**MAX -- A ONE - DIMENSIONAL
MAXIMUM HYPOTHETICAL
ACCIDENT CODE IN FORTRAN - IV**

W. W. LITTLE, JR.

MARCH, 1968

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DEVELOPMENT REPORT**

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MAX--A ONE-DIMENSIONAL MAXIMUM HYPOTHETICAL
ACCIDENT CODE IN FORTRAN-IV

By

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Nuclear Design and Analysis Section
Reactor Physics Department

FFTF Project

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MAX--A ONE-DIMENSIONAL MAXIMUM HYPOTHETICAL
ACCIDENT CODE IN FORTRAN-IV

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ABSTRACT

MAX is a one-dimensional (sphere, cylinder, plane), multi-zone code for computing the energy release in large nuclear excursions. The nuclear model consists of a point kinetics model with fixed worth and power distributions. Linear and Doppler reactivity feedback terms are included. The hydrodynamics model consists of many movable and compressible mesh intervals. Zone dependent equations of state, heats of fusion, etc., can be employed. The reactivity input can be any piecewise-linear function of time.

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MAX--A ONE-DIMENSIONAL MAXIMUM HYPOTHETICAL
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I. INTRODUCTION

The MAX code computes the energy release in large hypothetical nuclear excursions. In general, events in large excursions proceed in the following sequence. An extraneous reactivity increase causes the power level and temperature to increase rapidly. When the fuel temperature rises appreciably over the fuel melting point, internally generated pressures cause the core to expand. Since the peak pressures are usually generated in areas of high reactivity worths, core expansion rapidly reduces reactivity to terminate the excursion.

The neutronics model in MAX consists of the familiar lumped parameter kinetics equations with tabular power and worth profiles. Step and ramp reactivity insertions, and linear and Doppler reactivity feedback coefficients are included.

The hydrodynamics model consists of many movable and compressible mesh points. The effect of expansion work on each mesh point is included.

Up to three regions in spherical, cylindrical, or plane geometry can be used. A schematic diagram of the geometric model is shown in Figure 1.1. Region-dependent fuel densities, reactivity worths, feedback coefficients, heats of fusion, equations of state, etc., can be employed.

The code accepts spatially dependent initial fuel temperatures. The initial temperatures can be either above or below the melting point. If the initial temperatures are below the melting point, the energy and temperature integrations are carried through the heat of fusion.

FIGURE 1.1. Schematic Diagram of Geometric Model

Any number of time sectors, or breaks in the march-out calculation, can be made. At each break, a complete print-out of the spatially dependent variables is given. The input reactivity ramp can also be varied at each break. Thus, any piecewise-linear reactivity input function can be used.

MAX uses a rapid, variable time step march-out algorithm.⁽¹⁾ Although running times are problem dependent, a representative running time on a UNIVAC 1108 is 15 seconds.

1. K. F. Hansen, B. V. Koen, and W. W. Little, Jr. "Stable Numerical Solutions to the Reactor Kinetics Equations," Nucl. Sci. and Engr., vol 22, pp. 51-59. 1965.

II. MATHEMATICAL MODEL

Neutron Kinetics Equations

Consider the lumped parameter kinetics equations

$$\frac{dP}{dt} = \frac{\rho - \beta}{\Lambda} P + \sum_1^G \lambda^i C^i, \quad (2.1)$$

and

$$\frac{dC^i}{dt} = \frac{\beta^i P}{\Lambda} - \lambda^i C^i, \quad (2.2)$$

where:

ρ = Reactivity

P = Power density (W/cm^3)

C^i = Precursor density for group i (W/cm^3)

λ^i = Decay constant for group i (sec^{-1})

β^i = Delayed neutron fraction for group i

β = Total delayed neutron fraction

Λ = Neutron generation time (sec)

G = Number of precursor groups.

$-\omega_j P(t)$ is now added to both sides of Equation (2.1). Integration from t_j to t_{j+1} yields

$$P_{j+1} = e^{\omega_j h} \left[P_j + \int_0^h d\xi \left\{ \frac{\rho(\xi) - \rho_j}{\Lambda} P(\xi) e^{-\omega_j \xi} + \sum_1^G \lambda_j^i \left(C^i(\xi) - C_j^i \frac{P(\xi)}{P_j} \right) e^{-\omega_j \xi} \right\} \right], \quad (2.3)$$

where:

h = mesh spacing

j = time index

$$\omega_j = \frac{\rho_j - \beta}{\Lambda} + \frac{1}{P_j} \sum_1^G \lambda^i C_j^i.$$

In a similar manner, $-\gamma_j^i C_j^i(t)$ is added to both sides of Equation (2.2) and then integrated. Therefore,

$$C_{j+1}^i = e^{\gamma_j^i h} \left[C_j^i + \int_0^h d\xi e^{-\gamma_j^i \xi} \left\{ \frac{\beta_j^i}{\Lambda} \left(P(\xi) - \frac{P_j}{C_j^i} C^i(\xi) \right) \right\} \right], \quad (2.4)$$

where

$$\gamma_j^i = \frac{\beta_j^i P_j}{\Lambda C_j^i} - \lambda_i$$

Clearly, ω_j and γ_j^i 's are merely approximations to the instantaneous period at time mesh j for the power density and precursor densities, respectively.

To evaluate the integrals in Equations (2.3) and (2.4), the first approximations,

$$P(\xi) = e^{\omega_j \xi} P_j, \quad (2.5)$$

and

$$C^i(\xi) = e^{\gamma_j^i \xi} C_j^i, \quad (2.6)$$

are placed in the integrals, and the integration is performed using the trapezoidal rule. This leads to the final march-out algorithm

$$P_{j+1} = e^{\omega_j h} \left\{ P_j \left(1 + \frac{h}{2\Lambda} \left\{ \rho_{j+1} - \rho_j \right\} \right) + \sum_1^G \lambda^i C_j^i \cdot \left[\frac{e^{h(\gamma_j^i - \omega_j)} - 1}{\gamma_j^i - \omega_j} - h \right] \right\} \quad (2.7)$$

$$C_{j+1}^i = e^{\gamma_j^i h} \left[C_j^i + \frac{P_j \beta^i}{\Lambda} \left\{ \frac{e^{h(\omega_j - \gamma_j^i)} - 1}{\omega_j - \gamma_j^i} - h \right\} \right] \quad (2.8)$$

The variable time step, h , is determined by the requirement that the first approximation for P_{j+1} , Equation (2.5), agree with the second approximation, Equation (2.7), within a prescribed tolerance. That is,

$$\frac{P_{j+1}^{(2)} - P_{j+1}^{(1)}}{P_{j+1}^{(1)}} \leq \epsilon \quad , \quad (2.9)$$

where epsilon is an input parameter.

The spatial power density distribution, $PS(r)$, is computed by the equation

$$PS(r) = P_j N(r) \frac{d_j}{d_o} \quad (2.10)$$

where:

$N(r)$ = Input spatial distribution

d_j = Fuel density at time mesh j (gm/cc).

Thus, the magnitude of the power distribution is governed by the lumped parameter power, P_j , although the profile can be altered during the excursion by variations in the fuel density.

Reactivity Input and Feedback

The net reactivity at time mesh j is computed by the expression

$$\rho_j = a + bt_j + \sum_{i=1}^3 \rho_j^i \text{ (linear)} + \sum_{i=1}^3 \rho_j^i \text{ (Doppler)} + \rho_j \text{ (expansion)} \quad , \quad (2.11)$$

where:

$$\begin{aligned}\rho_j &= \text{Total reactivity } (\delta k) \\ \rho_j^i \text{ (linear)} &= \text{Linear reactivity feedback from} \\ &\quad \text{zone } i \text{ } (\delta k) \\ \rho_j^i \text{ (Doppler)} &= \text{Doppler feedback from zone } i \text{ } (\delta k) \\ \rho_j \text{ (expansion)} &= \text{Total expansion feedback } (\delta k) \\ t_j &= \text{Time (sec)} \\ a &= \text{Input reactivity step } (\delta k) \\ b &= \text{Input reactivity ramp } (\delta k/\text{sec}).\end{aligned}$$

The linear and Doppler reactivity feedback terms, $\rho_j^i \text{ (linear)}$ and $\rho_j^i \text{ (Doppler)}$, are based on the volume-averaged temperatures of each zone. The expansion reactivity, $\rho_j \text{ (expansion)}$, is computed by the expression

$$\rho_j \text{ (expansion)} = \sum_{k=1}^N [W_j^k - W_j^0] M_j^k \quad (2.12)$$

where:

$$\begin{aligned}W_j^k &= \text{Fuel worth at time } t_j \text{ and position} \\ &\quad r_j^k \text{ } (\delta k/\text{gm}) \\ M_j^k &= \text{Fuel mass at position } r_j^k \text{ (gm)} \\ r_j^k &= \text{Position of mesh point } k \text{ (cm)} \\ N &= \text{Number of mesh points.}\end{aligned}$$

The space and time dependent fuel worths, W_j^k , are determined by linear interpolation of the tabular input fuel reactivity coefficients.

Heat Content and Temperature Equations

Two energy variables are computed in MAX. One of these is simply the integrated power, ET (joules/cc), where

$$ET(r,t) = \int_0^t P(r,t') dt' \quad (2.13)$$

The second energy variable, E (joules/cc), is defined as the total heat content above the melting point (including the heat of fusion). Thus, if the excursion begins below the melting point, E is zero until the melting point is reached. Similarly, if the excursion begins above the melting point, the appropriate initial value for E is automatically computed. The differential equation for E (valid above the melting point) is

$$dE = d(ET) - dW, \quad (2.14)$$

where dW is the expansion work.

Finally, the local temperature, T ($^{\circ}\text{K}$), is computed by the expression

$$dT = \frac{d(ET) - dW}{\rho C_V}, \quad (2.15)$$

where

$$\begin{aligned} \rho &= \text{Fuel density (gm/cc)} \\ C_V &= \text{Heat capacity (joules/gm-}^{\circ}\text{C)}. \end{aligned}$$

Equations of State

Very little information is now available on the equation of state at the temperatures and pressures of interest in severe fast reactor excursions. Consequently, rather than binding the code to a particular equation of state, the MAX code is written to accept any reasonable functional form, i.e., a form that can be simulated by FORTRAN statements for the equation of state. Thus, we can symbolically write

$$P = F_0(E, T, \rho) \quad (2.16)$$

and

$$C_V = F_1(E, T, \rho) \quad (2.17)$$

where:

P = Pressure (bars)

C_v = Heat capacity (joules/gm-°C)

E = Heat content (joules/cc)

T = Temperature (°K)

ρ = Fuel density (gm/cc)

Six input parameters have been allocated for the calculation of pressure, and three input parameters have been provided for the calculation of heat capacity.

Expansion Equations

The geometric core expansion is computed by using implicit difference equation approximations to the differential equations

$$\dot{v}(r,t) = -\nabla P(r,t)/\rho(r,t) \quad (2.18)$$

and

$$\dot{r}(r,t) = v(r,t) \quad (2.19)$$

The pressure gradient, ∇P , is computed by using simple first order difference approximations. If the outer boundary is specified as free, a zero pressure is assumed at the boundary. If the outer boundary is specified as fixed, however, a zero pressure gradient is assumed at the boundary. As an option, the user can specify any initial velocity distribution.

APPENDIX A

FLOW DIAGRAM

APPENDIX A

FLOW DIAGRAM

Figure A.1 shows the calling sequence of all subroutines. A brief description of the function of each subroutine is given below.

MAIN	Program management
INPUT	Reads and prints preliminary input data
INPUT2	Reads and prints space dependent parameters
ADDINP	Computes initial geometric constants
CIT	Sets initial parameters
TEMDIS	Prints spatially dependent parameters
CONST	Reads and prints current reactivity status
CALC	Manages march-out calculation
SUBRHO	Calculates new reactivity
EXPAND	Calculates expansion
VOLCA	Calculates new volumes and areas
CPCAL	Calculates new temperatures and energy densities
PRES	Calculates new pressure and pressure gradients
AWDIS	Calculates new fuel worth distribution
SUBNEU	Calculates new power
PRECUR	Computes precursor densities and resets indices
WORK	Calculates total energy, heat energy, kinetic energy, and available work.

FIGURE A.1. MAX Flow Diagram

APPENDIX B

INPUT INSTRUCTIONS

APPENDIX B

INPUT INSTRUCTIONS

<u>Card</u>	<u>Cols.</u>	<u>Format</u>	<u>Definition</u>
1*	2-72	Hollerith	Identification
2	1-6	Integer	Number of delay groups ($1 \leq n \leq 6$).
2	7-12	Integer	Maximum number of time steps ($n \leq 9,999$).
2	13-18	Integer	Number of time intervals between prints (e.g., $n = 1$, print every step; $n = 2$, print every other step).
2	19-24	Integer	Initial precursor density control: = 0, equilibrium C_i 's, = 1, code reads initial C_i 's (see card 7').
2	25-30	Integer	Initial temperature control: = 0, flat initial profile, = 1, code reads initial temperatures (see card 9').
2	31-36	Integer	Initial velocity control: = 0, zero initial velocities, = 1, code reads initial velocity distribution (see card 9'').
2	37-42	Integer	Number of time sectors ($n \geq 1$).
2	43-48	Integer	Number of mesh intervals in Region I ($0 \leq n \leq 40$).
2	49-54	Integer	Number of mesh intervals in Region II ($0 \leq n \leq 40$).
2	55-60	Integer	Number of mesh intervals in Region III ($0 \leq n \leq 40$). The total number of mesh intervals in all regions must also be 40 or less.
2	61-66	Integer	Outer boundary condition: = 0, free, = 1, fixed.
2	67-72	Integer	Geometry: = 0, sphere, = 1, cylinder, = 2, plane

* To run a series of cases, repeat from this card.

Card	Cols.	Format	Definition
3	1-6	Integer	Equation of state option. See subroutine PRES for a precise definition.
3	7-12	Integer	Number of inner iterations ($n \geq 0$) (recommended value = 1).
4	1-12	Floating	Total delayed neutron fraction, β .
4	13-24	Floating	Initial reactivity (δk).
4	25-36	Floating	Minimum reactivity (δk). Code aborts when this value is reached.
4	37-48	Floating	Neutron generation time (sec).
4	49-60	Floating	Convergence criterion (recommended value = 0.001).
4	61-72	Floating	Maximum permissible time step (sec).
5	1-12	Floating	Initial central power density (w/cc).
5	13-24	Floating	Initial core temperature ($^{\circ}\text{K}$). This value is not used if temperature profile is read in.
5	25-36	Floating	Initial central fuel worth ($\delta k/\text{gm}$).
5	37-48	Floating	Threshold pressure (bars).
6	1-12	Floating	Relative delay fraction for first precursor group.
6	13-24	Floating	Relative delay fraction for second precursor group.
. . .			
7	1-12	Floating	Decay constant for first precursor group (sec^{-1}).
7	13-24	Floating	Decay constant for second precursor group (sec^{-1}).
. . .			
8	1-12	Floating	Relative power density at mesh point 1.
8	13-24	Floating	Relative power density at mesh point 2.
. . .			
9	1-24	Floating	Relative fuel worth at mesh point 1.
9	13-24	Floating	Relative fuel worth at mesh point 2.
. . .			
9" (opt)	1-12	Floating	Initial temperature at mesh point 1 ($^{\circ}\text{K}$)
9" (opt)	13-24	Floating	Initial temperature at mesh point 2 ($^{\circ}\text{K}$)
. . .			

<u>Card</u>	<u>Cols.</u>	<u>Format</u>	<u>Definition</u>
9" (opt)	1-12	Floating	Initial velocity at mesh point 1 (cm/sec).
9"	13-24	Floating	Initial velocity at mesh point 2 (cm/sec).
. . . .			
10	1-12	Floating	Thickness of Region I (cm).
10	13-24	Floating	Thickness of Region II (cm).
10	25-36	Floating	Thickness of Region III (cm).
10	37-48	Floating	Relative fuel worth in Region I.
10	49-60	Floating	Relative fuel worth in Region II.
10	61-72	Floating	Relative fuel worth in Region III.
11	1-12	Floating	Linear reactivity coefficient for Region I ($\delta k/^\circ\text{C}$).
11	13-24	Floating	Linear reactivity coefficient for Region II ($\delta k/^\circ\text{C}$).
11	25-36	Floating	Linear reactivity coefficient for Region III ($\delta k/^\circ\text{C}$).
11	37-48	Floating	Doppler coefficient in Region I ($T\delta k/dT$).
11	49-60	Floating	Doppler coefficient in Region II ($T\delta k/dT$).
11	61-72	Floating	Doppler coefficient in Region III ($T\delta k/dT$).
12	1-12	Floating	Fuel density in Region I (gm/cc).
12	13-24	Floating	Fuel density in Region II (gm/cc).
12	25-36	Floating	Fuel density in Region III (gm/cc).
12	37-48	Floating	Inertial density in Region I (gm/cc).
12	49-60	Floating	Inertial density in Region II (gm/cc).
12	61-72	Floating	Inertial density in Region III (gm/cc).
13	1-12	Floating	Melting point in Region I ($^\circ\text{K}$).
13	13-24	Floating	Melting point in Region II ($^\circ\text{K}$).
13	25-36	Floating	Melting point in Region III ($^\circ\text{K}$).
13	37-48	Floating	Heat of fusion in Region I (j/gm) (i.e., joules per gram of fuel).
13	49-60	Floating	Heat of fusion in Region II (j/gm).
13	61-72	Floating	Heat of fusion in Region III (j/gm).

<u>Card</u>	<u>Cols.</u>	<u>Format</u>	<u>Definition</u>
14	1-12	Floating	Equation of State parameter #1 for Region I.
14	13-24	Floating	Equation of State parameter #1 for Region II.
14	25-36	Floating	Equation of State parameter #1 for Region III.
14	37-48	Floating	Equation of State parameter #2 for Region I.
14	49-60	Floating	Equation of State parameter #2 for Region II.
14	61-72	Floating	Equation of State parameter #2 for Region III.
15	1-12	Floating	Equation of State parameter #3 for Region I.
15	13-24	Floating	Equation of State parameter #3 for Region II.
15	25-36	Floating	Equation of State parameter #3 for Region III.
15	37-48	Floating	Equation of State parameter #4 for Region I.
15	49-60	Floating	Equation of State parameter #4 for Region II.
15	61-72	Floating	Equation of State parameter #4 for Region III.
16	1-12	Floating	Equation of State parameter #5 for Region I.
16	13-24	Floating	Equation of State parameter #5 for Region II.
16	25-36	Floating	Equation of State parameter #5 for Region III.
16	37-48	Floating	Equation of State parameter #6 for Region I.
16	49-60	Floating	Equation of State parameter #6 for Region II.
16	61-72	Floating	Equation of State parameter #6 for Region III.
17	1-12	Floating	Heat capacity parameter #1 for Region I.

<u>Card</u>	<u>Cols.</u>	<u>Format</u>	<u>Definition</u>
17	13-24	Floating	Heat capacity parameter #1 for Region II.
17	25-36	Floating	Heat capacity parameter #1 for Region III.
17	37-48	Floating	Heat capacity parameter #2 for Region I.
17	49-60	Floating	Heat capacity parameter #2 for Region II.
17	61-72	Floating	Heat capacity parameter #2 for Region III.
18	1-12	Floating	Heat capacity parameter #3 for Region I.
18	13-24	Floating	Heat capacity parameter #3 for Region II.
18	25-36	Floating	Heat capacity parameter #3 for Region III.
19	1-12	Floating	Terminal time for first time sector (sec).
19	13-24	Floating	Reactivity ramp for first time sector ($\delta k/\text{sec}$).
20 (opt)	1-12	Floating	Terminal time for second time sector (sec).
20 (opt)	13-24	Floating	Reactivity ramp for second time sector ($\delta k/\text{sec}$).
. . .			

APPENDIX C

SAMPLE PROBLEM

APPENDIX C

SAMPLE PROBLEM

The input data (first page) and computer print-out for a sample case are listed on the following pages:

	6	5000	MAX SAMPLE CASE	200.	\$/SEC	RAMP	0	0	1	0	1	0	1
	3	1	25	0	0	18	0	0	1	0	1	0	1
.003	3	1	.0	-.0045	3.5	-07.001	.1						4
1.0			3000.	.5	-06								5
.035			.298	.211	.326	.086	.044						6
.0128			.0301	.124	.325	1.12	2.69						7
.9974			.9897	.9769	.9590	.9359	.9078						8
.8745			.8360	.7925	.7438	.6900	.6311						9
.5671			.4979	.4236	.3442	.2596	.1700						10
.9974			.9897	.9769	.9590	.9359	.9078						11
.8745			.8360	.7925	.7438	.6900	.6311						12
.5671			.4979	.4236	.3442	.2596	.1700						13
65.			.0	.0	1.0	1.0	1.0						14
.0			.0	.0	-.002	.0	.0						15
3.4			.0	.0	5.4	.0	.0						16
3000.			.0	.0	280.	.0	.0						17
1.0			.0	.0	1.0	.0	.0						18
.0			.0	.0	1.333	.0	.0						19
.0			.0	.0	.0	.0	.0						20
.35			.0	.0	.0	.0	.0						21
.0			.0	.0									22
.1			.6										23

* * * * * M A X * * * * *

MAX SAMPLE CASE 200. \$/SEC RAMP

NUMBER OF PRECURSOR GROUPS	6
MAXIMUM NUMBER OF TIME STEPS	5000
NUMBER OF INTERVALS BETWEEN PRINT OUT	25
NUMBER OF REACTIVITY SECTORS	1
NUMBER OF INTERVALS IN ZONE 1	18
NUMBER OF INTERVALS IN ZONE 2	0
NUMBER OF INTERVALS IN ZONE 3	0
BOUNDARY CONDITION(0/1=FREE/FIXED)	1
GEOMETRY(0/1/2=SPHERE/CYLINDER/PLANE)	0
EQUATION OF STATE OPTION	3
NUMBER OF INNER ITERATIONS	1
TOTAL PRECURSOR FRACTION	3.0000-03
INITIAL REACTIVITY(CENTS)	0.0000
MINIMUM REACTIVITY(CENTS)	-1.5000+02
GENERATION TIME(SEC)	3.5000-07
CONVERGENCE CRITERION	1.0000-03
MAXIMUM TIME STEP(SEC)	1.0000-01
INITIAL CENTRAL POWER(WATTS/CC)	1.0000+00
INITIAL CENTRAL TEMPERATURE(DEGREES K)	3.0000+03
INITIAL CENTRAL WORTH(DEL K/G)	5.0000-07
THRESHOLD PRESSURE(BARS)	-0.0000

C.3

BNWL-612

MAX SAMPLE CASE 200. \$/SEC RAMP

DELAYED NEUTRON PARAMETERS

GROUP	B(I)	LAMBDA(I)	C(I)
1	1.0500-04	1.2800-02	2.3438+04
2	8.9400-04	3.0100-02	8.4860+04
3	6.3300-04	1.2400-01	1.4585+04
4	9.7800-04	3.2500-01	8.5978+03
5	2.5800-04	1.1200+00	6.5816+02
6	1.3200-04	2.6900+00	1.4020+02

C.4

BNWL-612

PARAMETER	REGION 1	REGION 2	REGION 3
MESH POINTS PER REGION	18	0	0
REGION THICKNESS(CM)	6.5000+01	0.0000	0.0000
REGION VOLUME(CC)	1.1503+06	0.0000	0.0000
REGION POWER(MW)	5.3961-01	0.0000	0.0000
RELATIVE WORTH	1.0000+00	1.0000+00	1.0000+00
LINEAR TEMP COEF(PER DEG K)	0.0000	0.0000	0.0000
DOPPLER COEFFICIENT(T DK/DT)	-2.0000-03	0.0000	0.0000
INITIAL FUEL DENSITY(G/CC)	3.4000+00	0.0000	0.0000
INITIAL INERTIAL DENSITY(G/CC)	5.4000+00	0.0000	0.0000
MELTING POINT(DEG K)	3.0000+03	0.0000	0.0000
HEAT OF FUSION(JOULES/G)	2.8000+02	0.0000	0.0000
EQUATION OF STATE PARAMETERS			
NUMBER 1	1.0000+00	0.0000	0.0000
NUMBER 2	1.0000+00	0.0000	0.0000
NUMBER 3	0.0000	0.0000	0.0000
NUMBER 4	1.3330+00	0.0000	0.0000
NUMBER 5	0.0000	0.0000	0.0000
NUMBER 6	0.0000	0.0000	0.0000
HEAT CAPACITY PARAMETERS			
NUMBER 1	3.5000-01	0.0000	0.0000
NUMBER 2	0.0000	0.0000	0.0000
NUMBER 3	0.0000	0.0000	0.0000

C.5

BNWL-612

MAX SAMPLE CASE 200. %/SEC RAMP

GEOMETRY SPECIFICATIONS AND SPATIAL DEPENDENT PARAMETERS LISTED BELOW

I	ZONE	INIT R(CM)	CURRENT R	AREA(CM2)	VOL(CC)	FD(G/CC)	TEMP(K)	P(BARS)	E(J/CC)	VEL(CM/SEC)	POW(W/CC)	W(DK/G)
1	1	1.806+00	1.806+00	1.639+02	1.972+02	3.400+00	3.000+03	0.000	0.000	0.000	1.000+00	5.000-07
2	1	5.417+00	5.417+00	6.555+02	1.331+03	3.400+00	3.000+03	0.000	0.000	0.000	9.923-01	4.961-07
3	1	9.028+00	9.028+00	1.475+03	3.748+03	3.400+00	3.000+03	0.000	0.000	0.000	9.794-01	4.897-07
4	1	1.264+01	1.264+01	2.622+03	7.298+03	3.400+00	3.000+03	0.000	0.000	0.000	9.615-01	4.807-07
5	1	1.625+01	1.625+01	4.097+03	1.203+04	3.400+00	3.000+03	0.000	0.000	0.000	9.383-01	4.692-07
6	1	1.986+01	1.986+01	5.899+03	1.795+04	3.400+00	3.000+03	0.000	0.000	0.000	9.102-01	4.551-07
7	1	2.347+01	2.347+01	8.029+03	2.505+04	3.400+00	3.000+03	0.000	0.000	0.000	8.768-01	4.384-07
8	1	2.708+01	2.708+01	1.049+04	3.333+04	3.400+00	3.000+03	0.000	0.000	0.000	8.382-01	4.191-07
9	1	3.069+01	3.069+01	1.327+04	4.280+04	3.400+00	3.000+03	0.000	0.000	0.000	7.946-01	3.973-07
10	1	3.431+01	3.431+01	1.639+04	5.345+04	3.400+00	3.000+03	0.000	0.000	0.000	7.457-01	3.729-07
11	1	3.792+01	3.792+01	1.963+04	6.529+04	3.400+00	3.000+03	0.000	0.000	0.000	6.918-01	3.459-07
12	1	4.153+01	4.153+01	2.360+04	7.831+04	3.400+00	3.000+03	0.000	0.000	0.000	6.327-01	3.164-07
13	1	4.514+01	4.514+01	2.769+04	9.251+04	3.400+00	3.000+03	0.000	0.000	0.000	5.686-01	2.843-07
14	1	4.875+01	4.875+01	3.212+04	1.079+05	3.400+00	3.000+03	0.000	0.000	0.000	4.992-01	2.496-07
15	1	5.236+01	5.236+01	3.687+04	1.245+05	3.400+00	3.000+03	0.000	0.000	0.000	4.247-01	2.124-07
16	1	5.597+01	5.597+01	4.195+04	1.422+05	3.400+00	3.000+03	0.000	0.000	0.000	3.451-01	1.725-07
17	1	5.958+01	5.958+01	4.735+04	1.612+05	3.400+00	3.000+03	0.000	0.000	0.000	2.603-01	1.301-07
18	1	6.319+01	6.319+01	5.309+04	1.813+05	3.400+00	3.000+03	0.000	0.000	0.000	1.704-01	8.522-08

C.6

BNWL-612

MAX SAMPLE CASE 200. \$/SEC RAMP

REACTIVITY INPUT DATA LISTED BELOW . . .

THE CURRENT TIME (SEC) IS	0.0000
THE CURRENT REACTIVITY (CENTS) IS	0.0000
THE LINEAR COEFFICIENT (CENTS/SEC) IS	2.0000+04

C.7

BNWL-612

MAX SAMPLE CASE 200. %/SEC RAMP

SOLUTION OF KINETICS EQUATIONS BELOW

I	TIME(SEC)	POWER(W/CC)	RHO(CENTS)	R1/T1	R2/T2	R3/T3	RHO EXP/P(BARS)	C1/C4	C2/C5	C3/C6
1	0.000	1.000+00	0.000	0.000	0.000	0.000	0.000	2.344+04	8.486+04	1.459+04
				3.000+03	0.000	0.000	0.000	3.598+03	6.582+02	1.402+02
25	1.493-03	1.366+00	2.987+01	0.000	0.000	0.000	3.415-04	2.344+04	8.486+04	1.459+04
				3.000+03	0.000	0.000	1.524-02	8.598+03	6.583+02	1.403+02
50	3.856-03	3.383+00	7.712+01	0.000	0.000	0.000	3.415-04	2.344+04	8.487+04	1.459+04
				3.000+03	0.000	0.000	1.524-02	8.606+03	6.602+02	1.413+02
75	5.230-03	1.064+01	1.046+02	0.000	0.000	0.000	3.415-04	2.344+04	8.488+04	1.460+04
				3.000+03	0.000	0.000	1.524-02	3.624+03	6.652+02	1.438+02
100	6.105-03	4.338+01	1.221+02	0.000	0.000	0.000	3.415-04	2.345+04	8.493+04	1.464+04
				3.000+03	0.000	0.000	1.524-02	8.675+03	6.786+02	1.507+02
125	6.945-03	4.190+02	1.389+02	0.000	0.000	0.000	3.415-04	2.348+04	8.526+04	1.487+04
				3.000+03	0.000	0.000	1.524-02	9.031+03	7.725+02	1.986+02
150	7.528-03	3.943+03	1.506+02	0.000	0.000	0.000	3.415-04	2.375+04	8.750+04	1.645+04
				3.000+03	0.000	0.000	1.524-02	1.148+04	1.419+03	5.292+02
175	8.111-03	6.619+04	1.622+02	0.000	0.000	0.000	3.415-04	2.745+04	1.190+05	3.876+04
				3.000+03	0.000	0.000	1.524-02	4.595+04	1.051+04	5.178+03
200	8.695-03	1.990+06	1.739+02	0.000	0.000	0.000	3.415-04	1.224+05	9.277+05	6.112+05
				3.000+03	0.000	0.000	1.524-02	9.303+05	2.438+05	1.245+05
225	9.130-03	3.141+07	1.589+02	-2.318+01	0.000	0.000	-5.447-01	1.573+06	1.328+07	9.355+06
				4.247+03	0.000	0.000	5.423+02	1.444+07	3.807+06	1.947+06
250	9.271-03	4.768+07	8.614+01	-5.225+01	0.000	0.000	-4.704+01	3.342+06	2.834+07	2.002+07
				6.569+03	0.000	0.000	1.496+04	3.092+07	8.153+06	4.170+06
275	9.333-03	3.173+07	-6.841+01	-5.201+01	0.000	0.000	-1.931+02	4.114+06	3.491+07	2.467+07
				7.604+03	0.000	0.000	2.304+04	3.811+07	1.005+07	5.140+06
284	9.351-03	2.279+07	-1.541+02	-6.383+01	0.000	0.000	-2.773+02	4.265+06	3.620+07	2.559+07
				7.815+03	0.000	0.000	2.353+04	3.951+07	1.042+07	5.330+06

C.8

BNWL-612

MAX SAMPLE CASE 200. \$/SEC RAMP

GEOMETRY SPECIFICATIONS AND SPATIAL DEPENDENT PARAMETERS LISTED BELOW

I	ZONE	INIT R(CM)	CURRENT R	AREA(CM2)	VOL(CC)	FD(G/CC)	TEMP(K)	P(BARS)	E(J/CC)	VEL(CM/SEC)	POW(W/CC)	W(DK/G)
1	1	1.806+00	1.881+00	1.778+02	2.229+02	3.009+00	1.390+04	2.353+04	1.232+04	9.186+02	2.019+07	4.999-07
2	1	5.417+00	5.638+00	7.098+02	1.555+03	3.018+00	1.381+04	2.328+04	1.227+04	2.792+03	2.010+07	4.957-07
3	1	9.028+00	9.387+00	1.593+03	4.200+03	3.034+00	1.367+04	2.285+04	1.218+04	4.636+03	1.994+07	4.888-07
4	1	1.264+01	1.312+01	2.823+03	8.123+03	3.055+00	1.347+04	2.222+04	1.205+04	6.412+03	1.971+07	4.792-07
5	1	1.625+01	1.684+01	4.393+03	1.328+04	3.082+00	1.322+04	2.137+04	1.188+04	8.120+03	1.940+07	4.669-07
6	1	1.986+01	2.054+01	6.296+03	1.960+04	3.114+00	1.290+04	2.028+04	1.167+04	9.686+03	1.902+07	4.519-07
7	1	2.347+01	2.421+01	8.521+03	2.700+04	3.155+00	1.253+04	1.893+04	1.141+04	1.108+04	1.856+07	4.344-07
8	1	2.708+01	2.785+01	1.106+04	3.536+04	3.205+00	1.210+04	1.729+04	1.110+04	1.225+04	1.803+07	4.144-07
9	1	3.069+01	3.145+01	1.389+04	4.454+04	3.267+00	1.161+04	1.532+04	1.076+04	1.309+04	1.742+07	3.922-07
10	1	3.431+01	3.500+01	1.699+04	5.433+04	3.345+00	1.105+04	1.295+04	1.036+04	1.337+04	1.674+07	3.676-07
11	1	3.792+01	3.850+01	2.034+04	6.454+04	3.440+00	1.043+04	1.001+04	9.910+03	1.242+04	1.597+07	3.411-07
12	1	4.153+01	4.197+01	2.400+04	7.696+04	3.460+00	9.729+03	5.674+03	9.116+03	8.961+03	1.469+07	3.125-07
13	1	4.514+01	4.547+01	2.804+04	9.185+04	3.424+00	8.960+03	3.281+03	8.103+03	5.773+03	1.306+07	2.811-07
14	1	4.875+01	4.900+01	3.238+04	1.062+05	3.454+00	8.136+03	2.093+03	7.175+03	4.496+03	1.157+07	2.470-07
15	1	5.236+01	5.252+01	3.702+04	1.221+05	3.467+00	7.250+03	1.089+03	6.128+03	3.085+03	9.880+06	2.106-07
16	1	5.597+01	5.605+01	4.201+04	1.399+05	3.456+00	6.303+03	4.071+02	4.963+03	1.647+03	8.003+06	1.716-07
17	1	5.958+01	5.961+01	4.737+04	1.598+05	3.429+00	5.294+03	8.517+01	3.714+03	5.957+02	5.989+06	1.298-07
18	1	6.319+01	6.320+01	5.309+04	1.809+05	3.408+00	4.226+03	5.794+00	2.417+03	1.085+02	3.897+06	8.517-08

C.9

BNWL-612

MAX SAMPLE CASE 200. \$/SEC RAMP

TOTAL ENERGY RELEASED(MJOULES) =	7.6345+03
TOTAL HEAT ENERGY(MJOULES) =	7.6205+03
TOTAL KINETIC ENERGY(MJOULES) =	7.8613+00
PERCENT KINETIC ENERGY =	1.032-01
AVAILABLE WORK(MJOULES) =	1.6185+03

C.10

BNWL-612

Appendix D

LISTING OF CODE


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-IL POP INCL
ABC* FCOPY
  DIMENSION HOL(12), B(6), AL(6), GAM(6), ALPH(6), C(6,2), T(2),
  ^ AN(2), RH(2), RT(3), WIZ(3), DENI(3), DEN(3), TM(3),
  ^ HF(3), VOL(3), CEQ(3,6), CPP(3,3), RC(3,2), TEMP(3,2),
  ^ RCNT(3,2), PF(40), WF(40),
  ^ CP(40), RAD(40), RD(40,2), RADA(40), RA(40,2), AR(40,2),
  ^ VR(40,2), DI(40,2), D(40,2), E(40,2), ET(40,2), V(40,2),
  ^ PR(40,2), TP(40,2), AW(40,2), P(40,2),
  ^ REXP(2), RNOR(3)
  DIMENSION IZONE(40)
  COMMON HOL, B, AL, GAM, ALPH, C, T, AN, RH, RT, WIZ, DENI, DEN,
  ^ TM, HF, VOL, CEQ, CPP, RC, TEMP, RCNT,
  ^ PF, WF, CP, RAD, RD, RADA, RA, AR, VR, DI, D, E, ET, V,
  ^ PR, TP, AW, P, REXP, RNOR
  COMMON ERROR, BB, STEPM, TMAX, HMAX, ALIFE, ANZ, H, W, R1, R2,
  ^ TZERO, WZERO, RMIN, PTH
  COMMON IZONE, NIT, NOT, M, NMAX, NPRT, NSTART, NTEQ, NVEQ, IES,
  ^ IFB, IB, NCYC, IG, NFLAG, I1, I2, I3, IT, LJ, ITER
  END

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-ITC NOR MAIN,MAIN
  INCLUDE ABC

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```

C          GLOSSARY
C
C
C  NIT      NUMBER FOR INPUT TAPE
C  NOT      NUMBER FOR OUTPUT TAPE
C  M        NUMBER OF PRECURSOR GROUPS
C  NMAX     MAXIMUM NUMBER OF TIME STEPS
C  NPRT     NUMBER OF STEPS BETWEEN PRINTS
C  NSTART   INITIAL PRECURSOR OPTION CONTROL
C  NTEQ     INITIAL TEMPERATURE OPTION CONTROL
C  NVEQ     INITIAL VELOCITY OPTION CONTROL
C  NCYC     NUMBER OF TIME SECTORS
C  NFLAG    NOT USED
C  I1       NUMBER OF INTERVALS IN ZONE 1
C  I2       NUMBER OF INTERVALS IN ZONE 2
C  I3       NUMBER OF INTERVALS IN ZONE 3
C  IT       I1 + I2 + I3
C  IB       BOUNDARY CONTROL
C  IG       GEOMETRY CONTROL
C  IES      EQUATION OF STATE CONTROL
C  IFB      NOT USED
C  ITER     NUMBER OF INNER ITERATIONS
C
C  IZONE(I) ZONE INDICATOR

```

C		
C	ERROR	ERROR CRITERION
C	BB	DELAYED NEUTRON FRACTION
C	STEPM	STEP MULTIPLIER
C	TMAX	TERMINAL TIME
C	HMAX	MAXIMUM TIME STEP
C	ALIFE	NEUTRON GENERATION TIME
C	ANZ	PREDICTED POWER DENSITY
C	H	TIME STEP
C	W	INSTANTANEOUS PERIOD
C	R1	INITIAL REACTIVITY
C	R2	RAMP REACTIVITY RATE
C	TZERO	INITIAL CORE TEMPERATURE
C	WZERO	INITIAL CENTRAL WORTH
C	RMIN	MINIMUM REACTIVITY
C	PTH	PRESSURE THRESHOLD
C		
C	HOL(12)	IDENTIFICATION
C	B(6)	DELAYED NEUTRON FRACTIONS
C	AL(6)	DECAY CONSTANTS
C	C(6,2)	PRECURSOR DENSITIES
C	T(2)	ABSOLUTE TIME
C	AN(2)	POWER DENSITY
C	RH(2)	REACTIVITY
C	REXP(2)	EXPANSION REACTIVITY
C		
C	RT(3)	ZONE THICKNESS
C	WIZ(3)	RELATIVE WORTH OF EACH ZONE
C	DENI(3)	INITIAL INERTIAL DENSITY
C	DEN(3)	INITIAL FUEL DENSITY
C	TM(3)	MELTING POINT
C	HF(3)	HEAT OF FUSION
C	VOL(3)	REGION VOLUME
C	CEQ(3,6)	EQUATION OF STATE PARAMETERS FOR EACH ZONE
C	CPP(3,3)	HEAT CAPACITY PARAMETERS
C	RC(3,2)	REACTIVITY COEFFICIENTS
C	TEMP(3,2)	ZONE AVERAGED TEMPERATURES
C	RCNT(3,2)	REACTIVITY FEEDBACK FOR EACH ZONE
C		
C	PF(I)	RELATIVE POWER AT MESH POINT I
C	WF(I)	RELATIVE WORTH
C	CP(I)	HEAT CAPACITY
C	RAD(I)	OUTER RADIUS
C	RADA(I)	AVERAGE RADIUS
C	RD(I,2)	OUTER VARIABLE RADIUS
C	RA(I,2)	AVERAGE VARIABLE RADIUS
C	AR(I,2)	AREA

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C      VR(I,2)      VOLUME
C      DI(I,2)      INERTIAL DENSITY
C      D(I,2)      FUEL DENSITY
C      E(I,2)      ENERGY ABOVE MELTING POINT
C      ET(I,2)      INTEGRATED POWER
C      V(I,2)      VELOCITY
C      PR(I,2)      PRESSURE
C      TP(I,2)      TEMPERATURE
C      AW(I,2)      CURRENT WORTH
C      P(I,2)      CURRENT POWER DENSITY
C
      NIT = 5
      NOT = 6
      STEPM = 1.5
1     CONTINUE
      CALL INPUT
      CALL INPUT2
      CALL TEMDIS
      DO 6 IJK = 1,NCYC
      CALL CONST
      CALL CALC
      CALL TEMDIS
      CALL WORK
      IF (NMAX) 2,2,6
2     KK = IJK + 1
      IF (KK - NCYC) 3,3,1
3     DO 4 K = KK,NCYC
4     CALL CONST
      GO TO 1
6     CONTINUE
      GO TO 1
      END

-ITC  NOR TEMDIS,TEMDIS
      SUBROUTINE TEMDIS
      INCLUDE ABC
C     THIS SUBROUTINE PRINTS SPATIAL DEPENDENT PARAMETERS
      WRITE (NOT,2) (HOL(I), I=1,12)
2     FORMAT (1H1,12A6///70H GEOMETRY SPECIFICATIONS AND SPATIAL DEPENDENT
      ANT PARAMETERS LISTED BELOW///
      A32H I ZONE INIT R(CM) CURRENT R , 1X,
      A31H AREA(CM2) VOL(CC) FD(G/CC) , 2X,
      A29H TEMP(K) P(BARS) E(J/CC), 1X,
      A33H VEL(CM/SEC) POW(W/CC) W(DK/G)///
      DO 10 I = 1,IT
      IF (I - 1) 3,3,4
3     G = .5*V(I,1)

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```

      GO TO 6
4      G = (V(I,1) + V(I-1,1))*0.5
6      CONTINUE
      WRITE (NOT,12) I, IZONE(I), RADA(I), RA(I,1), AR(I,1), VR(I,1),
      ^ D(I,1), TP(I,1), PR(I,1), E(I,1), G,      P(I,1), AW(I,1)
10     CONTINUE
12     FORMAT (2I4, 1P11E11.3)
      RETURN
      END

-ITC ^OR INPUT, INPUT
      SUBROUTINE INPUT
      INCLUDE ABC
C      THIS SUBROUTINE READS AND PRINTS PRELIMINARY INPUT DATA
      READ (NIT,2) (HOL(I), I=1,12)
2      FORMAT (12A6)
      WRITE (NOT,3)
3      FORMAT (1H1,36X,30H * * * * * M A X * * * * *)
      WRITE (NOT,4) (HOL(I), I=1,12)
4      FORMAT (1H0/12A6//)
      READ (NIT,6) M, NMAX, NPRT, NSTART, NTEQ, NVEQ, NCYC, I1, I2, I3, IB,
      ^ IG
6      FORMAT (12I6)
      READ (NIT,6) IES, ITER
      IT = I1 + I2 + I3
      WRITE (NOT,8) M, NMAX, NPRT, NCYC, I1, I2, I3, IB, IG, IES, ITER
8      FORMAT (29H0NUMBER OF PRECURSOR GROUPS ,25X,I2//
      ^31H MAXIMUM NUMBER OF TIME STEPS ,20X,I5//
      ^40H NUMBER OF INTERVALS BETWEEN PRINT OUT ,13X,I3//
      ^32H NUMBER OF REACTIVITY SECTORS ,21X,I3//
      ^32H NUMBER OF INTERVALS IN ZONE 1 ,21X,I3//
      ^32H NUMBER OF INTERVALS IN ZONE 2 ,21X,I3//
      ^32H NUMBER OF INTERVALS IN ZONE 3 ,21X,I3//
      ^35H BOUNDARY CONDITION(0/1=FREE/FIXED),18X,I3//
      ^38H GEOMETRY(0/1/2=SPHERE/CYLINDER/PLANE),15X,I3//
      ^27H EQUATION OF STATE OPTION ,26X,I3//
      ^28H NUMBER OF INNER ITERATIONS ,25X,I3//
10     FORMAT (6E12.4)
      READ (NIT,10) BB, R1, RMIN, ALIFE, ERROR, HMAX
      READ (NIT,10) ANZ, TZERO, WZERO, PTH
      READ (NIT,10) (B(I), I=1, M)
      READ (NIT,10) (AL(I), I=1, M)
      G = 0.0
      DO 100 I = 1, M
100    G = G + B(I)
      DO 11 I = 1, M
11     B(I) = B(I) * BB / G

```



```

R1 = 100.*R1/BB
RMIN = 100.*RMIN/BB
DO 12 I = 1,6
  C(I,1) = .0
12  C(I,2) = .0
    IF(NSTART) 14, 14, 13
13  READ (NIT,10) (C(I,1), I = 1,M)
    GO TO 20
14  DO 15 I = 1, M
15  C(I,1) = ANZ * B(I)/(ALIFE*AL(I))
20  CONTINUE
    WRITE (NOT,22) BB, R1, RMIN, ALIFE, ERROR, HMAX, ANZ,TZERO,WZERO
    ^,PTH
22  FORMAT (26H TOTAL PRECURSOR FRACTION ,20X,1PE16.4//
    ^27H INITIAL REACTIVITY(CENTS) ,19X,1PE16.4//
    ^27H MINIMUM REACTIVITY(CENTS) ,19X,1PE16.4//
    ^22H GENERATION TIME(SEC) ,24X,1PE16.4//
    ^23H CONVERGENCE CRITERION ,23X,1PE16.4//
    ^24H MAXIMUM TIME STEP(SEC) ,22X,1PE16.4//
    ^33H INITIAL CENTRAL POWER(WATTS/CC) ,13X,1PE16.4//
    ^40H INITIAL CENTRAL TEMPERATURE(DEGREES K) , 6X,1PE16.4//
    ^33H INITIAL CENTRAL WORTH(DEL K/G) ,13X,1PE16.4//
    ^26H THRESHOLD PRESSURE(BARS) ,20X,1PE16.4)
    WRITE (NOT,23) (HOL(I), I = 1,12)
23  FORMAT (1H1//12A6///32H      DELAYED NEUTRON PARAMETERS ///
    ^48H GROUP      B(I)      LAMBDA(I)      C(I)///)
    DO 24 I = 1, M
24  WRITE (NOT,26) I, B(I), AL(I), C(I,1)
26  FORMAT (I3,1P3E16.4)
    AN(1) = ANZ
    H = 100.* ALIFE
    T(1) = .0
    RH(1) = .01*BB*R1
    RMIN = .01*BB*RMIN
    RETURN
    END

-ITC ^OR INPUT2,INPUT2
      SUBROUTINE INPUT2
        INCLUDE ABC
C      THIS SUBROUTINE READS AND PRINTS SPACE DEPENDENT VARIABLES
      DO 10 I = 1, IT
      IF (I - I1) 2, 2, 4
2      IZONE(I)=1
      GO TO 10
4      IF(I - I1 - I2) 6, 6, 8
6      IZONE(I)=2

```

```

      GO TO 10
8     IZONE(I)=3
10    CONTINUE
      READ (NIT,12) (PF(I), I =1,IT)
      READ (NIT,12) (WF(I), I =1,IT)
12    FORMAT (6E12.4)
      G = PF(1)
      GG = WF(1)
      DO 13 I = 1,IT
      PF(I) = PF(I)/G
      WF(I) = WF(I)/GG
13    CONTINUE
      IF (NTEQ) 16, 16, 14
14    READ (NIT,12) ( TP(I,1), I =1, IT)
      DO 150 I = 1,IT
      E(I,1) = .0
      IF (TP(I,1)) 15,150,150
15    E(I,1) = - TP(I,1)
150   CONTINUE
      GO TO 18
16    DO 17 I = 1, IT
      E(I,1) = .0
      TP(I,1) = TZERO
17    CONTINUE
      IF (NVEQ) 24, 24, 22
22    READ(NIT,12) ( V(I,1), I = 1, IT)
      GO TO 26
24    DO 25 I = 1, IT
25    V(I,1) = .0
26    CONTINUE
      READ (NIT,12) (RT(I), I=1,3), (WIZ(I),I=1,3)
      CALL ADDINP
      READ (NIT,12) (RC(I,1), I=1,3),(R3(I,2), I=1,3)
      READ (NIT,12) (DEN(I), I=1,3),(DENI(I), I=1,3)
      READ (NIT,12) (TM(I), I=1,3),(HF(I), I=1,3)
      READ (NIT,12) (CEQ(I,1), I=1,3),(CEQ(I,2), I=1,3)
      READ (NIT,12) (CEQ(I,3), I=1,3),(CEQ(I,4), I=1,3)
      READ (NIT,12) (CEQ(I,5), I=1,3),(CEQ(I,6), I=1,3)
      READ (NIT,12) (CPP(I,1), I=1,3), (CPP(I,2), I=1,3)
      READ (NIT,12) (CPP(I,3), I=1,3)
      DO 28 I = 1,IT
      J = IZONE(I)
      P(I,1) = PF(I)*ANZ
      AW(I,1)= WF(I)*WZERO* WIZ(J)
28    CONTINUE
      DO 30 I=1, IT
      IF(E(I,1)) 30,30,29

```

```

29  J=IZONE(I)
    TP(I,1)=TM(J)
30  CONTINUE
    CALL CIT
    G = .0
    GG = .0
    GGG = .0
    DO 35 I = 1,IT
      J = IZONE(I)
      IF(J - 2) 31, 32, 33
31  G = G + VR(I,1)*P(I,1)
      GO TO 35
32  GG = GG + VR(I,1)*P(I,1)
      GO TO 35
33  GGG = GGG + VR(I,1)*P(I,1)
35  CONTINUE
    G = G * 10. **(-6 )
    GG = GG * 10. **(-6 )
    GGG = GGG * 10. **(-6 )
C   PRINT ZONE DEPENDENT PARAMETERS
    WRITE (NOT,50)
50  FORMAT ( 14H1    PARAMETER,32X,39H REGION 1      REGION 2
    ^  REGION 3///)
    WRITE (NOT,55)  I1,I2,I3, (RT(I),I =1,3), (VOL(I),I=1,3),
    ^ G, GG, GGG, (WIZ(I),I=1,3),
    ^ (RC(I,1),I=1,3), (RC(I,2),I=1,3), (DEN(I),I=1,3), (DENI(I),I=1,3)
    ^ , (TM(I),I=1,3), (HF(I),I=1,3), ((CEQ(I,J), I=1,3),J=1,6) ,
    ^ ((CPP(I,J),I=1,3), J=1,3)
55  FORMAT (24H MESH POINTS PER REGION ,16X,3I15//
    ^22H REGION THICKNESS(CM) ,18X,1P3E15.4//
    ^19H REGION VOLUME(CC) ,21X,1P3E15.4//
    ^36H REGION POWER(MW) , 4X,1P3E15.4//
    ^16H RELATIVE WORTH ,24X,1P3E15.4//
    ^29H LINEAR TEMP COEF(PER DEG K) ,11X,1P3E15.4//
    ^30H DOPPLER COEFFICIENT(T DK/DT) ,10X1P3E15.4//
    ^28H INITIAL FUEL DENSITY(G/CC) ,12X,1P3E15.4//
    ^32H INITIAL INERTIAL DENSITY(G/CC) , 8X,1P3E15.4//
    ^22H MELTING POINT(DEG K) ,18X,1P3E15.4//
    ^26H HEAT OF FUSION(JOULES/G) ,14X,1P3E15.4//
    ^30H EQUATION OF STATE PARAMETERS ,//14H    NUMBER 1 ,26X,1P3E15.4
    ^//14H    NUMBER 2 ,26X,1P3E15.4//14H    NUMBER 3 ,26X,1P3E15.4//
    ^14H    NUMBER 4 ,26X,1P3E15.4//14H    NUMBER 5 ,26X,1P3E15.4//
    ^14H    NUMBER 6 ,26X,1P3E15.4//
    ^26H HEAT CAPACITY PARAMETERS ,//14H    NUMBER 1 ,26X,1P3E15.4//
    ^14H    NUMBER 2 ,26X,1P3E15.4//14H    NUMBER 3 ,26X,1P3E15.4)
    DO 100 I = 1,3
      RNOR(I) = .0

```

```

      RCNT (I,1) = .0
      RCNT (I,2) = .0
      RC(I,1) = 100.*RC(I,1)/BB
      RC(I,2) = 100.*RC(I,2)/BB
      IF (TEMP(I,1)) 100,100,99
99    RNOR(I) = - (RC(I,1) * TEMP(I,1) + RC(I,2) * ALOG(TEMP(I,1)))
100   CONTINUE
      REXP(1) = .0
      REXP(2) = .0
      RETURN
      END

-ITC  ^OR ADDINP,ADDINP
      SUBROUTINE ADDINP
      INCLUDE ABC
C     THIS SUBROUTINE COMPUTES INITIAL GEOMETRIC CONSTANTS
      RAD(IT) = RT(1) + RT(2) + RT(3)
      DO 20 II = 2, IT
        I = IT+1 - II
        IF (I - II) 2, 4, 4
2       G = I1
        DEL = RT(1)/G
        RAD(I) = RAD(I+1) - DEL
        GO TO 20
4       IF (I - I1 - I2) 6, 8, 8
6       G = I2
        DEL = RT(2)/G
        RAD(I) = RAD(I+1) - DEL
        GO TO 20
8       G = I3
        DEL = RT(3)/G
        RAD(I) = RAD(I+1) - DEL
20      CONTINUE
        RADA(1) = .5 * RAD(1)
        DO 24 I = 2, IT
24       RADA(I) = (RAD(I) + RAD(I-1))/2.
        DO 26 I = 1, IT
          RD(I,1) = RAD(I)
          RD(I,2) = RAD(I)
          RA(I,1) = RADA(I)
26       RA(I,2) = RADA(I)
        PI = 3.141592
        IF (IG - 1) 30, 40, 50
30       AR(1,1) = 4.*PI* RAD (1)**2
          VR(1,1) = 1.33333*PI* RAD(1)**3
          DO 35 I = 2, IT
            AR(I,1) = 4.*PI* RAD (I)**2

```

```

35  VR(I,1) = 1.33333*PI*(RAD(I)**3 - RAD(I-1)**3)
    GO TO 100
40  AR(1,1) = 2.*PI*RAD (1)
    VR(1,1) = PI* RAD(1)**2
    DO 45 I = 2,IT
    AR(I,1) = 2.*PI*RAD (I)
45  VR(I,1) = PI*(RAD(I)**2 - RAD(I-1)**2)
    GO TO 100
50  AR(1,1) = 1.0
    VR(1,1) = RAD(1)
    DO 55 I = 2,IT
    AR(I,1) = 1.0
55  VR (I,1) = RAD(I) - RAD(I-1)
100 CONTINUE
    VOL(1) = .0
    VOL(2) = .0
    VOL(3) = .0
    DO 120 I = 1, IT
    IF (IZONE(I) - 2) 105, 110, 115
105  VOL(1) = VOL(1) + VR(I,1)
    GO TO 120
110  VOL(2) = VOL(2) + VR(I,1)
    GO TO 120
115  VOL(3) = VOL(3) + VR(I,1)
120 CONTINUE
    DO 150 I = 1, IT
    AR(I,2) = AR(I,1)
150  VR(I,2) = VR(I,1)
    RETURN
    END

-ITC  ^OR CONST,CONST
      SUBROUTINE CONST
      INCLUDE ABC
      WRITE (NOT,1) (HOL(I), I =1,12)
1      FORMAT (1H1//12A6////)
      READ (NIT,10) TMAX, R2
10     FORMAT (6E12.4)
      RH(1) = 100.*RH(1)/BB
      R2 = 100.*R2/BB
      WRITE (NOT,12) T(1), RH(1), R2
12     FORMAT (41HOREACTIVITY INPUT DATA LISTED BELOW . . .////
      ^31H THE CURRENT TIME (SEC) IS      ,14X, 1PE16.4//
      ^39H THE CURRENT REACTIVITY (CENTS) IS      , 6X, 1PE16.4//
      ^40H THE LINEAR COEFFICIENT (CENTS/SEC) IS  , 5X, 1PE16.4//)
      WRITE (NOT,20) (HOL(I),I=1,12)
20     FORMAT (1H1//12A6//37H SOLUTION OF KINETICS EQUATIONS BELOW//

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      ^ 30H I TIME(SEC) POWER(W/CC), 2X,
      ^ 45H RHO(CENTS) R1/T1 R2/T2 R3/T3 , 1X,
      ^ 47H RHO EXP/P(BARS) C1/C4 C2/C5 C3/C6 ///)
      I = 1
      WRITE (NOT,25) I, T(I), AN(I), RH(I), (RCNT(J,I), J=1,3),
      ^ REXP(I), (C(J,I), J=1,3), (TEMP(J,I), J=1,3), PR(1,1),
      ^ (C(J,I), J=4,6)
25  FORMAT (I6, 1P10E12.3/42X, 1P7E12.3)
      RH(1) = .01*BB*RH(1)
      R2 = .01*BB*R2
      RETURN
      END

-ITC ^OR CALC,CALC
      SUBROUTINE CALC
      INCLUDE ABC
      IFND = 0
      JKL = 1
      JIG = 0
      NWWL = 1
      DO 50 LJ = 2,NMAX
      GC = .0
      DO 3 I=1,M
3      GC = GC + AL(I)*C(I,1)
      W = (RH(1) - BB)/ALIFE + GC/AN(1)
      DO 4 I=1,M
      GAM(I) = B(I)*AN(1)/(ALIFE*C(I,1)) - AL(I)
4      ALPH(I) = W - GAM(I)
5      G = W*H
8      ANZ = AN(1)*EXP(G)
9      T(2) = T(1) + H
      CALL SUBRHO
      CALL SUBNEU
      JIG = JIG + 1
      IF (JIG - 150) 10,20,20
10     IF (ABS(ANZ - AN(2))/ANZ - ERROR) 11,11,17
11     IF (H - HMAX) 12,24,22
12     IF (JIG - 1) 120,120,14
120    LMOD = LJ - 2
      LMOD = MOD (LMOD,10)
      IF (LMOD) 13,13,24
13     NNS = 1
      HSTO = H
      ANSTO = AN(2)
      RHSTO = RH(2)
      H = H*STPEM
      GO TO 5

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14      IF (NNS) 24,24,13
17      IF(JIG - 1) 18,18,19
18      NNS = 0
        H = H/STEPM
        GO TO 5
19      IF (NNS) 18,18,23
20      WRITE (NOT,21) H
21      FORMAT (23H0NO CONVERGENCE      H = 1PE16.4)
        GO TO 52
22      H = HMAX
        G = W*H
        ANZ = AN(1) * EXP(G)
        T(2) = T(1) + H
        CALL SUBRHO
        CALL SUBNEU
        GO TO 24
23      H = HSTO
        AN(2) = ANSTO
        ANZ = AN(2)
        T(2) = T(1) + H
        CALL SUBRHO
24      JIG = 0
        IF (RH(2) - RMIN) 25, 240, 240
240     IF (AN(2) - 10.**22) 26,26,25
25      IEND = 1
26      CONTINUE
        IF (T(2) - TMAX) 30,27,27
27      T(2) = TMAX
        IEND = 1
        H = TMAX - T(1)
        G = W*H
        ANZ = AN(1) * EXP(G)
        CALL SUBRHO
        CALL SUBNEU
30      CONTINUE
        CALL PRECUR
35      IF (IEND) 52,40,52
40      JKL = JKL + 1
43      IF (JKL - NPRT) 50,45,45
45      JKL = 0
        RH(1) = 100.*RH(1)/BB
        JZ = LJ
        I = 1
        WRITE (NOT,54)JZ, T(I),AN(I), RH(I), (RCNT(J,I), J = 1,3),
        ^ REXP(I) , (C(J,I), J =1,3), (TEMP(J,I),J=1,3), PR(1,1),
        ^ (C(J,I),J=4,6)
        RH(1) = .01*RH(1)*BB

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```

      NWWL = NWWL + 1
      IF (NWWL - 17) 50,50,46
46     NWWL = 0
      WRITE (NOT,47) (HOL(I), I= 1,12)
47     FORMAT (1H1//12A6///
      ^ 30H I TIME(SEC) POWER(W/CC), 2X,
      ^ 45H RHO(CENTS) R1/T1 R2/T2 R3/T3 , 1X,
      ^ 47H RHO EXP/P(BARS) C1/C4 C2/C5 C3/C6 ///)
50     CONTINUE
      NMAX = 0
52     CONTINUE
      RH(1) = 100.*RH(1)/BB
      JZ = LJ
      I = 1
      WRITE (NOT,54) JZ, T(I), AN(I), RH(I), (RCNT(J,I), J = 1,3),
      ^ REXP(I) , (C(J,I), J = 1,3), (TEMP(J,I), J=1,3), PR(1,1),
      ^ (C(J,I), J=4,6)
      RH(1) = .01*RH(1)*BB
54     FORMAT (I6, 1P10E12.3/42X, 1P7E12.3)
      RETURN
      END

-ITC ^OR PRESC,PRESC
      SUBROUTINE PRESC
      INCLUDE ABC
      C THIS SUBROUTINE CALCULATES PRESSURE AND PRESSURE GRADIENTS
      IF (IES - 3) 18, 5, 5
      5 CONTINUE
      C ENGLISH EQUATION OF STATE FOR UO2
      DO 15 I = 1,IT
      6 J = IZONE(I)
      IF (E(I,2)) 13, 13, 7
      7 GV = 3./(CEQ(J,4)*D(I,2))
      GG = E(I,2)/D(I,2)
      PR(I,2)=CEQ(J,1)*10.**(-6)*(EXP(-4.34*ALOG(TP(I,2))- 76800./TP(I,2
      ^) + 69.979))
      IF (GV - .6) 8,8,9
      8 IF (GV - .4) 880,881,881
      880 GV = .4
      881 G = 10.*CEQ(J,2)*(GG - (4250.*GV - 250.))/(1.9*GV - .69)
      GO TO 10
      9 IF (GV - 1.0) 991,991,990
      990 GV = 1.0
      991 G = 10.*CEQ(J,2)*(GG - (500.*GV + 2000.))/(1.9*GV - .69)
      10 IF (G - PR(I,2)) 15,15,11
      11 PR(I,2) = G
      GO TO 15

```



```

13  CONTINUE
    PR(I,2) = .0
15  CONTINUE
    GO TO 80
18  IF (IES - 1) 20,40,60
20  CONTINUE
C   THRESHOLD EQUATION OF STATE
    DO 30 I = 1,IT
      J = IZONE(I)
      GG = E(I,2)/D(I,2) - CEQ(J,1)
      IF (GG) 28,28,25
25  G = E(I,2)/D(I,2) - CEQ(J,2)
      IF (G) 26,27,27
26  PR(I,2) = CEQ(J,3) + CEQ(J,5)*GG
      GO TO 30
27  PR(I,2) = CEQ(J,4) + CEQ(J,6)*G
      GO TO 30
28  PR(I,2) = .0
30  CONTINUE
    GO TO 80
40  CONTINUE
C   LASL EQUATION OF STATE
    DO 50 I = 1,IT
      J = IZONE(I)
      GG = E(I,2)/D(I,2) - CEQ(J,1)
      IF (GG) 48,48,46
46  PR(I,2) = CEQ(J,4) + CEQ(J,2)*GG + CEQ(J,3)*D(I,2)
      GO TO 50
48  PR(I,2) = .0
50  CONTINUE
    GO TO 80
60  CONTINUE
C   APDA EQUATION OF STATE
    DO 70 I = 1,IT
      J = IZONE(I)
      GG = E(I,2)/D(I,2)
      IF (GG - CEQ(J,1)) 62,62,66
62  G = CEQ(J,3)/(GG + CEQ(J,2))
      PR(I,2) = CEQ(J,4)*EXP(-G)
      GO TO 70
66  PR(I,2) = CEQ(J,5) * (GG - CEQ(J,6))
70  CONTINUE
80  CONTINUE
    DO 81 I = 1,IT
      IF (PR(I,2) - PTH) 800, 81, 81
800 PR(I,2) = .0
81  CONTINUE

```

```

      RETURN
      END

-ITC  FOR SUBRHO,SUBRHO
      SUBROUTINE SUBRHO
      INCLUDE ABC
C     THIS SUBROUTINE COMPUTES THE NEW REACTIVITY FOR A GIVEN TIME STEP
C     AND ESTIMATED POWER
      CALL EXPAN
      CALL AWDIS
C     CALCULATION OF NEW AVERAGE TEMPERATURES
      DO 140 J = 1,3
140    TEMP(J,2) = .0
      DO 150 I = 1, IT
      J = IZONE (I)
      TEMP(J,2) = TEMP(J,2) + TP(I,2)*VR(I,2)
150    CONTINUE
      DO 160 J = 1,3
160    TEMP(J,2) = TEMP(J,2)/VOL(J)
C     CALCULATION OF ZONE AND EXPANSION REACTIVITY
      DO 170 I = 1,3
      IF (TEMP(I,2)) 170,170,169
169    RCNT(I,2) = RNOR(I) + RC(I,1)*TEMP(I,2)+RC(I,2) *ALOG(TEMP(I,2))
170    CONTINUE
      G = .0
      DO 180 I = 1,IT
      G = G + AW(I,2)*VR(I,2)*D(I,2) - AW(I,1)*VR(I,1)*D(I,1)
180    CONTINUE
      REXP(2) = REXP(1) + 100.*G/BB
C     CALCULATION OF TOTAL REACTIVITY
      G = .0
      DO 210 I = 1,3
210    G = G + RCNT(I,2) - RCNT(I,1)
      G = G + REXP(2) - REXP(1)
      RH(2) = RH(1) + H*R2 + .01*BB*G
      RETURN
      END

-ITC  FOR CIT,CIT
      SUBROUTINE CIT
      INCLUDE ABC
C     THIS SUBROUTINE SETS INITIAL PARAMETERS
      DO 10 I = 1, IT
      J = IZONE(I)
      DELT = TP(I,1)-TM(J)
      IF (DELT) 17,17,12
12    E(I,1) = (CPP(J,1)*DELT + CPP(J,2)*(TP(I,1)**2 - TM(J)**2)/2.

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```

      + CPP(J,3)*(TP(I,1)**3 - TM(J)**3)/3. + HF(J))*DEN(J)
17 E(I,2) = E(I,1)
   ET(I,1) = .0
   ET(I,2) = .0
   V(I,2) = V(I,1)
   TP(I,2) = TP(I,1)
   P(I,2) = P(I,1)
   AW(I,2) = AW(I,1)
   PR(I,1) = .0
   PR(I,2) = .0
10 CONTINUE
   DO 20 I = 1, IT
     J = IZONE (I)
     D(I,1) = DEN(J)
     D(I,2) = DEN(J)
     DI(I,1) = DENI(J)
     DI(I,2) = DENI(J)
20 CONTINUE
   DO 21 I = 1,3
     TEMP(I,1) = .0
21 CONTINUE
   DO 30 I = 1, IT
     J = IZONE(I)
     TEMP(J,1) = TEMP(J,1) + TP(I,1)*VR(I,1)
30 CONTINUE
   DO 40 I = 1,3
     TEMP(I,1) = TEMP(I,1)/VOL(I)
     TEMP(I,2) = TEMP(I,1)
40 CONTINUE
   RETURN
   END

-ITC ^OR CPCAL,CPCAL
      SUBROUTINE CPCAL
      INCLUDE ABC
C     THIS SUBROUTINE CALCULATES THE NEW TEMPERATURE AND ENERGY ABOVE
C     MELTING FOR A GIVEN TOTAL ENERGY DENSITY AND FUEL DENSITY
      DO 100 I = 1,IT
        J = IZONE (I)
        GT = VR(I,1)/VR(I,2)
        GDEL = .5*(P(I,1) + P(I,2))*H +(GT-1.0)*E(I,1)
        GVR = .5*(VR(I,1) + VR(I,2))
        GB = .5*(E(I,1) + E(I,2))
        GGB = .5*(D(I,1) + D(I,2))
        GCP = .5*(TP(I,1) + TP(I,2))
C     AT THIS POINT GB, GGB, AND GCP ARE PREDICTED AVERAGE VALUES OF
C     E, D, AND T, RESPECTIVELY.  THEY CAN BE USED IN CALCULATING

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C      THE HEAT CAPACITY, CP(I).
      GWT = .5*(VR(I,1) + VR(I,2))
      GWT = .5*10**(-1)*(PR(I,1) + PR(I,2))*(VR(I,2) - VR(I,1))/GWT
      G = GB/GGB
      CP(I) = (CPP(J,1) + CPP(J,2)*GCP + CPP(J,3)*GCP**2)*GGB
      IF (TP(I,1) - TM(J)) 30,50,80
30     GG = GDEL - GWT
      GTP = (ET(I,2)*VR(I,2) - ET(I,1) *VR(I,1))/GVR - GWT
      TP(I,2) = TP(I,1) +GTP/CP(I)
      IF (TP(I,2) - TM(J)) 100,100,40
40     GW = (TM(J) - TP(I,1)) * CP(I)
      GH = GG - GW - HF(J)*GGB
      GZZ = GTP - GW - HF(J)*GGB
      IF (GH) 45,45,42
42     TP(I,2) = TM(J) +GZZ/CP(I)
      E(I,2) = GG - GW
      GO TO 100
45     TP(I,2) = TM(J)
      E(I,2) = GG - GW
      GO TO 100
50     CONTINUE
      G = GDEL - GWT
      E(I,2) = E(I,1) + G
      GG = E(I,2) - HF(J)*D(I,2)
      IF (GG) 55,55,60
55     TP(I,2) = TM(J)
      GO TO 100
60     TP(I,2) = TM(J) + GG/CP(I)
      GO TO 100
80     CONTINUE
      G = GDEL - GWT
      GTP = (ET(I,2)*VR(I,2) - ET(I,1) *VR(I,1))/GVR - GWT
      E(I,2) = E(I,1) + G
      TP(I,2) = TP(I,1)+GTP/CP(I)
100    CONTINUE
      RETURN
      END

```

```

-ITC  NOR VOLCA,VOLCA
      SUBROUTINE VOLCA
      INCLUDE ABC
C      THIS SUBROUTINE CALCULATES TIME DEPENDENT VOLUMES AND AREAS
      PI = 3.141592
      IF (IG - 1) 30,40,50
30     AR(1,2) = 4.*PI*RD(1,2)**2
      VR(1,2) = 1.33333*PI*RD(1,2)**3
      DO 35 I = 2,IT

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```

      AR(I,2) = 4.*PI*RD(I,2)**2
35  VR(I,2) = 1.33333*PI*(RD(I,2)**3 - RD(I-1,2)**3)
      GO TO 100
40  AR(I,2) = 2.*PI*RD(I,2)
      VR(I,2) = PI*RD(I,2)**2
      DO 45 I = 2,IT
      AR(I,2) = 2.*PI*RD(I,2)
45  VR(I,2) = PI*(RD(I,2)**2 - RD(I-1,2)**2)
      GO TO 100
50  AR(I,2) = 1.0
      VR(I,2) = RD(I,2)
      DO 55 I = 2,IT
      AR(I,2) = 1.0
55  VR(I,2) = RD(I,2) - RD(I-1,2)
100 CONTINUE
      DO 140 J = 1,3
140 VOL(J) = .0
      DO 150 I = 1,IT
      J = IZONE(I)
150 VOL(J) = VOL(J) + VR(I,2)
      RETURN
      END
-ITC  FOR AWDIS,AWDIS
      SUBROUTINE AWDIS
      INCLUDE ABC
C     THIS SUBROUTINE CALCULATES THE CURRENT WORTH DISTRIBUTION, AW(I,2)
      DO 100 I = 1, IT
      J = IZONE(I)
      DO 30 KK= 1, IT
      K = KK
      G = RA (I,2) - RADA(K)
      IF (G) 60, 60, 30
30  CONTINUE
      G = RA(I,2) - RADA(IT-1)
      GG = RADA(IT) - RADA(IT-1)
      GGG = WF(IT) - WF(IT-1)
      GG = WF(IT-1) + GGG*G/GG
      GO TO 90
60  CONTINUE
      IF (K - 1) 70, 70, 80
70  GG = RADA(2) - RADA(1)
      GGG = WF(2) - WF(1)
      GG = WF(1) + GGG*G/GG
      GO TO 90
80  G = RA(I,2) - RADA(K-1)
      GG = RADA(K) - RADA(K-1)

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      GGG = WF(K) - WF(K-1)
      GG = WF(K-1) + GGG * G / GG
90    AW (I,2) = WZERO * WIZ(J) * GG
100   CONTINUE
      RETURN
      END

-ITC  ^OR SUBNEU,SUBNEU
      SUBROUTINE SUBNEU
      INCLUDE ABC
C     THIS SUBROUTINE COMPUTES THE NEW POWER USING THE OLD AND NEW REACTIVITY
      G = .0
      DO 6 I=1,M
      IF(ABS (ALPH(I)*H) - .01) 1,2,2
1     G = G + AL(I)*C(I,1 )*.5*H*H*(-ALPH(I) + H*ALPH(I)**2/3. -
      ^ H*H*ALPH(I)**3/12.)
      GO TO 6
2     G = G + AL(I)*C(I,1 )*((1.-EXP (-H*ALPH(I)))/ALPH(I) - H)
6     CONTINUE
      AN(2) = EXP (W*H)*(AN(1 )*(1+.5*H*(RH(2)-RH(1 ))/ALIFE) + G )
      RETURN
      END

-ITC  ^OR PRECUR,PRECUR
      SUBROUTINE PRECUR
      INCLUDE ABC
C     THIS SUBROUTINE COMPUTES PRECURSOR DENSITIES AND SETS INDICIES
      DO 15 I=1,M
      IF(ABS (ALPH(I)*H) - .4) 7,5,5
5     C(I,2) = EXP (GAM(I)*H)*(C(I,1 ) + AN(1 )*B(I)*((EXP (H*ALPH(I))
      ^ - 1.)/ALPH(I) - H)/ALIFE)
      GO TO 15
7     C(I,2) = EXP (H*GAM(I))*(C(I,1 ) + AN(1 )*B(I)*H*H*ALPH(I)*
      ^ (1. + ALPH(I)*H/3. + (ALPH(I)*H)**2/12. + (ALPH(I)*H)**3/60.)
      ^ /(2.*ALIFE))
15    CONTINUE
      RH(1) = RH(2)
      AN(1) = AN(2)
      T(1) = T(2)
      REXP(1) = REXP(2)
      DO 20 I = 1,3
      TEMP(I,1) = TEMP(I,2)
      RCNT(I,1) = RCNT(I,2)
20    CONTINUE
      DO 25 K = 1,M
25    C(K,1) = C(K,2)
      DO 30 I = 1,IT

```

```

RD(I,1) = RD(I,2)
RA(I,1) = RA(I,2)
AR(I,1) = AR(I,2)
VR(I,1) = VR(I,2)
DI(I,1) = DI(I,2)
D(I,1) = D(I,2)
E(I,1) = E(I,2)
ET(I,1) = ET(I,2)
V(I,1) = V(I,2)
PR(I,1) = PR(I,2)
AW(I,1) = AW(I,2)
P(I,1) = P(I,2)
TP(I,1) = TP(I,2)
30  CONTINUE
    RETURN
    END

-ITC ^OR EXPAN,EXPAN
      SUBROUTINE EXPAN
        INCLUDE ABC
C      THIS SUBROUTINE CALCULATES THE GEOMETRIC EXPANSION FOR A GIVEN
C      TIME STEP
      JJ = IT - 1
      DO 10 I = 1,JJ
        G = .5*(DI(I+1,1)*VR(I+1,1) + DI(I,1)*VR(I,1))
        V(I,2) = V(I,1) - H*10.**6*(PR(I+1,1) - PR(I,1))*AR(I,1)/G
10     RD(I,2) = RD(I,1) + H * V(I,1)
        IF (IB) 12,12,14
12     V(IT,2) = V(IT,1) + H*10.**6*PR(IT,1)*AR(IT,1)/(DI(IT,1)*VR(IT,1)
        ^
        RD(IT,2) = RD(IT,1) + H * V(IT,1)
        GO TO 16
14     V(IT,2) = .0
        RD(IT,2) = RD(IT,1)
16     RA(1,2) = .5*RD(1,2)
        DO 20 I = 2,IT
20     RA(I,2) = .5*(RD(I-1,2) + RD(I,2))
        CALL VOLCA
        DO 40 I = 1,IT
        J = IZONE (I)
        G = VR(I,1)/VR(I,2)
        DI(I,2) = DI(I,1)*G
        D(I,2) = D(I,1)*G
        P(I,2) = ANZ * PF(I) * DI(I,2) / DENI(J)
        ET(I,2) = .5* H * (P(I,1) + P(I,2)) + ET(I,1)*G
        PR(I,2) = PR(I,1)
        E(I,2) = E(I,1)

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40    TP(I,2) = TP(I,1)
      CONTINUE
      CALL CPCAL
      CALL PRESC
      IF (ITER) 110,110,45
45    CONTINUE
C     BEGIN SECOND ITERATION
      DO 100 K = 1,ITER
      DO 60 I = 1,JJ
      G = (PR(I+1,1)-PR(I,1))*AR(I,1)/(DI(I+1,1)*VR(I+1,1)+DI(I,1)*VR(I,1)
      ^
      )
      GG = (PR(I+1,2)-PR(I,2))*AR(I,2)/(DI(I+1,2)*VR(I+1,2)+DI(I,2)*VR(I,2)
      ^
      )
      V(I,2) = V(I,1) - H * 10.** (6) * (G + GG)
60    RD(I,2) = RD(I,1) + .5*H*(V(I,1) + V(I,2))
      IF (IB) 65,65,70
65    G = PR(IT,1)*AR(IT,1)/(DI(IT,1)*VR(IT,1))
      GG = PR(IT,2)*AR(IT,2)/(DI(IT,2)*VR(IT,2))
      V(IT,2) = V(IT,1) + H * 10.** (6) * .5 * (G + GG)
      RD(IT,2) = RD(IT,1) + .5* H * (V(IT,1) + V(IT,2))
70    CONTINUE
      RA(1,2) = .5*RD(1,2)
      DO 80 I = 2,IT
80    RA(I,2) = .5*(RD(I-1,2) + RD(I,2))
      CALL VOLCA
      DO 90 I = 1,IT
      J = IZONE (I)
      G = VR(I,1)/VR(I,2)
      DI(I,2) = DI(I,1)*G
      D(I,2) = D(I,1)*G
      P(I,2) = ANZ * PF(I) * DI(I,2) / DENI(J)
      ET(I,2) = .5* H * (P(I,1) + P(I,2)) + ET(I,1)*G
90    CONTINUE
      CALL CPCAL
      CALL PRESC
100   CONTINUE
110   CONTINUE
      RETURN
      END

```

```

-ITC  FOR WORK,WORK
      SUBROUTINE WORK
      INCLUDE ABC
C     THIS SUBROUTINE CALCULATES THE TOTAL AND AVAILABLE WORK
      WRITE (NOT,2) (HOL(I),I =1,12)
2     FORMAT (1H1,1X,12A6)
      G = .0

```



```

GG = .0
GS = .0
AVW = .0
DO 10 I = 1, IT
G = G + E(I,2)* VR(I,2)
GS = GS + ET(I,2)* VR(I,2)
10 GG = GG + .5*D(I,2)* V(I,2)**2* VR(I,2)
C AVAILABLE WORK TO 20 ATM A LA ENGLISH
DO 16 I = 1, IT
J = IZONE(I)
Q = (E(I,2)/D(I,2) - HF(J) + .42*2770.)*10.**(-3)
IF (Q - 1.5) 16,16,14
14 CONTINUE
GV = 3.0/(CEQ(J,4)*D(I,2))
GW = 90.6*Q**2 - 239.*Q + 272. + (54.5*Q**2 - 292.*Q + 390.)*
^ EXP ( 7.06*(.5 - GV))
IF (GW) 16,16,15
15 AVW = AVW + VR(I,2)*D(I,2)*GW
16 CONTINUE
AVW = AVW*10.**(-6)
G = G * 10.**(-6)
GS = GS * 10.**(-6)
GG = GG * 10.**(-13)
GGG = 100.* GG/G
WRITE (NOT,24) GS,G,GG,GGG,AVW
24 FORMAT (1H0///35H TOTAL ENERGY RELEASED(MJOULES) = ,1X,1PE16.4//
^30H TOTAL HEAT ENERGY(MJOULES) = ,6X,1PE16.4//
^34H TOTAL KINETIC ENERGY(MJOULES) = ,2X,1PE16.4//
^27H PERCENT KINETIC ENERGY = ,9X,1PE16.3//
^28H AVAILABLE WORK(MJOULES) = ,8X,1PE16.4)
RETURN
END

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