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THE FREADM - 1 CODE A FAST REACTOR EXCURSION AND ACCIDENT DYNAMICS MODEL

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PREPARED FOR THE
UNITED STATES ATOMIC ENERGY COMMISSION
UNDER CONTRACT NO. AT(04-3)-189
PROJECT AGREEMENT NO. 10

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GEAP-13608
AEC Research and
Development Report

THE FREAMD-1 CODE

A Fast Reactor
Excursion and
Accident Dynamics Model

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CONTENTS

		<u>Page</u>
	Abstract	
1.0	Summary	1-1
2.0	Introduction	2-1
	2.1 General Computational Model	2-3
	2.2 Code Options and Limitations	2-6
	2.3 Code Logic	2-9
3.0	Computational Models for Specific Computations	3-1
	3.1 Trigger Logic	3-12
	3.2 Temperature Calculations	3-15
	3.2.1 Steady State Heat Transfer	3-17
	3.2.2 Transient Heat Transfer	3-25
	3.3 Transient Power Calculations	3-31
	3.3.1 Fission Rate	3-32
	3.3.2 Fission Product Decay	3-35
	3.3.3 Power	3-37
	3.3.4 Program Logic	3-39
	3.4 Fuel Failure Modes	3-41
	3.4.1 Mode 1-Failure of a Single Axial Section	3-42
	3.4.2 Mode 2-Fuel Expelled from Clad Failure Fills Coolant Channel	3-44
	3.4.3 Mode 3-Gravity Collapse	3-47
	3.4.4 Mode 4-Uniform Bundle Collapse	3-49
	3.4.5 Propagation of Failure Modes	3-50
	3.4.6 Program Logic	3-50
	3.5 Coolant Flow and Voiding - The VOIDUM Calculation	3-52
	3.5.1 Problem Description	3-52
	3.5.2 Problem Solution	3-53
	3.5.3 Governing Equations	3-57
	3.5.4 Program Logic	3-70
	3.5.5 Running Experience	3-74

CONTENTS (Continued)

	Page
3.6 Reactivity Feedback	3-74
3.6.1 Doppler Feedback	3-75
3.6.2 Fuel Redistribution Reactivity	3-77
3.6.3 Sodium Voiding Reactivity	3-77
3.6.4 Control Action	3-79
3.6.5 Initiating Reactivity	3-79
3.6.6 Mixing of Reactivity Tables	3-79
4.0 Input Description	4-1
4.1 Details of DTA	4-2
4.1.1 Purpose	4-2
4.1.2 Restrictions	4-2
4.1.3 Description of Input	4-2
4.1.4 DTA error table	4-5
4.2 Input Card Sequence and Running Options	4-7
4.2.1 Control Cards for GE-635	4-9
4.3 DTA Input Names and Definitions - First DTA Call	4-10
4.3.1 Core Geometry	4-10
4.3.2 Fuel Pin Geometry	4-11
4.3.3 Material Properties	4-12
4.3.4 Coolant Inlet Conditions	4-14
4.3.5 Power and Kinetics	4-15
4.3.6 Tables for Reactivity Calculations	4-17
4.3.7 Time Step Control and Edit Specifications	4-21
4.4 DTA Input Names and Definitions - Second DTA Call	4-25
4.4.1 Fuel Failure Data	4-25
4.4.2 Fuel Failure Triggers	4-28
4.4.3 Voiding Data	4-29
4.4.4 Voiding Triggers	4-30
4.4.5 Reactivity Insertion Triggers	4-31
4.4.6 Scram Triggers	4-32
4.4.7 Flow Blockage Data	4-33

CONTENTS (Continued)

	Page
4.5 DTA Input Names and Definitions - Third DTA Call	4-35
4.5.1 System Geometry	4-35
4.5.2 Flow Rates and Pressure Drops	4-39
4.5.3 Gas and Coolant Properties	4-41
4.5.4 Running Options and Time Step Control	4-42
4.5.5 Accident Options and Forcing Functions	4-43
4.5.6 Coolant Voiding	4-46
4.6 Input Reduction	4-47
4.6.1 Scram Calculations	4-47
4.6.2 Reactivity Insertion Calculations	4-47
4.6.3 Fuel Failure Calculations	4-47
4.6.4 Voiding Calculations	4-47
4.6.5 Fission Product Decay Calculations	4-47
4.6.6 Flow Blockage	4-47
4.7 Output	4-48
4.8 Checkout Status	4-49
4.8.1 Checkout of Kinetics Package	4-49
4.8.2 Checkout of Heat Transfer Package	4-50
4.8.3 Checkout of Loop Flow and Voiding Package	4-51
4.8.4 Checkout of Trigger Logic	4-51
5.0 Sample Problems	5-1
Appendix A Detailed Continuity and Momentum Equations	A-1
Appendix B Solution of the Pressure Acceleration Equations	B-1

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LIST OF ILLUSTRATIONS

<u>Figure No.</u>		<u>Page</u>
2.3.1	Time Step Logic	2-11
3.2.1	Fuel Pin Geometry for Heat Transfer Calculations	3-16
3.2.2	Flow Diagram for Steady State Temperature Calculations	3-24
3.3.1	Flow Diagram for Transient Power Calculation	3-40
3.4.1	Calling Logic for Mode 1 Driving Force	3-43
3.4.2	Program Logic for Fuel Redistribution Calculation	3-51
3.5.1a	Primary Coolant Loop Geometry	3-54
3.5.1b	Input Flow Areas	3-55
3.5.1c	Input Flow Length and Heights	3-56
3.5.2	Control Volume for Momentum and Continuity Equations	3-60
3.5.3	Pump Model	3-65
3.5.4	Check Valve Model	3-69
3.5.5a	VOIDUM Flow Chart	3-72
3.5.5b	VOIDUM Flow Chart	3-73
A-1	Velocities Primary Coolant Loop	A-4
A-2	Pressures in Primary Coolant Loop	A-5

LIST OF TABLES

	<u>Page</u>
3.0.1 Nomenclature	3-2
3.1.1 Accident Initiating and Propagating Events and Associated Triggering Variables	3-13

ABSTRACT

- a. Name or Designation of Program: FREADM-1
- b. Computer for which Program is designed and Others upon which it is Operable: GE635
- c. Nature of Physical Problem Solved: FREADM-1 is a fast reactor multi-channel accident analysis program designed to efficiently simulate a reactor transient from initiation to the point of core disassembly. Models are included for nuclear kinetics (point model), core thermo-hydraulics, voiding, fuel redistribution, failure propagation, programmed reactivity insertion, and the dynamics of primary system coolant flow. A broad range of assumed accident initiating and propagating activities may be simulated using triggering logic included in the code. FREADM-1 is restricted to accidents which initiate and propagate uniformly within annular or cylindrical coaxial core regions.
- d. Method of Solution: Time integration of the equations for the dynamics of nuclear kinetics, heat transfer and primary loop coolant flow may be performed in a coupled mode, or independently. Transient temperature conditions computed for single pins, representative of a number of bundle types, may be used to initiate prescribed accident initiating and/or propagating activities. The user supplies criteria for initiating these activities. Reactivity feedback from the various activities may be computed using models in the code, or input from tables.
- e. Restrictions on the Complexity of the Problem: Heat transfer calculations for up to 12 radial core regions may be performed simultaneously with up to 12 separate bundle types subdivided into 9 or less axial sections. Radial heat transfer calculations are done using up to 10 radial fuel nodes, a clad node and a coolant node for each axial section. Loop flow may be treated using a maximum of 2 independent primary coolant loops (loops may be of different size to simulate more than 2 loops). Point kinetics with up to 6 delayed neutron precursor groups is used to compute the transient power level of the core.

f. Typical Running Time: Running times for FREADM-1 are strongly dependent on the running option used and values supplied for time step control. Sample problems which have been run indicate the following breakdown:

- a) 200 kinetics time steps with Doppler feedback for 12 bundle types, 9 axial sections used $\sim 1.5/100$ hrs. of GE-635 processor time.
- b) 87 coupled kinetics and heat transfer time steps using 12 bundle types and 9 axial sections used 7.3/100 hrs. of GE-635 processor time.
- c) 32 coupled loop flow, kinetics and heat transfer time steps using 12 bundle types and 9 axial sections used 7.7/100 hrs. of GE-635 processor time.

Computation time per time step for heat transfer calculations is proportional to $NBT \times NAX$ where NBT = number of bundle types and NAX = number of axial sections. Computation time per time step for an independent loop flow and voiding calculation is $\sim 0.4/100$ hrs. of GE-635 processor time.

g. Unusual Features of the Program: FREADM-1 is highly flexible both in the complexity of the problem solved and the selection of solution methods. Loop flow, kinetics and heat transfer calculations may be done separately or in a coupled mode. Trigger logic provided in FREADM-1 permits the sequence of accident initiating and propagating activities to be determined based on computed local conditions reaching preset levels input by the user. Tables are available which permit a flexible description of the processes for parametric studies. By controlling the time step size in the kinetics calculation, time steps for heat transfer and loop flow calculations are performed with time steps determined by accuracy requirements on these processes only. An integral number of kinetics steps may be taken per heat transfer step. Input to the code is in free form with much input which is optional.

- h. Related and Auxiliary Programs: None.
- i. Status: Production.
- j. References: Freeman, D. D. et al "The FREADM-1 Code - A Fast Reactor Excursion and Accident Dynamics Model", June 1970, (GEAP-13608).
- k. Machine Requirements: Computer memory -- 24K. Peripheral storage units - 3.
- l. Programming Languages Used: FORTRAN - IV (GE635).
- m. Operating system or Monitor under which Program is Executed: GECOS-III, System Development Letter-1.
- n. Other Programming or Operating Information or Restrictions: None.

1.0 SUMMARY

The FREADM-1 code is a fast reactor multi-channel accident analysis program designed to efficiently simulate a reactor transient from initiation to the point of explosive disassembly of the core. FREADM-1 is a flexible code designed to accomplish extensive scoping studies of the sensitivity of accidents to changes in parameters and accident mechanisms. Models for nuclear kinetics, core thermo-hydraulics, voiding, fuel redistribution, failure propagation, programmed reactivity insertion, and the dynamics of primary system coolant flow (in a reactor concept where the primary pumps and intermediate heat exchangers are immersed in sodium in the primary tank) are included.

In FREADM-1 events which affect the outcome of an accident, such as the mode of fuel failure or voiding, may be initiated deterministically based on selected computed variables exceeding preset (trigger) levels during the course of the accident. By a judicious selection of variables and these trigger levels the user may simulate a broad range of assumed mechanisms for accident initiation and propagation.

Time step control in the code is designed to minimize the cost of the many calculations required for sensitivity studies.

FREADM-1 is written entirely in FORTRAN IV and requires 24K memory and 3 peripheral storage units.

2.0 INTRODUCTION

Limiting accidents presently hypothesized for the containment of sodium cooled fast reactors involve loss of coolant, fuel redistribution and explosive disassembly of the core.

In these limiting accidents the computed energy release is dependent on the assumed mechanisms for accident initiation and propagation. FREADM-1 allows a consistent, comprehensive multi-channel evaluation of the effect of initiating conditions and mechanisms on the core energy release and distribution prior to core disassembly in order to:

- 1) develop safety related design criteria.
 - 2) properly weight the importance of the various types of initiating events as related to accident consequences
- and,
- 3) provide direction to safety experimental programs to insure that they are focused on the important parameters.

The FREADM-1 code combines models for the various dynamic processes which might occur during a postulated limiting (design basis) accident to permit an evaluation of the accident from the initial stages up to the point of core disassembly. FREADM-1 allows a description of the accident that includes up to twelve different radial fuel regions or fuel channel types. FREADM-1 is restricted to analyzing postulated accidents that are radially symmetric. (FREADM-2 which is in preparation will compute the accident through core disassembly.) Models are included for computing:

- 1) Steady state and transient core thermo-hydraulics.
- 2) Transient core power.
- 3) Primary system coolant flow
- 4) Core coolant flow and voiding.
- 5) Fuel failure reactivity effects.
- 6) Propagation of voids and failures.
- 7) Control action.

Events which can initiate and propagate accidents may be started when selected computed parameters reach preset (trigger) levels. The user controls the interaction of the various dynamic processes through the specification of these trigger levels.

2.1 GENERAL CALCULATIONAL MODEL

The FREADM-1 code is restricted to accidents where the assumption of radial symmetry is valid, i.e. accidents which are characterized as initiating and propagating uniformly within annular or cylindrical core regions. Conceptually, the core is divided into a number of annular regions, each region consisting of one or more bundle types. Variables that distinguish bundle types include material properties, flow parameters, power peaking factors and failure mechanisms.

Detailed temperature distributions are computed numerically for a single pin in each bundle type. Fuel failure and/or sodium voiding may be initiated (triggered) within a fuel bundle type when selected temperatures equal or exceed predetermined (trigger) levels.

Initial values for temperature and flow variables for each bundle type are computed within the code assuming steady state conditions. Nuclear kinetics parameters are normalized to an initial steady state relative neutron density of 1.0. An initial steady state average power density is input along with the fraction of fission power which is prompt. The fission rate is assumed proportional to the relative neutron density computed in the kinetic calculation. The fission power is then divided into a prompt component and a contribution to two delay groups which may be used to account for fission product decay. Transients may be initiated by perturbations in coolant flow and/or inlet temperature to one or more bundle types, local fuel failures, or by programmed reactivity insertions. Models are included for computing reactivity feedback effects due to:

1. sodium voiding by bundle type,
 2. local Doppler effect,
 3. fuel redistribution by bundle type,
- and,
4. fuel or coolant nodal temperature.

In addition to these reactivity feedback mechanisms, the user can modify core reactivity by means of input forcing and control rod reactivity tables.

The basic operations performed by the code for each bundle type are:

1. calculation of starting steady state temperatures,
 2. calculation of instantaneous power,
 3. calculation of fuel, clad, and coolant temperature for a pin representative of the bundle type,
 4. calculation of sodium flow rate,
 5. calculation of fuel axial position during fuel redistribution,
- and
6. calculation of reactivity effects due to feedback mechanisms.

FREADM-2, in preparation, will extend this analysis to include the core disassembly calculation and to estimate the available work potential released by the accident.

Models for fuel failure and failure propagation developed for the code are simple to use and flexible enough to include a broad range of failure types. Four modes of fuel failure are available, ranging from complete collapse of one bundle section upon another to failure of a single axial node with interaction with flow, gravity and/or voiding dynamics. A key idea of the failure modes is that once failure is triggered all subsequent motion is determined either from user input or known conditions within the bundle.

Temperature dependent reactivity feedback is computed using local coefficients with fuel temperatures averaged over each axial fuel node. Doppler coefficients for a bundle type are dependent on the extent of

voiding within that bundle type and the fraction of the total core Doppler that the bundle type represents. The fuel temperature distributions are computed assuming temperature-dependent fuel properties with constant values for clad and coolant properties and gap and film coefficients prior to fuel failure or voiding. Heat of fusion is included in the temperature calculations.

Numerical methods used in the various dynamics models are based mainly on previously used techniques. Integration of the nuclear kinetics equations follows the formulation used in the FORE-II code.⁽¹⁾ The implicit method is used for computing radial heat transfer with Crout's method⁽²⁾ for reducing the coefficient matrix. Sodium flow and voiding calculations are an extension of earlier work by Meinhardt and others.^(3,4) The reactivity effect of local voiding is computed using parabolic fits to static flux calculations.

2.2 CODE OPTIONS AND LIMITATIONS

One of three main operating modes may be selected by the user depending on the scope of the problem to be solved. These are:

1. a coupled kinetics and multi-channel (up to 12) core heat transfer calculation with coolant flow and voiding information input from tables,
 2. a coupled kinetics, multi-channel heat transfer and loop flow and core voiding calculation,
- and,
3. an independent loop flow and core voiding calculation.

Detailed steady state and transient heat transfer calculations may be performed for up to 12 separate core fuel bundle types to represent different radial core regions. Each fuel bundle type is simulated to have 9 axial sections or less for thermo-hydraulic calculations. Each axial section may have as many as 10 radial fuel nodes plus a cladding and an associated coolant node. Temperature dependent fuel properties, and the heat of fusion are included. An option to use a simple model for computing only the average fuel temperatures has been included to reduce computation time. Temperatures computed with this model are used to compute Doppler feedback and may also be used to trigger fuel failure and/or voiding.

An integral number of small time steps are taken by FREADM-1 to solve the reactor kinetics equations over the larger interval for which detailed heat transfer calculations are performed. By relating the integrating time steps to the time constants of blocks of related equations (such as reactor kinetics, and heat transfer), the system of equations can be advanced in time more economically than if advanced with the same time step size.

The user may select one of four basic modes of fuel motion following fuel failure for each bundle type:

1. failure of a single axial section in which the user specifies forces acting on the node which are conditional, depending on computer conditions in the bundle,
2. failed fuel expelled from pins filling coolant channel in which the user specifies the final fuel configuration and time required for redistribution,
3. gravity collapse of bundle in which all fuel above the failed node moves under the influence of a user specified force,

and,

4. uniform bundle collapse in which the user specifies the final fuel configuration and the redistribution time.

Specific limitations as to problem size are summarized below.

FREADM-1 will allow up to:

1. 6 delayed neutron precursor groups (space independent reactor kinetics)
2. 12 radial core regions
3. 12 bundle types
4. 9 axial fuel sections
5. 10 radial fuel nodes, one cladding and one coolant node per axial section per bundle type
6. 3 tables of fuel conductivity vs temperature with up to 10 values per table
7. 3 tables of fuel specific heat vs temperature with up to 10 values per table.
8. 3 tables of reactivity vs time with up to 10 values per table.
9. 12 axial fuel worth vs displacement curves with up to 10 values per table.
10. 3 void displacement vs time tables with up to 10 values per table.

11. 12 coolant velocity vs time tables with up to 10 values per table.
12. 3 inlet temperature vs time tables with up to 10 values per table.
13. 2 independent primary coolant loops.

2.3 CODE LOGIC

The transient logic has been arranged to minimize the number of heat transfer and voiding calculations required. Since these calculations involve the most computations, minimizing the number of discrete integration calculations should tend towards minimum computation costs. This approach is motivated by the following considerations:

1. Point reactor kinetics calculations are relatively inexpensive per time step prior to disassembly.
2. Updated, detailed temperature distributions are not required for prompt reactivity feedback over the small interval the reactor kinetics equations require because heat transfer is small for characteristic fuels in this interval.
3. Sodium voiding is essentially independent of the neutron kinetics, and for cases of high superheat proceeds independent of subsequent heat transfer.⁽⁴⁾

The sequence of calculations is shown in Figure 2.3.1

The procedure for computing transients with coupled kinetics, heat transfer and loop flow is as follows:

1. Compute loop flow and sodium voiding for one time step. This may determine the maximum allowable neutronics time step.
2. Check triggers and adjust reactivity for any new activities.
3. Compute relative power density (point kinetics). The time step is controlled by void time step, fractional power change, estimated fuel temperature, estimated reactivity change and/or the minimum time step which will reach an elapsed time trigger. Integrated power is used to estimate temperature changes required for feedback calculations. The estimated change in local

fuel temperature since the last heat transfer calculation is used to determine whether a new heat transfer calculation is required.

4. Perform heat transfer calculations if required, based on average fuel temperatures having changed by a predetermined amount.
5. Check to determine whether the end of a loop flow and voiding time step has been reached. If not, repeat sequence beginning with check of triggers. Otherwise, repeat sequence beginning with loop flow and voiding calculation.

The time step control is within the neutronics calculation. Maximum values of reactivity change, average fuel temperature change by axial node and relative neutron density change per time step are input. The maximum starting time step is determined either by the void time step, or by reactivity considerations. A detailed heat transfer calculation is called for whenever the estimated average fuel temperature change in a node exceeds a value input by the user, or whenever the number of kinetics steps taken since the previous heat transfer calculation reaches a number specified by the user.

Features of the time step control include the following:

1. Each process is computed using a time step determined by the accuracy requirements for that process.
2. Calculations are straight ahead, i.e., once a successful time step is taken for a given process no readjustment is required.
3. The various types of calculations are periodically converged to a common time by controlling the time step within the neutron kinetics calculation.

FIGURE 2.3.1

TIME STEP LOGIC

3.0 CALCULATIONAL MODELS FOR SPECIFIC COMPUTATIONS

Detailed descriptions of the various calculational models used in the code are given in this section. Nomenclature used in the development is given in Table 3.0.1.

TABLE 3.0.1

NOMENCLATUREHEAT TRANSFER

T_{fi}	- Average Fuel Temperature of ith Radial Node
$\bar{T}_c$	- Clad Average Temperature
$\bar{T}_N$	- Coolant Average Temperature
R_i	- outer Radius of ith Fuel Node
R_f	- Outer Radius of Fuel Region
R_o	- Radius of Fuel Pin Central Void
ΔR_i	- Distance between the Mid- Volume Radii of fuel Nodes i and i+1
R_c	- Outer Radius of Clad
R_N	- Outer Radius of Equivalent One Rod Cell
$T_f^1(R_i)$	- Radial Derivative of Fuel Temperature at indicated radius
$T_c^1(R)$	- Radial Derivative of Clad Temperature at Indicated Radius
$T_N^1(R)$	- Radial Derivative of Coolant Temperature at Indicated Radius
ρ_f, ρ_c, ρ_N	- Densities of Fuel Clad and Coolant
C_{fi}, C_c, C_N	- Specific Heats of the ith Fuel Node, Clad and Coolant
k_{fi}, k_c, k_N	- Conductivities of the ith Fuel Node, clad and Coolant
q_f	- Volumetric Heat Source in the Fuel
q_c	- Volumetric Heat Source in the Clad
V_N	- Coolant Velocity
ℓ	- Length of an Axial Section
Y_{fc}	- Thermal Admittance from Mid-Volume Radius of Outer Fuel Node to Mid-Volume Radius of Clad
Y_{cn}	- Thermal Admittance from Mid-Volume Radius of Clad to Mid-Volume Radius of Coolant
h_g	- Fuel - Clad Gap Coefficient
h_f	- Clad to Coolant film coefficient
h_j	- Heat Transfer Time Step

POWER CALCULATIONS

n	- Fission Rate (Neutron Density) Relative to an Initial Steady State Value of 1.0
Δk	- Reactivity
C_i	- Delayed Neutron Precursor Density
B_i	- Effective fraction of Fission Neutrons which are Included in Precursor Group i.
B	- Total Effective Delayed Neutron Fraction
N_i	- Decay Constant for Precursor Group i.
λ	- Prompt Neutron Lifetime
f_i	- Relative Fission Product Concentration for Decay Group i.
α_i	- Fraction of Fission Energy Stored in Decay Group i.
j_i	- Decay Constant for Fission Product Decay Group i.
P	- Average Power per Unit Volume of Fuel
P_0	- Initial Average Power per Unit Volume of Fuel
A_1	- Conversion Factor from Fission Rate to Prompt Power Density
A_2	- Conversion Factor from Fission Product Decay Rate to Power Density
F	- Fraction of Power due to Fission Product Decay at Equilibrium Conditions.

LOOP FLOW AND VOIDING

See Figures 3.5.1 a. b. and c. for a description of the physical model, flow areas and lengths in the primary loop calculation.

$A_{c,n}$	- Flow area in the core for bundle n.
$A_{g,1}$	- Cross sectional area of tank cover gas volume.
A_{g3n}	- Cross sectional area of heat exchanger n (n=1,2) cover gas volume.
A_p	- Cross sectional flow area of reactor tank.
$A_{p,n}$	- Cross sectional flow area of pump piping n.
$A_{IN,n}$	- Cross sectional flow area for heat exchanger inlet pipe n.
$A_{HXOT,n}$	- Cross sectional flow area for piping on heat exchanger n.
C_{OUT}^O	- Velocity head loss coefficient at the outlet of the upper blanket.
C_{PB}	- Friction loss coefficient in pump piping 1 after a pipe break
D_H	- Hydraulic diameter of flow passage in the core.
F_p	- Multiplying factor on frictional pressure drop in the core to account for wire wraps.
F_R	- Fraction of core pressure drop due to inlet orificing in Channel 1.
F_{SH}	- Factor multiplying curve fit to sodium super heat.
F_{p1}	- Multiplying factor on pump pressure rise to account for pump failure.
F_{pp}	- Multiplying factor on pump piping friction loss to simulate a pump piping blockage.
F_{OR}	- Multiplying factor on core inlet orificing to simulate blockage of bundle inlet.
F_{OT}	- Multiplying factor on outlet velocity head loss from the upper blanket to simulate blockage at the bundle outlet.
F_{HX}	- Multiplying factor on heat exchanger piping friction coefficient to simulate heat exchanger blockage.
H_p	- Fraction of design pressure rise across the pump at zero flow.

H_W	- Fraction of design flow rate thru the pump at zero pressure rise.
H_C	- Core height
J_P	- Number of time steps between printouts.
J_{MAX}	- Maximum number of time steps.
L_{BF}	- Check valve back flow length.
M^*	- Axial node number at which voiding is initiated (manual void trigger)
N_X	- Number of axial sections in the core.
N_{BT}	- Number of channels in the core.
N_{RB}	- Number of radial blankets.
N_{RUP}	- Fuel node number which is to be checked for fuel pin rupture.
P_{G1D}^o	- Initial tank cover gas pressure.
ΔP_{PP}	- Design value of pressure drop through pump piping.
ΔP_{HXIN}^D	- Design value of pressure drop through inlet heat exchanger piping.
ΔP_{HXOT}^D	- Design value of pressure drop through heat exchanger piping.
t_P	- time of the ramp to change the factor F_{P1}
t_{PP}	- time of the ramp to change the factor F_{PP}
t_{OR}	- Time of the ramp to change the factor F_{OR}
t_{OT}	- Time of the ramp to change the factor F_{OT}
t_{HX}	- Time of the ramp to change the factor F_{HX}
$t_{v,n}$	- Time at which channel n is to initiate voiding (manual void trigger)
T_B^*	- Input value of clad temperature to trigger voiding (manual void trigger)
t_{MAX}	- Maximum running time of the transient.
T_{FRUP}	- Fuel rupture temperature.
$V_{D,n}$	- Design value of coolant velocity in channel n.
$V_{DB,n}$	- Design value of coolant velocity in blanket region n.
ΔV_R^*	- Allowable maximum velocity change per step.

$V_{c,n}^{\circ}$	- Initial coolant velocity in channel n.
$V_{BL,n}^{\circ}$	- Initial coolant velocity in blanket region n.
$X_{BF,n}$	- Back flow length for simulation of check valve in pump piping n.
X_{LP}	- Distance between top of upper blanket and heat exchanger inlet piping.
X_{HX}	- Distance between heat exchanger piping and heat exchanger inlet piping.
X_{HXOT}	- Vertical rise of heat exchanger piping.
X_p	- Vertical rise of pump piping.
X_{pp}	- Length of pump piping.
X_{PB}	- Length of pump piping l after a pipe break.
X_V	- Vertical distance between pump piping and bottom of lower blanket
X_{SH}	- Vertical height from outlet of heat exchanger piping to surface of tank cover gas.
X_{BLT}	- Length of upper blanket and upper plenum
X_{BLB}	- Length of lower blanket.
Y_A, Y_B, Y_C	- Constants for curve fits of vapor pressure as a function of time since initial boiling.
Y_D, Y_E, Y_F	- Constants for curve fit of vapor pressure as a function of time since fuel pin rupture.
Z_{G2}°	- Vertical distance from heat exchanger inlet piping to the surface of the reactor cover gas.
Z_{HXIN}	- Length of the heat exchanger inlet piping.
$Z_{HX,n}^{\circ}$	- Vertical distance from heat exchanger n inlet piping to heat exchanger cover gas surface.
Z_{HXOT}	- Length of heat exchanger piping.

A	- Cross sectional flow area
$\tilde{A}_{kl}$	- Coefficient matrix for simultaneous pressure-acceleration equations.
$\hat{A}_{kl}$	- $\tilde{A}_{kl}$ matrix normalized to the diagonal element, $\tilde{A}_{kk}$.
$\tilde{B}_{kl}$	- Coefficient matrix for simultaneous pressure equations.
$\hat{B}_{kl}$	- $\tilde{B}_{kl}$ matrix in diagonalized form (Crout Elimination)
$C_{OUT,n}$	- Velocity head loss coefficient at the outlet of channel n.
$C_{OR,n}$	- Orificing coefficient for channel n.
C_f	- Frictional loss coefficient
$C_{HXIN,n}$	- Friction coefficient in inlet heat exchanger piping n. (n=1,2)
$C_{HXOT,n}$	- Friction coefficient in heat exchanger piping n (n=1,2)
$C_{P,n}$	- Friction coefficient in pump piping n (n=1,2)
$C_{BL,n}$	- Friction coefficient in blanket region n.
$\tilde{C}_k$	- Constant matrix for simultaneous pressure-acceleration equations.
$\hat{C}_k$	- $\tilde{C}_k$ matrix normalized to $\tilde{A}_{kk}$.
$\tilde{D}_k$	- Constant matrix for simultaneous pressure equations.
$\hat{D}_k$	- $\tilde{D}_k$ matrix in diagonalized form (Crout Elimination)
F	- Friction factor
F_f	- Multiplying factor on friction loss coefficient.
F_{NT}	- Friction factor for top slug in channel n.
F_{NR}	- Friction factor for bottom slug in channel n.
g_o	- Conversion factor, lbm to lbf.
g	- Gravitational acceleration.
j	- time step number.

L	- length, defined in figure 5.
M	- Axial node index.
N_{X1}	- $N_X + 1$
N_{X2}	- $N_X + 2$
ΔP_C^D	- Design pressure drop across the core and blankets
$P_{n,m}$	- Pressure in channel n at axial node m
P_G	- Cover gas pressure.
$P_{v,n}$	- Vapor pressure in channel n .
P_{BOT}	- Pressure at the bottom of the lower blanket.
P_{TOP}	- Pressure at the top of the upper blanket.
P_{GZ}	- Pressure of reactor cover gas.
$P_{HX,n}$	- Pressure in heat exchanger pot n ($n=1,2$) at the heat exchanger inlet pipe.
P_{OUT}	- Pressure in upper reactor pot at heat exchanger inlet pipe.
P_{G3n}	- Heat exchanger n cover gas ($n=1,2$)
$P_{HXL,n}$	- Pressure at the bottom of the heat exchanger pot n ($n=1,2$)
P_{HXO}	- Pressure at the outlet of heat exchanger piping.
P_{UMIN}	- Pressure at pump inlet
$\Delta P_{p,n}$	- Pressure rise across pump n ($n=1,2$)
P_{PPOUT}	- Pressure in bottom of reactor pot at pump outlet.
ΔP_{pp}^o	- Pressure drop across pump piping at initial flow rate.
ΔP_{HXIN}^o	- Pressure drop across inlet heat exchanger piping at initial flow rate.
ΔP_{HXOT}^o	- Pressure drop across heat exchanger piping at initial flow rate.

t	- Time
t_f	- Time of the ramp to change the factor C_f
T_{SAT}	- Sodium saturation temperature
ΔT_{SH}	- Sodium superheat
T_B	- Sodium boiling temperature.
$t_{B,n}$	- Time of initial boiling in channel n
$t_{R,n}$	- Time of pin rupture in channel n.
$T_{Wn,m}$	- Clad temperature in channel n at axial node n.
$\hat{T}_{W,n}$	- Max clad temperature in channel n ($^{\circ}F$)
$T_{W,n}^*$	- Max clad temperature in channel n ($^{\circ}K$)
$T_{Fi,n,m}$	- Fuel temperature in radial node i, axial section m, channel n.
$T_{Rn,m}$	- Maximum fuel temperature in radial node N_{RUP} in axial section m, channel n.
V	- Velocity
$V_{TOP,n}$	- Velocity of top voiding slug in channel n.
$V_{BOT,n}$	- Velocity of bottom voiding slug in channel n.
$V_{BL,n}$	- Velocity in blanket region n.
$V_{HXIN,n}$	- Velocity in heat exchanger inlet pipe n ($n=1,2$)
$V_{HX,n}$	- Velocity in heat exchanger pot n ($n=1,2$)
$V_{HXOT,n}$	- Velocity in heat exchanger pipe n ($n=1,2$)
$V_{P,n}$	- Velocity in pump pipe n ($n=1,2$)
V_{BP}	- Velocity in lower reactor pot
V_{LP}	- Velocity in upper reactor pot between the upper blanket and heat exchanger inlet pipe.
V_G	- Gas Volume
V_{G1}	- Tank cover gas volume
V_{G2}	- Reactor cover gas volume

V_{G3n}	- Volume of heat exchanger n cover gas
ΔV_R	- Relative velocity change per step, $ v_j^{j-1} - v_j / v_j $
ΔV_R^*	- Time step control. Maximum allowable value of ΔV_R .
W_1	- Net volume flow rate into main reactor tank.
W_2	- Volume flow rate in reactor cover gas region.
X	- Displacement
X_{LC}	- Length of core plus blankets
$X_{VT,n}$	- Distance of top of vapor bubble from bottom of lower blanket.
$X_{VB,n}$	- Distance of bottom of vapor bubble from bottom of lower blanket.
X_m	- Distance of axial node m from bottom of lower blanket.
X_ℓ	- Solution vector for simultaneous pressure-acceleration equations.
Y_ℓ	- Solution vector for simultaneous pressure equations.
Z_c	- Length of the axial sections in the core.
Z_{G2}	- Vertical distance from heat exchanger inlet pipe to reactor cover gas surface.
$\dot{Z}_{G2}$	- Velocity of reactor cover gas surface.
$Z_{HX,n}$	- Vertical distance from heat exchanger inlet pipe n to cover gas surface
$\dot{Z}_{G3n}$	- Velocity of reactor cover gas n surface

$\rho^{(*)}$	- Sodium density
τ	- time increment, $t^j - t^{j-1}$
γ	- Gas constant
$\gamma_1^{(*)}$	- Gas constant for tank cover gas
$\gamma_2^{(*)}$	- Gas constant for reactor cover gas.
$\gamma_3^{(*)}$	- Gas constant for heat exchanger cover gas
$\tau_{MIN}^{(*)}$	- Minimum size time increment
$\mu^{(*)}$	- Sodium absolute viscosity
0	- Initial value
J	- Value at time step j
$\cdot$	- Derivative with respect to time

(*) Input

3.1 TRIGGER LOGIC

Actions which may be initiated on a predetermined basis in FREADM-1 and the variables which initiate these actions when preset levels (triggers) are reached are summarized in Table 3.1.1. Tests on the selected variables are made in subroutine TRIPIT. Subroutines which provide the reactivity feedback associated with the triggers are also called from subroutine TRIPIT. Data to be supplied by the user includes indicators to determine whether a given activity should be initiated and trigger levels for the appropriate variables.

TABLE 3.1.1
ACCIDENT INITIATING AND PROPAGATING EVENTS AND ASSOCIATED
TRIGGERING VARIABLES

EVENT	TRIGGERING VARIABLE	FORTRAN	TEST AGAINST INPUT TRIGGER LEVEL
Reactor SCRAM	1. Elapsed time from start of transient	ET	$ET \geq TS\ 1$
	2. Power level	P	$P \geq TS\ 2$
	3. Reactor Period	RP	$RP \leq TS\ 3$
	4. Rate of Power Increase	RPI	$RP \geq TS\ 4$
	5. Elapsed time from fuel failure in a bundle type	ETf(I)	$ETf(I) \geq TS5(I)$
	6. Elapsed time from coolant voiding in a bundle type	ETv(I)	$ETv(I) \geq TS6(I)$
	7. Coolant velocity	V	$V \leq TS7(I)$
	8. Coolant outlet temperature from a bundle type	TOUT (I)	$TOUT\ (I) \geq TS8(I)$
Programed Reactivity Insertion	1. Elapsed time from start of transient	ET	$ET \geq TR\ 1$
	2. Elapsed time from fuel failure in a bundle type	ETF(I)	$ETF\ (I) \geq TR\ 2(I)$
	3. Elapsed time from coolant voiding on a bundle type	ETV(I)	$ETV\ (I) \geq TR\ 3(I)$

TABLE 3.1.1 (Continued)

EVENT	TRIGGERING VARIABLE	FORTRAN	TEST AGAINST INPUT TRIGGER LEVEL
Fuel Failure in a bundle type	1. Elapsed time from start of transient 2. Average fuel temperature of an axial section 3. Temperature of a radial fuel node 4. Clad temperature 5. Elapsed time from failure in another bundle type (propagation)	ET TDOP (J,I) TEMP(K,J,I) TEMP(NRN+1,J,I) ETF(I)	$ET \geq TF\ 1$ $TDOP(J,I) \geq TF2(I)$ $TEMP(K,J,I) \geq TF3(I)$ $TEMP(NRN+1,J,I) \geq TF4(I)$ $ETF(I) \geq TFP(J,I)$
Voiding in a bundle type	1. Elapsed time from start of transient 2. Clad temperature 3. Coolant temperature 4. Temperature of a radial fuel node 5. Average fuel temperature of an axial section 6. Elapsed time from voiding in another bundle type (propagation)	ET TEMP(NRN+1,J,I) TEMP(NRH,J,I) TEMP(K,J,I) TDOP(J,I) ETV(I)	$ET \geq TV\ 1$ $TEMP(NRN+1,J,I) \geq TV2(I)$ $TEMP(NRH,J,I) \geq TV3(J)$ $TEMP(K,J,I) \geq TV4(I)$ $TDOP(J,I) \geq TV5(I)$ $ETV(I) \geq TYP(J,I)$
Full or partial flow blockage in a bundle type	1. Elapsed time from start of transient 2. Average fuel temperature of an axial section 3. Clad temperature 4. Temperature of a radial fuel node 5. Elapsed time from flow blockage in another bundle (propagation) 6. Elapsed time from average fuel temperature exceeding trigger level in another bundle 7. Elapsed time from clad temperature exceeding trigger level in another bundle 8. Elapsed time from temperature of a radial node exceeding trigger level in another bundle	ET TDOP (J,I) TEMP(NRN+1,J,I) TEMP (K,J,I) _____ _____ _____ _____	$ET \geq TFB1\ (I)$ $TDOP(J,I) \geq TFB2\ (I)$ $TEMP(NRN+1,J,I) \geq TFB3(I)$ $TEMP(K,J,I) \geq TFB4(I)$ Elapsed Time from triggering activity in another bundle is reached.

GEAP-13608

3.2 TEMPERATURE CALCULATIONS

Fuel, clad, and coolant temperatures are computed in the core for each axial section in each bundle type. Temperatures are computed only for the core region as described by the user. These temperature distributions may be monitored for each bundle type in the FREADM code to trigger the sequence of accident initiating and propagating events. The heat transfer model used to compute temperature conditions within a bundle type consists of a single fuel pin and its associated clad and coolant. The fuel pin is divided axially into a user specified number (up to 9) of equal length sections. Each axial section is sub-divided into a central void region, a user specified number of uniformly thick radial fuel nodes, a clad node and a coolant node for performing numerical calculations of radial temperature profiles. The geometry is constant and uniform for all axial sections in all bundle types. Figure 3.2.1 shows a pin divided into five axial sections with four radial fuel nodes and a central void region.

Heat transfer within the fuel and clad is restricted to radial conduction. Axial heat transfer is by coolant convection. Temperature dependent fuel properties are allowed and heat of fusion is accounted for in the calculation when the input fuel melting temperature is exceeded. Clad, coolant material properties, the fuel-clad gap coefficient and film coefficient are held at the initial steady state values during the transient. Heat transfer to the coolant is stopped when voiding occurs in a bundle type.

Steady state calculations may be performed for transient initialization. The numerical treatment of spatial derivations in the steady state and transient temperature calculations is consistent. Subroutine SHTR is the main executive routine for steady state heat transfer. Transient heat transfer calculations are controlled in subroutine THTR.

FIGURE 3.2.1.

FUEL PIN GEOMETRY FOR HEAT TRANSFER CALCULATIONS Dimensions

- a - Central void radius
- b - Fuel radius
(clad inside radius)
- c - Clad outside radius
- d - radius of one rod cell
- e - core height/number of
axial sections

3.2.1 STEADY STATE HEAT TRANSFER

A user may elect to initiate a transient from specified steady state conditions for reactor thermal power level and primary system coolant flow. Initial values for fuel clad and coolant temperature distributions will be computed by FREADM-1, unless input by the user.

An iterative procedure is built into the FREADM-1 code for computing starting temperatures with temperature dependent material properties. Uniform fuel properties for a temperature value supplied by the user are assumed for the first iteration. Successive iterations use the computed temperature profile to update material property data for the next iteration. Iteration continues until user specified convergence criteria on the temperature profile is obtained or until a maximum number of iterations (supplied by the user) have been completed. A warning message will be printed whenever convergence criteria are not met after the maximum number of iterations and the calculation will proceed.

An implicit formulation of the transient heat transfer equations is used to avoid stability problems associated with simpler explicit methods and to achieve the economy associated with taking large time steps. Comparison of explicit and implicit techniques has shown significantly lower costs per transient calculation using implicit time integration. (5)

3.2.1.1 EQUATIONS FOR STEADY STATE RADIAL HEAT TRANSFER

Equations for nodal temperatures may be obtained from a radial steady state heat balance by multiplying by rdr and integrating over the radius intervals of interest. In the fuel we obtain:

$$R_1 T'_f(R_1) - R_{1-1} T'_f(R_{1-1}) + q_f \frac{R_1^2 - R_{1-1}^2}{2k_{fi}} = 0$$

where:

$$T'_f(R_i) = \left. \frac{\partial T_f}{\partial r} \right|_{r=R_i}$$

R_i is the outer radius of the i th fuel node,

q_f is the fuel volumetric heat source,

k_{fi} is the conductivity of fuel node,

and,

$$T'_f(R_o) = 0$$

where:

R_o is the radius at the central void.

In the clad,

$$R_c T'_c(R_c) - R_f T'_c(R_f) + q_c \frac{R_c^2 - R_f^2}{2k_c} = 0.0$$

where:

T_c is the clad temperature,

R_c is the outer clad radius,

R_f is the outer fuel radius,

q_c is the volumetric heat source in the clad, and,

k_c is the clad conductivity.

In the coolant,

$$-R_c T'_N(R_c) + \frac{R_N^2 - R_c^2}{k_N} \left\{ \frac{\rho_N C_N V_N}{l} \right\} (\bar{T}_1 - \bar{T}_N) = 0.0$$

where:

$\bar{T}_N$ is the average coolant temperature,

$\bar{T}_1$ is the coolant inlet temperature (inlet to the node),

ρ_N is the coolant density,

C_N is the specific heat of the coolant,

V_N is the coolant velocity,

l is the length of the axial section,

R_N is the equivalent outer radius of the coolant.

3.2.1.2 NUMERICAL METHODS

The derivatives in the above expressions are approximated numerically giving for the fuel:

$$T'_{fi}(R_i) = \frac{\bar{T}_{fi+1} - T_{fi}}{\Delta R_i}$$

$$T'_{fi}(R_{i-1}) = \frac{\bar{T}_{fi} - \bar{T}_{fi-1}}{\Delta R_{i-1}}$$

where:

$$\Delta R_i = \bar{R}_{i+1} - \bar{R}_i$$

and

$$\bar{R}_i = \sqrt{\frac{R_i^2 + R_{i-1}^2}{2}}$$

At the fuel clad interface,

$$T'_f(R_f) = \frac{Y_{fc}}{k_f} (\bar{T}_c - \bar{T}_{fm}) \times \frac{1}{2\pi R_f}$$

and

$$T'_c(R_f) = \frac{Y_{fc}}{k_c} (\bar{T}_c - \bar{T}_{fm}) \times \frac{1}{2\pi R_f}$$

where:

Y_{fc} is the thermal admittance between the outer fuel node (the mth) and the clad.

given by:

$$Y_{fc} = 2\pi \left[\frac{\ln(R_f/\bar{R}_{fm})}{k_{fm}} + \frac{\ln(\bar{R}_c/R_f)}{k_c} + \frac{1}{R_f h_g} \right]^{-1}$$

At the clad, coolant interface,

$$T'_c(R_c) = \frac{Y_{CN}}{k_c} (\bar{T}_N - \bar{T}_c) \times \frac{1}{2\pi R_c}$$

and,

$$T'_N(R_c) = \frac{Y_{CN}}{k_n} (\bar{T}_N - \bar{T}_c) \times \frac{1}{2\pi R_c}$$

where:

Y_{CN} is the clad coolant admittance

given by:

$$Y_{CN} = 2\pi \left[\frac{\ln(R_c/\bar{R}_c)}{k_c} + \frac{\ln(\bar{R}_N/R_c)}{k_n} + \frac{1}{R_c h_f} \right]^{-1}$$

Radial spatial derivatives at the inner fuel and outer coolant boundaries are zero.

Steady state clad and coolant temperature are computed first using a steady state heat balance for the axial section. The equations for nodal fuel temperatures in matrix notation are:

$$AT=P$$

where:

A is an operator matrix,

T is the vector of nodal temperatures,

P is the resultant product vector.

The array A is tridiagonal with the values shown below:

Row	Lower Diagonal	Center Diagonal	Upper Diagonal
1	None	$R_1/\Delta R_1$	$-R_1/\Delta R_1$
2	$-R_1/\Delta R_1$	$R_1/\Delta R_1 + R_2/\Delta R_2$	$-R_2/\Delta R_2$
	.	.	.
	.	.	.
	.	.	.
M	$-R_{m-1}/\Delta R_{m-1}$	$R_{m-1}/\Delta R_{m-1} + Y_{fc}/k_{fm}$	None

The solution vector and product vectors are:

$$T = \begin{bmatrix} \bar{T}_{f1} \\ \bar{T}_{f2} \\ . \\ . \\ . \\ . \\ \bar{T}_{fm} \end{bmatrix} \quad P = \begin{bmatrix} (q_f/2k_{f1}) \times (R_1^2 - R_o^2) \\ (q_f/2k_{f2}) \times (k_2^2 - R_1^2) \\ . \\ . \\ . \\ . \\ (q_f/2k_{fm}) \times (R_m^2 - R_{m-1}^2) \end{bmatrix}$$

Crout's method⁽²⁾ is used to obtain a solution vector for an initial value of material properties. The material properties are adjusted (from input tables) to their values at the temperatures of the solution vector and a new solution vector is obtained. The process is repeated until consecutive solutions are within user specified limits. A user may specify that constant material properties will be used in which case no iterating is required. The necessary operations on the operator matrix and product vector to obtain a solution vector are performed in subroutine CROUT.

3.2.1.3 PROGRAM LOGIC

A generalized flow chart of the logic used in the steady state temperature calculation is shown in Figure 3.2.2. The calculation is entered with geometry and material property data, and steady state heat generation and coolant flow rates.

FIGURE 3.2.2

FLOW DIAGRAM FOR STEADY STATE TEMPERATURE CALCULATIONS

3.2.2 TRANSIENT HEAT TRANSFER

Calculation of temperature profiles in the fuel clad and coolant is done when:

- 1) The change in average fuel temperature in an axial node (estimated in power calculation) since the previous profile calculation exceeds a user input number or,
- 2) The number of reactor kinetics time steps taken since the last profile calculation exceeds a user input number or,
- 3) The end of a void time step is reached and the user specifies that temperature profiles are to be computed.

3.2.2.1 EQUATIONS FOR RADIAL CONDUCTION

Expressions for average nodal temperatures in the fuel, clad and coolant nodes in an axial section are obtained by integrating the transient conduction equation over each node. This results in the following expressions:

for the fuel -

$$\rho_f C_{f1} \frac{\partial}{\partial t} \bar{T}_{f1} = \frac{2k_{f1}}{R_1^2 - R_{1-1}^2} \left[R_1 T'_f(R_1) - R_{1-1} T'_f(R_{1-1}) \right] + q_f$$

for the clad -

$$\rho_c C_c \frac{\partial}{\partial t} \bar{T}_c = \frac{2k_c}{R_c^2 - R_f^2} \left[R_c T'_c(R_c) - R_f T'_c(R_f) \right] + q_c$$

for the coolant -

$$\rho_N C_N \frac{\partial}{\partial t} \bar{T}_N = \frac{2k_N}{R_N^2 - R_C^2} \left[-R_C T'_N (R_C) \right] + \frac{2\rho_N C_N V_N}{\ell} (\bar{T}_1 - \bar{T}_N)$$

where:

$\bar{T}_{fi}$, $\bar{T}_c$ and $\bar{T}_N$ are nodal averages of the fuel clad and coolant temperature distributions.

T'_f , T'_c and T'_N are the spatial derivatives of the fuel, clad and coolant temperature distributions defined above.

ρ_f , ρ_c and ρ_N are fuel, clad and coolant densities.

C_{fi} , C_c and C_N are specific heats of the i^{th} fuel node, clad and coolant.

The other symbols are as defined in Table 3.0.1.

3.2.2.2 NUMERICAL METHODS

Time derivatives are approximated in the above equations by forward differences:

$$\frac{\partial \bar{T}_x^j}{\partial t} = \frac{\bar{T}_x^{j+1} - \bar{T}_x^j}{h^j}$$

where:

$\bar{T}_x$ is a nodal temperature

j is the time step index

h^j is the current time step size.

Spatial derivatives are evaluated at the end of the time step to give an implicit formulation for computing the nodal temperatures. In the fuel,

$$\left. \frac{\partial \bar{T}_f^j}{\partial r} \right|_{r=R_i} = \frac{\bar{T}_{i+1}^{j+1} - \bar{T}_i^{j+1}}{\Delta R_i}$$

where:

ΔR_i is the distance between the mid-volume radius of the i^{th} node and the mid-volume radius of the $(i+1)^{\text{th}}$ node.

At the fuel clad interface, the thermal admittance concept⁽⁶⁾ is used to give

$$\left. \frac{\partial \bar{T}_f^j}{\partial r} \right|_{r=R_f} = \frac{Y_{fc} (\bar{T}_c^{j+1} - \bar{T}_{fm}^{j+1})}{2\pi k_{fm} R_f}$$

and,

$$\left. \frac{\partial \bar{T}_c}{\partial r} \right|_{r=R_f} = \left. \frac{\partial \bar{T}_f}{\partial r} \right|_{r=R_f} \times \left(\frac{k_{fm}}{k_c} \right)$$

Similarly, at the clad, coolant interface,

$$\left. \frac{\partial \bar{T}_c^j}{\partial r} \right|_{r=R_c^n} = \frac{Y_{cn} (\bar{T}_N^{j+1} - \bar{T}_c^{j+1})}{2\pi k_c R_c}$$

and,

$$\left. \frac{\partial \bar{T}_N}{\partial r} \right|_{r=R_c} = \left. \frac{\partial \bar{T}_c}{\partial r} \right|_{r=R_c} \times \left(\frac{k_c}{k_N} \right)$$

The thermal admittances are given by:

$$Y_{fc} = 2\pi \left[\frac{\ln(R_f/\bar{R}_m)}{k_{fm}} + \frac{\ln(\bar{R}_c/R_f)}{k_c} + \frac{1}{R_f h_g} \right]^{-1}$$

and,

$$Y_{cn} = 2\pi \left[\frac{\ln(R_c/\bar{R}_c)}{k_c} + \frac{\ln(\bar{R}_N/R_c)}{k_N} + \frac{1}{R_c h_f} \right]^{-1}$$

where:

h_g is the fuel clad gap coefficient

h_f is the clad coolant film coefficient

The equations may be written in matrix form as :

$$MT = P$$

where:

M is a tridiagonal matrix of coefficients,

T is a vector of nodal temperatures at the end of the current time step,

P is the resultant product vector.

The matrix M has as its components the following:

Row	Lower Diagonal	Center Diagonal	Upper Diagonal
1	None	$1.0 + A_1 R_1 / \Delta R_1$	$-A_1 R_1 / \Delta R_1$
2	$-A_2 R_1 / \Delta R_1$	$1.0 + A_2 (R_2 / \Delta R_2 + R_1 / \Delta R_1)$	$-A_2 R_2 / \Delta R_2$
	.	.	.
	.	.	.
	.	.	.
M	$-A_M R_{M-1} / \Delta R_{M-1}$	$1.0 + A_M (Y_{fc} / k_{cm} + \frac{R_{M-1}}{\Delta R_{M-1}})$	$-A_M Y_{fc} / k_{fm}$
M+1	$A_c Y_{fc}$	$1.0 + A_c (Y_{fc} + Y_{cn})$	$-A_c Y_{cn}$
M+2	$A_n Y_{cn}$	$1.0 + A_n Y_{cn} + 2.0 \Delta t V_n / \ell$	None

where:

$$A_1 = 2 h^j k_{fi} / (\rho_f C_{fi} (R_1^2 - R_{i-1}^2))$$

$$A_c = 2 h^j / (\rho_c C_c (R_c^2 - R_M^2))$$

and,

$$A_n = 2 h^j / (\rho_n C_n (R_n^2 - R_1^2))$$

The solution vector is:

$$T = \begin{bmatrix} \bar{T}_{f1}^{j+1} \\ \bar{T}_{f2}^{j+1} \\ \vdots \\ \bar{T}_{fm}^{j+1} \\ \bar{T}_c^{j+1} \\ \bar{T}_N^{j+1} \end{bmatrix}$$

The product vector is:

$$P = \begin{bmatrix} \bar{T}_{f1}^j + \Delta t q_f / (\rho_f C_{f1}) \\ \bar{T}_{f2}^j + \Delta t q_f / (\rho_f C_{f2}) \\ \vdots \\ \bar{T}_{fm}^j + \Delta t q_f / (\rho_f C_{fm}) \\ \bar{T}_c^j + \Delta t q_c / (\rho_c C_c) \\ \bar{T}_N^j + 2\Delta t V_N^j T_{in} / \ell \end{bmatrix}$$

Crout's method for matrix reduction is used to solve the set of coupled linear algebraic equations for the temperature vector T.

The heat of fusion of the fuel is accounted for in nodes where fuel melting occurs. The local temperature profile is first computed as if no melting had occurred. The excess temperature over the melting temperature is then converted to an energy density. The energy density is stored and the local temperature is reset to the melting temperature until the heat of fusion is exceeded. The calculation then proceeds in the normal manner with tabulated fuel property data.

3.3 TRANSIENT POWER CALCULATION

The relative power level is computed in the FREADM code using a point or space independent reactor kinetics model with up to six delayed neutron precursor groups. Delayed thermal power due to fuel burnup prior to the accident being analyzed is accounted for through the use of two delayed power precursor groups. Local power densities are obtained using local power peaking factors which are constant throughout the accident.

Time step control is contained in the transient power calculation. A time step for nuclear kinetics may be limited either by accuracy considerations for the kinetics calculation or by requirements of other calculations.

Prompt reactivity feedback due to fuel temperature variations is computed within the power calculation. Local average fuel temperatures are computed independently of the detailed heat transfer and are renormalized each time a detailed heat transfer calculation is performed. The model used to compute fuel temperatures for feedback calculations is described in Section 3.6.1.

Numerical integration of the point kinetics follows generally that of the FORE II code,⁽¹⁾ with some modifications in the treatment of delayed neutrons and delayed power.

Transient power is computed in subroutine TPOWER.

3.3.1 FISSION RATE

The instantaneous fission rate is obtained from the point kinetics equations:

$$\frac{dn}{dt} = \frac{\Delta k - \beta(1 + \Delta k)}{\ell} n + \sum \lambda_i C_i$$

$$\frac{dC_i}{dt} = \frac{\beta_i}{\ell} (1 + \Delta k) n - \lambda_i C_i$$

where:

- n = relative instantaneous fission rate
- Δk = current excess multiplication
- β = total effective delayed neutron fraction per fission neutron
- C_i = delayed neutron precursor density for delay group i
in units consistent with n . ($0 \leq i \leq 6$)
- λ_i = decay constant for decay group i
- β_i = effective fraction of delayed neutrons per fission neutron
in decay group i
- ℓ = prompt neutron lifetime

In general, n , C_i and Δk will be time dependent. To obtain a numerical solution we assume that:

1. The precursor densities remain constant over a time step at their values at the start of the time step,
- and,
2. the excess multiplication remains constant over a time step at a value determined at the start of the time step.
(Tabulated reactivity is taken at the center of the time step, Doppler reactivity at the start of the time step.)

With these approximations, the fission rate equation may be integrated directly over a time step giving,

$$n^{j+1} = \left(n^j + \frac{b}{a} \right) e^{a\Delta t_j} - \frac{b}{a}$$

where:

n^{j+1} = relative fission rate at the end of time step j

n^j = relative fission rate at the start of time step j

Δt_j = j th time step size

$$b = \sum_1 \lambda_1 C_1^j$$

$$a = \frac{\Delta k^j - \beta(1 + \Delta k^j)}{\ell}$$

C_1^j and k^j are values at the start of time step j .

The integrated fission rate over the time step is,

$$\int_{t_u}^{t_j + \Delta t_j} n(t) dt = \frac{1}{a} \left\{ \left(n^j + \frac{b}{a} \right) (e^{a\Delta t_j} - 1) - b\Delta t_j \right\}$$

Stability is insured by checking the value of (a) . Whenever (a) is less than 10^{-5} ,

$$n^{j+1} = n^j = b\Delta t_j$$

and

$$\int_{t_j}^{t_j + \Delta t_j} n(t) dt = n^j \Delta t_j + \frac{b}{2} \Delta t_j^2$$

Knowing the fission rate over the time step, the equation for the delayed neutron precursor concentration may now be integrated directly giving,

$$C_i^{j+1} = C_i^j e^{-\lambda_i \Delta t_j} + p \left\{ \frac{q}{a + \lambda_i} \left[e^{a \Delta t_j} - e^{-\lambda_i \Delta t_j} \right] - \frac{b}{a \lambda_i} \left[1 - e^{-\lambda_i \Delta t_j} \right] \right\}$$

where:

C_i^{j+1} = precursor density for delay group i at the end of time step j .

C_i^j = precursor density for delay group i at the start of time step j .

$$p = \frac{\beta_i}{\ell} (1 + \Delta k^j)$$

$$q = n^j + \frac{b}{a}$$

For the case of $(a) \leq 10^{-5}$,

$$C_i^{j+1} = C_i^j e^{-\lambda_i \Delta t_j} + \frac{p}{\lambda_i} \left\{ \left(1 - e^{-\lambda_i \Delta t_j} \right) \left(n^j - \frac{b}{\lambda_i} \right) + b \Delta t_j \right\}$$

The precursor concentrations are updated to the end of each time step using these results.

3.3.2 FISSION PRODUCT DECAY

If the user specifies that a finite fraction of the power is delayed, the code will compute the contribution of the fission product decay to the instantaneous power. This model allows the user to account for the fraction of the total fission energy which is due to fission product decay.

The total fission product decay rate is assumed to be the composite decay of up to five fission product groups. Each fission product group is characterized by a decay constant λ_i and a constant for generation α_i . The values of α_i and λ_i , and the number of decay groups may be determined by fitting exponential decay curves to data for power decay following shutdown of a reactor with equilibrium fission products. If the generation constants, α_i , are set to 0.0 in the input, the fission product calculations are bypassed.

To determine the fission product decay rate define:

$f_i(t)$ = fission product concentration at time
t for decay in group i.

α_i = fraction of fissions contributing to $f_i(t)$
i.e. fraction of fission energy stored in
decay group i.

Then,

$$f_i(t) = \int_{-\infty}^t \alpha_i n(u) k_i(t-u) du$$

where:

$n(u)$ = fission rate at time u

$k_i(t-u)$ = concentration of fission products at time t
due to those born at time u for group i.

$\alpha_i n(u)du$ = group i fission products born in du about u.

Assuming exponential decay of the fission products gives,

$$f_1(t) = \int_{-\infty}^t \alpha_1 (n(u) e^{-\gamma_1(t-u)}) du$$

note that

$$\begin{aligned} f_1(0) &= \int_{-\infty}^0 \alpha_1 n(0) e^{\gamma_1 u} du \\ &= \frac{\alpha_1}{\gamma_1} n(0) \end{aligned}$$

and

$$f_1(t+\Delta t) = f_1(t) e^{-\gamma_1 \Delta t} + \int_t^{t+\Delta t} \alpha_1 n(u) e^{-\gamma_1(t+\Delta t-u)} du$$

With the above expression and the previously obtained expression for n , the fission product concentration at the end of a time step is,

$$\begin{aligned} f_1^{j+1} &= f_1^j e^{-\gamma_1 \Delta t_j} + \frac{\alpha_1 q}{a + \gamma_1} \left[e^{a \Delta t_j} - e^{-\gamma_1 \Delta t_j} \right] \\ &\quad - \frac{\alpha_1 b}{a \gamma_1} \left[1 - e^{-\gamma_1 \Delta t_j} \right] \end{aligned}$$

where:

f_1^{j+1} = fission product density for group 1 at the end of time step j .

f_1^j = fission product density for group 1 at the start of time step j .

These values are normalized to be consistent with the units of n .

The fission product decay rate integrated over the j th time step is given by,

$$\gamma_i \int_{t_j}^{t_j + \Delta t_j} f_i(t) dt = (1 - e^{-\gamma_i \Delta t_j}) \left\{ f_i(t) + \frac{\alpha_i q}{a + \gamma_i} - \frac{\alpha_i b}{a \gamma_i} \right\} \\ + \frac{\alpha_i \gamma_i q}{a(a + \gamma_i)} [e^{a \Delta t_j} - 1] - \frac{b \alpha_i}{a} \Delta t_j$$

For the case of $a \leq 10^{-5}$,

$$f_i^{j+1} = f_i^j e^{-\gamma_i \Delta t_j} + \frac{\alpha_i}{\gamma_i} \left[\left(n^j - \frac{b}{\gamma_i} \right) (1 - e^{-\gamma_i \Delta t_j}) + b \Delta t_j \right]$$

and

$$\int_{t_j}^{t_j + \Delta t_j} f_i(t) dt = \frac{\alpha_i}{\gamma_i} \left\{ (1 - e^{-\gamma_i \Delta t_j}) \left[\frac{f_i^j}{\alpha_i} - \frac{1}{\gamma_i} \left(n^j - \frac{b}{\gamma_i} \right) \right] \right. \\ \left. + \Delta t_j \left[\left(n^j - \frac{b}{\gamma_i} \right) + \frac{b \Delta t_j}{2} \right] \right\}$$

3.3.3. POWER

The instantaneous power is given by

$$P(t) = A_1 n(t) + A_2 \sum_i \gamma_i f_i(t)$$

where A_1 and A_2 are conversion constants used to convert relative fission rate and fission product decay rate to power density units. The values of A_1 and A_2 may be obtained from steady state formulas:

$$\begin{aligned} P(o) &= A_1 n(o) + A_2 \sum_1 \alpha_1 n(o) \\ &= n(o) A_1 + A_2 \sum_1 \alpha_1 \end{aligned}$$

Hence, A_1 and A_2 are chosen such that

$$\frac{\sum_1 \alpha_1}{A_1 + A_2 + \sum_1 \alpha_1} = F$$

where:

A_1 and F are supplied by the user,

F = the fraction of power due to fission product decay at equilibrium conditions,

and,

A_1 is the conversion factor from relative fission rate to power density units.

The power at the start of the j th time step is thus,

$$P^j = A_1 n^j + A_2 \sum_1 \gamma_1 f_1^j$$

and at the end of the j th time step

$$P^{j+1} = A_1 n^{j+1} + A_2 \sum_1 \gamma_1 f_1^{j+1}$$

The power integrated over the j th time step is given by:

$$\int_{t_j}^{t_j + \Delta t_j} P(t) dt = A_1 \int_{t_j}^{t_j + \Delta t_j} n(t) dt + A_2 \sum_1 \gamma_1 \int_{t_j}^{t_j + \Delta t_j} f_1(t) dt$$

The integrals on the right hand side are those which were computed in the kinetics and fission product decay sections.

3.3.4 PROGRAM LOGIC

Time step control for the entire transient calculation is contained in the kinetics package. Tests are made on the fractional fission rate change over a time step and on the integrated power over a time step. Since a heat transfer calculation may not be required after each kinetics time step, the integrated power since the last heat transfer calculation is used to estimate Doppler feedback until the next updating of fuel temperatures. A flow chart of the transient power calculation is provided in Figure 3.3.1. A table of reactivity vs. time for voiding and control action etc. is computed before entering the kinetics logic.

FIGURE 3.3.1

FLOW DIAGRAM FOR TRANSIENT POWER CALCULATION

3.4 FUEL FAILURE MODES

Four hypothetical modes for fuel redistribution are available to FREADM users, in order that the effects of different fuel redistribution reactivity on the consequences of various postulated accidents may be explored in a consistent way by the user of FREADM-1. Types of fuel redistribution which may be considered are:

1. Motion of one or more axial sections moving independently under the influence of gravitational, fluid flow and/or fuel coolant interaction forces,
2. Motion of fuel as a result of clad failure filling the coolant channel above and below the failure,
3. Collapse of one axial segment of the core into another (fuel fails and falls to or through the bottom of the core),
4. Uniform bundle collapse into a user specified geometry.

Modes 2, 3, and 4 are "whole bundle" failure modes in that once a failure threshold is reached, no further heat transfer calculations are performed in the bundle, and no further triggering of fuel redistribution is considered. Mode 1 is a "single section" failure in that heat transfer calculations continue for unfailed sections in the bundle.

A failure mode may be specified for each bundle type. In addition propagation of the last three failure modes from one bundle type to other bundle types may be specified.

Fuel motion and resultant reactivity effects are computed in subroutine FFAIL which is called from subroutine TRIPIT.

3.4.1 MODE 1 - FAILURE OF A SINGLE AXIAL SECTION

A single section failure occurs when a prescribed fuel or clad temperature is reached at a given axial fuel section. The failed section is assumed to move independently of all other sections in the bundle under a constant driving force. Hence, its motion is given by

$$(Z-Z_o) = \frac{Ft^2}{2\rho V}$$

where: $Z-Z_o$ is the displacement of the node from its original location,

t = elapsed time since trigger was reached.

ρV = mass of axial node

F = constant drive force

The driving force F is the sum of three parts, a gravity term, a coolant flow term, and a fuel coolant interaction term, each input by the user. The logic for determining which of these terms to include is shown in Figure 3.4.1. The user has the option of initiating sodium voiding upon failure of a single axial node and triggering the fuel coolant interaction term in the driving force.

Heat transfer calculations are required for those sections which have not yet failed. In the failed sections, heat is either promptly transferred to sodium or stored in the section. Coolant flow is not affected unless voiding is initiated.

FIGURE 3.4.1

CALLING LOGIC FOR MODE 1 DRIVING FORCE

3.4.2 MODE 2 - FUEL EXPELLED FROM CLAD FAILURE FILLS COOLANT CHANNEL

This mode may be used to simulate the motion of fuel as it leaves the clad under the influence of an internal driving force (such as fuel vapor pressure or released fission product gases) and moves in the coolant channel away from the failure location. The user specifies the sections which are affected by the clad failure (either all axial sections, or those sections above and including the failed section), the time required for fuel to leave the clad and the distance above and below the failure point which mark the extremities of the redistributed fuel. Mode 2 is triggered off a clad or fuel temperature, also input by the user.

Assumptions used in the analysis are:

1. All of the fuel in the affected axial sections leaves the clad,
2. the fuel leaves the clad at a constant rate,
3. the fuel density remains constant,

With these assumptions, the motion of the fuel may be simulated by considering two fuel columns, one shrinking inside the clad towards the point of failure and one growing outside the clad from the point of failure. Thus, if H is the total height of the fuel column in the core, τ is the time required for redistribution, and M is the number of axial fuel nodes, the position of the extremities of the two fuel columns for failure in the m th fuel section is:

$$Z_1(t) = H - (H - Z_0) t / \tau ; \quad t \leq \tau$$

$$Z_2(t) = Z_0 t / \tau ; \quad n=M \text{ or } 1$$

$$t \leq \tau$$

in the clad, and

$$\left. \begin{aligned} Z_3(t) &= Z_0 + d_1 t/\tau \\ Z_4(t) &= Z_0 - d_2 t/\tau \end{aligned} \right\} t \leq \tau$$

outside of the clad,

where: Z_0 is the axial location of the clad failure, given by;

$$Z_0 = \frac{H}{M} \left(\frac{2M-1}{2} \right)$$

t is the elapsed time since the mode 2 trigger was reached,

n is the number of the lowest axial section affected by the redistribution ($=1$ or m),

d_1 is the distance above the failure of the final upper endpoint of the redistributed fuel column,

d_2 is the distance below the failure of the final lower endpoint of the redistributed fuel column,

$Z_1(t)$ and $Z_2(t)$ are the upper and lower extremities of the fuel column inside the clad at time t ,

$Z_3(t)$ and $Z_4(t)$ are the upper and lower extremities of the fuel column outside the clad at time t .

For the purpose of determining the reactivity effect of a mode 2 redistribution from a fixed fuel worth curve, the axial sections may be treated as though they simultaneously shrink within the clad and grow outside the clad. Hence, the position of a section within the clad which is affected by the redistribution is given by:

$$X_j(t) = Z_2(t) + \frac{Z_1(t) - Z_2(t)}{M+1 - n} \quad \frac{2j-1}{2} \quad ; \quad j \geq n$$

$t \leq \tau$

where:

$X_j(t)$ is the midpoint of the j th fuel node at time t
after a mode 2 trigger is reached.

Outside of the clad,

$$Z_j(t) = Z_4(t) + \frac{Z_3(t) - Z_2(t)}{M+1 - n} \frac{2j-1}{2} ; \quad \begin{matrix} j \geq n \\ t \leq \tau \end{matrix}$$

The fraction of the fuel section which may be considered to be inside the clad is given by:

$$f_1(t) = 1.0 - (t/\tau) ; \quad t \leq \tau$$

from which the fraction of each affected fuel section outside the clad is given by:

$$f_2(t) = t/\tau ; \quad t \leq \tau$$

3.4.3 MODE 3 - GRAVITY COLLAPSE

Mode 3 may be used to simulate the motion of a fuel column dropping to or through the bottom of the core following failure of a user specified type. Upon reaching a mode 3 trigger in a given axial section all of the fuel in the section and in all of the axial sections above the failed section is assumed to fall under the influence of a constant driving force either to or through the bottom of the core. For a fuel column height H divided into M axial sections, with a failure in the mth section, the distance fuel will drop to reach the core bottom is given by:

$$Z(\tau) - Z_0 = \frac{H}{M} (m-1)$$

and at time t,

$$Z(t) - Z_0 = (Z(\tau) - Z_0) t^2 / \tau^2 \quad ; \quad t \leq \tau$$

where:

$Z(t)$ is the axial position of the center of the mth fuel section,

τ is the time required to reach the core bottom given by:

$$\tau = \sqrt{\frac{2[Z(\tau) - Z_0]}{F}}$$

where:

$Z(\tau)$ is the final axial position of the mth fuel section.

Z_0 is the initial axial position of the mth fuel section given by:

$$Z_0 = \frac{H}{M} \left(\frac{2m-1}{2} \right)$$

F is the constant driving force.

The distance the fuel column must travel to leave the core is simply the core height. Hence, in this case,

$$\tau = \sqrt{\frac{2H}{F}}$$

and

$$Z(t) - Z_0 = \frac{Ht^2}{\tau^2} \quad ; \quad t \leq \tau$$

The position of the center of the i th fuel node where $i \geq m$ is given by:

$$Z_i(t) - Z_i(0) = [Z(\tau) - Z_0] t^2 / \tau^2 \quad ; \quad t \leq \tau$$

where the value of $Z(\tau) - Z_0$ is:

$\frac{H}{M} (m-1)$ for case 1 (fuel falls to core bottom) and,

H for case 2 (fuel falls out of core).

After fuel has entered the blanket, it is no longer followed.

3.4.4 MODE 4 - UNIFORM BUNDLE COLLAPSE

The user may use Mode 4 to describe uniform compaction of fuel within a bundle, and the final geometry of the redistributed fuel. When a mode 4 trigger is reached, the whole fuel column (all axial sections) is assumed to compact either with constant velocity or with a constant acceleration based on the user specified final endpoints of the fuel column and the time required for fuel to reach its final configuration. For an initial fuel column height H , and final endpoints $Z_1(\tau)$ and $Z_2(\tau)$ the position of the endpoints of the fuel column during the redistribution ($0 \leq t \leq \tau$) is given by:

$$Z_1(t) = Z_1(\tau) (t/\tau)^k$$

$$Z_2(t) = H + [Z_2(\tau) - H] (t/\tau)^k$$

where $k=1$ for constant velocity, and $k=2$ for constant acceleration.

With m fuel sections, the position of the center of the m th fuel section is given by:

$$Z_m(t) = \frac{Z_2(t) - Z_1(t)}{M} \left(\frac{2m-1}{2} \right)$$

The unique feature of this mode is that the final fuel configuration does not depend on the location of the first fuel failure. The user is free to specify failure criteria and fuel motion.

3.4.5 PROPAGATION OF FAILURE MODES

The user may specify a simple time delay for propagation of failure modes 2, 3, and 4 from one bundle type to another. For each bundle type, separate time delays may be specified for each of the other bundle types. If fuel redistribution other than mode 1 has already been initiated in another bundle type, the propagation trigger has no effect. If a failure mode for a bundle other than the failed bundle has been prescribed, the propagated failure mode takes precedence if the prescribed failure mode has not been initiated in the other bundle at the time of propagation.

3.4.6 PROGRAM LOGIC

A general description of the program logic is shown in Figure 2. For each bundle type it is first determined whether a failure has occurred in the bundle during the time step. If a failure has occurred, the position of the nodes in the bundle is computed as a function of time using the appropriate failure mode.

The reactivity effect of moving fuel axially within a bundle will be computed assuming a constant material worth distribution or may be input by the user.

FIGURE 3.4.2

PROGRAM LOGIC FOR FUEL REDISTRIBUTION CALCULATION

3.5 COOLANT FLOW AND VOIDING - THE VOIDUM CALCULATION

When sodium voiding in a bundle is triggered, the growth of the voided region within a bundle type is obtained by computing the axial displacement of the upper and lower fluid - void interfaces. The detailed interaction of flow and voiding may be computed using the VOIDUM routine which accounts for the flow characteristics of all major components of the primary coolant loop. Alternately, the axial displacement of fluid void interfaces and resultant coolant flow perturbations may be pre-specified using input tables for void displacement vs. time and coolant flow vs. time. These calculations are performed in subroutine VOIDIT and COOLIT.

3.5.1 PROBLEM DESCRIPTION

Previous analysis of sodium voiding from a reactor channel has shown that the effects of the inertia and flow resistance of the entire primary coolant system are important in determining the voiding rate and voiding pattern from the core⁽⁴⁾. In order to describe the dynamic response of the primary coolant system to accident conditions such as sodium voiding, the flow equations for all of the flow paths of the system must be described and solved simultaneously as a function of time.

3.5.2 PROBLEM SOLUTION

The VOIDUM subroutine is available as an integral part of the FREADM-1 code and may be run independently for those who are interested in exploring the characteristics of primary system coolant dynamics separately in a tank or pot type sodium cooled reactor. This model has the flexibility to consider a variety of system designs and accident conditions. When it is used as a subroutine in FREADM-1, sodium voiding accidents involving the entire core can be simulated, with changes in core inlet flow due to in-core voiding properly taken into account.

The physical system considered is illustrated in Figure 3.5.1a. The primary coolant loop is simulated by 2 pumps and associated inlet piping, the reactor core, reactor pot and 2 intermediate heat exchangers with associated piping. The loops are emersed in a main tank.

Flow in the loops is perturbed by changes in frictional loss coefficients in the pump piping, inlet to the core, outlet of the core or in the heat exchanger piping. Also, flow changes may be initiated by changing the pump pressure rise or by causing voiding in any of 12 radial regions in the core.

The code then calculates the resulting pressures, flow acceleration velocities and fluid displacements in the primary system as a function of time.

Flow areas and lengths associated with the primary loop calculations are summarized in Figures 3.5.1b and 3.5.1c.

FIGURE 3.5.1a
PRIMARY COOLANT LOOP GEOMETRY

FIGURE 3.5.1b
INPUT FLOW AREAS

FIGURE 3.5.1c

INPUT FLOW LENGTH AND HEIGHTS

3.5.3 GOVERNING EQUATIONS

Typical equations for each type of phenomena treated by the VOIDUM module are described in this section. The detailed derivation of equations is given in Appendix A for the two flow loops in the primary system.

The following assumptions are used in the description of the model.

1. The response of any number of pumps and heat exchangers can be simulated with 2 pumps and 2 heat exchangers.
2. Sodium voids the fuel bundle (channel) in slug flow.
3. Voiding in any fuel bundle (channel) is initiated when:
 - (a) A specified fuel temperature limit is exceeded in that bundle.
 - (b) the required super heat is reached in that channel (as a function of pressure).
4. Once voiding is initiated in a channel, the vapor pressure can be described,
 - (a) As an input vs. time after voiding begins.
 - (b) By the saturation pressure of sodium at the insulated clad surface temperature where voiding initiates.
5. The liquid in the system is incompressible.
6. The vessels, channels and piping are rigid.
7. Mass storage can occur in the cover gas volumes by displacement and compression of the cover gas.
8. Flow pressure losses are due to
 - (a) Friction and spacer losses
 - (b) Velocity head losses
 - (c) Gravity head losses
9. When the top or bottom liquid slug has voided out of a channel either at the top or bottom of that channel, any further consideration of that channel is neglected. The re-entry phenomena is not described in the model.

3.5.3.1 ORIFICING AND LOSS COEFFICIENTS

The orificing and frictional loss coefficients are calculated from the design values of the flow rates and pressure drops.

The design pressure drop across core and blankets is, assuming the flow in the peak channel (channel 1) has the maximum flow rate,

$$\Delta P_c^D = F_p \frac{f \rho (V_{D,1})^2 X_{LC} (1 + F_R)}{2g_o D_H} + C_{out}^o \frac{\rho (V_{R1})^2}{2g_o}$$

where:

F_p accounts for wire wraps, F_R accounts for inlet orificing and C_{out}^o accounts for a velocity head loss at the outlet of the channel.

The orificing coefficient for each channel, n , in the core then becomes, assuming a constant radial pressure drop across the core,

$$C_{or,n}^o = \left(\frac{\Delta P_c^D}{\frac{\rho (V_{D,n})^2}{2g_o}} \right) - \frac{F_p f X_{LC}}{D_H} - C_{out}^o$$

The frictional loss in the remainder of the piping in either of the two loops is calculated from:

$$C_f^o = \left(\frac{\Delta P_c^D}{\frac{\rho (V_{D,n})^2}{2g_o}} \right)$$

where the pressure drop is specified and the velocity is determined from continuity considerations (knowing core flow rate and flow areas).

3.5.3.2 INITIAL FLOW RATES AND PRESSURE DROPS

From a specified coolant velocity in the core, a tank cover gas pressure and previously calculated friction coefficients, pressure drops and flow velocities through the loop are calculated.

The equations used for this are steady state continuity and momentum. From equations (8) and (9a), Section 3.5.3.4, with the time derivatives equal to zero (See Figure 3.5.2 for nomenclature),

$$A_{in} V_{in}^o = AV^o = A_{out} V_{out}^o$$

$$P_{out}^o - P_{in}^o = C_f^o \frac{\rho (V^o)^2}{2g_o} + \frac{\rho A_{in} (V_{in}^o)^2}{g_o A} - \frac{\rho A_{out} (V_{out}^o)^2}{g_o A} - \frac{\rho g L}{g_o}$$

3.5.3.3 TRANSIENT FORCING FUNCTIONS

To simulate blockages in various locations in the flow loop, the loss coefficient in the pump piping, core inlet, core outlet and heat exchanger piping may be changed as a linear function of time (ramp function).

$$C_f = C_f^o \left[1 + \frac{(F_f - 1)}{t_f} t \right] \quad t < t_f$$

$$C_f = C_f^o F_f \quad t > t_f$$

Also, to simulate a loss of pumping power, the pump pressure rise may be changed as a function of time (ramp function).

$$\Delta P_p = \Delta P_p^o \left[1 + \frac{(F_{pl} - 1)}{t^*} t \right] \quad t < t_p$$

$$\Delta P_p = \Delta P_p^o F_{pl} \quad t > t_p$$

CONTROL VOLUME FOR MOMENTUM

* CONTINUITY EQUATIONS

FIGURE 3.5.2

Since the loop contains 2 pumps and associated piping, and 2 heat exchangers and associated piping, these loss coefficients may be changed in one or both of the pumps and one of the heat exchangers, so that the loss of one pump loop may be simulated.

3.5.3.4 TRANSIENT FLOW EQUATIONS

The pressures and flow accelerations as a function of time are determined by formulating the appropriate momentum equation for control volumes through the primary loop. Conditions in the control volumes are then coupled by use of continuity equations.

To develop the required form of the transient momentum equation, consider a typical flow cross-section as shown in Figure 3.5.2. Conservation of momentum for the indicated control volume is

$$\begin{aligned} &\text{Momentum Rate Out} - \text{Momentum Rate In} \\ &+ \text{Momentum Storage Rate} = g_o \sum \text{FORCES} \end{aligned}$$

Expressing each of these terms in mathematical form, assuming a one dimensional model (i.e., no variations across the flow cross section) yields

$$\text{Momentum Rate Out} = \rho V_{\text{out}} A_{\text{out}} V_{\text{out}}$$

$$\text{Momentum Rate In} = \rho V_{\text{in}} A_{\text{in}} V_{\text{in}}$$

$$\text{Momentum Storage Rate} = \frac{d}{dt} (\rho V A L)$$

$$\sum \text{FORCES} = A P_{\text{in}} - A P_{\text{out}} - C_f \frac{\rho V^2 A}{2 g_o} - \frac{\rho g L A}{g_o}$$

Substituting the above expressions into the conservation equation, the momentum equation is written as

$$\frac{\rho L}{g_o} \dot{V} + C_f \frac{\rho V^2}{2g_o} - P_{in} + P_{out} = \frac{\rho A_{in}}{g_o A} V_{in}^2 - \frac{\rho A_{out}}{g_o A} V_{out}^2 - \frac{\rho g L}{g_o} \quad (8)$$

where

$$\dot{V} = \frac{dV}{dt} = \text{Acceleration}$$

Now, similarly, conservation of mass (continuity) is

$$\text{MASS RATE OUT} - \text{MASS RATE IN} + \text{MASS STORAGE RATE} = 0$$

Evaluating these terms,

$$\text{MASS RATE OUT} = \rho A_{out} \cdot V_{out}$$

$$\text{MASS RATE IN} = \rho A_{in} \cdot V_{in}$$

$$\text{MASS STORAGE RATE} = \frac{d}{dt} (\rho LA) = 0$$

Substituting into the mass conservation equation,

$$A_{out} V_{out} = A_{in} V_{in}$$

This equation is now expressed in terms of accelerations by differentiating it to yield the final form of the continuity equation.

$$A_{out} \dot{V}_{out} = A_{in} \dot{V}_{in} \quad (9a)$$

Similarly, by continuity, V can be related to V_{out} and V_{in}

$$AV = A_{in} V_{in}$$

(9b)

$$AV = A_{out} V_{out}$$

Finally, the velocities and displacements are obtained by integration of the accelerations.

$$V = V^0 + \int \dot{V} dt$$

$$X = X^0 + \int V dt$$

Equations of the form of (8) and (9) form the basis for the transient analysis of the flow problem. By writing continuity and momentum for all regions of the flow system, the result is a coupled set of equations for the pressures and accelerations. The complete set of equations is given in Appendix A.

A finite difference solution to this coupled set of equations is sought. From equation (8),

$$\frac{\rho L}{g_o} \dot{V}^{j+1} + \frac{C_{fp}}{2g_o} (V^j + \dot{V}^{j+1}_t)^2 - P_{in}^{j+1} + P_{out}^{j+1} =$$

$$\frac{\rho A_{in}}{g_o A} (V_{in}^j)^2 - \frac{\rho A_{out}}{g_o A} (V_{out}^j)^2 - \frac{\rho g L}{g_o}$$

Replacing $(\dot{V}^{j+1})^2$ by $(\dot{V}^j)^2$ in the expansion of the V^2 term on the left hand side of this equation,

$$(V^j + \dot{V}^{j+1}_t)^2 \approx (V^j)^2 + 2tV^j\dot{V}^{j+1}_t + (\dot{V}^j_t)^2$$

the momentum equation is written as

$$\left[\frac{\rho L}{g_o} + \frac{C_{fp} V^j_t}{g_o} \right] \dot{V}^{j+1} - P_{in}^{j+1} + P_{out}^{j+1} =$$

$$\frac{\rho A_{in}}{g_o A} (V_{in}^j)^2 - \frac{\rho A_{out}}{g_o A} (V_{out}^j)^2 - \frac{\rho g L}{g_o} - \frac{C_{fp}}{2g_o} [(V^j)^2 + (\dot{V}^j_t)^2] \quad (10)$$

Continuity in finite difference form is

$$A_{in} \dot{v}_{in}^{j+1} = A \dot{v}^{j+1} = A_{out} \dot{v}_{out}^{j+1}$$

In the form continuity and momentum have been cast, they constitute a set of linear simultaneous equations for the pressures and accelerations at time step $j+1$. Their solution is discussed in Appendix B. Having obtained the acceleration, velocities and displacements are calculated using

$$\begin{aligned} v^{j+1} &= v^j + \dot{v}^{j+1}_t \\ x^{j+1} &= x^j + v^{j+1}_t + \frac{\dot{v}^{j+1}_t^2}{2} \end{aligned}$$

3.5.3.5 PUMP MODEL

The pressure rise across the pump and the coolant flow rate through the pump are assumed to be related as shown in Figure 3.5.3.

Knowing H_p and H_w , the pump curve is fitted with a quadratic, and the pump pressure rise is calculated from

$$\Delta P_p = \Delta P_p^o \left\{ a_1 + a_2 \frac{v_p}{v_p^o} + a_3 \left(\frac{v_p}{v_p^o} \right)^2 \right\} \quad (11)$$

where

a_1 , a_2 and a_3 are functions of H_p and H_w .

3.5.3.6 COVER GAS MODEL

The change in gas volume is calculated by knowing the change in the level of the gas-coolant interface. Knowing the volume, the gas is assumed to compress isothermally in a polytropic process.

$$P_g = P_g^o \left(\frac{v_g^o}{v_g} \right)^\gamma \quad (12)$$

PUMP MODEL

FIGURE 3.5.3

3.5.3.7 VOIDING INITIATION MODEL

For the purpose of heat transfer calculations, each channel is divided into several axial sections. Using the pressure in each axial section and each channel, saturation temperatures and super heat temperatures for the sodium are calculated in each axial node in each channel.

$$T_{sat} = b_0 + b_1 P + b_2 P^2 + b_3 P^3 + b_4 P^4 + b_5 P^5 \quad (13)$$

$$\Delta T_{sh} = F_{sh} [b_0^* + b_1^* P + b_2^* P^2 + b_3^* P^3 + b_4^* P^4] \quad (14)$$

where the constants b and b^* are curve fits to experimental data (7). The local boiling temperature is then

$$T_B = T_{sat} + \Delta T_{sh} \quad (15)$$

The fuel pins in any given channel may be failed by the user in a number of ways, e.g. when a particular radial fuel node temperature (specified by the user) in any axial section exceeds a user specified value.

3.5.3.8 VOIDING PRESSURE MODEL

The sodium vapor pressure in each channel, n , may be calculated by a recommended curve. ⁽⁸⁾

$$P_{v,n}^o = (144)(14.7) 10^{[6,354 - 5567/T_{w,n}^* - 0.5 \log_{10}(T_{w,n}^*)]} \quad (16a)$$

for $T_{w,n}^* < 1250^\circ\text{K}$, or

$$P_{v,n}^o = (144)(14.7) 10^{[6,681 - 5544/T_{w,n}^* - 0.613 \log_{10}(T_{w,n}^*)]} \quad (16b)$$

for $T_{w,n}^* > 1250^\circ\text{K}$, where $T_{w,n}^*$ is the maximum clad temperature in channel n in $^\circ\text{K}$.

Of, if desired, the vapor pressure may be calculated from a user specified quadratic as a function of time since initial voiding, $t_{b,n}$, for that channel.

$$P_{v,n}^o = 144 [Y_a + Y_b(t-t_{b,n}) + Y_c(t-t_{b,n})^2] \quad (17)$$

In another option, the sodium vapor pressure for a failed fuel pin can be calculated as a specified function of time since pin rupture, $t_{r,n}$, for each channel, n .

$$P_{v,n}^o = 144 [Y_D + Y_E(t-t_{r,n}) + Y_F(t-t_{r,n})^2] \quad (18)$$

3.5.3.9 CHECK VALVE MODEL

The check valve in the pump piping is assumed to be closed when the flow in the pipe has moved backwards in the pipe a specified distance (back flow length), as illustrated schematically in Figure 3.5.4.

The closing of the check valve is modelled mathematically by increasing the pump piping frictional loss coefficient to a very high value so as to effectively stop the flow. During the closing, that is, from the time the flow is reversed until the back flow distance is reached, the frictional loss coefficient is increased in the form

$$C_f = C_f^* \left(\frac{L_{BF}}{L_{BF} - X_{BF}} \right) \quad (19)$$

where C_f^* is the value of C_f at the time of initial flow reversal.

3.5.3.10 TIME STEP CONTROL

As the equations are integrated, the program automatically adjusts the time step size so as to maintain an efficient solution and also to maintain control on the accuracy of the solution.

The quantities which are examined for the time step criteria are the relative velocity changes, ΔV_R .

$$\Delta V_R = \frac{|v^{j+1} - v^j|}{|v^j|} = \frac{|\dot{v}^{j+1}_t|}{|v^j|} \quad (20)$$

The user specifies a maximum value for ΔV_R , ΔV_R^* . If any ΔV_R , for a given time step, are larger than ΔV_R^* , the time step size is halved and the step reintegrated. If all the ΔV_R are a factor of 3 smaller than ΔV_R^* , the step size for the next time step is increased by a factor of 1.5.

CHECK VALVE MODEL

FIGURE 3.5.4

3.5.4 PROGRAM LOGIC

Figures 3.5.5a and 3.5.5b are a flow chart of the VOIDUM subroutine. The basic calculational procedure is as follows:

1. Input read and edited.
2. Subroutine INIT first calculates orificing and friction loss coefficients from the design flow rates and pressure drops. Then initial flow rates and pressure drops are set up.
3. The transient portion of the program is now entered.
4. The first set of calculations in each time step is to establish new values of the forcing functions as specified by the user.
5. Subroutine MATRIX is called to calculate the new pressures and accelerations around the loop. Within MATRIX, the coefficient and right hand side arrays are first determined for the set of simultaneous equations for the pressures and accelerations. These terms are then substituted into the equations for the simultaneous solution of the pressures. The pressure equations are solved by Crout elimination. The new pressures are substituted into the acceleration equations for the new accelerations. Control is returned to the main program.
6. The velocity change from the previous to the present step, is checked against a maximum allowable value. If the change was greater the allowable time step is halved and the step recalculated. If the change is within the allowable value, the calculation proceeds.
7. The accelerations are integrated to get new velocities and displacements and the cover gas pressures are calculated.
8. The manual void trigger is checked.
9. Each channel is checked for either coolant boiling or pin rupture. The vapor pressure is computed for each channel that is in a voiding condition.

10. The termination criteria is checked. If it has been reached, final editing is performed. If termination has not been reached, the program proceeds to the next time step (#4 above).

VOIDUM FLOW CHART

FIGURE 3.5.5a

VOIDUM FLOW CHART

FIGURE 3.5.5b

GEAP-13608

3-73

3.5.5 RUNNING EXPERIENCE

The execution time required for the VOIDUM subroutine (when run independent of the other portions of FREADM-1) has been found to be around 0.25 seconds of GE-635 time per time step.

It has also been found that with too large a time step, second order numerical problems may arise. This occurs in the calculation of accelerations in highly orificed channels in the core and blankets during voiding accidents.

In Section 3.5.3.4, it was necessary to replace $(\dot{v}^{j+1})^2$ by $(\dot{v}^j)^2$ in the equation for frictional pressure loss to resolve this difficulty. If too large a time step is used, this approximation becomes inaccurate. The result is that oscillations may occur in the accelerations in the highly orificed channels. This problem can be eliminated by using a smaller time step (smaller allowable ΔV).

3.6 REACTIVITY FEEDBACK

Reactivity in FREADM-1 may be due to sodium voiding, fuel redistribution, control action, an accident initiating event, Doppler and a programmed reactivity insertion. All of the types of reactivity except the temperature dependent values are combined in a table of reactivity vs. time. The temperature dependent feedback is computed each time step using the current best value of temperature.

3.6.1 DOPPLER FEEDBACK

The Doppler feedback is computed for each time step using the best estimate of average nodal fuel temperatures at the end of the previous time step. If A_n is the total Doppler coefficient associated with the n th axial fuel section of all the bundles of a given type, then the Doppler feedback corresponding to the current fuel temperature in the n th section is given by:

$$\Delta k^j = A_n \ln \left(\frac{T_n^j}{T_n^o} \right)$$

where:

Δk^j is the Doppler feedback at the end of the j th time step due to a temperature change in the n th axial node.

T_n^j is the average temperature of the n th axial node at the end of the j th time step.

T_n^o is the starting value of temperature in the n th axial fuel node.

Time step limitations due to accuracy requirements for prompt feedback in the nuclear kinetics are much more restrictive than time step limitations due to accuracy requirements for heat transfer calculations for a large number of cases. A method was developed for computing temperature dependent prompt feedback between detailed calculations of the temperature profile. The method treats only the average fuel temperature of each axial node. Clad and coolant temperatures are eliminated as variables, but changes in the rate of heat transfer from the fuel are accounted for.

The average fuel temperature for each axial fuel node is estimated between heat transfer calculations as follows:

1. Compute spatial averages for the fuel properties - conductivity, specific heat and thermal diffusivity.

2. Integration of the heat balance equation with constant coefficients over the node gives:

$$(\overline{\Delta^2 T}) = \frac{1}{\alpha} \frac{\partial \bar{T}}{\partial t} - \frac{\bar{Q}}{k}$$

where:

α and k are average values of thermal diffusivity and conductivity assumed to be constant over the time step,

$\bar{T}$ is the instantaneous average fuel temperature for the axial node,

$\bar{Q}$ is the instantaneous average power density in the fuel,

$(\overline{\Delta^2 T})$ is the instantaneous average value of the Laplacian in the fuel.

Estimate the Laplacian assuming $\frac{\partial T}{\partial t} = \frac{\delta T}{\delta t}$ for the previous time step, and using $\bar{Q}$ at the end of the previous step.

$$(\overline{\Delta^2 T}) \approx \frac{1}{\alpha} \frac{\delta \bar{T}}{\delta t} - \frac{\bar{Q}}{k}$$

3. Integrate the heat balance over one time step assuming that material properties and $(\overline{\Delta^2 T})$ remain constant over the time step at their values at the beginning of the time step giving,

$$\delta \bar{T} = \alpha \left[(\overline{\Delta^2 T}) \delta t + \frac{1}{k} \int_{t_1}^{t_2} \bar{Q}(\tau) d\tau \right]$$

The integral quantity is proportional to the integrated power over the time step given by the point kinetics model. The time derivative and the fuel temperature are renormalized each time a detailed heat transfer calculations is performed.

Note that the change in fuel average temperature has been computed independently of instantaneous clad or coolant temperatures. Starting values of the temperature and Laplacian are easily obtained from steady state considerations. This model has given good agreement with the more detailed heat transfer calculation in cases where heat transfer is

unimportant. Sufficient accuracy for scoping calculations may be obtained using only this model for transient heat transfer.⁽⁹⁾

3.6.2 FUEL REDISTRIBUTION REACTIVITY

The reactivity effect of fuel redistribution may be computed in the code, using one of the four available modes, (Section 3.4) or it may be input from a table which is triggered by a user specified temperature being reached. If the reactivity effect is computed by the code, the reactivity effect of each axial fuel node is computed separately. Each failure mode has a transit time associated with it which is divided into a number of equal segments for the purpose of constructing a reactivity table. The reactivity effect of a given displacement of a given axial fuel node is obtained from a fixed fuel worth distribution for the bundle in which the fuel node moves. The worth of the fuel node is taken at the center of the node and is assumed to vary linearly within a time segment. The first point in the table is the endpoint of the time step in which the prescribed failure mode is triggered.

3.6.3 SODIUM VOIDING REACTIVITY

The reactivity effect of voiding the coolant from a given bundle type may be computed by the code or input by the user. If the void reactivity effect is to be computed by the code the user must supply the axial and radial limits of the voiding pattern which gives the maximum positive voiding worth, and the voiding reactivity obtained with that configuration. If the user elects to input a curve of reactivity vs. time, a table is available which may be triggered by void initiation.

The calculation of void reactivity which is built into the code uses the input to construct integral void worth curves, assuming that voiding is initiated in the core center and propagates outward. The integral worth curves are assumed to be parabolic and of the form:

$$\frac{W}{W_{\max}} = \frac{1}{X_{\max}^2} [2XX_{\max} - X^2]$$

in both the axial and radial directions, where:

X = Distance void extends above or below the core midplane in the axial direction,
 = $(r/R)^2$ in the radial direction where r is the distance from the core central axis of the outer limit of the void and R is the core outer radius.

W = Relative worth of void extending from the core center to X in each direction

$W_{\max}$ = Maximum void worth for axial curve
 = 1.0 for radial curve.

$X_{\max}$ = Axial and radial values of X which give the maximum void worth.

Differentiation of the integral curve gives a differential worth curve

$$\frac{1}{W_{\max}} \frac{dW}{dX} = \frac{2}{X_{\max}^2} [X_{\max} - X]$$

which may be easily integrated to give void reactivity as a function of void limits. The axial limits as a function of time for a given bundle type are determined in the void calculation, or may be user input. The radial region assigned to the bundle type determines the radial limits of the void.

To compute the reactivity effect of voiding in a given bundle type,

integration is first performed over the axial void worth distribution assuming that the void extends radially from the core center axis to the radial location corresponding to the maximum void worth (RMAX). A radial factor is then computed by integrating the radial distribution (normalized to give a maximum integrated void worth of 1.0) over the limits defined by the radial region to which the given bundle type is assigned. The fraction of the radial region represented by the given bundle type appears as a third factor. Reactivity may be computed in this way whether voiding is from tables or from the loop flow calculation.

3.6.4 CONTROL ACTION

Control action may be triggered by transient overpower, excess coolant exit temperatures, loss of coolant flow or fuel failure. A table of reactivity vs. time is triggered by one of the specified trigger conditions being reached. The same input tables may be used to supply voiding and/or fuel failure reactivity as an alternate to using the built in feedback models.

3.6.5 INITIATING REACTIVITY

Values of reactivity vs. time may be input to the code and used directly in transient power calculations.

3.6.6 MIXING OF REACTIVITY TABLES

All of the non-temperature dependent feedback reactivities are combined in a single table of reactivity vs. time. The table consists of a number of points in time at which reactivity values are given. Linear interpolation is used to determine reactivity at times between the given points. The table is updated each time a new feedback mechanism is triggered. The main steps in updating the table are:

1. determine the number of new break points to add to the reactivity table,

2. adjust the subscripts on old break points following the new data, starting from the last point and moving toward the first,
3. insert new table values into the old table at the proper location.

A subroutine, MIXING, performs these operations. In addition, when time values for 40 points in the table have been exceeded by the elapsed problem time, these points are edited and the reactivity table is reindexed to minimize storage requirements for the table.

4.0 INPUT DESCRIPTION

Input to FREADM-1 is processed using a generalized data loading routine, DTA.⁽¹⁰⁾ Three separate calls to DTA are made in FREADM-1. The first call loads blank common with geometry information and data required for coupled kinetics and heat transfer calculations. Much of the data in this call is optional input. The second call to DTA loads labeled common with information used for triggering accident initiating and propagating events. All of the input in this call is optional. The third call to DTA loads labeled common with information used in the primary loop flow and core voiding module. This call is made only when the option to use this module is selected. A summary description of DTA is given in Section 4.1.

4.1 DETAILS OF DTA

4.1.1 PURPOSE

DTA is a Fortran IV compatible subroutine which reads and loads numeric and Hollerith (BCD) data punched "free style" (not bound by specific columns) on an 80-column card. The data consisting of single values, elements of arrays, or whole arrays may be identified symbolically in the same "free style" manner.

4.1.2 RESTRICTIONS

Errors and error exits: See error table at end.

4.1.3 DESCRIPTION OF INPUT

1. Symbol

The data identifying symbol may consist of from one to six alphabetic and/or numeric characters. The first character must be a letter of the alphabet.

2. Indexing

The symbol's index must be contained within parenthesis. The left parenthesis must not be separated from the symbol by blanks or unidentified characters. Indices within the parentheses must be separated by blanks or commas. No more than three indices should be used. Decimal points, plus, or minus signs are not permitted. When loading arrays with more than one index, the first index changes most rapidly.

3. Skipping

Locations may be skipped during loading by immediately following the symbol / by the number of integer locations to be skipped. Decimal points, plus, or minus signs should not be used. The / should be preceded by a blank or comma or undefined character unless it is the first item on a card.

4. Repeating

A given value may be loaded into n consecutive locations by following the value by one or more blanks then the symbol * immediately followed by n, the number of times to store the value. Decimal points, plus, or minus signs should not be used after the asterisk.

5. Input Values

The distinction between integers and floating point values is made by the programmer when he prepares the symbol table. The person preparing data has no control over this area other than his choice of identifying symbols with appropriate indexing. Under normal circumstances the program user will never have to concern himself with this distinction. Values to be loaded should be separated by one or more blanks, a comma, or an equal sign. The following examples will illustrate the required form. If commas are punched together or with nothing but blanks between them this implies a field and a zero will be loaded.

<u>Value</u>	<u>Card Form</u>
3.15	3.15
	+3.15
	315.OE-2
	315E-2
	315-2
	315.-2
	.315+1
	+0.315E+1 or 0.315EA01 or .315EA1
	0.315OE1
	+.315E+1

<u>Value</u>	<u>Card Form</u>
-4.7376	-47376-4 -4.7376 -0.47376+1 -473.76E-2 -.47376+1
-1000.0	-1E3 -1.0E+3 or -1.0EA03 or -1.0E3 -1.0+3 -1000 -1000 -1+3

6. Comments

Comments may be entered on cards provided they are enclosed within parentheses. The left parenthesis should be preceded by a blank. The comment must end on each card and the comment can contain other sets of parentheses, i.e., (comment (comment) comment (comment)). Do not put the left parenthesis which denotes the beginning of a comment in column 1 of an input card.

7. Card Termination (\$)

A \$ will terminate the conversion of a card. The use of the \$ sign speeds conversion time when the card being converted has only a few of the usable columns filled with data. The time is saved by not converting many columns on the card that are blank. Do not put the \$ in column 1 of a card.

8. Loading Termination (\$\$)

Data loading will halt and control will be returned to the calling program whenever the symbol \$\$ is encountered within the card columns specified by the calling arguments. Do not start \$\$ in column 1 of a card. The \$\$ must be punched in adjoining columns. The symbol \$\$ is required to terminate each call made to DTA whether or not any input is processed.

9. Error Procedure

In the event of an error, no loading will occur until a new symbol is defined. All of the data will be read, interpreted, and errors flagged (see the DTA error table) until the symbol \$\$ is encountered.

10. Input Edit

DTA output will consist of the input data exactly as read. Cards containing errors will always be printed. If an error is detected, the word ERROR followed by an error number and a card column will immediately follow the printed card on the right. The card column will indicate the point at which DTA detected the error. DTA will continue to scan the card for more errors. Each page of output bears the heading provided by subroutine DTA.

4.1.4 DTA ERROR TABLE

If an error is detected when the parameters are read in, an error message will be printed for each error found.

When errors are detected during normal processing, DTA will stop transferring data and attempt to scan the remainder of the input for more errors. Each card containing an error or errors will be printed showing the error number and column in which it occurred.

Following is the error table.

<u>No.</u>	<u>Error Type</u>
01	Less than 7 parameters received in DTA call.
02	First card column to be interpreted is less than 1.
03	First card column to be interpreted is greater than the last card column to be interpreted.
04	Last card column to be interpreted is greater than 80.
05	Edit option parameter is not: 0, 1 or 2 (N parameter).
06	A last card or filler block was found before a \$\$ card encountered F4TRBK exit.
07	Implied zero field encountered before any symbols.
08	First character of card is not a blank, comma, alphabetic or a left parenthesis signaling the start of a comment.

<u>No.</u>	<u>Error Type</u>
------------	-------------------

09	Repeat field encountered prior to the transfer of any value to repeat.
10	Repeat zero times specified in repeat field.
11	Illegal character in a repeat field.
12	Trying to repeat more than machine size.
13	Skip zero locations specified.
14	Illegal character in a skip field.
15	Trying to skip more than machine size.
16	Memory wrap around under the skip routine.
17	Illegal character found in symbol name from a card.
18	Symbol name over 6 characters.
19	Symbol name from card does not match any of the symbols of the symbol table.
20	More than 3 subscripts found following a symbol.
21	Illegal character found in a subscript field.
22	Right parenthesis found before any subscripts in a subscript field.
23	Illegal character after right parenthesis of comment or after last character of Hollerith input or after right parenthesis of a subscript.
24	First subscript is zero in a subscript field.
25	Illegal character in a numeric field.
26	Illegal character after the E in a numeric field.
27	Illegal character after mantissa sign.
28	Negative exponent illegal in fixed point field.
29	Illegal character after the exponent sign.
30	Fixed point values exceeds $(2^{*}36)-1$.
31	Input exponent too large.
32	Character to get indicator equals or exceeds the character limit. Error in either a comment or Hollerith field.
33	Transfer address too large.
34	Transfer address too large.
35	Zero Hollerith characters specified.
36	Hollerith field exceeds the character limit.
37	Mantissa exceeds 14 decimal digits.

4.2 INPUT CARD SEQUENCE AND RUNNING OPTIONS

The subroutine CASE⁽¹¹⁾ is used to run series of FREADM-1 problems and control printing of case headings and page numbers. Each case must begin with a CASE card having the following format:

<u>Column</u>	<u>Content</u>
1	)
2-5	FRDM

The last card of a series of FREADM-1 problems must have the following format:

<u>Column</u>	<u>Content</u>
1	)
2-5	LAST

The first data card of a FREADM-1 problem following the case card specifies the users choice of running options. The following choices are possible:

1. Perform coupled reactor kinetics and heat transfer calculations using input tables for flow rates and channel voiding. Data described in Sections 4.3 and 4.4 may be input.
2. Perform coupled reactor kinetics, heat transfer and primary loop flow and core voiding calculations. Data described in Sections 4.3, 4.4 and 4.5 may be input.
3. Perform primary loop flow and core voiding calculations only. Only data described in Section 4.5 may be input.

The user specifies the running option by inputting 1, 2 or 3 in column 10 (I10 format) of the option card.

The option card is followed by the DTA data cards. Termination of input for each DTA call is signaled by a \$\$ sign in the input field. Option 1 requires 2 \$\$ signs, even if no input is specified for the second DTA call. Option 2 requires 3 \$\$ signs and option 3 requires 1 \$\$ sign.

The sequence of input card types for a FREADM-1 problem is:

1. CASE card
2. Option Card
3. DTA input cards
4. CASE or LAST card.

4.2.1 CONTROL CARDS REQUIRED FOR GE-635 OPERATION

The following control cards precede the first)CASE card for normal operation

1	8	16
\$	IDENT	AXXX, YYY SVL, FRDM1
		(XXX = User Number YYY = User's initials)
\$	SELECT	FRDM1
\$	INCODE	IBMF

The following control card follows the)LAST card

1	8	16
\$	ENDJOB	

4.3 DTA INPUT NAMES AND DEFINITIONS - FIRST DTA CALL

Input processed by the first DTA call is used to perform coupled heat transfer and point kinetics calculations. Included are core and fuel pin geometry descriptions, material properties, coolant conditions (flow and inlet temperature), neutronics data and time step control parameters. The column to the right of the variable name contains an I if input is in fixed point (integer) format, and an F if input is in floating point (real) format. If running option 3 is selected, input from this section must be omitted and no \$\$ symbol is required for this section.

4.3.1 CORE GEOMETRY

The core is divided conceptually into a number of coaxial regions. Each region may contain one or more bundle types. Each bundle type is assigned to one region only.

NRR	I	The number of core regions (≤ 12)
RR(I), I=1, NRR	F	The outer radius of each core region, beginning with the center region (ft.).
NBT	I	The total number of bundle types in the problem (≤ 12 and $\geq$ NRR)
KRB(I), I=1, NBT	I	The radial region assigned to each bundle type.
CH	F	Core Height (Heat transfer calculations are done for the core only) (ft.).

4.3.2 FUEL PIN GEOMETRY

For heat transfer calculations, the fuel pin is divided into a number of uniform axial sections over the core height. Each axial section contains a central void region, a number of radial fuel nodes of uniform radial increment, a clad node and a coolant node. Fuel pin geometry is assumed constant for the purpose of heat transfer calculations.

NAX	I	The number of uniform axial sections used for heat transfer calculations (the length of an axial section = CH/NAX) (≤ 9)
NRN	I	The number of radial fuel nodes (spaced uniformly) (≤ 10)
RV	F	Radius of the central void region (ft.).
RF	F	Outer radius of the fuel region (ft.)
CT	F	Thickness of the clad region (ft.)
PD	F	Pitch to diameter ratio of fuel pins (assumes triangular pitch to compute outer radius of equivalent one rod cell.

4.3.3 MATERIAL PROPERTIES

Temperature dependent fuel conductivity and specific heat may be input in tabular form. Clad and coolant properties, gap and film coefficients are assumed constant through the calculation except that heat transfer to coolant is stopped upon void initiation in a given bundle type.

KPRP = 0	I	Fuel properties are constant.
= 1		Fuel properties are temperature dependent. (Affects calculation only. Tabular input required for either option).
RHOF	F	Fuel Density (lb./ft ³)
QHF	F	Fuel Heat of fusion (BTU/lb.)
TMELT	F	Fuel melting temperature (°F)
NCF	I	Number of fuel heat capacity tables (≤ 3)
NCL	I	Number of heat capacity values per table (≤ 10)
FCT(I,J) } I=1, NCL	F	Heat capacity values (BTU/lb.-°F)
TFC(I,J) } J=1, NCF	F	Corresponding temperature values (°F)

Note: If NCL (or NKL) < 10, rewrite FCT (I,J) = and TFC (I,J) = (or FKT (I,J) = and TFK (I,J) =) for each new value of J. Values are stored as (10, 3) arrays.

KCF (I) I=1, NBT	I	Heat capacity table assigned to bundle type I ($\leq$ NCF)
NKF	I	Number of fuel conductivity Tables (≤ 3)
NKL	I	Number of conductivity values per table (≤ 10)
FKT (I,J) } I=1, NKL	F	Conductivity values (BTU/sec-ft-°F)
TFK (I,J) } J=1, NKF	F	Corresponding temperature values (°F)

KKF (I) I=1, NBT	I	Conductivity table assigned to bundle type I ($\leq$ NKF).
RHOC	F	Clad density (lb./ft. ³)
CC	F	Clad heat capacity (BTU/lb.-°F)
CK	F	Clad thermal conductivity (BTU/sec.-ft. - °F)
RHON	F	Coolant density (lb./ft. ³)
SC	F	Coolant heat capacity (BTU/lb. - °F)
SK	F	Coolant thermal conductivity (BTU/sec - ft. - °F)
GC	F	Gap coefficient, fuel to clad (BTU/sec.-ft. ² - °F)
FLM	F	Film coefficient, clad to coolant (BTU/sec. - ft. ² -°F)

4.3.4 COOLANT INLET CONDITIONS

Coolant velocity and inlet temperature vs. time may be specified for each bundle type in tabular form. Steady state heat transfer calculations use the first values on the tables specified for the given bundle type.

NWT	I	Number of flow tables input (≤ 12)
NWL	I	Length of flow tables (≤ 10)
VT (I,J) } I=1, NWL J=1, NWT	F	Coolant velocity values (ft./sec.)
TVT (I,J)	F	Corresponding time values (sec.)

NOTE: Flow tables are used only with running option 1 when loop flow calculations are not done.

KWB(I) I=1, NBT	I	Flow table assigned to bundle type I ($\leq$ NWT).
NIT	I	Number of inlet coolant temperature tables input (≤ 3).
NIL	I	Length of inlet coolant temperature tables (≤ 10)
THI (I,J) } I=1, NIL J=1, NIT	F	Inlet temperature values ($^{\circ}$ F)
TTI (I,J)	F	Corresponding time values (sec.)
KIT (I) I=1, NBT	I	Inlet temperature table assigned to bundle type I ($\leq$ NIT)

NOTE: Two dimensional arrays stored as (10,12) and (10,3) (see note section 4.1.3)

4.3.5 POWER AND KINETICS

The average power density in the core is due to prompt fission energy and delayed fission energy (fission product decay). The power distribution is assumed to remain constant through the calculation. Heat may be generated either in the fuel or in the clad.

PO (P"ZERO")	F	Initial Core Average Power density (BTU/FT ³ -Sec.)
FPFPD	F	Fraction of power due to fission product decay at steady state.
Al	F	Conversion factor from relative neutron density ₃ to power density (BTU/FT ³ -Sec.) (=PO x (1-FPFPD))
PPF(I,J) I=1, NAX J=1, NBT	F	Power Peaking Factors for each Axial section of each bundle type.
FHF	F	Fraction of heat generated in the fuel (remainder assumed generated in clad)
NDG	I	Number of decay groups used to compute delayed power (≤ 5)
ALPH (I) } I=1, NDG } for NDG > 0	F	Fraction of fission energy stored in Group I (fission product decay)
GAMA (I) }	F	Group decay constant (sec ⁻¹) (Not required for NDG = 0)
NPG	I	Number of delayed neutron precursor groups (≤ 6)

$B(I)$ } $I=1, \text{ NPG}$
 } for $\text{NPG} > 0$
 $DC(I)$

PNL

$ADOP(I, J)$ $I=1, \text{ NAX}$
 $J=1, \text{ NBT}$

VDOFF

F Effective delayed neutron fraction for delay Group I.

F Decay constant for delay Group I

F Prompt Neutron Lifetime (sec.)

F Doppler coefficient ($T \frac{dk}{dT}$) for axial section I, bundle type J. Values include volume and importance weighting.

$$\Delta k_{DOP} = \sum_J \sum_I ADOP(I, J) \ln \left(\frac{T(I, J)}{T_o(I, J)} \right)$$

where: $T(I, J)$ is local average fuel temperature ($^{\circ}\text{R}$)

$T_o(I, J)$ is starting value of $T(I, J)$

Note: $\sum_J \sum_I ADOP(I, J) =$

Isothermal ($T \frac{dk}{dT}$)

F Doppler coefficients for a given bundle type are multiplied by VDOFF when coolant voiding is triggered in that bundle type.

4.3.6 TABLES FOR REACTIVITY CALCULATIONS

Tables for reactivity calculations are stored as two-dimensional arrays. Care should be taken in loading data not to exceed the maximum permitted values per table and to specify a change in the second index when using less than the maximum allowable input with more than one table of a given type. The only input which is required is that which is used based on the trigger logic (Section 4.4).

REACTIVITY TABLES

NTI	I	Number of input reactivity vs time tables (≤ 5)
		Note: These tables may be triggered to simulate reactivity effects of scram, voiding, fuel failure etc.
NTL	I	Number of reactivity values per table (≤ 10)
DKT (I,J) } I=1, NTL	F	Reactivity values (Δk)
TDK (I,J) } J=1, NTI	F	Corresponding time values (sec.)
KSCR	I	Reactivity table used to simulate scram ($\leq$ NTI).
KR1	I	Reactivity table which may be triggered on elapsed time ($\leq$ NTI)
KR2(I) } I=1, NBT	I	Reactivity table triggered by elapsed time from fuel failure in bundle type I.
KR3(I) }	I	Reactivity table triggered by elapsed time from void initiation in bundle type I.
		Note: If these values are omitted, code assumes 0, and associated trigger values (Sec.4.4.1 - 4.4.2) are not required.
NTB	I	Number of reactivity values input to table used to drive kinetics (≤ 300)(User may specify an initial reactivity insertion using this table.)

RTB(I)	}	I=1, NTB	F	Reactivity values input to kinetics calculation (Δk)
TTB(I)			F	Corresponding elapsed time (sec.)

NOTE: Reactivity due to triggered events is combined using this table.

FUEL WORTH TABLES

Input from this section is required if $KFM(I) > 0$.

NWC

I Number of tables of fuel worth vs. axial displacement input (≤ 12)

Note: The reactivity effect of fuel motion is computed using these tables. The axial displacement of the mid-point of each axial section at pre-determined time points is used to construct a table of reactivity vs. time. The mass of an axial section is computed in the code and multiplied by the number of pins represented by the given bundle type (KRP(I) Sec. 4.4.5).

NFW

I Number of fuel worth values per table (≤ 12)

AFW(I,J) } I=1, NFW
 J=1, NWC
 for
DFW(I,J) } NWC > 0

F Reactivity worth of fuel at axial locations (include all fuel represented by a given bundle type) ($\Delta k/lb.$)

F Corresponding axial positions measured from core inlet (ft.)
Note: If fuel moves outside the range of the assigned worth table an error exit will result.

KFW(I) I=1, NBT

I Fuel worth table assigned to bundle Type I (Not required if fuel failure calculations are omitted by setting $KFM(I)=0$ (sec. 4.4.5))

FFTOP

F Option for selecting heat transfer calculations following fuel failure.
Continue heat transfer calculations
Continue heat transfer calculations with no heat transfer to coolant in failed bundle type (simulates vapor blanketing of pin at failure e.g. fission gas release)
Discontinue heat transfer for the failed bundle, using Doppler temperature computed in kinetics module to update average fuel temperature.

= 0.0

= 1.0

= -1.0

VOIDING TABLES

Input from this section may be omitted if KVD(I) = 0 (or omitted).

NVT		I	Number of tables of void location vs. time input (≤ 3)
NVL		I	Number of time points per table (≤ 10)
TUD(I,J)	I=1, NVL J=1, NVT for NVT > 0	F	Input values of displacement of upper void-coolant interface from core mid-plane. (ft.)
TLD(I,J)		F	Input values of displacement of lower void-coolant interface. (ft.)
TVD(I,J)		F	Corresponding time points (sec)
KVD(I)		I	Voiding table assigned to bundle type I ($\leq$ NVT)

Note: negative values mean interface is below core mid-plane.

Note: If KVD(I) is omitted, code assumes 0 and associated trigger values are not required. (Sec. 4.4.4).

4.3.7 TIME STEP CONTROL AND EDIT SPECIFICATIONS

The sequence of calculations may be controlled through the use of time step controls in the kinetics calculation. The maximum kinetics time step before and after voiding initiates may be input to insure proper sequencing of accident propagating events. A problem may be terminated upon reaching a specified elapsed time, a specified maximum number of kinetics time steps, or a specified maximum number of heat transfer calculations. The detail of the printed temperature output may be controlled by the user.

ETLIM	F	Elapsed time in the calculation which will cause termination (sec.) A final heat transfer calculation will be performed.
NMK	I	The maximum number of nuclear kinetics time steps desired to terminate the problem.
NHT	I	The maximum number of heat transfer calculations desired to terminate the problem.
NSS	I	The maximum number of iterations desired in the steady state temperature calculation when temperature dependent fuel properties are used (KPRP=1). (See Sec. 3.2.1)
EPS	F	Desired convergence of the steady state temperature (°F). i.e. maximum difference in nodal fuel temperature between successive iterations. (The code will print a warning message and continue if convergence criteria is not met after NSS iterations).
TMP(I,J,K) I=1, NRN + 2 J=1, NAX K=1, NBT	I	Initial temperature guess to obtain fuel properties for steady state temperature calculations. Convergence to within 1°F using temperature dependent fuel properties and NSS = 5 has been obtained with smoothly varying fuel properties

DTKMX	F	Maximum kinetics time step prior to void initiation in a specified bundle type. This may be used to insure proper sequencing of voiding triggers. (sec.) Must be input and > 0.0 .
NHF	I	Maximum number of times kinetics time step may be halved before continuing. (See sec. 3.3.4)
NKS	I	Maximum number of kinetics time steps which may be taken between heat transfer calculations prior to void initiation in a specified bundle type. (MBVOID).
TMAX	F	The minimum change in average fuel temperature which will cause a new heat transfer calculation. Note: Large values of NKS and TMAX may be used to omit heat transfer calculations. For normal values, TMAX will override NKS when fuel temperature is rapidly increasing.
MKS	I	The maximum number of kinetics time steps per heat transfer after void initiation in a specified bundle type (MBVOID). If voiding is to be initiated by monitoring the coolant temperature (See 4.4.4), the user may wish to compute the coolant temperature more frequently prior to voiding than after voiding has been initiated. By inputting NKS=1 with large values of MKS and TMAX, the user could omit heat transfer calculations after void initiation in a specified bundle type. Doppler feedback would still be based on the average fuel temperature calculation in the kinetics module.

MBVOID

I The frequency of computing heat transfer will be changed to MKS when voiding is initiated in this bundle type. Must be input ≥ 1 .

E1

F Maximum ratio of final to initial neutron density per kinetics time step. (Initial to final for negative periods). Time step is halved and calculation repeated if this value is exceeded. (1.2 has given good results).

E2

F Maximum allowable change in fuel average temperature at any axial section over a kinetics time step. ($^{\circ}\text{F}$) (Suggest 50°F).

E3

F Maximum allowable total reactivity change per time step ($\$$). The numerical scheme uses a constant value over the time step with Doppler Δk taken at the beginning of the time step and all other Δk taken at the middle of the time step. A value of 0.1 has given good results.

KEDIT

I Controls the printing of the temperatures.

=0

Initial and final temperature distributions are printed with average fuel temperatures and coolant outlet temperatures.

= -1

Initial and final temperature distributions are printed plus average fuel temperatures and coolant outlet temperatures for each heat transfer time step.

= -2

Same as for KEDIT= -1 plus do heat transfer and edit temperature distributions, average fuel temperatures and coolant outlet temperatures when any trigger activity is initiated.

= N

Temperature distribution,
average fuel temperatures
and coolant outlet temperatures
are printed every Nth heat
transfer time step.

This concludes the data in the first DTA call. Termination of this
section of input with a \$\$ following the last input is required.

4.4 DTA INPUT NAMES AND DEFINITIONS - SECOND DTA CALL

Data for triggering accident initiating and propagating events is included in this call with fuel failure and voiding information. In general, if one trigger in a set is to be tested, all triggers will be tested. Hence, care should be taken to include values for triggers not used which will not cause spurious reactivity insertion. Trigger logic is summarized in Section 3.1. Input processed by this call is expected for running options 1 and 2. A \$\$ symbol is required when running these options, even if no data is input from this section.

4.4.1 FUEL FAILURE DATA

Specification of fuel failure modes and input required for fuel motion calculations is included in this section.

KFM(I) I=1, NBT

I Assigns a failure mode to bundle type I. (See Section 3.4 for description of available modes.) If KFM(I) is omitted, (for all I) none of the input in this section is required. KFM(I) = 0 means that failure triggers for bundle type I will be required. (≤ 4)

KRP(I) I=1, NBT

I Number of pins represented by bundle type I. (Appears as a multiplier when computing reactivity effect of fuel pin motion). Not required if KFM(I) = 0.

KFN(I) I=1, NBT

I Radial node for which a failure temperature (trigger) ($\leq$ NRN + 2) is specified for bundle type I.

Mode 1 Data (required only for KFM(I)₁ = 1)

Motion of a single axial section under the influence of user specified driving forces is treated.

FDRVF	F	Constant driving force applied to failed node due to coolant flow (lbf). Used only if failure precedes voiding.
FDRVG	F	Gravitational force applied to failed node (may be net force due to gravity and "other") (lbf). Used for all node 1 failures.
FDRVI	F	Constant force used to simulate fuel coolant interaction (lbf). Applied only if voiding is in conjunction with fuel failure.

Mode 2 Data - (Required only for KFM(I) = 2)

Fuel is assumed to leave the clad at the point of failure and grow axially outside the clad. User specifies the end points of the redistributed fuel column, the time increment for redistribution and the axial sections involved in the redistribution.

FFOPT2	F	Option to specify axial sections involved in the fuel redistribution.
= 0.0		All fuel in the pin is redistributed.
= 1.0		Fuel above and including axial section at which failure occurs is involved in redistribution.
D1(NBT)	F	Distance above failure of the final upper endpoint of the redistributed fuel column (ft.).
D2(NBT)	F	Distance below the failure of the final lower endpoint of the redistributed fuel column (ft.). (A positive value means the final lower endpoint is below the original failure point).
TAU2(NBT)	F	Time required for redistribution. (sec.).

Mode 3 Data - (Required only for KFM(I) = 3).

Collapse of core above and including failed axial section under a constant downward acceleration is assumed. User specifies fraction of gravitational acceleration and endpoint of travel.

FGRAV		F	Fraction of gravitational acceleration used to drive fuel.
ICASE(I)	I=1, NBT	I	Option for determining stopping point in motion of failed fuel column.
	= 1		Fuel column motion stopped at core boundary.
	= 2		Fuel column motion continues through core boundary.

Mode 4 Data - (Required only if KFM(I) = 4)

The user specifies the endpoints for a uniform axial compaction of the fuel and the time increment over which the redistribution takes place by bundle type. Fuel column endpoints are reached either at constant velocity at constant acceleration.

ZBOT(I)	I=1, NBT	F	Final fuel column lower endpoint, measured from core inlet (ft.) (Bundle Type I)
ZTOP(I)	I=1, NBT	F	Final fuel column upper endpoint measured from core inlet (ft.) (Bundle type I.)
TAU4(I)	I=1, NBT	F	Time required for redistribution (sec.) (Bundle type I)
JCASE(I)	I=1, NBT	I	Option for moving fuel column endpoints at constant velocity or constant acceleration.
	=1		Constant velocity option.
	=2		Constant acceleration option.

4.4.2 FUEL FAILURE TRIGGERS

Input is required for this section whenever a failure mode KFM(I) is specified for a bundle type. Trigger levels are input by bundle type. All triggers are checked for a given bundle type if KFM(I) > 0. Triggering of fuel failure requires input axial fuel worth tables (NWC > 0) (Sec. 4.3.5).

TF1(I)	I=1, NBT	F	Fuel failure will be triggered when the elapsed time reaches this value. (sec.) Time step control insures that failure will occur at the exact specified elapsed time. Code assumes 0.0 if this value is omitted.
TF2(I)	I=1, NBT	F	Fuel failure will be triggered when the average fuel temperature in an axial section first reaches or exceeds this value (°F). This trigger is checked against the local Doppler temperature computed in the kinetics module.
TF3(I)	I=1, NBT	F	Fuel failure will be triggered when a specified radial node (KFN(I)) first reaches or exceeds this value (°F). All axial sections of bundle type I are checked. This trigger may be used to trigger failure on a predetermined melt fraction, for example by setting TF3(I)=TMELT (Sec. 4.3.3) and KFN(I) = node whose outer radius includes the desired melt fraction.
TF4(I)	I=1, NBT	F	Fuel failure will be triggered when clad temperature first reaches or exceeds this value (°F).
TFP(I,J)	I=1, NBT J=1, NBT	F	Time for fuel failure to propagate from bundle type J to bundle type I.

4.4.3 VOIDING DATA

Data required for computing reactivity due to coolant voiding is included in this section. The user supplies the maximum central void worth reactivity for the core and the corresponding axial and radial coordinates. If $KVD(I) = 0$ for $1 \leq I \leq NBT$, then none of the input in this section is required.

WM		F	Maximum reactivity effect of coolant voiding (Δk).
RM		F	Corresponding radius of central void region (ft.).
ZM		F	Corresponding axial location of central void region measured from core midplane (ft.).
FRB(I)	I=1, NBT	F	Fraction of the core region represented by bundle type I. (Include control rod locations etc. as part of region.)
KVN(I)	I=1, NBT	I	Radial Node for which a voiding trigger temperature is specified in bundle type I. ($\leq NRN + 2$).

4.4.4 VOIDING TRIGGERS

When the loop flow module (VOIDUM) is not used (running option 1) coolant voiding can be simulated using input tables of void displacement vs. time. Trigger levels are input by bundle type. Input from this section is required whenever $KVD(I) > 0$ (Sec. 4.3.5).

TV1(I)	I=1, NBT	F	Voiding is initiated in bundle type I when elapsed time reaches this value (sec.)
TV2(I)	I=1, NBT	F	Voiding is initiated in bundle type I when clad temperature first reaches or exceeds this value (°F).
TV3(I)	I=1, NBT	F	Voiding is initiated in bundle type I when coolant temperature first reaches or exceeds this value (°F).
TV4(I)	I=1, NBT	F	Voiding is initiated in bundle type I when temperature at a specified node (KVN(I)) reaches or exceeds this value (°F).
TV5(I)	I=1, NBT	F	Voiding is initiated in bundle type I when the average fuel temperature of an axial section first reaches or exceeds this value (°F).
TVP(I,J)	I=1, NBT J=1, NBT	F	Voiding is initiated in bundle type I when the time since void initiation in bundle type J reaches or exceeds this value (sec.) If $KVD(I) > 0$ and these values are omitted, propagation of voiding will be instantaneous.
MFLVD(I)	I=1, NBT = 0 = 1	I	Option to trigger voiding when fuel failure occurs. Do not trigger voiding. Trigger voiding. If the VOIDUM module is run, an input pressure in the coolant will be assumed at the point of failure. If the VOIDUM routine is not run, voiding is from input tables specified for bundle type I.

4.4.5 REACTIVITY INSERTION TRIGGERS

Input is expected only for non-zero values of KR1, KR2(I) and/or KR3(I). Other trigger levels will not be checked. If KR1, KR2(I) and/or KR3(I) > 0 then NTI (Sec. 4.3.6) must be > 0.

TR1	F	Reactivity insertion will be from input table number KR1 when elapsed time reaches this value. (sec.) (Only if KR1 > 0).
TR2(I) I=1, NBT	F	Reactivity insertion will be from input table number KR2(I) when time after fuel failure in bundle type I reaches or exceeds this value (sec.). This trigger may be used to simulate instrumentation and control system response to assumed failures or as an alternate means of inserting reactivity due to fuel motion (See Sec. 4.3.5).
TR3(I) I=1, NBT	F	Reactivity insertion will be from input table number KR3(I) when time after void initiation in bundle type I reaches or exceeds this value (sec.). May be used to simulate instrumentation and control response to voiding or as an alternate means of inserting reactivity due to voiding (See Sec. 4.3.5).

4.4.6 SCRAM TRIGGERS

All scram trigger variables are monitored when KSCR > 0 (Sec. 4.3.6). Scram reactivity is input using table number KSCR. (Sec. 4.3.6). If KSCR > 0 then NTI must be > 0 (Sec. 4.3.6).

TS1		F	Scram is triggered when elapsed time reaches this value (sec.) (Use large value if no scram desired from this trigger and KSCR > 0.)
TS2		F	Scram is triggered when the average power density first reaches or exceeds this value (BTU/sec-ft ³). (Use large value if no scram desired from this trigger and KSCR > 0.)
TS3		F	Scram is triggered if the reactor period is positive and less than this value (sec.). (Use 0.0 if period scram is not desired and KSCR > 0).
TS4		F	Scram is triggered if the rate of power increase exceeds this value (BTU/sec-ft ³). (Use large value if no scram desired from this trigger and KSCR > 0.)
TS5(I)	I=1, NBT	F	Scram is triggered when the time since void initiation in bundle type I reaches or exceeds this value. (sec.).
TS6(I)	I=1, NBT	F	Scram is triggered when the time since fuel failure in bundle type I reaches or exceeds this value (sec.).
TS7(I)	I=1, NBT	F	Scram is triggered when coolant velocity in bundle type I is less than this value (ft./sec.) (Input 0.0 if no coolant velocity scram is desired and KSCR > 0.)
TS8(I)	I=1, NBT	F	Scram is triggered when coolant exit temperature in bundle type I exceeds this value (°F). (Core exit).

4.4.7 FLOW BLOCKAGE DATA

Full or partial flow blockage in a bundle type may be simulated using the input in this section. Blockage may be triggered due to computed variables either in the blocked bundle or another assigned bundle (propagation) reaching trigger conditions. Table values of coolant velocity are multiplied by a constant following blockage.

Data for Blockage

KFBI(I) I=1, NBT = 0 (or omitted) = 1	I	Option to include flow blockage. No flow blockage calculations are done for bundle type I (code continues to use table values of velocity vs. time.) Flow blockage triggers are input for bundle type I.
FLBLK(I) I=1, NBT	F	Coolant velocity multiplier applied to bundle type I after blockage.
KFBPP(I) I=1, NBT	I	Bundle type from which flow blockage in bundle type I may be triggered. If 0 (or omitted), no propagation triggers are required.
KFB(I) I=1, NBT	I	Radial node in bundle type I for which a flow blockage trigger temperature is specified.

Flow Blockage Triggers

Values are expected for all of the variables in this section when KFBI(I) > 0.

TFB1(I) I=1, NBT	F	Flow blockage is triggered in bundle type I when elapsed time from start of transient reaches this value. (sec.).
TFB2(I) I=1, NBT	F	Flow blockage is triggered in bundle type I when the average fuel temperature in an axial section reaches or exceeds this value. (°F).

TFB3(I) I=1, NBT	F	Flow blockage is triggered in bundle type I when the clad temperature reaches or exceeds this value. (°F).
TFB4(I) I=1, NBT	F	Flow blockage is triggered in bundle type I when the temperature of radial node KFB(I) reaches or exceeds this value. (°F).

Flow Blockage Propagation Triggers

Blockage of flow in a given bundle type may be triggered by conditions in another specified bundle type. Input from this section is required whenever KFBPP(I) > 0.

TFBP1(I) I=1, NBT	F	Flow blockage will be triggered in bundle type I when the elapsed time from blockage in bundle type KFBPP(I) reaches this value. (sec.)
TFBP2(I) I=1, NBT	F	Flow blockage will be triggered in bundle type I at a specified time interval after the average fuel temperature in bundle type KFBPP(I) reaches or exceeds this value. (°F).
TIMP2(I) I=1, NBT	F	Time interval corresponding to TFBP2(I). (Sec.).
TFBP3(I) I=1, NBT	F	Flow blockage will be triggered in bundle type I a specified time interval after the clad temperature in bundle type KFBPP(I) reaches or exceeds this value. (°F).
TIMP3(I) I=1, NBT	F	Time interval corresponding to TFBP3(I). (sec.)
TFBP4(I) I=1, NBT	F	Flow blockage will be triggered in bundle type I a specified time interval after the temperature of radial node KFB(I) in bundle type KFBPP(I) reaches or exceeds this value. (°F).
TIMP4(I) I=1, NBT	F	Time interval corresponding to TFBP4(I). (sec.)

4.5 DTA INPUT NAMES AND DEFINITIONS - THIRD DTA CALL

Input in this section is required whenever the value of KVOID (running option) = 2 or 3 (primary loop flow and channel voiding model used). If running option 1, this call to DTA is not used and no \$\$ sign is required to terminate data reading.

4.5.1 SYSTEM GEOMETRY

Input in this section is used to describe the primary loop coolant flow areas and path lengths and the position (vertical height) of the major loop components. Two independent loops may be used to simulate a multi-loop system. The system configuration is shown in Figure 3.5.1a. Input flow areas are shown in Figure 3.5.1b. Input flow path lengths are shown in Figure 3.5.1c.

CORE AND BLANKET GEOMETRY

Heat transfer calculations are performed for the core region only in FREADM. The effects of the axial and radial blankets or the primary loop coolant flow are included in the VOIDUM calculation.

NBT	I	Number of bundle types (≤ 12). (Required only when running option 3).
NAX	I	Number of axial fuel pin segments in core (≤ 9). (Required only when running option 3).
NRN	I	Number of radial fuel nodes in pin (≤ 10). (Required only when running option 3).
NRB	I	Number of radial blankets (≤ 3).

CH	F	Core height (ft.) (Required only when running option 3).
DH	F	Hydraulic diameter of the flow passages in the core coolant channels (ft.). (All core flow passages are assumed to have the same hydraulic diameter.)
AC(I), I=1, NBT	F	Total Cross sectional flow area by bundle type (ft. ²) Include flow area for all bundles represented by bundle type I.
ABL(I), I=1, NRB	F	Total cross sectional flow area by blanket region (ft. ²)
XBLBOT	F	Length of lower axial blanket (ft.)
XBLTOP	F	Length of upper axial blanket (ft.)

LOOP GEOMETRY

AP	F	Cross Sectional flow area of core inlet and outlet plenums (ft. ²)
XLP	F	Height of IHX inlet piping above reactor coolant channel outlet (ft.)
ZGAS2I	F	Height of reactor cover gas surface above IHX inlet piping (ft.)
AHX1IN	F	Cross sectional flow area of piping between reactor outlet plenum and IHX number 1. (ft. ²)
AHX2IN	F	Cross sectional flow area of piping between reactor outlet plenum and IHX number 2 (ft. ²)

ZHXIN	F	Length of piping between reactor outlet plenum and IHX (ft.) (assumed the same for each loop).
AGAS31	F	Area of gas surface in IHX number 1 (ft. ²).
AGAS32	F	Area of gas surface in IHX number 2 (ft. ²).
ZHX1I	F	Initial height of gas surface above IHX inlet (ft.).
XHX	F	Height from IHX inlet to IHX outlet piping (ft.).
AHX10T	F	Cross sectional flow area of outlet piping for IHX number 1 (ft. ²).
AHX20T	F	Cross sectional flow area of outlet piping for IHX number 2 (ft. ²).
ZHXOT	F	Length of IHX outlet piping (ft.) (Assumed the same for each loop).
XHXOT	F	Vertical height of IHX outlet piping (ft.).
AGAS1	F	Area of tank ₂ cover gas surface (ft. ²).
XSHXI	F	Initial height of pool cover gas surface above IHX outlet (ft.).
AP1	F	Cross sectional flow area of piping between pump number 1 and reactor vessel inlet (ft. ²).
AP2	F	Cross sectional flow area of piping between pump number 2 and reactor vessel inlet (ft. ²).
XPP	F	Length of piping from pump to reactor vessel (ft.). (Assumed the same for each loop.)

XP

F Height of pump outlet above
reactor vessel inlet (ft.).

XV

F Height of reactor coolant channel
inlets above reactor vessel
inlet (ft.).COVER GAS VOLUMES

VGAS1I

F Initial volume of pool cover
gas (ft.³).

VGAS2I

F Initial volume of cover₅ gas
in reactor vessel (ft.³).

VGS31I

F Initial volume of₃gas above
IHx number 1 (ft.³).

VGS32I

F Initial volume of₃gas above
IHx number 2 (ft.³).

4.5.2 FLOW RATES AND PRESSURE DROPS

The user specifies initial pressure drops for the loop components and initial coolant velocities for the core and blanket assemblies. The code computes coefficients for correlating pressure drop with coolant flow rate in the loop components, and orifice coefficients to equalize the pressure drop across the core coolant channels.

CORE AND BLANKETS

Frictional pressure drop across the reactor is computed based on input velocities and fuel rod geometry. Factors and coefficients to account for outlet losses, orificing and fuel rod spacers may be input. The code computes orificing coefficients for each bundle type to give uniform outlet pressures.

VO(I), I=1, NBT	F	Initial coolant velocities by bundle type (ft./sec.)
VS(I), I=1, NBT	F	Coolant velocities at normal operating conditions by bundle type (ft./sec.)
VOBL(I), I=1, NRB	F	Initial coolant velocities by radial blanket region (ft./sec.).
VSBL(I), I=1, NRB	F	Coolant velocities in radial blanket regions at normal operating conditions (ft./sec.).
COUTI	F	Initial outlet loss coefficient for core coolant channels. (Usually equal to 1.0).

FP	F	Ratio of pressure drop with fuel rod spacers to pressure drop computed neglecting fuel rod spacers. (Code computes core pressure drop based on one fuel rod flow channel geometry and multiplies by FP to account for losses due to fuel rod spacers.)
FR	F	Fraction of core pressure drop at inlet orifice in bundle type number 1. (Used to compute orificing coefficients for other bundle types).

PIPING

DPHXII	F	Initial pressure drop through IHX inlet piping (PSI).
DPHXOI	F	Initial pressure drop through IHX outlet piping (PSI).
DPPPI	F	Initial pressure drop through pipe connecting pump to reactor vessel (PSI).

PUMP CHARACTERISTIC

A quadratic pump characteristic is assumed with the design point, stopped flow and zero head points defining the curve. (Refer to Figure 3.5.3).

FD	F	Multiple of design flow which pump delivers at zero pressure increment.
HS	F	Multiple of design pressure head which pump delivers at stopped flow.

4.5.3 GAS AND COOLANT PROPERTIES

Coolant flow and voiding calculations are performed assuming incompressible fluid flow. The density of the liquid coolant is assumed constant throughout the calculation. The user may elect to specify the time dependence of sodium vapor pressure following voiding initiation by inputting coefficients of a quadratic function.

LIQUID COOLANT

RHON	F	Coolant density (lbm/ft. ³). (input only when running option 3)
XMV	F	Coolant viscosity (lbm/ft.sec.)

COOLANT VAPOR

YA, YB, YC	F	Constant, linear and second order coefficients used to specify void pressure as a function of time following void initiation due to coolant boiling. (Used only if NT2 = 2 (Sec. 4.5.4)). If NT2=1 built in vapor pressure correlation is used.
YD, YE, YF	F	Constant, linear and second order coefficients used to specify void pressure as a function of time following void initiation. Must be input if voiding is to be initiated from fuel pin rupture.

COVER GAS

PGS111	F	Initial pressure of pool cover gas (PSI).
XK1	F	Gas constant of gas above pool. (Pool cover gas pressure is computed using $P/P_o = (V_o/V)\gamma_1$. where $\gamma_1 = XK1$)
XK2	F	Gas constant of gas above core outlet plenum.
XK3	F	Gas constant of gas above IHX.

4.5.4 RUNNING OPTIONS AND TIME STEP CONTROL

DTI	F	Size of initial time step (sec.). (Suggest 10^{-4}).
DELTA	F	Allowable fractional change in velocity per time step for velocities > 1.0 . Allowable incremental change in velocity for velocities ≤ 1.0 (ft./sec.). Time step is halved whenever the projected velocity change over the time step exceeds this value.
DTMIN	F	Minimum allowable time step size (sec.).
JPRNT	I	Number of time steps between print out.
IT1	I	<p>= 1, IHX cover gas volumes are connected.</p> <p>$\neq$ 1, IHX cover gas volumes are not connected.</p>
NT2	I	<p>= 1, Void pressure is computed using built in sodium characteristic and clad temperature at initial void location when voiding is initiated by coolant boiling.</p> <p>= 2, Void pressure as a function of elapsed time from void initiation is computed using coefficients to a quadratic specified by the user (YA, YB and YC) when voiding is initiated by coolant boiling.</p>
ETMAX	F	Elapsed time of transient which will cause termination (to be used only with KVOID =3).
JSMAX	I	Maximum number of VOIDUM time steps in transient (used only if running option 3).

4.5.5 ACCIDENT OPTIONS AND FORCING FUNCTIONSPIPE BREAK

IPB	I	= 0, no pipe break between pump and reactor vessel. = 1, pipe break accident.
XPB	F	Length of pump piping after break (ft.) (Required for IPB = 1)
CP1B	F	Friction loss coefficient in pump piping after pipe break (Usually ≥ 1).

FLOW BLOCKAGES

Blockage of flow at the core inlet or outlet, and/or in the IHX outlet and/or pump piping may be simulated by specifying ramp changes in orificing and local loss coefficients. The user specifies fractional changes in the coefficients and the time increment over which the change takes place. All changes are assumed to initiate at time = 0.0.

ICOR(I), I=1, NBT	I	= 0, no plugging of core inlet for bundle type I. = 1, plugging of core inlet to be simulated for bundle type I.
FOR1	F	Multiplier of orificing coefficient after blockage when simulating core inlet blockage to a bundle (applies only to blocked bundles i.e. ICOR(I)=1) Should be $\gg 1.0$ to simulate total blockage, (suggest $\leq \sim 10,000$).
TOR1	F	Time increment over which orificing, coefficient to blocked bundle is ramped to FOR1 times the initial value for the bundle (sec.) (Starts at time = 0.0).

ICOT(I), I=1, NBT	I	Flag to simulate flow blockage at core outlet.
= 0		No simulation of plugging core outlet for bundle type I.
= 1		Plugging of core outlet to be simulated for bundle type I.
FOR01	F	Multiplier of core outlet local loss coefficient after blockage. Should be $\gg 1.0$ to simulate total blockage. (Required only if $ICOT(I) > 0$ for $1 \leq I \leq NBT$).
TOR01	F	Time increment for ramping core outlet loss coefficient (sec.).
FHX1	F	Multiplier of IHX outlet local loss coefficient to simulate a flow restriction at IHX outlet. Should be 1.0 if no restriction is to be simulated.
THX1	F	Time at which IHX outlet coefficient reaches FHX1 times the initial value. A ramp change in the value of the coefficient is assumed between time 0.0 and THX1.
FPP1	F	Multiplier of local loss coefficient for pump piping to simulate flow restriction in piping. Should be 1.0 if no simulation of piping restriction is desired.
TPP1	F	Time increment for ramping pump piping local loss coefficient to FPP1 times its initial value.

PUMP COASTDOWN

Loss of pumping power may be simulated by a ramp change in the pump pressure rise for a given flow rate.

FP1	F	Fraction of pump pressure rise to which pump ramps down.
TP1	F	Time increment over which pump pressure rise characteristic changes to FP1 times its initial value (starts at time = 0.0).

4.5.6 COOLANT VOIDING

Voiding may be initiated either through coolant boiling occurring at the clad surface or by fuel pin rupture, or it may be forced at a specified time (option 3 only). When running option 2, voiding initiation due to fuel rupture is triggered by triggers input to section 4.4. When simulating fuel pin rupture using running option 3 the user supplies failure criteria and failure axial location.

TRGTME(I), I=1, NBT	F	Elapsed time to initiate voiding in bundle type I (sec). (Used only when running option 3).
ATEMP	F	Voiding will be initiated in a bundle type if the input cladding temperature reaches or exceeds this value (°F). (used only when running option 3).
JB	I	Fuel pin axial section at which voiding is initiated. (Used only when running option 3).
NRUP	I	Radial fuel node the temperature of which is monitored to establish fuel pin rupture. (<12). (Used only when running option 3).
TFRUP	F	If the initial temperature of the NRUP radial fuel node reaches or exceeds this value fuel pin rupture leading to coolant voiding is assumed to occur (°F). (Used only when running option 3).
		Note: for KVOID#3 fuel pin failure is determined by input trigger levels (Sec. 4.4).
FSH	F	Factor which multiplies built in fit to superheat required for boiling (See section 3.5.3.7). May be used to change required superheat to initiate coolant boiling.
XLCV	F	Pump backflow length (ft.). (Distance for backflow to fully close check valve).

4.6 INPUT REDUCTION

In some cases it is not necessary to input all of the data described in Sections 4.1, 4.2, and 4.3. The following options are available.

4.6.1 Scram Calculations

To omit scram calculations, set KSCR=0. Scram triggers (Section 4.2.3) are not required.

4.6.2 Reactivity Insertion Calculations

To omit reactivity insertion calculations, set KR1, KR2(NBT) or KR3(NBT) equal to zero. The corresponding triggers (Section 4.2.2) are not required.

4.6.3 Fuel Failure Calculations

To omit fuel failure calculations when using option 1, set KVD(NBT)=0. Voiding input (Sections 4.2.4 and 4.2.6) is not required.

4.6.4 Voiding Calculations

To omit voiding calculations when using option 1, set KVD(NBT)=0. Voiding input (Sections 4.2.4 and 4.2.6) is not required.

4.6.5 Fission Product Decay Calculations

To omit fission product decay calculations, set NDG=0. Values for ALPH(NDG), GAMA(NDG) and FPFDP are not required.

4.6.6 Flow Blockage

To omit flow blockage set KFBI(NBT) = 0 and KFBPP(I) = 0.

4.7 OUTPUT

Four output sections are used in FREADM-1 problems.

1. DTA input edit
2. kinetics edit
3. temperature edit
4. primary loop flow and core voiding edit.

The DTA input edit prints the DTA input cards and DTA error messages. The kinetics edit provides a compact summary of the nuclear transient and contains messages indicating when accident activities are triggered. The content of these edits is shown in the sample problems.

Steady state and transient temperature distributions are printed in the temperature edit. The user may select to print only average fuel temperatures and coolant outlet temperatures or detailed temperature distributions at each edit, or combinations of detailed and average temperatures. The delayed neutron precursor densities are also printed in this section, normalized to an initial relative neutron density of 1.0. Sample edits are shown in the sample problems. A description of the temperature edit control (KEDIT) is given in Section 4.3.7.

The primary loop flow and voiding edit prints flow rates, pressures, accelerations and void distributions (see Section 4.5.3) every JPRNT VOIDUM time step. The output format is shown in the third sample problem.

4.8 CHECKOUT STATUS

Checkout includes testing the logic of each subroutine prior to insertion into the code, testing of the coupling logic to insure proper flow of logic between subroutines, and testing of the numerical methods against exact analytical methods and/or more detailed numerical calculations. The VOIDUM package was checked out independently prior to coupling with the heat transfer and neutronics. Calculations have been successfully performed using the three available options for selecting calculational modules.

4.8.1 Checkout of Kinetics Package

The point kinetics calculation in FREADM-1 has given good agreement with the following test calculations with the time step determined by the code based on suggested user input values for E1, E2 and E3 (Sec. 4.3.7).

- 1) A FORE II calculation for a slow continuous ramp insertion of reactivity with negligible feedback,
- and,
- 2) Analytical calculations of reactor period following subprompt critical step insertions of reactivity with no feedback.

Reactivity feedback calculations for coolant voiding in the core agree well with reactivity calculations based on static 2-D multi-group synthesis calculations. Extension of the voiding reactivity model to account for voiding of the axial blanket is expected to overpredict the negative effect of blanket voiding (for a typical LMFBR) when using the loop flow calculation. This may be compensated for when using input voiding tables specifying a fictitious displacement vs. time for voiding the axial blanket.

The calculation of average fuel temperature for computing local Doppler reactivity feedback effects was checked out and reported elsewhere⁽⁹⁾. The practical feasibility of taking many kinetics time steps per heat transfer calculation for many problems of interest was shown in this study.

4.8.2 Checkout of Heat Transfer Package

The steady state heat transfer calculation gives correct coolant ΔT and radial fuel ΔT using either constant or variable fuel material properties. Slowly varying fuel properties with no discontinuities are required to converge all steady state temperatures. Variance of less than 1°F in temperature between successive iterations after ~5 iterations is typical.

The fuel radial temperature distribution computed in the steady state calculation was compared with an analytical solution assuming quadratic dependence of the fuel conductivity. For a 0.25 inch O.D. fuel pin operating at ~ 11 kw/ft., the fuel temperature distribution computed by the code using six radial fuel nodes was ~ 200 °F above the analytical estimate. This difference appears to be proportional to the volume fraction of fuel contained in the outer radial fuel node and results from approximations made in the treatment of heat transfer from fuel to clad. A reduction in the fuel clad gap coefficient to compensate for this effect is possible.

At a constant power level the transient heat transfer calculation will give negligible drift in temperatures from the steady state values. For a step change in power level the transient heat transfer calculation computes the correct change in coolant ΔT and radial fuel ΔT for the new steady state power.

4.8.3 Checkout of Loop Flow and Voiding Package

Test cases have been successfully run using the loop flow and voiding calculation to simulate the following:

- 1) coolant channel blockage
- 2) pump piping break
- 3) pump coastdown
- 4) coolant voiding initiated by coolant boiling
- 5) coolant voiding initiated by fuel pin failure.

Care must be taken to provide a minimum time step size which is small enough to satisfy input criteria on the maximum allowable velocity change per time step. Too large a minimum time step size may lead to an unstable solution.

Simulation of loop systems may be done in principle, by specifying a small (approximately incompressible) tank cover gas volume. Numerical problems have arisen in attempting to simulate zero gas volumes, however, hence this approach requires further study and should be used with caution.

4.8.4 Checkout of Trigger Logic

The various fuel failure, voiding, flow blockage, and reactivity insertion triggers have been successfully used both separately and together. To compute proper sequencing of accident events when nodal temperatures are used as trigger variables it may be necessary to perform heat transfer calculations for each kinetics step and restrict the size of the time step. An alternate approach is to perform an initial calculation to determine exact trigger times and use these in subsequent calculations.

5.0 SAMPLE PROBLEMS

Three sample problems are included to demonstrate the use of the various running and edit options. All of the problems use the same model of an LMFBR core with 12 bundle types, 9 axial sections and 10 radial fuel nodes.

The first problem demonstrates the capability of FREADM to economically scope reactor transients. A \$1.30 control rod withdrawal from low power is simulated using only the reactor kinetics portion of the code with no accident triggers. Input is from the first DTA call only. Large values for NKS and TMAX were used to suppress transient heat transfer calculations. Tables for reactivity calculations were not required input since the trigger logic was not used. The code computed initial steady state temperatures and did one transient heat transfer calculation before terminating the problem. Transient power calculations are shown for 40 time steps. Doppler feedback was computed without an intervening heat transfer calculation. Edits include relative power and reactivity information for each kinetics time step. Initial and final temperature distributions were computed and edited also, but are not shown here.

The second problem demonstrates the use of the trigger logic. An initial flow blockage was simulated in the central channel with the core at operating conditions. Voiding was simulated by input tables of void displacement vs. time and initiated when the computed coolant temperature exceeded an input trigger level (TV3(I)). Propagation of flow blockage to surrounding channels was assumed to occur when voiding was initiated in the central channel. Similarly propagation of flow blockage to successive rows of coolant channels was assumed to occur when voiding was initiated in the adjacent inner row. Fuel failure using mode 2 was assumed to occur when 50% of the fuel at a given axial section reached the melting temperature (using TF3(I) and KFN(I)).

Coupled reactor kinetics and heat transfer calculations were performed using running option 1. Information on power, reactivity and accident propagation are printed in the kinetics edit. Steady state and final fuel temperatures were included in the temperature edit (KEDIT=0).

The third problem demonstrates the use of running option 2 in which coolant flow and voiding is computed using the loop flow and voiding module with input from the kinetics and heat transfer module. Plugging of the inlet orifice to the central 19 coolant channels was assumed to initiate an accident. Voiding was assumed to occur whenever the cladding temperature exceeded the saturation temperature of the sodium plus a superheat temperature (determined using input curve fits to experimental data). The voiding output is shown for a few time steps for illustration. Input to the code is required from all three DTA calls when using running option 2. The loop flow and voiding module may be run independently using running option 3 in which case the only input required is for the third DTA call (Section 4.5).

DTA CALL NO.....1

INPUT EDITS

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CRD NO....1 $ SAMPLE PROBLEM - ROD EJECTION FROM LOW POWER WITH TIME STEP)
CRD NO....2 $ (CONTROLLED BY THE CODE)
CRD NO....3 $ (TRANSIENT HEAT TRANSFER SUPPRESSED)
CRD NO....4 $ (CORE GEOMETRY INPUT)
CRD NO....5 NRR = 12 $ (NUMBER OF RADIAL CORE REGIONS USED IN THE CALCULATION)
CRD NO....6 $ (OUTER RADII OF CORE REGIONS - FT.)
CRD NO....7 RR(1) = .203 .538 .887 1.237 1.588 1.940 2.292 2.644 2.869 3.351 3.704 4.058
CRD NO....8 NBT = 12 $ (NUMBER OF BUNDLE TYPES USED IN CALCULATION)
CRD NO....9 KRB(1) = 1 2 3 4 5 6 7 8 9 10 11 12 $ (RADIAL REGION ASSIGNED TO BUNDLE TYPE)
CRD NO....10 CH = 2.5 $ (CORE HEIGHT - FT.)
CRD NO....11 $ (FUEL PIN GEOMETRY INPUT)
CRD NO....12 NAX = 9 $ (NUMBER OF AXIAL SECTIONS USED)
CRD NO....13 NRR = 12 $ (NUMBER OF RADIAL FUEL NODES USED)
CRD NO....14 RV = .0328 $ (RADIUS OF FUEL PIN CENTRAL VOID - FT.)
CRD NO....15 RF = 9.16667-3 $ (OUTER RADIUS OF FUEL REGION - FT.)
CRD NO....16 CT = .125 $ (CLADDING THICKNESS - FT.)
CRD NO....17 PL = 1.20 $ (FUEL PIN PITCH TO DIAMETER RATIO)
CRD NO....18 $ (MATERIAL PROPERTIES)
CRD NO....19 KPRP = 1 $ (FUEL PROPERTIES ARE TEMPERATURE DEPENDENT)
CRD NO....20 RHOF = 60.43 $ (FUEL DENSITY - LB./CU.FT.)
CRD NO....21 QHF = 125 $ (FUEL HEAT OF FUSION - BTU/LB.)
CRD NO....22 TMELT = 5. $ (FUEL MELTING TEMPERATURE - DEG.F)
CRD NO....23 NCF = 1 $ (NUMBER OF FUEL HEAT CAPACITY TABLES INPUT)
CRD NO....24 NCL = 1 $ (NUMBER OF VALUES PER TABLE)
CRD NO....25 $ (HEAT CAPACITY VALUES)
CRD NO....26 FCT(1,1) = .0067 .68 .73 .76 0.077 *2 0.078 .09 .104 0.112
CRD NO....27 $ (TEMPERATURE VALUES)
CRD NO....28 TFC(1,1) = 200. 400. 600. 980. 1300. 1780. 1980. 2800. 4000. 10000.
CRD NO....29 KCF(1) = 1 *12 $ (HEAT CAPACITY TABLE 1 ASSIGNED TO ALL BUNDLE TYPES)
CRD NO....30 NKF = 1 $ (NUMBER OF THERMAL CONDUCTIVITY TABLES INPUT)
CRD NO....31 NKL = 1 $ (NUMBER OF VALUES PER TABLE)
CRD NO....32 $ (THERMAL CONDUCTIVITY VALUES)
CRD NO....33 FKT(1,1) = 5.62E-4 4.95E-4 4.43E-4 4.02E-4 3.55E-4 3.20E-4 2.96E-4
CRD NO....34 FKT(8,1) = 2.80E-4 2.67E-4 2.49E-4 $ (CONDUCTIVITY VALUES)
CRD NO....35 $ (TEMPERATURE VALUES CORRESPONDING TO CONDUCTIVITY VALUES)
CRD NO....36 TFK(1,1) = 887. 1022. 1202. 1427. 1832. 2262. 2732. 3182. 3632. 100
CRD NO....37 KKF(1) = 1 *12 $ (THERMAL CONDUCTIVITY TABLE 1 ASSIGNED TO ALL BUNDLE TYPES)
CRD NO....38 RHOC = 501.07 $ (CLAD DENSITY - LB./CU.FT.)
CRD NO....39 CC = .12 $ (CLAD HEAT CAPACITY)
CRD NO....40 CK = .34 $ (CLAD THERMAL CONDUCTIVITY)
CRD NO....41 RHON = 52.416 $ (COOLANT DENSITY - LB./CU.FT.)
CRD NO....42 SC = .33 $ (COOLANT HEAT CAPACITY)
CRD NO....43 SK = .14 $ (COOLANT THERMAL CONDUCTIVITY)
CRD NO....44 GC = .4167 $ (GAP COEFFICIENT, FUEL TO CLAD)
CRD NO....45 FLM = 5.556 $ (FILM COEFFICIENT, CLAD TO COOLANT)
CRD NO....46 NWT = 12 $ (NUMBER OF FLOW TABLES INPUT)
CRD NO....47 NHL = 2 $ (LENGTH OF FLOW TABLES)
CRD NO....48 $ (COOLANT VELOCITIES)
CRD NO....49 VT(1,1) = 30.4 *2 $

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CRD NO...50 VT(1, 2) = 30.2 *2 $
CRD NO...51 VT(1, 3) = 30.0 *2 $
CRD NO...52 VT(1, 4) = 29.7 *2 $
CRD NO...53 VT(1, 5) = 29.3 *2 $
CRD NO...54 VT(1, 6) = 28.7 *2 $
CRD NO...55 VT(1, 7) = 27.8 *2 $
CRD NO...56 VT(1, 8) = 26.7 *2 $
CRD NO...57 VT(1, 9) = 26.1 *2 $
CRD NO...58 VT(1,10) = 28.5 *2 $
CRD NO...59 VT(1,11) = 23.5 *2 $
CRD NO...60 VT(1,12) = 17.1 *2 $
CRD NO...61 $ (CORRESPONDING TIME VALUES)
CRD NO...62 TVT(1, 1) = 0.0 100.0 $
CRD NO...63 TVT(1, 2) = 0.0 100.0 $
CRD NO...64 TVT(1, 3) = 0.0 100.0 $
CRD NO...65 TVT(1, 4) = 0.0 100.0 $
CRD NO...66 TVT(1, 5) = 0.0 100.0 $
CRD NO...67 TVT(1, 6) = 0.0 100.0 $
CRD NO...68 TVT(1, 7) = 0.0 100.0 $
CRD NO...69 TVT(1, 8) = 0.0 100.0 $
CRD NO...70 TVT(1, 9) = 0.0 100.0 $
CRD NO...71 TVT(1,10) = 0.0 100.0 $
CRD NO...72 TVT(1,11) = 0.0 100.0 $
CRD NO...73 TVT(1,12) = 0.0 100.0 $
CRD NO...74 KWB(1) = 1 2 3 4 5 6 7 8 9 10 11 12 $ (FLOW TABLE ASSIGNED TO BUNDLE TYPE 1)
CRD NO...75 NIT = 1 $ (NUMBER OF INLET COOLANT TEMPERATURE TABLES INPUT)
CRD NO...76 NIL = 2 $ (LENGTH OF INLET COOLANT TEMPERATURE TABLES INPUT)
CRD NO...77 TII(1,1) = 720.0 *2 $ (INLET TEMPERATURE VALUES)
CRD NO...78 TTI(1,1) = 0.0 100.0 $ (CORRESPONDING TIME VALUES)
CRD NO...79 KIT(1) = 1 *12 $ (INLET TEMPERATURE TABLE 1 ASSIGNED TO BUNDLE TYPE 1)
CRD NO...80 PU = 1.0-3 $ (INITIAL CORE AVERAGE POWER DENSITY)
CRD NO...81 FPFDP = 0.0 $ (FRACTION OF POWER DUE TO FISSION PRODUCT DECAY - STEADY STATE)
CRD NO...82 A1 = 1.0-3 $ (CONVERSION FACTOR - RELATIVE NEUTRON DENSITY TO POWER DENSITY)
CRD NO...83 $ (POWER PEAKING FACTORS)
CRD NO...84 PPF(1,1) = .8866 1.1008 1.2543 1.3971 1.4340 1.3971 1.2543 1.1008 .8866
CRD NO...85 PPF(1,2) = .8798 1.0924 1.2448 1.3865 1.4231 1.3865 1.2448 1.0924 .8798
CRD NO...86 PPF(1,3) = .8739 1.0850 1.2363 1.3771 1.4135 1.3771 1.2363 1.0850 .8739
CRD NO...87 PPF(1,4) = .8679 1.0776 1.2279 1.3677 1.4038 1.3677 1.2279 1.0776 .8679
CRD NO...88 PPF(1,5) = .8553 1.0619 1.2100 1.3478 1.3833 1.3478 1.2100 1.0619 .8553
CRD NO...89 PPF(1,6) = .8366 1.0388 1.1836 1.3184 1.3532 1.3184 1.1836 1.0388 .8366
CRD NO...90 PPF(1,7) = .8113 1.0073 1.1478 1.2785 1.3122 1.2785 1.1478 1.0073 .8113
CRD NO...91 PPF(1,8) = .7800 .9685 1.1035 1.2292 1.2616 1.2292 1.1035 .9685 .7800
CRD NO...92 PPF(1,9) = .7614 .9454 1.0772 1.1998 1.2315 1.1998 1.0772 .9454 .7614
CRD NO...93 PPF(1,10) = .8299 1.0305 1.1742 1.3078 1.3424 1.3078 1.1742 1.0305 .8299
CRD NO...94 PPF(1,11) = .6869 .8529 .9718 1.0824 1.1111 1.0824 .9718 .8529 .6869
CRD NO...95 PPF(1,12) = .4992 .6198 .7062 .7866 .8074 .7866 .7062 .6198 .4992
CRD NO...96 FHF = 1.0 $ (FRACTION OF HEAT GENERATED IN FUEL)
CRD NO...97 NDG = 1 $ (NUMBER OF DECAY GROUPS USED TO COMPUTE DELAYED POWER)
CRD NO...98 NPG = 6 $ (NUMBER OF DELAYED NEUTRON PRECURSOR GROUPS)
CRD NO...99 $ (EFFECTIVE DELAYED NEUTRON FRACTION FOR DELAY GROUP 1)
CRD NO...100 B(1) = .76-4 6.70-4 5.71-4 11.01-4 4.56-4 1.56-4 $
CRD NO...101 DC(1) = .0128 .0314 .1352 .3434 1.356 3.804 $ (DECAY CONSTANT FOR GROUP 1)

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CRD NO..102 PNL = .6-6 $ (PROMPT NEUTRON LIFETIME)
CRD NO..103 $ (DOPPLER COEFFICIENTS)
CRD NO..104 ADOP(1, 1) * -1.532-6 -2.3542-5 -3.0688-6 -3.8 66-6 -4.0 93-6
CRD NO..105 ADOP(6, 1) * -3.8 66-6 -3.0688-5 -2.3592-6 -1.532-6 $
CRD NO..106 ADOP(1, 2) * -9.150 -6 -1.4099-5 -1.8319-5 -2.2722-5 -2.3942-5
CRD NO..107 ADOP(6, 2) * -2.2722-5 -1.8319-5 -1.4099-5 -9.1500-6 $
CRD NO..108 ADOP(1, 3) * -1.7971-5 -2.7692-5 -3.5978-5 -4.4633-5 -4.7029-5
CRD NO..109 ADOP(6, 3) * -4.4633-5 -3.5978-5 -2.7692-5 -1.7971-5 $
CRD NO..110 ADOP(1, 4) * -2.6358-5 -4.0607-5 -5.2761-5 -6.5453-5 -6.8968-5
CRD NO..111 ADOP(6, 4) * -6.5453-5 -5.2761-5 -4.0607-5 -2.6358-5 $
CRD NO..112 ADOP(1, 5) * -3.415 -5 -5.2615-5 -6.8364-5 -8.48 6-5 -8.9359-5
CRD NO..113 ADOP(6, 5) * -8.4806-5 -6.8364-5 -5.2615-5 -3.4150-5 $
CRD NO..114 ADOP(1, 6) * -4.0672-5 -6.2668-5 -8.1422-5 -1.0101-4 -1.0643-4
CRD NO..115 ADOP(6, 6) * -1.0101-4 -8.1422-5 -6.2668-5 -4.0672-5 $
CRD NO..116 ADOP(1, 7) * -4.5468-5 -7.0055-5 -9.1017-5 -1.1291-4 -1.1897-4
CRD NO..117 ADOP(6, 7) * -1.1291-4 -9.1017-5 -7.0055-5 -4.5468-5 $
CRD NO..118 ADOP(1, 8) * -4.9100-5 -7.5653-5 -9.8294-5 -1.2194-4 -1.2848-4
CRD NO..119 ADOP(6, 8) * -1.2194-4 -9.8294-5 -7.5653-5 -4.9100-5 $
CRD NO..120 ADOP(1, 9) * -3.2966-5 -5.0795-5 -6.5997-5 -8.1867-5 -8.6270-5
CRD NO..121 ADOP(6, 9) * -8.1867-5 -6.5997-5 -5.0795-5 -3.2966-5 $
CRD NO..122 ADOP(1, 10) * -5.2716-5 -8.1221-5 -1.0553-4 -1.3091-4 -1.3794-4
CRD NO..123 ADOP(6, 10) * -1.3091-4 -1.0553-4 -8.1221-5 -5.2716-5 $
CRD NO..124 ADOP(1, 11) * -2.9858-5 -4.6004-5 -5.9772-5 -7.4148-5 -7.8126-5
CRD NO..125 ADOP(6, 11) * -7.4148-5 -5.9772-5 -4.6004-5 -2.9858-5 $
CRD NO..126 ADOP(1, 12) * -2.0015-5 -3.0838-5 -4.0066-5 -4.9702-5 -5.2372-5
CRD NO..127 ADOP(6, 12) * -4.9702-5 -4.0066-5 -3.0838-5 -2.0015-5 $
CRD NO..128 VDOPF = 1.0 $ (MULTIPLIER FOR DOPPLER COEFFICIENTS FOR GIVEN BUNDLE TYPE)
CRD NO..129 $ (WHEN COOLANT VOIDING IS TRIGGERED IN BUNDLE TYPE)
CRD NO..130 NTB = 3 $ (NUMBER OF REACTIVITY VALUES INPUT TO TABLE USED TO DRIVE KINETICS)
CRD NO..131 RTB(1) = 0.0 0.0416 *2 $ (REACTIVITY VALUES INPUT TO KINETICS CALCULATION)
CRD NO..132 TTB(1) = 0.0 1.0 1.0 0 *2 $ (CORRESPONDING ELAPSED TIME)
CRD NO..133 ETLIM = 0.0 $ (ELAPSED TIME IN CALC. WHICH WILL CAUSE TERMINATION)
CRD NO..134 NMK = 4 $ (MAX. NUMBER OF NUCLEAR KINETICS TIME STEPS TO END PROBLEM)
CRD NO..135 NHT = 4 $ (MAX. NUMBER OF HEAT TRANSFER CALCULATIONS TO END PROBLEM)
CRD NO..136 NSS = 5 $ (MAX. NUMBER OF ITERATIONS DESIRED IN STEADY STATE TEMP.)
CRD NO..137 $ (CALCULATIONS WHEN TEMP. DEPENDENT FUEL PROPERTIES ARE USED)
CRD NO..138 EPS = 1.0 $ (DESIRED CONVERGENCE OF STEADY STATE TEMPERATURES)
CRD NO..139 TMP(1,1,1) = 720. *1295 $ (INITIAL TEMP. GUESS TO OBTAIN FUEL PROPERTIES)
CRD NO..140 $ (FOR STEADY STATE TEMP. CALCULATIONS)
CRD NO..141 DTMAX = 0.1 $ (MAX. KINETICS TIME STEP PRIOR TO VOID INITIATION IN )
CRD NO..142 $ (SPECIFIED BUNDLE TYPE)
CRD NO..143 NHF = 1 $ (MAX. NUMBER OF TIMES KINETICS TIME STEP MAY BE HALVED BEFORE)
CRD NO..144 $ (CONTINUING)
CRD NO..145 YKS = 1 $ (MAX. NUMBER OF KINETICS TIME STEPS TAKEN BETWEEN HEAT)
CRD NO..146 $ (TRANSFER CALCULATIONS PRIOR TO VOID INITIATION)
CRD NO..147 TMAX = 10000. $ (MIN. CHANGE IN AVE. FUEL TEMP. WHICH WILL CAUSE NEW HEAT)
CRD NO..148 $ (TRANSFER CALCULATION)
CRD NO..149 MKS = 1 000 $ (MAX. NUMBER OF KINETICS TIME STEPS PER HEAT TRANSFER AFTER)
CRD NO..150 $ (VOID INITIATION)
CRD NO..151 MBVOID = 12 $ (FREQUENCY OF COMPUTING HEAT TRANSFER WILL BE CHANGED TO MKS)
CRD NO..152 $ (WHEN VOIDING INITIATED IN THIS BUNDLE TYPE)
CRD NO..153 E1 = 1.5 $ (MAX. RATIO OF FINAL TO INITIAL NEUTRON DENSITY PER KINETICS )

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CRD NO..154 \$ (TIME STEP)
CRD NO..155 E2 = 5 .0 \$ (MAX. CHANGE IN FUEL AVE. TEMP. AT ANY AXIAL SECTION OVER A)
CRD NO..156 \$ (KINETICS TIME STEP)
CRD NO..157 E3 = 0.1 \$ (MAX. TOTAL REACTIVITY CHANGE PER TIME STEP)
CRD NO..158 KEDIT = 0 \$\$ (CONTROLS PRINTING OF TEMPERATURES)
DTA CALL NO....2 INPUT EDITS

CRD NO....1 \$\$

NUMBER OF COMPLETED KINETICS TIME STEPS	NUMBER OF KINETICS TIME STEPS SINCE LAST HEAT TRANSFER CALC	ELAPSED TIME SINCE START OF TRANSIENT (SEC)	TIME STEP SIZE (SEC)	FUEL AVERAGE POWER DENSITY (BTU/SEC- CU. FT.)	RELATIVE ELECTRON DENSITY	REACTOR PERIOD (SEC)	RATE OF POWER INCREASE (BTU/SEC- CU. FT.) (SEC)	DOPPLER REACTIVITY (AT END) (OF TIME) (STEP)	TEMPERATURE INDEPENDENT REACTIVITY (AT) (CENTER OF) (TIME STEP)	TOTAL REACTIVITY (USED IN) (KINETICS) (CALC)
1	1	5.000E-02	5.00E-2	1.03507E-03	1.035E 0	1.476E 0	7.01E-4	1.089E-10	1.040E-04	1.040E-04
2	2	1.000E-01	5.00E-2	1.11421E-03	1.114E 0	7.04E-1	1.98E-03	1.089E-10	3.120E-04	3.120E-04
3	3	1.500E-01	5.00E-2	1.21873E-03	1.219E 0	6.394E-1	1.89E-03	1.089E-10	5.200E-04	5.200E-04
4	4	2.000E-01	5.00E-2	1.32318E-03	1.323E 0	5.785E-1	2.29E-03	1.089E-10	7.280E-04	7.280E-04
5	5	2.500E-01	5.00E-2	1.46355E-03	1.464E 0	5.21E-1	2.81E-03	1.089E-10	9.360E-04	9.360E-04
6	6	3.000E-01	5.00E-2	1.63939E-03	1.639E 0	4.661E-1	3.52E-03	1.089E-10	1.144E-03	1.144E-03
7	7	3.500E-01	5.00E-2	1.86474E-03	1.865E 0	4.137E-1	4.51E-03	1.089E-10	1.352E-03	1.352E-03
8	8	4.000E-01	5.00E-2	2.16219E-03	2.162E 0	3.635E-1	5.95E-03	1.089E-10	1.560E-03	1.560E-03
9	9	4.500E-01	5.00E-2	2.57002E-03	2.570E 0	3.151E-1	8.16E-03	1.089E-10	1.768E-03	1.768E-03
10	10	5.000E-01	5.00E-2	3.15819E-03	3.158E 0	2.685E-1	1.18E-02	1.089E-10	1.976E-03	1.976E-03
11	11	5.500E-01	5.00E-2	4.06827E-03	4.068E 0	2.235E-1	1.82E-02	5.204E-11	2.184E-03	2.184E-03
12	12	5.750E-01	2.500E-2	5.22989E-03	5.230E 0	1.126E-1	4.65E-02	5.204E-11	2.340E-03	2.340E-03
13	13	6.000E-01	2.500E-2	6.33681E-03	6.337E 0	1.431E-1	4.43E-02	5.204E-11	2.444E-03	2.444E-03
14	14	6.250E-01	2.500E-2	7.96381E-03	7.964E 0	1.624E-1	6.51E-02	2.938E-11	2.548E-03	2.548E-03
15	15	6.500E-01	2.500E-2	1.05458E-02	1.055E 01	1.021E-1	1.03E-01	4.386E-12	2.652E-03	2.652E-03
16	16	6.625E-01	1.250E-2	1.39862E-02	1.399E 01	5.082E-2	2.75E-01	-1.815E-11	2.730E-03	2.730E-03
17	17	6.750E-01	1.250E-2	1.73276E-02	1.733E 01	6.482E-2	2.67E-01	-5.250E-11	2.782E-03	2.782E-03
18	18	6.875E-01	1.250E-2	2.24021E-02	2.240E 01	5.518E-2	4.06E-01	-7.100E-11	2.834E-03	2.834E-03
19	19	6.9375E-01	6.250E-3	2.80543E-02	2.805E 01	3.102E-2	9.04E-01	-8.847E-11	2.873E-03	2.873E-03
20	20	7.000E-01	6.250E-3	3.36149E-02	3.360E 01	3.784E-2	8.88E-01	-1.328E-10	2.899E-03	2.899E-03
21	21	7.1625E-01	6.250E-3	4.09713E-02	4.097E 01	3.476E-2	1.18E 00	-1.578E-10	2.925E-03	2.925E-03
22	22	7.1250E-01	6.250E-3	5.13711E-02	5.137E 01	3.087E-2	1.66E 00	-2.087E-10	2.951E-03	2.951E-03
23	23	7.1875E-01	6.250E-3	6.67791E-02	6.678E 01	2.709E-2	2.47E 00	-2.361E-10	2.977E-03	2.977E-03
24	24	7.2500E-01	6.250E-3	9.09395E-02	9.094E 01	2.352E-2	3.87E 00	-3.017E-10	3.003E-03	3.003E-03
25	25	7.2813E-01	3.125E-3	1.14289E-01	1.143E 02	1.781E-2	6.19E 00	-3.297E-10	3.022E-03	3.022E-03
26	26	7.3125E-01	3.125E-3	1.35233E-01	1.352E 02	1.694E-2	7.98E 00	-3.836E-10	3.035E-03	3.035E-03
27	27	7.3437E-01	3.125E-3	1.68611E-01	1.686E 02	1.579E-2	1.07E 01	-4.112E-10	3.048E-03	3.048E-03
28	28	7.3750E-01	3.125E-3	2.14721E-01	2.147E 02	1.455E-2	1.48E 01	-4.577E-10	3.061E-03	3.061E-03
29	29	7.4062E-01	3.125E-3	2.80433E-01	2.804E 02	1.334E-2	2.10E 01	-4.999E-10	3.074E-03	3.074E-03
30	3	7.4375E-01	3.125E-3	3.77136E-01	3.771E 02	1.219E-2	3.09E 01	-5.763E-10	3.087E-03	3.087E-03
31	31	7.4687E-01	3.125E-3	5.24446E-01	5.244E 02	1.113E-2	4.71E 01	-6.860E-10	3.100E-03	3.100E-03
32	32	7.4844E-01	1.562E-3	6.29193E-01	6.291E 02	9.393E-3	6.70E 01	-7.643E-10	3.110E-03	3.110E-03
33	33	7.5000E-01	1.562E-3	7.61967E-01	7.620E 02	8.96E-3	8.50E 01	-8.407E-10	3.117E-03	3.117E-03
34	34	7.5156E-01	1.562E-3	9.32466E-01	9.325E 02	8.54E-3	1.09E 02	-9.343E-10	3.123E-03	3.123E-03
35	35	7.5313E-01	1.562E-3	1.25301E-01	1.154E 03	8.15E-3	1.42E 02	-1.048E-09	3.130E-03	3.130E-03
36	36	7.5469E-01	1.562E-3	1.44365E-01	1.444E 03	7.77E-3	1.86E 02	-1.190E-09	3.136E-03	3.136E-03
37	37	7.5625E-01	1.562E-3	1.62841E-01	1.828E 03	7.42E-3	2.46E 02	-1.365E-09	3.143E-03	3.143E-03
38	38	7.5781E-01	1.562E-3	2.04482E-01	2.345E 03	7.09E-3	3.31E 02	-1.587E-09	3.149E-03	3.149E-03
39	39	7.5937E-01	1.562E-3	3.04635E-01	3.046E 03	6.78E-3	4.49E 02	-1.887E-09	3.156E-03	3.156E-03
40	40	7.6094E-01	1.562E-3	4.01118E-01	4.011E 03	6.49E-3	6.17E 02	-2.414E-09	3.162E-03	3.162E-03

CURRENT COMPOSITE REACTIVITY-VERSUS TIME TABLE

ELAPSED TIME = 0.760937 SECONDS

TIME (SECONDS)	REACTIVITY
0.	0.
1.00000E 00	4.16000E-03
1.00000E 02	4.16000E-03
1.00000E 06	4.16000E-03

DTA CALL NO....1

INPUT EDITS

CRD NO....1 \$ (SAMPLE PROBLEM NO. 2)
 CRD NO....2 \$ (FLOW BLOCKAGE PROPAGATION WITH VOIDING AND FUEL FAILURE)
 CRD NO....3 \$ (CORE INITIALLY AT STEADY STATE OPERATING CONDITIONS)
 CRD NO....4 \$ (VOID AND FLOW INFORMATION FROM INPUT TABLES - OPTION 1)
 CRD NO....5 NRR = 12 \$ (NUMBER OF RADIAL CORE REGIONS USED IN THE CALCULATION)
 CRD NO....6 \$ (OUTER RADIUS OF CORE REGIONS - FT.)
 CRD NO....7 RR(1) = .203 .536 .887 1.237 1.588 1.940 2.292 2.644 2.869 3.351 3.704 4.058
 CRD NO....8 NBT = 12 \$ (NUMBER OF BUNDLE TYPES USED IN CALCULATION)
 CRD NO....9 KRB(1) = 1 2 3 4 5 6 7 8 9 10 11 12 \$ (RADIAL REGION ASSIGNED TO BUNDLE TYPE)
 CRD NO....10 CH = 2.5 \$ (CORE HEIGHT - FT.)
 CRD NO....11 \$ (FUEL PIN GEOMETRY INPUT)
 CRD NO....12 NAX = 9 \$ (NUMBER OF AXIAL SECTIONS USED)
 CRD NO....13 NRN = 12 \$ (NUMBER OF RADIAL FUEL NODES USED)
 CRD NO....14 RV = .0328 \$ (RADIUS OF FUEL PIN CENTRAL VOID - FT.)
 CRD NO....15 RF = 9.16667*3 \$ (OUTER RADIUS OF FUEL REGION - FT.)
 CRD NO....16 CT = .00125 \$ (CLADDING THICKNESS - FT.)
 CRD NO....17 PD = 1.20 \$ (FUEL PIN PITCH TO DIAMETER RATIO)
 CRD NO....18 \$ (MATERIAL PROPERTIES)
 CRD NO....19 KPRP = 1 \$ (FUEL PROPERTIES ARE TEMPERATURE DEPENDENT)
 CRD NO....20 RHOF = 609.48 \$ (FUEL DENSITY - LB./CU.FT.)
 CRD NO....21 QHF = 129.0 \$ (FUEL HEAT OF FUSION - BTU/LB.)
 CRD NO....22 TMELT = 5200. \$ (FUEL MELTING TEMPERATURE - DEG.F)
 CRD NO....23 NCF = 1 \$ (NUMBER OF FUEL HEAT CAPACITY TABLES INPUT)
 CRD NO....24 NCL = 10 \$ (NUMBER OF VALUES PER TABLE)
 CRD NO....25 \$ (HEAT CAPACITY VALUES)
 CRD NO....26 FCT(1,1) = 0.7063 3.068 0.073 0.076 0.077 0.2 0.078 0.090 0.104 0.112
 CRD NO....27 \$ (TEMPERATURE VALUES)
 CRD NO....28 TFC(1,1) = 280. 400. 640. 980. 1300. 1780. 1980. 2800. 4000. 10000.
 CRD NO....29 KCF(1) = 1 *12 \$ (HEAT CAPACITY TABLE 1 ASSIGNED TO ALL BUNDLE TYPES)
 CRD NO....30 NKF = 1 \$ (NUMBER OF THERMAL CONDUCTIVITY TABLES INPUT)
 CRD NO....31 NKL = 10 \$ (NUMBER OF VALUES PER TABLE)
 CRD NO....32 \$ (THERMAL CONDUCTIVITY VALUES)
 CRD NO....33 FKT(1,1) = 5.62E-4 4.95E-4 4.43E-4 4.02E-4 3.55E-4 3.20E-4 2.96E-4
 CRD NO....34 FKT(8,1) = 2.80E-4 2.67E-4 2.49E-4 \$ (CONDUCTIVITY VALUES)
 CRD NO....35 \$ (TEMPERATURE VALUES CORRESPONDING TO CONDUCTIVITY VALUES)
 CRD NO....36 TFK(1,1) = 887. 1022. 1202. 1427. 1832. 2282. 2732. 3182. 3632. 10000.
 CRD NO....37 KKF(1) = 1 *12 \$ (THERMAL CONDUCTIVITY TABLE 1 ASSIGNED TO ALL BUNDLE TYPES)
 CRD NO....38 RHOC = 501.27 \$ (CLAD DENSITY - LB./CU.FT.)
 CRD NO....39 CC = 0.12 \$ (CLAD HEAT CAPACITY)
 CRD NO....40 CK = .0034 \$ (CLAD THERMAL CONDUCTIVITY)
 CRD NO....41 RMON = 52.416 \$ (COOLANT DENSITY - LB./CU.FT.)
 CRD NO....42 SC = .303 \$ (COOLANT HEAT CAPACITY)
 CRD NO....43 SK = .114 \$ (COOLANT THERMAL CONDUCTIVITY)
 CRD NO....44 GC = 0.4167 \$ (GAP COEFFICIENT, FUEL TO CLAD)
 CRD NO....45 FLN = 5.556 \$ (FILM COEFFICIENT, CLAD TO COOLANT)
 CRD NO....46 NWT = 12 \$ (NUMBER OF FLOW TABLES INPUT)
 CRD NO....47 NHL = 2 \$ (LENGTH OF FLOW TABLES)
 CRD NO....48 \$ (COOLANT VELOCITIES)
 CRD NO....49 VT(1,1) = 80.4 *2 \$

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CRD NO...50 VT(1, 2) = 30.2 *2 $
CRD NO...51 VT(1, 3) = 30.0 *2 $
CRD NO...52 VT(1, 4) = 29.7 *2 $
CRD NO...53 VT(1, 5) = 29.3 *2 $
CRD NO...54 VT(1, 6) = 28.7 *2 $
CRD NO...55 VT(1, 7) = 27.8 *2 $
CRD NO...56 VT(1, 8) = 26.7 *2 $
CRD NO...57 VT(1, 9) = 26.1 *2 $
CRD NO...58 VT(1,10) = 25.5 *2 $
CRD NO...59 VT(1,11) = 23.9 *2 $
CRD NO...60 VT(1,12) = 17.1 *2 $
CRD NO...61 $ (CORRESPONDING TIME VALUES)
CRD NO...62 TVT(1, 1) = 0.0 100.0 $
CRD NO...63 TVT(1, 2) = 0.0 100.0 $
CRD NO...64 TVT(1, 3) = 0.0 100.0 $
CRD NO...65 TVT(1, 4) = 0.0 100.0 $
CRD NO...66 TVT(1, 5) = 0.0 100.0 $
CRD NO...67 TVT(1, 6) = 0.0 100.0 $
CRD NO...68 TVT(1, 7) = 0.0 100.0 $
CRD NO...69 TVT(1, 8) = 0.0 100.0 $
CRD NO...70 TVT(1, 9) = 0.0 100.0 $
CRD NO...71 TVT(1,10) = 0.0 100.0 $
CRD NO...72 TVT(1,11) = 0.0 100.0 $
CRD NO...73 TVT(1,12) = 0.0 100.0 $
CRD NO...74 KWB(1) = 1 2 3 4 5 6 7 8 9 10 11 12 $ (FLOW TABLE ASSIGNED TO BUNDLE TYPE 1)
CRD NO...75 NIT = 1 $ (NUMBER OF INLET COOLANT TEMPERATURE TABLES INPUT)
CRD NO...76 NIL = 2 $ (LENGTH OF INLET COOLANT TEMPERATURE TABLES INPUT)
CRD NO...77 TII(1,1) = 720.0 *2 $ (INLET TEMPERATURE VALUES)
CRD NO...78 TII(1,1) = 0.0 100.0 $ (CORRESPONDING TIME VALUES)
CRD NO...79 KIT(1) = 1 *12 $ (INLET TEMPERATURE TABLE 1 ASSIGNED TO BUNDLE TYPE 1)
CRD NO...80 P0 = 36000. $ (INITIAL CORE AVERAGE POWER DENSITY)
CRD NO...81 FPPFD = 0.0 $ (FRACTION OF POWER DUE TO FISSION PRODUCT DECAY - STEADY STATE)
CRD NO...82 A1 = 36000. $ (CONVERSION FACTOR - RELATIVE NEUTRON DENSITY TO POWER DENSITY)
CRD NO...83 $ (POWER PEAKING FACTORS)
CRD NO...84 PPF(1,1) = .8865 1.1008 1.2543 1.3971 1.4340 1.3971 1.2543 1.1008 .8865
CRD NO...85 PPF(1,2) = .8798 1.0924 1.2448 1.3865 1.4231 1.3865 1.2448 1.0924 .8798
CRD NO...86 PPF(1,3) = .8739 1.0850 1.2363 1.3771 1.4135 1.3771 1.2363 1.0850 .8739
CRD NO...87 PPF(1,4) = .8679 1.0776 1.2279 1.3677 1.4038 1.3677 1.2279 1.0776 .8679
CRD NO...88 PPF(1,5) = .8593 1.0619 1.2100 1.3478 1.3833 1.3478 1.2100 1.0619 .8593
CRD NO...89 PPF(1,6) = .8366 1.0388 1.1836 1.3184 1.3532 1.3184 1.1836 1.0388 .8366
CRD NO...90 PPF(1,7) = .8113 1.0073 1.1478 1.2785 1.3122 1.2785 1.1478 1.0073 .8113
CRD NO...91 PPF(1,8) = .7800 .9685 1.1039 1.2292 1.2616 1.2292 1.1039 .9685 .7800
CRD NO...92 PPF(1,9) = .7614 .9454 1.0772 1.1999 1.2315 1.1999 1.0772 .9454 .7614
CRD NO...93 PPF(1,10) = .8299 1.0305 1.1742 1.3078 1.3424 1.3078 1.1742 1.0305 .8299
CRD NO...94 PPF(1,11) = .6889 .8529 .9718 1.0824 1.1110 1.0824 .9718 .8529 .6889
CRD NO...95 PPF(1,12) = .4992 .6198 .7062 .7866 .8074 .7866 .7062 .6198 .4992
CRD NO...96 FHF = 1.0 $ (FRACTION OF HEAT GENERATED IN FUEL)
CRD NO...97 NDG = 0 $ (NUMBER OF DECAY GROUPS USED TO COMPUTE DELAYED POWER)
CRD NO...98 NPG = 6 $ (NUMBER OF DELAYED NEUTRON PRECURSER GROUPS)
CRD NO...99 $ (EFFECTIVE DELAYED NEUTRON FRACTION FOR DELAY GROUP 1)
CRD NO...100 B(1) = .76-8 6.70-4 5.71-4 11.01-4 4.86-4 1.56-4 $
CRD NO...101 DC(1) = .0128 .0314 .1352 .3434 1.366 3.804 $ (DECAY CONSTANT FOR GROUP 1)

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CRD NO..102 PNL # .6-6 $ (PROMPT NEUTRON LIFETIME)
CRD NO..103 $ (DOPPLER COEFFICIENTS)
CRD NO..104 ADOP(1, 1) # -1.532-6 -2.3592-6 -3.0688-6 -3.8066-6 -4.0093-6
CRD NO..105 ADOP(6, 1) # -3.8066-6 -3.0688-6 -2.3592-6 -1.532-6 $
CRD NO..106 ADOP(1, 2) # -9.1500-6 -1.4099-5 -1.8319-5 -2.2722-5 -2.3942-5
CRD NO..107 ADOP(6, 2) # -2.2722-5 -1.8319-5 -1.4099-5 -9.1500-6 $
CRD NO..108 ADOP(1, 3) # -1.7971-5 -2.7692-5 -3.5978-5 -4.4633-5 -4.7029-5
CRD NO..109 ADOP(6, 3) # -4.4633-5 -3.5978-5 -2.7692-5 -1.7971-5 $
CRD NO..110 ADOP(1, 4) # -2.6358-5 -4.0607-5 -5.2761-5 -6.5453-5 -6.8968-5
CRD NO..111 ADOP(6, 4) # -6.5453-5 -5.2761-5 -4.0607-5 -2.6358-5 $
CRD NO..112 ADOP(1, 5) # -3.4150-5 -5.2615-5 -6.8364-5 -8.4806-5 -8.9359-5
CRD NO..113 ADOP(6, 5) # -8.4806-5 -6.8364-5 -5.2615-5 -3.4150-5 $
CRD NO..114 ADOP(1, 6) # -4.0672-5 -6.2668-5 -8.1422-5 -1.0101-4 -1.0643-4
CRD NO..115 ADOP(6, 6) # -1.0101-4 -8.1422-5 -6.2668-5 -4.0672-5 $
CRD NO..116 ADOP(1, 7) # -4.5468-5 -7.0055-5 -9.1017-5 -1.1291-4 -1.1897-4
CRD NO..117 ADOP(6, 7) # -1.1291-4 -9.1017-5 -7.0055-5 -4.5468-5 $
CRD NO..118 ADOP(1, 8) # -4.9100-5 -7.5653-5 -9.8294-5 -1.2194-4 -1.2848-4
CRD NO..119 ADOP(6, 8) # -1.2194-4 -9.8294-5 -7.5653-5 -4.9100-5 $
CRD NO..120 ADOP(1, 9) # -3.2966-5 -5.8795-5 -8.5997-5 -8.1867-5 -8.6270-5
CRD NO..121 ADOP(6, 9) # -8.1867-5 -8.5997-5 -5.8795-5 -3.2966-5 $
CRD NO..122 ADOP(1, 10) # -5.2716-5 -8.1221-5 -1.0553-4 -1.3091-4 -1.3794-4
CRD NO..123 ADOP(6, 10) # -1.3091-4 -1.0553-4 -8.1221-5 -5.2716-5 $
CRD NO..124 ADOP(1, 11) # -2.9858-5 -4.6004-5 -5.9772-5 -7.4148-5 -7.8126-5
CRD NO..125 ADOP(6, 11) # -7.4148-5 -5.9772-5 -4.6004-5 -2.9858-5 $
CRD NO..126 ADOP(1, 12) # -2.0015-5 -3.0838-5 -4.0066-5 -4.9702-5 -5.2372-5
CRD NO..127 ADOP(6, 12) # -4.9702-5 -4.0066-5 -3.0838-5 -2.0015-5 $
CRD NO..128 VDOFF # 1.0 $ (MULTIPLIER FOR DOPPLER COEFFICIENTS FOR GIVEN BUNDLE TYPE)
CRD NO..129 $ (WHEN COOLANT VOIDING IS TRIGGERED IN BUNDLE TYPE)
CRD NO..130 $ (TABLES FOR REACTIVITY CALCULATIONS)
CRD NO..131 $ (FUEL WORTH TABLES)
CRD NO..132 NWC # 12 $ (NUMBER OF FUEL WORTH TABLES)
CRD NO..133 NFW # 5 $ (NUMBER OF WORTH VALUES PER TABLE)
CRD NO..134 $ (AXIAL FUEL WORTH VALUES)
CRD NO..135 AFW(1, 1) # 7.8286-6 1.5657-5 2.0441-5 1.9657-5 7.8286-6 $
CRD NO..136 AFW(1, 2) # 7.7143-6 1.5429-5 2.0143-5 1.9429-5 7.7143-6 $
CRD NO..137 AFW(1, 3) # 7.6000-6 1.5200-5 1.9844-5 1.9200-5 7.6000-6 $
CRD NO..138 AFW(1, 4) # 7.4857-6 1.4971-5 1.9546-5 1.4971-5 7.4857-6 $
CRD NO..139 AFW(1, 5) # 7.3143-6 1.4629-5 1.9098-5 1.4629-5 7.3143-6 $
CRD NO..140 AFW(1, 6) # 6.9714-6 1.3943-5 1.8203-5 1.3943-5 6.9714-6 $
CRD NO..141 AFW(1, 7) # 6.5714-6 1.3143-5 1.7159-5 1.3143-5 6.5714-6 $
CRD NO..142 AFW(1, 8) # 6.0571-6 1.2114-5 1.5816-5 1.2114-5 6.0571-6 $
CRD NO..143 AFW(1, 9) # 5.7714-6 1.1543-5 1.5070-5 1.1543-5 5.7714-6 $
CRD NO..144 AFW(1, 10) # 6.8571-6 1.3714-5 1.7905-5 1.3714-5 6.8571-6 $
CRD NO..145 AFW(1, 11) # 4.6857-6 9.3714-6 1.2235-5 9.3714-6 4.6857-6 $
CRD NO..146 AFW(1, 12) # 2.4571-6 4.9143-6 6.4159-6 4.9143-6 2.4571-6 $
CRD NO..147 $ (CORRESPONDING AXIAL LOCATIONS)
CRD NO..148 DFW(1, 1) # 0.0 ,625 1.25 1.875 2.5 $
CRD NO..149 DFW(1, 2) # 0.0 ,625 1.25 1.875 2.5 $
CRD NO..150 DFW(1, 3) # 0.0 ,625 1.25 1.875 2.5 $
CRD NO..151 DFW(1, 4) # 0.0 ,625 1.25 1.875 2.5 $
CRD NO..152 DFW(1, 5) # 0.0 ,625 1.25 1.875 2.5 $
CRD NO..153 DFW(1, 6) # 0.0 ,625 1.25 1.875 2.5 $

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CRD NO..154 DFW(1, 7) = 0.0 .625 1.25 1.875 2.5 $
CRD NO..155 DFW(1, 8) = 0.0 .625 1.25 1.875 2.5 $
CRD NO..156 DFW(1, 9) = 0.0 .625 1.25 1.875 2.5 $
CRD NO..157 DFW(1,10) = 0.0 .625 1.25 1.875 2.5 $
CRD NO..158 DFW(1,11) = 0.0 .625 1.25 1.875 2.5 $
CRD NO..159 DFW(1,12) = 0.0 .625 1.25 1.875 2.5 $
CRD NO..160 KFW(1) = 1 2 3 4 5 6 7 8 9 10 11 12 $ (WORTH TABLE ASSIGNED TO A BUNDLE)
CRD NO..161 $ (TYPE)
CRD NO..162 FFTOP = 1.0 $ (SIMULATE VAPOR BLANKETING)
CRD NO..163 $ (VOIDING TABLES)
CRD NO..164 NVT = 1 $ (NUMBER OF VOIDING TABLES)
CRD NO..165 NVL = 6 $ (NUMBER OF TIME POINTS PER TABLE)
CRD NO..166 $ (DISPLACEMENT OF UPPER COOLANT SLUG)
CRD NO..167 TUD(1,1) = 0.0 0.25 0.50 0.75 1.00 1.25 $
CRD NO..168 $ (DISPLACEMENT OF LOWER COOLANT SLUG)
CRD NO..169 TLD(1,1) = 0.0 -0.25 -0.50 -0.75 -1.00 -1.25 $
CRD NO..170 $ (CORRESPONDING TIME POINTS)
CRD NO..171 TVD(1,1) = 0.0 0.2 0.4 0.6 0.8 1.0 $
CRD NO..172 KVD(1) = 1 *12 $ (VOID TABLE 1 ASSIGNED TO ALL BUNDLE TYPES)
CRD NO..173 ETLM = 3.0 $ (ELAPSED TIME IN CALC. WHICH WILL CAUSE TERMINATION)
CRD NO..174 NMK = 150 $ (MAX. NUMBER OF NUCLEAR KINETICS TIME STEPS TO END PROBLEM)
CRD NO..175 NHT = 300 $ (MAX. NUMBER OF HEAT TRANSFER CALCULATIONS TO END PROBLEM)
CRD NO..176 NSS = 10 $ (MAX. NUMBER OF ITERATIONS DESIRED IN STEADY STATE TEMP.)
CRD NO..177 $ (CALCULATIONS WHEN TEMP. DEPENDENT FUEL PROPERTIES ARE USED)
CRD NO..178 EPS = 1.0 $ (DESIRED CONVERGENCE OF STEADY STATE TEMPERATURES)
CRD NO..179 TMP(1,1,1) = 2000, *1296 $ (INITIAL TEMP. GUESS TO OBTAIN FUEL PROPERTIES)
CRD NO..180 $ (FOR STEADY STATE TEMP. CALCULATIONS)
CRD NO..181 DTKMX = 0.1 $ (MAX. KINETICS TIME STEP PRIOR TO VOID INITIATION IN )
CRD NO..182 $ (SPECIFIED BUNDLE TYPE)
CRD NO..183 NHF = 10 $ (MAX. NUMBER OF TIMES KINETICS TIME STEP MAY BE HALVED BEFORE)
CRD NO..184 $ (CONTINUING)
CRD NO..185 NKS = 1 $ (MAX. NUMBER OF KINETICS TIME STEPS TAKEN BETWEEN HEAT)
CRD NO..186 $ (TRANSFER CALCULATIONS PRIOR TO VOID INITIATION)
CRD NO..187 TMAX = 30.0 $ (MIN. CHANGE IN AVE. FUEL TEMP. WHICH WILL CAUSE NEW HEAT)
CRD NO..188 $ (TRANSFER CALCULATION)
CRD NO..189 MKS = 10 $ (MAX. NUMBER OF KINETICS TIME STEPS PER HEAT TRANSFER AFTER)
CRD NO..190 $ (VOID INITIATION)
CRD NO..191 MBVOID = 1 $ (FREQUENCY OF COMPUTING HEAT TRANSFER WILL BE CHANGED TO MKS)
CRD NO..192 $ (WHEN VOIDING INITIATED IN THIS BUNDLE TYPE)
CRD NO..193 E1 = 1.5 $ (MAX. RATIO OF FINAL TO INITIAL NEUTRON DENSITY PER KINETICS )
CRD NO..194 $ (TIME STEP)
CRD NO..195 E2 = 50.0 $ (MAX. CHANGE IN FUEL AVE. TEMP. AT ANY AXIAL SECTION OVER A )
CRD NO..196 $ (KINETICS TIME STEP)
CRD NO..197 E3 = 0.1 $ (MAX. TOTAL REACTIVITY CHANGE PER TIME STEP)
CRD NO..198 KEDIT = 0 $ (CONTROLS PRINTING OF TEMPERATURES)
CRD NO..199 $$ (END OF FIRST DTA CALL)
DTA CALL NO.....2 INPUT EDITS

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CRD NO....1 $ (TRIGGER INPUT)
CRD NO....2 $ (FAILURE DATA)
CRD NO....3 $ (NUMBER OF PINS REPRESENTED BY BUNDLE TYPE)

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CRD NO...4 KFM(1) = 2 *12 $ (MODE 2 FAILURE)
CRD NO...5 KRP(1) = 216 1296 2592 3888 5184 6480 7776 9072 10368 11664
CRD NO...6 KRP(11) = 12960 14256 $
CRD NO...7 KFN(1) = 7 *12 $ (FAILURE WHEN 50 PERCENT MOLTEN FUEL)
CRD NO...8 D1(1) = 1.25 *12 $ (DISTANCE ABOVE FAILURE)
CRD NO...9 D2(1) = 1.25 *12 $ (DISTANCE BELOW FAILURE)
CRD NO...10 TAU2(1) = 1.0 *12 $ (TIME INCREMENT FOR REDISTRIBUTION)
CRD NO...11 $ (FUEL FAILURE TRIGGERS - USE NODE TEMPERATURE TRIGGERS ONLY)
CRD NO...12 TF1(1) = 100.0 *12 $ (ELAPSED TIME)
CRD NO...13 TF2(1) = 1.0 *12 $ (AVERAGE FUEL TEMP)
CRD NO...14 TF3(1) = 5200.0 *12 $ (NODAL FUEL TEMP)
CRD NO...15 TF4(1) = 1.0 *12 $ (CLAD TEMP)
CRD NO...16 TF(1,1) = 190.0 *144 $ (PROPAGATION TIME)
CRD NO...17 $ (VOIDING DATA)
CRD NO...18 WM = 0.016 $ (MAXIMUM VOIDING NORTH)
CRD NO...19 RM = 3.25 $ (RADIUS FOR MAXIMUM VOID NORTH)
CRD NO...20 ZM = 1.0 $ (AXIAL DISPLACEMENT FOR MAXIMUM VOID NORTH)
CRD NO...21 FRB(1) = 1.0 *12 $ (FRACTION OF REGION WHICH CONTAINS BUNDLE TYPE)
CRD NO...22 $ (VOIDING TRIGGERS - USE COOLANT TEMPERATURE TRIGGERS ONLY)
CRD NO...23 TV1(1) = 10070 *12 $ (ELAPSED TIME)
CRD NO...24 TV2(1) = 1.0 *12 $ (CLAD TEMP)
CRD NO...25 TV3(1) = 1750.0 *12 $ (COOLANT TEMP)
CRD NO...26 TV4(1) = 1.0 *12 $ (NODAL FUEL TEMP)
CRD NO...27 TV5(1) = 1.0 *12 $ (AVERAGE FUEL TEMP)
CRD NO...28 TVP(1,1) = 180.0 *144 $ (PROPAGATION TIME)
CRD NO...29 $ (FLOW BLOCKAGE DATA)
CRD NO...30 KFB1(1) = 1 $ (FLOW BLOCKAGE TRIGGERS INPUT FOR BUNDLE TYPE 1 ONLY)
CRD NO...31 KFB(1) = 12 *12 $ (COOLANT NODAL TEMP CHECKED AGAINST TRIGGER LEVEL)
CRD NO...32 $ (TRIGGERS FOR FLOW BLOCKAGE)
CRD NO...33 TFB1(1) = 0.8 $ (BLOCKAGE IN BUNDLE TYPE 1 AT TIME T 0.0)
CRD NO...34 TFB2(1) = 1.0 *12 $ (AVERAGE FUEL TEMPERATURE)
CRD NO...35 TFB3(1) = 1.0 *12 $ (CLAD TEMPERATURE)
CRD NO...36 TFB4(1) = 1.0 *12 $ (NODAL TEMPERATURE)
CRD NO...37 $ (BLOCKAGE PROPAGATION BUNDLES)
CRD NO...38 KFBPP(2) = 1 2 3 4 5 6 7 8 9 10 11 $
CRD NO...39 $ (PROPAGATION TRIGGERS - USE VOIDING ONLY)
CRD NO...40 TFBP1(1) = 300.0 *12 $ (ELAPSED TIME)
CRD NO...41 TFBP2(1) = 1.0 *12 $ (AVERAGE FUEL TEMP)
CRD NO...42 TFBP3(1) = 1.0 *12 $ (CLAD TEMP)
CRD NO...43 TFBP4(1) = 1750.0 *12 $ (FLOW BLOCKAGE PROPAGATES WHEN BUNDLE TYPE KFBPP(1))
CRD NO...44 $ (VOIDS)
CRD NO...45 $$ (END OF SECOND DTA CALL)

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THE ELAPSED TIME IS 0.

SECONDS-COOLANT VELOCITIES FOR BUNDLE TYPE 1 HAVE CHANGED

NUMBER OF COMPLETED KINETICS TIME STEPS	NUMBER OF KINETICS TIME STEPS SINCE LAST HEAT TRANSFER CALC	ELAPSED TIME SINCE START OF TRANSIENT (SEC)	TIME STEP SIZE (SEC)	FUEL AVERAGE POWER DENSITY (BTU/) (SEC-) (CU, FT)	RELATIVE NEUTRON DENSITY	REACTOR PERIOD (SEC)	RATE OF POWER INCREASE (BTU/SEC-) (CU, FT/) (SEC)	DOPPLER REACTIVITY (AT END) (OF TIME) (STEP)	TEMPERATURE INDEPENDENT REACTIVITY (AT) (CENTER OF) (TIME STEP)	TOTAL REACTIVITY (USED IN) (KINETICS) (CALC)
1	1	1.0000E+01	1.000E-01	3.60000E 04	1.000E 00	-6.711E 06	-4.88E-03	-3.593E-06	0.	0.
2	1	2.0000E+01	1.000E-01	3.59579E 04	9.988E-01	-8.542E 01	-4.21E 02	-7.741E-06	0.	-3.593E-06
3	1	3.0000E-01	1.000E-01	3.59073E 04	9.974E-01	-7.089E 01	-5.06E 02	-1.158E-05	0.	-7.741E-06
4	1	4.0000E-01	1.000E-01	3.58581E 04	9.961E-01	-7.296E 01	-4.91E 02	-1.489E-05	0.	-1.158E-05
5	1	5.0000E+01	1.000E-01	3.58133E 04	9.948E-01	-7.987E 01	-4.48E 02	-1.770E-05	0.	-1.489E-05
6	1	6.0000E-01	1.000E-01	3.57730E 04	9.937E-01	-8.885E 01	-4.03E 02	-2.007E-05	0.	-1.770E-05
7	1	7.0000E-01	1.000E-01	3.57368E 04	9.927E-01	-9.877E 01	-3.62E 02	-2.208E-05	0.	-2.007E-05

THE COOLANT TEMPERATURE FOR BUNDLE TYPE 1, AXIAL NODE 5 IS 1.7856E 03 DEGREES FAHRENHEIT-VOIDING HAS BEEN INITIATED

A TEMPERATURE FOR RADIAL NODE 12 BUNDLE TYPE 1 EXCEEDED 1.7500E 03 DEGREES FAHRENHEIT AT TIME 7.0000E-01 SECONDS,
COOLANT VELOCITY CHANGES HAVE PROPAGATED TO BUNDLE TYPE 2

8	1	8.0000E-01	1.000E-01	3.58622E 04	9.962E-01	2.860E 01	1.25E 03	-2.466E-05	1.363E-05	-8.453E-06
9	1	9.0000E+01	1.000E-01	3.61458E 04	1.004E 00	1.274E 01	2.84E 03	-2.925E-05	4.089E-05	1.585E-05
10	1	9.5000E+01	5.000E-02	3.63272E 04	1.009E 00	1.002E 01	3.63E 03	-3.194E-05	5.938E-05	3.001E-05
11	2	1.000E 00	5.000E-02	3.64235E 04	1.012E 00	1.890E 01	1.93E 03	-3.473E-05	6.912E-05	3.717E-05
12	1	1.0500E 00	5.000E-02	3.65199E 04	1.014E 00	1.894E 01	1.93E 03	-3.766E-05	7.885E-05	4.416E-05
13	2	1.100E 00	5.000E-02	3.66158E 04	1.017E 00	1.911E 01	1.92E 03	-4.084E-05	8.858E-05	5.093E-05
14	1	1.1500E 00	5.000E-02	3.66885E 04	1.019E 00	2.922E 01	1.45E 03	-4.401E-05	9.637E-05	5.564E-05
15	2	1.200E 00	5.000E-02	3.67360E 04	1.020E 00	3.864E 01	9.51E 02	-4.738E-05	1.022E-04	5.820E-05
16	1	1.2500E 00	5.000E-02	3.67843E 04	1.022E 00	3.813E 01	9.65E 02	-5.064E-05	1.081E-04	6.081E-05
17	2	1.300E 00	5.000E-02	3.68306E 04	1.023E 00	3.971E 01	9.27E 02	-5.414E-05	1.139E-04	6.325E-05
18	1	1.3500E 00	5.000E-02	3.68541E 04	1.024E 00	7.846E 01	4.70E 02	-5.743E-05	1.178E-04	6.381E-05
19	2	1.400E 00	5.000E-02	3.68517E 04	1.024E 00	-7.726E 02	-4.77E 01	-6.088E-05	1.197E-04	6.230E-05

THE COOLANT TEMPERATURE FOR BUNDLE TYPE 2, AXIAL NODE 5 IS 1.8056E 03 DEGREES FAHRENHEIT-VOIDING HAS BEEN INITIATED

A TEMPERATURE FOR RADIAL NODE 12 BUNDLE TYPE 2 EXCEEDED 1.7500E 03 DEGREES FAHRENHEIT AT TIME 1.4000E 00 SECONDS,
COOLANT VELOCITY CHANGES HAVE PROPAGATED TO BUNDLE TYPE 3

20	1	1.4500E 00	5.000E-02	3.73529E 04	1.038E 00	3.726E 00	1.00E 04	-6.520E-05	1.622E-04	1.014E-04
21	2	1.5000E 00	5.000E-02	3.83960E 04	1.067E 00	1.841E 00	2.09E 04	-7.198E-05	2.451E-04	1.799E-04
22	1	1.5500E 00	5.000E-02	3.94561E 04	1.096E 00	1.861E 00	2.12E 04	-8.224E-05	3.260E-04	2.533E-04
23	1	1.6000E 00	5.000E-02	4.05437E 04	1.126E 00	1.864E 00	2.18E 04	-9.387E-05	4.051E-04	3.230E-04
24	1	1.6500E 00	5.000E-02	4.15013E 04	1.153E 00	2.167E 00	1.92E 04	-1.074E-04	4.725E-04	3.788E-04
25	1	1.7000E 00	5.000E-02	4.23057E 04	1.179E 00	2.630E 00	1.61E 04	-1.222E-04	5.284E-04	4.213E-04
26	1	1.7500E 00	5.000E-02	4.31442E 04	1.198E 00	2.573E 00	1.68E 04	-1.385E-04	5.853E-04	4.634E-04
27	1	1.8000E 00	5.000E-02	4.40180E 04	1.223E 00	2.519E 00	1.75E 04	-1.562E-04	6.431E-04	5.090E-04
28	1	1.8500E 00	5.000E-02	4.47062E 04	1.242E 00	3.248E 00	1.38E 04	-1.749E-04	6.894E-04	5.336E-04
29	1	1.9000E 00	5.000E-02	4.51928E 04	1.259E 00	4.644E 00	9.73E 03	-1.941E-04	7.241E-04	5.496E-04
30	1	1.9500E 00	5.000E-02	4.56776E 04	1.269E 00	4.710E 00	9.70E 03	-2.138E-04	7.588E-04	5.651E-04
31	1	2.0000E 00	5.000E-02	4.61610E 04	1.282E 00	4.775E 00	9.67E 03	-2.341E-04	7.935E-04	5.801E-04
32	1	2.0500E 00	5.000E-02	4.64260E 04	1.290E 00	8.759E 00	5.30E 03	-2.543E-04	8.166E-04	5.830E-04

THE COOLANT TEMPERATURE FOR BUNDLE TYPE 3, AXIAL NODE 5 IS 1.7831E 03 DEGREES FAHRENHEIT-VOIDING HAS BEEN INITIATED

A TEMPERATURE FOR RADIAL NODE 12 BUNDLE TYPE 3 EXCEEDED 1.7500E 03 DEGREES FAHRENHEIT AT TIME 2.0500E 00 SECONDS,
 COOLANT VELOCITY CHANGES HAVE PROPAGATED TO BUNDLE TYPE 4

33	1	2.1000E 00	5.000E-02	4.7973E 04	1.333E 00	1.551E 00	3.09E 04	-2.774E-04	9.064E-04	6.525E-04
34	1	2.1500E 00	5.000E-02	5.1291E 04	1.425E 00	7.729E-01	6.64E 04	-3.078E-04	1.074E-03	7.969E-04
35	1	2.2000E 00	5.000E-02	5.5003E 04	1.528E 00	7.409E-01	7.42E 04	-3.450E-04	1.242E-03	9.349E-04
36	1	2.2250E 00	2.500E-02	5.7774E 04	1.605E 00	9.212E-01	1.11E 05	-3.654E-04	1.362E-03	1.018E-03
37	2	2.2500E 00	2.500E-02	5.9573E 04	1.655E 00	8.278E-01	7.20E 04	-3.883E-04	1.435E-03	1.070E-03
38	1	2.2750E 00	2.500E-02	6.1121E 04	1.698E 00	9.869E-01	6.19E 04	-4.111E-04	1.496E-03	1.109E-03
39	2	2.3000E 00	2.500E-02	6.2328E 04	1.731E 00	1.292E 00	4.82E 04	-4.361E-04	1.546E-03	1.138E-03
40	1	2.3250E 00	2.500E-02	6.3581E 04	1.766E 00	1.268E 00	9.01E 04	-4.604E-04	1.596E-03	1.161E-03

NUMBER OF COMPLETED KINETICS TIME STEPS	NUMBER OF KINETICS SINCE LAST HEAT TRANSFER CALC	ELAPSED TIME SINCE START OF TRANSIENT (SEC)	TIME STEP SIZE (SEC)	FUEL AVERAGE POWER DENSITY (BTU/) (SEC-) (CU, FT)	RELATIVE NEUTRON DENSITY	REACTOR PERIOD (SEC)	RATE OF POWER INCREASE (BTU/SEC-) (CU, FT/) (SEC)	DOPPLER REACTIVITY (AT END) (OF TIME) (STEP)	TEMPERATURE INDEPENDENT REACTIVITY (AT) (CENTER OF) (TIME STEP)	TOTAL REACTIVITY (USED IN) (KINETICS) (CALC)
41	2	2.3500E 00	2.500E-02	6.48245E 04	1.801E 00	1.304E 00	4.97E 04	-4.871E-04	1.646E-03	1.186E-03
42	1	2.3750E 00	2.500E-02	6.61194E 04	1.837E 00	1.276E 00	5.18E 04	-5.130E-04	1.696E-03	1.211E-03
43	2	2.4000E 00	2.500E-02	6.73976E 04	1.872E 00	1.318E 00	5.11E 04	-5.412E-04	1.747E-03	1.234E-03
44	1	2.4250E 00	2.500E-02	6.88409E 04	1.912E 00	1.192E 00	5.77E 04	-5.687E-04	1.799E-03	1.260E-03
45	1	2.4500E 00	2.500E-02	7.03975E 04	1.955E 00	1.131E 00	6.23E 04	-5.981E-04	1.855E-03	1.287E-03
46	1	2.4750E 00	2.500E-02	7.15275E 04	1.987E 00	1.382E 00	4.52E 04	-6.281E-04	1.900E-03	1.302E-03
47	1	2.5000E 00	2.500E-02	7.22038E 04	2.006E 00	2.669E 00	2.70E 04	-6.582E-04	1.934E-03	1.306E-03
48	1	2.5250E 00	2.500E-02	7.28767E 04	2.024E 00	2.707E 00	2.69E 04	-6.884E-04	1.967E-03	1.309E-03
49	1	2.5500E 00	2.500E-02	7.35466E 04	2.043E 00	2.745E 00	2.68E 04	-7.186E-04	2.001E-03	1.313E-03
50	1	2.5750E 00	2.500E-02	7.42136E 04	2.061E 00	2.782E 00	2.67E 04	-7.490E-04	2.034E-03	1.316E-03
51	1	2.6000E 00	2.500E-02	7.48780E 04	2.080E 00	2.818E 00	2.66E 04	-7.794E-04	2.068E-03	1.319E-03

THE COOLANT TEMPERATURE FOR BUNDLE TYPE 4, AXIAL NODE 5 IS 1.7644E 03 DEGREES FAHRENHEIT-VOIDING HAS BEEN INITIATED

A TEMPERATURE FOR RADIAL NODE 12 BUNDLE TYPE 4 EXCEEDED 1.7500E 03 DEGREES FAHRENHEIT AT TIME 2.6000E 00 SECONDS.
COOLANT VELOCITY CHANGES HAVE PROPAGATED TO BUNDLE TYPE 5

52	1	2.6250E 00	2.500E-02	7.79871E 04	2.166E 00	6.271E-01	1.24E 05	-8.122E-04	2.156E-03	1.377E-03
53	1	2.6500E 00	2.500E-02	8.40704E 04	2.335E 00	3.455E-01	2.43E 05	-8.503E-04	2.299E-03	1.487E-03
54	1	2.6750E 00	2.500E-02	9.02225E 04	2.506E 00	3.666E-01	2.46E 05	-8.933E-04	2.431E-03	1.581E-03
55	1	2.7000E 00	2.500E-02	9.62539E 04	2.674E 00	3.990E-01	2.41E 05	-9.407E-04	2.552E-03	1.659E-03
56	1	2.7250E 00	2.500E-02	1.02799E 05	2.856E 00	3.927E-01	2.62E 05	-9.929E-04	2.673E-03	1.733E-03
57	1	2.7375E 00	1.250E-02	1.07314E 05	2.981E 00	2.971E-01	3.61E 05	-1.020E-03	2.763E-03	1.771E-03
58	2	2.7500E 00	1.250E-02	1.10886E 05	3.080E 00	3.881E-01	2.86E 05	-1.049E-03	2.824E-03	1.804E-03
59	1	2.7625E 00	1.250E-02	1.14634E 05	3.184E 00	3.823E-01	3.00E 05	-1.079E-03	2.884E-03	1.836E-03
60	2	2.7750E 00	1.250E-02	1.18454E 05	3.290E 00	3.876E-01	3.06E 05	-1.110E-03	2.949E-03	1.866E-03
61	1	2.7875E 00	1.250E-02	1.22453E 05	3.401E 00	3.828E-01	3.20E 05	-1.142E-03	3.005E-03	1.896E-03
62	2	2.8000E 00	1.250E-02	1.26507E 05	3.514E 00	3.901E-01	3.24E 05	-1.176E-03	3.065E-03	1.923E-03
63	1	2.8125E 00	1.250E-02	1.29840E 05	3.607E 00	4.869E-01	2.67E 05	-1.211E-03	3.118E-03	1.942E-03
64	1	2.8250E 00	1.250E-02	1.32240E 05	3.673E 00	6.889E-01	1.92E 05	-1.246E-03	3.163E-03	1.953E-03
65	1	2.8375E 00	1.250E-02	1.34647E 05	3.740E 00	6.993E-01	1.93E 05	-1.281E-03	3.208E-03	1.962E-03
66	1	2.8500E 00	1.250E-02	1.37060E 05	3.807E 00	7.099E-01	1.93E 05	-1.317E-03	3.252E-03	1.971E-03
67	1	2.8625E 00	1.250E-02	1.38767E 05	3.895E 00	1.016E 00	1.37E 05	-1.354E-03	3.291E-03	1.974E-03
68	1	2.8750E 00	1.250E-02	1.39757E 05	3.882E 00	1.765E 00	7.92E 04	-1.390E-03	3.325E-03	1.972E-03
69	1	2.8875E 00	1.250E-02	1.40755E 05	3.910E 00	1.764E 00	7.98E 04	-1.426E-03	3.359E-03	1.969E-03
70	1	2.9000E 00	1.250E-02	1.41760E 05	3.938E 00	1.763E 00	8.04E 04	-1.462E-03	3.392E-03	1.967E-03
71	1	2.9125E 00	1.250E-02	1.42773E 05	3.966E 00	1.761E 00	8.11E 04	-1.497E-03	3.426E-03	1.964E-03

THE TEMPERATURE AT RADIAL NODE 7, AXIAL NODE 5 AND BUNDLE TYPE 1 IS 5.2000E 03 DEGREES FAHRENHEIT-THE FUEL HAS FAILED

72	1	2.9250E 00	1.250E-02	1.44484E 05	4.013E 00	1.056E 00	1.37E 05	-1.533E-03	3.465E-03	1.968E-03
73	1	2.9375E 00	1.250E-02	1.46900E 05	4.081E 00	7.599E-01	1.93E 05	-1.570E-03	3.509E-03	1.976E-03
74	1	2.9500E 00	1.250E-02	1.49322E 05	4.148E 00	7.707E-01	1.94E 05	-1.606E-03	3.553E-03	1.984E-03
75	1	2.9625E 00	1.250E-02	1.51745E 05	4.215E 00	7.827E-01	1.94E 05	-1.643E-03	3.597E-03	1.991E-03
76	1	2.9750E 00	1.250E-02	1.54172E 05	4.283E 00	7.942E-01	1.94E 05	-1.681E-03	3.641E-03	1.998E-03
77	1	2.9875E 00	1.250E-02	1.56602E 05	4.350E 00	8.054E-01	1.94E 05	-1.718E-03	3.685E-03	2.005E-03
78	1	3.0000E 00	1.250E-02	1.59037E 05	4.418E 00	8.166E-01	1.95E 05	-1.757E-03	3.729E-03	2.011E-03

THE COOLANT TEMPERATURE FOR BUNDLE TYPE 5, AXIAL NODE 6 IS 1.7627E 03 DEGREES FAHRENHEIT-VOIDING HAS BEEN INITIATED

A TEMPERATURE FOR RADIAL NODE 12 BUNDLE TYPE 5 EXCEEDED 1.7500E 03 DEGREES FAHRENHEIT AT TIME 3.0000E 00 SECONDS.
COOLANT VELOCITY CHANGES HAVE PROPAGATED TO BUNDLE TYPE 6.

79 1 3.0125E 00 1.250E-02 1.65462E 05 4.596E 00 3.219E-01 5.14E 05 -1.796E-03 3.799E-03 2.043E-03

CURRENT COMPOSITE REACTIVITY-VERSUS TIME TABLE

ELAPSED TIME = 3.012500 SECONDS

TIME (SECONDS)	REACTIVITY
0.	0.
7.00000E-01	0.
9.00000E-01	5.45137E-05
1.10000E 00	9.34520E-05
1.30000E 00	1.16815E-04
1.40000E 00	1.20709E-04
1.50000E 00	2.86538E-04
1.60000E 00	4.44580E-04
1.70000E 00	5.56355E-04
1.80000E 00	6.72023E-04
2.00000E 00	8.10826E-04
2.05000E 00	8.22392E-04
2.20000E 00	1.32629E-03
2.25000E 00	1.47112E-03
2.40000E 00	1.77156E-03
2.45000E 00	1.88327E-03
2.60000E 00	2.08436E-03
2.65000E 00	2.37070E-03
2.80000E 00	3.09568E-03
2.85000E 00	3.27468E-03
2.91250E 00	3.44257E-03
3.00000E 00	3.75152E-03
3.00000E 00	3.75152E-03
3.01250E 00	3.84638E-03
3.05000E 00	4.12439E-03
3.11250E 00	4.61567E-03
3.20000E 00	5.28605E-03
3.20000E 00	5.28605E-03
3.21250E 00	5.34718E-03
3.31250E 00	5.81739E-03
3.40000E 00	6.21221E-03
3.40000E 00	6.21221E-03
3.41250E 00	6.23398E-03
3.51250E 00	6.38973E-03
3.60000E 00	6.50939E-03
3.60000E 00	6.50939E-03
3.61250E 00	6.51535E-03
3.71250E 00	6.54415E-03
3.80000E 00	6.55194E-03

CURRENT COMPOSITE REACTIVITY-VERSUS TIME TABLE

ELAPSED TIME = 3.012500 SECONDS

TIME (SECONDS)	REACTIVITY
3.81250E 00	6.53409E-03
3.91250E 00	6.37375E-03
4.00000E 00	6.30736E-03
1.00000E 06	6.30736E-03

STEADY STATE NODAL TEMPERATURES
(DEGREES FAHRENHEIT)

TEMPERATURES FOR BUNDLE TYPE 1

AX.NODE/RA.NODE	1	2	3	4	5	6	7	8	9	10	11	12
1	2408.14	2375.62	2314.66	2228.12	2118.31	1987.23	1836.63	1668.07	1483.45	1284.50	782.09	730.55
2	2984.25	2940.18	2857.56	2740.26	2591.23	2413.21	2208.61	1979.81	1729.37	1459.97	818.19	754.19
3	3430.40	3377.97	3278.53	3137.95	2959.42	2746.02	2500.42	2229.63	1924.63	1600.85	855.13	782.21
4	3843.82	3783.55	3670.27	3508.77	3303.12	3056.90	2773.34	2455.53	2107.12	1732.16	894.97	813.75
5	3970.85	3908.90	3792.49	3626.49	3414.42	3160.07	2866.76	2537.79	2176.83	1788.01	930.80	847.43
6	3916.40	3856.08	3742.71	3581.09	3374.86	3127.65	2842.67	2523.07	2172.36	1794.50	962.33	881.11
7	3590.85	3537.11	3436.37	3293.40	3111.81	2894.66	2644.69	2364.65	2057.49	1726.64	985.57	912.65
8	3219.81	3174.46	3089.40	2968.67	2815.32	2631.84	2420.63	2184.05	1924.53	1644.70	1004.66	940.66
9	2703.70	2669.45	2609.27	2514.22	2398.61	2260.38	2101.20	1922.90	1727.12	1515.68	1015.85	964.31

TEMPERATURES FOR BUNDLE TYPE 2

AX.NODE/RA.NODE	1	2	3	4	5	6	7	8	9	10	11	12
1	2391.47	2359.29	2298.96	2213.32	2104.67	1974.99	1825.99	1659.22	1476.56	1279.69	781.68	730.54
2	2962.02	2918.40	2836.64	2720.54	2573.07	2396.91	2194.45	1968.07	1720.25	1453.68	817.66	754.15
3	3404.66	3352.37	3254.35	3119.20	2938.50	2727.28	2484.18	2212.20	1914.31	1593.85	854.51	782.14
4	3817.84	3758.05	3645.66	3485.42	3281.53	3037.48	2756.49	2441.59	2096.41	1724.98	894.26	813.65
5	3943.81	3882.35	3766.84	3602.16	3391.91	3139.83	2849.20	2523.29	2165.72	1780.59	930.03	847.29
6	3890.25	3830.40	3717.93	3557.57	3353.10	3108.08	2825.69	2509.03	2161.59	1787.29	961.55	880.94
7	3565.01	3511.82	3412.12	3270.61	3090.87	2875.91	2628.47	2351.26	2047.21	1719.68	984.82	912.45
8	3197.70	3152.79	3068.60	2949.09	2797.30	2615.66	2406.60	2172.40	1915.52	1638.50	1003.95	940.44
9	2686.12	2652.24	2588.75	2498.66	2384.28	2247.49	2089.99	1913.55	1719.80	1510.54	1015.20	964.05

TEMPERATURES FOR BUNDLE TYPE 3

AX.NODE/RA.NODE	1	2	3	4	5	6	7	8	9	10	11	12
1	2377.02	2345.14	2285.36	2200.49	2092.85	1964.36	1816.75	1651.54	1470.57	1275.51	781.34	730.53
2	2942.46	2899.25	2818.23	2703.19	2557.06	2382.58	2182.01	1957.75	1712.25	1448.17	817.23	754.15
3	3381.60	3329.79	3232.67	3094.79	2919.72	2710.44	2469.61	2209.17	1905.97	1587.59	854.01	752.13
4	3794.55	3735.17	3623.57	3464.52	3262.22	3020.14	2741.47	2429.18	2085.90	1718.62	893.76	713.64
5	3920.16	3859.13	3744.43	3580.90	3372.25	3122.15	2833.68	2510.44	2155.04	1774.15	925.45	77.28
6	3967.25	3907.83	3796.14	3536.91	3333.99	3090.80	2810.40	2496.73	2152.17	1781.01	966.98	761.92
7	3542.19	3489.49	3390.71	3250.49	3072.38	2859.75	2614.18	2339.49	2038.18	1713.62	984.29	712.42
8	3178.48	3135.97	3050.56	2932.13	2781.66	2601.65	2394.45	2162.75	1907.77	1633.22	1003.48	748.41
9	2671.18	2637.62	2574.72	2485.47	2372.14	2236.59	2080.52	1905.48	1713.66	1506.28	1014.82	764.12

TEMPERATURES FOR BUNDLE TYPE 4

AX.NODE/RA.NODE	1	2	3	4	5	6	7	8	9	10	11	12
1	2362.23	2330.64	2271.42	2187.37	2080.77	1953.44	1807.35	1643.71	1464.48	1271.26	761.53	730.57
2	2923.17	2880.35	2797.07	2636.18	2441.33	2258.45	2169.76	1947.41	1704.48	1442.79	816.91	754.26
3	3359.19	3307.85	3211.62	3074.99	2901.51	2694.13	2455.51	2188.85	1896.18	1581.62	853.72	762.33
4	3770.98	3712.03	3601.22	3443.42	3242.78	3002.75	2728.43	2416.77	2077.51	1712.42	893.45	713.64
5	3896.78	3836.19	3722.30	3559.93	3352.89	3104.79	2818.88	2498.12	2146.70	1768.05	929.30	747.66
6	3844.88	3785.68	3674.98	3516.88	3315.50	3074.38	2796.50	2485.10	2143.30	1775.24	960.94	781.43
7	3520.52	3468.30	3370.42	3231.46	3054.94	2843.85	2600.62	2328.59	2029.95	1718.26	984.42	713.74
8	3160.13	3116.13	3033.35	2915.99	2766.90	2588.48	2383.13	2153.79	1900.78	1628.65	1003.76	741.11
9	2657.13	2623.85	2561.57	2473.14	2360.65	2226.52	2071.87	1898.62	1708.33	1512.78	1015.26	764.12

TEMPERATURES FOR BUNDLE TYPE 5

AX.NODE/RA.NODE	1	2	3	4	5	6	7	8	9	10	11	12
1	2331.26	2300.33	2242.23	2159.88	2055.46	1930.13	1787.58	1627.28	1451.67	1262.29	761.26	730.56
2	2882.24	2840.25	2751.53	2649.74	2517.86	2358.43	2183.58	1927.16	1687.59	1431.17	815.96	754.22
3	3311.03	3260.75	3166.34	3032.87	2862.29	2658.96	2425.16	2163.77	1876.71	1588.45	852.61	762.26
4	3720.19	3662.12	3552.98	3397.84	3200.72	2964.95	2693.67	2389.82	2156.79	1898.53	892.19	713.83
5	3846.48	3786.80	3674.64	3514.73	3311.07	3067.19	2786.28	2471.77	2126.14	1754.23	927.96	77.54
6	3796.18	3738.07	3628.84	3473.13	3275.15	3037.96	2764.96	2458.91	2123.38	1781.83	959.61	761.25
7	3472.83	3421.64	3325.66	3189.40	3016.27	2809.24	2570.66	2303.77	2010.95	1695.41	983.17	712.72
8	3119.34	3076.11	2995.05	2879.97	2733.75	2558.74	2357.34	2131.70	1884.23	1617.30	1002.60	740.76
9	2625.41	2592.83	2531.76	2445.98	2335.00	2203.29	2051.66	1881.78	1695.16	1493.56	1014.25	764.13

TEMPERATURES FOR BUNDLE TYPE 6

AX.NODE/RA.NODE	1	2	3	4	5	6	7	8	9	10	11	12
1	2285.46	2255.40	2199.10	2119.29	2018.10	1897.30	1758.41	1603.01	1432.72	1249.01	779.18	730.54
2	2823.35	2782.58	2706.11	2597.57	2459.88	2295.48	2106.45	1895.17	1663.81	1414.92	814.57	754.17
3	3240.61	3191.74	3100.10	2970.05	2804.96	2607.55	2380.54	2126.54	1848.44	1549.12	850.99	782.18
4	3643.41	3586.65	3480.24	3329.22	3137.49	2908.27	2644.57	2349.32	2025.76	1677.69	890.35	813.70
5	3771.91	3713.58	3603.94	3447.79	3249.24	3011.61	2738.15	2431.61	2095.55	1733.81	926.04	847.37
6	3721.84	3665.04	3558.28	3406.48	3213.58	2982.81	2717.18	2419.47	2093.04	1741.56	957.68	881.03
7	3402.65	3352.94	3259.74	3127.40	2959.29	2758.20	2526.69	2267.39	1982.91	1676.41	981.37	912.56
8	3059.29	3017.31	2938.60	2826.84	2684.80	2514.86	2319.31	2100.19	1859.86	1600.56	1000.96	940.56
9	2578.86	2547.25	2488.01	2403.90	2297.06	2169.18	2021.99	1857.06	1675.82	1460.01	1012.83	964.20

TEMPERATURES FOR BUNDLE TYPE 7

AX.NODE/RA.NODE	1	2	3	4	5	6	7	8	9	10	11	12
1	2223.04	2194.52	2140.52	2064.22	1967.45	1851.85	1718.85	1570.04	1406.90	1230.86	777.72	730.55
2	2742.91	2703.75	2630.38	2526.35	2394.41	2236.85	2055.74	1853.31	1631.54	1392.91	812.77	754.21
3	3145.54	3098.65	3010.77	2886.56	2727.69	2538.28	2320.52	2076.85	1810.09	1522.96	848.98	782.25
4	3535.10	3480.64	3378.58	3233.72	3049.76	2829.85	2576.79	2293.54	1983.07	1649.03	888.14	813.81
5	3667.22	3610.71	3504.64	3354.74	3162.61	2934.12	2660.98	2374.26	2053.20	1705.51	923.80	847.51
6	3617.93	3562.98	3460.01	3313.88	3126.33	2906.44	2651.09	2365.06	2051.44	1713.76	955.54	881.21
7	3308.38	3260.65	3171.15	3044.04	2882.62	2689.54	2467.23	2218.28	1945.24	1650.99	979.51	912.78
8	2979.31	2939.00	2863.43	2756.09	2619.63	2456.46	2268.70	2058.30	1827.53	1578.47	999.37	940.81
9	2517.48	2487.16	2430.31	2349.58	2246.99	2124.24	1982.97	1824.62	1650.56	1462.45	1011.64	964.47

TEMPERATURES FOR BUNDLE TYPE 8

AX.NODE/RA.NODE	1	2	3	4	5	6	7	8	9	10	11	12
1	2147.23	2120.10	2069.29	1997.20	1905.71	1796.34	1670.51	1529.69	1375.23	1208.53	775.91	730.56
2	2642.84	2605.84	2536.51	2438.17	2313.39	2164.26	1992.91	1801.33	1591.40	1365.42	810.55	754.25
3	3027.51	2983.10	2899.83	2781.63	2631.46	2451.99	2245.68	2014.85	1762.12	1490.13	846.47	782.31
4	3402.36	3350.74	3253.97	3116.58	2942.10	2733.51	2493.39	2224.58	1930.26	1613.41	885.37	813.91
5	3531.01	3477.30	3376.62	3233.73	3052.24	2835.26	2585.53	2305.93	1999.38	1669.42	920.99	847.64
6	3485.58	3433.50	3335.83	3197.29	3021.22	2810.70	2568.34	2296.95	1999.30	1678.77	952.84	881.38
7	3192.69	3147.35	3052.35	2941.72	2788.49	2605.17	2394.19	2157.91	1898.82	1619.51	977.13	912.98
8	2880.62	2842.33	2757.53	2651.50	2521.40	2364.40	2185.19	1987.17	1750.80	1550.80	997.35	941.40
9	2442.56	2413.77	2359.01	2283.15	2185.70	2069.17	1935.06	1784.69	1619.41	1440.72	1010.67	964.72

TEMPERATURES FOR BUNDLE TYPE 9

AX.NODE/RA.NODE	1	2	3	4	5	6	7	8	9	10	11	12
1	2103.84	2077.63	2028.51	1956.83	1870.35	1764.55	1642.86	1506.65	1357.20	1195.89	774.82	730.55
2	2584.11	2548.36	2481.37	2386.33	2265.69	2121.50	1955.84	1770.57	1567.59	1349.01	809.16	754.20
3	2958.37	2915.39	2834.79	2720.35	2574.96	2401.26	2201.62	1978.30	1733.77	1470.61	844.85	782.22
4	3323.27	3273.30	3179.61	3046.56	2877.67	2675.73	2443.36	2183.32	1898.46	1591.83	883.53	813.77
5	3450.07	3398.09	3308.65	3162.31	2986.61	2776.51	2534.67	2263.95	1967.15	1647.64	919.06	847.46
6	3407.00	3356.59	3262.07	3127.88	2957.42	2753.59	2518.48	2256.08	1967.89	1657.52	950.90	881.15
7	3124.08	3080.19	2997.92	2881.13	2732.75	2555.17	2350.65	2122.00	1871.79	1600.52	975.33	912.70
8	2822.02	2784.91	2715.32	2616.47	2490.96	2340.99	2168.36	1975.03	1762.91	1533.98	995.69	940.73
9	2397.70	2369.82	2317.54	2243.26	2148.89	2036.07	1906.20	1760.55	1600.46	1427.33	1008.64	964.38

TEMPERATURES FOR BUNDLE TYPE 10

AX.NODE/RA.NODE	1	2	3	4	5	6	7	8	9	10	11	12
1	2268.84	2239.13	2183.50	2104.63	2004.62	1885.21	1747.90	1594.26	1425.88	1244.20	778.78	730.53
2	2802.26	2761.91	2686.24	2578.89	2442.71	2280.11	2093.14	1884.18	1655.33	1409.13	814.05	754.14
3	3215.62	3167.26	3076.60	2947.95	2784.62	2589.31	2364.73	2113.46	1838.35	1542.22	850.38	782.11
4	3614.57	3558.39	3453.10	3303.71	3114.03	2887.28	2626.41	2334.36	2014.30	1669.97	889.64	813.61
5	3744.37	3686.52	3577.79	3423.08	3226.44	2991.18	2720.40	2416.95	2084.30	1726.26	925.28	847.24
6	2977.70	2936.18	2858.34	2747.79	2607.29	2439.34	2246.17	2029.85	1792.76	1537.16	937.77	877.44
7	3369.25	3320.11	3227.97	3097.13	2930.94	2732.19	2503.27	2246.94	1965.78	1662.87	973.77	905.51
8	3029.33	2987.84	2910.05	2799.58	2659.18	2491.24	2297.99	2081.44	1843.95	1587.71	993.39	933.48
9	2553.53	2522.31	2463.80	2380.73	2275.18	2148.86	2003.48	1840.57	1661.53	1468.11	1005.34	957.09

TEMPERATURES FOR BUNDLE TYPE 11

AX.NODE/RA.NODE	1	2	3	4	5	6	7	8	9	10	11	12
1	1937.24	1914.47	1871.79	1811.17	1734.16	1642.16	1536.37	1417.86	1287.63	1146.98	770.51	730.57
2	2355.73	2324.72	2266.58	2184.07	2079.42	1954.49	1810.90	1650.15	1474.01	1284.05	803.85	754.27
3	2686.90	2649.47	2579.36	2479.93	2353.78	2203.04	2029.78	1836.02	1623.63	1394.93	838.85	782.35
4	3012.71	2969.22	2887.69	2771.94	2624.86	2449.08	2246.97	2020.77	1773.02	1506.24	876.89	813.96
5	3131.20	3085.89	3000.97	2880.44	2727.34	2544.18	2333.52	2097.67	1839.29	1560.87	912.30	847.71
6	3098.55	3054.59	2972.19	2855.20	2706.59	2526.78	2324.25	2095.19	1844.13	1573.48	944.40	881.47
7	2853.86	2815.57	2743.75	2641.74	2512.20	2357.40	2179.28	1979.84	1761.10	1525.15	969.58	913.08
8	2589.61	2557.33	2496.82	2410.93	2301.83	2171.28	2021.05	1852.75	1667.86	1468.19	990.75	941.16
9	2225.22	2200.89	2155.28	2090.56	2008.36	1916.02	1796.69	1669.47	1529.54	1378.01	1004.79	964.86

TEMPERATURES FOR BUNDLE TYPE 12

AX.NODE/RA.NODE	1	2	3	4	5	6	7	8	9	10	11	12
1	1538.55	1523.80	1496.14	1456.83	1406.82	1346.92	1277.90	1200.43	1115.15	1022.86	759.58	730.56
2	1818.62	1798.64	1761.20	1706.11	1640.73	1560.19	1467.48	1363.46	1249.10	1125.40	790.26	754.22
3	2042.12	2018.15	1973.22	1909.44	1828.40	1731.43	1619.84	1494.86	1357.55	1209.15	823.32	782.27
4	2270.81	2242.64	2139.87	2115.04	2020.11	1906.71	1776.23	1630.07	1469.71	1296.48	859.57	813.84
5	2363.31	2333.92	2278.81	2200.53	2101.21	1982.56	1846.11	1693.18	1525.39	1344.21	894.49	847.55
6	2355.58	2326.98	2273.35	2197.19	2100.53	1985.04	1852.18	1703.23	1539.71	1363.05	926.99	861.26
7	2205.35	2180.45	2133.79	2067.57	1983.49	1852.91	1767.02	1637.01	1494.12	1339.46	953.89	912.83
8	2045.80	2024.75	1985.27	1929.19	1857.90	1772.48	1674.01	1563.49	1441.83	1309.86	976.91	940.87
9	1818.42	1802.33	1772.15	1729.30	1674.85	1609.66	1534.45	1449.87	1356.51	1255.05	993.56	964.54

STEADY STATE AVERAGE FUEL TEMPERATURES
(DEGREES FAHRENHEIT)

AX,NODE/BN,TYPE	1	2	3	4	5	6	7	8	9	10	11	12
1	1871.54	1860.63	1851.08	1841.32	1820.87	1790.64	1749.57	1699.45	1670.61	1779.72	1560.52	1293.25
2	2256.33	2241.70	2228.83	2216.15	2189.18	2150.62	2098.06	2032.84	1994.40	2136.83	1844.17	1488.39
3	2557.21	2540.41	2525.34	2510.75	2479.25	2433.17	2371.01	2293.59	2248.06	2416.81	2070.05	1645.21
4	2837.75	2820.48	2805.05	2789.58	2755.95	2705.37	2635.13	2548.76	2497.02	2686.58	2293.74	1806.12
5	2932.35	2914.38	2898.69	2883.31	2849.90	2800.49	2731.43	2642.93	2590.25	2762.25	2382.04	1877.34
6	2906.59	2889.20	2873.94	2859.27	2826.93	2777.79	2709.65	2623.88	2572.65	2290.58	2371.19	1882.45
7	2701.86	2685.05	2670.24	2656.37	2625.33	2579.59	2516.09	2442.50	2397.61	2555.61	2220.16	1793.09
8	2468.86	2454.34	2441.76	2430.01	2403.30	2363.92	2311.54	2246.59	2207.86	2342.09	2055.24	1795.84
9	2137.44	2125.82	2116.00	2107.12	2086.08	2055.35	2014.93	1965.37	1935.52	2036.42	1821.99	1550.82

COOLANT EXIT TEMPERATURES (DEGREES FAHRENHEIT)

ELAPSED TIME = 0. SECONDS

BUNDLE TYPE	1	2	3	4	5	6	7	8	9	10	11	12
	974.85	974.59	974.55	975.37	975.08	974.74	975.02	975.29	974.93	967.62	975.43	975.18

PRECURSOR DENSITIES

GROUP	1	2	3	4	5	6
	9.89583E 03	3.55626E 04	7.03895E 03	5.34362E 03	5.92972E 02	6.83491E 01

TRANSIENT NODAL TEMPERATURES
(DEGREES FAHRENHEIT)

ELAPSED TIME = 3.612500 SECONDS

TEMPERATURES FOR BUNDLE TYPE 1

AX.NODE/RA.NODE	1	2	3	4	5	6	7	8	9	10	11	12
1	3949.02	3936.70	3913.21	3878.83	3833.08	3774.53	3700.51	3606.58	3485.96	3328.92	2974.59	1298.39
2	4723.94	4707.22	4675.53	4629.57	4569.16	4493.02	4398.34	4280.14	4130.45	3937.46	3513.32	1471.69
3	5200.00	5200.00	5200.00	5192.39	5121.45	5030.93	4919.24	4781.28	4608.40	4387.47	3998.71	1606.46
4	5200.00	5200.00	5200.00	5200.00	5200.00	5200.00	5200.00	5200.00	5046.11	4807.17	4276.72	1731.74
5	5200.00	5200.00	5200.00	5200.00	5200.00	5200.00	5200.00	5200.00	5146.40	4925.58	4389.26	1785.66
6	5200.00	5200.00	5200.00	5200.00	5200.00	5200.00	5200.00	5200.00	5093.30	4860.63	4332.24	1792.74
7	5200.00	5200.00	5200.00	5200.00	5200.00	5148.00	5036.76	4897.83	4724.02	4502.44	4023.47	1728.82
8	4903.21	4885.77	4852.76	4805.05	4742.57	4664.22	4567.35	4447.20	4295.98	4102.04	3680.07	1650.81
9	4165.39	4152.44	4127.86	4092.12	4044.96	3985.23	3910.32	3815.54	3694.98	3537.62	3187.36	1526.31

TEMPERATURES FOR BUNDLE TYPE 2

AX.NODE/RA.NODE	1	2	3	4	5	6	7	8	9	10	11	12
1	3685.96	3671.69	3644.63	3605.43	3553.95	3489.12	3408.64	3308.50	3182.44	3021.46	2455.67	1391.05
2	4416.48	4396.92	4360.11	4307.36	4239.11	4154.73	4052.02	3926.48	3769.64	3569.00	3128.62	1478.08
3	4971.17	4946.91	4901.38	4836.46	4753.03	4650.77	4527.58	4378.79	4196.22	3967.16	3474.84	1617.29
4	5200.00	5200.00	5200.00	5200.00	5200.00	5114.83	4974.89	4804.80	4597.77	4340.44	3795.16	1747.56
5	5200.00	5200.00	5200.00	5200.00	5200.00	5200.00	5104.60	4934.00	4721.71	4457.29	3897.79	1805.61
6	5200.00	5200.00	5200.00	5200.00	5200.00	5169.13	5035.33	4865.73	4658.36	4400.73	3855.48	1816.83
7	5108.96	5083.97	5037.12	4970.40	4884.85	4786.29	4654.79	4503.90	4319.63	4089.39	3598.59	1756.16
8	4613.97	4593.39	4554.73	4499.48	4426.29	4340.72	4234.79	4106.24	3947.73	3746.75	3310.26	1680.97
9	3927.94	3912.92	3884.55	3843.63	3790.22	3723.45	3641.20	3539.57	3412.34	3250.29	2888.92	1558.35

TEMPERATURES FOR BUNDLE TYPE 3

AX.NODE/RA.NODE	1	2	3	4	5	6	7	8	9	10	11	12
1	3456.65	3438.09	3403.23	3353.49	3289.51	3211.05	3116.60	3003.02	2864.96	2694.45	2305.88	1288.54
2	4160.46	4134.93	4087.31	4020.09	3934.76	3831.40	3708.61	3562.71	3387.04	3171.13	2700.47	1461.05
3	4694.01	4662.09	4602.65	4519.64	4413.68	4287.84	4141.04	3970.19	3767.32	3518.88	2990.72	1597.15
4	5200.00	5162.63	5091.94	4992.69	4868.01	4719.78	4547.93	4349.44	4117.05	3838.14	3257.65	1725.09
5	5200.00	5200.00	5200.00	5135.47	5007.06	4853.92	4674.48	4468.63	4228.32	3940.92	3347.12	1783.10
6	5200.00	5200.00	5160.62	5060.71	4934.89	4785.33	4612.08	4412.23	4178.68	3899.10	3319.86	1795.78
7	4840.51	4807.57	4746.27	4660.09	4551.66	4422.44	4272.13	4097.79	3892.71	3643.22	3117.98	1738.63
8	4370.87	4343.85	4293.49	4222.53	4132.92	4025.56	3899.59	3751.11	3573.29	3355.53	2885.49	1667.78
9	3718.53	3698.75	3681.69	3609.00	3541.61	3459.56	3361.63	3244.84	3103.93	2930.89	2547.32	1550.69

TEMPERATURES FOR BUNDLE TYPE 4

AX.NODE/RA.NODE	1	2	3	4	5	6	7	8	9	10	11	12
1	3305.89	3279.67	3230.61	3161.12	3072.87	2966.79	2842.81	2699.43	2533.08	2337.99	1897.25	1282.97
2	4002.94	3967.79	3902.09	3809.22	3691.66	3551.05	3387.53	3200.63	2985.41	2734.87	2197.26	1450.10
3	4528.50	4485.31	4404.86	4291.77	4149.86	3982.15	3789.39	3569.41	3317.76	3026.16	2419.80	1581.64
4	5028.00	4977.28	4882.76	4749.87	4583.15	4386.24	4161.55	3909.42	3624.19	3294.88	2625.89	1755.57
5	5180.64	5128.01	5029.92	4891.97	4718.82	4514.30	4280.96	4019.21	3725.02	3366.07	2702.35	1764.35
6	5102.25	5051.23	4956.14	4822.40	4654.53	4456.20	4229.89	3975.99	3689.89	3360.03	2693.49	1779.89
7	4682.97	4638.82	4556.54	4440.84	4295.60	4123.88	3927.66	3705.18	3451.33	3157.85	2555.24	1728.36
8	4225.94	4189.31	4121.06	4025.05	3904.20	3759.93	3592.69	3401.36	3162.27	2928.27	2395.85	1664.18
9	3587.36	3559.91	3508.59	3435.94	3343.82	3233.34	3104.66	2956.57	2785.95	2587.01	2152.79	1554.94

TEMPERATURES FOR BUNDLE TYPE 5

AX.NODE/RA.NODE	1	2	3	4	5	6	7	8	9	10	11	12
1	3225.49	3192.87	3131.26	3042.72	2928.31	2788.27	2621.86	2427.23	2201.24	1939.85	1332.48	1275.55
2	3915.96	3873.77	3794.03	3679.29	3530.81	3349.10	3133.51	2882.03	2590.69	2253.07	1503.81	1434.75
3	4434.14	4383.80	4288.97	4153.27	3979.05	3766.72	3514.51	3220.15	2879.17	2484.69	1636.79	1559.51
4	4928.65	4870.43	4760.72	4603.67	4401.90	4156.98	3869.59	3535.79	3149.16	2701.63	1764.38	1679.79
5	5080.96	5020.84	4907.53	4745.25	4536.74	4283.55	3986.26	3642.62	3244.67	2783.70	1827.11	1741.10
6	5005.58	4947.29	4837.45	4680.17	4478.05	4232.63	3944.51	3610.81	3224.24	2776.42	1846.32	1762.69
7	4592.11	4541.32	4445.62	4308.64	4132.67	3919.10	3666.55	3371.56	3029.71	2633.97	1798.04	1722.41
8	4144.61	4101.93	4021.51	3906.25	3757.16	3574.36	3357.22	3103.79	2810.37	2469.76	1736.11	1669.27
9	3516.12	3483.27	3421.21	3332.02	3216.72	3075.52	2907.81	2711.85	2484.11	2219.59	1628.51	1574.02

TEMPERATURES FOR BUNDLE TYPE 6

AX.NODE/RA.NODE	1	2	3	4	5	6	7	8	9	10	11	12
1	3164.41	3131.66	3069.37	2978.65	2858.96	2708.29	2522.36	2295.51	2020.00	1688.00	549.93	780.06
2	3840.71	3798.71	3718.84	3602.56	3449.39	3256.80	3019.71	2730.43	2378.04	1950.39	918.19	834.78
3	4346.15	4296.53	4202.56	4066.71	3889.21	3666.41	3391.85	3056.66	2648.21	2151.20	985.47	891.98
4	4831.39	4774.34	4665.49	4508.74	4304.32	4050.22	3741.05	3363.61	2902.56	2340.05	1055.28	953.82
5	4983.67	4924.41	4812.24	4650.30	4439.18	4176.93	3858.48	3471.37	2998.52	2421.51	1115.70	1013.60
6	4909.79	4852.37	4743.71	4586.64	4382.36	4128.39	3820.02	3444.54	2986.98	2428.74	1166.91	1069.02
7	4504.48	4454.49	4359.86	4223.23	4045.01	3823.31	3551.28	3219.62	2815.87	2324.68	1201.82	1115.25
8	4069.46	4027.37	3947.63	3831.82	3679.55	3488.37	3253.91	2968.55	2622.96	2203.52	1228.38	1153.71
9	3455.38	3422.72	3360.68	3270.57	3152.14	3003.64	2821.66	2600.72	2333.28	2010.43	1239.12	1180.77

TEMPERATURES FOR BUNDLE TYPE 7

AX.NODE/RA.NODE	1	2	3	4	5	6	7	8	9	10	11	12
1	3083.64	3052.06	2991.97	2904.43	2788.95	2643.32	2463.73	2244.55	1978.94	1657.75	836.57	741.24
2	3739.75	3699.17	3621.97	3509.68	3361.83	3175.88	2946.99	2667.68	2327.42	1913.84	902.30	767.61
3	4229.00	4181.39	4091.22	3960.87	3789.68	3574.29	3309.07	2985.37	2591.00	2110.64	968.05	841.06
4	4698.68	4643.59	4539.30	4388.68	4192.23	3948.04	3649.64	3284.98	2839.74	2295.87	1036.58	899.06
5	4850.82	4793.77	4685.78	4529.87	4326.61	4074.02	3767.02	3392.65	2935.46	2377.01	1097.06	959.28
6	4779.61	4724.37	4619.83	4466.91	4272.18	4027.75	3730.41	3367.71	2925.19	2385.16	1149.13	1017.40
7	4387.66	4339.66	4248.79	4117.55	3946.41	3732.49	3469.57	3149.28	2759.64	2285.08	1186.21	1070.37
8	3969.73	3929.20	3852.19	3740.29	3593.12	3408.52	3182.20	2907.12	2573.40	2168.33	1214.92	1115.74
9	3375.64	3344.15	3284.32	3197.41	3083.17	2939.95	2764.42	2551.20	2293.15	1981.39	1228.53	1152.02

TEMPERATURES FOR BUNDLE TYPE 8

AX.NODE/RA.NODE	1	2	3	4	5	6	7	8	9	10	11	12
1	2984.15	2953.99	2876.59	2812.95	2702.49	2563.13	2391.28	2181.59	1927.41	1621.48	832.97	741.27
2	3614.58	3575.79	3502.04	3394.76	3253.52	3075.82	2857.98	2599.13	2264.99	1870.14	898.11	787.91
3	4084.23	4039.13	3953.63	3829.34	3665.60	3459.50	3205.96	2896.67	2519.99	2061.58	963.45	841.24
4	4535.24	4482.94	4383.93	4240.90	4054.21	3821.79	3536.21	3187.40	2761.96	2242.81	1031.75	899.31
5	4683.17	4628.96	4526.35	4378.17	4184.93	3944.84	3651.52	3293.30	2856.21	2322.65	1092.10	959.38
6	4616.59	4564.12	4464.81	4321.41	4134.41	3902.07	3617.80	3270.85	2847.89	2332.04	1144.25	1017.66
7	4243.83	4198.28	4112.05	3987.50	3824.36	3619.65	3368.10	3061.92	2689.81	2237.14	1181.72	1070.53
8	3846.30	3807.53	3733.87	3626.82	3486.09	3309.69	3093.44	2830.72	2512.08	2125.67	1210.68	1115.68
9	3277.17	3247.11	3189.99	3107.06	2997.94	2861.17	2693.51	2489.84	2243.40	1946.04	1224.65	1151.66

TEMPERATURES FOR BUNDLE TYPE 9

AX.NODE/RA,NODE	1	2	3	4	5	6	7	8	9	10	11	12
1	2925.66	2896.32	2840.48	2759.09	2651.52	2515.81	2348.48	2144.36	1897.13	1599.91	830.76	741.24
2	3540.30	3502.59	3430.90	3326.61	3189.22	3016.40	2803.69	2544.02	2227.85	1844.17	895.52	787.84
3	3999.09	3955.36	3872.21	3751.24	3591.83	3391.33	3144.73	2843.93	2477.67	2032.16	960.46	841.11
4	4437.83	4387.20	4291.33	4152.82	3972.07	3746.16	3468.12	3128.73	2715.17	2210.64	1028.49	899.10
5	4583.40	4530.68	4431.47	4287.89	4100.59	3867.71	3582.22	3233.66	2808.60	2289.96	1088.71	959.08
6	4519.51	4468.69	4372.49	4233.57	4052.33	3826.87	3550.15	3212.59	2801.34	2299.93	1140.79	1017.23
7	4158.66	4114.56	4031.05	3910.26	3751.54	3552.18	3307.42	3009.60	2647.82	2208.03	1178.36	1069.92
8	3772.31	3734.60	3662.92	3558.77	3421.93	3250.41	3040.12	2784.72	2474.97	2099.57	1267.38	1114.86
9	3218.13	3188.91	3133.39	3052.74	2946.74	2813.79	2650.76	2452.73	2213.17	1924.30	1221.51	1150.57

TEMPERATURES FOR BUNDLE TYPE 10

AX.NODE/RA,NODE	1	2	3	4	5	6	7	8	9	10	11	12
1	3142.99	3110.56	3045.65	2958.97	2840.41	2691.84	2506.52	2281.95	2008.86	1679.21	838.65	741.18
2	3814.15	3772.52	3693.35	3578.10	3426.32	3235.47	3000.53	2713.85	2364.52	1939.80	904.70	787.84
3	4315.27	4266.18	4173.21	4038.80	3863.02	3642.17	3370.05	3037.85	2632.96	2139.48	970.57	840.77
4	4798.06	4739.31	4631.89	4476.76	4274.45	4022.97	3716.72	3342.63	2885.62	2327.14	1039.18	898.62
5	4948.61	4889.93	4778.86	4618.49	4409.42	4149.70	3834.28	3450.50	2981.63	2408.60	1099.59	958.52
6	3990.71	3948.79	3869.13	3753.34	3600.92	3409.52	3174.58	2888.63	2541.25	2119.22	1117.83	1010.73
7	4465.10	4415.64	4322.02	4186.84	4010.53	3790.85	3521.06	3192.17	2791.77	2303.86	1176.91	1057.80
8	4034.37	3992.76	3913.74	3798.94	3647.96	3458.44	3226.62	2943.42	2600.44	2183.92	1205.63	1103.49
9	3425.14	3392.79	3331.34	3242.08	3124.74	2977.61	2797.27	2578.22	2312.99	1992.38	1219.15	1140.14

TEMPERATURES FOR BUNDLE TYPE 11

AX.NODE/RA,NODE	1	2	3	4	5	6	7	8	9	10	11	12
1	2695.61	2669.37	2619.40	2546.50	2450.17	2328.65	2178.87	1996.67	1776.65	1513.77	822.16	741.29
2	3246.07	3212.59	3148.93	3056.27	2934.16	2780.52	2591.25	2360.33	2079.68	1740.43	885.53	788.04
3	3659.74	3620.61	3546.81	3439.23	3297.62	3119.57	2900.56	2633.51	2308.50	1913.88	949.11	841.39
4	4054.79	4010.75	3927.15	3805.60	3645.52	3444.19	3196.74	2895.11	2528.12	2061.81	1016.27	899.38
5	4188.85	4143.98	4056.41	3931.10	3766.43	3559.44	3304.97	2994.93	2617.82	2159.02	1076.30	959.29
6	4137.16	4092.87	4009.02	3887.53	3727.79	3527.14	3280.51	2980.40	2615.69	2172.29	1128.45	1017.21
7	3821.94	3783.02	3709.06	3601.54	3460.20	3282.97	3065.59	2801.38	2480.77	2091.96	1166.53	1069.41
8	3476.61	3443.20	3379.73	3287.53	3166.33	3014.32	2827.95	2601.57	2327.32	1995.63	1195.88	1113.56
9	2986.02	2960.12	2910.89	2839.36	2745.31	2627.22	2482.40	2306.73	2094.54	1839.37	1210.96	1148.28

TEMPERATURES FOR BRIDLE TYPE 12

AX.NODE/RA.NODE	1	2	3	4	5	6	7	8	9	10	11	12
1	2112.49	2093.84	2058.34	2006.58	1938.30	1852.67	1748.06	1622.38	1472.76	1295.50	799.97	741.21
2	2517.49	2494.06	2449.45	2384.38	2298.46	2190.29	2057.16	1895.68	1701.59	1470.68	858.00	787.55
3	2818.53	2791.65	2740.47	2665.86	2567.38	2443.74	2290.69	2104.97	1880.66	1611.66	918.06	840.15
4	3109.58	3079.15	3021.29	2937.12	2826.25	2686.84	2515.32	2306.62	2053.41	1748.23	981.36	897.44
5	3216.23	3184.86	3125.25	3038.59	2924.53	2781.29	2605.23	2390.93	2131.05	1817.30	1039.21	955.36
6	3191.66	3161.24	3103.44	3019.43	2908.91	2770.18	2599.76	2392.48	2141.32	1838.25	1090.13	1011.08
7	2978.86	2952.64	2901.07	2826.97	2729.48	2606.99	2456.66	2274.16	2053.68	1788.51	1128.59	1060.48
8	2746.98	2723.86	2679.89	2615.95	2531.61	2426.21	2296.00	2140.05	1951.49	1725.75	1158.29	1101.35
9	2409.11	2390.92	2356.35	2306.08	2239.97	2157.17	2056.69	1934.28	1765.82	1616.34	1174.68	1132.47

AVERAGE FUEL TEMPERATURES (DEGREES FAHRENHEIT)

ELAPSED TIME = 3.012500 SECONDS

AX, NODE/BN, TYPE	1	2	3	4	5	6	7	8	9	10	11	12
1	3689.36	3401.55	3118.49	2859.53	2639.07	2518.59	2460.04	2387.77	2345.43	2502.94	2177.19	1750.37
2	4388.92	4048.07	3715.66	3413.62	3156.80	3014.51	2941.86	2852.20	2798.07	2995.20	2567.45	2056.57
3	4895.74	4528.13	4157.12	3824.24	3542.31	3385.82	3303.02	3200.36	3139.44	3365.83	2896.18	2289.05
4	5123.51	4713.81	4371.61	4008.57	3705.53	3737.26	3644.78	3539.90	3462.56	3712.43	3191.92	2512.02
5	5154.01	4986.57	4680.46	4331.12	4024.75	3856.65	3753.88	3647.24	3577.56	3831.94	3300.34	2602.95
6	5137.41	4950.59	4630.41	4278.10	3981.18	3818.24	3727.38	3613.92	3545.88	3171.05	3276.60	2597.87
7	4975.75	4657.14	4293.74	3965.61	3695.21	3547.60	3465.60	3364.32	3303.87	3517.03	3063.19	2455.77
8	4559.65	4233.54	3910.23	3620.60	3380.25	3251.17	3179.71	3091.33	3038.19	3223.17	2826.40	2297.35
9	3900.57	3635.25	3366.07	3123.84	2925.09	2820.51	2763.18	2692.36	2649.66	2795.91	2481.82	2057.91

COOLANT EXIT TEMPERATURES (DEGREES FAHRENHEIT)

ELAPSED TIME = 3.012500 SECONDS

BUNDLE TYPE	1	2	3	4	5	6	7	8	9	10	11	12
	1877.06	1910.04	1896.31	1905.03	1932.20	1222.11	1167.57	1167.02	1165.79	1155.89	1162.97	1145.28

PRECURSOR DENSITIES

GROUP	1	2	3	4	5	6
	1.00906E 04	3.72673E 04	8.43641E 03	7.84541E 03	1.40588E 03	2.27485E 02

DTA CALL NO....1

INPUT EDITS

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CRD NO...1 $ (SAMPLE PROBLEM - FLOW COASTDOWN WITH FULL POWER)
CRD NO...2 $ (COUPLED LOOP FLOW AND VOIDING, KINETICS, HEAT TRANSFER)
CRD NO...3 $ (CORE GEOMETRY INPUT)
CRD NO...4 NRR = 12 $ (NUMBER OF RADIAL CORE REGIONS USED IN THE CALCULATION)
CRD NO...5 $ (OUTER RADIUS OF CORE REGIONS - FT.)
CRD NO...6 RR(1) = .203 .338 .887 1.237 1.988 1.940 2.292 2.644 2.869 3.351 3.704 4.058
CRD NO...7 NBT = 12 $ (NUMBER OF BUNDLE TYPES USED IN CALCULATION)
CRD NO...8 KRB(1) = 1 2 3 4 5 6 7 8 9 10 11 12 $ (RADIAL REGION ASSIGNED TO BUNDLE TYPE)
CRD NO...9 CH = 2.5 $ (CORE HEIGHT - FT.)
CRD NO...10 $ (FUEL PIN GEOMETRY INPUT)
CRD NO...11 NAX = 9 $ (NUMBER OF AXIAL SECTIONS USED)
CRD NO...12 NRN = 10 $ (NUMBER OF RADIAL FUEL NODES USED)
CRD NO...13 RV = .00320 $ (RADIUS OF FUEL PIN CENTRAL VOID - FT.)
CRD NO...14 RF = 9.16667E-3 $ (OUTER RADIUS OF FUEL REGION - FT.)
CRD NO...15 CT = .00128 $ (CLADDING THICKNESS - FT.)
CRD NO...16 PD = 1.20 $ (FUEL PIN PITCH TO DIAMETER RATIO)
CRD NO...17 $ (MATERIAL PROPERTIES)
CRD NO...18 KPRP = 1 $ (FUEL PROPERTIES ARE TEMPERATURE DEPENDENT)
CRD NO...19 RHOF = 609.43 $ (FUEL DENSITY - LB./CU.FT.)
CRD NO...20 QHF = 125.0 $ (FUEL HEAT OF FUSION - BTU/LB.)
CRD NO...21 TMELT = 5200. $ (FUEL MELTING TEMPERATURE - DEG.F)
CRD NO...22 NCF = 1 $ (NUMBER OF FUEL HEAT CAPACITY TABLES INPUT)
CRD NO...23 NCL = 10 $ (NUMBER OF VALUES PER TABLE)
CRD NO...24 $ (HEAT CAPACITY VALUES)
CRD NO...25 PCT(1,1) = 0.063 0.068 0.073 0.076 0.077 *2 0.078 0.090 0.104 0.112
CRD NO...26 $ (TEMPERATURE VALUES)
CRD NO...27 TFC(1,1) = 280. 400. 640. 980. 1300. 1780. 1980. 2800. 4000. 18000.
CRD NO...28 KCF(1) = 1 *12 $ (HEAT CAPACITY TABLE 1 ASSIGNED TO ALL BUNDLE TYPES)
CRD NO...29 NKF = 1 $ (NUMBER OF THERMAL CONDUCTIVITY TABLES INPUT)
CRD NO...30 NKL = 10 $ (NUMBER OF VALUES PER TABLE)
CRD NO...31 $ (THERMAL CONDUCTIVITY VALUES)
CRD NO...32 PKT(1,1) = 5.62E-4 4.95E-4 4.43E-4 4.02E-4 3.55E-4 3.20E-4 2.96E-4
CRD NO...33 PKT(8,1) = 2.80E-4 2.67E-4 2.49E-4 $ (CONDUCTIVITY VALUES)
CRD NO...34 $ (TEMPERATURE VALUES CORRESPONDING TO CONDUCTIVITY VALUES)
CRD NO...35 TFK(1,1) = 887. 1022. 1202. 1427. 1832. 2282. 2732. 3182. 3632. 10000.
CRD NO...36 KKF(1) = 1 *12 $ (THERMAL CONDUCTIVITY TABLE 1 ASSIGNED TO ALL BUNDLE TYPES)
CRD NO...37 RHOC = 501.07 $ (CLAD DENSITY - LB./CU.FT.)
CRD NO...38 CC = 0.12 $ (CLAD HEAT CAPACITY)
CRD NO...39 CK = .0034 $ (CLAD THERMAL CONDUCTIVITY)
CRD NO...40 RHON = 52.615 $ (COOLANT DENSITY - LB./CU.FT.)
CRD NO...41 SC = .303 $ (COOLANT HEAT CAPACITY)
CRD NO...42 SK = .014 $ (COOLANT THERMAL CONDUCTIVITY)
CRD NO...43 GC = 0.4167 $ (GAP COEFFICIENT, FUEL TO CLAD)
CRD NO...44 PLM = 5.556 $ (FILM COEFFICIENT, CLAD TO COOLANT)
CRD NO...45 $ (NOTE - FLJH TABLES NOT REQUIRED FOR RUNNING OPTION 2)
CRD NO...46 NIT = 1 $ (NUMBER OF INLET COOLANT TEMPERATURE TABLES INPUT)
CRD NO...47 NIL = 2 $ (LENGTH OF INLET COOLANT TEMPERATURE TABLES INPUT)
CRD NO...48 TII(1,1) = 720.0 *2 $ (INLET TEMPERATURE VALUES)
CRD NO...49 TTI(1,1) = 0.0 180.0 $ (CORRESPONDING TIME VALUES)

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CRD NO...50 KIT(1) = 1 * 12 $ (INLET TEMPERATURE TABLE 1 ASSIGNED TO BUNDLE TYPE 1)
CRD NO...51 P0 = 36000. $ (INITIAL CORE AVERAGE POWER DENSITY)
CRD NO...52 FPFPD = 0.8 $ (FRACTION OF POWER DUE TO FISSION PRODUCT DECAY - STEADY STATE)
CRD NO...53 A1 = 36000. $ (CONVERSION FACTOR - RELATIVE NEUTRON DENSITY TO POWER DENSITY)
CRD NO...54 $ (POWER PEAKING FACTORS)
CRD NO...55 PPF( 1,1) = .8866 1.1008 1.2543 1.3971 1.4340 1.3971 1.2543 1.1008 .8866
CRD NO...56 PPF( 1,2) = .8798 1.0924 1.2448 1.3865 1.4231 1.3865 1.2448 1.0924 .8798
CRD NO...57 PPF( 1,3) = .8739 1.0850 1.2363 1.3771 1.4135 1.3771 1.2363 1.0850 .8739
CRD NO...58 PPF( 1,4) = .8679 1.0776 1.2279 1.3677 1.4038 1.3677 1.2279 1.0776 .8679
CRD NO...59 PPF( 1,5) = .8658 1.0619 1.2100 1.3478 1.3833 1.3478 1.2100 1.0619 .8658
CRD NO...60 PPF( 1,6) = .8366 1.0388 1.1836 1.3184 1.3532 1.3184 1.1836 1.0388 .8366
CRD NO...61 PPF( 1,7) = .8113 1.0073 1.1478 1.2785 1.3122 1.2785 1.1478 1.0073 .8113
CRD NO...62 PPF( 1,8) = .7808 .9685 1.1035 1.2292 1.2616 1.2292 1.1035 .9685 .7808
CRD NO...63 PPF( 1,9) = .7614 .9454 1.0772 1.1998 1.2315 1.1998 1.0772 .9454 .7614
CRD NO...64 PPF( 1,10) = .8299 1.0305 1.1742 1.3078 1.3424 1.3078 1.1742 1.0305 .8299
CRD NO...65 PPF( 1,11) = .6869 .8529 .9718 1.0824 1.1110 1.0824 .9718 .8529 .6869
CRD NO...66 PPF( 1,12) = .4992 .6198 .7062 .7866 .8074 .7866 .7062 .6198 .4992
CRD NO...67 FHF = 1.0 $ (FRACTION OF HEAT GENERATED IN FUEL)
CRD NO...68 NDG = 0 $ (NUMBER OF DECAY GROUPS USED TO COMPUTE DELAYED POWER)
CRD NO...69 NPG = 6 $ (NUMBER OF DELAYED NEUTRON PRECURSOR GROUPS)
CRD NO...70 $ (EFFECTIVE DELAYED NEUTRON FRACTION FOR DELAY GROUP 1)
CRD NO...71 B(1) = .76-4 6.70-4 5.71-4 11.01-4 4.86-4 1.56-4 $
CRD NO...72 DC(1) = .8128 .8314 .1352 .3434 1.366 3.804 $ (DECAY CONSTANT FOR GROUP 1)
CRD NO...73 PNL = 6-6 $ (PROMPT NEUTRON LIFETIME)
CRD NO...74 $ (DOPPLER COEFFICIENTS)
CRD NO...75 ADOP(1, 1) = -1.532-6 -2.3592-6 -3.0688-6 -3.8066-6 -4.0093-6
CRD NO...76 ADOP(6, 1) = -3.8066-6 -3.0688-6 -2.3592-6 -1.532-6 $
CRD NO...77 ADOP(1, 2) = -9.1500-6 -1.4099-5 -1.8319-5 -2.2722-5 -2.3942-5
CRD NO...78 ADOP(6, 2) = -2.2722-5 -1.8319-5 -1.4099-5 -9.1500-6 $
CRD NO...79 ADOP(1, 3) = -1.7971-5 -2.7692-5 -3.5978-5 -4.4633-5 -4.7029-5
CRD NO...80 ADOP(6, 3) = -4.4633-5 -3.5978-5 -2.7692-5 -1.7971-5 $
CRD NO...81 ADOP(1, 4) = -2.6358-5 -4.0607-5 -5.2761-5 -6.5453-5 -6.8968-5
CRD NO...82 ADOP(6, 4) = -6.5453-5 -5.2761-5 -4.0607-5 -2.6358-5 $
CRD NO...83 ADOP(1, 5) = -3.4150-5 -5.2615-5 -6.8364-5 -8.4806-5 -8.9359-5
CRD NO...84 ADOP(6, 5) = -8.4806-5 -6.8364-5 -5.2615-5 -3.4150-5 $
CRD NO...85 ADOP(1, 6) = -4.0672-5 -6.2668-5 -8.1422-5 -1.0101-4 -1.0643-4
CRD NO...86 ADOP(6, 6) = -1.0101-4 -8.1422-5 -6.2668-5 -4.0672-5 $
CRD NO...87 ADOP(1, 7) = -4.5468-5 -7.0055-5 -9.1017-5 -1.1291-4 -1.1897-4
CRD NO...88 ADOP(6, 7) = -1.1291-4 -9.1017-5 -7.0055-5 -4.5468-5 $
CRD NO...89 ADOP(1, 8) = -4.9100-5 -7.5653-5 -9.8294-5 -1.2194-4 -1.2848-4
CRD NO...90 ADOP(6, 8) = -1.2194-4 -9.8294-5 -7.5653-5 -4.9100-5 $
CRD NO...91 ADOP(1, 9) = -3.2966-5 -5.0795-5 -6.5997-5 -8.1867-5 -8.6270-5
CRD NO...92 ADOP(6, 9) = -8.1867-5 -6.5997-5 -5.0795-5 -3.2966-5 $
CRD NO...93 ADOP(1,10) = -5.2716-5 -8.1221-5 -1.0553-4 -1.3091-4 -1.3794-4
CRD NO...94 ADOP(6,10) = -1.3091-4 -8.1221-5 -1.0553-4 -5.2716-5 $
CRD NO...95 ADOP(1,11) = -2.9858-5 -4.6004-5 -5.9772-5 -7.4148-5 -7.8126-5
CRD NO...96 ADOP(6,11) = -7.4148-5 -5.9772-5 -4.6004-5 -2.9858-5 $
CRD NO...97 ADOP(1,12) = -2.0015-5 -3.0838-5 -4.0066-5 -4.9702-5 -5.2372-5
CRD NO...98 ADOP(6,12) = -4.9702-5 -4.0066-5 -3.0838-5 -2.0015-5 $
CRD NO...99 VDOPF = 1.0 $ (MULTIPLIER FOR DOPPLER COEFFICIENTS FOR GIVEN BUNDLE TYPE)
CRD NO...100 $ (WHEN COOLANT VOIDING IS TRIGGERED IN BUNDLE TYPE)
CRD NO...101 $ (FUEL WORTH TABLES)

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CRD NO..102 NWC = 12 $ (NUMBER OF FUEL WORTH TABLES)
CRD NO..103 NFW = 5 $ (NUMBER OF WORTH VALUES PER TABLE)
CRD NO..104 $ (AXIAL FUEL WORTH VALUES)
CRD NO..105 AFW(1, 1) = 7.8286-6 1.5657-5 2.0441-5 1.5657-5 7.8286-6 $
CRD NO..106 AFW(1, 2) = 7.7143-6 1.5429-5 2.0143-5 1.5429-5 7.7143-6 $
CRD NO..107 AFW(1, 3) = 7.6800-6 1.5200-5 1.9844-5 1.5200-5 7.6800-6 $
CRD NO..108 AFW(1, 4) = 7.4857-6 1.4971-5 1.9546-5 1.4971-5 7.4857-6 $
CRD NO..109 AFW(1, 5) = 7.3143-6 1.4629-5 1.9098-5 1.4629-5 7.3143-6 $
CRD NO..110 AFW(1, 6) = 6.9714-6 1.3943-5 1.8203-5 1.3943-5 6.9714-6 $
CRD NO..111 AFW(1, 7) = 6.5714-6 1.3143-5 1.7159-5 1.3143-5 6.5714-6 $
CRD NO..112 AFW(1, 8) = 6.0571-6 1.2114-5 1.5816-5 1.2114-5 6.0571-6 $
CRD NO..113 AFW(1, 9) = 5.7714-6 1.1543-5 1.5070-5 1.1543-5 5.7714-6 $
CRD NO..114 AFW(1,10) = 6.8571-6 1.3714-5 1.7905-5 1.3714-5 6.8571-6 $
CRD NO..115 AFW(1,11) = 4.6857-6 9.3714-6 1.2235-5 9.3714-6 4.6857-6 $
CRD NO..116 AFW(1,12) = 2.4971-6 4.9143-6 6.4159-6 4.9143-6 2.4971-6 $
CRD NO..117 $ (CORRESPONDING AXIAL LOCATIONS)
CRD NO..118 DFW(1, 1) = 0.0 ,625 1.25 1.875 2.5 $
CRD NO..119 DFW(1, 2) = 0.0 ,625 1.25 1.875 2.5 $
CRD NO..120 DFW(1, 3) = 0.0 ,625 1.25 1.875 2.5 $
CRD NO..121 DFW(1, 4) = 0.0 ,625 1.25 1.875 2.5 $
CRD NO..122 DFW(1, 5) = 0.0 ,625 1.25 1.875 2.5 $
CRD NO..123 DFW(1, 6) = 0.0 ,625 1.25 1.875 2.5 $
CRD NO..124 DFW(1, 7) = 0.0 ,625 1.25 1.875 2.5 $
CRD NO..125 DFW(1, 8) = 0.0 ,625 1.25 1.875 2.5 $
CRD NO..126 DFW(1, 9) = 0.0 ,625 1.25 1.875 2.5 $
CRD NO..127 DFW(1,10) = 0.0 ,625 1.25 1.875 2.5 $
CRD NO..128 DFW(1,11) = 0.0 ,625 1.25 1.875 2.5 $
CRD NO..129 DFW(1,12) = 0.0 ,625 1.25 1.875 2.5 $
CRD NO..130 KFW(1) = 1 2 3 4 5 6 7 8 9 10 11 12 $ (WORTH TABLE ASSIGNED TO A BUNDLE)
CRD NO..131 $ (TYPE)
CRD NO..132 PFTOP=1.0 $ (SIMULATES VAPOR BLANKETING OF FAILED FUEL)
CRD NO..133 ETLM = 3.0 $ (ELAPSED TIME IN CALC. WHICH WILL CAUSE TERMINATION)
CRD NO..134 NMK = 100 $ (MAX. NUMBER OF NUCLEAR KINETICS TIME STEPS TO END PROBLEM)
CRD NO..135 NHT = 100 $ (MAX. NUMBER OF HEAT TRANSFER CALCULATIONS TO END PROBLEM)
CRD NO..136 NSS = 10 $ (MAX. NUMBER OF ITERATIONS DESIRED IN STEADY STATE TEMP.)
CRD NO..137 $ (CALCULATIONS WHEN TEMP. DEPENDENT FUEL PROPERTIES ARE USED)
CRD NO..138 EPS = 1.0 $ (DESIRED CONVERGENCE OF STEADY STATE TEMPERATURES)
CRD NO..139 TMP(1,1,1) = 720.0 *1296 $ (INITIAL TEMP. GUESS TO OBTAIN FUEL PROPERTIES
CRD NO..140 $ (FOR STEADY STATE TEMP. CALCULATIONS)
CRD NO..141 DTKMX = 0.1 $ (MAX. KINETICS TIME STEP PRIOR TO VOID INITIATION IN )
CRD NO..142 $ (SPECIFIED BUNDLE TYPE)
CRD NO..143 NHF = 10 $ (MAX. NUMBER OF TIMES KINETICS TIME STEP MAY BE HALVED BEFORE)
CRD NO..144 $ (CONTINUING)
CRD NO..145 NKS = 1 $ (MAX. NUMBER OF KINETICS TIME STEPS TAKEN BETWEEN HEAT)
CRD NO..146 $ (TRANSFER CALCULATIONS PRIOR TO VOID INITIATION)
CRD NO..147 TMAX = 50.0 $ (MIN. CHANGE IN AVE. FUEL TEMP. WHICH WILL CAUSE NEW HEAT)
CRD NO..148 $ (TRANSFER CALCULATION)
CRD NO..149 MKS = 10 $ (MAX. NUMBER OF KINETICS TIME STEPS PER HEAT TRANSFER AFTER)
CRD NO..150 $ (VOID INITIATION)
CRD NO..151 MVOID = 1 $ (FREQUENCY OF COMPUTING HEAT TRANSFER WILL BE CHANGED TO MKS)
CRD NO..152 $ (WHEN VOIDING INITIATED IN THIS BUNDLE TYPE)
CRD NO..153 E1 = 1.5 $ (MAX. RATIO OF FINAL TO INITIAL NEUTRON DENSITY PER KINETICS )

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CRD NO..154 $ (TIME STEP)
CRD NO..155 E2 = 50.0 $ (MAX. CHANGE IN FUEL AVE. TEMP. AT ANY AXIAL SECTION OVER A)
CRD NO..156 $ (KINETICS TIME STEP)
CRD NO..157 E3 = 0.1 $ (MAX. TOTAL REACTIVITY CHANGE PER TIME STEP)
CRD NO..158 KEDIT = 0 $ (CONTROLS PRINTING OF TEMPERATURES)
CRD NO..159 $ (*****
CRD NO..160 $ (END OF FIRST DTA CALL)
CRD NO..161 $ (*****
CRD NO..162 $$
DTA CALL NO.....2 INPUT EDITS

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CRD NO....1 $ (TRIGGER INPUT)
CRD NO....2 $ (FAILURE DATA)
CRD NO....3 KFM(1) = 2 *12 $ (MODE 2 FAILURE)
CRD NO....4 $ (NUMBER OF PINS REPRESENTED BY BUNDLE TYPE)
CRD NO....5 KRP(1) = 216 1296 2592 3888 5184 6480 7776 9072 10368 11664
CRD NO....6 KRP(11) = 12960 14256 $
CRD NO....7 KFN(1) = 7 *12 $ (FAILURE WHEN 50 PERCENT MOLTEN FUEL)
CRD NO....8 D1(1) = 1.25 *12 $ (DISTANCE ABOVE FAILURE)
CRD NO....9 D2(1) = 1.25 *12 $ (DISTANCE BELOW FAILURE)
CRD NO...10 TAU2(1) = 1.0 *12 $ (TIME INCREMENT FOR REDISTRIBUTION)
CRD NO...11 $ (FUEL FAILURE TRIGGERS - USE NODE TEMPERATURE TRIGGERS ONLY)
CRD NO...12 TF1(1) = 180. *12 $ (ELAPSED TIME)
CRD NO...13 TF2(1) = 1.046 *12 $ (AVERAGE FUEL TEMP)
CRD NO...14 TF3(1) = 5200. *12 $ (NODAL FUEL TEMP)
CRD NO...15 TF4(1) = 1.046 *12 $ (CLAD TEMP)
CRD NO...16 TFP(1,1) = 100.0 *144 $ (PROPAGATION TIME)
CRD NO...17 $ (VOIDING DATA)
CRD NO...18 HM = 0.016 $ (MAXIMUM VOIDING NORTH)
CRD NO...19 RM = 3.25 $ (RADIUS FOR MAXIMUM VOID NORTH)
CRD NO...20 ZM = 1.0 $ (AXIAL DISPLACEMENT FOR MAXIMUM VOID NORTH)
CRD NO...21 FRB(1) = 1.0 *12 $ (FRACTION OF REGION WHICH CONTAINS BUNDLE TYPE)
CRD NO...22 $ (*****
CRD NO...23 $ (END OF SECOND DTA CALL)
CRD NO...24 $ (*****
CRD NO...25 $$

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DTA CALL NO....1

INPUT EDITS

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CRD NO...1  $ (LOOP FLOW AND VOIDING INPUT)
CRD NO...2  $ (GEOMETRY)
CRD NO...3  NRB = 1  $ (NUMBER OF RADIAL BLANKETS)
CRD NO...4  DH = 0.0122  $ (HYDRAULIC DIAMETER OF CORE COOLANT CHANNELS)
CRD NO...5  $ (TOTAL CROSS SECTIONAL FLOW AREAS FOR BUNDLE TYPES)
CRD NO...6  AC(1) = .0452 .2711 .5422 .8133 1.0844 1.3555 1.6266 1.8977 1.3555
CRD NO...7  AC(10) = 3.2531 2.7110 2.9821  $
CRD NO...8  ABL(1) = 4.5  $ (TOTAL CROSS SECTIONAL FLOW AREAS FOR BLANKET REGIONS)
CRD NO...9  XBLBOT = 1.25  $ (LENGTH OF BOTTOM BLANKET)
CRD NO...10 XBLTOP = 4.25  $ (LENGTH OF TOP BLANKET)
CRD NO...11 AP = 160  $ (CROSS SECTIONAL FLOW AREA OF OUTLET PLENUM)
CRD NO...12 XLP = 4.0  $ (DEPTH OF CHANNEL OUTLETS BELOW IHX INLETS)
CRD NO...13 ZGAS2I = 8.  $ (INITIAL DISTANCE FROM REACTOR COVER GAS TO IHX INLETS)
CRD NO...14 AHX1IN = 13.7  $ (CROSS SECTIONAL FLOW AREA OF PIPING BETWEEN REACTOR AND)
CRD NO...15 $ (IHX 1)
CRD NO...16 AHX2IN = 13.7  $ (CROSS SECTIONAL FLOW AREA OF PIPING BETWEEN REACTOR AND)
CRD NO...17 $ (IHX 2)
CRD NO...18 ZHXIN = 17.0  $ (LENGTH OF HEAT EXCHANGER INLET PIPING)
CRD NO...19 AGAS31 = 100.  $ (SURFACE AREA OF GAS IN IHX 1)
CRD NO...20 AGAS32 = 100.  $ (SURFACE AREA OF GAS IN IHX 2)
CRD NO...21 ZHX1I = 3.0  $ (INITIAL DISTANCE FROM IHX COVER GAS)
CRD NO...22 XHX = 0.1  $ (HEIGHT FROM HX INLET TO HX PIPING)
CRD NO...23 AHX1OT = 29.8  $ (CROSS SECTIONAL FLOW AREA OF IHX, 1 PIPING)
CRD NO...24 AHX2OT = 29.8  $ (CROSS SECTIONAL FLOW AREA OF IHX, 2 PIPING)
CRD NO...25 ZHXOT = 22.5  $ (LENGTH OF HEAT EXCHANGER OUTLET PIPING)
CRD NO...26 XHXOT = 18.  $ (HEIGHT OF HX PIPING)
CRD NO...27 AGAS1 = 1200.  $ (SURFACE AREA OF GAS SURFACE ABOVE TANK)
CRD NO...28 XSHX1 = 25.0  $ (INITIAL DISTANCE FROM POOL SURFACE TO IHX OUTLETS)
CRD NO...29 AP1 = 3.10  $ (CROSS SECTIONAL FLOW AREA OF PUMP 1 PIPING)
CRD NO...30 AP2 = 6.20  $ (CROSS SECTIONAL FLOW AREA OF PUMP 2 PIPING)
CRD NO...31 XPP = 18.  $ (LENGTH OF PUMP PIPING)
CRD NO...32 XP = 4.0  $ (HEIGHT OF PUMP OUTLET ABOVE REACTOR VESSEL INLET)
CRD NO...33 XV = 5.  $ (DEPTH OF VESSEL INLET BELOW CHANNEL INLETS)
CRD NO...34 VGAS1I = 3500.  $ (INITIAL VOLUME OF GAS ABOVE POOL)
CRD NO...35 VGAS2I = 500.  $ (INITIAL VOLUME OF GAS ABOVE CORE)
CRD NO...36 VGS31I = 300.  $ (INITIAL VOLUME OF GAS ABOVE IHX 1)
CRD NO...37 VGS32I = 300.  $ (INITIAL VOLUME OF GAS ABOVE IHX 2)
CRD NO...38 $ (INITIAL BUNDLE COOLANT VELOCITIES)
CRD NO...39 VO(1) = 30.4 30.2 30.0 29.7 29.3 28.7 27.8 26.7 26.1 28.5 23.5 17.1
CRD NO...40 $ (BUNDLE COOLANT VELOCITIES UNDER NORMAL REACTOR OPERATING CONDITIONS)
CRD NO...41 VS(1) = 30.4 30.2 30.0 29.7 29.3 28.7 27.8 26.7 26.1 28.5 23.5 17.1
CRD NO...42 VQBL(1) = 2.1  $ (INITIAL RADIAL BLANKET COOLANT VELOCITIES)
CRD NO...43 VSBL(1) = 2.1  $ (BLANKET COOLANT VELOCITIES UNDER NORMAL REACTOR OPERATING)
CRD NO...44 $ (CONDITIONS)
CRD NO...45 COUTI = 1.0  $ (INITIAL BUNDLE OUTLET LOSS COEFFICIENTS)
CRD NO...46 FP = 1.2  $ (FACTOR TIMES FRICTIONAL PRESSURE DROP TO ACCOUNT FOR SPACER)
CRD NO...47 $ (PRESSURE LOSSES)
CRD NO...48 FR = 0.25  $ (FRACTION OF CORE PRESSURE DROP AT ORIFICE IN CHANNEL 1)
CRD NO...49 DPHX1I = 1.0  $ (INITIAL PRESSURE DROP THROUGH IHX INLET PIPING)

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CRD NO...50 DPHXOI = 3.0 $ (INITIAL PRESSURE DROP THROUGH IHX OUTLET PIPING)
CRD NO...51 DPPPI = 10.0 $ (INITIAL PRESSURE DROP THROUGH PUMP PIPING)
CRD NO...52 FD = 1.75 $ (FRACTION OF DESIGN FLOW WHICH PUMP PUTS OUT AT ZERO PRESSURE)
CRD NO...53 HS = 1.4 $ (FRACTION OF PRESSURE HEAD PUMP PUTS OUT OVER DESIGN PRESSURE)
CRD NO...54 $ (HEAT AT STOPPED FLOW)
CRD NO...55 XHV = 0.00019 $ (COOLANT VISCOSITY)
CRD NO...56 YA = 250.0 $ (CONSTANTS TO CALCULATE NA VAPOR PRESSURE FOR BOILING ACCIDENT)
CRD NO...57 YB = 0.0 $
CRD NO...58 YC = 0.0 $
CRD NO...59 YD = 249.0 $ (CONSTANTS TO CALCULATE NA VAPOR PRESSURE AFTER PIN RUPTURE)
CRD NO...60 YE = 0.0 $ (ACCIDENT)
CRD NO...61 YF = 0.0 $
CRD NO...62 PGS111 = 15.0 $ (INITIAL PRESSURE OF POOL COVER GAS)
CRD NO...63 XK1 = 1.67 $ (GAS CONSTANT ABOVE POOL)
CRD NO...64 XK2 = 1.67 $ (GAS CONSTANT ABOVE CORE)
CRD NO...65 XK3 = 1.67 $ (GAS CONSTANT ABOVE IHX)
CRD NO...66 $ (OPTIONS)
CRD NO...67 DTI = .0001 $ (SIZE OF INITIAL TIME STEP)
CRD NO...68 DELTA = 0.1 $ (ALLOWABLE CHANGE IN THE VELOCITY PER STEP)
CRD NO...69 DTMIN = .00001 $ (MINIMUM TIME STEP SIZE)
CRD NO...70 JPRNT = 10 $ (NUMBER OF STEPS BETWEEN PRINTOUT)
CRD NO...71 IT1 = 0 $ (FLAG TO INDICATE WHETHER GAS1 AND GAS2 ARE CONNECTED)
CRD NO...72 NT2 = 2 $ (FLAG INDICATING METHOD OF CALCULATING NA VAPOR PRESSURE)
CRD NO...73 FHX1 = 1. $ (FRACTION OF OUTLET HX LOCAL LOSS COEFFICIENT AFTER)
CRD NO...74 FPP1 = 1. $ (FRACTION OF LOCAL LOSS COEFFICIENT IN PUMP PIPING AFTER)
CRD NO...75 FP1 = 0.1 $ (FRACTION OF PUMP PRESSURE RISE AFTER INITIALIZATION)
CRD NO...76 TP1 = 3.0 $ (TIME TO CHANGE COEFFICIENT FP1)
CRD NO...77 $ (VOIDING INFORMATION)
CRD NO...78 FSH = 1.0 $ (FACTOR MULTIPLIED BY SUPERHEAT FIT TO FIND REQUIRED SUPERHEAT)
CRD NO...79 XLCV = 2.0 $ (PUMP BACKFLOW LENGTH)
CRD NO...80 $ (*****
CRD NO...81 $ (END OF THIRD DTA CALL)
CRD NO...82 $ (*****
CRD NO...83 $$

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NUMBER OF COMPLETED KINETICS TIME STEPS	NUMBER OF KINETICS TIME STEPS SINCE LAST HEAT TRANSFER CALC	ELAPSED TIME SINCE START OF TRANSIENT (SEC)	TIME STEP SIZE (SEC)	FUEL AVERAGE POWER DENSITY (BTU/) (SEC-) (CU, FT)	RELATIVE NEUTRON DENSITY	REACTOR PERIOD (SEC)	RATE OF POWER INCREASE (BTU/SEC-) (CU, FT/) (SEC)	DOPPLER REACTIVITY (AT END) (OF TIME) (STEP)	TEMPERATURE INDEPENDENT REACTIVITY (AT) (CENTER OF) (TIME STEP)	TOTAL REACTIVITY (USED IN) (KINETICS) (CALC)
1	1	1.0000E+04	1.000E-04	3.60000E 04	1.000E 00	-1.342E 04	-4.88E 00	-1.462E-11	0.	0.
2	1	2.5000E-04	1.500E-04	3.60000E 04	1.000E 00	1.000E 12	0.	-9.422E-11	0.	-1.462E-11
3	1	4.7500E-04	2.250E-04	3.60000E 04	1.000E 00	-1.007E 04	-2.17E 00	-2.549E-10	0.	-9.422E-11
4	1	8.1250E-04	3.375E-04	3.60000E 04	1.000E 00	-6.471E 03	-5.79E 00	-6.313E-10	0.	-2.549E-10
5	1	1.3188E-03	5.063E-04	3.60000E 04	1.000E 00	-3.997E 03	-8.68E 00	-1.548E-09	0.	-6.313E-10
6	1	2.0781E-03	7.594E-04	3.60000E 04	1.000E 00	-2.548E 03	-1.41E 01	-3.658E-09	0.	-1.548E-09
7	1	3.2172E-03	1.139E-03	3.60000E 04	1.000E 00	-1.662E 03	-2.19E 01	-8.374E-09	0.	-3.658E-09
8	1	4.9258E-03	1.709E-03	3.59999E 04	1.000E 00	-1.103E 03	-3.26E 01	-1.873E-08	0.	-8.374E-09
9	1	7.4887E-03	2.563E-03	3.59998E 04	1.000E 00	-7.593E 02	-4.74E 01	-4.095E-08	0.	-1.873E-08
10	1	1.1333E+02	3.844E-03	3.59995E 04	1.000E 00	-5.303E 02	-6.78E 01	-8.752E-08	0.	-4.095E-08
11	1	1.7100E-02	5.767E-03	3.59990E 04	1.000E 00	-3.798E 02	-9.48E 01	-1.825E-07	0.	-8.752E-08
12	1	2.5749E-02	8.650E-03	3.59979E 04	9.999E-01	-2.787E 02	-1.29E 02	-3.707E-07	0.	-1.825E-07
13	1	3.8724E-02	1.297E-02	3.59956E 04	9.999E-01	-2.106E 02	-1.71E 02	-7.329E-07	0.	-3.707E-07
14	1	5.8186E-02	1.946E-02	3.59914E 04	9.998E-01	-1.637E 02	-2.20E 02	-1.405E-06	0.	-7.329E-07
15	1	8.7379E-02	2.919E-02	3.59834E 04	9.995E-01	-1.318E 02	-2.73E 02	-2.589E-06	0.	-1.405E-06
16	1	1.3117E+01	4.379E-02	3.59693E 04	9.991E-01	-1.114E 02	-3.23E 02	-4.531E-06	0.	-2.589E-06
17	1	1.9685E-01	6.568E-02	3.59458E 04	9.985E-01	-1.008E 02	-3.56E 02	-7.435E-06	0.	-4.531E-06
18	1	2.9530E-01	9.853E-02	3.59101E 04	9.975E-01	-9.909E 01	-3.62E 02	-1.139E-05	0.	-7.435E-06
19	1	3.9390E-01	9.853E-02	3.58599E 04	9.961E-01	-7.031E 01	-5.10E 02	-1.484E-05	0.	-1.139E-05
20	1	4.9243E-01	9.853E-02	3.58137E 04	9.948E-01	-7.634E 01	-4.69E 02	-1.790E-05	0.	-1.484E-05
21	1	5.9096E-01	9.853E-02	3.57707E 04	9.936E-01	-8.195E 01	-4.36E 02	-2.065E-05	0.	-1.790E-05
22	1	6.8948E-01	9.853E-02	3.57300E 04	9.925E-01	-8.658E 01	-4.13E 02	-2.320E-05	0.	-2.065E-05
23	1	7.8801E-01	9.853E-02	3.56910E 04	9.914E-01	-9.006E 01	-3.96E 02	-2.559E-05	0.	-2.320E-05
24	1	8.8654E-01	9.853E-02	3.56529E 04	9.904E-01	-9.240E 01	-3.86E 02	-2.789E-05	0.	-2.559E-05
25	1	9.3588E-01	4.926E-02	3.56135E 04	9.893E-01	-4.686E 01	-7.60E 02	-2.897E-05	0.	-2.789E-05
26	1	9.8500E-01	4.926E-02	3.55970E 04	9.888E-01	-9.473E 01	-3.76E 02	-3.005E-05	0.	-2.897E-05
27	1	1.0343E 00	4.926E-02	3.55784E 04	9.883E-01	-9.447E 01	-3.77E 02	-3.113E-05	0.	-3.005E-05
28	1	1.0836E 00	4.926E-02	3.55598E 04	9.878E-01	-9.427E 01	-3.77E 02	-3.220E-05	0.	-3.113E-05
29	1	1.1329E 00	4.926E-02	3.55412E 04	9.873E-01	-9.404E 01	-3.78E 02	-3.326E-05	0.	-3.220E-05
30	1	1.1821E 00	4.926E-02	3.55226E 04	9.867E-01	-9.371E 01	-3.79E 02	-3.432E-05	0.	-3.326E-05
31	1	1.2314E 00	4.926E-02	3.55038E 04	9.862E-01	-9.324E 01	-3.81E 02	-3.539E-05	0.	-3.432E-05
32	1	1.2806E 00	4.926E-02	3.54849E 04	9.857E-01	-9.262E 01	-3.83E 02	-3.646E-05	0.	-3.539E-05
33	1	1.3053E 00	2.463E-02	3.54659E 04	9.852E-01	-4.592E 01	-7.72E 02	-3.698E-05	0.	-3.646E-05
34	1	1.3299E 00	2.463E-02	3.54564E 04	9.849E-01	-9.195E 01	-3.86E 02	-3.750E-05	0.	-3.698E-05
35	1	1.3545E 00	2.463E-02	3.54468E 04	9.846E-01	-9.131E 01	-3.88E 02	-3.803E-05	0.	-3.750E-05
36	1	1.3792E 00	2.463E-02	3.54372E 04	9.844E-01	-9.068E 01	-3.91E 02	-3.857E-05	0.	-3.803E-05
37	1	1.4038E 00	2.463E-02	3.54275E 04	9.841E-01	-9.004E 01	-3.93E 02	-3.910E-05	0.	-3.857E-05
38	1	1.4284E 00	2.463E-02	3.54178E 04	9.838E-01	-8.941E 01	-3.96E 02	-3.965E-05	0.	-3.910E-05
39	1	1.4531E 00	2.463E-02	3.54079E 04	9.836E-01	-8.879E 01	-3.99E 02	-4.019E-05	0.	-3.965E-05
40	1	1.4777E 00	2.463E-02	3.53981E 04	9.833E-01	-8.815E 01	-4.02E 02	-4.074E-05	0.	-4.019E-05

NUMBER OF COMPLETED KINETICS TIME STEPS	NUMBER OF KINETICS TIME STEPS SINCE LAST HEAT TRANSFER CALC	ELAPSED TIME SINCE START OF TRANSIENT (SEC)	TIME STEP SIZE (SEC)	FUEL AVERAGE POWER DENSITY (BTU/) (SEC-) (CU, FT)	RELATIVE NEUTRON DENSITY	REACTOR PERIOD (SEC)	RATE OF POWER INCREASE (BTU/SEC-) (CU, FT/) (SEC)	DOPPLER REACTIVITY (AT END) (OF TIME) (STEP)	TEMPERATURE INDEPENDENT REACTIVITY (AT) (CENTER OF) (TIME STEP)	TOTAL REACTIVITY (USED IN) (KINETICS) (CALC)
41	1	1.5023E 00	2.463E-02	3.53881E 04	9.830E-01	-8.750E 01	-4.04E 02	-4.129E-05	0.	-4.074E-05
42	1	1.5144E 00	1.232E-02	3.53781E 04	9.827E-01	-4.342E 01	-8.15E 02	-4.156E-05	0.	-4.129E-05
43	1	1.5270E 00	1.232E-02	3.53730E 04	9.826E-01	-8.680E 01	-4.07E 02	-4.184E-05	0.	-4.156E-05
44	1	1.5393E 00	1.232E-02	3.53680E 04	9.824E-01	-8.643E 01	-4.09E 02	-4.211E-05	0.	-4.184E-05
45	1	1.5516E 00	1.232E-02	3.53629E 04	9.823E-01	-8.604E 01	-4.11E 02	-4.239E-05	0.	-4.211E-05
46	1	1.5639E 00	1.232E-02	3.53578E 04	9.822E-01	-8.564E 01	-4.13E 02	-4.267E-05	0.	-4.239E-05
47	1	1.5762E 00	1.232E-02	3.53527E 04	9.820E-01	-8.525E 01	-4.15E 02	-4.295E-05	0.	-4.267E-05
48	1	1.5885E 00	1.232E-02	3.53476E 04	9.819E-01	-8.485E 01	-4.17E 02	-4.323E-05	0.	-4.295E-05
49	1	1.6008E 00	1.232E-02	3.53425E 04	9.817E-01	-8.445E 01	-4.19E 02	-4.352E-05	0.	-4.323E-05
50	1	1.6079E 00	6.158E-03	3.53373E 04	9.816E-01	-4.202E 01	-8.41E 02	-4.366E-05	0.	-4.352E-05
51	1	1.6132E 00	6.158E-03	3.53347E 04	9.815E-01	-8.400E 01	-4.21E 02	-4.380E-05	0.	-4.366E-05
52	1	1.6193E 00	6.158E-03	3.53321E 04	9.814E-01	-8.382E 01	-4.22E 02	-4.394E-05	0.	-4.380E-05
53	1	1.6253E 00	6.158E-03	3.53295E 04	9.814E-01	-8.356E 01	-4.23E 02	-4.408E-05	0.	-4.394E-05
54	1	1.6316E 00	6.158E-03	3.53269E 04	9.813E-01	-8.340E 01	-4.24E 02	-4.423E-05	0.	-4.408E-05
55	1	1.6378E 00	6.158E-03	3.53243E 04	9.812E-01	-8.316E 01	-4.25E 02	-4.437E-05	0.	-4.423E-05
56	1	1.6440E 00	6.158E-03	3.53216E 04	9.812E-01	-8.297E 01	-4.26E 02	-4.451E-05	0.	-4.437E-05
57	1	1.6501E 00	6.158E-03	3.53190E 04	9.811E-01	-8.273E 01	-4.27E 02	-4.466E-05	0.	-4.451E-05
58	1	1.6563E 00	6.158E-03	3.53164E 04	9.810E-01	-8.253E 01	-4.28E 02	-4.480E-05	0.	-4.466E-05
59	1	1.6624E 00	6.158E-03	3.53137E 04	9.809E-01	-8.233E 01	-4.29E 02	-4.495E-05	0.	-4.480E-05
60	1	1.6685E 00	3.079E-03	3.53111E 04	9.809E-01	-4.105E 01	-8.60E 02	-4.502E-05	0.	-4.495E-05
61	1	1.6746E 00	3.079E-03	3.53084E 04	9.808E-01	-8.205E 01	-4.30E 02	-4.509E-05	0.	-4.502E-05
62	1	1.6717E 00	3.079E-03	3.53084E 04	9.808E-01	-8.196E 01	-4.31E 02	-4.516E-05	0.	-4.509E-05
63	1	1.6747E 00	3.079E-03	3.53071E 04	9.808E-01	-8.189E 01	-4.31E 02	-4.524E-05	0.	-4.516E-05
64	1	1.6778E 00	3.079E-03	3.53058E 04	9.807E-01	-8.173E 01	-4.32E 02	-4.531E-05	0.	-4.524E-05
65	1	1.6809E 00	3.079E-03	3.53044E 04	9.807E-01	-8.167E 01	-4.32E 02	-4.538E-05	0.	-4.531E-05
66	1	1.6840E 00	3.079E-03	3.53031E 04	9.806E-01	-8.149E 01	-4.33E 02	-4.545E-05	0.	-4.538E-05
67	1	1.6871E 00	3.079E-03	3.53018E 04	9.806E-01	-8.144E 01	-4.33E 02	-4.553E-05	0.	-4.545E-05
68	1	1.6903E 00	3.079E-03	3.53004E 04	9.806E-01	-8.132E 01	-4.34E 02	-4.560E-05	0.	-4.553E-05
69	1	1.6932E 00	3.079E-03	3.52991E 04	9.805E-01	-8.122E 01	-4.35E 02	-4.567E-05	0.	-4.560E-05
70	1	1.6948E 00	1.539E-03	3.52978E 04	9.805E-01	-4.054E 01	-8.71E 02	-4.571E-05	0.	-4.567E-05
71	1	1.6963E 00	1.539E-03	3.52971E 04	9.805E-01	-8.110E 01	-4.35E 02	-4.575E-05	0.	-4.571E-05
72	1	1.6978E 00	1.539E-03	3.52964E 04	9.805E-01	-8.103E 01	-4.35E 02	-4.578E-05	0.	-4.575E-05
73	1	1.6994E 00	1.539E-03	3.52958E 04	9.804E-01	-8.094E 01	-4.36E 02	-4.582E-05	0.	-4.578E-05
74	1	1.7009E 00	1.539E-03	3.52951E 04	9.804E-01	-8.093E 01	-4.36E 02	-4.586E-05	0.	-4.582E-05
75	1	1.7025E 00	1.539E-03	3.52944E 04	9.804E-01	-8.089E 01	-4.37E 02	-4.589E-05	0.	-4.586E-05
76	1	1.7040E 00	1.539E-03	3.52937E 04	9.804E-01	-8.087E 01	-4.36E 02	-4.593E-05	0.	-4.589E-05
77	1	1.7055E 00	1.539E-03	3.52931E 04	9.804E-01	-8.074E 01	-4.37E 02	-4.597E-05	0.	-4.593E-05
78	1	1.7071E 00	1.539E-03	3.52924E 04	9.803E-01	-8.077E 01	-4.37E 02	-4.600E-05	0.	-4.597E-05
79	1	1.7086E 00	1.539E-03	3.52917E 04	9.803E-01	-8.048E 01	-4.39E 02	-4.604E-05	0.	-4.600E-05
80	1	1.7102E 00	1.539E-03	3.52910E 04	9.803E-01	-8.070E 01	-4.37E 02	-4.608E-05	0.	-4.604E-05

NUMBER OF COMPLETED KINETICS TIME STEPS	NUMBER OF KINETICS TIME STEPS SINCE LAST HEAT TRANSFER CALC	ELAPSED TIME SINCE START OF TRANSIENT (SEC)	TIME STEP SIZE (SEC)	FUEL AVERAGE POWER DENSITY (BTU/) (SEC-) (CU, FT)	RELATIVE NEUTRON DENSITY	REACTOR PERIOD (SEC)	RATE OF POWER INCREASE (BTU/SEC-) (CU, FT/) (SEC)	DOPPLER REACTIVITY (AT END) (OF TIME) (STEP)	TEMPERATURE INDEPENDENT REACTIVITY (AT) (CENTER OF) (TIME STEP)	TOTAL REACTIVITY (USED IN) (KINETICS) (CALC)
81	1	1.7117E 00	1.539E-03	3.52904E 04	9.803E=01	-8.041E 01	-4.39E 02	-4.611E=05	0.	-4.608E=05
82	1	1.7132E 00	1.539E-03	3.52897E 04	9.803E=01	-8.050E 01	-4.38E 02	-4.619E=05	0.	-4.611E=05
83	1	1.7148E 00	1.539E-03	3.52890E 04	9.803E=01	-8.037E 01	-4.39E 02	-4.619E=05	0.	-4.615E=05
84	1	1.7163E 00	1.539E-03	3.52883E 04	9.802E=01	-8.040E 01	-4.39E 02	-4.623E=05	0.	-4.619E=05
85	1	1.7178E 00	1.539E-03	3.52877E 04	9.802E=01	-8.028E 01	-4.39E 02	-4.626E=05	0.	-4.623E=05
86	1	1.7194E 00	1.539E-03	3.52870E 04	9.802E=01	-8.024E 01	-4.40E 02	-4.630E=05	0.	-4.626E=05
87	1	1.7209E 00	1.539E-03	3.52863E 04	9.802E=01	-8.021E 01	-4.40E 02	-4.634E=05	0.	-4.630E=05
88	1	1.7232E 00	2.309E-03	3.52856E 04	9.802E=01	-1.202E 02	-2.94E 02	-4.639E=05	0.	-4.634E=05
89	1	1.7255E 00	2.309E-03	3.52846E 04	9.801E=01	-8.003E 01	-4.41E 02	-4.645E=05	0.	-4.639E=05
90	1	1.7279E 00	2.309E-03	3.52836E 04	9.801E=01	-7.996E 01	-4.41E 02	-4.650E=05	0.	-4.645E=05
91	1	1.7302E 00	2.309E-03	3.52826E 04	9.801E=01	-7.989E 01	-4.42E 02	-4.656E=05	0.	-4.650E=05
92	1	1.7325E 00	2.309E-03	3.52816E 04	9.800E=01	-7.975E 01	-4.43E 02	-4.662E=05	0.	-4.656E=05
93	1	1.7348E 00	2.309E-03	3.52805E 04	9.800E=01	-7.970E 01	-4.43E 02	-4.667E=05	0.	-4.662E=05
94	1	1.7371E 00	2.309E-03	3.52795E 04	9.800E=01	-7.959E 01	-4.43E 02	-4.673E=05	0.	-4.667E=05
95	1	1.7394E 00	2.309E-03	3.52785E 04	9.800E=01	-7.951E 01	-4.44E 02	-4.679E=05	0.	-4.673E=05
96	1	1.7417E 00	2.309E-03	3.52775E 04	9.799E=01	-7.944E 01	-4.44E 02	-4.684E=05	0.	-4.679E=05
97	1	1.7440E 00	2.309E-03	3.52764E 04	9.799E=01	-7.938E 01	-4.44E 02	-4.690E=05	0.	-4.684E=05
98	1	1.7463E 00	2.309E-03	3.52754E 04	9.799E=01	-7.925E 01	-4.45E 02	-4.695E=05	0.	-4.690E=05
99	1	1.7498E 00	3.464E-03	3.52744E 04	9.798E=01	-1.188E 02	-2.97E 02	-4.704E=05	0.	-4.695E=05
100	1	1.7533E 00	3.464E-03	3.52728E 04	9.798E=01	-7.905E 01	-4.46E 02	-4.712E=05	0.	-4.704E=05

CURRENT COMPOSITE REACTIVITY-VERSUS TIME TABLE

ELAPSED TIME = 1.753257 SECONDS

TIME (SECONDS)	REACTIVITY
0.	0.
1.00000E 04	0.

CURRENT COMPOSITE REACTIVITY-VERSUS TIME TABLE

ELAPSED TIME • 1.753257 SECONDS

TIME (SECONDS)	REACTIVITY
0.	0.
1.00000E 06	0.

STEADY STATE NODAL TEMPERATURES
(DEGREES FAHRENHEIT)

TEMPERATURES FOR BUNDLE TYPE 1

AX.NODE/RA.NODE	1	2	3	4	5	6	7	8	9	10	11	12
1	2408.30	2375.78	2314.81	2228.26	2118.43	1987.34	1836.72	1668.14	1483.51	1284.53	782.09	730.55
2	2984.26	2940.19	2857.57	2740.27	2591.24	2413.22	2208.62	1979.82	1729.37	1459.97	818.19	754.19
3	3430.47	3377.64	3278.60	3138.01	2959.47	2746.07	2500.45	2225.66	1924.65	1600.86	855.13	782.21
4	3843.84	3783.57	3670.29	3508.79	3303.14	3056.91	2773.36	2455.54	2107.12	1732.16	894.97	813.75
5	3970.75	3908.80	3792.37	3626.39	3414.32	3159.98	2866.68	2537.74	2176.79	1787.99	930.80	847.43
6	3916.30	3855.98	3742.62	3580.99	3374.77	3127.57	2842.60	2523.01	2172.33	1794.48	962.33	881.11
7	3590.93	3537.18	3436.44	3293.46	3111.87	2894.70	2644.73	2364.68	2057.51	1726.65	985.57	912.65
8	3219.85	3174.46	3089.44	2968.70	2815.35	2631.87	2420.65	2184.07	1924.54	1644.70	1004.66	940.66
9	2703.70	2669.46	2605.28	2514.22	2398.62	2260.38	2101.20	1922.90	1727.12	1515.68	1015.85	964.31

TEMPERATURES FOR BUNDLE TYPE 2

AX.NODE/RA.NODE	1	2	3	4	5	6	7	8	9	10	11	12
1	2391.62	2359.44	2299.11	2213.45	2104.80	1975.10	1826.08	1659.29	1476.61	1279.72	781.68	730.54
2	2962.03	2918.41	2836.65	2720.55	2573.07	2396.92	2194.46	1968.07	1720.26	1453.69	817.66	754.15
3	3404.73	3352.44	3254.42	3115.26	2938.56	2727.33	2484.22	2212.24	1914.33	1593.86	854.51	782.14
4	3817.86	3758.07	3645.68	3485.44	3281.55	3037.49	2756.51	2441.60	2096.42	1724.98	894.26	813.65
5	3943.70	3882.25	3766.74	3602.36	3391.81	3139.74	2849.13	2523.23	2165.68	1780.57	930.03	847.29
6	3890.35	3830.31	3717.83	3557.48	3353.01	3108.00	2825.62	2508.97	2161.55	1787.27	961.55	880.94
7	3565.68	3511.89	3412.18	3270.57	3090.92	2875.96	2628.51	2351.29	2047.22	1719.69	984.82	912.45
8	3197.74	3152.83	3068.63	2949.12	2797.32	2615.69	2406.61	2172.42	1915.53	1638.51	1003.95	940.44
9	2686.12	2652.24	2588.75	2498.67	2384.29	2247.49	2089.99	1913.55	1719.80	1510.54	1015.20	964.05

TEMPERATURES FOR BUNDLE TYPE 3

AX.NODE/RA.NODE	1	2	3	4	5	6	7	8	9	10	11	12
1	2377.17	2345.29	2285.50	2200.62	2092.97	1964.48	1816.84	1651.61	1470.63	1275.54	781.34	730.53
2	2947.47	2899.26	2818.24	2703.20	2557.09	2382.59	2182.01	1957.75	1712.25	1448.17	817.23	754.15
3	3381.66	3329.66	3232.74	3094.85	2919.77	2710.49	2469.65	2200.20	1905.09	1587.60	854.01	782.13
4	3794.58	3735.20	3623.60	3464.55	3262.25	3020.16	2741.49	2429.20	2086.91	1718.62	893.70	813.64
5	3920.05	3859.32	3744.32	3580.80	3372.15	3122.06	2833.81	2510.58	2156.00	1774.13	929.45	847.28
6	3867.15	3807.73	3695.05	3536.82	3333.90	3090.82	2810.74	2496.68	2152.14	1780.99	960.98	880.92
7	3542.25	3489.45	3390.77	3250.55	3072.43	2859.42	2614.21	2339.52	2038.20	1713.63	984.29	912.42
8	3176.51	3134.00	3050.57	2932.13	2781.69	2601.67	2394.47	2162.36	1907.78	1633.22	1003.48	940.40
9	2671.18	2637.62	2574.73	2485.47	2372.14	2236.59	2080.52	1905.68	1713.66	1506.28	1014.82	964.02

TEMPERATURES FOR BUNDLE TYPE 4

AX.NODE/RA.NODE	1	2	3	4	5	6	7	8	9	10	11	12
1	2362.38	2330.79	2271.56	2187.50	2080.89	1953.64	1807.42	1643.78	1464.53	1271.29	781.03	730.57
2	2923.17	2880.35	2800.07	2686.08	2541.33	2368.47	2169.76	1947.61	1704.41	1442.79	816.91	754.26
3	3359.25	3307.91	3211.68	3075.04	2901.56	2694.17	2455.55	2188.58	1896.20	1581.63	853.72	782.33
4	3771.03	3712.07	3601.26	3443.46	3242.82	3002.76	2726.46	2416.85	2077.52	1712.43	893.45	813.94
5	3896.67	3836.08	3722.20	3559.83	3352.79	3104.70	2818.81	2498.26	2146.66	1768.03	929.30	847.68
6	3844.78	3785.78	3674.88	3516.78	3315.41	3074.25	2796.43	2484.94	2143.26	1775.22	960.94	881.43
7	3520.58	3468.36	3370.47	3231.51	3054.99	2843.89	2600.85	2328.61	2029.97	1708.26	984.42	913.04
8	3160.17	3116.06	3033.38	2916.02	2766.93	2588.50	2383.15	2153.11	1900.79	1628.66	1003.76	941.11
9	2657.13	2623.88	2561.57	2473.14	2360.85	2226.52	2071.87	1898.62	1708.33	1502.78	1015.26	964.80

TEMPERATURES FOR BUNDLE TYPE 5

AX.NODE/RA.NODE	1	2	3	4	5	6	7	8	9	10	11	12
1	2331.39	2300.42	2242.35	2159.99	2055.56	1930.91	1787.65	1627.34	1451.71	1262.32	780.28	730.56
2	2882.24	2840.26	2761.54	2649.75	2507.86	2338.44	2143.68	1925.96	1687.59	1431.17	815.96	754.22
3	3311.09	3260.76	3166.39	3032.42	2862.34	2659.00	2425.09	2163.40	1876.83	1568.46	852.61	782.26
4	3720.23	3662.16	3553.02	3397.87	3200.76	2964.99	2693.69	2389.82	2056.80	1698.53	892.19	813.83
5	3846.37	3786.69	3674.53	3514.62	3310.97	3067.10	2786.20	2471.31	2126.00	1754.21	927.96	847.54
6	3796.21	3738.10	3628.87	3473.16	3275.08	3037.99	2764.98	2458.93	2123.29	1761.83	959.61	881.25
7	3472.89	3421.69	3325.71	3189.44	3016.31	2809.27	2570.89	2303.89	2010.97	1695.41	983.17	912.82
8	3119.37	3076.13	2995.07	2879.99	2733.78	2558.76	2357.35	2131.72	1884.24	1617.30	1002.60	940.86
9	2625.40	2592.82	2531.76	2445.08	2334.99	2203.28	2051.66	1881.78	1695.16	1493.56	1014.25	964.53

TEMPERATURES FOR BUNDLE TYPE 6

AX.NODE/RA.NODE	1	2	3	4	5	6	7	8	9	10	11	12
1	2285.55	2255.48	2199.18	2119.36	2018.17	1897.36	1758.46	1603.05	1432.75	1249.03	779.18	730.54
2	2423.35	2782.57	2706.11	2597.57	2459.88	2295.47	2106.45	1895.17	1663.81	1414.92	814.57	754.17
3	3240.66	3191.78	3160.14	2970.09	2804.99	2607.58	2380.56	2126.56	1848.46	1549.13	850.99	782.18
4	3643.48	3586.72	3480.30	3329.29	3137.55	2908.32	2644.61	2349.35	2025.79	1677.71	890.35	813.70
5	3771.94	3713.61	3603.97	3447.83	3249.27	3011.68	2738.17	2431.62	2095.56	1733.82	926.04	847.37
6	3721.88	3665.08	3558.31	3406.51	3213.61	2982.84	2717.20	2419.49	2093.05	1741.57	957.68	881.03
7	3402.70	3352.89	3259.79	3127.45	2959.33	2758.27	2526.72	2267.41	1982.92	1676.42	981.37	912.56
8	3059.31	3017.33	2938.62	2826.86	2684.82	2514.88	2319.32	2100.20	1859.87	1600.56	1000.96	940.56
9	2578.84	2547.24	2487.99	2403.89	2297.04	2169.17	2021.98	1857.06	1675.82	1480.00	1012.83	964.20

TEMPERATURES FOR BUNDLE TYPE 7

AX.NODE/RA.NODE	1	2	3	4	5	6	7	8	9	10	11	12
1	2223.07	2194.34	2140.54	2064.24	1967.47	1851.87	1718.86	1570.05	1406.90	1230.87	777.72	730.55
2	2742.90	2703.74	2630.37	2526.34	2394.40	2236.84	2055.73	1853.30	1631.54	1392.91	812.77	754.21
3	3145.58	3098.69	3010.81	2886.09	2727.72	2538.30	2320.54	2076.87	1810.10	1522.97	848.98	782.25
4	3535.17	3480.71	3378.64	3233.79	3049.82	2829.90	2576.83	2293.57	1983.09	1649.04	888.14	813.81
5	3667.28	3610.78	3504.70	3354.10	3162.86	2934.17	2671.02	2376.29	2053.22	1705.52	923.80	847.51
6	3618.01	3563.06	3460.09	3313.95	3128.39	2906.50	2651.14	2365.10	2051.46	1713.78	955.54	881.21
7	3308.43	3260.69	3171.19	3044.09	2882.65	2689.58	2467.26	2218.30	1945.25	1651.00	979.51	912.78
8	2979.33	2939.02	2863.44	2756.10	2619.65	2456.47	2268.71	2058.31	1827.54	1578.47	999.37	940.81
9	2517.44	2487.12	2430.27	2349.55	2246.96	2124.21	1982.94	1824.61	1650.55	1462.45	1011.64	964.47

TEMPERATURES FOR BUNDLE TYPE 8

AX.NODE/RA.NODE	1	2	3	4	5	6	7	8	9	10	11	12
1	2147.28	2120.16	2069.34	1997.24	1905.74	1796.37	1670.53	1529.70	1375.23	1208.51	775.91	730.56
2	2642.82	2605.82	2536.43	2438.15	2313.37	2164.24	1992.90	1801.31	1591.40	1365.41	810.55	754.25
3	3027.54	2983.12	2899.85	2781.64	2631.47	2452.01	2245.70	2014.86	1762.13	1490.13	846.47	782.31
4	3402.43	3350.80	3254.03	3116.63	2942.15	2733.56	2493.43	2224.71	1930.28	1613.42	885.37	813.91
5	3531.08	3477.36	3376.69	3233.79	3052.29	2835.30	2585.56	2305.96	1999.40	1669.43	920.99	847.64
6	3485.64	3433.56	3335.93	3197.33	3021.26	2810.74	2568.37	2296.98	1999.31	1678.78	952.84	881.38
7	3192.73	3147.39	3062.39	2941.75	2788.52	2605.19	2394.21	2157.93	1898.83	1619.52	977.13	912.98
8	2880.63	2842.35	2770.54	2668.54	2538.97	2384.08	2205.85	2006.19	1787.18	1550.80	997.35	941.04
9	2442.50	2413.72	2359.75	2283.11	2185.65	2069.13	1935.03	1784.66	1619.39	1440.71	1010.07	964.72

TEMPERATURES FOR BUNDLE TYPE 9

AX.NODE/RA.NODE	1	2	3	4	5	6	7	8	9	10	11	12
1	2103.61	2077.41	2028.30	1958.63	1870.17	1764.38	1642.70	1506.51	1357.06	1195.76	774.82	730.55
2	2584.08	2548.33	2481.34	2386.30	2265.66	2121.48	1955.82	1770.56	1567.58	1349.01	809.16	754.20
3	2958.39	2915.40	2834.80	2720.36	2574.97	2401.28	2201.63	1978.31	1733.78	1470.62	844.85	782.22
4	3323.32	3273.35	3179.66	3046.63	2877.71	2675.77	2443.39	2183.35	1898.48	1591.84	883.53	813.77
5	3450.13	3398.15	3300.71	3162.37	2986.65	2776.56	2534.71	2263.98	1967.16	1647.65	919.06	847.46
6	3407.05	3356.64	3262.12	3127.92	2957.46	2753.62	2518.91	2256.11	1967.91	1657.52	950.90	881.15
7	3124.11	3080.22	2997.95	2881.16	2732.78	2555.19	2350.87	2122.02	1871.10	1600.52	975.33	912.70
8	2823.03	2784.92	2715.33	2616.48	2490.98	2341.00	2168.36	1975.03	1762.91	1533.98	995.69	940.73
9	2397.65	2369.77	2317.48	2243.21	2148.85	2036.03	1906.17	1760.53	1600.44	1427.32	1008.64	964.38

TEMPERATURES FOR BUNDLE TYPE 10

AX.NODE/RA.NODE	1	2	3	4	5	6	7	8	9	10	11	12
1	2268.91	2239.21	2183.57	2104.69	2004.68	1885.26	1747.94	1594.29	1425.91	1244.22	778.78	730.53
2	2802.25	2761.90	2686.24	2578.88	2442.71	2280.10	2093.14	1884.18	1655.33	1409.13	814.05	754.14
3	3215.66	3167.30	3076.64	2947.99	2784.65	2589.34	2364.76	2113.48	1838.36	1542.23	850.38	782.11
4	3614.65	3558.47	3453.18	3303.78	3114.10	2887.34	2626.46	2334.40	2014.32	1669.99	889.64	813.61
5	3744.41	3686.56	3577.83	3423.12	3226.47	2991.21	2720.42	2416.97	2084.31	1726.26	925.28	847.24
6	2977.72	2936.20	2858.36	2747.81	2607.31	2439.36	2246.18	2029.86	1792.76	1537.17	937.77	877.44
7	3369.30	3320.16	3228.02	3097.16	2930.98	2732.23	2503.31	2246.97	1965.80	1662.88	973.77	905.51
8	3029.36	2987.86	2910.07	2799.60	2659.20	2491.25	2298.00	2081.45	1843.96	1587.71	993.39	933.48
9	2553.71	2522.49	2463.97	2380.88	2275.32	2148.96	2003.58	1840.66	1661.59	1468.14	1005.34	957.09

TEMPERATURES FOR BUNDLE TYPE 11

AX.NODE/RA.NODE	1	2	3	4	5	6	7	8	9	10	11	12
1	1936.77	1914.01	1871.35	1810.75	1733.78	1641.83	1536.08	1417.62	1287.44	1146.84	770.51	730.57
2	2355.87	2324.86	2266.71	2184.19	2079.53	1954.58	1810.98	1650.22	1474.06	1284.07	803.85	754.27
3	2686.88	2649.46	2579.34	2479.91	2353.76	2203.03	2029.77	1836.01	1623.62	1394.93	838.85	782.35
4	3012.73	2969.24	2887.71	2771.96	2624.88	2449.09	2246.98	2020.78	1773.03	1506.24	876.89	813.96
5	3131.23	3085.93	3001.01	2880.47	2727.37	2544.20	2333.54	2097.69	1839.30	1560.87	912.30	847.71
6	3098.58	3054.62	2972.21	2855.23	2706.61	2528.80	2324.27	2095.20	1844.14	1573.48	944.40	881.47
7	2853.67	2815.58	2743.76	2641.74	2512.21	2357.41	2179.28	1979.84	1761.11	1525.15	969.58	913.08
8	2589.80	2557.52	2497.00	2411.09	2301.98	2171.42	2021.16	1852.84	1667.92	1468.23	990.75	941.16
9	2225.13	2200.80	2155.20	2090.48	2008.29	1909.96	1796.64	1669.43	1529.52	1378.00	1004.79	964.86

TEMPERATURES FOR BUNDLE TYPE 12

AX.NODE/RA.NODE	1	2	3	4	5	6	7	8	9	10	11	12
1	1538.39	1523.64	1495.99	1456.69	1406.69	1346.81	1277.80	1200.35	1115.09	1022.83	759.58	730.56
2	1818.36	1798.38	1760.95	1717.88	1640.53	1560.02	1467.34	1363.35	1249.02	1125.35	790.26	754.22
3	2041.80	2017.85	1972.93	1909.17	1828.16	1731.21	1619.66	1494.71	1357.43	1209.07	823.32	782.27
4	2270.88	2242.71	2189.93	2115.10	2020.17	1906.76	1776.27	1630.10	1469.73	1296.50	859.57	813.84
5	2363.42	2334.02	2278.90	2200.62	2101.29	1982.63	1846.16	1693.23	1525.42	1344.23	894.49	847.55
6	2355.47	2326.88	2273.25	2197.10	2100.45	1984.97	1852.12	1703.18	1539.68	1363.03	926.99	881.26
7	2205.24	2180.34	2133.69	2067.48	1983.40	1882.84	1766.96	1636.97	1494.09	1339.44	953.89	912.83
8	2045.71	2024.66	1985.19	1929.12	1857.83	1772.42	1673.96	1563.45	1441.80	1309.84	976.91	940.87
9	1818.16	1802.07	1771.91	1729.08	1674.65	1609.48	1534.30	1449.76	1356.42	1255.00	993.56	964.54

STEADY STATE AVERAGE FUEL TEMPERATURES
(DEGREES FAHRENHEIT)

AX.NODE/BN.TYPE	1	2	3	4	5	6	7	8	9	10	11	12
1	1871.74	1860.73	1851.17	1841.42	1820.94	1790.69	1749.58	1699.47	1670.64	1779.76	1560.22	1293.14
2	2256.34	2241.70	2228.83	2216.16	2189.18	2150.62	2098.05	2032.83	1994.38	2136.82	1844.25	1488.24
3	2557.25	2540.45	2525.38	2510.79	2479.29	2433.20	2371.03	2293.60	2248.07	2416.84	2070.04	1645.01
4	2837.76	2820.49	2805.07	2789.61	2755.97	2705.42	2635.17	2548.79	2497.06	2686.63	2293.76	1806.17
5	2932.28	2914.30	2898.61	2883.23	2849.82	2800.51	2731.47	2642.97	2590.29	2782.27	2382.06	1877.40
6	2906.52	2889.13	2873.88	2859.20	2826.95	2777.81	2709.70	2623.91	2572.69	2290.60	2371.21	1882.39
7	2701.90	2685.08	2670.27	2656.40	2625.36	2579.62	2518.11	2442.52	2397.63	2555.64	2220.17	1792.98
8	2468.88	2454.36	2441.78	2430.03	2403.32	2363.93	2311.55	2246.60	2207.87	2342.10	2055.32	1695.78
9	2137.44	2125.82	2116.00	2107.02	2086.08	2055.34	2014.90	1965.34	1935.49	2036.53	1821.94	1550.67

COOLANT EXIT TEMPERATURES (DEGREES FAHRENHEIT)

ELAPSED TIME = 0. SECONDS

BUNDLE TYPE	1	2	3	4	5	6	7	8	9	10	11	12
	974.85	974.59	974.55	975.37	975.08	974.74	975.02	975.29	974.93	967.62	975.43	975.10

PRECURSOR DENSITIES

GROUP	1	2	3	4	5	6
	9.89583E 03	3.55626E 04	7.03895E 03	5.34362E 03	5.92972E 02	6.83491E 01

TRANSIENT NODAL TEMPERATURES
(DEGREES FAHRENHEIT)

ELAPSED TIME = 1.753257 SECONDS

TEMPERATURES FOR BUNDLE TYPE 1

AX.NODE/RA.NODE	1	2	3	4	5	6	7	8	9	10	11	12
1	2403.40	2371.18	2310.80	2225.08	2116.36	1986.63	1837.64	1670.97	1488.50	1291.96	797.17	736.18
2	2980.47	2936.94	2855.34	2739.53	2592.43	2416.79	2215.02	1989.51	1742.80	1477.55	848.57	772.51
3	3427.76	3375.70	3278.13	3139.68	2963.92	2753.95	2512.45	2242.43	1946.81	1629.02	902.30	815.57
4	3841.79	3782.50	3671.11	3512.37	3310.35	3068.64	2790.48	2478.99	2137.79	1770.80	959.29	863.70
5	3970.40	3909.64	3795.49	3632.83	3425.15	3176.26	2889.48	2568.20	2215.98	1836.81	1010.79	914.29
6	3918.33	3859.39	3748.67	3590.93	3389.80	3148.93	2871.55	2560.85	2220.27	1853.57	1056.64	963.98
7	3597.01	3544.81	3446.99	3308.26	3132.22	2921.91	2680.13	2409.52	2113.07	1794.02	1091.20	1009.60
8	3230.43	3186.73	3104.80	2968.58	2841.11	2664.89	2462.24	2235.55	1987.09	1719.50	1118.69	1049.02
9	2720.63	2688.05	2627.04	2540.54	2430.83	2299.82	2149.13	1980.53	1795.69	1596.26	1134.29	1080.88

TEMPERATURES FOR BUNDLE TYPE 2

AX.NODE/RA.NODE	1	2	3	4	5	6	7	8	9	10	11	12
1	2386.79	2354.91	2295.15	2210.33	2102.77	1974.42	1827.02	1662.11	1481.57	1287.10	796.63	736.15
2	2958.30	2915.22	2834.46	2719.84	2574.27	2400.48	2200.83	1977.70	1733.59	1471.14	847.81	772.40
3	3402.13	3350.61	3254.04	3117.01	2943.07	2735.26	2496.22	2228.97	1936.41	1621.89	901.40	815.37
4	3815.90	3757.19	3646.58	3489.11	3288.82	3049.26	2773.65	2465.05	2127.04	1763.53	958.34	863.43
5	3943.47	3883.19	3769.95	3608.60	3402.72	3156.07	2871.96	2553.67	2204.77	1829.20	1009.75	913.98
6	3892.28	3833.81	3723.97	3567.47	3368.06	3129.32	2854.46	2546.61	2209.21	1845.97	1055.53	963.60
7	3571.30	3519.64	3422.86	3285.57	3111.35	2903.21	2663.91	2396.10	2102.70	1786.92	1090.09	1009.15
8	3208.44	3165.18	3084.09	2969.08	2823.14	2648.73	2448.18	2223.83	1977.96	1713.12	1117.57	1048.49
9	2703.15	2670.94	2610.60	2525.06	2416.55	2286.95	2137.67	1971.08	1788.20	1590.88	1133.20	1080.27

TEMPERATURES FOR BUNDLE TYPE 3

AX.NODE/RA.NODE	1	2	3	4	5	6	7	8	9	10	11	12
1	2372.37	2340.78	2281.57	2197.52	2090.96	1963.81	1817.77	1654.41	1475.55	1282.86	796.17	736.14
2	2938.78	2896.09	2816.03	2702.49	2558.29	2386.13	2188.35	1967.32	1725.50	1465.52	847.17	772.34
3	3379.12	3328.08	3232.42	3096.64	2924.32	2718.44	2481.64	2216.89	1927.09	1615.52	900.66	815.27
4	3792.73	3734.34	3624.62	3468.30	3269.60	3031.99	2758.67	2452.65	2117.50	1757.10	957.57	863.30
5	3919.92	3860.07	3747.64	3587.43	3383.14	3138.46	2856.68	2541.04	2195.08	1822.71	1008.98	913.83
6	3859.39	3811.34	3702.28	3546.89	3349.01	3112.17	2839.54	2534.22	2199.60	1839.41	1054.73	963.44
7	3548.60	3497.43	3401.55	3265.55	3092.94	2886.74	2649.64	2384.32	2093.63	1780.76	1089.29	1008.94
8	3189.34	3146.47	3066.13	2952.18	2807.57	2634.75	2436.04	2213.74	1970.13	1707.71	1116.80	1048.24
9	2688.30	2656.40	2596.65	2511.91	2404.43	2276.05	2128.37	1963.13	1781.94	1586.45	1132.48	1079.97

TEMPERATURES FOR BUNDLE TYPE 4

AX.NODE/RA.NODE	1	2	3	4	5	6	7	8	9	10	11	12
1	2357.61	2326.32	2267.66	2184.42	2078.89	1952.97	1808.34	1646.56	1469.42	1278.56	795.75	736.17
2	2919.52	2877.23	2797.95	2685.41	2542.55	2372.01	2176.08	1957.14	1717.60	1460.06	846.70	772.45
3	3356.78	3306.21	3211.42	3076.89	2906.15	2702.15	2467.55	2205.26	1918.17	1609.49	900.22	815.46
4	3769.31	3711.34	3602.41	3447.35	3250.31	3014.72	2743.76	2440.38	2108.16	1750.92	957.24	863.61
5	3897.66	3837.25	3725.63	3566.59	3363.90	3121.21	2841.79	2528.81	2185.80	1816.65	1008.79	914.29
6	3847.16	3789.53	3681.25	3527.00	3330.66	3095.72	2825.35	2522.55	2190.73	1833.56	1054.66	964.02
7	3527.08	3476.39	3381.41	3246.66	3075.64	2871.33	2636.40	2373.51	2085.48	1775.46	1089.38	1009.63
8	3171.15	3128.68	3049.10	2936.21	2792.94	2621.70	2424.83	2204.57	1963.20	1703.19	1117.03	1049.00
9	2674.38	2642.79	2583.61	2499.70	2393.25	2266.07	2119.80	1956.13	1776.64	1582.98	1132.84	1080.78

TEMPERATURES FOR BUNDLE TYPE 5

AX.NODE/RA.NODE	1	2	3	4	5	6	7	8	9	10	11	12
1	2326.68	2296.00	2238.49	2156.94	2053.58	1930.24	1788.54	1630.05	1456.50	1269.45	794.75	736.12
2	2878.66	2837.20	2759.46	2649.10	2509.08	2341.94	2149.92	1935.36	1700.60	1448.19	845.32	772.28
3	3308.75	3259.17	3166.24	3034.34	2866.96	2666.97	2437.04	2179.96	1898.60	1596.05	898.58	815.16
4	3718.70	3661.62	3554.36	3401.94	3208.40	2977.07	2711.08	2413.35	2087.35	1736.84	955.47	863.21
5	3846.56	3788.06	3678.16	3521.55	3322.23	3083.72	2809.24	2501.86	2165.07	1802.68	1006.98	913.81
6	3798.81	3742.06	3635.46	3483.57	3290.48	3059.57	2793.95	2496.54	2170.69	1820.01	1052.84	963.49
7	3479.64	3429.96	3336.86	3204.78	3037.11	2836.81	2606.47	2348.75	2066.34	1762.37	1087.51	1009.01
8	3130.59	3088.97	3010.98	2900.33	2759.90	2592.01	2399.01	2183.07	1946.45	1691.53	1115.18	1048.26
9	2642.82	2611.89	2553.92	2471.72	2367.42	2242.80	2099.46	1939.08	1763.16	1573.34	1131.07	1079.91

TEMPERATURES FOR BUNDLE TYPE 6

AX.NODE/RA.NODE	1	2	3	4	5	6	7	8	9	10	11	12
1	2280.92	2251.15	2195.39	2116.37	2016.22	1896.69	1759.32	1605.68	1437.40	1255.96	793.26	736.05
2	2819.63	2779.34	2703.81	2596.64	2460.72	2298.51	2112.11	1903.88	1676.00	1430.99	843.31	772.05
3	3238.50	3190.37	3100.14	2972.12	2809.67	2615.54	2392.42	2142.94	1869.95	1576.33	896.19	814.75
4	3642.25	3586.47	3481.91	3333.59	3145.36	2920.52	2662.02	2372.81	2056.13	1715.68	952.84	862.64
5	3772.43	3715.27	3607.88	3455.00	3260.73	3028.44	2761.27	2462.13	2134.48	1782.03	1004.33	913.14
6	3724.88	3669.45	3565.32	3417.31	3229.36	3004.72	2746.40	2457.19	2140.39	1799.52	1050.12	962.72
7	3409.89	3361.69	3271.35	3143.17	2980.45	2786.05	2562.46	2312.30	2038.16	1743.06	1084.76	1008.11
8	3076.92	3030.54	2954.89	2847.51	2711.21	2548.27	2360.98	2151.40	1921.77	1674.31	1112.47	1047.18
9	2596.59	2566.60	2510.41	2430.71	2329.56	2208.66	2069.63	1914.05	1743.36	1559.18	1128.48	1078.65

TEMPERATURES FOR BUNDLE TYPE 7

AX.NODE/RA.NODE	1	2	3	4	5	6	7	8	9	10	11	12
1	1216.57	2190.13	2136.86	2061.34	1965.57	1851.21	1719.68	1572.58	1411.39	1237.54	791.26	735.99
2	2739.43	2700.75	2628.30	2525.59	2395.38	2239.94	2061.36	1861.86	1643.45	1408.57	840.88	771.90
3	3143.80	3097.64	3011.14	2888.42	2732.66	2546.45	2332.49	2093.24	1831.47	1549.84	893.25	814.50
4	3534.32	3480.53	3380.58	3238.37	3057.86	2842.21	2594.25	2316.91	2013.16	1686.58	949.59	862.28
5	3668.31	3612.98	3509.14	3361.78	3174.77	2951.31	2694.41	2406.91	2092.06	1753.44	1001.10	912.72
6	3621.64	3568.05	3467.65	3325.26	3144.58	2928.72	2680.56	2402.84	2098.65	1771.37	1046.90	962.26
7	3316.23	3269.99	3183.34	3060.35	2904.27	2717.80	2503.28	2263.33	2000.35	1717.24	1081.65	1007.54
8	2991.43	2952.71	2880.14	2777.14	2646.34	2490.06	2310.43	2109.38	1889.10	1651.66	1109.51	1046.46
9	2535.61	2506.89	2453.05	2376.67	2279.70	2163.76	2030.47	1881.29	1717.56	1540.87	1125.78	1077.76

TEMPERATURES FOR BUNDLE TYPE 8

AX.NODE/RA.NODE	1	2	3	4	5	6	7	8	9	10	11	12
1	2149.93	2116.08	2065.76	1994.41	1903.87	1795.67	1671.24	1532.05	1379.44	1214.82	788.77	735.91
2	2639.67	2603.13	2534.69	2437.63	2314.52	2167.46	1998.56	1809.81	1603.11	1380.72	837.81	771.68
3	3026.09	2982.38	2900.45	2784.17	2636.54	2460.18	2257.56	2030.97	1783.05	1516.36	889.44	814.10
4	3402.09	3351.41	3256.42	3121.61	2950.50	2746.07	2510.92	2247.97	1960.03	1650.38	945.40	861.69
5	3532.65	3480.09	3381.53	3241.85	3064.48	2852.58	2608.94	2336.37	2037.81	1716.68	996.75	911.98
6	3459.83	3439.07	3343.97	3209.03	3037.73	2833.89	2597.76	2334.48	2046.03	1735.66	1042.52	961.37
7	3201.06	3157.19	3074.97	2958.34	2810.34	2633.46	2430.09	2202.59	1953.33	1684.90	1077.42	1006.47
8	2893.36	2856.64	2787.81	2690.10	2566.06	2417.93	2247.68	2057.13	1848.34	1623.19	1105.45	1045.18
9	2460.97	2433.75	2382.73	2310.33	2218.38	2108.52	1982.22	1840.82	1685.57	1517.99	1122.05	1076.24

TEMPERATURES FOR BUNDLE TYPE 9

AX.NODE/RA.NODE	1	2	3	4	5	6	7	8	9	10	11	12
1	2099.27	2073.32	2024.69	1955.71	1868.16	1763.49	1643.15	1508.51	1360.85	1201.56	787.29	735.83
2	2581.10	2545.81	2479.69	2385.91	2266.90	2124.72	1961.46	1778.96	1579.12	1364.06	835.88	771.45
3	2957.13	2914.93	2835.54	2723.00	2580.08	2409.42	2213.37	1994.20	1754.37	1496.40	887.00	813.68
4	3324.27	3274.22	3182.29	3051.81	2886.21	2688.35	2460.85	2206.44	1927.91	1628.33	942.58	861.05
5	3452.07	3401.23	3305.93	3170.72	2999.07	2794.00	2558.15	2294.35	2005.35	1694.48	993.76	911.14
6	3411.65	3362.55	3270.53	3139.95	2974.20	2776.18	2548.40	2293.60	2014.40	1713.95	1039.42	960.34
7	3137.74	3090.29	3010.75	2897.90	2754.66	2583.42	2386.58	2166.36	1925.11	1665.25	1074.33	1005.24
8	2835.03	2799.47	2732.81	2638.16	2518.10	2374.75	2209.96	2025.59	1823.54	1605.63	1102.37	1043.74
9	2416.26	2389.92	2340.55	2270.46	2181.46	2075.15	1952.96	1816.13	1665.89	1503.70	1119.10	1074.60

TEMPERATURES FOR BUNDLE TYPE 10

AX.NODE/RA.NODE	1	2	3	4	5	6	7	8	9	10	11	12
1	2264.31	2234.90	2179.60	2101.72	2002.74	1884.59	1748.78	1596.89	1430.51	1251.08	792.71	736.02
2	2798.60	2758.74	2684.00	2577.99	2443.57	2283.12	2098.74	1892.77	1667.35	1424.97	842.60	771.94
3	3213.58	3165.96	3076.69	2950.06	2789.36	2597.30	2376.59	2129.80	1859.76	1569.29	895.31	814.56
4	3617.53	3558.32	3454.88	3308.16	3121.99	2899.55	2643.86	2357.81	2044.57	1707.82	951.81	862.37
5	3745.05	3688.37	3581.89	3430.45	3238.07	3008.10	2743.63	2447.52	2123.21	1774.38	1003.26	912.79
6	2965.36	2945.12	2869.70	2762.65	2626.70	2464.30	2277.67	2068.83	1840.13	1593.73	1023.93	956.79
7	3375.99	3328.30	3238.92	3112.09	2951.11	2758.78	2537.53	2290.03	2018.77	1726.80	1072.97	996.68
8	3040.36	3000.42	2925.56	2819.34	2684.47	2523.27	2338.00	2130.66	1903.50	1658.70	1100.82	1035.86
9	2570.69	2541.04	2485.47	2406.64	2306.58	2186.98	2049.46	1895.56	1726.70	1544.51	1116.98	1067.40

TEMPERATURES FOR BUNDLE TYPE 11

AX.NODE/RA.NODE	1	2	3	4	5	6	7	8	9	10	11	12
1	1933.09	1910.57	1868.34	1808.38	1732.24	1641.31	1536.77	1419.71	1291.14	1152.35	782.06	735.78
2	2353.63	2323.04	2265.70	2184.33	2081.17	1958.07	1816.64	1658.40	1485.10	1298.33	828.75	771.14
3	2666.10	2649.30	2580.36	2482.62	2358.66	2210.62	2040.55	1850.48	1642.29	1418.26	878.15	812.87
4	3013.83	2971.21	2891.34	2777.97	2634.01	2462.04	2264.44	2043.43	1801.53	1541.18	932.37	859.63
5	3134.44	3090.21	3007.31	2889.70	2740.42	2561.94	2356.83	2127.41	1876.24	1605.84	982.96	909.15
6	3104.54	3061.82	2981.77	2868.20	2724.02	2551.65	2353.55	2131.92	1889.21	1627.81	1028.38	957.78
7	2867.85	2826.93	2757.73	2659.48	2534.80	2385.94	2214.84	2023.42	1813.70	1587.62	1063.54	1002.08
8	2603.83	2572.97	2515.16	2433.15	2329.08	2204.70	2061.69	1901.67	1726.14	1536.78	1091.81	1039.89
9	2243.78	2220.83	2177.85	2116.88	2039.54	1947.13	1840.80	1721.60	1590.72	1449.33	1109.38	1070.06

TEMPERATURES FOR BUNDLE TYPE 12

AX.NCDE/RA.NCDE	1	2	3	4	5	6	7	8	9	10	11	12
1	1536.01	1521.43	1494.09	1455.24	1405.84	1346.68	1278.54	1202.10	1117.98	1027.01	768.11	735.30
2	1817.63	1797.97	1761.14	1708.91	1642.66	1563.50	1472.42	1370.29	1258.07	1136.77	810.15	769.48
3	2043.21	2019.74	1975.73	1913.27	1833.96	1739.09	1629.98	1507.86	1373.81	1229.03	855.40	809.59
4	2274.13	2246.62	2195.10	2122.07	2029.47	1918.92	1791.81	1649.52	1493.53	1325.22	905.15	854.28
5	2368.95	2340.39	2286.84	2210.83	2114.40	1999.30	1867.03	1718.95	1556.61	1381.52	952.80	901.40
6	2363.75	2336.12	2284.33	2210.30	2117.53	2006.18	1878.19	1734.88	1577.71	1408.12	996.39	947.43
7	2216.92	2193.07	2148.38	2085.00	2004.59	1908.50	1797.92	1674.00	1537.99	1391.03	1031.58	989.15
8	2060.26	2040.30	2002.88	1949.78	1882.32	1801.62	1708.68	1604.53	1490.10	1366.29	1060.43	1024.61
9	1835.84	1820.84	1792.72	1752.84	1702.22	1641.71	1572.06	1493.94	1407.96	1314.74	1079.98	1052.84

VOID CALCULATION EDITS

ELAPSED TIME = 0. SECONDS
NUMBER OF COMPLETED VOID TIME STEPS = 0

BUNDLE TYPE	1	2	3	4	5	6	7	8	9	10	11	12
VAPOR PRESSURE (PSI)	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
UPPER COOLANT SLUG ACCELERATION (FT/SEC-SEC)	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
LOWER COOLANT SLUG ACCELERATION (FT/SEC-SEC)	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
UPPER COOLANT SLUG VELOCITY (FT/SEC)	30.40	30.20	30.00	29.70	29.30	28.70	27.80	26.70	26.10	28.50	23.50	17.10
LOWER COOLANT SLUG VELOCITY (FT/SEC)	30.40	30.20	30.00	29.70	29.30	28.70	27.80	26.70	26.10	28.50	23.50	17.10
DISTANCE BETWEEN CORE INLET AND UPPER VOID BOUNDARY (FT)	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
DISTANCE BETWEEN CORE INLET AND LOWER VOID BOUNDARY (FT)	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.

RADIAL BLANKET 1

COOLANT
ACCELERATION
(FT/SEC-SEC) 0.

COOLANT
VELOCITY
(FT/SEC) 2.10

PRESSURES (PSI)

PUMP 1 PRESSURE RISE	=	108.87	PUMP 2 PRESSURE RISE	=	108.87
PRESSURE AT OUTLET OF PUMP PIPING	=	122.57	PRESSURE AT BOTTOM OF THE CORE	=	119.89
PRESSURE AT TOP OF THE CORE	=	22.00	PRESSURE AT INLET OF HEAT EXCHANGER INLET PIPING	=	21.30
PRESSURE OF REACTOR COVERGAS	=	18.39	PRESSURE AT OUTLET OF THE HEAT EXCHANGER 1 INLET PIPING	=	20.30
PRESSURE AT OUTLET OF THE HEAT EXCHANGER 2 INLET PIPING	=	20.30	PRESSURE FOR HEAT EXCHANGER 1 COVERGAS	=	19.21
PRESSURE FOR HEAT EXCHANGER 2 COVERGAS	=	19.21	PRESSURE AT INLET OF THE HEAT EXCHANGER 1 PIPING	=	20.55
PRESSURE AT INLET OF THE HEAT EXCHANGER 2 PIPING	=	20.55	PRESSURE OF HEAT EXCHANGER OUTLET	=	24.10
PRESSURE OF POOL COVERGAS	=	15.00	PUMP INLET PRESSURE	=	22.24

ACCELERATIONS (FT/SEC**2)

ACCELERATION FOR FLOW IN PUMP 1 PIPING	=	0.	ACCELERATION FOR FLOW IN PUMP 2 PIPING	=	0.
ACCELERATION FOR FLOW IN THE LOWER REACTOR POT	=	0.	ACCELERATION FOR COOLANT IN POOL ABOVE THE CORE	=	0.
ACCELERATION FOR THE REACTOR COVERGAS	=	0.	ACCELERATION FOR THE INLET FLOW TO HEAT EXCHANGER 1 PIPING	=	0.
ACCELERATION FOR THE INLET FLOW TO HEAT EXCHANGER 2 PIPING	=	0.	ACCELERATION FOR COOLANT IN POOL ABOVE HEAT EXCHANGER 1	=	0.
ACCELERATION FOR COOLANT IN POOL ABOVE HEAT EXCHANGER 2	=	0.	ACCELERATION OF HEAT EXCHANGER 1 POOL SURFACE	=	0.
ACCELERATION OF HEAT EXCHANGER 2 POOL SURFACE	=	0.	ACCELERATION FOR THE EXIT FLOW FROM HEAT EXCHANGER 1	=	0.
ACCELERATION FOR THE EXIT FLOW FROM HEAT EXCHANGER 2	=	0.			

VELOCITIES (FT/SEC)

VELOCITY FOR FLOW IN PUMP 1 PIPING	=	50.36	VELOCITY FOR FLOW IN PUMP 2 PIPING	=	50.36
VELOCITY FOR FLOW IN THE LOWER REACTOR POT	=	2.93	VELOCITY FOR COOLANT IN POOL ABOVE REACTOR CORE	=	2.93
VELOCITY OF REACTOR POOL SURFACE	=	0.	COOLANT VELOCITY FOR THE INLET FLOW TO HEAT EXCHANGER 1	=	17.09
COOLANT VELOCITY FOR THE INLET FLOW TO HEAT EXCHANGER 2	=	17.09	VELOCITY FOR COOLANT IN POOL ABOVE HEAT EXCHANGER 1	=	2.34
VELOCITY FOR COOLANT IN POOL ABOVE HEAT EXCHANGER 2	=	2.34	VELOCITY OF HEAT EXCHANGER 1 POOL SURFACE	=	0.
VELOCITY OF HEAT EXCHANGER 2 POOL SURFACE	=	0.	COOLANT VELOCITY FOR FLOW FROM HEAT EXCHANGER 1	=	9.08
COOLANT VELOCITY FOR FLOW FROM HEAT EXCHANGER 2	=	9.08			

GAS DISPLACEMENTS (FT)

DEPTH OF HEAT EXCHANGER INLET BELOW REACTOR COVER GAS SURFACE	=	8.00	VERTICAL DISTANCE FROM HEAT EXCHANGER PIPING INLET TO HEAT EXCHANGER 1 COVERGAS	=	3.00
VERTICAL DISTANCE FROM HEAT EXCHANGER PIPING INLET TO HEAT EXCHANGER 2 COVERGAS	=	3.00	HEIGHT OF HEAT EXCHANGER OUTLET BELOW POOL SURFACE (FT)	=	25.00

VOID CALCULATION EDITS

ELAPSED TIME = 0.000100 SECONDS
NUMBER OF COMPLETED VOID TIME STEPS = 1

BUNDLE TYPE	1	2	3	4	5	6	7	8	9	10	11	12
VAPOR PRESSURE (PSI)	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
UPPER COOLANT SLUG ACCELERATION (FT/SEC-SEC)	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33
LOWER COOLANT SLUG ACCELERATION (FT/SEC-SEC)	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33
UPPER COOLANT SLUG VELOCITY (FT/SEC)	30.40	30.20	30.00	29.70	29.30	28.70	27.80	26.70	26.10	28.50	23.50	17.10
LOWER COOLANT SLUG VELOCITY (FT/SEC)	30.40	30.20	30.00	29.70	29.30	28.70	27.80	26.70	26.10	28.50	23.50	17.10
DISTANCE BETWEEN CORE INLET AND UPPER VOID BOUNDARY (FT)	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
DISTANCE BETWEEN CORE INLET AND LOWER VOID BOUNDARY (FT)	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.

RADIAL BLANKET 1

COOLANT
ACCELERATION
(FT/SEC-SEC) 0.30

COOLANT
VELOCITY
(FT/SEC) 2.10

PRESSURES(PSI)

PUMP 1 PRESSURE RISE	=	108.86	PUMP 2 PRESSURE RISE	=	108.87
PRESSURE AT OUTLET OF PUMP PIPING	=	122.51	PRESSURE AT BOTTOM OF THE CORE	=	119.93
PRESSURE AT TOP OF THE CORE	=	22.00	PRESSURE AT INLET OF HEAT EXCHANGER INLET PIPING	=	21.30
PRESSURE OF REACTOR COVERGAS	=	18.39	PRESSURE AT OUTLET OF THE HEAT EXCHANGER 1 INLET PIPING	=	20.31
PRESSURE AT OUTLET OF THE HEAT EXCHANGER 2 INLET PIPING	=	20.31	PRESSURE FOR HEAT EXCHANGER 1 COVERGAS	=	19.21
PRESSURE FOR HEAT EXCHANGER 2 COVERGAS	=	19.21	PRESSURE AT INLET OF THE HEAT EXCHANGER 1 PIPING	=	20.17
PRESSURE AT INLET OF THE HEAT EXCHANGER 2 PIPING	=	20.17	PRESSURE OF HEAT EXCHANGER OUTLET	=	24.10
PRESSURE OF POOL COVERGAS	=	15.00	PUMP INLET PRESSURE	=	22.24

ACCELERATIONS(FT/SEC**2)

ACCELERATION FOR FLOW IN PUMP 1 PIPING	=	0.27	ACCELERATION FOR FLOW IN PUMP 2 PIPING	=	0.28
ACCELERATION FOR FLOW IN THE LOWER REACTOR POT	=	0.05	ACCELERATION FOR COOLANT IN POOL ABOVE THE CORE	=	0.05
ACCELERATION FOR THE REACTOR COVERGAS	=	0.05	ACCELERATION FOR THE INLET FLOW TO HEAT EXCHANGER 1 PIPING	=	-0.04
ACCELERATION FOR THE INLET FLOW TO HEAT EXCHANGER 2 PIPING	=	-0.04	ACCELERATION FOR COOLANT IN POOL ABOVE HEAT EXCHANGER 1	=	-0.38
ACCELERATION FOR COOLANT IN POOL ABOVE HEAT EXCHANGER 2	=	-0.38	ACCELERATION OF HEAT EXCHANGER 1 POOL SURFACE	=	0.38
ACCELERATION OF HEAT EXCHANGER 2 POOL SURFACE	=	0.38	ACCELERATION FOR THE EXIT FLOW FROM HEAT EXCHANGER 1	=	-1.48
ACCELERATION FOR THE EXIT FLOW FROM HEAT EXCHANGER 2	=	-1.48			

VELOCITIES(FT/SEC)

VELOCITY FOR FLOW IN PUMP 1 PIPING	=	50.36	VELOCITY FOR FLOW IN PUMP 2 PIPING	=	50.36
VELOCITY FOR FLOW IN THE LOWER REACTOR POT	=	2.93	VELOCITY FOR COOLANT IN POOL ABOVE REACTOR CORE	=	2.93
VELOCITY OF REACTOR POOL SURFACE	=	0.00	COOLANT VELOCITY FOR THE INLET FLOW TO HEAT EXCHANGER 1	=	17.09
COOLANT VELOCITY FOR THE INLET FLOW TO HEAT EXCHANGER 2	=	17.09	VELOCITY FOR COOLANT IN POOL ABOVE HEAT EXCHANGER 1	=	2.34
VELOCITY FOR COOLANT IN POOL ABOVE HEAT EXCHANGER 2	=	2.34	VELOCITY OF HEAT EXCHANGER 1 POOL SURFACE	=	0.00
VELOCITY OF HEAT EXCHANGER 2 POOL SURFACE	=	0.00	COOLANT VELOCITY FOR FLOW FROM HEAT EXCHANGER 1	=	9.08
COOLANT VELOCITY FOR FLOW FROM HEAT EXCHANGER 2	=	9.08			

GAS DISPLACEMENTS(FT)

DEPTH OF HEAT EXCHANGER INLET BELOW REACTOR COVER GAS SURFACE	=	8.00	VERTICAL DISTANCE FROM HEAT EXCHANGER PIPING INLET TO HEAT EXCHANGER 1 COVERGAS	=	3.00
VERTICAL DISTANCE FROM HEAT EXCHANGER PIPING INLET TO HEAT EXCHANGER 2 COVERGAS	=	3.00	HEIGHT OF HEAT EXCHANGER OUTLET BELOW POOL SURFACE (FT)	=	25.00

VOID CALCULATION EDITS

ELAPSED TIME = 1.753257 SECONDS
NUMBER OF COMPLETED VOID TIME STEPS = 100

BUNDLE TYPE	1	2	3	4	5	6	7	8	9	10	11	12
VAPOR PRESSURE (PSI)	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
UPPER COOLANT SLUG ACCELERATION (FT/SEC-SEC)	-5.82	-5.78	-5.74	-5.68	-5.59	-5.47	-5.29	-5.06	-4.94	-5.43	-4.42	-3.17
LOWER COOLANT SLUG ACCELERATION (FT/SEC-SEC)	-5.82	-5.78	-5.74	-5.68	-5.59	-5.47	-5.29	-5.06	-4.94	-5.43	-4.42	-3.17
UPPER COOLANT SLUG VELOCITY (FT/SEC)	23.41	23.26	23.11	22.88	22.59	22.14	21.46	20.63	20.18	21.99	18.21	13.31
LOWER COOLANT SLUG VELOCITY (FT/SEC)	23.41	23.26	23.11	22.88	22.59	22.14	21.46	20.63	20.18	21.99	18.21	13.31
DISTANCE BETWEEN CORE INLET AND UPPER VOID BOUNDARY (FT)	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
DISTANCE BETWEEN CORE INLET AND LOWER VOID BOUNDARY (FT)	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.

RADIAL BLANKET

1

COOLANT
ACCELERATION
(FT/SEC-SEC)

-0.38

COOLANT
VELOCITY
(FT/SEC)

1.64

PRESSURES (PSI)

PUMP 1 PRESSURE RISE	=	51.61	PUMP 2 PRESSURE RISE	=	75.01
PRESSURE AT OUTLET OF PUMP PIPING	=	84.02	PRESSURE AT BOTTOM OF THE CORE	=	81.78
PRESSURE AT TOP OF THE CORE	=	20.81	PRESSURE AT INLET OF HEAT EXCHANGER INLET PIPING	=	19.83
PRESSURE OF REACTOR COVERGAS	=	16.97	PRESSURE AT OUTLET OF THE HEAT EXCHANGER 1 INLET PIPING	=	19.74
PRESSURE AT OUTLET OF THE HEAT EXCHANGER 2 INLET PIPING	=	19.73	PRESSURE FOR HEAT EXCHANGER 1 COVERGAS	=	18.67
PRESSURE FOR HEAT EXCHANGER 2 COVERGAS	=	18.66	PRESSURE AT INLET OF THE HEAT EXCHANGER 1 PIPING	=	19.65
PRESSURE AT INLET OF THE HEAT EXCHANGER 2 PIPING	=	19.64	PRESSURE OF HEAT EXCHANGER OUTLET	=	24.37
PRESSURE OF POOL COVERGAS	=	15.26	PUMP INLET PRESSURE	=	22.51

ACCELERATIONS (FT/SEC**2)

ACCELERATION FOR FLOW IN PUMP 1 PIPING	=	-41.54	ACCELERATION FOR FLOW IN PUMP 2 PIPING	=	5.92
ACCELERATION FOR FLOW IN THE LOWER REACTOR POT	=	-0.55	ACCELERATION FOR COOLANT IN POOL ABOVE THE CORE	=	-0.55
ACCELERATION FOR THE REACTOR COVERGAS	=	-0.03	ACCELERATION FOR THE INLET FLOW TO HEAT EXCHANGER 1 PIPING	=	-3.09
ACCELERATION FOR THE INLET FLOW TO HEAT EXCHANGER 2 PIPING	=	-3.07	ACCELERATION FOR COOLANT IN POOL ABOVE HEAT EXCHANGER 1	=	-0.38
ACCELERATION FOR COOLANT IN POOL ABOVE HEAT EXCHANGER 2	=	-0.39	ACCELERATION OF HEAT EXCHANGER 1 POOL SURFACE	=	-0.05
ACCELERATION OF HEAT EXCHANGER 2 POOL SURFACE	=	-0.03	ACCELERATION FOR THE EXIT FLOW FROM HEAT EXCHANGER 1	=	-1.47
ACCELERATION FOR THE EXIT FLOW FROM HEAT EXCHANGER 2	=	-1.50			

VELOCITIES (FT/SEC)

VELOCITY FOR FLOW IN PUMP 1 PIPING	=	-2.32	VELOCITY FOR FLOW IN PUMP 2 PIPING	=	59.24
VELOCITY FOR FLOW IN THE LOWER REACTOR POT	=	2.26	VELOCITY FOR COOLANT IN POOL ABOVE REACTOR CORE	=	2.26
VELOCITY OF REACTOR POOL SURFACE	=	-0.16	COOLANT VELOCITY FOR THE INLET FLOW TO HEAT EXCHANGER 1	=	14.14
COOLANT VELOCITY FOR THE INLET FLOW TO HEAT EXCHANGER 2	=	14.18	VELOCITY FOR COOLANT IN POOL ABOVE HEAT EXCHANGER 1	=	2.01
VELOCITY FOR COOLANT IN POOL ABOVE HEAT EXCHANGER 2	=	2.01	VELOCITY OF HEAT EXCHANGER 1 POOL SURFACE	=	-0.07
VELOCITY OF HEAT EXCHANGER 2 POOL SURFACE	=	-0.06	COOLANT VELOCITY FOR FLOW FROM HEAT EXCHANGER 1	=	7.78
COOLANT VELOCITY FOR FLOW FROM HEAT EXCHANGER 2	=	7.78			

GAS DISPLACEMENTS (FT)

DEPTH OF HEAT EXCHANGER INLET BELOW REACTOR COVER GAS SURFACE	=	7.84	VERTICAL DISTANCE FROM HEAT EXCHANGER PIPING INLET TO HEAT EXCHANGER 1 COVERGAS	=	2.95
VERTICAL DISTANCE FROM HEAT EXCHANGER PIPING INLET TO HEAT EXCHANGER 2 COVERGAS	=	2.95	HEIGHT OF HEAT EXCHANGER OUTLET BELOW POOL SURFACE (FT)	=	25.03

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APPENDIX ADETAILED CONTINUITY AND MOMENTUM EQUATIONS

In this section, the transient momentum and mass conservation equations throughout the loop of the primary coolant system are derived.

The starting point of each derivation is the momentum and mass balances specified in Section 3.5.

For an explanation of the nomenclature, see Figures A-1 and A-2.

A.1 CORE REGION n BEFORE VOIDING AND RADIAL BLANKETS

Taking a control volume around the reactor coolant channel (channel n), with $V_n = V_{top, n} = V_{bot, n}$ (since there is no voiding),

$$\sum F = A_{c,n} P_{bot} - A_{c,n} P_{top} - (C_{out,n} + C_{or,n}) \frac{\rho V_n^2}{2g_o} A_{c,n} - \frac{F_{fp} \rho V_n^2 A_{c,n} X_{Lc}}{2g_o D_H} \\ - \rho X_{Lc} A_{c,n} \frac{g}{g_o}$$

$$\text{Momentum Rate in} - \text{Momentum Rate out} = \frac{\rho A_{c,n}}{g_o} (V_n^2 - V_n^2) = 0$$

$$\text{Momentum storage rate} = \frac{\rho X_{Lc} A_{c,n}}{g_o} \dot{V}$$

$$\therefore \dot{V}_n \left(\frac{\rho X_{Lc}}{g_o} \right) - P_{bot} + P_{top} + \frac{\rho V_n^2}{2g_o} \left(f F_P \frac{X_{Lc}}{D_H} + C_{out,n} + C_{or,n} \right) = -\rho X_{Lc} \quad (A-1)$$

Similarly, for each blanket,

$$\dot{V}_{BL,n} \left(\frac{\rho X_{Lc}}{g_o} \right) - P_{bot} + P_{top} + \frac{\rho V_{BL,n}^2}{2g_o} \left(f F_P \frac{X_{Lc}}{D_H} + C_{out,n} + C_{or,n} \right) = -\rho X_{Lc} \quad (A-2)$$

A.2 CORE REGION n DURING VOIDING

The channel is separated into 2 regions, one above and one below the vapor bubble. The upper column of liquid moves with velocity $V_{top,n}$ and the lower column with velocity $V_{bot,n}$.

Two control volumes within the channel are used, with a common boundary between the 2 at the initial void location.

A.2.1 ABOVE THE VOID

$$\begin{aligned} \sum F = (P_{V,n} - P_{top}) A_{c,n} - \left[C_{out,n} + \frac{F_P f}{D_H} (X_{Lc} - X_{Vt,n}) \right] \frac{\rho V_{top,n}^2 A_{c,n}}{2g_o} \\ - \rho A_{c,n} (X_{Lc} - X_{Vt,n}) \frac{g}{g_o} \end{aligned}$$

$$\text{Momentum Rate in} - \text{Momentum Rate out} = - \frac{\rho A_{c,n}}{g_o} V_{top,n}^2$$

$$\text{Momentum Storage Rate} = \frac{d}{dt} \left[\frac{\rho A_{c,n} (X_{Lc} - X_{Vt,n})}{g_o} V_{top,n} \right]$$

Since $\dot{X}_{Vt} = V_{top}$, momentum equation becomes

$$\begin{aligned} \frac{\rho(X_{Lc} - X_{Vt,n})}{g_o} \dot{V}_{top,n} + P_{top,n} + \left(C_{out,n} + F_{Pf} \frac{(X_{Lc} - X_{Vt,n})}{D_H} \right) \frac{\rho V_{top,n}^2}{2g_o} \\ = P_{V,n} - \rho(X_{Lc} - X_{Vt,n}) \frac{g}{g_o} \end{aligned} \quad (A-3)$$

A.2.2 BELOW THE VOID

Defining $V_{bot,n}$ as positive upward, the momentum equation becomes

$$\left(\frac{\rho X_{VB,n}}{g_o} \right) \dot{V}_{bot,n} - P_{bot} + \left(C_{or,n} + F_{Pf} \frac{X_{VB,n}}{D_H} \right) \frac{\rho V_{bot,n}^2}{2g_o} = -P_{V,n} - \rho X_{VB,n} \left(\frac{g}{g_o} \right) \quad (A-4)$$

The sign on the frictional term is positive for upward motion and negative for downward motion.

A.3 UPPER REACTOR POT

The upper reactor pot is divided, at the centerline of the heat exchanger inlet piping, into 2 control volumes (See Figures A-1 and A-2).

FIGURE A-1

VELOCITIES PRIMARY COOLANT LOOP

FIGURE A-2
PRESSURES IN PRIMARY COOLANT LOOP

GEAP-13608

A.3.1 LOWER REGION

$$\sum F = A_p P_{top} - A_p P_{out} - \rho A_p X_{LP} \frac{g}{g_0}$$

Momentum Rate in - Momentum Rate out =

$$\frac{\rho}{g_0} \left[\sum_{n=1}^{NBT} A_{c,n} V_{top,n}^2 + \sum_{n=1}^{NRB} A_{BL,n} V_{BL,n}^2 - A_p V_p^2 \right]$$

$$\text{Momentum Storage Rate} = \frac{\rho A_p X_{LP} \dot{V}_p}{g_0}$$

$$\therefore \left(\frac{\rho X_{LP}}{g_0} \right) \dot{V}_p - P_{top} + P_{out} = \frac{\rho}{g_0 A_p} \left[\sum_{n=1}^{NBT} A_{c,n} V_{top,n}^2 + \sum_{n=1}^{NRB} A_{BL,n} V_{BL,n}^2 \right] - \frac{\rho}{g_0} V_p^2 - \rho X_{LP} \frac{g}{g_0} \quad (A-5)$$

Also, continuity at the top of the upper blanket gives

$$\sum_{n=1}^{NBT} A_{c,n} V_{top,n} + \sum_{n=1}^{NRB} A_{BL,n} V_{BL,n} = A_p V_{LP} \quad (A-6)$$

A.3.2 UPPER REGION

$$\sum F = A_p P_{out} - A_p P_{G2} - \rho A_p Z_{G2} \frac{g}{g_0}$$

$$\text{Momentum Rate in} - \text{Momentum Rate out} = \frac{\rho}{g_o} A_P \dot{z}_{G2}^2$$

$$\text{Momentum Storage Rate} = \frac{d}{dt} \left[\frac{\rho}{g_o} A_P z_{G2} \dot{z}_{G2} \right]$$

$$\therefore \left(\frac{\rho z_{G2}}{g_o} \right) \ddot{z}_{G2} - P_{out} - P_{G2} - \rho z_{G2} \frac{g}{g_o} \quad (A-7)$$

The velocities in these 2 control volumes, and in the heat exchanger inlet pipes, are related by the following continuity equation.

$$A_P V_P = A_P \dot{z}_{G2} + A_{HXIN,1} + A_{HXIN,2} V_{HXIN,2} \quad (A-8)$$

A.4 INLET PIPING TO HEAT EXCHANGERS

Taking a control volume around the inlet pipe for heat exchanger 1,

$$[F = A_{HXIN,1} \left[P_{out} - P_{HX,1} - C_{HXIN,1} \frac{\rho V_{HXIN,1}^2}{2g_o} \right]$$

$$\text{Momentum Rate in} - \text{Momentum Rate out} = 0$$

$$\text{Momentum Storage Rate} = \frac{\rho}{g_o} A_{HXIN} z_{HXIN} \dot{V}_{HXIN,1}$$

$$\therefore \left(\frac{\rho z_{HXIN}}{g_o} \right) \ddot{v}_{HXIN,1} - P_{out} + P_{HX,1} + C_{HXIN,1} \frac{\rho v_{HXIN,1}^2}{2g_o} = 0 \quad (A-9)$$

Similarly, for the second heat exchanger,

$$\left(\frac{\rho z_{HXIN}}{g_o} \right) \ddot{v}_{HXIN,2} - P_{out} + P_{HX,2} + C_{HXIN,2} \frac{\rho v_{HXIN,2}^2}{2g_o} = 0 \quad (A-10)$$

A.5 HEAT EXCHANGER POT

The heat exchanger pot is divided, at the centerline of the heat exchanger inlet piping, into 2 control volumes (See Figures A-1 and A-2).

A.5.1 UPPER REGION

Following the development of Equation (A.7), the momentum equations become, for the 2 heat exchangers,

$$\left(\frac{\rho z_{HX,1}}{g_o} \right) \ddot{z}_{G31} - P_{HX,1} = - P_{G31} - \rho z_{HX,1} \frac{g}{g_o} \quad (A-11)$$

$$\left(\frac{\rho z_{HX,2}}{g_o} \right) \ddot{z}_{G32} - P_{HX,2} = - P_{G32} - \rho z_{HX,2} \frac{g}{g_o} \quad (A-12)$$

A.5.2 LOWER REGION

For heat exchanger 1,

$$\sum F = A_{G31} P_{HX,1} - A_{G31} P_{HXL,1} + \rho A_{G31} X_{HX} \frac{g}{g_o}$$

Momentum Rate in - Momentum Rate out =

$$\frac{\rho}{g_o} (A_{G31} V_{HX,1}^2 - A_{HXOT,1} V_{HXOT,1}^2)$$

$$\text{Momentum Storage Rate} = \frac{\rho}{g_o} A_{G31} X_{HX} \dot{V}_{HX,1}$$

$$\therefore \left(\frac{\rho X_{HX}}{g_o} \right) \dot{V}_{HX,1} - P_{HX,1} + P_{HXL,1} =$$

$$\frac{\rho}{g_o A_{G31}} [A_{G31} V_{HX,1}^2 - A_{HXOT,1} V_{HXOT,1}^2] + \rho X_{HX} \frac{g}{g_o} \quad (A-13)$$

Similarly, for heat exchanger 2,

$$\left(\frac{\rho X_{HX}}{g_o} \right) \dot{V}_{HX,2} - P_{HX,2} + P_{HXL,2} =$$

$$\frac{\rho}{g_o A_{G32}} [A_{G32} V_{HX,2}^2 - A_{HXOT,2} V_{HXOT,2}^2] + \rho X_{HX} \frac{g}{g_o} \quad (A-14)$$

Writing continuity at the inlet to the heat exchanger pot,

$$A_{HXIN,1} V_{HXIN,1} = A_{G31} V_{HX,1} + A_{G31} \dot{Z}_{G31} \quad (A-15)$$

$$A_{HXIN,2} V_{HXIN,2} = A_{G32} V_{HX,2} + A_{G32} \dot{Z}_{G32} \quad (A-16)$$

A.6 HEAT EXCHANGER PIPING

Taking a control volume around the piping on heat exchanger 1, and following the development of the momentum equation for the heat exchanger inlet pipe,

$$\left(\frac{\rho Z_{HXOT}}{g_o} \right) \dot{V}_{HXOT,1} - P_{HXL,1} + P_{HXO} + C_{HXOT,1} \frac{\rho V_{HXOT,1}^2}{2g_o} = \rho X_{HXOT} \frac{g}{g_o} \quad (A-19)$$

Similarly, for heat exchanger 2,

$$\left(\frac{\rho Z_{HXOT}}{g_o} \right) \dot{V}_{HXOT,2} - P_{HXL,2} + P_{HXO} + C_{HXOT,2} \frac{\rho V_{HXOT,2}^2}{2g_o} = \rho X_{HXOT} \frac{g}{g_o} \quad (A-20)$$

A.7 PUMP PIPING

Taking a control volume on the piping from pump 1,

$$\sum F = A_{P,1} \left[P_{UMIN} + \Delta P_{P,1} - P_{PPout} \right] \pm C_{P,1} \frac{\rho V_{P,1}^2}{2g_o} A_{P,1} + \rho X_P \frac{g}{g_o} A_{P,1}$$

Momentum Rate in - Momentum Rate out = 0

$$\text{Momentum Storage Rate} = \frac{\rho A_{P,1} X_{PP}}{g_o} \dot{V}_{P,1}$$

$$\therefore \left(\frac{\rho X_{PP}}{g_o} \right) \dot{V}_{P,1} + P_{PPout} \pm C_{P,1} \frac{\rho V_{P,1}^2}{2g_o} = P_{UMIN} + \Delta P_{P,1} + \rho X_P \frac{g}{g_o} \quad (A-21)$$

Similarly, for pump piping 2,

$$\left(\frac{\rho X_{PP}}{g_o} \right) \dot{V}_{P,2} - P_{PPout} \pm C_{P,2} \frac{\rho V_{P,2}^2}{2g_o} = P_{UMIN} + \Delta P_{P,2} - \rho X_P \frac{g}{g_o} \quad (A-22)$$

A.8 LOWER REACTOR POT

Taking a control volume on the area in the lower reactor pot between the pump piping and the bottom of the lower blanket,

$$\sum F = A_P P_{PPout} - A_P P_{bot} - \rho X_V A_P \frac{g}{g_o}$$

Momentum Rate in - Momentum Rate out =

$$\frac{\rho}{g_o} \left[\pm \sum_{n=1}^{N_{BT}} A_{c,n} V_{bot,n}^2 - \sum_{n=1}^{N_{RB}} A_{BL,n} V_{BL,n}^2 \right] \pm \frac{\rho}{g_o} A_P V_P^2$$

(Minus sign is associated with flow upward into the core. Positive sign with flow downward.)

$$\text{Momentum Storage Rate} = \frac{\rho X_V A_P}{g_o} \dot{V}_{BP}$$

$$\therefore \left(\frac{\rho X_V}{g_o} \right) \dot{V}_{BP} - P_{PPout} + P_{bot} = \frac{\rho}{g_o} A_P \pm \left[\sum_{n=1}^{N_{BT}} A_{c,n} V_{bot,n}^2 - \sum_{n=1}^{N_{RB}} A_{BL,n} V_{BL,n}^2 \right] - \rho X_V \frac{g}{g_o} \pm \frac{\rho}{g_o} V_P^2 \quad (A-23)$$

Writing continuity at the outlet of the pump piping,

$$A_P V_{BP} = A_{P,1} V_{P,1} + A_{P,2} V_{P,2} \quad (A-24)$$

Writing continuity at the bottom of the lower blanket,

$$A_P V_{BP} = \sum_{n=1}^{N_{BT}} A_{c,n} V_{bot,n} + \sum A_{BL,n} V_{BL,n} \quad (A-25)$$

APPENDIX BSOLUTION OF THE PRESSURE-ACCELERATION EQUATIONS

When the equations for pressure and acceleration derived in Appendix A have been finite-differenced and conditioned as described in Section 3.5, they form a set of linear simultaneous algebraic equations.

$$\tilde{A}_{k\ell} X_k = \tilde{C}_k \quad k = 1, 48 \quad (B.1)$$

The array X_k denotes the pressures and accelerations for the time step, for which a solution is sought. There are a total of 48 unknowns in the X_k array, and thus 48 equations are represented by equation (B.1). The detailed equations are written out in matrix form in Figure (B.1).

By examining Figure (B.1), it can be seen that the coefficient matrix is very sparse, i.e., it contains many zero elements. Therefore, to speed the computation of the solution of these equations, they have been algebraically reduced by eliminating the accelerations in equations (41) - (48), with the result being a set of 8 simultaneous equations for the pressures.

The resulting 8 simultaneous equations for the pressures are as follows. The notation A and C is used, which represent the $\tilde{A}$ and $\tilde{C}$ arrays that have been normalized to the diagonal element, $\tilde{A}_{kk}$.

$$\begin{aligned} (B.2) \quad P_{top} & \left\{ 1 + \hat{A}_{41,28} \left[\sum_{k=1}^{NBT} \hat{A}_{28,k} \hat{A}_{k,41} + \sum_{k=1}^{NRB} \hat{A}_{28,k+24} \hat{A}_{k+24,41} \right] \right\} \\ & + P_{bot} \left\{ \hat{A}_{41,28} \left[\sum_{k=1}^{NBT} \hat{A}_{28,k} \hat{A}_{k,42} + \sum_{k=1}^{NRB} \hat{A}_{28,k+24} \hat{A}_{k+24,42} \right] \right\} \\ -P_{out} & = \hat{C}_{41} - \hat{A}_{41,28} \left\{ \hat{C}_{28} - \sum_{k=1}^{NBT} \hat{A}_{28,k} \hat{C}_k - \sum_{k=1}^{NRB} \hat{A}_{28,k+24} \hat{C}_{k+24} \right\} \end{aligned}$$

$$\begin{aligned}
 (B.3) \quad P_{top} & \left\{ \hat{A}_{42,40} \left[\sum_{k=1}^{NBT} \hat{A}_{40,k+12} \hat{A}_{k+12,41} + \sum_{k=1}^{NRB} \hat{A}_{40,k+24} \hat{A}_{k+24,41} \right] \right\} \\
 & + P_{pot} \left\{ 1 + \hat{A}_{42,40} \left[\sum_{k=1}^{NBT} \hat{A}_{40,k+12} \hat{A}_{k+12,42} + \sum_{k=1}^{NRB} \hat{A}_{40,k+24} \hat{A}_{k+24,42} \right] \right\} \\
 - P_{ppout} & = \hat{C}_{42} - \hat{A}_{42,40} \left\{ \hat{C}_{40} - \sum_{k=1}^{NBT} \hat{A}_{40,k+12} \hat{C}_{k+12} - \sum_{k=1}^{NRB} \hat{A}_{40,k+24} \hat{C}_{k+24} \right\}
 \end{aligned}$$

$$\begin{aligned}
 (B.4) \quad P_{top} & \left\{ \hat{A}_{43,24} \left[- \hat{A}_{29,28} \left(\sum_{k=1}^{NBT} \hat{A}_{28,k} \hat{A}_{k,41} + \sum_{k=1}^{NRB} \hat{A}_{28,k+24} \hat{A}_{k+24,41} \right) \right] \right\} \\
 & + P_{bot} \left\{ \hat{A}_{43,29} \left[- \hat{A}_{29,28} \left(\sum_{k=1}^{NBT} \hat{A}_{28,k} \hat{A}_{k,42} + \sum_{k=1}^{NRB} \hat{A}_{28,k+24} \hat{A}_{k+24,42} \right) \right] \right\} \\
 & + P_{out} \left\{ 1 + \hat{A}_{43,29} \left[\hat{A}_{29,30} \hat{A}_{30,43} + \hat{A}_{29,31} \hat{A}_{31,43} \right] \right\} \\
 & + P_{hx,1} \left\{ \hat{A}_{43,29} \hat{A}_{29,30} \hat{A}_{30,44} \right\} + P_{hx,2} \left\{ \hat{A}_{43,29} \hat{A}_{29,31} \hat{A}_{31,45} \right\} \\
 & = \hat{C}_{43} - \hat{A}_{43,29} \left\{ \hat{C}_{29} - \hat{A}_{29,28} \left[\hat{C}_{28} - \sum_{k=1}^{NBT} \hat{A}_{28,k} \hat{C}_k - \sum_{k=1}^{NRB} \hat{A}_{28,k+24} \hat{C}_{k+24} \right. \right. \\
 & \quad \left. \left. - \hat{A}_{29,30} \hat{C}_{30} - \hat{A}_{29,31} \hat{C}_{31} \right] \right\}
 \end{aligned}$$

$$\begin{aligned}
 (B.5) \quad P_{out} & \left\{ \hat{A}_{44,32} \hat{A}_{32,30} \hat{A}_{30,43} \right\} + P_{hx,1} \left\{ 1 + \hat{A}_{44,32} \hat{A}_{32,30} \hat{A}_{30,44} \right\} \\
 & + P_{hx1,1} \left\{ \hat{A}_{44,32} (-\hat{A}_{32,34} \hat{A}_{34,36} \hat{A}_{36,46}) \right\} \\
 & = \hat{C}_{44} - \hat{A}_{44,32} \left\{ \hat{C}_{32} - \hat{A}_{32,30} \hat{C}_{30} - \hat{A}_{32,34} (\hat{C}_{34} - \hat{A}_{34,36} \hat{C}_{36}) \right\}
 \end{aligned}$$

$$\begin{aligned}
 (B.6) \quad P_{out} & \left\{ \hat{A}_{45,33} \hat{A}_{33,31} \hat{A}_{31,43} \right\} + P_{HX,2} \left\{ 1 + \hat{A}_{45,33} \hat{A}_{33,31} \hat{A}_{31,45} \right\} \\
 & + P_{HXL,2} \left\{ \hat{A}_{45,33} (-\hat{A}_{33,35} \hat{A}_{35,37} \hat{A}_{37,47}) \right\} \\
 & = \hat{C}_{45} - \hat{A}_{45,33} \left\{ \hat{C}_{33} - \hat{A}_{33,31} \hat{C}_{31} - \hat{A}_{33,35} (\hat{C}_{35} - \hat{A}_{35,37} \hat{C}_{37}) \right\}
 \end{aligned}$$

$$\begin{aligned}
 (B.7) \quad P_{HX,1} & \left\{ -1 \right\} + P_{HXL,1} \left\{ 1 + \hat{A}_{46,34} \hat{A}_{34,36} \hat{A}_{36,46} \right\} \\
 & = \hat{C}_{46} - \hat{A}_{46,34} \left\{ \hat{C}_{34} - \hat{A}_{34,36} \hat{C}_{36} \right\}
 \end{aligned}$$

$$\begin{aligned}
 (B.8) \quad P_{HX,2} & \left\{ -1 \right\} + P_{HXL,2} \left\{ 1 + \hat{A}_{47,35} \hat{A}_{35,37} \hat{A}_{37,47} \right\} \\
 & = \hat{C}_{47} - \hat{A}_{47,35} \left\{ \hat{C}_{35} - \hat{A}_{35,37} \hat{C}_{37} \right\}
 \end{aligned}$$

$$\begin{aligned}
 (B.9) \quad P_{top} & \left\{ \hat{A}_{48,39} (-\hat{A}_{39,40}) \left(\sum_{k=1}^{NBT} \hat{A}_{40,k+12} \hat{A}_{k+12,41} + \sum_{k=1}^{NRB} \hat{A}_{40,k+24} \hat{A}_{k+24,41} \right) \right\} \\
 & + P_{bot} \left\{ \hat{A}_{48,39} (-\hat{A}_{39,40}) \left(\sum_{k=1}^{NBT} \hat{A}_{40,k+12} \hat{A}_{k+12,42} + \sum_{k=1}^{NRB} \hat{A}_{40,k+24} \hat{A}_{k+24,42} \right) \right\} \\
 & + P_{ppout} \left\{ 1 + \hat{A}_{48,39} \hat{A}_{39,28} \hat{A}_{33,48} \right\} \\
 & = \hat{C}_{48} - \hat{A}_{48,39} \left\{ \hat{C}_{39} - \hat{A}_{39,38} \hat{C}_{38} - \hat{A}_{39,40} \left[\hat{C}_{40} - \sum_{k=1}^{NBT} \hat{A}_{40,k+12} \hat{C}_{k+12} \right. \right. \\
 & \quad \left. \left. - \sum_{k=1}^{NRB} \hat{A}_{40,k+24} \hat{C}_{k+24} \right] \right\}
 \end{aligned}$$

This set of 8 equations is now solved directly by Crout Elimination⁽⁵⁾. Having found the pressures, they can then be substituted into equations (1) - (40) (Figure B.1) for the accelerations.

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