.006953 - 0.5345 - 0.009431)(161.75 - 144.625)/12 = 18.8551 ft^3

Total Volume = 94.0538 ft^3

6. Analytical fits for the level versus volume curves

6.1 Inside Shroud - Comprised of two straight line segments.

The first line passes through points (0,0) and (53.6774,72.5).

$$L = \frac{72.5}{53.6774} V = 1.3507 V$$

The second line passes through points (73.0695, 101.219) and (84.4332, 144.625).

$$L - 101.219 = \frac{144.625 - 101.219}{84.4332 - 73.0695} (V - 73.0695)$$

$$L = 3.8197 V - 177.8851$$

The lines intersect at (72.0474, 97.3145).

$L = 1.3507 V$ for $V \leq 72.0474$

$L = 3.8197 V - 177.8851$ for $V > 72.0474$

$V = 0.7404 L$ for $L \leq 97.3145$

$V = 0.2618\ L + 46.5704 \qquad \text{for } L > 97.3145$

6.2 Downcomer - comprised of two straight line segments.

The first line passes through the points (0,0) and (18.3218, 88.125)

$$L = \frac{88.125}{18.3218} V = 4.8098\ V$$

The second line passes through the points (28.1017, 101.395) and (50.3980, 122.0)

$$L - 101.395 = \frac{122.0 - 101.395}{50.3980 - 28.1017} (V - 28.1017)$$

$$L = 0.9241\ V + 75.4250$$

The lines intersect at (19.4109, 93.3626)

$L = 4.8098\ V \qquad \text{for } V \leq 19.4109$

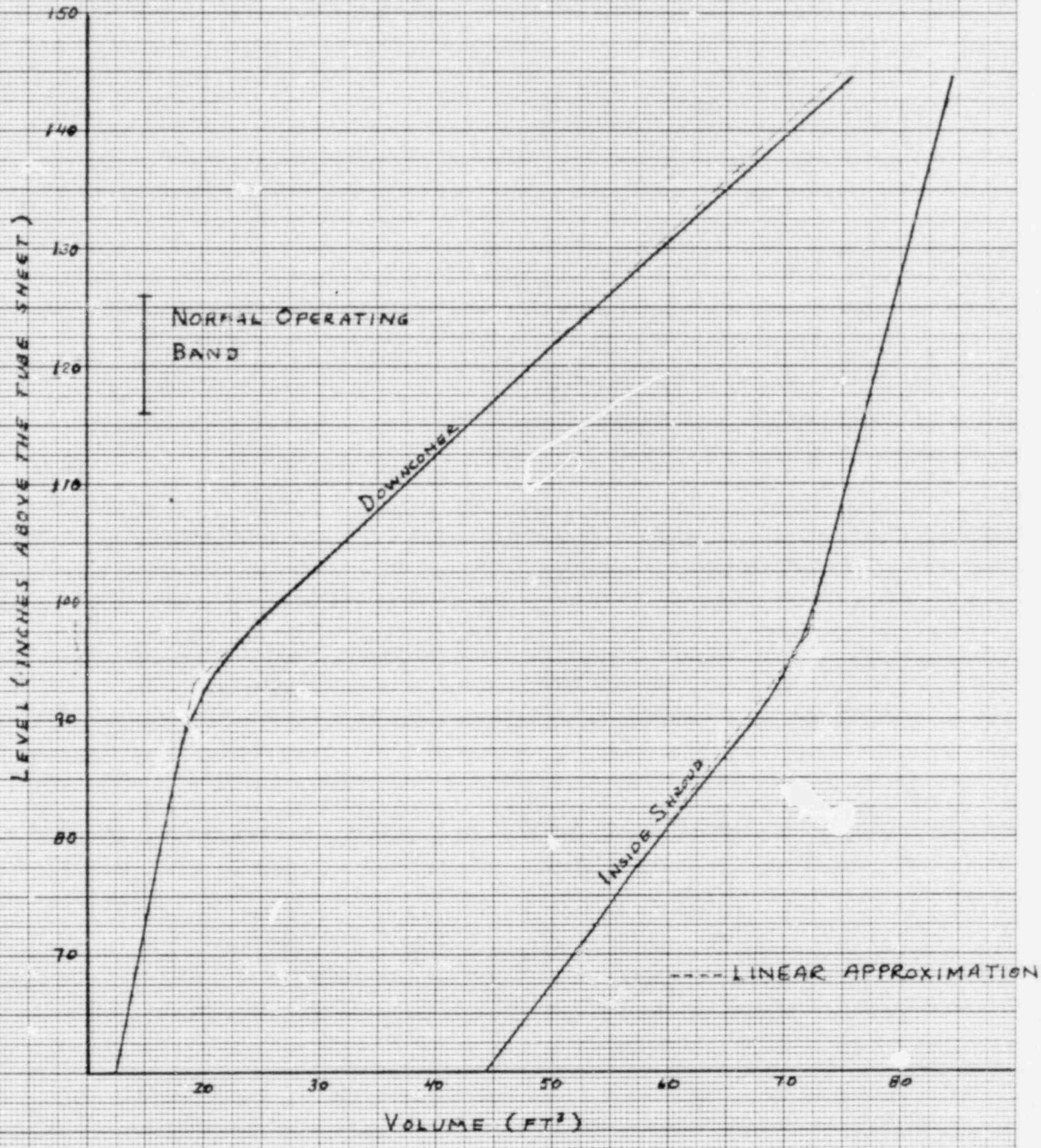
$L = 0.9241\ V + 75.4250 \qquad \text{for } V > 19.4109$

$V = 0.2079\ L \qquad \text{for } L \leq 93.3626$

$V = 1.0821\ L - 81.6200 \qquad \text{for } L > 93.3626$

FIGURE E-1

STEAM GENERATOR LEVEL VS. VOLUME



APPENDIX F

ANALYSIS OF STEAM GENERATOR SHRINK DATA RECORDED DURING POWER RANGE SCRAMS

F.1 Steam Generator Mass Distribution During Normal Operation

By performing a mass balance before and after a reactor scram the normal operating mass distributions inside the steam generator can be determined.

1. Following a scram the water level inside the shroud and the downcomer are equal. See the data sheet for a tabulation of the total steam generator mass. Because the level instrument actually measures differential pressure and is calibrated for saturated water, the mass of the steam in the downcomer and shroud is included with the water masses.

2. During a scram the steam valve closes much slower than the feed valve. This results in a net mass loss which is calculated as follows:

2.1 $$\Delta M = \int W(t)dt = \int_0^{W_i/R} (W_i - Rt)\, dt = \frac{1}{2R} W_i^2$$

W_i = initial mass flow

R = flow change ramp rate

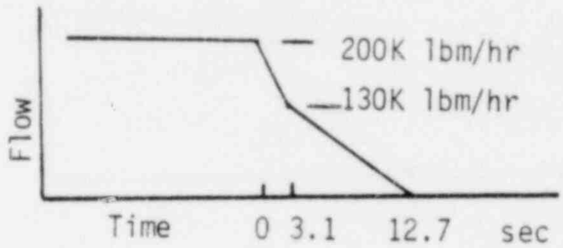
2.2 From 100% plant proof trip (281:23:14:51.429)

2.2.1 Mass added through feedwater valve while the valve was closing. Feed valve shut in 0.7 sec. Feed flow was 206,000 lbm/hr.

$$\Delta M_f = 1/2\ 1/R\ W_i^2,\ R = W_i/\Delta t$$

$$\Delta M_f = 1/2\ (0.7)\ (206{,}000)/3600 = 20.0 \text{ lbm}$$

2.2 Steam flow trace:



Mass loss through steam valve while the valve was closing.

$\Delta M_s = [1/2\ (70K)\ (3.1) + (130K)\ (3.1) + 1/2\ (130K)\ (9.6)]/3600 = 315.4$ lbm

2.2.3 Net $\Delta M = -295.4$ lbm

2.3 Linearized approximation for net mass lost as a function of the initial feed flow.

$$\frac{1}{2R} = \frac{\Delta M}{W_i^2} = \frac{-295.4}{(206K/3600)^2} = -0.09$$

$\Rightarrow$ Net $\Delta M = -0.09\ W_i^2$

See data sheet for the calculated mass changes and the initial mass values.

3. The steam generator shroud mass can now be found by subtracting the downcomer, dome, and steam line masses from the total mass. See the data sheet for the calculated values.

4. $$\bar{\nu}_{shrd} = \frac{V_{shrd}}{M_{shrd}}$$

$$\bar{X}_{shrd} = (\bar{\nu}_{shrd} - \nu_f)/\nu_{fg}$$

DATA SHEET F.1

Power Level	100 %	75 %	30 %	0%	
Post Scram Data					
Level(1)	87.9(2)	94.7(3)	109.9(4)	116	inches
Dwn Water Vol	18.3	21.7	37.3	43.9	cuft
Shroud Water Vol	65.7	70.4	75.3	76.9	cuft
Pressure	925.0(2)	938.0(3)	907.0(4)	963.0(6)	psia
v_f	0.02132	0.02136	0.02126	0.02146	cuft/lbm
v_{fg}	0.46479	0.45738	0.47543	0.44367	cuft/lbm
v_g	0.48611	0.47871	0.49669	0.46513	cuft/lbm
Masses					
Dwncmr	858.3	1015.9	1754.5	2045.7	lbm
Shroud	3081.6	3295.9	3541.9	3583.4	lbm
Dome	105.9	107.6	103.7	116.1	lbm
Steam line	84.3	85.6	82.5	88.1	lbm
TOTAL	4130.1	4505.0	5482.6	5833.3	lbm
Pre-Scram Data					
Steam Flow	55.56(2)	41.67(3)	17.5(5)	0	lbm/sec
Feed Flow	57.22(2)	45.00(3)	17.5(5)	0	lbm/sec
Mass Change	295.4	182.3	27.6	0	lbm
Initial S/G Mass	4425.5	4687.3	5510.2	5833.3	lbm
Level(1)	126.1(2)	124.5	121.6	N/A	inches
Dwncmr Water Vol	55.1	53.3	50.0	N/A	cuft
Pressure	740	780	843	N/A	psia
v_f	0.02065	0.02080	0.02102	N/A	cuft/lbm
v_{fg}	0.59757	0.56377	0.51678	N/A	cuft/lbm
v_g	0.61822	0.58457	0.53780	N/A	cuft/lbm
Masses					
Dwncmr	2668.3	2562.5	2378.7	N/A	lbm
Dome	83.3	88.1	95.8	N/A	lbm
Steam line	66.3	70.1	76.2	N/A	lbm
TOTAL	2817.9	2720.7	2550.7	N/A	lbm
Shroud Mass	1607.6	1966.[illegible]	2959.0	N/A	lbm
v_{shrd}	0.05524	0.04515	0.03001	0.02478	cuft/lbm
X_{shrd}	0.05788	0.04319	0.01740	0.00748	

DATA SHEET F.1 (cont'd)

Volumes

Shroud	88.8 cuft
Downcomer	94.7 cuft
Dome	51.5 cuft
Steam line	41.0 cuft
TOTAL	276.0 cuft

---

(1) The levels given here are referenced to the top of the tube sheet. Indicated level is referenced to 116 inches above the tube sheet.

(2) IP-01.07PR Step 6.11.9, Att 11 Step 6.3, Plant Proof Trip, 100 (281:23:14:51.429).

(3) IP-01.07 Step 6.9.14, Att 11 Step 6.3, Plant Proof Trip, 75 (279:10:35:50.024).

(4) IP-01.07PR Step 6.7.8, Att 11 Step 6.3, Plant Proof Trip 30 (257:22:30:09.436).

(5) Estimated value

(6) Assumed 540°F.

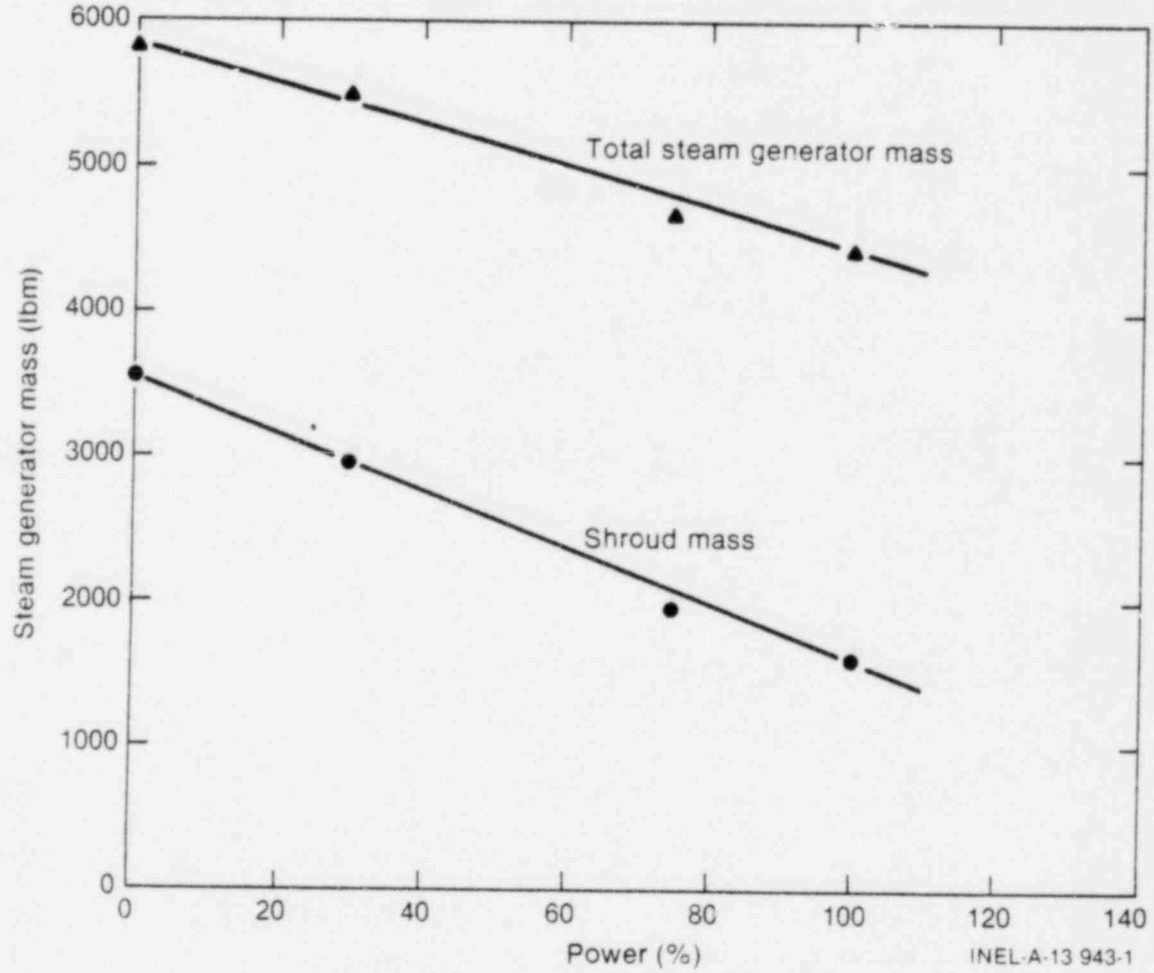


FIGURE F.1-1

STEAM GENERATOR MASS AS A FUNCTION OF POWER

F.2 Steam Generator Natural Circulation Flow Calculation

1. The steam generator gravity head is calculated as follows:

$$\Delta P = \left[\frac{L_{DWN}}{\nu_D} - \frac{Z_{riser}}{\nu_{riser}} - \frac{Z_{drum}}{\nu_{drum}} \right] \times \frac{ft^3}{1728\ in^3}$$

1.1 The L_{DWN}/ν_D term is calculated by assuming $\nu_D = \nu_f$.

1.2 Z_{riser} = 161.75 - 97.31 = 64.44 inches. Assume that the velocity of the steam and recirculation flows are equal. Then,

$$X_{riser} = \frac{W_S}{W_S + W_R} = \frac{1}{R} .$$

From LTR-115-51, Performance Evaluation of LOFT Steam Generator and Air Cooled Condenser during the Power Range Test W. C. Townsend, nominal values of the circulation ratio R were chosen. See Figure F.2-1. ν_{riser} is then calculated by:

$$\nu_{riser} = \nu_f + X_{riser} \nu_{fg}$$

1.3 Z_{drum} = 97.31 inches. This is the height where the inside shroud volume versus level lines (see Figure E-1) for the upper and lower volumes cross. The specific volume of the drum is found by dividing the drum volume by the shroud mass minus the riser mass. The distribution of the mass between the riser and the drum affects the gravity head calculation because the cross sectional areas are not the same.

$$V_{riser} = 17.13\ ft^3$$

$$V_{drum} = 71.67 \text{ ft}^3$$

2. Assume that the flow losses are proportional to the square of the downcomer and riser volumetric flow.

$$\Delta P = k_1 \dot{V}_D^{\,2} + k_2 \dot{V}^2_{riser}$$

$$= k_1 v_D^2 (W_S + W_R)^2 + k_2 (v_g W_S + v_f W_R)^2$$

$$= k_1 v_f^2 R^2 W_S^2 + k_2 (v_g + v_f (R-1))^2 W_S^2$$

$$= \left[k_1 v_f^2 + k_2(v_f + X_{riser} v_{fg})^2\right] \cdot (RW_S)^2$$

$$= (k_1 v_f^2 + k_2 v^2_{riser}) (RW_S)^2$$

3. Least square fit for $c_i = a_i k_1 + b_i k_2$

$$\varepsilon = \sum (c_i - a_i k_i - b_i k_2)^2$$

Minimize ε with respect to k_1 and k_2

$$\frac{\partial \varepsilon}{\partial k_1} = 0 = \sum 2 (c_i - a_i k_1 - b_i k_2)(-a_i)$$

$$\sum a_i c_i = (\sum a_i^2) k_1 + (\sum a_i b_i) k_2$$

$$\frac{\partial \varepsilon}{\partial k_2} = 0 = \sum 2 (c_i - a_i k_1 - b_i k_2)(-b_i)$$

$$\sum b_i c_i = (\sum a_i b_i) k_1 + (\sum b_i^{\,2}) k_2$$

$$\begin{bmatrix} (\sum a_i^2) & (\sum a_i b_i) \\ (\sum a_i b_i) & (\sum b_i^2) \end{bmatrix} \begin{bmatrix} k_1 \\ k_2 \end{bmatrix} = \begin{bmatrix} (\sum a_i c_i) \\ (\sum b_i c_i) \end{bmatrix}$$

$$\begin{bmatrix} k_1 \\ k_2 \end{bmatrix} = \frac{1}{(\sum a_i^2)(\sum b_i^2) - (\sum a_i b_i)^2} \begin{bmatrix} \sum b_i^2 & -\sum a_i b_i \\ -\sum a_i b_i & \sum a_i^2 \end{bmatrix} \begin{bmatrix} \sum a_i c_i \\ \sum b_i c_i \end{bmatrix}$$

$$\begin{bmatrix} k_1 \\ k_2 \end{bmatrix} = \frac{\begin{bmatrix} \sum b_i^2 \sum a_i c_i - \sum a_i b_i \sum b_i c_i \\ \sum a_i^2 \sum b_i c_i - \sum a_i b_i \sum a_i c_i \end{bmatrix}}{(\sum a_i^2)(\sum b_i^2) - (\sum a_i b_i)^2}$$

4. Solve the flow loss equation for R

$$\Delta P = (k_1 \, \nu_f^2 + k_2 \, \nu_{riser}^2) \, (R \, W_S)^2$$

$$(\frac{1}{R})^2 \, \Delta P = W_S^2 \cdot (k_1 \, \nu_f^2 + k_2(\nu_f + (\frac{1}{R})\nu_{fg})^2)$$

$$(\frac{1}{R})^2 \, \frac{\Delta P}{W_S^2} = \nu_f^2 k_1 + \nu_f^2 k_2 + 2\frac{1}{R} \, \nu_{fg} \, \nu_f \, k_2 + (\frac{1}{R})^2 \, \nu_{fg}^2 \, k_2$$

$$0 = (\frac{1}{R})^2 \, (\frac{\Delta P}{W_S^2} - \nu_{fg}^2 \, k_2) - (\frac{1}{R}) \, (2 \, \nu_{fg} \, \nu_f \, k_2) - \nu_F^2(k_1 + k_2)$$

$$\frac{1}{R} = \frac{2 \, \nu_{fg} \, \nu_f \, k_2 \pm \sqrt{4 \, \nu_{fg}^2 \, \nu_f^2 \, k_2^2 + 4(\frac{\Delta P}{W_S^2} - \nu_{fg}^2 k_2) \, \nu_f^2 \, (k_1 + k_2)}}{2 \, (\frac{\Delta P}{W_S^2} - \nu_{fg}^2 \, k_2)}$$

$$\frac{1}{R} = \nu_f \left[\frac{\nu_{fg}\, k_2 \pm \sqrt{\nu_{fg}^2 k_2^2 + \frac{\Delta P}{W_S^2}(k_1 + k_2) - \nu_{fg}^2\, k_1 k_2 - \nu_{fg}^2 k_2^2}}{\frac{\Delta P}{W_S^2} - \nu_{fg}^2 k_2} \right]$$

$$R = \frac{1}{\nu_f} \left\{ \frac{\frac{\Delta P}{W_S^2} - \nu_{fg}^2 k_2}{\nu_{fg} k_2 \pm \sqrt{k_1 \left(\frac{\Delta P}{W_S^2} - \nu_{fg}^2 k_2\right) + \frac{\Delta P}{W_S^2} k_2}} \right\}$$

5. The least squares method given in step 3 was used to estimate k_1 and k_2 using R values from Figure F.2-1. Then the equation given in step 4 was used to determine corresponding values of the circulation ratios, R. This process was repeated several times until the R's used for the least squares fit equaled the results of the step 4 equation. The following results were obtained:

	Percent Power		
	100	75	30
Initial R's	5	7	13
Final R's	5.2104	6.6717	13.0688

$k_1 = 2.2028 \times 10^{-2}$ psi/(cuft/sec)^2

$k_2 = 7.8888 \times 10^{-4}$ psi/(cuft/sec)^2

Figure F.2-2 shows the gravity head and flow losses as a function of power.

6. Assume that R is a function of power and $\overline{X}_{shrd}$:

$$R = \frac{1}{\beta(P) \cdot \overline{X}_{shrd}}; \quad \beta(P) = A_0 + A_1 \frac{1}{P}$$

From the values of R computed in Step 5 and the shroud quality values calculated on Data Sheet F.1, the following values of β were obtained:

	Percent Power		
	100	75	30
$\beta(P)$	3.3159	3.4704	4.3976

A least squares fit yields:

$$\beta = 2.8523 + \frac{46.3590}{P}, \text{ Power in percent}$$

$$\beta = 2.8523 + \frac{21974}{\dot{Q}}, \text{ Power in Btu/sec}$$

7. Determine the resulting circulation ratio as a function of power. Assume that the pressure varies linearly with power: Press = 954 - 2.38 x percent Power.

$$\bar{X}_{shrd} = \frac{\bar{\nu}_{shrd} - \nu_f}{\nu_{fg}} = \frac{\frac{89}{M_{shrd}} - \nu_f}{\nu_{fg}}$$

M_{shrd} = 3583.4 - 19.758 P, Power in percent (from Mass vs Power curve)

$$R = \frac{1}{\beta(P)\ \bar{X}_{shrd}}$$

See plot of data on Figure F.2-1.

DATA SHEET F.2

Power Level	100 %	75%	30%	
Downcomer Gravity Head				
Level	126.1	124.5	121.6	inches
v_f	0.02065	0.02080	0.02102	cuft/lbm
ΔP	3.5339	3.4639	3.3478	psi
Riser Gravity Head				
R	5	7	13	
v_{fg}	0.59757	0.56377	0.51678	cuft/lbm
v_{riser}	0.1402	0.1013	0.0608	cuft/lbm
ΔP	0.2660	0.3681	0.6133	psi
Drum Gravity Head				
Shroud Mass	1607.6	1966.6	2959.5	lbm
Riser Mass	122.2	169.1	281.7	lbm
Drum Mass	1485.4	1797.5	2677.8	lbm
v_{drum}	0.04825	0.03987	0.02676	cuft/lbm
ΔP	1.1671	1.4124	2.1044	psi
TOTAL Head				
ΔP	2.1008	1.6834	0.6301	psi

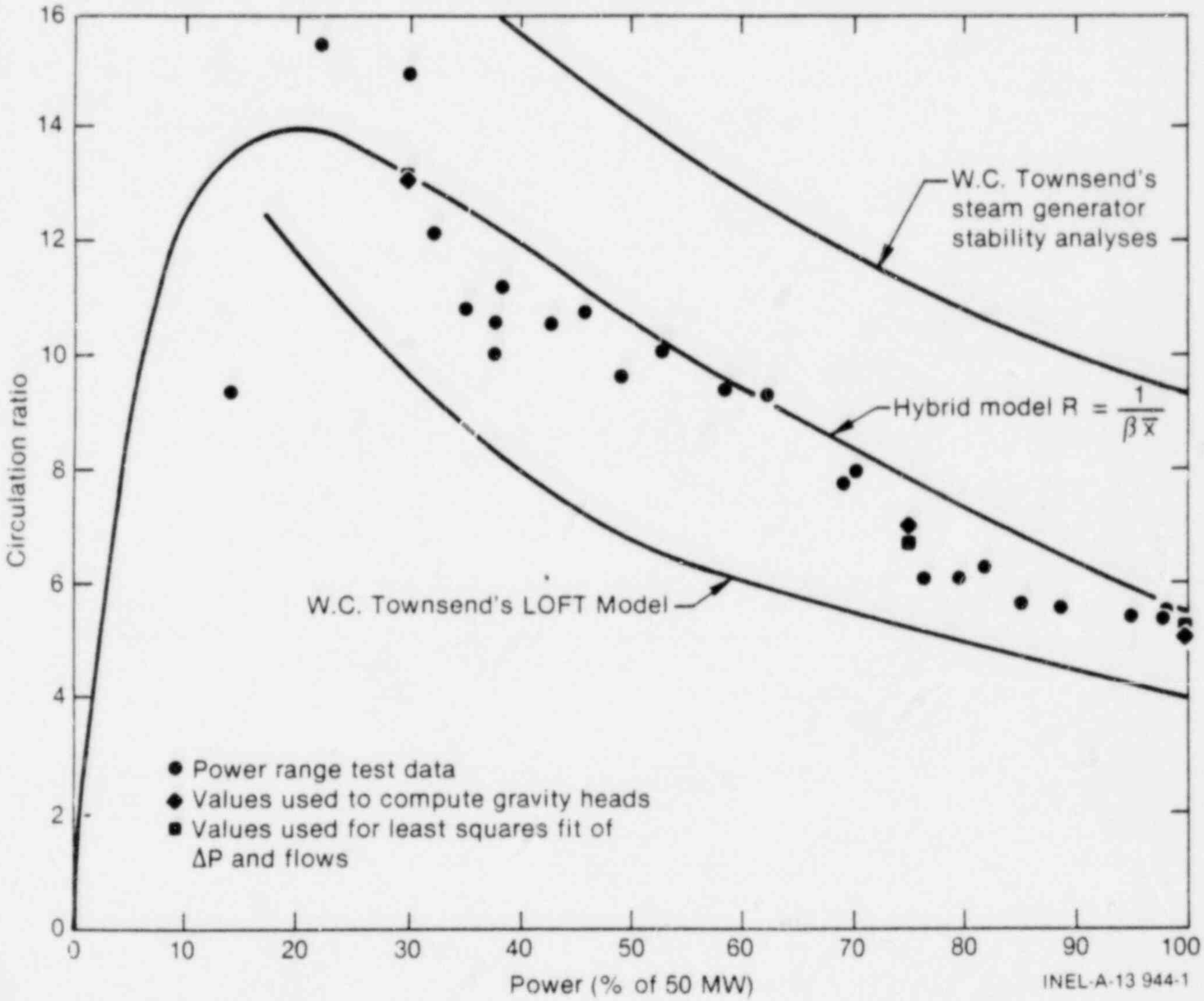


FIGURE F.2-1

LOFT STEAM GENERATOR PERFORMANCE

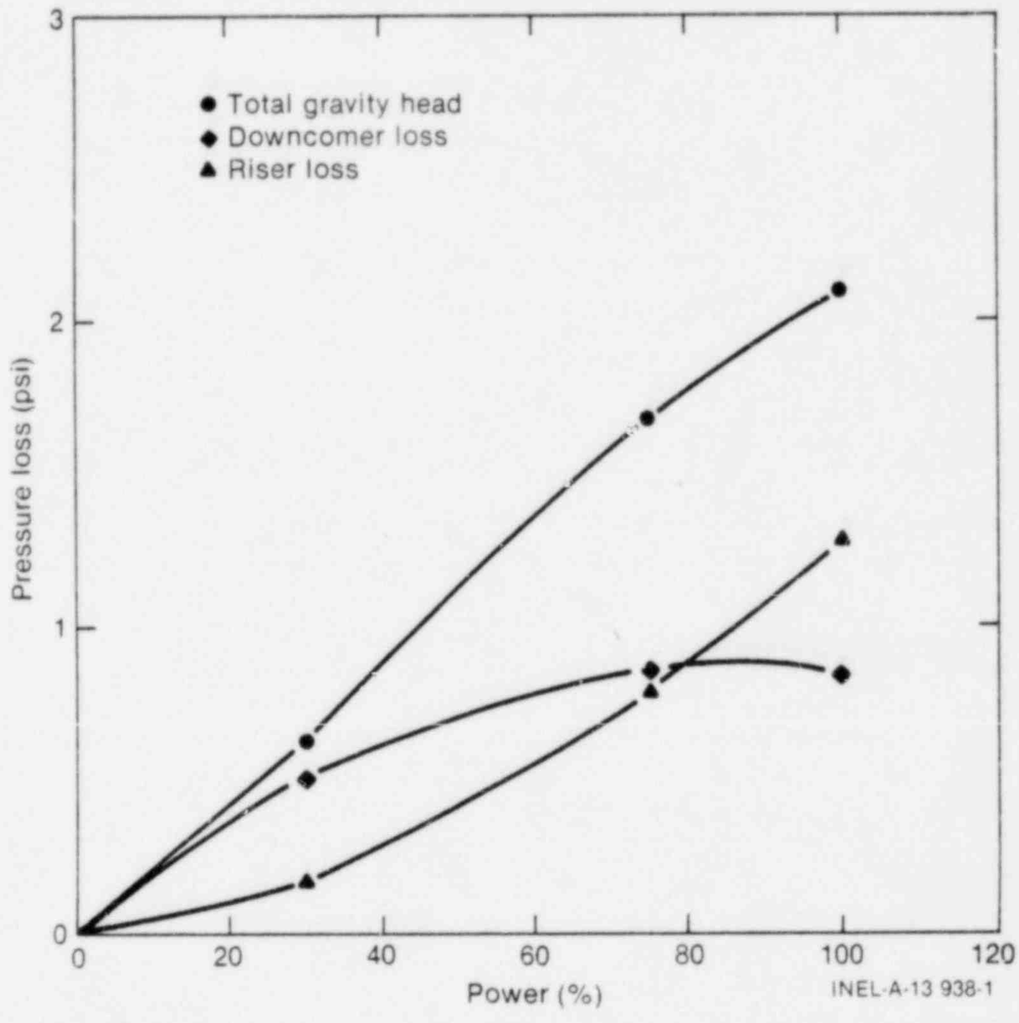
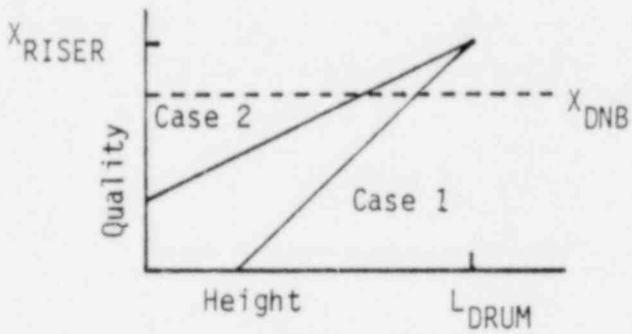


FIGURE F.2.2

STEAM GENERATOR FLOW LOSSES AS A FUNCTION OF POWER

F.3 Steam Generator Dry Out Factor

1. Assume that the quality inside the steam drum is linearly distributed with height.



$$X(h) = mh + b$$

2. Determine b.

$$X(L_{DRUM}) = X_{RISER}$$

$$mL_{DRUM} + b = X_{RISER}$$

$$b = X_{RISER} - mL_{DRUM}$$

$$X(h) = mh + X_{RISER} - mL_{DRUM}$$

$$= X_{RISER} - m\,(L_{DRUM} - h)$$

3. Determine m.

$$X_{DRUM} = \frac{1}{L_{DRUM}} \int_{h_o}^{L_{DRUM}} X(h)\, dh$$

$$X_{DRUM} L_{DRUM} = \int_{h_o}^{L_{DRUM}} \left(X_{RISER} - m (L_{DRUM} - h)\right) \quad dh$$

$$X_{DRUM} L_{DRUM} = X_{RISER} (L_{DRUM} - h_o) - \frac{m}{2} (L_{DRUM} - h_o)^2$$

$$m = 2 \left\{ \frac{X_{RISER}}{(L_{DRUM} - h_o)} - \frac{X_{DRUM} L_{DRUM}}{(L_{DRUM} - h_o)^2} \right\}$$

4. Determine h_o.

For case 1, h_o is the X-axis intercept.

$$X(h_o) = 0$$

$$X_{RISER} - m (L_{DRUM} - h_o) = 0$$

$$h_o = L_{DRUM} - X_{RISER}/m$$

For case 2, $h_o = 0$

5. Solve for m.

Case 1

$$m = 2 \left\{ \frac{X_{RISER}}{X_{RISER/m}} - \frac{X_{DRUM} L_{DRUM}}{(X_{RISER/m})^2} \right\}$$

$$m/2 = m - m^2 \; X_{DRUM} L_{DRUM} / X_{RISER}^2$$

$$m = \frac{X^2_{RISER}}{2X_{DRUM} L_{DRUM}}$$

Case 2

$$m = 2\left\{ \frac{X_{RISER}}{L_{DRUM}} - \frac{X_{DRUM} L_{DRUM}}{L^2_{DRUM}} \right\}$$

$$m = \frac{2 (X_{RISER} - X_{DRUM})}{L_{DRUM}}$$

6. Determine Case 1 and 2 Criteria.

Division between case 1 and 2 occurs when $m = X_{RISER}/L_{DRUM}$

Case 1 applies for $m \geq X_{RISER}/L_{DRUM}$.

$$\frac{X^2_{RISER}}{2 X_{DRUM} L_{DRUM}} \geq \frac{X_{RISER}}{L_{DRUM}}$$

$$X_{RISER} \geq 2 X_{DRUM}$$

Case 2 applies for $m \leq X_{RISER}/L_{DRUM}$

$$\frac{2 (X_{RISER} - X_{DRUM})}{L_{DRUM}} \leq \frac{X_{RISER}}{L_{DRUM}}$$

$$X_{RISER} \leq 2 X_{DRUM}$$

7. Determine L_{DNB}.

$$X(L_{DNB}) = X_{DNB}$$

$$X_{RISER} - m (L_{DRUM} - L_{DNB}) = X_{DNB}$$

$$L_{DNB} = L_{DRUM} - (X_{RISER} - X_{DNB})/m$$

8. Solve for the dryout factor.

$$f = L_{DNB}/L_{DRUM}$$

$$f = 1 - (X_{RISER} - X_{DNB})/mL_{DRUM}$$

Case 1: $X_{RISER} \geq 2\ X_{DRUM}$

$$f = 1 - 2\ (X_{RISER} - X_{DNB})\ X_{DRUM}/X^2_{RISER}$$

Case 2: $X_{RISER} \leq 2\ X_{DRUM}$

$$f = 1 - (X_{RISER} - X_{DNB})/2\ (X_{RISER} - X_{DRUM})$$

9. Values of f are limited to $0.01 \leq f \leq 1.0$.

The upper limit is reached when $X_{DNB} \geq X_{RISER}$. In this case no reduction of the heat transfer will occur and f equals 1. The minimum value of f is held at 0.01 to simulate the reduction of heat transfer by a factor of 1/100 when DNB is exceeded.

APPENDIX G

Computer Program Used to Generate the Pressure Versus Volume and Enthalpy Table

```
PROGRAM SGTBL       76/76    OPT=2                 FTN 4.6+452          08/13/79  11.01.55          PAGE      1

          PROGRAM SGTBL(INPUT,OUTPUT,PUNCH,TAPE5=INPUT,TAPE6=OUTPUT,TAPE15,
         1   TAPE7=PUNCH)
          DIMENSION S(23),P(23,19),CK(23,19)
          COMMON/LCM/A(8000)
          LOGICAL ERR
          LEVEL 2, A
          N=15
          NUSE=8000
          CALL STH2OI(A,N,NUSE)
          IF(NUSE.LE.0) STOP 1
          HK=0.
          S(9)=1.
          DO 500 I=1,23
          VBARI=10.**(I*.1-1.9)
          PK=20.
          DP=2.5
          DO 500 J=1,19
          HBARJ=300.+J*50.
  100     IF(PK.GT.200.) DP=5.
          IF(PK.GT.400.) DP=10.
          IF(PK.GT.1300.) DP=20.
          PK=PK+DP
          S(2)=PK*6894.8
          IF(PK.LE.3000.) GO TO 200
          P(I,J)=3000.
          GO TO 500
  200     CALL STH2O2(A,S,ERR)
          IF(ERR) GO TO 899
          VF=S(11)*16.0185
          VG=S(12)*16.0185
          HF=S(15)*0.0004299
          HG=S(16)*0.0004299
          HK1=HK
          HK=HF+(VBARI-VF)*(HG-HF)/(VG-VF)
          IF(HK.LT.HBARJ) GO TO 100
          P(I,J)=PK-DP+(HBARJ-HK1)*DP/(HK-HK1)
  500     CONTINUE
          DO 800 J=1,19
  800     WRITE(7,1001)(P(I,J),I=1,23)
  1001    FORMAT(2(5X,"1",2X,8(F7.2,",")/),5X,"1",2X,7(F7.2,","))
  899     DO 900 N=1,12,11
          K=N+11
          WRITE(6,8)
  8       FORMAT("1ENTHALPY",T40,"PRESSURE"//)
          WRITE(6,10)((1300.-J*50.),(P(I,20-J),I=N,K),J=1,19)
  10      FORMAT(1X,13F9.2)
  900     WRITE(6,7)(10.**(I*.1-1.9),I=N,K)
  7       FORMAT("0",9X,12F9.5)
          DO 700 J=1,19
          S(5)=(300.+J*50.)*2326.
          DO 700 I=1,23
          IF(P(I,J).LT.3000.) GO TO 600
          CK(I,J)=10.
          GO TO 700
  600     S(2)=P(I,J)*6894.8
          CALL STH2O5(A,S,IT,ERR)
          IF(ERR) STOP 3
```

```
              CK(I,J)=10.**(I*.1-1.9)-S(3)*16.0185
        700   CONTINUE
              DO 950 N=1,12,11
              K=N+11
              WRITE(6,9)
          9   FORMAT("1ENTHALPY",T30,"COMPUTED SP VOL - TABLE SP VOL"//)
              WRITE(6,11)((1300.-J*50.),(CK(I,20-J),I=N,K),J=1,19)
         11   FORMAT([illegible]X,F9.2,12F9.[illegible])
        950   WRITE(6,7)(10.**(I*.[illegible]1.9),I=N,K)
              STOP
              END
```

```
SYMBOLIC REFERENCE MAP (R=3)

ENTRY POINTS     DEF LINE     REFERENCES
  111  SGTBL         1

VARIABLES     SN  TYPE              RELOCATION
    0  A          REAL       ARRAY   LCM       REFS        4         6         9        27        56
 1544  CK         REAL       ARRAY             REFS        3        64   DEFINED        53        58
  616  DP         REAL                         REFS       22      2*36   DEFINED        16        19        20        21
  607  ERR        LOGICAL                      REFS        5        27        28        56        57
  620  HBARJ      REAL                         REFS       35        36   DEFINED        18
  623  HF         REAL                         REFS     2*34   DEFINED        31
  624  HG         REAL                         REFS       34   DEFINED        32
  612  HK         REAL                         REFS       33        35        36   DEFINED        11        34
  625  HK1        REAL                         REFS     2*36   DEFINED        33
  613  I          INTEGER                      REFS       14        25        36        39        45        47        52
                                                 53       55      2*58        64        66   DEFINED        13        39
                                                 45       47        51        64        66
  627  IT      *  INTEGER                      REFS       56
  617  J          INTEGER                      REFS       18        25        36        39      2*45        50        52
                                                 53       5'        58      2*64   DEFINED        17        38        45
                                                 49
  626  K          INTEGER                      REFS       45        47        64        66   DEFINED        42        61
  610  N          INTEGER                      REFS        9        42        45        47        61        64        66
                                            DEFINED        7        41        60
  611  NUSE       INTEGER                      REFS        9        10   DEFINED         8
  657  P          REAL       ARRAY             REFS        3        39        45        52        55
                                            DEFINED       25        36
  615  PK         REAL                         REFS       19        20        21        22        23        24        36
                                            DEFINED       15        22
  630  S          REAL       ARRAY             REFS        3        27        29        30        31        32        56
                                                 58  DEFINED        12        23        50        55
  614  VBARI      REAL                         REFS       34   DEFINED        14
  621  VF         REAL                         REFS     2*34   DEFINED        29
  622  VG         REAL                         REFS       34   DEFINED        30

FILE NAMES        MODE
    0  INPUT
   20  OUTPUT
   40  PUNCH
   60  [illegible]5
```

ENTHALPY	PRESSURE											
1250.00	3000.00	3000.00	3000.00	3000.00	3000.00	3000.00	3000.00	3000.00	3000.00	3000.00	2722.92	2238.01
1200.00	3000.00	3000.00	3000.00	3000.00	3000.00	3000.00	3000.00	3000.00	3000.00	3000.00	2530.26	2088.48
1150.00	3000.00	3000.00	3000.00	3000.00	3000.00	3000.00	3000.00	3000.00	3000.00	2827.13	2350.11	1940.78
1100.00	3000.00	3000.00	3000.00	3000.00	3000.00	3000.00	3000.00	3000.00	3000.00	2601.68	2168.51	1792.23
1050.00	3000.00	3000.00	3000.00	3000.00	3000.00	3000.00	3000.00	3000.00	2840.87	2388.35	1990.82	1646.83
1000.00	3000.00	3000.00	3000.00	3000.00	3000.00	3000.00	3000.00	3000.00	2578.18	2172.02	1813.90	1502.64
950.00	3000.00	3000.00	3000.00	3000.00	3000.00	3000.00	3000.00	2734.50	2324.75	1961.33	1640.62	1361.58
900.00	3000.00	3000.00	3000.00	3000.00	3000.00	3000.00	2824.57	2430.85	2073.40	1753.59	1470.42	1223.99
850.00	3000.00	3000.00	3000.00	3000.00	3000.00	2837.38	2473.02	2136.84	1826.57	1551.28	1305.34	1090.33
800.00	3000.00	3000.00	3000.00	3000.00	2751.85	2437.02	2135.62	1851.96	1591.62	1355.94	1145.86	961.27
750.00	3000.00	3000.00	2835.49	2573.16	2315.17	2057.41	1811.43	1579.68	1364.90	1169.00	993.06	837.21
700.00	2659.44	2483.11	2298.75	2097.68	1896.31	1698.41	1506.48	1322.70	1150.58	991.80	847.73	718.86
650.00	2066.80	1937.97	1804.57	1661.47	1516.77	1370.15	1224.87	1084.49	950.61	825.67	710.84	606.86
600.00	1547.49	1465.45	1375.80	1279.03	1176.69	1074.69	970.04	866.90	766.97	671.96	583.33	501.96
550.00	1120.03	1069.78	1013.37	951.56	885.79	816.05	744.65	672.37	601.04	531.95	466.28	404.96
500.00	778.78	750.03	717.07	680.15	639.75	596.14	550.18	502.67	454.63	407.01	360.80	316.76
450.00	516.68	501.39	483.62	463.36	440.54	415.32	388.05	359.11	329.04	298.47	268.01	238.27
400.00	324.00	316.71	308.05	297.94	286.32	273.14	258.50	242.47	225.37	207.43	189.00	170.53
350.00	189.87	186.78	183.05	178.62	173.41	167.34	160.39	152.57	143.96	134.60	124.67	114.37
	.01585	.01995	.02512	.03162	.03981	.05012	.06310	.07943	.10000	.12589	.15849	.19953

ENTHALPY PRESSURE

1250.00	2238.01	1832.34	1488.41	1201.62	965.91	773.28	617.13	491.14	389.96	308.98	244.41	193.03
1200.00	2068.48	1710.94	1390.02	1123.53	904.09	724.72	579.08	461.42	366.77	290.93	230.37	182.12
1150.00	1940.78	1589.31	1293.24	1046.39	843.30	676.90	541.57	432.08	343.89	273.10	216.48	171.33
1100.00	1792.23	1469.58	1197.26	970.64	783.30	629.73	504.59	403.17	321.30	255.50	202.78	160.67
1050.00	1646.83	1351.80	1103.18	895.87	724.29	583.32	468.20	374.67	299.04	238.14	189.26	150.14
1000.00	1502.64	1236.09	1010.91	822.68	666.43	537.74	432.40	346.64	277.13	221.04	175.93	139.76
950.00	1361.58	1122.73	920.55	750.84	609.69	493.04	397.29	319.11	255.59	204.21	162.80	129.53
900.00	1223.99	1012.26	832.34	680.77	554.19	449.28	362.86	292.10	234.45	187.68	149.89	119.47
850.00	1090.33	904.87	746.45	612.47	500.08	406.56	329.22	265.67	213.72	171.46	137.21	109.57
800.00	961.27	800.96	663.25	546.16	447.46	364.92	296.39	239.85	193.46	155.58	124.79	99.87
750.00	837.21	700.87	582.95	482.03	396.47	324.52	264.47	214.70	173.68	140.06	112.64	90.36
700.00	718.86	605.09	505.88	420.32	347.26	285.43	233.53	190.27	154.44	124.94	100.78	81.07
650.00	606.86	514.09	432.37	361.26	300.03	247.82	203.67	166.64	135.80	110.26	89.24	72.02
600.00	501.96	428.41	362.85	305.16	255.00	211.82	175.01	143.90	117.80	96.06	78.05	63.22
550.00	404.96	348.65	297.75	252.35	212.40	177.63	147.69	122.14	100.53	82.39	67.26	54.72
500.00	316.76	275.54	237.61	203.25	172.55	145.47	121.86	101.48	84.07	69.32	56.91	46.54
450.00	238.27	209.82	183.05	158.31	135.80	115.61	97.72	82.08	68.54	56.92	47.05	38.72
400.00	170.53	152.31	134.74	118.09	102.57	88.37	75.54	64.12	54.06	45.31	37.77	31.33
350.00	114.37	103.87	93.40	83.18	73.37	64.15	55.60	47.82	40.82	34.60	29.16	24.43
	.19953	.25119	.31623	.39811	.50119	.63096	.79433	1.00000	1.25893	1.58489	1.99526	2.51189

ENTHALPY COMPUTED SP VOL - TABLE SP VOL

ENTHALPY												
1250.00	10.00000	10.00000	10.00000	10.00000	10.00000	10.00000	10.00000	10.00000	10.00000	10.00000	-.02896	-.02796
1200.00	10.00000	10.00000	10.00000	10.00000	10.00000	10.00000	10.00000	10.00000	10.00000	10.00000	-.01874	-.01653
1150.00	10.00000	10.00000	10.00000	10.00000	10.00000	10.00000	10.00000	10.00000	10.00000	-.01323	-.01019	-.00248
1100.00	10.00000	10.00000	10.00000	10.00000	10.00000	10.00000	10.00000	10.00000	10.00000	-.00496	.00002	.00003
1050.00	10.00000	10.00000	10.00000	10.00000	10.00000	10.00000	10.00000	10.00000	-.00048	.00002	.00002	.00002
1000.00	10.00000	10.00000	10.00000	10.00000	10.00000	10.00000	10.00000	10.00000	.00001	.00002	.00003	.00002
950.00	10.00000	10.00000	10.00000	10.00000	10.00000	10.00000	10.00000	.00001	.00002	.00002	.00002	.00002
900.00	10.00000	10.00000	10.00000	10.00000	10.00000	10.00000	.00001	.00001	.00002	.00002	.00002	.00003
850.00	10.00000	10.00000	10.00000	10.00000	10.00000	.00001	.00001	.00001	.00002	.00002	.00002	.00003
800.00	10.00000	10.00000	10.00000	10.00000	.00001	.00001	.00001	.00002	.00002	.00002	.00002	.00003
750.00	10.00000	10.00000	-.00404	.00001	.00001	.00001	.00001	.00002	.00002	.00002	.00003	.00003
700.00	-.01064	-.00666	-.00169	.00001	.00001	.00002	.00002	.00002	.00002	.00002	.00003	.00003
650.00	-.00875	-.00473	.00001	.00001	.00002	.00001	.00002	.00002	.00002	.00003	.00003	.00004
600.00	-.00719	-.00313	.00001	.00002	.00002	.00002	.00002	.00002	.00003	.00003	.00003	.00004
550.00	-.00590	-.00181	.00002	.00002	.00002	.00002	.00003	.00003	.00003	.00003	.00004	.00005
500.00	-.00461	-.00072	.00003	.00003	.00003	.00003	.00003	.00003	.00004	.00005	.00005	.00005
450.00	-.00390	.00003	.00003	.00003	.00004	.00004	.00004	.00004	.00004	.00005	.00005	.00006
400.00	-.00313	.00004	.00004	.00004	.00005	.00005	.00005	.00005	.00006	.00006	.00006	.00007
350.00	-.00247	.00006	.00006	.00006	.00006	.00006	.00006	.00006	.00008	.00008	.00008	.00009
	.01585	.01995	.02512	.03162	.03981	.05012	.06310	.07943	.10000	.12589	.15849	.19953

ENTHALPY COMPUTED SP VOL - TABLE SP VOL

1250.00	-.02796	-.02708	-.02812	-.03187	-.03601	-.04095	-.04619	-.05711	-.07518	-.10100	-.13898	-.19315
1200.00	-.01653	-.01386	-.01087	-.00633	-.00405	.00006	.00008	.00009	.00010	.00014	.00017	-.01447
1150.00	-.00248	.00003	.00003	.00004	.00005	.00006	.00007	.00008	.00011	.00013	.00017	.00020
1100.00	.00005	.00003	.00003	.00004	.00005	.00006	.00006	.00009	.00011	.00014	.00016	.00020
1050.00	.00002	.00003	.00003	.00004	.00005	.00006	.00008	.00009	.00011	.00014	.00016	.00019
1000.00	.00002	.00003	.00003	.00004	.00005	.00007	.00007	.00009	.00011	.00015	.00017	.00020
950.00	.00002	.00003	.00004	.00004	.00005	.00006	.00007	.00009	.00012	.00016	.00017	.00021
900.00	.00003	.00003	.00004	.00005	.00005	.00007	.00008	.00009	.00013	.00014	.00017	.00022
850.00	.00003	.00003	.00004	.00005	.00006	.00008	.00008	.00010	.00013	.00015	.00017	.00022
800.00	.00003	.00003	.00004	.00005	.00007	.00007	.00009	.00011	.00012	.00015	.00018	.00022
750.00	.00003	.00004	.00004	.00005	.00006	.00007	.00009	.00012	.00013	.00015	.00018	.00024
700.00	.00003	.00004	.00005	.00006	.00006	.00008	.00010	.00011	.00013	.00015	.00021	.00029
650.00	.00004	.00004	.00005	.00006	.00007	.00008	.00010	.00012	.00014	.00017	.00023	.00029
600.00	.00004	.00005	.00005	.00006	.00008	.00009	.00010	.00013	.00014	.00020	.00024	.00035
550.00	.00005	.00005	.00006	.00006	.00007	.00009	.00010	.00013	.00016	.00018	.00024	.00032
500.00	.00005	.00006	.00006	.00008	.00006	.00010	.00012	.00016	.00020	.0002[illegible]	.00033	.00052
450.00	.00006	.00007	.00007	.00009	.00010	.00012	.00013	.00017	.00025	.00030	.00038	.00070
400.00	.00007	.00007	.00008	.00010	.00011	.00015	.00017	.00024	.00033	.00032	.00041	.00102
350.00	.00009	.00011	.00013	.00014	.00018	.00021	.00025	.00026	.00048	.00051	.00101	.00132
	.19953	.25119	.31623	.39811	.50119	.63096	.79433	1.00000	1.25893	1.58489	1.99526	2.51189

APPENDIX H

ANALOG WIRING SCHEMATICS

FIGURE H-1
REACTOR KINETICS ANALOG CIRCUITRY

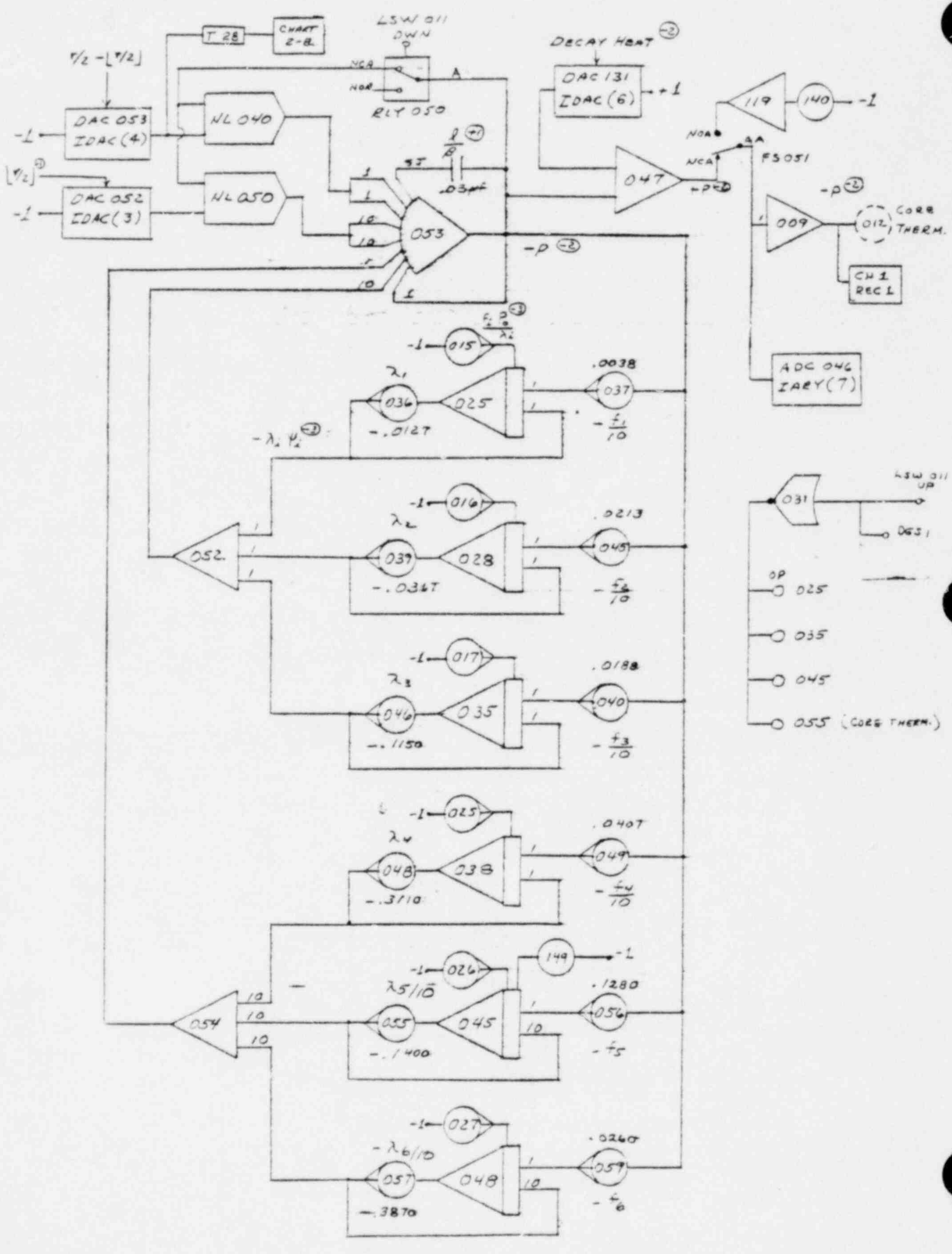
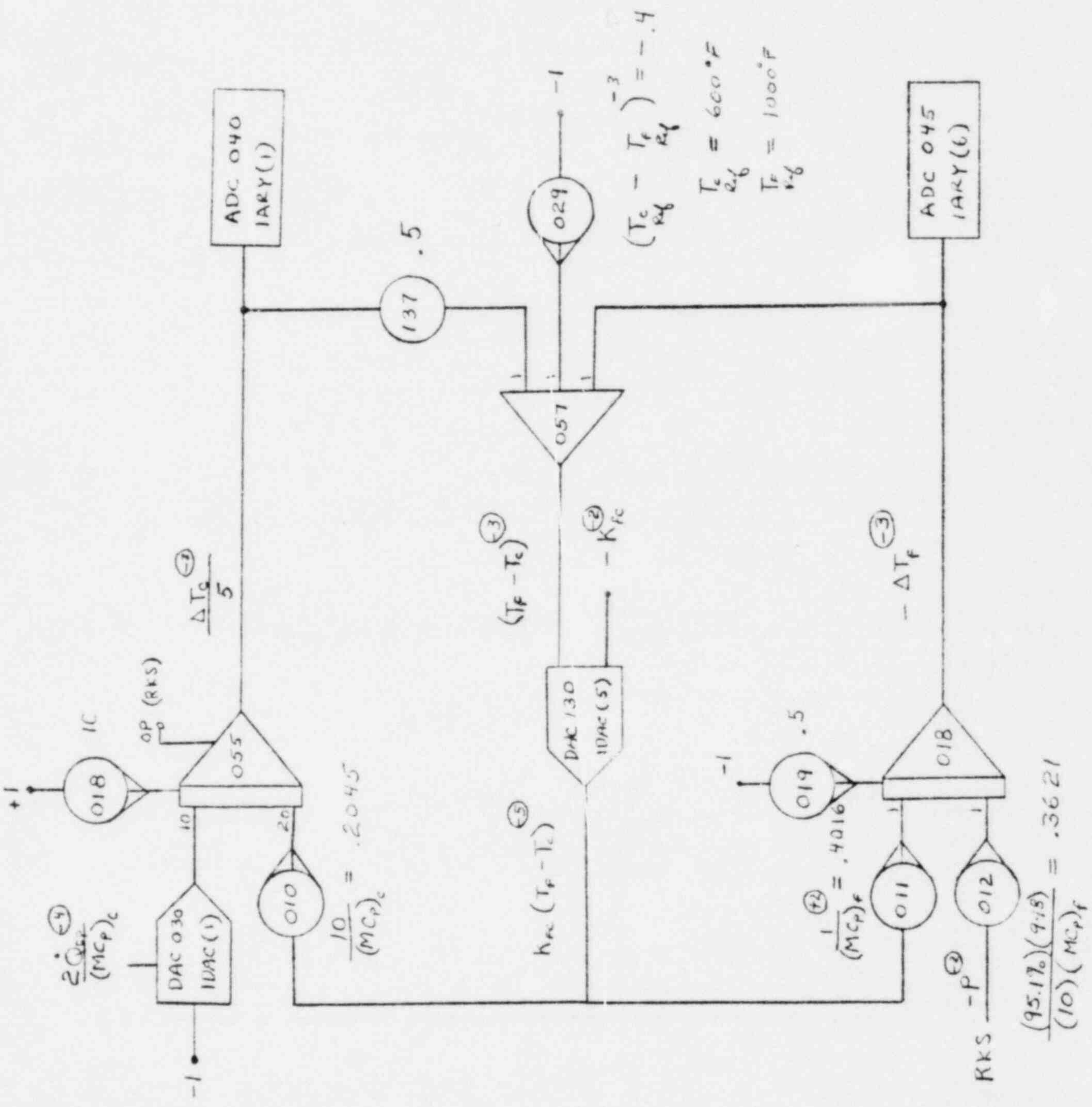


FIGURE H-2

CORE THERMAL ANALOG CIRCUITRY



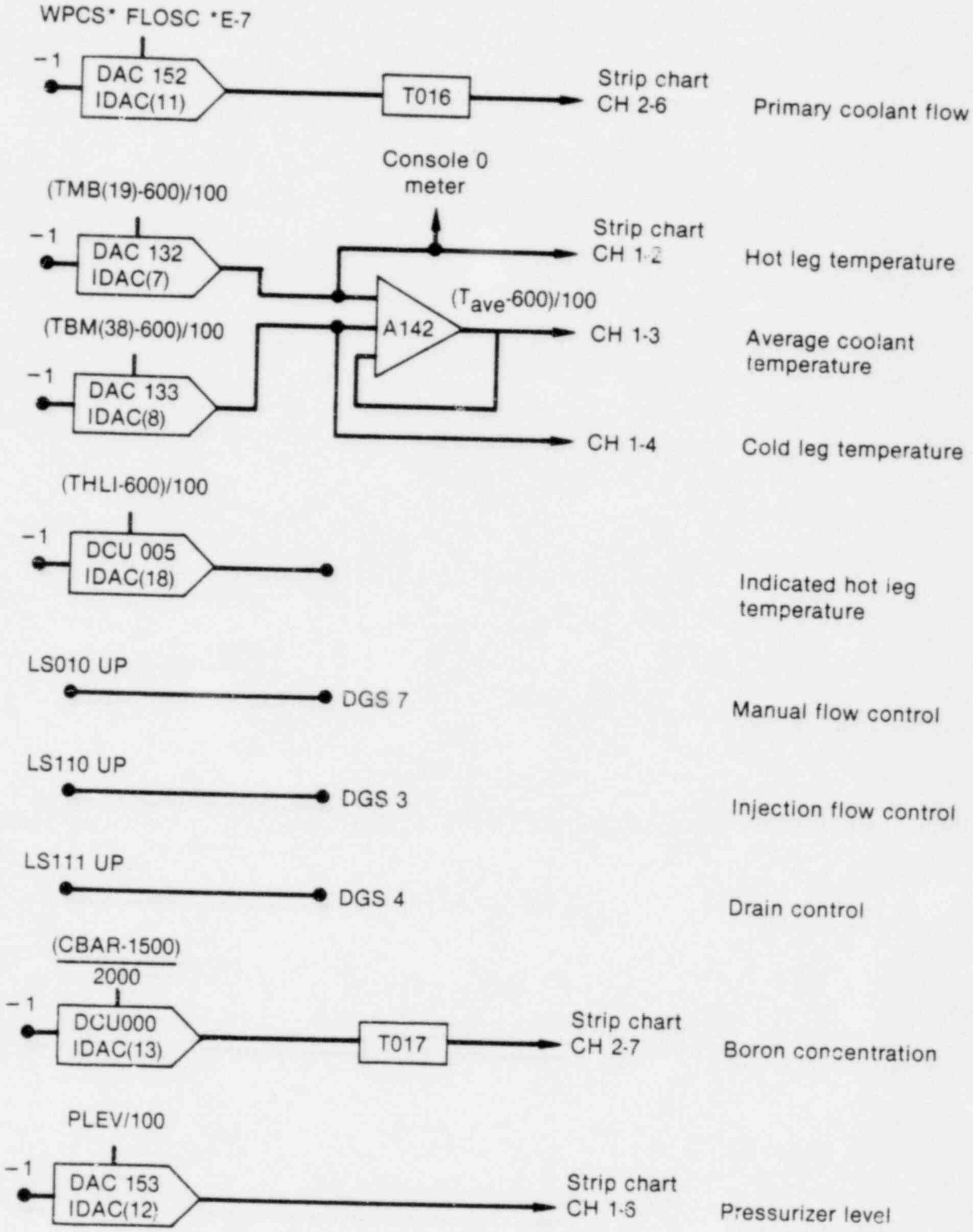
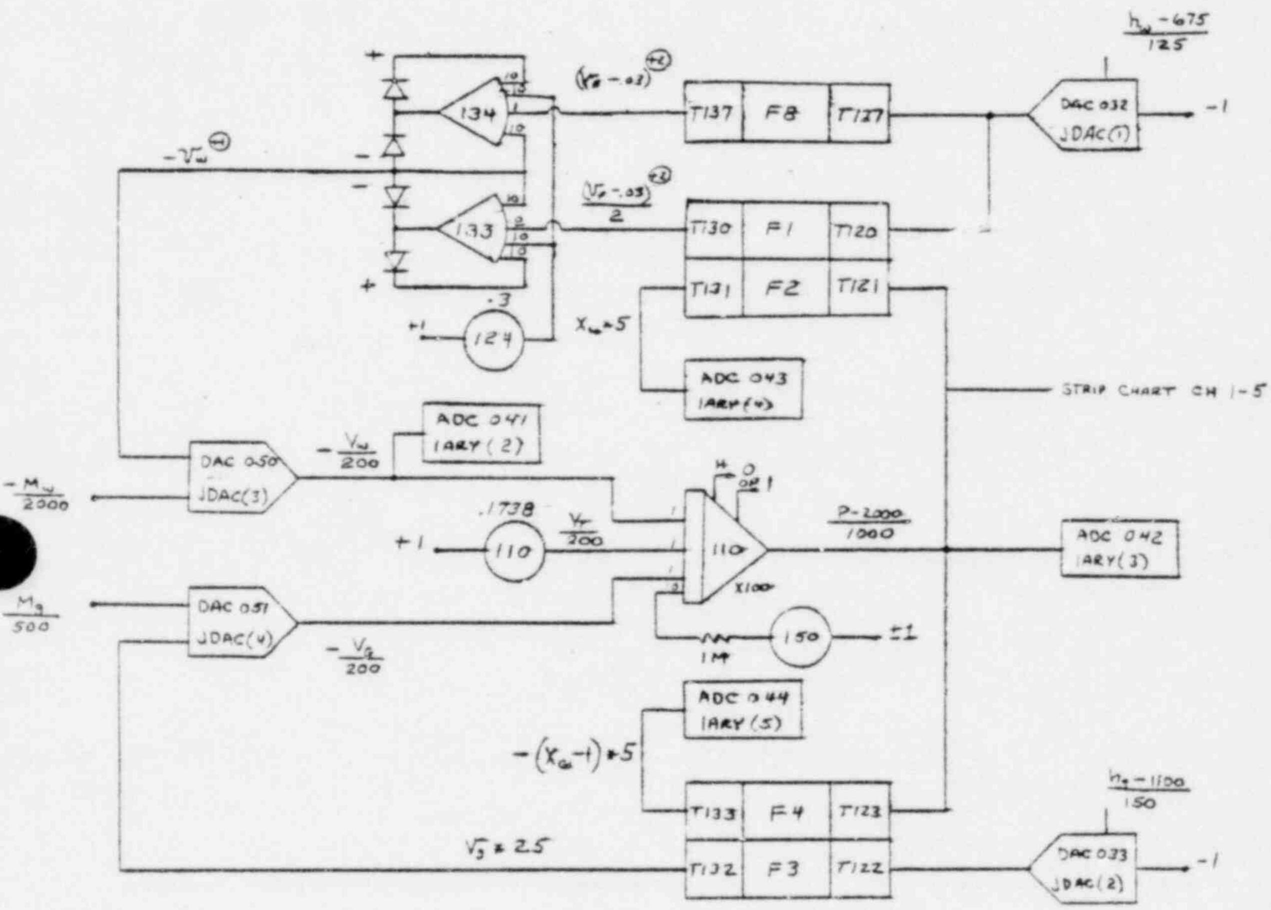


Figure H-3

PRIMARY COOLANT CONTROL
AND INDICATION CIRCUITRY

FIGURE H-4

PRESSURIZER ANALOG CIRCUITRY



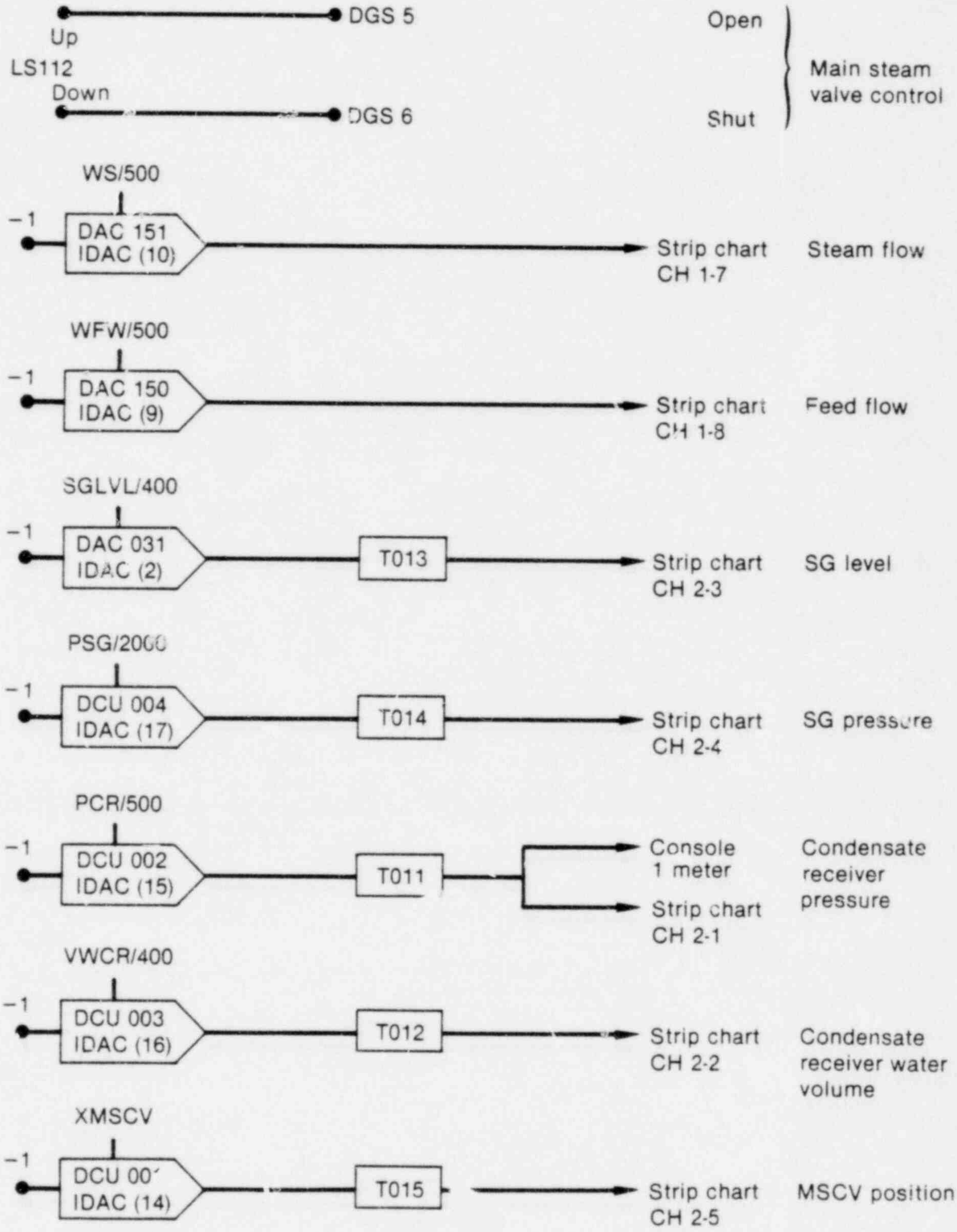
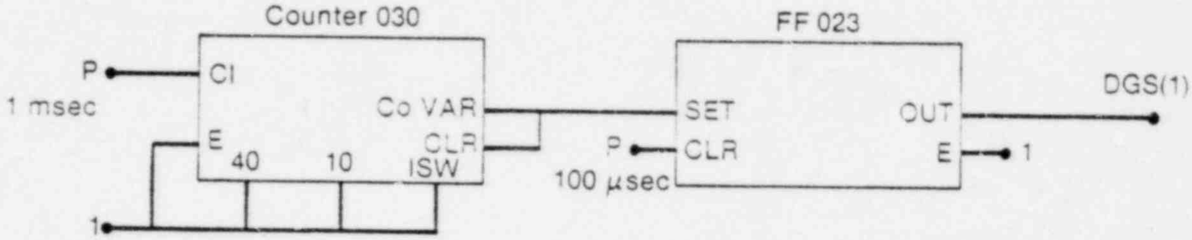
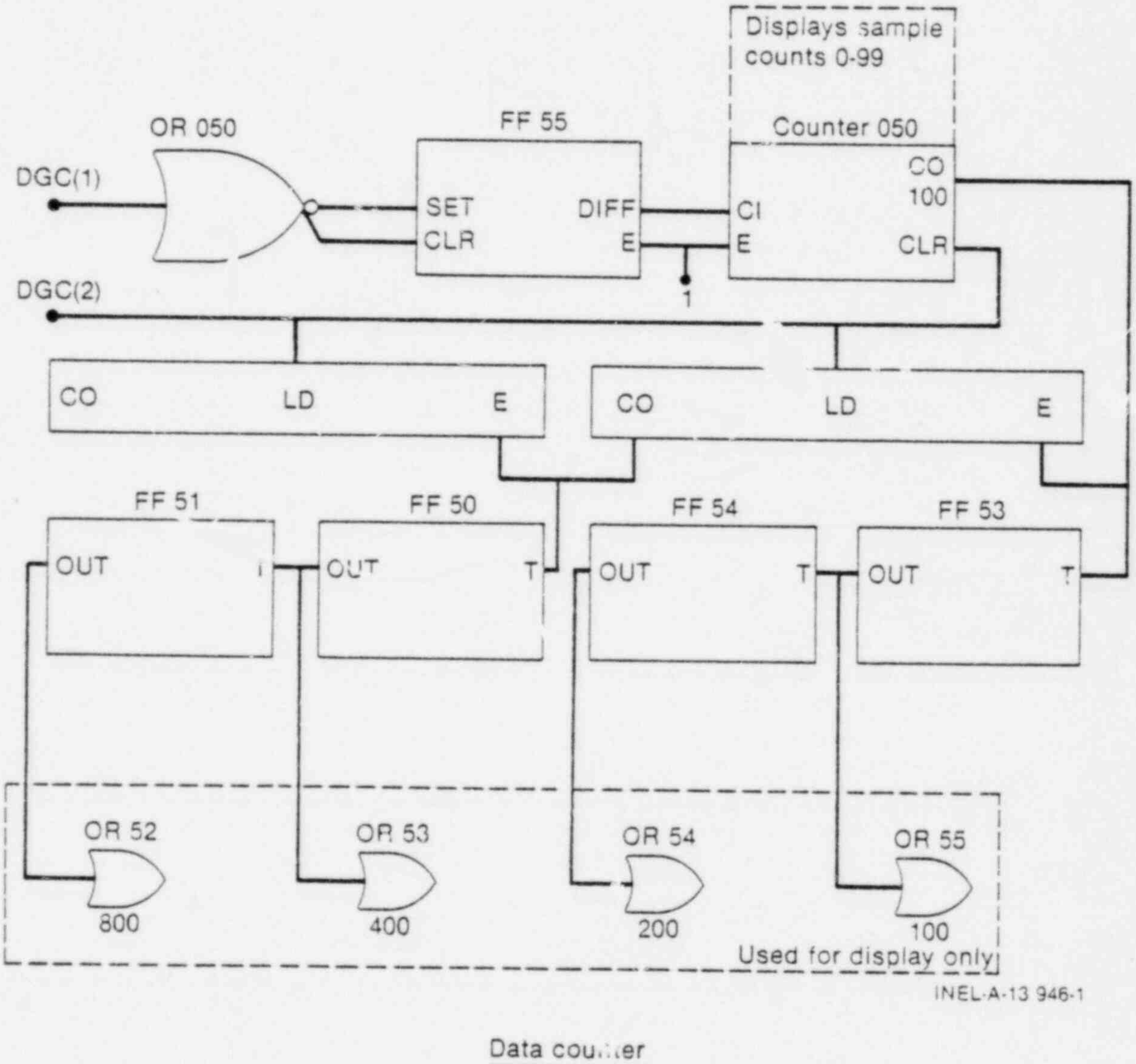


Figure H-5

SECONDARY COOLANT SYSTEM ANALOG CIRCUITRY



50 msec timer



Data counter

FIGURE H-6

TIMER AND DATA COUNTER

FIGURE H-7

IHI Program Used to Set Potentiometers

```
FILE..DK1:COFSET0.CPD       DATE..19-DEC-79          PAGE.. 1

/CO
01.02    ;LOFT HYBRID POT SETUP
01.03    ;CONSOLE 0
01.04    ;6 /25/79 C. D. CLAYTON
01.05    ;LINE 1N.NN CORRESPONDS TO COFNNN, WITH COF000 SET AT LINE 09.99
01.06    ;AND COF100 SET AT LINE 10.99.

03.01    CALL INITA(0)
03.02    CALL HON(0)
03.03    FOR N=1,2
;FIELD 0
10.10    COF010=.2045
10.11    COF011=.4016
10.12    COF012=.3621
10.15    ;COF015 THRU 018 SET BY INIT
10.19    COF019=.5000
10.25    ;COF025 THRU 027 SET BY INIT
10.29    COF029=-.4000
10.36    COF036=-.0127
10.37    COF037=.0038
10.39    COF039=-.0317
10.40    COF040=.0188
10.45    COF045=.0213
10.46    COF046=-.1150
10.48    COF048=-.3110
10.49    COF049=.0407
10.55    COF055=-.1400
10.56    COF056=.1280
10.57    COF057=-.3870
10.59    COF059=.0260
;FIELD 1
11.10    COF110=.1738
11.24    COF124=0.3
11.37    COF137=.5000
15.05    SET $V='VER'
15.06    SET $T=.0003
15.10    NEXT N
16.01    WRITE(0,16.02)
16.02    FORMAT('0CONSOLE 0 HAND SET POTS')
16.03    PRH COF140
16.04    WRITE(0,16.05)
16.05    FORMAT('+                    FIX PWR')
16.29    PRH COF149
16.30    WRITE(0,16.31)
16.31    FORMAT('+                    INITIAL POWER TRIM')
16.50    PRH COF150
16.60    WRITE(0,16.61)
16.61    FORMAT('+                    PZR PRESSURE TRIM')
19.99    STOP
RUN
```

11/11/7[illegible] 11:29:55

FUNCTION NUMBER 1

FIGURE H-8

AD-10 INPUT TABLE

Z1=-0.6000 Z2=-0.5000 Z3=-0.4000 Z4=-0.2000 Z5= 0.0000 Z6= 0.2000 Z7= 0.3000 Z8= 0.5000 Z9= 0.7000 Z10= 1.0000

	X	Y1	Y2	Y3	Y4	Y5	Y6	Y7	Y8	Y9	Y10
1	-1.0000	-1.0000	-1.0000	-1.0000	-1.0000	-1.0000	-1.0000	-1.0000	-1.0000	-1.0000	-1.0000
2	-1.0000	-1.0000	-1.0000	-1.0000	-1.0000	-1.0000	-1.0000	-1.0000	-1.0000	-1.0000	-1.0000
3	-1.0000	-1.0000	-1.0000	-1.0000	-1.0000	-1.0000	-1.0000	-1.0000	-1.0000	-1.0000	-1.0000
4	-1.0000	-1.0000	-1.0000	-1.0000	-1.0000	-1.0000	-1.0000	-1.[illegible]	-1.0000	-1.0000	-1.0000
5	-1.0000	-1.0000	-1.0000	-1.0000	-1.0000	-1.0000	-1.0000	-1.0000	-1.0000	-1.0000	-1.0000
6	-1.0000	-1.0000	-1.0000	-1.0000	-1.0000	-1.0000	-1.0000	-1.0000	-1.0000	-1.0000	-1.0000
7	-1.0000	-1.0000	-1.0000	-1.0000	-1.0000	-1.0000	-1.0000	-1.0000	-1.0000	-1.0000	-1.0000
8	-1.0000	-1.0000	-1.0000	-1.0000	-1.0000	-1.0000	-1.0000	-1.0000	-1.0000	-1.0000	-1.0000
9	-0.9200	-1.0000	-1.0000	-1.0000	-1.0000	-1.0000	-1.0000	-1.0000	-1.0000	-1.0000	-1.0000
10	-0.8400	-1.0000	-1.0000	-1.0000	-1.0000	-1.0000	-1.0000	-1.0000	-1.0000	-1.0000	-1.0000
11	-0.7600	-0.8017	-1.0000	-1.0000	-1.0000	-1.0000	-1.0000	-1.0000	-1.0000	-1.0000	-1.0000
12	-0.6800	-0.5600	-0.8200	-1.0000	-1.0000	-1.0000	-1.0000	-1.0000	-1.0000	-1.0000	-1.0000
13	-0.6000	-0.3182	-0.5928	-0.8252	-1.0000	-1.0000	-1.0000	-1.0000	-1.0000	-1.0000	-1.0000
14	-0.5200	-0.0765	-0.3656	-0.6109	-1.0000	-1.0000	-1.0000	-1.0000	-1.0000	-1.0000	-1.0000
15	-0.4400	0.1653	-0.1384	-0.3965	-0.8122	-1.0000	-1.0000	-1.0000	-1.0000	-1.0000	-1.0000
16	-0.3600	0.4071	0.0888	-0.1822	-0.6198	-0.9521	-1.0000	-1.0000	-1.0000	-1.0000	-1.0000
17	-0.2800	0.6488	0.3160	0.0322	-0.4274	-0.7776	-1.0000	-1.0000	-1.0000	-1.0000	-1.0000
18	-0.2000	0.8906	0.5432	0.2465	-0.2349	-0.6032	-0.8899	-1.0000	-1.0000	-1.0000	-1.0000
19	-0.1200	1.0000	0.7703	0.4609	-0.0425	-0.4288	-0.7306	-0.8571	-1.0000	-1.0000	-1.0000
20	-0.0400	1.0000	0.9975	0.6752	0.1499	-0.2543	-0.5712	-0.7044	-0.9418	-1.0000	-1.0000
21	0.0400	1.0000	1.0000	0.8896	0.3423	-0.0799	-0.4119	-0.5516	-0.8006	-0.9958	-1.0000
22	0.1200	1.0000	1.0000	1.0000	0.5347	0.0946	-0.2525	-0.3989	-0.6594	-0.8652	-1.0000
23	0.2000	1.0000	1.0000	1.0000	0.7271	0.2690	-0.0932	-0.2462	-0.5182	-0.7346	-0.9682
24	0.2800	1.0000	1.0000	1.0000	0.9195	0.4435	0.0662	-0.0934	-0.3770	-0.6039	-0.8521
25	0.3600	1.0000	1.0000	1.0000	1.0000	0.6179	0.2256	0.0593	-0.2358	-0.4733	-0.7360
26	0.4400	1.0000	1.0000	1.0000	1.0000	0.7924	0.3849	0.2120	-0.0946	-0.3427	-0.6200
27	0.5200	1.0000	1.0000	1.0000	1.0000	0.9668	0.5443	0.3648	0.0466	-0.2120	-0.5039
28	0.6000	1.0000	1.0000	1.0000	1.0000	1.0000	0.7036	0.5175	0.1877	-0.0814	-0.3878
29	0.6800	1.0000	1.0000	1.0000	1.0000	1.0000	0.8630	0.6703	0.3289	0.0492	-0.2717
30	0.7600	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.8230	0.4701	0.1799	-0.1556
31	0.8400	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.9757	0.6113	0.3105	-0.0395
32	0.9200	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.7525	0.4412	0.0766
33	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.8937	0.5718	0.1926

FIGURE H-9

AD-10 INPUT TABLE

11/14/73 11:30:34

FUNCTION NUMBER 2

Z1=-0.6060 Z2=-0.5000 Z3=-0.4000 Z4=-0.2000 Z5= 0.0000 Z6= 0.2000 Z7= 0.3000 Z8= 0.5000 Z9= 0.7000 Z10= 1.0000

	Y	Y1	Y2	Y3	Y4	Y5	Y6	Y7	Y8	Y9	Y10
1	-1.0000	-0.4235	-0.5525	-0.6867	-0.9775	-1.0000	-1.0000	-1.0000	-1.0060	-1.0000	-1.0000
2	-1.0000	-0.4235	-0.5525	-0.6867	-0.9775	-1.0000	-1.0000	-1.0000	-1.0000	-1.0000	-1.0000
3	-1.0000	-0.4235	-0.5525	-0.6867	-0.9775	-1.0000	-1.0000	-1.0000	-1.0000	-1.0000	-1.0000
4	-1.0000	-0.4235	-0.5525	-0.6867	-0.9775	-1.0000	-1.0000	-1.0000	-1.0000	-1.0000	-1.0000
5	-1.0000	-0.4235	-0.5525	-0.6867	-0.9775	-1.0000	-1.0000	-1.0000	-1.0000	-1.0000	-1.0000
6	-1.0000	-0.4235	-0.5525	-0.6867	-0.9775	-1.0000	-1.0000	-1.0000	-1.0000	-1.0000	-1.0000
7	-1.0000	-0.4235	-0.5525	-0.6867	-0.9775	-1.0000	-1.0000	-1.0000	-1.0000	-1.0000	-1.0000
8	-1.0000	-0.4235	-0.5525	-0.6867	-0.9775	-1.0000	-1.0000	-1.0000	-1.0000	-1.0000	-1.0000
9	-0.9200	-0.3368	-0.4629	-0.5941	-0.8782	-1.0000	-1.0000	-1.0000	-1.0000	-1.0000	-1.0000
10	-0.8400	-0.2501	-0.3734	-0.5016	-0.7790	-1.0000	-1.0000	-1.0000	-1.0000	-1.0000	-1.0000
11	-0.7600	-0.1633	-0.2838	-0.4090	-0.6797	-0.9879	-1.0000	-1.0000	-1.0000	-1.0000	-1.0000
12	-0.6800	-0.0766	-0.1943	-0.3165	-0.5805	-0.8806	-1.0000	-1.0000	-1.0000	-1.0000	-1.0000
13	-0.6000	0.0101	-0.1048	-0.2239	-0.4812	-0.7733	-1.0000	-1.0000	-1.0000	-1.0000	-1.0000
14	-0.5200	0.0969	-0.0152	-0.1314	-0.3820	-0.6661	-1.0000	-1.0000	-1.0000	-1.0000	-1.0000
15	-0.4400	0.1836	0.0743	-0.0389	-0.2827	-0.5589	-0.8841	-1.0000	-1.0000	-1.0000	-1.0000
16	-0.3600	0.2704	0.1639	0.0537	-0.1835	-0.4516	-0.7670	-0.9504	-1.0000	-1.0000	-1.0000
17	-0.2800	0.3571	0.2534	0.1462	-0.0843	-0.3444	-0.6498	-0.8273	-1.0000	-1.0000	-1.0000
18	-0.2000	0.4436	0.3429	0.2388	0.0150	-0.2371	-0.5326	-0.7042	-1.0000	-1.0000	-1.0000
19	-0.1200	0.5306	0.4325	0.3313	0.1142	-0.1299	-0.4155	-0.5810	-0.9916	-1.0000	-1.0000
20	-0.0400	0.6173	0.5220	0.4238	0.2135	-0.0226	-0.2983	-0.4579	-0.8533	-1.0000	-1.0000
21	0.0400	0.7040	0.6116	0.5164	0.3127	0.0846	-0.1811	-0.3347	-0.7150	-1.0000	-1.0000
22	0.1200	0.7908	0.7011	0.6089	0.4120	0.1919	-0.0640	-0.2116	-0.5768	-1.0000	-1.0000
23	0.2000	0.8775	0.7907	0.7015	0.5112	0.2991	0.0532	-0.0884	-0.4385	-0.9179	-1.0000
24	0.2800	0.9642	0.8802	0.7940	0.6104	0.4064	0.1704	0.0347	-0.3002	-0.7578	-1.0000
25	0.3600	1.0000	0.9697	0.8865	0.7097	0.5136	0.2875	0.1579	-0.1619	-0.5977	-1.0000
26	0.4400	1.0000	1.0000	0.9791	0.8089	0.6209	0.4047	0.2810	-0.0236	-0.4376	-1.0000
27	0.5200	1.0000	1.0000	1.0000	0.9082	0.7281	0.5219	0.4042	0.1146	-0.2776	-1.0000
28	0.6000	1.0000	1.0000	1.0000	1.0000	0.8354	0.6390	0.5273	0.2529	-0.1175	-1.0000
29	0.6800	1.0000	1.0000	1.0000	1.0000	0.9426	0.7562	0.6505	0.3912	0.0426	-0.9576
30	0.7600	1.0000	1.0000	1.0000	1.0000	1.0000	0.8734	0.7736	0.5295	0.2027	-0.7287
31	0.8400	1.0000	1.0000	1.0000	1.0000	1.0000	0.9905	0.8968	0.6677	0.3627	-0.4999
32	0.9200	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.8060	0.5228	-0.2710
33	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.9443	0.6829	-0.0421

FIGURE H-10

AD-10 INPUT TABLE

11/11/79 1:30:22

FUNCTION NUMBER 1

Z1=-0.6000 Z2=-0.4000 Z3=-0.2000 Z4= 0.0000 Z5= 0.2000 Z6= 0.3000 Z7= 0.5000 Z8= 0.7000 Z9= 0.9000 Z10= 1.0000

	X	Y1	Y2	Y3	Y4	Y5	Y6	Y7	Y8	Y9	Y10
1	-1.0000	0.4822	0.4089	0.3519	0.3065	0.2695	0.2536	0.2256	0.2016	0.1812	0.1717
2	-1.0000	0.4822	0.4089	0.3519	0.3065	0.2695	0.2536	0.2256	0.2016	0.1812	0.1717
3	-1.0000	0.4822	0.4089	0.3519	0.3065	0.2695	0.2536	0.2256	0.2016	0.1812	0.1717
4	-0.9333	0.4942	0.4196	0.3615	0.3152	0.2775	0.2613	0.2326	0.2081	0.1873	0.1775
5	-0.8667	0.5063	0.4303	0.3711	0.3240	0.2855	0.2689	0.2397	0.2146	0.1933	0.1833
6	-0.8000	0.5184	0.4410	0.3807	0.3327	0.2934	0.2765	0.2468	0.2212	0.1994	0.1891
7	-0.7333	0.5305	0.4517	0.3904	0.3414	0.3014	0.2842	0.2538	0.2277	0.2054	0.1949
8	-0.6667	0.5426	0.4624	0.4000	0.3501	0.3094	0.2918	0.2609	0.2342	0.2114	0.2007
9	-0.6000	0.5547	0.4732	0.4096	0.3588	0.3173	0.2994	0.2679	0.2408	0.2175	0.2065
10	-0.5333	0.5668	0.4839	0.4192	0.3676	0.3253	0.3071	0.2750	0.2473	0.2235	0.2123
11	-0.4667	0.5789	0.4946	0.4288	0.3763	0.3333	0.3147	0.2821	0.2538	0.2296	0.2205
12	-0.4000	0.5910	0.5053	0.4385	0.3850	0.3413	0.3223	0.2891	0.2604	0.2357	0.2287
13	-0.3333	0.6030	0.5160	0.4481	0.3937	0.3492	0.3300	0.2962	0.2669	0.2445	0.2369
14	-0.2667	0.6151	0.5268	0.4577	0.4025	0.3572	0.3376	0.3032	0.2734	0.2533	0.2451
15	-0.2000	0.6272	0.5375	0.4673	0.4112	0.3652	0.3453	0.3103	0.2801	0.2622	0.2537
16	-0.1333	0.6393	0.5482	0.4769	0.4199	0.3731	0.3529	0.3174	0.2900	0.2710	0.2624
17	-0.0667	0.6514	0.5589	0.4866	0.4286	0.3811	0.3605	0.3244	0.2999	0.2798	0.2711
18	0.0000	0.6635	0.5696	0.4962	0.4373	0.3891	0.3682	0.3339	0.3098	0.2889	0.2797
19	0.0667	0.6756	0.5803	0.5058	0.4461	0.3970	0.3758	0.3449	0.3197	0.2984	0.2886
20	0.1333	0.6877	0.5911	0.5154	0.4548	0.4050	0.3864	0.3560	0.3299	0.3078	0.2977
21	0.2000	0.6997	0.6018	0.5250	0.4635	0.4168	0.3986	0.3670	0.3403	0.3173	0.3069
22	0.2667	0.7118	0.6125	0.5347	0.4732	0.4297	0.4110	0.3783	0.3507	0.3269	0.3161
23	0.3333	0.7239	0.6232	0.5443	0.4875	0.4425	0.4234	0.3896	0.3611	0.3364	0.3253
24	0.4000	0.7360	0.6339	0.5589	0.5020	0.4558	0.4360	0.4010	0.3716	0.3462	0.3346
25	0.4667	0.7481	0.6486	0.5749	0.5165	0.4692	0.4487	0.4125	0.3821	0.3559	0.3441
26	0.5333	0.7642	0.6669	0.5913	0.5313	0.4825	0.4614	0.4241	0.3927	0.3658	0.3537
27	0.6000	0.7853	0.6853	0.6078	0.5461	0.4959	0.4741	0.4358	0.4035	0.3758	0.3634
28	0.6667	0.8065	0.7038	0.6243	0.5608	0.5093	0.4870	0.4476	0.4143	0.3857	0.3730
29	0.7333	0.8277	0.7224	0.6407	0.5758	0.5227	0.4998	0.4593	0.4252	0.3957	0.3826
30	0.8000	0.8490	0.7411	0.6573	0.5906	0.5362	0.5126	0.4712	0.4362	0.4060	0.3925
31	0.8667	0.8705	0.7597	0.6740	0.6055	0.5498	0.5257	0.4831	0.4473	0.4163	0.4024
32	0.9333	0.8920	0.7788	0.6906	0.6206	0.5635	0.5387	0.4952	0.4583	0.4267	0.4124
33	1.0000	0.9137	0.7977	0.7075	0.6358	0.5773	0.5519	0.5073	0.4694	0.4371	0.4223

FIGURE H-11

AD-10 INPUT TABLE

11/14/79 11:40:2[illegible]

FUNCTION NUMBER 1

Z1=-0.6000 Z2=-0.4000 Z3=-0.2000 Z4= 0.0000 Z5= 0.2000 Z6= 0.3000 Z7= 0.5000 Z8= 0.7000 Z9= 0.9000 Z10= 1.0000

	X	Y1	Y2	Y3	Y4	Y5	Y6	Y7	Y8	Y9	Y10
1	-1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
2	-1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
3	-1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
4	-0.9333	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
5	-0.8667	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
6	-0.8000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.9224
7	-0.7333	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.9777	0.6935
8	-0.6667	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.7814	0.4646
9	-0.6000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.9556	0.5851	0.2357
10	-0.5333	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.7956	0.3887	0.0069
11	-0.4667	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.8753	0.6355	0.1924	-0.2220
12	-0.4000	1.0000	1.0000	1.0000	1.0000	0.9631	0.9014	0.7370	0.4754	-0.0039	-0.4509
13	-0.3333	1.0000	1.0000	1.0000	0.9470	0.8459	0.7783	0.5987	0.3153	-0.2003	-0.6798
14	-0.2667	1.0000	0.9671	0.9160	0.8398	0.7288	0.6551	0.4605	0.1553	-0.3966	-0.9086
15	-0.2000	0.9133	0.8745	0.8168	0.7325	0.6116	0.5320	0.3222	-0.0048	-0.5929	-1.0000
16	-0.1333	0.8266	0.7820	0.7175	0.6253	0.4944	0.4088	0.1839	-0.1649	-0.7893	-1.0000
17	-0.0667	0.7398	0.6894	0.6183	0.5180	0.3773	0.2857	0.0456	-0.3249	-0.9856	-1.0000
18	0.0000	0.6531	0.5969	0.5190	0.4108	0.2601	0.1626	-0.0926	-0.4850	-1.0000	-1.0000
19	0.0667	0.5664	0.5043	0.4198	0.3035	0.1429	0.0394	-0.2309	-0.6451	-1.0000	-1.0000
20	0.1333	0.4796	0.4118	0.3206	0.1963	0.0258	-0.0837	-0.3692	-0.8052	-1.0000	-1.0000
21	0.2000	0.3929	0.3193	0.2213	0.0890	-0.0914	-0.2069	-0.5075	-0.9652	-1.0000	-1.0000
22	0.2667	0.3062	0.2267	0.1221	-0.0182	-0.2086	-0.3300	-0.6458	-1.0000	-1.0000	-1.0000
23	0.3333	0.2194	0.1342	0.0228	-0.1255	-0.3257	-0.4532	-0.7840	-1.0000	-1.0000	-1.0000
24	0.4000	0.1327	0.0416	-0.0764	-0.2327	-0.4429	-0.5763	-0.9223	-1.0000	-1.0000	-1.0000
25	0.4667	0.0460	-0.0509	-0.1757	-0.3400	-0.5601	-0.6995	-1.0000	-1.0000	-1.0000	-1.0000
26	0.5333	-0.0408	-0.1434	-0.2749	-0.4472	-0.6772	-0.8226	-1.0000	-1.0000	-1.0000	-1.0000
27	0.6000	-0.1275	-0.2360	-0.3741	-0.5545	-0.7944	-0.9458	-1.0000	-1.0000	-1.0000	-1.0000
28	0.6667	-0.2142	-0.3285	-0.4734	-0.6617	-0.9116	-1.0000	-1.0000	-1.0000	-1.0000	-1.0000
29	0.7333	-0.3010	-0.4211	-0.5726	-0.7690	-1.0000	-1.0000	-1.0000	-1.0000	-1.0000	-1.0000
30	0.8000	-0.3877	-0.5136	-0.6719	-0.8763	-1.0000	-1.0000	-1.0000	-1.0000	-1.0000	-1.0000
31	0.8667	-0.4744	-0.6061	-0.7711	-0.9835	-1.0000	-1.0000	-1.0000	-1.0000	-1.0000	-1.0000
32	0.9333	-0.5612	-0.6987	-0.8704	-1.0000	-1.0000	-1.0000	-1.0000	-1.0000	-1.0000	-1.0000
33	1.0000	-0.6479	-0.7912	-0.9696	-1.0000	-1.0000	-1.0000	-1.0000	-1.0000	-1.0000	-1.0000

FIGURE H-12

AD-10 INPUT TABLE

11/14/79 14:31:16

	X	Y
1	-1.0000	-0.8230
2	-1.0000	-0.8230
3	-1.0000	-0.8230
4	-1.0000	-0.8230
5	-1.0000	-0.8230
6	-1.0000	-0.8230
7	-1.0000	-0.8230
8	-1.0000	-0.8230
9	-1.0000	-0.8230
10	-1.0000	-0.8230
11	-1.0000	-0.8230
12	-1.0000	-0.8230
13	-1.0000	-0.8230
14	-1.0000	-0.8230
15	-1.0000	-0.8230
16	-1.0000	-0.8230
17	-1.0000	-0.8230
18	-1.0000	-0.8230
19	-1.0000	-0.8230
20	-1.0000	-0.8230
21	-1.0000	-0.8230
22	-1.0000	-0.8230
23	-1.0000	-0.8230
24	-0.6094	-0.5940
25	-0.5064	-0.6540
26	-0.3061	-0.6130
27	-0.2121	-0.5260
28	-0.0231	-0.4350
29	0.1637	-0.3110
30	0.2574	-0.2730
31	0.4537	-0.1410
32	0.6567	0.0290
33	1.0000	0.4097

APPENDIX I

CONDENSATE VELOCITY IN THE AIR-COOLED CONDENSER TUBES

I.1 Flow Method

Assume that at maximum flow the tubes are half full of condensate.

$$W_{max} = \dot{Q}_{max}/(h_{g_{SG}} - h_{f_{CR}})$$

$\dot{Q}_{max}$ = 194,626,016 Btu/hr (Reference 6, page 258, Table XXXIII)

$h_{g_{SG}}$ = 1200 Btu/lbm

$h_{f_{CR}}$ at 300 psi = 394 Btu/lbm

$$W_{max} = 67 \text{ lbm/sec}$$

$\dot{V}_{max} = W_{max} / \rho \qquad \rho = \frac{1}{0.01889}$ (saturated water at 300 psi)

$\dot{V}_{max}$ = 1.2656 cu ft/sec

$$\text{Cross sectional area} = \begin{pmatrix}\text{fraction of} \\ \text{tubes filled} \\ \text{with condensate}\end{pmatrix} \begin{pmatrix}\text{cross} \\ \text{section} \\ \text{of tubes}\end{pmatrix} \begin{pmatrix}\text{number} \\ \text{of} \\ \text{tubes}\end{pmatrix}$$

$$A = (\frac{1}{2}) (\frac{\pi}{4} (\frac{0.83}{12})^2) (230 \times 3) = 1.2963 \text{ ft}^2$$

$$v = \dot{V}_{max} \quad A = 0.9763 \text{ ft/sec}$$

I.2 Friction Loss Method

Assuming that the tubes are half full

$$\text{Equiv. Diameter} = 4 \times \text{hydraulic radius} = 4 \times \frac{\text{area}}{\text{wetted perimeter}}$$

$$= 4 \frac{\frac{1}{2} \frac{\pi}{4} (0.83)^2}{\frac{1}{2} \pi (0.83)} = 0.83 \text{ inches}$$

Absolute roughness from Reference 10, page 3:

$$\varepsilon = 0.001$$

Relative Roughness

$$\frac{\varepsilon}{D} = \frac{0.001}{0.83} \times 12 = 0.01446$$

Reynolds number (assume 1 ft/sec)

$$R_e = \frac{(0.83/12 \text{ ft}) \ (1 \text{ ft/sec})}{(0.01889 \ \frac{\text{ft}^3}{\text{lbm}}) \ (0.13 \text{ centipoise}) \ (\frac{0.000672 \text{ lbm/ft sec}}{\text{centipoise}})}$$

$$= 42{,}000$$

Friction Factor from Crane Technical Paper No. 410, Flow of Fluids, page A-24:

$$f = 0.044$$

Darcy's Formula:

$$v = \sqrt{\frac{h_L \ D2g}{L \ f}}$$

$$v = \sqrt{\frac{(1 \text{ ft}) \ (0.83/12 \text{ ft}) \ 2 \ (32 \text{ ft/sec}^2)}{(44 \text{ ft}) \ (0.044)}} = 1.512 \text{ ft/sec}$$

APPENDIX J

FEEDWATER SYSTEM CALCULATIONS

J.1 Subcooler Heat Transfer Coefficient

Assume 10^oF subcooling at feed flow corresponding to 50 MW operation.

$$(1)\quad Q = W\,C_p\,(T_{CR} - T_{FW}) \qquad T_{FW} = T_{CR} - \frac{Q}{WC_p}$$

$$(2)\quad Q = UA\,(T_{FW} - T_{AMB})$$

$$Q = UA\left(T_{CR} - \frac{Q}{WC_p} - T_{AMB}\right)$$

$$Q = \frac{UA}{C_p}\left(h_{CR} - \frac{Q}{W} - h_{AMB}\right)$$

$$\frac{UA}{C_p} = \frac{Q}{h_{CR} - h_{AMB} - \frac{Q}{W}} = \frac{W\,C_p\,\Delta T}{h_{CR} - h_{AMB} - C_p\,\Delta T}$$

W = 60 lbm/sec

ΔT = 10^oF

C_p = 1.093 Btu/lbm ^oF

h_{CR} = 394.0 Btu/lbm

h_{AMB} = 100 Btu/lbm

$$\frac{UA}{C_p} = \frac{(60)\ (10.93)}{(294 - 10.93)} = 2.3167 \text{ lbm/sec.}$$

J.2 Feedwater Pump Internal Resistance

Shut off head 2360 ft (Pacific Pump Data Sheet)

$$(2360 \text{ ft})\ (53.36 \text{ lbm/ft}^3)\ (\text{ft}^2/144 \text{ in}^2) = 874.51 \text{ psi}$$

head at 600 gpm = 2040 ft

Δh = 2360 - 2040 = 320 ft 118.5778 psi

$$\frac{600 \text{ gal}}{\text{min}} \times \frac{1 \text{ ft}^3}{7.48 \text{ gal}} \times \frac{53.36 \text{ lbm}}{\text{ft}^3} \times \frac{\text{min}}{60 \text{ sec}} = 71.3369 \text{ lbm/sec}$$

$$R_p = \frac{118.5778}{(71.3369)^2} = 0.02330 \quad \text{psi/(lbm/sec)}^2$$

APPENDIX K

ANALOG/DIGIT INTERFACE

IDAC	DAC	Variable	Use
1	030	Q_{CLAD}/MCCL * 2E-4	Core Thermal
2	031	SGLVL/400	Chart 2-3
3	052	SDL/20	RKS
4	053	ΔSDL/2	RKS/Chart 2-8
5	130	-KFC/100	Core Thermal
6	131	DECAY/100	RKS
7	132	(TBM(19) - 600)/100	T_{AVE}/Chart 1-2
8	133	(TBM(38) - 600)/100	T_{AVE}/Chart 1-4
9	150	WFW/500	Chart 1-8
10	151	WS/500	Chart 1-7
11	152	WPCS * FLOSC * E-7	Chart 2-6
12	153	PRLEV/100	Chart 1-6

IDAC	DCU's	Variable	Use
13	000	(CBAR-1500) * 5E-4	Chart 2-7
14	001	XMSCV	Chart 2-5
15	002	PCR/500	Chart 2-1
16	003	VWCR/400	Chart 2-2
17	004	PSG * 5E-4	Chart 2-4
18	005	(THLI-600)/100	Misc. Indication

APPENDIX K (Cont'd)

ANALOG/DIGIT INTERFACE

IARY	ADC	Variable	Use
1	040	$(T_{CLAD}-600)/500$	A055
2	041	-VWP/200	D050
3	042	(PPR-2000) * E-3	A110
4	043	XW * 5	T131
5	044	(1-XG) * 5	T133
6	045	-(TFUEL-1000) * E-3	A018
7	046	RPA/100	A047

JDAC	DAC	Variable	Use
1	032	$(h_w - 675)/125$	Pressurizer
2	033	$(h_g - 1100)/150$	Pressurizer
3	050	$-M_w/2000$	Pressurizer
4	051	Mg/500	Pressurizer

APPENDIX L

PLAN14 DIGITAL PROGRAM LISTING

```
      PROGRAM PLAN14
      INCLUDE 'DK1:COMM13.FTN/LIST'
      DIMENSION  DAT(128),PA(256),IPA(33),PSGT(23,19)
      COMMON /DAT/
     1 TIM,         RPA,         VLOOP,       PLA,         PPR,          ! 1-5
     2 WG,          OCLAD,       SPL,         QSG,         PSG,          ! 6-10
     3 PCR,         XSFW,        WFW,         XMSCV,       CP,           ! 11-15
     4 RANG,        TCLAD,       CBAR,        TCLI,        PZRMW,        ! 16-20
     5 PZRHW,       WRABV,       DLMSPT,      WR,          HFW,          ! 21-25
     6 WLNC,        WBNC,        WCNC,        PZRMG,                     ! 26-29
     7 WPCS,        WCORE,       DCYHT,       TTUBE(3),    QAIR(3),      ! 30-38
     8 WAIR(3),     RODPOS,      PZRHG,       DLMOD,       DLF,          ! 39-45
     9 DLB,         DCR,         XRISER,      PMASS,       HWCR,         ! 46-50
     0 DMSURT,      TRM(51),     SGLVL,       SGV,         HDWN,         ! 51-105
     1 DWMASS,      SGMASS,      WD,          SHRDX,       HSG,          ! 106-110
     2 WSGRV,       CRMSTM,      CRHSTM,      CONDMF,      CRHW,         ! 111-115
     3 HWPR,        HGPR,        PZRDMT,      CRMW,        DLMRT,        ! 116-120
     4 VCRP,        DEXT,        RPI,         THLI,        PLI,          ! 121-125
     5 VLI,         PRLEV,       TFUEL                                   ! 126-128
      COMMON /PA/
     1 RPSCRM,      HTSCRM,      VSCRM,       HPSCRM,      LPSCRM,       ! 1-5
     2 TCRP,        TCHLT,       TCLF,        TCLP,        KSURGE,       ! 6-10
     3 DELT,        SMTSLO,      WPCSI,       ALPHAB,      SCDLY,        ! 11-15
     4 SMTEST,      SVTC,        DOPC,        DPPO,        TCCLT,        ! 16-20
     5 STMLKG,      VSFR(60),    SSP,         HTSUP,                     ! 21-83
     6 SPACE9(2),   FLTMD,       FLTMX,       RPSP,        PCSP,         ! 84-89
     7 HT1SP,       HT2SP,       RASCRM,      SPAC10(3),                 ! 90-95
     8 SURMIN,      CLIC,        CPIC,        VDRAIN,                    ! 96-99
     9 VINJ,        RAHFR(60),   SPAC1(3),                               ! 100-163
     0 FFRMN,       SPACE2(11),  DLS(23),     AIRSW([illegible]),    HAYSW(3),     ! 164-204
     1 SPACE3,      AIRTSL,      WAIRBN(3),   CRRLSP,      CRRLDB,       ! 205-211
     2 CRRLF,       TAMB,        FWRMP[illegible],      FWDLY,       TIMSCM,       ! 212-216
     3 SPACE4,      DCOR,        REACEX,      TIMEX,       SPACE5,       ! 217-221
     4 SVRMPN,      PMSVHS,      PMSVLS,      PMSVDB,      CINO,         ! 222-226
     5 CKCORE,      CKSG,        RXPWR,       THOT,        SGLSP,        ! 227-231
     6 PCRI,        SPACE6(2),   PLOOP1,      HAPZR,                     ! 232-236
     7 SPRCNT,      PZLEVL,      LPHPIS,      SPRNOM,      RCDB,         ! 237-241
     8 RPDB,        SGXDRB,      SGRS1,       SGRS2                      ! 242-245
      COMMON /IPA/
     1 ITRNTP,      KSCRAM,      IRUNTM,      ISMTM,       IDLZER,       ! 1-5
     2 KNOHTR,      ICONC,       IZDP,        ISCRP,       ISVRMP,       ! 6-10
     3 KHYR,        ISMP,        ISMTD,       IZDM,        ICPRP,        ! 11-15
     4 KSCMN,       ID,          KSPRA,       KFOR,        KNSPRR,       ! 16-20
     5 JINJ,        JDRAIN,      IOPMSV,      ICLMSV,                    ! 21-24
     6 IFLMN,       IHPIS,                                               ! 25-26
     7 IC015,       IC016,       IC017,                                  ! 27-29
     8 IC018,       IC025,       IC026,       IC027                      ! 30-33
      COMMON
     0 AIRFLO(15),  AIRDOZ,      C(51),       CDPFW,       CFLTRN,
     1 CINJ,        CK(51),      CO(51),      CONDAR,      CONMFI,
     2 CPAIR,       CPO,         CRDH,        CRDM,        CRDVZ,
     3 CRHF,        CRHG,        CRHSTI,      CRHWI,       CRMWI,
     4 CRRL,        CRRLT,       CRSTMI,      CRVF,
     5 CRXG,        CRXW,        CVFW,
     6 CVFWI,       CVMSCF(14),  [illegible],        C2RO,        DECAY(8),
     7 DELTAD,      DENCOR,      [illegible],         DHRPF,       DHMF,
```

```
      *        8 DLHSUR,     DLMDRN,     DLMINJ,     DLMR,
      *        9 DLMRC,      DLMRH,      DLMRP,      DLMSP,      DLMSUR,
      *        0 DOMEM,      DTAIR(3),   DTOTZ,      DVDH,       DWELL,
      *        1 DWMASI      ERR,        EXTARA,     FANFR(3),   FLOLP,
      *        2 FLOSC,      FLOTRN,     FLOW,       FLTNSC,     FPMAS,
      *        3 FWTIM,      GHBP,       GHCP,       GHLP,       H(51),
      *        4 HAMB,       HC(51),     HCWAL(51),  HDIFF,      HDWNI,
      *        5 HF,         HFCRI,      HFTAB(19),  HG,         HGAS,
      *        6 HGCR,       HGTAB(19),  HHL,        HPFF(51),   HSC,
      *        7 HSCI,       HSGC,       HSGI,       HSP,        HSTMI,
      *        8 HSUP,       HTQ,        HT1Q,       HT2Q,       HT1T,
      *        9 HT2T,       H1DB,       H2DB,       IARY(16),   IBSPR,
      *        0 IDAC(18),   IDELTA,
      *        1 IDISC,      IOS,        IOSB(2),    IPARM(6),   IPRINT,
      *        2 ISET(18),   IT,         ITINF,      ITMSK,
      *        3 ITR(11),    ITRNP,      JDAC(4),    JSET(4),    KSCRMS,  !JSP'S INSERTED SO
      *        4 KSCSET,     JSP2,       LASTI,      LISTPA(69), LPA(33), !VARIABLES ARE ON
      *        5 MCCL,       MCTUB,      MRC,        MRP,                 !4 BYTE BOUNDARIES.
      *        6 NBR,        JSP3,       NDAT(128),  PAHFAD(69), PANGI
0008  *          COMMON
      *        1 PANGL,      PCORR,      PCRO,       PCRSP,      PMASSO,
      *        2 PL11C,      PMSVHT,     PMSVLF,     PRESSF,     PSATI,
      *        3 PSGO,       PSGT1(23,10),PSGT2(23,9),PZRDH,     PZRDM,
      *        4 PZRHGI,     PZRHWI,     PZRLOS,     PZRMGI,     PZRMWI,
      *        5 Q(51),      QAIRI,      QCBPI,      QCLBK(4),   GCOND(3),
      *        6 QCONDI,     QCORE,      QDIR,       QDIRI,      QSC,
      *        7 RABFRV,     RB,         RC,         RCSPT,      REACTN,
      *        8 RHO(51),    RL,         RMPM,       RMPMSV,     RP11C,
      *        9 RPSPT,      RXBTU,      QCBP,       SCMAS,      SCRAM(8),
      *        0 SCRMTM,     SDB,        SGBETA,     SGDPZ,      SGHEAD,
      *        1 SGHF,       SGHG,       SGK1,       SGK2,       SGLI,
      *        2 SGLVLI,     SGMASI,     SGRB1,      SGRB2,      SGRT1,
      *        3 SGRT2,      SGVF,       SGVG,       SGWLC,      SHRDM,
      *        4 SHRDV,      SLP(11),    SPRAYG,     SPRAYW,     SSPT,
      *        5 SURFLO,     SVGT(8),    TAIR,       TAUCL,
      *        6 TBN(51),    TCALC(51),  TCLADC,     TCOLD,      THL11C,
      *        7 TIML,       TIN,        THOT,       TOUT,
      *        8 TSAT,       TSATC,      TSATCR,     TSATSG(19), TSTCRI,
      *        9 TTUBEI,     TWALL(51),  UACC,       UAIN(3),    UAINI,
      *        0 UAOUT(3),   UAOUTI,     UASC,
      *        1 UB(51),     UBCORE,     UBF,        UBSG,       UFOUL,
      *        2 UINF(3),    UOUTF(3),   V(51),      VAIR,       VBPB,
      *        3 VCORE,      VCORB,      VDRUM,      VFTAB(19),
      *        4 VGTAB(19),  VRABP,
      *        5 VREF,       VRISER,     VSFRO,      VSFRV,      VSTMCR,
      *        6 VOTO,       VSTCRI,     VVESSL,     VWCR,       VWCRI,
      *        7 VWP,        WATBOF(3),  WBAY,
      *        8 WCAIR(3),   WCOND(3),   WCONDT,     WCRRV,
      *        9 WDRAIN,     WDSO,       WFACC,      WGACC,      WGMIN,
      *        0 WINJ,       WS,         WSGI,       WSGRV1,     WSGRV2,
      *        1 XDRUM,      XG,         XMSCVL,
      *        2 XMSCVO,     XSFWI,      XW,         Z(51)
0009  *          COMMON /DATID/ IDAT(512),TNAM,HNAM,NFA
0010  *          EQUIVALENCE (DAT,T10),(PA,RPSCRM),(I??,ITRNTP),(PSGT,PSGT1)
0011  *          DOUBLE PRECISION PAHEAD,SCRAM,LPA,TNAM,HNAM
0012  *          LOGICAL*1 IDAT,PARF(20),DUMMY(512)
```

```
PLAN14,          /TRIBLOCKS/WR

*             REAL KFC,MCCL,MRC,MRP,KO,LPSCRM,KSURGE,ITR,
*           1      NDAT,MCTUR,LPHPIS
*             INTEGER*4 ITIME,INCHE,IPRINT
              LOGICAL*1 IBR,JBR
              DATA TNAM,HNAM/2*'PLAN14'/
              CALL  DATID(1,2,0)
              IDISC=0
      100     TYPE101
      101       FORMAT(1X,'LOFT? ',$)
                ACCEPT 998,IBR,JBR
      998       FORMAT(2A1)
                NIBR=IBR
                NJBR=JBR
                NBR=NIBR+NJBR-136
                IF(NBR.NE.8) GO TO 103
                PAUSE
                GO TO 100
      103       IF (NBR.GT.16)NBR=NBR-16
                IF(NBR.NE.8)GO TO 102
                CALL MAIN
                GO TO 100
      102       IF (NBR.NE.9.AND.NBR.NE.2)GO TO 104
                CALL DUMP
                GO TO 100
      104       IF(NBR.NE.16) GO TO 105
                TYPE 999
                GO TO 100
      105       IF(NBR.EQ.5) GO TO 160
                CALL INIT
              GO TO 100
      160       IF(IDISC.EQ.0)GO TO 161
                TYPE 997
      997       FORMAT('+',10X,'CLOSE FILE')
                GO TO 100
      161     CALL CONSO(0)
              CALL DETACH
              CALL EXIT
      999     FORMAT('0','PARMFILE-PR',T16,'TITLE/OPEN-TO',T32,'CHANGE-CH',
             1  T43,'TRAN TYPE-TR',T59,'IC-IC',T70,'RUN-RN',T80,
             2  'DSCRPT/SAVE-DS'/1X,'LIST-LI',T16,'DUMP-DM',T32,
             3  'OPEN-OP',T43,'SAVE-SA',T59,'DELETE-DE',T70,'EXIT-EX',
             4  T80,'FULL DUMP-FD'/1X,'MCR-MC',T16,'HELP-HP'/)
              END
```

PROGRAM SECTIONS

NAME	SIZE		ATTRIBUTES
$CODE1	000500	160	RW,I,CON,LCL
$PDATA	000014	6	RW,D,CON,LCL
$IDATA	000376	127	RW,D,CON,LCL
$VARS	001046	275	RW,D,CON,LCL
DAT	001000	256	RW,D,OVR,GBL
PA	002000	512	RW,D,OVR,GBL
IPA	000102	33	RW,D,OVR,GBL

```
PLAN14.FTN      /TR:BLOCKS/WR

.$$$$.  017664  4058          RW,D,OVR,GBL
DATID   001022   265          RW,D,OVR,GBL

TOTAL SPACE ALLOCATED = 026170  5692

NO FPP INSTRUCTIONS GENERATED
```

```
[illegible]                      15:43:19    08-FEB-80
PLAN14.                /TR:BLOCKS/WR

C
C
        FUNCTION TABLE (X,F)
        DIMENSION F(1)
        RMOD=F(1)                  ! SPACING BETWEEN INPUT VALUES
        OFFSET=F(2)                ! INPUT VALUE OF THE FIRST TABLE VALUE
        N=F(3)                     ! DIMENSION OF TABLE
        PT=DIM(X,OFFSET)/RMOD+4.
        I=INT(PT)
        FR=PT-I
        I=MIN0(N,I)
        J=MIN0(N,I+1)
        TABLE=F(I)+(F(J)-F(I))*FR
        RETURN
        END

PROGRAM SECTIONS

 NAME       SIZE                 ATTRIBUTES

$CODE1   000314    102           RW,I,CON,LCL
$IDATA   000040     16           RW,D,CON,LCL
$VARS    000026     11           RW,D,CON,LCL

TOTAL SPACE ALLOCATED = 000402   129
```

```
0001            SUBROUTINE ZERO(FUNCT,X)
          C
          C     THIS SUBROUTINE FINDS X SUCH THAT FUNCT(X)=0.
          C     'FUNCT' IS THE NAME OF THE FUNCTION SUBROUTINE WHICH DEFINES FUNCT(X)
          C     THE INPUT VALUE OF X IS USED AS THE INITIAL GUESS.
          C     THE OUTPUT VALUE OF X IS DETERMINED TO WITHIN .01%.
          C
0002            DX=X*1.E-4
0003            DO 300 N=1,20
0004            Y0=FUNCT(X-DX)
0005            Y2=FUNCT(X+DX)
0006            Y1=FUNCT(X)
0007            DY=(Y2-Y0)/2.
0008            IF(DY.EQ.0.) DY=Y1                ! INFLECTION POINT. BUMP X BY DX.
0009            X=X-Y1*DX/DY                      ! USE NEWTON'S METHOD TO UPDATE X
0010            IF(Y0*Y2.LT.0.) RETURN            ! IF Y0 AND Y2 HAVE DIFFERENT SIGNS
          C                                       ! THEY BRACKET THE ZERO VALUE.
0011      300   CONTINUE
0012            TYPE 1, X,Y0,Y1,Y2
0013      1     FORMAT(' SUBROUTINE ZERO FAILED TO CONVERGE. X= ',E20.10/
                1     ' Y0,Y1,Y2= ',3E20.10)
0014            RETURN
0015            END
```

PROGRAM SECTIONS

NAME	SIZE		ATTRIBUTES
$CODE1	000414	134	RW,I,CON,LCL
$PDATA	000004	2	RW,D,CON,LCL
$IDATA	000104	34	RW,D,CON,LCL
$VARS	000026	11	RW,D,CON,LCL

TOTAL SPACE ALLOCATED = 000552 181

DK1:PLAN14,PLAN14=DK1:PLAN14.FTN;10/CO:60/LI:1

L-9

LTR-10-2-Rev. C

```
0001        SUBROUTINE INIT
0002        INCLUDE 'DK1:COMM14.FTN/NOLIST'
0015          EXTERNAL SGDP,AIRDQ
0016          DATA PAHEAD/'RPSCRM','HTSCRM','VSCRM','HPSCRM','LPSCRM','TCPP',
          1   'TCHLT','TCLF','TCLP','KSURGE','DELT','SMTSLO','FLOW','ALPHAB',
          1   'SCDLY','SMTEST','SVTC','DOPC','DPPO','TCCLT','STMLKG',
          1   'SSP','HTSUP','FLTMD','FLTMX',
          1   'RPSP','RCSP','HT1SP','HT2SP',
          1   'RASCRM','SURMIN','CLIC','CPIC',
          1   'VDRAIN','VINJ','FERMN','AIRTSL',
          1   'CRRLSP','CRRLDB','CRRLF','TAMB','FWRMPT','FWDLY','TIMSCM',
          1   'DCOR','REACEX','TIMEX','SVRMPN',
          1   'PMSVHS','PMSVLS','PMSVDB','CIDO','CKCORE','CKSG',
          1   'RXPWR', 'THOT', 'SGLSP','PCRI','PLOOPI',
          1   'GAPZR','SPRCNT','PZLEVI','LPHPIS','SPRNOM','RCDB','RPDB',
          1   'SGXDNB','SGRS1','SGRS2'/
0017        DATA LISTPA/1,2,3,4,5,6,7,8,9,10,
          1       11,12,13,14,15,16,17,18,19,20,21,
          1       82,83,86,87,88,89,90,
          1       91,92,96,97,98,99,100,
          1       164,206,210,211,212,213,
          1       214,215,216,218,219,220,222,223,
          1       224,225,226,227,228,229,230,231,232,
          1       235,236,237,238,239,240,241,242,243,
          1       244,245/
0018        DATA LPA/
          1   'ITRNTP','KSCRAM','IRUNTM','ISMTM','IDIZER',
          2   'KNOPTR','ICONC','IZDP','ISCRP','ISVRMP',
          3   'KHTR','ISMP','ISMTD','IZDM','ICPHP',
          4   'KSCMN',' ID','KSPRA','KPOR','KNSFRR',
          5   'JINJ','JDRAIN','IOPMSV','ICLOSV',
          6   'IFLMN','IHPIS','IC015','IC016','IC017',
          7   'IC018','IC025','IC026','IC027'/
0019        DATA SCRAM/'MANUAL  ','HI POWER','HI TEMP','HI PRESS',
          1             'LO PRESS','LOW FLOW','RABV    ','TIMED   '/
0020        DATA UASC/2.3/
0021        DATA UACC,UFOUL,CPAIR/0.0151,.2778,.242/
0022        DATA EXTARA/56128./
0023        DATA CONDAR/2210./
0024        DATA DWELL/22.87/
0025        DATA MCTUB/1009.68/
0026        DATA HAMB,SCMAS/100.,430./
0027        DATA FPMAS/1665./
0028        DATA AIRFLO/2.,0.,15.,0.,65.,84.,100.,114.,126.,137.,148.,156.,
          1                 164.,170.,174./
       C
0029          DATA ISET/0,1,6,7,8,9,10,11,12,13,14,15,64,65,66,67,68,69/
0030          DATA JSET/2,3,4,5/
0031          DATA SLP/300.,450.,11.,7.525E-3,5.607E-3,4.100E-3,2.879E-3,
          1    1.782E-3,0.732E-3,-0.429E-3,-1.889E-3/
0032          DATA ITR/300.,450.,11.,50.510,52.171,53.097,53.707,
          1    54.339,55.286,56.869,59.474/
0033        DATA V/
          1   4*2.54,10*2.43,2*6.87,7.40,12.30,5*2.76,11.84,2*1.56,11.84,
          1   4*3.00,2*3.50,4*2.86,9.65,5*5.07,3*7.91,3.28,7.64,6.69,3.28,
          1   0.49/
```

```
        C
0034          DATA HC/
             1  4*151.,10*144.59,2*536.25,526.41,1333.94,5*168.93,
             1   725.62,95.57,91.30,693.21,4*175.65,2*204.84,4*167.59,564.85,
             1   5*296.99,3*462.76,195.21,455.1,398.59,195.21,29.18/
        C
0035          DATA HCWAL/
             1  14*0.0,2*61.65,62.49,237.75,5*83.28,143.66,2*242,92,1  ..66,
             1  4*90.,2*124.46,4*94.14,1588.4,5*1657.87,3*115.68,
             1  101.03,207.29,181.13,101.03,1185.56/
        C
0036          DATA HREF/
             1  4*342.55,10*588.64,2*10.80,11.29,63.15,5*23.84,20.64,378.15,
             1  384.81,21.00,4*25.9,2*40.99,4*31.14,165.89,5*131.75,3*3.15,
             1  29.74,137.94,120.81,29.74,11657.53/
        C
0037          DATA CK/
             1  4*508.00,10*170.49,2*4.37,4.57,2.45,5*1.56,1.14,2*49.31,1.14,
             1  4*1.68,2*3.11,4*1.74,17.51,5*12.06,3*1.19,1.88,7.83,6.85,1.88,
             1  48.77/
        C
0038          DATA Z/
             1  4*1.375,5*-1.408,5*1.408,2*2.735,-1.751,6*0.0,-2.583,
             1  -0.958,0.958,2.583,2.833,2*0.0,-2.083,-.75,5*0.0,1.858,
             1  5*2.514,2*0.0,-1.707,4*0.0,10.97/
        C
0039          DATA SGK1,SGK2/2.2028E-2,7.8888E-4/
0040          DATA WSGRV1,WSGRV2/25.,25./
0041          DATA SGRB1,SGRB2/55.,56./
0042          DATA H1DB,H2DB/30.,15./
0043          DATA HT10,HT20/2*22.752/                    ! 24KW EACH
0044          DATA MRC,MRP/45232.,7200./
0045          DATA SDB/25./
        C
0046          DATA MCCL/48.8950/
0047          DATA VREF/30.764/
0048          DATA RC,RB,RL/2.0835,39.5869,3.5408/
        C
0049            DATA TSATSG/100.,100.,19.,327.8,381.8,417.4,444.6,467.0,
                1 486.2,503.1,518.2,532.0,544.6,556.3,567.2,577.4,
                1 587.1,596.2,604.87/
0050            DATA HFTAB/100.,100.,19., 298.5,355.5,394.0,424.2,449.5,471.7,
                1 491.6,509.9,526.7,542.6,557.5,571.9,585.6,598.8,611.7,624.2/
0051            DATA HGTAB/100.,100.,19., 1187.2,1198.3,1202.9,1204.6,1204.7,
                1 1203.7,1201.8,1199.4,1196.4,1192.9,1189.1,1184.8,1180.2,
                1 1175.3,1170.1,1164.5/
0052            DATA VFTAB/100.,100.,19., .01774,.01839,.01889,.01934,.01975,
                1 .02013,.02050,.02087,.02123,.02159,.02195,.02232,.02269,
                1 .02307,.02346,.02387/
0053            DATA VGTAB/100.,100.,19., 4.4310,2.2873,1.54274,1.16095,
                1 .92762,.76975,.65556,.56896,.50091,.44596,.40058,.36245,
                1 .32991,.30178,.27719,.25545/
0054            DATA CVHSCF/.1,0.,19.,0.,.0223,.0289,.0388,.0520,
                1 .0685,.0907,.1196,.1592,.217,.2805/
0055            DATA DECAY/1.,-1.,8.,.06725,.06281,.04844,.03163,.01937/
0056            DATA SVGT/100.,2000.,8.,.1883,.1750,.1627,.1513,.1408/
```

```
FORTRAN [illegible] V02-51        [illegible]      [illegible]
INIT14.F[illegible]  /TRIPLOCKS/NR

0057          DATA PSGT1/
         1     189.87, 186.78, 183.05, 178.62, 173.41, 167.34, 160.39, 152.57,
         1     143.96, 134.60, 124.67, 114.37, 103.87,  93.40,  83.18,  73.37,
         1      64.15,  55.60,  47.82,  40.82,  34.60,  29.16,  24.43,
         1     324.00, 316.71, 308.05, 297.94, 286.32, 273.14, 258.50, 242.47,
         1     225.37, 207.43, 189.00, 170.53, 152.31, 134.74, 118.09, 102.57,
         1      88.37,  75.54,  64.12,  54.06,  45.31,  37.77,  31.33,
         1     516.68, 501.39, 483.62, 463.36, 440.54, 415.32, 388.05, 359.11,
         1     329.04, 298.47, 268.01, 238.27, 209.82, 183.05, 158.31, 135.80,
         1     115.61,  97.72,  82.08,  68.54,  56.92,  47.05,  38.72,
         1     778.78, 750.03, 717.07, 680.15, 639.75, 596.14, 550.18, 502.67,
         1     454.63, 407.01, 360.80, 316.76, 275.54, 237.61, 203.25, 172.55,
         1     145.17, 121.86, 101.48,  84.07,  69.32,  56.91,  46.54,
         1    1120.03,1069.78,1013.17, 951.56, 885.79, 816.05, 744.65, 672.37,
         1     601.04, 531.95, 466.28, 404.96, 348.65, 297.75, 252.35, 212.40,
         1     177.63, 147.69, 122.14, 100.53,  82.39,  67.26,  54.72,
         1    1547.19,1465.45,1375.80,1279.03,1176.69,1074.89, 970.04, 866.90,
         1     766.97, 671.96, 583.33, 501.96, 428.41, 362.85, 305.16, 255.00,
         1     211.82, 175.01, 143.90, 117.80,  96.06,  78.05,  63.22,
         1    2066.80,1937.97,1804.57,1661.47,1516.77,1370.15,1224.87,1084.49,
         1     950.61, 825.67, 710.84, 606.86, 514.09, 432.37, 361.26, 300.03,
         1     247.82, 203.67, 166.64, 135.80, 110.26,  89.24,  72.02,
         1    2659.44,2483.11,2298.75,2097.68,1896.31,1698.41,1506.48,1322.70,
         1    1150.58, 991.80, 847.73, 718.86, 605.09, 505.88, 420.32, 347.26,
         1     285.43, 233.53, 190.27, 154.44, 124.94, 100.78,  81.07,
         1    3000.00,3000.00,2835.49,2573.16,2315.17,2057.41,1811.43,1579.68,
         1    1364.90,1169.00, 993.06, 837.21, 700.87, 582.95, 482.03, 396.47,
         1     324.52, 264.47, 214.70, 173.68, 140.06, 112.64,  90.36,
         1    3000.00,3000.00,3000.00,3000.00,2751.85,2437.02,2135.62,1851.96,
         1    1591.62,1355.94,1145.86, 961.27, 800.96, 663.25, 546.16, 44[illegible].46,
         1     364.92, 296.39, 239.85, 193.46, 155.58, 124.79,  99.87/
0058          DATA PSGT2/
         1    3000.00,3000.00,3000.00,3000.00,3000.00,2837.38,2473.02,2136.84,
         1    1828.57,1551.28,1305.34,1090.33, 904.87, 746.45, 612.47, 500.08,
         1     406.56, 329.22, 265.67, 213.72, 171.46, 137.21, 109.57,
         1    3000.00,3000.00,3000.00,3000.00,3000.00,3000.00,2824.57,2430.35,
         1    2073.40,1753.59,1470.42,1223.99,1012.26, 832.34, 680.77, 554.19,
         1     449.28, 362.86, 292.10, 234.45, 187.68, 149.89, 119.47,
         1    3000.00,3000.00,3000.00,3000.00,3000.00,3000.00,3000.00,2734.50,
         1    2324.75,1961.33,1640.62,1361.58,1122.73, 920.55, 750.84, 609.69,
         1     493.04, 397.29, 319.11, 255.59, 204.21, 162.80, 129.53,
         1    3000.00,3000.00,3000.00,3000.00,3000.00,3000.00,3000.00,3000.00,
         1    2578.18,2172.02,1813.90,1502.64,1236.09,1010.91, 822.68, 666.43,
         1     537.74, 432.40, 346.64, 277.13, 221.04, 175.93, 139.76,
         1    3000.00,3000.00,3000.00,3000.00,3000.00,3000.00,3000.00,3000.00,
         1    2840.87,2388.35,1990.82,1646.83,1351.80,1103.18, 895.87, 724.29,
         1     583.32, 468.20, 374.67, 299.04, 238.14, 189.26, 150.14,
         1    3000.00,3000.00,3000.00,3000.00,3000.00,3000.00,3000.00,3000.00,
         1    3000.00,2601.68,2168.51,1792.23,1469.58,1197.26, 970.64, 783.30,
         1     629.73, 504.[illegible]9, 403.17, 321.30, 255.50, 202.78, 160.67,
         1    3000.00,3000.00,3000.00,3000.00,3000.00,3000.00,3000.00,3000.00,
         1    3000.00,2827.13,2350.11,1940.78,1589.31,1293.24,1046.39, 843.30,
         1     676.90, 541.57, 432.08, 343.89, 273.10, 216.48, 171.33,
         1    3000.00,3000.00,3000.00,3000.00,3000.00,3000.00,3000.00,3000.00,
         1    3000.00,3000.00,253[illegible].28,2088.48,1710.94,1390.02,1123.53, 904.09,
         1     724.72, 579.08, 461.42, 366.77, 290.93, 230.37, 182.12,
```

```
        1  3000.00,3000.00,3000.00,3000.00,3000.00,3000.00,3000.00,3000.00,
        1  3000.00,3000.00,2722.92,2238.01,1832.34,1488.41,1201.62, 965.91,
        1   773.28, 617.13, 491.14, 389.96, 308.98, 244.41, 193.03/
C
C           DF  FD  CH  IC  EX  MC  OP  RN  DM  PR  TO  SA  LI  TR  DS
       GO TO(550,800,250,260,800,800,130,800,400,400,130,500,210,122,500)
        1  NBR
80      TYPE*,'INVALID COMMAND'
        GO TO 800
C
C       PARAMETERS FROM DISC ROUTINE
C
400     CONTINUE
        IF(IDISC.EQ.0) GO TO 403
        TYPE 131
        GO TO 800
403     TYPE 405
405     FORMAT('+',10X,'ENTER PARM FILE NAME: ',$)
        ACCEPT 401, PARF
401     FORMAT (20A1)
        PARF(20)=0
        OPEN(UNIT=2,NAME=PARF,TYPE='OLD',ACCESS='DIRECT',
        1  FORM='UNFORMATTED',ERR=800)
        READ(2'1,ERR=800)(IDAT(I),I=1,512)
        DECODE(4,402,IDAT(452))NPAR
402     FORMAT(I4)
        READ(2'NPAR+6,ERR=409)(PA(I),I=1,128)
        READ(2'NPAR+7,ERR=409)(PA(I),I=129,256)
        READ(2'NPAR+8,ERR=409)IPA
409     CLOSE(UNIT=2,DISPOSE='SAVE',ERR=800)
        TIM=(IRUNTM+32768)*DELT
        SCRMTM=(ISMTM+32768)*DELT
        GO TO 800
C
500     IRUNTM=TIM/DELT-32768.
        ISMTM=SCRMTM/DELT-32768.
        WRITE(2'IPARM(5),ERR=800)(PA(I),I=1,128)
        WRITE(2'IPARM(5)+1,ERR=800) (PA(I),I=129,256)
        WRITE(2'IPARM(5)+2,ERR=800) IPA
        CALL DATIO(72/NBR,2,IPARM(5)-6)
        IDISC=0
        GOTO 800
550     CLOSE(UNIT=2,DISPOSE='DELETE')
        TYPE 551
551     FORMAT('+',10X,'FILE DELETED')
        IDISC=0
        GOTO 800
C
122     TYPE 920
920     FORMAT(1X,'ENTER TRANSIENT TYPE',2X,$)
        ACCEPT*,ITRNTP
        GO TO 123
C
C       DISC SETUP
C
130     IF(IDISC.EQ.0)GO TO 132
```

L-10

LTR-10-2-Rev. C

```
              TYPE 131
      131     FORMAT('+',10X,'CLOSE OLD FILE')
              GO TO 800
      132     CALL DATID(3*(NBR-7)/4,2,0)
              IPARM(2)=512
              IPARM(4)=0
              IPARM(5)=6
              CALL SETFF(3)
              IOSB(1)=1
              IDISC=1
              GO TO 800
      C
      C       LIST ROUTINE
      C
      210     OPEN(UNIT=6,TYPE='NEW',NAME='INIT.LST',RECORDSIZE=132)
              WRITE(6,908) (IDAT(I),I=1,72),(IDAT(I),I=456,495)
              WRITE(6,910) (IDAT(I),I=73,144)
              IF(KSCRAM.EQ.0)GO TO 211
              I=NINT(LOG(FLOAT(KSCRAM))/LOG(2.))+1
              PRINT 940, TIM,SCRMTM,SCRAM(I)
      940     FORMAT(1X,'RUN TIME=',F8.2,'SEC    SCRAM TIME=',F8.2,
           1          'SEC    SCRAM TYPE= ',A8)
      211     PRINT 930
              DO 220 I=0,5
              WRITE(6,907) (PAHEAD(10*I+J),LISTPA(10*I+J),J=1,10)
              WRITE(6,906) (PA(LISTPA(10*I+J)),J=1,10)
      220     CONTINUE
              WRITE(6,907) (PAHEAD(J),LISTPA(J),J=61,69)
              WRITE(6,906) (PA(LISTPA(J)),J=61,69)
              PRINT 914,'AIRSW (199-201)','BAYSW (202-204)','WAIRMN (207-209)'
              PRINT 912,AIRSW,BAYSW,WAIRMN
              PRINT 914,'VSFR (22-81)'
              WRITE(6,912) VSFR
              PRINT 914,'RABFR (101-160)'
              WRITE(6,912) RABFR
              PRINT 914,'DLS (176-198)'
              WRITE(6,912) DLS
              PRINT 930,(LPA(I),I=1,4),(LPA(I),I=21,27)
              PRINT 931,(IPA(I),I=1,4),(IPA(I),I=21,27)
              PRINT 930,(LPA(I),I=20,5,-1)
              PRINT 931,(IPA(I),I=20,5,-1)
              PRINT 930,(LPA(I),I=28,33)
              PRINT 932,(IPA(I),I=28,33)
      930     FORMAT(3X,16A8)
      931     FORMAT(1X,I5,15I8)
      932     FORMAT(1X,I7,15I8)
              PRINT 930
              WRITE(6,910) (IDAT(I),I=1,52)
      941     CLOSE(UNIT=6,DISP='PRINT')
              GO TO 800
      C
      C       CHANGE ROUTINE
      C
      250     TYPE 917
      917     FORMAT('+',10X,'ENTER:INDEX,VALUE OR INDEX1-INDEX2 (<CR>=RTN)')
      251     TYPE 918
```

```
918     FORMAT(1X,'CHG?',2X,$)
        ACCEPT 919,IQ,(DUMMY(I),I=1,IQ)
919     FORMAT(Q,72A1)
        IF(IQ.EQ.0)GO TO 800
        DO 252 I=1,IQ
        IF(DUMMY(I).EQ.',')GO TO 253
        IF(DUMMY(I).EQ.'-')GO TO 254
252     CONTINUE
        GO TO 250
253     DECODE(IQ,921,DUMMY)INDEX,X,PA(INDEX)
921     FORMAT(I<I-1>,A1,F<IQ-I>.0)
        GO TO 251
254     DECODE(IQ,922,DUMMY) NSTRT,X,NSTOP
922     FORMAT(I<I-1>,A1,I<IQ-I>)
        TYPE 923
923     FORMAT(1X,'CARDS?',2X,$)
        ACCEPT 902,ICARDS
        IF (ICARDS.EQ.'Y')GO TO 259
        TYPE*, 'ENTER VALUES'
        DO 258 I=NSTRT,NSTOP
        TYPE 257,I
257     FORMAT (1X,I3,'. ',$)
258     ACCEPT*,PA(I)
        GOTO 800
259     READ(3,*) (PA(I),I=NSTRT,NSTOP)
        READ(3,*,END=800)DUMMY
        GOTO 800
C
C       IC SETUP
C
260     CALL ASHYLN(0,7)
        CALL SPHYFF(0,1)
        CALL ATTACH(1)
        CALL CONSO(0)
        CALL HON(0)
        CALL LEX(0)
        CALL STREF(0)
        CALL TSCAL(0)
        CALL LRUN
        CALL IC
        CALL SETCL(1,0)
        CALL SETCL(2,1)
        CALL SETCL(2,0)                    !INITIALIZE THE SAMPLE COUNTER
C
C   COMPUTE INITIAL STEADY STATE TEMPERATURES
C
            RXBTU=RXPWR*948.
            QDIRI=RXBTU*.0187/4.           ! DIRECT HEAT PER NODE
            QCBPI=RXBTU*.0303              ! BYPASS HEAT
            QCORE=RXBTU-QCBPI              ! CORE HEAT:CLD+DIR
      RHOHOT=41.58+.089033*THOT-1.44741E-4*THOT*THOT
     1  +(PLOOP1-2200.)*(.00025+3.89E-7*EXP(.01287*THOT))
       FLOW=WPCSI/(RHOHOT*3600.)
          WC=FLOW*HC(1)/V(1)
          TCOLD=THOT-RXBTU/WC
```

```
            H1=HREF(1)*(FLOW*.95/VREF)**.8
            HACORE=(1./CKCORE+1./H1)**-1
            FCORE=(1.+1./(.95*(WC/HACORE-DELT*FLOW/V(1))))**-1
         TCLADC=TCOLD+QCORE/(.95*WC*(1.-FCORE**4) )-QDIRI/HACORE
            H5=HREF(5)*(FLOW/VREF)**.8
            HASG=(1./CKSG+1./H5)**-1
            FSG=(1.+1./(WC/HASG-DELT*FLOW/V(5)))**-1
         TSATC=THOT+(TCOLD-THOT)/(1.-FSG**10)
         TSAT=TSATC
C
C DETERMINE THE TEMP OF EACH NODE (TCALC'S) AND INITIALIZE TBM AND TWALL
C
C    CORE
            XX=(TCLADC+QDIRI/HACORE)*(1.-FCORE)
         TCALC(1)=XX*(1.-.95*FLOW*DELT/V(1))+(FCORE+.95*FLOW*
     1       DELT/V(1)*(1.-FCORE))*TCOLD
            TBM(1)=TCALC(1)
            TWALL(1)=TCLADC
         DO 281 K=2,4
            TCALC(K)=XX+TCALC(K-1)*FCORE
            TBM(K) =TCALC(K)
  281       TWALL(K)=TCLADC
C    STEAM GENERATOR
            YY=TSATC*(1.-FSG)
         TCALC(5)=YY*(1.-FLOW*DELT/V(5))+(FSG+FLOW*DELT/V(5)*
     1       (1.-FSG))*THOT
            TBM(5)=TCALC(5)
            TWALL(5)=TSATC
         DO 282 K=6,14
            TCALC(K)=YY+TCALC(K-1)*FSG
            TBM(K) =TCALC(K)
  282       TWALL(K)=TSATC
C    CORE UPPER PLENUM
         DO 2825 K=15,16
         TCALC(K)=TCOLD+QCORE/(.95*WC)
            TBM(K)=TCALC(K)
  2825      TWALL(K)=TCALC(K)
C    HOT LEG
         DO 283 K=17,25
            TCALC(K)=THOT
            TBM(K) =THOT
  283       TWALL(K)=THOT
C    COLD LEG AND RABV
         DO 284 K=26,50
            TCALC(K)=TCOLD
            TBM(K)=TCOLD
  284       TWALL(K)=TCOLD
            TCLT=TCOLD
            TAUCL=DELT/TCCLT
C    CORE BYPASS
         TCALC(51)=TCOLD+(20./WC-DELT/HC(51))*QCBPI
            TBM(51)=TCALC(51)
            TWALL(51)=TCALC(51)
C
C DETERMINE THE INITIAL CONDITIONS OF THE STEAM GENERATOR
C
```

```
C    STEAM PRESSURE
          DO 286 I=5,18
286       IF(TSATC.LT.TSATSG(I)) GOTO 287
          TYPE*,'PSATI ERROR'
          GOTO 800
287       PSATI=100.+100.*((I-5)+(TSATC-TSATSG(I-1))/
          1    (TSATSG(I)-TSATSG(I-1)))
          PSG=PSATI
          PSGO=PSATI
          TSAT=TSATC
C    STEAM FLOW
          HSTMI=TABLE(PSATI,HGTAB)
          HFCRI=TABLE(PCRI,HFTAB)
             B=(UASC*(HSTMI-HAMB)-RXBTU)/(HSTMI-HFCRI)
             C1=-RXBTU*UASC/(HSTMI-HFCRI)
          WSGI=(-B+SQRT(B**2-4.*C1))/2.
          WGMIN=WSGI*STMLKG/(RXPWR*.02)
          WG=WSGI
C    MSCV POSITION
          CVMSCI=WSGI/SQRT((PSATI**2-PCRI**2)/2.)
          DO 288 I=5,14
288       IF(CVMSCI.LT.CVMSCF(I)) GOTO 289
          TYPE*,'XMSCVO ERROR'
          GOTO 800
289       XMSCVO=0.1*((I-5)+(CVMSCI-CVMSCF(I-1))/
          1    (CVMSCF(I)-CVMSCF(I-1)))
          XMSCV=XMSCVO
          XMSCVL=XMSCVO
C   FEED VALVE POSITION
          CDENOM=53.36*(PCRI+DPPO-PSATI-0.0233*WSGI*WSGI)
          IF(CDENOM.GT.0.0) GOTO 291
          TYPE*,'CVFW ERROR',CDENOM
          GOTO 800
291       CVFWI=WSGI/SQRT(CDENOM)
          XSFWI=CVFWI/1.0725
          XSFW=XSFWI
C    STEAM GEN LEVEL
          SGLVLI=SGLSP+.27*WSGI-12.5*XSFWI
          SGLI=SGLVLI
          SGLVL=SGLI
C    SG MASS
          SGVG=TABLE(PSATI,VGTAB)
          SGVF=TABLE(PSATI,VFTAB)
             DWMASS=1.0821*(SGLVLI-75.43)/SGVF
             DOMEN=(182.2-DWMASS*SGVF)/SGVG
             SGBETA=2.8523+21974./RXBTU
             SGMASS=2000.
             CALL ZERO(SGDP,SGMASS)
          SHRDV=88.8/SHRDM
294       WD=WR+WSGI
C    SG ENERGY
          SGHF=TABLE(PSATI,HFTAB)
          HDWN=(WSGI*HSTMI+WR*SGHF-RXBTU)/WD
          SGV=(276.-DWMASS*SGVF)/SGMASS
          VLOGSG=ALOG10(SGV)*10.+19.
          IV=VLOGSG
```

```
             FRV=VLOGSG-IV
             DO 292  IH=1,1[illegible]
             P2=PSGT(IV,IH)+(PSGT(IV+1,IH)-PSGT(IV,IH))*FRV
             IF(PSATI.LE.P2) GO TO 290
      292    P1=P2
      293    TYPE*,'PSGT ERROR'
             GO TO 800
      290    IF(IH.EQ.1) GO TO 293
             HSGI=50.*(IH-(P2-PSATI)/(P2-P1))+300.
             HSGC=(HSTMI*DOMEM+(SGMASS-DOMEM)*(SGHF+SHRDX*(HSTMI-SGHF)))/
             1   SGMASS
             SGMASI=SGMASS
             DWMASI=DWMASS
             HDWNI=HDWN
             HSG=HSGI
      C   FEED WATER
             HSCI=HSTMI-RXBTU/WSCI
             HSC=HSCI
             HFW=HSCI
      C  CLAD TEMP IC POT SET
             IC018=(TCLADC-600.)*20.
      C   PRESSURIZER INITIALIZATION
             HF=438.1+0.117*PLOOPI
             HG=1320.2-0.09*PLOOPI
             SVF=0.4957E-4*HF-0.00778
             PZRMWI=(PZLEVI/2.02)/SVF
             SVG=TABLE(PLOOPI,SVGT)
             PZRMGI=(34.75-PZLEVI/2.02)/SVG
             PZRHWI=PZRMWI*HF
             PZRHGI=PZRMGI*HG
             JDAC(1)=(HF-675.)*80.
             JDAC(2)=(HG-1100.)*66.67
             JDAC(3)=-PZRMWI*5.
             JDAC(4)=PZRMGI*20.
             CALL STBLK(JSET,JDAC,1,4)
             IBSPR=0
             SSPT=SSP
             RPSPT=RPSP
             RCSPT=RCSP
             HT1T=HT1SP
             HT2T=HT2SP
             PZRMW=PZRMWI
             PZRHW=PZRHWI
             PZRMG=PZRMGI
             PZRHG=PZRHGI
             HFPR=HF
             HGPR=HG
             DLMSPT=0.
             DLMRT=0.
             DMSURT=0.
             PZRDMT=0.
             PPR=PLOOPI
             PPRO=PLOOPI
             PLA=PLOOPI
             PMASS=0.0
             PCORR=(PLA-2200.)*(.00025+3.89E-7*EXP(.01287*
```

```
      1  (TBM(25)+TBM(26))/2.))
         DO 570 K=1,51
         RHO(K)=(.0890337-1.4174E-4*TBM(K))*TBM(K)+PCORR
         PMASS=PMASS+V(K)*RHO(K)
  570    RHO(K)=RHO(K)+41.58                !ADD OFFSET
         PMASSO=PMASS
C   RKS IC
         PNEUT=RXPWR*(1.-0.06725)*100.
         IC015=PNEUT*0.29921
         IC016=PNEUT*0.67192
         IC017=PNEUT*0.16348
         IC025=PNEUT*0.13087
         IC026=PNEUT*0.09143
         IC027=PNEUT*0.006718
C
         TYPE 950
  950    FORMAT('+',10X,'SET POTS (Y/N)',$)
         ACCEPT 902,ICREST
         IF(ICREST.NE.'Y') GOTO 295
         CALL SETPOT(1018,IC018)
         CALL SETPOT(1015,IC015)
         CALL SETPOT(1016,IC016)
         CALL SETPOT(1017,IC017)
         CALL SETPOT(1025,IC025)
         CALL SETPOT(1026,IC026)
         CALL SETPOT(1027,IC027)
         TYPE 915,'RXPWR','TCOLD','THOT','FLOW','TSATC','PSATI','WSGI',
      1     'XMSCVO'
  915    FORMAT(8(3X,A6))
         TYPE 916,RXPWR,TCOLD,THOT,FLOW,TSATC,PSATI,WSGI,XMSCVO
  916    FORMAT(7F9.2,F9.4)
  295    CONTINUE
         CALL STREE(1)
         CALL HOFF(0)
         RPI=RXPWR
         PLI=PLOOPI
         VLI=WPCSI
         THLI=THOT
         WFW=WSGI
         WINJ=VINJ*.1390                    !CONVERTS GPM INTO
         WDRAIN=VDRAIN*.1390                !LBM/SEC AT 60 F
C
        DO 300 I=1,51
  300    CO(I) = CLIC
        CPO = CPIC
        VTOTO = 0.
        VPL = 0.
         DELTAD=0.0
         FLOSC=1.
         PMSVHT=PMSVHS
         PMSVLT=PMSVLS
         RMPMSV=0.0
         FWTIM=0.0
         WSCRV=0.0
         SGRT1=SGRS1
         SGRT2=SGRS2
```

```
      CRBLT=CRBLSP
      SMPT=SMT
      DHBPF=0.0303*9.48
      DHMF=0.004675*9.48
      DLMRC=MRC/3600.*DELT
      DLMRP=MRP/3600.*DELT
C
C   CONDENSER
C
      TSATCR=TABLE(PCRI,TSATSG)
      CRHF=TABLE(PCRI,HFTAB)
      CRHG=TABLE(PCRI,HGTAB)
      CRVF=TABLE(PCRI,VFTAB)
      CRVG=TABLE(PCRI,VGTAB)
      BAYN=BAYSW(1)+BAYSW(2)+BAYSW(3)
      IF(BAYN.GT.0.) GO TO 620
      TYPE*,'ACC SECURED - SET BAYSW TO 1'
      GO TO 800
620   IF(BAYSW(1).EQ.1.) GO TO 625
      BAYSW(1)=BAYSW(2)
      BAYSW(2)=BAYSW(3)
      BAYSW(3)=0.
      GO TO 620
625   WCOND(1)=WSGI/BAYN
      QCOND(1)=WCOND(1)*(HSTMI-CRHF)
      UINF(1)=1.77*WCOND(1)**-.3333
      UAIN(1)=UINF(1)*UFOUL/(UINF(1)+UFOUL)*CONDAR
      TTUBE(1)=TSATCR-QCOND(1)/UAIN(1)
      WAIR(1)=200.
      CALL ZERO(AIRDQ,WAIR)
650   TAIR=TAMB+459.67+.5*QAIR(1)/WCAIR(1)
      VAIR=WAIR(1)*TAIR*.8898E-3
      DO 651 I=5,15
651   IF(VAIR.LT.AIRFLO(I)) GO TO 652
      TYPE*, 'ACC AIRFLO GT 174000 CUFT/MIN'
      GO TO 860
652   PANG=2.*((I-5)+(VAIR-AIRFLO(I-1))/(AIRFLO(I)-AIRFLO(I-1)))
      PANGL=PANG
      PCRSP=PCRI-(PANG-30.*XMSCV0)/.8475
      PCR=PCRI
      PCRO=PCRI
      DO 655 I=2,3
      TTUBE(I)=TTUBE(1)*BAYSW(I)+TSATCR*(1.-BAYSW(I))
      QCOND(I)=QCOND(1)*BAYSW(I)
655   UAIN(I)=UAIR(1)
      CRBLT=CRBLSP
      CONDMF=WCOND(1)*BAYN*DWELL
      CRMW=12120.
      CRMSTM=(745.86-(CRMW+CONDMF)*CRVF)/CRVG
      CRHW=CRMW*CRVF
      CRHSTM=CRMSTM*CRHG
      HWCR=CRHF
      HGCR=CRHG
      CRXW=0.
      CRXG=1.
      VWCR=CRVF*CRMW
```

```
                VSTMCR=CRVG*CRMSTM
                TSTCRI=TSATCR
                PANGI=PANG
                CONMFI=CONDMF
                CRMWI=CRMW
                CRSTMI=CRMSTM
                CRHWI=CRHW
                CRHSTI=CRHSTM
                VWCRI=VWC2
                VSTCRI=VSTMCR
                TTUBFI=TTUBF(1)
                QCONDI=QCOND(1)
                QAIRI=QAIR(1)
                HAINI=HAIN(1)
                HAOUTI=HAOUT(1)
        C
                VLOOP=FLOW
                ITIME=0
                IDELTA=DELT*1000.+.5
                IPRINT=0
                TMOT = 0.
                TIM=0.0
                PRINTM=0.0
                DEXT=0.0
                ITMSW=0
                IDS=0
                IHPIS=0
                KSCRMS=0
                KSCRAM=0
                KSCSFT=0
                LASTI=1
        123     FLOTRN=0.0
                IF(ITRNTP.EQ.1)FLOTRN=1.0
                CFLTRN=1.-FLOTRN
                TIMI=0.0
                FLTNSC=1.+19.*FLOTRN
                REACTN=0.0
                IF(ITRNTP.EQ.3)REACTN=1.0
                IF(IDISC.EQ.1)GOTO 296
                TYPE*,'OPEN FILE'
                GOTO 800
        296     IF(IPARM(5).EQ.6) GO TO 310
                TYPE*,' CLOSE OLD FILE AND OPEN NEW FILE'
        310   CONTINUE
        902   FORMAT(3A1)
        906   FORMAT(10F13.4/)
        907   FORMAT(10(3X,A6,I4))
        908   FORMAT('1',72A1,10X,'TASK ',40A1)
        910   FORMAT(' ',72A1)
        912   FORMAT(10F13.4)
        914   FORMAT('0',2X,3(A16,23X))
        800      RETURN
              END
```

PROGRAM SECTIONS

L-18

LTR-10-2-Rev. C

```
FORTRAN [illegible] OS V02-51          [illegible]    [illegible]        [illegible]
INIT14.[illegible]   /TF:BLOCKS/WR

 NAME        SIZE                        ATTRIBUTES

$CODE1   015722   3561                   RW,I,CON,LCL
$PDATA   001166    315                   RW,D,CON,LCL
$IDATA   001360    376                   RW,D,CON,LCL
$VARS    00[illegible]254    342                   RW,D,CON,LCL
$TEMPS   000014      6                   RW,D,CON,LCL
DAT      001000    256                   RW,D,OVR,GBL
PA       002000    512                   RW,D,OVR,GBL
IPA      000102     33                   RW,D,OVR,GBL
.$$$$.   017664   4058                   RW,D,OVR,GBL
DATID    001022    265                   RW,D,OVR,GBL

TOTAL SPACE ALLOCATED = 045770  9724
```

```
      FUNCTION AIRDQ(FLO)
      INCLUDE 'DK1:COMM14.FTN/NOLIST'
      UOUTE(1)=3.784E-5*FLO**.72
      UAOUT(1)=UOUTE(1)*UACC/(UOUTE(1)+UACC)*EXTARA
      WCAIR(1)=FLO*CPAIR
      QAIR(1)=(TTUBE(1)-TAMB)*(1.-EXP(-UAOUT(1)/WCAIR(1)))*WCAIR(1)
      AIRDQZ=QAIR(1)-QCOND(1)
      AIRDQ=AIRDQZ
      RETURN
      END
```

PROGRAM SECTIONS

NAME	SIZE		ATTRIBUTES
$CODE1	000214	70	RW,I,CON,LCL
$PDATA	000010	4	RW,D,CON,LCL
$IDATA	000004	2	RW,D,CON,LCL
$VARS	001040	272	RW,D,CON,LCL
DAT	001000	256	RW,D,OVR,GBL
PA	002000	512	RW,D,OVR,GBL
IPA	000102	33	RW,D,OVR,GBL
.$$$$.	017664	4058	RW,D,OVR,GBL
DATIO	001022	265	RW,D,OVR,GBL

TOTAL SPACE ALLOCATED = 025300 5472

```
      FUNCTION SGDP(SGM)
      INCLUDE 'DK1:COMM14.FTN/NOLIST'
      SHRDM=SGM-DOMEM
      SHRDX=(88.8/SHRDM-SGVF)/(SGVG-SGVF)
      XRISER=SGBETA*SHRDX
      VRISER=SGVF+XRISER*(SGVG-SGVF)
      VDRUM=71.67/(SHRDM-17.13/VRISER)
      WR=WSGI*(1./XRISER-1.)
      SGDPZ=SGK1*(SGVF*(WR+WSGI))**2+SGK2*(SGVF*WR+SGVG*WSGI)**2
     1   -(SGLVLI/SGVF-64.44/VRISER-97.31/VDRUM)/1728.
      SGDP=SGDPZ
      RETURN
      END
```

PROGRAM SECTIONS

NAME	SIZE		ATTRIBUTES
$CODE1	000302	97	RW,I,CON,LCL
$PDATA	000024	10	RW,D,CON,LCL
$IDATA	000004	2	RW,D,CON,LCL
$VARS	001040	272	RW,D,CON,LCL
DAT	001000	256	RW,D,OVR,GBL
PA	002000	512	RW,D,OVR,GBL
IPA	000102	33	RW,D,OVR,GBL
.$$$$.	017664	4058	RW,D,OVR,GBL
DATID	001022	265	RW,D,OVR,GBL

TOTAL SPACE ALLOCATED = 025402 5505

```
FORTRAN IV-PLUS V02-51          15:46:52     08-FEB-80            PAGE 16
INIT14.FTN        /TR:BLOCKS/WR

                SUBROUTINE SETPOT(IADR,N)
                CALL STIND(IADR,N)
                CALL READ(IADR,NVAL)
                IF(IADR.LT.1100) NVAL=-NVAL
                IF(ABS(NVAL-N).LT.4) GOTO 2
                TYPE 100,IADR,NVAL,N,N-NVAL
        100     FORMAT(1X,'POT',I5,' READS',I5,', SHOULD BE',I5,', ERROR=',I5)
        2       RETURN
                END

PROGRAM SECTIONS

 NAME        SIZE                   ATTRIBUTES

$CODE1   000222     73              RW,I,CON,LCL
$IDATA   000072     29              RW,D,CON,LCL
$VARS    000002      1              RW,D,CON,LCL

TOTAL SPACE ALLOCATED = 000316   103

NO FPP INSTRUCTIONS GENERATED

DK1:INIT14,INIT14=DK1:INIT14.FTN;10/CO:60/LI:1
```

```
FORTRAN      V02-51        15:46:57     08-FEB-80
MAIN14.          /TR:BLOCKS/WR

            SUBROUTINE MAIN
            INCLUDE 'DK1:COMM14.FTN/NOLIST'
            EXTERNAL CRDV
            CALL DSINH
      100   IF(ITSTS(0).EQ.1) GOTO 100
            GO TO 120
      110   CALL DSINH
            IF(ITSTS(0).EQ.0) GO TO 120
            TYPE *, 'FRAME TIME EXCEEDED'
            RETURN
      120   IF(ITSTS(0).EQ.0) GO TO 120
C
              KNOHTR=ITSTD(1)           !NO HEATERS
              ICONC=ITSTD(2)            !BORON,ON/DILUTE,OFF/CONC
              IZDP=IYSTD(3)             ! +.01$/SEC REACT
              ISCBP=ITSTD(4)            !SCRAM BYPASS
              ISVRMP=ITSTD(5)           !TRIM MSCV=ON
              KHTR=ITSTD(6)             !HTR*10
              ISMP=ITSTD(7)             !STRT TRN TIM
              ISMTD=ITSTD(8)            !SAMPL*10
              IZDM=ITSTD(9)             ! -.01$/SEC REACT
              ICPBP=ITSTD(10)           !BORON LOOP=PRESS
              KSCMN=ITSTD(11)           !MAN SCRM
              IG=ITSTD(12)              !HALT DP
              KSPRA=ITSTD(13)           !MAN SPRA
              KPOR=ITSTD(14)            !MAN RELF
              KNSPPR=ITSTD(15)          !SPRA INHIB
C
              IDLZER=ITSTS(1)           !POWER IC
              JINJ = ITSTS(3)           !INJECT LSW 110 UP
              JDRAIN = ITSTS(4)         !DRAIN LSW 111 UP
              IOPMSV=ITSTS(5)           !MAN OPEN SV LSW 112 UP
              ICLMSV=ITSTS(6)           !MAN CLOSE SV LSW 112 DN
              IFLMN=ITSTS(7)            !MAN FLOW CONTROL
C
            CALL SCANH(0,IARY,16)
            CALL STBLK(ISET,IDAC,1,18)
            CALL ENIHH
C
              IF(ITMSW.EQ.1)GOTO 170
              IF(ISMP.NE.0)ITMSW=1
              DO 160 I=1,128
      160     NDAT(I)=DAT(I)
      170     CONTINUE
C
C           PRESSURIZER CALCULATIONS
C
      560     PPRO=PPR
              PPR=IARY(3)*0.1+2000.
              XW=IARY(4)*2.E-5
              XW=MAX(XW,0.0)
              XG=1-IARY(5)*2.E-5
              XG=MIN(XG,1.0)
              VWP=-IARY(2)*.02
              HSP=1.25*TBM(34)-140.
              HHL=1.25*TBM(21)-140.
```

```
0062            HF=438.1+0.117*PPR
0063            HG=1320.2-0.09*PPR
          C
          C     INJECTION AND DRAIN FLOW
          C
0064            IF(PLI.LE.LPHPIS)IHPIS=1                    !  ECC-HPIS
0065            JINJ=IHPIS+JINJ-IHPIS*JINJ
0066            DLMINJ=WINJ*DELT*JINJ
0067            DLMDRN = WDRAIN*DELT*JDRAIN
          C
          C     PCS DENSITY & MASS
          C
0068            PMASS=0.0
0069            PCORR=(PLA-2200.)*(.00025+3.89E-7*EXP(.01287*
               (TBM(25)+TBM(26))/2.))
0070            DO 570 K=1,51
0071            RHO(K)=(.0890337-1.4474E-4*TBM(K))*TBM(K)+PCORR
0072            PMASS=PMASS+V(K)*RHO(K)
0073      570   RHO(K)=RHO(K)+41.58                  !ADD OFFSET
          C
          C     PZR SPRAY
          C
0074            IBSPR=KSPRA*(1-KNSPPR)
0075            IF(PPR.GE.SSPT) IBSPR=1-KNSPPR
0076            SSPT=SSP-SDB*IBSPR
0077            SPRFLO=SPRNOM*IBSPR+SPRCNT*(1-IBSPR-KNSPPR)
0078            DLMSP=0.00223*SPRFLO*(VLOOP/22.)*RHO(34)*DELT
0079            SPRAYG = DLMSP*(HF-HSP)
0080            SPRAYW = DLMSP*HF
          C
          C     PZR SURGE
          C
0081            DLMSUR=DLMSP+DLMDRN-DLMINJ
0082            IF(ABS(PMASS-PMASSO).LT.SURMIN) GO TO 580
0083            DLMSUR=DLMSUR+(PMASS-PMASSO)
0084            PMASSO=PMASS
0085      580   IF(DLMSUR.GT.0.0) GOTO 690
0086            HSUR=HHL
0087            SPV=1./RHO(21)
0088            GOTO 700
0089      690   HSUR=HWPR
0090            SPV=VWP/PZRMW
0091      700   DLMSUR=DLMSUR*HSUR
0092            SURFLO=DLMSUR*SPV/DELT
          C
          C     PZR RELIEFS
          C
0093            RPOD=KPOR*(1-KNSPPR)
0094            RCOD=0.
0095            IF(PPR.GE.RPSPT) RPOD=1.-KNSPPR
0096            IF(PPR.GE.RCSPT) RCOD=1.
0097            RPSPT=RPSP-RPDB*RPOD
0098            RCSPT=RCSP-RCDB*RCOD
0099            DLMR=(DLMRP*RPOD+DLMRC*RCOD)
0100            DLMRH = DLMR*HGPR
          C
```

```
C          PZR HEATERS
C
           H1QD=0.
           H2QD=0.
           IF(PPR.LE.HT1T) H1QD=1.-KNOHTR
           IF(PPR.LE.HT2T) H2QD=1.-KNOHTR
           HT1T=HT1SP+H1DB*H1QD
           HT2T=HT2SP+H2DB*H2QD
           HTQ=(HT1Q*H1QD+HT2Q*H2QD+HTSUP*KHTR)*DFLT
C
C          PZR AMBIENT LOSSES
C
           PZRLOS=0.5*UAPZR*(HF-100.)*DFLT     !HEAT LOSS PER PHASE
C
C          PZR CONDENSATION AND BOIL OFF
C
           PZRDM=PZRMW*XW-PZRMG*(1.-XG)
           PZRDH=PZRMW*XW*HG-PZRMG*(1.-XG)*HF
C
C          PZR MASS AND ENERGY UPDATE
C
           PZRMW=PZRMW-PZRDM-DLMSUR+DLMSP
           PZRHW=PZRHW-PZRDH+HTQ+SPRAYW-DLHSUR-PZRLOS+VWP*(PPR-PPRO)*.1851
           PZRMG=PZRMG+PZRDM-DLMR
         PZRHG=PZRHG+PZRDH-DLMRH-SPRAYG-PZRLOS+(34.76-VWP)*(PPR-PPRO)*.1851
           HWPR=PZRHW/PZRMW
           HGPR=PZRHG/PZRMG
           JDAC(1)=(HWPR-675.)*80.
           JDAC(2)=(HGPR-1100.)*66.67
           JDAC(3)=-PZRMW*5.
           JDAC(4)=PZRMG*20.
           CALL STBLK(JSET,JDAC,1,4)
           DLMSPT=DLMSPT+DLMSP
           DLMRT=DLMRT+DLMR
           DMSURT=DMSURT+DLMSUR
           PZRDMT=PZRDMT+PZRDM
C   PZR LEVEL
           PRLEV=VWP*2.02
           IDAC(12)=PRLEV*100.
C   LOOP PRESSURE
           PLA=PPR-KSURGE*SURFLO*ABS(SURFLO)
C
C   FORM NAT CIRC PRESS
C
           GHC=0.0
           GHL=RHO(17)*Z(17)
           DO 180 I=1,4
           GHC=GHC+RHO(I)*Z(I)
    180    CONTINUE
           DO 190 I=5,14
           GHL=GHL+RHO(I)*Z(I)
    190    CONTINUE
           DO 200 I=15,16
           GHC=GHC+RHO(I)*Z(I)
   200   CONTINUE
           DO 210 I=24,46
```

```
              GHL=GHL+RHO(I)*Z(I)
      210   CONTINUE
            GHBP=RHO(51)*Z(51)*.00694444
            GHCP=GHC*.00694444
            GHLP=GHL*.00694444
      C
      C
      C
      C  FORM FLOWS
              TIML=TIM*FLOTRN+TIML*CFLTRN+DFLT*IFLMN*ISMP
              IF(TIML.GT.FLTMX)TIML=FLTMX
              FT = (TIML/FLTMD)+1.0
              IFT=FT
              VSFRV=VSFR(IFT)+(VSFR(IFT+1)-VSFR(IFT))*(FT-IFT)
              RABFRV=RABFR(IFT)+(RABFR(IFT+1)-RABFR(IFT))*(FT-IFT)
              FLOLP=FLOW
              VSFRO=VSFRV
              IF(VSFRV.LT.FFRMN)VSFRO=FFRMN
              RCL=VSFRO*RC
              RBL=VSFRO*RB
              RLL=VSFRO*RL
              R1=RCL*RBL+RCL*RLL+RBL*RLL
              WLNC=((RCL+RBL)*GHLP-RBL*GHCP-RCL*GHBP)/R1
              WBNC=(RCL*GHLP+RLL*GHCP-(RCL+RLL)*GHBP)/R1
              WCNC=WLNC-WBNC
              IF(ISMP.EQ.1)GO TO 220
              VCORB=0.95*FLOLP-WCNC
              VBPB=0.05*FLOLP-WBNC
      220     CONTINUE
              VRABP=FLOLP*RABFRV
              VCORE=VCORB*VSFRV+WCNC
              VCBP=VBPB*VSFRV+WBNC
              VVESSL=VCORE+VCBP
              VLOOP=VRABP+VCORE+VCBP
              VUP=VLOOP*0.8
              VUPHP=VLOOP-VUP
      C       DEFINE WALL TEMPERATURES
      C
              IF(IDLZER.EQ.1) GO TO 241
            DO 230 K=1,4
      230   TWALL(K)=IARY(1)*.05+600.
            DO 240 K=5,14
      240   TWALL(K)=TSAT
      241   TCLAD = TWALL(1)
              WCORE = VCORE*3600.*RHO(23)
              WRABV = VRABV*3600.*RHO(23)
      C
      C       FORM WLOOP
      C
            WL46 = VLOOP*3600.*44.11
            WPCS = VLOOP*3600.*RHO(23)
              IF(TIM.GT.60.)FLOSC=FLTNSC
            IDAC(11)=WPCS*FLOSC*.001
      C
      C     FORM HEAT TRANSFER COEFF BETWEEN WALL AND FLUID FOR 51 NODES
      C
```

```
          AVV=(ABS(VCORE)/VREF)**0.8
          HCORE=HREF(1)*AVV
  250     UBCORE = CKCORE*HCORE/(CKCORE+HCORE)
          H(15)=HREF(15)*AVV
          UB(15) = CK(15)*H(15)/(CK(15)+H(15))
            XDRUM=(VDRUM-SGVF)/(SGVG-SGVF)
            IF(XDRUM.GT.0.98) GOTO 1400
            UBF=1.-(XRISER-SGXDNB)*2.*XDRUM/XRISER**2
            IF(2.*XDRUM.GT.XRISER) UBF=1.-(XRISER-SGXDNB)/2./(XRISER-XDRUM)
            IF(UBF.LT..01) UBF=.01
            IF(UBF.GT.1.) UBF=1.
          AVLV=(ABS(VLOOP)/VREF)**0.8
  280      UBSG = UBF*CKSC*HREF(5)*AVLV/(CKSG+HREF(5)*AVLV)
          DO 290 K=19,38
          H(K)=HREF(K)*AVLV
  290     UB(K) = CK(K)*H(K)/(CK(K)+H(K))
          H(51) = HREF(51)*(ABS(VCBP)/VREF)**.8
          UB(51) = CK(51)*H(51)/(CK(51)+H(51))
          H(18) = HREF(18)*(ABS(VUPBP)/VREF)**.8
          UB(18) = CK(18)*H(18)/(CK(18)+H(18))
          H(17)=HREF(17)*AVLV
          UB(17) = CK(17)*H(17)/(CK(17)+H(17))
          AVVV=(ABS(VVESSL)/VREF)**0.8
          DO 300 K=39,46
          H(K)=HREF(K)*AVVV
  300     UB(K) = CK(K)*H(K)/(CK(K)+H(K))
          AVRV=(ABS(VRABP)/VREF)**0.8
          DO 310 K=47,50
          H(K)=HREF(K)*AVRV
  310     UB(K) = CK(K)*H(K)/(CK(K)+H(K))
          H(16)=HREF(16)*AVVV
          UB(16) = CK(16)*H(16)/(CK(16)+H(16))
C
C         FORM CLAD,STEAM GENERATOR AND PIPE HEAT
C
            RPA=IARY(7)*.01
            IF (IDLZER.EQ.1) RPA =RXPWR
            QCBP = RPA*DHBPF*100.
            QDIR=RPA*DHMF*100.
          DO 330 K=1,4
          Q(K) = UBCORE*(TWALL(K)-TBM(K))
  330     QCLBK(K) = Q(K)+QDIR
          QCLAD = Q(1)+Q(2)+Q(3)+Q(4)
            IDAC(1)=QCLAD*2./MCCL
          QSG = 0
          DO 350 K=5,14
            Q(K)=UBSG*(TWALL(K)-TBM(K))
  350     QSG =QSG+Q(K)
C
C         SEND CLAD AND STEAM GENERATOR TOTAL HEAT TO ANALOG VIA DAC'S
C
  356     DO 360 K=15,51
  360     Q(K) = UB(K)*(TWALL(K)-TBM(K))
C
C         FORM 51 BULK TEMPERATURES
C
```

```
        DO 370 K=1,4
  370   TBN(K) = TBM(K)+QCLBK(K)*DELT/HC(K)
        DO 380 K=5,50
  380   TBN(K) = TBM(K)+Q(K)*DELT/HC(K)
          TBN(51)=TBM(51)+DELT*(Q(51)+QCBP)/HC(51)
C
C       FORM 51 BULK MOVE TEMPERATURES
C PERFORM BORON TRANSPORT CALCULATION
C
        VCD=VCORE*DELT
        TBM(1) = TBN(1)+(VCD/V(1))*(TBN(46)-TBN(1))
        C(1)=CO(1)+VCD/V(1)*(CO(46)-CO(1))
        DO 390 K=2,4
        TBM(K) = TBN(K)+(VCD/V(K))*(TBN(K-1)-TBN(K))
  390     C(K) = CO(K)+VCD/V(K)*(CO(K-1)-CO(K))
        VLD=VLOOP*DELT
        TBM(5) = TBN(5)+(VLD/V(5))*(TBN(25)-TBN(5))
        C(5) = CO(5)+VLD/V(5)*(CO(25)-CO(5))
        DO 400 K=6,14
        TBM(K) = TBN(K)+(VLD/V(K))*(TBN(K-1)-TBN(K))
  400     C(K) = CO(K)+VLD/V(K)*(CO(K-1)-CO(K))
        TBM(15) = TBN(15)+(VCD/V(15))*(TBN(4)-TBN(15))
        C(15) = CO(15)+VCD/V(15)*(CO(4)-CO(15))
        TBM(16) = TBN(16)+(VCD/V(16))*(TBN(15)-TBN(16))
        C(16) = CO(16)+VCD/V(16)*(CO(15)-CO(16))
          VCBD=VCBP*DELT
        VVD=VVESSL*DELT
        VBD=VBABP*DELT
          BPREV=0.0
          IF(VCBF.LT.0.) BPREV=1.0
        TBM(17) = TBN(17)+(VCD*(TBN(16)-TBN(17))+
     1 VBD*(TBN(50)-TBN(17))+VCBD*(TBN(51)-TBN(17))*(1.-BPREV))/V(17)
        C(17) = CO(17)+(VCD*(CO(16)-CO(17))+
     1 VBD*(CO(50)-CO(17))+VCBD*(CO(51)-CO(17))*(1.-BPREV))/V(17)
        VUD=VUPBP*DELT
        TBM(18) = TBN(18)+(VUD/V(18))*(TBN(17)-TBN(18))
        C(18) = CO(18)+VUD/V(18)*(CO(17)-CO(18))
        TBM(19) = TBN(19)+(VUD/V(19))*(TBN(18)-TBN(19))+(VUP*DELT/V
     1(19))*(TBN(17)-TBN(19))
        C(19) = CO(19)+VUD/V(19)*(CO(18)-CO(19))
     1                  +(VUP)*DELT/V(19)*(CO(17)-CO(19))
        C(20) = CO(20)+VLD/V(20)*(CO(19)-CO(20))
        C(21) = CO(21)+VLD/V(21)*(CO(20)-CO(21))
     1      +MAX(SURFLO,0.0)*DELT/V(21)*(CPO-CO(21))
        DO 430 K=22,25
  430     C(K) = CO(K)+VLD/V(K)*(CO(K-1)-CO(K))
        DO 440 K=20,25
  440   TBM(K) = TBN(K)+(VLD/V(K))*(TBN(K-1)-TBN(K))
        TBM(26) = TBN(26)+(VLD/V(26))*(TBN(14)-TBN(26))
        C(26) = CO(26)+VLD/V(26)*(CO(14)-CO(26))
          TBM(27)=TBN(27)+(VLD/V(27))*(TBN(26)-TBN(27))   !ASSUMES TEMP DIFF OF 100 F AND
     1    -JINJ*.2228*VINJ*DELT/V(27)                      !CONVERTS VINJ TO CUFT/SEC.
        CINJ = CIMO*ICONC
        C(27) = CO(27)+VLD/V(27)*(CO(26)-CO(27))
     1  +JINJ*(CINJ-CO(27))*.002228*VINJ*DELT/V(27)
        DO 460 K=28,38
```

```
            C(K) = CO(K)+VLD/V(K)*(CO(K-1)-CO(K))
      460   TBM(K) = TBN(K)+(VLD/V(K))*(TBN(K-1)-TBN(K))
            DO 470 K=39,45
            TBM(K) = TBN(K)+(VVD/V(K))*(TBN(K-1)-TBN(K))
      470   C(K) = CO(K)+VVD/V(K)*(CO(K-1)-CO(K))
              TBM(46)=TBN(46)+(VVD*(TBN(45)-TBM(46))+
             1 VCBD*(TBN(46)-TBN(51))*BPREV)/V(46)
              C(46)=CO(46)+(VVD*(CO(45)-CO(46))+
             1 VCBD*(CO(46)-CO(51))*BPREV)/V(46)
            TBM(47) = TBN(47)+(VBD/V(47))*(TBN(38)-TBN(47))
            C(47) = CO(47)+VBD/V(47)*(CO(38)-CO(47))
            DO 480 K=48,50
            TBM(K) = TBN(K)+(VBD/V(K))*(TBN(K-1)-TBN(K))
      480   C(K) = CO(K)+VBD/V(K)*(CO(K-1)-CO(K))
              TBM(51)=TBN(51)+(VCBD*(TBN(46)-TBN(51))*(1.-BPREV)+
             1 VCBD*(TBM(51)-TBN(17))*BPREV)/V(51)
            C(51) = CO(51)+(VCBD*(CO(46)-CO(51))*(1.-BPREV)+
             1 VCBD*(CO(51)-CO(17))*BPREV)/V(51)
              CP=CPO+MIN(SURFLO,0.0)*DELT*(CPO-CO(21))/VWP+
          1       DLMSP/PZRMW*(CO(34)-CPO)
            IF(ICPBP.EQ.1)CP = C(21)
            DO 510 I=1,51
        510   CO(I) = C(I)
            CPO = CP
            CBAR=(C(1)+C(2)+C(3)+C(4))*0.25
              IDAC(13)=(CBAR-1500)*5.
      540     DO 550 I=15,51
      550   TWALL(I)=TWALL(I)-Q(I)*DELT/HCWAL(I)
      C
              TCLI=TCLI+TAUCL*(TBM(37)-TCLI)
      C
      C TEST FOR REACTOR SCRAM
      C
                KSCRP=0
                KSCHT=0
                KSCHP=0
                KSCLP=0
                KSCLF=0
                KSCRA=0
                KSCRT=0
      C REACTOR POWER SCRAM
            RPI=RPI+DELT*(RPA-RPI)/TCRP
            IF(RPI.GE.RPSCRM) KSCRP=2
      C HIGH TEMPERATURE SCRAM
            THLI=THLI+DELT*(TBM(20)-THLI)/TCHLT
              IDAC(18)=(THLI-600.)*100.
            IF(THLI.GE.HTSCRM) KSCHT=4
      C HIGH PRESSURE SCRAM
            PLI=PLI+DELT*(PLA-PLI)/TCLP
            IF(PLI.GE.HPSCRM)  KSCHP=8
      C LOW PRESSURE SCRAM
            IF(PLI.LE.LPSCRM) KSCLP=16
      C LOW FLOW SCRAM
            VLI=VLI+DELT*(WPCS-VLI)/TCLF
            IF(VLI.LE.VSCRM) KSCLF=32
      C REFLOOD ASSIST BYPASS SCRAM
```

```
      IF(RABFRV.GE.RASCRM) KSCRA=64
C TIME  SCRAM
      IF(TIM.GE.TIMSCM) KSCRA=128
C    TEST SCRAM
        IF(KSCSET.EQ.1) GOTO 1030
        KSCRAM=KSCMN+KSCRP+KSCHT+KSCHP+KSCLP+KSCLF+KSCRA+KSCRT
        IF((KSCRAM.GT.0).AND.(TIM.GT.0)) KSCSFT=1-ISCBP
        SCRMTM=TIM
1030  CONTINUE
        SCRMTD=TIM-SCRMTM
        IF(SCRMTD.LT.SCDLY) GOTO 1040
        KSCRMS=1
        TMOT=SCRMTD-SCDLY
1040    CALL SCRAMT(TMOT,DLS,RODPOS,DCR,LASTI)
C   COMPUTE MODERATOR REACTIVITY
        DENCOR=(RHO(1)+RHO(2)+RHO(3)+RHO(4))*0.25
        DLMOD=DENCOR*DCOR
C   FUEL REACTIVITY
        TFUEL=1000.-IARY(6)*.1
        DLF = TFUEL*DOPC
C   BORON REACTIVITY
      DLB = -ALPHAB*CBAR
C  SET EXTERNAL REACTIVITY
      IF (KSCRMS.EQ.1) GO TO 1060
      DEXT=(REACEX/TIMEX)*TIM*REACTN
       F (ABS(DEXT).GE.ABS(REACEX)) DEXT=REACEX
1060  CONTINUE
        DELTAD=DELTAD+0.0005*(IZDP-IZDM)
C TOTAL REACTIVITY
      DTOT=DLMOD+DLF+DCR+DLB+DEXT+DELTAD
      IF(IDLZER.EQ.1) DTOTZ=DTOT  ! 1=ZERO REACTIVITY
      SDL=DTOT-DTOTZ
        ISDL=SDL/2.
        IDAC(3)=ISDL*1000.
        ID  (4)=(SDL/2.-ISDL)*10000.
        SL=TABLE(TFUEL,SLP)
        KO=TABLE(TFUEL,ITR)
      KFC=(KO+SL*TWALL(1))
        IDAC(5)= -KFC*100.
C
C   CALL DECAY HEAT SUBROUTINE
C
        R=.06725
        IF(TMOT.GT..1) R=TABLE(LOG10(TMOT),DECAY)
      DCYHT = R*RXPWR
C
C
      IDAC(6) = DCYHT*100.
      IDAC(7) = (TBM(19)-600.)*100.
      IDAC(8) = (TBM(38)-600.)*100.
C
C  FEED FLO
C
        IF(ITRNTP+ISMP.EQ.4)GO TO 1091
        IF(SCRMTD.GT.FWD Y) GOTO 1091
        SGLI=SGLI+(SGLVL-SGLI)*DELT
```

```
FORTRAN    VIUS V02-51         15:46:57    08-FEB-80
MAIN14             /TR:BLOCKS/WR

0359            SGWLC=.0216*WG-.08*(SGLI-SGLSP)
0360            IF(SGWLC.LT.0.0) SGWLC=0.0
0361            IF(SGWLC.GT.1.0)SGWLC=1.0
0362            XSFW=XSFW+(SGWLC-XSFW)*DELT
0363            GOTO 1100
0364     1091   XSFW=XSFW+FWRMPT*DELT
0365     1100   CONTINUE
0366            IF(XSFW.LE.0.0) XSFW=0.0
0367            IF(XSFW.GE.1.)XSFW=1.0
0368            DCVFW=0
0369            DXSFW=XSFW-0.75
0370            IF(DXSFW.GT.0.0) DCVFW=1.
0371            CVFW=1.0725*(XSFW+DCVFW*DXSFW)
0372            C2RO=CVFW*CVFW*53.36
0373            CDPFW=C2RO*(PCR-PSG+DPP0)/(1.+C2RO*0.0233)
0374            IF(CDPFW.LT.0.0) CDPFW=0.
0375            WFW=CDPFW**0.5
0376            IDAC(9) = WFW*20.
         C
         C    STEAM VALVE POSITION
         C
0377            MSVC=0
0378            MSVO=0
0379            IF(PSG.LT.PMSVLT) MSVC=KSCSET*(1-IDLZER)
0380            IF(PSG.GT.PMSVHT) MSVO=1-IDLZER
0381            RMPMSV=(MSVO-MSVC)*SVRMPN
0382            RSVMAN=(IOPMSV-ICLMSV)*SVRMPN*(1.-.9*ISVRMP)*(1-MSVC-MSVO)
0383     1179   PMSVLT=PMSVLS+PMSVDB*MSVC
0384            PMSVHT=PMSVHS-PMSVDB*MSVO
         C
0385     1180   XMSCVL=XMSCVL+(RMPMSV+RSVMAN)*DELT
0386            IF(XMSCVL.LT.0.) XMSCVL=0.
0387            IF(XMSCVL.GT.1.) XMSCVL=1.
0388            XMSCV=XMSCV+(XMSCVL-XMSCV)*DELT/SVTC
0389            IDAC(14)=XMSCV*10000.
         C
         C  STEAM FLOW
         C
0390            CVMSC=TABLE(XMSCV,CVMSCF)
0391            WGSRT=PSG*PSG-PCH*PCH
0392            IF(WGSRT.LE.0.) WGSRT = 0.
0393            WG=CVMSC*((WGSRT*0.5)**0.5)
0394            IF(WG.LT.WGMIN) WG=WGMIN
         C  STM GEN RELIEF FLOW
0395            SGRF1=0.0
0396            SGRF2=0.0
0397            IF(PSG.GE.SGRT1)SGRF1=1.0
0398            IF(PSG.GE.SGRT2)SGRF2=1.0
0399            SGRT1=SGRS1-SGRB1*SGRF1
0400            SGRT2=SGRS2-SGRB2*SGRF2
0401            WSGRV=WSGRV+((WSGRV1*SGRF1+WSGRV2*SGRF2)-WSGRV)*DELT
0402            WS=WG+WSGRV
0403            IDAC(10) =WS*20.
         C  STM GEN RECIRC AND DWNCMR FLOWS
0404            SGVG=TABLE(PSG,VGTAB)
0405            SGVF=TABLE(PSG,VFTAB)
```

```
0406        SGHF=TABLE(PSG,HFTAB)
0407        SGHG=TABLE(PSG,HGTAB)                    ! 89=VOL SHRD
0408        VDWN=DWMASS*SGVF
0409        SHRDM=SGMASS-(187.2-VDWN)/SGVG   ! 187.2=TOT VOL-SHRD VOL
0410        SHRDV=88.8/SHRDM
0411        SHRDX=(SHRDV-SGVF)/(SGVG-SGVF)           ! QUALITY IN SHRD
0412        IF(SHRDX.GT.1.) SHRDX=1.
0413        SGBETA=2.8523+21974./-QSG
0414        XRISER=SGBETA*SHRDX
0415        IF(XRISER.GT.1.) XRISER=1.
0416        WR=WS*(1./XRISER-1.)
      C
0417        VRISER=SGVF+XRISER*(SGVG-SGVF)
0418        VDRUM=71.67/(SHRDM-17.13/VRISER)
0419        SGHEAD=(SGLVL/SGVF-64.44/VRISER-97.31/VDRUM)/1728.
0420        WDSQ=(SGHEAD-SGK2*(WR*SGVF+WS*SGVG)**2)/(SGK1*SGVF**2)
0421        AWDSQ=ABS(WDSQ)
0422        WD=AWDSQ**.5
0423        IF(WD.LT.10.) WD=0.1*AWDSQ
0424        IF(WDSQ.LT.0.0) WD=-WD
      C
      C   SG MASS AND ENERGY BALANCES
      C
0425        DWMASS=DWMASS+(WFW+WR-WD)*DELT
0426        SGMASS=SGMASS+(WD-WR-WS)*DELT
0427        SGV=(276.-VDWN)/SGMASS   !SG SP. VOL.
0428        HWDPOS=1.0
0429        IF(WD.LT.0.) HWDPOS=0.0
0430        HDWN=HDWN+(WFW*(HFW-HDWN)+WR*(SGHF-HDWN)+WD*(HDWN-HSG)*
            1          (1.-HWDPOS))*DELT/DWMASS+(PSG-PSGO)*SGVF*.1851
0431        HSG=HSG+(WD*(HDWN-HSG)*HWDPOS-WS*(SGHG-HSG)-WR*(SGHF-HSG)-QSG)*
            1   DELT/SGMASS+(PSG-PSGO)*SGV*.1851
      C
      C   STM GEN LEVEL
      C
0432        SGLVL=4.8098*VDWN
0433        IF(VDWN.GT.19.41) SGLVL=75.41+0.9241*VDWN
0434        IDAC(2)=SGLVL*25.
      C
      C   SG PRESSURE
      C
0435        PSGO=PSG
0436        VLOGSG=ALOG10(SGV)*10.+19.
0437        HBARSG=(HSG-300.)*.02
0438        IV=VLOGSG
0439        IH=HBARSG
0440        IF((IH.GT.18).OR.(IH.LT.1).OR.(IV.GT.22)) GOTO 1450
0441        FRV=VLOGSG-IV
0442        FRH=HBARSG-IH
0443        PSG=PSGT(IV,IH)*(1.-FRH)*(1.-FRV)+PSGT(IV+1,IH)*FRV*(1.-FRH)+
            1       PSGT(IV,IH+1)*FRH*(1.-FRV)+PSGT(IV+1,IH+1)*FRV*FRH
0444        TSAT=TABLE(PSG,TSATSG)
0445        IDAC(17)=PSG*5.
      C
      C   AIR-COOLED CONDENSER
      C
```

```
            PANGL=30.*XMSCV+(PCR-PCRSP)*.8475
            IF(PANGL.LT.0.) PANGL=0.
            IF(PANGL.GT.25.) PANGL=25.
            PANG=PANG+(PANGL-PANG)*DELT/.2122
            VAIR=TABLE(PANG,AIRFLO)          ! 1000 CUFT/MIN PER FAN
            ROAIR=33.72/TAIR
            WBAY=VAIR*ROAIR*33.333
            TSATCR=TABLE(PCR,TSATSG)
            DO 1210 I=1,3
            FANFR(I)=MAX(1.-TIM*AIRTSL*AIRSW(I),WAIRMN(I))*BAYSW(I)
            WAIR(I)=WBAY*FANFR(I)
            UOUTF(I)=3.784E-5*WAIR(I)**.72
            UAOUT(I)=UOUTF(I)*UACC/(UOUTF(I)+UACC)*EXTARA
            WCAIR(I)=WAIR(I)*CPAIR
            EDT=0.
            IF(WAIR(I).GT.0.) EDT=EXP(-UAOUT(I)/WCAIR(I))
            DTAIR(I)=(TTUBE(I)-TAMB)*(1.-EDT)
            QAIR(I)=DTAIR(I)*WCAIR(I)
            WCOND(I)=QCOND(I)/(SGHG-CRHF)
            IF(WCOND(I).LE.0.) GO TO 1200
            UINF(I)=1.77*WCOND(I)**-.3333
            UAIN(I)=UINF(I)*UFOUL/(UINF(I)+UFOUL)*CONDAR
      1200  QCOND(I)=UAIN(I)*(TSATCR-TTUBE(I))
      1210  TTUBE(I)=TTUBE(I)+(QCOND(I)-QAIR(I))*DELT/MCTUB
            TAIR=TAMB+459.67+DTAIR(1)*.5              ! ABSOLUTE TEMP
      C
      C   CONDENSATE RECIEVER
      C
            CRRL=0.0
            IF(PCR.GE.CRRLT) CRRL=1.
            CRRLT=CRRLSP-CRRLDB*CRRL
            WCRRV=CRRFL*CRRL                          ! RELIEF VALVE FLOW
            WCONDT=WCOND(1)+WCOND(2)+WCOND(3)         ! CONDENSATE FLOW INTO ACC
            WFACC=CONDMF/DWELL                        ! CONDENSATE FLOW FROM ACC
            WGACC=WG-WCONDT                           ! STEAM FLOW THRU ACC
            CRDM=CRMW*CRXW-CRMSTM*(1.-CRXG)
            CRDH=CRMW*CRXW*CRHG-CRMSTM*(1.-CRXG)*CRHF
            CONDMF=CONDMF+(WCONDT-WFACC)*DELT
            CRMW=CRMW+(WFACC-WFW)*DELT-CRDM
            CRHW=CRHW-CRDH+(WFACC*CRHF-WFW*HWCR)*DELT+VWCR*(PCR-PCRO)*.1851
            CRMSTM=CRMSTM+(WGACC-WCRRV)*DELT+CRDM
            CRHSTM=CRHSTM+CRDH+(WGACC*SGHG-WCRRV*HGCR)*DELT
            1    +VSTMCR*(PCR-PCRO)*.1851
            HWCR=CRHW/CRMW
            HGCR=CRHSTM/CRMSTM
      C
      C   CONDENSATE RECIEVER PRESSURE
      C
            PCRO=PCR
            CALL ZERO(CRDV,PCR)
      1220  CRHG=TABLE(PCR,HGTAB)
            CRXW=MAX(HDIFF/(CRHG-CRHF),0.)
            CRXG=MIN((HGAS-CRHF)/(CRHG-CRHF),1.)
            IDAC(15)=PCR*20.
            IDAC(16)=VWCR*25.
      C
```

```
      C     SUBCOOLER
      C
                 QSC=UASC*(HSC-HAMB)
                 HSC=HSC+(WFW*(HWCR-HSC)-QSC)*DELT/SCMAS
                 HFW=HFW+(WFW*(HSC-HFW))*DELT/FPMAS
       1230  CONTINUE
      C
      C
              IF(ISMP.EQ.0) GO TO 1320
              IF(TIM.NE.0)GO TO 1235
              CALL GETADR(IPARM(1),NDAT(1))
              GO TO 1270
       1235    IF(IPARM(5).GT.NPA+5) GO TO 1310
               INCRE=1000.*(SMTSLO*(1-ISMTD)+SMTFST*ISMTD)+.5
               IF (IPRINT+INCRE-ITIME) 1236,1236,1310
       1236    IPRINT=ITIME
       1260  CALL WAITFR(3,IDS)
              IF(IDS.NE.1) GO TO 1260
                DO 1240 I=1,128
       1240  NDAT(I)=DAT(I)
              IF(IOSB(1).EQ.1) GO TO 1270
                TYPE 9000,IOSB
                GO TO 1330
       1270    CALL SETCL(1,1)                    ! DATA COUNTER
       1280  CALL QIO(4608,2,3,50,IOSB,IPARM,IDS)
              IF(IDS.NE.1)GO TO 1280
              IPARM(5)=IPARM(5)+1
                DLMPT=0.
                DLMSPT=0.
                DMSURT=0.
                PZRDMT=0.
                CALL SETCL(1,0)                   ! DATA COUNTER
       1300  CONTINUE
       1310    ITIME=ITIME+IDELTA
               TIM=ITIME*.001
       1320  IF(ID.EQ.0)GO TO 110
       1330  CONTINUE
              RETURN
       1400    TYPE*,'STEAM GENERATOR DRY'
               RETURN
       1450    TYPE*,'SG PRESSURE TABLE EXCEEDED'
               RETURN
       9000    FORMAT(' ***DISC ERROR***',2O7)
              END
```

PROGRAM SECTIONS

NAME	SIZE		ATTRIBUTES
$CODE1	022042	4625	RW,I,CON,LCL
$PDATA	000624	202	RW,D,CON,LCL
$IDATA	000444	146	RW,D,CON,LCL
$VARS	001414	390	RW,D,CON,LCL
$TEMPS	000020	8	RW,D,CON,LCL
DAT	001000	256	RW,D,OVR,GBL

```
F4P1640 [illegible]PLUS V02.51        15:46:57     04-FEB-80        [illegible] 11
MAIN14.           /TR:BLOCKS/WR

PA        002000    512          RW,D,OVR,GBL
IPA       000102     33          RW,D,OVR,GBL
.$$$$.    017664   4058          RW,D,OVR,GBL
DATID     001022    265          RW,D,OVR,GBL

TOTAL SPACE ALLOCATED = 050776 10495
```

```
0001            SUBROUTINE SCRAMT(T,ROD,X,D,I)
0002            DIMENSION TABLE(2,22),ROD(23)
        C                                              CRDM
        C                            TIME             POSITION
0003            DATA TABLE/          0.000,            54.0,
               2                     0.075,            53.9,
               3                     0.160,            52.8,
               4                     0.245,            51.4,
               5                     0.331,            49.5,
               6                     0.417,            47.2,
               7                     0.503,            43.6,
               8                     0.589,            39.3,
               9                     0.672,            34.6,
               0                     0.753,            29.2,
               1                     0.830,            23.7,
               2                     0.905,            19.7,
               3                     0.977,            16.2,
               4                     1.050,            13.5,
               5                     1.127,            11.1,
               6                     1.211,             9.0,
               7                     1.265,             8.0,
               8                     1.336,             7.0,
               9                     1.403,             5.9,
               0                     1.514,             4.1,
               1                     1.590,             3.0,
               2                     1.710,             0.0/
0004            IF (T.GT.TABLE(1,22)) GO TO 200
0005            DO 100 J=I+1,22
0006            IF (T.GT.TABLE(1,J)) GO TO 100
0007      5     K=J-1
0008            FRAC=(T-TABLE(1,K))/(TABLE(1,J)-TABLE(1,K))
0009            X=(TABLE(2,J)-TABLE(2,K))*FRAC+TABLE(2,K)
0010            D=(ROD(K)-ROD(J))*FRAC-ROD(K)
0011            I=K
0012            RETURN
0013      100   CONTINUE
0014      200   X=TABLE(2,22)
0015            D=-ROD(22)
0016            RETURN
0017            END
```

PROGRAM SECTIONS

NAME	SIZE		ATTRIBUTES
$CODE1	000314	114	RW,I,CON,LCL
$IDATA	000012	5	RW,D,CON,LCL
$VARS	000270	92	RW,D,CON,LCL

TOTAL SPACE ALLOCATED = 000646 211

DK1:MAIN14,MAIN14=DK1:MAIN14.FTN;10/CO:60/LI:1

```
      FUNCTION CRDV(PSI)
      INCLUDE 'DK1:COMM14.FTN/NOLIST'
      HWTR=HWCR+VWCR/CRMW*(PSI-PCRO)*.1851
      HGAS=HGCR+VSTMCR/CRMSTM*(PSI-PCRO)*.1851
      CRHF=TABLE(PSI,HFTAB)
      HDIFF=HWTR-CRHF
      DVDH=.0002284+.496124/PSI
      CRVF=TABLE(PSI,VFTAB)
      VWCR=(CRVF+13.838E-6*HDIFF)*CRMW               ! SUBCOOLED CASE
      IF(HDIFF.GT.0.) VWCR=(CRVF+HDIFF*DVDH)*CRMW    ! QUALITY REGION
      VSTMCR=(CRVF+(HGAS-CRHF)*DVDH)*CRMSTM
      CRDVZ=VWCR+CRVF*CONDMF+VSTMCR-745.86
      CRDV=CRDVZ
      RETURN
      END
```

PROGRAM SECTIONS

NAME	SIZE		ATTRIBUTES
$CODE1	000402	129	RW,I,CON,LCL
$PDATA	000024	10	RW,D,CON,LCL
$IDATA	000020	8	RW,D,CON,LCL
$VARS	001044	274	RW,D,CON,LCL
DAT	001000	256	RW,D,OVR,GBL
PA	002000	512	RW,D,OVR,GBL
IPA	000102	33	RW,D,OVR,GBL
.$$$$.	017664	4058	RW,D,OVR,GBL
DATID	001022	265	RW,D,OVR,GBL

TOTAL SPACE ALLOCATED = 0...22 5545

```
      SUBROUTINE DUMP
      INCLUDE 'DK1:COMM14.FTN/NOLIST'
        DIMENSION DMP1(2000)
        EQUIVALENCE (AIRFLO,DMP1)
        OPEN (UNIT=6,TYPE='NEW',NAME='DUMP.LST',RECORDSIZE=132)
        WRITE(6,900) (IDAT(I),I=1,72)
        WRITE(6,902) (IDAT(I),I=73,144)
        WRITE(6,903)
        WRITE(6,904) (K,Q(K),TBM(K),TBN(K),RHO(K),TWALL(K),TCALC(K),
        1  C(K),UB(K),H(K),K=1,51)
        PRINT 900
        PRINT*,'NO. OF DATA RECORDS=',(IPARM(5)-6)
        WRITE(6,800)
  800   FORMAT('0',10X,'HEAT BALANCES',T65,'ERROR')
        WRITE(6,801) RXPWR,RXBTU
  801   FORMAT(' INITIAL POWER',T20,F10.2,' MW',T40,F10.2,' BTU/SEC')
        WRITE(6,802) 948.*RPA,948.*RPA-RXBTU
  802   FORMAT(' CORE POWER (RPA)',T40,F10.2,' BTU/SEC',T60,F10.2)
        QT=QCLAD+QCBP+4.*QDIR
        WRITE(6,803) QCLAD,QCBP,4.*QDIR,QT,QT-RXBTU
  803   FORMAT(' QCLAD',T20,F10.2,' BTU/SEC'/' QCBP',T20,F10.2,
        1    ' BTU/SEC'/' QDIR*4',T20,F10.2,' BTU/SEC'/' TOTAL CORE HEAT'
        1    ,T40,F10.2,' BTU/SEC',T60,F10.2)
        QPCS=VLOOP*HC(1)/V(1)*(TBM(25)-TBM(26))
        WRITE(6,804) QPCS,QPCS-RXBTU
  804   FORMAT(' PCS POWER',T40,F10.2,' BTU/SEC',T60,F10.2)
        WRITE(6,805) -QSG,-QSG-RXBTU
  805   FORMAT(' SG HEAT (-QSG)',T40,F10.2,' BTU/SEC',T60,F10.2)
        SGPOW=WS*SGHG-WFW*HFW
        WRITE(6,806) SGPOW,SGPOW-RXBTU
  806   FORMAT(' STM GEN POWER',T40,F10.2,' BTU/SEC',T60,F10.2)
        ACCPOW=WG*SGHG-QCONDT*CRHF
        SCLPOW=WFW*(HWCR-HFW)
        WRITE(6,807) ACCPOW,SCLPOW,ACCPOW+SCLPOW,ACCPOW+SCLPOW-RXBTU
  807   FORMAT(' ACC POWER',T20,F10.2,' BTU/SEC'/' SUB-COOLER POWER',
        1    T20,F10.2,' BTU/SEC'/' TOTAL SECONDARY POWER',T40,F10.2,
        1    ' BTU/SEC',T60,F10.2)
        WRITE(6,808) QSC,(QCOND(K),QAIR(K),K=1,3)
  808   FORMAT(' QSC',T20,F10.2/' QCOND/QAIR',3(T20,2F10.2/))
        QCONDT=QCOND(1)+QCOND(2)+QCOND(3)
        QAIRT=QAIR(1)+QAIR(2)+QAIR(3)
        WRITE(6,809) QCONDT,QAIRT
  809   FORMAT(' TOTAL ACC HEAT',T20,2F10.2)
        WRITE(6,810) QCONDT+QSC,QAIRT+QSC,QCONDT+QSC-RXBTU,QAIRT+
        1    QSC-RXBTU
  810   FORMAT(' TOTAL SECONDARY HEAT REJECTION',T40,2F10.2,T60,2F10.2)
        PRINT 811
  811   FORMAT(//'              *** STEAM GENERATOR ***')
        PRINT 910,'TSATC','PSATI','SGLVLI','WSGI','SGMASI'
        PRINT 912,TSATC,PSATI,SGLVLI,WSGI,SGMASI
        PRINT 910,'TSAT','PSG','SGLVL','WS','SGMASS'
        PRINT 912,TSAT,PSG,SGLVL,WS,SGMASS
        PRINT 910,'DWMASI','HDWNI','HSGI','XMSCV0','XSFWI'
        PRINT 912,DWMASI,HDWNI,HSGI,XMSCV0,XSFWI
        PRINT 910,'DWMASS','HDWN','HSG','XMSCV','XSFW'
        PRINT 912,DWMASS,HDWN,HSG,XMSCV,XSFW
```

```
      PRINT 910,'WFW','SGVF','SGVG','SGV','SGHF','SGHG'
      PRINT 912,WFW,SGVF,SGVG,SGV,SGHF,SGHG
      PRINT 910,'SHRDM','SHRDV','SHRDX','XRISER','VRISER','VDRUM'
     1   ,'XDRUM'
      PRINT 912,SHRDM,SHRDV,SHRDX,XRISER,VRISER,VDRUM,XDRUM
      PRINT 910,'SGBETA','SGHEAD','WDSQ','WR','WD','SGDPZ'
      PRINT 912,SGBETA,SGHEAD,WDSQ,WR,WD,SGDPZ
      PRINT 910,'HSCI','HSC','HFW','UBF','RECIRC','HSGC'
      WSG=WS
      IF(WS.EQ.0.)WSG=1.
      PRINT 912,HSCI,HSC,HFW,UBF,(WR+WSG)/WSG,HSGC
      PRINT 812
812   FORMAT('1','          *** CONDENSER-RECEIVER ***')
      PRINT 910,'PCRI','TSTCRI','PANGI','CONMFI','CRMWI'
      PRINT 912,PCRI,TSTCRI,PANGI,CONMFI,CRMWI
      PRINT 910,'PCR','TSATCR','PANG','CONDMF','CRMW'
      PRINT 912,PCR,TSATCR,PANG,CONDMF,CRMW
      PRINT 910,'CRSTMI','CRHWI','CRHSTI','VWCRI','VSTCRI'
      PRINT 912,CRSTMI,CRHWI,CRHSTI,VWCRI,VSTCRI
      PRINT 910,'CRMSTM','CRHW','CRHSTM','VWCR','VSTMCR'
      PRINT 912,CRMSTM,CRHW,CRHSTM,VWCR,VSTMCR
      PRINT 914,'TTUBEI','TTUBE(1)','TTUBE(2)','TTUBE(3)'
      PRINT 912,TTUBEI,TTUBE(1),TTUBE(2),TTUBE(3)
      PRINT 914,'QCONDI','QCOND(1)','QCOND(2)','QCOND(3)',
      PRINT 912,QCONDI,QCOND(1),QCOND(2),QCOND(3)
      PRINT 914,'QAIRI','QAIR(1)','QAIR(2)','QAIR(3)'
      PRINT 912,QAIRI,QAIR(1),QAIR(2),QAIR(3)
      PRINT 914,'UAINI','UAIN(1)','UAIN(2)','UAIN(3)'
      PRINT 912,UAINI,UAIN(1),UAIN(2),UAIN(3)
      PRINT 914,'UAOUTI','UAOUT(1)','UAOUT(2)','UAOUT(3)'
      PRINT 912,UAOUTI,UAOUT(1),UAOUT(2),UAOUT(3)
      PRINT 910,'AIRDQZ','CRDVZ','DVDH','HDIFF'
      PRINT 912,AIRDQZ,CRDVZ,DVDH,HDIFF
      PRINT 900
      PRINT 910,'GHBP','GHCP','GHLP','VBPB',
     1   'WLNC','WBNC','WCNC','VVESSL'
      PRINT 912, GHBP,GHCP,GHLP,VBPB,WLNC,WBNC,WCNC,VVESSL
      PRINT 910,'FLOLP','FLOW','VCORB',
     1   'VSFRV','RABFRV','VSFRO','WPCS'
      PRINT 912, FLOLP,FLOW,VCORB,VSFRV,RABFRV,VSFRO,WPCS
      PRINT 910,'VRABP','VCORE','VCBP','VLOOP'
      PRINT 912,VRABP,VCORE,VCBP,VLOOP
      PRINT 910,'DTOTZ','PPR','PLA'
      PRINT*,DTOTZ,PPR,PLA
      PRINT 910,'DENCOR','SCRMTM','TIM'
      PRINT*,DENCOR,SCRMTM,TIM,WACTO
      PRINT910,'XG','XW','PLOOPI','SURFLO'
      PRINT912,XG,XW,PLOOPI,SURFLO
      PRINT 910,'HSP','HF','HG','VWP'
      PRINT 912,HSP,HF,HG,VWP
      PRINT 910,'HHL','HWPR','HSUR','HGPR','PRLEV'
      PRINT 912,HHL,HWPR,HSUR,HGPR,PRLEV
      PRINT 910,'DLMPL','DLMINJ','DLMDRN','DLMSP','DLMR'
      PRINT 912,DLMPL,DLMINJ,DLMDRN,DLMSP,DLMR
      PRINT 910,'HTO','DLMSUR','P2RLOS','DLMRH','DLHSUR',
     1       'SPRAYG','SPRAYW'
```

```
          PRINT 912,HTQ,DLMSUR,PZRLOS,DLMRH,DLHSUR,SPRAYG,SPRAYW
          PRINT 910,'PZRMW','PZRHW','PZRMG','PZRHG','PZRMWI','PZRHWI',
     1    'PZRMGI','PZRHGI'
          PRINT 912,PZRMW,PZRHW,PZRMG,PZRHG,PZRMWI,PZRHWI,PZRMGI,PZRHGI
          PRINT 910,'RXPWR','TCOLD','THOT','TCLADC','PZRDM','PZRDH'
          PRINT 912,RXPWR,TCOLD,THOT,TCLADC,PZRDM,PZRDH
          PRINT 913, DAT
          PRINT*,'IDAC'
          PRINT*,IDAC
          PRINT*,'JDAC'
          PRINT*,JDAC
          PRINT*,'IARY'
          PRINT*,IARY
          IF(NBR.EQ.2) PRINT 913,DMP1
          CLOSE (UNIT=6,DISP='PRINT')
 913      FORMAT(('1'/5(10(10E13.5/)/)))
 900     FORMAT('1',72A1)
 902     FORMAT(' ',72A1)
 903     FORMAT('0',T10,'NODE',T21,'Q',T34,'TBM',T47,'TBN',T60,'RHO',T72,
     1          'TWALL',T85,'TCALC',T97,'BORON',T112,'UB',T125,'H')
 904     FORMAT(' ',T10,I2,9F13.4)
 909      FORMAT('1',4X,8(A6,9X))
 910      FORMAT('0',4X,8(A6,9X))
 912      FORMAT(1X,8(1PG15.7))
 914      FORMAT('0',4X,8(A8,7X))
 500     RETURN
         END
```

L-40

PROGRAM SECTIONS

NAME	SIZE		ATTRIBUTES
$CODE1	011034	2318	RW,I,CON,LCL
$PDATA	002042	529	RW,D,CON,LCL
$IDATA	001530	428	RW,D,CON,LCL
$VARS	001114	294	RW,D,CON,LCL
DAT	001000	256	RW,D,OVR,GBL
PA	002000	512	RW,D,OVR,GBL
IPA	000102	33	RW,D,OVR,GBL
.$$$$.	017664	4058	RW,D,OVR,GBL
DATID	001022	265	RW,D,OVR,GBL

TOTAL SPACE ALLOCATED = 041752 8693

DK1:DUMP14,DUMP14=DK1:DUMP14.FTN;10/CO:60/LI:1

LTR-10-2-Rev.

APPENDIX M

INPUT ARRAY

Index	Name	Variable	Nominal Value
1	RPSCRM	Reactor power scram setpoint	54 MW
2	HTSCRM	High hot leg temperature scram setpoint	605°F
3	VSCRM	Low PCS flow scram setpoint	3.23×10^6 lbm/hr
4	HPSCRM	High pressure scram setpoint	2281 psia
5	LPSCRM	Low pressure scram setpoint	2058 psia
6	TCRP	Reactor power instrument time constant	0.25 sec
7	TCHLT	Hot leg temperature instrument time constant	18 sec
8	TCLF	PCS flow instrument time constant	1 sec
9	TCLP	PCS pressure instrument time constant	1 sec
10	KSURGE	Surge line resistance	0.1 psi/(ft^3/sec)^2
11	DELT	Program step time interval	50 msec
12	SMTSLO	Slow sampling interval	1 sec
13	FLOW	PCS initial flow rate	3.8×10^6 lbm/hr
14	ALPHAB	Boron worth	0.0103 $/ppm
15	SCDLY	Scram delay time	0.05 sec
16	SMTFST	Fast sampling interval	0.2 sec
17	SVTC	Steam valve time constant	1.25 sec
18	DOPC	Doppler reactivity coefficient	-0.00125 $/°F

APPENDIX M (Cont'd)

INPUT ARRAY

Index	Name	Variable	Nominal Value
19	DPPO	Feed pump zero flow discharge pressure	874 psia
20	TCCLT	Cold leg temperature instrument time constant	18 sec
21	STMLKG	Steam leakage fraction	0.00
22-81	VSFR	Variable flow fraction table	See Tables M-2 and M-3
82	SSP	Pressurizer spray setpoint	2275 psia
83	HTSUP	Start up heaters	455 BTU/sec
84-85		Not Assigned	
86	FLTMD	Flow table spacing	See Tables M-2 and M-3
87	FLTMX	Flow table end point	See Tables M-2 and M-3
88	RPSP	Power operated relief setpoint	2422 psia
89	RCSP	Safety relief valves setpoint	2525 psia
90	HT1SP	Pressurizer cycling heaters setpoint	2153 psia
91	HT2S'	Pressurizer backup heaters setpoint	2148 psia
92	RASCRM	RABV flow fraction scram setpoint	0.2354
93-95		Not Assigned	
96	SURMIN	Surge line mass flow threshold	0.2 lbm
97	CLIC	PCS loop initial boron concentration	1500 ppm

APPENDIX M (Cont'd)

INPUT ARRAY

Index	Name	Variable	Nominal Value
98	CPIC	Pressurizer initial boron concentration	1500 ppm
99	VDRAIN	PCS loop drain rate	6 gpm
100	VINJ	HPIS Injection rate	6 gpm
101-160	RABFR	RABV variable flow fraction table	See Table M-3
161-163		Not Assigned	
164	FFRMN	Natural circulation transition flow fraction	0.08
165-175		Not Assigned	
176-198	DLS	Scram curve	See Table M-1
199-201	AIRSW	ACC transient switches	0
202-204	BAYSW	ACC operating bay select switches	1
205		Not Assigned	
206	AIRTSL	ACC air flow reduction rate	0.2/sec
207-209	WAIRMN	ACC minimum air flow fractions	0
210	CRRLSP	Condensate receiver relief setpoint	400 psia
211	CRRLDB	Condensate receiver relief valve reset dead band	10 psia
212	CRRLF	Condensate receiver relief valve flow	81 lbm/sec

APPENDIX M (Cont'd)

INPUT ARRAY

Index	Name	Variable	Nominal Value
213	TAMB	ACC air temperature	80oF
214	, WRMPT	Feed water valve ramp rate	-0.3/sec
215	FWDLY	Feed water valve delay time	1.25 sec
216	TIMSCM	Timed scram setpoint	∞
217		Not Assigned	
218	DCOR	Moderator reactivity coefficient	0.765 $/(lbm/ft3)
219	REACEX	Reactivity insertion Accident - total reactivity	8.35$
220	TIMEX	Reactivity insertion accident time interval	None
221		Not Assigned	
222	SURMPN	Steam valve ramp rate	0.05/sec
223	PMSVHS	Steam valve high pressure setpoint	1020 psia
224	PMSVLS	Steam valve low pressure setpoint	920 psia
225	PMSVDB	Steam valve reset dead band	10 psia
226	CINO	HPIS boron concentration	3000 ppm
227	CKCORE	Core clad heat transfer coefficient	496.6 Btu/secoF
228	CKSG	Steam generator heat transfer coefficient	188.0 Btu/secoF

APPENDIX M (Cont'd)

INPUT ARRAY

Index	Name	Variable	Nominal Value
229	RXPWR	Initial reactor power	50 MW
230	TMOT	Initial hot leg temperature	588.3°F
231	SGLSP	Steam generator level setpoint	116 inches
232	PCRI	Initial condensate receiver pressure	300 psia
233-234		Not Assigned	
235	PLOOPI	Initial PCS loop pressure	2262 psia
236	UAPZR	Pressurizer ambient loss heat transfer coefficient	0
237	SPRCNT	Pressurizer continuous spray flow	0 gpm
238	PZLEVI	Initial pressurizer level	44.5 inches
239	LPHPIS	HPIS low pressure setpoint	1800 psia
240	SPRNOM	Pressurizer nominal spray flow	20 gpm
241	RCDB	Safety relief valve reset dead band	50 psia
242	RPDB	Power operated relief valve reset dead band	20 psia
243	SGXDNB	Steam generator shroud steam quality at which DNB begins	85%
244	SGRS1	Steam generator relief valve R136 setpoint	1100 psia
245	SGRS2	Steam generator relief valve R137 setpoint	1200 psia
246-256		Not Assigned	

TABLE M-1

SCRAM REACTIVITY TABLES

TIME (sec)	INPUT ARRAY INDEX	3 BANK WORST CASE REACTIVITY[1] $	4 BANK BEST ESTIMATE REACTIVITY[2] $
0.000	176	0	0.5642
0.075	177	0.00171	0.5711
0.160	178	0.00806	0.6482
0.245	179	0.02028	0.7460
0.331	180	0.04026	0.8791
0.417	181	0.07052	1.040
0.503	182	0.11372	1.482
0.589	183	0.17231	2.084
0.672	184	0.25592	2.876
0.753	185	0.37906	4.425
0.830	186	0.54421	6.464
0.905	187	0.76336	8.667
0.977	188	1.0548	11.46
1.050	189	1.4890	12.50
1.127	190	2.2810	17.49
1.211	191	3.3843	19.94
1.265	192	4.1556	21.10
1.336	193	5.1377	22.18
1.403	194	6.0083	22.61
1.514	195	7.4449	23.11
1.590	196	8.3554	23.42
1.710	197	9.4449	23.55
	198	(not used)	

1 Supplied by S. A. Atkinson, 2-13-79.

2 Computed from rod drop time test data supplied by M. A. Bray on 5-31-79 and the rod worth curve in LTR-111-82, Figure A1.

TABLE M-2

PCS FLOW TRANSIENT TABLES

INPUT ARRAY INDEX	ONE PUMP RAPID COASTDOWN[1]	TWO PUMP RAPID COASTDOWN[2]	TWO PUMP FLYWHEEL ASSISTED COASTDOWN[3]
22	1.0000	1.0000	1.0000
23	0.9340	0.9800	0.9361
24	0.8395	0.9750	0.8530
25	0.7595	0.9100	0.7821
26	0.6975	0.7450	0.7224
27	0.6501	0.6150	0.6710
28	0.6141	0.5120	0.6266
29	0.5874	0.4420	0.5877
30	0.5632	0.3850	0.5534
31	0.5461	0.3450	0.5227
32	0.5348	0.3150	0.4952
33	0.5267	0.2900	0.4702
34	0.5206	0.2620	0.4475
35	0.5160	0.2400	0.4277
36	0.5128	0.2220	0.4076
37	0.5108	0.2100	0.3900
38	0.5099	0.1980	0.3735
39	0.5102	0.1860	0.3582
40	0.5113	0.1740	0.3438
41	0.5133	0.1620	0.3304
42	0.5162	0.1500	0.3176
43	0.5202	0.1380	0.3056
44	0.5233	0.1260	0.2941
45	0.5247	0.1140	0.2832
46	0.5256	0.1020	0.2728
47	0.5262	0.0900	0.2628

TABLE M-2 (cont'd)

INPUT ARRAY INDEX	ONE PUMP RAPID COASTDOWN	TWO PUMP RAPID COASTDOWN	TWO PUMP FLYWHEEL ASSISTED COASTDOWN
48	0.5267	0.0780	0.2532
49	0.5271	0.0660	0.2439
50	0.5274	0.0540	0.2350
51	0.5276	0.0420	0.2263
52	0.5279	0.0300	0.2178
53	0.5280	0.0180	0.2095
54	0.5282	0.0060	0.2014
55	0.5283	0.0000	0.1935
56	0.5284	0.0000	0.1856
57	0.5285	NA	0.1779
58	0.5285	NA	0.1701
59	0.5286	NA	0.1624
60	0.5286	NA	0.1547
61	0.5287	NA	0.1469
62	0.5287	NA	0.1390
63	0.5287	NA	0.1310
64	0.5287	NA	0.1228
65	0.5287	NA	0.1143
66	0.5288	NA	0.1055
67	0.5288	NA	0.0961
68	NA	NA	0.0830
69	NA	NA	0.0730
70	NA	NA	0.0620
71	NA	NA	0.0520
72	NA	NA	0.0420
73	NA	NA	0.0320
74	NA	NA	0.0220
75	NA	NA	0.0140

TABLE M-2 (cont'd)

INPUT ARRAY INDEX	ONE PUMP RAPID COASTDOWN	TWO PUMP RAPID COASTDOWN	TWO PUMP FLYWHEEL ASSISTED COASTDOWN
76	NA	NA	0.0080
77	NA	NA	0.0040
78	NA	NA	0.0020
79	NA	NA	0.0010
80	NA	NA	0.0000
81	NA	NA	0.0000
FLTMD	0.2 sec	0.2 sec	1 sec
FLTMX	8.8 sec	6.6 sec	58 sec

(1) SICLOPS Analysis, Loss of One Pump Flow, 3.295 MLBM/HR initial flow.

(2) LTR 111-104, page 163.

(3) SICLOPS Analysis, Loss of Prime Mover Motor, 3.295 MLBM/HR initial flow.

TABLE M-3

RABV FLOW TRANSIENT TABLES

RABV OPENING AT 5%/sec

INPUT ARRAY INDEX	VESSEL FRACTION	INPUT ARRAY INDEX	RABV FRACTION
22	1.000	101	0.000
23	0.924	102	0.113
24	0.854	103	0.215
25	0.781	104	0.297
26	0.724	105	0.356
27	0.684	106	0.400
28	0.655	107	0.428
29	0.635	108	0.449
30	0.620	109	0.465
31	0.605	110	0.478
32	0.596	111	0.485
33	0.591	112	0.491
34	0.582	113	0.495
35	0.577	114	0.499
36	0.575	115	0.500
37	0.573	116	0.503
38	0.571	117	0.506
39	0.570	118	0.510
40	0.569	119	0.511
41	0.568	120	0.513
42-43	0.567	121-122	0.514
44-81	(not used)	123-160	(not used)

FLTMD = 1 sec

FLTMX = 20 sec

TABLE M-3 (con't)

RABV OPENNING AT 10%/sec

INPUT ARRAY INDEX	VESSEL FRACTION	INPUT ARRAY INDEX	RABV FRACTION
22	1.000	101	0.000
23	0.854	102	0.215
24	0.724	103	0.356
25	0.655	104	0.428
26	0.620	105	0.465
27	0.596	106	0.485
28	0.582	107	0.495
29	0.575	108	0.500
30	0.571	109	0.506
31	0.569	110	0.511
32-33	0.567	111-112	0.514
34-81	(not used)	113-160	(not used)

FLTMD = 1 sec

FLTMX = 10 sec

Reference: LTR 112-58, Figures 2 and 5

APPENDIX N

Recursive Solution For PCS Steady State Temperatures

1. From Section 3, equations 3-16, 3-12, and 3-17 are:

$$T_{NEW} = T_{OLD} + \dot{Q}\ \Delta t/mc_p$$

$$\dot{Q} = UA\ (T_{WALL} - T_{NODE}) + \dot{Q}_{DIR}$$

$$T_{NODE} = T_{NEW} + \frac{\dot{V}\ \Delta t}{V}\ (T_{IN} - T_{NEW})$$

2. Solve for T_{NODE} in terms of T_{WALL} and T_{IN}.

$$T_{NODE} = (T_{OLD} + \frac{\dot{Q}\ \Delta t}{mc_p}) + \frac{\dot{V}\ \Delta t}{V}\ (T_{IN} - (T_{OLD} + \frac{\dot{Q}\ \Delta t}{mc_p}))$$

For steady state conditions $T_{OLD} = T_{NODE}$.

$$\text{let } k = \frac{\dot{V}\ \Delta t}{V}$$

$$0 = \frac{\dot{Q}\ \Delta t}{mc_p} + k\ T_{IN} - k\ T_{NODE} - k\ (\frac{\dot{Q}\ \Delta t}{mc_p})$$

$$0 = \frac{(\dot{Q}\ \Delta t)}{mc_p}\ (1 - k) + k\ (T_{IN} - T_{NODE})$$

$$0 = \frac{\Delta t}{mc_p} \left(UA\left(T_{WALL} - T_{NODE}\right) + \dot{Q}_{DIR}\right)(1-k) + k\left(T_{IN} - T_{NODE}\right)$$

$$T_{NODE}\left(\frac{UA\,\Delta t}{mc_p}(1-k) + k\right) = \frac{\Delta t}{mc_p}\left(UA\,T_{WALL} + \dot{Q}_{DIR}\right)(1-k) + kT_{IN}$$

$$T_{NODE} = \frac{\left(UA\,T_{WALL} + \dot{Q}_{DIR}\right)(1-k) + \frac{mc_p}{\Delta t}kT_{IN}}{UA(1-k) + \frac{mc_p}{\Delta t}k}$$

for $\frac{mc_p}{\Delta t}k = \frac{mc_p}{\Delta t}\frac{\dot{V}\Delta t}{V} = \frac{m}{V}\dot{V}c_p = Wc_p$

$$T_{NODE} = \frac{\left(UA\,T_{WALL} + \dot{Q}_{DIR}\right)(1-k) + Wc_p\,T_{IN}}{UA(1-k) + Wc_p}$$

3. Define $F = \frac{Wc_p - kUA}{Wc_p + (1-k)UA} = \frac{1}{1 + \frac{1}{\frac{Wc_p}{UA} - k}}$

$$(1-F) = \frac{UA}{Wc_p + (1-k)UA}$$

$$T_{NODE} = (1-F)\left[(1-k)\left(T_{WALL} + \frac{\dot{Q}_{DIR}}{UA}\right) + \frac{Wc_p}{UA}T_{IN}\right]$$

4. Solve for T_{NODE} in terms of the upstream node temperature. Let $T_j = T_{NODE}$ and define T_{j-1} as the upstream temperature. It is assumed the $\dot{T}_{Wall}$, $\dot{Q}_{DIR}$, k, UA, and Wc_p are the same for each node.

$$T_{IN} = T_{\substack{NEW \\ j-1}} = T_{j-1} + \frac{\dot{Q}\ \Delta t}{mc_p}$$

$$= T_{j-1} + \frac{\Delta t}{mc_p} \left(UA\ (T_{WALL} - T_{j-i}) + \dot{Q}_{DIR}\right)$$

$$= T_{j-i}\ \left(1 - k\ \frac{UA}{Wc_p}\right) + k\ \frac{UA}{Wc_p}\ \left(T_{WALL} + \frac{\dot{Q}_{DIR}}{UA}\right)$$

$$\frac{Wc_p}{UA}\ T_{IN} = T_{j-i}\ \left(\frac{Wc_p}{UA} - k\right) + k\ \left(T_{WALL} + \frac{\dot{Q}_{DIR}}{UA}\right)$$

$$= \frac{1}{\frac{1}{F} - 1}\ T_{j-1} + k\ \left(T_{WALL} + \frac{\dot{Q}_{DIR}}{UA}\right)$$

$$T_j = (1-F) \left[(1-k)\ \left(T_{WALL} + \frac{\dot{Q}_{DIR}}{UA}\right) + \frac{T_{j-1}}{\frac{1}{F} - 1} + k\ \left(T_{WALL} + \frac{\dot{Q}_{DIR}}{UA}\right)\right]$$

$$T_j = (1-F) \left[\left(T_{WALL} + \frac{\dot{Q}_{DIR}}{UA}\right) + \frac{T_{j-1}}{\frac{(1 - F)}{F}}\right]$$

$$T_j = (1-F)\ \left(T_{WALL} + \frac{\dot{Q}_{DIR}}{UA}\right) + F\ T_{j-1}$$

5. Solve for T_j in terms of T_{j-n}. Use induction to show that if

$$T_j = A + F\ T_{j-1}$$

then,

$$T_j = A \sum_{m=1}^{n} F^{k-1} + F^n T_{j-n}$$

Proof: for n = 1

$$T_j = A \sum_{1}^{1} F^{m-1} + F\, T_{j-1} = A + FT_{j-1}$$

Show that if the formula is valid for n=i-1 it is valid for n=i.

$$T_j = A \sum_{m=1}^{i-1} F^{m-1} + F^{i-1}\, T_{j-i+1}$$

$$= A \sum_{m=1}^{i-1} F^{m-1} + F^{i-1}\,(A+FT_{j-i})$$

$$= A \sum_{m=1}^{i-1} F^{m-1} + AF^{i-1} + F^{i}\, T_{j-i}$$

$$= A \sum_{m=1}^{i-1} F^{m-1} + F^{i-1} T_{j-i+1} = A \sum_{m=1}^{i} F^{m-1} + F^{i} T_{j-i}$$

$$T_j = (1-F)\,(T_{WALL} + \frac{\dot{Q}_{DIR}}{UA}) \sum_{m=1}^{n} F^{m-1} + F^n\, T_{j-n}$$

for $\sum_{m=1}^{n} F^{m-1} = \frac{1-F^n}{1-F}$

$$T_j = (1-F^n)\,(T_{WALL} + \frac{\dot{Q}_{DIR}}{UA}) + F^n\, T_{j-n}$$

6. Find the node outlet temperature. $T_{out_j} = T_{in_{j+1}}$ see step 4 above.

$$T_{out_j} = \frac{UA}{Wc_p} \left[\left(\frac{Wc_p}{UA} - k\right) T_j + k \left(T_{WALL} + \frac{\dot{Q}_{DIR}}{UA}\right) \right]$$

7. Find the core T_{clad} in terms of T_{cold}, $\dot{Q}_{core}$, $\dot{Q}_{DIR}$, and W.

From the core model

$$T_{out} = \frac{UA}{Wc_p} \left[\frac{F}{1-F} T_4 + k \left(T_{clad} + \frac{\dot{Q}_{DIR}}{UA}\right) \right]$$

$$T_4 = (1-F^3)\left(T_{clad} + \frac{\dot{Q}_{DIR}}{UA}\right) + F^3\, T_1$$

$$T_1 = (1-F) \left[(1-k)\left(T_{clad} + \frac{\dot{Q}_{DIR}}{UA}\right) + \frac{Wc_p}{UA} T_{cold} \right]$$

let $T' = T_{clad} + \dfrac{\dot{Q}_{DIR}}{UA}$

$$T_4 = (1-F^3)\, T' + F^3 (1-F) \left[(1-k)\, T' + \frac{Wc_p}{UA} T_{cold} \right]$$

$$= \left[1-F^3 + F^3 (1-F)(1-k)\right] T' + F^3 (1-F) \frac{Wc_p}{UA} T_{cold}$$

$$= \left[(1-F^4) - k(F^3)(1-F)\right] T' + F^3(1-F) \frac{Wc_p}{UA} T_{cold}$$

$$\frac{F}{1-F} T_4 = \left(\frac{F\,(1-F^4)}{1-F} - kF^4\right) T' + F^4 \frac{Wc_p}{UA} T_{cold}$$

$$T_{out} = \frac{UA}{Wc_p} \left[\left(\frac{F(1-F^4)}{1-F} - kF^4\right) T' + F^4 \frac{Wc_p}{UA} T_{cold} + kT' \right]$$

$$= \frac{UA}{Wc_p} T' \left[\frac{F(1-F^4)}{1-F} + k(1-F^4) \right] + F^4 T_{cold}$$

$$= \frac{UA}{Wc_p} T' (1-F^4) \left(\frac{F}{1-F} + k\right) + F^4 T_{cold}$$

from definition of F

$$\frac{F}{1-F} = \frac{Wc_p}{UA} - k$$

$$T_{out} = (1-F^4) \left(T_{clad} + \frac{\dot{Q}_{DIR}}{UA}\right) + F^4 T_{cold}$$

$$T_{clad} = \frac{T_{out} - F^4 T_{cold}}{(1-F^4)} - \frac{\dot{Q}_{DIR}}{UA}$$

$$= \frac{(T_{out} - T_{cold}) + (1-F^4) T_{cold}}{(1-F^4)} - \frac{\dot{Q}_{DIR}}{UA}$$

$$= T_{cold} + \frac{\dot{Q}_{core}}{Wc_p (1-F^4)} - \frac{\dot{Q}_{DIR}}{UA}, \text{ where } \dot{Q}_{core} = Wc_p (T_{out} - T_{cold})$$

8. Find T_{sat} in the steam generator. The method is the same as for the core, except $\dot{Q}_{DIR} = 0$, the number of nodes is 10, and F is computed using steam generator properties including heat conductivity of the secondary film.

$$T_{sat} = T_{hot} + \frac{\dot{Q}_{SG}}{Wc_p\ (1-F^{10})}$$

APPENDIX D

OUTPUT PARAMETERS

PLAN14.HDR;003

1 - TIME
2 - POWER
3 - LOOP FLO
4 - PCS PRES
5 - PZR PRES
6 - STM FLOW
7 - QCLAD
8 - REACT
9 - Q SG
10 - PRES SG
11 - PRES CR
12 - XFWV
13 - FW FLOW
14 - XMSCV
15 - PZR CONC
16 - BLD ANG
17 - TCLAD 1
18 - CORE BOR
19 - T COLD
20 - MW PZR
21 - HW PZR
22 - RABV FLO
23 - PZR SPRY
24 - RECIRFLO
25 - H FW
26 - NAT CIRC
27 - NAT CIRC
28 - NAT CIRC
29 - MG PZR
30 - PCS FLOW
31 - CORE FLO
32 - DECAY HT
33 - T TUBE 1
34 - T TUBE 2
35 - T TUBE 3
36 - QAIR 1
37 - QAIR 2
38 - QAIR 3
39 - AIRFLOW1
40 - AIRFLOW2
41 - AIRFLOW3
42 - CNTR ROD
43 - HG PZR
44 - MOD REAC
45 - FUELREAC
46 - BOR REAC
47 - ROD REAC
48 - RISER
49 - PCS MASS
50 - HW CR
51 - PZR SRGE
52 - T CORE 1
53 - T CORE 2
54 - T CORE 3
55 - T CORE 4
56 - T SG 5
57 - T SG 6
58 - T SG 7
59 - T SG 8
60 - T SG 9
61 - T SG 10
62 - T SG 11
63 - T SG 12
64 - T SG 13
65 - T SG 14
66 - T UP 15
67 - T UP 16
68 - T NZL 17
69 - T THD 18
70 - T HL 19
71 - T HOT 20
72 - T HL 21
73 - T HL 22
74 - T HL 23
75 - T SGP 24
76 - T HOT 25
77 - T COLD26
78 - T SGP 27
79 - T CL 28
80 - T CL 29
81 - T CL 30
82 - T CL 31
83 - T P1 32
84 - T P2 33
85 - T CL 34
86 - T CL 35
87 - T CL 36
88 - T COLD37
89 - T DC 38
90 - T DC 39
91 - T DC 40
92 - T DC 41
93 - T DC 42
94 - T DC 43
95 - T LP 44
96 - T LP 45
97 - T LP 46
98 - T RABV47
99 - T RABV48
100 - T RABV49
101 - T RABV50
102 - T CBP 51
103 - SG LVL
104 - V SG
105 - H DWNC
106 - M DWNC
107 - M SG
108 - W DWNC
109 - X SHRD
110 - H SG
111 - SG RV
112 - MG CR
113 - CR-GAS
114 - MG ACC
115 - CR-WTR
116 - HW PZR
117 - HG PZR
118 - PZR BOIL
119 - MW CR
120 - RV FLOW
121 - CBP FLOW
122 - EXT REAC
123 - PWR IND
124 - T HOT
125 - PCS PRES
126 - PCS FLOW
127 - PZR LVL
128 - T FUEL