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ABSTRACT

This report describes a computer program which simulates power excursions in experimental fission reactors. A point reactor kinetics model is coupled with a one-dimensional heat conduction capability which allows the code to determine reactivity feedback produced as a result of density and temperature variations within the reactor. External reactivity step insertions and ramps may be included in the calculation. A simple treatment of coolant flow is available. Test cases are provided, including one which simulates a run from the SPERT series of experiments.

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The following descriptors have been selected from the INIS Thesaurus to describe the subject content of this report for information retrieval purposes. For further details please refer to IAEA-INIS-12 (INIS: Manual for Indexing) and IAEA-INIS-13 (INIS: Thesaurus) published in Vienna by the International Atomic Energy Agency.

COMPUTERIZED SIMULATION; EXCURSIONS; FEEDBACK; FLUID FLOW; HEAT TRANSFER; REACTIVITY; REACTOR KINETICS; REACTOR KINETICS EQUATIONS; TRANSIENTS; Z CODES

CONTENTS

(Continued)

1. INTRODUCTION

ZAPP was originally designed to simulate power excursions in experimental arrays of solid fuel elements in plane geometry and so be a tool for safety assessments of proposed experiments in the AAEC critical facility. However, it was quickly realised that, with little modification (principally the inclusion of a cylindrical geometry option), the code could be more generally applied to problems where simulation of the coupled kinetics and temperature behaviour of reactor systems is important. It transpires that almost all experience with the code has been gained with simulation of liquid cooled experimental reactors.

The code* has been used successfully by Connolly and Harrington [1977] to analyse a number of feedback-terminated transients in the SPERT series of experiments and is being used in safety related studies for the AAEC research reactor HIFAR.

1.1 Reactor Model for Simulation

For simulation purposes the power behaviour of the reactor is treated with a point kinetics model. The reactive part of the core is assumed to be divided into a number of zones, each generating a constant fraction of the reactor power, and having a constant 'statistical weight' for the purpose of calculating temperature-dependent feedback. Thus the product of the power and the total adjoint flux has been assumed separable in space and time.

Next, each zone is assumed to consist of a specified (integral) number of identical units called cells and each one of these is composed of regions. Each region contains a single specified material.

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* Two versions of the ZAPP code are being maintained. The formally correct version uses SI units throughout, whereas the other version uses calorie - c.g.s. units. The second version is retained because there is a substantial amount of available data used for safety assessment and work with the AAEC research reactor HIFAR, and conversion of these input data to SI units is inappropriate. In this report, the calorie - c.g.s. units version is the one described since it is only in such a version that units need to be spelt out in detail. For the SI version, all units of input or output quantities are automatically defined. The FORTRAN sources of the two versions differ only in the value defined for Joule's constant in the main routine of the program.

The cells in any one zone must be identical in shape and size but can be totally different from the cells in another zone. Because all cells within a zone are assumed to generate power identically, the number of cells in the zone determines the fraction of the zone power produced within a cell. The temperature behaviour of all cells within a zone is thus assumed to be identical.

Two one-dimensional geometry options are available - plane or cylindrical. If the plane geometry option is selected, each cell is taken to consist of an array of 1 cm^2 plane homogeneous regions. The thickness of each region must be specified, as well as the thicknesses of the 'void' gaps assumed to be present at the right-hand face of each region, including that at the right-most region. It is assumed that there is another identical cell beyond this right-most gap and that periodic boundary conditions apply between the cells. The length of a cell then is just the sum of the region thicknesses and gaps, and the volume of the cell is numerically equal to its length. Heat conduction is along the length of the cell and no transverse heat conduction is allowed. The void gaps, which modify heat conduction between regions, can be of zero thickness. A reflective boundary condition at the ends of the cells can be selected for appropriate systems. To do this, the user nominates the gap size at the right-most face of the array as greater than 10^{20} cm in thickness, i.e. effectively infinite.

If the cylindrical geometry option is selected, each cell can be thought of as a section, 1 cm high, through a vertical cylinder composed of homogeneous regions, again separated radially by void gaps. Again the gaps can, if desired, be of zero thickness. Heat conduction is assumed to be in the radial direction and the boundary condition at the outermost face of the cylinder is that which asserts zero temperature gradient at this face.

Initially, the whole reactor is assumed to be at a constant temperature (300 K unless otherwise specified) and temperature variations are calculated during a power transient. The temperature history is established for one cell per zone, all other cells in the zone being assumed to follow identical histories.

Heat conduction within a cell is not the only process modelled for the transfer of heat energy within the reactor. The input data allow the user to specify 'flow loops', each with a nominated 'flow velocity'. When nominating a flow loop, the user specifies a sequence of zone region pairs which are

supposed to be connected such that material from one zone region pair flows at the nominated flow velocity to the next zone region pair in the loop, displacing material which flows on to the third pair and so on until the loop is closed with flow back into the first zone region pair. A zone region pair in this context is simply a nominated region in a nominated zone. The flow velocity is actually a volumetric flow rate expressed as cubic centimetres per second; it can be changed by the user at any stage of the calculation, but is not affected by any of the quantities calculated by the code. For the flow loops to be valid, the materials specified as filling each zone region pair must be the same so that no mixing of materials is allowed. When material flows from one pair to another, it is assumed that complete thermal mixing of the flowing material occurs between leaving one pair and reaching the next.

If, for example, a volume X at average temperature T1 is transferred to a region of volume Y at average temperature T2, the second region takes up an average temperature

$$T2' = (X.T1 + (Y-X).T2)/Y$$

so that

$$dT2 = (T2' - T2)$$

$$= X(T1 - T2)/Y$$

The temperature profile established earlier within the second region is then modified by adding dT2 to each of the temperatures within the region.

An example of a problem for which the flow loop concept provides a simple, though primitive, way of modelling a complex situation is given in Section 8.2.

Reactivity changes for the whole reactor can be of two kinds:

(a) user-supplied ramps or steps which can be introduced at the beginning of the excursion or at any time during the excursion; and

(b) feedback changes which are calculated by the code. Two options are available here, either

(i) a feedback of the form d.k(eff) = CSHUT . ENERGY RELEASE, where CSHUT is the user supplied feedback coefficient, or

(ii) feedback produced by averaging the various zonal reactivity changes determined from changes in the region temperatures and/or densities and from user supplied temperature and density coefficients. The averaging uses the statistical weights nominated for the different zones.

2. SOLUTION OF POINT KINETICS EQUATIONS

2.1 Solution with Delayed Neutrons

The equations to be solved may be written - see, for example, Templin [1961, Section 5]:

$$dP/dt = a(t).P(t) + \Sigma\lambda_i C_i(t) + S \qquad (2.1)$$

$$dC_i/dt = b_i(t).P(t) - \lambda_i C_i(t) \quad ,i=1,NBETA \qquad (2.2)$$

where

$P(t)$ is the reactor power,

C_i are the precursor concentrations,

$a(t) = (k-1-\overline{\beta}\ k)/\ell$,

$b_i(t) = k\beta_i/\ell$,

$\overline{\beta} = \Sigma\beta_i$ is the effective total delayed neutron fraction,

λ_i are the delayed neutron relaxation constants.

ℓ is the prompt neutron lifetime,

k is the time-dependent effective neutron multiplication factor, assumed to vary linearly with time during a kinetics time step,

S is a constant source contribution which is usually zero, and

NBETA is the number of delayed neutron precursor groups.

The power and precursor concentrations will be known at the beginning of a time step but their values at the end of the time step must be calculated, as well as the energy generated during the step.

The kinetics time step DTRY is broken into a suitable number of equal sub-intervals of duration 'h' and a simple integration scheme adopted to solve the kinetics equations across these sub-intervals. The scheme is a modification of that implemented in various versions of the AIREK code [Schwartz 1959].

The precursor equations admit of the solution

$$C_i(j) = C_i(0)e^{-h\lambda_i} + e^{-h\lambda_i} \int_0^h b_i(t)\, P(t) e^{t\lambda_i}\, dt$$

which is approximated by assuming that $b_i(t).P(t)$ varies linearly through the sub-interval, so that we write

$$b_i(t)P(t) = b_i(0)P(0) + t(b_i(h)P(h) - b_i(0)P(0))/h$$

and then

$$C_i(h) = C_i(0)\exp(-h\lambda_i) + b_i(0)P(0)U_i/h\lambda_i^2 + b_i(h)P(h)V_i/h\lambda_i^2 \quad , \tag{2.3}$$

where $U_i = 1 - (1+h\lambda_i)\exp(-h\lambda_i)$, and

$$V_i = \exp(-h\lambda_i) - (1-h\lambda_i) \quad .$$

Denoting dP/dt by $P'(t)$, we have an approximation for $P(h)$ as

$$P(h) = P(0) + h(P'(0) + P'(h))/2$$

$$= P(0) + hS + h[a(0)P(0) + a(h)P(h) + \Sigma\{\lambda_i C_i(0) + \lambda_i C_i(h)\}]/2$$

Substitution of equation (2.3) leads, after some algebra, to the result

$$P(h) = \frac{2hS + P(0)\,[2+ha(0) + \Sigma b_i(0)U_i/\lambda_i] + h\Sigma\lambda_i C_i(0)(1+\exp(-h\lambda_i))}{2-ha(h) - \Sigma b_i(h)V_i/\lambda_i} \tag{2.4}$$

This last equation is used to advance the reactor power through the sub-interval $0 < t < h$.

With both P(0) and P(h) available, the various precursor concentrations can then be advanced through the same sub-interval by using equations (2.3).

This process is then repeated again and again until either the reactor power has changed by the factor PWERFR, read in as data, or else the full kinetics time step DTRY has been covered.

For the energy release

$$dE = \int_0^h P(t)dt$$

during the sub-interval, the approximation

$$dE = h(4P(0) + 2P(h) + hP'(0))/6 \qquad (2.5)$$

is used, all of the terms being available from the calculation of the power during the sub-interval.

Since $h\lambda_i$ is small, there is ample opportunity for round-off error to occur in equations (2.3) and (2.4). The terms which would suffer from this defect are therefore approximated by fifth-order polynomials.

2.2 Solution Without Delayed Neutrons

The solutions described by equations (2.3) and (2.4) are invalid if there are no delayed groups and the prompt kinetics approximation is required. In this event, the appropriate one of five analytic solutions is selected to advance the power through the complete kinetics time step $0 < t < H = DTRY$. Throughout the time step

$$a(t) = a(0) + tr$$

where $r = (dk/dt)/\ell$, and, for convenience, we write

$$\langle a \rangle = (a(0) + a(H))/2$$

$$p = 1/\sqrt{(2|r|)}$$

The five analytic solutions are

(i) if $S \neq 0$ $\quad P(H) = P(0)E,$

(ii) if $S \neq 0$, $a(0) = r = 0$ $\quad P(H) = P(0) + HS,$

(iii) if $S \neq 0$, $a(0) = 0$, $r \neq 0$ $\quad P(H) = P(0)E + S(E-1)/\langle a \rangle,$

(iv) if $S \neq 0$, $r > 0$ $\quad P(H) = P(0)E + pS\sqrt{\pi}[\mathrm{erf}(pa(H)) - \mathrm{erf}(pa(0))],$

(v) if $S \neq 0$, $r < 0$ $\quad P(H) = P(0)E + 2pS[E.F(pa(0)) - F(pa(H))].$

Here $E = \exp(H\langle a \rangle)$, $\mathrm{erf}(x) = (2/\sqrt{\pi}) \int_0^x \exp(-t^2)dt$ is the usual error function, and $F(x) = \exp(-x^2) \int_0^x \exp(t^2)dt$ is Dawson's integral. Both are given in the notation of Abramowitz and Stegun [1965], who described methods for numerical evaluation of the functions.

3. SOLUTION OF HEAT CONDUCTION EQUATIONS

After completion of a kinetics time step, the energy generated during the step can be allocated to the various reactor zones and specifically to the various regions within the zones. A heat conduction subroutine within ZAPP is then used to follow the diffusion of this heat energy.

The temperature profile within a region is modelled by calculating the temperatures at discrete nodes within the regions. These nodes are each at the centre of one of the equal thickness mesh intervals into which the region is assumed to be divided. The number and thickness of the mesh intervals are specified in the problem input.

3.1 Plane Geometry Problem

For a plane geometry problem, part of a typical layout of nodes is shown below:

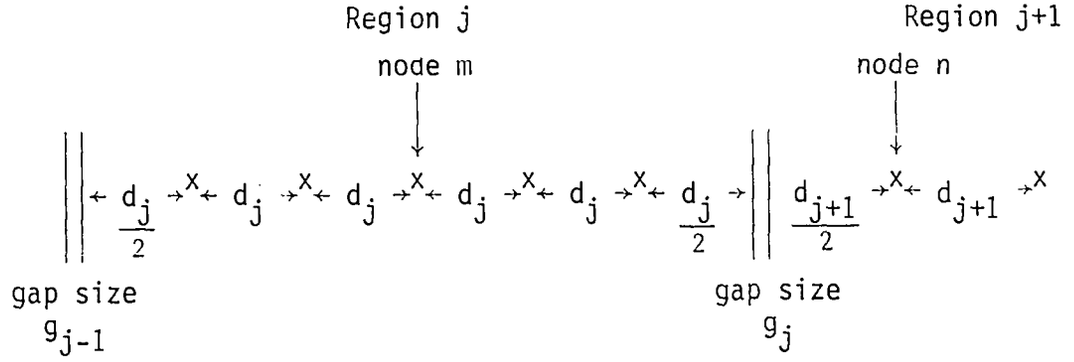

FIGURE 1

At the beginning of a time step, an average density is known for each region. A preliminary assumption is made that the region will, during one time step, receive, on average, half the heat energy released directly from the region heat source computed in the kinetics subroutine. From this, from the known mass of the region and from the material-specific heat tables provided in the input data, the code predicts an average region temperature which could reasonably be expected to apply during the time step. Values of the material specific heat and thermal conductivity at this temperature are then calculated. The region density selected is that which applies to the original temperature. These nominal values are then assumed to apply, throughout the kinetics time step, to all mesh intervals within the region. The kinetics time step is divided into a number of heat conduction time steps of length dt, and an implicit solution method is then used to advance the original temperatures T_i^o to the values T_i' appropriate to the time dt later.

For an interior node such as that labelled 'm' in the preceding figure, the implicit form of the finite difference equation to be solved can be written as

$$\frac{T'_m - T^o_m}{dt} = S_j + \frac{k_j}{d_j c_j \rho_j}\left[\frac{T'_{m+1} - 2T'_m + T'_{m-1}}{d_j}\right]$$

$$= S_j + \frac{1}{c_j \rho_j}\left[\frac{T'_{m+1} - T'_m}{d_j R_{m,m+1}} - \frac{T'_m - T'_{m-1}}{d_j R_{m,m-1}}\right] \qquad (3.1)$$

where $k_j c_j \rho_j S_j$ are the conductivity, specific heat, material density and heat source density in region 'j', all being constant in space over the region and constant in time over the kinetics time step dt. The symbol $R_{m,m+1}$ is introduced temporarily to denote the heat resistance between the nodes m,m +1 and is simply equal to d_j/k_j. For a node, such as that labelled 'n', which is not surrounded by two nodes in the same region the finite difference equation to be solved is still of the form (3.1) provided that the heat resistance between nodes n,n-1 is interpreted as

$$R_{n,n-1} = d_j/2k_j + h_j + d_{j+1}/2k_{j+1}$$

and $1/h_j$ is the gap conductance of the gap g_j.

In the case where only one node occurs within a region, both inter-node resistance terms in equation (3.1) will include a gap resistance contribution.

For the gap conductance, ZAPP assumes a simple correlation and a gap conductance which varies inversely with the gap size g_j, and linearly with the 'gap temperature' T_j^{gap}, so that

$$g_j/h_j = GCONA.T_j^{gap} + GCONB \qquad (3.3)$$

and the constants GCONA, GCONB are part of the input data.

If there are N nodes in a particular cell, the periodic boundary condition forces the final necessary modification of equation (3.1) and we interpret T_0 as T_N, and T_{N+1} as T_1.

3.2 Cylindrical Geometry Problem

If a cylindrical geometry problem is specified, then equation (3.1) is modified in an obvious fashion and becomes

$$\frac{T'_m - T^o_m}{dt} = S_j + \frac{1}{c_j \rho_j}\left[\frac{T'_{m+1} - T'_m}{\Delta_{m+1/2}\ R_{m,m+1}} - \frac{T'_m - T'_{m-1}}{\Delta_{m-1/2}\ R_{m-1,m}}\right]$$

in which

$$\Delta_{m+1/2} = r_m d_j/(r_m + d_j/2)$$

$$\Delta_{m-1/2} = r_m d_j/(r_m - d_j/2)$$

and node m is supposed at a distance r_m from the cylindrical axis of the cell. These coefficients are just the ratios of the volume of the mesh interval to its outer or inner surface areas.

Repeated solution of equation (3.1) provides predicted nodal temperatures T^f_i at the end of the kinetics time step and these, in turn, lead to a first estimate of the final region temperatures θ^f_j. From the average region temperatures θ^o_j which applied at the beginning of the time step, the nominal temperature rise $\theta^f_j - \theta^o_j$ is computed. Multiplication of this by the nominal specific heat $\langle C_j \rangle$, which is used in the heat conduction calculation, gives the measure of the heat energy density increase in the region. To allow for the variation of the specific heat $C_j(T)$ with temperature, a revised estimate θ^{f*}_j of the final region average temperature is then calculated from the equation

$$\int_{\theta^o_j}^{\theta^{f*}_j} C_j(T)dT = \langle C_j \rangle \left[\theta^f_j - \theta^o_j\right]$$

The ratio, α , of the revised temperature rise $(\theta^{f*}_j - \theta^o_j)$ to the original estimate $(\theta^f_j - \theta^o_j)$ is then used to modify the first estimates T^f_i of the nodal temperatures at the end of the time step and to give

$$T^{f*}_i = T^o_i + \alpha\ [T^f_i - T^o_i]$$

which are the nodal temperatures retained by the code. This correction procedure ensures conservation of energy for the time step.

3.3 Choice of Heat Conduction Time Steps

In the preceding section, it was stated that the kinetics time step was subdivided into a number N (say) of heat conduction time steps, all of size dt, through each of which an implicit solution procedure is used to advance the temperature profile. Apart from the requirement that N.dt be equal to the kinetics time step, the value of N to be used is as yet unspecified.

For an interior node, such as that labelled 'm' in Figure 1, the heat conduction equation solved in plane geometry is a finite difference representation of

$$dT/dt = S + q \frac{\partial^2 T}{\partial x^2}$$

where q is constant. If it is assumed that the second derivative term is proportional to the temperature, this equation may be written

$$dT/dt = S + pT \qquad (3.4)$$

with the initial condition

$$T = T(0) \text{ at } t = 0$$

The quantity required is the temperature at the later time t = Ndt. The analytic solution of equation (3.4) with the initial condition gives

$$DT = T(Ndt) - T(0)$$

$$= (T(0) + S/p)(\exp(pNdt)-1) \qquad (3.5)$$

The implicit solution method applied to equation (3.4) yields

$$DT' = (T(0) + S/p)((1-pdt)^{-N} -1) \quad , \qquad (3.6)$$

which naturally converges to (3.5) as N tends to infinity. The proportional error in the temperature change caused by using (3.6) instead of (3.5) is

$$E = (DT'-DT)/DT$$

$$= \frac{p^2a^2 \exp(pa)}{2N\,(\exp(pa)-1)} = O\left(\frac{1}{N^2}\right)$$

where a = Ndt.

If we assume that pa is small

$$E = pa/2N \text{ (approx.)} \tag{3.7}$$

To estimate pa, we note that

$$\frac{T(Ndt) - 2T(Ndt/2) + T(0)}{T(Ndt) - T(0)} = \frac{T(a) - 2T(a/2) + T(0)}{T(a) - T(0)}$$

$$= (\exp(pa/2)-1)^2/(\exp(pa)-1)$$

$$= pa/4 \text{ (approx.)} \tag{3.8}$$

These last two results can be used to estimate the error E which will occur when the N implicit time steps are used.

The technique implemented in the code is to make a preliminary calculation covering the kinetics time step in just two implicit steps. These provide, for each node, estimates for T(a) and T(a/2) from the known starting temperature T(0). Equations (3.7) and (3.8) then allow a value of N to be selected such that the error at any node is as low as required. The accuracy requirement selected in the code is that no temperature change should be in error by more than 5 per cent unless any predicted change is less than 1 K, in which case an error of 0.05 K is tolerated. Should the resulting value for N exceed two, the heat conduction calculation is repeated with this value of N.

4. MATERIAL MOVEMENT

4.1 Material Expansion with Temperature

Following the calculation of new nodal temperatures resulting from heat conduction, the code then attempts a simple simulation of the resultant expansion/contraction. This simulation is correct only for plane geometry problems but has been retained for cylindrical geometry ones as an approximation.

After the heat conduction solution, the nodal temperatures are used to determine average temperatures for each material region. As part of the case input data, the user will have supplied material-property tables which inter alia specify the material densities as a function of temperature. From these tables and from the region temperatures before and after the heat conduction step, a density change for each region is computed and, from this, a volume change. The expansion is assumed to be isotropic; a width change for each region can then be calculated and new inter-nodal spacings (d_j of Figure 1) deduced. Expansion or contraction of the regions reduces or increases any gaps between the regions and these modified gap sizes are used at the next time step. However, if any gap closes to zero, it is assumed to remain closed during the remainder of the transient. Density and volume changes are correlated by the requirement that the region mass stays constant.

4.2 Material Flow Loops

Following the region expansion/contraction simulation, the code then goes on to simulate the way in which material is transported around the reactor by flow loops, provided that these have been nominated in the input data. The concept of flow loops was discussed briefly in Section 1.1.

As a result of one or other of the two material movement calculations - expansion/contraction of flow in a loop - the code finally yields new temperatures and densities for each region in each zone at the end of the kinetics time step. To complete the time step simulation, it only remains to determine the reactivity effects which result from these changes.

5. REACTIVITY FEEDBACK

Feedback effects to be calculated are usually the changes in k(eff) and in k(excess) produced as a result of the region temperature and density changes already calculated. If a non-zero value for the input item CSHUT has been entered, the feedback will have to be calculated solely in terms of the total energy released. If an external reactivity ramp is in operation, then it will also be necessary to modify the multiplication factors to allow for this.

It is obvious that insertion of the feedback reactivity changes as small steps at the end of the simulated time step is not correct. Preliminary

testing of the code showed that this procedure also produced spurious fluctuations in the calculated reactor period and even the reactor power. To obviate this, the code keeps track of the reactivity feedback produced during two previous time steps and attempts a prediction of the feedback which will be produced during the next time step. This is done by fitting a quadratic function of time and extrapolating forward. An artificial ramp is then inserted into the kinetics calculation with a ramp-rate which would produce the predicted feedback at the end of the next time step.

If the computed temperature and density changes in region i of zone j are denoted by dT_{ij} and $d\rho_{ij}$, the resultant change in reactivity dk/k for the reactor is calculated from the formula

$$dk/k = \sum_j W_j \sum_i (C^{\rho}_{ij}\, d\rho_{ij} + C^{T}_{ij}\, dT_{ij}) \qquad (5.1)$$

where C^{ρ}_{ij} are density coefficients of reactivity specified as part of the input data, C^{T}_{ij} are temperature coefficients of reactivity evaluated by interpolation in tables provided as part of the input data, and W_j are constants - called the zone statistical weights - also supplied as input.

The interpolation within the temperature coefficient tables is linear with temperature but, if extrapolation is needed beyond the range of the supplied tables, the value used is that corresponding to the nearest temperature available. It follows that, if no variation in the temperature coefficient is required, i.e. (dk/k) is constant, then the input tables need contain only one entry.

6. INPUT DATA

Except for the title card(s), all input items are read by the free input subroutine SCAN [Bennett and Pollard 1967] and only the first 72 columns of any input line are examined. In the description following, the FORTRAN names of the input items which can be entered are given together with their meanings. Naming of the input items follows the standard FORTRAN convention that variables whose names begin with I, J, K, L, M or N shall be integers while other names refer to real (floating point) variables. Because the SCAN routine 'skips over' unwanted alphabetic items when searching for numeric items, the user can annotate the input almost at will by inserting descriptive words between numeric items. In a very few places, the code will examine any

alphabetic input items in case they correspond to significant keywords and in these areas the user should be careful that a keyword is not inadvertently included.

6.1 General Input

Input items should be given in the order specified except where the description below allows differently.

Input item	FORTRAN name	Meaning
1		Title or comment cards. Insert an * in column 72 if another title card follows
2	XFLAG(20)	Minutes of CPU time allowed for this case
3	NFLAG(19)	Maximum number of time steps allowed
4	DTRY	Desired length of time step (seconds)
5	TMAX	Maximum excursion/transient time allowed (seconds)
6	PWERFR	Maximum fractional power change allowed in a time step (must be in the range 1 to 1.5)
7a	EXCESK	k(excess) for $-\infty < t < 0$ from which the code deduces the delayed neutron precursor concentrations from the assumption that the reactor was initially on a steady period. If the user wishes to specify this period, then item 7a is omitted, the keyword PERIOD inserted and then follows
7b	PERIOD	the required asymptotic period for $t < 0$ (in seconds)
8	STEP	Step dk to be inserted at time t = 0
9	DKDT	Ramp dk/dt inserted at time t = 0
10	CSHUT	The total reactivity feedback coefficient (joule^{-1}). If CSHUT is non-zero, the multiplication of the system will, at any time $t > 0$, be simply k = 1+EXCESK+STEP+t.DKDT+CSHUT.ENERGY, where ENERGY is the energy release since time zero
11	POWER(1)	Reactor power (watts) at t=0
12	SOURCE	Parameter which specifies whether or not a fixed source is to be included in the kinetics equations. The parameter is specified as zero if no source is required. A non-zero value can only be specified if EXCESK < 0 has been entered. In this event, the true strength is calculated from the initial power

13	ELL	Prompt neutron lifetime
14	NBETA	Number of delayed neutron groups
15	BETA(J), J=1,NBETA	The delayed neutron group yields summing to BETALL
16	XLAM(J), J=1, NBETA	The delayed group relaxation constants λ_j (seconds^{-1})

If NBETA is specified as zero, items 15 and 16 are omitted and the following default values are provided:

NBETA=11

J	BETA(J)	XLAM(J)
1	0.00021	0.0124
2	0.00142	0.0305
3	0.00127	0.111
4	0.00256	0.301
5	0.00075	1.136
6	0.00027	3.013
7	0.00065	0.277
8	0.000202	0.0169
9	0.0000695	0.0048
10	0.0000333	0.0015
11	0.0000205	0.0004

BETALL= 0.0074553

These data are acceptable values for use with the AAEC research reactor HIFAR, the first six groups being true delayed fission neutrons and the last five being photo-neutron emissions from the heavy water moderator. If NBETA is specified as negative then, in lieu of items 15-16, the code expects the real number BETALL to appear in the input stream. The same 11 delayed groups are then chosen but with their yields re-normalised to BETALL. To force the code to omit delayed neutrons altogether and to use the prompt kinetics approximation, input data items 14-16 must be given in a way which specifies BETALL < 0.00001, e.g. NBETA = -1, BETALL = 0.0.

If at input item 10, CSHUT was specified as non-zero, the next item to be entered is item 49, else items 17-48 appear.

17	NFLAG(14)	± the number of time steps between each printing of average region temperatures. If entered as positive,

		the individual nodal temperatures are printed, as well as the region temperatures. If entered as zero, no temperatures are printed at all
18	GCOMAX	Maximum value allowed for any of the gap conductances defined in equation (3.2). Units are calories/cm^2/s/K.
19	GCONA	Units are calories/cm/s/K/K
20	GCONB	Units are calories/cm/s/K GCONA, GCONB are the gap conductance terms defined in (3.3). If no gap resistance is wanted then enter data as follows: GCOMAX=1.0E+50 GCONA=0.0 GCONB=1.0E+50
21	NMATER	Number of materials for which heat conduction data will be entered. For each of the materials, the block of data given in items 22-27 must be specified
22	LABEL	Up to eight alphabetic characters as a name for the material. This can be omitted if desired, and the material name is blank
23	NTVALS	Number of temperatures at which properties of the current material IM will be entered
24	TVALS(I,IM) I=1,NTVALS	The temperatures (K) at which the properties are given. These must be in increasing order
25	VALK(I,IM), I=1,NTVALS	The material conductivities at these temperatures (calories/cm/s/K)
26	VALC(I,IM), I=1,NTVALS	The material specific heats (calories/g/K)
27	VALR(I,IM), I=1,NTVALS	The material densities (g/cm^3) Initially all temperatures in the reactor are set to 300 K. If this is satisfactory go to item 29. If some other value of the starting temperature is wanted the keyword TEMPST should be inserted and followed by item 28.
28	TEMPST	The preferred constant starting temperature (K)
29	NZONES	± the number of feedback zones in the reactor. If a negative number is inserted, this is used as an indication that cylindrical geometry is required After setting an appropriate flag, the code sets NZONES > 0. For each zone IZ in turn, items 30-41 must then be given
30	dummy	An optional keyword NOPRINT can be entered at the beginning of data for each zone. If present, the

		printout of most of the input data entered for this particular zone is disabled
31	STATWT(IZ)	The statistical weight of zone IZ, the weight W_j of equation (5.1)
32	NCELL(IZ)	The number of identical cells in zone IZ
33	NNR(IZ)	The number of homogeneous regions in each cell (often addressed as NREG)
34	FRP(IZ)	The fraction of the reactor power released in zone IZ
35	MATSTR(I,IZ), I=1,NREG	The material numbers appropriate to the successive regions of the cells in zone IZ
36	NODER(I,IZ), I=1,NREG	The number of temperature nodes in the successive regions
37	DXRZ(I,IZ), I=1,NREG	If positive, these numbers are the internode spacings for the regions. Negative numbers are interpreted by the code as the actual width of the regions and the inter-node spacing is calculated from the number of nodes
38	GAP(I,IZ), I=1,NREG	The inter region gaps - the g_j of Figure 1 (Section 3.1)
39	QFACT(I,IZ), I=1,NREG	The fraction of the power in each cell released in the regions
40	ERHO(I,IZ), I=1,NREG	The reactivity density coefficients for the regions, i.e. the C^{ρ}_{ij} of equation (5.1)
41		The reactivity temperature coefficients C^{T}_{ij} of equation (5.1) are obtained by interpolating in tables of C^{T}_{ij} against temperature. For each region I,I=1,NREG, the code expects to find items 41a, 41b, and 41c with meanings
41a	NDOPPL	The number of temperatures at which coefficients are tabulated
41b	TOPPL(L), L=1,NDOPPL	± the temperature in the table
41c	DOPPL(L), L=1,NDOPPL	The corresponding C^{T}_{ij} values for region I
		If NDOPPL is zero, items 41b, 41c are omitted and no temperature feedback operates in the region. If any or all of the temperatures TOPPL(L) have been entered as negative, a special input option applies. In this case, the corresponding DOPPL(L) entries are assumed to have been entered as though they had been divided by the

volume of the particular region, and the code corrects this by multiplying the entered values by the region volume. This mode of entry makes it easier for the user to change the input data from one case to another in which, say, the number of regions and their widths are to be altered.

6.2 Saved Temperatures

Before describing the next three input items, we remark that an optional part of the output for a case is a graph against reactor time of the temperature of a particular region or of a particular node. If this option is to be utilised, it is necessary to specify the zone number and the region/node number for which the temperatures are to be saved for later plotting. The necessary information is contained in input items 42-44. To signal to the code that these items are being provided, the keyword SAVE should be given and followed by items 42, 43 and 44.

42	NFLAG(4)	The zone number for the 'save temperature'
43	NDOREG	One of two possible alphabetic keywords NODE or REGION according to whether a node or region temperature is to be saved
44	NFLAG(16)	The region or node number to be saved. The saved temperature can also be used to control the course of the calculation, as described later.

6.3 Flow Loop Data

If it is desired to define any flow loops in the reactor - as discussed in Section 1 - the user should insert the keyword FLOW in the input and follow this with items 45-48. If no loops are to be defined, go directly to item 49.

45	NFLOW	The number of flow loops to be defined. For each loop items 46, 47 and 48 are then needed
46	FLO(IFL)	The loop flow rate (volume/second) in loop IFL. Then follow as many pairs of items 47 and 48 as are necessary to define the loop
47	IFLO(1,K)	The zone number
48	IFLO(2,K)	Region number for the K-th element of the loop. When data for a particular loop is being entered the code

keeps reading pairs of items 47 and 48 until a pair identical with the first pair of the loop is detected. The loop is then completed. For a valid loop the zone-region pairs must all be filled with the same material and the code checks this as the data are read.

6.4 Interrupt Facilities

The final four input items provide a means of specifying changes to the kinetics parameters so that external control of the reactor may be simulated. Alternatively the code can be requested to produce graphical output of some feature of interest at an appropriate stage of the reactor excursion.

The course of the calculation defined by the input items already read is allowed to continue until an event specified by input items 49 and 50 occurs. The simulation is then interrupted and items 51 and 52 are read to determine what action is to be taken., After this interrupt action, items 49 and 50 are then re-specified and the calculation continues until a new interrupt occurs.

48 INTOPT — The interrupt option specified
= 0 means that no more interrupts are to be scheduled. Data for the case is complete
= ±1 means that an interrupt is to occur when the reactor power exceeds/is less than the parameter PARINT read in at item 50
= 2 means that an interrupt is to occur after a reactor time lapse of PARINT seconds. The time is counted from the occurrence of the last interrupt (or time zero if no previous interrupts have occurred)
= 3 means an interrupt is to occur when the total energy release exceeds PARINT joules
= ±4 means an interrupt is to occur when k(excess) exceeds/is less than PARINT
= ±5 means an interrupt is to occur when the instantaneous reactor period exceeds/is less than PARINT seconds
= ±6 means an interrupt is to occur when the saved temperature exceeds/is less than PARINT (K)
= ±7 means that an interrupt is to occur immediately. PARINT is not needed and the next input item read is

item 51. This provides a facility for taking more than one interrupt action when an interrupt option occurs

50 PARINT The interrupt parameter needed for $1 \leq |INTOPT| \leq 6$

51 INTACT Specifies the interrupt action to be taken when an interrupt option is satisfied

= 0 means that no interrupt action is to be taken. The code then reads input item 49 in preparation for any further interrupts

= 1 means read input item 52 (PARNEW) and add it to the existing ramp rate dk/dt

= 2 means read input item 52 (PARNEW) and add it to the existing k(excess); a step reactivity insertion

= 3 means read input item 52 (PARNEW) and treat it as the new time step DTRY

After processing PARNEW for any of these last three actions the code returns to item 49

= 4 means produce a plot of reactor power against time up to the present time. The power is on a log scale

= 5 is the same as 4 except that the power is plotted on a linear scale

= 6 means produce a plot of total reactivity feedback dk against time. The absolute value of dk is plotted on a log scale

= 7 is the same as 6 except that a linear scale is used

= 8 means produce a plot of the saved temperature (specified in items 42-44) against time. A log scale is used for the temperature

= 9 is the same as 8 except that a linear scale is used

After any of the actions 3-9, the code returns to input 49 to prepare for further interrupts

= 10 means change the flow rate in one of the flow loops. If this action is selected item 52 is skipped and items 53 and 54 must appear next in the input stream. When they have been read and interpreted, the code returns to item 49

= 11 means that the temperature profile in some zone of the reactor is to be plotted. Items 52-54 are skipped and item 55, nominating the zone to be plotted,

		must appear as the next numeric input quantity in the input. After the plot is produced, the code returns to item 49 = 12 means that the arrays of memory containing the history to date of power, temperature and feedback are to be cleared and the history is to start again from the present time. This procedure is useful for a transient in which little of interest happens in the early stages. Use of this procedure results in the uninteresting history being deleted from any plots produced at some later stage > 12 means the calculation is to terminate immediately
52	PARNEW	A new value for dk/dt, k(excess) or DTRY when INTACT=1,2,3
53	NUFLOW	The number of the previously defined flow loops whose velocity is to be changed
54	VNUFLO	The new flow velocity (volume/second)
55	NOWZON	The number of the zone for which a temperature profile plot is required.

6.5 Unserviced Interrupts

Frequently, a particular case will terminate before all planned interrupts have been serviced. This termination will happen if the maximum allowable number of time steps has been reached, if a particular variable fails to reach the value for which an interrupt was planned, or if the allowed computer time for the case is insufficient. In such an event, the code will service all the planned interrupts as if they had occurred at the last time step. This ensures that graphical output for a particular case is not lost.

7. OUTPUT

7.1 Printed Output

Printed output for any case appears on two data sets. That on FORTRAN logical unit 6 is simply a listing of the input cards produced as they are read by the SCAN input routine. In the event that an input error is detected by SCAN, the card in error will be the last one listed in this output data set.

The major part of the output is written on logical unit 3. This falls naturally into two components - of which the first is a description of the problem as defined by the input items 1-48. For a large problem, this output will be voluminous unless use is made of the output restriction provided with input item 30.

The second component of the output written to logical unit 3 describes the course of the reactor transient. At the end of each time step, a monitor line is printed listing the reactor time, reactor power, the excess multiplication factor, the cumulative energy released, an estimate of the instantaneous reactor period and the cumulative reactivity feedback calculated to date; this last item is broken into components resulting from temperature and density changes.

At intervals determined by input item 17, the average temperatures of the various regions in each zone are printed, together with the nodal temperatures, if item 17 specifies this.

Independently of item 17, a printout of the region temperatures is produced on the first occasion that the reactor power reaches a local maximum and starts to fall. This additional printout is also produced on each occasion that an interrupt is serviced.

7.2 Graphical Output

Output in this form is produced in accordance with the user's requests as described in input item 51.

7.3 Other Output

At each time step, the code can write an unformatted record containing the nodal temperatures for each zone on a dump file suitable for interactive plotting with the MOVIES and other programs of Turner [1982]. This output will automatically be produced if the user's job control language (JCL) allocates a dataset to FORTRAN logical unit 8.

When using Turner's program, it can be convenient to have the node positions also available on a data set. If the user's JCL allocates a data set to logical unit 9, the node positions for each zone will be written on that data set in card image format.

If either of these datasets is not allocated, the code notes this fact and no attempt to write the information is made.

8. TEST PROBLEMS

The two test cases discussed in this section serve two purposes:

(a) to illustrate how the input procedures are used to model a problem; and

(b) to serve as a partial validation of the numerical procedures implemented in the code.

8.1 Case 1

This case is a partial solution of the Benchmark Problem 7-A1 defined and documented by the Benchmark Problem Committee of the American Nuclear Society (Mathematics and Computation Division) in their 1972 report. It was selected as an easy introductory model and because it serves to validate the coding of one of the solutions to the prompt kinetics equations described in Section 2.2.

The benchmark problem equations may be written

$$dP/dt = (k-1)P/\ell$$

with $k = 1+At+(B/C)E$, E being the energy released.

in which $A = 0.05$

$= 0.0005$

$B = -0.0001$

$C = 2.0$

and power $P = 10.0$ at $t = 0$

ZAPP solves these equations if the prompt kinetics approximation is chosen, there is no source term, the initial power is set to 10 watts and the input item 10 (CSHUT) is set to -0.00005.

The input for this test case is shown in Appendix A. In preparing the input, liberal use has been made of the capacity of the SCAN input routine to skip over alphabetic items when it is searching for a numeric item. The input

has thus been extensively annotated to make it largely self-descriptive. Columns 73-80 of each input record are omitted from the data scan and would typically be sequence numbered if the input were a true deck of cards. As indicated in the input lines, the time steps used in the calculation are largely controlled by interrupt specifications - chosen to ensure small time steps in the neighbourhood of the power maxima and minima. These were selected so that the period of the power oscillations could easily be deduced from the monitor lines as could the peak power values and the energy release per period.

Several pages of the case output are reproduced in Appendix B, from which we deduce

Period of power oscillation (seconds)	0.81975	(0.8198)
Maximum power density (W/cm^3)	6484.1	(6484.6)
Energy release period (J)	819.75	
Temperature rise per period (deduced)	409.88	(409.9)

The values in parentheses are the analytic solutions of the problem given in the benchmark report. The plot of reactor power produced by the code is shown in Appendix C.

It is tempting to tackle the same problem using a direct simulation of the system as a small slab of material with thermodynamic properties described in the benchmark problem solution. This would be an error since ZAPP treats the temperature coefficients of reactivity of equation (5.1) as (1/k)(dk/dT). The benchmark specifies a reactivity coefficient as (dk/dT). The multiplication factor k swings far enough from unity to make the 1/k factor significant and this results in a solution which is not a simple oscillation. As a one off check on the code validity, the 1/k factor was removed from the calculation of reactivity feedback. Not unexpectedly, this produced a result identical with that found using the data of Appendix C. The required modification to the code is to delete the statement numbered 9999 from SUBROUTINE FEEDBK.

8.2 Case 2

This case is a simulation of a power transient in the SPERT II reactor with the close packed core, designated B16/68 which is moderated and cooled by heavy water. This core has been described by Johnson et al. [1965] and the

experiment simulated in this test case is the one which they designate Run 29. The methods of analysis used to produce the reactivity coefficients are those described by Connolly and Harrington [1977].

The active volume of the pseudo-cylindrical core was divided into eight zones as shown in Figure 2. The extra zones, 9 and 10, simulate coolant volume above and below the active core, and the forced coolant flow is indicated by the arrows in the figure. The coolant loop flow rates for that loop passing through zone 1 is simply the volumetric rate at which coolant enters zone 1 and this is the product of linear coolant velocity and that cross-sectional area of zone 1 which is occupied by flowing coolant. For the linear flow speed of 732 mm/s this gives a volumetric flow rate of 86 litres per second into zone 1. The rate into zone 2 is similarly found to be 47.5 litres per second.

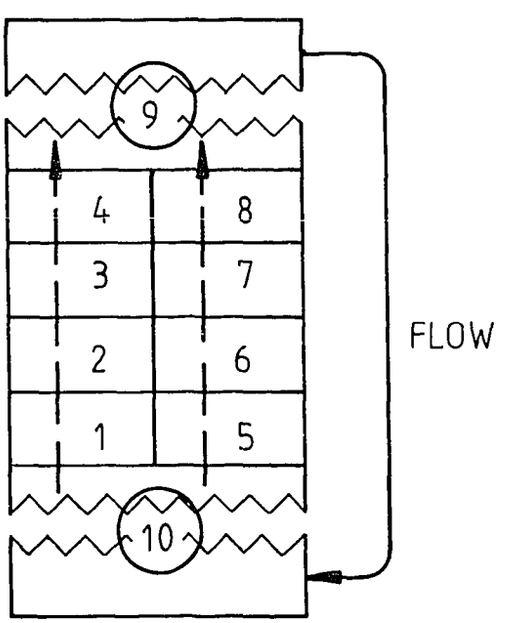

FIGURE 2

The input for this test case is given in Appendix D and again we have annotated the input data items so that their meaning is clear. Of interest will be:

(i) the use of the keyword PERIOD and then input item 7b to specify the initial reactivity of the system and to specify the state of the delayed neutron precursors;

(ii) the nomination of a region temperature to be saved (this corresponds to an average fuel meat temperature in the centre of the core); and

(iii) the use of INTACT=12 to delete from all plots the first second of the transient during which the power is simply rising on a steady period.

Several pages of the case output are given in Appendix E and the graphical output produced in shown in Appendix F.

9. EXECUTION OF THE PROGRAM

On the Lucas Heights Research Laboratories' IBM3033 computer, the program ZAPP is invoked through a catalogued procedure, itself named ZAPP. The procedure is listed below.

```
//*            "ZAPP" - ZERO POWER REACTOR ACCIDENT ANALYSIS. B.E..CLANCY
//*
//ZAPP         PROC   PRG=VPLOT,SYSOUT=C,REGGO=512K,PROG=PROGPGM
//PLT          EXEC   PGM=AEBUFF,REGION=52K
//SYSLIB         DD   DSN=PDP.LINKLIB(&PRG),DISP=SHR
//SYSUT2         DD   SYSOUT= SYSOUT,SPACE=(TRK,(1,1))
//GO           EXEC   PGM=&PROG,REGION=&REGGO
//STEPLIB        DD   DSN=BEC.ZAPP.PROGRAM,DISP=SHR
//AEPLOT         DD   SYSOUT=&SYSOUT
//FT01F001       DD   DDNAME=SYSIN
//FT03F001       DD   SYSOUT=A
//FT06F001       DD   SYSOUT=A,DCB=(RECFM=FBA,BLKSIZE=1330,LRECL=1331)
//FT08F001       DD   DUMMY
//FT09F001       DD   DUMMY
//*
//*PROG=PROGPGM IS "STANDARD"
//*PROG=SIPGM   IS SI UNITS VERSION
//*
//* UNIT 6 FOR DUMPING OF INPUT CARDS
//* UNIT 8 FOR DUMPING OF TEMPERATURES
//* UNIT 9 FOR DUMPING OF NODE POSITIONS
//*            END OF PROCEDURE "ZAPP"
```

10. ACKNOWLEDGEMENTS

The author would like to thank W.J. Turner for making available his subroutines for writing dump files of zone temperatures, and for his advice in using them to visualise the time development of temperature profiles. Thanks are due to R.J. Cawley for providing his clever subroutine which determines at execution time whether data sets have been allocated to units 8 or 9. A particular debt of gratitude is owed to J.W. Connolly for his advice and interest in development of the code. He willingly served as a guinea-pig user of the code and not only attempted to prepare input for it but also suffered the consequences of running versions of it before it had been properly debugged.

11. REFERENCES

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APPENDIX A
INPUT FOR CASE 1

```
ANL BENCHMARK 7-A1 POWER SOLUTION ONLY
CPUTIME ALLOWED 1.0 MINUTES
990 TIMESTEPS MAXIMUM
DTRY 0.002
MAXIMUM TRANSIENT TIME 1.75
PWERFR 1.5
EXCESK 0.0 AT START
STEP 0.0 INSERTED
DKDT 0.05 RAMP INSERTED AT START
CSHUT -5.0E-5
STARTPOWER 10.0
SOURCE 0.0
ELL 5.E-4
NBETA -1 BETALL 0.0 FORCES PROMPT SOLUTION
INTOPT 2 AFTER TIME .4076
INTACT 3 SET DT= .0001
INTOPT -5 WHEN PERIOD LESS THAN 0.
INTACT 3 SET DT= .002
INTOPT 2 AFTER TIME .4076
INTACT 3 SET DT= .0001
INTOPT  5 WHEN PERIOD GREATER THAN 0.
INTACT 3 SET DT= .002
INTOPT 2 AFTER TIME .4076
INTACT 3 SET DT= .0001
INTOPT -5 WHEN PERIOD LESS THAN 0.
INTACT 3 SET DT= .002
INTOPT 2 AFTER TIME .4076
INTACT 3 SET DT= .0001
INTOPT  5 WHEN PERIOD GREATER THAN 0.
INTACT 3 SET DT= .002
INTOPT 2 AFTER TIME .4
INTACT 4 PLOT LOG POWER
INTOPT 7 IMMEDIATE THEN INTACT 13 EXIT
```

APPENDIX B

PART OF PRINTED OUTPUT FOR CASE 1

```
************************ ZAPP  UNITS=CALORIE C.G.S ************************
  TEMPERATURES WILL NOT BE DUMPED
NODE POSITIONS WILL NOT BE DUMPED
ANL BENCHMARK 7-A1 POWER SOLUTION ONLY
      1.0 MINUTES CPU TIME AND   990 TIMESTEPS ALLOWED   FOR THIS CASE
KINETICS TIME STEP =  2.000E-03 SECS

AT T = 0-
 K.EFF        K.EXCESS                RAMP DK/SEC                  POWER(WATTS)  SOURCE PARAM.
 1.00000D+00  0.0          = $  0.0   5.00000E-02  = $******* /SEC  1.00000E+01  0.0
MAX. POWER CHANGE PER TIME STEP  1.50000E+00 MAX. TRANSIENT TIME  1.75000E+00
PROMPT LIFETIME =  5.00000E-04
PROMPT KINETICS SOLUTION

SHUTDOWN COEFFT. = CSHUT =  -5.0000E-05  = $********
DK SHUT = CSHUT * ENERGY

-------------------------------------------------------------------------------------------------------------------------------
PROBLEM NOW DEFINED, CALCULATION BEGINS
-------------------------------------------------------------------------------------------------------------------------------

        OPTION  2
INTERRUPT WILL OCCUR WHEN     TIME IS GREATER THAN  4.0760E-01                                                  TIME  0.0   MINS.

 TIME         POWER        K.EFF        K.EXCESS      ENERGY       DK/K TEMP    DK/K EXPAND  DK TOTAL     PERIOD
 SEC.         WATTS                                   JOULES       CUMULATIVE   CUMULATIVE   CUMULATIVE   SEC.
 2.00000E-03 1.00020E+01 1.00010D+00  9.9000D-05 2.00013E-02  0.0          0.0          -1.0001D-06  1.0035E+01
 4.00000E-03 1.00079E+01 1.00020D+00  1.9800D-04 4.00106E-02  0.0          0.0          -2.0005D-06  3.3999E+00
 6.00000E-03 1.00178E+01 1.00030D+00  2.9700D-04 6.00356E-02  0.0          0.0          -3.0018D-06  2.0156E+00
 8.00000E-03 1.00317E+01 1.00040D+00  3.9600D-04 8.00845E-02  0.0          0.0          -4.0042D-06  1.4433E+00
 1.00000E-02 1.00496E+01 1.00049D+00  4.9499D-04 1.00165E-01  0.0          0.0          -5.0083D-06  1.1225E+00
 1.20000E-02 1.00715E+01 1.00059D+00  5.9399D-04 1.20286E-01  0.0          0.0          -6.0143D-06  9.1839E-01
 1.40000E-02 1.00975E+01 1.00069D+00  6.9298D-04 1.40454E-01  0.0          0.0          -7.0227D-06  7.7715E-01
 1.60000E-02 1.01275E+01 1.00079D+00  7.9197D-04 1.60678E-01  0.0          0.0          -8.0339D-06  6.7360E-01
 1.80000E-02 1.01617E+01 1.00089D+00  8.9095D-04 1.80967E-01  0.0          0.0          -9.0483D-06  5.9425E-01
 2.00000E-02 1.02000E+01 1.00099D+00  9.8993D-04 2.01328E-01  0.0          0.0          -1.0066D-05  5.3179E-01
 2.20000E-02 1.02425E+01 1.00109D+00  1.0889D-03 2.21769E-01  0.0          0.0          -1.1088D-05  4.8112E-01
 2.40000E-02 1.02892E+01 1.00119D+00  1.1879D-03 2.42300E-01  0.0          0.0          -1.2115D-05  4.3928E-01
 2.60000E-02 1.03403E+01 1.00129D+00  1.2869D-03 2.62929E-01  0.0          0.0          -1.3146D-05  4.0414E-01
 2.80000E-02 1.03957E+01 1.00139D+00  1.3858D-03 2.83664E-01  0.0          0.0          -1.4183D-05  3.7422E-01
 3.00000E-02 1.04555E+01 1.00148D+00  1.4848D-03 3.04514E-01  0.0          0.0          -1.5226D-05  3.4838E-01
 3.20000E-02 1.05199E+01 1.00158D+00  1.5837D-03 3.25489E-01  0.0          0.0          -1.6274D-05  3.2594E-01
 3.40000E-02 1.05888E+01 1.00168D+00  1.6827D-03 3.46597E-01  0.0          0.0          -1.7330D-05  3.0617E-01
 3.60000E-02 1.06625E+01 1.00178D+00  1.7816D-03 3.67848E-01  0.0          0.0          -1.8392D-05  2.8867E-01
 3.80000E-02 1.07409E+01 1.00188D+00  1.8805D-03 3.89250E-01  0.0          0.0          -1.9462D-05  2.7307E-01
 4.00000E-02 1.08241E+01 1.00198D+00  1.9795D-03 4.10814E-01  0.0          0.0          -2.0541D-05  2.5908E-01
 4.20000E-02 1.09123E+01 1.00208D+00  2.0784D-03 4.32550E-01  0.0          0.0          -2.1627D-05  2.4645E-01
 4.40000E-02 1.10056E+01 1.00218D+00  2.1773D-03 4.54467E-01  0.0          0.0          -2.2723D-05  2.3500E-01
 4.60000E-02 1.11040E+01 1.00228D+00  2.2762D-03 4.76575E-01  0.0          0.0          -2.3829D-05  2.2455E-01
 4.80000E-02 1.12078E+01 1.00238D+00  2.3751D-03 4.98886E-01  0.0          0.0          -2.4944D-05  2.1502E-01
 5.00000E-02 1.13170E+01 1.00247D+00  2.4739D-03 5.21410E-01  0.0          0.0          -2.6070D-05  2.0624E-01
 5.20000E-02 1.14318E+01 1.00257D+00  2.5728D-03 5.44158E-01  0.0          0.0          -2.7208D-05  1.9815E-01
 5.40000E-02 1.15524E+01 1.00267D+00  2.6716D-03 5.67141E-01  0.0          0.0          -2.8357D-05  1.9068E-01
 5.60000E-02 1.16788E+01 1.00277D+00  2.7705D-03 5.90371E-01  0.0          0.0          -2.9519D-05  1.8376E-01
 5.80000E-02 1.18113E+01 1.00287D+00  2.8693D-03 6.13860E-01  0.0          0.0          -3.0693D-05  1.7732E-01
 6.00000E-02 1.19500E+01 1.00297D+00  2.9681D-03 6.37621E-01  0.0          0.0          -3.1881D-05  1.7132E-01
             ************ ****       MONITOR OUTPUT FOR TIMES 0.0620 - 0.3980 OMITTED ************************
 4.00000E-01 6.31366E+03 1.00268D+00  2.6814D-03 3.46372E+02  0.0          0.0          -1.7319D-02  1.6976E-01
 4.02000E-01 6.37493E+03 1.00215D+00  2.1469D-03 3.59063E+02  0.0          0.0          -1.7953D-02  2.0711E-01
 4.04000E-01 6.42298E+03 1.00161D+00  1.6069D-03 3.71863E+02  0.0          0.0          -1.8593D-02  2.0636E-01
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 4.06000E-01 6.45737E+03 1.00106D+00  1.0627D-03 3.84745E+02  0.0          0.0          -1.9237D-02  3.7456E-01
 4.08000E-01 6.47780E+03 1.00052D+00  5.1586D-04 3.97683E+02  0.0          0.0          -1.9884D-02  6.3324E-01

INTERRUPTING BECAUSE     TIME =   4.08000E-01 IS GREATER THAN    4.07600E-01
MAXIMUM KINETICS TIME STEP NOW =  1.0000E-04 SEC.

          OPTION -5
INTERRUPT WILL OCCUR WHEN   PERIOD IS    LESS THAN  0.0

 TIME         POWER        K.EFF        K.EXCESS     ENERGY       DK/K TEMP    DK/K EXPAND  DK TOTAL     PERIOD
 SEC.         WATTS                                  JOULES       CUMULATIVE   CUMULATIVE   CUMULATIVE   SEC.
 4.08100E-01 6.47845E+03 1.00049D+00  4.8848D-04 3.98331E+02  0.0          0.0          -1.9917D-02  1.0083E+00
 4.08200E-01 6.47906E+03 1.00046D+00  4.6109D-04 3.98978E+02  0.0          0.0          -1.9949D-02  1.0592E+00
 4.08300E-01 6.47964E+03 1.00043D+00  4.3370D-04 3.99626E+02  0.0          0.0          -1.9981D-02  1.1276E+00
 4.08400E-01 6.48018E+03 1.00041D+00  4.0631D-04 4.00274E+02  0.0          0.0          -2.0014D-02  1.2053E+00
 4.08500E-01 6.48070E+03 1.00038D+00  3.7891D-04 4.00922E+02  0.0          0.0          -2.0046D-02  1.2788E+00
 4.08600E-01 6.48117E+03 1.00035D+00  3.5151D-04 4.01570E+02  0.0          0.0          -2.0078D-02  1.3798E+00
 4.08700E-01 6.48161E+03 1.00032D+00  3.2412D-04 4.02218E+02  0.0          0.0          -2.0111D-02  1.4980E+00
 4.08800E-01 6.48201E+03 1.00030D+00  2.9672D-04 4.02866E+02  0.0          0.0          -2.0143D-02  1.6132E+00
 4.08900E-01 6.48238E+03 1.00027D+00  2.6931D-04 4.03514E+02  0.0          0.0          -2.0176D-02  1.7773E+00
 4.09000E-01 6.48271E+03 1.00024D+00  2.4190D-04 4.04162E+02  0.0          0.0          -2.0208D-02  1.9785E+00
 4.09100E-01 6.48300E+03 1.00021D+00  2.1449D-04 4.04810E+02  0.0          0.0          -2.0241D-02  2.2311E+00
 4.09200E-01 6.48326E+03 1.00019D+00  1.8708D-04 4.05458E+02  0.0          0.0          -2.0273D-02  2.4967E+00
 4.09300E-01 6.48349E+03 1.00016D+00  1.5967D-04 4.06107E+02  0.0          0.0          -2.0305D-02  2.9128E+00
 4.09400E-01 6.48368E+03 1.00013D+00  1.3226D-04 4.06755E+02  0.0          0.0          -2.0338D-02  3.4953E+00
 4.09500E-01 6.48383E+03 1.00010D+00  1.0485D-04 4.07403E+02  0.0          0.0          -2.0370D-02  4.3691E+00
 4.09600E-01 6.48395E+03 1.00008D+00  7.7440D-05 4.08051E+02  0.0          0.0          -2.0403D-02  5.5189E+00
 4.09700E-01 6.48403E+03 1.00005D+00  5.0031D-05 4.08699E+02  0.0          0.0          -2.0435D-02  8.0660E+00
 4.09800E-01 6.48408E+03 1.00002D+00  2.2621D-05 4.09348E+02  0.0          0.0          -2.0467D-02  1.4980E+01
 4.09900E-01 6.48409E+03 9.99995D-01 -4.7846D-06 4.09996E+02  0.0          0.0          -2.0500D-02  1.0486E+02
 4.10000E-01 6.48407E+03 9.99968D-01 -3.2198D-05 4.10644E+02  0.0          0.0          -2.0532D-02 -2.7504E+01

INTERRUPTING BECAUSE   PERIOD =  -2.75036E+01 IS    LESS THAN    0.0
MAXIMUM KINETICS TIME STEP NOW =  2.0000E-03 SEC.

          OPTION  2
INTERRUPT WILL OCCUR WHEN     TIME IS GREATER THAN  8.1760E-01

 TIME         POWER        K.EFF        K.EXCESS     ENERGY       DK/K TEMP    DK/K EXPAND  DK TOTAL     PERIOD
 SEC.         WATTS                                  JOULES       CUMULATIVE   CUMULATIVE   CUMULATIVE   SEC.
 4.12000E-01 6.47613E+03 9.99420D-01 -5.8032D-04 4.23606E+02  0.0          0.0          -2.1180D-02 -1.6319E+00
 4.14000E-01 6.45407E+03 9.98873D-01 -1.1269D-03 4.36539E+02  0.0          0.0          -2.1827D-02 -5.8627E-01
 4.16000E-01 6.41809E+03 9.98329D-01 -1.6707D-03 4.49413E+02  0.0          0.0          -2.2471D-02 -3.5775E-01
 4.18000E-01 6.36848E+03 9.97790D-01 -2.2101D-03 4.62202E+02  0.0          0.0          -2.3110D-02 -2.5774E-01
 4.20000E-01 6.30570E+03 9.97256D-01 -2.7439D-03 4.74878E+02  0.0          0.0          -2.3744D-02 -2.0189E-01
 4.22000E-01 6.23031E+03 9.96729D-01 -3.2708D-03 4.87416E+02  0.0          0.0          -2.4371D-02 -1.6628E-01
 4.24000E-01 6.14296E+03 9.96210D-01 -3.7895D-03 4.99791E+02  0.0          0.0          -2.4990D-02 -1.4165E-01
 4.26000E-01 6.04439E+03 9.95701D-01 -4.2990D-03 5.11980E+02  0.0          0.0          -2.5599D-02 -1.2364E-01
 4.28000E-01 5.93543E+03 9.95202D-01 -4.7981D-03 5.23961E+02  0.0          0.0          -2.6198D-02 -1.0993E-01
             ***************          MONITOR OUTPUT FOR TIMES 0.4300 - 0.7980 OMITTED **********************
 8.00000E-01 1.01970E+01 9.99022D-01 -9.7753D-04 8.19551E+02  0.0          0.0          -4.0978D-02 -4.8684E-01
 8.02000E-01 1.01592E+01 9.99121D-01 -8.7854D-04 8.19571E+02  0.0          0.0          -4.0979D-02 -5.3876E-01
 8.04000E-01 1.01256E+01 9.99220D-01 -7.7956D-04 8.19591E+02  0.0          0.0          -4.0980D-02 -6.0309E-01
 8.06000E-01 1.00961E+01 9.99319D-01 -6.8056D-04 8.19611E+02  0.0          0.0          -4.0981D-02 -6.8485E-01
 8.08000E-01 1.00706E+01 9.99418D-01 -5.8156D-04 8.19631E+02  0.0          0.0          -4.0982D-02 -7.9234E-01
 8.10000E-01 1.00492E+01 9.99517D-01 -4.8256D-04 8.19651E+02  0.0          0.0          -4.0983D-02 -9.3972E-01
 8.12000E-01 1.00318E+01 9.99616D-01 -3.8356D-04 8.19671E+02  0.0          0.0          -4.0984D-02 -1.1545E+00
 8.14000E-01 1.00184E+01 9.99715D-01 -2.8456D-04 8.19691E+02  0.0          0.0          -4.0985D-02 -1.4968E+00
 8.16000E-01 1.00090E+01 9.99814D-01 -1.8556D-04 8.19711E+02  0.0          0.0          -4.0986D-02 -2.1270E+00
 8.18000E-01 1.00036E+01 9.99913D-01 -8.6552D-05 8.19731E+02  0.0          0.0          -4.0987D-02 -3.6742E+00
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INTERRUPTING BECAUSE     TIME =   8.18000E-01 IS GREATER THAN     8.17600E-01
MAXIMUM KINETICS TIME STEP NOW =  1.0000E-04 SEC.

          OPTION  5
INTERRUPT WILL OCCUR WHEN   PERIOD IS GREATER THAN  0.0

 TIME         POWER        K.EFF        K.EXCESS     ENERGY       DK/K TEMP    DK/K EXPAND  DK TOTAL     PERIOD
 SEC.         WATTS                                  JOULES       CUMULATIVE   CUMULATIVE   CUMULATIVE   SEC.
 8.18100E-01  1.00034E+01  9.99918D-01  -8.1600D-05  8.19732E+02   0.0          0.0          -4.0987D-02  -5.9493E+00
 8.18200E-01  1.00032E+01  9.99923D-01  -7.6649D-05  8.19733E+02   0.0          0.0          -4.0987D-02  -6.3072E+00
 8.18300E-01  1.00031E+01  9.99928D-01  -7.1698D-05  8.19734E+02   0.0          0.0          -4.0987D-02  -6.7108E+00
 8.18400E-01  1.00029E+01  9.99933D-01  -6.6747D-05  8.19735E+02   0.0          0.0          -4.0987D-02  -7.2315E+00
 8.18500E-01  1.00028E+01  9.99938D-01  -6.1796D-05  8.19736E+02   0.0          0.0          -4.0987D-02  -7.7672E+00
 8.18600E-01  1.00027E+01  9.99943D-01  -5.6845D-05  8.19737E+02   0.0          0.0          -4.0987D-02  -8.4307E+00
 8.18700E-01  1.00026E+01  9.99948D-01  -5.1893D-05  8.19738E+02   0.0          0.0          -4.0987D-02  -9.1678E+00
 8.18800E-01  1.00025E+01  9.99953D-01  -4.6942D-05  8.19739E+02   0.0          0.0          -4.0987D-02  -1.0046E+01
 8.18900E-01  1.00024E+01  9.99958D-01  -4.1991D-05  8.19740E+02   0.0          0.0          -4.0987D-02  -1.1260E+01
 8.19000E-01  1.00023E+01  9.99963D-01  -3.7040D-05  8.19741E+02   0.0          0.0          -4.0987D-02  -1.2614E+01
 8.19100E-01  1.00023E+01  9.99968D-01  -3.2089D-05  8.19742E+02   0.0          0.0          -4.0987D-02  -1.4339E+01
 8.19200E-01  1.00022E+01  9.99973D-01  -2.7138D-05  8.19743E+02   0.0          0.0          -4.0987D-02  -1.6777E+01
 8.19300E-01  1.00021E+01  9.99978D-01  -2.2186D-05  8.19744E+02   0.0          0.0          -4.0987D-02  -2.0460E+01
 8.19400E-01  1.00021E+01  9.99983D-01  -1.7235D-05  8.19745E+02   0.0          0.0          -4.0987D-02  -2.4672E+01
 8.19500E-01  1.00021E+01  9.99988D-01  -1.2284D-05  8.19746E+02   0.0          0.0          -4.0987D-02  -3.3554E+01
 8.19600E-01  1.00021E+01  9.99993D-01  -7.3328D-06  8.19747E+02   0.0          0.0          -4.0987D-02  -5.2429E+01
 8.19700E-01  1.00020E+01  9.99998D-01  -2.3816D-06  8.19748E+02   0.0          0.0          -4.0987D-02  -1.0486E+02
 8.19800E-01  1.00020E+01  1.00000D+00   2.5695D-06  8.19749E+02   0.0          0.0          -4.0987D-02   0.0

INTERRUPTING BECAUSE   PERIOD =   0.0          IS GREATER THAN     0.0
MAXIMUM KINETICS TIME STEP NOW =  2.0000E-03 SEC.

          OPTION  2
INTERRUPT WILL OCCUR WHEN      TIME IS GREATER THAN  1.2274E+00

 TIME         POWER        K.EFF        K.EXCESS     ENERGY       DK/K TEMP    DK/K EXPAND  DK TOTAL     PERIOD
 SEC.         WATTS                                  JOULES       CUMULATIVE   CUMULATIVE   CUMULATIVE   SEC.
 8.21800E-01  1.00041E+01  1.00010D+00   1.0158D-04  8.19769E+02   0.0          0.0          -4.0988D-02   9.6210E+00
              ***************** MONITOR OUTPUT FOR TIMES 8.823A - 1.2258 OMITTED **********************
 1.22780E+00  6.47846E+03  1.00050D+00   4.9729D-04  1.21785E+03   0.0          0.0          -6.0893D-02   6.4867E-01

INTERRUPTING BECAUSE     TIME =   1.22780E+00 IS GREATER THAN     1.22740E+00
MAXIMUM KINETICS TIME STEP NOW =  1.0000E-04 SEC.

          OPTION -5
INTERRUPT WILL OCCUR WHEN   PERIOD IS    LESS THAN  0.0

 TIME         POWER        K.EFF        K.EXCESS     ENERGY       DK/K TEMP    DK/K EXPAND  DK TOTAL     PERIOD
 SEC.         WATTS                                  JOULES       CUMULATIVE   CUMULATIVE   CUMULATIVE   SEC.
 1.22790E+00  6.47909E+03  1.00047D+00   4.6990D-04  1.21850E+03   0.0          0.0          -6.0925D-02   1.0382E+00
 1.22800E+00  6.47968E+03  1.00044D+00   4.4252D-04  1.21915E+03   0.0          0.0          -6.0957D-02   1.1038E+00
 1.22810E+00  6.48023E+03  1.00042D+00   4.1512D-04  1.21980E+03   0.0          0.0          -6.0990D-02   1.1782E+00
 1.22820E+00  6.48075E+03  1.00039D+00   3.8772D-04  1.22045E+03   0.0          0.0          -6.1022D-02   1.2484E+00
 1.22830E+00  6.48124E+03  1.00036D+00   3.6033D-04  1.22109E+03   0.0          0.0          -6.1055D-02   1.3444E+00
 1.22840E+00  6.48169E+03  1.00033D+00   3.3293D-04  1.22174E+03   0.0          0.0          -6.1087D-02   1.4564E+00
 1.22850E+00  6.48210E+03  1.00031D+00   3.0553D-04  1.22239E+03   0.0          0.0          -6.1119D-02   1.5888E+00
 1.22860E+00  6.48248E+03  1.00028D+00   2.7812D-04  1.22304E+03   0.0          0.0          -6.1152D-02   1.7190E+00
 1.22870E+00  6.48282E+03  1.00025D+00   2.5071D-04  1.22369E+03   0.0          0.0          -6.1184D-02   1.9419E+00
 1.22880E+00  6.48313E+03  1.00022D+00   2.2330D-04  1.22433E+03   0.0          0.0          -6.1217D-02   2.1400E+00
 1.22890E+00  6.48340E+03  1.00020D+00   1.9589D-04  1.22498E+03   0.0          0.0          -6.1249D-02   2.3832E+00
 1.22900E+00  6.48364E+03  1.00017D+00   1.6848D-04  1.22563E+03   0.0          0.0          -6.1282D-02   2.8340E+00
 1.22910E+00  6.48384E+03  1.00014D+00   1.4107D-04  1.22628E+03   0.0          0.0          -6.1314D-02   3.2768E+00
 1.22920E+00  6.48400E+03  1.00011D+00   1.1366D-04  1.22693E+03   0.0          0.0          -6.1346D-02   3.8837E+00
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 1.22930E+00 6.48413E+03 1.00009D+00  8.6253D-05 1.22758E+03  0.0          0.0          -6.1379D-02  5.2429E+00
 1.22940E+00 6.48423E+03 1.00006D+00  5.8843D-05 1.22822E+03  0.0          0.0          -6.1411D-02  6.9906E+00
 1.22950E+00 6.48429E+03 1.00003D+00  3.1434D-05 1.22887E+03  0.0          0.0          -6.1444D-02  1.1651E+01
 1.22960E+00 6.48431E+03 1.00000D+00  4.0239D-06 1.22952E+03  0.0          0.0          -6.1476D-02  3.4953E+01
 1.22970E+00 6.48430E+03 9.99977D-01 -2.3386D-05 1.23017E+03  0.0          0.0          -6.1508D-02 -5.4120E+01

INTERRUPTING BECAUSE   PERIOD =  -5.41200E+01 IS     LESS THAN     0.0
MAXIMUM KINETICS TIME STEP NOW =  2.0000E-03 SEC.

          OPTION  2
INTERRUPT WILL OCCUR WHEN      TIME IS GREATER THAN  1.6373E+00

 TIME         POWER        K.EFF        K.EXCESS     ENERGY       DK/K TEMP    DK/K EXPAND DK TOTAL     PERIOD
 SEC.         WATTS                                  JOULES       CUMULATIVE   CUMULATIVE  CUMULATIVE   SEC.
 1.23170E+00 6.47659E+03 9.99428D-01 -5.7154D-04 1.24313E+03  0.0           0.0          -6.2157D-02 -1.6808E+00
             ********************    MONITOR OUTPUT FOR TIMES 1.2337 - 1.6357 OMITTED **********************
 1.63770E+00 1.00020E+01 9.99912D-01 -8.8348D-05 1.63947E+03  0.0           0.0          -8.1973D-02 -3.6265E+00

INTERRUPTING BECAUSE      TIME =   1.63770E+00 IS GREATER THAN     1.63730E+00
MAXIMUM KINETICS TIME STEP NOW =  1.0000E-04 SEC.

          OPTION  5
INTERRUPT WILL OCCUR WHEN   PERIOD IS GREATER THAN  0.0

 TIME         POWER        K.EFF        K.EXCESS     ENERGY       DK/K TEMP    DK/K EXPAND DK TOTAL     PERIOD
 SEC.         WATTS                                  JOULES       CUMULATIVE   CUMULATIVE  CUMULATIVE   SEC.
 1.63780E+00 1.00018E+01 9.99917D-01 -8.3397D-05 1.63947E+03  0.0           0.0          -8.1973D-02 -5.7852E+00
 1.63790E+00 1.00017E+01 9.99922D-01 -7.8446D-05 1.63947E+03  0.0           0.0          -8.1973D-02 -6.1908E+00
 1.63800E+00 1.00015E+01 9.99927D-01 -7.3495D-05 1.63947E+03  0.0           0.0          -8.1973D-02 -6.5536E+00
 1.63810E+00 1.00014E+01 9.99931D-01 -6.8543D-05 1.63947E+03  0.0           0.0          -8.1974D-02 -7.0197E+00
 1.63820E+00 1.00012E+01 9.99936D-01 -6.3592D-05 1.63947E+03  0.0           0.0          -8.1974D-02 -7.5915E+00
 1.63830E+00 1.00011E+01 9.99941D-01 -5.8641D-05 1.63947E+03  0.0           0.0          -8.1974D-02 -8.1840E+00
 1.63840E+00 1.00010E+01 9.99946D-01 -5.3690D-05 1.63947E+03  0.0           0.0          -8.1974D-02 -8.8768E+00
 1.63850E+00 1.00009E+01 9.99951D-01 -4.8739D-05 1.63948E+03  0.0           0.0          -8.1974D-02 -9.6978E+00
 1.63860E+00 1.00008E+01 9.99956D-01 -4.3788D-05 1.63948E+03  0.0           0.0          -8.1974D-02 -1.0755E+01
 1.63870E+00 1.00007E+01 9.99961D-01 -3.8836D-05 1.63948E+03  0.0           0.0          -8.1974D-02 -1.2157E+01
 1.63880E+00 1.00007E+01 9.99966D-01 -3.3885D-05 1.63948E+03  0.0           0.0          -8.1974D-02 -1.3752E+01
 1.63890E+00 1.00006E+01 9.99971D-01 -2.8934D-05 1.63948E+03  0.0           0.0          -8.1974D-02 -1.5828E+01
 1.63900E+00 1.00005E+01 9.99976D-01 -2.3983D-05 1.63948E+03  0.0           0.0          -8.1974D-02 -1.8641E+01
 1.63910E+00 1.00005E+01 9.99981D-01 -1.9032D-05 1.63948E+03  0.0           0.0          -8.1974D-02 -2.3302E+01
 1.63920E+00 1.00005E+01 9.99986D-01 -1.4080D-05 1.63948E+03  0.0           0.0          -8.1974D-02 -2.9959E+01
 1.63930E+00 1.00004E+01 9.99991D-01 -9.1293D-06 1.63948E+03  0.0           0.0          -8.1974D-02 -4.3018E+01
 1.63940E+00 1.00004E+01 9.99996D-01 -4.1782D-06 1.63948E+03  0.0           0.0          -8.1974D-02 -7.2944E+01
 1.63950E+00 1.00004E+01 1.00000D+00  7.7302D-07 1.63948E+03  0.0           0.0          -8.1974D-02 -2.3967E+02
 1.63960E+00 1.00004E+01 1.00001D+00  5.7242D-06 1.63949E+03  0.0           0.0          -8.1974D-02  0.0

INTERRUPTING BECAUSE   PERIOD =   0.0          IS GREATER THAN     0.0
MAXIMUM KINETICS TIME STEP NOW =  2.0000E-03 SEC.

          OPTION  2
INTERRUPT WILL OCCUR WHEN      TIME IS GREATER THAN  2.0396E+00

 TIME         POWER        K.EFF        K.EXCESS     ENERGY       DK/K TEMP    DK/K EXPAND DK TOTAL     PERIOD
 SEC.         WATTS                                  JOULES       CUMULATIVE   CUMULATIVE  CUMULATIVE   SEC.
 1.64160E+00 1.00026E+01 1.00010D+00  1.0474D-04 1.63951E+03  0.0           0.0          -8.1975D-02  9.0796E+00
 1.64360E+00 1.00088E+01 1.00020D+00  2.0375D-04 1.63953E+03  0.0           0.0          -8.1976D-02  3.2474E+00
 1.64560E+00 1.00189E+01 1.00030D+00  3.0275D-04 1.63955E+03  0.0           0.0          -8.1977D-02  1.9757E+00
             ***************         MONITOR OUTPUT FOR TIMES 1.6476 -   END  OMITTED **********************
PLOTTING POWER AGAINST TIME
```
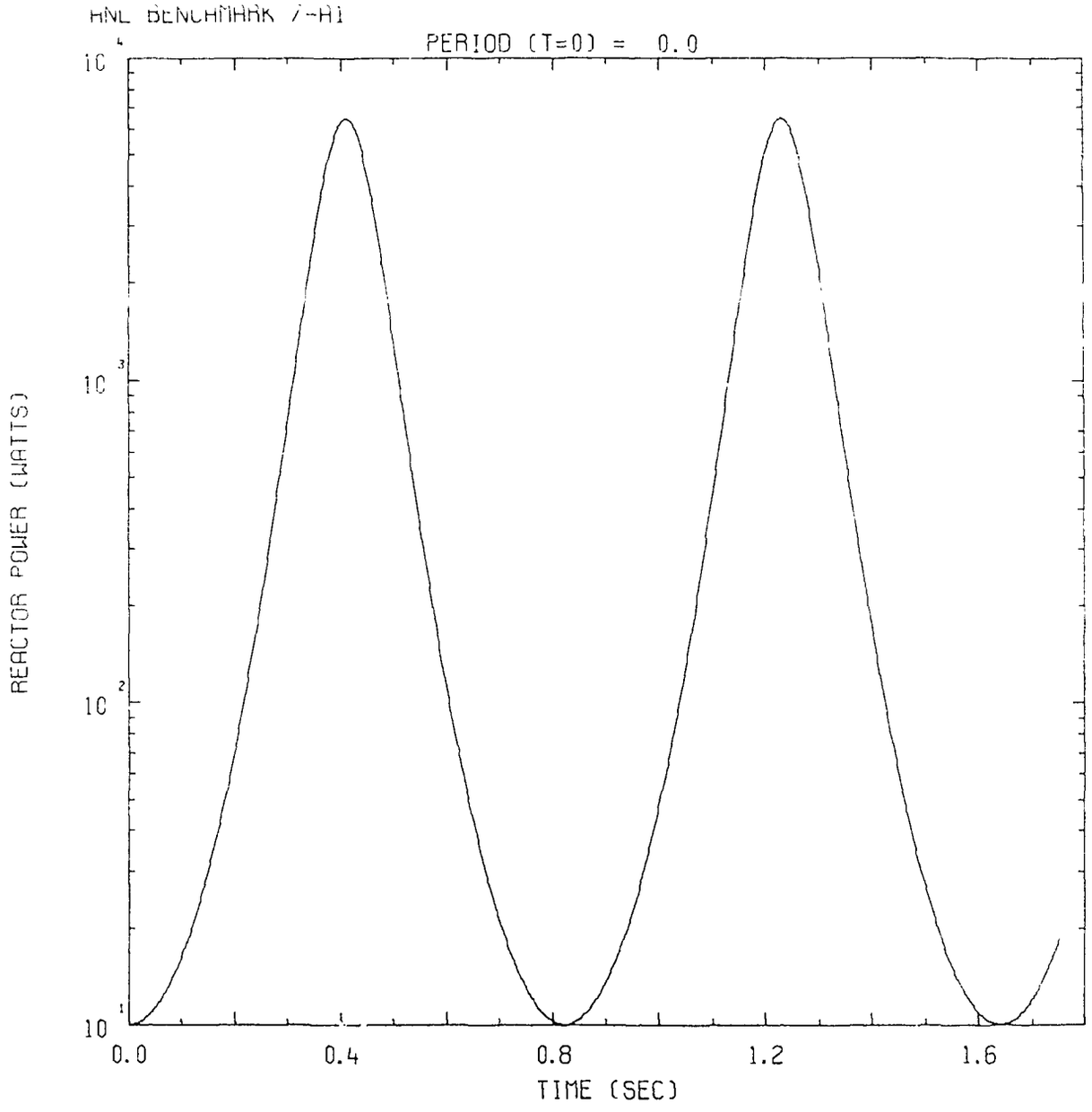

APPENDIX C
GRAPHICAL OUTPUT FOR CASE 1



APPENDIX D
INPUT FOR CASE 2

```
B16/68 200PSIG 2.5FPS ALPHA 3.57 RUN 29
MAX CPUTIME 3.0 ALLOW 900 TIMESTEPS OF DTRY .04
MAX TRANSIENT TIME 10. SECONDS PWRSFR= 1.5
PERIOD .28 SECONDS
STEP 0.0 RAMP 0.0
CSHUT=0.0  POWER 100.0  SOURCES 0.0  LIFETIME 4.8E-4
NBETA  11
BETAS ARE
2.1E-4 1.42E-3 1.27E-3 2.56E-3 7.5E-4 2.7E-4 6.5E-4 2.02E-4 6.95E-5
3.33E-5 2.05E-5
LAMDAS ARE
0.0124  0.0305 0.111 0.301 1.136 3.013 0.277 0.0169 0.0048 0.0015
0.0004
PRINT EACH 400 STEPS
GCOMAX 1.E+50   GCONA 0.0 GCONB 1.E+20
NMATERIALS 4
FUEL
7 TEMPS 293. 373.(100.)873.
CONDS .413 .405(-.01).355
S.HEATS .541 .566 .596 .623 .647 .668 .686
DENS  7*1.0
CLAD
7 TEMPS 293. 373.(100.)873.
CONDS    .394 .409 .421 .429 .434 .437 .44
S.HEATS .58 .602 .63 .657 .685 .712 .739
DENS  7*1.0
WATER
4 TEMPS  300.0  445.0  445.5  600.0
CONDS 0.0015  0.0015  1.0  1.0
SHEATS 1.108  1.10  1.0934  1.0934
DENS   4*1.0
WATERA
4 TEMPS  300.0  458.0  458.5  600.0
CONDS  1.0  1.0  1.0  1.0
SHEATS 1.108 1.10  1.0934  1.0934
DENS 4*1.0
TEMPST 299.0
10 ZONES
* DATA FOR ZONE 1  (* IN COLUMN 1 MEANS THIS CARD IGNORED BY SCAN)
STATWT 1.0  NCELL 150475  NNR 4  FRP 0.1315
MATS 1  2  3  4
NODES  5 5 5 10
DX 0.00508  0.01016  0.0006  0.01164
GAPS  3*0.0  1.0E+50
QFACT 0.949  0.011  0.0  0.04
ERHO  4*0.0
1 300.0 -2.12E-7
1 300.0 -4.23E-7
1 300.0  0.0
4 293.0 313.0 353.0 423.0 -1.26E-5 -2.31E-5 -3.84E-5 -5.64E-5
* DATA FOR ZONE 2
NOPR
STATWT 1.0  NCELL 150475  NNR 4  FRP 0.1315
MATS 1  2  3  4
NODES  5 5 5 10
DX 0.00508  0.01016  0.0006  0.01164
GAPS  3*0.0  1.0E+50
QFACT 0.949  0.011  0.0  0.04
ERHO  4*0.0
1 300.0 -2.12E-7
```

(Continued)

```
1 300.0 -4.23E-7
1 300.0  0.0
4 293.0 313.0 353.0 423.0 -1.26E-5 -2.31E-5 -3.84E-5 -5.64E-5
* DATA FOR ZONE 3
NOPR
STATWT 1.0  NCELL 150475  NNR 4  FRP 0.1315
MATS 1  2  3  4
NODES  5 5 5 10
DX 0.00508  0.01016  0.0006  0.01164
GAPS  3*0.0  1.0E+50
QFACT 0.949  0.011  0.0  0.04
ERHO  4*0.0
1 300.0 -2.11E-7
1 300.0 -4.23E-7
1 300.0  0.0
4 293.0 313.0 353.0 423.0 -1.26E-5 -2.31E-5 -3.84E-5 -5.64E-5
* DATA FOR ZONE 4
STATWT 1.0  NCELL 150475  NNR 4  FRP 0.1315
MATS 1  2  3  4
NODES  5 5 5 10
DX 0.00508  0.01016  0.0006  0.01164
GAPS  3*0.0  1.0E+50
QFACT 0.949  0.011  0.0  0.04
ERHO  4*0.0
1 300.0 -1.06E-7
1 300.0 -2.11E-7
1 300.0  0.0
4 293.0 313.0 353.0 423.0 -6.30E-6 -1.15E-5 -1.93E-5 -2.83E-5
* DATA FOR ZONE 5
STATWT 1.0  NCELL 82075  NNR 4  FRP 0.118
MATS 1  2  3  4
NODES  5 5 5 10
DX 0.00508  0.01016  0.0006  0.01164
GAPS  3*0.0  1.0E+50
QFACT 0.949  0.011  0.0  0.04
ERHO  4*0.0
1 300.0 -7.3E-8
1 300.0 -1.47E-7
1 300.0  0.0
4 293.0 313.0 353.0 423.0 -8.10E-6 -1.18E-5 -1.72E-5 -2.34E-5
* DATA FOR ZONE 6
NOPR
STATWT 1.0  NCELL 82075  NNR 4  FRP 0.118
MATS 1  2  3  4
NODES  5 5 5 10
DX 0.00508  0.01016  0.0006  0.01164
GAPS  3*0.0  1.0E+50
QFACT 0.949  0.011  0.0  0.04
ERHO  4*0.0
1 300.0 -7.3E-8
1 300.0 -1.47E-7
1 300.0  0.0
4 293.0 313.0 353.0 423.0 -8.10E-6 -1.18E-5 -1.72E-5 -2.34E-5
* DATA FOR ZONE 7
NOPR
STATWT 1.0  NCELL 82075  NNR 4  FRP 0.118
MATS 1  2  3  4
NODES  5 5 5 10
DX 0.00508  0.01016  0.0006  0.01164
GAPS  3*0.0  1.0E+50
QFACT 0.949  0.011  0.0  0.04
```

```
ERHO  4*0.0
1 300.0 -7.3E-8
1 300.0 -1.47E-7
1 300.0  0.0
4 293.0 313.0 353.0 423.0 -8.10E-6 -1.18E-5 -1.72E-5 -2.34E-5
* DATA FOR ZONE 8
STATWT 1.0  NCELL 82075  NNR 4  FRP 0.118
MATS 1  2  3  4
NODES  5 5 5 10
DX 0.00508  0.01016  0.0006  0.01164
GAPS  3*0.0  1.0E+50
QFACT 0.949  0.011  0.0  0.04
ERHO  4*0.0
1 300.0 -3.9E-8
1 300.0 -7.8E-8
1 300.0  0.0
4 293.0 313.0 353.0 423.0 -4.30E-6 -6.30E-6 -9.20E-6 -1.25E-5
* DATA FOR ZONE 9
STATWT 1.0  NCELL 10000  NNR 1  FRP 0.0
MATS 4
NODES 5
DX 1000.0
GAP 1.0E+50
QFACT 0.0
0.0
1  300.0  0.0
* DATA FOR ZONE 10
STATWT 1.0  NCELL 10000  NNR 1  FRP 0.0
MATS 4
NODES 5
DX 1000.0
GAP 1.0E+50
QFACT 0.0
0.0
1  300.0  0.0
SAVE ZONE 4 REGION 1
FLOW 2 LOOPS
8.60E+4 10 1   1 4  2 4  3 4  4 4    9 1  10 1
4.75E+4 10 1   5 4  6 4  7 4  8 4    9 1  10 1
INTOPT 2 AFTER TIME 2.0 INTACT 12 RESAVE
INTOPT 2 AFTER TIME 3.18 INTACT 4 PLOT LOG POWER
INTOPT 7 (IMMEDIATE)    INTACT 5 PLOT LIN POWER
INTOPT 7 (IMMEDIATE)    INTACT 7 PLOT LIN REACTIVITY
INTOPT 7 (IMMEDIATE)    INTACT 9 PLOT LIN TSAVED
INTOPT 7 (IMMEDIATE)    INTACT 11 PLOT ZONE 1 TEMPS
INTOPT 7 (IMMEDIATE)    INTACT 13 STOP
```

APPENDIX E

PART OF PRINTED OUTPUT FOR CASE 2

```
********** ZAPP  UNITS=CALORIE C.G.S **********
  TEMPERATURES WILL NOT BE DUMPED
NODE POSITIONS WILL NOT BE DUMPED
816/68 200PSIG 2.5FPS ALPHA 3.57 RUN 29
       3.0 MINUTES CPU TIME AND   900 TIMESTEPS ALLOWED   FOR THIS CASE
KINETICS TIME STEP =  4.000E-02 SECS

AT T = 0-
 K.EFF        K.EXCESS                 RAMP DK/SEC                  POWER(WATTS)  SOURCE PARAM.
 1.00863D+00  8.626290-03  = $  1.15  0.0          = $  0.0  /SEC  1.00000E+02  0.0
MAX. POWER CHANGE PER TIME STEP  1.50000E+00 MAX. TRANSIENT TIME  1.00000E+01
PROMPT LIFETIME =  4.80000E-04
  11 DELAYED GROUPS
        BETA          LAMBDA
TOTAL  7.45528E-03
   1   2.10000E-04  1.24000E-02
   2   1.42000E-03  3.05000E-02
   3   1.27000E-03  1.11000E-01
   4   2.56000E-03  3.01000E-01
   5   7.50000E-04  1.13600E+00
   6   2.70000E-04  3.01300E+00
   7   6.50000E-04  2.77000E-01
   8   2.02000E-04  1.69000E-02
   9   6.95000E-05  4.80000E-03
  10   3.33000E-05  1.50000E-03
  11   2.05000E-05  4.00000E-04

ASYMPTOTIC PERIOD =  2.8000D-01 SECONDS
REGION & NODAL TEMPERATURES PRINTED EVERY  400 TIME STEPS

GAP HEAT CONDUCTANCE DATA
MAXIMUM GAP CONDUCTANCE =  1.0000E+50
CONDUCTANCE = (A*GAPTEMP + B)/GAPSIZE
COEFFTS A, B =  0.0          1.0000E+20

MATERIAL PROPERTY TABLES
************************

MATERIAL  1   FUEL
TEMP    2.9300E+02  3.7300E+02  4.7300E+02  5.7300E+02  6.7300E+02  7.7300E+02  8.7300E+02  8.7300E+52
 K      4.1300E-01  4.0500E-01  3.9500E-01  3.8500E-01  3.7500E-01  3.6500E-01  3.5500E-01  3.5500E-01
 C      5.4100E-01  5.6600E-01  5.9600E-01  6.2300E-01  6.4700E-01  6.6800E-01  6.8600E-01  6.8600E-01
 RHO    1.0000E+00  1.0000E+00  1.0000E+00  1.0000E+00  1.0000E+00  1.0000E+00  1.0000E+00  1.0000E+00

MATERIAL  2   CLAD
TEMP    2.9300E+02  3.7300E+02  4.7300E+02  5.7300E+02  6.7300E+02  7.7300E+02  8.7300E+02  8.7300E+52
 K      3.9400E-01  4.0900E-01  4.2100E-01  4.2900E-01  4.3400E-01  4.3700E-01  4.4000E-01  4.4000E-01
 C      5.8000E-01  6.0200E-01  6.3000E-01  6.5700E-01  6.8500E-01  7.1200E-01  7.3900E-01  7.3900E-01
 RHO    1.0000E+00  1.0000E+00  1.0000E+00  1.0000E+00  1.0000E+00  1.0000E+00  1.0000E+00  1.0000E+00

MATERIAL  3   WATER
TEMP    3.0000E+02  4.4500E+02  4.4550E+02  6.0000E+02  6.0000E+52
 K      1.5000E-03  1.5000E-03  1.0000E+00  1.0000E+00  1.0000E+00
 C      1.1080E+00  1.1000E+00  1.0934E+00  1.0934E+00  1.0934E+00
 RHO    1.0000E+00  1.0000E+00  1.0000E+00  1.0000E+00  1.0000E+00

MATERIAL  4   WATERA
TEMP    3.0000E+02  4.5800E+02  4.5850E+02  6.0000E+02  6.0000E+52
 K      1.0000E+00  1.0000E+00  1.0000E+00  1.0000E+00  1.0000E+00
 C      1.1080E+00  1.1000E+00  1.0934E+00  1.0934E+00  1.0934E+00
 RHO    1.0000E+00  1.0000E+00  1.0000E+00  1.0000E+00  1.0000E+00
```

ALL REACTOR TEMPERATURES ARE INITIALLY 299.0 DEG. K

PLANE GEOMETRY FOR 10 ZONES

ZONE 1 STATISTICAL WEIGHT 1.00000E+00 GENERATES 1.31500E-01 OF POWER
CONTAINS 150475 CELLS, EACH OF 4 REGIONS

REGN.	MATERIAL #	NODES	DELTAX	WIDTH	MASS/CELL	POWER FRACT	GAP
							1.00000E+50
1	1	5	5.08000E-03	2.54000E-02	2.54000E-02	9.49000E-01	0.0
2	2	5	1.01600E-02	5.08000E-02	5.08000E-02	1.10000E-02	0.0
3	3	5	6.00000E-04	3.00000E-03	3.00000E-03	0.0	0.0
4	4	10	1.16400E-02	1.16400E-01	1.16400E-01	4.00000E-02	1.00000E+50
TOTAL		25		1.95600E-01	1.95600E-01	1.00000E+00	

MATERIAL NO.	TOTAL VOLUME	TOTAL MASS	POWER FRACTION
1	3.82206E+03	3.82206E+03	1.24793E-01
2	7.64413E+03	7.64413E+03	1.44650E-03
3	4.51425E+02	4.51425E+02	0.0
4	1.75153E+04	1.75153E+04	5.26000E-03

REACTIVITY COEFFICIENTS

REGION	(1/K) DK/DRHO	TEMP	(1/K) DK/DT
1	0.0	300.000	-2.12000E-07
2	0.0	300.000	-4.23000E-07
3	0.0	300.000	0.0
4	0.0	293.000	-1.26000E-05
		313.000	-2.31000E-05
		353.000	-3.84000E-05
		423.000	-5.64000E-05

ZONE 1 NODE POSITIONS

0.00254	0.00762	0.01270	0.01778	0.02286	0.03048	0.04064	0.05080	0.06096	0.07112
0.07650	0.07710	0.07770	0.07830	0.07890	0.08502	0.09666	0.10830	0.11994	0.13158
0.14322	0.15486	0.16650	0.17814	0.18978					

ZONE 2 STATISTICAL WEIGHT 1.00000E+00 GENERATES 1.31500E-01 OF POWER
CONTAINS 150475 CELLS, EACH OF 4 REGIONS

ZONE 3 STATISTICAL WEIGHT 1.00000E+00 GENERATES 1.31500E-01 OF POWER
CONTAINS 150475 CELLS, EACH OF 4 REGIONS

(Continued)

ZONE 4 STATISTICAL WEIGHT 1.00000E+00 GENERATES 1.31500E-01 OF POWER
CONTAINS 150475 CELLS, EACH OF 4 REGIONS

REGN.	MATERIAL #	NODES	DELTAX	WIDTH	MASS/CELL	POWER FRACT	GAP
							1.00000E+50
1	1	5	5.08000E-03	2.54000E-02	2.54000E-02	9.49000E-01	0.0
2	2	5	1.01600E-02	5.08000E-02	5.08000E-02	1.10000E-02	0.0
3	3	5	6.00000E-04	3.00000E-03	3.00000E-03	0.0	0.0
4	4	10	1.16400E-02	1.16400E-01	1.16400E-01	4.00000E-02	1.00000E+50
TOTAL		25		1.95600E-01	1.95600E-01	1.00000E+00	

MATERIAL NO.	TOTAL VOLUME	TOTAL MASS	POWER FRACTION
1	3.82206E+03	3.82206E+03	1.24793E-01
2	7.64413E+03	7.64413E+03	1.44650E-03
3	4.51425E+02	4.51425E+02	0.0
4	1.75153E+04	1.75153E+04	5.26000E-03

REACTIVITY COEFFICIENTS

REGION	(1/K) DK/DRHO	TEMP	(1/K) DK/DT
1	0.0	300.000	-1.06000E-07
2	0.0	300.000	-2.11000E-07
3	0.0	300.000	0.0
4	0.0	293.000	-6.30000E-06
		313.000	-1.15000E-05
		353.000	-1.93000E-05
		423.000	-2.83000E-05

ZONE 4 NODE POSITIONS

0.00254	0.00762	0.01270	0.01778	0.02286	0.03048	0.04064	0.05080	0.06096	0.07112
0.07650	0.07710	0.07770	0.07830	0.07890	0.08502	0.09666	0.10830	0.11994	0.13158
0.14322	0.15486	0.16650	0.17814	0.18978					

ZONE 5 STATISTICAL WEIGHT 1.00000E+00 GENERATES 1.18000E-01 OF POWER
CONTAINS 82075 CELLS, EACH OF 4 REGIONS

REGN.	MATERIAL #	NODES	DELTAX	WIDTH	MASS/CELL	POWER FRACT	GAP
							1.00000E+50
1	1	5	5.08000E-03	2.54000E-02	2.54000E-02	9.49000E-01	0.0
2	2	5	1.01600E-02	5.08000E-02	5.08000E-02	1.10000E-02	0.0
3	3	5	6.00000E-04	3.00000E-03	3.00000E-03	0.0	0.0
4	4	10	1.16400E-02	1.16400E-01	1.16400E-01	4.00000E-02	1.00000E+50
TOTAL		25		1.95600E-01	1.95600E-01	1.00000E+00	

MATERIAL NO.	TOTAL VOLUME	TOTAL MASS	POWER FRACTION
1	2.08470E+03	2.08470E+03	1.11982E-01
2	4.16941E+03	4.16941E+03	1.29800E-03
3	2.46225E+02	2.46225E+02	0.0
4	9.55352E+03	9.55352E+03	4.72000E-03

REACTIVITY COEFFICIENTS

REGION	(1/K) DK/DRHO	TEMP	(1/K) DK/DT
1	0.0	300.000	-7.30000E-08
2	0.0	300.000	-1.47000E-07
3	0.0	300.000	0.0
4	0.0	293.000	-8.10000E-06
		313.000	-1.18000E-05
		353.000	-1.72000E-05
		423.000	-2.34000E-05

ZONE 5 NODE POSITIONS

0.00254	0.00762	0.01270	0.01778	0.02286	0.03048	0.04064	0.05080	0.06096	0.07112
0.07650	0.07710	0.07770	0.07830	0.07890	0.08502	0.09666	0.10830	0.11994	0.13158
0.14322	0.15486	0.16650	0.17814	0.18978					

ZONE 6 STATISTICAL WEIGHT 1.00000E+00 GENERATES 1.18000E-01 OF POWER
CONTAINS 82075 CELLS, EACH OF 4 REGIONS

ZONE 7 STATISTICAL WEIGHT 1.00000E+00 GENERATES 1.18000E-01 OF POWER
CONTAINS 82075 CELLS, EACH OF 4 REGIONS

(Continued)

ZONE 8 STATISTICAL WEIGHT 1.00000E+00 GENERATES 1.18000E-01 OF POWER
CONTAINS 82075 CELLS, EACH OF 4 REGIONS

REGN.	MATERIAL	# NODES	DELTAX	WIDTH	MASS/CELL	POWER FRACT	GAP
							1.00000E+50
1	1	5	5.08000E-03	2.54000E-02	2.54000E-02	9.49000E-01	0.0
2	2	5	1.01600E-02	5.08000E-02	5.08000E-02	1.10000E-02	0.0
3	3	5	6.00000E-04	3.00000E-03	3.00000E-03	0.0	0.0
4	4	10	1.16400E-02	1.16400E-01	1.16400E-01	4.00000E-02	1.00000E+50
TOTAL		25		1.95600E-01	1.95600E-01	1.00000E+00	

MATERIAL NO.	TOTAL VOLUME	TOTAL MASS	POWER FRACTION
1	2.08470E+03	2.08470E+03	1.11982E-01
2	4.16941E+03	4.16941E+03	1.29800E-03
3	2.46225E+02	2.46225E+02	0.0
4	9.55352E+03	9.55352E+03	4.72000E-03

REACTIVITY COEFFICIENTS

REGION	(1/K) DK/DRHO	TEMP	(1/K) DK/DT
1	0.0	300.000	-3.90000E-08
2	0.0	300.000	-7.80000E-08
3	0.0	300.000	0.0
4	0.0	293.000	-4.30000E-06
		313.000	-6.30000E-06
		353.000	-9.20000E-06
		423.000	-1.25000E-05

ZONE 8 NODE POSITIONS

0.00254	0.00762	0.01270	0.01778	0.02286	0.03048	0.04064	0.05080	0.06096	0.07112
0.07650	0.07710	0.07770	0.07830	0.07890	0.08502	0.09666	0.10830	0.11994	0.13158
0.14322	0.15486	0.16650	0.17814	0.18978					

```
ZONE  9 STATISTICAL WEIGHT  1.00000E+00 GENERATES  0.0          OF POWER
    CONTAINS   10000 CELLS, EACH OF   1 REGIONS

REGN, MATERIAL # NODES  DELTAX        WIDTH        MASS/CELL     POWER FRACT
                                                                              GAP
                                                                              1.00000E+50
   1         4      5  1.00000E+03  5.00000F+03  5.00000E+03  0.0
                                                                              1.00000E+50


WARNING! ZONE (CELL) POWER FRACTION SUM =  0.0         (NON-UNITY)
*******


TOTAL                5                5.00000F+03  5.00000E+03  0.0

MATERIAL  TOTAL            TOTAL            POWER
   NO.    VOLUME           MASS             FRACTION
    4     5.00000E+07      5.00000E+07      0.0

REACTIVITY COEFFICIENTS
REGION   (1/K) DK/DRHO       TEMP        (1/K) DK/DT

    1     0.0               300.000      0.0

ZONE   9 NODE POSITIONS
         500.00000 1500.00000 2500.00000 3500.00000 4500.00000
```


(Continued)

ZONE 10 STATISTICAL WEIGHT 1.00000E+00 GENERATES 0.0 OF POWER
CONTAINS 10000 CELLS, EACH OF 1 REGIONS

REGN.	MATERIAL	# NODES	DELTAX	WIDTH	MASS/CELL	POWER FRACT	GAP
							1.00000E+50
1	4	5	1.00000E+03	5.00000F+03	5.00000E+03	0.0	1.00000E+50

WARNING: ZONE (CELL) POWER FRACTION SUM = 0.0 (NON-UNITY)
****

TOTAL		5	5.00000F+03	5.00000E+03	0.0

MATERIAL NO.	TOTAL VOLUME	TOTAL MASS	POWER FRACTION
4	5.00000E+07	5.00000E+07	0.0

REACTIVITY COEFFICIENTS

REGION	(1/K) DK/DRHO	TEMP	(1/K) DK/DT
1	0.0	300.000	0.0

ZONE 10 NODE POSITIONS
500.00000 1500.00000 2500.00000 3500.00000 4500.00000

WARNING: REACTOR POWER FRACTIONS SUM TO 9.9800E-01 (NON-UNITY)
****

TOTAL FOR ALL ZONES

MATERIAL NO.	TOTAL VOLUME	TOTAL MASS	POWER FRACTION
1	2.36271E+04	2.36271E+04	9.47102E-01
2	4.72541E+04	4.72541E+04	1.09780E-02
3	2.79060E+03	2.79060E+03	0.0
4	1.00108E+08	1.00108E+08	3.99200E-02

2 FLOW LOOPS

LOOP 1 PUMPING RATE (VOL/SEC) = 8.60000E+04

ZONE	REGION	MAT.#
10	1	4
1	4	
2	4	
3	4	
4	4	
9	1	
10	1	

LOOP 2 PUMPING RATE (VOL/SEC) = 4.75000E+04

ZONE	REGION	MAT.#
10	1	4
5	4	
6	4	
7	4	
8	4	
9	1	
10	1	

PROBLEM NOW DEFINED, CALCULATION BEGINS

OPTION 2
INTERRUPT WILL OCCUR WHEN TIME IS GREATER THAN 2.0000E+00 TIME 0.0 MINS.

TIME SEC.	POWER WATTS	K.EFF	K.EXCESS	ENERGY JOULES	DK/K TEMP CUMULATIVE	DK/K EXPAND CUMULATIVE	DK TOTAL CUMULATIVE	PERIOD SEC.
4.00000E-02	1.15384E+02	1.00863D+00	8.6263D-03	4.30036E+00	-1.8929E-10	0.0	-1.9092D-10	2.7953E-01
8.00000E-02	1.33134E+02	1.00863D+00	8.6263D-03	9.26227E+00	-5.5646E-10	0.0	-5.6127D-10	2.7955E-01
1.20000E-01	1.53612E+02	1.00863D+00	8.6263D-03	1.45874E+01	-1.0513E-09	0.0	-1.0604D-09	2.7957E-01
1.60000E-01	1.77240E+02	1.00863D+00	8.6263D-03	2.10932E+01	-1.6508E-09	0.0	-1.6650D-09	2.7958E-01
2.00000E-01	2.04501E+02	1.00863D+00	8.6263D-03	2.92151E+01	-2.3476E-09	0.0	-2.3678D-09	2.7959E-01
2.40000E-01	2.35954E+02	1.00863D+00	8.6263D-03	3.80092E+01	-3.1437E-09	0.0	-3.1708D-09	2.7960E-01
2.80000E-01	2.72243E+02	1.00863D+00	8.6263D-03	4.81558E+01	-4.0477E-09	0.0	-4.0827D-09	2.7960E-01
3.20000E-01	3.14113E+02	1.00863D+00	8.6263D-03	5.98630E+01	-5.0727E-09	0.0	-5.1164D-09	2.7961E-01
3.60000E-01	3.62422E+02	1.00863D+00	8.6263D-03	7.33707E+01	-6.2354E-09	0.0	-6.2892D-09	2.7961E-01
4.00000E-01	4.18160E+02	1.00863D+00	8.6263D-03	8.89558E+01	-7.5564E-09	0.0	-7.6216D-09	2.7961E-01
4.40000E-01	4.82469E+02	1.00863D+00	8.6263D-03	1.06938E+02	-9.0599E-09	0.0	-9.1381D-09	2.7962E-01
4.80000E-01	5.56668E+02	1.00863D+00	8.6263D-03	1.27685E+02	-1.0774E-08	0.0	-1.0867D-08	2.7962E-01
5.20000E-01	6.42277E+02	1.00863D+00	8.6263D-03	1.51623E+02	-1.2733E-08	0.0	-1.2843D-08	2.7962E-01
5.60000E-01	7.41051E+02	1.00863D+00	8.6263D-03	1.79243E+02	-1.4973E-08	0.0	-1.5103D-08	2.7962E-01
6.00000E-01	8.55015E+02	1.00863D+00	8.6263D-03	2.11110E+02	-1.7540E-08	0.0	-1.7691D-08	2.7962E-01
6.40000E-01	9.86504E+02	1.00863D+00	8.6263D-03	2.47878E+02	-2.0484E-08	0.0	-2.0661D-08	2.7963E-01
6.80000E-01	1.13821E+03	1.00863D+00	8.6263D-03	2.90300E+02	-2.3864E-08	0.0	-2.4069D-08	2.7963E-01
7.20000E-01	1.31325E+03	1.00863D+00	8.6263D-03	3.39246E+02	-2.7747E-08	0.0	-2.7986D-08	2.7963E-01
7.60000E-01	1.51521E+03	1.00863D+00	8.6263D-03	3.95719E+02	-3.2213E-08	0.0	-3.2490D-08	2.7963E-01
8.00000E-01	1.74822E+03	1.00863D+00	8.6263D-03	4.60876E+02	-3.7351E-08	0.0	-3.7673D-08	2.7963E-01
8.40000E-01	2.01707E+03	1.00863D+00	8.6263D-03	5.36054E+02	-4.3265E-08	0.0	-4.3638D-08	2.7963E-01
8.80000E-01	2.32726E+03	1.00863D+00	8.6262D-03	6.22793E+02	-5.0076E-08	0.0	-5.0508D-08	2.7963E-01
9.20000E-01	2.68515E+03	1.00863D+00	8.6262D-03	7.22870E+02	-5.7923E-08	0.0	-5.8423D-08	2.7963E-01
9.60000E-01	3.09807E+03	1.00863D+00	8.6262D-03	8.38338E+02	-6.6966E-08	0.0	-6.7543D-08	2.7964E-01
1.00000E+00	3.57449E+03	1.00863D+00	8.6262D-03	9.71563E+02	-7.7388E-08	0.0	-7.8056D-08	2.7964E-01
	**********		MONITOR OUTPUT FOR TIMES 1.00 - 1.92 OMITTED				**********	
1.96000E+00	1.10585E+05	1.00862D+00	8.6239D-03	3.09137E+04	-2.4107E-06	0.0	-2.4315D-06	2.7995E-01
2.00000E+00	1.27568E+05	1.00862D+00	8.6235D-03	3.56687E+04	-2.7822E-06	0.0	-2.8062D-06	2.8000E-01
2.04000E+00	1.47154E+05	1.00862D+00	8.6231D-03	4.11538E+04	-3.2105E-06	0.0	-3.2382D-06	2.8005E-01

(Continued)

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ZONE  1 REGION TEMPERATURES
   299.062     299.060     299.044     299.016

ZONE  2 REGION TEMPERATURES
   299.070     299.068     299.051     299.028

ZONE  3 REGION TEMPERATURES
   299.073     299.072     299.054     299.033

ZONE  4 REGION TEMPERATURES
   299.075     299.074     299.056     299.036

ZONE  5 REGION TEMPERATURES
   299.100     299.098     299.072     299.026

ZONE  6 REGION TEMPERATURES
   299.114     299.111     299.083     299.045

ZONE  7 REGION TEMPERATURES
   299.120     299.119     299.089     299.055

ZONE  8 REGION TEMPERATURES
   299.125     299.121     299.092     299.060

ZONE  9 REGION TEMPERATURES
   299.000

ZONE 10 REGION TEMPERATURES
   299.000

INTERRUPTING BECAUSE     TIME =   2.04000E+00 IS GREATER THAN    2.0[illegible]00E+00
PREVIOUSLY SAVED PLOTTING ARRAYS DISCARDED

         OPTION  2
INTERRUPT WILL OCCUR WHEN     TIME IS GREATER THAN  5.2200E+00

 TIME         POWER        K.EFF        K.EXCESS     ENERGY       DK/K TEMP    DK/K EXPAND DK TOTAL     PERIOD
 SEC.         WATTS                                  JOULES       CUMULATIVE   CUMULATIVE  CUMULATIVE   SEC.
2.08000E+00 1.69741E+05 1.00862D+00  8.6226D-03 4.74810E+04 -3.7067E-06  0.0         -3.7387D-06  2.8012E-01
2.12000E+00 1.95788E+05 1.00862D+00  8.6220D-03 5.47792E+04 -4.2740E-06  0.0         -4.3109D-06  2.8020E-01
2.16000E+00 2.25821E+05 1.00862D+00  8.6213D-03 6.31972E+04 -4.9281E-06  0.0         -4.9706D-06  2.8028E-01
2.20000E+00 2.60449E+05 1.00862D+00  8.6206D-03 7.29061E+04 -5.6882E-06  0.0         -5.7373D-06  2.8039E-01
2.24000E+00 3.00368E+05 1.00862D+00  8.6197D-03 8.41036E+04 -6.5636E-06  0.0         -6.6202D-06  2.8050E-01
2.28000E+00 3.46381E+05 1.00862D+00  8.6187D-03 9.7016AE+04 -7.5698E-06  0.0         -7.6351D-06  2.8064E-01
2.32000E+00 3.99413E+05 1.00862D+00  8.6175D-03 1.11908E+05 -8.7340E-06  0.0         -8.8093D-06  2.8079E-01
2.36000E+00 4.60521E+05 1.00862D+00  8.6161D-03 1.29077E+05 -1.0072E-05  0.0         -1.0159D-05  2.8097E-01
2.40000E+00 5.30923E+05 1.00861D+00  8.6146D-03 1.48873E+05 -1.1622E-05  0.0         -1.1722D-05  2.8118E-01
2.44000E+00 6.12012E+05 1.00861D+00  8.6128D-03 1.71694E+05 -1.3418E-05  0.0         -1.3534D-05  2.8142E-01    TIME  0.050 MINS.
2.48000E+00 7.05387E+05 1.00861D+00  8.6107D-03 1.97998E+05 -1.5472E-05  0.0         -1.5605D-05  2.8170E-01
2.52000E+00 8.12881E+05 1.00861D+00  8.6083D-03 2.28313E+05 -1.7849E-05  0.0         -1.8003D-05  2.8201E-01
2.56000E+00 9.36576E+05 1.00861D+00  8.6055D-03 2.63244E+05 -2.0586E-05  0.0         -2.0763D-05  2.8239E-01
2.60000E+00 1.07887E+06 1.00860D+00  8.6023D-03 3.03487E+05 -2.3745E-05  0.0         -2.3949D-05  2.8282E-01
            ********************     MONITOR OUTPUT FOR TIMES 2.64 -  3.72 OMITTED **********************
3.76000E+00 3.50209E+07 1.00739D+00  7.3905D-03 1.38126E+07 -1.2260E-03  0.0         -1.2358D-03  6.3875E-01
3.80000E+00 3.69556E+07 1.00725D+00  7.2475D-03 1.52528E+07 -1.3680E-03  0.0         -1.3788D-03  7.4389E-01
3.84000E+00 3.86387E+07 1.00710D+00  7.0955D-03 1.67657E+07 -1.5189E-03  0.0         -1.5308D-03  8.9811E-01
3.88000E+00 4.00163E+07 1.00694D+00  6.9360D-03 1.83399E+07 -1.6772E-03  0.0         -1.6903D-03  1.1418E+00
3.92000E+00 4.10494E+07 1.00677D+00  6.7711D-03 1.99624E+07 -1.8410E-03  0.0         -1.8552D-03  1.5694E+00    TIME  0.100 MINS.
3.96000E+00 4.17149E+07 1.00660D+00  6.6029D-03 2.16189E+07 -2.0081E-03  0.0         -2.0234D-03  2.4870E+00
4.00000E+00 4.20094E+07 1.00643D+00  6.4338D-03 2.32946E+07 -2.1761E-03  0.0         -2.1925D-03  5.6880E+00
4.04000E+00 4.19502E+07 1.00627D+00  6.2666D-03 2.49749E+07 -2.3423E-03  0.0         -2.3597D-03 -2.8387E+01
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ZONE  1 REGION TEMPERATURES
   325.020     324.357     316.713     307.288
ZONE  1 HEAT FLUXES (CALS/CM**2/SEC) & NODE TEMPS (K)
REGION   1 LEFT & RIGHT FLUXES   1.595E+00   6.342E+00
   325.099     325.080     325.040     324.981     324.902
REGION   2 LEFT & RIGHT FLUXES   7.793E+00   7.360E+00
   324.746     324.548     324.353     324.162     323.975
REGION   3 LEFT & RIGHT FLUXES   7.191E+00   7.103E+00
   322.444     319.568     316.702     313.846     311.005
REGION   4 LEFT & RIGHT FLUXES   6.355E+00   6.922E-01
   307.523     307.449     307.383     307.325     307.276     307.234     307.201     307.177     307.160     307.152

ZONE  2 REGION TEMPERATURES
   330.991     330.342     323.130     314.815
ZONE  2 HEAT FLUXES (CALS/CM**2/SEC) & NODE TEMPS (K)
REGION   1 LEFT & RIGHT FLUXES   1.573E+00   6.077E+00
   331.069     331.049     331.010     330.951     330.876
REGION   2 LEFT & RIGHT FLUXES   7.583E+00   7.015E+00
   330.717     330.525     330.337     330.154     329.976
REGION   3 LEFT & RIGHT FLUXES   6.780E+00   6.631E+00
   328.529     325.817     323.119     320.418     317.766
REGION   4 LEFT & RIGHT FLUXES   5.789E+00   6.712E-01
   315.035     314.967     314.904     314.850     314.803     314.764     314.733     314.710     314.695     314.687

ZONE  3 REGION TEMPERATURES
   334.508     333.869     326.974     319.485
ZONE  3 HEAT FLUXES (CALS/CM**2/SEC) & NODE TEMPS (K)
REGION   1 LEFT & RIGHT FLUXES   1.533E+00   6.072E+00
   334.584     334.565     334.527     334.469     334.394
REGION   2 LEFT & RIGHT FLUXES   7.442E+00   6.766E+00
   334.234     334.046     333.863     333.686     333.515
REGION   3 LEFT & RIGHT FLUXES   6.497E+00   6.107E+00
   332.131     329.532     326.932     324.358     321.915
REGION   4 LEFT & RIGHT FLUXES   5.306E+00   6.292E-01
   319.691     319.630     319.572     319.519     319.474     319.437     319.407     319.385     319.370     319.363
            ********************  TEMPERATURE OUTPUT FOR ZONES 4    - 7    OMITTED **********************

ZONE  8 REGION TEMPERATURES
   360.431     359.392     348.333     336.969
ZONE  8 HEAT FLUXES (CALS/CM**2/SEC) & NODE TEMPS (K)
REGION   1 LEFT & RIGHT FLUXES   2.577E+00   1.101E+01
   360.563     360.531     360.466     360.366     360.228
REGION   2 LEFT & RIGHT FLUXES   1.255E+01   1.083E+01
   359.987     359.673     359.379     359.096     358.826
REGION   3 LEFT & RIGHT FLUXES   1.033E+01   1.074E+01
   356.622     352.492     348.370     344.240     339.943
REGION   4 LEFT & RIGHT FLUXES   9.942E+00   1.007E+00
   337.315     337.200     337.103     337.020     336.949     336.890     336.844     336.808     336.785     336.773

ZONE  9 REGION TEMPERATURES
   299.032
ZONE  9 HEAT FLUXES (CALS/CM**2/SEC) & NODE TEMPS (K)
REGION   1 LEFT & RIGHT FLUXES   0.0         0.0
   299.032     299.032     299.032     299.032     299.032

ZONE 10 REGION TEMPERATURES
   299.000
ZONE 10 HEAT FLUXES (CALS/CM**2/SEC) & NODE TEMPS (K)
REGION   1 LEFT & RIGHT FLUXES   0.0         0.0
   299.000     299.000     299.000     299.000     299.000
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(Continued)

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 TIME         POWER        K.EFF        K.EXCESS     ENERGY       DK/K TEMP    DK/K EXPAND  DK TOTAL     PERIOD
 SEC.         WATTS                                  JOULES       CUMULATIVE   CUMULATIVE   CUMULATIVE   SEC.
 4.08000E+00 4.15745E+07 1.00610D+00  6.1041D-03 2.66463E+07 -2.5038E-03  0.0          -2.5222D-03 -4.4462E+00
 4.12000E+00 4.09333E+07 1.00595D+00  5.9488D-03 2.82973E+07 -2.6581E-03  0.0          -2.6775D-03 -2.5735E+00
 4.16000E+00 4.00869E+07 1.00580D+00  5.8031D-03 2.99182E+07 -2.8030E-03  0.0          -2.8232D-03 -1.9144E+00
 4.20000E+00 3.90998E+07 1.00567D+00  5.6689D-03 3.15023E+07 -2.9364E-03  0.0          -2.9574D-03 -1.6044E+00
             ********************      MONITOR OUTPUT FOR TIMES 4.24 - 5.12 OMITTED **********************
 5.16000E+00 3.41852E+07 1.00504D+00  5.0386D-03 6.32150E+07 -3.5633E-03  0.0          -3.5877D-03  3.5675E+00
 5.20000E+00 3.45597E+07 1.00503D+00  5.0272D-03 6.45900E+07 -3.5746E-03  0.0          -3.5990D-03  3.6713E+00
 5.24000E+00 3.49230E+07 1.00501D+00  5.0134D-03 6.59797E+07 -3.5884E-03  0.0          -3.6129D-03  3.8247E+00

ZONE  1 REGION TEMPERATURES
   323.731     323.171     316.416     307.733

ZONE  2 REGION TEMPERATURES
   334.566     334.005     327.246     318.563

ZONE  3 REGION TEMPERATURES
   345.309     344.750     338.005     329.346

ZONE  4 REGION TEMPERATURES
   355.383     354.829     348.179     339.711

ZONE  5 REGION TEMPERATURES
   339.450     338.529     327.426     313.143

ZONE  6 REGION TEMPERATURES
   357.055     356.137     345.026     330.744

ZONE  7 REGION TEMPERATURES
   374.544     373.632     362.545     348.291

ZONE  8 REGION TEMPERATURES
   390.989     390.083     379.151     365.204

ZONE  9 REGION TEMPERATURES
   299.179

ZONE 10 REGION TEMPERATURES
   299.000

INTERRUPTING BECAUSE     TIME =   5.24000E+00 IS GREATER THAN    5.22000E+00
PLOTTING POWER AGAINST TIME

                                                                                                    RR

IMMEDIATE INTERRUPT
PLOTTING POWER AGAINST TIME

IMMEDIATE INTERRUPT
PLOTTING COMPENSATED REACTIVITY AGAINST TIME

IMMEDIATE INTERRUPT
PLOTTING SAVED TEMPERATURE AGAINST TIME

IMMEDIATE INTERRUPT
PLOTTING TEMPERATURES IN ZONE  1

IMMEDIATE INTERRUPT

CASE TERMINATING
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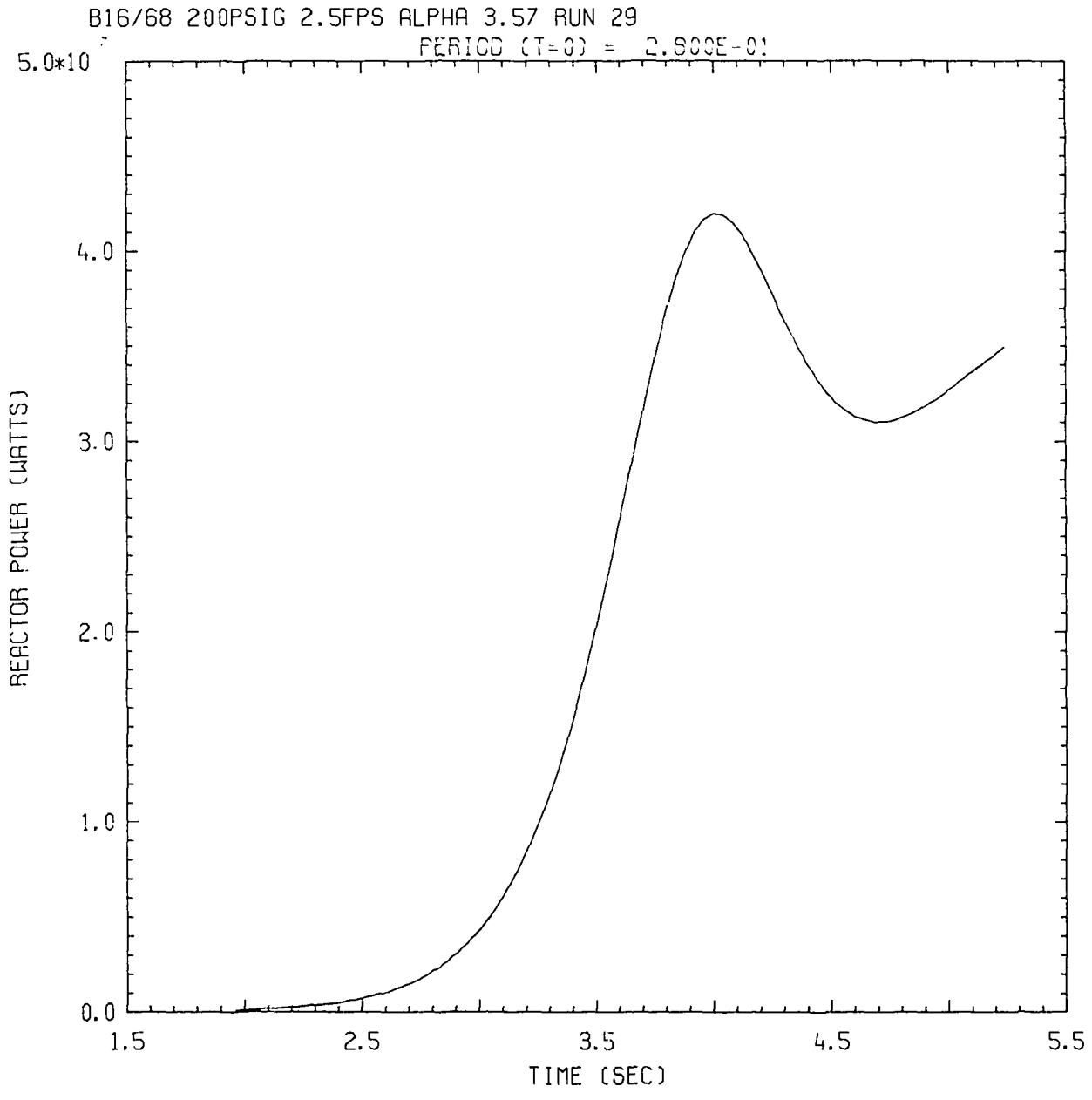
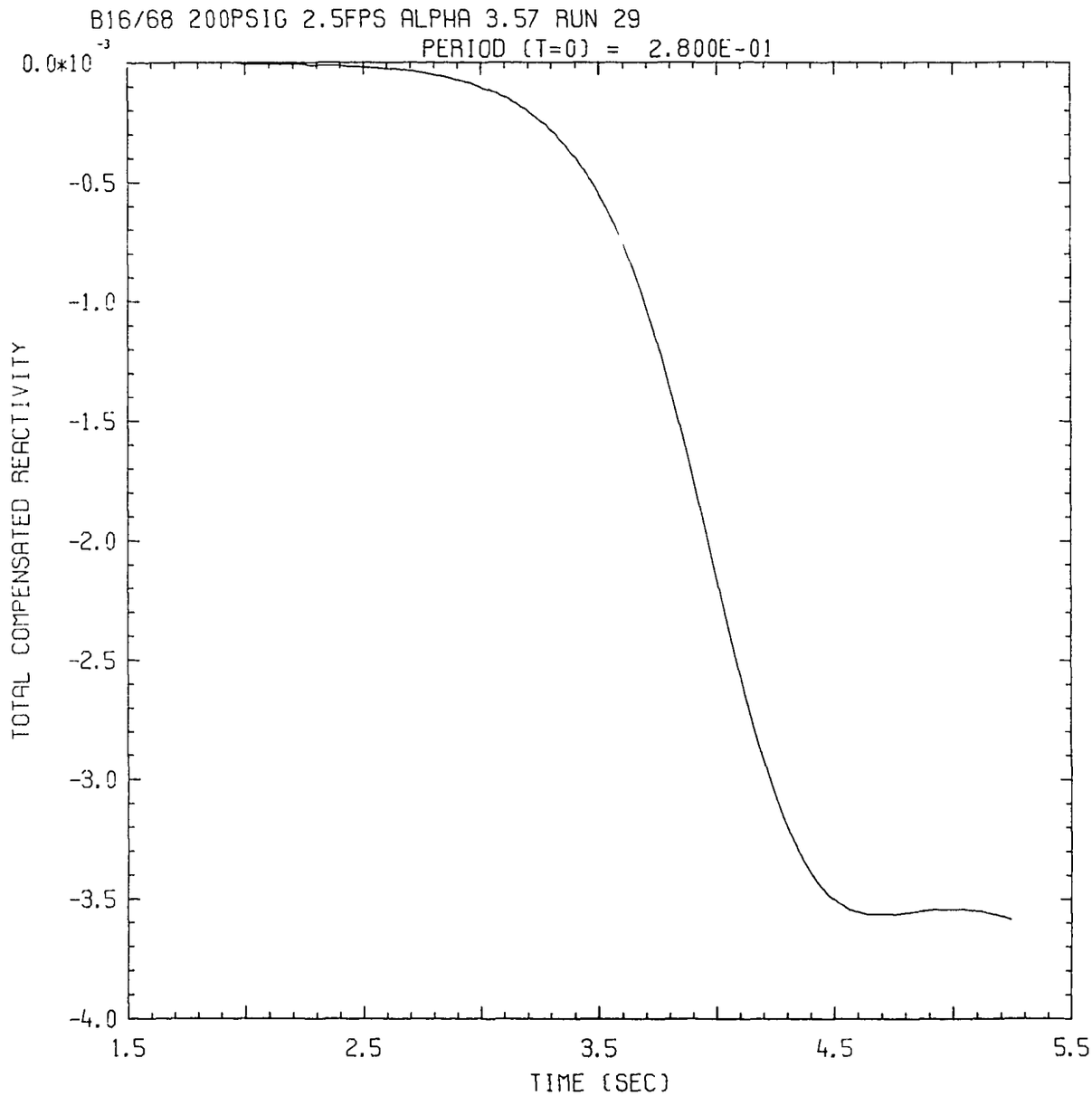
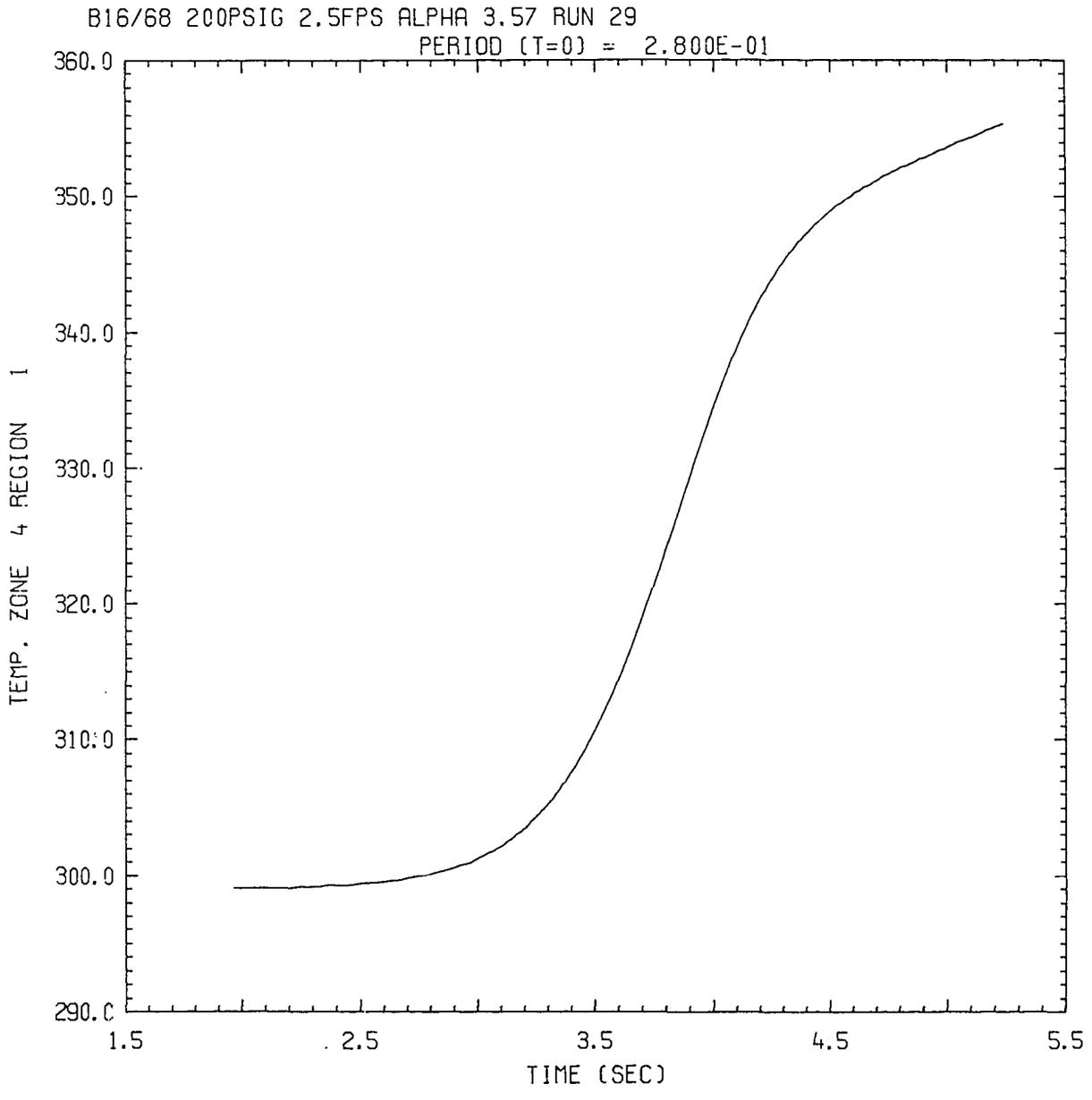
APPENDIX F
GRAPHICAL OUTPUT FOR CASE 2

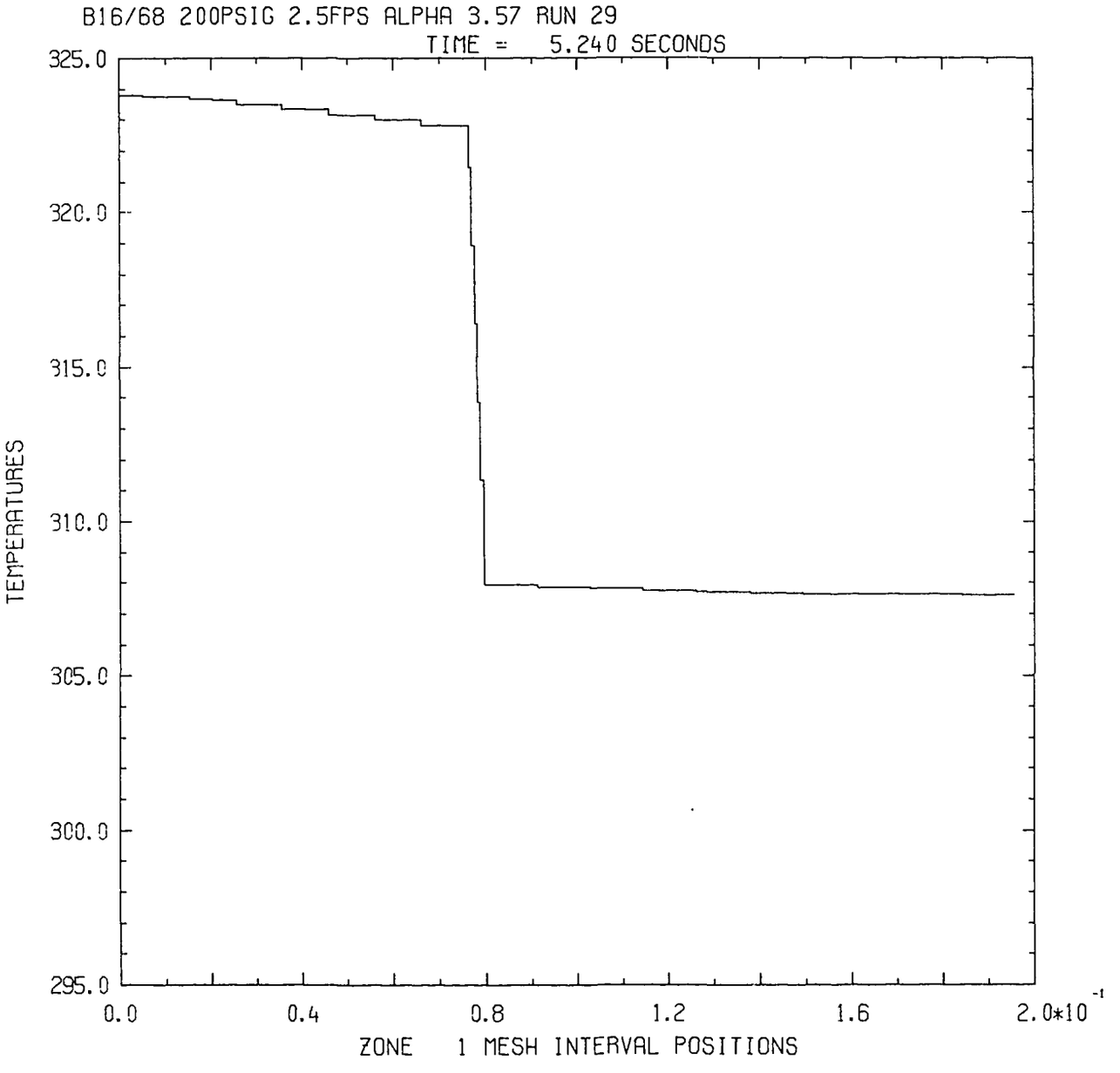


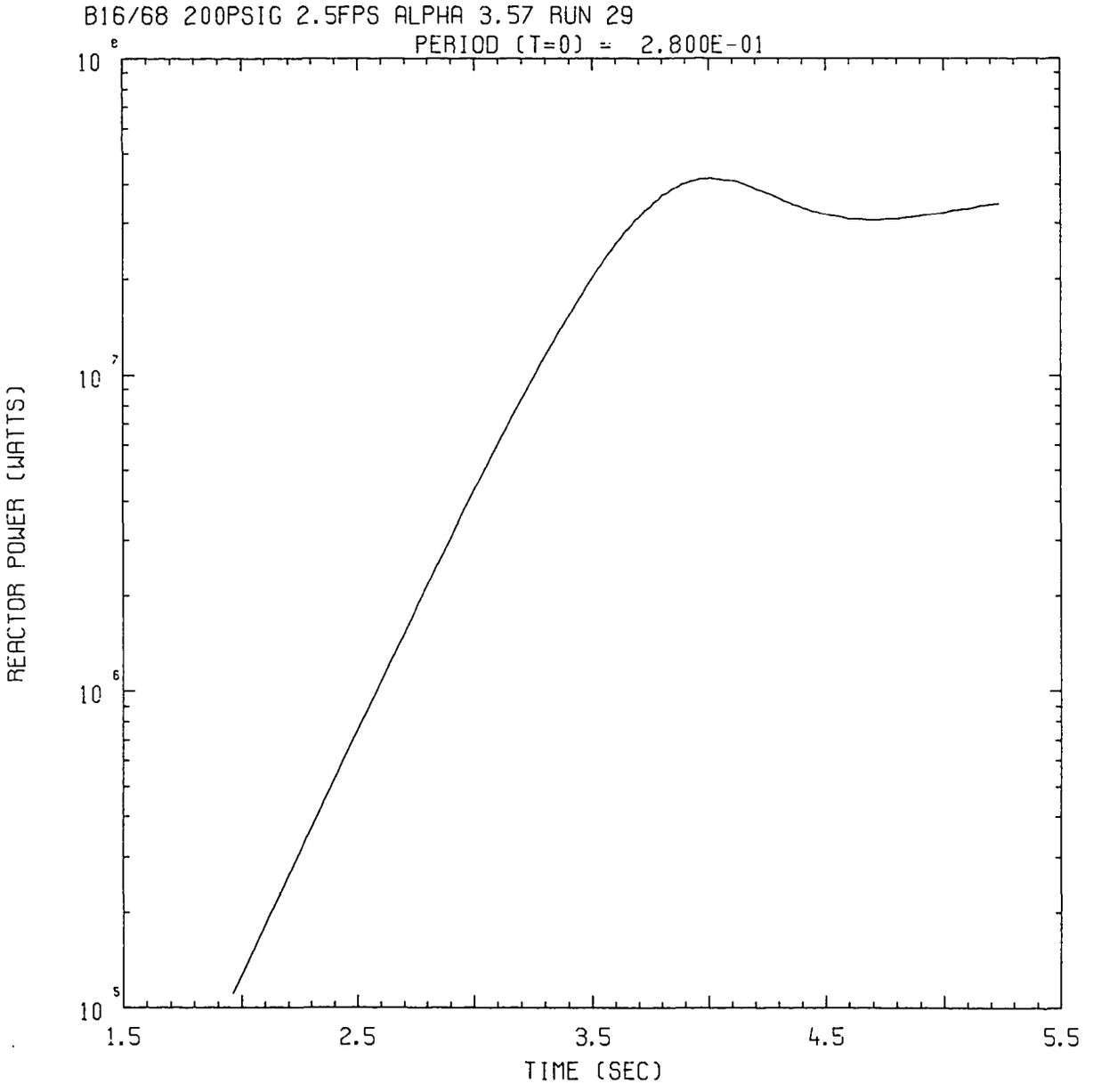
(Continued)


B16/68 200PSIG 2.5FPS ALPHA 3.57 RUN 29
PERIOD (T=0) = 2.800E-01
0.0*10^-3
-0.5
-1.0
-1.5
-2.0
-2.5
-3.0
-3.5
-4.0
TOTAL COMPENSATED REACTIVITY
1.5
2.5
3.5
4.5
5.5
TIME (SEC)


B16/68 200PSIG 2.5FPS ALPHA 3.57 RUN 29
PERIOD (T=0) = 2.800E-01
360.0
350.0
340.0
330.0
320.0
310.0
300.0
290.0
TEMP. ZONE 4 REGION 1
1.5
2.5
3.5
4.5
5.5
TIME (SEC)

(Continued)


B16/68 200PSIG 2.5FPS ALPHA 3.57 RUN 29
TIME = 5.240 SECONDS
325.0
320.0
315.0
310.0
305.0
300.0
295.0
TEMPERATURES
0.0
0.4
0.8
1.2
1.6
2.0*10
-1
ZONE 1 MESH INTERVAL POSITIONS


B16/68 200PSIG 2.5FPS ALPHA 3.57 RUN 29
PERIOD (T=0) = 2.800E-01
REACTOR POWER (WATTS)
10^8
10^7
10^6
10^5
1.5
2.5
3.5
4.5
5.5
TIME (SEC)