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University of California
LOS ALAMOS • NEW MEXICO

RAPID
(Reactor and Plant Integrated Dynamics)
Computer Program

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by

Carl A. Anderson, Jr.

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ABSTRACT

RAPID is a digital computer program for the IBM 7094 computer, intended for steady-state and transient analysis of an entire reactor plant. It treats core neutronics and heat transfer in core, reflector, primary loop, secondary loop, heat exchangers, heat dump, and piping and is applicable to a large number of plants, rather than one specific reactor plant. Mathematical and FORTRAN equations are derived and discussed. Capabilities, limitations, and desirable improvements are detailed.

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TABLE OF CONTENTS

	<u>Page</u>
ABSTRACT	3
ACKNOWLEDGMENTS	3
LIST OF ILLUSTRATIONS	6
LIST OF TABLES	6
I. INTRODUCTION	7
II. GENERAL DISCUSSION	10
A. The Main Routine, RAPID	10
B. The Subroutines DETST and DETTR	21
C. Heat Transfer Coefficient Subroutines, HXFUEL and COEFHX	22
D. Decay Heating Subroutine, DECAY	23
E. Heat Dump Subroutine, XLOAD	24
F. Neutron Kinetics Subroutine, XNKIN	24
III. DETAILS OF EQUATIONS AND PROCEDURES OF SOLUTION	25
A. Main Program, RAPID	25
1. Development of the Finite Difference Solutions to the Heat Transfer Equations	25
a. Explicit vs Implicit Solutions	25
b. Various Explicit Method Formulations	36
(1) First Formulation	36
(2) Second Formulation	38
(3) Third Formulation	40
2. Steady-State Heat Balance	40
3. Change of Coolant Flow Rate	49
4. Heat Transfer	49
5. Maximum Allowable Time Step	51
6. Coolant Transport Time Delay	51
7. Core Outlet Manifold	54
8. Power	54
9. Reactivity	55
a. Ramp Reactivity Insertion	55
b. Control Rod Rundown	55
c. Feedback Controlled Shutdown Based on Core Outlet Coolant Temperature	56
d. Reactivity Feedback Due to Temperature Changes	57

TABLE OF CONTENTS (Continued)

	<u>Page</u>
B. Detailed Temperatures, DETST and DETTR	59
1. Analytic Steady-State Solution	59
2. Transient Solution	61
C. Heat Transfer Coefficients, HXFUEL and COEFHX	70
1. Fuel and Reflector Rods	70
2. Pipes and Hot Trap	70
3. Shielding and Vessel	71
4. Intermediate Heat Exchangers	71
5. Heat Dumps	71
D. Decay Heating, DECAY	72
E. Neutron Kinetics, XNKIN	72
IV. FORTRAN LISTINGS	78
A. RAPID	79
B. DETST	113
C. DETTR	116
D. HXFUEL	119
E. COEFHX	120
F. DECAY	121
G. XLOAD	122
H. XNKIN	123
V. NUMERICAL EXAMPLE	125
VI. FURTHER WORK NEEDED	162
A. Neutron Kinetics	162
B. Heat Transfer	162
C. Primary and Secondary Coolant Loops	163
D. Heat Dump	164
E. Miscellaneous	164
VII. REFERENCES	165
VIII. APPENDICES	167
A. Symbolic Multidimensional Input Subroutine (BCDCON etc.)	167
B. Linear Equations Solution (LEQ etc.)	173
C. Film Plotting and Labeling Subroutines	177
D. Clock Function	183

LIST OF ILLUSTRATIONS

		<u>Page</u>
Fig. 1	Nuclear Reactor Plant Model	11
Fig. 2	FRCTF Schematic	12
Fig. 3	Block Diagram of Main Routine	26
Fig. 4	Portion of RAPID Steady-State Matrix	48
Fig. 5	Block Diagram of DETST Subroutine	62
Fig. 6	Block Diagram of DETTR Subroutine	68
Fig. 7	Block Diagram of COEFHX Subroutine	73
Fig. 8	Block Diagram of XNKIN Subroutine	77
Fig. 9	Deck Arrangement	126
Fig. 10	Sample Problem: Core and Heat Dump Power vs Time	156
Fig. 11	Sample Problem: System Flow Rates vs Time	157
Fig. 12	Sample Problem: Heat Dump Temperatures vs Time	158
Fig. 13	Sample Problem: Intermediate Heat Exchanger Temperature vs Time	159
Fig. 14	Sample Problem: Core Temperatures vs Time	160
Fig. 15	Sample Problem: Core Excess Reactivity vs Time	161

LIST OF TABLES

Table I	System Constants	13
Table II	Program Control Options	16
Table III	Problem Definition Variables	17
Table IV	Sample Problem Data	127
Table V	Printout Glossary	128

I. INTRODUCTION

Transient analysis of an entire reactor plant is of importance both for studies of plant and reactor safety and for application to design of plant components. Some of the items of importance for reactor safety studies are core power, core reactivity, and core temperature versus time. In problems involving load demand changes, for example, this information cannot be obtained by analyses which treat only the reactor core, since the entire plant--from core to heat dump--affects core response to a load demand. Similarly, for proper analysis of thermal stresses in the plant, the information of importance for component design includes the temperatures of coolants and components versus time, which likewise cannot be developed without consideration of the entire plant as a unit.

Complete treatment of the effects of plant transients is impossible without a tool capable of analyzing the behavior of the entire plant. Such transient analysis is best performed with a digital computer. Hand calculations are precluded by the complexity of the systems to be analyzed. Transfer function analyses do not go into nearly enough detail and are not very useful for large perturbations. An analog computer solution comparable to RAPID would require an unduly large number of amplifiers, would have poorer accuracy than a digital program, and could not treat coolant transport time delays correctly.

It is essential, in the transient studies, to adequately treat coolant transport time delays, loop coupling, time varying coolant flow rate, coolant heat capacity, and reactivity feedback effects. Many existing computer programs treat pieces of the problem rather than the whole, or are otherwise limited. Thus, for example, while there are many computer programs which predict fast reactor core kinetics, the computation time required by them renders them nearly useless as parts of overall plant calculations.

RAPID was originally developed to predict the dynamic behavior of the Molten Plutonium Burnup Experiment (MPBE)¹ in the Fast Reactor

Core Test Facility (FRCTF),² and while certain peculiarities of this plant (such as the coolant mixing region above the core) were incorporated as options in the computer program, every attempt has been made to make RAPID as generally applicable as possible within the constraints of computer storage space, computation time, and author's time.

This program, written in FORTRAN II, Version 3, language for the IBM 7094 computer, is intended for calculation of the steady-state and transient temperatures, reactivity, and power of a nuclear reactor plant which can be described by a model consisting of core, upper and lower axial reflectors; intermediate heat exchanger; heat dump; primary, secondary, and tertiary coolant systems; and connecting pipes. The mass, volume, and surface area of each component may be specified, and the program calculates the appropriate coolant transport times and calculational time steps. The steady-state heat balance is solved internally, as is the initial temperature distribution.

Up to six delayed neutron groups may be used in the point kinetics equations. Multipoint heat transfer equations are solved by finite difference techniques in the transient portion of the program. Thermal feedback to the neutronics equations is provided via space-dependent thermal expansion and/or Doppler feedback. A variety of reactivity input options is available, as are power demand options and flow rate change options.

Subroutines provide for calculation of fission-product decay heating following shutdown, detailed fuel temperature distributions, and flow-dependent heat transfer coefficients throughout the plant.

Since this program has undergone continued revision and since the number of permutations and combinations of variables, operating conditions, and constants possible with RAPID is legion, they have not all been tested. So, although the program has been debugged and tested for several reactor systems and a large number of transients, there may be some combinations that will not work.

The user should understand the capabilities and limitations of each subroutine and the functions performed by it, as well as how the finite difference calculation technique may affect these functions and thereby

affect the results. For example, the reactivity calculations are performed in the main routine. The maximum calculational time steps required for stability of the system of equations in the main routine are automatically determined throughout a transient. However, these time steps, while ensuring stability, do not guarantee an accurate solution. Thus, if a ramp reactivity insertion of \$5/sec is approximated by the program using 0.050-sec time steps, there results a succession of 25¢ step insertions of reactivity. One's intuition (or a second calculation) may lead one to prefer 0.010-sec time steps. This may be specified in the input either by DMUL = 0.2 or, preferably, TMAX1 = 0.010 (see Table III).

Different time steps are used in different parts of the calculation; this speeds up the calculation considerably. For example, the neutron kinetics equations might require 0.0006-sec time steps for stability, while the primary loop might require 0.06-sec time steps. If the same time step were used for both, the primary loop calculations would take 100 times as long as they do in RAPID.

One might ask why a modified-Euler type of finite difference calculation is not used instead of the simple Euler method. The answer is that, first, the variable to be used as the criterion of accuracy is not apparent and second, the computation time would be lengthened by a factor of two or more. The DMUL and TMAX input options may be used to indicate the dependence of accuracy on size of time step in important problems.

Major limitations of the program are: core reactivity must be less than β , the delayed neutron fraction; material properties are temperature independent; heat capacity is finite for primary and secondary coolants; heat capacity is negligible for tertiary coolant; no flux depression is considered within a fuel pin; the heat transfer coefficient is the same at all points in a component (such as in the heat exchanger primary); no material phase changes are considered; the same material properties are specified for the primary as for the secondary coolant; the same material properties are specified for all structural materials (pipes, vessel, etc.); the HD and IHX are counter-flow.

II. GENERAL DISCUSSION

A. The Main Routine, RAPID

The nuclear reactor plant model treated by RAPID is shown in Fig. 1. This model may be used to calculate the dynamic response of many nuclear plants which do not, superficially, bear any resemblance to Fig. 1. Thus, for example, the program has been used to calculate the behavior of a plant (MPBE in FRCTF) with two parallel primary loops, two parallel secondary loops, and a hot trap (Fig. 2). This is done by considering each component in the model to be a composite component which has the total flow rate, area, mass, and coolant volume of the true components (e.g., intermediate heat exchangers), with a heat transfer coefficient calculated on the basis of the true flow in the true component. Such a procedure treats well the plant in which multiple parallel loops are slaved together in operation, but cannot consider the interaction of multiple parallel loops with one another.

The user must exercise some ingenuity to make his plant fit the model of Fig. 1. All component areas, masses, sodium masses, fuel rod sizes, and other input variables (Table I) are entered by means of the BCDCON routine (App. A), as are the operating options (Table II) and the initial conditions for the problem (Table III). The heat transfer coefficients given by the subroutines COEFHX and HXFUEL should be altered, if necessary (See Section III-C for descriptions of these subroutines).

Any values needed in the calculation which are not provided through BCDCON will be taken as the program internal values (such as those listed in Section IV-A for the MPBE). When running a series of problems for one basic reactor plant, it will be more convenient for the user first to alter the program internal values in the source deck appropriately.

The first calculation performed by the program (See Section III) is the steady-state heat balance, which establishes the log mean temperature difference for the intermediate heat exchanger, and, thence, the tertiary coolant flow rate required to establish steady-state operating conditions in the plant for the given values of power, primary coolant

(X) = NUMBER OF HEAT TRANSFER NODES

X = NUMBER OF TIME DELAY NODES

Fig. 1. Nuclear Reactor Plant Model.

Fig. 2. FRCTF Schematic.

TABLE I
SYSTEM CONSTANTS (MASSES, AREAS, ETC.) WHICH MAY BE SUPPLIED AS INPUT DATA

Item	Definition	Units	Value presently in program
ANB	Heat transfer area in bypass pipe	ft ²	3782.
AND	Heat transfer area inside heat dump tubes	ft ²	1549.
ANP1	Heat transfer area in pipe #1	ft ²	350.
ANP2	Heat transfer area in pipe #2	ft ²	453.
ANP3	Heat transfer area in pipe #3	ft ²	272.
ANP4	Heat transfer area in pipe #4	ft ²	437.
ANX	Heat transfer area, IHX* tubes	ft ²	1171.
ARRAY	If = 1., use hex core array. If = 2., use square core array		1.0
AVI	Heat transfer area of material between vessel inlet and core inlet	ft ²	2940.
AXS	Heat transfer area, IHX shell	ft ²	600.
BA(1)	Delayed neutron fraction in group #1		0.000080
BA(2)	Delayed neutron fraction in group #2		0.000588
BA(3)	Delayed neutron fraction in group #3		0.000454
BA(4)	Delayed neutron fraction in group #4		0.000689
BA(5)	Delayed neutron fraction in group #5		0.000216
BA(6)	Delayed neutron fraction in group #6		0.000074
CA	Specific heat of tertiary coolant	Btu lb ⁻¹ °C ⁻¹	0.427
CF	Specific heat of fuel	Btu lb ⁻¹ °C ⁻¹	0.11
CN	Specific heat of primary and secondary coolant	Btu lb ⁻¹ °C ⁻¹	0.547
CR	Specific heat of reflector	Btu lb ⁻¹ °C ⁻¹	0.20
CSS	Specific heat of structural material (vessel, piping)	Btu lb ⁻¹ °C ⁻¹	0.216
DB	Diameter of bypass pipe	ft	0.03175
DP1	Diameter of pipe #1	ft	0.7335

TABLE I. (Continued)

Item	Definition	Unit	Value presently in program
DP2	Diameter of pipe #2	ft	0.7133
DP3	Diameter of pipe #3	ft	0.4395
DP4	Diameter of pipe #4	ft	0.4202
EL	Prompt neutron lifetime	hr	2.78E-12
FELS	Number of fuel pins in core		637.0
FK	Thermal conductivity of fuel	Btu hr ⁻¹ ft ⁻¹ °C ⁻¹	25.2
FUEHT	Height of fuel	ft	1.0
HMUL	True component flow rate/composite component flow rate		0.75
P	Center-to-center spacing of fuel pins	ft	0.04375
QFRBR	Fraction of total thermal power generated in bottom reflector		0.03
QFRTR	Fraction of total thermal power generated in top reflector		0.01
RA(1)	Precursor decay constant, delayed neutron group #1	sec ⁻¹	46.44
RA(2)	Precursor decay constant, delayed neutron group #2	sec ⁻¹	112.0
RA(3)	Precursor decay constant, delayed neutron group #3	sec ⁻¹	482.4
RA(4)	Precursor decay constant, delayed neutron group #4	sec ⁻¹	1191.6
RA(5)	Precursor decay constant, delayed neutron group #5	sec ⁻¹	4536.
RA(6)	Precursor decay constant, delayed neutron group #6	sec ⁻¹	11556.
REFHT	Height of top reflector	ft	2.0
RIP	Inner radius of clad	ft	0.01566
RK	Thermal conductivity of reflector	Btu hr ⁻¹ ft ⁻¹ °C ⁻¹	64.0
ROFUL	Density of fuel	lb ft ⁻³	686.4
RONA	Density of primary and secondary coolant	lb ft ⁻³	51.0
ROSS	Density of structural material (vessel, piping)	lb ft ⁻³	486.7
RW	Outer radius of clad	ft	0.01750
SODK	Thermal conductivity of coolant	Btu hr ⁻¹ ft ⁻¹ °C ⁻¹	66.2
SODMU	Viscosity of coolant	lb ft ⁻¹ hr ⁻¹	0.537

TABLE I (Continued)

Item	Definition	Unit	Value presently in program
VB	Mass of bypass pipe	lb	2120.
VD	Mass of heat dump tubes	lb	20811.
VNB	Coolant mass in bypass pipe	lb	1360.
VND	Mass of coolant in heat dump	lb	3242.
VNM	Coolant mass in core outlet plenum	lb	260.
VNP1	Coolant mass in pipe #1	lb	3173.
VNP2	Coolant mass in pipe #2	lb	3588.
VNP3	Coolant mass in pipe #3	lb	1628.
VNP4	Coolant mass in pipe #4	lb	2880.
VNVI	Mass of coolant between vessel inlet and core inlet	lb	2560.
VNX1	Mass of primary coolant in IHX*	lb	3133.
VNX2	Mass of secondary coolant in IHX*	lb	1050.
VP1	Mass of pipe #1	lb	5010.
VP2	Mass of pipe #2	lb	5748.
VP3	Mass of pipe #3	lb	3125.
VP4	Mass of pipe #4	lb	5573.
VVI	Mass of solid material between vessel inlet and core inlet	lb	121500.
VXS	Mass of IHX* shell	lb	8652.
VXT	Mass of IHX* tubes	lb	4350.
WK	Thermal conductivity of clad	Btu hr ⁻¹ ft ⁻¹ °C ⁻¹	78.5

*IHX defines intermediate heat exchanger

TABLE II

PROGRAM CONTROL OPTIONS WHICH MAY BE SUPPLIED AS INPUT DATA

Item	Definition	Unit	Value presently in program
DMUL	Fraction by which time steps (from convergence criteria) are multiplied prior to use in calculations		1.0
EPSI	Error criterion for kinetics equation approximation check		0.01
IP	Number of radial fuel subdivisions in DETST and DETTR		3
ITER	Number of iterations in approximate steady-state calculation		60
IZ	Number of axial fuel subdivisions in DETST and DETTR		2
J2	If < 150, causes J2 printouts at PT sec intervals, then (150-J2) printouts until total time, TT, has elapsed		150
J5	If = 2, bypasses kinetics approximation check		1
K5	If = 2, causes execution of DETST and DETTR routines		1
MIX	If = 2, five percent of each pipe is used as mixing volume		1
NPROB	Problem number		0
N6	If = 2, complete DETTR temperature distribution is printed		1
N7	If = 2, core outlet manifold is deleted		1
PT	Time interval between printouts	sec	1.0
TFB	Temperature span within which the core outlet temperature controlled feedback shutdown operates	°C	5.0
TMAXD	Maximum allowable time step for DETST loop calculations	sec	1.0E06
TMAXK	Maximum allowable time step for XNKIN loop calculations	sec	1.0E06
TMAX1	Maximum allowable time step for primary loop calculations	sec	1.0E06
TMAX2	Maximum allowable time step for secondary loop calculations	sec	1.0E06
TT	Total real time for calculation	sec	150.0

TABLE III
PROBLEM DEFINITION VARIABLES (FLOWS, POWER, ETC.) WHICH MAY BE SUPPLIED
AS INPUT DATA

Item	Definition	Unit	Value presently in program
BUCKS(I)	Reactivity worth of scram rod #I	\$	0.0
DEMA	Fraction of original tertiary coolant flow rate desired after time TDEMA		0.0
DEMQ	Power level desired after time TDEMQ	Btu hr ⁻¹	0.0
FLOC	Flow rate at pin C/average flow rate per pin		1.218
FLOE	Flow rate at pin E/average flow rate per pin		0.780
PA1 } PA2 } PA3 }	Constants to fit cosine shaped axial power distribution		0.594
			2.88
			0.245
PA4	Constant to fit control rod worth shape		0.791
PCA	Power in pin C/power in average pin		1.218
PEA	Power in pin E/power in average pin		0.780
PUM10	Time at which primary coolant speed change begins	sec	1.0E06
PUM11	Time at which primary coolant speed change finishes	sec	1.0E06
PUM20	Time at which secondary coolant speed change begins	sec	1.0E06
PUM21	Time at which secondary coolant speed change finishes	sec	1.0E06
Q	Initial core power	Btu hr ⁻¹	6.83E07
RAMBUC	Reactivity per sec in ramp	\$ sec ⁻¹	0.0
RAMTO	Time at which ramp insertion of reactivity begins	sec	1.0E06
RAMT1	Time at which ramp insertion of reactivity ceases	sec	1.0E06
RCON	Fuel cladding contact resist- ance (inverse of gap con- ductance)	Btu ⁻¹ hr ft ² °C	0.0

TABLE III (Continued)

Item	Definition	Unit	Value presently in program
RCCR	Reactivity coefficient due to bottom reflector expansion	$^{\circ}\text{C}^{-1}$	-0.00037
RCCD(I)	C pin Doppler coefficient $= T \, d\rho/dT$ (T in $^{\circ}\text{K}$)	\$	0.0
RCCN(I)	Reactivity coefficient due to expansion of coolant at C pin	$^{\circ}\text{C}^{-1}$	-0.0057
RCCX	Reactivity coefficient due to C pin fuel expansion	$^{\circ}\text{C}^{-1}$	-0.0162
RCED(I)	E pin Doppler coefficient $= T \, d\rho/dT$ (T in $^{\circ}\text{K}$)	\$	0.0
RCEN(I)	Reactivity coefficient due to expansion of coolant at E pin	$^{\circ}\text{C}^{-1}$	-0.0057
RCEX	Reactivity coefficient due to E pin fuel expansion	$^{\circ}\text{C}^{-1}$	-0.0162
RCTR	Reactivity coefficient due to top reflector expansion	$^{\circ}\text{C}^{-1}$	-0.00038
RODW	Reactivity worth of control rod used in core outlet sodium temperature controlled feed- back shutdown	\$	3.17
SCRTO(I)	Time at which scram rod I begins to move	sec	1.0E06
SCRT1(I)	Time at which scram rod I stops moving	sec	1.0E06
SODFBT	Time at which core outlet sodium temperature con- trolled feedback shutdown begins	sec	1.0E06
TAIR8	Heat dump (tertiary) coolant inlet temperature	$^{\circ}\text{C}$	20.0
TDEMA	Time at which change in ter- tiary coolant flow occurs	sec	1.0E06
TDEMQ	Time at which change in power demand occurs	sec	1.0E06
TDT	Time during which control rod moves at initial velocity V_0	sec	0.15
THR	Fraction of primary coolant flow which bypasses the IHX		0.2
TN10	Initial core inlet coolant temperature	$^{\circ}\text{C}$	480.0

TABLE III (Continued)

Item	Definition	Units	Value presently in program
TOP	Length of time reactor was at power Q prior to transient	sec	1.0E+08
TVO	Dead time for actuation of control rod having reactivity worth RODW	sec	0.5
VO	Initial velocity of control rod having reactivity worth RODW	ft sec ⁻¹	0.508
V1	Final velocity of control rod having reactivity worth RODW	ft sec ⁻¹	1.482
WTE	Volume fraction of core to be considered as fuel pins E		0.667
WN1	Primary coolant initial mass flow rate	lb hr ⁻¹	1.043E6
WN1SB	Primary coolant final mass flow rate	lb hr ⁻¹	52150.0
WN2	Secondary coolant initial mass flow rate	lb hr ⁻¹	1.04E6
WN2SB	Secondary coolant final mass flow rate	lb hr ⁻¹	52000.0
XO	Initial height of control rod having reactivity worth RODW	ft	1.8
XO(I)	Initial height of scram rod #I	ft	1.8

flow rate, etc. Because the equations for the tertiary coolant heat transfer coefficient are nonlinear, this iterative solution for the tertiary coolant flow rate is required before the next calculation is performed. The next calculation solves the simultaneous steady-state heat balance equations for the entire plant by use of the matrix solution routine LEQ (App. B). This establishes all of the steady-state system temperatures needed prior to the transient calculation, with the exception of the detailed fuel temperatures, which, if wanted, are called from the subroutine DETST, discussed in Section II-B.

The primary and secondary coolant speeds are adjusted next, if desired, and heat transfer coefficients are recalculated for the new flow rates.

Twenty-four convergence criteria are calculated for all the finite difference equations pertaining to the primary loop. The criterion giving the smallest of all maximum allowable time steps then defines the maximum allowable time step to be used in the finite difference calculation for the primary loop transient. The distance travelled by the sodium through the vessel during this time step is calculated, and new core and vessel temperatures are determined. The new detailed fuel temperature distribution may be called from DETTR (Section II-B). Heat transfer and transit distance is similarly calculated for the core outlet manifold, vessel inlet and outlet pipes, bypass pipe, and intermediate heat exchanger shell.

At this point in the program (and at any real time) various reactivity changes may be instituted. Each of six control rods of any worth may be moved from any initial position at any rate; their worth follows the usual S-shaped curve of reactivity versus height. A reactivity ramp of any rate and any duration may be imposed on the system. A bang-bang, temperature controlled feedback, control rod rundown scheme may be used. The net reactivity due to these perturbations, plus the reactivity due to temperature changes (fuel expansion, coolant expansion, reflector and structure expansion, Doppler effect) is then used by the subroutine XNKIN (Section II-E) to determine the new neutron power level.

The fission product decay heating subroutine, DECAY (Section II-D), is called, and the total thermal power is given as the sum of the decay heating power and the neutron power.

Fifteen convergence criterion time steps are calculated for the secondary loop, the smallest of these being the maximum allowable time step to be used in secondary loop calculations. The remaining intermediate heat exchanger equations involve convergence requirements for both the primary and secondary loops, and so these calculations must be performed with the smaller of the primary and secondary loop time steps. Elapsed time is observed in each loop calculation, and the number of calculations made for each loop per unit of real time is such that the elapsed time is the same in both loops. For example, if the primary loop time step were 0.13 sec and the secondary loop time step were 0.05 sec, one primary loop calculation would be made, then three secondary, then one primary, three secondary, one primary, two secondary, and so on, the two loops never being out of phase in real time by more than 0.05 sec.

Heat transfer and sodium transit time in the secondary loop piping and the heat dump primary are calculated next.

Data storage, printout, and program termination options are exercised, and, finally, the program begins another cycle of the transient calculation.

B. The Subroutines DETST and DETTR

DETST is a subroutine for calculation of the steady-state fuel and core coolant temperatures. DETTR does the same during the transient. The detailed temperature distribution is calculated by finite difference techniques for two fuel pins, each of which may be power and flow weighted to correspond to any two core locations. Each fuel pin may be considered as composed of three to ten radial heat transfer lumps and two to ten axial heat transfer lumps. The associated coolant is not subdivided radially, but has axial divisions corresponding to those of the fuel. Axial heat conduction is assumed to be negligible.

An analytic solution exists for the fuel temperature distribution in the steady state, but, at the time RAPID was written, an analytic

solution did not exist for the transient problem (See Section VI, however). Use of the temperature distribution given by the analytic steady-state solution as a starting point for the finite difference transient solution leads to difficulties (hunting, or oscillations, in the early part of the transient) since the analytic temperature distribution is not the same as the distribution which would result from solution of the steady-state portion of the finite difference approximation equations. Because of the fact that the number of heat transfer lumps per fuel pin is variable from 6 to 100, use of LEQ (App. B), the matrix solution program, to solve the steady-state portion of the finite difference approximation equations is unwieldy and requires a large amount of computer core storage. Instead of doing this, the analytic temperature distribution is used in a mock transient calculation, the results of which are temperatures which very nearly satisfy the steady-state portion of the finite difference equations. These results (labeled "approximate fuel temperature" in the printout) are then used as the starting point for the true transient. A printout of the successive results of the mock transient indicates the convergence attained.

Five time convergence criteria are used to establish the time step for DETTR calculations, and elapsed time is kept in phase with primary loop elapsed time in the manner discussed in Section 11-A.

A fuel-cladding contact resistance may be considered. The heat capacity of the clad is neglected in comparison with that of the fuel, but its thermal conductivity is considered. To obtain a better estimate of the inner clad temperature than is provided by the outermost fuel lump temperature, the curvature of the temperature profile given by the analytic steady-state solution in the small region defined by the three points--outermost fuel lump, inner clad, and coolant--is assumed to be the same throughout the transient, thereby using the calculated outermost fuel lump and coolant temperatures to determine the approximate inner clad temperature.

C. Heat Transfer Coefficient Subroutines, HXFUEL and COEFHX

The heat transfer coefficients are relegated to subroutines separate from the main routine so that the user may alter them for different

geometries, different fractional flows per component, and different manufacturer's recommendations for component heat transfer coefficients. The calculations are based on the assumption that the coefficients for an instantaneous value of a time-varying flow rate are the same as would be obtained for the same value of steady-state flow rate.

The subroutine HXFUEL presently calculates the heat transfer coefficient, or film coefficient, for an array of cylindrical fuel rods on an equilateral hexagonal pitch in turbulently flowing sodium. HXFUEL is used to calculate the film coefficient for the fuel pins and for the upper axial reflector.

The subroutine COEFHX calculates the heat transfer coefficients for turbulently flowing sodium in pipes, vessel, intermediate heat exchanger, and heat dump. The coefficients for pipes are applicable generally; the vessel heat transfer coefficient is for parallel slabs (which is a close approximation to the vessel and shielding which usually forms the bulk of the material contacted by the coolant prior to entering the core); the heat transfer coefficients for the intermediate heat exchanger and heat dump are based on the manufacturer's recommendations for these components in the FRCTF, and may need to be altered for other plants.

D. Decay Heating Subroutine, DECAY

The fission product decay heating compilation of Shure and Dudziak³ is used to determine the thermal power due to decay heating, as a function of core operating time and shutdown time. Although this compilation is based on U-235 fission-product decay heating, it is only slightly conservative for Pu-239 fission-product decay heating.⁴

Even in problems where power changes occur (e.g., ramp reactivity insertions), the fission-product decay heating is calculated on the basis of the initial, steady-state power. The shutdown time begins at time SCRT10, which is the time at which scram rod 1 begins to move. This subroutine is bypassed if the core operating time prior to transients, TOP, is specified as zero in the input data.

E. Heat Dump Subroutine, XLOAD

This is, presently, a rather trivial subroutine for calculation of the tertiary coolant (e.g., air) temperatures. It has been separated from the main program only to enable its alteration for consideration of other tertiary coolant schemes without tampering with the more complex main routine. XLOAD also treats optional heat dump power demand or flow demand.

F. Neutron Kinetics Subroutine, XNKIN

An approximate form of the point reactor kinetics equations is used to calculate the neutron power level, delayed neutron precursor concentrations, reactivity, and neutron period. Six convergence criteria are checked to determine the maximum allowable time step, and elapsed time is kept in step with elapsed time for the primary loop in the manner described in Section II-A. The approximations involved in the derivation of the modified neutron kinetics equations are checked at each time step. If the program determines that the approximations are invalid (by greater than an arbitrarily small amount, EPSI), the problem is terminated with an explanatory printout.

III. DETAILS OF EQUATIONS AND PROCEDURES OF SOLUTION

Section II of this report attempts to follow the sequence of operations involved in a calculation and discusses the operations in a general manner. The present section picks out certain characteristic features of the program and treats these features in more detail. Those features of the program which are believed to be adequately explained by Sections II and IV of this report will not be discussed in further detail.

A. Main Program, RAPID

The block diagram of the main routine is shown in Fig. 3.

1. Development of the Finite Difference Solutions to the Heat Transfer Equations

a. Explicit vs Implicit Solutions. The finite difference approximation is used for solution of the partial differential equations which describe the reactor and plant. There are many different forms into which the finite difference approximation may be cast. To see this, consider the heat conduction equation in one dimension and time:

$$\frac{\partial T}{\partial \tau} = a_t \frac{\partial^2 T}{\partial x^2} \quad (1)$$

where

T = temperature

τ = time

x = distance,

$$a_t = \frac{k}{\rho c} \quad (2)$$

k = conductivity

ρ = density

c = heat capacity.

Fig. 3. Block Diagram of Main Routine.

Fig. 3 (Cont'd). Block Diagram of Main Routine.

Fig. 3 (Cont'd). Block Diagram of Main Routine.

Fig. 3 (Cont'd). Block Diagram of Main Routine.

Fig. 3 (Cont'd). Block Diagram of Main Routine.

Fig. 3 (Cont'd). Block Diagram of Main Routine.

The finite difference mesh is illustrated below.

We shall consider, as two major categories of finite difference solutions, that by the implicit formulation and that by the explicit formulation. The implicit method solves for all temperatures at as nearly the same point in space and time as is possible. The explicit method solves for one temperature at a new time in terms of all other parameters--such as temperature--at the previously calculated time. In the explicit method, Eq. (1) becomes

$$\left(\frac{\partial T}{\partial \tau}\right)_{n,\tau + \frac{\Delta \tau}{2}} = a_t \left(\frac{\partial^2 T}{\partial x^2}\right)_{n,\tau} \quad (3)$$

where the subscripts have the meaning:

n is the space mesh point

τ is time

$\Delta \tau$ is the time step.

By the standard finite difference approximation, we define

$$\left(\frac{\partial T}{\partial \tau}\right)_{n,\tau + \frac{\Delta \tau}{2}} = \frac{T_{n,\tau + \Delta \tau} - T_{n,\tau}}{\Delta \tau} \quad (4)$$

and

$$\left(\frac{\partial^2 T}{\partial x^2}\right)_{n,\tau} = \frac{\frac{T_{n+1,\tau} - T_{n,\tau}}{\Delta x} - \frac{T_{n,\tau} - T_{n-1,\tau}}{\Delta x}}{\Delta x} \quad (5)$$

Substituting Eqs. (4) and (5) in Eq. (3), we get

$$T_{n,\tau + \Delta \tau} = \frac{1}{M} \left[T_{n-1,\tau} + (M - 2) T_{n,\tau} + T_{n+1,\tau} \right] \quad (6)$$

where

$$M = \frac{(\Delta x)^2}{a_t \Delta \tau} \quad (7)$$

From Eq. (6) it is apparent that, regardless of the values of $T_{n-1,\tau}$ and $T_{n+1,\tau}$, if

$$M < 2, \quad (8)$$

then the larger T_n is at time τ , the smaller it will be at time $\tau + \Delta \tau$. In the extreme, if inequality (8) is true, as $T_{n,\tau} \rightarrow +\infty$, $T_{n,\tau+\Delta\tau} \rightarrow -\infty$. Therefore, physical reality requires that inequality (8) be false and that a "convergence criterion,"

$$M \geq 2, \quad (9)$$

must apply in order that the solution, Eq. (6), converge toward the correct value. The amount by which M should exceed 2 is not always apparent. $M = 2$ is often referred to as the criterion of Schmidt and Binder;⁵ larger values have been suggested by Dusenberre.^{6,7} Some studies⁸ indicate that, while all values of $M \geq 2$ satisfy the convergence requirement, some values of M introduce artificial oscillations into the solution to a greater extent than do other values of M . However, since, from Eq. (7):

$$\Delta \tau = \frac{(\Delta x)^2}{M a_t}, \quad (10)$$

it is desirable, for a given Δx , to use as small a value of M as possible, in order to maximize the time step per calculation, $\Delta \tau$, and thereby reduce the computation time.

In the implicit method, the finite difference approximation to Eq. (1) is, instead of Eq. (3):

$$\left(\frac{\partial T}{\partial \tau} \right)_{n,\tau} + \frac{\Delta \tau}{2} = a_t \left(\frac{\partial^2 T}{\partial x^2} \right)_{n,\tau} + \frac{\Delta \tau}{2} \quad (11)$$

Equation (5) expresses $(\partial^2 T / \partial x^2)_{n,\tau}$ and

$$\left(\frac{\partial^2 T}{\partial x^2} \right)_{n,\tau + \Delta \tau} = \frac{T_{n+1,\tau+\Delta\tau} - 2 T_{n,\tau+\Delta\tau} + T_{n-1,\tau+\Delta\tau}}{(\Delta x)^2} \quad (12)$$

Taking

$$\left(\frac{\partial^2 T}{\partial x^2}\right)_{n, \tau + \frac{\Delta \tau}{2}} = \frac{1}{2} \left(\frac{\partial^2 T}{\partial x^2}\right)_{n, \tau} + \frac{1}{2} \left(\frac{\partial^2 T}{\partial x^2}\right)_{n, \tau + \Delta \tau} \quad (13)$$

and combining Eqs. (4), (11), and (13), and simplifying:

$$\left[T_{n+1} + T_{n-1} - (2M + 2) T_n\right]_{\tau + \Delta \tau} + \left[T_{n+1} + T_{n-1} + (2M + 2) T_n\right]_{\tau} = 0. \quad (14)$$

Equation (14) cannot be solved explicitly for any unknown temperature (at time $\tau + \Delta \tau$) in terms of known temperatures (at time τ). A set of such equations, one for each space mesh point, must be solved simultaneously at each time step. It has been shown, however,⁹ that Eq. (14) requires no convergence criterion such as inequality (9).

Before comparing the advantages and disadvantages of the explicit and implicit methods, let us consider boundary conditions. Since it is necessary for the development of RAPID, we shall consider the convective boundary condition.

The heat balance for the solid lump S_n is heat stored = heat generated - heat removed, or, by the explicit method,

$$M_{S_n} C_S \left(\frac{\partial T_S}{\partial \tau}\right)_{n, \tau + \frac{\Delta \tau}{2}} = q_{S_n, \tau} - U_{S_n} A_{S_n} [T_{S_n, \tau} - T_{Cn, \tau}] \quad (15)$$

where

M_S = solid mass per unit length

C_S = solid specific heat

q = heat generation

T_S = solid temperature

T_C = coolant temperature

U_{S_n} = overall heat transfer coefficient based on area A_{S_n} .

The solution to Eq. (15) is

$$T_{Sn, \tau + \Delta\tau} = \left[1 - \frac{U_{Sn} A_{Sn} \Delta\tau}{M_{Sn} C_S} \right] T_{Sn, \tau} + \frac{U_{Sn} A_{Sn} \Delta\tau}{2 M_{Sn} C_S} [T_{Cn+1, \tau} + T_{Cn, \tau}] + \frac{\Delta\tau}{M_{Sn} C_S} q_{Sn, \tau} \quad (16)$$

By the same argument made earlier, it is seen that Eq. (16) has the convergence criterion

$$\Delta\tau \leq \frac{M_{Sn} C_S}{U_{Sn} A_{Sn}} \quad (17)$$

Thus, both inequalities (9) and (17) limit the allowable time step.

The implicit solution solves

$$M_{Sn} \left(\frac{\partial T}{\partial \tau} \right)_{n, \tau + \frac{\Delta\tau}{2}} = q_{Sn, \tau + \frac{\Delta\tau}{2}} - U_{Sn} A_{Sn} \left[T_{Sn, \tau + \frac{\Delta\tau}{2}} - T_{Cn, \tau + \frac{\Delta\tau}{2}} \right] \quad (18)$$

assuming

$$q_{Sn, \tau + \frac{\Delta\tau}{2}} = \frac{1}{2} q_{Sn, \tau} + \frac{1}{2} q_{Sn, \tau + \Delta\tau} \quad (19)$$

to obtain

$$\begin{aligned} & 2(1 - M_1) T_{Sn, \tau + \Delta\tau} - M_1 \Delta\tau T_{Cn, \tau + \Delta\tau} - \frac{\Delta\tau}{M_{Sn} C_S} q_{Sn, \tau + \Delta\tau} - M_1 \Delta\tau T_{Cn+1, \tau + \Delta\tau} \\ & = 2(1 - M_1) T_{Sn, \tau} + M_1 \Delta\tau T_{Cn, \tau} + M_1 \Delta\tau T_{Cn+1, \tau} + \frac{\Delta\tau}{M_{Sn} C_S} q_{Sn, \tau} \end{aligned} \quad (20)$$

where

$$M_1 = \frac{U_{Sn} A_{Sn}}{M_{Sn} C_S} \quad (21)$$

The question is, "Are there convergence criteria which must be satisfied in order to use Eq. (20)?" This is not known, since implicit solutions to finite difference equations have been very scanty studied. While it is known that the implicit solution of

$$\frac{\partial T}{\partial \tau} = a \frac{\partial^2 T}{\partial x^2} \quad (22)$$

needs no convergence criteria, it is known that the implicit solution of

$$\frac{\partial^2 T}{\partial \tau} = b \frac{\partial^2 T}{\partial x^2} \quad (23)$$

does require satisfaction of convergence criteria,¹⁰ albeit less restrictive than for the explicit solution. Determining the convergence criteria for equations similar to Eq. (20) has not been attempted and will not be attempted here inasmuch as the effort involved might not bear fruit; the simultaneous solution of equations such as Eq. (20) at each time step might not result in a net saving in computational time over the explicit method, even if it were determined that convergence criteria are not needed for the implicit solution.

Consequently, the explicit solution of the finite difference equations will be used throughout this work.

b. Various Explicit Method Formulations. The explicit solution described above was not derived with any rigor; rigor was dispensed with in order to effect a comparison between the explicit and implicit formulations. It should be emphasized, however, that there is more than one finite difference approximation explicit solution to a given partial differential equation. These will now be discussed.

(1) First Formulation. Consider a calculational technique in which the heat transfer nodes in the solid are staggered relative to those in the coolant, as in the last illustration above.

We shall assume, in the following, that the coolant mass flow rate variation with time is slow enough that the approximations $W(\tau) = W(\tau + \Delta\tau)$ and $U(\tau) = U(\tau + \Delta\tau)$ are reasonably accurate. Heat conduction in the direction of flow is neglected.

A finite difference heat balance between coolant points C1 and C2 gives

$$M_C C_C \left[\frac{T_{C2}' - T_{C2}}{2} + \frac{T_{C1}' - T_{C1}}{2} \right] + \frac{W C_C \Delta\tau}{2} \left[(T_{C1}' - T_{C2}') + (T_{C1} - T_{C2}) \right] \\ + \frac{U A}{2} \left\{ \left[T_{S2}' - \frac{T_{C1}' + T_{C2}'}{2} \right] + \left[T_{S2} - \frac{T_{C1} + T_{C2}}{2} \right] \right\}, \quad (24)$$

where

W = coolant mass flow rate

M_C = mass associated with coolant node

C_C = coolant specific heat.

The primed temperatures are evaluated at time $\tau + \Delta\tau$, and the unprimed temperatures, at time τ . Other terms have been defined earlier. To obtain an explicit solution we must make the approximations:

$$T_{C1}' - T_{C2}' \approx T_{C1} - T_{C2} \quad (25a)$$

and

$$T_{S2}' - \frac{T_{C1}' + T_{C2}'}{2} \approx T_{S2} - \frac{T_{C1} + T_{C2}}{2} \quad (25b)$$

Equations (25a) and (25b) amount to assuming that the temperature gradients at time τ and at time $\tau + \Delta\tau$ are the same. These are good approximations as $\Delta\tau \rightarrow 0$.

Considering Eqs. (25a) and (25b) as equalities rather than approximations, and substituting them in Eq. (24):

$$M_C C_C (T_{C2}' - T_{C2}) = W C_C \Delta\tau (T_{C1} - T_{C2}) + U A \left[T_{S2} - \frac{T_{C1} + T_{C2}}{2} \right] \Delta\tau \quad (26)$$

Solving for T_{C2}' :

$$T_{C2}' = \left[1 - \frac{W C_C \Delta\tau}{M_C C_C} - \frac{U A \Delta\tau}{2 M_C C_C} \right] T_{C2} + \left[\frac{W C_C \Delta\tau}{M_C C_C} - \frac{U A \Delta\tau}{2 M_C C_C} \right] T_{C1} + \frac{U A \Delta\tau}{M_C C_C} T_{S2} \quad (27)$$

Using the argument introduced earlier, it is seen that, in order for the succession of solutions for T_{C2} to converge, the two brackets on the right-hand side of Eq. (27) must be positive. That is, the convergence criteria

$$\Delta\tau \leq \frac{M_C C_C}{U A + 2 W C_C} \quad (28)$$

and

$$U A \leq 2 W C_C \quad (29)$$

must be satisfied. Another physical interpretation of these two convergence criteria is obtained by substituting inequalities (28) and

(29) into Eq. (26). Inequality (29) states that the largest value of $U A$ allowed is $U A = 2 W C_C$, in which case Eq. (26) becomes

$$M_C C_C \frac{(T_{C2}' - T_{C2})}{\Delta\tau} = 2 W C_C (T_{S2}' - T_{C2}) \quad (30)$$

Inequality (29) combined with inequality (28) gives

$$\Delta\tau \leq \frac{M_C}{2 W C_C} \quad (31)$$

From inequality (31) and Eq. (30):

$$T_{C2}' \leq T_{S2} \quad (32)$$

That is, the coolant temperature cannot increase during a time step to a value greater than that of the solid from which it obtains its heat. The convergence criterion of inequality (29), $U A \leq 2 W C_C$, is difficult to satisfy since, regardless of how small one makes the mesh size to decrease A , there is always a nonzero flow rate which can violate the criterion. In practice, if this criterion is violated during a calculation, one may justifiably set $U = 2 W C_C / A$; this follows from the physical argument of relations (30) through (32). That is, the heat transfer coefficient is set at the value which would cause T_{C2}' to equal T_{S2} , its maximum physically possible value.

It should be mentioned that Dusenberre⁶ has given a rule which enables one to establish convergence criteria without going through reasoning as involved as the above. He simply asserts that the coefficients in an explicit finite difference solution should never be allowed to be negative. That sounds too simple, but it works!

(2) Second Formulation. One may also consider a calculational technique in which the heat transfer nodes are opposed, rather than staggered:

Now, a heat balance between coolant points C1 and C2 gives

$$M_C C_C \left[\frac{T_{C2}' - T_{C2}}{2} + \frac{T_{C1}' - T_{C1}}{2} \right] = \frac{W C_C \Delta \tau}{2} \left[(T_{C1}' - T_{C2}') + (T_{C1} - T_{C2}) \right] \\ + \frac{U A}{2} \left\{ \left[\frac{T_{S1}' - T_{C1}'}{2} + \frac{T_{S2}' - T_{C2}'}{2} \right] + \left[\frac{T_{S1} - T_{C1}}{2} + \frac{T_{S2} - T_{C2}}{2} \right] \right\} \quad (33)$$

To obtain an explicit solution to Eq. (33), we must again make the assumption of Eq. (25a) but, instead of Eq. (25b), we must assume the equivalent

$$T_{S1}' - T_{C1}' \approx T_{S1} - T_{C1} \quad (34a)$$

$$T_{S2}' - T_{C2}' \approx T_{S2} - T_{C2} \quad (34b)$$

whence there results

$$M_C C_C (T_{C2}' - T_{C2}) = W C_C \Delta \tau (T_{C1} - T_{C2}) + U A \left[\frac{T_{S1} + T_{S2}}{2} - \frac{T_{C1} + T_{C2}}{2} \right] \Delta \tau \quad (35)$$

Solving for T_{C2}' :

$$T_{C2}' = \left[1 - \frac{W C_C \Delta \tau}{M_C C_C} - \frac{U A \Delta \tau}{2 M_C C_C} \right] T_{C2} + \left[\frac{W C_C \Delta \tau}{M_C C_C} - \frac{U A \Delta \tau}{2 M_C C_C} \right] T_{C1} \\ + \frac{U A \Delta \tau}{2 M_C C_C} [T_{S1} + T_{S2}] \quad (36)$$

Equation (36) is similar to Eq. (27) and has the same convergence criteria of inequalities (28) and (29). However, this formulation allows one to eliminate the convergence criterion of inequality (29) if one makes an additional approximation

$$T_{S2} - T_{C2} \approx T_{S1} - T_{C1} \quad (37)$$

Then, Eqs. (35) and (37) yield

$$M_C C_C (T_{C2}' - T_{C2}) = W C_C \Delta \tau (T_{C1} - T_{C2}) + U A (T_{S2} - T_{C2}) \Delta \tau \quad (38)$$

the solution to which is

$$T_{C2}' = \left[1 - \frac{W C_C \Delta \tau}{M_C C_C} - \frac{U A \Delta \tau}{M_C C_C} \right] T_{C2} + \frac{W C_C \Delta \tau}{M_C C_C} T_{C1} + \frac{U A \Delta \tau}{M_C C_C} T_{S2} \quad (39)$$

Equation (39) has only one convergence criterion:

$$\Delta\tau \leq \frac{M_C C_C}{W C_C + U A} \quad (40)$$

Thus, the assumption of Eq. (37) eliminates the restriction on $U A$ and mitigates the restriction on $\Delta\tau$. Equation (39) is less accurate than Eq. (36) because of approximation of Eq. (37). Equation (39) is one given by Dusenberre⁷ and has no convergence problem if inequality (40) is satisfied.

(3) Third Formulation. A third formulation of the finite difference explicit solution may be obtained by taking a heat balance in the region about point C2 of the last illustration above and making an additional approximation

$$\frac{\partial T_C}{\partial x} = \frac{T_{C3} - T_{C1}}{x_3 - x_1} \quad (41)$$

where x is distance in the direction of flow. The approximation of Eq. (25a) need not be made. The heat balance is

$$M_C C_C (T_{C2}' - T_{C2}) = W C_C \Delta\tau \frac{(T_{C1} - T_{C3})}{2} + U A [T_{S2} - T_{C2}] \Delta\tau, \quad (42)$$

giving

$$T_{C2}' = \left[1 - \frac{U A \Delta\tau}{M_C C_C} \right] T_{C2} + \frac{U A \Delta\tau}{M_C C_C} T_{S2} + \frac{W \Delta\tau}{2 M_C} T_{C1} - \frac{W \Delta\tau}{2 M_C} T_{C3} \quad (43)$$

The only convergence criterion for Eq. (43) is

$$\Delta\tau \leq \frac{M C_C}{U A} \quad (44)$$

However, the approximation of Eq. (41) is a bad one, since it assumes a linear fluid temperature profile, which may be far from reality.

2. Steady State Heat Balance

Following the definition of input data, the first calculation performed is the steady-state heat balance to determine the heat dump

tertiary coolant outlet temperature and tertiary coolant mass flow rate using the system model shown below:

The various distinct heat balance equations are

$$Q = W_{N1} C_N (T_2 - T_1) \quad (45)$$

$$Q = W_{N2} C_N (T_4 - T_3) \quad (46)$$

$$Q = W_A C_A (T_6 - T_5) \quad (47)$$

$$Q = U_x A_x (\text{LMTD})_x \quad (48)$$

$$Q = U_D A_D (\text{LMTD})_A \quad (49)$$

where

Q = thermal power

W_{N1} = primary coolant mass flow rate

W_{N2} = secondary coolant mass flow rate

C_N = primary and secondary coolant specific heat

W_A = tertiary coolant mass flow rate

C_A = tertiary coolant specific heat

U_x = overall heat transfer coefficient of intermediate heat exchanger (IHX)

U_D = overall heat transfer coefficient of heat dump (HD)

A_x = heat transfer area of IHX

A_D = heat transfer area of HD

$(LMTD)_x$ = log mean temperature difference of IHX

$(LMTD)_D$ = log mean temperature difference of HD

The latter two terms are defined by

$$(LMTD)_x = \frac{(T_2 - T_4) - (T_1 - T_3)}{\ln \left(\frac{T_2 - T_4}{T_1 - T_3} \right)} \quad (50a)$$

and

$$(LMTD)_D = \frac{(T_4 - T_6) - (T_3 - T_5)}{\ln \left(\frac{T_4 - T_6}{T_3 - T_5} \right)} \quad (51a)$$

It should be noted that, as $T_2 - T_4$ approaches $T_1 - T_3$, Eq. (50a) becomes indeterminate. Moreover, a simpler expression for $(LMTD)_x$ may then be applied:

$$(LMTD)_x \approx \frac{T_2 - T_4}{2} + \frac{T_1 - T_3}{2} \quad (50b)$$

Similarly, for $(LMTD)_D$:

$$(LMTD)_D \approx \frac{T_4 - T_6}{2} + \frac{T_3 - T_5}{2} \quad (51b)$$

Now, what criterion should be employed to decide whether Eq. (50a) or Eq. (50b) should be used? Jakob¹¹ rewrites Eq. (50a) as

$$(LMTD)_x = \frac{\frac{1}{2} (\theta_0 + \theta_A)}{1 + \frac{1}{3} \left(\frac{\theta_0 - \theta_A}{\theta_0 + \theta_A} \right)^2 + \frac{1}{5} \left(\frac{\theta_0 - \theta_A}{\theta_0 + \theta_A} \right)^4 + \dots} \quad (52)$$

where

$$\theta_0 = T_2 - T_4$$

$$\theta_A = T_1 - T_3$$

So, for

$\Theta = 2$, the denominator of Eq. (52) becomes 1.04;

for

$\Theta = 1.25$, the denominator of Eq. (52) becomes 1.004;

and for

$\Theta = 1.1$, the denominator of Eq. (52) becomes 1.00075;

i.e., for $1 \leq \Theta_0/\Theta_A \leq 1.1$, Eq. (50a) and (50b) differ by less than 0.075%. Therefore, if $0.9 \leq \Theta_0/\Theta_A \leq 1.1$, use Eq. (50b), otherwise use Eq. (50a).

The overall heat transfer coefficients are defined by

$$U_x = \left[\frac{1}{H_{Nx1}} + \frac{1}{H_{Nx2}} \right]^{-1} \quad (53)$$

and

$$U_D = \left[\frac{1}{H_{ND}} + \frac{1}{H_A} \right]^{-1} \quad (54)$$

where

H_{Nx1} = primary coolant film coefficient in IHX, including 1/2 of the tube conductance

H_{Nx2} = secondary coolant film coefficient in IHX, including 1/2 of the tube conductance

H_{ND} = secondary coolant film coefficient in HD including the tube conductance

H_A = tertiary coolant film coefficient in HD.

In Eqs. (53) and (54), H_{Nx1} is a function of W_{N1} , H_{Nx2} and H_{ND} are functions of W_{N2} , and H_A a function of W_A . W_{N1} and W_{N2} are known; W_A is unknown. The heat dump and core inlet coolant temperatures are specified. Thus, we have as known quantities: Q , W_{N1} , W_{N2} , T_1 , T_5 , A_x , A_D , C_A , and C_N . The unknown quantities are T_2 , T_3 , T_4 , T_6 , U_x , U_D , W_A , $(LMTD)_x$, and $(LMTD)_D$. The procedure of solution is: Eq. (45) gives T_2 ; Eq. (53) gives U_x ; Eq. (48) gives $(LMTD)_x$; Eqs. (46) and (50) are solved simultaneously to give T_3 and T_4 ; Eqs. (47), (49) and (50a), and (51a) are solved simultaneously to give T_6 , W_A , U_D , and $(LMTD)_D$. But Eqs. (50a), (51), and (54) are generally nonlinear; hence, an iterative solution must be employed.

From Eq. (45):

$$T_2 = T_1 + \frac{Q}{W_{N1} C_N} \quad (55)$$

From Eq. (48):

$$(LMTD)_x = \frac{Q}{U_x A_x} \quad (56)$$

From Eq. (46):

$$T_4 = T_3 + \frac{Q}{W_{N2} C_N} \quad (57)$$

Put Eqs. (56) and (57) into Eq. (50b):

$$\frac{Q}{U_x A_x} = \frac{1}{2} \left(T_2 + T_1 - 2 T_3 - \frac{Q}{W_{N2} C_N} \right) \quad (58)$$

whence

$$T_3 = \frac{1}{2} \left(T_2 + T_1 - \frac{Q}{W_{N2} C_N} - \frac{2 Q}{U_x A_x} \right) \quad (59)$$

Before using Eq. (59), one must check

$$0.9 \leq \frac{T_2 - T_4}{T_1 - T_3} \leq 1.1 ; \quad (60a)$$

i.e., check

$$0.9 \leq \frac{T_2 - T_1 - \frac{Q}{W_{N2} C_N} + \frac{2 Q}{U_x A_x}}{T_1 - T_2 + \frac{Q}{W_{N2} C_N} + \frac{2 Q}{U_x A_x}} \leq 1.1 \quad (60b)$$

If inequality (60b) is satisfied, Eq. (59) may be used; otherwise, Eq. (50a) must be employed instead of Eq. (50b). To apply Eq. (50a), Eqs. (57) and (56) still apply. Putting them into (50a):

$$\frac{Q}{U_x A_x} = \frac{T_2 - T_3 - \frac{Q}{W_{N2} C_N} - T_1 + T_3}{\ln \left[\frac{T_2 - T_3 - \frac{Q}{W_{N2} C_N}}{T_1 - T_3} \right]} \quad (61)$$

or

$$\ln \left[\frac{T_2 - T_3 - \frac{Q}{W_{N2} C_N}}{T_1 - T_3} \right] = \left[\frac{T_2 - T_1 - \frac{Q}{W_{N2} C_N}}{Q} \right] U_x A_x \quad (62)$$

Let

$$\Delta = \exp \left\{ \left(T_2 - T_1 - \frac{Q}{W_{N2} C_N} \right) \left(\frac{U_x A_x}{2} \right) \right\} \quad (63)$$

Then Eqs. (62) and (63) give

$$\Delta = \frac{T_2 - T_3 - \frac{Q}{W_{N2} C_N}}{T_1 - T_3} \quad (64)$$

$$T_3 = \frac{T_2 - \Delta T_1 - \frac{Q}{W_{N2} C_N}}{1 - \Delta} \quad (65)$$

So, when inequality (60b) is satisfied, T_3 is given by Eq. (59).

When inequality (60b) is not satisfied, Eq. (65) gives T_3 .

Proceeding to the heat dump, Eq. (47) gives

$$T_6 = T_5 + \frac{Q}{W_A C_A} \quad (66)$$

where W_A is unknown; and an iterative solution must now be employed.

For positive values of Q , we know

$$T_6 < T_4 \quad (67)$$

From relations (47) and (67), we then know

$$W_A > \frac{Q}{C_A (T_4 - T_5)} \quad (68)$$

For the iteration procedure, we shall use

$$W_{A,n} = \frac{C_m Q}{C_A (T_4 - T_5)} \quad (69)$$

where

$W_{A,n}$ = nth iteration value of W_A

C_m = mth iteration value of the constant, C ,

starting the iteration with $C_m = 1.1$ and checking $W_{A,n}$ after each iteration to ensure that inequality (68) is not violated. If the iteration procedure acts so as to violate inequality (68), the iteration procedure is begun again, with $C_m = 1.01$. The procedure is repeated (decreasing $C_m - 1$ by a factor of ten) until satisfactory convergence of $W_{A,n}$ is obtained.

In order to decide whether Eq. (51a) or (51b) should be used, we apply the criterion

$$0.9 \leq \frac{T_4 - T_6}{T_3 - T_5} \leq 1.1 \quad (70)$$

From relations (66) and (70):

$$0.9 \leq \frac{T_4 - T_5 - \frac{Q}{C_A W_A}}{T_3 - T_5} \leq 1.1 \quad (71)$$

When inequality (71) is satisfied, Eqs. (66) and (51b) are used to yield

$$(\text{LMTD})_D = \frac{1}{2} \left[T_4 + T_3 - 2 T_5 - \frac{Q}{W_A C_A} \right] \quad (72)$$

When inequality (71) is not satisfied, Eqs. (66) and (51a) give

$$(\text{LMTD})_D = \frac{T_4 - T_3 - \frac{Q}{W_A C_A}}{\ln \left[\frac{T_4 - T_3 - \frac{Q}{W_A C_A}}{T_3 - T_5} \right]} \quad (73)$$

The solution procedure is: Starting with a guess for $W_{A,n}$ from Eq. (69), evaluate inequality (71) to decide on use of Eqs. (72) or (73). Using Eq. (72) or (73) to get $(\text{LMTD})_D$, put this and Eq. (53) into Eq. (49) and obtain an incorrect value of heat dump demand power Q_n^D . After a first guess for W_A , the second guess can be

$$W_{A,n+1} = \frac{W_{A,n} Q}{Q_n^D} \quad (74)$$

which may then be put through Eqs. (71), (72) or (73), (53), and (49) to get Q_{n+1}^D , the second approximation to the heat dump power demand.

This procedure could be continued until the desired convergence is obtained (i.e., the desired difference between Q_n^D and Q , as used in this program), but it converges very slowly. After two applications of Eq. (74), convergence is much more rapid if one uses

$$W_{A,n+1} = W_{A,n} + \left[\frac{Q - Q_n^D}{Q_{n+1}^D - Q_n^D} \right] [W_{A,n} - W_{A,n-1}] \quad (75)$$

Each time $W_{A,n}$ is changed, inequality (68) is checked. If inequality (68) is not satisfied, the constant C_m is reduced and the iteration begun again. Finally, Eq. (66) is used to obtain T_6 .

The preceding solution of the steady-state heat balance is performed in order to find the tertiary coolant flow rate and outlet coolant temperature. Had the describing equations been linear, that procedure would not have been necessary, and the following matrix solution of the simultaneous linear equations describing the plant would have sufficed. Although temperatures are calculated for thousands of nodes during a transient, only a few of these need be handled in the steady state. Thus, while all 200 time delay nodes in the IHX need to be considered during a transient, only the seven heat transfer nodes need be considered in the steady-state calculation. The pipes (in which heat loss to the atmosphere is considered negligible) need not be considered at all in the steady state, and core outlet coolant temperature is the same as the IHX primary coolant inlet temperature. Instead of the 4,232 temperatures calculated and stored at each time step during the transient, only 56 need be treated in the steady state. The steady-state heat balance equations are solved by the matrix solution subroutine LEQ (App. B). Figure 4 illustrates a portion of the matrix layout; the remainder can be obtained from the program listing (Section IV-A of this report). The equations themselves will not be described here, since they compose the

This matrix:

X(1)	X(2)	X(3)	X(4)	...	X(56)	
A(1,1)	A(1,2)	A(1,3)	A(1,4)	...	A(1,56)	= B(1)
A(2,1)	A(2,2)	A(2,3)	A(2,4)	...	A(2,56)	= B(2)
A(3,1)	A(3,2)	A(3,3)	A(3,4)	...	A(3,56)	= B(3)

denotes this set of equations:

$$A(1,1) X(1) + A(1,2) X(2) + A(1,3) X(3) + \dots + A(1,56) X(56) = B(1)$$

$$A(2,1) X(1) + A(2,2) X(2) + \dots + A(2,56) X(56) = B(2)$$

⋮

$$A(56,1) X(1) + A(56,2) X(2) + \dots + A(56,56) X(56) = B(56)$$

The steady-state matrix in RAPID has the form:

$T_A(1)$	$T_D(1)$	$T_{ND}(1)$	$T_A(2)$	$T_D(2)$	$T_{ND}(I)$ $I=2,66$		
$\frac{C_A W_A}{H_A A_{ND}} +$ $\frac{H_A A_{ND}}{2.0}$	$- H_A A_{ND}$	0	$-\frac{C_A W_A}{H_A A_{ND}} +$ $\frac{H_A A_{ND}}{2.0}$	0	0		= 0
$\frac{H_A A_{ND}}{2.0}$	$-\frac{H_{ND} A_{ND}}{H_A A_{ND}}$	$\frac{H_{ND} A_{ND}}{2.0}$	(2,1)	0	(2,3)	...	= 0
0	$H_{ND} A_{ND}$	$\frac{C_N W_{N2}}{H_{ND} A_{ND}} -$ $\frac{H_{ND} A_{ND}}{2.0}$	0	0	$-\frac{C_N W_{N2}}{H_{ND} A_{ND}} -$ $\frac{H_{ND} A_{ND}}{2.0}$	...	= 0
0	0	0	(1,1)	(2,1)	0	...	= 0

Fig. 4. Portion of RAPID Steady-State Matrix.

steady-state portion of the general system equations to be described later. When the equations have been solved, all previously unestablished temperatures are fixed. For example, the temperatures of the pipe and of the coolant in the pipe are all initially set at the pipe coolant inlet temperature, which is the same as the temperature (given by LEQ) of the component to which the pipe is attached.

Initial values are next set for the calculation of temperature-dependent reactivity feedback, and the transient solution is begun.

3. Change of Coolant Flow Rate

The primary (and secondary) coolant flow rates may each be altered once during a problem, starting at W_{N1} (W_{N2}) lb/h and changing between times PUM10 (PUM20) and PUM11 (PUM21) seconds to the final value W_{N1SB} (W_{N2SB}). Without going to the (presumably) unnecessarily complex step of having flow rate versus time as input data, it was difficult to decide upon a functional relation of flow versus time that properly modeled the plant. A simple cosine curve has been used in RAPID, but recent preliminary calculations of the coolant coast down for the MPBE in the FRCTF¹² indicate that a cosine curve or a simple exponential are equally poor assumptions. The coolant coast down in the primary is fit fairly well by

$$\text{new } W_{N1} = W_{N1SB} + \text{old } W_{N1} [0.55 e^{-1.42\tau} + 3.2 e^{-0.36\tau} + 1.3 e^{-0.065\tau}] \quad (76)$$

It is not known whether the sum of three exponentials would be a good fit for other plants, and so the simple cosine fit has been retained in RAPID. It should be changed if the user has better knowledge of flow rate versus time for the plant under consideration.

4. Heat Transfer

Of the three formulations described in Section II-A-1-b, the first involves better approximations than do the other two. Consequently, the formulation of Section III-A-1-b-(1) is used in RAPID.

The heat transfer calculations will be illustrated by detailing the procedure used for one reflector node. The equations for pipes, IHX, and HD primary will be similar, except for the number of nodes and the lack of internal heat generation in the extra-vessel components.

The transient calculation begins with the vessel inlet initial coolant temperature. From vessel inlet to vessel outlet, the sodium passes successively through

- 1 bottom reflector heat transfer node
- 100 time delay nodes
- 1 bottom reflector heat transfer node
- 100 time delay nodes
- either 2 fuel heat transfer nodes (coarse model) or the detailed fuel temperature calculation
- 10 time delay nodes
- 1 top reflector heat transfer node
- 10 time delay nodes
- 1 top reflector heat transfer node

All of the material contacted by sodium from vessel inlet to core inlet is considered as bottom reflector (thus, in the FRCTF, this includes the reactor vessel, shielding, and bottom reflector proper). All the material from core outlet to vessel outlet is considered as top reflector (thus, in the FRCTF, this includes top reflector proper, a portion of the fuel element handles, and outlet flow guides within the vessel). The time required for coolant to traverse the core is generally so small compared to other in-vessel coolant transit times that the lack of coolant time delay nodes in the core should be satisfactory.

The heat transfer equations for the first bottom reflector node are similar to Eqs. (16) and (27) and are typical of those for the other core and reflector nodes:

$$T_V'(1) = \left[1.0 - \frac{\Delta\tau H_{VI} A_{VI}}{C_V V_{VI}} \right] T_V(1) + \frac{\Delta\tau H_{VI} A_{VI}}{2 C_V V_{VI}} \left[T_{NV}(1) + T_{NP2}(200) \right] + \frac{\Delta\tau Q_{BR}}{2 C_V V_{VI}} \quad (77)$$

$$T_{NV}'(1) = \left[1.0 - \frac{W_{N1} \Delta\tau}{V_{NVI}} - \frac{H_{VI} A_{VI} \Delta\tau}{2 C_N V_{NVI}} \right] T_{NV}(1) + \left[\frac{W_{N1} \Delta\tau}{V_{NVI}} - \frac{H_{VI} A_{VI} \Delta\tau}{2 C_N V_{NVI}} \right] T_{NP2}(200) + \frac{H_{VI} A_{VI} \Delta\tau}{C_N V_{NVI}} T_V(1) \quad (78)$$

where the prime refers to the value after a time step $\Delta\tau$

- H_{VI} = heat transfer coefficient of bottom reflector
- A_{VI} = heat transfer area of bottom reflector
- C_V = specific heat of bottom reflector
- V_{VI} = mass of bottom reflector
- T_V = temperature of bottom reflector
- T_{NV} = temperature of sodium in bottom reflector
- T_{NP2} = temperature of sodium in pipe No. 2
- Q_{BR} = power generated in bottom reflector
- C_N = specific heat of primary coolant
- V_{NVI} = mass of primary coolant in bottom reflector

5. Maximum Allowable Time Step

Before any of the heat transfer calculations for the primary loop are performed, the convergence criteria for the heat transfer equations, given by relations of the form of inequalities (28) and (29), must be satisfied. These establish the maximum allowable time steps in each of the heat transfer equations, and the smallest of these then determines the maximum allowable time step for stability of the primary loop calculations. An externally imposed upper limit (TMAX1 seconds) and a multiplicative reduction factor (DMUL) may be applied to the resultant time step, if desired.

A similar procedure is used to determine the calculational time step for the secondary loop.

6. Coolant Transport Time Delay

In order that the computer program correctly describe the reactor and plant, it is necessary that the coolant be transported at the correct rate during the calculation. Many finite difference solutions for systems

containing a flowing fluid neglect the coolant transport time. Using the formulation of Section III-A-1-b-(1), let us examine the relation between the true transit time of the coolant and the calculational time given by the successive time steps in the heat transfer solution, taking account of the convergence criteria limits on time step size. We shall consider a section of a pipe, of length L , for which we assume a thin wall:

$$M_S = \pi D t \rho_S \quad (79a)$$

$$M_C = \frac{\pi D^2 L}{4} \rho_C \quad (79b)$$

where

ρ_S = density of pipe

ρ_C = density of coolant

$$A = \pi D L \quad (79c)$$

The convergence criteria are

$$\Delta \tau \leq \frac{M_S C_S}{U A} = \frac{\rho_S C_S t}{U} \quad (80a)$$

$$\Delta \tau \leq \frac{2 M_C C_C}{2 W C_C + U A} = \frac{\pi D^2 L \rho_C C_C}{4 W C_C + 2 \pi U D L} \quad (80b)$$

$$U \leq \frac{2 W C_C}{A} = \frac{2 W C_C}{\pi D L} \quad (80c)$$

The transit time for coolant through the length, L, of pipe is

$$\theta = \frac{M_C}{W} = \frac{\pi D^2 L \rho_C}{4 W} \quad (81)$$

Putting Eq. (81) into Eq. (80b), i.e., setting $\Delta\tau = \theta$, gives

$$\frac{\pi D^2 L \rho_C}{4 W} = \frac{\pi D^2 L \rho_C C_C}{4 W C_C + 2 \pi D L U} \quad (82)$$

or

$$2 W C_C + \pi D L U \leq 2 W C_C, \quad (83)$$

which is impossible unless L, D, or U are zero. Therefore, the calculational time step required for the convergence criterion of inequality (80b) can never be large enough to be correct for transit time of the coolant, and an artificial time delay must be used between heat exchange lumps. The other two convergence criteria are not restrictive. The troublesome criterion, inequality (80b), is that associated with coolant flow.

In RAPID, each component of the plant (e.g., a pipe) is considered to have 7 heat exchange nodes and 200 time delay nodes.

Let us consider such a pipe.

If

M_S = total pipe mass

M_C = total coolant mass in pipe

W = coolant mass flow rate,

then the time required for coolant to pass through the pipe is

$$\theta_P = \frac{M_C}{W}, \quad (84a)$$

and the transit time between heat transfer nodes is

$$\theta_N = \frac{M_C}{7 W}, \quad (84b)$$

which, as was shown above, must be greater than the calculational time step, $\Delta\tau$, as defined by the convergence criteria. Thus

$$\theta_N > \Delta\tau$$

(84c)

What is done in this program is that, for $\theta_p > 200 \Delta\tau$, the sodium temperature in each node (except heat transfer nodes) is held constant until a sufficient number of $\Delta\tau$ steps have passed to allow the sodium to travel 1/200 of the pipe length. For $\theta_p < 200 \Delta\tau$, the sodium temperature is advanced a number of time delay nodes equal to $200 \Delta\tau / \theta_p$.

Heat transfer is calculated between pipe nodes numbered 1 through 7 and the corresponding coolant nodes numbered 2, 35, 68, 101, 134, 167, and 200. The heat transfer is calculated in the manner described earlier, with one-seventh of the pipe mass being associated with each of these pipe nodes and one-seventh of the coolant mass being associated with each of these coolant nodes.

7. Core Outlet Manifold

This calculation is introduced expressly for the core-vessel configuration of the FRCTF, and will be used only if $N7 = 2$ is provided as input data. It may, however, be useful in modeling other plants.

The coolant flowing upward from the core is directed radially outward from the core to a collecting header, which connects at one point to the vessel outlet pipe. Thus, while coolant leaving the fuel element nearest the vessel outlet pipe is not delayed in time prior to entering the vessel outlet pipe, the coolant leaving the fuel element furthest from the vessel outlet pipe is delayed considerably (about 2.8 seconds for FRCTF full flow), and temperature transients are damped thereby. The manifold is treated as twenty-four parallel flow paths stored for various lengths of time according to their distance from the vessel outlet pipe, then summed. A modification of the time delay treatment mentioned earlier is employed. Heat transfer is neglected.

8. Power

The total steady-state power generation, Q , is provided as input data. The appropriate fission product decay heating, Q_{DEC} , corresponding to this is calculated by the subroutine Q_{DEC} , and the difference, $Q - Q_{DEC}$, is then the fission power which is the starting point for the neutron kinetics

calculation. During a transient other than a scram, QDEC is not altered. A scram-type of transient, defined by assignation of a value to SCRT10 (time at which scram begins) which is less than TT (total problem time), causes the fission product decay heating, QDEC, to fall off according to the compilation of Shure and Dudziak,³ while the fission power, $Q - QDEC$, follows the neutron kinetics equations.

The total power may be divided into that fraction generated in bottom reflector (QFRBR), top reflector (QFRTR), and core ($Q - QFRBR - QFRTR$). No provision is made for heat generation within the coolant. Since the vessel and shielding will normally be contacted by coolant before the coolant enters the core, they are considered, in this program, as part of the bottom reflector. Hence, QFRBR should include the power fraction deposited in the shielding.

9. Reactivity

a. Ramp reactivity insertion. Reactivity may be inserted at a rate RAMBUC dollars per second, beginning at time RAMT0 and ending at time RAMT1.

b. Control rod rundown. Six control rods may each be inserted or withdrawn at any time during a problem. For control rod No. I, movement begins from height $X0(I)$ at time SCRT0(I), and terminates at time SCRT1(I), at which time it has been fully inserted. The integral control rod worth is fit by

$$\rho = \rho_{\text{total}} \left[\sin^2 \left(\frac{PA4x}{H_c} \right) - \sin^2 \left(\frac{PA4x_0}{H_c} \right) \right], \quad (85)$$

where

x = control rod height

H_c = fuel height

x_0 = initial control rod height.

The constant PA4 in Eq. (85) allows the effective control rod height to exceed the fuel height, with the center of control rod motion at the fuel center (for MPBE, PA4 = 0.791 provides a control rod travel = 1.65 times fuel height). This allows one to account for the worth of control rods in the axial reflectors. The control rod is assumed to move at constant velocity between SCRT0(I) and SCRT1(I).

c. Feedback controlled shutdown based on core outlet coolant temperature.

Early design studies of the MPBE showed that a reactor scram leads to a very rapid drop in core outlet temperature, and this temperature drop--it was feared-- could lead to severe thermal shock problems downstream of the core (particularly at the reactor vessel outlet nozzle). This problem is caused by the high power density of the core, and so is likely to arise in all fast power reactors.

A solution employed by RAPSODIE¹³ is to isolate the vessel outlet nozzle from the outlet coolant by many concentric thermal sleeves. This, however, merely moves the problem downstream so that one needs to worry more about thermal shock in, say, the intermediate heat exchanger or pump. The solution proposed for the MPBE-FRCTF is embodied as an option in the code. It is assumed that one can anticipate scrams with a controlled shutdown. Thus, if, for example, a scram were to be initiated by a 7-second reactor period, a controlled shutdown would be initiated by a 10-second period, with the scram held in abeyance.

The controlled shutdown begins by turning off the primary coolant pump. The core outlet sodium temperature is monitored, and if it exceeds its steady-state value by more than TFB°C, the control rod is run down until the core outlet sodium temperature is at the steady-state value. Control rod motion then stops, not to begin again until the core outlet sodium temperature again rises TFB°C.

The controlled shutdown begins at time SODFBT, moving a control rod of worth RODW (After a dead time of TVO seconds) at an initial rate, V0, for the first TDT seconds and at the final rate, V1, thereafter. The control rod starts at height X0 and has a relative reactivity worth versus height as described in the preceding section.

The dead time, TVO, while neglected in the case of scram rods, is considered here because it is an appreciable portion of the total operating time in bang-bang control.

d. Reactivity feedback due to temperature changes. Averaging core temperatures prior to application of lumped temperature coefficients of reactivity is the simplest and least satisfactory treatment. For reactivity feedback effects such as absorption changes with temperature (but not for the sodium void effect), a better method could be used: the temperatures at each point could be weighted by the flux times the adjoint flux, the weighted average temperatures then being used with core average reactivity coefficients (flux times adjoint flux could be approximated by flux squared for large plants).

Neither of the above two methods satisfactorily treats the sodium void coefficient of a fast reactor. The approach used in RAPID (detailed fuel temperature option only) is believed better. It employs distributed reactivity coefficients, provided as input data. The distributed coefficients are applied to node temperatures prior to summing. Thermal reactivity feedback is calculated separately for bottom reflector expansion, top reflector expansion, fuel expansion, coolant expansion, and fuel Doppler effect.

Separate reactivity coefficients for top and bottom reflectors enable one to separate the effects of, say, bottom core plate heating and top rod handle heating. The same reflector calculations are performed for the coarse (K5=2) or detailed (K5=2) calculation. For the purpose of reactivity feedback, the bottom reflector reactivity coefficient is applied to only the second of the two bottom reflector nodes; the top reflector reactivity coefficient is applied to only the first of the two top reflector nodes.

Other reactivity coefficients use the distributed reactivity coefficients when the detailed fuel temperature option is chosen (K5=2), but average the distributed coefficients and apply them to the average temperatures when the coarse fuel temperature option (K5=2) is chosen. When information on distributed reactivity coefficients is not available, a single value may be applied at all points. In any event, the number of axial values (e.g., number of values of RCCDOP(J)) input to the calculation must correspond to the number of axial fuel nodes (IZ) specified for the calculation. As a first example, the Doppler feedback reactivity is expressed as:

$$\Delta k(\text{Doppler}) = \text{WTC} \sum_J \text{RCCDOP}(J) \sum_I \{ [\text{TFC}(I,J) - \text{TFC}_{\text{initial}}(I,J)] / [\text{TFC}(I,J) + 273.] \} \\ + \text{WTE} \sum_J \text{RCEDOP}(J) \sum_I \{ [\text{TFC}(I,J) - \text{TFC}_{\text{initial}}(I,J)] / [\text{TFC}(I,J) + 273.] \} \quad (86)$$

where

Subscript "initial" refers to the steady-state value

Subscript I refers to radial node

Subscript J refers to axial node

WTC = volume fraction of core represented by pin C

WTE = volume fraction of core represented by pin E

RCCDOP = Doppler coefficient for pin C

RCEDOP = Doppler coefficient for pin E

TFC = C pin fuel temperature

TFE = E pin fuel temperature.

The fuel expansion reactivity feedback is assumed to be a cumulative effect, so no axial variation of the fuel expansion feedback coefficient is considered:

$$\begin{aligned} \Delta k(\text{fuel expansion}) = & (WTC) (RCCX) \sum_J \sum_I [TFC(I,J) - TFC_{\text{initial}}(I,J)] \\ & + (WTE) (RCEX) \sum_J \sum_I [TFE(I,J) - TFE_{\text{initial}}(I,J)] \end{aligned} \quad (87)$$

where

RCCX = fuel expansion coefficient for C pin

RCEX = fuel expansion coefficient for E pin.

The coolant expansion reactivity feedback is given by:

$$\begin{aligned} \Delta k(\text{coolant expansion}) = & WTC \sum_J RCC2(J) \sum_I [TNC(I,J) - TNC_{\text{initial}}(I,J)] \\ & + WTE \sum_J RCE2(J) \sum_I [TNE(I,J) - TNE_{\text{initial}}(I,J)] \end{aligned} \quad (88)$$

Equation (88) enables one to calculate the behavior of a large fast reactor in which the sodium temperature coefficient of reactivity is positive at the center and negative near the edge.

The Doppler coefficient of reactivity, $T \frac{d\rho}{dT}$, has the unit $\$$ at input. All other reactivity coefficients have the unit $\$ \text{ } ^\circ\text{C}^{-1}$. Note that the reactivity coefficients are not per unit volume. Thus, the core average value of, for example, the Doppler coefficient to be used in a coarse calculation is:

$$RC1DOP = \sum_J [RCCDOP(J) + RCEDOP(J)] / [2(JMAX)] \quad (89)$$

B. Detailed Temperatures, DETST and DETTR

1. Analytic Steady-State Solution

Lacking an analytic solution to the transient problem, it is impossible to estimate the error of the transient solution (although one intuitively assumes that smaller space and time steps more closely approach the true solution). A comparison of an analytic steady-state solution with the approximate steady-state solution of the finite difference equations provides some guidance, and this is the only purpose of the analytic steady-state solution.

We shall determine the analytic radial temperature distribution in a cylindrical fuel rod, neglecting axial conduction and assuming the usual finite difference scheme in the axial direction. Thus:

where F refers to fuel, W to wall, N to coolant.

Let

α = fuel-wall thermal contact resistance (inverse of thermal conductance)

R_F = outer radius of fuel

R_{WI} = inner radius of wall

R_{WO} = outer radius of wall

T_{FO} = temperature at outer radius of fuel

T_{WO} = temperature at outer radius of wall

T_{WI} = temperature at inner radius of wall.

In the j th fuel lump, the radial temperature distribution is given by

$$\nabla^2 T_j(r) = - \frac{q_j'''(r)}{k_{Fj}}, \quad (90)$$

where

$q_j'''(r)$ = volumetric heat generation rate in lump j
 k_F = fuel thermal conductivity.

Multiplying Eq. (90) by r and integrating:

$$r \frac{dT_{Fj}(r)}{dr} = - \int \frac{q_j''' r dr}{k_{Fj}} \quad (91)$$

We now assume that the heat generation rate per unit volume, q_j''' , and the fuel conductivity, k_{Fj} , are independent of radius within a fuel rod. The first assumption is satisfactory for a fast reactor, but-- usually--not for a thermal reactor; the second assumption is satisfactory for fuel pins with small temperature gradients (e.g., metallic fuels) but poor for fuel pins with large temperature gradients (e.g., oxide fuels). The integration of Eq. (91) may then be performed.

$$r \frac{dT_{Fj}(r)}{dr} = C_1 - \frac{q_j''' r^2}{2k_{Fj}} \quad (92)$$

Integrating again, between the limits r and R_F ,

$$T_{Fj}(r) - T_{FOj} = \frac{q_j'''}{4k_{Fj}} (R_F^2 - r^2) + C_1 \ln \left(\frac{R_F}{r} \right) \quad (93)$$

But $T_{Fj}(r) - T_{FOj}$ is finite at $r = 0$, $\therefore C_1 = 0$, and

$$T_{Fj}(r) = T_{FOj} + \frac{q_j'''}{4k_{Fj}} (R_F^2 - r^2) \quad (94)$$

But

$$q_j''' = \frac{q_j}{\pi R_F^2 L} \quad (95)$$

where

q_i = total heat generated in lump i ,

whence

$$T_{Fj}(r) = T_{FOj} + \frac{q_j}{4\pi L k_{Fj}} \left(1 - \frac{r^2}{R_F^2} \right) \quad (96)$$

The heat transferred across the gap is

$$q_j = \frac{2\pi R_F L}{\alpha} (T_{FOj} - T_{WIj}) \quad (97)$$

Through the clad:

$$q_j = 2\pi L k_W \frac{(T_{WIj} - T_{WOj})}{\ln\left(\frac{R_{WO}}{R_{WI}}\right)} \quad (98)$$

Through the coolant film:

$$q_j = 2\pi R_{WO} L H_j \left(T_{WOj} - \frac{T_{Nj} + T_{Nj-1}}{2} \right) \quad (99)$$

Finally, the heat transported by flowing coolant is

$$q_j = C_N W_N (T_{Nj} - T_{Nj-1}) \quad (100)$$

where

H = coolant film heat transfer coefficient

T_{Nj} = bulk coolant temperature in j th lump

k_W = wall thermal conductivity

L = length of fuel lump

C_N = coolant specific heat

W_N = coolant flow rate per fuel pin.

Combining Eqs. (96) through (100):

$$T_{Fj}(r) = T_{Nj-1} + \left[\frac{1}{4\pi L k_{Fj}} \left(1 - \frac{r^2}{R_F^2} \right) + \frac{\alpha}{2\pi R_F L} + \frac{1}{2C_N W_N} + \frac{\ln\left(\frac{R_{WO}}{R_{WI}}\right)}{2\pi L k_W} + \frac{1}{2\pi R_{WO} L H_j} \right] q_j \quad (101)$$

The block diagram for DETST is given in Fig. 5.

2. Transient Solution

The applicable equation is

$$\rho C \frac{\partial T(r, z, \tau)}{\partial \tau} - k \nabla^2 T(r, z, \tau) = q'''(r, z, \tau) \quad (102)$$

Fig. 5. Block Diagram of DETST Subroutine.

where

ρ = density .

Neglecting axial conduction, this becomes

$$\rho C \frac{\partial T(r, \tau)}{\partial \tau} - \frac{k}{r} \frac{\partial}{\partial r} \left[r \frac{\partial T(r, \tau)}{\partial r} \right] = q'''(r, \tau) \quad (103)$$

Writing Eq. (103) in finite difference format:

$$\rho C \frac{\Delta T}{\Delta \tau} - \frac{k}{r} \frac{\Delta \left[r \frac{\Delta T}{\Delta r} \right]}{\Delta r} = q''' \quad (104)$$

Note that

$$\Delta(r^2) = 2r\Delta r \quad (105)$$

whence

$$\frac{\Delta \psi}{\Delta(r^2)} = \frac{\Delta \psi}{2r\Delta r} \quad (106)$$

while

$$2 \frac{\partial}{\partial(r^2)} \left[r \frac{\partial T}{\partial r} \right] = 2 \left[\frac{\partial r}{\partial(r^2)} \right] \cdot \left[\frac{\partial T}{\partial r} \right] + 2r \frac{\partial}{\partial(r^2)} \left[\frac{\partial T}{\partial r} \right] \quad (107)$$

In finite difference format, Eq. (107) becomes

$$2 \frac{\Delta \left(r \frac{\Delta T}{\Delta r} \right)}{\Delta(r^2)} = 2 \left[\frac{\Delta r}{\Delta(r^2)} \right] \cdot \left[\frac{\Delta T}{\Delta r} \right] + 2r \frac{\Delta \left(\frac{\Delta T}{\Delta r} \right)}{\Delta(r^2)} \quad (108)$$

From Eqs. (106) and (108):

$$2 \frac{\Delta \left(r \frac{\Delta T}{\Delta r} \right)}{\Delta(r^2)} = \frac{1}{r} \frac{\Delta T}{\Delta r} + \frac{\Delta \left(\frac{\Delta T}{\Delta r} \right)}{\Delta r} \quad (109)$$

Now, Eq. (104) may be written

$$\rho C \frac{\Delta T}{\Delta \tau} - k \left[\frac{1}{r} \frac{\Delta T}{\Delta r} + \frac{\Delta \left(\frac{\Delta T}{\Delta r} \right)}{\Delta r} \right] = q''' \quad (110)$$

From Eqs. (109) and (110):

$$\rho C \frac{\Delta T}{\Delta \tau} - 2k \frac{\Delta \left[r \frac{\Delta T}{\Delta r} \right]}{\Delta(r^2)} = q''' \quad (111)$$

or

$$\rho_i C_i \frac{(T'_i - T_i)}{\Delta \tau} - 2k_i \frac{R_i \left[\frac{T_{i+1} - T_i}{r_{i+1} - r_i} \right] - R_{i-1} \left[\frac{T_i - T_{i-1}}{r_i - r_{i-1}} \right]}{R_i^2 - R_{i-1}^2} = q_i''' \quad (112)$$

where T'_i is the value of T_i at a time $\Delta \tau$ later, and the radii are indicated in the figure below:

T_i = temperature of lump i
 T'_i = temperature of lump i
 at a time Δt later

Multiplying Eq. (112) by $\pi L(R_i^2 - R_{i-1}^2)$ gives

$$m_i C_i \frac{T'_i - T_i}{\Delta \tau} - 2k_i \pi L \left\{ R_i \left[\frac{T_{i+1} - T_i}{r_{i+1} - r_i} \right] - R_{i-1} \left[\frac{T_i - T_{i-1}}{r_i - r_{i-1}} \right] \right\} = q_i \quad (113)$$

where

m_i = mass of lump i .

For the central region, which we shall designate as region 1, Eq. (113) becomes:

$$m_1 C_1 \frac{(T'_1 - T_1)}{\Delta \tau} - \frac{2\pi k_1 R_1 (T_2 - T_1) L}{r_2 - r_1} = q_1 \quad (114)$$

For all fuel lumps except the innermost and outermost, Eq. (113) becomes:

$$\frac{m_i C_i}{\Delta \tau} (T'_i - T_i) - 2\pi k_i L \left\{ R_i \left[\frac{T_{i+1} - T_i}{r_{i+1} - r_i} \right] - R_{i-1} \left[\frac{T_i - T_{i-1}}{r_i - r_{i-1}} \right] \right\} = q_i \quad (115)$$

Designating the outermost fuel lump by $i = M$, the heat gained by lump M from lump $M-1$ is

$$2\pi k_M \frac{(T_M - T_{M-1})L}{\ln \left(\frac{r_M}{r_{M-1}} \right)} \quad , \quad (116)$$

and the heat lost through the gap to the wall is

$$U_A^M (T_M - T_W) \quad , \quad (117)$$

where

$$\frac{1}{U_A^M} = \frac{\alpha}{2\pi R_W L} \quad . \quad (118)$$

The heat balance for the outermost fuel lump is, then,

$$\frac{m_M C_M}{\Delta \tau} (T_M' - T_M) + U_A^M (T_M - T_W) + \frac{2\pi k_M L}{\ln \left(\frac{r_M}{r_{M-1}} \right)} (T_M - T_{M-1}) = q_M \quad . \quad (119)$$

The transient heat transfer equation for the wall should be considered next. This was done in an early version of the RAPID program, but it was found that, because of the small heat capacity of the wall, that equation put a very small upper bound on the allowable time step (from convergence criteria). With this in mind, the wall heat capacity was neglected. In effect, this leads to replacement of Eqs. (117) through (119) by the following:
heat lost by lump M to coolant is

$$UA(T_M - T_{Na}) \quad , \quad (120)$$

where

$$T_{Na} = \text{bulk coolant temperature.}$$

$$\frac{1}{UA} = \frac{\alpha}{2\pi R_W L} + \frac{1}{2\pi H L R_W} + \frac{\ln\left(\frac{R_W}{r_M}\right)}{\pi L(k_W + k_M)} \quad (121)$$

where

k_W = wall thermal conductivity .

$$\frac{m_M C_M}{\Delta \tau} (T'_M - T_M) + UA(T_M - T_{Na}) + \frac{2\pi k_M L}{\ln\left(\frac{r_M}{r_{M-1}}\right)} [T_M - T_{M-1}] = q_M \quad (122)$$

Solving for the unknown temperatures, from Eq. (114):

$$T'_1 = \left[1 - \frac{2\pi k_1 R_1 L \Delta t}{(r_2 - r_1) m_1 C_1} \right] T_1 + \frac{2\pi k_1 R_1 L \Delta t}{(r_2 - r_1) m_1 C_1} + \frac{q_1 \Delta t}{C_1 m_1} \quad (123)$$

From Eq. (115):

$$T'_i = \left\{ 1 - \frac{2\pi k_i L \Delta t}{m_i C_i} \left[\frac{R_i}{r_{i+1} - r_i} + \frac{R_{i-1}}{r_i - r_{i-1}} \right] \right\} T_i + \frac{q_i \Delta t}{m_i C_i} + \frac{2\pi k_i L \Delta t R_i}{m_i C_i (r_{i+1} - r_i)} T_{i+1} + \frac{2\pi k_i L \Delta t R_{i-1}}{m_i C_i (r_i - r_{i-1})} T_{i-1} \quad (124)$$

From Eq. (122):

$$T'_M = \left[1 - \frac{UA \Delta t}{m_M C_M} - \frac{2\pi k_M \Delta t}{m_M C_M \ln\left(\frac{r_M}{r_{M-1}}\right)} \right] T_M + \frac{UA \Delta t}{m_M C_M} T_{Na} + \frac{2\pi k_M L \Delta t}{m_M C_M \ln\left(\frac{r_M}{r_{M-1}}\right)} T_{M-1} + \frac{q_M \Delta t}{m_M C_M} \quad (125)$$

The convergence criteria dictated by the last three equations are:

$$\Delta \tau < \frac{(r_2 - r_1) R_1 C_1 \rho_1}{2k_1} \quad (126)$$

$$\Delta \tau < \frac{m_i C_i}{2\pi k_i L \left[\frac{R_i}{r_{i+1} - r_i} + \frac{R_{i-1}}{r_i - r_{i-1}} \right]} \quad (127)$$

$$\Delta \tau < \frac{m_M C_M \ln \left(\frac{r_M}{r_{M-1}} \right)}{UA \ln \left(\frac{r_M}{r_{M-1}} \right) + 2\pi k_M L} \quad (128)$$

Throughout these equations, the mean radius of the lump will be approximated by

$$r_i = \frac{R_i + R_{i-1}}{2} \quad (129)$$

Now, bringing the axial dimension into play, we may write the coolant heat transport equation:

$$C_N m_{Nj} \frac{T'_{Nj} - T_{Nj}}{\Delta \tau} = UA \left[T_{Mj} - \frac{T_{Nj} + T_{Nj-1}}{2} \right] - C_N W_N [T_{Nj} - T_{Nj-1}] \quad (130)$$

whence

$$T'_{Nj} = \left[1 - \frac{UA \Delta t}{2C_N m_{Nj}} - \frac{W_N \Delta t}{m_{Nj}} \right] T_{Nj} + \frac{UA \Delta t}{C_N m_{Nj}} T_{Mj} + \left[\frac{W_N \Delta t}{m_{Nj}} - \frac{UA \Delta t}{2C_N m_{Nj}} \right] T_{Nj-1} \quad (131)$$

The convergence criteria for Eq. (131) are:

$$\Delta \tau < \frac{2C_N m_{Nj}}{UA + 2C_N W_N} \quad (132)$$

$$UA < 2C_N W_N \quad (133)$$

with UA given by Eq. (121) and

$$T_{Naj} = \frac{T_{Nj} + T_{Nj-1}}{2} \quad (134)$$

The block diagram of the DETTR subroutine is given in Fig. 6.

Fig. 6. Block Diagram of DETTR Subroutine.

Fig. 6 (Con't). Block Diagram of DETTR Subroutine.

C. Heat Transfer Coefficients, HXFUEL and COEFHX

1. Fuel and Reflector Rods

The relation given in the HXFUEL subroutine provides for calculation of the mean heat transfer coefficient from cylindrical rods in a hexagonal array to flowing sodium. The relation, from Maresca and Dwyer,¹⁴ is:

$$Nu = \alpha \left\{ 6.66 + 3.126 \left(\frac{P}{D} \right) + 1.184 \left(\frac{P}{D} \right)^2 + 0.0155 (\bar{\Psi} Pe)^{0.86} \right\} \quad (135)$$

The parameter α is intended to account for closely packed lattices and is approximately¹⁵

$$\alpha = \begin{cases} 1.0 & \text{for } P/D \geq 1.4 \\ 0.95 & 1.3 \leq P/D < 1.4 \\ 0.9 & 1.2 \leq P/D < 1.3 \\ 0.8 & P/D < 1.2 \end{cases} \quad (136)$$

where

Nu = Nusselt number

D = rod diameter

P = pitch = center-to-center spacing of rods

Pe = Peclet number = Re Pr

$\bar{\Psi}$ = ratio of heat transfer eddy diffusivity to momentum transfer eddy diffusivity

Re = Reynolds number

Pr = Prandtl number.

2. Pipes and Hot Trap

Measurements on sodium heat transfer at Los Alamos have agreed best with the Martinelli and Lyon relations. The Lyon equation¹⁶ is used for pipe-to-sodium and hot trap-to-sodium heat transfer in RAPID:

$$Nu = 7 + 0.025 Pe^{0.8} \quad (137)$$

3. Shielding and Vessel

Because of their large radii of curvature, heat transfer for the vessel and shielding is calculated by the relation for sodium flowing between parallel slabs:¹⁶

$$Nu = 10.5 + 0.036 Pe^{0.8} \quad (138)$$

4. Intermediate Heat Exchangers

The heat transfer relations used for the intermediate heat exchangers are those used by the Baldwin-Lima-Hamilton Company in their design of the 5 MW and 15 MW heat exchangers for the Fast Reactor Core Test Facility. For the tube-side, the Lubarsky-Kaufman relation is used:¹⁶

$$Nu = 0.625 (Pe)^{0.4} \quad (139)$$

For the shell side, a modified Donahue equation is used:¹⁶

$$Nu = 0.128 (De Pe)^{0.6} \quad (140)$$

where

De = equivalent diameter.

5. Heat Dumps

For the heat dumps, the relation followed is that used by the manufacturer of the FRCTF heat dump (Struthers-Wells). They use the Colburn relation for the exterior of unbaffled staggered tubes:¹⁷

$$Nu = 0.33 Pr^{1/3} Re^{0.6} \quad (141)$$

Using the heat transfer coefficient, h , determined from Eq. (141), a correction for fin efficiency is applied based on Jackson¹⁸ curve JCF-4. For the FRCTF, which had fins 0.042-in. thick by 0.75-in. high with $11.1 \text{ Btu/hr}^{-1} \text{ ft}^{-1} \text{ }^{\circ}\text{F}^{-1}$ conductivity, the heat transfer coefficient including fin efficiency, h' , is related to the heat transfer coefficient without fin efficiency, h (given by Eq. (141)), as

$$h' = 0.860h + \frac{195h}{h + 22} \quad (142)$$

for h in units of $\text{Btu hr}^{-1} \text{ft}^{-2} \text{°F}^{-1}$.

The block diagram of the heat transfer coefficient subroutine COEFHX is shown in Fig. 7.

D. Decay Heating, DECAV

The heating due to fission product decay used in RAPID is based on the results of a review of available information on fission product energy release for U-235 thermal fission.³ Recent LASL work⁴ indicates that fission product decay heating following Pu-239 fast fission is only slightly less than that following U-235 thermal fission. The aforementioned review summarizes the results by an expression of the form:

$$M(\infty, t_s) = A t_s^{-a}, \quad (143)$$

where

t_s = shutdown time, seconds

$M(\infty, t_s)$ = MeV ($\beta + \gamma$) per fission at time t_s following infinite reactor operation.

For constant reactor operation at power, P , for t_0 seconds, the total decay power, P_d , can be found from the expression

$$P_d = 0.005P [M(\infty, t_s) - M(\infty, t_0 + t_s)] \quad (144)$$

The constants A and a depend on t_s or $t_0 + t_s$ thus:

$$10^{-1} \leq t \leq 10^1, A = 12.05, a = 0.0639$$

$$10^1 < t \leq 1.5 \times 10^2, A = 15.31, a = 0.1807$$

$$1.5 \times 10^2 < t \leq 8 \times 10^8, A = 27.43, a = 0.2962$$

E. Neutron Kinetics, XNKIN

The point reactor kinetics equations may be written

Fig. 7. Block Diagram of COEFHX Subroutine.

$$\frac{dq}{d\tau} = \left(\frac{\rho - \beta}{\ell^*} \right) q + \sum_{i=1}^N \lambda_i C_i, \quad (145)$$

$$\frac{dC_i}{d\tau} = \frac{\beta_i}{\ell^*} q - \lambda_i C_i, \quad i=1, N. \quad (146)$$

In solving these equations by a forward step finite-difference technique, it is necessary to use a small enough calculational time step to ensure stability of the calculation (note: convergence of the calculation to the correct solution will not be discussed here, only stability). Scarborough¹⁹ states that the finite difference approximation solution to

$$\frac{dx}{d\tau} = f_1(x, y, \tau) \quad (147)$$

$$\frac{dy}{d\tau} = f_2(x, y, \tau) \quad (148)$$

is stable if

$$\Delta\tau < \frac{1}{\left| \frac{\partial f_1}{\partial x} \right|_{\max} + \left| \frac{\partial f_2}{\partial x} \right|_{\max}} \quad (149)$$

and

$$\Delta\tau < \frac{1}{\left| \frac{\partial f_1}{\partial y} \right|_{\max} + \left| \frac{\partial f_2}{\partial y} \right|_{\max}} \quad (150)$$

Applying relation (149) to Eqs. (145) and (146):

$$\Delta\tau < \frac{1}{\left| \frac{\rho - \beta}{\ell^*} \right|_{\max} + \sum_{i=1}^N \left| \frac{\beta_i}{\ell^*} \right|_{\max}}, \quad (151)$$

or, since $\frac{\beta_i}{\ell^*}$ is positive,

$$\Delta\tau < \frac{1}{\left| \frac{\rho - \beta}{\ell^*} \right|_{\max} + \frac{\beta}{\ell^*}} \quad (152)$$

Similarly, applying relation (150) to Eqs. (145) and (146):

$$\Delta\tau_i < \frac{1}{\left| \lambda_i \right|_{\max} + \sum_{i=1}^N \left| -\lambda_i \right|_{\max}}, \quad i=1, N, \quad (153)$$

or, since all λ_i are positive,

$$\Delta\tau_i < \frac{1}{\lambda_i + \lambda}, \quad i=1, N. \quad (154)$$

Inequality (152) illustrates the difficulty of a straightforward application of the point reactor kinetics equations to a fast reactor such as the MPBE. For the MPBE, $\ell^* \sim 10^{-8}$ sec and $\beta \sim 0.0021$. Thus, in two extremes, relation (152) shows that

as $\rho \rightarrow 0$, $\Delta\tau \rightarrow \ell^*/2\beta = 2.5 \times 10^{-6}$ sec

as $\rho \rightarrow \beta$, $\Delta\tau \rightarrow \ell^*/\beta \rightarrow 5 \times 10^{-6}$ sec.

while, for a typical U-235 fueled thermal reactor,

as $\rho \rightarrow 0$, $\Delta\tau \rightarrow 0.07$ sec

as $\rho \rightarrow \beta$, $\Delta\tau \rightarrow 0.14$ sec.

Hence, in performing kinetics calculations for the MPBE, the IBM 7094 computing time would be many orders of magnitude greater than real time, in order to achieve a computational time step of a few microseconds. To avoid this difficulty, it is observed that $dq/d\tau$ is very much smaller than the other terms in Eq. (145) when $\rho \ll \beta$. Thus, Eq. (145) may be approximated by

$$0 = \frac{\rho - \beta}{\ell^*} q + \sum_{i=1}^N \lambda_i C_i, \quad i=1, N. \quad (155)$$

This has the solution

$$q = \frac{\ell^*}{\beta - \rho} \sum_{i=1}^N \lambda_i C_i \quad (156)$$

Equations (146) and (156) combine to

$$\frac{dC_i}{d\tau} = \frac{\beta_i}{\beta - \rho} \sum_{i=1}^N \lambda_i C_i - \lambda_i C_i, \quad i=1, N \quad (157)$$

Applying relation (149) to the N equations of the type of Eq. (157):

$$\Delta\tau_i < \frac{1}{\left| -\lambda_i + \frac{\beta_i \lambda_i}{\beta - \rho} \right|_{\max} + \sum_{j=1}^N \left| \frac{\beta_j \lambda_i}{\beta - \rho} \right|_{\max}}, \quad i=1, N \quad (158)$$

or

$$\Delta\tau_i < \frac{1}{\left| \frac{1 - \beta_i}{\beta - \rho} \lambda_i \right|_{\max} + \left| \frac{\beta \lambda_i}{\beta - \rho} \right|_{\max}}, \quad i=1, N \quad (159)$$

Within the limits $-\infty < \rho < \beta$,

$$\Delta\tau_i < \frac{\beta - \rho}{\lambda_i (1 + \beta - \beta_i)} \quad (160)$$

Relation (160) avoids the small computational time step requirement of relation (152). To ensure the suitability of the approximation, the calculation is terminated when

$$\left| \frac{dq}{d\tau} \right| > \varepsilon \left| \frac{\rho - \beta}{\ell^*} q \right|, \quad (161)$$

where ε is an arbitrarily small number, less than unity.

The block diagram for the subroutine XNKIN is given in Fig. 8.

Fig. 8. Block Diagram of XNKIN Subroutine.

IV. FORTRAN LISTINGS

RAPID

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COMMON A,B,Q,FELS,IP,JP,WN1,AF,RIP,FUEHT,RW ,FK,WK
1,CN,RCN ,CF,VF,VNC,ET,ETD, M,DMUL
2,TNAC ,TF0C,TFC,CURVC,TNAE ,TF0E,TFE,CURVE
3,DQD,TFD ,ZD,TN,TF0,RD,R1,PD
4,P,S0DK,S0DMU,DWN1,QINIT,T0P,SCRT0
5,TNV2,N6,R2,DELTD,TMAXD,TMAXK,QFRC
6,PA1,PA2,PA3,PCA,PEA,FL0C,FL0E,W,X,TA,TD
7,BE,BA,RA,EL,SUMC,DELK,DELTAK,ETK,K2,TAU,EPSI,J5,QN,QDEC
8,K4,TDEMA,DEMA,WA,TDEMQ,DEMQ,CA,HMUL,ITER
DIMENSIONA( 56, 56),B( 56,1)
DIMENSIONAA(3192)
DIMENSIONTA(10),TD(10),TND(210),TNP4(210),TNB(210),TNBP(210),
1TNP3(210),TNX2(210),TXT(10),TNX1(210),TAT(50),TNP1(210),TNP2(210)
2,TXS(10),TNV(230),TV(6),SCRT1(6),X0(6),BUCKS(6),X3(6),
3TF(3),TDP(10),TNDP(210),TNP4P(210),TNP3P
4(210),TNX2P(210),TXTP(10),TNX1P(210),TNP1P(210),TNM(210),TNMP
5(210),TNP2P(210),TXSP(10),TNVP(230),TVP(6),
6TFP(3),T1(150),T2(150),T3(150),T4(150),T5(150),
7T6(150),Q1(150),W1(150),W2(150),W3(150),NW0RDS
8(150),X1(150),XYBND(4),BA(6),RA(6) ,Q2(150),
9T7(150),T8(150),T9(150),T10(150),T11(150),T12(150)
DIMENSIONT13(150),T14(150),T15(150),T16(150),R0D (150),RH0 (150)
DIMENSIONTNAC(15) ,TF0C(15),TFC(10,15),CURVC(15),TNAE
1(15) ,TF0E(15),TFE(10,15),CURVE(15)
2,DQD(15),TFD(10,15) ,ZD(15),TN(15),RD(10),R1(10)
3,PD(15),TF0(15),XMX(12)
4,TFCI(10,15),TFEI(10,15),RCCD0P(13),RCED0P(13),RCC2(13),RCE2(13)
5,RCCD(10),RCED(10),RCCN(10),RCEN(10)
DIMENSIONZELT1(32),ZELT2(20)
1,TP1(10),TP1P(10),TP2(10),TP2P(10),TP3(10),TP3P(10),TP4(10),TP4P(1
20),TB(10),TBP(10)
DIMENSIONR2(10),SCRT0(6)
EQUIVALENCE(A,AA),(B,AA(3137)),(RCCN,RCC2(4)),(RCEN,RCE2(4)),
1(RCCD,RCCD0P(4)),(RCED,RCED0P(4))
EQUIVALENCE(AA,X1),(AA(151),T1),(AA(301),T2),(AA(451),T3),(AA(601)
1,T4),(AA(751),T5),(AA(901),T6),(AA(1051),T7),(AA(1201),T8),(AA(135
21),T9),(AA(1501),T10),(AA(1651),T11),(AA(1801),T12),(AA(1951),T13)
3,(AA(2101),T14),(AA(2251),TFCI),(AA(2401),TFEI),(AA(2551),R0D),
4(AA(2701),RH0),(AA(2851),Q1),(AA(3001),Q2)
CALL BCDC0N(420HQ,WN1,WN2,WN1SB,WN2SB,RIP,P,TN10,TAIR8,IP,IZ,NPR0B
1,TT,T0P,FELS,FUEHT,REFHT,EL,RW,CR,CF,CN,CA,CSS,WK,FK,RK,S0DK,S0DMU
2,EPSI
3
4
5
6
7,Q,WN1,WN2,WN1SB,WN2SB,RIP,P,TN10,TAIR8,IP,IZ,VPR0B,TT,T0P,FELS,FU
8EHT,REFHT,EL,RW,CR,CF,CN,CA,CSS,WK,FK,RK,S0DK,S0DMU,EPSI)
CALL BCDC0N(420HDP1,DP2,DP3,DP4,DB,VP1,VP2,VP3,VP4,VB,VNP1,VNP2,VN
1P3,VNP4,VNB,ANP1,ANP2,ANP3,ANP4,ANB,AXS,VXS,ANX,VXT,VNX2,VNX1,AND,
2VND,VD,VVI,AVI,VNVI
3
4
5
6

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RAPID

7,DP1,DP2,DP3,DP4,DB,VP1,VP2,VP3,VP4,VB,VNP1,VNP2,VNP3,VNP4,VNB,ANP
81,ANP2,ANP3,ANP4,ANB,AXS,VXS,ANX,VXT,VNX2,VNX1,AND,VND,VD,VVI,AVI,
9VNV1)

CALL BCDCON(420HTHR,R0DW,V0,V1,S0DFBT,TV0,X0,BA(6),RA(6),SCRT0(6),
1SCRT1(6),X0(6),BUCKS(6),PA4,TFB,TDI

2

3

4

5

6

7,T4R,R0DW,V0,V1,S0DFBT,TV0,X0,BA,RA,SCRT0,SCRT1,X0,BUCKS,PA4,TFB,T
8DT)

CALL BCDCON(420HRAMBUC,RAMTO,RAMT1,PT,DEMA,DEMQ,TDEMA,TDEMQ,MIX,QF
1RBR,QFRTR,R0SS,R0NA,R0FUL,ARRAY,J2,J5,K5,N6,N7,VNM,RC0N

2

3

4

5

6

7,RAMBUC,RAMTO,RAMT1,PT,DEMA,DEMQ,TDEMA,TDEMQ,MIX,QFRBR,QFRTR,R0SS,
8R0NA,R0FUL,ARRAY,J2,J5,K5,N6,N7,VNM,RC0N)

CALL BCDCON(420HWTE,PA1,PA2,PA3,PCA,PEA,FL0C,FL0E,PUM10,PUM20,PUM1
11,PUM21,DMUL,TMAX1,TMAX2,TMAXD,TMAXK,HMUL,ITER

2

3

4

5

6

7,WTF,PA1,PA2,PA3,PCA,PEA,FL0C,FL0E,PUM10,PUM20,PUM11,PUM21,DMUL,TM
8AX1,TMAX2,TMAXD,TMAXK,HMUL,ITER)

CALL BCDCON(420HRCCD(10),RCED(10),RCCN(10),RCEV(10),RCCX,RCEX,RCBR
1,RCTR

2

3

4

5

6

7,RCCD,RCED,RCCN,RCEN,RCCX,RCEX,RCBR,RCTR)

1 CALL ADVFLM(0,5)

C-----
C BUCKS(I) \$ OF REACTIVITY ADDED BETWEEN TIME=SCRT0(I) AND
C SCRT1(I) SECONDS, FROM ROD HEIGHT=X0(I), WHERE I=1,2,3,4,5,6.
C PUMP SHUTDOWN BETWEEN PUM10 AND PUM11 SECONDS FOR PRIMARY, PUM20
C AND PUM21 SECONDS FOR SECONDARY.
C CORE OUTLET NA F.B. CONTROLLED SHUTDOWN STARTS AT S0DFBT SECONDS,
C AT V0 FPS INITIAL VELOCITY AND V1 FPS TERMINAL VELOCITY. ROD
C WORTH=R0DW \$. INITIAL ROD HEIGHT=X0.
C J2 LESS THAN 150 CAUSES J2 PRINTOUTS AT PT SECOND INTERVALS, THEN
C (150-J2) PRINTOUTS UNTIL TOTAL TIME, TT, HAS ELAPSED.
C AIR FLOW CHANGES TO DEMA * ORIGINAL AT TIME=TDEMA
C POWER DEMAND CHANGES TO DEMQ AT TIME=TDEMQ
C RAMP REACTIVITY INPUT AT RAMBUC \$/SEC, BETWEEN RAMTO AND RAMT1
C SECONDS.
C K5 OF 2 CAUSES EXECUTION OF DETST AND DETTR SUBROUTINES
C PT OF X CAUSES PRINTOUT EVERY X SECONDS. MAXIMUM OF 150 PRINTOUTS.
C DMUL=TIME STEP MULTIPLIER

RAPID

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C      N6 OF 2 PRINTS COMPLETE DETTR TEMPERATURE DISTRIBUTION
C      N7 OF 2 DELETES CORE OUTLET MANIFOLD
C      IZ=NUMBER OF AXIAL NODES PER FUEL PIN, IZMIN=2, IZMAX=10.
C      IP=NUMBER OF RADIAL NODES PER FUEL PIN, IPMIN=3, IPMAX=10.
C      NOTE-RCCD, RCED, RCCN, AND RCEN MUST EACH HAVE IZ VALUES. E.G.
C          IF IZ=5, THEN RCCD(1) THRU RCCD(5) MUST BE INPUT, AND
C          RCCD(6) THRU RCCD(10) ARE NOT USED IN THE CALCULATION.
C      TOP=TIME AT POWER, SECONDS. IF TOP=0.0, QDEC IS BYPASSED.
C      JS=2 BYPASSES KINETICS APPROXIMATION CHECK
C      MIX OF 2 CONVERTS 5 PERCENT OF EACH PIPE TO A MIXING VOLUME
C      TMAX1,TMAX2,TMAXD,TMAXK=MAX TIME STEP (SECS) FOR CALCS IN
C          PRIMARY, SECONDARY, DETTR, XNKIN, RESPECTIVELY.
C      ARRAY=1.USES HEX CORE ARRAY,2.USES SQUARE CORE ARRAY
C      HMUL=TRUE COMPONENT FLOW/ TOTAL COMPONENTS FLOW, IS A FLOW
C          REDUCTION FACTOR USED WHEN CALCULATING H FOR COMPOSITE
C          IHX AND HD
C      ITER=NUMBER OF ITERATIONS TO GO FROM ANALYTIC TO APPROX IN DETST
C-----
C      PROGRAM INTERNAL VALUES
C      SYSTEM CONSTANTS
C      ANB=3782.
C      AND=1549.
C      ANP1=350.
C      ANP2=453.
C      ANP3=272.
C      ANP4=437.
C      ANX=1171.
C      ARRAY=1.0
C      AVI=2940.
C      AXS=600.
C      BA(1)=0.000080
C      BA(2)=0.000588
C      BA(3)=0.000454
C      BA(4)=0.000689
C      BA(5)=0.000216
C      BA(6)=0.000074
C      CA=0.427
C      CF=0.11
C      CN=0.547
C      CR=0.20
C      CSS=0.216
C      DB=0.03175
C      DP1=0.7335
C      DP2=0.7133
C      DP3=0.4395
C      DP4=0.4202
C      EL=2.78E-12
C      FELS=637.0
C      FK=25.2
C      FUEHT=1.0
C      HMUL=0.75
C      P=0.04375
C      QFRBR=0.03
C      QFRTR=0.01
C      RA(1)= 46.44
C      RA(2)= 112.0

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RAPID

RA(3)= 482.4
 RA(4)= 1191.6
 RA(5)= 4536.0
 RA(6)=11556.0
 REFHT=2.0
 RIP=0.01566
 RK=64.0
 RGFUL=686.4
 RONA=51.0
 ROSS=486.7
 RW=0.01750
 SODK=66.2
 SODMU=0.537
 VB=2120.
 VD=20811.
 VNB=1360.
 VND=3242.
 VNM=260.
 VNP1=3173.
 VNP2=3588.
 VNP3=1628.
 VNP4=2880.
 VNV1=2560.
 VNX1=3133.
 VNX2=1050.
 VP1=5010.
 VP2=5748.
 VP3=3125.
 VP4=5573.
 VVI=121500.
 VXS=8652.
 VXT=4350.
 WK=78.5

C PROGRAM CONTROL OPTIONS

DMUL=1.0
 EPSI=0.01
 IP=3
 ITER=60
 IZ=2
 J2=150
 J5=1
 K5=1
 MIX=1
 NPR0B=0
 N6=1
 N7=1
 PT=1.0
 TMAXD=1000000.
 TMAXK=1000000.
 TMAX1=1000000.
 TMAX2=1000000.
 TT=150.0

C PROBLEM DEFINITION VARIABLES

DEMA=0.0
 DEMQ=0.0
 FL3C=1.218

RAPID

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FLGE=0.780
PA1=0.594
PA2=2.88
PA3=0.245
PA4=0.791
PCA=1.213
PEA=0.780
PUM10=1000000.0
PUM11=1000000.0
PUM20=1000000.0
PUM21=1000000.0
Q=5.826E+07
RAMBUC=0.0
RAMT0=1000000.0
RAMT1=1000000.0
RCUN=0.0
D05503I=1,10
RCCD(I)=0.0
RCED(I)=0.0
RCCN(I)=-0.0057
5503 RCEN(I)=-0.0057
RCCX=-0.0162
RCEX=-0.0162
RCBR=-0.00037
RCTR=-0.00038
D05504I=1,6
SCRT0(I)=1000000.0
SCRT1(I)=1000000.0
X0(I)=1.8
5504 BUCKS(I)=0.0
R0DW=0.0
S0DFBT=1000000.0
TAIR8=20.0
TDEMA=1000000.0
TDEMQ=1000000.0
TDT=0.15
TFB=5.0
THR=0.2
TN10=480.0
TOP=1.0E+08
TV0=0.5
VO=0.508
V1=1.482
WTE=0.667
WN1=1.043E+06
WN1SB=52150.0
WN2=1.040E+06
WN2SB=52000.0
X0=1.8
C INITIAL VALUES
DELK=0.0
DN=0.0
ET=0.0
ETD=0.0
ETK=0.0
ET2=0.0

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RAPID

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ET3=0.0
ET31=0.0
IC=0
IT=0
J9=0
K2=1
K4=1
L1=1
LUMB=0
LUMBR=0
LUMHD=0
LUMM=0
LUMP1=0
LUMP2=0
LUMP3=0
LUMP4=0
LUMTR=0
LUMX1=0
LUMX2=0
QDEC=0.0
RR=0.0
RRX=0.0
RR1=0.0
RR2=0.0
R7=0.0
R8=0.0
R9=0.0
SUMDOP=0.0
SUMEX=0.0
XLUMB=0.0
XLUMBR=0.0
XLUMHD=0.0
XLUMM=0.0
XLUMP1=0.0
XLUMP2=0.0
XLUMP3=0.0
XLUMP4=0.0
XLUMTR=0.0
XLUMX1=0.0
XLUMX2=0.0
XM=1.0
2 CALL SYMBOL(I1,10)
IP=IP
ITER=ITER
IZ=IZ
J2=J2
J5=J5
K5=K5
MIX=MIX
NPROB=NPROB
N6=N6
N7=N7
CALL HDTAPE(9)
X3=X0
JP=IZ+5
JP1=JP-1

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RAPID

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      JP2=JP-2
      JP5=JP-5
      WTC=1.0-WTE
      WNB=THR*WN1
      CV=CSS
      TA(8)=TAIRB
      BE=0.0
      DO 10 I=1,6
10    BE=BE+BA(I)
C    CONVERT UNIT SIZE TO HEAT TRANSFER NODE SIZE
      VP1=VP1/7.
      VP2=VP2/7.
      VP3=VP3/7.
      VP4=VP4/7.
      VB=VB/7.
      VNP1=VNP1/7.
      VNP2=VNP2/7.
      VNP3=VNP3/7.
      VNP4=VNP4/7.
      VNB=VNB/7.
      ANP1=ANP1/7.
      ANP2=ANP2/7.
      ANP3=ANP3/7.
      ANP4=ANP4/7.
      ANB=ANB/7.
      AXS=AXS/7.
      VXS=VXS/7.
      ANX=ANX/7.
      VXT=VXT/7.
      VNX2=VNX2/7.
      VNX1=VNX1/7.
      AND=AND/7.
      VND=VND/7.
      VD=VD/7.
      VVI=VVI/2.
      AVI=AVI/2.
      VNVI=VNVI/2.
C    CALCULATE CORE AND VESSEL MASSES AND AREAS
      AF=3.1416*RW*FELS*FUEHT
      VF=1.5708*(RW**2.0)*FELS*FUEHT*R0FUL
      AV0=3.1416*RW*FELS*REFHT
      VV0=1.5708*(RW**2.0)*FELS*REFHT*R0SS
      IF (ARRAY-2.0) 1629,1630,1630
1629 VNC=(0.4617*P**2.0-1.5708*RW**2.0)*FUEHT*FELS*R0NA
      GOT01628
1630 VNC=FUEHT*FELS*R0NA*P**2.0/2.0-VF
1628 VNV0=VNC*REFHT/FUEHT
      QFRC=1.0-QFRBR-QFRTR
      PUMS1=PUM11-PUM10
      PUMS2=PUM21-PUM20
104  FORMAT(1H0,10X,10HWA           =F15.6)
107  FORMAT(1H0,10X,10HHNX1        =F15.6)
108  FORMAT(1H0,10X,10HHNX2        =F15.6)
109  FORMAT(1H0,10X,10HHND         =F15.6)
110  FORMAT(17H   EDGE INTERFACE10F7.1)
111  FORMAT(16H  FRACT FUEL HT =10F7.3)

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RAPID

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112 FORMAT(17H CENTER INTERFACE10F7.1)
120 FORMAT(20H CENTER SODIUM      12F7.1)
121 FORMAT(20H  EDGE SODIUM      12F7.1)
200 FORMAT(1H0,24X,2HTA,18X,2HTD,18X,3HTND)
201 FORMAT(1H ,10X,3F20.4)
202 FORMAT(1H ,50X,1F20.4)
203 FORMAT(1H0,24X,4HTNX2,18X,3HTXT,18X,4HTNX1)
204 FORMAT(1H ,10X,3F20.4)
205 FORMAT(1H ,10X,1F20.4)
206 FORMAT(1H ,50X,1F20.4)
207 FORMAT(1H0,24X,5HSOLID,5X,6HCORENA)
208 FORMAT(1H ,21X,2F10.3)
299 FORMAT(1H ,97X,F11.1)
302 FORMAT(17H FR. FUEL RADIUS=11F7.3)
303 FORMAT(14H FR. FUEL HT.=F5.2,11F7.1)
304 FORMAT(1H ,6X,32HAPPROXIMATE EDGE PIN FUEL TEMP C,63X,6HSODIUM)
306 FORMAT(1H ,5X,34HAPPROXIMATE CENTER PIN FUEL TEMP C,63X,6HSODIUM)
1000 FORMAT(1H0,3X,10HINPUT DATA)
1001 FORMAT(1H0,10X,10HTA(8)      =F15.6)
1002 FORMAT(1H0,10X,10HWN1       =F15.6)
1003 FORMAT(1H0,10X,10HWN2       =F15.6)
1004 FORMAT(1H ,24X,4HWNB=1P1E12.4)
1007 FORMAT(1H0,10X,10HNPGB      =I3)
1008 FORMAT(1H0,10X,10HQ         =F15.6)
1011 FORMAT(1H0,10X,10HHF        =F15.6)
1012 FORMAT(1H0,10X,10HRADHR     =F15.6)
1013 FORMAT(1H0,10X,10HTT        =F15.6)
1014 FORMAT(1H0,10X,10HPCR       =1P1E12.6)
1015 FORMAT(1H0,10X,10HTPA       =F15.6)
1016 FORMAT(1H0,10X,10HQA        =F15.6)
1017 FORMAT(1H0,10X,10HPCR       =F15.6)
1018 FORMAT(1H0,39H****END STEADY STATE CALC. PRINTOUT****)
1019 FORMAT(1H0,38H****START TRANSIENT CALC. PRINTOUT****)
1020 FORMAT(1H0,24H****SUMMARY PRINTOUT****)
1200 FORMAT(1H0,3X,6HDELT10,1X,6HDELT20,2X,5HDELT0,1X,6HDELTAK,3X,2HET
1,7X,3HET2,6X,3HETD,7X,3HETK,7X,3HQKW,9X,4HSUMC,6X,3HTAU)
1201 FORMAT(1H ,2X,4F7.4,4F9.4,1P3E12.4)
1250 FORMAT(1H1,10X,5HTIME=F10.2)
1251 FORMAT(1H0,10X,5HTIME=F10.2)
1600 FORMAT(30X,19HREACTOR POWER PROB I3)
1601 FORMAT(3X,3HBTU)
1602 FORMAT(3X,3HPER)
1603 FORMAT(4X,2HHR)
1604 FORMAT(40X,9HTIME SECS)
1606 FORMAT(30X,16HCORE TEMPS PROB I5)
1607 FORMAT(3X,4HDEGC)
1608 FORMAT(40X,9HTIME SECS)
1610 FORMAT(30X,21HHEAT DUMP TEMPS PROB I3)
1611 FORMAT(2X,4HDEGC)
1612 FORMAT(40X,9HTIME SECS)
1614 FORMAT(30X,18HSYSTEM FLOW RATES I3)
1615 FORMAT(1X,5HLB/HR)
1616 FORMAT(40X,9HTIME SECS)
1618 FORMAT(30X,32HIHX INLET AND OUTLET TEMPS PROB I3)
1620 FORMAT(30X,23HEXCESS REACTIVITY PROB I3)
1621 FORMAT(2X,7HDOLLARS)

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RAPID

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1650 FORMAT(30X,7HC CORE,5X,12HD HEAT DUMP)
1651 FORMAT(30X,15HF FUEL AVERAGE)
1652 FORMAT(30X,15HI INLET SODIUM)
1653 FORMAT(30X,16HO OUTLET SODIUM)
1654 FORMAT(30X,15HI INLET SODIUM)
1655 FORMAT(30X,16HO OUTLET SODIUM)
1656 FORMAT(30X,13HA OUTLET AIR)
1657 FORMAT(30X,17HP PRIMARY SODIUM)
1658 FORMAT(30X,19HS SECONDARY SODIUM)
1659 FORMAT(30X,6HA AIR)
1660 FORMAT(30X,12HA HOT INLET)
1661 FORMAT(30X,13HB HOT OUTLET)
1662 FORMAT(30X,13HC COLD INLET)
1663 FORMAT(30X,14HD COLD OUTLET)
1801 FORMAT(1H ,24X,5HTN1I=F10.4)
1802 FORMAT(1H ,24X,5HTN1X=F10.4)
1803 FORMAT(1H ,24X,5HTN2I=F10.4)
1804 FORMAT(1H ,24X,5HTN2O=F10.4)
1805 FORMAT(1H ,24X,3HQ9=1P1E12.4)
1806 FORMAT(1H ,24X,3HWA=1P1E12.4)
1807 FORMAT(1H ,24X,4HTA0=F10.4)
1808 FORMAT(1H ,21X,6HWAMIN=1P1E12.4)
1809 FORMAT(1H0,10X,10HHA =F15.6)
2300 FORMAT(1H0,8X,2HET,7X,4HTFUL,6X,4HTSOD,5X,2HTR,6X
1,3HROD,7X,3HRHO,7X,4HTNF0,7X,4HTNV0)
2301 FORMAT(1H ,1X,8F10.2)
2309 FORMAT(42H COARSE FUEL TEMPERATURE CALCULATION***** )
2310 FORMAT(44H DETAILED FUEL TEMPERATURE CALCULATION***** )
      CALL CLOCK(TIMEA,TIMEB)
      WRITE OUTPUT TAPE 9,1250,TIMEA
      WRITE OUTPUT TAPE 9,1000
      WRITE OUTPUT TAPE 9,1001,TA(8)
      WRITE OUTPUT TAPE 9,1002,WN1
      WRITE OUTPUT TAPE 9,1003,WN2
      WRITE OUTPUT TAPE 9,1004,WNB
      WRITE OUTPUT TAPE 9,1008,Q
      WRITE OUTPUT TAPE 9,1013,TT
      WRITE OUTPUT TAPE 9,1007,NPROB
      QINIT=Q
398  CONTINUE
      TAI=TA(8)
      WNX=WN1-WNB
      CALL HXFUEL(HF)
      HF=1.0/(1.0/HF+RW/(4.0*FK))
      CALL COEFHX(HVI,2,0.0,WN1,AVI)
      CALL HXFUEL(HV0)
      HV0=1.0/(1.0/HV0+RW/(4.0*RK))
      CALL COEFHX(HNX1,3,625800.0,WNX,ANX)
      CALL COEFHX(HNX2,4,623700.0,WN2,ANX)
      CALL COEFHX(HND,8,623700.0,WN2,AND)
62  CONTINUE
C IHX HEAT BALANCE
      TN1I=TN10+Q/(WN1*CN)
      TN1X=TN10-(WNB*Q)/(WNX+WN1*CN)
      AX=7.0*ANX
      AD=7.0*AND

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RAPID

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      UX=1.0/(1.0/HNX1+1.0/HNX2)
      BETA=Q/(WN2*CN)
      XLM=Q/(UX*AX)
      BARF=(TN1I-TN1X-BETA+2.0*XLM)/(TN1X-TN1I+BETA+2.0*XLM)
      IF(BARF-0.9)401,405,405
405  IF(BARF-1.1)406,406,401
406  TN2I=0.5*(TN1I+TN1X-BETA-2.0*XLM)
      GOT0404
401  XDEL=EXP((TN1I-TN1X-BETA)/XLM)
      TN2I=(TN1I-BETA-TN1X*XDEL)/(1.0-XDEL)
404  TN20=TN2I+BETA
      WRITEOUTPUTTAPE9,1801,TN1I
      WRITEOUTPUTTAPE9,1802,TN1X
      WRITEOUTPUTTAPE9,1803,TN2I
      WRITEOUTPUTTAPE9,1804,TN20
CHEAT DUMP HEAT BALANCE
      C1=TN20+TN2I-2.0*TAI
      C3=Q/CA
      C4=TN20-TAI
      C5=TN2I-TAI
      WAMIN=Q/(CA*C4)
      WRITEOUTPUTTAPE9,1808,WAMIN
      C6=1.1
      ND=0
      N0PR=0
419  WA=C6*WAMIN
      IF(C6-1.0005)412,412,413
413  CALL C0EFHX(HA,7,0.01264,WA,0.0)
      WRITEOUTPUTTAPE9,1805,Q9
      WRITEOUTPUTTAPE9,1806,WA
      UD=1.0/(1.0/HA+1.0/HND)
      CK=(C4-C3/WA)/C5
      IF(CK-0.9)407,408,408
408  IF(CK-1.1)409,409,407
409  DLM=0.5*(C1-C3/WA)
      GOT0410
407  DLM=(BETA-C3/WA)/LOGF(CK)
410  IF(ND-1)411,416,416
411  Q9=AU*UD*DLM
      Q1=Q9
      WA1=WA
      IF(ABSF(Q9/Q-1.0)-0.002)412,412,414
414  ND=1
      WA=WA1*Q/Q1
      IF(WA-WAMIN)420,420,421
420  C6=0.9+0.1*C6
      GOT0419
421  WA2=WA
      GOT0413
416  Q9=AD*UD*DLM
      IF(ABSF(Q9/Q-1.0)-0.002)412,412,415
415  WA=WA2+(WA2-WA1)*(Q-Q9)/(Q9-Q1)
      IF(WA-WAMIN)417,417,418
417  WA=WA2*Q/Q9
      IF(WA-WAMIN)422,422,418
422  C6=0.9+0.1*C6

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RAPID

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      GOT0419
418 WA1=WA2
      WA2=WA
      Q1=Q9
      N0PR=N0PR+1
      IF(N0PR-50)413,413,1
412 TA0=TAI+Q/(WA*CA)
      WRITEOUTPUTTAPE9,1806,WA
      WRITEOUTPUTTAPE9,1807,TA0
      CALL C0EFHX(HA,7,0.01264,WA,0.0)
C    STEADY STATE MATRIX SOLUTION
      D07I=1,56
      D08J=1,56
      A(I,J)=0.0
6    CONTINUE
7    CONTINUE
      D09I=1,56
9    B(I,1)=0.0
      A(1,1)=CA*WA+HA*AND/2.0
      A(1,2)=-HA*AND
      A(1,4)=-CA*WA+HA*AND/2.0
      A(2,1)=HA*AND/2.0
      A(2,2)=-HND*AND-HA*AND
      A(2,3)=HND*AND/2.0
      A(2,4)=A(2,1)
      A(2,6)=A(2,3)
      A(3,2)=HND*AND
      A(3,3)=CN*WN2-HND*AND/2.0
      A(3,6)=-CN*WN2-HND*AND/2.0
      D0 950K=1,6
      A(3K+1,3K+1)=A(1,1)
950 CONTINUE
      D0 60K=1,6
      A(3K+1,3K+2)=A(1,2)
60  CONTINUE
      D0 70K=1,5
      A(3K+1,3K+4)=A(1,4)
70  CONTINUE
      D0 8K=1,6
      A(3K+2,3K+1)=A(2,1)
8    CONTINUE
      D0 90K=1,6
      A(3K+2,3K+2)=A(2,2)
90  CONTINUE
      D0 910K=1,6
      A(3K+2,3K+3)=A(2,3)
910 CONTINUE
      D0 91K=1,5
      A(3K+2,3K+4)=A(2,1)
91  CONTINUE
      D0 912K=1,5
      A(3K+2,3K+6)=A(2,3)
912 CONTINUE
      D0 913K=1,6
      A(3K+3,3K+2)=A(3,2)
913 CONTINUE

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      D0 914K=2,7
      A(3K,3K)=A(3,3)
914  CONTINUE
      D0 915K=2,6
      A(3K,3K+3)=A(3,6)
915  CONTINUE
      A(20,22)=A(2,3)
      A(21,22)=A(3,6)
      A(22,3)=1.0
      A(22,24)=-1.0
      A(23,22)=-CN*WN2
      A(23,23)=+CN*WN2
      A(24,24)=CN*WN2+HNX2*ANX/2.0
      A(24,25)=-HNX2*ANX
      A(24,27)=-CN*WN2+HNX2*ANX/2.0
      A(25,24)=HNX2*ANX/2.0
      A(25,25)=-HNX1*ANX-HNX2*ANX
      A(25,26)=HNX1*ANX/2.0
      D0 916K=8,13
      A(3K+1,3K+3)=A(25,24)
916  CONTINUE
      D0917K=8,13
      A(3K+1,3K+5)=A(25,26)
917  CONTINUE
      A(26,25)=HNX1*ANX
      A(26,26)=CN*WNX-HNX1*ANX/2.0
      A(26,29)=-CN*WNX-HNX1*ANX/2.0
      D0918K=9,14
      A(3K,3K)=A(24,24)
918  CONTINUE
      D0919K=9,14
      A(3K,3K+1)=A(24,25)
919  CONTINUE
      D0920K=9,13
      A(3K,3K+3)=A(24,27)
920  CONTINUE
      D0921K=9,14
      A(3K+1,3K)=A(25,24)
921  CONTINUE
      D022K=9,14
      A(3K+1,3K+1)=A(25,25)
22  CONTINUE
      D023K=9,14
      A(3K+1,3K+2)=A(25,26)
23  CONTINUE
      D024K=9,14
      A(3K+2,3K+1)=A(26,25)
24  CONTINUE
      D025K=9,14
      A(3K+2,3K+2)=A(26,26)
25  CONTINUE
      D026K=9,13
      A(3K+2,3K+5)=A(26,29)
26  CONTINUE
      A(42,23)=A(24,27)
      A(43,23)=A(25,24)

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A(43,45)=A(25,26)
A(44,45)=A(26,29)
A(45,26)=CN*WNB-HVI*AVI*WNB/(2.0*WN1)
A(46,26)=-WNB*HVI*AVI/(2.0*WN1)
A(45,45)=CN*WNX-HVI*AVI*WNX/(2.0*WN1)
A(45,46)=HVI*AVI
A(45,47)=-CN*WN1-HVI*AVI/2.0
A(46,45)=-HVI*AVI*WNX/(2.0*WN1)
A(46,46)=A(45,46)
A(46,47)=-HVI*AVI/2.0
A(47,47)=CN*WN1-HVI*AVI/2.0
A(47,48)=A(45,46)
A(47,49)=A(45,47)
A(48,47)=A(46,47)
A(48,48)=A(46,46)
A(48,49)=A(46,47)
A(49,49)=CN*WN1-HF*AF/2.0
A(49,50)=HF*AF
A(49,51)=-CN*WN1-HF*AF/2.0
A(50,49)=-HF*AF/2.0
A(50,50)=A(49,50)
A(50,51)=A(50,49)
A(51,51)=A(49,49)
A(51,52)=A(49,50)
A(51,53)=A(49,51)
A(52,51)=A(50,49)
A(52,52)=A(50,50)
A(52,53)=A(50,51)
A(53,53)=CN*WN1-HV0*AV0/2.0
A(53,54)=HV0*AV0
A(53,55)=-CN*WN1-HV0*AV0/2.0
A(54,53)=-HV0*AV0/2.0
A(54,54)=A(53,54)
A(54,55)=A(54,53)
A(55,55)=A(53,53)
A(55,56)=A(53,54)
A(55,26)=A(53,55)
A(56,55)=A(54,53)
A(56,56)=A(53,54)
A(56,26)=A(54,53)
B(46,1)=QFRBR*Q/2.0
B(48,1)=B(46,1)
B(50,1)=QFRC*Q/2.0
B(52,1)=B(50,1)
B(54,1)=QFRTR*Q/2.0
B(56,1)=B(54,1)
B(19,1)=TA(8)*(CA*WA-HA*AND/2.0)
B(20,1)=TA(8)*(-HA*AND/2.0)
CALLLEQ(A,B,56,1,56,56,DET)
WRITE OUTPUT TAPE 9,104,WA
WRITE OUTPUT TAPE 9,107,HNX1
WRITE OUTPUT TAPE 9,108,HNX2
WRITE OUTPUT TAPE 9,109,HND
WRITEOUTPUTTAPE9,1809,HA
WRITE OUTPUT TAPE 9,200
WRITE OUTPUT TAPE 9,201,(B(I,1),I=1,21)

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WRITE OUTPUT TAPE 9,202,B(22,1)
WRITE OUTPUT TAPE 9,203
WRITE OUTPUT TAPE 9,204,(B(I,1),I=24,44)
WRITE OUTPUT TAPE 9,205,B(23,1)
WRITE OUTPUT TAPE 9,206,B(45,1)
WRITE OUTPUT TAPE 9,207
WRITE OUTPUT TAPE 9,208,(B(I,1),I=46,56)
C  FIX STEADY STATE TEMPERATURES
    TA(1)=B(1,1)
    TD(1)=B(2,1)
    TND(1)=B(3,1)
    D03301I=2,34
3301 TND(I)=B(6,1)
    TA(2)=B(4,1)
    TD(2)=B(5,1)
    D03302I=35,67
3302 TND(I)=B(9,1)
    TA(3)=B(7,1)
    TD(3)=B(8,1)
    D03303I=68,100
3303 TND(I)=B(12,1)
    TA(4)=B(10,1)
    TD(4)=B(11,1)
    D03304I=101,133
3304 TND(I)=B(15,1)
    TA(5)=B(13,1)
    TD(5)=B(14,1)
    D03305I=134,166
3305 TND(I)=B(18,1)
    TA(6)=B(16,1)
    TD(6)=B(17,1)
    D03306I=167,199
3306 TND(I)=B(21,1)
    TA(7)=B(19,1)
    TD(7)=B(20,1)
    TND(200)=B(22,1)
    D03308I=1,200
3308 TNP4(I)=TND(200)
    TNX2(200)=TNP4(200)
    TNX2(1)=B(24,1)
    TXT(1)=B(25,1)
    TNX1(1)=B(26,1)
    D03309I=2,34
3309 TNX1(I)=B(29,1)
    D03310I=2,34
3310 TNX2(I)=B(27,1)
    TXT(2)=B(28,1)
    D03311I=35,67
3311 TNX1(I)=B(32,1)
    D03312I=35,67
3312 TNX2(I)=B(30,1)
    D03313I=68,100
3313 TNX1(I)=B(35,1)
    TXT(3)=B(31,1)
    D03314I=68,100
3314 TNX2(I)=B(33,1)

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      TXT(4)=B(34,1)
      D03315I=101,133
3315  TNX1(1)=B(38,1)
      D03316I=101,133
3316  TNX2(1)=B(36,1)
      TXT(5)=B(37,1)
      D03317I=134,166
3317  TNX1(1)=B(41,1)
      D03318I=134,166
3318  TNX2(1)=B(39,1)
      TXT(6)=B(40,1)
      D03319I=167,199
3319  TNX1(1)=B(44,1)
      D03320I=167,199
3320  TNX2(1)=B(42,1)
      TXT(7)=B(43,1)
      TNX1(200)=B(45,1)
      D03322I=1,200
3322  TNP3(1)=TNX2(1)
      D03323I=1,7
      TP1(1)=TNX1(1)
      TP2(1)=(WNX*TNX1(200)+WNB*TNX1(1))/WN1
      TP3(1)=TNX2(1)
      TP4(1)=TND(200)
3323  TB(1)=TNX1(1)
      TV(1)=B(46,1)
      TNV(1)=B(47,1)
      TV(2)=B(48,1)
      TF(1)=B(50,1)
      TF(2)=B(52,1)
      TV(3)=B(54,1)
      D03325I=2,100
3325  TNV(1)=TNV(1)
      TNV(101)=B(49,1)
      D03326I=102,199
3326  TNV(1)=TNV(101)
      TNV(200)=B(51,1)
      TNV(201)=B(53,1)
      D03327I=202,210
3327  TNV(1)=TNV(201)
      TNV(211)=B(55,1)
      D03328I=212,220
3328  TNV(1)=TNV(211)
      TNV2=TNV(199)
      TV(4)=B(56,1)
      D03324I=1,200
      TNP2(1)=TP2(1)
      TNB(1)=TB(1)
      TNM(1)=TP1(1)
3324  TNP1(1)=TP1(1)
      TXS(1)=0.5*(TNX1(1)+TNX1(2))
      TXS(2)=0.5*(TNX1( 34)+TNX1( 35))
      TXS(3)=0.5*(TNX1( 57)+TNX1( 68))
      TXS(4)=0.5*(TNX1(100)+TNX1(101))
      TXS(5)=0.5*(TNX1(133)+TNX1(134))
      TXS(6)=0.5*(TNX1(166)+TNX1(167))

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        TXS(7)=0.5*(TNX1(199)+TNX1(200))
        TR=(TV(1)+TV(2)+TV(3)+TV(4))/4.0
        IF(K5-2)6690,6691,6691
6691  SUMN=0.0
        SUMF=0.0
        SUMRN=0.0
        CALL CLOCK(TIMEA,TIMEB)
        WRITEOUTPUTTAPE9,1251,TIMEA
        CALL DETST
        WRITE OUTPUT TAPE9,1018
        CALL CLOCK(TIMEA,TIMEB)
        WRITEOUTPUTTAPE9,1250,TIMEA
        WRITE OUTPUT TAPE9,1019
C      NORMALIZE REACTIVITY
        D06693J=4,JP2
        SUMN=SUMN+WTE*TNAE(J)+WTC*TNAC(J)
        SUMRN=SUMRN+WTC*RCC2(J)*TNAC(J)+WTE*RCE2(J)*TNAE(J)
        D06693I=1,IP
        TFCI(I,J)=TFC(I,J)
        TFEI(I,J)=TFE(I,J)
6693  SUMF=SUMF+WTE*TFE(I,J)+WTC*TFC(I,J)
        TS0D=SUMN/FL0ATF(JP5)
        TFUL=SUMF/(FL0ATF(JP5)*FL0ATF(IP))
        TNR0CS=TNAC(JP2)
        RN=SUMRN/FL0ATF(JP5)
        RRI=RN+RCBR*TV(2)+RCTR*TV(3)
        G0T04700
C      NORMALIZE REACTIVITY
6690  D05505J=4,JP2
        RC2=(RCC2(J)+RCE2(J))/(2.0*FL0ATF(JP5))
5505  RC1D0P=(RCCD0P(J)+RCED0P(J))/(2.0*FL0ATF(JP5))
        RCX=(RCCX+RCX)/2.0
        TS0D=(TNV(199)+TNV(200)+TNV(201))/3.0
        TFUL=(TF(1)+TF(2))/2.0
        TNR0CS=TNV(201)
5701  RC1=RCX+RC1D0P/(TFUL+273.0)
        RRI=RC1*TFUL+RC2*TS0D+RCBR*TV(2)+RCTR*TV(3)
4700  CONTINUE
        WN1P=WN1
        WN2P=WN2
        65  IF(ET-TT)39,1300,1300
        39  CONTINUE
C      BEGIN TRANSIENT CALCULATION
        83  CONTINUE
C      PRIMARY PUMP COASTDOWN
        IF(ET-PUM10)143,141,141
        141 IF(ET-PUM11)142,142,167
        142 WN1=WN1P+(WN1P-WN1SB)*COSF(1.571*(1.0+ET/PUMS1))
        WNB=THR*WN1
        WNX=WN1-WNB
        IF(WNX-WN1SB)220,220,143
        220 WNX=WN1SB
        WNB=WN1-WNX
        IF(WN1-WN1SB)6980,6980,143
        6980 WN1=WN1SB
        WNX=WN1

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WNB=0.0
143 CONTINUE
CALL HXFUEL(HF)
HF=1.0/(1.0/HF+RW/(4.0*FK))
CALL C0EFHX(HVI,2,0.0,WN1,AVI)
CALL HXFUEL(HV0)
HV0=1.0/(1.0/HV0+RW/(4.0*RK))
CALL C0EFHX(HNXS,5,0.0,WNX,AXS)
165 CALL C0EFHX(HNP1,1,DP1,WN1,ANP1)
CALL C0EFHX(HNP2,1,DP2,WN1,ANP2)
CALL C0EFHX(HNB,1,DB,WNB,ANB)
A1=HNP1*ANP1/(CSS*VP1*2.0)
A11=WN1/VNP1
A12=HNP1*ANP1/(CN*VNP1*2.0)
A2=HNP2*ANP2/(CSS*VP2*2.0)
A21=WN1/VNP2
A22=HNP2*ANP2/(CN*VNP2*2.0)
A5=HNB*ANB/(CSS*VB*2.0)
A51=WNB/VNB
A52=HNB*ANB/(CN*VNB*2.0)
CALL C0EFHX(HNX1,3,625800.0,WNX,ANX)
AAAI=WN1/VNVI
AAAG=WN1/VNV0
BBBI=HVI*AVI/(CN*VNVI*2.0)
BBB0=HV0*AV0/(CN*VNV0*2.0)
CCI=HVI*AVI/(CV*VVI*2.0)
CC0=HV0*AV0/(CV*VV0*2.0)
D=WN1/VNC
E=HF*AF/(CN*VNC*2.0)
EE=HF*AF/(2.0*VF*CF)
F=HNXS*AXS/(CSS*VXS*2.0)
G=HNX1*ANX/(CSS*VXT*2.0)
T=WNX/VNX1
U=HNXS*AXS/(CN*VNX1*2.0)
V=HNX1*ANX/(CN*VNX1*2.0)
167 CONTINUE
C SECONDARY PUMP COASTDOWN
IF(ET-PUM20)148,146,146
146 IF(ET-PUM21)147,147,149
147 WN2=WN2P+(WN2P-WN2SB)*C0SF(1.571*(1.0+ET/PUMS2))
IF(WN2-WN2SB)221,221,148
221 WN2=WN2SB
148 CONTINUE
CALL C0EFHX(HNP3,1,DP3,WN2,ANP3)
CALL C0EFHX(HNP4,1,DP4,WN2,ANP4)
CALL C0EFHX(HND,8,623700.0,WN2,AND)
CALL C0EFHX(HNX2,4,623700.0,WN2,ANX)
A3=HNP3*ANP3/(CSS*VP3*2.0)
A31=WN2/VNP3
A32=HNP3*ANP3/(CN*VNP3*2.0)
A4=HNP4*ANP4/(CSS*VP4*2.0)
A41=WN2/VNP4
A42=HNP4*ANP4/(CN*VNP4*2.0)
171 CONTINUE
H=HNX2*ANX/(CSS*VXT*2.0)
R=WN2/VNX2

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      S=HMX2*ANX/(CN*VNX2*2.0)
      Y=WN2/VND
      Z=HND*AND/(CN*VND*2.0)
      ZZ=HND*AND/(CSS*VD*2.0)
149  CONTINUE
      CALL COEFHX(HA,7,0.01264,WA,0.0)
      W=CA*WA
      X=HA*AND/2.0
      YY=HA*AND/(CSS*VD*2.0)
      IF(ET-ET2)53,53,56
C    DETERMINE ALLOWABLE TIME STEP FOR PRIMARY
53   ZELT1(1)=TMAX1/3600.0
      ZELT1(2)=1.0/(AAAI+BBBI)
      ZELT1(3)=1.0/(2.0*CCI)
      IF(K5-2)96,97,97
97   ZELT1(4)=1000000.0
      ZELT1(5)=1000000.0
      GOT099
96   ZELT1(4)=1.0/(E+D)
      ZELT1(5)=1.0/(2.0*EE)
99   ZELT1(6)=1.0/(AAAG+BBBG)
      ZELT1(7)=1.0/(2.0*CCG)
      ZELT1(8)=1.0/(2.0*A1)
      ZELT1(9)=1.0/(2.0*F)
      ZELT1(10)=1.0/(2.0*A2)
      ZELT1(11)=1.0/(2.0*(G+H))
      ZELT1(12)=1.0/(R+S)
      ZELT1(13)=1.0/(T+U+V)
      ZELT1(14)=1.0/(2.0*A5)
      ZELT1(15)=0.9/A11
      ZELT1(16)=1.0/(A11+A12)
      ZELT1(17)=0.9/A21
      ZELT1(18)=1.0/(A21+A22)
      ZELT1(19)=0.9*VNX1/WNX
      ZELT1(20)=0.9/A51
      ZELT1(21)=1.0/(A51+A52)
      ZELT1(22)=0.9*VNX2/WN2
      ZELT1(23)=(0.9*VNVG+1.8*VNC)/WN1
      ZELT1(24)=(0.9*VNVI+1.8*VNC)/WN1
      ZELT1(25)=3.0*VNM/WN1
      ZELT10=1000000.0
      D05578I=1,25
      IF(ZELT1(I)-ZELT10)5577,5578,5578
5577 ZELT10=ZELT1(I)
5578 CONTINUE
      ZELT10=DMUL*ZELT10
      DELT=ZELT10
      DELTA=3600.0*DELT
C    CALCULATE NEW POWER
      IF(TGP-1.0E-06)604,5003,5003
5003 CALL DECAY
604  CALL XNKIN
      IF(K2-2)5004,52,52
5004 CONTINUE
      Q=QN+QDEC
3    CONTINUE

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C      TIME DELAY, VESSEL
      LUMBR0=XLUMBR
      XLUMBR=XLUMBR+DELT*200.0*WN1/(VNV1*2.0+VNC/2.0)
      LUMBR=XLUMBR-FLGATF(LUMBR0)
      IF(LUMBR)6781,6781,6782
6781  D06783I=2,200
6783  TNVP(I)=TNV(I)
      GOT06793
6782  ILUM=LUMBR
      D06784I=2,ILUM
6784  TNVP(I)=TNV(1)
      ILUM=LUMBR+1
      D06785I=ILUM,100
      ILL=I-LUMBR
6785  TNVP(I)=TNV(ILL)
6790  ILUM=101+LUMBR
      D06791I=102,ILUM
6791  TNVP(I)=TNV(101)
      ILUM=102+LUMBR
      D06792I=ILUM,200
      ILL=I-LUMBR
6792  TNVP(I)=TNV(ILL)
6793  CONTINUE
      LUMTR0=XLUMTR
      XLUMTR=XLUMTR+DELT*20.0*WN1/(VNV0*2.0+VNC/2.0)
      LUMTR=XLUMTR-FLGATF(LUMTR0)
      IF(LUMTR)6761,6761,6762
6761  D06763I=202,220
6763  TNVP(I)=TNV(I)
      GOT06773
6762  ILUM=LUMTR+201
      D06764I=202,ILUM
6764  TNVP(I)=TNV(201)
      ILUM=202+LUMTR
      D06765I=ILUM,210
      ILL=I-LUMTR
6765  TNVP(I)=TNV(ILL)
6770  ILUM=211+LUMTR
      D06771I=212,ILUM
6771  TNVP(I)=TNV(211)
      ILUM=212+LUMTR
      D06772I=ILUM,220
      ILL=I-LUMTR
6772  TNVP(I)=TNV(ILL)
6773  CONTINUE
C      CALCULATE NEW CORE AND VESSEL TEMPS.
      TNVP(1)=TNV(1)*(1.0-(AAAI+BBBI)*DELT)+TNP2(200)*(AAAI
1-BBBI)*DELT+TV(1)*2.0*BBBI*DELT
      TVP(1)=TV(1)*(1.0-2.0*CCI*DELT)+(TNV(1)+TNP2(200))*CCI*DELT
1+QFRBR*Q*DELT/(2.0*VVI*CV)
      TNVP(101)=TNV(101)*(1.0-(AAAI+BBBI)*DELT)+TNV(100)*(AAAI-BBBI)
1*DELT+TV(2)*2.0*BBBI*DELT
      TNV2=TNV(199)
      TVP(2)=TV(2)*(1.0-2.0*CCI*DELT)+(TNV(100)+TNV(101))*CCI*DELT
1+QFRBR*Q*DELT/(2.0*VVI*CV)
      IST=0

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      IF(K5-2)1999,1998,1998
1998 CALDETTR(IST)
      TNVP(201)=(WTE*FLGE*TNAE(JP2)+WTC*FLGC*TNAC(JP2))/(WTE*FLGE+WTC*
      1FLGC)
      GOT07800
1999 TNVP(200)=TNV(200)*(1.0-(D+E)*DELT)+TNV(199)*(D-E)
      1*DELT+TF(1)*2.0*E*DELT
      TFP(1)=TF(1)*(1.0-2.0*EE*DELT)+(TNV(199)+TNV(200))*EE*DELT
      1+QFRC*Q*DELT/(2.0*VF*CF)
      TNVP(201)=TNV(201)*(1.0-(D+E)*DELT)+TNV(200)*(D-E)
      1*DELT+TF(2)*2.0*E*DELT
      TFP(2)=TF(2)*(1.0-2.0*EE*DELT)+(TNV(200)+TNV(201))*EE*DELT
      1+QFRC*Q*DELT/(2.0*VF*CF)
7800 TNC0=TNVP(201)
      TNVP(211)=TNV(211)*(1.0-(AAAG+BBB0)*DELT)+TNV(210)*(AAAG-BBB0)
      1*DELT+TV(3)*2.0*BBB0*DELT
      TVP(3)=TV(3)*(1.0-2.0*CC0*DELT)+(TNV(210)+TNV(211))*CC0*DELT
      1+QFRTR*Q*DELT/(2.0*VV0*CV)
      TNMP(1)=TNM(1)*(1.0-(AAAG+BBB0)*DELT)+TNV(220)*(AAAG-BBB0)
      1*DELT+TV(4)*2.0*BBB0*DELT
      TVP(4)=TV(4)*(1.0-2.0*CC0*DELT)+(TNV(220)+TNM(1))*CC0*DELT
      1+QFRTR*Q*DELT/(2.0*VV0*CV)
C   CORE OUTLET MANIFOLD
      IF(N7-2)36,37,37
36  SUM=0.0
      D038IX=1,11
      XI=IX
      SUM=SUM+1.0/(12.0-XI)
88  XMX(IX)=SUM
      LUMMO=XLUMM
      XLUMM=XLUMM+200.0*DELT*WN1/(VNM*XMX(11))
      LUMM=XLUMM-FLGATF(LUMMO)
      IF(LUMM)7801,7801,7802
7801 D07803I=2,200
7803 TNMP(I)=TNM(I)
      GOT07809
7802 ILUM=LUMM
      D07804I=2,ILUM
7804 TNMP(I)=TNM(I)
      ILUM=LUMM+1
      D07805I=ILUM,200
      ILL=I-LUMM
7805 TNMP(I)=TNM(ILL)
7809 SUM=TNMP(1)
      D089IX=1,11
      IMX=XMX(IX)*200.0/XMX(11)
89  SUM=SUM+TNMP(IMX)
      TNPIP(1)=SUM/12.0
      GOT038
37  TNPIP(1)=TNMP(1)
C   TIME DELAY, PIPE 1
38  LUMP01=XLUMP1
      XLUMP1=XLUMP1+DELT*200.0*WN1/(VNP1*7.0)
      LUMP1=XLUMP1-FLGATF(LUMP01)
      IF(LUMP1)6801,6801,6802
6801 D06803I=3,199

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RAPID

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6803 TNP1P(I)=TNP1(I)
      GOT06809
6802 IQP=0
6811 IQR=33*IQP+2
      IQS=IQR+1
      IQT=33*(IQP+1)+1
      ILUM=IQR+LUMP1
      D06804I=IQS,ILUM
6804 TNP1P(I)=TNP1(IQR)
      ILUM=IQS+LUMP1
      D06805I=ILUM,IQT
      ILL=I-LUMP1
6805 TNP1P(I)=TNP1(ILL)
      IQP=IQP+1
      IF(IQP-6)6811,6809,6809
6809 IF(MIX-2)6810,6810,6808
6808 SUM=0.0
      D05806I=2,11
6806 SUM=SUM+TNP1P(I)
      D05807I=2,11
6807 TNP1P(I)=SUM/10.0
6810 CONTINUE
C   CALCULATE NEW PIPE 1 TEMPS
      TP1P(1)=(1.0-2.0*A1*DELT)*TP1(1)+A1*DELT*(TNP1( 1)+TNP1( 2))
      TP1P(2)=(1.0-2.0*A1*DELT)*TP1(2)+A1*DELT*(TNP1( 34)+TNP1( 35))
      TP1P(3)=(1.0-2.0*A1*DELT)*TP1(3)+A1*DELT*(TNP1( 67)+TNP1( 68))
      TP1P(4)=(1.0-2.0*A1*DELT)*TP1(4)+A1*DELT*(TNP1(100)+TNP1(101))
      TP1P(5)=(1.0-2.0*A1*DELT)*TP1(5)+A1*DELT*(TNP1(133)+TNP1(134))
      TP1P(6)=(1.0-2.0*A1*DELT)*TP1(6)+A1*DELT*(TNP1(166)+TNP1(167))
      TP1P(7)=(1.0-2.0*A1*DELT)*TP1(7)+A1*DELT*(TNP1(199)+TNP1(200))
      TNP1P( 2)=(1.0-(A11+A12)*DELT)*TNP1( 2)+(A11-A12)*DELT*TNP1( 1)
      1+2.0*A12*DELT*TP1(1)
      TNP1P( 35)=(1.0-(A11+A12)*DELT)*TNP1( 35)+(A11-A12)*DELT*TNP1( 34)
      1+2.0*A12*DELT*TP1(2)
      TNP1P( 68)=(1.0-(A11+A12)*DELT)*TNP1( 68)+(A11-A12)*DELT*TNP1( 67)
      1+2.0*A12*DELT*TP1(3)
      TNP1P(101)=(1.0-(A11+A12)*DELT)*TNP1(101)+(A11-A12)*DELT*TNP1(100)
      1+2.0*A12*DELT*TP1(4)
      TNP1P(134)=(1.0-(A11+A12)*DELT)*TNP1(134)+(A11-A12)*DELT*TNP1(133)
      1+2.0*A12*DELT*TP1(5)
      TNP1P(167)=(1.0-(A11+A12)*DELT)*TNP1(167)+(A11-A12)*DELT*TNP1(166)
      1+2.0*A12*DELT*TP1(6)
      TNP1P(200)=(1.0-(A11+A12)*DELT)*TNP1(200)+(A11-A12)*DELT*TNP1(199)
      1+2.0*A12*DELT*TP1(7)
      TNBP(1)=TNP1(200)
C   TIME DELAY, BYPASS LINE
      LUMB0=XLUMB
      XLUMB=XLUMB+DELT*200.0*WNB/(VNB*7.0)
      LUMB=XLUMB-FLGATF(LUMB0)
      IF(LUMB)6881,6881,6882
6881 D06883I=3,199
6883 TNBP(I)=TNBP(I)
      GOT06889
6882 IQP=0
6891 IQR=33*IQP+2
      IQS=IQR+1

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      IQT=33*(IQP+1)+1
      ILUM=IQR+LUMB
      D05884I=IQS,ILUM
6884  TNBP(I)=TNB(IQR)
      ILUM=IQS+LUMB
      D06885I=ILUM,IQT
      ILL=I-LUMB
6885  TNBP(I)=TNB(ILL)
      IQP=IQP+1
      IF(IQP-6)6891,6889,6889
6889  IF(MIX-2)6890,6890,6888
6888  SUM=0.0
      D06886I=2,11
6886  SUM=SUM+TNBP(I)
      D05887I=2,11
6887  TNBP(I)=SUM/10.0
6890  CONTINUE
C    CALCULATE NEW BYPASS TEMPS.
      TBP(1)=(1.0-2.0*A5*DELT)*TB(1)+A5*DELT*(TNB( 1)+TNB( 2))
      TBP(2)=(1.0-2.0*A5*DELT)*TB(2)+A5*DELT*(TNB( 34)+TNB( 35))
      TBP(3)=(1.0-2.0*A5*DELT)*TB(3)+A5*DELT*(TNB( 67)+TNB( 68))
      TBP(4)=(1.0-2.0*A5*DELT)*TB(4)+A5*DELT*(TNB(100)+TNB(101))
      TBP(5)=(1.0-2.0*A5*DELT)*TB(5)+A5*DELT*(TNB(133)+TNB(134))
      TBP(6)=(1.0-2.0*A5*DELT)*TB(6)+A5*DELT*(TNB(166)+TNB(167))
      TBP(7)=(1.0-2.0*A5*DELT)*TB(7)+A5*DELT*(TNB(199)+TNB(200))
      TNBP( 2)=(1.0-(A51+A52)*DELT)*TNB( 2)+(A51-A52)*DELT*TNB( 1)
      1+2.0*A52*DELT*TB(1)
      TNBP( 35)=(1.0-(A51+A52)*DELT)*TNB( 35)+(A51-A52)*DELT*TNB( 34)
      1+2.0*A52*DELT*TB(2)
      TNBP( 68)=(1.0-(A51+A52)*DELT)*TNB( 68)+(A51-A52)*DELT*TNB( 67)
      1+2.0*A52*DELT*TB(3)
      TNBP(101)=(1.0-(A51+A52)*DELT)*TNB(101)+(A51-A52)*DELT*TNB(100)
      1+2.0*A52*DELT*TB(4)
      TNBP(134)=(1.0-(A51+A52)*DELT)*TNB(134)+(A51-A52)*DELT*TNB(133)
      1+2.0*A52*DELT*TB(5)
      TNBP(167)=(1.0-(A51+A52)*DELT)*TNB(167)+(A51-A52)*DELT*TNB(166)
      1+2.0*A52*DELT*TB(6)
      TNBP(200)=(1.0-(A51+A52)*DELT)*TNB(200)+(A51-A52)*DELT*TNB(199)
      1+2.0*A52*DELT*TB(7)
C    CALCULATE NEW IHX SHELL TEMPS
      TNX1P(1)=TNP1(200)
      TXSP(1)=TXS(1)*(1.0-2.0*F*DELT)+(TNX1(1)+TNX1(2))
      1*F*DELT
      TXSP(2)=TXS(2)*(1.0-2.0*F*DELT)+(TNX1( 34)+TNX1( 35))*F*DELT
      TXSP(3)=TXS(3)*(1.0-2.0*F*DELT)+(TNX1( 67)+TNX1( 68))*F*DELT
      TXSP(4)=TXS(4)*(1.0-2.0*F*DELT)+(TNX1(100)+TNX1(101))*F*DELT
      TXSP(5)=TXS(5)*(1.0-2.0*F*DELT)+(TNX1(133)+TNX1(134))*F*DELT
      TXSP(6)=TXS(6)*(1.0-2.0*F*DELT)+(TNX1(166)+TNX1(167))*F*DELT
      TXSP(7)=TXS(7)*(1.0-2.0*F*DELT)+(TNX1(199)+TNX1(200))*F*DELT
C    TIME DELAY, IHX PRIMARY
      LUMX10=XLUMX1
      XLUMX1=XLUMX1+DELT*200.0*WNX/(7.0*VNX1)
      LUMX1=XLUMX1-FL0ATF(LUMX10)
      IF(LUMX1)6901,6901,6902
6901  D06903I=3,199
6903  TNX1P(I)=TNX1(I)

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      GOT06908
6902 IQP=0
6906 IQR=33*IQP+2
      IQS=IQR+1
      IQT=33*(IQP+1)+1
      ILUM=IQR+LUMX1
      D05904I=IQS,ILUM
6904 TNX1P(I)=TNX1(IQR)
      ILUM=IQS+LUMX1
      D05905I=ILUM,IQT
      ILL=I-LUMX1
6905 TNX1P(I)=TNX1(ILL)
      IQP=IQP+1
      IF(IQP-6)6906,6908,6908
6908 CONTINUE
      TNP2(1)=(WNX*TNX1(200)+WNB*TNB(200))/WN1
C    TIME DELAY, PIPE 2
      LUMP02=XLUMP2
      XLUMP2=XLUMP2+DELT*200.0*WN1/(VNP2*7.0)
      LUMP2=XLUMP2-FL0ATF(LUMP02)
      IF(LUMP2)6821,6821,6822
6821 D05823I=3,199
6823 TNP2P(I)=TNP2(I)
      GOT06829
6822 IQP=0
6831 IQR=33*IQP+2
      IQS=IQR+1
      IQT=33*(IQP+1)+1
      ILUM=IQR+LUMP2
      D05824I=IQS,ILUM
6824 TNP2P(I)=TNP2(IQR)
      ILUM=IQS+LUMP2
      D05825I=ILUM,IQT
      ILL=I-LUMP2
6825 TNP2P(I)=TNP2(ILL)
      IQP=IQP+1
      IF(IQP-6)6831,6829,6829
6829 IF(MIX-2)6830,6830,6828
6828 SUM=0.0
      D05826I=2,11
6826 SUM=SUM+TNP2P(I)
      D06827I=2,11
6827 TNP2P(I)=SUM/10.0
6830 CONTINUE
C    CALCULATE NEW PIPE 2 TEMPS.
      TP2P(1)=(1.0-2.0*A2*DELT)*TP2(1)+A2*DELT*(TNP2( 1)+TNP2( 2))
      TP2P(2)=(1.0-2.0*A2*DELT)*TP2(2)+A2*DELT*(TNP2( 34)+TNP2( 35))
      TP2P(3)=(1.0-2.0*A2*DELT)*TP2(3)+A2*DELT*(TNP2( 67)+TNP2( 68))
      TP2P(4)=(1.0-2.0*A2*DELT)*TP2(4)+A2*DELT*(TNP2(100)+TNP2(101))
      TP2P(5)=(1.0-2.0*A2*DELT)*TP2(5)+A2*DELT*(TNP2(133)+TNP2(134))
      TP2P(6)=(1.0-2.0*A2*DELT)*TP2(6)+A2*DELT*(TNP2(166)+TNP2(167))
      TP2P(7)=(1.0-2.0*A2*DELT)*TP2(7)+A2*DELT*(TNP2(199)+TNP2(200))
      TNP2P( 2)=(1.0-(A21+A22)*DELT)*TNP2( 2)+(A21-A22)*DELT*TNP2( 1)
      1+2.0*A22*DELT*TP2(1)
      TNP2P( 35)=(1.0-(A21+A22)*DELT)*TNP2( 35)+(A21-A22)*DELT*TNP2( 34)
      1+2.0*A22*DELT*TP2(2)

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RAPID

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      TNP2P( 68)=(1.0-(A21+A22)*DELT)*TNP2( 68)+(A21-A22)*DELT*TNP2( 67)
      1+2.0*A22*DELT*TP2(3)
      TNP2P(101)=(1.0-(A21+A22)*DELT)*TNP2(101)+(A21-A22)*DELT*TNP2(100)
      1+2.0*A22*DELT*TP2(4)
      TNP2P(134)=(1.0-(A21+A22)*DELT)*TNP2(134)+(A21-A22)*DELT*TNP2(133)
      1+2.0*A22*DELT*TP2(5)
      TNP2P(167)=(1.0-(A21+A22)*DELT)*TNP2(167)+(A21-A22)*DELT*TNP2(166)
      1+2.0*A22*DELT*TP2(6)
      TNP2P(200)=(1.0-(A21+A22)*DELT)*TNP2(200)+(A21-A22)*DELT*TNP2(199)
      1+2.0*A22*DELT*TP2(7)
5576 CONTINUE
      TR=(TVP(1)+TVP(2)+TVP(3)+TVP(4))/4.0
      RQDP=RR
      RHQP=DELK/BE
C RAMP REACTIVITY INPUT AT-RAMBUC DOLLARS PER SECOND
      IF(ET-RAMT0)5603,5601,5601
5601 IF(ET-RAMT1)5602,5602,5603
5602 R9=RAMBUC*(ET-RAMT0)
5603 CONTINUE
CRQD RUNDOWN ROUTINE
      D05502I=1,6
      IF(ET-SCRT0(I))5502,5500,5500
5500 IF(ET-SCRT1(I))5501,5501,5502
5501 X3(I)=(1.0-(ET-SCRT0(I))/(SCRT1(I)-SCRT0(I)))*X0(I)
      R8=BUCKS(I)*((SINF(PA4*X0(I)/FUEHT))*2.0-(SINF(PA4*
      1X3(I)/FUEHT))*2.0)
5502 CONTINUE
C NA TEMP FEEDBACK CONTROLLED SHUTDOWN
5530 IF(ET-SQDFBT)5546,5534,5534
5534 IF(J9-1)5550,5551,5551
5551 IF(ET31-TV0)5535,5535,5550
5550 IF((TNAC(JP-2)-TNR0CS)-TFB)5544,5535,5535
5535 ET31=ET-ET3-DELTA
      IF(ET31-TDT)5538,5538,5539
5538 X2=X3-V0*ET31
      GOT05541
5539 X2=-V1*ET31-V0*0.15+X3
      IF(X2)5540,5540,5541
5540 X2=0.0
5541 R7=RQDW*((SINF(PA4*X0/FUEHT))*2.0-(SINF(PA4*X2/FUEHT))*2.0)
      IF(R7-RRX)5547,5547,5548
5548 R7=RRX
5547 CONTINUE
      RRX=R7
      J9=1
      GOT05546
5544 ET3=ET
      J9=0
      IF(ET31-TV0)5546,5546,5552
5552 X3=X2
      ET31=0.0
5546 CONTINUE
      RR=R9+R8+R7
      K3=2
C TEMPERATURE FEEDBACK REACTIVITY
      IF(K5-2)6836,6832,6832

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6832 SUMN=0.0
    SUMF=0.0
    SUMRN=0.0
    D05833J=4,JP2
    SUMN=SUMN+WTE*TNAE(J)+WTC*TNAC(J)
    SUMRN=SUMRN+WTC*RCC2(J)*TNAC(J)+WTE*RCE2(J)*TNAE(J)
    D05833I=1,IP
    SUMDGP=SUMDGP+WTC*RCCDGP(J)*(TFC(I,J)-TFCI(I,J))/(TFC(I,J)+273.0)
    1+WTE*RCEDGP(J)*(TFE(I,J)-TFEI(I,J))/(TFE(I,J)+273.0)
    SUMEX=SUMEX+WTC*RCCX*(TFC(I,J)-TFCI(I,J))+WTE*RCEX*(TFE
    1(I,J)-TFEI(I,J))
    TFCI(I,J)=TFC(I,J)
    TFEI(I,J)=TFE(I,J)
6833 SUMF=SUMF+WTE*TFE(I,J)+WTC*TFC(I,J)
    TS0D=SUMN/((WTE+WTC)*FLOATF(JP-5))
    TFUL=SUMF/((WTE+WTC)*FLOATF(JP-5)*FLOATF(IP))
    RN=SUMRN/FLOATF(JP5)
    RDGP=SUMDGP/(FLOATF(IP)*FLOATF(JP5))
    RFEX=SUMEX/(FLOATF(IP)*FLOATF(JP5))
    DELK=BE*(RN+RDGP+RFEX+RCBR*TV(2)+RCTR*TV(3)+RR-RR1)
    G0T05562
5836 CONTINUE
    TS0D=(TNVP(199)+TNVP(200)+TNVP(201))/3.0
    TFUL=(TFP(1)+TFP(2))/2.0
5575 TNAC(JP-2)=TNV(201)
5705 RC1=RCX+RC1DGP/(TFUL+273.0)
5561 DELK=BE*(RC1*TFUL+RC2*TS0D+RCBR*TV(2)+RCTR*TV(3)+RR-RR1)
5562 CONTINUE
    ZT=ET
    ET=DELTA+ET
C    DETERMINE ALLOWABLE TIME STEP FOR SECONDARY
    ZELT2(1)=ZELT1(11)
    ZELT2(2)=ZELT1(12)
    ZELT2(3)=ZELT1(13)
    ZELT2(4)=1.0/(Y+Z)
    ZELT2(5)=1.0/(2.0*(ZZ+YY))
    ZELT2(6)=1.0/(2.0*A3)
    ZELT2(7)=1.0/(2.0*A4)
    ZELT2(8)=1000000.0
    ZELT2( 9)=0.9/A31
    ZELT2(10)=1.0/(A31+A32)
    ZELT2(11)=0.9/A41
    ZELT2(12)=1.0/(A41+A42)
    ZELT2(13)=ZELT1(22)
    ZELT2(14)=0.9*VND/WN2
    ZELT2(15)=ZELT1(19)
    ZELT2(16)=TMAX2/3600.0
    ZELT20=1000000.0
    D05580I=1,16
    IF(ZELT2(I)-ZELT20)5579,5580,5580
5579 ZELT20=ZELT2(I)
5580 CONTINUE
    ZELT20=DMUL*ZELT20
    IF(ZELT20-ZELT10)56,54,54
    54 CONTINUE
C    CALCULATE NEW IHX TUBE TEMPS.

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      TXTP(1)=TXT(1)*(1.0-(2.0*G+2.0*H)*DELT)+(TNX1(1)+
1 TNX1(2))*G*DELT+(TNX2(1)+TNX2(2))*H*DELT
      TXTP(2)=TXT(2)*(1.0-(2.0*G+2.0*H)*DELT)+(TNX1(34)+
1 TNX1(35))*G*DELT+(TNX2(34)+TNX2(35))*H*DELT
      TXTP(3)=TXT(3)*(1.0-(2.0*G+2.0*H)*DELT)+(TNX1(67)+
1 TNX1(68))*G*DELT+(TNX2(67)+TNX2(68))*H*DELT
      TXTP(4)=TXT(4)*(1.0-(2.0*G+2.0*H)*DELT)+(TNX1(100)+
1 TNX1(101))*G*DELT+(TNX2(100)+TNX2(101))*H*DELT
      TXTP(5)=TXT(5)*(1.0-(2.0*G+2.0*H)*DELT)+(TNX1(133)+
1 TNX1(134))*G*DELT+(TNX2(133)+TNX2(134))*H*DELT
      TXTP(6)=TXT(6)*(1.0-(2.0*G+2.0*H)*DELT)+(TNX1(166)+
1 TNX1(167))*G*DELT+(TNX2(166)+TNX2(167))*H*DELT
      TXTP(7)=TXT(7)*(1.0-(2.0*G+2.0*H)*DELT)+(TNX1(199)+
1 TNX1(200))*G*DELT+(TNX2(199)+TNX2(200))*H*DELT
C     TIME DELAY, IHX SECONDARY
      LUMX2=XLUMX2
      XLUMX2=XLUMX2+DELT*200.0*WN2/(7.0*VNX2)
      LUMX2=XLUMX2-FL0ATF(LUMX20)
      IF(LUMX2)6931,6931,6932
6931 D06933I=2,198
6933 TNX2P(I)=TNX2(I)
      G0T06938
6932 IQP=5
6936 IQR=33*IQP+2
      IQT=33*(IQP+1)+1
      IQV=IQT-1
      ILUM=IQT-LUMX2
      D06934I=ILUM,IQV
6934 TNX2P(I)=TNX2(IQT)
      ILUM=IQV-LUMX2
      D06935I=IQR,ILUM
      ILL=I+LUMX2
6935 TNX2P(I)=TNX2(ILL)
      IQP=IQP-1
      IF(IQP+1)6938,6938,6936
6938 CONTINUE
C     CALCULATE NEW IHX COOLANT TEMPS.
      TNX2P(1)=TNX2(1)*(1.0-(R+S)*DELT)+TNX2(2)*
1 (R-S)*DELT+TXT(1)*2.0*S*DELT
      TNX2P( 34)=TNX2( 34)*(1.0-(R+S)*DELT)+TNX2( 35)*
1 (R-S)*DELT+TXT(2)*2.0*S*DELT
      TNX2P( 67)=TNX2( 67)*(1.0-(R+S)*DELT)+TNX2( 68)*
1 (R-S)*DELT+TXT(3)*2.0*S*DELT
      TNX2P(100)=TNX2(100)*(1.0-(R+S)*DELT)+TNX2(101)*
1 (R-S)*DELT+TXT(4)*2.0*S*DELT
      TNX2P(133)=TNX2(133)*(1.0-(R+S)*DELT)+TNX2(134)*
1 (R-S)*DELT+TXT(5)*2.0*S*DELT
      TNX2P(166)=TNX2(166)*(1.0-(R+S)*DELT)+TNX2(167)*
1 (R-S)*DELT+TXT(6)*2.0*S*DELT
      TNX2P(199)=TNX2(199)*(1.0-(R+S)*DELT)+TNX2(200)*
1 (R-S)*DELT+TXT(7)*2.0*S*DELT
      TNX1P(2)=TNX1(2)*(1.0-(T+U+V)*DELT)+TNX1(1)*
1 (T-U-V)*DELT+TXS(1)*2.0*U*DELT+TXT(1)*2.0*V*DELT
      TNX1P( 35)=TNX1( 35)*(1.0-(T+U+V)*DELT)+TNX1( 34)*
1 (T-U-V)*DELT+TXS(2)*2.0*U*DELT+TXT(2)*2.0*V*DELT
      TNX1P( 68)=TNX1( 68)*(1.0-(T+U+V)*DELT)+TNX1( 67)*

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1(T-U-V)*DELT+TXS(3)*2.0*U*DELT+TXT(3)*2.0*V*DELT
  TNX1P(101)=TNX1(101)*(1.0-(T+U+V)*DELT)+TNX1(100)*
1(T-U-V)*DELT+TXS(4)*2.0*U*DELT+TXT(4)*2.0*V*DELT
  TNX1P(134)=TNX1(134)*(1.0-(T+U+V)*DELT)+TNX1(133)*
1(T-U-V)*DELT+TXS(5)*2.0*U*DELT+TXT(5)*2.0*V*DELT
  TNX1P(167)=TNX1(167)*(1.0-(T+U+V)*DELT)+TNX1(166)*
1(T-U-V)*DELT+TXS(6)*2.0*U*DELT+TXT(6)*2.0*V*DELT
  TNX1P(200)=TNX1(200)*(1.0-(T+U+V)*DELT)+TNX1(199)*
1(T-U-V)*DELT+TXS(7)*2.0*U*DELT+TXT(7)*2.0*V*DELT
  IF(ZELT20-ZELT10)57,55,55
55 IF(ET-ET2)57,56,56
56 DELT=ZELT20
  DELT=DMUL*DELT
  DELTA=3600.0*DELT
C   TIME DELAY, HEAT DUMP
  LUMHDO=XLUMHD
  XLUMHD=XLUMHD+DELT*200.0*WN2/(7.0*VND)
  LUMHD=XLUMHD-FLGATF(LUMHDO)
  IF(LUMHD)6911,6911,6912
6911 D06913I=3,199
6913 TNDP(I)=TND(I)
  GOT06918
6912 IQP=0
6916 IQR=33*IQP+2
  IQS=IQR+1
  IQT=33*(IQP+1)+1
  ILUM=IQR+LUMHD
  D06914I=IQS,ILUM
6914 TNDP(I)=TND(IQR)
  ILUM=IQS+LUMHD
  D06915I=ILUM,IQT
  ILL=I-LUMHD
6915 TNDP(I)=TND(ILL)
  IQP=IQP+1
  IF(IQP-6)6916,6916,6918
6918 CONTINUE
  TNDP(1)=TNP3(200)
C   CALCULATE NEW HEAT DUMP TEMPS.
  TNDP(2)=TND(2)*(1.0-(Y+Z)*DELT)+TND(1)*(Y-Z)*DELT+
1TD(1)*2.0*Z*DELT
  TNDP(35)=TND(35)*(1.0-(Y+Z)*DELT)+TND(34)*
1(Y-Z)*DELT+TD(2)*2.0*Z*DELT
  TNDP(68)=TND(68)*(1.0-(Y+Z)*DELT)+TND(67)*
1(Y-Z)*DELT+TD(3)*2.0*Z*DELT
  TNDP(101)=TND(101)*(1.0-(Y+Z)*DELT)+TND(100)*
1(Y-Z)*DELT+TD(4)*2.0*Z*DELT
  TNDP(134)=TND(134)*(1.0-(Y+Z)*DELT)+TND(133)*
1(Y-Z)*DELT+TD(5)*2.0*Z*DELT
  TNDP(167)=TND(167)*(1.0-(Y+Z)*DELT)+TND(166)*
1(Y-Z)*DELT+TD(6)*2.0*Z*DELT
  TNDP(200)=TND(200)*(1.0-(Y+Z)*DELT)+TND(199)*
1(Y-Z)*DELT+TD(7)*2.0*Z*DELT
  TDP(1)=TD(1)*(1.0-(2.0*ZZ+2.0*YY)*DELT)+(TND(1)+TND(2))
1*ZZ*DELT+(TA(1)+TA(2))*YY*DELT
  TDP(2)=TD(2)*(1.0-2.0*DELT*(ZZ+YY))+(TND(34)+TND(35))
1*ZZ*DELT+(TA(2)+TA(3))*YY*DELT

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RAPID

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TDP(3)=TD(3)*(1.0-2.0*DELT*(ZZ+YY))+(TND( 67)+TND( 68))
1*ZZ*DELT+(TA(3)+TA(4))*YY*DELT
TDP(4)=TD(4)*(1.0-2.0*DELT*(ZZ+YY))+(TND(100)+TND(101))
1*ZZ*DELT+(TA(4)+TA(5))*YY*DELT
TDP(5)=TD(5)*(1.0-2.0*DELT*(ZZ+YY))+(TND(133)+TND(134))
1*ZZ*DELT+(TA(5)+TA(6))*YY*DELT
TDP(6)=TD(6)*(1.0-2.0*DELT*(ZZ+YY))+(TND(166)+TND(167))
1*ZZ*DELT+(TA(6)+TA(7))*YY*DELT
TDP(7)=TD(7)*(1.0-2.0*DELT*(ZZ+YY))+(TND(199)+TND(200))
1*ZZ*DELT+(TA(7)+TA(8))*YY*DELT
TNP3P(1)=TNX2(1)
C TIME DELAY, PIPE 3
LUMP03=XLUMP3
XLUMP3=XLUMP3+DELT*200.0*WN2/(VNP3*7.0)
LUMP3=XLUMP3-FL0ATF(LUMP03)
IF(LUMP3)6841,6841,6842
6841 D06843I=3,199
6843 TNP3P(I)=TNP3(I)
GOT06849
6842 IQP=0
6851 IQR=33*IQP+2
IQS=IQR+1
IQI=33*(IQP+1)+1
ILUM=IQR+LUMP3
D06844I=IQS,ILUM
6844 TNP3P(I)=TNP3(IQR)
ILUM=IQS+LUMP3
D06845I=ILUM,IQT
ILL=I-LUMP3
6845 TNP3P(I)=TNP3(ILL)
IQP=IQP+1
IF(IQP-6)6851,6849,6849
6849 IF(MIX-2)6850,6850,6848
6848 SUM=0.0
D06846I=2,11
6846 SUM=SUM+TNP3P(I)
D06847I=2,11
6847 TNP3P(I)=SUM/10.0
6850 CONTINUE
C CALCULATE NEW PIPE 3 TFMP3.
TP3P(1)=(1.0-2.0*A3*DELT)*TP3(1)+A3*DELT*(TNP3( 1)+TNP3( 2))
TP3P(2)=(1.0-2.0*A3*DELT)*TP3(2)+A3*DELT*(TNP3( 34)+TNP3( 35))
TP3P(3)=(1.0-2.0*A3*DELT)*TP3(3)+A3*DELT*(TNP3( 67)+TNP3( 68))
TP3P(4)=(1.0-2.0*A3*DELT)*TP3(4)+A3*DELT*(TNP3(100)+TNP3(101))
TP3P(5)=(1.0-2.0*A3*DELT)*TP3(5)+A3*DELT*(TNP3(133)+TNP3(134))
TP3P(6)=(1.0-2.0*A3*DELT)*TP3(6)+A3*DELT*(TNP3(166)+TNP3(167))
TP3P(7)=(1.0-2.0*A3*DELT)*TP3(7)+A3*DELT*(TNP3(199)+TNP3(200))
TNP3P( 2)=(1.0-(A31+A32)*DELT)*TNP3( 2)+(A31-A32)*DELT*TNP3( 1)
1+2.0*A32*DELT*TP3(1)
TNP3P( 35)=(1.0-(A31+A32)*DELT)*TNP3( 35)+(A31-A32)*DELT*TNP3( 34)
1+2.0*A32*DELT*TP3(2)
TNP3P( 68)=(1.0-(A31+A32)*DELT)*TNP3( 68)+(A31-A32)*DELT*TNP3( 67)
1+2.0*A32*DELT*TP3(3)
TNP3P(101)=(1.0-(A31+A32)*DELT)*TNP3(101)+(A31-A32)*DELT*TNP3(100)
1+2.0*A32*DELT*TP3(4)
TNP3P(134)=(1.0-(A31+A32)*DELT)*TNP3(134)+(A31-A32)*DELT*TNP3(133)

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RAPID

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1+2.0*A32*DELT*TP3(5)
  TNP3P(167)=(1.0-(A31+A32)*DELT)*TNP3(167)+(A31-A32)*DELT*TNP3(166)
1+2.0*A32*DELT*TP3(6)
  TNP3P(200)=(1.0-(A31+A32)*DELT)*TNP3(200)+(A31-A32)*DELT*TNP3(199)
1+2.0*A32*DELT*TP3(7)
  TNP4P(1)=TND(200)
C   TIME DELAY, PIPE4
  LUMP04=XLUMP4
  XLUMP4=XLUMP4+DELT*200.0*WN2/(VNP4*7.0)
  LUMP4=XLUMP4-FLUATF(LUMP04)
  IF(LUMP4)6861,6861,6862
6861 D06863I=3,199
6863 TNP4P(I)=TNP4(I)
  GOT06869
6862 IQP=0
6871 IQR=33*IQP+2
  IQS=IQR+1
  IQT=33*(IQP+1)+1
  ILUM=IQR+LUMP4
  D06864I=IQS,ILUM
6864 TNP4P(I)=TNP4(IQR)
  ILUM=IQS+LUMP4
  D06865I=ILUM,IQT
  ILL=I-LUMP4
6865 TNP4P(I)=TNP4(ILL)
  IQP=IQP+1
  IF(IQP-6)6871,6869,6869
5869 IF(MIX-2)6870,6870,6868
6868 SUM=0.0
  D06866I=2,11
6866 SUM=SUM+TNP4P(I)
  D06867I=2,11
6867 TNP4P(I)=SUM/10.0
6870 CONTINUE
C   CALCULATE NEW PIPE 4 TEMPS.
  TP4P(1)=(1.0-2.0*A4*DELT)*TP4(1)+A4*DELT*(TNP4( 1)+TNP4( 2))
  TP4P(2)=(1.0-2.0*A4*DELT)*TP4(2)+A4*DELT*(TNP4( 3)+TNP4( 35))
  TP4P(3)=(1.0-2.0*A4*DELT)*TP4(3)+A4*DELT*(TNP4( 67)+TNP4( 68))
  TP4P(4)=(1.0-2.0*A4*DELT)*TP4(4)+A4*DELT*(TNP4(100)+TNP4(101))
  TP4P(5)=(1.0-2.0*A4*DELT)*TP4(5)+A4*DELT*(TNP4(133)+TNP4(134))
  TP4P(6)=(1.0-2.0*A4*DELT)*TP4(6)+A4*DELT*(TNP4(166)+TNP4(167))
  TP4P(7)=(1.0-2.0*A4*DELT)*TP4(7)+A4*DELT*(TNP4(199)+TNP4(200))
  TNP4P( 2)=(1.0-(A41+A42)*DELT)*TNP4( 2)+(A41-A42)*DELT*TNP4( 1)
1+2.0*A42*DELT*TP4(1)
  TNP4P( 35)=(1.0-(A41+A42)*DELT)*TNP4( 35)+(A41-A42)*DELT*TNP4( 34)
1+2.0*A42*DELT*TP4(2)
  TNP4P( 68)=(1.0-(A41+A42)*DELT)*TNP4( 68)+(A41-A42)*DELT*TNP4( 67)
1+2.0*A42*DELT*TP4(3)
  TNP4P(101)=(1.0-(A41+A42)*DELT)*TNP4(101)+(A41-A42)*DELT*TNP4(100)
1+2.0*A42*DELT*TP4(4)
  TNP4P(134)=(1.0-(A41+A42)*DELT)*TNP4(134)+(A41-A42)*DELT*TNP4(133)
1+2.0*A42*DELT*TP4(5)
  TNP4P(167)=(1.0-(A41+A42)*DELT)*TNP4(167)+(A41-A42)*DELT*TNP4(166)
1+2.0*A42*DELT*TP4(6)
  TNP4P(200)=(1.0-(A41+A42)*DELT)*TNP4(200)+(A41-A42)*DELT*TNP4(199)
1+2.0*A42*DELT*TP4(7)

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RAPID

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        TNX2P(200)=TNP4(200)
        CALL XL0AD
        ZT2=ET2
        ET2=ET2+DELTA
        IF(ZELT20-ZELT10)54,57,57
57      CONTINUE
        XL=ET+1.0
        IF(J2-150)101,103,103
101     IF(IT-J2)103,102,102
102     PT=(TT-ET)/FL0ATF(150-J2)
        J2=150
103     CONTINUE
        IF(XL-XM)50,52,52
52      QKW=Q/3413.0
        DELT10=3600.0*ZELT10
        DELT20=3600.0*ZELT20
        WRITE OUTPUT TAPE 9,1200
        WRITEOUTPUTTAPE9,1201,DELT10,DELT20,DELTD,DELTAK,ZT,ZT2,ETD,ETK,
1      QKW,SUMC,TAU
        IF(K5-2)1198,1199,1199
1199    CONTINUE
        WRITEOUTPUTTAPE9,111,(ZD(J),J=4,JP2)
        WRITEOUTPUTTAPE9,112,(TF0C(J),J=4,JP2)
        WRITEOUTPUTTAPE9,120,(TNAC(J),J=4,JP2)
        WRITEOUTPUTTAPE9,110,(TF0E(J),J=4,JP2)
        WRITEOUTPUTTAPE9,121,(TNAE(J),J=4,JP2)
        IF(N6-2)1198,305,305
305     CONTINUE
        R3=1.0
        WRITEOUTPUTTAPE9,306
        WRITEOUTPUTTAPE9,302,((R2(I),I=1,IP),R3)
        WRITEOUTPUTTAPE9,299,TNV2
        DO320J=4,JP2
        WRITEOUTPUTTAPE9,303,(ZD(J),(TFU(I,J),I=1,IP),TF0C(J))
320     WRITEOUTPUTTAPE9,299,TNAC(J)
        WRITEOUTPUTTAPE9,304
        WRITEOUTPUTTAPE9,302,((R2(I),I=1,IP),R3)
        WRITEOUTPUTTAPE9,299,TNV2
        DO321J=4,JP2
        WRITEOUTPUTTAPE9,303,(ZD(J),(TFE(I,J),I=1,IP),TF0E(J))
321     WRITEOUTPUTTAPE9,299,TNAE(J)
1198    CONTINUE
        IF(K2-2)662,1300,1300
662     CONTINUE
C      STORE DATA
        IT=IT+1
        X1(IT)=ZT
        T1(IT)=TNV2
        T2(IT)=TNC0
        T3(IT)=TFUL
        T4(IT)=TNP3(200)
        T5(IT)=TNP4(1)
        T6(IT)=TA(1)
        T7(IT)=TS0D
        T8(IT)=TR
        T9(IT)=TNP1(200)

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RAPID

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      T10(IT)=TNX1(200)
      T11(IT)=TNP3(1)
      T12(IT)=TNP4(200)
      T13(IT)=TNP1(1)
      T14(IT)=0.0
      R00(IT)=R00P
      RH0(IT)=RH0P
      Q1(IT)=Q
      DQ=WA*(TA(1)-TA(8))*CA
      Q2(IT)=DQ
      W1(IT)=WN1
      W2(IT)=WN2
      W3(IT)=WA
      XM=XM+PT
      L1=L1+1
      IF(IT-150)50,1300,1300
50    CONTINUE
C    REMOVE PRIMES FOR NEXT ITERATION
      D0700I=1,220
700   TNV(I)=TNVP(I)
      D0701I=1,4
701   TV(I)=TVP(I)
      TNC=TNCP
      D0702I=1,2
702   TF(I)=TFP(I)
      D0703I=1,200
      TNP1(I)=TNP1P(I)
      TNP2(I)=TNP2P(I)
      TNP3(I)=TNP3P(I)
      TNP4(I)=TNP4P(I)
      TNB(I)=TNBP(I)
      TNM(I)=TNMP(I)
      TNX1(I)=TNX1P(I)
      TNX2(I)=TNX2P(I)
703   TND(I)=TNDP(I)
      D0704I=1,7
      TP1(I)=TP1P(I)
      TP2(I)=TP2P(I)
      TP3(I)=TP3P(I)
      TP4(I)=TP4P(I)
      TB(I)=TBP(I)
      TXS(I)=TXSP(I)
      TXT(I)=TXTP(I)
704   TD(I)=TDP(I)
      TN10=TNP2(200)
      GOT065
1300  CONTINUE
      CALL CLOCK(TIMEA,TIMEB)
      WRITE OUTPUT TAPE 9,1250,TIMEA
      WRITE OUTPUT TAPE9,1020
      IF(K5-2)2307,2308,2308
2307  WRITEOUTPUTTAPE9,2309
      GOT02302
2308  WRITEOUTPUTTAPE9,2310
2302  WRITEOUTPUTTAPE9,2300
      WRITEOUTPUTTAPE9,2301,(X1(IT),T3(IT),T7(IT),T8(IT),R00(IT))

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RAPID

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1,RH0(IT),T2(IT),T13(IT),IT=1,L1)
2306 CONTINUE
C  WRITE ON FILM
    CALL LINCNT(3)
    WRITE OUTPUT TAPE 12,1600,NPROB
    CALL LINCNT(6)
    WRITE OUTPUT TAPE 12,1650
    CALL LINCNT(25)
    WRITE OUTPUT TAPE 12,1601
    CALL LINCNT(28)
    WRITE OUTPUT TAPE 12,1602
    CALL LINCNT(31)
    WRITE OUTPUT TAPE 12,1603
    CALL LINCNT(61)
    WRITE OUTPUT TAPE 12,1604
    XYBND(1)=0.0
    XYBND(2)=1.25*TT
    XYBND(3)=0.0
    XYBND(4)=1.5E+03
    CALL SELGRD(6,8)
    CALL LBLGRD(6,8,XYBND)
    CALL PLFILM(IT,NWORDS,X1(1),-1,Q2(1),-1,XYBND,20,1)
1605 CALL PLFILM(IT,NWORDS,X1(1),-1,Q1(1),-1,XYBND,19,1)
    CALL ADVFLM(0,2)
    CALL LINCNT(3)
    WRITE OUTPUT TAPE 12,1606,NPROB
    CALL LINCNT(6)
    WRITE OUTPUT TAPE 12,1651
    CALL LINCNT(7)
    WRITE OUTPUT TAPE 12,1652
    CALL LINCNT(8)
    WRITE OUTPUT TAPE 12,1653
    CALL LINCNT(25)
    WRITE OUTPUT TAPE 12,1607
    CALL LINCNT(61)
    WRITE OUTPUT TAPE 12,1608
    XYBND(1)=0.0
    XYBND(2)=1.25*TT
    XYBND(3)=0.0
    XYBND(4)=1000.0
    CALL SELGRD(6,8)
    CALL LBLGRD(6,8,XYBND)
    CALL PLFILM(IT,NWORDS,X1(1),-1,T1(1),-1,XYBND,25,1)
    CALL PLFILM(IT,NWORDS,X1(1),-1,T2(1),-1,XYBND,38,1)
1609 CALL PLFILM(IT,NWORDS,X1(1),-1,T3(1),-1,XYBND,22,1)
    CALL ADVFLM(0,2)
    CALL LINCNT(3)
    WRITE OUTPUT TAPE 12,1610,NPROB
    CALL LINCNT(6)
    WRITE OUTPUT TAPE 12,1654
    CALL LINCNT(7)
    WRITE OUTPUT TAPE 12,1655
    CALL LINCNT(8)
    WRITE OUTPUT TAPE 12,1656
    CALL LINCNT(25)
    WRITE OUTPUT TAPE 12,1611

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RAPID

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CALL LINCNT(61)
WRITE OUTPUT TAPE 12,1612
XYBND(1)=0.0
XYBND(2)=1.25*TT
XYBND(3)=0.0
XYBND(4)=1000.0
CALL SELGRD(6,8)
CALL LBLGRD(6,8,XYBND)
CALL PLFILM(IT,NWORDS,X1(1),-1,T4(1),-1,XYBND,25,1)
CALL PLFILM(IT,NWORDS,X1(1),-1,T5(1),-1,XYBND,38,1)
1613 CALL PLFILM(IT,NWORDS,X1(1),-1,T6(1),-1,XYBND,17,1)
CALL ADVFLM(0,2)
CALL LINCNT(3)
WRITE OUTPUT TAPE 12,1614,NPR0B
CALL LINCNT(6)
WRITE OUTPUT TAPE 12,1657
CALL LINCNT(7)
WRITE OUTPUT TAPE 12,1658
CALL LINCNT(8)
WRITE OUTPUT TAPE 12,1659
CALL LINCNT(25)
WRITE OUTPUT TAPE 12,1615
CALL LINCNT(61)
WRITE OUTPUT TAPE 12,1616
XYBND(1)=0.0
XYBND(2)=1.25*TT
XYBND(3)=0.0
XYBND(4)=1.5E+06
CALL SELGRD(6,8)
CALL LBLGRD(6,8,XYBND)
CALL PLFILM(IT,NWORDS,X1(1),-1,W1(1),-1,XYBND,39,1)
CALL PLFILM(IT,NWORDS,X1(1),-1,W2(1),-1,XYBND,50,1)
1617 CALL PLFILM(IT,NWORDS,X1(1),-1,W3(1),-1,XYBND,17,1)
CALL ADVFLM(0,2)
CALL LINCNT(3)
WRITE OUTPUT TAPE 12,1618,NPR0B
CALL LINCNT(6)
WRITE OUTPUT TAPE 12,1660
CALL LINCNT(7)
WRITE OUTPUT TAPE 12,1661
CALL LINCNT(8)
WRITE OUTPUT TAPE 12,1662
CALL LINCNT(9)
WRITE OUTPUT TAPE 12,1663
CALL LINCNT(25)
WRITE OUTPUT TAPE 12,1611
CALL LINCNT(61)
WRITE OUTPUT TAPE 12,1612
XYBND(1)=0.0
XYBND(2)=1.25*TT
XYBND(3)=0.0
XYBND(4)=1000.0
CALL SELGRD(6,8)
CALL LBLGRD(6,8,XYBND)
CALL PLFILM(IT,NWORDS,X1(1),-1,T9(1),-1,XYBND,17,1)
CALL PLFILM(IT,NWORDS,X1(1),-1,T10(1),-1,XYBND,18,1)

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RAPID

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      CALL PLFILM(IT,NWORDS,X1(1),-1,T11(1),-1,XYBND,20,1)
1619 CALL PLFILM(IT,NWORDS,X1(1),-1,T12(1),-1,XYBND,19,1)
      CALL ADVFLM(0,2)
      CALL LINCNT(3)
      WRITE OUTPUT TAPE 12,1620,NPR08
      CALL LINCNT(25)
      WRITE OUTPUT TAPE 12,1621
      CALL LINCNT(61)
      WRITE OUTPUT TAPE 12,1612
      XYBND(1)=0.0
      XYBND(2)=1.25*TT
      XYBND(3)=-4.0
      XYBND(4)=1.0
      CALL SELGRD(6,8)
      CALL LBLGRD(6,8,XYBND)
1622 CALL PLFILM(IT,NWORDS,X1(1),-1,RH0(1),-1,XYBND,42,1)
      CALL ADVFLM(0,2)
      GO TO 1
      END(1,0,0,0,0,0,1,0,0,1,0,0,0,0,0)

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DETST

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C    CALCULATE STEADY STATE-DETAILED FUEL TEMPS.
      SUBROUTINE DETST
      COMMON A,B,Q,FELS,IP,JP,WN1,AF,RIP,FUEHT,RW ,FK,WK
      1,CN,RCON ,CF,VF,VNC,ET,ETD, M,DMUL
      2,TNC ,TF0C,TFC,CURVC,TNE ,TF0E,TFE,CURVE
      3,DQ ,TF ,Z ,TN,TF0,R,R1,PD
      4,P,S0DK,S0DMU,DWN1,QINIT,TOP,SCRT0
      5,TNV2,N6,R2,DELTD,TMAXD,TMAXK,QFRC
      6,PA1,PA2,PA3,PCA,PEA,FL0C,FL0E,W,X,TA,TD
      7,BE,BA,RA,EL,SUMC,DELK,DELTAK,ETK,K2,TAU,EPSI,J5,QN,QDEC
      8,K4,TEMA,DEMA,WA,TEMQ,DEMQ,CA,HMUL,ITER
      DIMENSIONBA(6),RA(6),SCRT0(6)
      DIMENSIONTA(10),TD(10)
      DIMENSIONA(56,56),B(56,1)
      DIMENSIONDQ(15),TN(15) ,TF0(15),TF(10,15),TNC(15)
      1 ,TF0C(15),TFC(10,15),TNE(15) ,TF0E(15),TFE(10,15),
      2R(10),R1(10),R2(10),Z(15),PD(15),CURVC(15),CURVE(15)
      99 FORMAT(1H ,97X,F11.1)
      101 FORMAT(1H ,5X,34HAPPROXIMATE CENTER PIN FUEL TEMP C,63X,6HSODIUM)
      102 FORMAT(17H FR. FUEL RADIUS=11F7.3)
      103 FORMAT(14H FR. FUEL HT.=F5.2,11F7.1)
      104 FORMAT(1H ,6X,32HAPPROXIMATE EDGE PIN FUEL TEMP C,63X,6HSODIUM)
      105 FORMAT(4H HW=F10.1)
      106 FORMAT(1H ,8X,31HANALYTIC CENTER PIN FUEL TEMP C,63X,6HSODIUM)
      107 FORMAT(1H ,9X,29HANALYTIC EDGE PIN FUEL TEMP C,63X,6HSODIUM)
      FUELL=FUEHT/FL0ATF(JP-5)
      R3=1.0
      DWN1=FL0C*WN1
      DWN=DWN1/FELS
      TN(3)=TNV2
      KD=0
      JP2=JP-2
      JP1=JP-1
      D01J=4,JP2
      Z(J)=FL0ATF(2*J-7)/FL0ATF(2*JP-10)
      1 PD(J)=PA1*PCA*(1.0+SINF(PA2*Z(J)+PA3))
      AW=6.2832*RW*FUELL
      D09I=1,IP
      9 R(I)=(FL0ATF(I)/FL0ATF(IP))*0.5*RIP
      R1(1)=R(1)/2.0
      R2(1)=R1(1)/RIP
      D010I=2,IP
      R1(I)=(R(I)+R(I-1))/2.0
      10 R2(I)=R1(I)/RIP
      IP1=IP-1
      PIP=FL0ATF(IP)
      4 CONTINUE
      D05J=4,JP2
      5 DQ(J)=QFRC*Q*PD(J)/(FELS*FL0ATF(JP-5))
      20 D06J=4,JP
      6 TN(J)=TN(J-1)+DQ(J)/(CN*DWN)
      CALL HXFUEL(HW)
      UW=1.0/(1.0/HW+2.0*RW*LOGF(RW/R1(IP))/(FK+WK))
      IF(UW*AW-2.0*CN*DWN)81,81,91
      91 UW=2.0*CN*DWN/AW

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DETST

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81 IF(HW*AW-2.0*CN*DWN)22,22,21
21 HW=2.0*CN*DWN/AW
22 D011J=4,JP2
   TF0(J)=(LOGF(RW/RIP)/(6.2832*WK*FUELL)+1.0/(HW*AW))*DQ(J)
   1+(TN(J)+TN(J-1))/2.0
   D011I=1,IP
11  TF(I,J)=TF0(J)+DQ(J)*((1.0-R1(I)**2.0/RIP**2.0)/(12.5664*
   1FK*FUELL)+RC0N*DQ(J)/AW
   IF(KD-1)109,110,110
109 WRITEOUTPUTTAPE9,106
   WRITEOUTPUTTAPE9,102,((R2(I),I=1,IP),R3)
   D0122J=4,JP2
   WRITEOUTPUTTAPE9,103,(Z(J),(TF(I,J),I=1,IP),TF0(J))
122 WRITEOUTPUTTAPE9,99,TN(J)
   GOT0500
110 WRITEOUTPUTTAPE9,107
   WRITEOUTPUTTAPE9,102,((R2(I),I=1,IP),R3)
   D0123J=4,JP2
   WRITEOUTPUTTAPE9,103,(Z(J),(TF(I,J),I=1,IP),TF0(J))
123 WRITEOUTPUTTAPE9,99,TN(J)
500 CONTINUE
   IF(KD-1)200,250,250
200 CONTINUE
   D0204J=3,JP2
201 TNC(J)=TN(J)
   TF0C(J)=TF0(J)
   D0204I=1,IP
204 TFC(I,J)=TF(I,J)
257 CONTINUE
   KD=1
   DWN1=FL0E*WN1
   DWN=DWN1/FELS
   2 D05J=4,JP2
   3 PD(J)=PEA*PD(J)/PCA
   GOT04
250 CONTINUE
   D0255J=3,JP2
251 TNE(J)=TN(J)
   TF0E(J)=TF0(J)
   D0254I=1,IP
254 TFE(I,J)=TF(I,J)
   CURVE(J)=(TFE(IP,J)-TF0E(J))/(TF0E(J)-(TNE(J)+TNE(J-1))/2.0)
   CURVC(J)=(TFC(IP,J)-TF0C(J))/(TF0C(J)-(TNC(J)+TNC(J-1))/2.0)
255 CONTINUE
256 CONTINUE
   IST=1
   CALL DETTR(IST)
   WRITEOUTPUTTAPE9,101
   WRITEOUTPUTTAPE9,102,((R2(I),I=1,IP),R3)
   WRITEOUTPUTTAPE9,99,TNC(3)
   D0120J=4,JP2
   WRITEOUTPUTTAPE9,103,(Z(J),(TFC(I,J),I=1,IP),TF0C(J))
120 WRITEOUTPUTTAPE9,99,TNC(J)
   WRITEOUTPUTTAPE9,104
   WRITEOUTPUTTAPE9,102,((R2(I),I=1,IP),R3)
   WRITEOUTPUTTAPE9,99,TNE(3)

```

DETST

```
      DO 121 J=4,JP2
        WRITEOUTPUTTAPE9,103,(Z(J),(TFE(I,J),I=1,IP),TFGE(J))
121  WRITEOUTPUTTAPE9,99,TNE(J)
      WRITEOUTPUTTAPE9,105,HW
      RETURN
      END(1,0,0,0,0,0,1,0,0,1,0,0,0,0,0)
```

DETTR

```

C      CALCULATE TRANSIENT-DETAILED FUEL TEMPS.
      SUBROUTINE DETTR(IST)
      COMMON A,B,Q,FELS,IP,JP,WN1,AF,RIP,FUEHT,RW ,FK,WK
1,CN,RCGN ,CF,VF,VNC,ET,ETD, M,DMUL
2,TNC ,TFGC,TFC,CURVC,TNE ,TFGE,TFE,CURVE
3,DQ ,TF ,Z ,TN,TFO,R,R1,PD
4,P,SODK,SODMU,DWN1,QINIT,TOP,SCRTO
5,TNV2,N6,R2,DELTD,TMAXD,TMAXK,QFRC
6,PA1,PA2,PA3,PCA,PEA,FLGC,FLGE,W,X,TA,TD
7,BE,BA,RA,EL,SUMC,DELK,DELTAK,ETK,K2,TAU,EPSI,J5,QN,QDEC
8,K4,TDEMA,DEMA,WA,TDEMQ,DEMQ,CA,HMUL,ITER
      DIMENSIONBA(6),RA(6),SCRTO(6)
      DIMENSIONTA(10),TD(10)
      DIMENSIONA(56,56),B(56,1)
      DIMENSIONDQ(15),TN(15) ,TF(10,15),R(10),R1(10),Z(15),
1PD(15),CURV(15),TNC(15) ,TFC(10,15),TFO(15),TFGC(15),TNE(15
2) ,TFE(10,15),TFGE(15),TNP(15),TRP(15),TFP(10,15),TFOP(15)
3,CURVE(15),CURVC(15),ZE(15),R2(10)
      ISTI=0
112 FORMAT(3F8.2)
113 FORMAT(24H TFO MIN TFC MAX TFO MAX)
      IF(IST-1)699,114,114
114 WRITEOUTPUTTAPE9,113
697 IF(ISTI-ITER)698,103,103
699 IF(ETD-ET)698,104,104
698 CONTINUE
      TN(3)=TNV2
      TNP(3)=TNV2
      K=0
      PIP=FLOATF(IP)
      JP2=JP-2
      JP1=JP-1
      IP1=IP-1
      FUELL=FUEHT/FLGATF(JP-5)
99 AW=6.2832*KW*FUELL
      CO=1.0/FLGATF(2*JP-10)
      C1=PA1*PCA
      DO1J=4,JP2
      Z(J)=CO*FLGATF(2*J-7)
1 PD(J)=C1*(1.0+SINF(PA2*Z(J)+PA3))
700 CONTINUE
      DO704J=4,JP2
701 TN(J)=TNC(J)
      CURV(J)=CURVC(J)
      DO704I=1,IP
704 TF(I,J)=TFC(I,J)
      XF=2.0*VF/(FELS*PIP*FLGATF(JP-5))
      XNF=VNC/(FELS*FLGATF(JP-5))
      IF(K-1)2,4,4
2 DWN1=FLGE*WN1
      DWN=DWN1/FELS
      CALLHXFUEL(HW)
      UW=1.0/(RCGN+1.0/HW+2.0*RW*LOGF(RW/R1(IP)))/(FK+WK))
      IF(UW*AW-2.0*CN*DWN)6,7,7
7 UW=2.0*CN*DWN/AW

```


DETR

```

6 CONTINUE
  ZE(1)=XF*CF*(R1(IP)-R1(IP-1))/(UW*AW*(R1(IP)-R1(IP-1))+
16.2832*FK*FUELL*R(IP-1))
  ZE(2)=2.0*CN*XNF/(2.0*CN*DWN+UW*AW)
  DWN1=FLGC*WNI
  DWN=DWN1/FELS
4 CONTINUE
  C2=QFRC*Q/(FELS*FLGATF(JP-5))
  D05J=4,JP2
5 DQ(J)=C2*PD(J)
513 CONTINUE
25 CALL HXFUEL(HW)
  UW=1.0/(RCUN+1.0/HW+2.0*RW*LOGF(RW/R1(IP)))/(FK+WK))
  IF(UW*AW-2.0*CN*DWN)420,12,12
12 UW=2.0*CN*DWN/AW
420 CONTINUE
  IF(K-1)21,29,29
21 CONTINUE
  ZE(3)=XF*CF*(R1(IP)-R1(IP-1))/(UW*AW*(R1(IP)-R1(IP-1))+
16.2832*FK*FUELL*R(IP-1))
  ZE(4)=2.0*CN*XNF/(2.0*CN*DWN+UW*AW)
  ZE(5)=TMAXD/3600.0
  ZE(6)=XF*CF*(R1(2)-R1(1))/(6.2832*FK*FUELL*R(1))
  C3=XF*CF/(6.2832*FK*FUELL)
  D023I=2,IP1
  JD=I+4
23 ZE(JD)=C3/(R(I)/(R1(I+1)-R1(I))+R(I-1)/(R1(I)-R1(I-1)))
  ZELTD0=1000000.0
  JD=IP+3
  D024I=1,JD
  IF(ZE(I)-ZELTD0)22,24,24
22 ZELTD0=ZE(I)
24 CONTINUE
  DELT=ZELTD0
  DELT=DMUL*DELT
  DELTD=3600.0*DELT
29 CONTINUE
  C4=6.2832*FK*FUELL*DELT*R(1)/(XF*CF*(R1(2)-R1(1)))
  C5=DELT/(CF*XF*PIPI)
  C6=6.2832*FK*FUELL*DELT/(XF*CF)
  C7=UW*AW*DELT/(XF*CF)
  C8=6.2832*FK*FUELL*DELT*R(IP1)/(XF*CF*(R1(IP)-R1(IP1)))
  C9=DWN*DELT/XNF
  C10=UW*AW*DELT/(2.0*CN*XNF)
  D033J=4,JP2
  TFP(1,J)=(1.0-C4)*TF(1,J)+C5*DQ(J)+C4*TF(2,J)
  D032I=2,IP1
32 TFP(I,J)=(1.0-C6*(R(I)/(R1(I+1)-R1(I))+R(I-1)/(R1(I)-R1(I-1))))*
1TF(I,J)+C5*DQ(J)+C6*R(I)*TF(I+1,J)/(R1(I+1)-R1(I))+C6*R(I-1)*
2TF(I-1,J)/(R1(I)-R1(I-1))
  TFP(IP,J)=(1.0-C7)*TF(IP,J)+C8*(TF(IP1,J)-TF(IP,J))+C5*DQ(J)+
1C7*(TN(J)+TN(J-1))/2.0
33 TNP(J)=C10*(2.0*TF(IP,J)-TN(J-1)-TN(J))+C9*(TN(J-1)-TN(J))+TN(J)
  D0199J=4,JP2
199 TFP(J)=(TFP(IP,J)+0.5*CURV(J)*(TNP(J)+TNP(J-1)))/(1.0+CURV(J))
  IF(K-1)200,250,250

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DETTR

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200 CONTINUE
    D0204 J=4, JP2
201 TNC(J)=TNP(J)
    TF0C(J)=TF0P(J)
    D0204 I=1, IP
204 TFC(I,J)=TFP(I,J)
205 CONTINUE
    K=1
    DWN1=FL0E*WN1
    DWN=DWN1/FELS
    D03 J=4, JP2
3 PD(J)=PEA*PD(J)/PCA
750 CONTINUE
    D0754 J=4, JP2
751 TN(J)=TNE(J)
    CURV(J)=CURVE(J)
    D0754 I=1, IP
754 TF(I,J)=TFE(I,J)
    GOT04
250 CONTINUE
    D0254 J=4, JP2
251 TNE(J)=TNP(J)
    TF0E(J)=TF0P(J)
    D0254 I=1, IP
254 TFE(I,J)=TFP(I,J)
    IF(IST-1)506,696,696
696 TF0MAX=TF0C(4)
    D0503 J=5, JP2
501 IF(TF0MAX-TF0C(J))502,503,503
502 TF0MAX=TF0C(J)
503 CONTINUE
    TF0MIN=TF0E(4)
    TFCMAX=TFC(1,4)
    D0505 J=5, JP2
504 IF(TFCMAX-TFC(1,J))505,506,506
505 TFCMAX=TFC(1,J)
506 CONTINUE
    IF(IST-1)255,256,256
256 IST=IST+1
115 WRITEOUTPUTTAPE9,112,TF0MIN,TFCMAX,TF0MAX
    GO TO 697
255 CONTINUE
    ETD=ETD+DELTD
    GO TO 699
104 CONTINUE
103 RETURN
    END(1,0,0,0,0,0,1,0,0,1,0,0,0,0,0)

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C0EFHX

```

C    CALCULATE HEAT TRANSFER COEFFICIENTS
      SUBROUTINE C0EFHX(H,I,D,W,X)
      COMMON A,B,Q,FELS,IP,JP,WN1,AF,RIP,FUEHT,RW ,FK,WK
      1,CN,RC0N ,CF,VF,VNC,ET,ETD, M,DMUL
      2,TNAC ,TF0C,TFC,CURVC,TNAE ,TF0E,TFE,CURVE
      3,DQD,TFD ,ZD,TN,TF0,RD,R1,PD
      4,P,S0DK,S0DMU,DWN1,QINIT,T0P,SCRT0
      5,TNV2,N6,R2,DELTD,TMAXD,TMAXK,QFRC
      6,PA1,PA2,PA3,PCA,PEA,FLUC,FL0E,W,X,TA,TD
      7,BE,BA,RA,EL,SUMC,DELK,DELTAK,ETK,K2,TAU,EPSI,J5,QN,QDEC
      8,K1,TDEMA,DEMA,WA,TDEMQ,DEMQ,CA,HMUL,ITER
      DIMENSIONBA(6),RA(6)
      DIMENSIONTA(10),TD(10)
      DIMENSIONA(56,56),B(56,1)
      DIMENSIONTNAC(15) ,TF0C(15),TFC(10,15),CURVC(15),TNAE
      1(15) ,TF0E(15),TFE(10,15),CURVE(15)
      2,DQD(15),TFD(10,15) ,ZD(15),TN(15),RD(10),R1(10)
      3,PD(15),TF0(15)
      DIMENSIONR2(10),SCRT0(6)
      IF(I-2)1,2,3
      3 W=HMUL*W
      IF(I-4)4,5,6
      6 IF(I-6)7,8,9
      9 IF(I-8)10,11,12
C-----ALL PIPES
      1 H=S0DK*(7.0+0.025*((1.2732*CN*W/(S0DK*D))**0.8))/D
      GO T015
C-----VESSEL AND SHIELDING
      2 H=S0DK*(202.0+0.692*((0.0308*CN*W/S0DK)**0.8))
      GO T015
C-----IHX PRIMARY, 5MW AND 15MW
      4 H=1.0/(0.000236*(D/W)**0.6+0.000175)
      GO T013
C-----IHX SECONDARY, 5MW AND 15MW
      5 H=1.0/(0.000138*(D/W)**0.4+0.000175)
      GO T013
C-----IHX SHELL, 15MW
      7 H=S0DK*(7.7+0.0275*(0.837*W*CN/S0DK)**0.8)
      GO T013
C-----IHX SHELL, 5MW
      8 H=S0DK*(10.95+0.0391*(1.301*W*CN/S0DK)**0.8)
      GO T013
C-----HD TUBES TO AIR, 5MW AND 15MW
      10 R=D*W**0.6
      H=1.0/(0.00023+1.0/(0.86*R+351.9*R/(R+39.6)))
      W=W/HMUL
      GO T012
C-----NA TO HD TUBES, 5MW AND 15MW
      11 H=1.0/(0.00011*(D/W)**0.4+0.00023)
      13 W=W/HMUL
      15 IF(H*X-2.0*CN*W)12,12,14
      14 H=2.0*CN*W/X
C-----REDUCED FLOW USED TO CALCULATE H FOR COMPOSITE IHX AND HD
      12 RETURN
      END(1,0,0,0,0,0,1,0,0,1,0,0,0,0,0)

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HXFUEL

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C   FUEL HEAT TRANSFER COEFFICIENT
C   BASED ON MARESCA-DWYER CORRELATION.
SUBROUTINE HXFUEL(H)
COMMON A,B,Q,FELS,IP,JP,WN1,AF,RIP,FUEHT,RW,FK,WK
1,CN,RCN,CF,VF,VNC,ET,ETD,M,DMUL
2,TNAC,TF0C,TFC,CURVC,TNAE,TF0E,TFE,CURVE
3,DQD,TFD,ZD,TN,TF0,RD,R1,PD
4,P,S0DK,S0DMU,DWN1,QINIT,T0P,SCRT0
5,TNV2,N6,R2,DELTD,TMAXD,TMAXK,QFRC
6,PA1,PA2,PA3,PCA,PEA,FL0C,FL0E,W,X,TA,TD
7,BE,BA,RA,EL,SUMC,DELK,DELTAK,ETK,K2,TAU,EPSI,J5,QN,QDEC
8,K4,TDEMA,DEMA,WA,TDEMQ,DEMQ,CA,HMUL,ITER
DIMENSIONBA(6),RA(6)
DIMENSIONTA(10),TD(10)
DIMENSIONA(56,56),B(56,1)
DIMENSIONTNAC(15),TF0C(15),TFC(10,15),CURVC(15),TNAE
1(15),TF0E(15),TFE(10,15),CURVE(15)
2,DQD(15),TFD(10,15),ZD(15),TN(15),RD(10),R1(10)
3,PD(15),TF0(15)
DIMENSIONNR2(10),SCRT0(6)
PT0D=P/(2.0*RW)
VM=DWN1*FUEHT/(2.0*VNC)
DE=2.0*RW*(1.10266*PT0D**2.0-1.0)
PR=CN*S0DMU/S0DK
RE=51.0*DE*VM/S0DMU
PE=RE*PR
ETA=4.0+0.002897*RE**0.919
PSI=1.0-1.82/(PR*ETA**1.4)
IF(PSI)1,1,2
1 PSI=0.0
2 GNU=6.66+3.126*PT0D+1.184*PT0D**2.0+0.0155*(PSI*PE)**0.86
IF(PT0D-1.4)4,3,3
3 ALF=1.00
GOTO9
4 IF(PT0D-1.3)6,5,5
5 ALF=0.95
GOTO9
6 IF(PT0D-1.2)8,7,7
7 ALF=0.90
GOTO9
8 ALF=0.80
9 GNU=ALF*GNU
10 HH=S0DK*GNU/DE
H=HH
RETURN
END(1,0,0,0,0,0,1,0,0,1,0,0,0,0,0)

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DECAY

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C      F.P. DECAY HEATING CALCULATION, BASED ON U-235
C      COMPILATION OF SHURE AND DUDZIAK
      SUBROUTINE DECAY
      COMMON A,B,Q,FELS,IP,JP,WN1,AF,RIP,FUEHT,RW ,FK,WK
1,CN,RCN ,CF,VF,VNC,ET,ETD, M,DMUL
2,TNAC ,TF0C,TFC,CURVC,TNAE ,TF0E,TFE,CURVE
3,DQD,TFD ,ZD,TN,TF0,RD,R1,PD
4,P,S0DK,S0DMU,DWN1,QINIT,T0P,SCRT0
5,TNV2,N6,R2,DELTD,TMAXD,TMAXK,QFRC
6,PA1,PA2,PA3,PCA,PEA,FL0C,FL0E,W,X,TA,TD
7,BE,BA,RA,EL,SUMC,DELK,DELTAK,ETK,K2,TAU,EPSI,J5,QN,QDEC
8,K4,TDEMA,DEMA,WA,TDEMQ,DEMQ,CA,HMUL,ITER
      DIMENSIONBA(6),RA(6)
      DIMENSIONTA(10),TD(10)
      DIMENSIONA(56,56),B(56,1)
      DIMENSIONTNAC(15) ,TF0C(15),TFC(10,15),CURVC(15),TNAE
1(15) ,TF0E(15),TFE(10,15),CURVE(15)
2,DQD(15),TFD(10,15) ,ZD(15),TN(15),RD(10),R1(10)
3,PD(15),TF0(15)
      DIMENSIONR2(10),SCRT0(6)
      ETDEC=ET-SCRT0(1)
      IF(ETDEC-0.1)11,12,12
11 ETDEC=0.1
12 IF(ETDEC-10.0)1,1,2
1 A1=12.05
  A2=0.0639
  GOT05
2 IF(ETDEC-150.0)3,3,4
3 A1=15.31
  A2=0.1807
  GOT05
4 A1=27.43
  A2=0.2962
5 IF((T0P+ETDEC)-10.0)6,6,7
6 A3=12.05
  A4=0.0639
  GOT010
7 IF((T0P+ETDEC)-150.0)8,8,9
8 A3=15.31
  A4=0.1807
  GOT010
9 A3=27.43
  A4=0.2962
10 QDEC=0.005*QINIT*(A1*ETDEC**(-A2)-A3*(T0P+ETDEC)**(-A4))
  IF(QDEC)13,13,14
13 QDEC=0.0
14 RETURN
      END(1,0,0,0,0,0,0,1,0,0,1,0,0,0,0,0)

```

XLOAD

```

C      LOAD DEMAND SUBROUTINE
      SUBROUTINE XLOAD
      COMMON A,B,Q,FELS,IP,JP,WN1,AF,RIP,FUEHT,RW ,FK,WK
      1,CN,RCN ,CF,VF,VNC,ET,ETD, M,DMUL
      2,TNAC ,TF0C,TFC,CURVC,TNAE ,TF0E,TFE,CURVE
      3,DQD,TFD ,ZD,TN,TF0,RD,R1,PD
      4,P,S0DK,S0DMU,DWN1,QINIT,T0P,SCRT0
      5,TNV2,N6,R2,DELTD,TMAXD,TMAXK,QFRC
      6,PA1,PA2,PA3,PCA,PEA,FL0C,FL0E,W,X,TA,TD
      7,BE,BA,RA,EL,SUMC,DELK,DELTAK,ETK,K2,TAU,EPSI,J5,QN,QDEC
      8,K4,TDEMA,DEMA,WA,TDEM0,DEM0,CA,HMUL,ITER
      DIMENSIONBA(6),RA(6)
      DIMENSIONTA(10),TD(10)
      DIMENSIONA(56,56),B(56,1)
      DIMENSIONTNAC(15) ,TF0C(15),TFC(10,15),CURVC(15),TNAE
      1(15) ,TF0E(15),TFE(10,15),CURVE(15)
      2,DQD(15),TFD(10,15) ,ZD(15),TN(15),RD(10),R1(10)
      3,PD(15),TF0(15)
      DIMENSIONR2(10),SCRT0(6)
C      HEAT DUMP DEMAND OPTION
      IF(K4-7)5620,5622,5622
5620 IF(ET-TDEMA)5622,5621,5621
5621 WA=DEMA*WA
      K4=7
5622 CONTINUE
5623 IF(ET-TDEM0)5625,5624,5624
5624 WA=DEM0/(CA*(TA(1)-TA(8)))
5625 CONTINUE
C      CALCULATE AIR TEMPS
      C0=(W-X)/(W+X)
      C1=2.0*X/(W+X)
      D0300K=1,7
      I=0-K
300 TA(I)=C0*TA(I+1)+C1*TD(I)
      RETURN
      END(1,0,0,0,0,0,0,1,0,0,1,0,0,0,0,0)

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XNKIN

CNEUTRON KINETICS SUBROUTINE

```

      SUBROUTINE XNKIN
      COMMON A,B,Q,FELS,IP,JP,WN1,AF,RIP,FUEHT,RW ,FK,WK
      1,CN,RCN ,CF,VF,VNC,ET,ETD, M,DMUL
      2,TNAC ,TF0C,TFC,CURVC,TNAE ,TF0E,TFE,CURVE
      3,DQD,TFD ,ZD,TN,TF0,RD,R1,PD
      4,P,S0DK,S0DMU,DWN1,QINIT,T0P,SCRT0
      5,TNV2,N6,R2,DELTD,TMAXD,TMAXK,QFRC
      6,PA1,PA2,PA3,PCA,PEA,FL0C,FL0E,W,X,TA,TD
      7,BE,BA,RA,EL,SUMC,DELK,DELTAK,ETK,K2,TAU,EPSI,J5,QN,QDEC
      8,K4,TDEMA,DEMA,WA,TDEMQ,DEMQ,CA,HMUL,ITER
      DIMENSIONBA(6),RA(6),C(6),ZELTK(7)
      DIMENSIONTA(10),TD(10)
      DIMENSIONA(56,56),B(56,1)
      DIMENSIONTNAC(15) ,TF0C(15),TFC(10,15),CURVC(15),TNAE
      1(15) ,TF0E(15),TFE(10,15),CURVE(15)
      2,DQD(15),TFD(10,15) ,ZD(15),TN(15),RD(10),R1(10)
      3,PD(15),TF0(15)
      DIMENSIONR2(10),SCRT0(6)
      670 FORMAT(1H0,5H***ET,7X,12HDN***** )
      671 FORMAT(1H0,F7.3,1PE12.4)
      674 FORMAT(1H0,24HKINETICS APPROX VIOLATED)
      IF(ETK-1.0E-12)599,599,94
      599 CONTINUE
      QN=Q-QDEC
      CO=QN/EL
      D0600I=1,6
      600 C(I)=CO*BA(I)/RA(I)
      94 CONTINUE
      Q0=QN
      C1=BE-DELK
      C2=1.0+BE
      D095I=1,6
      95 ZELTK(I)=C1/(RA(I)*(C2-BA(I)))
      ZELTK(7)=TMAXK/3600.0
      ZELTK0=1000000.
      D098I=1,7
      IF(ZELTK(I)-ZELTK0)97,97,98
      97 ZELTK0=ZELTK(I)
      98 CONTINUE
      ZELTK0=DMUL*ZELTK0
      DELTK=ZELTK0
      DELTAK=3600.0*DELTK
      605 SUMC=0.0
      D0501I=1,6
      601 SUMC=SUMC+RA(I)*C(I)
      C3=SUMC*DELTK/C1
      D0502I=1,6
      602 C(I)=C(I)*(1.0-DELTK*RA(I))+C3*BA(I)
      QN=EL*SUMC/(BE-DELK)
      TAU=QN*DELTAK/(QN-Q0)
      C CHECK KINETICS EQUATIONS APPROXIMATIONS
      IF(J5-2)648,5004,5004
      648 CONTINUE
      DN=(QN-Q0)/DELTK

```

XNKIN

```
      IF(ABSF(DN)-EPSI*ABSF((DELK-BE)*QN/EL))5004,656,656
656  WRITEOUTPUTTAPE9,670
      WRITEOUTPUTTAPE9,671,ET,DN
      WRITEOUTPUTTAPE9,674
      K2=2
      GOT0700
5004  ETK=ETK+DELTAK
      IF(ETK-ET) 94,700,700
700  RETURN
      END(1,0,0,0,0,0,1,0,0,1,0,0,0,0,0)
```


V. NUMERICAL EXAMPLE

The general operating procedure has been outlined in the body of this report. The deck is assembled in the manner shown in Fig. 9. Having decided on the problem to be run, one consults the internal variables (at the beginning of the main program listing--see Section IV-A), explained in Tables I, II, and III to see what needs to be changed.

As an example, consider the following problem: For the MPBE, it is desired to determine the core and plant response when a \$3 per second reactivity input ramp persists for one second, followed by insertion of all control rods (worth a total of \$30 reactivity) in one second. As the control rod begins to move, the primary and secondary coolant pumps are turned off, the former coasting down to the standby flow rate in 20 seconds, the latter in 60 seconds. The heat dump is untouched. It is desired to have a detailed fuel temperature solution with five axial and five radial increments per fuel pin. The problem is to run for 120 seconds of real time with a printout every 0.25 seconds for 10 seconds, then every 1 second. It will be assumed that a previous similar problem ran with allowable time steps of more than 4 seconds for the secondary loop, and that it is desired to limit those to 1 second for this problem. All other variables in the program are suitable for the problem.

The input data will be as shown in Table IV. The initial P on a card indicates that that data are to be printed before the problem is run. A blank followed by a dollar sign (\$) causes the remainder of the card to be printed, but not used in the calculation. = ends a problem, E ends the calculational series. Table V gives a glossary for use in interpreting the printout which follows it. Figures 10-15 are solutions to sample problems.

Fig. 9. Deck Arrangement

TABLE IV

SAMPLE PROBLEM DATA
(One line per card)

(Column 1)

↓
PNPROB 1 \$ \$3/SEC RAMP FOR 1 SEC, THEN SCRAM AND SHUT DOWN PUMPS.
PRAMBUC 3.0
PRAMTO 0.0
PRAMT1 1.0
PBUCKS(1) -30.0
PSCRT0(1) 1.0
PSCRT1(1) 2.0
PPUM10 1.0
PPUM11 21.0
PPUM20 1.0
PPUM21 61.0
PT 0.25
TT 120.0
J2 40
K5 2
IP 5
IZ 5
PTMAX2 1.0
=
E

TABLE V
PRINTOUT GLOSSARY

TA(8)	=	Heat dump air inlet temperature, °C
WN1	=	Primary coolant mass flow rate, lbm hr ⁻¹
WN2	=	Secondary coolant mass flow rate, lbm hr ⁻¹
WNB	=	Primary coolant mass flow rate bypassing IHX, lbm hr ⁻¹
Q	=	Core thermal power Btu hr ⁻¹
TT	=	Problem duration, sec
NPROB	=	Problem number
TN1I	=	IHX primary inlet temperature, °C
TN1X	=	IHX primary outlet temperature, °C
TN2I	=	IHX secondary inlet temperature, °C
TN2O	=	IHX secondary outlet temperature, °C
WAMIN	=	Starting heat dump air flow rate for iteration calculation, lbm hr ⁻¹
Q9	=	Heat dump power in iteration calculation, Btu hr ⁻¹
WA	=	Heat dump air flow rate, lbm hr ⁻¹
HNX1	=	IHX primary heat transfer coefficient, Btu hr ⁻¹ ft ⁻² °C ⁻¹
HNX2	=	IHX secondary heat transfer coefficient, Btu hr ⁻¹ ft ⁻² °C ⁻¹
HND	=	Heat dump primary heat transfer coefficient, Btu hr ⁻¹ ft ⁻² °C ⁻¹
HA	=	Heat dump secondary heat transfer coefficient, Btu hr ⁻¹ ft ⁻² °C ⁻¹
TA	=	Heat dump secondary temperature, °C
TD	=	Heat dump tubes temperature, °C
TND	=	Heat dump primary temperature, °C
TNX2	=	IHX secondary coolant temperature, °C
TXT	=	IHX tubes coolant temperature, °C
TNX1	=	IHX secondary coolant temperature, °C
SOLID	=	Reflector, fuel, and reflector average temperature, °C
CORENA	=	Vessel sodium temperature, °C
TFOMIN	=	Minimum fuel temperature, °C
TFCMAX	=	Maximum fuel temperature, °C
TFOMAX	=	Maximum clad temperature, °C
} For iteration process		
HW	=	Fuel heat transfer coefficient, Btu hr ⁻¹ ft ⁻² °C ⁻¹
DELT10	=	Primary loop time step, sec
DELT20	=	Secondary loop time step, sec

TABLE V (Continued)

DELTD	= Detailed fuel temperature calculation time step, sec
DELTAK	= Neutron kinetics time step, sec
ET	= Elapsed time, primary loop, sec
ET2	= Elapsed time, secondary loop, sec
ETD	= Elapsed time, detailed fuel calculations, sec
ETK	= Elapsed time, neutron kinetics calculations, sec
QKW	= Core power, kW
SUMC	= $\sum_i \lambda_i C_i$ for neutron kinetics
TAU	= Reactor period, sec
TFUL	= Average fuel temperature, °C
TSOD	= Average core sodium temperature, °C
TR	= Average reflector temperature, °C
ROD	= External reactivity added to core, \$
RHO	= Core reactivity, \$
TNFO	= Sodium temperature leaving core, °C
TNVO	= Sodium temperature leaving vessel, °C

Sample Problem Printout

TIME= 606.72

INPUT DATA

TA(8) = 20.000000

WN1 = 1043000.000000

WN2 = 1040000.000000
WNB= 2.0860E 05

Q = 68260000.000000

TT = 120.000000

NPROB = 1

TN1I= 599.6450

TN1X= 450.0887

TN2I= 421.6166

TN2X= 541.6068

WAMIN= 3.0648E 05

Q9= 0.

WA= 3.3712E 05

Q9= 3.4401E 07

WA= 6.6893E 05

Q9= 8.9759E 07

WA= 5.4007E 05

Q9= 7.5219E 07

WA= 4.7840E 05

Q9= 6.6375E 07

WA= 4.9155E 05

Q9= 6.8402E 07

WA= 4.9063E 05

WA= 4.9063E 05

TA0= 345.8279

WA = 490625.531250
 MNX1 = 2433.090027
 MNX2 = 3320.142242
 HND = 3024.915375
 HA = 162.072357

TA
 345.8273
 312.3382
 275.2254
 234.0970
 188.5184
 138.0080
 82.0324

TD
 524.7058
 510.5717
 494.9082
 477.5499
 458.3154
 436.9955
 413.3709

TND
 541.3535
 529.0207
 515.3535
 500.2074
 483.4225
 464.8214
 444.2077
 421.3635

TNX2
 541.3535
 518.5633
 497.9794
 479.5884
 462.5973
 447.4318

TXT
 553.3013
 529.3543
 507.7257
 488.1912
 470.5478
 454.6126

TNX1
 599.3575
 570.9515
 545.2957
 522.1238
 501.1953
 482.2929

100670 EXECUTION
 NPK03 1 \$ \$3/SEC RAMP FOR 1 SEC, THEN SCRAM AND SHUT DOWN PUMPS.
 RAMBUC 3.0
 RAMT0 0.0
 RAMT1 1.0
 BUCKS(1) -30.0
 SCRT0(1) 1.0
 SCRT1(1) 2.0
 PUM10 1.0
 PUM11 21.0
 PUM20 1.0
 PUM21 61.0
 THAX2 1.0

433.7346
421.3635

440.2202

465.2206
449.8012

SOLID CORENA
481.507 481.507
483.302 483.302
706.439 540.731
763.869 598.161
598.960 598.759
599.558

TIME= 606.73

ANALYTIC CENTER PIN FUEL TEMP C

FR. FUEL RADIUS= 0.224 0.540 0.704 0.835 0.947 1.000
FR. FUEL HT.= 0.10 885.5 799.9 727.8 656.4 585.2 548.8
FR. FUEL HT.= 0.30 1009.3 901.8 811.1 721.4 632.0 586.2
FR. FUEL HT.= 0.50 1061.4 948.3 852.9 758.5 664.5 616.3
FR. FUEL HT.= 0.70 1029.3 928.8 844.1 760.2 676.6 633.8
FR. FUEL HT.= 0.90 927.8 854.0 791.8 730.3 669.0 637.5

SODIUM

503.9

529.7

556.9

581.1

598.8
SODIUM

ANALYTIC EDGE PIN FUEL TEMP C

FR. FUEL RADIUS= 0.224 0.540 0.704 0.835 0.947 1.000
FR. FUEL HT.= 0.10 746.6 691.8 645.6 599.8 554.2 530.9
FR. FUEL HT.= 0.30 834.7 765.8 707.8 650.3 593.0 563.7
FR. FUEL HT.= 0.50 877.7 805.3 744.2 683.8 623.5 592.7
FR. FUEL HT.= 0.70 866.1 801.7 747.5 693.8 640.3 612.9
FR. FUEL HT.= 0.90 808.0 760.8 721.0 681.5 642.3 622.2

503.9

529.7

556.9

581.1

598.8

TFOMIN TFCMAX TFCMAX
530.72 1061.94 637.53
530.56 1062.47 637.66
530.42 1062.96 637.82
530.31 1063.44 637.94
530.21 1063.89 637.95
530.13 1064.33 637.89
530.06 1064.74 637.81
530.00 1065.14 637.72
529.94 1065.52 637.64
529.89 1065.89 637.55
529.84 1066.24 637.46
529.80 1066.57 637.37
529.75 1066.90 637.28
529.71 1067.21 637.20
529.68 1067.51 637.11
529.64 1067.80 637.03
529.61 1068.07 636.95
529.58 1068.34 636.88
529.55 1068.60 636.80
529.52 1068.84 636.73
529.49 1069.08 636.66
529.47 1069.31 636.59
529.44 1069.53 636.53
529.42 1069.74 636.46
529.39 1069.95 636.40

529.37 1070.15 636.34
 529.35 1070.34 636.28
 529.33 1070.52 636.23
 529.31 1070.70 636.17
 529.30 1070.87 636.12
 529.28 1071.03 636.07
 529.26 1071.19 636.02
 529.25 1071.35 635.98
 529.23 1071.49 635.93
 529.22 1071.64 635.89
 529.21 1071.77 635.84
 529.19 1071.91 635.80
 529.18 1072.03 635.76
 529.17 1072.16 635.73
 529.16 1072.28 635.69
 529.15 1072.39 635.65
 529.14 1072.51 635.62
 529.13 1072.61 635.59
 529.12 1072.72 635.56
 529.11 1072.82 635.53
 529.10 1072.92 635.50
 529.09 1073.01 635.47
 529.09 1073.10 635.44
 529.08 1073.19 635.42
 529.07 1073.27 635.39
 529.07 1073.36 635.37
 529.06 1073.44 635.35
 529.05 1073.51 635.33
 529.05 1073.59 635.31
 529.04 1073.66 635.29
 529.04 1073.73 635.27
 529.03 1073.80 635.25
 529.03 1073.87 635.23
 529.02 1073.93 635.21
 529.02 1073.99 635.20

APPROXIMATE CENTER PIN FUEL TEMP C
 FR. FUEL RADIUS= 0.224 0.540 0.704 0.835 0.947 1.000

FR. FUEL HT.= 0.10 894.9 796.2 723.4 651.7 580.4 545.9
 FR. FUEL HT.= 0.30 1021.2 897.2 805.7 715.6 625.9 582.5
 FR. FUEL HT.= 0.50 1074.0 943.6 847.3 752.5 658.2 612.5
 FR. FUEL HT.= 0.70 1040.6 924.8 839.2 755.0 671.1 630.5
 FR. FUEL HT.= 0.90 936.2 851.2 788.5 726.6 665.0 635.2

APPROXIMATE EDGE PIN FUEL TEMP C
 FR. FUEL RADIUS= 0.224 0.540 0.704 0.835 0.947 1.000

FR. FUEL HT.= 0.10 752.6 689.4 642.8 596.9 551.2 529.0
 FR. FUEL HT.= 0.30 842.4 763.0 704.4 646.7 589.2 561.4
 FR. FUEL HT.= 0.50 885.8 802.4 740.7 680.0 619.6 590.2
 FR. FUEL HT.= 0.70 873.4 799.3 744.5 690.6 636.8 610.8
 FR. FUEL HT.= 0.90 813.5 759.1 719.0 679.4 639.9 620.7

MW= 30930.4

END STEADY STATE CALC. PRINTOUT

SODIUM

483.3

503.9

529.7

556.9

581.1

598.9
SODIUM

483.3

503.9

529.7

557.0

581.2

599.0

TIME = 606.77

****START TRANSIENT CALC. PRINTOUT****

	DELTD	DELTAK	ET	ET2	ETD	ETK	QKW	SUMC	TAU
DELTD DELTAK ET ET2 ETD	0.0561	0.3489	0.0066	0.0007	0.	0.	0.		
FRAC FUEL HT =	0.100	0.300	0.500	0.700	0.900	0.0007	2.0000E 04	4.8017E 16	-2.3750E 04
CENTER INTERFACE	545.9	582.5	612.5	630.5	635.2				
CENTER SODIUM	503.9	529.7	556.9	581.1	598.9				
EDGE INTERFACE	529.0	561.4	590.2	610.8	620.7				
EDGE SODIUM	503.9	529.7	557.0	581.2	599.0				

	DELTD	DELTAK	ET	ET2	ETD	ETK	QKW	SUMC	TAU
DELTD DELTAK ET ET2 ETD	0.0561	0.3489	0.0066	0.0004	0.2244	0.	0.2254		
FRAC FUEL HT =	0.100	0.300	0.500	0.700	0.900	0.2247	2.9053E 04	4.9038E 16	6.3686E 00
CENTER INTERFACE	553.7	594.0	626.2	644.7	648.0				
CENTER SODIUM	506.3	534.9	564.6	590.5	608.9				
EDGE INTERFACE	534.4	569.6	600.3	621.1	630.0				
EDGE SODIUM	506.2	534.4	563.6	588.9	606.8				

	DELTD	DELTAK	ET	ET2	ETD	ETK	QKW	SUMC	TAU
DELTD DELTAK ET ET2 ETD	0.0561	0.3489	0.0066	0.0004	0.4488	0.3489	0.4508		
FRAC FUEL HT =	0.100	0.300	0.500	0.700	0.900	0.4492	3.2722E 04	5.1083E 16	5.7272E 00
CENTER INTERFACE	564.3	610.5	647.1	667.7	670.7				
CENTER SODIUM	509.9	542.7	576.8	606.3	627.1				
EDGE INTERFACE	542.1	582.2	616.8	639.8	648.8				
EDGE SODIUM	509.6	542.0	575.3	603.8	623.4				

	DELTD	DELTAK	ET	ET2	ETD	ETK	QKW	SUMC	TAU
DELTD DELTAK ET ET2 ETD	0.0561	0.3489	0.0066	0.0004	0.7293	0.6978	0.7358		
FRAC FUEL HT =	0.100	0.300	0.500	0.700	0.900	0.7293	3.7524E 04	5.3905E 16	4.9951E 00
CENTER INTERFACE	576.8	629.9	672.0	695.5	698.6				
CENTER SODIUM	513.9	551.8	591.0	624.9	648.7				
EDGE INTERFACE	551.1	597.1	636.8	662.9	672.7				
EDGE SODIUM	513.7	550.9	589.1	621.7	644.0				

	DELTD	DELTAK	ET	ET2	ETD	ETK	QKW	SUMC	TAU
DELTD DELTAK ET ET2 ETD	0.0561	0.3489	0.0066	0.0004	0.9537	0.6978	0.9546		
FRAC FUEL HT =	0.100	0.300	0.500	0.700	0.900	0.9540	3.9004E 04	5.6288E 16	5.6015E 00
CENTER INTERFACE	585.4	643.6	689.8	715.6	719.2				
CENTER SODIUM	516.8	558.3	601.3	638.6	664.7				
EDGE INTERFACE	557.4	607.8	651.3	680.1	690.9				
EDGE SODIUM	516.5	557.4	599.3	635.2	659.7				

	DELTD	DELTAK	ET	ET2	ETD	ETK	QKW	SUMC	TAU
DELTD DELTAK ET ET2 ETD	0.0597	0.3570	0.0072	0.0028	1.2467	1.0467	1.2487		
FRAC FUEL HT =	0.100	0.300	0.500	0.700	0.900	1.2488	6.2317E 03	5.3722E 16	-2.9961E 00
CENTER INTERFACE	558.1	605.7	646.7	674.2	685.7				
CENTER SODIUM	510.1	544.5	581.6	615.6	641.8				
EDGE INTERFACE	538.8	581.8	622.2	653.1	670.9				
EDGE SODIUM	510.4	545.7	583.8	618.8	645.6				

	DELTD	DELTAK	ET	ET2	ETD	ETK	QKW	SUMC	TAU
DELTD DELTAK ET ET2 ETD	0.0604	0.3586	0.0074	0.0078	1.4866	1.4022	1.4902		
FRAC FUEL HT =	0.100	0.300	0.500	0.700	0.900	1.4913	2.8508E 03	4.9580E 16	-3.1289E 00
CENTER INTERFACE	536.0	571.0	602.2	624.6	636.0				
CENTER SODIUM	502.4	527.5	554.9	580.8	601.6				
EDGE INTERFACE	522.8	555.1	586.6	612.5	629.7				
EDGE SODIUM	502.9	529.0	558.0	585.8	608.5				

	DELTD	DELTAK	ET	ET2	ETD	ETK	QKW	SUMC	TAU
DELTD DELTAK ET ET2 ETD	0.0612	0.3602	0.0075	0.0135	1.7295	1.7600	1.7361		
FRAC FUEL HT =	0.100	0.300	0.500	0.700	0.900	1.7402	2.0847E 03	4.6103E 16	-3.5822E 00

CENTER INTERFACE 521.9 548.3 572.4 590.4 600.8
 CENTER SODIUM 497.5 516.3 537.2 557.2 573.8
 EDGE INTERFACE 512.5 537.2 562.0 583.2 598.5
 EDGE SODIUM 497.9 517.8 540.3 562.4 581.3

DELT10	DELT20	DELTD	DELTAK	ET	ET2	ETD	ETK	QKW	SUMC	TAU
0.0620	0.3619	0.0076	0.0166	1.9755	1.7600	1.9790	1.9919	1.8531E 03	4.3224E 16	-4.0973E 00
FRACT FUEL HT = 0.100 0.300 0.500 0.700 0.900										
CENTER INTERFACE 512.4 532.8 551.8 566.5 575.6										
CENTER SODIUM 494.2 508.7 525.0 540.8 554.2										
EDGE INTERFACE 505.4 524.8 544.6 562.1 575.5										
EDGE SODIUM 494.6 510.0 527.9 545.7 561.4										

DELT10	DELT20	DELTD	DELTAK	ET	ET2	ETD	ETK	QKW	SUMC	TAU
0.0628	0.3636	0.0078	0.0165	2.2248	2.1202	2.2265	2.2411	1.8055E 03	4.0833E 16	-4.6220E 00
FRACT FUEL HT = 0.100 0.300 0.500 0.700 0.900										
CENTER INTERFACE 505.7 521.7 536.9 548.9 556.6										
CENTER SODIUM 491.8 503.2 516.1 528.8 539.7										
EDGE INTERFACE 500.4 515.7 531.7 546.2 557.7										
EDGE SODIUM 492.1 504.4 518.7 533.2 546.2										

DELT10	DELT20	DELTD	DELTAK	ET	ET2	ETD	ETK	QKW	SUMC	TAU
0.0637	0.3654	0.0079	0.0161	2.4775	2.4830	2.4790	2.4848	1.7730E 03	3.8841E 16	-5.0898E 00
FRACT FUEL HT = 0.100 0.300 0.500 0.700 0.900										
CENTER INTERFACE 500.8 513.6 525.8 535.7 542.3										
CENTER SODIUM 490.1 499.2 509.6 519.8 528.7										
EDGE INTERFACE 496.8 509.1 522.0 534.0 543.8										
EDGE SODIUM 490.3 500.2 511.8 523.7 534.6										

DELT10	DELT20	DELTD	DELTAK	ET	ET2	ETD	ETK	QKW	SUMC	TAU
0.0646	0.3671	0.0081	0.0159	2.7337	2.4830	2.7367	2.7405	1.7417E 03	3.7022E 16	-5.5362E 00
FRACT FUEL HT = 0.100 0.300 0.500 0.700 0.900										
CENTER INTERFACE 497.4 507.7 517.7 525.8 531.4										
CENTER SODIUM 488.8 496.3 504.8 513.1 520.5										
EDGE INTERFACE 494.1 504.1 514.8 524.7 533.0										
EDGE SODIUM 489.0 497.1 506.6 516.4 525.5										

DELT10	DELT20	DELTD	DELTAK	ET	ET2	ETD	ETK	QKW	SUMC	TAU
0.0656	0.3690	0.0083	0.0157	2.9936	2.8483	2.9998	3.0084	1.7115E 03	3.5342E 16	-5.9656E 00
FRACT FUEL HT = 0.100 0.300 0.500 0.700 0.900										
CENTER INTERFACE 494.8 503.4 511.7 518.5 523.1										
CENTER SODIUM 487.9 494.1 501.2 508.2 514.3										
EDGE INTERFACE 492.2 500.5 509.3 517.7 524.7										
EDGE SODIUM 488.1 494.8 502.7 510.9 518.5										

DELT10	DELT20	DELTD	DELTAK	ET	ET2	ETD	ETK	QKW	SUMC	TAU
0.0663	0.3704	0.0084	0.0156	3.1910	3.2159	3.1925	3.1959	1.6911E 03	3.4276E 16	-6.2476E 00
FRACT FUEL HT = 0.100 0.300 0.500 0.700 0.900										
CENTER INTERFACE 493.5 501.1 508.4 514.4 518.5										
CENTER SODIUM 487.4 493.0 499.2 505.4 510.8										
EDGE INTERFACE 491.1 498.5 506.3 513.7 519.9										
EDGE SODIUM 487.6 493.6 500.6 507.8 514.6										

DELT10	DELT20	DELTD	DELTAK	ET	ET2	ETD	ETK	QKW	SUMC	TAU
0.0672	0.3723	0.0086	0.0155	3.4575	3.2159	3.4658	3.4596	1.6645E 03	3.2903E 16	-6.6226E 00
FRACT FUEL HT = 0.100 0.300 0.500 0.700 0.900										
CENTER INTERFACE 492.1 498.6 504.9 510.0 513.4										
CENTER SODIUM 486.9 491.7 497.2 502.5 507.1										
EDGE INTERFACE 490.0 496.3 503.0 509.3 514.5										
EDGE SODIUM 487.0 492.2 498.3 504.5 510.2										

DELT10	DELT20	DELTD	DELTAK	ET	ET2	ETD	ETK	QKW	SUMC	TAU
0.0682	0.3742	0.0088	0.0154	3.7278	3.5863	3.7280	3.7372	1.6383E 03	3.1592E 16	-6.9948E 00

FRACT FUEL HT = 0.100 0.300 0.500 0.700 0.900
 CENTER INTERFACE 491.1 496.9 502.5 506.9 509.9
 CENTER SODIUM 486.6 490.9 495.8 500.5 504.5
 EDGE INTERFACE 489.3 494.8 500.7 506.2 510.7
 EDGE SODIUM 486.7 491.3 496.7 502.1 507.1

DELTD DELT20	DELTD DELTAK	ET	ET2	ETD	ETK	QKW	SUMC	TAU
0.0690 0.3757	0.0090 0.0153	3.9332	3.9591	3.9421	3.9368	1.6204E 03	3.0721E 16	-7.2516E 00
FRACT FUEL HT =	0.100 0.300 0.500 0.700 0.900							
CENTER INTERFACE	490.6 495.9 501.0 505.1 507.7							
CENTER SODIUM	486.4 490.5 495.0 499.3 502.9							
EDGE INTERFACE	488.8 493.9 499.3 504.2 508.3							
EDGE SODIUM	486.5 490.8 495.7 500.6 505.1							

DELTD DELT20	DELTD DELTAK	ET	ET2	ETD	ETK	QKW	SUMC	TAU
0.0700 0.3778	0.0092 0.0153	4.2106	3.9591	4.2154	4.2123	1.5971E 03	2.9604E 16	-7.5935E 00
FRACT FUEL HT =	0.100 0.300 0.500 0.700 0.900							
CENTER INTERFACE	490.0 495.0 499.7 503.3 505.7							
CENTER SODIUM	486.2 490.0 494.2 498.2 501.5							
EDGE INTERFACE	488.4 493.1 498.0 502.4 505.9							
EDGE SODIUM	486.3 490.3 494.8 499.3 503.2							

DELTD DELT20	DELTD DELTAK	ET	ET2	ETD	ETK	QKW	SUMC	TAU
0.0711 0.3799	0.0094 0.0153	4.4923	4.3348	4.4956	4.5023	1.5743E 03	2.8521E 16	-7.9424E 00
FRACT FUEL HT =	0.100 0.300 0.500 0.700 0.900							
CENTER INTERFACE	489.7 494.3 498.7 502.1 504.2							
CENTER SODIUM	486.1 489.8 493.7 497.4 500.4							
EDGE INTERFACE	488.1 492.5 497.0 501.0 504.1							
EDGE SODIUM	486.2 489.9 494.2 498.3 501.8							

DELTD DELT20	DELTD DELTAK	ET	ET2	ETD	ETK	QKW	SUMC	TAU
0.0719 0.3315	0.0096 0.0152	4.7064	4.7131	4.7153	4.7156	1.5584E 03	2.7778E 16	-8.1936E 00
FRACT FUEL HT =	0.100 0.300 0.500 0.700 0.900							
CENTER INTERFACE	489.4 493.9 498.1 501.3 503.3							
CENTER SODIUM	486.1 489.6 493.5 497.0 499.4							
EDGE INTERFACE	487.9 492.1 496.4 500.2 503.1							
EDGE SODIUM	486.1 489.8 493.8 497.7 501.0							

DELTD DELT20	DELTD DELTAK	ET	ET2	ETD	ETK	QKW	SUMC	TAU
0.0731 0.3337	0.0099 0.0152	4.9959	4.7131	4.9988	5.0047	1.5381E 03	2.6836E 16	-8.5297E 00
FRACT FUEL HT =	0.100 0.300 0.500 0.700 0.900							
CENTER INTERFACE	489.2 493.6 497.6 500.7 502.5							
CENTER SODIUM	486.0 489.5 493.3 496.7 499.4							
EDGE INTERFACE	487.8 491.8 495.9 499.5 502.1							
EDGE SODIUM	486.1 489.6 493.5 497.2 500.3							

DELTD DELT20	DELTD DELTAK	ET	ET2	ETD	ETK	QKW	SUMC	TAU
0.0740 0.3354	0.0101 0.0152	5.2162	5.0947	5.2190	5.2175	1.5238E 03	2.6185E 16	-8.7754E 00
FRACT FUEL HT =	0.100 0.300 0.500 0.700 0.900							
CENTER INTERFACE	489.1 493.4 497.4 500.4 502.1							
CENTER SODIUM	486.0 489.5 493.2 496.5 499.2							
EDGE INTERFACE	487.7 491.6 495.6 499.1 501.5							
EDGE SODIUM	486.0 489.6 493.4 497.0 499.9							

DELTD DELT20	DELTD DELTAK	ET	ET2	ETD	ETK	QKW	SUMC	TAU
0.0750 0.3871	0.0103 0.0152	5.4392	5.4789	5.4438	5.4453	1.5095E 03	2.5525E 16	-9.0377E 00
FRACT FUEL HT =	0.100 0.300 0.500 0.700 0.900							
CENTER INTERFACE	489.0 493.3 497.2 500.1 501.8							
CENTER SODIUM	486.0 489.5 493.1 496.5 499.0							
EDGE INTERFACE	487.6 491.5 495.4 498.8 501.1							
EDGE SODIUM	486.0 489.5 493.3 496.8 499.6							

DELTD DELT20	DELTD DELTAK	ET	ET2	ETD	ETK	QKW	SUMC	TAU
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0.0762 0.3895 0.0106 0.0152 5.7410 5.4789 5.7479 5.7489 1.4914E 03 2.4699E 16 -9.3881E 00
 FRACT FUEL HT = 0.100 0.300 0.500 0.700 0.900
 CENTER INTERFACE 488.9 493.2 497.0 500.0 501.6
 CENTER SODIUM 486.0 489.5 493.2 496.5 499.0
 EDGE INTERFACE 487.5 491.4 495.3 498.5 500.8
 EDGE SODIUM 486.1 489.6 493.3 496.7 499.4

DELT10 DELT20 DELTD DELTAK ET ET2 ETD ETK QKW SUMC TAU
 0.0773 0.3913 0.0138 0.0152 5.9707 5.8661 5.9739 5.9765 1.4785E 03 2.4116E 16 -9.6520E 00
 FRACT FUEL HT = 0.100 0.300 0.500 0.700 0.900
 CENTER INTERFACE 488.9 493.1 497.0 499.9 501.6
 CENTER SODIUM 486.1 489.6 493.3 496.6 499.0
 EDGE INTERFACE 487.5 491.4 495.2 498.5 500.7
 EDGE SODIUM 486.1 489.6 493.4 496.7 499.4

DELT10 DELT20 DELTD DELTAK ET ET2 ETD ETK QKW SUMC TAU
 0.0783 0.3932 0.0111 0.0152 6.2035 6.2562 6.2051 6.2040 1.4662E 03 2.3563E 16 -9.9178E 00
 FRACT FUEL HT = 0.100 0.300 0.500 0.700 0.900
 CENTER INTERFACE 488.8 493.1 497.0 499.9 501.6
 CENTER SODIUM 486.1 489.6 493.4 496.7 499.2
 EDGE INTERFACE 487.5 491.4 495.2 498.4 500.6
 EDGE SODIUM 486.1 489.7 493.4 496.8 499.4

DELT10 DELT20 DELTD DELTAK ET ET2 ETD ETK QKW SUMC TAU
 0.0793 0.3951 0.0114 0.0152 6.4394 6.2562 6.4419 6.4466 1.4538E 03 2.3002E 16 -1.0203E 01
 FRACT FUEL HT = 0.100 0.300 0.500 0.700 0.900
 CENTER INTERFACE 488.8 493.1 497.0 500.0 501.7
 CENTER SODIUM 486.1 489.7 493.5 496.9 499.3
 EDGE INTERFACE 487.4 491.4 495.2 498.5 500.6
 EDGE SODIUM 486.2 489.7 493.5 496.9 499.5

DELT10 DELT20 DELTD DELTAK ET ET2 ETD ETK QKW SUMC TAU
 0.0804 0.3970 0.0116 0.0152 6.6785 6.6493 6.6845 6.6892 1.4420E 03 2.2470E 16 -1.0492E 01
 FRACT FUEL HT = 0.100 0.300 0.500 0.700 0.900
 CENTER INTERFACE 488.8 493.1 497.1 500.1 501.8
 CENTER SODIUM 486.2 489.8 493.7 497.0 499.5
 EDGE INTERFACE 487.4 491.4 495.3 498.5 500.7
 EDGE SODIUM 486.2 489.8 493.7 497.1 499.6

DELT10 DELT20 DELTD DELTAK ET ET2 ETD ETK QKW SUMC TAU
 0.0816 0.3990 0.0119 0.0152 6.9210 6.6493 6.9213 6.9318 1.4307E 03 2.1964E 16 -1.0783E 01
 FRACT FUEL HT = 0.100 0.300 0.500 0.700 0.900
 CENTER INTERFACE 488.8 493.2 497.2 500.2 502.0
 CENTER SODIUM 486.3 490.0 493.8 497.3 499.8
 EDGE INTERFACE 487.4 491.4 495.4 498.6 500.8
 EDGE SODIUM 486.3 490.0 493.8 497.3 499.8

DELT10 DELT20 DELTD DELTAK ET ET2 ETD ETK QKW SUMC TAU
 0.0831 0.4017 0.0124 0.0152 7.2496 7.0457 7.2507 7.2502 1.4165E 03 2.1337E 16 -1.1171E 01
 FRACT FUEL HT = 0.100 0.300 0.500 0.700 0.900
 CENTER INTERFACE 488.8 493.2 497.4 500.5 502.3
 CENTER SODIUM 486.3 490.1 494.1 497.6 500.2
 EDGE INTERFACE 487.4 491.5 495.5 498.9 501.1
 EDGE SODIUM 486.3 490.1 494.1 497.6 500.1

DELT10 DELT20 DELTD DELTAK ET ET2 ETD ETK QKW SUMC TAU
 0.0839 0.4031 0.0126 0.0152 7.4163 7.4454 7.4261 7.4169 1.4095E 03 2.1024E 16 -1.1376E 01
 FRACT FUEL HT = 0.100 0.300 0.500 0.700 0.900
 CENTER INTERFACE 488.8 493.3 497.5 500.6 502.5
 CENTER SODIUM 486.4 490.3 494.3 497.9 500.4
 EDGE INTERFACE 487.4 491.5 495.6 499.0 501.2
 EDGE SODIUM 486.4 490.2 494.3 497.8 500.4

DELT10 DELT20 DELTD DELTAK ET ET2 ETD ETK QKW SUMC TAU

0.0852 0.4053	0.0129 0.0152	7.6694	7.4454	7.6695	7.6747	1.3991E 03	2.0560E 16	-1.1696E 01
FRACT FUEL HT =	0.100 0.300 0.500 0.700 0.900							
CENTER INTERFACE	488.8 493.4 497.6 500.9 502.8							
CENTER SODIUM	486.5 490.4 494.6 498.2 500.8							
EDGE INTERFACE	487.5 491.6 495.8 499.2 501.5							
EDGE SODIUM	486.5 490.4 494.5 498.1 500.7							

DELT10 DELT20	DELT0 DELTAK	ET	ET2	ETD	ETK	QKW	SUMC	TAU
0.0865 0.4075	0.0133 0.0152	7.9262	7.8485	7.9327	7.9324	1.3891E 03	2.0119E 16	-1.2019E 01
FRACT FUEL HT =	0.100 0.300 0.500 0.700 0.900							
CENTER INTERFACE	488.8 493.4 497.8 501.2 503.1							
CENTER SODIUM	486.6 490.6 494.8 498.6 501.2							
EDGE INTERFACE	487.5 491.7 496.0 499.5 501.8							
EDGE SODIUM	486.5 490.6 494.8 498.4 501.1							

DELT10 DELT20	DELT0 DELTAK	ET	ET2	ETD	ETK	QKW	SUMC	TAU
0.0878 0.4097	0.0137 0.0152	8.1869	8.2553	8.1901	8.1902	1.3795E 03	1.9698E 16	-1.2345E 01
FRACT FUEL HT =	0.100 0.300 0.500 0.700 0.900							
CENTER INTERFACE	488.8 493.5 498.0 501.5 503.5							
CENTER SODIUM	486.6 490.8 495.2 499.0 501.7							
EDGE INTERFACE	487.5 491.8 496.2 499.8 502.2							
EDGE SODIUM	486.6 490.8 495.1 498.8 501.5							

DELT10 DELT20	DELT0 DELTAK	ET	ET2	ETD	ETK	QKW	SUMC	TAU
0.0891 0.4120	0.0141 0.0152	8.4516	8.2553	8.4549	8.4632	1.3700E 03	1.9274E 16	-1.2694E 01
FRACT FUEL HT =	0.100 0.300 0.500 0.700 0.900							
CENTER INTERFACE	488.9 493.7 498.2 501.8 503.9							
CENTER SODIUM	486.7 491.0 495.5 499.4 502.2							
EDGE INTERFACE	487.5 492.0 496.4 500.1 502.6							
EDGE SODIUM	486.7 491.0 495.4 499.2 501.9							

DELT10 DELT20	DELT0 DELTAK	ET	ET2	ETD	ETK	QKW	SUMC	TAU
0.0905 0.4144	0.0145 0.0152	8.7204	8.6650	8.7278	8.7211	1.3611E 03	1.8892E 16	-1.3026E 01
FRACT FUEL HT =	0.100 0.300 0.500 0.700 0.900							
CENTER INTERFACE	488.9 493.8 498.5 502.2 504.4							
CENTER SODIUM	486.8 491.3 495.9 499.9 502.7							
EDGE INTERFACE	487.6 492.1 496.7 500.5 503.0							
EDGE SODIUM	486.8 491.2 495.7 499.7 502.4							

DELT10 DELT20	DELT0 DELTAK	ET	ET2	ETD	ETK	QKW	SUMC	TAU
0.0920 0.4168	0.0150 0.0152	8.9935	9.0786	8.9945	8.9942	1.3523E 03	1.8505E 16	-1.3380E 01
FRACT FUEL HT =	0.100 0.300 0.500 0.700 0.900							
CENTER INTERFACE	488.9 493.9 498.8 502.6 504.9							
CENTER SODIUM	487.0 491.5 496.3 500.4 503.3							
EDGE INTERFACE	487.6 492.3 496.9 500.9 503.5							
EDGE SODIUM	487.0 491.5 496.1 500.1 503.0							

DELT10 DELT20	DELT0 DELTAK	ET	ET2	ETD	ETK	QKW	SUMC	TAU
0.0930 0.4185	0.0153 0.0152	9.1779	9.0786	9.1922	9.1914	1.3462E 03	1.8238E 16	-1.3637E 01
FRACT FUEL HT =	0.100 0.300 0.500 0.700 0.900							
CENTER INTERFACE	488.9 494.0 499.0 502.9 505.3							
CENTER SODIUM	487.0 491.7 496.5 500.8 503.8							
EDGE INTERFACE	487.6 492.4 497.2 501.2 503.8							
EDGE SODIUM	487.0 491.6 496.4 500.5 503.4							

DELT10 DELT20	DELT0 DELTAK	ET	ET2	ETD	ETK	QKW	SUMC	TAU
0.0945 0.4210	0.0158 0.0152	9.4584	9.4954	9.4735	9.4646	1.3379E 03	1.7881E 16	-1.3995E 01
FRACT FUEL HT =	0.100 0.300 0.500 0.700 0.900							
CENTER INTERFACE	489.0 494.2 499.3 503.4 505.9							
CENTER SODIUM	487.2 492.0 497.0 501.4 504.4							
EDGE INTERFACE	487.7 492.6 497.5 501.6 504.4							
EDGE SODIUM	487.2 491.9 496.8 501.1 504.0							

DELT10 DELT20	DELT0 DELTAK	ET	ET2	ETD	ETK	QKW	SUMC	TAU
0.0960 0.4236	0.0163 0.0152	9.7434	9.4954	9.7484	9.7530	1.3296E 03	1.7521E 16	-1.4374E 01

FRACT FUEL HT = 0.100 0.300 0.500 0.700 0.900
 CENTER INTERFACE 489.0 494.4 499.7 503.9 506.5
 CENTER SODIUM 487.3 492.3 497.5 502.0 505.2
 EDGE INTERFACE 487.7 492.8 497.8 502.1 505.0
 EDGE SODIUM 487.3 492.2 497.3 501.7 504.6

DELT10	DELT20	DELTD	DELTAK	ET	ET2	ETD	ETK	QKW	SUMC	TAU
0.0971	0.4254	0.0167	0.0152	9.9360	9.9165	9.9478	9.9504	1.3242E 03	1.7285E 16	-1.4634E 01
FRACT FUEL HT = 0.100 0.300 0.500 0.700 0.900										
CENTER INTERFACE 489.1 494.6 500.0 504.3 507.0										
CENTER SODIUM 487.4 492.6 497.9 502.5 505.7										
EDGE INTERFACE 487.8 492.9 498.1 502.5 505.4										
EDGE SODIUM 487.4 492.5 497.7 502.1 505.1										

DELT10	DELT20	DELTD	DELTAK	ET	ET2	ETD	ETK	QKW	SUMC	TAU
0.1027	0.4549	0.0189	0.0152	10.9318	10.7701	10.9483	10.9381	1.2988E 03	1.6204E 16	-1.5935E 01
FRACT FUEL HT = 0.100 0.300 0.500 0.700 0.900										
CENTER INTERFACE 489.3 495.5 501.6 506.6 509.8										
CENTER SODIUM 488.1 494.0 500.0 505.2 508.8										
EDGE INTERFACE 488.0 493.8 499.7 504.7 508.0										
EDGE SODIUM 488.0 493.8 499.7 504.7 508.0										

DELT10	DELT20	DELTD	DELTAK	ET	ET2	ETD	ETK	QKW	SUMC	TAU
0.1087	0.4453	0.0211	0.0152	11.9857	12.0809	12.0010	11.9880	1.2342E 03	1.5212E 16	-1.7305E 01
FRACT FUEL HT = 0.100 0.300 0.500 0.700 0.900										
CENTER INTERFACE 489.5 496.4 503.4 509.2 513.0										
CENTER SODIUM 488.8 495.6 502.5 508.4 512.5										
EDGE INTERFACE 488.3 494.8 501.5 507.2 511.1										
EDGE SODIUM 488.8 495.4 502.1 507.7 511.4										

DELT10	DELT20	DELTD	DELTAK	ET	ET2	ETD	ETK	QKW	SUMC	TAU
0.1145	0.4556	0.0211	0.0153	12.9872	12.9760	12.9929	12.9939	1.2044E 03	1.4384E 16	-1.8584E 01
FRACT FUEL HT = 0.100 0.300 0.500 0.700 0.900										
CENTER INTERFACE 489.9 497.8 505.8 512.6 517.1										
CENTER SODIUM 489.8 497.7 505.7 512.5 516.9										
EDGE INTERFACE 488.7 496.1 503.8 510.3 514.7										
EDGE SODIUM 489.7 497.4 505.0 511.3 515.3										

DELT10	DELT20	DELTD	DELTAK	ET	ET2	ETD	ETK	QKW	SUMC	TAU
0.1197	0.4556	0.0211	0.0153	13.9211	13.8897	13.9215	13.9255	1.1794E 03	1.3701E 16	-1.9727E 01
FRACT FUEL HT = 0.100 0.300 0.500 0.700 0.900										
CENTER INTERFACE 490.4 499.5 508.8 516.7 521.8										
CENTER SODIUM 491.0 500.2 509.5 517.2 522.1										
EDGE INTERFACE 489.3 497.8 506.5 513.9 518.7										
EDGE SODIUM 490.7 499.5 508.1 515.2 519.5										

DELT10	DELT20	DELTD	DELTAK	ET	ET2	ETD	ETK	QKW	SUMC	TAU
0.1248	0.4765	0.0211	0.0153	14.8965	14.8237	14.9134	14.9056	1.1555E 03	1.3056E 16	-2.0877E 01
FRACT FUEL HT = 0.100 0.300 0.500 0.700 0.900										
CENTER INTERFACE 491.1 501.9 512.8 522.1 528.1										
CENTER SODIUM 492.6 503.6 514.6 523.4 528.9										
EDGE INTERFACE 490.4 500.3 510.3 518.5 523.8										
EDGE SODIUM 492.0 502.2 512.1 519.9 524.5										

DELT10	DELT20	DELTD	DELTAK	ET	ET2	ETD	ETK	QKW	SUMC	TAU
0.1296	0.4883	0.0224	0.0154	15.9118	15.7796	15.9260	15.9199	1.1327E 03	1.2453E 16	-2.2006E 01
FRACT FUEL HT = 0.100 0.300 0.500 0.700 0.900										
CENTER INTERFACE 492.3 505.0 518.0 528.7 535.6										
CENTER SODIUM 494.5 507.6 520.4 530.6 536.7										
EDGE INTERFACE 491.8 503.5 515.0 524.3 529.9										
EDGE SODIUM 493.8 505.7 517.0 525.8 530.6										

DELT10	DELT20	DELTD	DELTAK	ET	ET2	ETD	ETK	QKW	SUMC	TAU
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0.1337 0.5011 0.0239 0.0155 16.9634 16.7563 16.9856 16.9697 1.1109E 03 1.1887E 16 -2.3104E 01
 FRACT FUEL HT = 0.100 0.300 0.500 0.700 0.900
 CENTER INTERFACE 494.2 509.5 524.6 537.1 544.7
 CENTER SODIUM 496.8 512.4 527.4 539.1 545.7
 EDGE INTERFACE 493.7 507.6 521.0 531.4 537.3
 EDGE SODIUM 496.0 510.1 523.2 533.0 537.9

DELTD DELTAK ET ET2 ETD ETK QKW SUMC TAU
 0.1366 0.5130 0.0239 0.0156 17.9084 17.7585 17.9157 17.9163 1.0927E 03 1.1420E 16 -2.4034E 01
 FRACT FUEL HT = 0.100 0.300 0.500 0.700 0.900
 CENTER INTERFACE 496.1 513.9 531.4 545.4 553.6
 CENTER SODIUM 499.2 517.4 534.6 547.6 554.6
 EDGE INTERFACE 495.5 511.6 526.8 538.3 544.4
 EDGE SODIUM 498.2 514.5 529.3 540.0 544.9

DELTD DELTAK ET ET2 ETD ETK QKW SUMC TAU
 0.1385 0.5257 0.0239 0.0156 18.8706 18.7846 18.8936 18.8836 1.0754E 03 1.0978E 16 -2.4930E 01
 FRACT FUEL HT = 0.100 0.300 0.500 0.700 0.900
 CENTER INTERFACE 498.1 518.6 538.6 554.4 563.4
 CENTER SODIUM 501.7 522.6 542.2 556.9 564.5
 EDGE INTERFACE 497.3 515.8 533.1 545.9 552.2
 EDGE SODIUM 500.5 519.1 535.9 547.6 552.6

DELTD DELTAK ET ET2 ETD ETK QKW SUMC TAU
 0.1387 0.5410 0.0239 0.0157 19.9820 19.8397 19.9907 19.9820 1.0570E 03 1.0514E 16 -2.5887E 01
 FRACT FUEL HT = 0.100 0.300 0.500 0.700 0.900
 CENTER INTERFACE 499.7 522.7 545.4 563.4 573.7
 CENTER SODIUM 503.7 527.2 549.6 566.4 575.1
 EDGE INTERFACE 498.9 519.9 539.4 553.8 560.8
 EDGE SODIUM 502.5 523.7 542.7 555.9 561.3

DELTD DELTAK ET ET2 ETD ETK QKW SUMC TAU
 0.1392 0.5550 0.0239 0.0158 20.9556 20.9217 20.9686 20.9599 1.0420E 03 1.0130E 16 -2.6690E 01
 FRACT FUEL HT = 0.100 0.300 0.500 0.700 0.900
 CENTER INTERFACE 499.8 523.8 548.3 568.5 580.8
 CENTER SODIUM 503.9 528.7 553.1 572.1 582.6
 EDGE INTERFACE 499.4 521.7 543.2 559.4 567.6
 EDGE SODIUM 503.2 526.0 547.0 561.9 568.4

DELTD DELTAK ET ET2 ETD ETK QKW SUMC TAU
 0.1387 0.5695 0.0239 0.0158 21.9263 22.0358 21.9465 21.9409 1.0282E 03 9.7696E 15 -2.7455E 01
 FRACT FUEL HT = 0.100 0.300 0.500 0.700 0.900
 CENTER INTERFACE 499.6 523.8 549.3 571.1 585.3
 CENTER SODIUM 503.6 528.8 554.3 575.1 587.6
 EDGE INTERFACE 499.4 522.5 545.5 563.4 573.2
 EDGE SODIUM 503.3 527.1 549.7 566.4 574.3

DELTD DELTAK ET ET2 ETD ETK QKW SUMC TAU
 0.1387 0.5847 0.0239 0.0159 22.8969 22.6053 22.9005 22.9082 1.0154E 03 9.4358E 15 -2.8165E 01
 FRACT FUEL HT = 0.100 0.300 0.500 0.700 0.900
 CENTER INTERFACE 499.4 523.6 549.5 572.3 588.0
 CENTER SODIUM 503.4 528.7 554.7 576.6 590.7
 EDGE INTERFACE 499.4 522.9 546.9 566.3 577.6
 EDGE SODIUM 503.3 527.6 551.3 569.6 579.1

DELTD DELTAK ET ET2 ETD ETK QKW SUMC TAU
 0.1387 0.6029 0.0239 0.0159 24.0062 23.7726 24.0215 24.0198 1.0017E 03 9.0756E 15 -2.8929E 01
 FRACT FUEL HT = 0.100 0.300 0.500 0.700 0.900
 CENTER INTERFACE 499.2 523.2 549.2 572.7 589.7
 CENTER SODIUM 503.2 528.2 554.5 577.2 592.7
 EDGE INTERFACE 499.3 523.0 547.7 568.5 581.5
 EDGE SODIUM 503.1 527.7 552.4 572.2 583.4

DELTD DELTAK ET ET2 ETD ETK QKW SUMC TAU

0.1387	0.6195	0.0239	0.0159	24.9769	24.9783	24.9994	24.9895	9.9041E 02	8.7798E 15	-2.9554E 01
FRACT FUEL HT = 0.100 0.300 0.500 0.700 0.900										
CENTER INTERFACE 499.0 522.8 548.7 572.4 590.1										
CENTER SODIUM 502.9 527.8 554.0 577.0 593.3										
EDGE INTERFACE 499.2 522.7 548.0 569.7 583.9										
EDGE SODIUM 503.0 527.6 552.8 573.6 586.2										
DELT10 DELT20 DELTD DELTAK ET ET2 ETD ETK QKW SUMC TAU										
0.1387	0.6443	0.0239	0.0159	25.9476	25.5978	25.9534	25.9595	9.7974E 02	8.4991E 15	-3.0140E 01
FRACT FUEL HT = 0.100 0.300 0.500 0.700 0.900										
CENTER INTERFACE 498.8 522.4 548.2 571.9 589.9										
CENTER SODIUM 502.7 527.3 553.4 576.5 593.2										
EDGE INTERFACE 499.0 522.6 547.9 570.2 585.5										
EDGE SODIUM 502.8 527.4 552.8 574.3 588.0										
DELT10 DELT20 DELTD DELTAK ET ET2 ETD ETK QKW SUMC TAU										
0.1387	0.6754	0.0239	0.0159	26.9182	26.8824	26.9313	26.9296	9.6960E 02	8.2325E 15	-3.0692E 01
FRACT FUEL HT = 0.100 0.300 0.500 0.700 0.900										
CENTER INTERFACE 498.7 522.0 547.5 571.2 589.4										
CENTER SODIUM 502.5 526.9 552.7 575.8 592.8										
EDGE INTERFACE 498.9 522.3 547.7 570.4 586.5										
EDGE SODIUM 502.6 527.0 552.6 574.6 589.2										
DELT10 DELT20 DELTD DELTAK ET ET2 ETD ETK QKW SUMC TAU										
0.1387	0.7090	0.0239	0.0159	27.8689	27.5532	27.9092	27.8997	9.5995E 02	7.9786E 15	-3.1209E 01
FRACT FUEL HT = 0.100 0.300 0.500 0.700 0.900										
CENTER INTERFACE 498.5 521.6 546.9 570.4 588.6										
CENTER SODIUM 502.3 526.4 552.0 575.0 592.0										
EDGE INTERFACE 498.7 522.0 547.3 570.2 586.9										
EDGE SODIUM 502.4 526.7 552.2 574.5 589.9										
DELT10 DELT20 DELTD DELTAK ET ET2 ETD ETK QKW SUMC TAU										
0.1387	0.7506	0.0239	0.0159	28.9982	28.9666	29.0063	29.0126	9.4943E 02	7.7016E 15	-3.1764E 01
FRACT FUEL HT = 0.100 0.300 0.500 0.700 0.900										
CENTER INTERFACE 498.3 521.1 546.1 569.4 587.6										
CENTER SODIUM 502.1 525.9 551.2 574.0 591.0										
EDGE INTERFACE 498.5 521.6 546.7 569.8 587.0										
EDGE SODIUM 502.2 526.2 551.6 574.1 590.1										
DELT10 DELT20 DELTD DELTAK ET ET2 ETD ETK QKW SUMC TAU										
0.1387	0.7901	0.0239	0.0159	29.9688	29.7118	29.9842	29.9820	9.4067E 02	7.4718E 15	-3.2214E 01
FRACT FUEL HT = 0.100 0.300 0.500 0.700 0.900										
CENTER INTERFACE 498.2 520.8 545.5 568.6 586.6										
CENTER SODIUM 501.9 525.5 550.5 573.1 590.0										
EDGE INTERFACE 498.4 521.2 546.2 569.3 586.8										
EDGE SODIUM 502.0 525.8 551.1 573.6 589.9										
DELT10 DELT20 DELTD DELTAK ET ET2 ETD ETK QKW SUMC TAU										
0.1387	0.8328	0.0239	0.0159	30.9395	30.4903	30.9621	30.9511	9.3227E 02	7.2519E 15	-3.2638E 01
FRACT FUEL HT = 0.100 0.300 0.500 0.700 0.900										
CENTER INTERFACE 498.0 520.4 544.9 567.8 585.6										
CENTER SODIUM 501.7 525.1 549.9 572.2 589.0										
EDGE INTERFACE 498.2 520.9 545.6 568.6 586.3										
EDGE SODIUM 501.8 525.4 550.5 573.0 589.5										
DELT10 DELT20 DELTD DELTAK ET ET2 ETD ETK QKW SUMC TAU										
0.1387	0.8791	0.0239	0.0159	31.9101	31.2983	31.9161	31.9197	9.2420E 02	7.0412E 15	-3.3033E 01
FRACT FUEL HT = 0.100 0.300 0.500 0.700 0.900										
CENTER INTERFACE 497.9 520.1 544.4 567.0 584.7										
CENTER SODIUM 501.6 524.7 549.3 571.4 588.1										
EDGE INTERFACE 498.1 520.5 545.1 568.0 585.7										
EDGE SODIUM 501.7 525.0 549.9 572.3 588.9										
DELT10 DELT20 DELTD DELTAK ET ET2 ETD ETK QKW SUMC TAU										
0.1387	0.9294	0.0239	0.0159	32.8808	32.1439	32.8940	32.8879	9.1644E 02	6.8390E 15	-3.3403E 01

FRACT FUEL HT = 0.100 0.300 0.500 0.700 0.900
 CENTER INTERFACE 497.8 519.7 543.8 566.2 583.8
 CENTER SODIUM 501.4 524.3 548.7 570.6 587.1
 EDGE INTERFACE 498.0 520.2 544.6 567.3 585.0
 EDGE SODIUM 501.5 524.7 549.3 571.6 588.3

DELT10 DELT20 DELTD DELTAK ET ET2 ETD ETK QKW SUMC TAU
 0.1387 0.9921 0.0239 0.0159 33.9901 33.9669 33.9911 33.9983 9.0790E 02 6.6167E 15 -3.3799E 01
 FRACT FUEL HT = 0.100 0.300 0.500 0.700 0.900
 CENTER INTERFACE 497.6 519.4 543.2 565.4 582.7
 CENTER SODIUM 501.2 523.9 548.0 569.7 586.0
 EDGE INTERFACE 497.8 519.8 544.0 566.5 584.2
 EDGE SODIUM 501.3 524.2 548.7 570.8 587.4

DELT10 DELT20 DELTD DELTAK ET ET2 ETD ETK QKW SUMC TAU
 0.1387 1.0000 0.0239 0.0159 34.9607 34.9508 34.9689 34.9654 9.0073E 02 6.4310E 15 -3.4124E 01
 FRACT FUEL HT = 0.100 0.300 0.500 0.700 0.900
 CENTER INTERFACE 497.5 519.1 542.7 564.7 581.9
 CENTER SODIUM 501.1 523.6 547.5 569.0 585.1
 EDGE INTERFACE 497.7 519.5 543.4 565.8 583.4
 EDGE SODIUM 501.2 523.9 548.1 570.1 586.6

DELT10 DELT20 DELTD DELTAK ET ET2 ETD ETK QKW SUMC TAU
 0.1387 1.0000 0.0239 0.0159 35.9314 35.9508 35.9468 35.9320 8.9381E 02 6.2523E 15 -3.4429E 01
 FRACT FUEL HT = 0.100 0.300 0.500 0.700 0.900
 CENTER INTERFACE 497.4 518.8 542.2 564.0 581.0
 CENTER SODIUM 500.9 523.2 546.9 568.2 584.2
 EDGE INTERFACE 497.6 519.2 542.9 565.1 582.6
 EDGE SODIUM 501.0 523.6 547.6 569.3 585.8

DELT10 DELT20 DELTD DELTAK ET ET2 ETD ETK QKW SUMC TAU
 0.1387 1.0000 0.0239 0.0159 36.9020 36.9508 36.9247 36.9141 8.8708E 02 6.0772E 15 -3.4718E 01
 FRACT FUEL HT = 0.100 0.300 0.500 0.700 0.900
 CENTER INTERFACE 497.3 518.5 541.7 563.3 580.2
 CENTER SODIUM 500.8 522.9 546.4 567.5 583.4
 EDGE INTERFACE 497.5 518.9 542.4 564.4 581.8
 EDGE SODIUM 500.9 523.2 547.0 568.6 585.0

DELT10 DELT20 DELTD DELTAK ET ET2 ETD ETK QKW SUMC TAU
 0.1387 1.0000 0.0239 0.0159 38.0114 37.9508 38.0218 38.0222 8.7970E 02 5.8872E 15 -3.5025E 01
 FRACT FUEL HT = 0.100 0.300 0.500 0.700 0.900
 CENTER INTERFACE 497.2 518.2 541.2 562.6 579.3
 CENTER SODIUM 500.6 522.6 545.9 566.8 582.5
 EDGE INTERFACE 497.4 518.6 541.9 563.7 580.9
 EDGE SODIUM 500.7 522.9 546.5 567.8 584.0

DELT10 DELT20 DELTD DELTAK ET ET2 ETD ETK QKW SUMC TAU
 0.1387 1.0000 0.0239 0.0159 38.9820 38.9508 38.9997 38.9874 8.7347E 02 5.7278E 15 -3.5275E 01
 FRACT FUEL HT = 0.100 0.300 0.500 0.700 0.900
 CENTER INTERFACE 497.1 517.9 540.8 562.0 578.6
 CENTER SODIUM 500.5 522.3 545.4 566.1 581.7
 EDGE INTERFACE 497.2 518.3 541.4 563.0 580.1
 EDGE SODIUM 500.6 522.6 546.0 567.2 583.2

DELT10 DELT20 DELTD DELTAK ET ET2 ETD ETK QKW SUMC TAU
 0.1387 1.0000 0.0239 0.0159 39.9527 39.9508 39.9537 39.9680 8.6740E 02 5.5713E 15 -3.5513E 01
 FRACT FUEL HT = 0.100 0.300 0.500 0.700 0.900
 CENTER INTERFACE 497.0 517.7 540.4 561.4 577.9
 CENTER SODIUM 500.4 522.0 544.9 565.5 581.0
 EDGE INTERFACE 497.1 518.1 541.0 562.4 579.3
 EDGE SODIUM 500.5 522.3 545.5 566.5 582.5

DELT10 DELT20 DELTD DELTAK ET ET2 ETD ETK QKW SUMC TAU

0.1387 1.0000	0.0239 0.0158	40.9233	40.9508	40.9316	40.9323	8.6155E 02	5.4226E 15	-3.5737E 01
FRACT FUEL HT =	0.100 0.300 0.500 0.700 0.900							
CENTER INTERFACE	496.9 517.5 559.9 560.8 577.2							
CENTER SODIUM	500.3 521.7 544.5 564.9 580.2							
EDGE INTERFACE	497.0 517.8 540.6 561.8 578.6							
EDGE SODIUM	500.3 522.0 545.0 565.9 581.7							

DELT10 DELT20	DELTD DELTAK	ET	ET2	ETD	ETK	QKW	SUMC	TAU
0.1387 1.0000	0.0239 0.0158	41.8939	41.9508	41.9094	41.8962	8.5587E 02	5.2788E 15	-3.5950E 01
FRACT FUEL HT =	0.100 0.300 0.500 0.700 0.900							
CENTER INTERFACE	496.8 517.2 539.5 560.3 576.5							
CENTER SODIUM	500.1 521.5 544.1 564.3 579.5							
EDGE INTERFACE	497.0 517.6 540.2 561.3 577.9							
EDGE SODIUM	500.2 521.7 544.6 565.3 580.9							

DELT10 DELT20	DELTD DELTAK	ET	ET2	ETD	ETK	QKW	SUMC	TAU
0.1387 1.0000	0.0239 0.0158	43.0033	42.9508	43.0065	43.0177	8.4954E 02	5.1172E 15	-3.5181E 01
FRACT FUEL HT =	0.100 0.300 0.500 0.700 0.900							
CENTER INTERFACE	496.7 517.0 539.1 559.7 575.7							
CENTER SODIUM	500.0 521.2 543.6 563.7 578.7							
EDGE INTERFACE	496.8 517.3 539.7 560.6 577.1							
EDGE SODIUM	500.1 521.4 544.1 564.6 580.1							

DELT10 DELT20	DELTD DELTAK	ET	ET2	ETD	ETK	QKW	SUMC	TAU
0.1387 1.0000	0.0239 0.0158	43.9739	43.9508	43.9044	43.9807	8.4422E 02	4.9432E 15	-3.6370E 01
FRACT FUEL HT =	0.100 0.300 0.500 0.700 0.900							
CENTER INTERFACE	496.6 516.7 538.7 559.2 575.1							
CENTER SODIUM	499.9 520.9 543.2 563.2 578.1							
EDGE INTERFACE	496.8 517.1 539.3 560.1 576.4							
EDGE SODIUM	500.0 521.2 543.7 564.0 579.4							

DELT10 DELT20	DELTD DELTAK	ET	ET2	ETD	ETK	QKW	SUMC	TAU
0.1387 1.0000	0.0239 0.0158	44.9446	44.9508	44.9623	44.9592	8.3901E 02	4.8513E 15	-3.6556E 01
FRACT FUEL HT =	0.100 0.300 0.500 0.700 0.900							
CENTER INTERFACE	496.5 516.5 538.4 558.7 574.5							
CENTER SODIUM	499.8 520.7 542.8 562.6 577.4							
EDGE INTERFACE	496.7 516.8 538.9 559.5 575.8							
EDGE SODIUM	499.9 520.9 543.3 563.5 578.7							

DELT10 DELT20	DELTD DELTAK	ET	ET2	ETD	ETK	QKW	SUMC	TAU
0.1387 1.0000	0.0239 0.0158	45.9152	45.9508	45.9163	45.9215	8.3397E 02	4.7255E 15	-3.6724E 01
FRACT FUEL HT =	0.100 0.300 0.500 0.700 0.900							
CENTER INTERFACE	496.4 516.3 538.0 558.2 573.9							
CENTER SODIUM	499.7 520.4 542.4 562.1 576.8							
EDGE INTERFACE	496.6 516.6 538.6 559.0 575.1							
EDGE SODIUM	499.8 520.7 542.9 562.9 578.1							

DELT10 DELT20	DELTD DELTAK	ET	ET2	ETD	ETK	QKW	SUMC	TAU
0.1387 1.0000	0.0239 0.0158	46.8859	46.9508	46.8942	46.8992	8.2904E 02	4.6017E 15	-3.6892E 01
FRACT FUEL HT =	0.100 0.300 0.500 0.700 0.900							
CENTER INTERFACE	496.3 516.1 537.7 557.7 573.3							
CENTER SODIUM	499.6 520.2 542.0 561.6 576.2							
EDGE INTERFACE	496.5 516.4 538.2 558.5 574.5							
EDGE SODIUM	499.7 520.4 542.5 562.4 577.5							

DELT10 DELT20	DELTD DELTAK	ET	ET2	ETD	ETK	QKW	SUMC	TAU
0.1387 1.0000	0.0239 0.0158	47.9952	47.9508	48.0151	48.0027	8.2360E 02	4.4665E 15	-3.7075E 01
FRACT FUEL HT =	0.100 0.300 0.500 0.700 0.900							
CENTER INTERFACE	496.3 515.9 537.3 557.2 572.7							
CENTER SODIUM	499.5 520.0 541.6 561.1 575.6							
EDGE INTERFACE	496.4 516.2 537.8 558.0 573.8							
EDGE SODIUM	499.5 520.2 542.1 561.8 576.7							

DELT10 DELT20	DELTD DELTAK	ET	ET2	ETD	ETK	QKW	SUMC	TAU
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0.1387 1.0000 0.0239 0.0158 48.9658 48.9508 48.9692 48.9797 8.1894E 02 4.3506E 15 -3.7228E 01
 FRACT FUEL HT = 0.100 0.300 0.500 0.700 0.900
 CENTER INTERFACE 496.2 515.7 537.0 556.7 572.1
 CENTER SODIUM 499.4 519.7 541.3 560.6 575.0
 EDGE INTERFACE 496.3 516.0 537.5 557.5 573.3
 EDGE SODIUM 499.5 519.9 541.7 561.3 576.2

DELT10 DELT20 DELTD DELTAK ET ET2 ETD ETK QKW SUMC TAU
 0.1387 1.0000 0.0239 0.0158 49.9365 49.9508 49.9470 49.9406 8.1444E 02 4.2399E 15 -3.7374E 01
 FRACT FUEL HT = 0.100 0.300 0.500 0.700 0.900
 CENTER INTERFACE 496.1 515.5 536.7 556.3 571.6
 CENTER SODIUM 499.3 519.5 540.9 560.1 574.5
 EDGE INTERFACE 496.3 515.8 537.2 557.1 572.7
 EDGE SODIUM 499.4 519.7 541.4 560.9 575.6

DELT10 DELT20 DELTD DELTAK ET ET2 ETD ETK QKW SUMC TAU
 0.1387 1.0000 0.0239 0.0157 50.9071 50.9508 50.9249 50.9169 8.1002E 02 4.1308E 15 -3.7518E 01
 FRACT FUEL HT = 0.100 0.300 0.500 0.700 0.900
 CENTER INTERFACE 496.0 515.3 536.4 555.9 571.1
 CENTER SODIUM 499.2 519.3 540.6 559.7 573.9
 EDGE INTERFACE 496.2 515.6 536.9 556.6 572.1
 EDGE SODIUM 499.3 519.5 541.0 560.4 575.0

DELT10 DELT20 DELTD DELTAK ET ET2 ETD ETK QKW SUMC TAU
 0.1387 1.0000 0.0239 0.0157 52.0164 51.9508 52.0220 52.0188 8.0513E 02 4.0115E 15 -3.7673E 01
 FRACT FUEL HT = 0.100 0.300 0.500 0.700 0.900
 CENTER INTERFACE 496.0 515.1 536.0 555.4 570.5
 CENTER SODIUM 499.1 519.1 540.3 559.2 573.3
 EDGE INTERFACE 496.1 515.4 536.5 556.2 571.6
 EDGE SODIUM 499.2 519.3 540.6 559.9 574.4

DELT10 DELT20 DELTD DELTAK ET ET2 ETD ETK QKW SUMC TAU
 0.1387 1.0000 0.0239 0.0157 52.9871 52.9508 52.9999 52.9944 8.0095E 02 3.9092E 15 -3.7807E 01
 FRACT FUEL HT = 0.100 0.300 0.500 0.700 0.900
 CENTER INTERFACE 495.9 514.9 535.7 555.0 570.0
 CENTER SODIUM 499.0 518.9 539.9 558.8 572.8
 EDGE INTERFACE 496.0 515.2 536.2 555.7 571.0
 EDGE SODIUM 499.1 519.1 540.3 559.4 573.8

DELT10 DELT20 DELTD DELTAK ET ET2 ETD ETK QKW SUMC TAU
 0.1387 1.0000 0.0239 0.0157 53.9577 53.9508 53.9777 53.9698 7.9687E 02 3.8098E 15 -3.7939E 01
 FRACT FUEL HT = 0.100 0.300 0.500 0.700 0.900
 CENTER INTERFACE 495.8 514.8 535.5 554.6 569.5
 CENTER SODIUM 498.9 518.7 539.6 558.4 572.3
 EDGE INTERFACE 496.0 515.1 535.9 555.3 570.5
 EDGE SODIUM 499.0 518.9 540.0 559.0 573.3

DELT10 DELT20 DELTD DELTAK ET ET2 ETD ETK QKW SUMC TAU
 0.1387 1.0000 0.0239 0.0157 54.9284 54.9508 54.9318 54.9291 7.9291E 02 3.7149E 15 -3.8066E 01
 FRACT FUEL HT = 0.100 0.300 0.500 0.700 0.900
 CENTER INTERFACE 495.8 514.6 535.2 554.3 569.1
 CENTER SODIUM 498.9 518.5 539.3 558.0 571.9
 EDGE INTERFACE 495.9 514.9 535.6 554.9 570.1
 EDGE SODIUM 498.9 518.7 539.7 558.6 572.8

DELT10 DELT20 DELTD DELTAK ET ET2 ETD ETK QKW SUMC TAU
 0.1387 1.0000 0.0239 0.0157 55.8990 55.9508 55.9096 55.9039 7.8902E 02 3.6211E 15 -3.8194E 01
 FRACT FUEL HT = 0.100 0.300 0.500 0.700 0.900
 CENTER INTERFACE 495.7 514.5 534.9 553.9 568.6
 CENTER SODIUM 498.8 518.4 539.1 557.6 571.4
 EDGE INTERFACE 495.8 514.7 535.4 554.6 569.6
 EDGE SODIUM 498.8 518.5 539.4 558.2 572.3

DELT10 DELT20 DELTD DELTAK ET ET2 ETD ETK QKW SUMC TAU
 0.1387 1.0000 0.0239 0.0157 57.0084 56.9508 57.0306 57.0198 7.8468E 02 3.5171E 15 -3.8335E 01

FRACT FUEL HT = 0.100 0.300 0.500 0.700 0.900
 CENTER INTERFACE 495.6 514.3 534.6 553.5 568.1
 CENTER SODIUM 498.7 518.2 538.7 557.1 570.9
 EDGE INTERFACE 495.8 514.5 535.1 554.1 569.0
 EDGE SODIUM 498.7 518.3 539.1 557.7 571.8

DELT10 DELT20	DELTD DELTAK	ET	ET2	ETD	ETK	QKW	SUMC	TAU
0.1387 1.0000	0.0239 0.0157	57.9790	57.9508	57.9846	57.9940	7.8098E 02	3.4290E 15	-3.8454E 01
FRACT FUEL HT =	0.100 0.300 0.500 0.700 0.900							
CENTER INTERFACE	495.6 514.1 534.4 553.1 567.7							
CENTER SODIUM	498.6 518.0 538.5 556.8 570.4							
EDGE INTERFACE	495.7 514.4 534.8 553.8 568.6							
EDGE SODIUM	498.7 518.1 538.8 557.4 571.3							

DELT10 DELT20	DELTD DELTAK	ET	ET2	ETD	ETK	QKW	SUMC	TAU
0.1387 1.0000	0.0239 0.0157	58.9497	58.9508	58.9625	58.9522	7.7739E 02	3.3447E 15	-3.8572E 01
FRACT FUEL HT =	0.100 0.300 0.500 0.700 0.900							
CENTER INTERFACE	495.5 514.0 534.1 552.8 567.3							
CENTER SODIUM	498.5 517.8 538.2 556.4 570.0							
EDGE INTERFACE	495.6 514.2 534.5 553.4 568.2							
EDGE SODIUM	498.6 518.0 538.5 557.0 570.9							

DELT10 DELT20	DELTD DELTAK	ET	ET2	ETD	ETK	QKW	SUMC	TAU
0.1387 1.0000	0.0239 0.0157	59.9203	59.9508	59.9404	59.9258	7.7386E 02	3.2615E 15	-3.8693E 01
FRACT FUEL HT =	0.100 0.300 0.500 0.700 0.900							
CENTER INTERFACE	495.4 513.8 533.9 552.4 566.9							
CENTER SODIUM	498.5 517.7 537.9 556.1 569.6							
EDGE INTERFACE	495.6 514.1 534.3 553.1 567.7							
EDGE SODIUM	498.5 517.8 538.2 556.6 570.4							

DELT10 DELT20	DELTD DELTAK	ET	ET2	ETD	ETK	QKW	SUMC	TAU
0.1387 1.0000	0.0239 0.0157	61.0296	60.9508	61.0375	61.0405	7.6992E 02	3.1691E 15	-3.8827E 01
FRACT FUEL HT =	0.100 0.300 0.500 0.700 0.900							
CENTER INTERFACE	495.4 513.7 533.6 552.1 566.4							
CENTER SODIUM	498.4 517.5 537.6 555.7 569.1							
EDGE INTERFACE	495.5 513.9 534.0 552.7 567.3							
EDGE SODIUM	498.4 517.6 538.0 556.2 569.9							

DELT10 DELT20	DELTD DELTAK	ET	ET2	ETD	ETK	QKW	SUMC	TAU
0.1387 1.0000	0.0239 0.0157	62.0003	61.9508	62.0153	62.0136	7.6655E 02	3.0908E 15	-3.8944E 01
FRACT FUEL HT =	0.100 0.300 0.500 0.700 0.900							
CENTER INTERFACE	495.3 513.5 533.4 551.8 566.0							
CENTER SODIUM	498.3 517.3 537.4 555.3 568.7							
EDGE INTERFACE	495.5 513.8 533.8 552.4 566.8							
EDGE SODIUM	498.4 517.5 537.7 555.9 569.5							

DELT10 DELT20	DELTD DELTAK	ET	ET2	ETD	ETK	QKW	SUMC	TAU
0.1387 1.0000	0.0239 0.0157	62.9709	62.9508	62.9932	62.9865	7.6326E 02	3.0146E 15	-3.9059E 01
FRACT FUEL HT =	0.100 0.300 0.500 0.700 0.900							
CENTER INTERFACE	495.3 513.4 533.2 551.4 565.6							
CENTER SODIUM	498.3 517.2 537.1 555.0 568.3							
EDGE INTERFACE	495.4 513.6 533.6 552.0 566.4							
EDGE SODIUM	498.3 517.3 537.4 555.5 569.1							

DELT10 DELT20	DELTD DELTAK	ET	ET2	ETD	ETK	QKW	SUMC	TAU
0.1387 1.0000	0.0239 0.0157	63.9416	63.9508	63.9472	63.9435	7.6006E 02	2.9418E 15	-3.9175E 01
FRACT FUEL HT =	0.100 0.300 0.500 0.700 0.900							
CENTER INTERFACE	495.2 513.3 532.9 551.2 565.3							
CENTER SODIUM	498.2 517.0 536.9 554.7 567.9							
EDGE INTERFACE	495.3 513.5 533.3 551.7 566.1							
EDGE SODIUM	498.2 517.2 537.2 555.2 568.7							

DELT10 DELT20	DELTD DELTAK	ET	ET2	ETD	ETK	QKW	SUMC	TAU
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0.1387 1.0000 0.0239 0.0157 64.9122 64.9508 64.9251 64.9159 7.5691E 02 2.8698E 15 -3.9290E 01
 FRAC FUEL HT = 0.100 0.300 0.500 0.700 0.900
 CENTER INTERFACE 495.2 513.1 532.7 550.9 564.9
 CENTER SODIUM 498.1 516.9 536.7 554.4 567.5
 EDGE INTERFACE 495.2 513.4 532.1 551.4 565.7
 EDGE SODIUM 498.2 517.0 537.0 554.9 568.3

DELT10 DELT20 DELTD DELTAK ET ET2 ETD ETK QKW SUMC TAU
 0.1387 1.0000 0.0239 0.0157 66.0215 65.9508 66.0222 66.0292 7.5339E 02 2.7898E 15 -3.9421E 01
 FRAC FUEL HT = 0.100 0.300 0.500 0.700 0.900
 CENTER INTERFACE 495.1 513.0 532.5 550.5 564.5
 CENTER SODIUM 498.1 516.7 536.4 554.0 567.1
 EDGE INTERFACE 495.2 513.2 532.9 551.1 565.3
 EDGE SODIUM 498.1 516.8 536.7 554.5 567.9

DELT10 DELT20 DELTD DELTAK ET ET2 ETD ETK QKW SUMC TAU
 0.1387 1.0000 0.0239 0.0157 66.9922 66.9508 67.0001 67.0011 7.5037E 02 2.7219E 15 -3.9540E 01
 FRAC FUEL HT = 0.100 0.300 0.500 0.700 0.900
 CENTER INTERFACE 495.1 512.9 532.3 550.2 564.2
 CENTER SODIUM 498.0 516.6 536.2 553.7 566.8
 EDGE INTERFACE 495.2 513.1 532.6 550.8 564.9
 EDGE SODIUM 498.0 516.7 536.5 554.2 567.5

DELT10 DELT20 DELTD DELTAK ET ET2 ETD ETK QKW SUMC TAU
 0.1387 1.0000 0.0239 0.0157 67.9628 67.9508 67.9780 67.9728 7.4743E 02 2.6560E 15 -3.9653E 01
 FRAC FUEL HT = 0.100 0.300 0.500 0.700 0.900
 CENTER INTERFACE 495.0 512.7 532.1 550.0 563.8
 CENTER SODIUM 497.9 516.4 536.0 553.4 566.4
 EDGE INTERFACE 495.1 513.0 532.4 550.5 564.5
 EDGE SODIUM 498.0 516.6 536.2 553.9 567.1

DELT10 DELT20 DELTD DELTAK ET ET2 ETD ETK QKW SUMC TAU
 0.1387 1.0000 0.0239 0.0157 68.9335 68.9508 68.9558 68.9444 7.4454E 02 2.5918E 15 -3.9769E 01
 FRAC FUEL HT = 0.100 0.300 0.500 0.700 0.900
 CENTER INTERFACE 495.0 512.6 531.9 549.7 563.5
 CENTER SODIUM 497.9 516.3 535.8 553.2 566.1
 EDGE INTERFACE 495.1 512.9 532.2 550.2 564.2
 EDGE SODIUM 497.9 516.4 536.0 553.6 566.7

DELT10 DELT20 DELTD DELTAK ET ET2 ETD ETK QKW SUMC TAU
 0.1387 1.0000 0.0239 0.0157 69.9041 69.9508 69.9098 69.9157 7.4171E 02 2.5294E 15 -3.9883E 01
 FRAC FUEL HT = 0.100 0.300 0.500 0.700 0.900
 CENTER INTERFACE 494.9 512.5 531.7 549.4 563.2
 CENTER SODIUM 497.8 516.2 535.6 552.9 565.7
 EDGE INTERFACE 495.0 512.7 532.0 549.9 563.9
 EDGE SODIUM 497.9 516.3 535.8 553.3 566.4

DELT10 DELT20 DELTD DELTAK ET ET2 ETD ETK QKW SUMC TAU
 0.1387 1.0000 0.0239 0.0157 71.0134 71.9508 71.0308 71.0277 7.3854E 02 2.4599E 15 -4.0019E 01
 FRAC FUEL HT = 0.100 0.300 0.500 0.700 0.900
 CENTER INTERFACE 494.9 512.4 531.5 549.1 562.8
 CENTER SODIUM 497.8 516.0 535.3 552.6 565.4
 EDGE INTERFACE 495.0 512.6 531.8 549.6 563.5
 EDGE SODIUM 497.8 516.1 535.6 553.0 566.0

DELT10 DELT20 DELTD DELTAK ET ET2 ETD ETK QKW SUMC TAU
 0.1387 1.0000 0.0239 0.0157 71.9841 71.9508 71.9848 71.9936 7.3583E 02 2.4011E 15 -4.0133E 01
 FRAC FUEL HT = 0.100 0.300 0.500 0.700 0.900
 CENTER INTERFACE 494.8 512.3 531.3 548.9 562.5
 CENTER SODIUM 497.7 515.9 535.1 552.3 565.0
 EDGE INTERFACE 494.9 512.5 531.6 549.4 563.2
 EDGE SODIUM 497.7 516.0 535.4 552.7 565.7

DELT10 DELT20 DELTD DELTAK ET ET2 ETD ETK QKW SUMC TAU

0.1387 1.0300 0.0239 0.0157 72.9547 72.9508 72.9627 72.9693 7.3316E 02 2.3438E 15 -4.0253E 01
 FRACT FUEL HT = 0.100 0.300 0.500 0.700 0.900
 CENTER INTERFACE 494.8 512.2 531.1 548.6 562.2
 CENTER SODIUM 497.6 515.8 534.9 552.0 564.7
 EDGE INTERFACE 494.9 512.4 531.4 549.1 562.8
 EDGE SODIUM 497.7 515.9 535.2 552.4 565.3

DELTD DELTAK ET ET2 ETD ETK QKW SUMC TAU
 0.1387 1.0300 0.0239 0.0157 73.9254 73.9508 73.9406 73.9398 7.3057E 02 2.2880E 15 -4.0371E 01
 FRACT FUEL HT = 0.100 0.300 0.500 0.700 0.900
 CENTER INTERFACE 494.7 512.1 530.9 548.4 561.9
 CENTER SODIUM 497.6 515.7 534.7 551.8 564.4
 EDGE INTERFACE 494.9 512.3 531.3 548.9 562.5
 EDGE SODIUM 497.6 515.8 535.0 552.2 565.0

DELTD DELTAK ET ET2 ETD ETK QKW SUMC TAU
 0.1387 1.0000 0.0239 0.0156 75.0347 74.9508 75.0377 75.0353 7.2767E 02 2.2269E 15 -4.0506E 01
 FRACT FUEL HT = 0.100 0.300 0.500 0.700 0.900
 CENTER INTERFACE 494.7 511.9 530.7 548.1 561.6
 CENTER SODIUM 497.5 515.5 534.5 551.5 564.1
 EDGE INTERFACE 494.8 512.1 531.1 548.6 562.2
 EDGE SODIUM 497.6 515.6 534.8 551.9 564.7

DELTD DELTAK ET ET2 ETD ETK QKW SUMC TAU
 0.1387 1.0000 0.0239 0.0156 76.0054 75.9508 76.0156 76.0054 7.2517E 02 2.1743E 15 -4.0625E 01
 FRACT FUEL HT = 0.100 0.300 0.500 0.700 0.900
 CENTER INTERFACE 494.6 511.8 530.6 547.9 561.3
 CENTER SODIUM 497.5 515.4 534.3 551.2 563.8
 EDGE INTERFACE 494.8 512.0 530.9 548.3 561.9
 EDGE SODIUM 497.5 515.5 534.6 551.6 564.4

DELTD DELTAK ET ET2 ETD ETK QKW SUMC TAU
 0.1387 1.0000 0.0239 0.0156 76.9760 76.9508 76.9934 76.9910 7.2271E 02 2.1223E 15 -4.0748E 01
 FRACT FUEL HT = 0.100 0.300 0.500 0.700 0.900
 CENTER INTERFACE 494.6 511.7 530.4 547.6 561.0
 CENTER SODIUM 497.4 515.3 534.2 551.0 563.5
 EDGE INTERFACE 494.7 511.9 530.7 548.1 561.6
 EDGE SODIUM 497.5 515.4 534.4 551.4 564.1

DELTD DELTAK ET ET2 ETD ETK QKW SUMC TAU
 0.1387 1.0000 0.0239 0.0156 77.9467 77.9508 77.9474 77.9608 7.2030E 02 2.0724E 15 -4.0869E 01
 FRACT FUEL HT = 0.100 0.300 0.500 0.700 0.900
 CENTER INTERFACE 494.6 511.6 530.2 547.4 560.7
 CENTER SODIUM 497.4 515.2 534.0 550.8 563.2
 EDGE INTERFACE 494.7 511.8 530.5 547.9 561.3
 EDGE SODIUM 497.4 515.3 534.2 551.1 563.8

DELTD DELTAK ET ET2 ETD ETK QKW SUMC TAU
 0.1387 1.0000 0.0239 0.0156 78.9173 78.9508 78.9253 78.9303 7.1794E 02 2.0239E 15 -4.0992E 01
 FRACT FUEL HT = 0.100 0.300 0.500 0.700 0.900
 CENTER INTERFACE 494.5 511.5 530.1 547.2 560.5
 CENTER SODIUM 497.3 515.1 533.8 550.5 562.9
 EDGE INTERFACE 494.6 511.7 530.4 547.6 561.0
 EDGE SODIUM 497.4 515.2 534.0 550.9 563.5

DELTD DELTAK ET ET2 ETD ETK QKW SUMC TAU
 0.1387 1.0000 0.0239 0.0156 80.0266 79.9508 80.0463 80.0405 7.1530E 02 1.9699E 15 -4.1131E 01
 FRACT FUEL HT = 0.100 0.300 0.500 0.700 0.900
 CENTER INTERFACE 494.5 511.4 529.9 546.9 560.1
 CENTER SODIUM 497.3 515.0 533.6 550.3 562.0
 EDGE INTERFACE 494.6 511.6 530.2 547.4 560.7
 EDGE SODIUM 497.3 515.1 533.8 550.6 563.1

DELTD DELTAK ET ET2 ETD ETK QKW SUMC TAU
 0.1387 1.0300 0.0239 0.0156 80.9973 80.9508 81.0003 81.0097 7.1303E 02 1.9241E 15 -4.1256E 01

FRACT FUEL HT = 0.100 0.300 0.500 0.700 0.900
 CENTER INTERFACE 494.4 511.3 529.7 546.7 559.9
 CENTER SODIUM 497.2 514.9 533.4 550.1 562.3
 EDGE INTERFACE 494.6 511.5 530.0 547.2 560.5
 EDGE SODIUM 497.3 514.9 533.6 550.4 562.9

DELT10	DELT20	DELTD	DELTAK	ET	ET2	ETD	ETK	QKW	SUMC	TAU
0.1387	1.0000	0.0239	0.0156	81.9679	81.9508	81.9782	81.9788	7.1080E 02	1.8795E 15	-4.1381E 01
FRACT FUEL HT = 0.100 0.300 0.500 0.700 0.900										
CENTER INTERFACE 494.4 511.3 529.6 546.5 559.6										
CENTER SODIUM 497.2 514.7 533.3 549.8 562.1										
EDGE INTERFACE 494.5 511.4 529.9 546.9 560.2										
EDGE SODIUM 497.2 514.8 533.5 550.2 562.6										

DELT10	DELT20	DELTD	DELTAK	ET	ET2	ETD	ETK	QKW	SUMC	TAU
0.1387	1.0000	0.0239	0.0156	82.9386	82.9508	82.9560	82.9477	7.0861E 02	1.8361E 15	-4.1509E 01
FRACT FUEL HT = 0.100 0.300 0.500 0.700 0.900										
CENTER INTERFACE 494.4 511.2 529.4 546.3 559.4										
CENTER SODIUM 497.1 514.6 533.1 549.6 561.8										
EDGE INTERFACE 494.5 511.4 529.7 546.7 559.9										
EDGE SODIUM 497.2 514.7 533.3 549.9 562.3										

DELT10	DELT20	DELTD	DELTAK	ET	ET2	ETD	ETK	QKW	SUMC	TAU
0.1387	1.0000	0.0239	0.0156	83.9092	83.9508	83.9100	83.9165	7.0646E 02	1.7938E 15	-4.1636E 01
FRACT FUEL HT = 0.100 0.300 0.500 0.700 0.900										
CENTER INTERFACE 494.3 511.1 529.3 546.1 559.1										
CENTER SODIUM 497.1 514.6 533.0 549.4 561.6										
EDGE INTERFACE 494.5 511.3 529.6 546.5 559.7										
EDGE SODIUM 497.1 514.6 533.2 549.7 562.1										

DELT10	DELT20	DELTD	DELTAK	ET	ET2	ETD	ETK	QKW	SUMC	TAU
0.1387	1.0000	0.0239	0.0156	85.0185	84.9508	85.0310	85.0257	7.0405E 02	1.7468E 15	-4.1781E 01
FRACT FUEL HT = 0.100 0.300 0.500 0.700 0.900										
CENTER INTERFACE 494.3 511.0 529.1 545.9 558.9										
CENTER SODIUM 497.0 514.4 532.8 549.2 561.3										
EDGE INTERFACE 494.4 511.2 529.4 546.3 559.4										
EDGE SODIUM 497.1 514.5 533.0 549.5 561.8										

DELT10	DELT20	DELTD	DELTAK	ET	ET2	ETD	ETK	QKW	SUMC	TAU
0.1387	1.0000	0.0239	0.0156	85.9892	85.9508	86.0089	85.9942	7.0198E 02	1.7068E 15	-4.1914E 01
FRACT FUEL HT = 0.100 0.300 0.500 0.700 0.900										
CENTER INTERFACE 494.3 510.9 529.0 545.7 558.6										
CENTER SODIUM 497.0 514.3 532.6 549.0 561.0										
EDGE INTERFACE 494.4 511.1 529.3 546.1 559.1										
EDGE SODIUM 497.0 514.4 532.8 549.3 561.5										

DELT10	DELT20	DELTD	DELTAK	ET	ET2	ETD	ETK	QKW	SUMC	TAU
0.1387	1.0000	0.0239	0.0156	86.9598	86.9508	86.9629	86.9625	6.9995E 02	1.6679E 15	-4.2042E 01
FRACT FUEL HT = 0.100 0.300 0.500 0.700 0.900										
CENTER INTERFACE 494.2 510.8 528.9 545.5 558.4										
CENTER SODIUM 497.0 514.3 532.5 548.8 560.8										
EDGE INTERFACE 494.3 511.0 529.1 545.9 558.9										
EDGE SODIUM 497.0 514.3 532.7 549.1 561.3										

DELT10	DELT20	DELTD	DELTAK	ET	ET2	ETD	ETK	QKW	SUMC	TAU
0.1387	1.0000	0.0239	0.0156	87.9305	87.9508	87.9408	87.9306	6.9795E 02	1.6300E 15	-4.2175E 01
FRACT FUEL HT = 0.100 0.300 0.500 0.700 0.900										
CENTER INTERFACE 494.2 510.7 528.7 545.3 558.2										
CENTER SODIUM 496.9 514.2 532.3 548.6 560.6										
EDGE INTERFACE 494.3 510.9 529.0 545.7 558.7										
EDGE SODIUM 496.9 514.2 532.5 548.9 561.0										

DELT10	DELT20	DELTD	DELTAK	ET	ET2	ETD	ETK	QKW	SUMC	TAU
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0.1387 1.0000	0.0239 0.0156	89.0398	88.9508	89.0617	89.0548	6.9570E 02	1.5872E 15	-4.2329E 01
FRACT FUEL HT =	0.100 0.300	0.500	0.700	0.900				
CENTER INTERFACE	494.2	510.6	528.6	545.1	557.9			
CENTER SODIUM	496.9	514.1	532.2	548.3	560.3			
EDGE INTERFACE	494.3	510.8	528.8	545.5	558.4			
EDGE SODIUM	496.9	514.1	532.3	548.6	560.8			
DELT10 DELT20	DELTD DELTAK	ET	ET2	ETD	ETK	QKW	SUMC	TAU
0.1387 1.0000	0.0239 0.0156	90.0104	89.9508	90.0158	90.0226	6.9377E 02	1.5514E 15	-4.2464E 01
FRACT FUEL HT =	0.100 0.300	0.500	0.700	0.900				
CENTER INTERFACE	494.1	510.6	528.4	544.9	557.7			
CENTER SODIUM	496.8	514.0	532.0	548.2	560.1			
EDGE INTERFACE	494.2	510.7	528.7	545.3	558.2			
EDGE SODIUM	496.9	514.0	532.2	548.5	560.5			
DELT10 DELT20	DELTD DELTAK	ET	ET2	ETD	ETK	QKW	SUMC	TAU
0.1387 1.0000	0.0239 0.0156	90.9811	90.9508	90.9936	90.9903	6.9188E 02	1.5165E 15	-4.2600E 01
FRACT FUEL HT =	0.100 0.300	0.500	0.700	0.900				
CENTER INTERFACE	494.1	510.5	528.3	544.8	557.5			
CENTER SODIUM	496.8	513.9	531.9	548.0	559.9			
EDGE INTERFACE	494.2	510.7	528.6	545.1	558.0			
EDGE SODIUM	496.8	514.0	532.1	548.3	560.3			
DELT10 DELT20	DELTD DELTAK	ET	ET2	ETD	ETK	QKW	SUMC	TAU
0.1387 1.0000	0.0239 0.0156	91.9517	91.9508	91.9715	91.9579	6.9001E 02	1.4825E 15	-4.2740E 01
FRACT FUEL HT =	0.100 0.300	0.500	0.700	0.900				
CENTER INTERFACE	494.1	510.4	528.2	544.6	557.3			
CENTER SODIUM	496.8	513.8	531.8	547.8	559.6			
EDGE INTERFACE	494.2	510.6	528.4	545.0	557.7			
EDGE SODIUM	496.8	513.9	531.9	548.1	560.1			
DELT10 DELT20	DELTD DELTAK	ET	ET2	ETD	ETK	QKW	SUMC	TAU
0.1387 1.0000	0.0239 0.0156	92.9224	92.9508	92.9255	92.9254	6.8818E 02	1.4494E 15	-4.2877E 01
FRACT FUEL HT =	0.100 0.300	0.500	0.700	0.900				
CENTER INTERFACE	494.0	510.3	528.1	544.4	557.1			
CENTER SODIUM	496.7	513.7	531.6	547.6	559.4			
EDGE INTERFACE	494.1	510.5	528.3	544.8	557.5			
EDGE SODIUM	496.7	513.8	531.8	547.9	559.9			
DELT10 DELT20	DELTD DELTAK	ET	ET2	ETD	ETK	QKW	SUMC	TAU
0.1387 1.0000	0.0239 0.0156	94.0317	93.9508	94.0465	94.0332	6.8612E 02	1.4125E 15	-4.3034E 01
FRACT FUEL HT =	0.100 0.300	0.500	0.700	0.900				
CENTER INTERFACE	494.0	510.2	527.9	544.2	556.8			
CENTER SODIUM	496.7	513.6	531.5	547.4	559.2			
EDGE INTERFACE	494.1	510.4	528.2	544.6	557.3			
EDGE SODIUM	496.7	513.7	531.6	547.7	559.6			
DELT10 DELT20	DELTD DELTAK	ET	ET2	ETD	ETK	QKW	SUMC	TAU
0.1387 1.0000	0.0239 0.0156	95.0024	94.9508	95.0244	95.0160	6.8434E 02	1.3806E 15	-4.3177E 01
FRACT FUEL HT =	0.100 0.300	0.500	0.700	0.900				
CENTER INTERFACE	494.0	510.2	527.8	544.1	556.6			
CENTER SODIUM	496.6	513.5	531.3	547.2	559.0			
EDGE INTERFACE	494.1	510.3	528.1	544.4	557.1			
EDGE SODIUM	496.7	513.6	531.5	547.5	559.4			
DELT10 DELT20	DELTD DELTAK	ET	ET2	ETD	ETK	QKW	SUMC	TAU
0.1387 1.0000	0.0239 0.0156	95.9730	95.9508	95.9784	95.9830	6.8260E 02	1.3501E 15	-4.3316E 01
FRACT FUEL HT =	0.100 0.300	0.500	0.700	0.900				
CENTER INTERFACE	493.9	510.1	527.7	543.9	556.4			
CENTER SODIUM	496.6	513.5	531.2	547.1	558.8			
EDGE INTERFACE	494.1	510.3	527.9	544.2	556.9			
EDGE SODIUM	496.6	513.5	531.4	547.3	559.2			
DELT10 DELT20	DELTD DELTAK	ET	ET2	ETD	ETK	QKW	SUMC	TAU

0.1387 1.0300	0.0239	0.0156	96.9437	96.9508	96.9562	96.9500	6.8089E 02	1.3204E 15	-4.3462E 01
FRACT FUEL HT =	0.100	0.300	0.500	0.700	0.900				
CENTER INTERFACE	493.9	510.0	527.6	543.7	556.2				
CENTER SODIUM	496.6	513.4	531.1	546.9	558.6				
EDGE INTERFACE	494.0	510.2	527.8	544.1	556.7				
EDGE SODIUM	496.6	513.4	531.2	547.2	559.0				
DELTD DELTAK ET ET2 ETD ETK QKW SUMC TAU	0.1387 1.0300	0.0239 0.0156	97.9143 97.9508	97.9341 97.9168	6.7920E 02	1.2914E 15	-4.3604E 01		
FRACT FUEL HT =	0.100	0.300	0.500	0.700	0.900				
CENTER INTERFACE	493.9	510.0	527.5	543.6	556.1				
CENTER SODIUM	496.5	513.3	531.0	546.7	558.4				
EDGE INTERFACE	494.0	510.1	527.7	543.9	556.5				
EDGE SODIUM	496.6	513.4	531.1	547.0	558.8				
DELTD DELTAK ET ET2 ETD ETK QKW SUMC TAU	0.1387 1.0000	0.0239 0.0156	99.0236 98.9508	99.0312 99.0239	6.7730E 02	1.2591E 15	-4.3773E 01		
FRACT FUEL HT =	0.100	0.300	0.500	0.700	0.900				
CENTER INTERFACE	493.9	509.9	527.3	543.4	555.8				
CENTER SODIUM	496.5	513.2	530.8	546.5	558.2				
EDGE INTERFACE	494.0	510.1	527.6	543.7	556.3				
EDGE SODIUM	496.5	513.3	531.0	546.8	558.5				
DELTD DELTAK ET ET2 ETD ETK QKW SUMC TAU	0.1387 1.0000	0.0239 0.0156	99.9943 99.9508	100.0091 100.0060	6.7566E 02	1.2312E 15	-4.3923E 01		
FRACT FUEL HT =	0.100	0.300	0.500	0.700	0.900				
CENTER INTERFACE	493.8	509.8	527.2	543.3	555.7				
CENTER SODIUM	496.5	513.1	530.7	546.4	558.0				
EDGE INTERFACE	493.9	510.0	527.5	543.6	556.1				
EDGE SODIUM	496.5	513.2	530.9	546.6	558.3				
DELTD DELTAK ET ET2 ETD ETK QKW SUMC TAU	0.1387 1.0300	0.0239 0.0156	100.9649 100.9508	100.9870 100.9725	6.7405E 02	1.2044E 15	-4.4070E 01		
FRACT FUEL HT =	0.100	0.300	0.500	0.700	0.900				
CENTER INTERFACE	493.8	509.8	527.1	543.1	555.5				
CENTER SODIUM	496.4	513.1	530.6	546.2	557.8				
EDGE INTERFACE	493.9	509.9	527.3	543.4	555.9				
EDGE SODIUM	496.5	513.1	530.7	546.5	558.1				
DELTD DELTAK ET ET2 ETD ETK QKW SUMC TAU	0.1387 1.0000	0.0239 0.0156	101.9356 101.9508	101.9410 101.9389	6.7247E 02	1.1784E 15	-4.4220E 01		
FRACT FUEL HT =	0.100	0.300	0.500	0.700	0.900				
CENTER INTERFACE	493.8	509.7	527.0	543.0	555.3				
CENTER SODIUM	496.4	513.0	530.5	546.1	557.6				
EDGE INTERFACE	493.9	509.9	527.2	543.3	555.7				
EDGE SODIUM	496.4	513.1	530.6	546.3	558.0				
DELTD DELTAK ET ET2 ETD ETK QKW SUMC TAU	0.1387 1.0000	0.0239 0.0156	103.0449 102.9508	103.0620 103.0454	6.7069E 02	1.1493E 15	-4.4391E 01		
FRACT FUEL HT =	0.100	0.300	0.500	0.700	0.900				
CENTER INTERFACE	493.8	509.6	526.9	542.8	555.1				
CENTER SODIUM	496.4	512.9	530.3	545.9	557.4				
EDGE INTERFACE	493.9	509.8	527.1	543.1	555.5				
EDGE SODIUM	496.4	513.0	530.5	546.1	557.7				
DELTD DELTAK ET ET2 ETD ETK QKW SUMC TAU	0.1387 1.0000	0.0239 0.0156	104.0155 103.9508	104.0160 104.0271	6.6915E 02	1.1242E 15	-4.4546E 01		
FRACT FUEL HT =	0.100	0.300	0.500	0.700	0.900				
CENTER INTERFACE	493.7	509.6	526.8	542.7	554.9				
CENTER SODIUM	496.3	512.8	530.2	545.8	557.2				
EDGE INTERFACE	493.8	509.7	527.0	543.0	555.3				
EDGE SODIUM	496.4	512.9	530.4	546.0	557.6				
DELTD DELTAK ET ET2 ETD ETK QKW SUMC TAU	0.1387 1.0000	0.0239 0.0156	104.9862 104.9508	104.9938 104.9931	6.6764E 02	1.1001E 15	-4.4701E 01		

FRACT FUEL HT = 0.100 0.300 0.500 0.700 0.900
 CENTER INTERFACE 493.7 509.5 526.7 542.5 554.8
 CENTER SODIUM 496.3 512.8 530.1 545.6 557.0
 EDGE INTERFACE 493.8 509.7 526.9 542.8 555.1
 EDGE SODIUM 496.3 512.8 530.3 545.8 557.4

DELT10 DELT20	DELTD DELTAK	ET	ET2	ETD	ETK	QKW	SUMC	TAU
0.1387 1.0000	0.0239 0.0156	105.9568	105.9508	105.9717	105.9590	6.6615E 02	1.0767E 15	-4.4853E 01
FRACT FUEL HT =	0.100 0.300 0.500 0.700 0.900							
CENTER INTERFACE	493.7 509.4 526.6 542.4 554.6							
CENTER SODIUM	496.3 512.7 530.0 545.5 556.9							
EDGE INTERFACE	493.8 509.6 526.8 542.7 555.0							
EDGE SODIUM	496.3 512.8 530.1 545.7 557.2							

DELT10 DELT20	DELTD DELTAK	ET	ET2	ETD	ETK	QKW	SUMC	TAU
0.1387 1.0000	0.0239 0.0156	106.9275	106.9508	106.9496	106.9404	6.6467E 02	1.0534E 15	-4.5012E 01
FRACT FUEL HT =	0.100 0.300 0.500 0.700 0.900							
CENTER INTERFACE	493.7 509.4 526.5 542.2 554.4							
CENTER SODIUM	496.2 512.6 529.9 545.3 556.7							
EDGE INTERFACE	493.8 509.5 526.7 542.5 554.8							
EDGE SODIUM	496.3 512.7 530.0 545.5 557.0							

DELT10 DELT20	DELTD DELTAK	ET	ET2	ETD	ETK	QKW	SUMC	TAU
0.1387 1.0000	0.0239 0.0156	108.0368	107.9508	108.0467	108.0462	6.6302E 02	1.0279E 15	-4.5191E 01
FRACT FUEL HT =	0.100 0.300 0.500 0.700 0.900							
CENTER INTERFACE	493.6 509.3 526.4 542.1 554.2							
CENTER SODIUM	496.2 512.6 529.8 545.2 556.5							
EDGE INTERFACE	493.7 509.5 526.6 542.4 554.6							
EDGE SODIUM	496.2 512.6 529.9 545.4 556.8							

DELT10 DELT20	DELTD DELTAK	ET	ET2	ETD	ETK	QKW	SUMC	TAU
0.1387 1.0000	0.0239 0.0156	109.0074	108.9508	109.0246	109.0118	6.6160E 02	1.0062E 15	-4.5349E 01
FRACT FUEL HT =	0.100 0.300 0.500 0.700 0.900							
CENTER INTERFACE	493.6 509.2 526.3 542.0 554.1							
CENTER SODIUM	496.2 512.5 529.7 545.0 556.3							
EDGE INTERFACE	493.7 509.4 526.5 542.3 554.4							
EDGE SODIUM	496.2 512.6 529.8 545.2 556.7							

DELT10 DELT20	DELTD DELTAK	ET	ET2	ETD	ETK	QKW	SUMC	TAU
0.1387 1.0000	0.0239 0.0156	109.9781	109.9508	109.9786	109.9929	6.6019E 02	9.8472E 14	-4.5510E 01
FRACT FUEL HT =	0.100 0.300 0.500 0.700 0.900							
CENTER INTERFACE	493.6 509.2 526.2 541.8 553.9							
CENTER SODIUM	496.2 512.4 529.6 544.9 556.2							
EDGE INTERFACE	493.7 509.3 526.4 542.1 554.3							
EDGE SODIUM	496.2 512.5 529.7 545.1 556.5							

DELT10 DELT20	DELTD DELTAK	ET	ET2	ETD	ETK	QKW	SUMC	TAU
0.1387 1.0000	0.0239 0.0156	110.9487	110.9508	110.9564	110.9583	6.5880E 02	9.6409E 14	-4.5669E 01
FRACT FUEL HT =	0.100 0.300 0.500 0.700 0.900							
CENTER INTERFACE	493.6 509.1 526.1 541.7 553.8							
CENTER SODIUM	496.1 512.4 529.5 544.7 556.0							
EDGE INTERFACE	493.7 509.3 526.3 542.0 554.1							
EDGE SODIUM	496.1 512.4 529.6 544.9 556.3							

DELT10 DELT20	DELTD DELTAK	ET	ET2	ETD	ETK	QKW	SUMC	TAU
0.1387 1.0000	0.0239 0.0156	112.0581	111.9507	112.0774	112.0637	6.5724E 02	9.4109E 14	-4.5855E 01
FRACT FUEL HT =	0.100 0.300 0.500 0.700 0.900							
CENTER INTERFACE	493.5 509.1 526.0 541.6 553.6							
CENTER SODIUM	496.1 512.3 529.4 544.6 555.8							
EDGE INTERFACE	493.6 509.2 526.2 541.8 553.9							
EDGE SODIUM	496.1 512.3 529.5 544.8 556.1							

DELT10 DELT20	DELTD DELTAK	ET	ET2	ETD	ETK	QKW	SUMC	TAU
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0.1387 1.0000	0.0239	0.0156	113.0287	112.9507	113.0314	113.0289	6.5590E 02	9.2152E 14	-4.6018E 01
FRACT FUEL HT =	0.100	0.300	0.500	0.700	0.900				
CENTER INTERFACE	493.5	509.0	525.9	541.4	553.4				
CENTER SODIUM	496.1	512.2	529.3	544.5	555.7				
EDGE INTERFACE	493.6	509.2	526.1	541.7	553.8				
EDGE SODIUM	496.1	512.3	529.4	544.7	556.0				

DELT10 DELT20	DELT0	DELTAK	ET	ET2	ETD	ETK	QKW	SUMC	TAU
0.1387 1.0000	0.0239	0.0156	113.9994	113.9507	114.0093	114.0096	6.5457E 02	9.0213E 14	-4.6183E 01
FRACT FUEL HT =	0.100	0.300	0.500	0.700	0.900				
CENTER INTERFACE	493.5	509.0	525.8	541.3	553.3				
CENTER SODIUM	496.0	512.2	529.2	544.3	555.5				
EDGE INTERFACE	493.6	509.1	526.0	541.6	553.6				
EDGE SODIUM	496.1	512.2	529.3	544.5	555.8				

DELT10 DELT20	DELT0	DELTAK	ET	ET2	ETD	ETK	QKW	SUMC	TAU
0.1387 1.0000	0.0239	0.0156	114.9700	114.9507	114.9872	114.9746	6.5326E 02	8.8351E 14	-4.6348E 01
FRACT FUEL HT =	0.100	0.300	0.500	0.700	0.900				
CENTER INTERFACE	493.5	508.9	525.7	541.2	553.1				
CENTER SODIUM	496.0	512.1	529.1	544.2	555.4				
EDGE INTERFACE	493.6	509.1	525.9	541.5	553.5				
EDGE SODIUM	496.0	512.2	529.2	544.4	555.7				

DELT10 DELT20	DELT0	DELTAK	ET	ET2	ETD	ETK	QKW	SUMC	TAU
0.1387 1.0000	0.0239	0.0156	115.9407	115.9507	115.9412	115.9550	6.5197E 02	8.6505E 14	-4.6519E 01
FRACT FUEL HT =	0.100	0.300	0.500	0.700	0.900				
CENTER INTERFACE	493.4	508.9	525.6	541.1	553.0				
CENTER SODIUM	496.0	512.1	529.0	544.1	555.2				
EDGE INTERFACE	493.5	509.0	525.8	541.3	553.3				
EDGE SODIUM	496.0	512.1	529.1	544.3	555.5				

DELT10 DELT20	DELT0	DELTAK	ET	ET2	ETD	ETK	QKW	SUMC	TAU
0.1387 1.0000	0.0239	0.0156	117.0500	116.9507	117.0622	117.0599	6.5051E 02	8.4479E 14	-4.6709E 01
FRACT FUEL HT =	0.100	0.300	0.500	0.700	0.900				
CENTER INTERFACE	493.4	508.8	525.5	540.9	552.8				
CENTER SODIUM	496.0	512.0	528.9	543.9	555.0				
EDGE INTERFACE	493.5	508.9	525.7	541.2	553.2				
EDGE SODIUM	496.0	512.0	529.0	544.1	555.3				

DELT10 DELT20	DELT0	DELTAK	ET	ET2	ETD	ETK	QKW	SUMC	TAU
0.1387 1.0000	0.0239	0.0156	118.0206	117.9507	118.0400	118.0246	6.4926E 02	8.2756E 14	-4.6875E 01
FRACT FUEL HT =	0.100	0.300	0.500	0.700	0.900				
CENTER INTERFACE	493.4	508.7	525.4	540.8	552.7				
CENTER SODIUM	495.9	511.9	528.8	543.8	554.9				
EDGE INTERFACE	493.5	508.9	525.6	541.1	553.0				
EDGE SODIUM	495.9	512.0	528.9	544.0	555.2				

DELT10 DELT20	DELT0	DELTAK	ET	ET2	ETD	ETK	QKW	SUMC	TAU
0.1387 1.0000	0.0239	0.0156	118.9913	118.9507	118.9940	119.0048	6.4801E 02	8.1047E 14	-4.7046E 01
FRACT FUEL HT =	0.100	0.300	0.500	0.700	0.900				
CENTER INTERFACE	493.4	508.7	525.4	540.7	552.6				
CENTER SODIUM	495.9	511.9	528.7	543.7	554.8				
EDGE INTERFACE	493.5	508.8	525.6	541.0	552.9				
EDGE SODIUM	495.9	511.9	528.8	543.9	555.0				

TIME= 610.76

****SUMMARY PRINTOUT****
DETAILED FUEL TEMPERATURE CALCULATION*****

ET	TFUL	TSOD	TR	ROD	RHO	TNFO	TNVU
0.	745.45	554.14	540.83	0.	0.	598.96	599.56
0.22	763.30	560.35	540.90	0.50	0.31	607.72	599.36
0.45	798.14	571.40	541.65	1.18	0.37	625.03	599.59
0.73	844.44	584.61	544.71	2.02	0.42	646.03	599.74
0.95	879.76	594.40	548.66	2.69	0.42	661.89	600.88
1.25	829.47	580.17	555.19	-1.34	-3.23	643.95	603.83
1.49	752.85	555.70	558.22	-10.55	-11.01	605.49	607.66
1.73	691.76	538.75	556.89	-20.29	-19.62	577.99	612.59
1.98	646.05	526.81	552.53	-26.04	-24.47	558.27	616.49
2.22	611.12	517.92	546.38	-26.46	-24.22	543.37	618.75
2.48	584.61	511.24	539.45	-26.46	-23.71	532.00	618.85
2.73	564.54	506.19	532.43	-26.46	-23.32	523.21	616.41
2.99	549.40	502.39	525.74	-26.46	-23.03	516.67	611.95
3.19	540.91	500.28	521.10	-26.46	-22.87	512.94	607.71
3.46	531.67	497.99	515.54	-26.46	-22.69	508.83	600.52
3.73	525.16	496.40	510.73	-26.46	-22.56	505.95	592.37
3.93	521.11	495.43	507.61	-26.46	-22.48	504.15	586.26
4.21	517.18	494.52	504.06	-26.46	-22.41	502.45	577.46
4.49	514.24	493.87	501.14	-26.46	-22.35	501.20	569.63
4.71	512.49	493.52	499.31	-26.46	-22.32	500.50	563.03
5.00	510.79	493.21	497.31	-26.46	-22.28	499.88	555.86
5.22	509.80	493.07	496.08	-26.46	-22.26	499.56	550.91
5.44	509.00	492.49	495.06	-26.46	-22.25	499.35	545.74
5.74	508.21	492.96	493.98	-26.46	-22.23	499.22	539.76
5.97	507.78	492.99	493.33	-26.46	-22.23	499.22	535.66
6.20	507.44	493.05	492.81	-26.46	-22.22	499.29	531.63
6.44	507.18	493.15	492.46	-26.46	-22.22	499.41	528.26
6.68	507.00	493.28	492.07	-26.46	-22.21	499.58	524.75
6.92	506.88	493.43	491.83	-26.46	-22.21	499.80	521.86
7.25	506.78	493.68	491.60	-26.46	-22.21	500.17	517.97
7.42	506.77	493.82	491.52	-26.46	-22.21	500.39	516.74
7.67	506.77	494.05	491.44	-26.46	-22.21	500.73	514.59
7.93	506.81	494.30	491.41	-26.46	-22.21	501.13	512.49
8.19	506.87	494.58	491.41	-26.46	-22.22	501.56	510.93
8.45	506.97	494.89	491.45	-26.46	-22.22	502.03	509.49
8.72	507.10	495.22	491.52	-26.46	-22.22	502.55	507.99
8.99	507.25	495.58	491.61	-26.46	-22.23	503.11	506.77
9.18	507.38	495.85	491.69	-26.46	-22.23	503.57	506.46
9.46	507.59	496.26	491.83	-26.46	-22.24	504.18	505.62
9.74	507.82	496.71	491.99	-26.46	-22.24	504.87	504.97
9.94	508.01	497.04	492.10	-26.46	-22.25	505.39	504.41
10.93	509.16	498.97	492.84	-26.46	-22.28	508.37	503.16
11.99	510.37	501.22	493.73	-26.46	-22.31	511.85	502.55
12.99	512.09	504.00	494.70	-26.46	-22.35	516.02	502.44
13.92	514.31	507.05	495.64	-26.46	-22.41	520.64	502.60
14.90	517.49	510.96	496.73	-26.46	-22.48	526.42	502.83
15.91	521.66	515.70	497.79	-26.46	-22.57	533.26	503.16
16.96	527.07	521.47	498.95	-26.46	-22.69	541.32	503.38
17.91	532.53	527.13	500.02	-26.46	-22.81	549.15	503.70
18.87	538.59	533.28	501.03	-26.46	-22.94	557.79	503.96
19.98	544.97	539.59	502.32	-26.46	-23.09	567.30	504.18
20.96	549.23	543.56	503.65	-26.46	-23.19	574.60	504.54
21.93	551.98	546.06	505.18	-26.46	-23.25	580.14	504.84
22.90	553.79	547.73	506.80	-26.46	-23.29	584.20	505.13
24.01	555.08	548.90	508.61	-26.46	-23.33	587.48	505.41
24.98	555.64	549.42	510.34	-26.46	-23.34	589.29	505.48
25.95	555.83	549.59	512.13	-26.46	-23.35	590.31	505.81

26.92	555.76	549.51	512.93	-26.46	-23.35	590.77	505.99
27.89	555.49	549.26	515.77	-26.46	-23.34	590.81	506.40
29.00	555.04	548.85	517.74	-26.46	-23.34	590.48	506.81
29.97	554.55	548.40	519.43	-26.46	-23.33	589.95	507.47
30.94	554.01	547.90	521.04	-26.46	-23.32	589.29	508.33
31.91	553.45	547.39	522.55	-26.46	-23.31	588.56	509.15
32.88	552.87	546.86	523.95	-26.46	-23.29	587.75	510.51
33.99	552.22	546.26	525.41	-26.46	-23.28	586.81	512.26
34.96	551.64	545.73	526.53	-26.46	-23.27	585.96	513.92
35.93	551.08	545.21	527.53	-26.46	-23.26	585.11	515.59
36.90	550.52	544.70	528.41	-26.46	-23.24	584.27	517.61
38.01	549.92	544.15	529.28	-26.46	-23.23	583.36	520.04
38.98	549.39	543.67	529.91	-26.46	-23.22	582.56	522.34
39.95	548.90	543.22	530.43	-26.46	-23.21	581.80	524.75
40.92	548.41	542.77	530.86	-26.46	-23.20	581.05	526.69
41.89	547.93	542.33	531.21	-26.46	-23.19	580.32	529.34
43.00	547.41	541.86	531.49	-26.46	-23.18	579.52	532.44
43.97	546.97	541.45	531.67	-26.46	-23.17	578.84	534.27
44.94	546.53	541.05	531.78	-26.46	-23.16	578.17	536.75
45.92	546.12	540.68	531.84	-26.46	-23.15	577.54	539.28
46.89	545.72	540.31	531.84	-26.46	-23.14	576.92	541.75
48.00	545.26	539.89	531.80	-26.46	-23.13	576.22	543.89
48.97	544.89	539.55	531.72	-26.46	-23.12	575.65	546.24
49.94	544.52	539.21	531.61	-26.46	-23.11	575.08	548.36
50.91	544.15	538.88	531.48	-26.46	-23.10	574.52	549.81
52.02	543.76	538.51	531.29	-26.46	-23.10	573.92	552.19
52.99	543.41	538.20	531.11	-26.46	-23.09	573.39	553.63
53.96	543.08	537.90	530.91	-26.46	-23.08	572.88	555.38
54.93	542.76	537.61	530.70	-26.46	-23.07	572.40	557.12
55.90	542.44	537.31	530.48	-26.46	-23.07	571.91	558.63
57.01	542.09	536.99	530.22	-26.46	-23.06	571.37	560.19
57.98	541.80	536.72	529.99	-26.46	-23.05	570.92	561.55
58.95	541.50	536.45	529.75	-26.46	-23.05	570.47	562.65
59.92	541.22	536.19	529.51	-26.46	-23.04	570.04	563.44
61.03	540.90	535.90	529.24	-26.46	-23.03	569.56	564.68
62.00	540.63	535.66	529.00	-26.46	-23.03	569.14	565.40
62.97	540.36	535.41	528.75	-26.46	-23.02	568.74	566.26
63.94	540.11	535.18	528.51	-26.46	-23.02	568.35	567.21
64.91	539.85	534.95	528.27	-26.46	-23.01	567.96	567.97
66.02	539.57	534.69	528.01	-26.46	-23.00	567.54	568.70
66.99	539.33	534.47	527.77	-26.46	-23.00	567.17	569.33
67.96	539.09	534.25	527.54	-26.46	-22.99	566.80	569.92
68.93	538.86	534.04	527.31	-26.46	-22.99	566.45	570.40
69.90	538.64	533.83	527.09	-26.46	-22.98	566.11	570.78
71.01	538.38	533.60	526.84	-26.46	-22.98	565.72	571.31
71.98	538.17	533.41	526.62	-26.46	-22.97	565.40	571.47
72.95	537.96	533.21	526.41	-26.46	-22.97	565.08	571.73
73.93	537.75	533.02	526.20	-26.46	-22.96	564.76	571.94
75.03	537.52	532.81	525.96	-26.46	-22.96	564.41	571.95
76.01	537.32	532.63	525.76	-26.46	-22.95	564.10	571.88
76.98	537.12	532.45	525.57	-26.46	-22.95	563.81	571.76
77.95	536.93	532.28	525.38	-26.46	-22.94	563.52	571.69
78.92	536.74	532.10	525.19	-26.46	-22.94	563.23	571.57
80.03	536.53	531.91	524.97	-26.46	-22.94	562.91	571.56
81.00	536.35	531.75	524.79	-26.46	-22.93	562.64	571.54
81.97	536.17	531.58	524.61	-26.46	-22.93	562.37	571.56
82.94	536.00	531.42	524.44	-26.46	-22.92	562.11	571.68
83.91	535.83	531.27	524.27	-26.46	-22.92	561.86	571.73
85.02	535.64	531.09	524.08	-26.46	-22.92	561.56	571.79
85.99	535.47	530.94	523.92	-26.46	-22.91	561.31	571.90
86.96	535.32	530.80	523.76	-26.46	-22.91	561.07	571.88
87.93	535.16	530.65	523.60	-26.46	-22.91	560.83	571.94
89.04	534.98	530.49	523.43	-26.46	-22.90	560.56	571.94

90.01	534.83	530.35	523.27	-26.46	-22.90	560.33	571.93
90.98	534.68	530.21	523.13	-26.46	-22.90	560.11	571.85
91.95	534.53	530.06	522.98	-26.46	-22.89	559.88	571.79
92.92	534.39	529.95	522.84	-26.46	-22.89	559.67	571.65
94.03	534.22	529.80	522.68	-26.46	-22.89	559.42	571.47
95.00	534.08	529.67	522.55	-26.46	-22.88	559.21	571.30
95.97	533.95	529.55	522.41	-26.46	-22.88	559.00	571.09
96.94	533.81	529.42	522.28	-26.46	-22.88	558.80	570.93
97.91	533.68	529.30	522.15	-26.46	-22.87	558.59	570.68
99.02	533.53	529.17	522.01	-26.46	-22.87	558.37	570.42
99.99	533.40	529.05	521.89	-26.46	-22.87	558.18	570.12
100.96	533.27	528.93	521.77	-26.46	-22.86	557.98	569.81
101.94	533.15	528.82	521.65	-26.46	-22.86	557.80	569.51
103.04	533.01	528.69	521.52	-26.46	-22.86	557.59	569.20
104.02	532.89	528.58	521.40	-26.46	-22.86	557.41	568.87
104.99	532.77	528.47	521.29	-26.46	-22.85	557.23	568.55
105.96	532.65	528.36	521.17	-26.46	-22.85	557.05	568.30
106.93	532.54	528.26	521.06	-26.46	-22.85	556.87	567.96
108.04	532.41	528.14	520.94	-26.46	-22.85	556.68	567.55
109.01	532.30	528.04	520.84	-26.46	-22.84	556.51	567.27
109.98	532.19	527.94	520.74	-26.46	-22.84	556.35	566.94
110.95	532.08	527.84	520.63	-26.46	-22.84	556.18	566.62
112.06	531.96	527.73	520.52	-26.46	-22.84	556.00	566.28
113.63	531.85	527.63	520.42	-26.46	-22.83	555.84	565.96
114.00	531.75	527.54	520.33	-26.46	-22.83	555.68	565.64
114.97	531.65	527.44	520.23	-26.46	-22.83	555.53	565.39
115.94	531.55	527.35	520.14	-26.46	-22.83	555.38	565.06
117.05	531.43	527.25	520.03	-26.46	-22.82	555.21	564.69
118.02	531.33	527.16	519.94	-26.46	-22.82	555.06	564.44
118.99	531.24	527.07	519.85	-26.46	-22.82	554.92	564.14

Fig. 10. Sample Problem: Core and Heat Dump Power vs Time.

Fig. 11. Sample Problem: System Flow Rates vs Time.

Fig. 12. Sample Problem: Heat Dump Temperatures vs Time.

Fig. 13. Sample Problem: Intermediate Heat Exchanger Temperature vs Time.

Fig. 14. Sample Problem: Core Temperatures vs Time.

Fig. 15. Sample Problem: Core Excess Reactivity vs Time.

VI. FURTHER WORK NEEDED

A. Neutron Kinetics

Because of the very small prompt neutron generation time in a fast reactor, calculation of the neutron kinetic behavior of a fast reactor by the common forward-step finite difference approximation of the point kinetics equations requires very small computational time steps, and consequently, very long running times. This problem is averted in RAPID by the ruse described in Section III-E; that is, the calculation is restricted to the domain in which $\rho \ll \beta$. Thus, one is presently unable to use RAPID for kinetics problems which approach prompt criticality. To overcome this limitation without reverting to the extremely time-consuming standard approach, the procedure developed by J. C. Vigil²⁰ should be incorporated into RAPID. Vigil has applied the method of continuous analytic continuation to the nonlinear reactor kinetics equation. Basically, the method consists of expanding those variables which are analytic functions of time in Taylor series over successive intervals in the time domain. The method yields a definitive criterion for the magnitude of each time step, each of which can be much larger than the prompt neutron generation time. The use of this criterion guarantees that the error in the results increases at most linearly with the number of time steps so that specification of a maximum allowable error defines the maximum truncation error in each Taylor expansion.

B. Heat Transfer

R. Axford²¹ has derived an analytic solution for the transient temperature response of cylindrical fuel rods and associated coolant (which can be extended to other--e.g., plate--geometry), considering time-and-space dependence of power density, coolant temperature, and coolant speed. This analytic solution, employing Finite Hankel Transforms, has several advantages over the more common finite-difference approximation calculations such as that presently used in RAPID. First, the approximations inherent in any finite difference approximation are

avoided, and second, the computational time is much less for the same mesh size. Axford's method can also require much less storage space. Incorporation of this method in RAPID will significantly improve the core transient heat transfer calculations.

C. Primary and Secondary Coolant Loops

Presently, RAPID is restricted to consideration of a single primary loop and a single secondary loop. While this does not prevent study of multiple-loop plants in which the loops act together (as mentioned in Section II), problems in which interaction of loops is of concern cannot presently be treated by RAPID. The addition of multiple primary and secondary loops is a straightforward matter, since equations for other loops can be identical to those for the existing loops, and coupling of loops is a simple matter (the coupling will be the same as is now done for the bypass pipe and intermediate heat exchanger primary in RAPID). Computer storage capacity will be the only restriction. The present version of RAPID taxes the 32K memory of the IBM 7094. Addition of more loops will require either

1. reducing the number of heat transfer and time delay nodes per component, or
2. using semifast disc storage, or
3. exploiting the larger storage capacity of computers such as the CDC 6600.

Since it is intended that RAPID be a generally available tool, option (3) is undesirable, in that few establishments have access to such large machines. The type of calculations performed for the heat removal loops makes option (2) look useful; that is, calculations can be performed for primary loop No. 1 and the results dumped to disc storage, the program may then call data for primary loop No. 2 from disc storage and perform calculations on primary loop No. 2, etc. This should be tried; if it works, the sacrifice implied by option (1) may be avoided.

D. Heat Dump

The ultimate heat removal in RAPID is now an air (or other gas) heat dump. In order to extend RAPID to power generating plants based on the steam cycle, the air heat dump must be replaced by a steam generator. This will probably be the most difficult programming job remaining for RAPID. The preheater, boiler, superheater, reheater, turbines, etc., must be treated in a general manner, and different heat transfer mechanisms--convection, nucleate boiling, film boiling--may apply at a given location during a transient. The finite difference techniques require different equations for heat transfer to fluids with negligible heat capacities (such as steam) than for heat transfer to fluids having finite heat capacities (such as water), and the program logic must consider this. Phase changes, not considered in RAPID hitherto, must be included. Coolant transit time will be more complex. Finally, computer storage capacity will be an even greater problem than was mentioned in Section VI-C.

E. Miscellaneous

Some other useful improvements to RAPID which should be considered are:

1. A larger library of heat transfer coefficients, to be selected by the user,
2. Phase changes in fuel and coolants,
3. Temperature dependent properties (such as conductivity),
4. More fuel pins in DETST and DETTR,
5. Radial reflector temperatures,
6. Natural convection heat removal,
7. Heat exchangers utilizing cross-flow or parallel-flow.

It should be apparent that much work remains to be done before RAPID is a completely useful tool.

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VIII. APPENDICES

APPENDIX A

FORTRAN II - Symbolic Multi-Dimensional Input Subroutine (For the IBM 7090)

(Adapted for the IBM 7090 from Share Subroutine AR SYM1 by J. B. Payne)

PURPOSE: To read and convert data from tape. These data may be of the following formats:

1. Numeric
 - 1.1 Fixed point constants
 - 1.2 Floating point constants
 - 1.3 Integers
 - 1.4 Block of storage set to a single value
 - 1.5 Table set by incrementing
 - 1.6 BCD information
2. Alpha-Numeric Information
3. Octal Integers
4. End of Run Card

Each unit record contains Items 1 through 5 but no mixture of them. Data are stored in standard FORTRAN style either row-wise or column-wise depending on the subscripts given.

USAGE: The subroutine is entered by the following statements:

1. CALL BCDCON (Hollerith argument, List)

Where the Hollerith argument contains the external names of the variables and their dimensions and the list contains the internal name of the variables.

For Example:

```
CALL BCDCON (62H--A-MATRIX (10, 5, 3),-  
MACH-TABLE(4,3),-VELOCITY,-TIME-----  
-----,A,XMACH, VEL, TIME)
```

In the above example A MATRIX is equivalent to A, MACHTABLE to XMACH, VELOCITY to VEL, and TIME is equivalent to TIME.

The size of the Hollerith argument must be equal to or greater than:

$$N = 18i + 12j$$

where i = number of variables having two or three subscripts,

j = number of variables having one or less subscripts.

A maximum of any single BCDCON CALL statement is 35 variables, however, multiple entries to BCDCON may be made but all must be in sequence in the source language program. From the blocks of BCD words of several BCDCON entries, one integrated converted table is created. The generated table contains the first six BCD characters of a name obtained from the CALL statement, the equivalent machine location obtained from the CALL list, and various subscripting information, which is also obtained from the CALL statement. The BCDCON CALL statements must be entered before entering the below CALL statement.

2. CALL SYMBOL (I, INTAPE) or CALL SYMBOL (I, INTAPE, A)

This entry causes data to be read from logical "INTAPE". The logical and actual tape correspondences are the same as used at LASL. A digit, 0-9 or =, in Col. 1 of a data card will be stored in location I. Upon completion of processing the data on this card, control is sent to the instruction following the CALL SYMBOL in the source program. If an END OF FILE is encountered before a digit in Col. 1, the EXIT subroutine is called. The first word of the header card will be stored in A(12). If no A is given, the head card is stored in HDTAPE for later use.

DATA CARD FORMATS:

1. Numeric, including location symbols:

A unit record, identified by Column 1 blank, contains data in Column 2 to 72. Data may be read in as integers, fixed point or floating point variables. Plus is assumed but may be key punched. No over punching for signs may be made. If either a "." or "E" or both appear in a numeric field, then the number is converted as a normalized floating point number. If the point is omitted in an "E" type conversion it is assumed at the right of the number. Only eight

significant digits will be converted. Leading zeros are omitted. Integers are stored in the decrement and must not be greater than 32767. One or more blanks or Column 73 end a field. A BCD name, which was given in the BCDCON CALL statement, punched on a card causes the location of storing to be set or reset. This name need not be the same as the FORTRAN internal symbol used, but must be identical with that given in the BCDCON Hollerith argument. One or more blanks must separate the variable from the data. The variable may or may not have subscripts punched. If no subscripts are punched, the data following the variable will be stored "row-wise", starting in the first location of the array; i.e., only the last subscript will vary. If only one subscript is given, data will be stored "col-wise", starting in the location specified by the subscripts. A subscript increment may be given as (I*P), where the subscript, I, will be incremented by P for the successive values of the variable. The storing of data will be referenced to the same location until another variable or subscript, (or both) is read in. Some examples of variables and subscripts are:

AMATRIX(1,1,1), AMATRIX - These two have the same meaning. Loading begins at AMATRIX(1,1,1). The next value will be assigned to AMATRIX(1,1,2), etc.

AMATRIX(1,1,1*2) - Loading begins at AMATRIX(1,1,1). The next value will be assigned to AMATRIX(1,1,3), etc.

AMATRIX(1) - Loading begins at AMATRIX(1,1,1). The next value will be assigned to AMATRIX(2,1,1), etc.

AMATRIX(1*3) - Loading begins at AMATRIX(1,1,1). The next value will be assigned to AMATRIX(4,1,1), etc.

AMATRIX(3) - Loading begins at AMATRIX(3,1,1). The next value will be assigned to AMATRIX(4,1,1), etc.

AMATRIX(3,6*-2) - Loading begins at AMATRIX(3,6,1). The next value will be assigned to AMATRIX(3,4,1), etc.

AMATRIX(16) - Loading begins at AMATRIX(6,2,1). The next value will be assigned to AMATRIX(7,2,1), etc.

A special case of the numeric type field is built into SYMBOL to perform the following functions:

- a. To set a block of storage to a given value at input time, and,
- b. To start a table at a given value X, and proceed to a value Y in equal increments Δ . If desired, the table may be continued with new Δ and Y.

To accomplish a, above, a special case of the subscript notation is used; i.e., (I,J,K-M). This would set the first location at (I,J,K) and store the same number in (I,J,K), (I,J,K+1), ..., (I,J,M). This type of subscript may also be modified by an increment as (I-J*P) or (I,J-K*P) or (I,J,K-M*P). An example would be:

Input Card TABLE (1,1-3) - 5.0
All Cells TABLE (1,1) thru TABLE (1,3) will contain -5.0.
Another example:

Input Card TABLE (1,1*2) 1.0 (0.1) 1.3
TABLE (1,1) 1.0
 (1,3) 1.1
 (1,5) 1.2
 (1,7) 1.3

To accomplish b, above, a special format is used; X(Δ)Y where X is the starting value, Δ is the increment, and Y is the final value. Any number of changes in Δ may be given with the corresponding stopping value Y. Δ may be either positive or negative. X, Y, and Δ may be integers or floating point numbers but not mixed. An example:

Input Card TABLE (1,1) 1.0(-0.2).8 (1.0E-2).81
TABLE (1,1)1.00
 (1,2)0.80
 (1,3)0.81

Another example:

Input Card TABLE (1) 5(1)8 (-2) 0(3)12
TABLE (1,1) 5 (1,2) 6 (1,3) 3
 (1,2) 6 (2,2) 4 (2,3) 6
 (3,1) 7 (3,2) 2 (3,3) 9
 (4,1) 8 (4,2) 0 (4,3) 12

2. Alpha-Numeric

A unit record, identified by an "H" or "*" in Column 1, will be stored for later printout. The "H" is changed to a "1" to restore paper and the "*" is changed to a "2". This line can be written by either of the following call statements:

CALL HDTAPE(J), or CALL HDTAPE(J,I), or

CALL HDTAPE(J,I,A), or CALL HDTAPE(J,A)

where "J" is the logical output tape number, and "I" is carriage control, and "A" is a variable, dimensioned 12, where the head card is stored.

3. Octal Integers

A unit record, identified by an "O" in Column 1, contains data in column 2 to 72. This card is the same as a numeric card, except all data will be stored as right-most octal integers.

4. BCD Information

A BCD name from BCDCON CALL statement, followed by *N*, causes N BCD words to be stored in the locations specified by the BCD name. N is the number of words of BCD information which is to be read in. The BCD information should immediately follow the *N* and may be continued on any number of cards. BCD information begins in column 1 of these continuation cards; therefore, a digit in column 1, indicating that this is the last card to be read, is not permissible.

5. End of Run Card

If Column 1 contains an "E", then the remainder of the record is skipped and a "CALL EXIT" is executed.

6. End of Card Processing Signal

Of any data card, a dollar sign preceded by one or more blanks will cause the remainder of the card to be bypassed. This will allow remarks to be key punched for further identification of data.

7. If column 1 contains a "P", then the card will be printed with the output.

ERRORS: One of seven lines will be printed off-line on tape A-3, when an error is encountered. They are as follows:

1. NO SYMBOL = (name of undefined symbol) = LISTED.
2. MORE THAN 3 SUBSCRIPTS ARE GIVEN is printed when a third comma is encountered within a subscript.
3. LIST OF ENTRIES TOO SHORT is printed when the list of arguments is shorter than the BCD text in the BCDCON CALL statement.
4. MORE ENTRIES IN LIST THAN IN TEXT is printed under the reverse condition of line 3 above.
5. BCD N INCOMPLETE is printed when column 73 is reached before *N* is completed.
6. INCOMPLETE SUBSCRIPT is printed when column 73 is reached before the subscript is completed.
7. ILLEGAL CHARACTER IN SUBSCRIPT is printed when a character other than a digit, a comma, or a minus is encountered in a subscript.

If one of the above errors occurs, the program bypasses all cards until an = is encountered in column 1. Data following this card is treated as a new problem.

APPENDIX B

Linear Equations Solution by N. Morgan (FAP Coded)

Purpose: To solve the matrix equation

$$AX = B$$

with an option to also evaluate the determinant of A.

Method: The Gauss elimination method is used. The matrices are normalized row-wise by dividing by the largest element of $A(I,J)$ in that row, then the A matrix is reduced to triangular form by $(N-1)$ transformations using a pivotal condensation process after which $X(I,K)$ is computed by a back-substitution process. This transforms B into X and leaves the product of the diagonal elements as the determinant of A.

Input: This routine assumes the coder has stored the $N \times N$ matrix A and the $N \times M$ matrix B in core the way FORTRAN does, that is, in order of decreasing absolute location. A 2-dimensional array A should be stored sequentially as

$$a_{11}, a_{21}, \dots, a_{n1}, a_{12}, \dots, a_{n2}, \dots, a_{nn},$$

where the first subscript is the row index and the second subscript is the column index, similarly for B.

Usage: The routine has 2 entries.

1. If the value of the determinant is not desired but only the solution of the matrix equation, use:

CALL LEQ(A, B, N, M, IA, IB, DET).

2. If the determinant is desired as well as the solution of the matrix equation, use:

CALL LEQD (A, B, N, M, IA, IB, DET).

(As described under Method, the value of the Determinant is generated without much additional effort, however, it seems advisable to have 2 entries so that those not interested in the determinant would avoid possible overflow signals which do not affect the solution of the matrix).

The symbols shown as arguments represent the following variables:

A a 2-dimensional array with dimension (IA, IX);

IA, IX are fixed point integers $\geq N$ specified in the Dimension statement.

That is, the dimension of A may be greater than or equal to the size of the square system to be solved.

IA supplies the information as to where a_{12} is in relation to a_{11} , etc. As an argument it may be given as an integer variable.

IX is not required as an argument.

B a one- or two-dimensional array with dimension (IB,IY); and IB and IY are fixed point integers specified in the Dimension statement such that $IB \geq N$ and $IY \geq M$.

IY is not required as an argument. If $IY = 1$, the one-dimensional format for arrays is acceptable. As an argument, IB may be given as an integer variable.

N the number of equations and unknowns.

M the number of vector solutions desired. If LEQD is called, and $m = 0$, the determinant of A will be computed but not the solution of the equations.

IA,IB are defined with A and B respectively.

DET the name of the variable where the value of the determinant will be stored. If LEQ is called, DET will contain zero, but DET must not be omitted from the argument list.

Output: The elements of the solution matrix X are stored in B(I,K) where $I = 1, 2, \dots, N$ and $K = 1, 2, \dots, M$.

Note: The original A and B matrices are destroyed; hence, they should be saved if the coder desires to use them after using this routine.

Accuracy: 1. The "ill-conditioned" Hilbert matrix H_n with elements $h_{ij} = (i+j-1)^{-1}$, $i, j = 1, 2, \dots, n$ whose true inverse is known*, imposes a severe test upon any inversion routine.

This matrix was tested with the following results:

<u>n</u>	<u>Determinant</u>	<u>(Correct not computed value)</u>	<u>Accuracy of Inverse</u>
4	1.65×10^{-7}		about 5 sig figures
5	3.75×10^{-12}		about 4 sig figures
6	5.37×10^{-18}		about 3 sig figures
7	4.84×10^{-25}		max. error in any term about 6%.

2. The "well conditioned" matrix $\bar{m}$ with elements $\gamma_{ij} = \gamma_{ji} = i(n+1-j)/(n+1)$, $i \leq j$, $i, j = 1, 2, \dots, n$ whose true inverse is known* was tested with the following results:

*Contribution to the Solution of Systems of Linear Equations and the Determination of Eigenvalues, NBS Appl. Math. Series 39, 105, 112 (1954).

<u>n</u>	<u>Determinant</u>
60	1.64×10^{-2}
100	?

<u>Accuracy of Inverse</u>
about 5 sig figures
about 5 sig figures

Time: The time required for inverting the n matrices on the 7090 is approximately:

<u>n</u>	<u>Time</u>
60	(I didn't get a chance to accurately time these).
100	

Storage: Requires $430)_8$ memory locations + locations 77770 - 77777 for temporary storage.

Cards: Symbolic cards LEQ 001 - LEQ 287 or Binary cards LEQ 000 - LEQ 014.

Author: Max Goldstein - May, 1961.

Example: Use the above routine to find and print the inverse of a 3 x 3 matrix, whose elements are $1 - (i+j-1)$.

C for COMMENT

Statement No.

FORTRAN STATEMENT

C SOLUTION OF LINEAR EQUATIONS USING FORTRAN LEQ
DIMENSION A(60,60), B(60,60)

C GENERATE ELEMENTS OF A MATRIX

DO 1 I = 1,3

DO 1 J = 1,I

A(I,J) = 1.0/FLOATF(I+J-1)

1 A(J,I) = A(I,J)

C GENERATE IDENTITY MATRIX FOR B

DO 2 I = 1,3

DO2 J = 1,I

IF (I-J) 3,4,3

3 B(I,J) = 0.0

B(J,I) = 0.0

GO TO 2

4 B(I,J) = 1.0

2 CONTINUE

C DEFINITIONS BEFORE ENTRANCE TO LEQ

N = 3

M = 3

IA = 60

IB = 60

C ENTRANCE TO LEQ

CALL LEQ (A,B,N,M,IA,IB,DET)

C RESULTS ARE STORED OVER ORIGINAL B MATRIX

PRINT 10, ((B(I,J), J = 1,3), I = 1,3)

10 FORMAT (1P3E17.7)

APPENDIX C
Film Plotting and Labeling Subroutines

1. Plot Film

BY: K. Crandall

PURPOSE: To plot linearly a set of points with a specified symbol, with an option of connecting successive points with a straight line.

CALLING SEQUENCE: CALL PLFILM (N, NWORDS, X, IX, Y, IY, XYBND, L, IOP)

where: N = number of points

NWORDS = location of N words (stored backward) that may be used for temporary storage by the subroutine.

X = origin of table of abscissa

IX = memory spacing between members of the X table

Y = origin of table of ordinates

IY = memory spacing between members of the Y table

XYBND = origin of an array of 4 values defining the boundaries of the graph

XYBND(1) = X-value at left boundary ($X_{\min}$)

XYBND(2) = X-value at right boundary ($X_{\max}$)

XYBND(3) = Y-value at lower boundary ($Y_{\min}$)

XYBND(4) = Y-value at upper boundary ($Y_{\max}$)

L = integer value of the BCD code for the plot symbol.

If superposition of two symbols is desired calculate

$L = 64 \times \text{symbol } 2 + \text{symbol } 1$

IOP = 0 -- don't connect points

1 == connect points

N, IX, IY, L, and IOP are fixed point integers.

DESCRIPTION: Each point is positioned relative to the boundaries of the graph. If any point falls outside the range of the graph it will be plotted at the boundary.

STORAGE: 305 words.

2. Label Grid

BY: K. Crandall

PURPOSE: To label the grid drawn by the Select Grid subroutine in one of several ways.

1. Linear - equally spaced intervals will be labeled at 1, 2, 3, 4, 5, 10, 15, 20, or 25 spaces
2. Log - each cycle will be labeled at the lines corresponding to 1, 2, 4, 6, and 8. (Up to 6 cycles).

CALLING SEQUENCE: CALL LBLGRD (I, J, XYBND)

where: I = integer specifying option for labeling x boundary
J = integer specifying option for labeling y boundary
XYBND = origin of an array of 4 values defining the boundaries of the graph

XYBND(1) = x-value at left boundary ($X_{\min}$)

XYBND(2) = x-value at right boundary ($X_{\max}$)

XYBND(3) = y-value at lower boundary ($y_{\min}$)

XYBND(4) = y-value at upper boundary ($y_{\max}$)

For logarithmic labeling, the above values must be the powers of ten.

I and J are fixed point integers from 1 to 16 specifying one of the 16 options.

<u>option</u>	<u>meaning</u>
1	1 linear interval
2	2 linear intervals
3	3 linear intervals
4	4 linear intervals
5	5 linear intervals
6	10 linear intervals
7	15 linear intervals
8	20 linear intervals
9	25 linear intervals
10	25 linear intervals
11	1 log cycle
12	2 log cycles

<u>option</u>	<u>meaning</u>
13	3 log cycles
14	4 log cycles
15	5 log cycles
16	6 log cycles

DESCRIPTION: Linear labeling consists of + marks placed along the left and lower border at points defined by the option and a 3 digit signed integer at each + mark, with a 2 digit signed power of 10 at the origin.

Example: For $I = 5$, $J = 11$, $X_{\min} = -10.$, $X_{\max} = 10.$, $Y_{\min} = -1.$, $Y_{\max} = 0.$, the labeling would look as follows:

STORAGE: 504 words.

3. Select Grid

BY: L. Egbert

PURPOSE: To select various grids both horizontally and vertically for the SC-4020 Tape to film device.

CALLING SEQUENCE: CALL SELGRD (I, J)

where: I is the horizontal option

J is the vertical option

option	number of intervals
<u>≤ 1</u>	1 (Border only)
2	2
3	3
4	4
5	5
6	10
7	15
8	20
9	25
10	50
11	1 cycle logarithmic
12	2 cycle logarithmic
13	3 cycle logarithmic
14	4 cycle logarithmic
15	5 cycle logarithmic
16	6 cycle logarithmic
<u>>17</u>	Border only

DESCRIPTION: Whenever this routine is used a border is drawn as follows:

The grids are always drawn inside this border leaving additional room on the left and bottom edges of each frame for labeling purposes. (The dashed lines are not drawn on film).

EXAMPLE: With $I = 2$ $J = 1$ the following would result:

$I = 1$ $J = 2$

$I = 4$ $J = 2$

STORAGE: 352_{10} words (540_8)

- NOTE:
1. On the logarithm grids the main division lines are drawn twice, making them heavier on film.
 2. All combinations of options may be used.
 3. The program writes on tape B-5 in low density.

4. Advance Film

BY: K. Crandall

PURPOSE: To advance the film a specified number of frames and to mark the film if a hard copy of the next frame is desired.

CALLING SEQUENCE: CALL ADVFLM (IP, IF)

where: IP = 0 -- hard copy is not requested
1 -- hard copy is requested

IF = number of additional frames to advance

Both IP and IF are fixed point integers.

DESCRIPTION: Upon entry to this subroutine, the film is advanced one frame. If a hard copy is requested, this frame is marked with a series of vertical lines and the film is advanced one more frame. The film is then advanced IF additional frames.

STORAGE: 33 words.

APPENDIX D
Clock Function

BY: Barbara Bacon 12/13/61

PURPOSE: To record or check the time at any moment.

ENTRANCE: The routine is entered by the statement:
CALL CLOCK (A, BCD)
where A = time in floating point form
BCD = time in BCD form for printing
The time is printed on-line every time this program is entered.

FORMAT: The clock records time in minutes plus hundredths of minutes. The leading four positions of the BCD word are the minutes and the remaining two are the hundredths positions.

E.G. 030339 = 5:03: 23.4 A.M.
1084.55 = 18:04: 33 P.M. or 6:04: 33 P.M.

BOARD: Share No. 2 clock board.