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TITLE Non-Symmetrical Main Coolant System Analysis (NOMACS) PART I

AUTHOR R. C. Larsen

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TITLE: NON-SYMMETRICAL MAIN COOLANT SYSTEM ANALYSIS (NOMACS) PART I

ABSTRACT

This is Part I of a two part report. Part I describes the system and its mathematical representation for solution using the IBM704 digital computer. Part II is the actual symbolic coding of the program.

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by

R. C. Larsen

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SYSTEM CONSTANTS

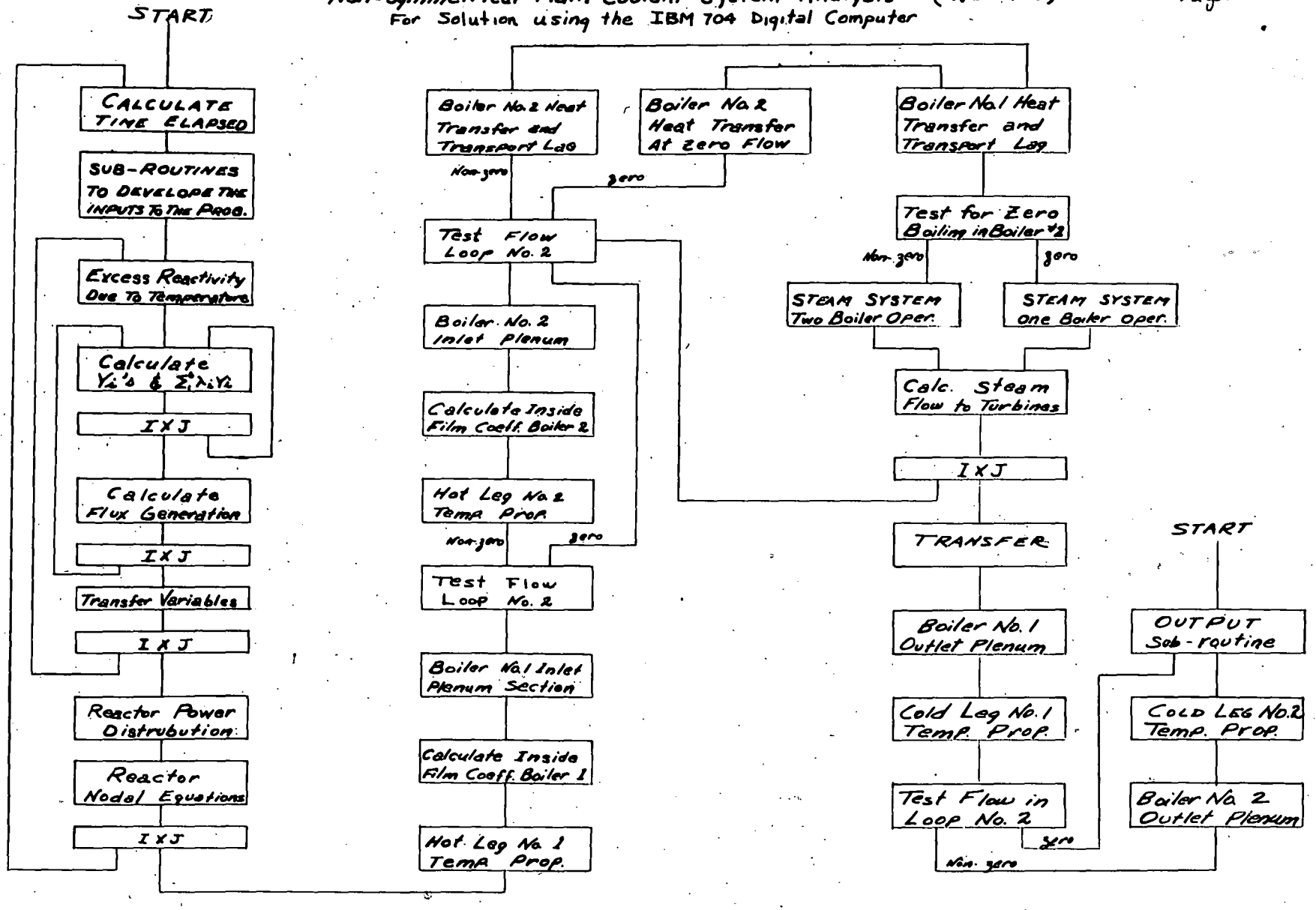
Program Symbolic Code	Equation Symbols	Meaning
TAU	τ_o	Flux generation time constant
PHIB	P_b	Power Base
NEGR		Residual Fraction
AF1) AF2)	$\frac{A_f}{2}$	One-half of an active core sectional area between the fuel element and primary coolant for 1st pass and 2nd pass sections resp.
2CWC1= 2CWC2=	$2c/WC_1$ $2c/WC_2$	WC_1 = 1st pass active core section heat capacity WC_2 = 2nd pass active core section heat capacity
1WCF1= 1WCF2=	$1/WC_{f1}$ $1/WC_{f2}$	WC_{f1} = 1st pass fuel section heat capacity WC_{f2} = 2nd pass fuel section heat capacity
2/WC1= 2/WC2=	WC_1 WC_2	WC_1 same as above WC_2 " " "
PTAU1) PTAU2) PTAU3) PTAU4)	τ_1 τ_2 τ_3 τ_4	The four reactor plenums time constant
HCAPI	WC_I/c	WC_I heat capacity of the lumped metal inlet plenum
HCAPA	$2cE_a/WC_a$	WC_a = 1st pass inlet section heat capacity E_a = percent of total reactor flow passing through this section
HCAPC	$2cE_c/WC_c$	WC_c = 1st pass exit section heat capacity E_c = percent of total reactor flow passing through this section
HCAP2	WC_2/c	WC_2 = lumped heat capacity of the metal in the first pass exit plenum
HCAPD	$2cE_d/WC_d$	WC_d = interpass heat capacity per section E_d = percent of total reactor flow passing through this section
HCAP3	WC_3/c	WC_3 lumped heat capacity of the metal in the second pass inlet plenum
HCAPE	$2cE_e/WC_e$	WC_e second pass inlet section heat capacity E_e percent of total reactor flow passing through this section
HCAPG	$2cE_g/WC_g$	WC_g second pass exit section heat capacity E_g percent of total reactor flow passing through this section
HCAP4	WC_4/c	WC_4 lumped heat capacity of the metal in the reactor outlet plenum

Program Symbolic Code	Equation Symbols	Meaning
HCAPH	$2c/WC_h$	WC_h heat capacity of the boiler tubes per section
HCAP5) HCAP6)	c/WC	WC heat capacity of the boiler plenums
HCAPP	$2/W_P$	W_P weight of primary coolant per foot of pipe
EE1	E_1	Percent of reactor flow passing through 1st pass active core
EE2	E_2	Percent of reactor flow passing through 2nd pass active core
E20	E_{20}	Percent of reactor flow passing through the interpass plus leakage ℓ_5
E2I	E_{2i}	Percent of reactor flow passing through first pass exit section less leakage ℓ_4
E1	ℓ_1	Percent leakage flow ℓ_1 (see reactor nodal representation diagram)
E_{30}	E_{30}	Percent reactor flow passing through second pass inlet section
E3I	E_{3i}	Percent reactor flow leaving interpass section
E3	ℓ_3	Percent leakage flow ℓ_3
E4I	E_{4i}	Percent reactor flow leaving second pass exit section
E2	ℓ_2	Percent leakage flow ℓ_2
E4	ℓ_4	" " " ℓ_4
E5	ℓ_5	" " " ℓ_5 — see Figure 1, Part I
2/WCB	$2/WC_B$	WC_B heat capacity of boiler tube sections
FR	r_f	Boiler tube fouling resistance
A/2	1/2 A	One-half boiler tube area per section
AREA	A	Boiler tube area per section
HOTL1) HOTL2)		Hot leg piping length (ft)
CLDL1) CLDL2)		Cold leg piping length (ft)
SENL1		Distance from reactor outlet to the hot leg sensing point (ft)
SENL2		Distance from the boiler outlet to the cold leg sensing point (ft)
FLOWB		Base flow
STFLB		Steam flow base
ATSF		Steam flow to auxiliaries
KSF	K_{sf}	Steam pipe pressure drop constant
KT	K_t	Main turbine steam flow constant

FLOW DIAGRAM

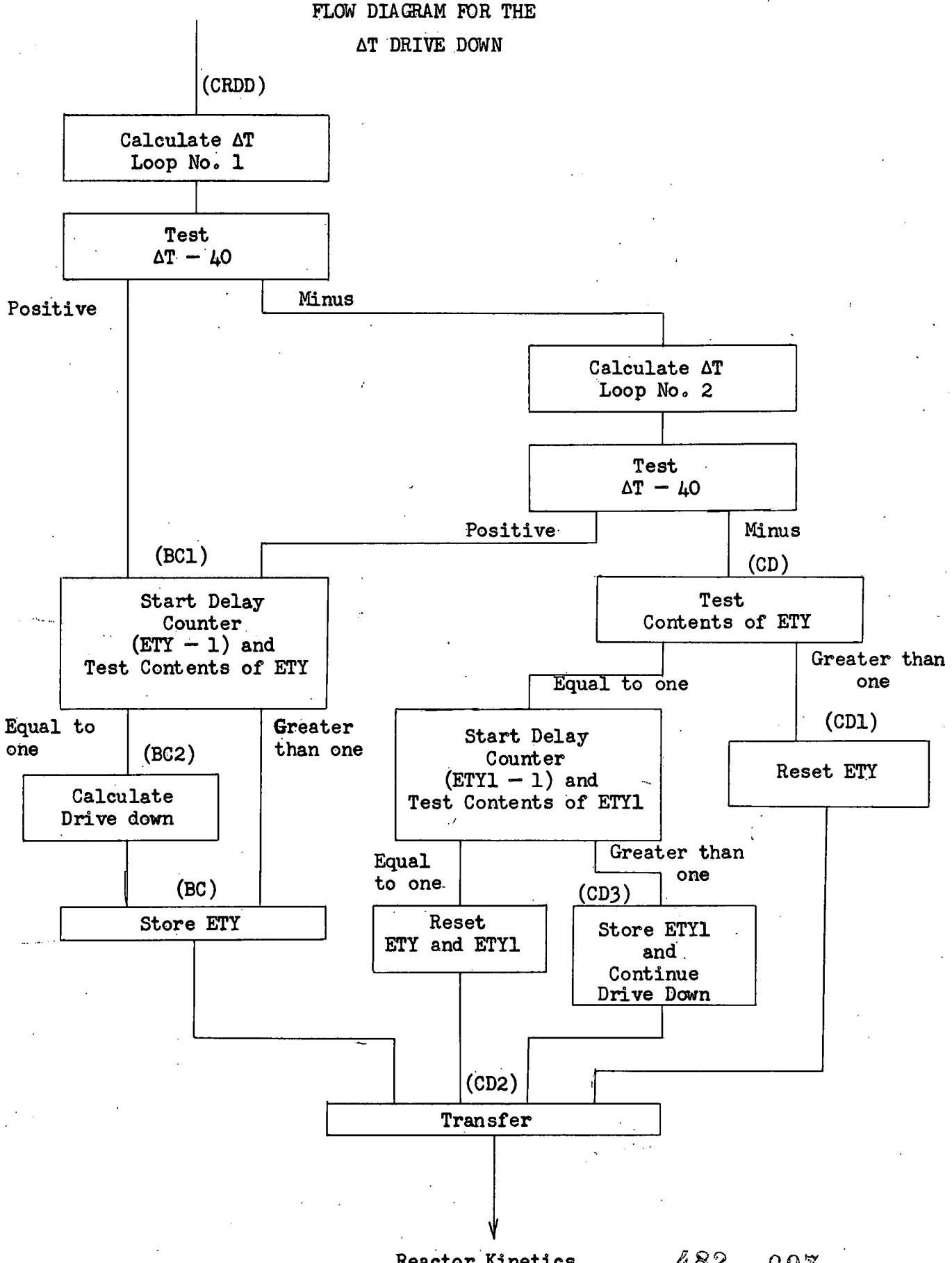
Non-Symmetrical Main Coolant System Analysis (NOMACS)

For Solution using the IBM 704 Digital Computer



FLOW DIAGRAM FOR THE

ΔT DRIVE DOWN



NON-SYMMETRICAL MAIN COOLANT SYSTEM ANALYSIS (NOMACS)

I. INTRODUCTION

Non-symmetrical main coolant system analysis (NOMACS) is an IBM 704 digital program for calculating the reactor power generation, primary coolant temperature distribution and steam temperature, pressure, and flow to the main and auxiliary turbines during a transient period. It is desirable to know the transient values of these variables when the system is subjected to a disturbance such as pump switching, accidental bulk head valve closure, up and down maneuver and many other conditions that cause transient disturbances. Such information is necessary in planning the proper reactor controls and safe guards needed for safe, efficient, and fast operation of the entire reactor system.

This program represents a system composed of a two-pass high pressure water cooled reactor with two main primary coolant loops each having its own steam generator, separator, and drum. The generated steam from each loop is piped into a common header which is then piped to the main and auxiliary turbines and other steam loads in the system. Such auxiliary piping and apparatus as the pressurizer, purging and drain piping, isolating valves, etc. are not included or described in this report as their functions are not required in this study. Figure 1 is a nodal representation of the reactor and primary coolant system.

The representation of the system involves equations for the following processes:

1. Neutron generation described by the kinetics equations.
2. Reactivity due to temperature.
3. Reactivity due to control rod position.
4. Heat transfer from the fuel element to the coolant.
5. Heat transfer from the coolant to the steam generator feedwater to produce saturated steam.
6. Steam flow from the two generators to the turbines.
7. Transport delays in the hot and cold leg piping.
8. Mixing in the reactor and boiler inlet and outlet plenums.
9. Transport delays in the reactor and boiler.

Primary coolant flow in each loop is a known input function to the problem. This flow may be constant and equal in both loops during a run or it may vary as

a function of time and be equal or unequal during a run. At the beginning of a run the reactor is assumed to be in a critical state at some given power and reactor flow. The transient can be initiated in one or more of the following ways:

1. Change in the primary coolant pump speed which results in a change in coolant flow.
2. Change in the main turbine throttle position causing an increase or decrease in steam demand.
3. Accidental closure of the bulk head valve causing a sudden stoppage of steam flow.
4. Change in the control rod position causing the reactor to increase or decrease its power level.
5. Any combination of the above items such as reducing pump speed with rod drive down when power level has reached a given value.

The program is written in symbolic form describing all the arithmetic and logical operation necessary to perform the desired calculations. The written program is punched one instruction per card or what is called a decimal card. The decimal deck is then compiled and assembled using the 704 computer and sub-routine called CAGE. This sub-routine assigns storage location to the instructions and data and punches out a program deck in binary form which is the language of the machine. This binary deck along with another binary deck consisting of sub-routines necessary to the operation of the program then comes the input deck or program to the machine to start calculation. Description of the contents of the sub-routine deck is given in Appendix IV. Briefly this deck contains an output program, natural log, exponential, square root, table look-up, and binary punch sub-routines.

II. INPUT FUNCTION SUB-ROUTINES

The starting point of the program is used to program small sub-routines that define the type of run. Five different sub-routines have been developed so that many different runs can be made with only small changes and additions to the program. Such sub-routines are as follows:

1. Main turbine throttle position. This is used to give a linear hand wheel position as a function of time starting at any initial position in either closing or opening of the throttle. A table look-up process is used to give the throttle position constants as a function of hand wheel position.
2. A table look-up sub-routine for getting each loop flow as a function of time. This is used in flow coastdown or start-up type of run. The loop flow can be symmetrical or non-symmetrical.
3. A pump switching sub-routine to simulate the effect on flow when the pumps are switched from half speed to full speed or full to half speed. This pump switching occurs when the reactor power has reached a given value during an up maneuver or a down maneuver.
4. A control rod drive down sub-routine is used to insert control rod into the reactor at rate to give negative excess of reactivity of so many cents per second. This drive down is initiated when the temperature difference across the reactor has reached x* degrees F and after a y* second delay. The drive down will continue for y* seconds after the temperature difference has fallen below x* degrees. The temperature difference at which the drive down is started and time delays can be any desired value. A flow diagram of how this sub-routine operates can be found on page ix.
5. Control rod scram drive down. The sub-routine was first used to scram the reactor; that is, to insert a negative excess reactivity at a certain rate up to a max. of 25 dollars. However, with a few modifications this sub-routine can be used to insert or remove excess reactivity at any rate and cut off at any desired value.

*x,y,z, can be any predetermined values.

III. SYSTEM EQUATIONS

A. Reactor Kinetics

Nuclear reactors produce, maintain, and control nuclear chain reaction. The correct conditions must exist for the chain reaction to be self-sustaining. At least one neutron must be produced, on the average, for each nucleus capturing a neutron and undergoing fission. This in turn causes fission of another nucleus. The kinetic energy of fission degenerates immediately into heat, and the amount of heat generated or power level is proportional to the neutron density within the reactor. However, some of the fission neutrons are lost by capture in the structural materials, coolant, and fission products and others are lost outside the reactor. Criticality of a nuclear reactor can be described in terms of its reproduction constant, which is equal to the ratio of the number of neutrons born in the second generation to the number of neutrons born in the first generation. A critical reactor is one in which the reproduction constant is unity. An increase or decrease in reactivity will increase or decrease the reproduction constant causing an increase or decrease in power. The total reactivity is a sum of the built-in reactivity, reactivity due to poisons, reactivity due to temperature, and reactivity due to position of the control rods. This study is concerned with a change of reactivity due to coolant temperature and position of control rods. Poisons and built-in reactivity are assumed not to change.

The generation of the neutrons is described by the following reactor kinetic equations.

$$\tau_o \frac{d\phi_n}{dt} = \sum_{i=i}^{6} \lambda_i y_i + (\Delta K - 1)\,\phi_n \qquad (1)$$

$$\left.\begin{array}{l} \\ \end{array}\right\} \quad \frac{dy_i}{dt} = f_i \phi_n - \lambda_i y_i \qquad \left.\begin{array}{l} i=6 \\ \\ i=1 \end{array}\right. \qquad (2)$$

$$\phi = \phi_n + R\phi_i \qquad (3)$$

ΔK (excess reactivity) $= \Delta K_T + \Delta K_C$.
ΔK_T = excess reactivity due to temperature.
ΔK_C = excess reactivity due to rod movement.

$$\Delta K_T = \alpha \left[\sum_{1}^{N} \alpha_n (T_n - T_{ni}) \right] \qquad (4)$$

T_n = average coolant temperature in node n.
T_{ni} = average coolant temperature in node n with critical reactor under initial condition of flow and power.
α_n = fraction of the total temperature coefficient assigned to node n. $\sum_{1}^{n} \alpha_n = 1$
α = total temperature coefficient of reactivity (- $ per ^{o}F)

The f_i and λ_i are constants and depend upon the nature and fractional yields of the various fission products whose decay produces the delayed neutrons. These factors are a function of the type of fuel used.

ϕ = total power generated in reactor.
ϕ_i = initial power.
R = residual fraction.

During steady state condition R is zero. For transients in which the power increases or decreases R = 0.03.

The primary coolant temperature effect on the excess reactivity is calculated by using four temperatures in the first pass, eight temperatures in the interpass and four temperatures in the second pass. The program is designed so that any or all of the reactor temperatures may have an effect on the excess reactivity. The present set up is such that only the above listed 16 reactor temperatures have an effect on excess reactivity. This is accomplished by storing the desired value in the list of α_n for each of the reactor sections and filling in the table with zeros where this effect is not wanted.

The delayed neutrons are produced by the decay of precursor fission products and will be proportional to their concentration. There are six groups of such fission products, each having a specific decay constant. The yields of these precursor groups are calculated by equation 2 which is arranged as follows for digital solution.

$$y + 6_t = y + 6_{(t-\Delta t)} + \frac{\Delta t_K}{2} (\dot{y} + 6_t + \dot{y} + 6_{(t-\Delta t)}) \qquad (5)$$

$y+6_t$ denotes the 6th precursor group
the subscript (t) denotes the present time interval
the subscript (t-Δt) denotes the value of the variable at the previous time interval

$(\dot{y} + 6)_t$ denotes the rate of change of the 6th precursor group

$\frac{\Delta t_K}{2}$ = 1/2 of the time interval used in calculating the reactor kinetics

$$\dot{y} + 6_t = (f + 6)\,\phi_n - (\lambda + 6)(y_t + 6_t) \qquad (6)$$

Equations 5 and 6 are solved together by an iteration process for each value of y in the six precursor groups. The summation of $\lambda_i y_i$ is also calculated to be used in calculating the flux generation in equation 1.

Equation 1 is an expression for calculating the generated flux in the reactor and is solved by use of the following equations.

$$\phi_{nt} = \phi_{n,t-\Delta t} + \frac{\Delta t_K}{2}\,(\dot{\phi}_{n,t} + \dot{\phi}_{n,t-\Delta t}) \qquad (7)$$

$$\dot{\phi}_{n,t} = \frac{1}{\gamma_o}\left[\sum_1^6 \lambda_i y_i + (\Delta K - 1)\,\phi_{n,t}\right] \qquad (8)$$

The whole process of the solution of the reactor kinetics equations is by an iteration method. Equations 5 and 6 are solved by iteration to obtain the y values and hence the $\sum_{i=1}^{6} \lambda_i y_i$. The summation of $\lambda_i y_i$ is used in turn to calculate the flux which is solved for by the iteration procedure of equations 7 and 8. Upon obtaining improved values of $\phi_{n,t}$ this is used in getting improved values of y's and $\sum_1^6 \lambda_i y_i$. Hence, equations 5, 6, 7, and 8 are solved together by iteration to obtain improved values of y's and ϕ in the reactor kinetics equations.

The total reactor power can now be calculated by equation 3.

Upon leaving the reactor kinetics calculation it is necessary to transfer the newly calculated values of y_t, $\dot{y}_t$, ϕ_{nt}, and $\dot{\phi}_t$ to storage location of $y_{t-\Delta t}$, $\dot{y}_{t-\Delta t}$, $\phi_{n,t-\Delta t}$, and $\dot{\phi}_{n,t-\Delta t}$ respectively to be ready for the calculation of the next time interval.

It is important to mention the time interval used in calculating the reactor kinetics. Because of the nature of the equations, the stability of their solution depends upon the size of the time interval $(\Delta t_K/2)$ when the excess reactivity term

becomes a large negative number say during a scram or types of drive down in which a large amount of ΔK is introduced, the time interval needs to be made smaller. For any particular run that the excess reactivity may be greater than about negative one dollar, time interval (DELTK) = $\Delta t_K/2$ should be shortened. This time interval is normally the same magnitude as (DELTA) = $\Delta t_a/2$, which is used in the reactor nodal equations. Therefore, if it becomes necessary to shorten (DELTK) it must be shortened by some integral value such as 1/5 or 1/10 or 1/N. This is necessary so that N iterations will bring the elapsed time equal to that which will occur in the nodal equations.

Reactor Nodal Representation

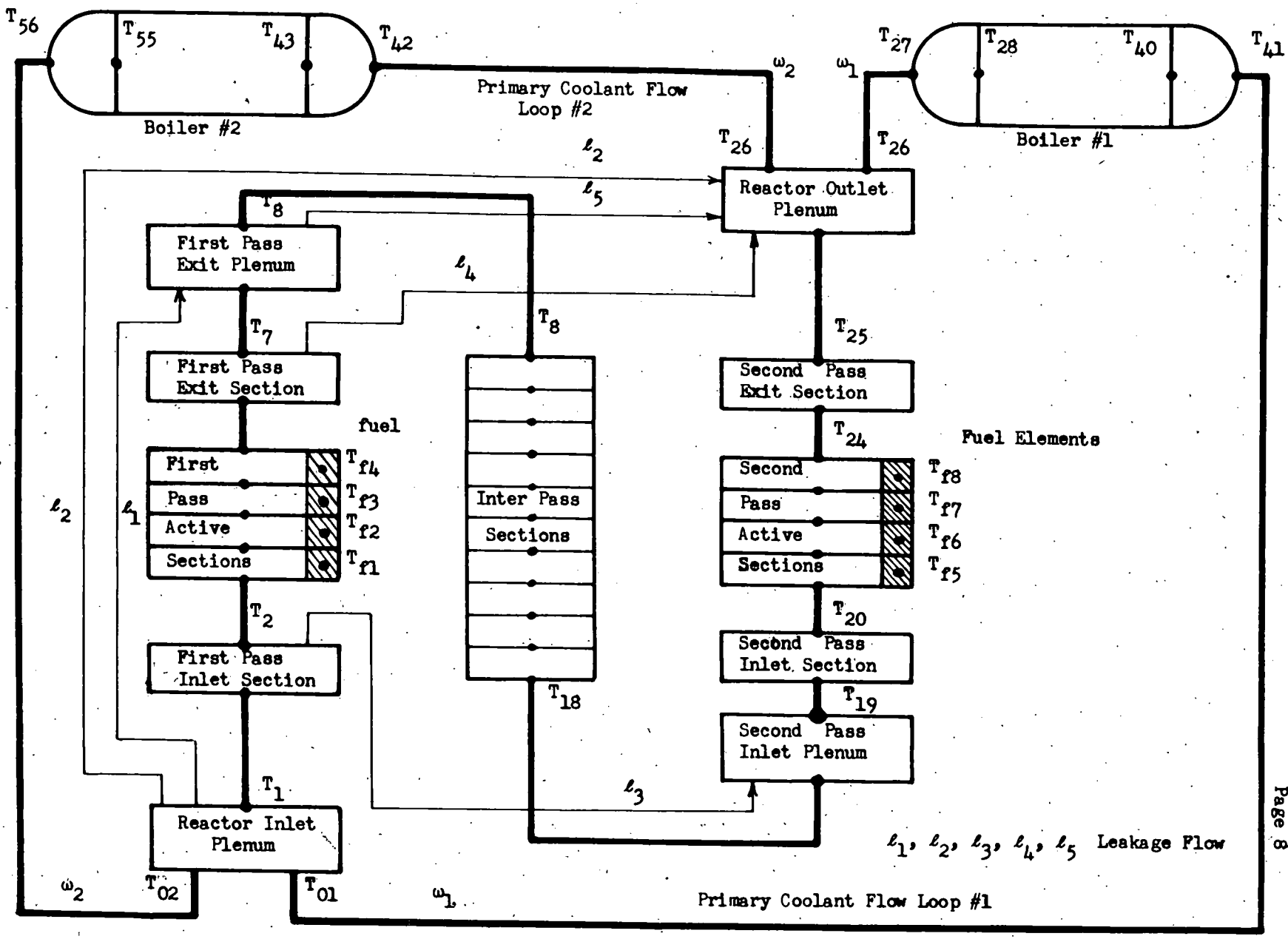


Figure 1

B. Reactor Nodal Representation

1. Plenum Sections

The inlet plenum of the reactor is represented the same as the other three plenum chambers in the reactor except the inlet plenum receives primary coolant flow from two sources. In the past it was assumed that there existed in the plenum a perfect mixing phenomenon with a constant heat capacity composed of the volume of coolant plus a certain amount of lumped metal. However, based upon the studies of the flow patterns being conducted on various air and water models, the heat capacity of the coolant in the plenum is represented by function of flow through the plenum.

One possible form of the plenum equation which could be used is:

$$\omega_1 cT_{01} + \omega_2 cT_{02} - (\omega_1 + \omega_2)\, cT_1 = \left[\gamma_1\, (\omega_1 + \omega_2)\, c + WC_M\right] \frac{dT_1}{dt} \qquad (9)$$

This equation for digital solution is arranged as follows:

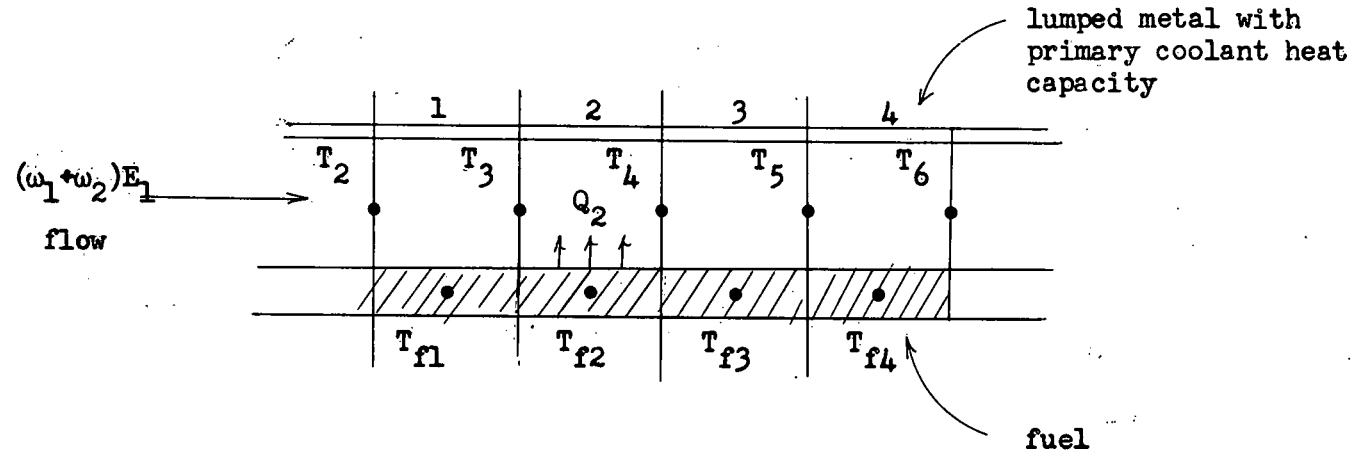
$$\dot{T}_{1,t} = \left[\frac{1}{\gamma_1\, (\omega_1+\omega_2) + \frac{WC_M}{c}}\right]\left[\omega_1 T_{01} + \omega_2 T_{02} - (\omega_1+\omega_2)\, T_1\right] \qquad (10)$$

$$T_{1,t} = T_{1,t-\Delta t} + \frac{\Delta t_a}{2}\left[\dot{T}_{1,t} + \dot{T}_{1,t-\Delta t}\right] \qquad (11)$$

The other three reactor plenum equations are identical to the above equation with the exception of having only one source of inlet flow with the possible exception of a small amount of leakage flow to some of these sections.

2. Active Core Sections

The active core of the reactor for the purpose of this study is composed of primary coolant, metal and the fuel. The figure below shows the nodal division of the core.



The core is divided into four equal sections. The weight of primary coolant and lumped metal make up the heat capacity of the node and adjacent to this node is the heat capacity of the lumped fuel. A heat balance written for node (n) is the following equations.

$$Q_n + (\omega_1+\omega_2)\, E_1 c\, (T_{n-1}-T_n) = WC \frac{d}{dt}\left(\frac{T_{n-1}+T_n}{2}\right) \quad \text{Heat balance of coolant node} \qquad (12)$$

$$P_n - Q_n = W_f C_f \frac{dT_{fn}}{dt} \quad \text{Heat balance of the fuel section} \qquad (13)$$

$$Q_n = U_{f1} A_{f1} \left(T_{fn} - \frac{T_{n-1}+T_n}{2}\right) \quad \text{Heat transferred from fuel to coolant} \qquad (14)$$

$$U_{f1} = K_{f1} \left[(\omega_1+\omega_2)\, E_1\right]^{.8} \quad \text{Heat transfer coefficient} \qquad (15)$$

The above equations arranged for digital solution are the following:

$$\dot{T}_{n,t} = \frac{2c}{WC} E_1 (\omega_1+\omega_2)(T_{n-1}-T_n) - \dot{T}_{n-1} + \frac{2}{WC} Q_n \qquad (16)$$

$$T_{n,t} = T_{n,t-\Delta t} + \frac{\Delta t_a}{2}\left(\dot{T}_{n,t} + \dot{T}_{n,t-\Delta t}\right) \qquad (17)$$

$$\dot{T}_{fn} = \frac{1}{W_f C_f}(P_n - Q_n) \qquad (18)$$

$$T_{fn,t} = T_{fn,t-\Delta t} + \frac{\Delta t_a}{2}\left(\dot{T}_{fn,t} + \dot{T}_{fn,t-\Delta t}\right) \qquad (19)$$

$$Q_n = U_{f1} \frac{A_{f1}}{2} (2T_{fn} - T_{n-1} - T_n) \tag{20}$$

$$U_{f1} = K_{f1} \left[(\omega_1 + \omega_2) E_1 \right]^{.8} \tag{21}$$

$$\ell n\, U_{f1} = \underbrace{\ell n\, K_{f1} + .8\, \ell n\, (\omega_1 + \omega_2) E_1}_{x} \tag{22}$$

$$U_{f1} = e^x \tag{23}$$

3. Transport Lag Section

The sections of the reactor that fall in this category are the inlet and exit section of the first and second passes and also the sections in the interpass. Their purpose is merely to transport the fluid and its temperature waves from one location to the next without any addition or loss of heat.

The equation for a transport lag is the following.

$$\omega c\, (T_{n-1} - T_n) = WC \frac{d}{dt} \left(\frac{T_{n-1} + T_n}{2} \right) \tag{24}$$

Therefore,

$$\dot{T}_{n,t} = \frac{2\omega c}{WC} (T_{n-1,t} - T_{n,t}) - \dot{T}_{n-1,t} \tag{25}$$

$$T_{n,t} = T_{n,t-\Delta t} + \frac{\Delta t_a}{2} (\dot{T}_{n,t} + \dot{T}_{n,t-\Delta t}) \tag{26}$$

C. Method for Propagating the Temperature Waves Through the Primary Coolant Piping

The time interval used in the reactor calculations is 1/5 that used in the boiler and steam system, this means that every fifth reactor outlet temperature is an input temperature to the hot leg piping. These input temperatures are stored in a table. The distance in which these temperatures have propagated during the time interval is calculated and stored in an adjacent table.

Distance propagated

$$\Delta X = \left(\frac{2}{\rho \times Vol}\right) \omega \left(\frac{\Delta t_b}{2}\right) \qquad (27)$$

ρ = density of coolant lbs/ft
Vol = volume per foot
ΔX = distance in feet
ω = coolant flow lbs/sec)
Δt_b = time interval

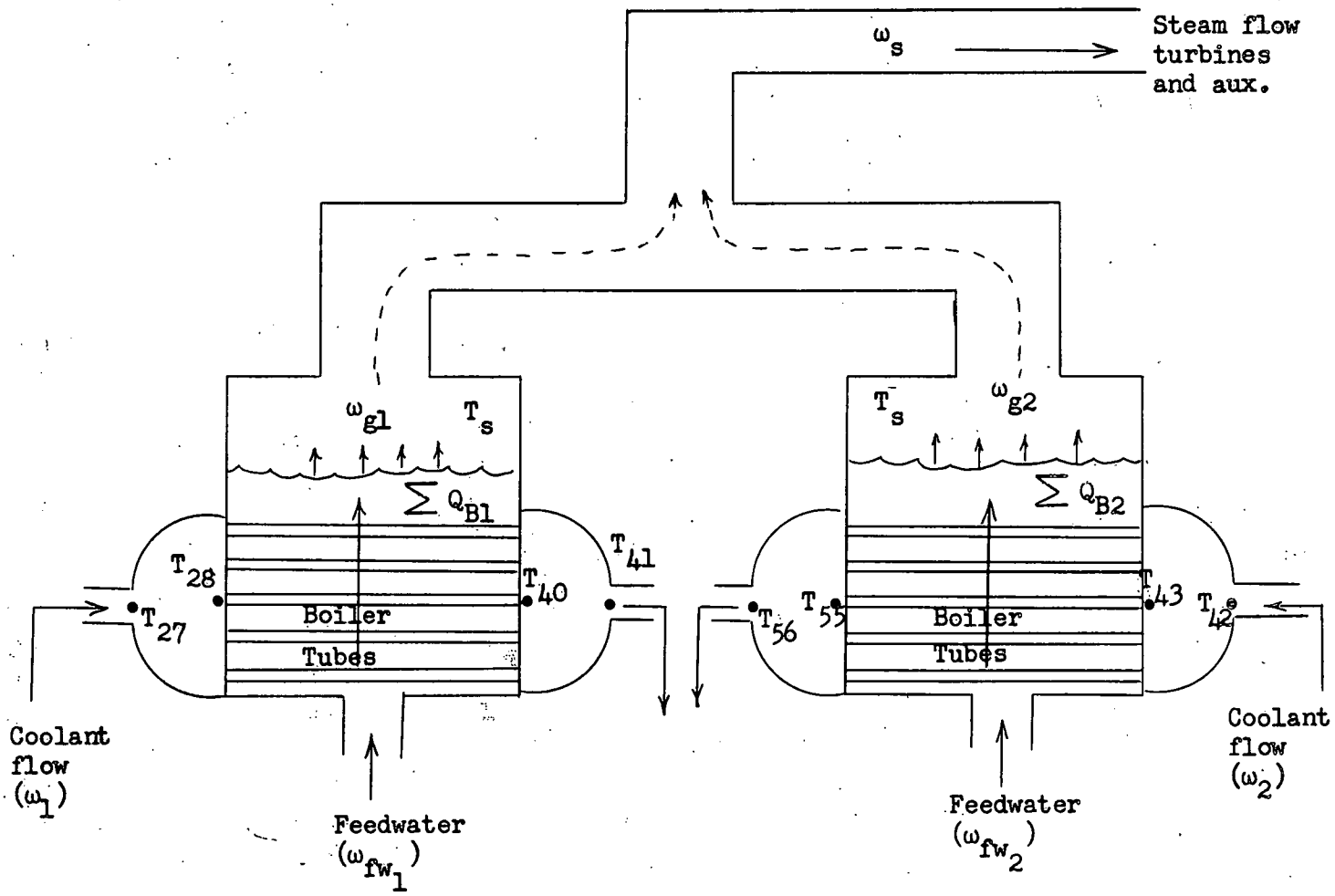
The summation of these ΔX's is maintained in two separate counters used to determine, first when the temperature has reached the sensing point and second when it has reached the end of the pipe. For example, the contents of the sensing point summation counter is tested against the length of pipe to the sensing point. If the test fails, then the program continues to the next part. If the test is satisfied, then the difference between the contents of the address field of the instruction referring to the stored table of temperatures and that of the index register tagged will give the effective storage location of the temperature that has propagated to the sense point. This temperature is stored in the sense point storage location to be used later. The contents of the table remains unchanged. The sense point summation counter is reduced by the amount of ΔX adjacent to the above temperature. This distance is obtained from its table in the same manner as the temperature. The new contents of the summation counter will be the total propagated distance of the next temperature that will eventually reach the sense point.

The temperature propagation to the end of the pipe; i.e., to the boiler inlet or to the reactor inlet, is accomplished in the same manner as described above using the other summation counter and proper tagged index register.

The number of storage locations in each table for storing temperatures and ΔX's was chosen so that in the majority of the runs made the table was of sufficient length so that when the table was filled and the next temperature would be stored at the beginning of the table, this temperature had already propagated the full length of the pipe and was no longer needed. However, if a run is made in which the coolant flow decreases to a very low value (2 or 3 percent) and remains at this value, it is possible that the temperatures at the beginning of the table have not reached the end of the pipe when the table is again filled and starts

storing at the beginning. In this case the temperatures at the start of the table would be destroyed before having served their purpose. To prevent this from happening it is necessary to increase the time interval or it is possible to alter the program so that every n^{th} input temperature will be stored in the table.

D. Boiler and Steam System



The above figure is a schematic diagram of the boiler and steam system representation used in this study. The primary coolant flow through the boiler tubes is divided into 12 equal sections used to calculate the heat transfer between coolant and secondary water.

The secondary side of the system is considered to be one lumped heat capacity composed of the water, portion of the boiler tubes and surrounding metal. The following equations describe the operation of the system studied.

$$\omega c\,(T_{n-1}-T_n) - Q_B = WC\,\frac{d}{dt}\left(\frac{T_{n-1}+T_n}{2}\right) \quad \text{Boiler tube section} \tag{28}$$

$$\omega c\,(T_{n-1}-T_n) = WC\,\frac{dT_n}{dt} \quad \text{Boiler plenum section} \tag{29}$$

$$Q_{B1} = U_{T1}A_1\left[\frac{T_n+T_{n-1}}{2} - T_s\right] \quad \text{Heat transferred} \tag{30}$$

$$U_{T1} = \frac{1}{\frac{1}{U_i} + \frac{1}{U_o} + r_f} \quad \text{Total heat transfer coeff.} \tag{31}$$

$$U_i = k_i\omega_1^{.8}\ \frac{BTU}{sec\ ft^2\ ^oF} \quad \text{Inside film coeff.} \tag{32}$$

$$U_o = k_o\, e^{P_s/900}\, Q_{B1}^{.75}\ \frac{BTU}{sec\ ft^2\ ^oF} \quad \text{Outside film coeff.} \tag{33}$$

r_f = constant (fouling resistance)
P_s = steam pressure (psia)

Two boiler operation in the boiling state

$$\omega_{g1} + \omega_{g2} = \omega_s \tag{34}$$

$$\omega_{fw1}h_{fw} + \sum Q_{B1} - \omega_{g1}h_g = \frac{d}{dt}\,(W_{w1}h_{f1}) \tag{35}$$

$$h_{f1} = h_{f2} \qquad \text{(36a)} \qquad \text{(36b)}$$

$$\frac{dW_{w1}}{dt} = \omega_{fw1} - \omega_{g1} \qquad \frac{dW_{w2}}{dt} = \omega_{fw2} - \omega_{g2} \tag{36 a and b}$$

Turbine flow equation

$$W_T = K_T\,\Omega_T\,\sqrt{P_T\,\rho_T} \quad \text{Main turbine} \tag{37}$$

Ω_T = throttle position

$$P_T = P_s - K_{SF}\omega_s^2 \quad \text{Steam piping pressure drop} \tag{38}$$

W_A = constant Auxiliary steam flow

Arranging these boiler and steam system equations in the form for digital solution we have the following.

$$\dot{T}_{n,t} = \frac{2\omega c}{WC}(T_{n-1}-T_n) - \dot{T}_{n-1} - \frac{2}{WC}Q_B \quad \text{Boiler tube node} \tag{39}$$

$$\dot{T}_{n,t} = \frac{\omega c}{WC}(T_{n-1}-T_n) \quad \text{Boiler plenum} \tag{40}$$

$$T_{n,t} = T_{n,t-\Delta t} + \frac{\Delta t_b}{2}(\dot{T}_{n,t} + \dot{T}_{n,t-\Delta t}) \tag{41}$$

$$Q_B = U_{T1}\frac{A}{2}\left[T_n + T_{n-1} - 2T_s\right] \tag{42}$$

$$U_{T1} = \frac{1}{\frac{1}{U_i} + \frac{1}{U_o} + r_f} \tag{43}$$

$$U_i = k_i\omega^{.8}, \; U_o = k_o e^{P_s/900} Q_B^{.75} \tag{44}$$

Two boiler operation in the boiling state

$$\omega_{g1} + \omega_{g2} = \omega_s \tag{45}$$

$$\omega_{g2} = \frac{W_{w2}}{W_{w1}}\omega_{g1} + \frac{1}{h_{fg}}\left[\sum Q_{B2} - \frac{W_{w2}}{W_{w1}}\sum Q_{B1} + \left\{(\omega_{fw2} - \left(\frac{W_{w2}}{W_{w1}}\right)(\omega_{fw1})\right\}(h_{fw}-h_f)\right] \tag{46}$$

$$\omega_{g1} = \frac{\omega_s - \frac{1}{h_{fg}}\left[\sum Q_{B2} - \frac{W_{w2}}{W_{w1}}\sum Q_{B1} + (\omega_{fw2} - \frac{W_{w2}}{W_{w1}}\omega_{fw1})(h_{fw}-h_f)\right]}{1 + \frac{W_{w2}}{W_{w1}}} \tag{47}$$

$$\dot{h}_{f,t} = \frac{1}{W_{w1}}\left[\sum Q_{B1} + \omega_{B1} + \omega_{fw1}(h_{fw}-h_{f1}) - \omega_{g1}h_{fg1}\right] \tag{48}$$

$$h_{f,t} = h_{f,t-\Delta t} + \frac{\Delta t_b}{2}(\dot{h}_{f,t} + \dot{h}_{f,t-\Delta t}) \tag{49}$$

$$h_{f,t} \xrightarrow{\text{Table Look Up}} T_S, P_S, h_{fg}$$

When operating with two boilers in the boiling state a test on $\omega_{g2} \approx 0$ can be made to determine when boiling stops in boiler #2.

One Boiler Operation - Boiler #2 has stopped boiling.

$$h_{f1} \neq h_{f2}$$

$$\omega_{g1} = \omega_s, \ \omega_{g2} = 0 \tag{50}$$

$$\dot{h}_{f1,t} = \frac{1}{W_{w1}} \left[\sum Q_{B1} + \omega_{fw1} (h_{fw} - h_{f1}) - \omega_{g1} h_{fg1} \right] \tag{51}$$

$$\dot{h}_{f2,t} = \frac{1}{W_{w2}} \left[\sum Q_{B2} + \omega_{fw2} (h_{fw} - h_{f2}) \right] \tag{56}$$

When operating with boiler #1 in the boiling mode a test of $h_{f2} = h_{f1}$ can be made to determine when boiling will exist in boiler #2.

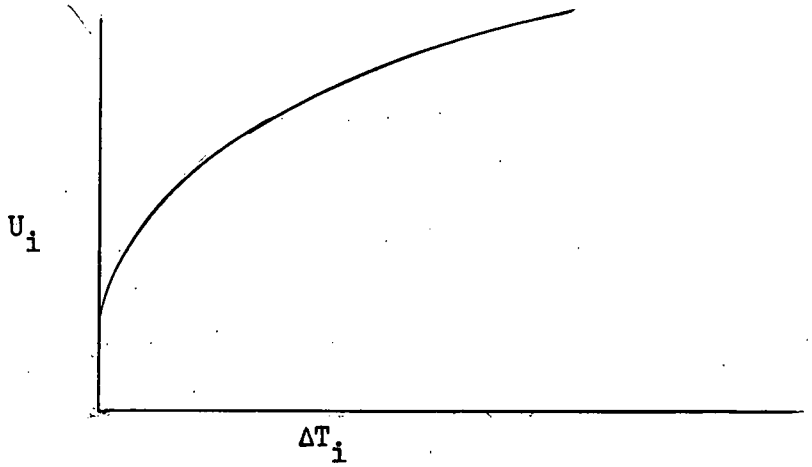
When the primary coolant flow goes to zero in one loop it becomes necessary to modify the equations representing the inside film coefficient and the boiler tube node equations. Since there is no convected heat in the section the only heat being transferred to the steam side will be that which is given up from the storage heat capacity. For zero flow in one loop these equations become:

$$- Q_B = \frac{WC}{2} \frac{d}{dt} (T_n + T_{n-1}) \tag{53}$$

where

$$\dot{T}_n = - \frac{2}{WC} Q_B - \dot{T}_{n-1} \tag{54}$$

The inside film coefficient is a function of the inside film temperature difference.



A relationship between the heat transferred through a median of several materials is

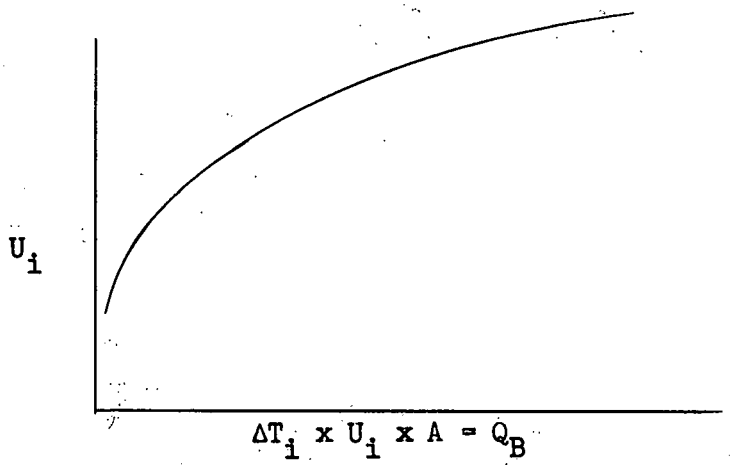
$$Q = U_1 A\ \Delta T_1 = U_2 A\ \Delta T_2 = \ldots.$$

$\Delta T_1 + \Delta T_2 + \ldots = \Delta T$ total temp. diff.

Therefore, the heat transferred from coolant to the steam is

$$Q_B = U_i A\ \Delta T_i$$

A new relation can be calculated from the above curve that will relate the inside film coefficient to the heat transferred term



At zero flow the inside film coefficient is obtained by a table look up process knowing the heat flux per section.

IV. PROGRAM OPERATING HINTS AND EXAMPLES

A. Time Intervals

There are five different time intervals used in this program and there will be cases where it will be necessary to alter some of these time intervals. These time intervals are as follows:

Symbolic Code	
DELTK	Used in reactor kinetics
DELTA	Used in reactor nodal equations
DELTB	Used in boiler and steam system and piping temp. prop.
INTVL	Used in calculating system average volume
DELTP	Used in calculating system average temp.

The reactor kinetics calculation is sensitive to large values of negative excess reactivity and also large values of temperature coefficient, therefore, there may be cases where a shorter time interval is necessary in the reactor kinetics calculation to give a stable and accurate solution.

If the coolant flow in a loop becomes small, 2 or 3 percent, and remains at this value for a long period of time, there is a possibility of over running the tables used in the pipe line temperature propagation. One way of correcting this is to increase the time interval DELTB. This means that less storage locations are required to propagate the temperature the full length of pipe.

If any of the time intervals are changed, make certain that the correct adjustment is made in the program so that the elapsed time in each part will be the same for one pass through the complete program.

B. Program Continuity

The program should be examined part by part to insure that none of the necessary parts are by-passed and also it is conservative time wise to by-pass the parts that are not needed. For example, if steam flow to the main turbine is to be held constant then it is wise to bypass that part of the program that calculates steam flow to the turbine.

C. Primary Coolant Flow vs. Time

To add flexibility and speed in preparing a run several flow tables have been compiled. The sub-routine for introducing flow into the problem uses these flow function tables. This sub-routine should be checked and the necessary corrections made to be sure the correct flow function table is used for the particular run being made. The following is a list of the compiled tables:

	Symbolic Code			
1.	Flow 1) Flow 2)	flow loop #1 flow loop #2	flow coastdown of loop #2	100% to 0
2.	Flow 4) Flow 5)	Start up of one dead loop 0 to 100%		
3.	Flow 6) Flow 7)	flow coastdown loop #2 50% to 0		
4.	Flow 8) Flow 9)	start up of dead loop 0 to 50%		
	TIME I	Argument for above eight tables.		
5.	TIME 3) Flow 3)	Argument and flow function Simultaneous pump switching from 1/2 to full speed, symmetrical flow.		

D. Preparing for a Run

A description of the program changes necessary in preparing to make a 15 second up maneuver run will be discussed.

The initial conditions for this run are:

20 percent reactor power

50 percent reactor flow

20 percent steam flow to auxiliary turbine

Main turbine throttle to travel from the closed position to full open in 15 seconds. Main coolant pumps will be switched from half speed to full speed when reactor power has increased to 50 percent.

After calculating elapsed time transfer to (MTTPO) main turbine throttle position opening. The throttle will start opening at time = zero, therefore, THPO is zero. The initial position of the valve is closed, therefore, IVOOP is zero.

This sub-routine contains two transfer instructions (TRA), which should transfer to pump switching (PUMP). Reactor power is tested and when equal to 0.5 a branch is made and flow is increased as a function of time. When 100% flow is reached a branch operation adjusts the program to by-pass the Pump switching sub-routine. After, pump switching transfer is made to the reactor kinetics program. The reactor kinetics calculation counter should be one; i.e., ITERA = one and ITEM = one. Since the time interval used in the kinetics is equal to that used in the reactor nodal equations only one pass is necessary to allow the elpased time to be equal in these two parts. After completing the kinetics and reactor nodal calculations the program then continues to the temperature propagation in the hot leg piping and then to the boiler and steam system.

E. Output Program

The output program is composed of three parts, each controlled to print at any desired time.

1. Part 1 is set up to print the following every 0.1 seconds. Time in seconds, reactor power, total excess reactivity minus one, reactivity due to temperature, reactivity due to rod position, first pass core outlet temperature, second pass core outlet temperature, reactor outlet temperature, fourth fuel element section temperature, eighth fuel element section temperature, and rate of change of reactor power.

2. Part 2 is set up to print the following quantities every 0.5 seconds. Reactor flow, flow in each loop, reactor inlet temperature from each loop, each of the sensing point temperatures, temperature difference between the hot and cold leg sensing point temperatures, inlet and outlet temperature of each boiler, system volume, rate of change of system volume, boiler steam temperature and pressure, total heat transferred in each boiler, feeder water flow in each boiler, weight of equivalent water in each boiler, turbine steam pressure, rate of evaporation in each boiler, total steam flow from boilers, main turbine steam flow, auxiliary turbine steam flow, astern turbine steam flow, system average temperature, main turbine throttle position, and astern turbine throttle position.
Part 2 contains two sub-routines for calculating the system primary coolant volume due to changes in temperature and also the system average

2. temperature. These sub-routines involve time intervals (INTVL and DELTP) in their calculations, therefore, if the printing interval is changed it is necessary to change these two time intervals to correspond with the time elapsed.

3. Part 3 is set up to print the following every 5 seconds.
The complete primary coolant temperature distribution, and the boiler heat transfer coefficients of sections #1, 4, 9, 12 in each boiler.

APPENDIX I

Equations Used for Calculating the System Initial Conditions

This program is designed so that the necessary initial conditions are calculated and stored in the exact location as used in the main program. Given the percent power and flow the program will calculate the initial conditions and punch out a binary deck that can be added to the main deck to begin a run. The program is intended for calculating a balanced two loop operation. If an unbalanced system is wanted it will be necessary to study this sub-routine and make the necessary changes.

The following are the steady state equations used in calculating the initial conditions.

Given Input Quantities

ϕ = percent power (PHI)

Flow = per reactor flow (FLOW)

Percent steam flow to auxiliaries (PERCT)

Neutron Decay Groups

$$y_i = \frac{f_i}{\tau_i} \phi$$

Fuel Temperature

$$T_f = \frac{Q_f}{U_f A_f} + \frac{T_{n-1} + T_n}{2}$$

Power Generation Distribution Per Section

Q_{fi} = $FRAC_i$ x POWER

i = 8 sections

Temperature Rise Across Reactor

$$\Delta T = \frac{\text{Power Base} \times \phi}{c \times \text{Flow Base} \times \text{Flow}}$$

Temperature of Active Core Sections

$$T_n = \frac{Q_{fn}}{\omega c} + T_{n-1}$$

where ω = reactor flow less leakage

c = specific heat coolant

Plenum Temperatures Due to Mixing of Leakage Flows

$$T_8 = \frac{E_{2i}T_7 + \ell_1 T_1}{E_{20}}$$ First pass exit plenum

$$T_{19} = \frac{E_{3i}T_{18} + \ell_3 T_2}{E_{30}}$$ Second pass inlet plenum

$$T_{26} = E_{4i}T_{25} + \ell_2 T_1 + \ell_4 T_7 + \ell_5 T_8$$ Reactor outlet plenum

Steam Temperature

$$T_s = \frac{BIT - BOT\, e^{\frac{U_T A}{\omega c}}}{1 - e^{\frac{U_T A}{\omega c}}}$$

U_T = overall boiler heat transfer coeff.

A = total area of boiler tubes

ω = boiler primary coolant flow

c = specific heat primary coolant

BIT = boiler inlet temperature

BOT = boiler outlet temperature

After steam temperature is calculated, the other steam properties (pressure, enthalpy) are obtained by a table look-up process.

Boiler Sectional Heat Transfer Coefficient and Primary Coolant Temperature Distribution

$$T_n = T_{n-1} - \frac{1}{\omega c} Q_B \qquad (1)$$

$$T_n = -\frac{2}{AU} Q_B = 2T_s - T_{n-1} \qquad (2)$$

$$U = \frac{1}{\frac{1}{U_i} + \frac{1}{U_o} + r_f} \qquad \frac{1}{U_i} = \text{constant} \qquad (3)$$

Therefore,

$$U = \frac{1}{\frac{1}{U_o} + c'} \qquad U_o = k' Q_B^{.75}$$

Solve (1) and (2) eliminate T_n

$$T_{n-1} - \frac{1}{\omega c} Q_B = 2T_s - T_{n-1} + \frac{2}{AU} Q_B \qquad (4)$$

$$\left(\frac{1}{2\omega c} + \frac{c'}{A}\right) Q_B + \frac{1}{Ak'} Q_B^{.25} = T_{n-1} - T_s \qquad (5)$$

T_s is known from steam temperature calculation

T_{n-1} is the boiler inlet temperature when calculating the first boiler section, and thus becomes the sectional temperature of previous section calculated.

Equation 5 is solved for Q_B by iteration.

Then from equations (1) and (3) the primary coolant temperature and sectional heat transfer coefficient are solved.

Steam Flow from Boilers

$$\omega_s = \frac{\emptyset \text{ x Power Base}}{h_g - h_{fw}}$$

h_g = enthalpy of saturated steam

h_{fw} = enthalpy of feedwater

The steam flow to the main turbine and throttle position is calculated as follows:

$$W_T = \omega_s - W_A$$

ω_s = total steam flow from boilers

W_A aux. steam flow (fixed percentage)

$$\Omega_T = \frac{W_T}{K_T \sqrt{P_T \rho_T}}$$

P_T turbine steam pressure

ρ_T turbine steam density

K_T constant

APPENDIX II

Equations Used in Calculating the System Rate of Change of Volume Due to Changes in Primary Coolant Temperature

$$\frac{dV_s}{dt} = \beta \left[\sum_{1}^{P} V_P \dot{T}_P + \sum_{1}^{a} V_a \left(\frac{\dot{T}_a + \dot{T}_{a-1}}{2} \right) \right.$$

$$+ \frac{\omega_1}{\rho} \left(T_{Ro} - T_{Bi1} + T_{Bo1} - T_{Ri1} \right)$$

$$\left. + \frac{\omega_2}{\rho} \left(T_{Ro} - T_{Bi2} + T_{Bo2} - T_{Ri2} \right) \right]$$

V_P = plenum volume

T_P = plenum temperature

P = number of plenums in system

V_a = sectional volumes

T_a = sectional outlet temperature

T_{a-1} = sectional inlet temperature

a = number of sections in system

T_{Ro} = reactor outlet temperature

T_{Bi1} = boiler #1 inlet temp.

T_{Bo1} = boiler #1 outlet temp.

T_{Bi2} = boiler #2 inlet temp.

T_{Bo2} = boiler #2 outlet temp.

T_{Ri1} = reactor inlet temp. loop #1

T_{Ri2} = reactor inlet temp. loop #2

$\beta = 1.2 \times 10^{-3} \frac{1}{^oF}$ (expansion coefficient)

ρ = primary coolant density (average value)

A positive value of dV_s/dt means an out surge from main system.

APPENDIX III

Equations Used in Calculating the System Average Temperature

$$T_{sa} = \frac{1}{V_s}\left[\sum_{1}^{P} V_P T_P + \sum_{1}^{a} V_a \left(\frac{T_a + T_{a-1}}{2}\right) + V_H\,(PAT1 + PAT3) + V_C\,(PAT2 + PAT4)\right]$$

$$PAT_t = PAT_{t-\Delta t} + \frac{\omega}{PVOL}\frac{1}{\rho}\Delta t_p\,(T_{in} - T_{out})$$

T_{sa} = system average temperature
V_s = system volume ft^3
V_P = plenum volume
T_P = plenum outlet temp.
$\frac{T_a + T_{a-1}}{2}$ = average node temp.
V_H = volume of hot leg piping
V_C = volume of cold leg piping
PAT1 = hot leg pipe #1 average temperature
PAT3 = " " " #2 " "
PAT2 = Cold " " #1 " "
PAT4 = " " " #2 " "
ω = pipe flow (lbs/sec)
PVOL = pipe volume (ft^3)
ρ = average primary coolant density (lbs/ft^3)
PAT_t = pipe average temp. at time t
$PAT_{t-\Delta t}$ = pipe average temp. at previous time interval

APPENDIX IV

General Purpose Sub-Routine Package

This package contains six sub-routines used in operating the program. These sub-routines have been assembled by CAGE independently of the main program and occupying the first 809 storage locations. The control cards are:

```
OUT     EQU     30
LAGIN   EQU     436
LN      EQU     566
EXP     EQU     616
SQRT    EQU     674
PUNCH   EQU     701
```

The following is a brief description of these sub-routines and their calling sequence.

Identification

General Purpose Output Program, GLOUT Original Program by Georgia Division of Lockheed Aircraft Modified by Jane E. King, 8-10-56, G.E., LST-G, Schenectady, New York.

Purpose

To set up and print one line (72 or 120 columns) or to output a complete line to tape, or both. Any desired format may be used and conversions from floating binary to fixed decimal, floating binary to floating decimal or fixed binary to fixed decimal are made as indicated. Locations of words to be output may be indexed if desired.

Method

For floating to fixed conversions, fractional and integral parts are converted separately as integers. A polynomial approximation method is used in the floating to floating conversions. All output words are converted to binary coded decimal form and are stored according to the print wheel position specified. Conversion to card image is made just before printing.

Usage

The calling sequence consists of the machine language instruction

```
TSX OUT,4
```

followed by psuedo-operations which give the type of conversion desired. One word of calling sequence is needed for each word to be output in the line (except for Hollerith information where one word of calling sequency initiates printing of up to 120 columns). The calling sequency is completed by giving a pseudo-operation to specify the type of output desired.

The pseudo-operations which may be used are:

OP	A,T,D	OP MNEMONIC SIGNIFICANCE
Indexable		
F*F	k,T,1000D_1+PP	Floating to Floating
F*X	k,T,1000D_2+PP	Floating to Fixed
I*I	k,T,PP	Integer to Integer
B*B	k,T,1000N+PP	BCD to BCD
X*X	k,T,1000D_2+PP	Fixed to Fixed
Non-Indexable		
ZER	BP	Binary Point
WR*	INSTR.	Write
PRT	INSTR.	Print

In these pseudo-operations, PP specifies the rightmost print wheel position which will be used for this calling sequence instruction and consecutive print wheel positions from right to left will be used as needed. Characters using print positions less than 1 will be lost. Specifying a print position greater than 120 will cause an error indication. It is the coder's responsibility to avoid unintentional overlapping of fields. If fields should overlap, a later calling sequence word will take precedence over any earlier one of this calling sequence.

In any of the calling sequence words which may be indexed, T may have the value 0, 1, or 2 and the effective address L will be k minus the contents of the corresponding index register.

Output may be to both printer and tape. In this case the WR* instruction must precede the PR* instruction.

The error indication mentioned above or those described later under X*X will give the octal address of the calling sequence word causing the error by replacing positions 2-19 of the incorrect line with "ERROR IN LOC XXXXX". The incorrect calling sequence word will be destroyed.

Specifications for the output pseudo-commands are given in the following paragraphs.

F*F

The operation F*F will convert the word in location L from floating binary to floating decimal. The answer is rounded to D_1 significant digits where $1 \leq D_1 \leq 8$. The format of the answer will be

±YY,±.XXXXXX

Positive characteristic signs are indicated by blanks and lead zeros in the characteristic YY do not print. If the mantissa is zero, no characteristic will print.

F*X

The operation F*F will convert the word in location L from floating binary to fixed decimal rounded to D_2 decimal places. D_2 should not exceed 8. If D_2 equals zero, a rounded integer will be entered without a decimal point. If the number is negative, a minus sign will print immediately to the left of the leftmost character. No lead zeros to the left of the decimal point will print. If the number is zero, it will be printed with D_2 zeros to the right of the point. If the absolute value of the number exceeds 34, 359, 738, 367, it will be printed in floating decimal form as described above.

I*I

The operation I*I will convert the word in location L to a decimal integer and print it without a decimal point. If the word is negative, a minus sign will print immediately to the left of the high order digit.

B*B

The B*B operation is used in printing headings or words of alpha-numeric information. The N words of information starting in location L will be set up for printing across from left to right so that the rightmost character will fall in the print position specified. N should not exceed 20. Normally, the calling sequence for a full line of heading will be:

```
TSX OUT,4
B*B L,,20120
PR*
```

The words from L through L + 19 will print from left to right across the sheet.

X*X

The operation X*X must be followed by the operation code ZER. (X*X not followed by ZER, or ZER not preceded by X*X will give an error indication). BP gives the binary point of the word in location L of the preceding X*X operation. This word is converted to fixed decimal rounded to D_2 decimal places and printed with a format similar to that for the F*X operation. D_2 should not exceed 8. A BP value outside the range 0 through 35 gives an error indication.

WR*

The operation WR* signifies that the entire line which has been set up is to be written on tape unit #3 unless sense switch #3 is down in which case WR* will be interpreted as PR*. Two special operations are possible with either WR* or PR*. If the address of the instruction is RESTO, the paper will be restored before printing; and if the address is ZSPAC, an extra space will be inserted after printing.

PR*

The PR* command initiates the setting up of the card image(s) and the printing of the output line. The use of the address is described under WR*.

Coding Information

The sub-routine including all constants occupies 396 storages and uses COMON thru COMON+50. The symbols used are OUT, RESTO, and ZSPAC.

Special Notes

Print position 1 may not be used with WR*.

When output is to tape, the record is checked for a tape error. If an error occurs, the record is rewritten until correct and a card is punched showing the number and type of tape errors encountered.

An attempt to print an illegal BCD character will cause a blank to be inserted in its place.

The on-line printer may be restored independently of the subroutine by the instructions

WPR
SPR 1

If any of the print positions specified exceed 72 for some line, then two print cycles are required to print that line.

A modified version of MCAGE is available which contains the special operation codes described above. The feature which causes the paper to restore when a LOC card is encountered has been removed from this version of MCAGE.

Identification

Lagrangian Interpolation Subroutine (LAGIN)
L. J. Dwyer
General Electric - Evendale
10-18-55

Purpose

To compute $y = f(x)$, given a set of values for x and y.

Method

$$y = \sum_{k=1}^{P} \left[Y_k \prod_{j \neq k} \frac{x - x_j}{x_k - x_j} \right]$$

It is assumed that $x_{n-1} < x_n < x_{n+1}$

The program finds and uses the best P points of the given sets.

Usage

Floating normalized x in accumulator
Calling sequence

SXJ LAGIN, 4
ZER $L(x_i)$, 0, $L(y_i)$ i denoting initial
ZER N , 0, P
Error Return, indicator in accumulator, decrement field
Normal Return, floating normalized y in accumulator.

N is the number of x, y pairs and P is the number of points to be used in interpolation.

Two types of input storage are accommodated. Normally x values are stored sequentially in one table and y values are stored sequentially in another table. In this case

$L(x_k) = L(x_i) + k-1$
$L(y_k) = L(y_i) + k-1$

However, values of x and y may be stored alternately in one table. In this case

$L(x_k) = L(x_i) + 2k - 2$

$L(y_k) = L(y_i) + 2k - 2$

$L(y_i) > L(x_i)$

The error return will be made if the given x lies outside the given table of x values. The indicator will be 1 if $x < x_i$; the indicator will be 2 if $x > x_n$.

Accuracy: Complete floating point calculation.

Space Required: 123 locations.

Coding Information

Constants: 3 constants are a part of the subroutine.

Subroutine Temporary Storage: FREE - FREE + 7

Timing: Approximate time for 3-point interpolation, x in the first interval assuming minimum cycles for floating operations: 7.728 m.s.

Identification

Natural Logarithm Subroutine (LN)

L. J. Dwyer

General Electric - Evandale

10-18-55

Purpose

To compute the natural logarithm of a floating point number

Method

$\ln x = \ln(f.2^E) = \ln F + E\ln 2$

Continued fraction approximation for $\frac{1}{2} \leq F < 1$.

$$\ln F = \ln 0.725 + \cfrac{r}{0.725 + \cfrac{r}{2 + \cfrac{r}{2.175 + \cfrac{r}{1 + \cfrac{r}{3.625 + \cfrac{r}{2/3 + \cfrac{r}{5.075 + \cfrac{r}{0.5}}}}}}}}$$

where $r = (F - 0.725)$

Accuracy: At least 26 significant binary digits except near $x = 1$, where the result is accurate to 26 binary places.

Usage

Floating x in accumulator

Calling Sequence

SXJ LN, 4

Error Return for $x \leq 0$, x in accumulator

Normal Return, floating normalized lnx in accumulator

Space Required: 46 locations

Coding Information

Constants: 14 constants are a part of the subroutine.

Subroutine Temporary Storage: FREE - FREE + 3

Timing: 4.728 m.s. assuming minimum cycles for floating operations.

Identification

Exponential Subroutine - EXP2

D. L. Shell

General Electric - Evendale

12-15-55

Purpose

To compute the exponential of a floating point number.

Method

Range of values: $|x| < 88$.

$$e^{-x} = \left[1 + \frac{y}{1 - \frac{y}{2}F}\right] 2^{N-1}$$

where $F = \frac{y^2}{40}\left(\frac{y^2 + 42 + 98}{y^2 + 42}\right)$

$x = f.2^E$

for $E \leq -3$, $y = x$ and $N = 1$

for $E > -3$, $y = f.2^{-3}$ and $N = E + 4$

Accuracy: 26 significant bits for $|x| \leq \frac{1}{8}$

at least 26 - n for $|x| < (\frac{1}{8})^{2n}$

Usage

Floating normalized x in Accumulator

Calling Sequence:

SXJ EXP,4

Error Return: for $|x| \geq 88$, x in accumulator

Normal Return: floating normalized e^x in accumulator

Space Required: 58 locations

Coding Information

Constants: 7 constants are a part of the subroutine

"Common" Storage: FREE - FREE + 4

Timing: 2.148 m.s. for $E \leq -3$

$[2.244 + .276(N-1)]$ m.s. for $E > -3$

For positive x: add .384 m.s.

Identification

Square Root Subroutine - SQRT

L.J. Dwyer

General Electric - Evendale

10-18-55

Purpose

To compute the square root of a floating point number.

Method

$y = \sqrt{x} = \sqrt{F.2^E}$

$y_o = \left[\frac{1}{2}(F-.5) + .5\right] 2^e$ where e is the integral part of $\frac{1}{2}$ (E+1), E odd, or $\frac{1}{2}$ (E), E even.

$y_{n+1} = \frac{1}{2}\left(y_n + \frac{F}{y_n}\right)$

Accuracy: At least 26 significant binary digits.

Reference: Preliminary Report on R-S.

Usage

Floating normalized x in accumulator.

Calling Sequence:

SXJ SQRT, 4
Error Return, for $x < 0$, x in accumulator
Normal Return, floating normalized $\sqrt{x}$ in accumulator

Usage (cont'd)

Space Required: 23 locations

Coding Information

Constants: 3 constants are a part of the subroutine.
Subroutine Temporary Storage: FREE - FREE + 3
Timing: 1.610 m.s. assuming minimum cycles for floating operations.

Identification

Binary Punch Subroutine - PUNCH
J.A. Porter and G. Williams
General Electric - Evendale
August 24, 1956

Purpose

This subroutine is designed to punch out a block of memory in 704 type binary cards. The nine left side of the card will contain a punch in column one, word count in columns 14 to 18 and the initial location in columns 22 to 36. The nine right side will contain the check sum. The contents of the initial location will appear in row eight left with succeeding locations being punched in 8-right, 7-left, 7-right, etc.

Optional Feature

At the option of the programmer, an additional control word may be given in the calling sequence. This control word specifies the location of the initial address where it is desired to relocate the punched cards.

Note: When the programmer uses the additional control word, index register C will be reduced by one.

Usage

Calling sequence

```
SXJ  PUNCH,C
ZER  IA,O,FA
```

IA - - - is the initial address of the block to be punched.
FA - - - is the final address.

Usage (cont'd)

Optional calling sequence

```
SXJ  PUNCH+1,C
ZER  IA OF RE
ZER  IA,0,FA
     IA - - -
     FA - - -
```

IA OF RE is the initial address where it is desired to relocate punched cards.

Space required: 60 locations.

Coding Information

Subroutine temporary storage FREE - FREE + 2

Timing - 100 cards per minute.

R.C. Larsen, Control Systems Engrg. Unit
Analytical Engineering Section
September 11, 1957

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