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Monterey, California

THESIS

A COMPARISON OF INTEGRATION METHODS FOR THE SOLUTION OF NONLINEAR REACTOR DYNAMICS PROBLEMS THROUGH THE USE OF FINITE ELEMENTS

by

Ralph Carroll Sheldrick

December 1976

Thesis Advisor: David Salinas

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The other noteworthy result was in the effect of the error criterion on solution. It was shown that for a range of error from 10^{-4} to 1.0, the steady state solution value remained the same. This results in a significant reduction in computer processing time since the time required decreases substantially as the error conditions imposed are relaxed.

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A Comparison of Integration Methods for the Solution of Nonlinear Reactor Dynamics Problems Through the Use of Finite Elements

by

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Submitted in partial fulfillment of the requirements for the degree of

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NAVAL POSTGRADUATE SCHOOL
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ABSTRACT

A comparison of numerical methods utilized by the finite element technique for solving a nonlinear nuclear reactor dynamics problem was conducted. Using the Crank-Nicolson, DVOGER (Gear) and Implicit Gear methods, the results showed the Implicit to be the superior method investigated. This is based on the fact that all three methods yielded the same steady state solutions; but, the Implicit Gear method used significantly less CPU time and comparable storage to Crank-Nicolson. This was particularly apparent as the degrees of freedom were increased. In addition, the transient solution in all cases was better than that obtained in Crank-Nicolson and compared favorably to that of Gear's method.

The other noteworthy result was in the effect of the error criterion on solution. It was shown that for a range of error from 10^{-4} to 1.0, the steady state solution value remained the same. This results in a significant reduction in computer processing time since the time required decreases substantially as the error conditions imposed are relaxed.

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LIST OF SYMBOLS

A_{ij} -- matrix

a -- constant

B_{ij} -- matrix

b -- constant

C_{ij} -- matrix

c -- constant

D -- neutron diffusion coefficient

H -- reactor height

R -- reactor radius

t -- time

v -- neutron velocity

α -- reactivity temperature coefficient

ε -- fission energy

ν -- number of neutrons per fission

Σ_a -- neutron absorption cross-section

Σ_f -- neutron fission cross-section

ψ -- neutron dynamic flux

ω -- constant

$\bar{h}A/V$ -- modified convection heat transfer coefficient

I. INTRODUCTION

A. PURPOSE

This research project has been undertaken to compare several numerical methods of solving a nonlinear nuclear reactor dynamics problem. Three methods have been investigated in this thesis, including the Crank-Nicolson, the DVOGER (Gear) and the Implicit Gear methods of solution.

A nuclear reactor dynamics problem with temperature-dependent feedback, when it entails either a non-homogeneous or multi-region reactor, results in a nonlinear field equation in space and time. This problem does not lend itself to solution by analytical means [5, 6]. However, when the physical and neutronic properties of the problem are known, a model can be formulated using the finite element method which will yield the transient and steady state flux solutions. In particular, the partial differential equations investigated were of the form

$$a \frac{\partial \psi}{\partial t} = b\nabla^2 \psi + c\psi - \omega\psi^2 \qquad (1)$$

where a, b, c, and ω are constants and $\psi(r, z, t)$ is the flux. The finite element method reduces Equation (1) to the system of ordinary differential equations

$$\sum_{j=1}^{N} A_{ij} \dot{\psi}_j(t) = \sum_{j=1}^{N} B_{ij} \psi_j(t) \qquad i = 1, \ldots, N \qquad (2)$$

when the nonlinear term is linearized. Nguyen and Salinas [5] and more recently Olsen [6] discuss the problem and methods of solution.

In this work, a comparison of three numerical integration schemes for Equation (2) was made. The comparisons will be made on several bases: computer storage requirements, computer processing time, rapidity with which solution was obtained and the relative accuracy of the solution.

At steady state, it is expected that all three methods will provide the same solution value. This is due to the fact that at steady state the time derivative of the flux ($\dot{\psi}$), Equation (2), is zero.

In order to explore the relative value of the various methods, the model has been discretized into finite element grids of various degrees of freedom (DOF). The effect on the solution by finer discretizations of the finite element has been investigated to determine if the various methods of solution are similarly influenced to provide a better solution for a finer mesh. To have a method of solution relatively independent of mesh size would greatly reduce computer storage and processing time requirements since a larger grid with fewer elements could be utilized.

In order to test the flexibility of the various equation solvers, an initial disturbance was introduced at different points in the model. This provided both a check of the ability of the method to accept a random disturbance as well as information on how rapidly a solution is obtained with a particular disturbance input. Two nodal points of the system were considered, a point at the origin and a point on the core-reflector interface. This was done to determine if the tracking ability was consistent throughout the model.

Additional comparisons investigated include the effects of the convergence criterion on the solution for all methods and the effects of the size of the time step on the Crank-Nicolson method.

Modifications have been made to the programs provided in Ref. [6] which was the basis of this research project. In that work, core properties were arbitrarily assigned to the reflector elements at the interface. This occurred because the material and nuclear properties were provided at the nodal points rather than by elements. The properties were introduced in this manner as a means of computer storage reduction. Regardless of the mesh size, there were always fewer nodes than elements. In this project, all properties were provided on an element basis to eliminate this discrepancy while at the same time sacrificing the minor storage savings it represented.

II. DATA GENERATORS

A. GENERAL

The data generators formulated in this work are useable only for regular rectangular grids (Figures 1-3). Having selected the number of horizontal and vertical points for the discretization of the model, the data generators will provide the numbering of each nodal point, the horizontal and vertical position of each node and the nodal neighbors of each node.

In addition, the outer boundary nodes, at which the dynamic flux is zero, will be numbered last in order to reduce the number of equations required by the particular method of solution being used. This will substantially decrease the storage requirements. For example, in a one hundred thirty-two node discretization, only one hundred ten equations will be solved.

B. PROPERTY INPUTS

1. Purpose

A simple data generator has been provided which will produce a data deck containing the physical properties of the reactor core and reflector in the format required by the Crank-Nicolson and DVOGER (Gear) methods. These properties are neutron velocity, neutron diffusion length, neutron absorption cross-section, neutron fission cross-section and reactivity temperature coefficient.

This generator will accommodate any size mesh and will process an indefinite number of grids simultaneously.

The user must provide this routine with a data deck which contains the total number of elements in the grid and the type of each element, core or reflector. This has been simplified by the designation of all core elements by ITYPE=0 and reflector elements by ITYPE=1.

2. Programming Notes

a. The property values in the two regions must be provided as an integral part of the program.

b. The type of element, core or reflector, must be provided.

c. The routine will process an unlimited number of models. It, therefore, must be halted when all data has been utilized. This is done by specifying the final value of the number of elements in an IF-STOP statement.

3. Parameters

a. NEL - number of elements in the discretized model

b. ITYPE - type of element; ITYPE=0 is a core element and ITYPE=1 is a reflector element.

c. D - vector containing the diffusion length of the core and reflector elements.

d. SGA - vector containing the absorption cross-section of the core and reflector elements.

e. SGF - vector containing the fission cross-section of the core and reflector elements.

f. V - vector containing the neutron velocity.

g. ALPHA - vector containing the reactivity temperature coefficient.

C. NODAL POINT COORDINATES AND ELEMENT NODAL POINT CONNECTIVITY

1. Purpose

Nodal point positioning in the model is readily obtained in data deck form from this routine. Once the model to be investigated has been discretized into the finite element grid desired, the user provides the number of vertical and horizontal nodal points and their dimensional position along the axes. By the use of a nested loop, the nodal points are consecutively numbered and assigned the proper coordinate dimensions.

The element connectivity, that is, the nodal points for each element, is also resolved by the use of a nested loop and several counters. Each iteration will yield two elements with their respective nodal point boundaries. This will continue until the nodal points for each element have been computed.

The output of this routine will consist of two data decks. The first will provide the nodal point with its vertical and horizontal coordinates. The second will yield the element nodal point connectivity.

Omitted from the element connectivity data deck, but required by the thesis program, is the type of element, core or reflector. This must be added to the deck individually.

Example of output (See Figure 1):

nodal point coordinates

nodal point	horizontal position	vertical position
1	0.0	0.0

element connectivity

element	nodal point connectivity			type element*
1	1	9	10	0

*Note: must be added manually to data card.

2. Programming Notes

a. The maximum number of vertical and horizontal nodal points in the discretized model must be provided.

b. The horizontal and vertical positions of the discretization must be provided.

c. The boundary points of the model will be numbered such that these nodal points are the last in the numerical sequence.

d. The routine is written such that it will process an indefinite number of models. Therefore, it must be halted when all the data has been utilized. This will be accomplished by specifying the maximum number of vertical points in the model in an IF-STOP statement.

3. Parameters

a. NH - maximum number of horizontal nodal points in the discretized model.

b. NV - maximum number of vertical nodal points in the discretized model.

c. X - vector containing the horizontal positions of the NH points.

d. Y - vector containing the vertical positions of the NV points.

e. SYSNOD - vector providing the total number of nodal points.

f. R - vector providing the radial position of the nodal points.

g. Z - vector providing the vertical position of the nodal points.

h. ELNOD - array providing the nodal point boundaries for each element.

i. NEL - the total number of elements in the discretized model.

D. NODAL NEIGHBOR CONNECTIVITY

1. Purpose

This routine produces a data deck for the Crank-Nicolson and Implicit Gear methods containing each nodal point and the nodal points connected to it by the finite element discretization.

The regular rectangular grids are such that no more than six nodal points contribute to any one; therefore, an Nx7 array can be formulated for nodal neighbor connectivity. For example, nodal point 26 in the 112 element grid would be stored as follows (Figure 4):

26 17 18 27 35 34 25

and nodal point 58

58 49 50 59 57 0 0.

As written, zeros are inputted whenever a nodal point does not have six neighbors to maintain the symmetry of the matrix. This could, however, be compacted further by reading the data as a single vector with a starting point counter to indicate when the next nodal point has been reached in the sequence. This would eliminate the need for the zeros to be supplied.

This routine will provide a data deck for any rectangular grid and for an indefinite number of grids.

2. Algorithm

This algorithm provides a dense, compacted matrix which reduces the storage size required by the main program. The use of a finite element method allows a certain amount of compacting, i.e., the banded matrix. This is a function of the finite element size, that is, the greater the number of nodal points, the larger the band. The size of the band is determined by the largest difference between nodal neighbors plus one. For example, in Figure 1, node 11 has a maximum difference of 20 - 2 = 18, while at node 16 the difference is 43 - 7 = 36 which is the largest difference in the forty-five node system. As the number of nodal points increases, this maximum band width also increases. In Figure 2, the maximum difference is at node 16 (67 - 7 = 60); and, in Figure 3, the maximum difference of 124 - 10 = 114 exists at node 22. Therefore, although the size of the system is reduced from NxN to Nxq, the size is not constant and may not be small. In general, if one used banded storage, the numbering would proceed consecutively in the direction of fewest nodes. However, this would require the identification of those nodes on the boundary since they are of constant value and do not require integration.

In the particular scheme of discretization utilized in this project, no nodal point has more than six nodal point contributors. This allows the matrix to be compacted further from Nxq to Nx7.

3. Programming Notes

a. The total number of nodal points, the maximum number of nodal point contributors and the maximum number of horizontal and vertical nodal points must be provided.

b. The routine will satisfy any rectangular grid. However, it must be instructed when a sufficient number of nodal points have been generated. This is accomplished by using the total number of nodal points desired in an IF-GO TO statement.

c. This routine requires a positive means of stopping. This is accomplished by the use of the maximum number of vertical nodal points in the last data set in an IF-STOP statement.

d. The output of this routine will place the central nodal point first with the contributors following.

4. Parameters

a. NV - number of vertical nodal points in the model.

b. NH - number of horizontal nodal points in the model.

c. NVH - total number of nodal points in the model. NVH = NV x NH.

d. LCON - maximum number of contributing nodal points. (LCON = 7).

e. MNOD - an array, NVH x LCON, providing the central and contributing nodal points.

III. CRANK-NICOLSON METHOD OF SOLUTION

A. DESCRIPTION

The Crank-Nicolson formulation is a numerical method originally presented by J. Crank and P. Nicolson in 1947. Crank-Nicolson, being an implicit method, does not require the inverse of the matrix to be calculated. Therefore, advantage is taken of the sparse matrix inherently provided by the finite element method. If the inverse of the sparse matrix is formed, it will be full.

The Crank-Nicolson method will solve the set of linear differential equations represented by

$$\sum_{j=1}^{N} A_{ij} \dot{\psi}_j(t) = \sum_{j=1}^{N} B_{ij} \psi_j(t) \qquad i=1, \ldots, N. \tag{3}$$

Crank-Nicolson, after some algebra, yields

$$A \left[\frac{\psi_t - \psi_{t-\Delta t}}{\Delta t} \right] = C \left[\frac{\psi_t + \psi_{t-\Delta t}}{2} \right] . \tag{4}$$

The implicit system (4) may be solved by an iterative process; in this case, the Gauss-Seidel method is used to solve the set of simultaneous algebraic equations (4) formulated. Of all the stable numerical methods in the case of single step implicit, Crank-Nicolson has the smallest truncation error [2]. The Gauss-Seidel method of iteration is continuously using the newest solution values allowing convergence to the solution to be the most rapid.

B. EFFECT OF DEGREES OF FREEDOM

As might be expected, as the grid size became finer, the computer core requirements increase. In addition, more time is required for the problem to reach a steady state solution. At the same time, as shown in Figures 5-7, the solution values converged, as the mesh size became finer, to a more accurate solution.

As shown in Table I and Figure 8, storage and processing time, that is, CPU time to reach a steady state solution, increased markedly between a forty-five node grid and a one hundred thirty-two node grid. This yielded a fifty-nine percent increase in storage and better than a five hundred percent increase in processing time. At the same time there is an improvement in the solution of only four and one-half percent.

Comparison to a seventy-two node grid yielded far more satisfying results. At seventy-two nodes, there is an eighty percent increase in CPU time and a sixteen percent increase in storage requirements while obtaining a two and one-half percent improvement in the solution.

Similar results were obtained in problem time to solution. For one hundred thirty-two nodes, the time more than doubles; while for seventy-two nodes, the time was increased by twenty percent.

C. EFFECT OF ERROR CRITERION

The error criterion used throughout this thesis informs the integration routine when it has achieved sufficient agreement between iterates (i.e., when it can stop and go to the next iteration step).

In Crank-Nicolson, the error criterion simply consisted of the difference in successive Gauss-Seidel iterates divided by the current iterative value.

The error criterion was varied from 10^{-1} to 10^{-4} to observe the effects on the solution and computer requirements. For Crank-Nicolson the steady state solution value remained the same regardless of the error criterion. This demonstrated that the extra time required to satisfy a tighter error criterion at each iteration was not necessary to reach a satisfactory steady state solution. As was expected, the computer processing time did increase significantly as the error criterion was made smaller. An unusual result occurred when the error criterion was set to 10^{-4}. This particular value resulted in a processing time less than that required for 10^{-1}. It would appear that this might have been the result of two contributing factors. With the closeness of the error, each time an iteration was performed, it was using a better solution, and each new time step also had a better solution value. Although there were many more time steps required for this error criterion, the steady state value was rapidly approached because fewer iterations were required at each new time. These results are shown in Table II. These results for an error criterion between 10^{-1} and 10^{-4} do not imply that this would be the result obtained for all problems of this type.

D. EFFECT OF INCREASE IN TIME STEP SIZE

In this method, the time step can be increased or not depending on the solution. If a solution is not obtained with a particular time step, that same time step is reduced; and the routine attempts to attain solution with the smaller time step. This continues until either a satisfactory solution value is obtained or the built in default value is reached which terminates the routine. When a solution is attained, the routine compares the number of iterations required to reach that value to that of the previous time step and to a specified number of iterations. If the current number of iterations is less than either of those numbers, the program increases the time step by an input constant value.

The change made to the initial time step as the steady state was approached was the critical value if the solution was to converge to a steady state. It appeared that Crank-Nicolson was particularly sensitive to the amount the time step was increased as the solution was approached (Figure 9). The method was unable to recover if, when nearing the knee of the curve, the size of the increase was such that the steady state value was exceeded. Once the solution was passed, the results indicated a diverging oscillation about the steady state value.

Several values of the initial time step were utilized in all grids to attempt to locate the steady state. The results of these trials are provided in Table III. It is noteworthy that if the increase was greater than 1.2 times the initial step size, the steady state would never be achieved. Whether this would be the case for all grids is not obvious. This is particularly evident in view of the results obtained by Olsen [6], who utilized an increase of 1.5 times the initial step for a thirty-eight node grid. It would, therefore, seem that a trial and error approach would be necessary until an increase in step size resulted in a steady state solution.

IV. DVOGER (GEAR) METHOD OF SOLUTION

A. DESCRIPTION

The DVOGER (Gear) routine is an IMSL library routine which integrates a system of explicit first order differential equations. Within this library routine is the capability of solving both stiff and nonstiff systems by selection of an indicator. In solving the nonstiff system, the Adams predictor-corrector is utilized. For the stiff system, Gear's predictor-corrector is used. Gear's method computes the Jacobian for the system of ordinary differential equations in order to optimize the time step for each integration.

B. EFFECT OF DEGREES OF FREEDOM

Gear's method placed a much greater demand on the computer in terms of processing time and storage than the other methods considered. This was primarily due to three causes: 1) the calculation of the Jacobian, 2) the transformation of Equation (3) to explicit form, and 3) the initial absolute value of the solution. The first two items require a substantial increase in both CPU time and computer storage. Several variances were implemented in this program to determine if better use could be made of the method to make it competitive with Crank-Nicolson or the Implicit Gear methods.

When the system was considered nonstiff, the storage requirements decreased since the Jacobian was not calculated; but, the processing time increased by one order of magnitude when compared to the stiff system treatment due to the small time steps taken to solution. The routine calls for an initial absolute solution value of one to be supplied. This, however, adversely affects the progress of the problem since this value of one is initially compared to values of 10^{16}. This limits the time step taken by the routine initially and continues to affect the progress until the steady state solution is neared. When an initial value of 10^{14} was utilized, the processing time was decreased by forty percent. This was due to the fact that larger time steps were allowed from the outset, since the previous solution value (in this case the initial value) was comparable to the value obtained in the first calculation.

At best, when utilizing Gear's method, the processing times were two orders of magnitude greater than that required for the Implicit Gear method and twenty times the Crank-Nicolson processing times for the 132 DOF system, as shown in Table I. Core requirements were also increased significantly, particularly at one hundred thirty-two degrees of freedom. For this grid, DVOGER (Gear) was approximately three times Crank-Nicolson and the Implicit Gear core requirements.

Gear's method provided the same steady state solution values as the other two methods, and the transient curves were very similar to those obtained in the Implicit Gear method (Figures 10-15).

C. EFFECT OF ERROR CRITERION

In Gear's method, the time step size is adjusted so that the single step error estimate divided by the previous maximum solution value is less than the error criterion in the Euclidean norm. The single step error estimate is a multiple of the difference between the predicted and corrected values of the variable.

The error criterion, Table II, was varied for this method as it was for the others. The results were the same; as the criterion was tightened, CPU time increased. In this case, however, the time became excessive very rapidly, more than an hour for 10^{-3} and almost four hours for 10^{-4} for the model with 45 DOF. Similarly, the solution values were the same regardless of the criterion utilized.

V. IMPLICIT GEAR METHOD OF SOLUTION

A. DESCRIPTION

This numerical method is particularly useful for the solution of large, sparse systems of implicit, stiff differential equations [4]. In contrast to Gear's method, the Implicit Gear method eliminates the need of an exact NxN Jacobian, but rather requires only an exact Nx7 Jacobian. This is due to the fact that Equations (3) are handled directly, thereby retaining the sparseness of the matrix.

Gear's predictor-corrector method and the compact matrix makes use of storage because the implicit Equations (3) are handled directly. This results in very efficient use of the computer both in terms of storage and processing time requirements.

The user is required to provide a subroutine that evaluates the system of equations being investigated, as well as, for efficiency, a subroutine to evaluate the Jacobian of the system of equations.

This program is a modification by Franke [4] to the routine DFASUB [7]. One of the major changes to the routine is in the treatment of the error. In the Implicit Gear method, instead of using the Euclidean norm, the root mean square norm is utilized. This is no more than the Euclidean norm divided by the square root of the number of components. In addition, the maximum value of the component is updated before the norm of the relative error is computed.

B. EFFECT OF DEGREES OF FREEDOM

The steady state values obtained in this method were the same as those obtained in Crank-Nicolson and DVOGER (Gear) as shown in Figures 11-18. This result does not imply that these methods will always give identical steady state solutions. Certainly they do give different transient solutions. The major advantages of this method are 1) the computer processing time was reduced as the grid size became finer and 2) the storage requirements are slightly greater than that required in the Crank-Nicolson method due to the computation of the Jacobian and the storage of up to seven past solutions which control the size of the time step. Implicit Gear requires about Nx25 more storage locations than Crank-Nicolson. This amounts to about only thirteen thousand bytes for the one hundred thirty-two degrees of freedom system (single precision). The magnitudes of the increase in processing time dropped dramatically in this method. For the same initial disturbance, the time increased eighty percent for the one hundred thirty-two node grid and twenty-four percent for the seventy-two degrees of freedom. In addition, Implicit Gear gave a more accurate transient solution. The results of this method are shown in Table I and comparison to the other methods will be made in Chapter VI.

C. EFFECT OF ERROR CRITERION

In Implicit Gear, the error criterion is defined as in DVOGER (Gear) except that the root mean square of the Euclidean norm and the updated maximum solution value are used in the computation.

The error criterion was varied substantially to determine what effect it had on computer storage and time requirements, as well as its effect on the accuracy of solution. As shown in Table II and Figures 19-20, a wide range of convergence, 1.0 to 10^{-4}, was investigated with interesting results. Expectedly, the processing time did increase as a tighter error criterion was required. However, the criterion had little effect on the track through the transient solution for values of less than 10^{-1}. When using an error of one-half and one, the transient solution varied substantially. The same steady state solution was obtained, although at a later point in problem time as shown in Figure 19. For the stiffer error criterion requirements, the processing time necessary is doubled by utilizing a criterion of 10^{-4} instead of a value greater than 10^{-1}. This, certainly, did not appear to warrant the closer tolerance level.

VI. RESULTS

A. COMPARISON OF TIME AND STORAGE REQUIREMENTS

With all three methods yielding the same steady state solution (Figures 10-18), the comparison of methods became one of time and storage requirements placed on the computer rather than one based on which provided the best solution. In the transient stage, Gear tracked slightly better than Implicit Gear, but both Gear and Implicit Gear tracked better than Crank-Nicolson (See Figures 10-18). For the three systems of equations utilized, the Implicit Gear method performed significantly better than either Crank-Nicolson or DVOGER (Gear) in CPU time and was comparable to Crank-Nicolson and superior to Gear in storage requirements (Table I). This becomes more significant as the number of degrees of freedom increase. The Implicit Gear is less sensitive to the increase in size of the system of equations as shown in Figure 8.

Comparing the forty-five and the one hundred thirty-two degrees of freedom, the core requirements increased slightly and the time doubled for the Implicit Gear method. In contrast, for Crank-Nicolson, the time increased by six times and the core by 100K bytes; and, for DVOGER (Gear), there was a ten times and 500K byte increase in time and storage respectively.

B. DEGREE OF FREEDOM EFFECT ON SOLUTION

Varying the degrees of freedom resulted in a better solution value as shown in Figures 5-7 and 21-26. There was a four and one-half percent better solution obtained for the one hundred thirty-two degrees of freedom compared to the forty-five degrees of freedom. This better solution is very costly both in terms of computer core requirements and CPU time (Figure 8).

C. ERROR CRITERION

Error criterion was varied for all methods to determine the effect on solution and computer. As might be expected, the computer processing time increased for all methods as more rigid tolerance was imposed (Table II). However, although the criterion was made very close, there was no appreciable effect on the transient solution until the error criterion was greater than 10^{-1} and no effect on the steady state solution. This is significant in that, as stated above, the processing time increases greatly as the criterion is tightened. This shows that for the particular problem considered here, some close error criteria yield no advantage, only the disadvantage of requiring more time in the computer.

D. INITIAL DISTURBANCES

The input of various initial disturbances (central, skewed at the core-reflector interface and uniform throughout the core) yielded the same steady state solution value. The transient solution varied substantially due to the input position of the disturbance. In most cases, due to the magnitude and scope of the initial disturbance, the uniform disturbance required the least processing time to reach the steady state value.

E. COMPARISON OF SOLUTION TRACKING

Two nodal points were investigated graphically for each disturbance, integration method and DOF, as shown in Figures 5-7, 10-18 and 21-26. At these test points, the methods performed similarly in all cases in both the transient and steady state solutions.

VII. TEST PROBLEMS

A. PHYSICAL MODEL

A cylindrical reactor with the dimensions and properties given in Table IV was used as a model. A radial slice of this model was discretized by various finite element grids as shown in Figures 1-3.

B. COMPUTER PROCESSING CONSIDERATIONS

The programs presented in this thesis, Appendix A, were written in the FORTRAN IV language and all computer runs, Table V, processed on the IBM 360/67 computer using the FORTRAN 'G' compiler. It is expected that the FORTRAN 'H' compiler would have supplied results similar to those obtained with the FORTRAN 'G' compiler. This was not done because the FORTRAN 'H' compiler requires 350K bytes as a minimum core requirement. The majority of the runs performed in this thesis required significantly less than 300K storage. Single precision (six to seven significant digits) was used throughout this research. As has been shown [6], double precision solutions are at variance by less than 0.01 percent with single precision solutions.

C. PROBLEM ANALYSIS

The techniques used by Olsen [6], modified as described, and the Implicit Gear method [4] were utilized to solve the problem delineated in Ref. [5]. The problem was approached using finite element discretizations with forty-five, seventy-two and one hundred thirty-two degrees of freedom and providing an initial disturbance. Three initial disturbances were provided as follows: central at the core center (R = 0 cm., Z = 0 cm.); uniform throughout the core; and, a skewed disturbance at the core-reflector interface (R = 60 cm., Z = 0 cm.).

D. PROGRAM USAGE

In order to properly utilize the routines presented in this thesis, several points must be considered.

In the Crank-Nicolson routine, there was difficulty in obtaining a steady state solution. The ultimate cause was the size with which the previous time step increases. This requires a trial and error approach for the particular grid size. For this project, an increase of ten or twenty percent yields satisfactory results; but, anything larger results in a divergent oscillation about the steady state value.

In all three methods, the dimensioning should be set by the particular problem being solved, i.e., determined by the degrees of freedom. If this is done, most efficient use will be made of the computer, and the user will experience better turn around time on the equipment.

In the use of the Implicit Gear method, the data cards for nodal neighbor connectivity must have the contributing nodes listed consecutively, with the zeros, used for nodes not having six neighbors, being last on the cards. For example, in the one hundred thirty-two degrees of freedom system

(Figure 3), the nodal neighbor connectivity for node 122 would be written as

122 123 11 0 0 0 0.

The data deck arrangement for all three methods is given in Table VI.

VIII. CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

It has been shown in this research project that of the three methods investigated in the solution of the test problem that the Implicit Gear performed in a superior manner in CPU time requirements and was comparable to the storage requirements of Crank-Nicolson. In addition, Implicit Gear was the least sensitive to the change in the degrees of freedom.

The method used had no effect on the steady state solution value obtained as all three yielded the same results for the same DOF. In the transient solution, Implicit Gear conformed very closely to DVOGER (Gear). As shown in Figures 10-15, as the DOF increased, the transient solutions moved in the direction of the transient solution of Gear's method.

As the DOF in the discretized finite element was increased, a better solution was obtained. This, however, was counteracted by the fact that for the small increase in accuracy obtained by the finer mesh, the time and storage need of the computer increased significantly.

A very important result of this project was the effect of varying the error requirements of the problem. This yielded essentially no change in the accuracy of the transient solution for a range of 10^{-1} to 10^{-4} and no variance in the steady state solution for a range from 1.0 to 10^{-4}. In using these methods of integration, the error criterion selected would be a function of the solution desired. If the user is only concerned with the steady state solution, the tolerance could be relaxed to 1.0. However, if the transient solution is needed, an error of 10^{-1} appears to be the least rigid value which will still provide a satisfactory track to steady state.

B. RECOMMENDATIONS

It would be of value to investigate further the Implicit Gear method through the use of other problems solving a non-linear system of ordinary differential equations. In addition, larger degrees of freedom should be attempted to evaluate any limitations that may exist in this method of integration.

TABLE I

COMPARISON OF SOLUTION METHODS

METHOD	CORE (K)	PROCESSING TIME* (min.) Central	Skewed	Uniform
		45 Nodes		
CRANKO	158	1.67	1.73	3.57
DVOGER (GEAR)	148	17.8	19.5	12.5
IMPLICIT GEAR	124	1.05	1.00	1.20
		72 Nodes		
CRANKO	184	3.07	5.49	2.38
DVOGER (GEAR)	244	89.5	114.1	59.5
IMPLICIT GEAR	124	1.3	1.30	1.25
		132 Nodes		
CRANKO	252	9.1	9.1	9.1
DVOGER (GEAR)	610	>400	>400	>400
IMPLICIT GEAR	124	1.9	2.0	2.0

* Processing time is that required to reach a steady state solution.

TABLE II

EFFECTS OF SOLUTION ERROR CRITERION

45 Nodes

SOLUTION ERROR CRITERION	PROCESSING TIME (min.)	TIME AT SOLUTION (sec.)
	CRANK-NICOLSON	
0.1	1.8	3.69×10^{-5}
0.01	5.5	3.70×10^{-5}
0.001	14.2	3.57×10^{-5}
0.0001	0.83	3.87×10^{-5}
	IMPLICIT GEAR	
1.0	0.99	7.56×10^{-4}
0.5	0.92	1.48×10^{-2}
0.1	1.05	7.06×10^{-5}
0.01	1.20	7.64×10^{-5}
0.001	1.45	6.36×10^{-5}
0.0001	1.58	6.44×10^{-5}
	DVOGER (GEAR)	
0.1	18.6	5.64×10^{-5}
0.01	29.5	5.79×10^{-5}
0.001	78.8	5.55×10^{-5}
0.0001	>300	—

TABLE III

EFFECTS OF VARYING THE INCREASE OF THE INITIAL TIME STEP IN CRANK-NICOLSON METHOD

INCREASE	CORE	PROCESSING TIME (min.)	SOLUTION TIME (sec.)
		45 NODES	
1.1	158K	4.99	3.18×10^{-5}
1.2	158K	1.65	2.69×10^{-5}
1.5	184K	7.42	OSCILLATING
		72 NODES	
1.1	252K	3.5	4.38×10^{-5}
1.2	184K	3.05	3.23×10^{-5}
1.3	252K	3.5	OSCILLATING
1.4	252K	9.1	OSCILLATING
1.5	184K	6.1	OSCILLATING
		132 NODES	
1.1	252K	9.1	5.58×10^{-5}
1.2	252K	8.4	8.03×10^{-5}
1.5	184K	2.6	OSCILLATING

TABLE IV

PHYSICAL CONSTANTS

SYMBOL	COMPUTER SYMBOL	DEFINITION	VALUE
	C-N, D / IG		
R	R	Total radius	90 cm.
R_c	R	Core radius	60 cm.
H_c	Z	Core height	160 cm.
H	Z	Total height	220 cm.
v	V/VELOCT	Neutron velocity	4.8×10^7 cm/sec
D_c	D/DSUBF	Neutron diffusion coefficient (core)	0.913 cm.
D_r	D/DSUBC	Neutron diffusion coefficient (reflector)	1.20 cm.
Σ_{ac}	SGA/SGMAAF	Neutron absorption cross-section (core)	0.01401 cm^{-1}
Σ_{ar}	SGA/SGMAAC	Neutron absorption cross-section (reflector)	0.008 cm^{-1}
ν	ZNU	Number of neutrons per fission	2.54
Σ_{fc}	SGF/SGMAF	Neutron fission cross-section (core)	0.008 cm^{-1}
Σ_{fr}	SGF/ -	Neutron fission cross-section	0.0 cm^{-1}
ε	FISFAC	Fission energy	7.652×10^{-12} cal/fis
$\bar{h}A/V$	HBAR	Modified convection heat transfer coefficient	0.0632 cal/cm^3-sec-°C
α	ALPHA	Reactivity temperature coefficient	1×10^{-5} / °C

TABLE V

LIST OF COMPUTER RUNS

RUN	METHOD	NODES	DISTURBANCE	COVERGENCE	TIME STEP CHANGE
1	CRANK-NICOLSON	45	CENTRAL	0.1	1.1
2					1.2
3					1.5
4				0.01	1.2
5				0.001	
6				0.0001	
7			UNIFORM	0.1	
8			SKEWED		
9		72	CENTRAL	0.1	1.0
10					1.1
11					1.2
12					1.3
13					1.4
14					1.5
15			UNIFORM		1.2
16			SKEWED		
17		132	CENTRAL	0.1	1.1
18					1.2
19					1.5
20			UNIFORM		1.2
21			SKEWED		
22	DVOGER MTH=0	45	CENTRAL	0.1	N.A.
23	DVOGER MTH=1 YMAX=1			0.1	

TABLE V (Continued)

RUN	METHOD	NODES	DISTURBANCE	CONVERGENCE	TIME STEP CHANGE
24				0.01	
25				0.001	
26	DVOGER MTH=1 YMAX=1	45	CENTRAL	0.0001	
27			UNIFORM	0.1	
28			SKEWED		
29		72	CENTRAL		
30			UNIFORM		
31			SKEWED		
32		132	CENTRAL		
33			UNIFORM		
34			SKEWED		
35	IMPLICIT GEAR	45	CENTRAL	0.1	
36				0.01	
37				0.001	
38				0.0001	
39			UNIFORM	0.1	
40			SKEWED		
41		72	CENTRAL	0.1	
42			UNIFORM		
43			SKEWED		
44		132	CENTRAL	0.1	
45			UNIFORM		
46			SKEWED		
47		45	CENTRAL	0.5	

TABLE V (Continued)

RUN	METHOD	NODES	DISTURBANCE	CONVERGENCE	TIME STEP CHANGE
48				1.0	
49	DVOGER MTH=1 YMAX=10^{14}	45	CENTRAL	0.1	

TABLE VI

DATA DECK ARRANGEMENT

CRANK-NICOLSON

Title

NUMEL,NUPBP,NUMSNP,NFULEL

List of outer boundary points

MTH,MAXDER,NCOUNT

ZNU,FISFAC,HBAR,EPSVAL,ERRVAL,AFUEL

TO,H,TF,HMIN,HMAX

V - neutron velocity

D - diffusion length

SGA - absorption cross-section

SGF - fission cross-section

ALPHA - reactivity temperature coefficient

PSIIV - initial disturbance flux

System nodal points with axial and radial position

Element nodal connectivity

Nodal neighbor connectivity

DVOGER

Title

NUMEL,NUPBP,NUMSNP,NFULEL

List of outer boundary points

MTH,MAXDER,NCOUNT

ZNU,FISFAC,HBAR,EPSVAL,ERRVAL,AFUEL

TO,H,TF,HMIN,HMAX

V

TABLE VI (Continued)

D

SGA

SGF

ALPHA

PSIIV

System nodal points with radial and axial position

Element nodal connectivity

IMPLICIT GEAR

NCORE] with uniform initial disturbance

List of core elements]

Title

NUMEL,NBP,NUMSNP,NFULEL,NELROW,MXEVAL,NCOUNT,NCMPK

NDE,NL

List of outer boundary points

VELOCT,DSUBF,DSUBC,SGMAAF,SGMAAC,SGMAF,FISFAC,HBAR

ZNU,ALPHA,RMSEPS,AFUEL,TSTART,TEND,PINITV,SCALE

HMIN,HMAX

MTH,MAXDER,NPROB,NTYPE,JPLOT,NPLOT,IRUN

Nodal neighbor connectivity

System nodal points with radial and axial position

Element nodal connectivity

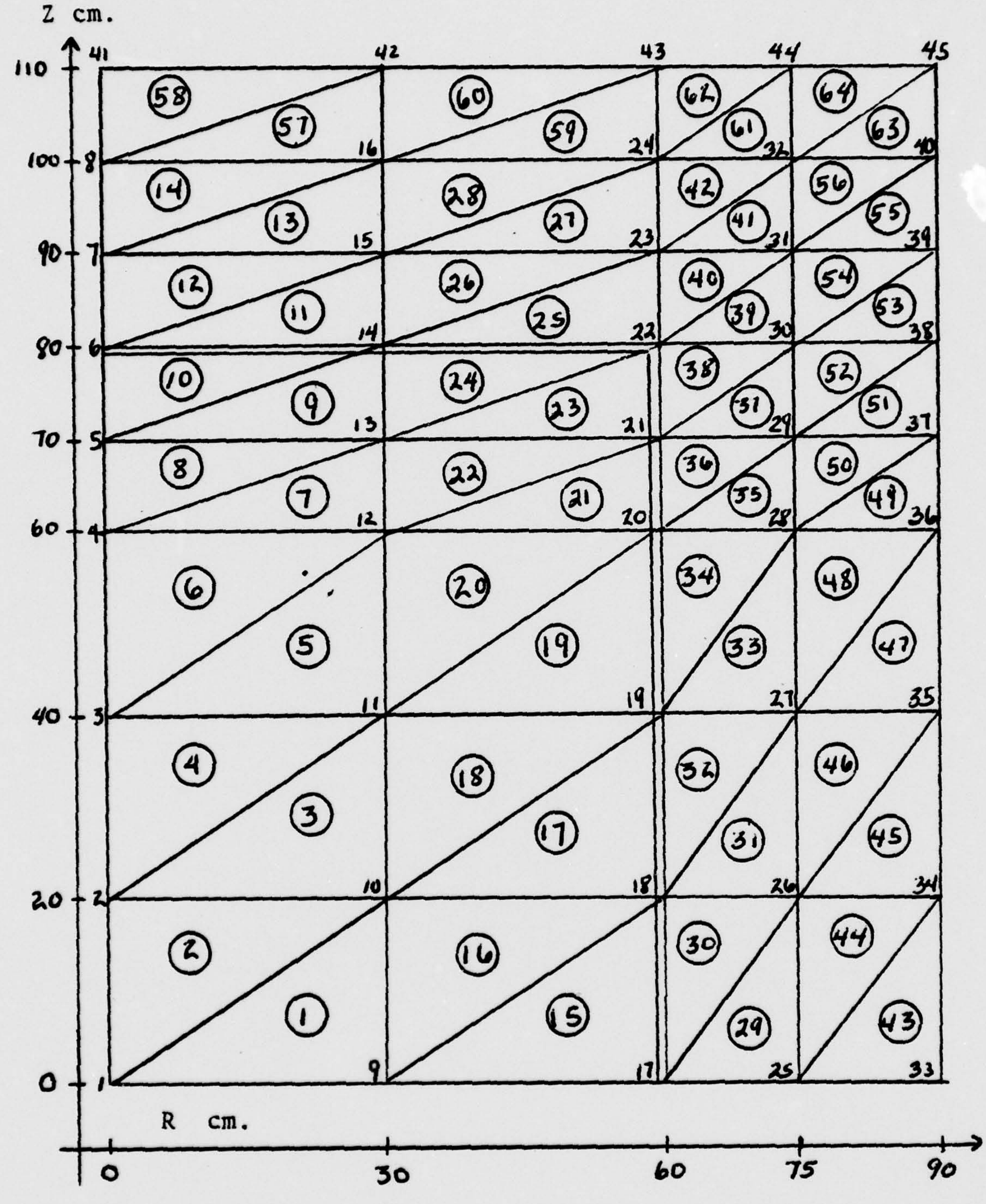

Figure 1. Reactor Model with 45 Nodes

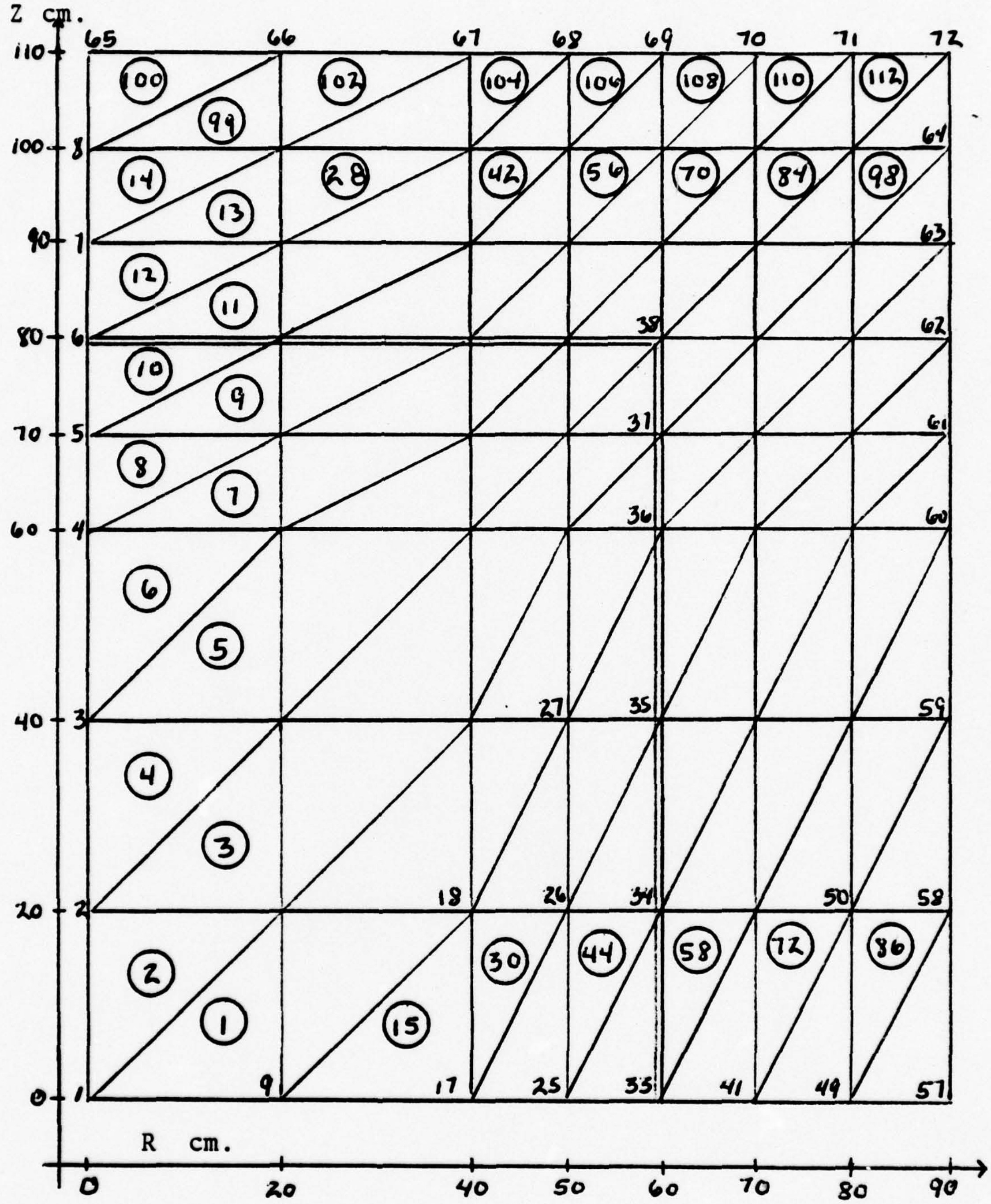

Figure 2. Reactor Model with 72 Nodes

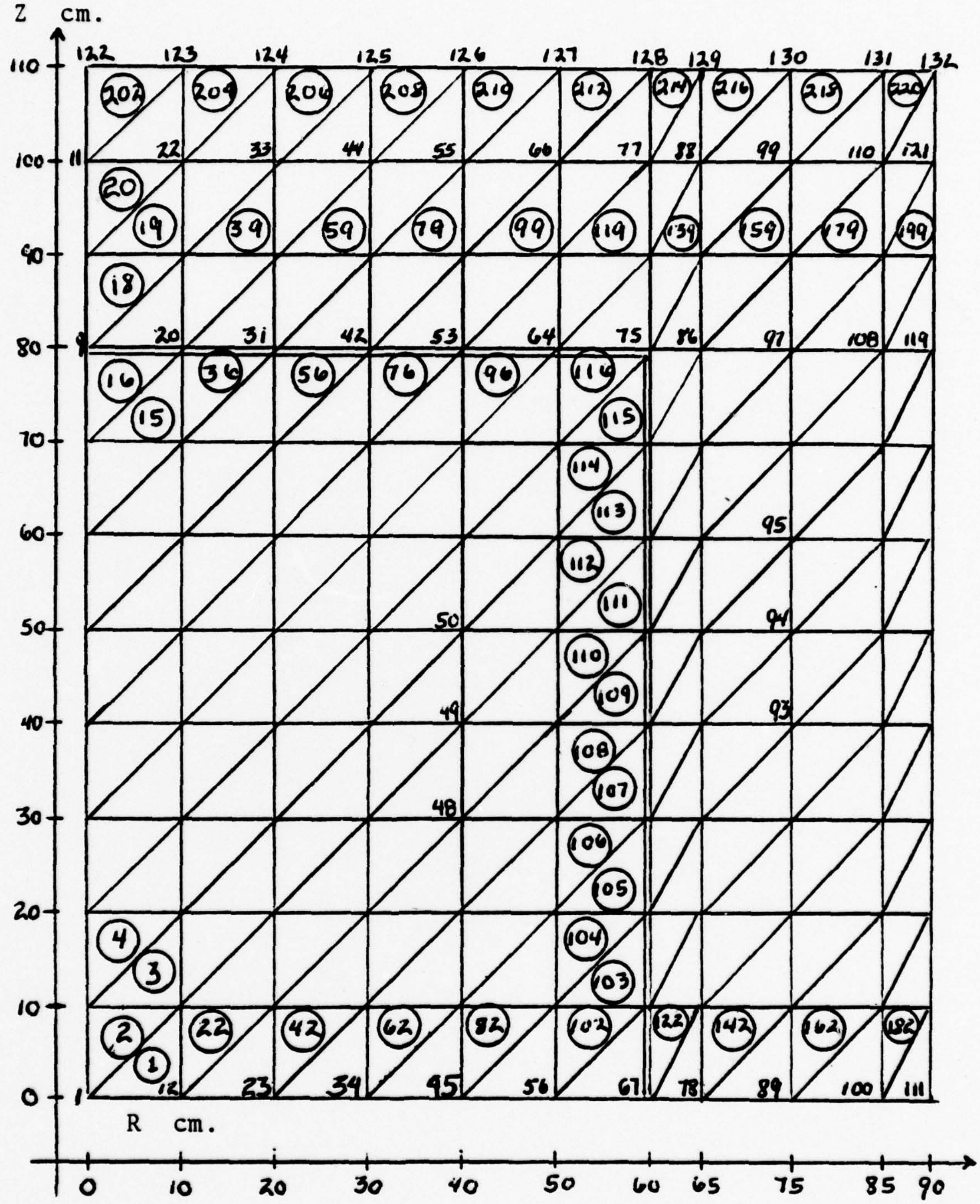

Figure 3. Reactor Model with 132 Nodes

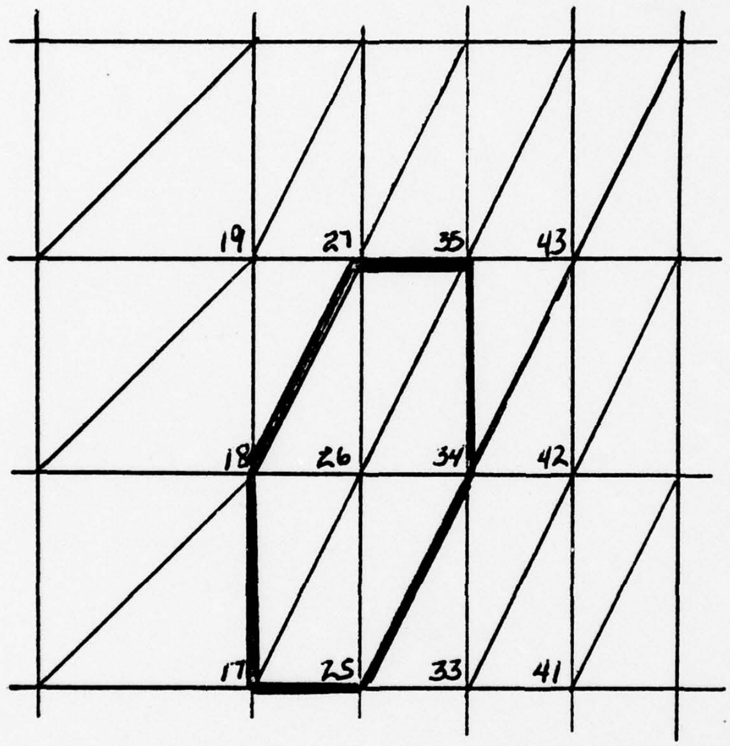

Figure 4. Nodal Neighbor Connectivity

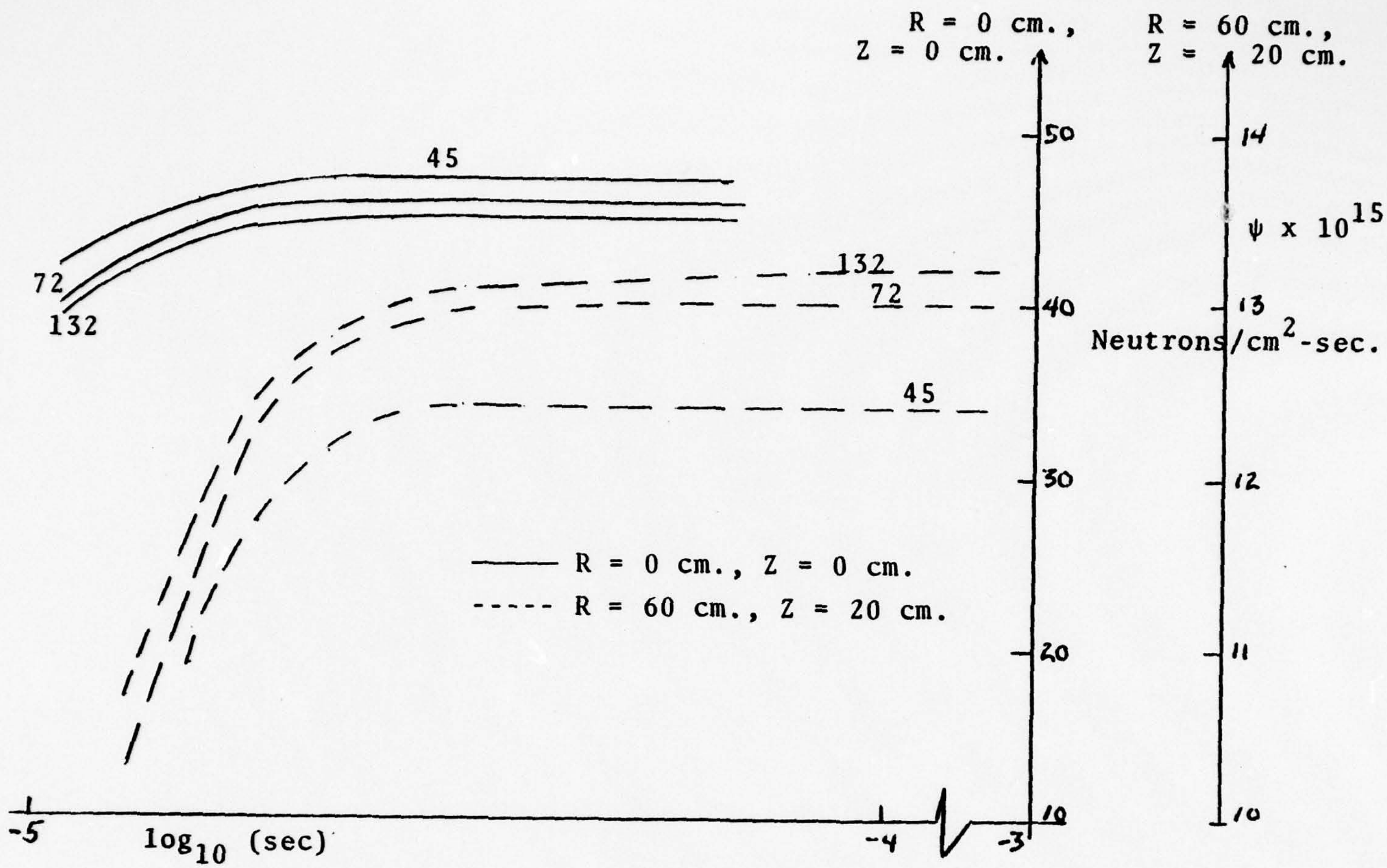

Figure 5. Time Dependent Neutron Flux for All DOF Using Crank-Nicolson Method for a Uniform Disturbance Throughout the Core.

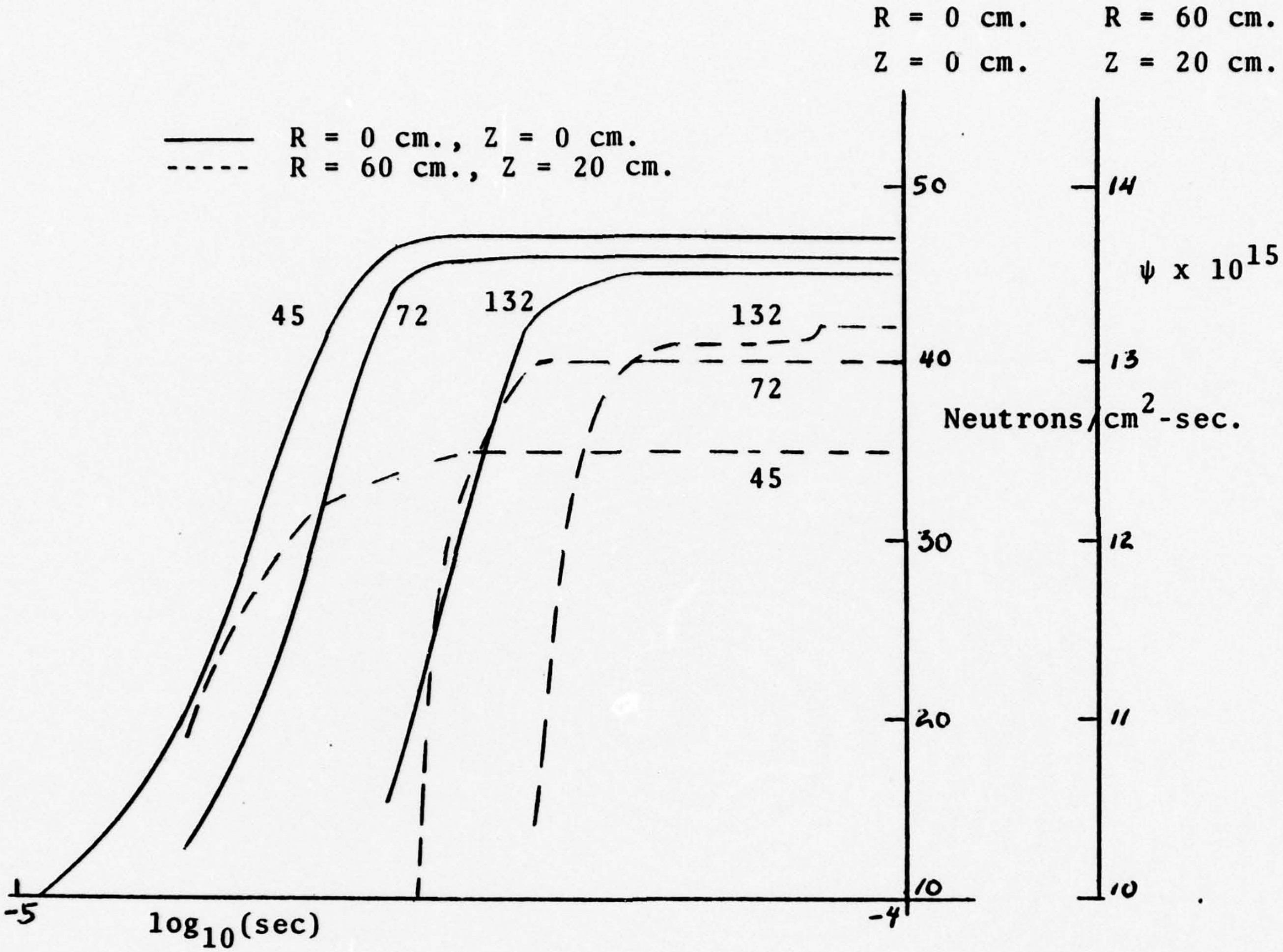

Figure 6. Time Dependent Neutron Flux for All DOF Using Crank-Nicolson Method for a Central Disturbance (R = 0 cm., Z = 0 cm.)

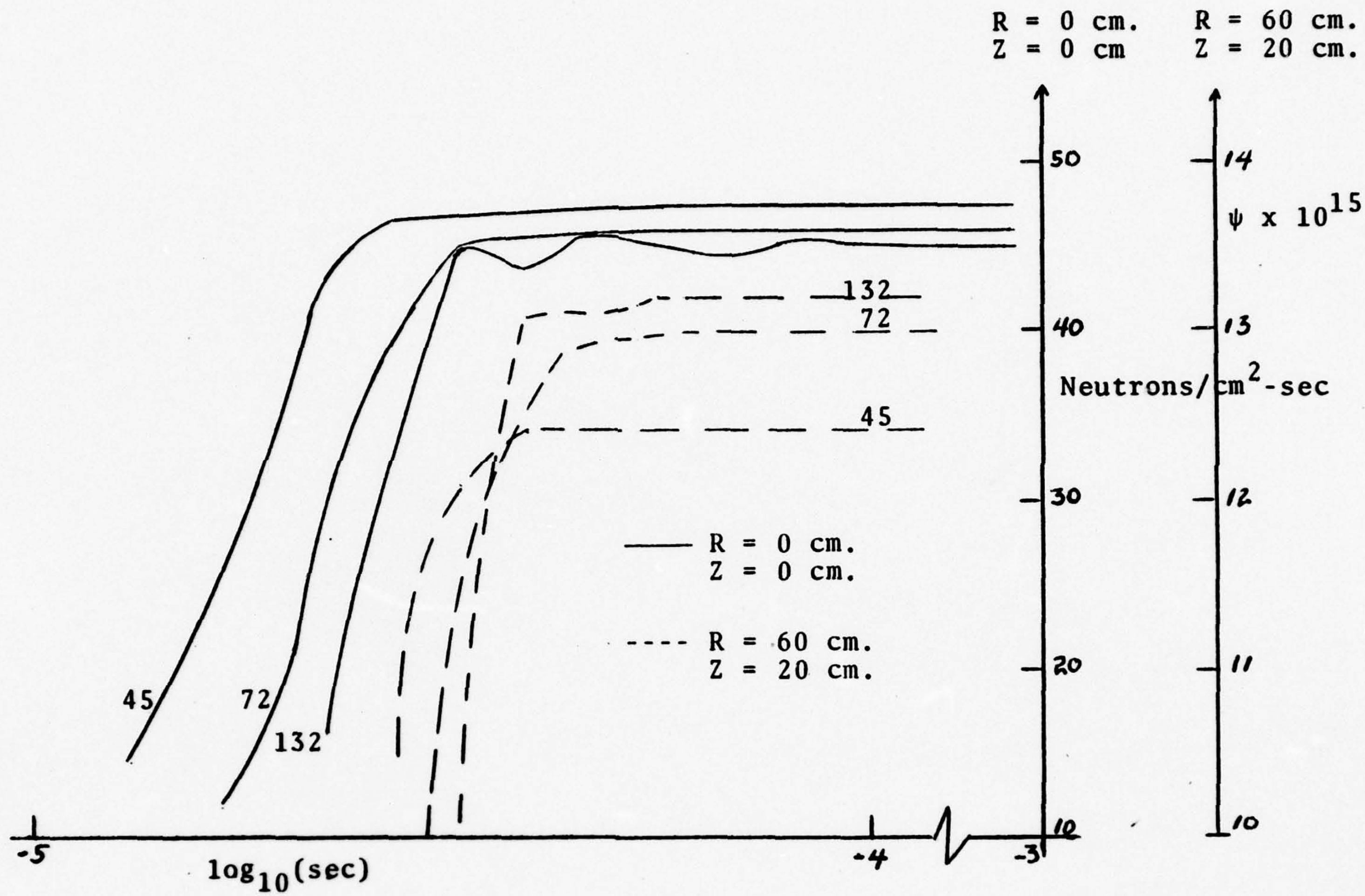

Figure 7. Time Dependent Neutron Flux for All DOF Using Crank-Nicolson Method for a Skewed Disturbance (R = 60 cm., Z = 0 cm.)

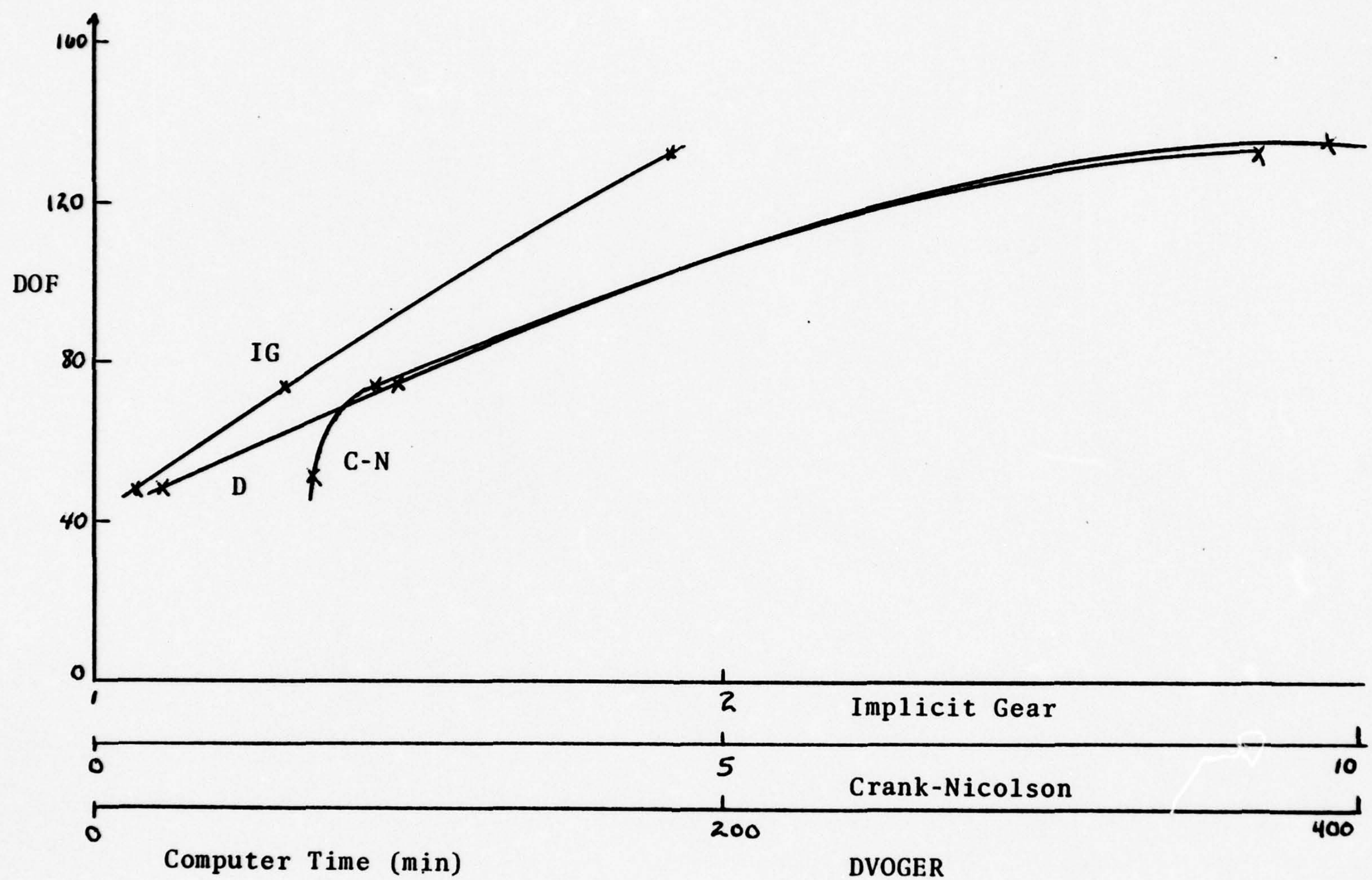

Figure 8. Plot Comparing Degrees of Freedom to Computer Processing Time

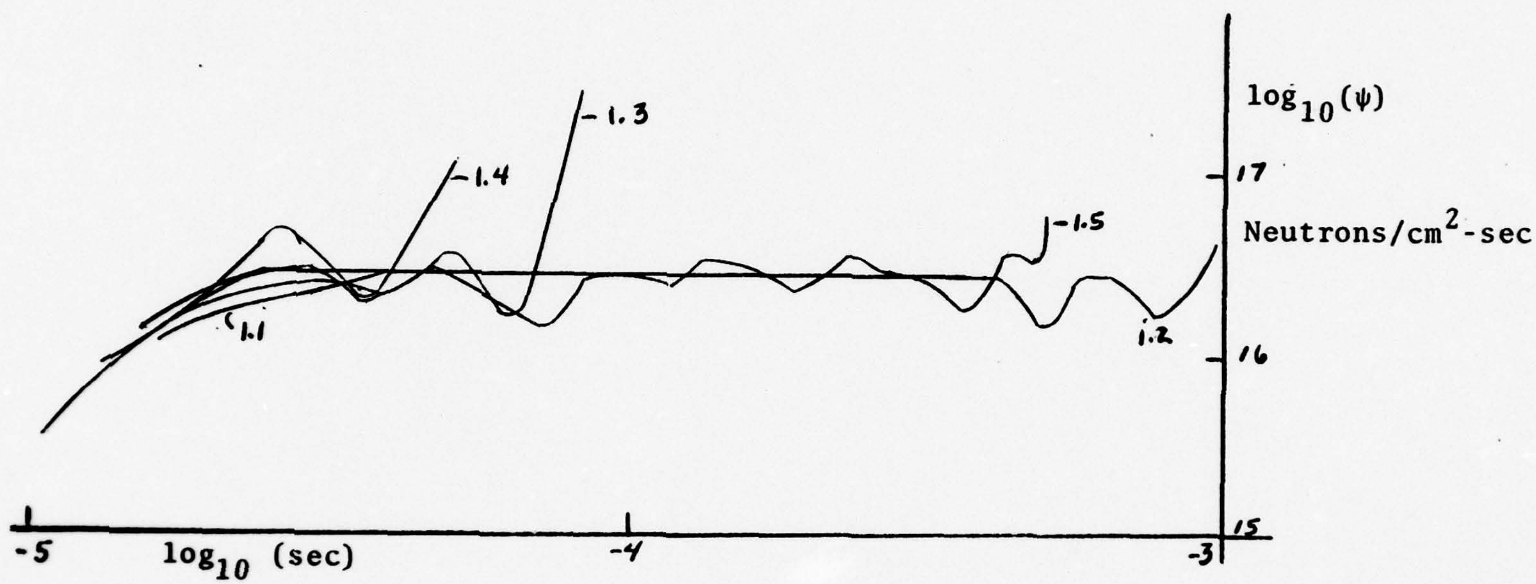

Figure 9. Effect of Time Step Change in Crank-Nicolson on Achieving Steady State.

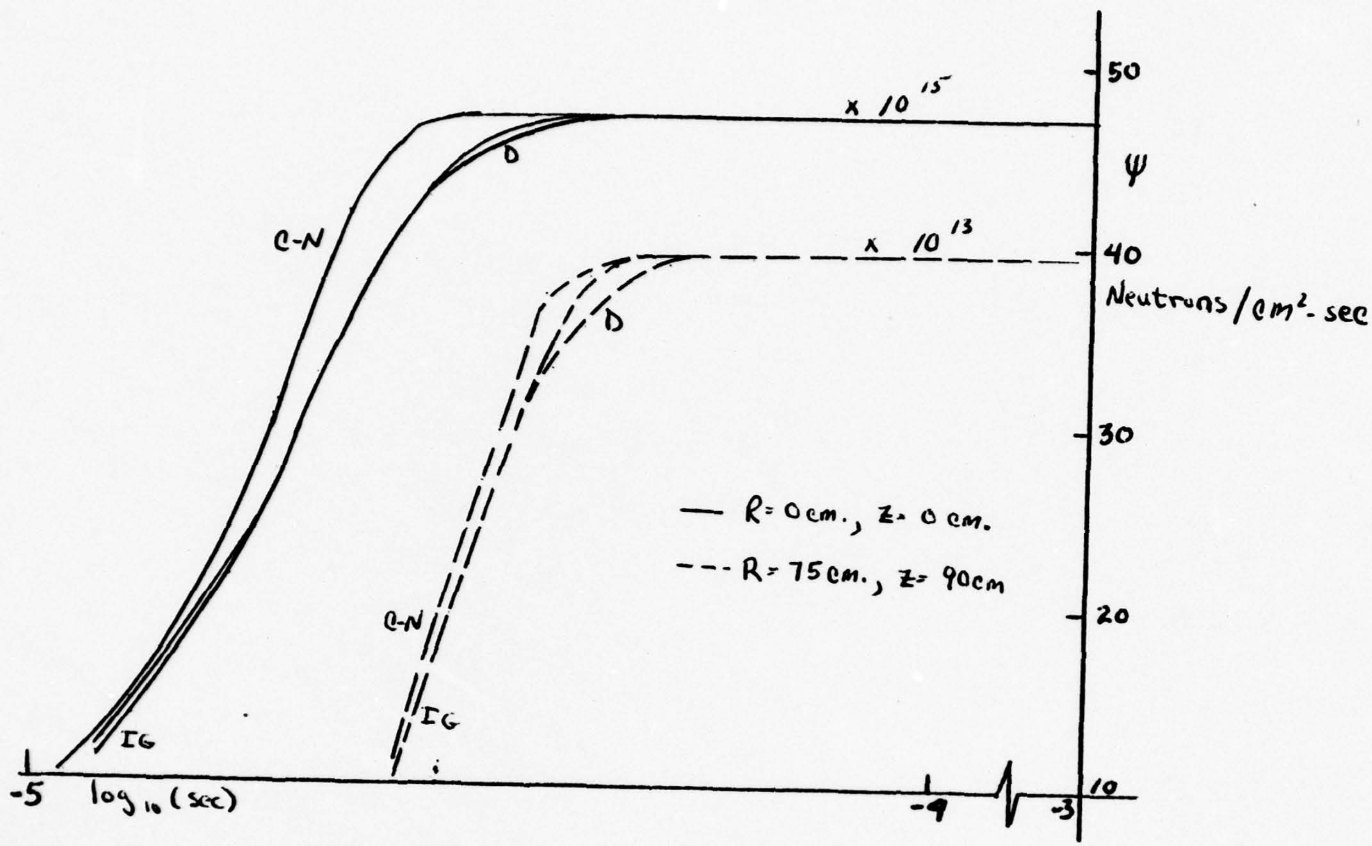

Figure 10. Time Dependent Neutron Flux for All Methods with 45 DOF for a Central Disturbance (R = 0 cm., Z = 0 cm.).

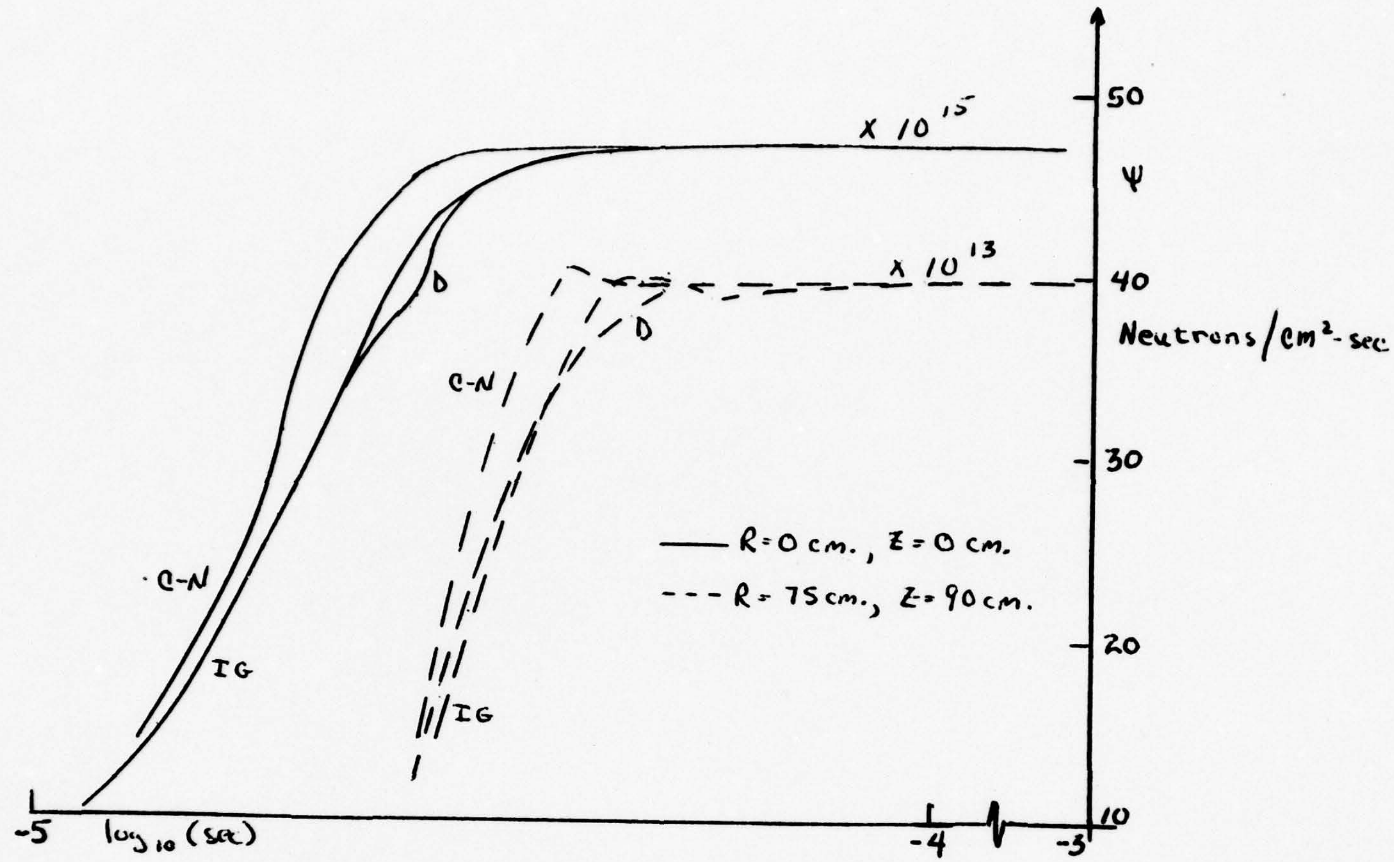

Figure 11. Time Dependent Neutron Flux for All Methods with 45 DOF for a Skewed Disturbance (R = 60 cm., Z = 0 cm.).

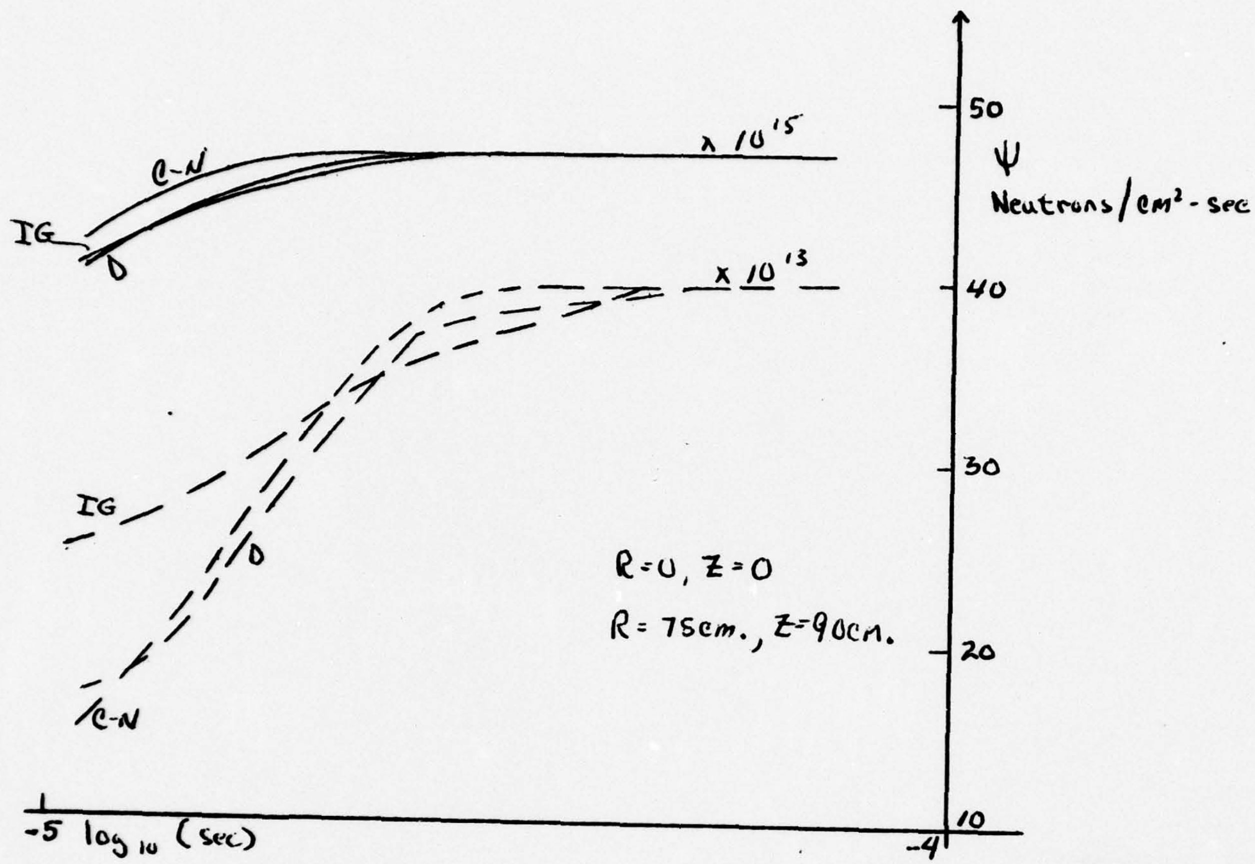

Figure 12. Time Dependent Neutron Flux for All Methods with 45 DOF for a Uniform Disturbance Throughout Core.

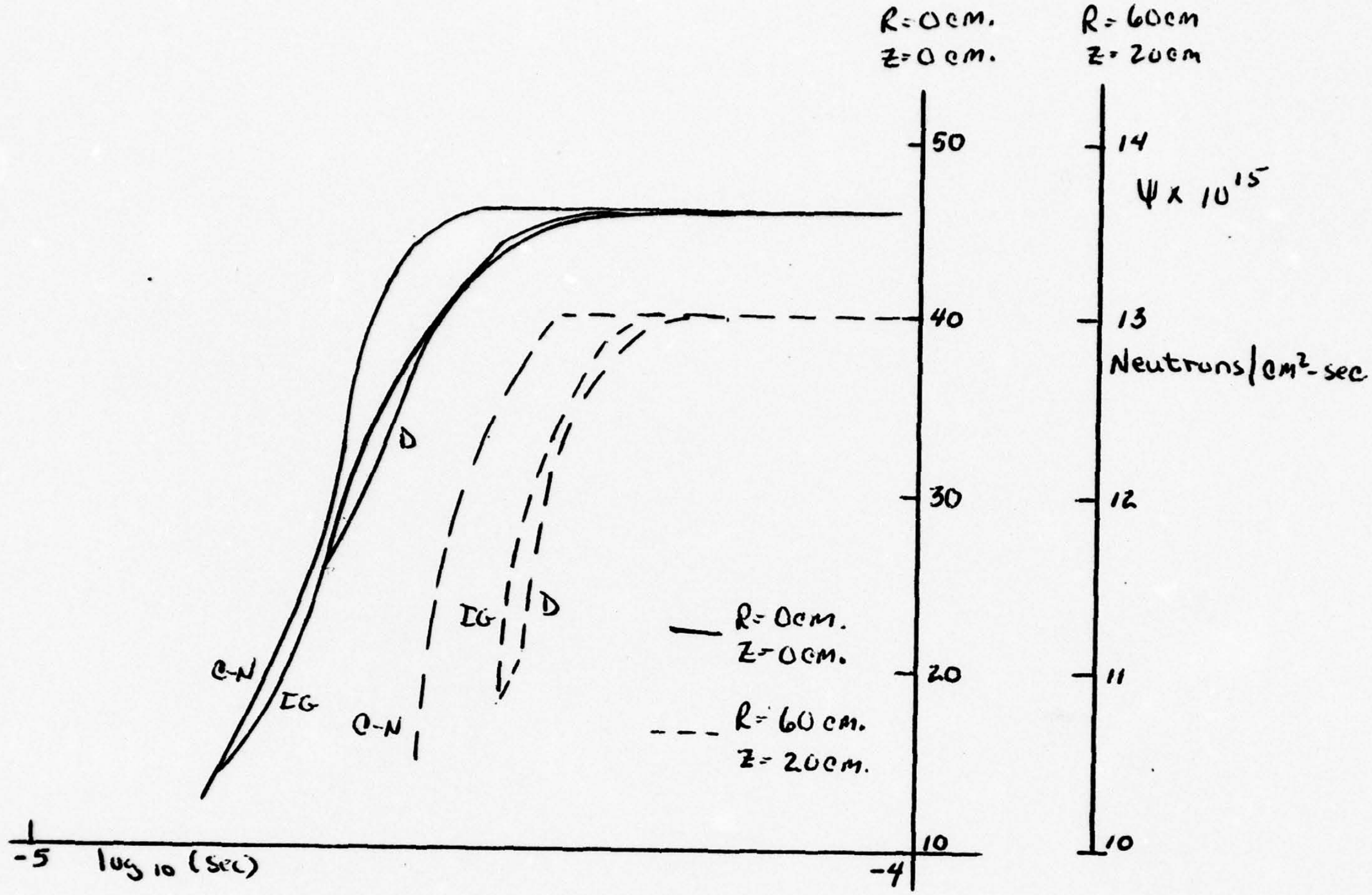

Figure 13. Time Dependent Neutron Flux for All Methods with 72 DOF for a Central Disturbance (R = 0 cm., Z = 0 cm.).

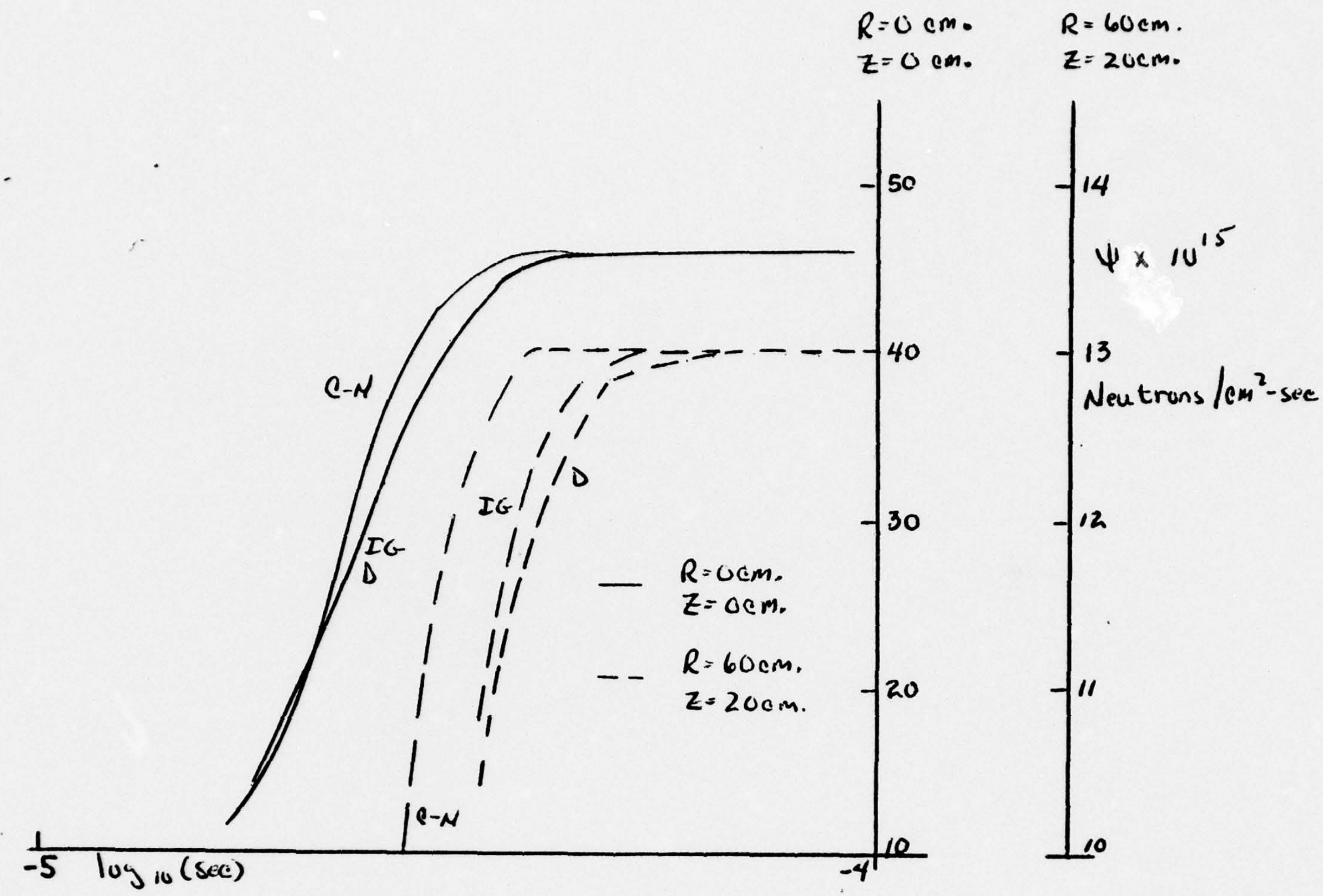

Figure 14. Time Dependent Neutron Flux for All Methods with 72 DOF for a Skewed Disturbance (R = 60 cm., Z = 0 cm.).

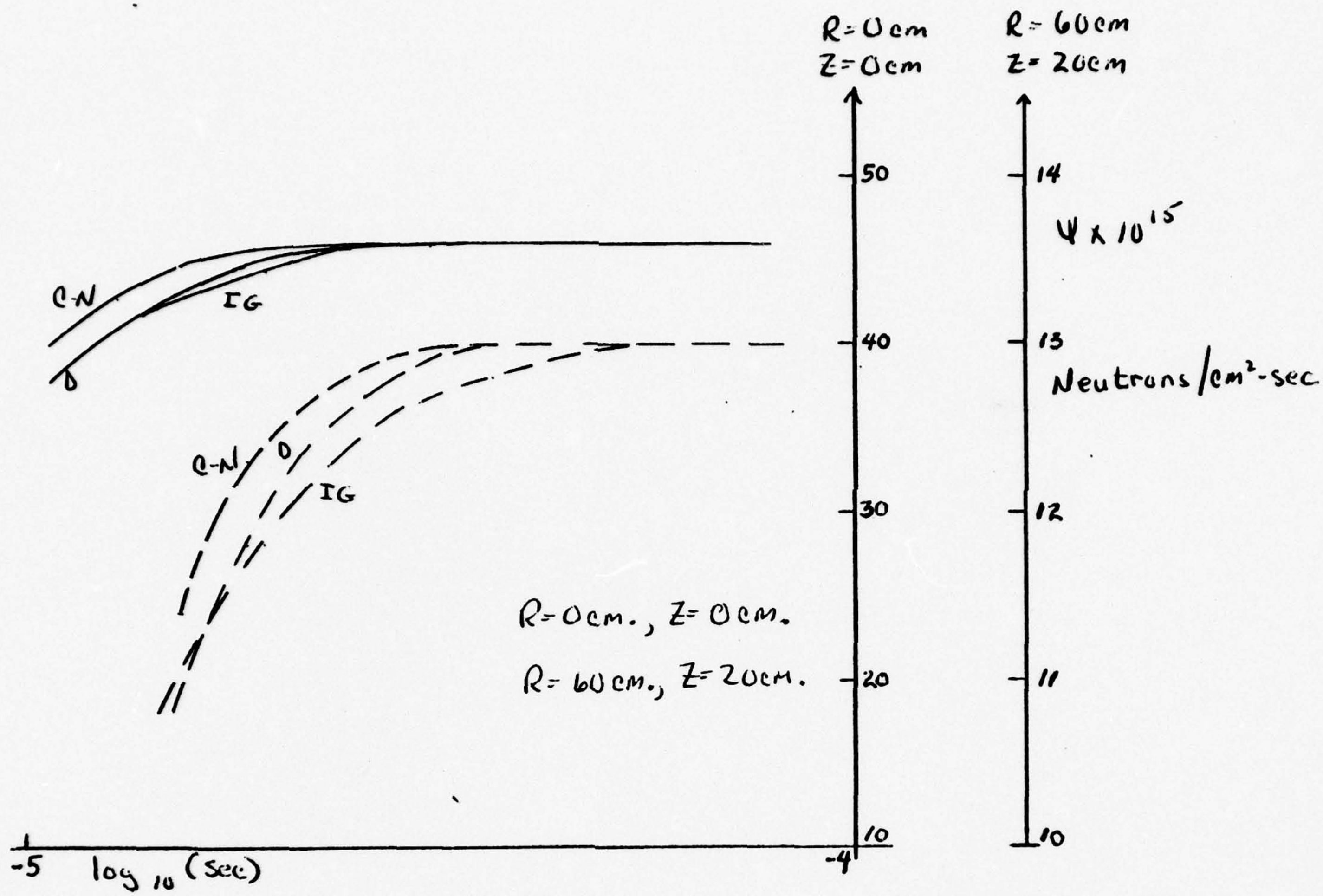

Figure 15. Time Dependent Neutron Flux for All Methods with 72 DOF for a Uniform Disturbance Throughout Core.

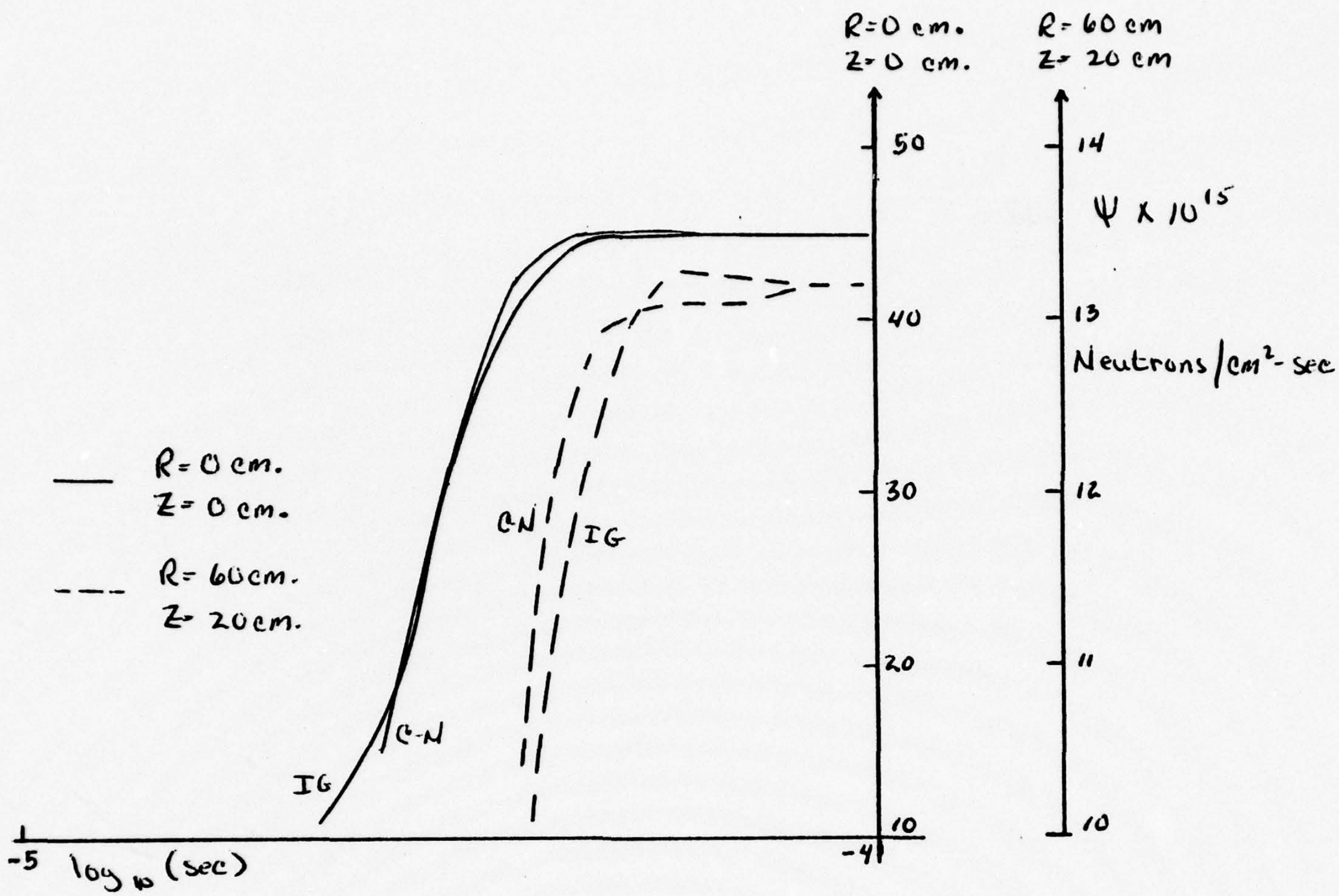

Figure 16. Time Dependent Neutron Flux for Crank-Nicolson and Implicit Gear Methods with 132 DOF for Central Disturbance (R = 0 cm., Z = 0 cm.)

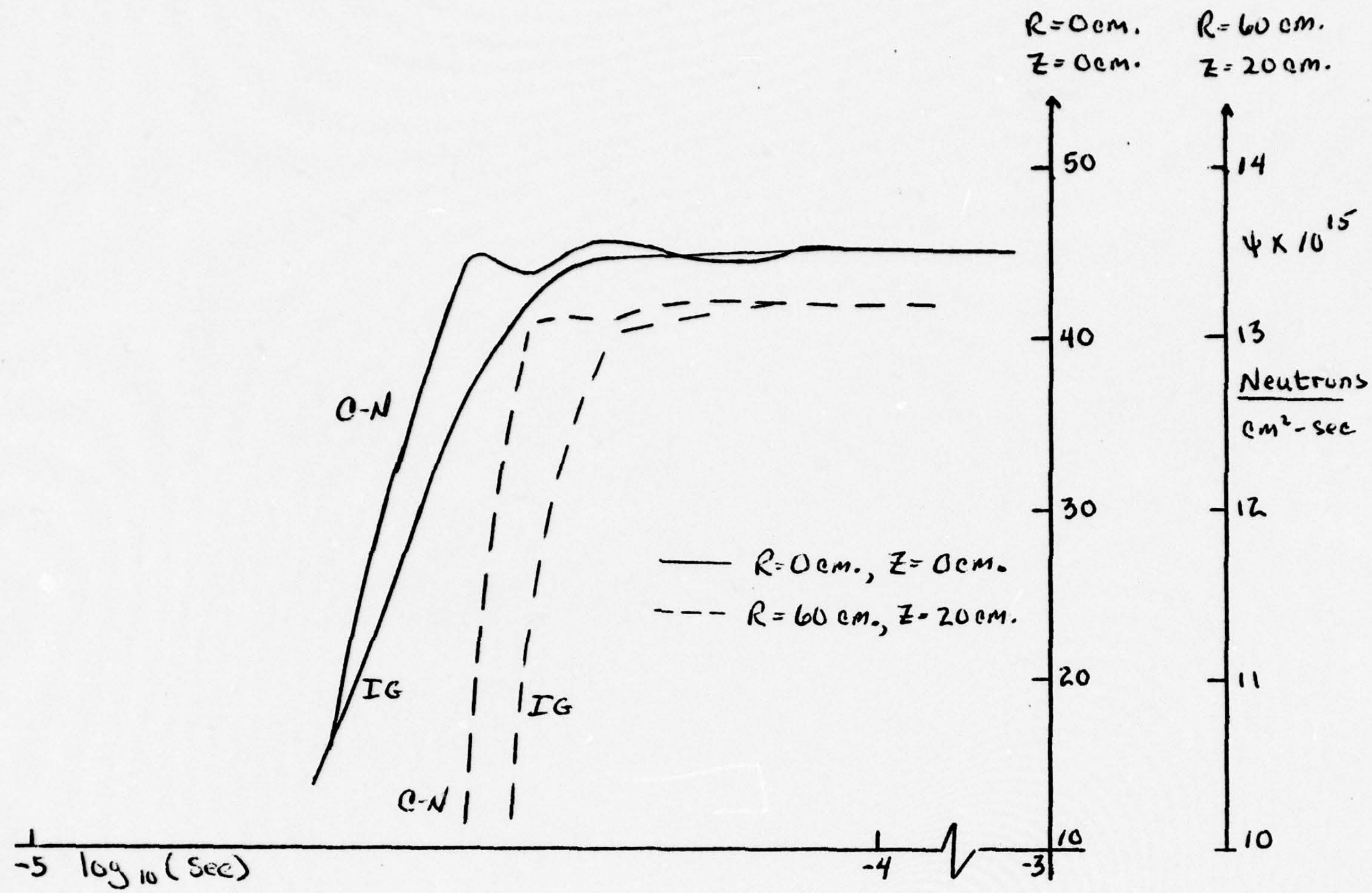

Figure 17. Time Dependent Neutron Flux for Crank-Nicolson and Implicit Gear Methods with 132 DOF for Skewed Disturbance (R = 60 cm., Z = 0 cm.)

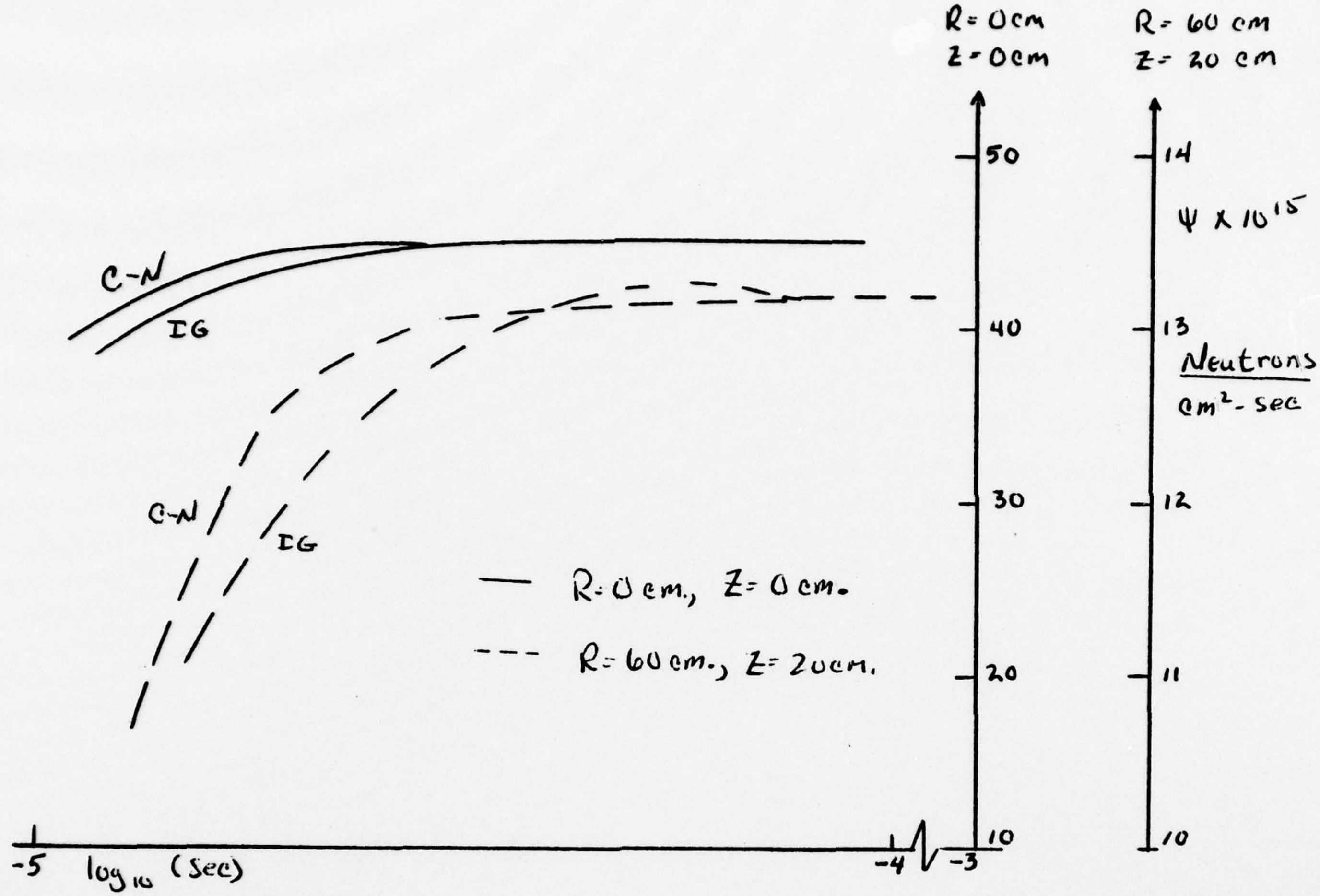

Figure 18. Time Dependent Neutron Flux for Crank-Nicolson and Implicit Gear Methods with 132 DOF for a Uniform Disturbance Throughout the Core.

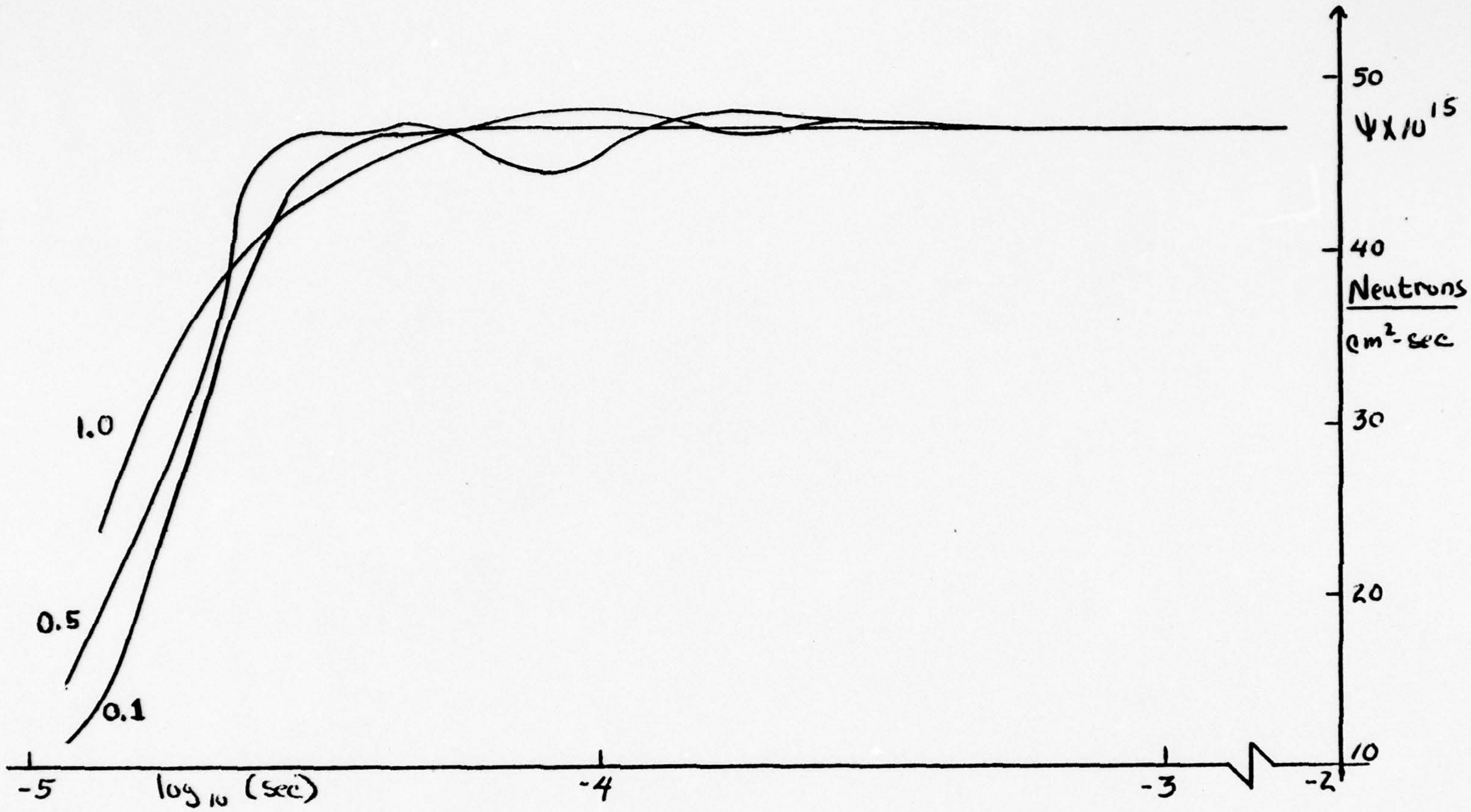

Figure 19. Comparison of Error Criterion for Implicit Gear Method.

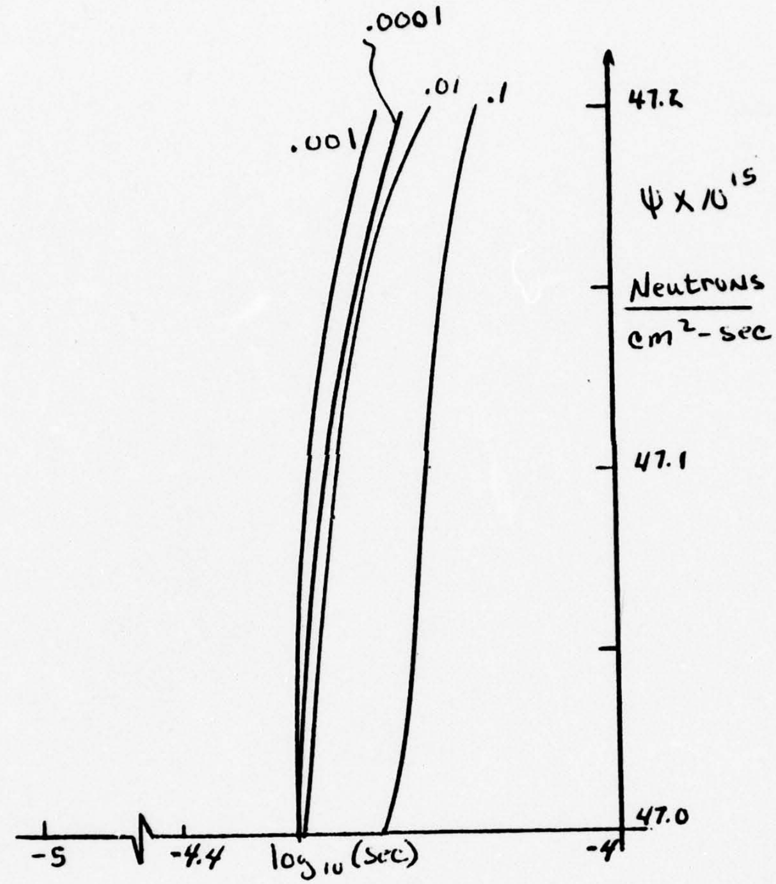

Figure 20. Typical Approach to Steady State Solution Value with Various Error Criterion (Implicit Gear).

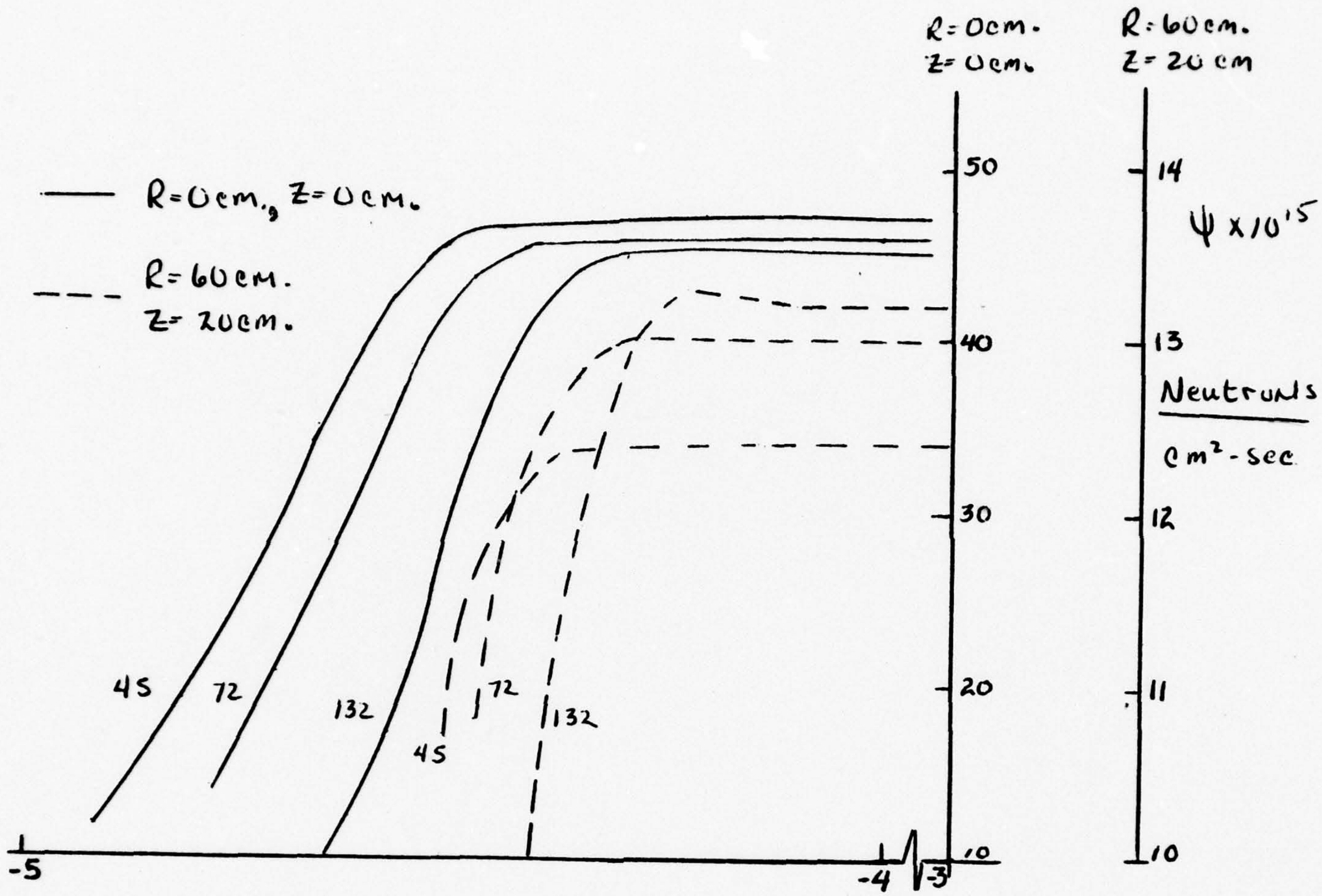

Figure 21. Time Dependent Neutron Flux for All DOF Using Implicit Gear Method for a Central Disturbance (R - 0 cm., Z = 0 cm.)

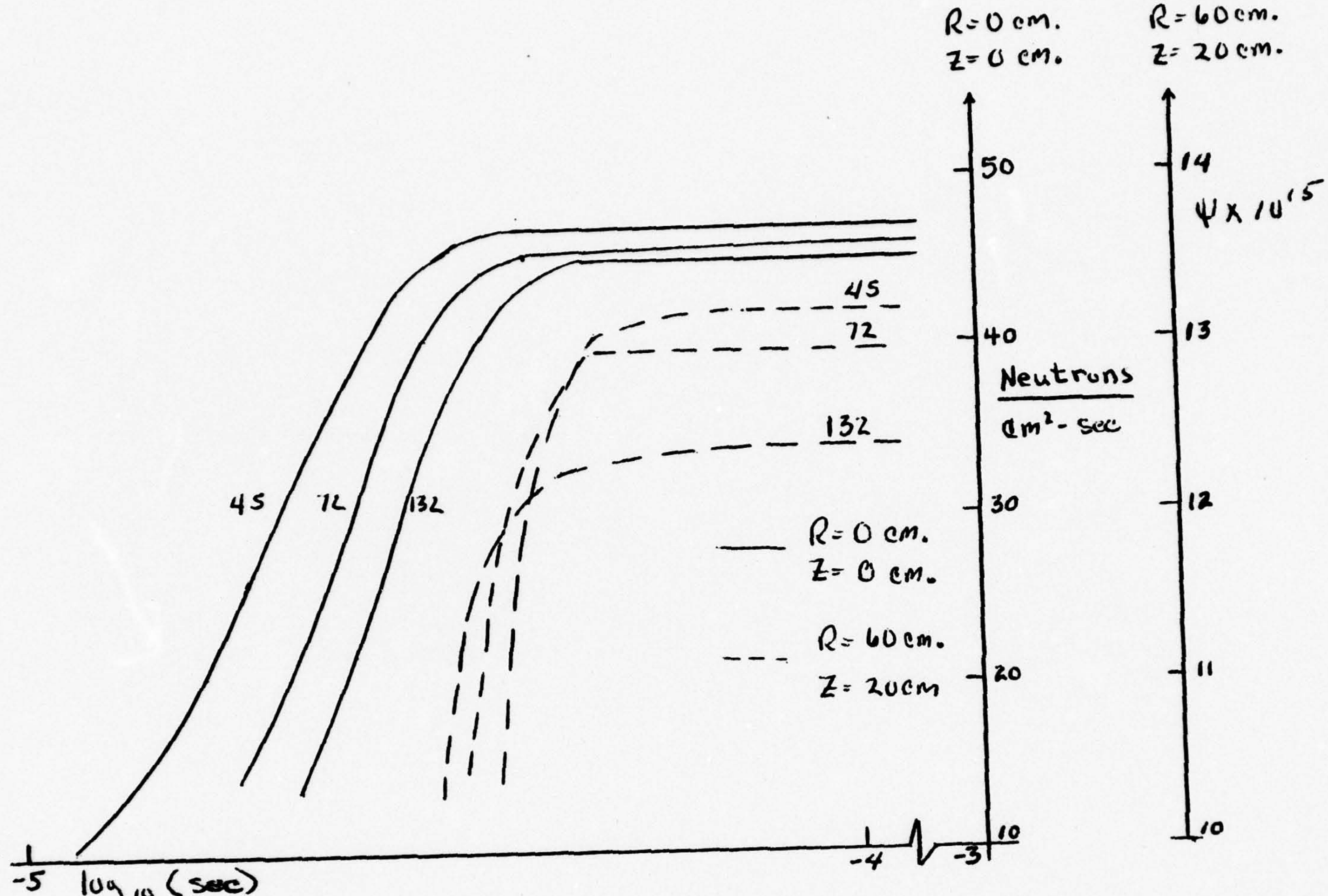

Figure 22. Time Dependent Neutron Flux for All DOF Using Implicit Gear Method for a Skewed Disturbance (R = 60 cm., Z = 0 cm.).

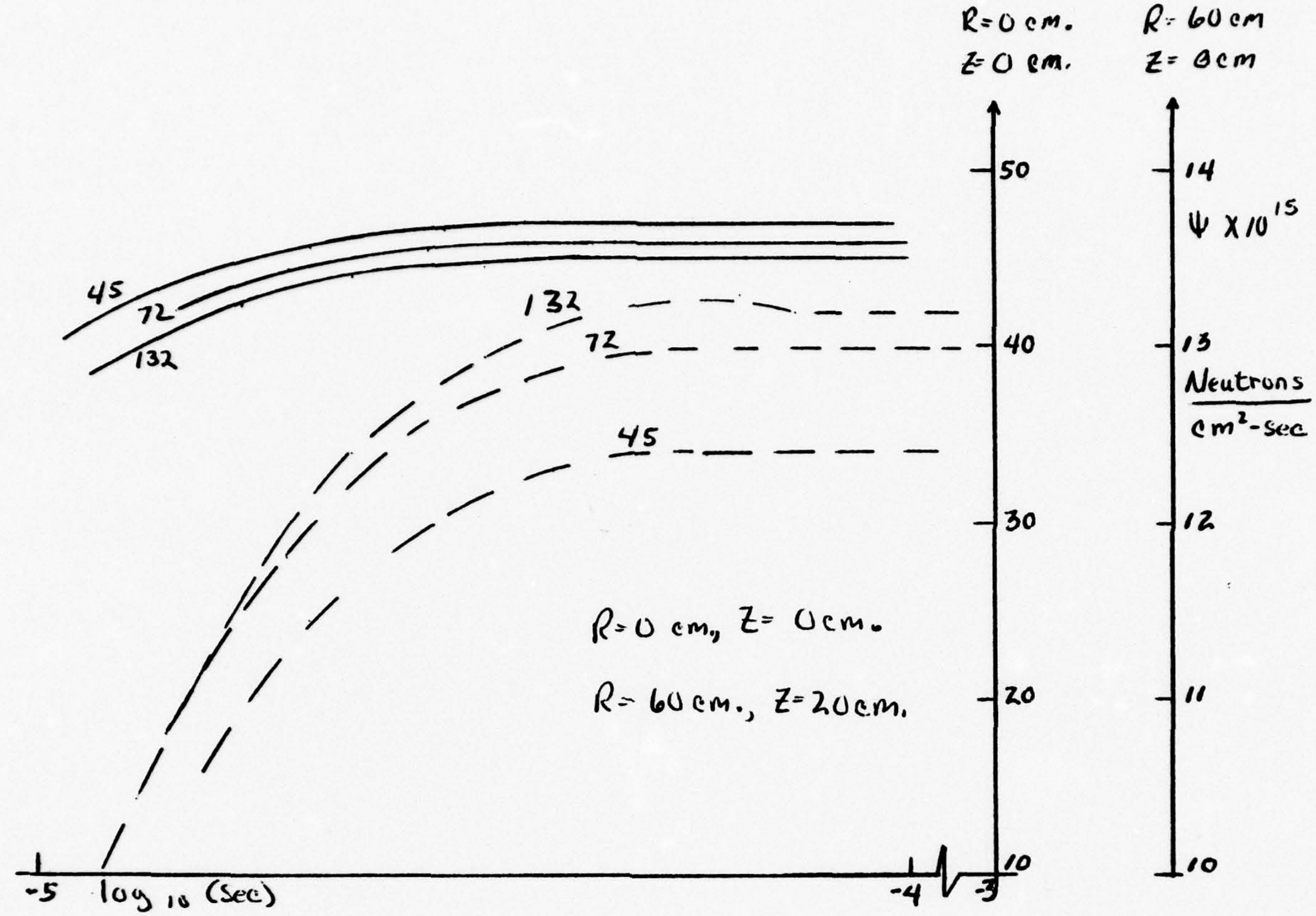

Figure 23. Time Dependent Neutron Flux for All DOF Using Implicit Gear Method for a Uniform Disturbance Throughout the Core.

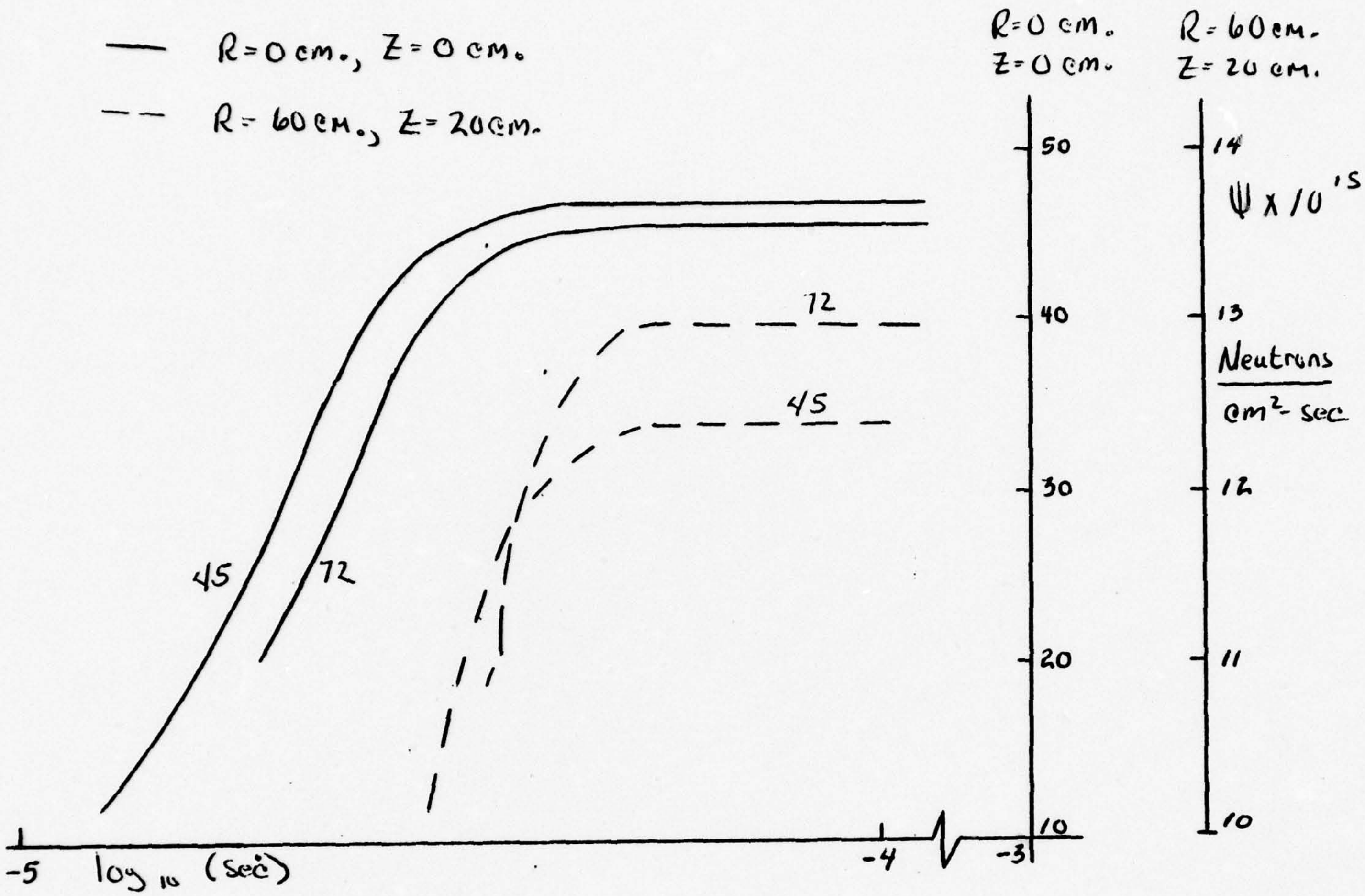

Figure 24. Time Dependent Neutron Flux for 45 and 72 DOF Using the DVOGER (Gear) Method for a Central Disturbance (R = 0 cm., Z = 0 cm.).

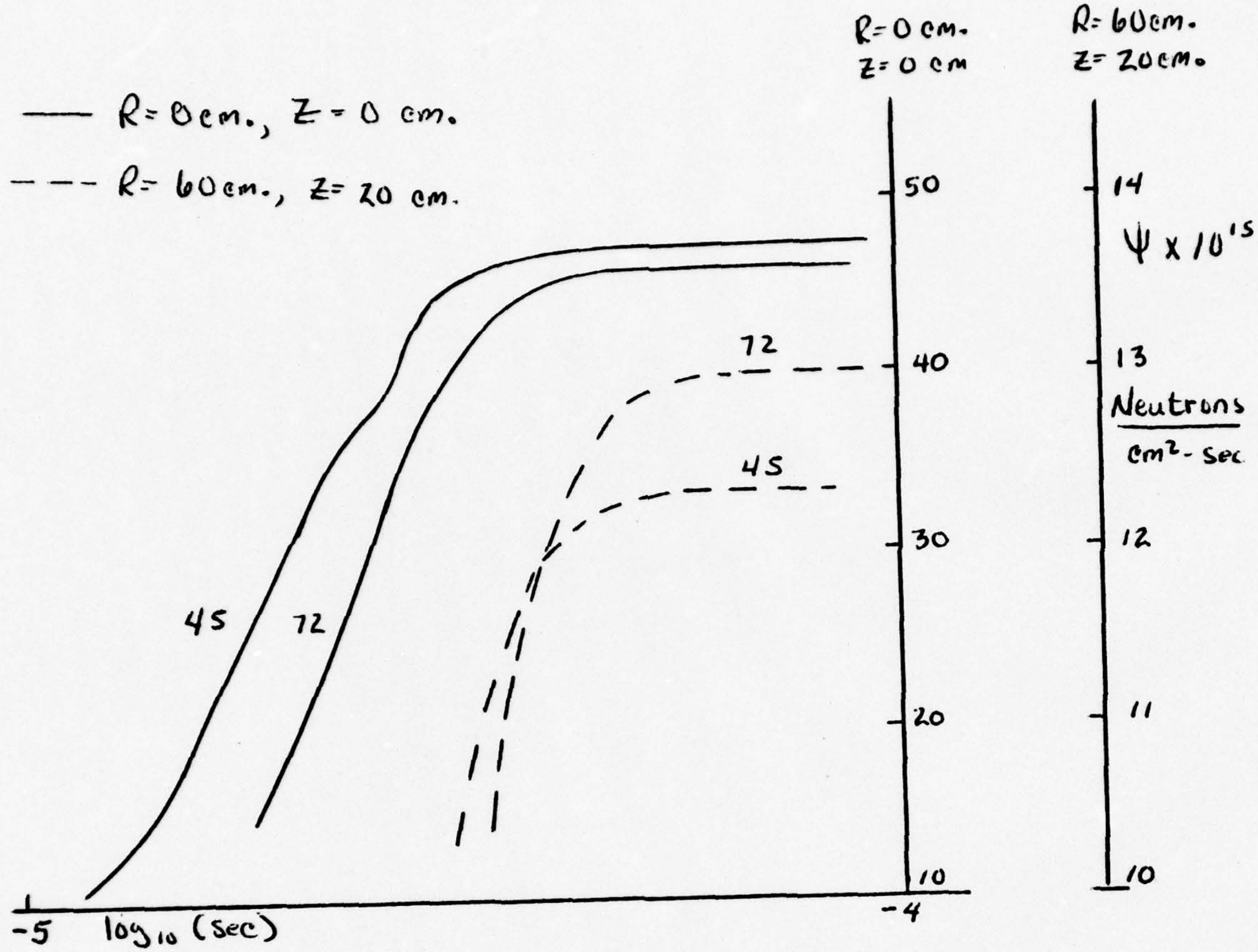

Figure 25. Time Dependent Neutron Flux for 45 and 72 DOF Using the DVOGER (Gear) Method for a Skewed Disturbance (R = 60 cm., Z = 0 cm.).

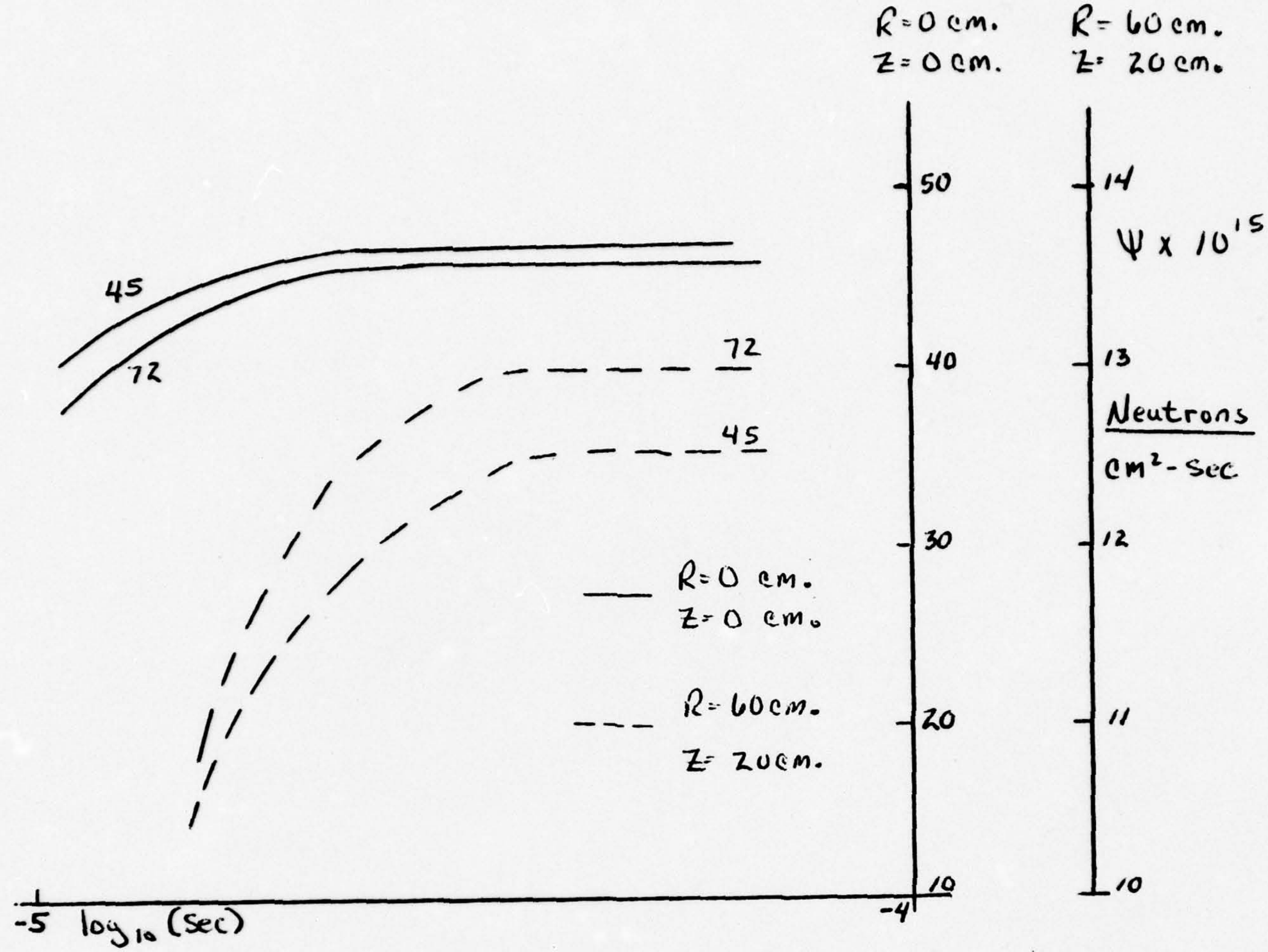

Figure 26. Time Dependent Neutron Flux for 45 and 72 DOF Using the DVOGER (Gear) Method for a Uniform Disturbance Throughout the Core.

APPENDIX A: Computer Programming Codes

```
C     ************************************************************
C     *    FINITE ELEMENT SOLUTION OF NONLINEAR REACTOR DYNAMICS *
C     *         IN TWO DIMENSIONAL SPACE                          *
C     *          LINEARIZED VERSION
C     *                                                          *
C     *   SOLUTION METHOD --  DVOGER (IMSL)                      *
C     *   OPTIONS                                                *
C     *       1-  MTH=0  INDICATES A PREDICTOR CORRECTER         *
C     *           (ADAMS) METHOD                                 *
C     *       2- MTH=1  INDICATES A VARIABLE ORDER METHOD        *
C     *          SUITABLE FOR SYSTEMS OF STIFF DIFFERENTIAL      *
C     *          EQUATIONS. PROGRAM USES THE JACOBIAN.           *
C     *                                                          *
C     *  INPUT PARAMETERS AND DIMENSIONING REQUIREMENTS.         *
C     *  SINGLE ITEMS                                            *
C     *     NUMSNP IS THE SYSTEM
C     *     NUMSNP IS THE NUMBER OF SYSTEM NODAL POINTS          *
C     *     NUMEL IS THE NUMBER OF TRIANGULAR ELEMENTS           *
C     *     NUPBP IS THE NUMBER OF OUTER BOUNDARY POINTS         *
C     *     NFULEL IS THE NUMBER OF ELEMENTS IN THE CORE         *
C     *     EPSVAL IS THE CONVERGENCE CRITERIA                   *
C     *     ITYPE=0 DENOTES CORE ELEMENTS                        *
C     *     ITYPE=1 DENOTES REFLECTOR ELEMENTS                   *
C     *                                                          *
C     *          DIMENSIONING REQUIREMENTS                       *
C     *  NUMSNP BY NUMSNP                                        *
C     *  PART,BIGA,BIGAB,BIGC,BIGCC,WP                           *
C     *                                                          *
C     *  NUMSNP                                                  *
C     *  SYSNOD R,Z,YMAX,ERROR,PSIIV,DPSI,PV                     *
C     *                                                          *
C     *  NUMEL                                                   *
C     *  ELEMNT,ITYPE,V,VD,SGA,SGF,ALPHA,D,ZLMBDA,VLMBDA,        *
C     *  ZOMEGA,R1,R2,R3,Z1,Z2,Z3,AREA                           *
C     *  ELNOD(NUMEL,3), IJPBP(NJPBP), CM(NUMEL,3,3,3), PW(NWK)  *
C     ************************************************************
```

```
      INTEGER*4 SYSNOD,ELEMNT,ELNOD
C
      DIMENSION TITLE(20),ALFA(3,3)

      DIMENSION PART(132,132),BIGA(132,132),BIGAB(132,132),BIGC(132,132)
     1   ,BIGCC(132,132),SYSNOD(132),ELEMNT(220),ELNOD(220,3),IUPBP(22),
     2   ITYPE(220),V(220),VD(220),D(220),SGA(220),SGF(220),ALPHA(220),
     3   ZLMBDA(220),VLMBDA(220),ZOMEGA(220),RHO(220),R(132),Z(132),
     4   R1(220),Z1(220),R2(220),Z2(220),R3(220),Z3(220),A(220,3),
     5   B(220,3),YMAX(132),ERROR(132),AREA(220),CM(220,3,3,3),DPSI(132)
     6   ,PSIIV(132),PDPSI(132),PW(20000),PSI(8,132),PV(132),S(132),
     7   WP(132,132)

      READ (5,998) TITLE
      READ(5,10) NUMEL,NUPBP,NUMSNP,NFULEL
  998 FORMAT(20A4)
   10 FORMAT(8I10)
C     *  FOR  MTH NOT EQUAL TO ZERO  NWK = NUMSNP * (NUMSNP + 17)
      NWK=NUMSNP*17
      CALL ERRSET(207,256,0,1,1,209)
C
C
      DO 05 I=1,NUMSNP
      ERROR(I)=0.
       PDPSI(I)=0.
      YMAX(I)=1.
   05 CONTINUE
C
C
      NUF=NUMSNP/5
      XNP=NUMSNP
      XNUF=XNP/5.
      IF ((XNUF-FLOAT(NUF)) .LT. 1.)  NUF=NUF+1
C
C
C GENERAL PROBLEM DATA
C
      READ(5,12) (IUPBP(I),I=1,NUPBP)
      READ(5,10) MTH,MAXDER,NCOUNT
   12 FORMAT(16I5)
C
      WRITE(6,11) NUMEL,NUPBP,NUMSNP,NFULEL
   11 FORMAT(//2X,'# OF ELEMENTS=',I5//2X,'# OF UPPER BDRY NODAL POINTS=
     1',I5//2X,'# OF SYSTEM NODAL POINTS=',I5//2X,'# OF FUEL ELEMENTS=',
     2I5)
C
      READ(5,15) ZNJ,FISFAC,HBAR,EPSVAL,ERRVAL,AFUEL
      READ(5,19)TO,H,TF,HMIN,HMAX
```

```
      READ(5,15) (V(I),I=1,NUMEL)
      READ(5,15) (D(I),I=1,NUMEL)
      READ(5,15) (SGA(I),I=1,NUMEL)
      READ(5,15) (SGF(I),I=1,NUMEL)
      READ(5,1000) (ALPHA(I),I=1,NUMEL)
      READ(5,18) (PSIIV(I),I=1,NUMSNP)
 1000 FORMAT(5F15.8)
   15 FORMAT(8G10.5)
C
C
C     CALCULATE PHYSICAL CONSTANTS FROM NUCLEAR DATA
C
      PI= 3.1415927
C
      DO 25 I=1,NUMEL
      VD(I)=V(I)*D(I)
      ZLMBDA(I)=ZNU*SGF(I)/SGA(I)-1.
      VLMBDA(I)=V(I)*ZLMBDA(I)*SGA(I)
      ZOMEGA(I)=V(I)*SGA(I)*ALPHA(I)*FISFAC*SGF(I)/HBAR
   25 CONTINUE
C
C
   18 FORMAT(5E15.4)
   19 FORMAT(2E20.4,4G10.5)
C
C
C
C
C
C
C--------- GEOMETRY OF SYSTEM NODAL POINTS -------------------------------------
C
      WRITE(6,40)
   40 FORMAT    (///1X,'GEOMETRY OF SYSTEM NODAL POINTS'///)
C
      READ(5,41) (SYSNOD(I),R(I),Z(I),I=1,NUMSNP)
 41   FORMAT(5X,I5,2F15.5)
C
C
      WRITE      (6,60) (SYSNOD(I),R(I),Z(I),I=1,NUMSNP)
   60 FORMAT (1X,'SYSTEM NODAL POINT NO. ',I3,5X,'R COORD.= ',F10.6,5X,'
     1Z COORD.= ',F10.6)
C
C
C
C***************************************************************************
C CORRESPONDENCE TABLE BETWEEN SYSTEM AND ELEMENT NODAL POINTS
C***************************************************************************@
C
```

```
C
      WRITE(6,73)
   73 FORMAT(//2X,'CONNECTIVITY MATRIX',//,' EL #',33X,'TYPE'//)
      DO 75 I=1,NUMEL
      READ(5,76) ELEMNT(I),ELNOD(I,1),ELNOD(I,2),ELNOD(I,3),ITYPE(I)
      WRITE(6,77) ELEMNT(I),ELNOD(I,1),ELNOD(I,2),ELNOD(I,3),ITYPE(I)
   75 CONTINUE
   76 FORMAT (5I10)
   77 FORMAT (2X,I3,4I10)
C
C
C CALCULATE GEOMETRY FOR EACH ELEMENT
C*********************************************************************@
C
      WRITE(6,110)
  110 FORMAT (1X///1X,'GEOMETRY CALCULATIONS FOR EACH ELEMENT')
C
C----------------------------------------------------------------------
C LOAD SYSTEM NODE COORDINATES (R,Z) INTO
C ELEMENT NODE COORDINATES (R1,R2,R3,Z1,Z2,Z3)
C
      WRITE(6,95)
   95 FORMAT (1X///1X,'ELEMENT',5X,'R1',9X,'Z1',9X,'R2',9X,'Z2',9X,'R3',
     19X,'Z3'/)
C
      DO 100 I=1,NUMEL
C
      J=ELNOD(I,1)
      R1(I)=R(J)
      Z1(I)=Z(J)
C
      K=ELNOD(I,2)
      R2(I)=R(K)
      Z2(I)=Z(K)
C
      L=ELNOD(I,3)
      R3(I)=R(L)
      Z3(I)=Z(L)
C
      WRITE      (6,105) I,R1(I),Z1(I),R2(I),Z2(I),R3(I),Z3(I)
C
  100 CONTINUE
  105 FORMAT (3X,I3,3X,    7(F10.6,1X))
C
C COMPUTE A1,A2,A3,B1,B2,B3,AREA FOR EACH ELEMENT
C----------------------------------------------------------------------
C
      WRITE      (6,120)
```

```
  120 FORMAT (1X///1X,'ELEMENT',5X,'A1',9X,'A2',9X,'A3',9X,'B1',9X,'B2',
     19X,'B3',8X,'AREA'/)
C
      DO 140 I=1,NUMEL
      A(I,1)=R3(I)-R2(I)
      A(I,2)=R1(I)-R3(I)
      A(I,3)=R2(I)-R1(I)
      B(I,1)=Z2(I)-Z3(I)
      B(I,2)=Z3(I)-Z1(I)
      B(I,3)=Z1(I)-Z2(I)
      AREA(I)=0.5*(A(I,2)*B(I,1)-A(I,1)*B(I,2))
C
      WRITE(6,130) I,A(I,1),A(I,2),A(I,3),B(I,1),B(I,2),B(I,3),
     1AREA(I)
  140 CONTINUE
C
  130 FORMAT (3X,I3,3X,    7(F12.7,1X))
C
C
C
C--------- ZERO THE BIGA,      BIGC AND BIGAB MATRICES----------------------
C
C
C
      DO 194  KK=1,NUMSNP
      DO 193 II=1,NUMSNP
      BIGA(KK,II)=0.
      PART(KK,II)=.0
      BIGAB(KK,II)=0.0
      BIGC(KK,II)=.0
  193 CONTINUE
  194 CONTINUE
C
C
C*********************************************************************************
C
C
C---------------------------------------------------------------------------------
C     PEPSI CALCULATES THE BIGA MATRIX AND PART OF THE BIGAB
C---------------------------------------------------------------------------------
C
      CALL PEPSI (NUMEL,NUMSNP,R1,R2,R3,AREA,ELNOD,
     1     BIGA,BIGAB,VLMBDA)
C
      WRITE(6,195)
  195 FORMAT(//5X,'BIGA MATRIX',//)
      WRITE(6,196)
  196 FORMAT(//5X,'BIGAB MATRIX FROM PEPSI, NO DEL**2 CONTRIBUTION',//)
```

```
C
C
C-----------------------------------------------------------------------
C      CRUISE CALCULATES THE BIGAB MATRIX
C-----------------------------------------------------------------------
C
      CALL CRUISE (NJMEL,NJMSNP,       R1,R2,R3,AREA,ELNOD,
     1     BIGAB,        A,B,VD)
C
      WRITE(6,197)
  197 FORMAT(//5X,'BIGAB MATRIX FROM CRUISE, WITH DEL**2 TERM',//)
C
C-----------------------------------------------------------------------
C
C
C
C
      DO 255 I=1,NUPBP
      II=IUPBP(I)
      DO 251 J=1,NUMSNP
      BIGA(J,II)=0
      BIGA(II,J)=0
      BIGAB(J,II)=0
      BIGAB(II,J)=0
  251 CONTINUE
      BIGA(II,II)=1.
      BIGAB(II,II)=0
  255 CONTINUE
C
C
      D1=1.
      CALL LINV3F(BIGA,B,1,NUMSNP,NUMSNP,D1,D2,PART,IER)
      WRITE(6,250)
 250  FORMAT(//5X,'BIGA INVERSE',//)
C
C
C
C
C
C
C     WRITE OUT NUCLEAR DATA
C
      WRITE(6,3105) ZNJ,FISFAC,HBAR,EPSVAL,ERRVAL,AFUEL
 3105 FORMAT(//5X,'NUCLEAR DATA'/2X,'ZNU=',G12.6/2X,'FISFAC=',G12.6/2X,
     1 'HBAR=',G12.6/2X,'EP SVAL=',G12.6/2X,'ERRVAL=',G12.6/2X,'AFUEL=',
     2 G12.6)
      WRITE(6,3110)
 3110 FORMAT(1H0,2X,'ELEM',6X,'D',8X,'SGA',9X,'SGF',8X,'ALPHA',9X,'VD',
     1    7X,'ZLMBDA',7X,'VLMBDA',7X,'ZOMEGA',8X,'V')
      DO 3115 I=1,NJMEL
```

```
      WRITE(6,3120) (I,D(I),SGA(I),SGF(I),ALPHA(I),VD(I),ZLMBDA(I),
     1    VLMBDA(I),ZOMEGA(I),V(I))
 3115 CONTINUE
 3120 FORMAT(2X,I4,10(1PE12.4))
C
C
C
      NUMEQ=NUMSNP-NJPBP
C
C
      EXTERNAL YVETTE
C
      CALL YVET (NUMEL,NUMEQ,NUMSNP,       IUPBP,PSIIV,NUPBP,BIGC,
     1    ITYPE,ELNOD,CM,BIGA,BIGAB,       BIGCC,PART,NWK,PSI,PW,DPSI,
     2    PDPSI,PV,NCOUNT,ZOMEGA,WP)
C--------- INITIALIZE ARGUMENTS OF DVOGER ---------------------------------------
C
      PTIME= 1.E-17
      STAR=0.01
      NIT=0
      T=TO
      JSTART=0
      EPS= EPSVAL
      IER=0
C
      WRITE(6,999) TITLE
  999 FORMAT(1H1,20A4)
C
      WRITE(6,317)
      WRITE(6,318) T,MTH,MAXDER,JSTART,H,HMIN,HMAX,EPS,NCOUNT
  317 FORMAT  (//10X,'INITIAL ARGUMENTS',//)
  318 FORMAT(2X,'T=',G10.4,2X,'MTH=',I4,2X,'MAXDER=',I4,2X,'JSTART=',I4,
     12X,'H=',G10.4,2X,'HMIN=',G10.4,2X,'HMAX=',G10.4,2X,'EPS=',G10.4,2X
     2,'NCOUNT=',I2,/)
C
C
      DO 320 I=1,NUMSNP
      PSI(1,I)=PSIIV(I)
  320 CONTINUE
C
      DO 321 I=1,NUPBP
      J=IUPBP(I)
      PSI(1,J)=0.0
  321 CONTINUE
C
      NUMEQ=NUMSNP-NJPBP
C
C
```

```
C
C      CONSTRUCT THE 3IGC MATRIX DN THE ELEMENT LEVEL
C-----------------------------------------------------------------------------------------
C
       DO 200 L=1,NUMEL
C
       DO 583 I=1,3
       DO 582 J=1,3
       DO 581 K=1,3
       CM(L,I,J,K) =0.
  581  CONTINUE
  582  CONTINUE
  583  CONTI\NUE
       LL=ITYPE(L)
       IF (LL .NE. 0) GO TO 200
C
       CC=PI*AREA(L)/180.
C
       CM(L,3,3,3)=CC*(6.0*R1(L)+6.0*R2(L)+24.*R3(L))
       CM(L,3,3,2)=CC*(2.0*R1(L)+4.0*R2(L)+6.0*R3(L))
       CM(L,3,3,1)=CC*(4.0*R1(L)+2.0*R2(L)+6.0*R3(L))
       CM(L,3,2,3)=CC*(2.0*R1(L)+4.0*R2(L)+6.0*R3(L))
       CM(L,3,2,2)=CC*(2.0*R1(L)+6.0*R2(L)+4.0*R3(L))
       CM(L,3,2,1)=CC*(2.0*R1(L)+2.0*R2(L)+2.0*R3(L))
       CM(L,3,1,3)=CC*(4.0*R1(L)+2.0*R2(L)+5.0*R3(L))
       CM(L,3,1,2)=CC*(2.0*R1(L)+2.0*R2(L)+2.0*R3(L))
       CM(L,3,1,1)=CC*(6.0*R1(L)+2.0*R2(L)+4.0*R3(L))
       CM(L,2,3,3)=CC*(2.0*R1(L)+4.0*R2(L)+6.0*R3(L))
       CM(L,2,3,2)=CC*(2.0*R1(L)+6.0*R2(L)+4.0*R3(L))
       CM(L,2,3,1)=CC*(2.0*R1(L)+2.0*R2(L)+2.0*R3(L))
       CM(L,2,2,3)=CC*(2.0*R1(L)+6.0*R2(L)+4.0*R3(L))
       CM(L,2,2,2)=CC*(6.0*R1(L)+24.*R2(L)+6.0*R3(L))
       CM(L,2,2,1)=CC*(4.0*R1(L)+6.0*R2(L)+2.0*R3(L))
       CM(L,2,1,3)=CC*(2.0*R1(L)+2.0*R2(L)+2.0*R3(L))
       CM(L,2,1,2)=CC*(4.0*R1(L)+6.0*R2(L)+2.0*R3(L))
       CM(L,2,1,1)=CC*(6.0*R1(L)+4.0*R2(L)+2.0*R3(L))
       CM(L,1,3,3)=CC*(4.0*R1(L)+2.0*R2(L)+6.0*R3(L))
       CM(L,1,3,2)=CC*(2.0*R1(L)+2.0*R2(L)+2.0*R3(L))
       CM(L,1,3,1)=CC*(6.0*R1(L)+2.0*R2(L)+4.0*R3(L))
       CM(L,1,2,3)=CC*(2.0*R1(L)+2.0*R2(L)+2.0*R3(L))
       CM(L,1,2,2)=CC*(4.0*R1(L)+6.0*R2(L)+2.0*R3(L))
       CM(L,1,2,1)=CC*(6.0*R1(L)+4.0*R2(L)+2.0*R3(L))
       CM(L,1,1,3)=CC*(6.0*R1(L)+2.0*R2(L)+4.0*R3(L))
       CM(L,1,1,2)=CC*(6.0*R1(L)+4.0*R2(L)+2.0*R3(L))
       CM(L,1,1,1)=CC*(24.*R1(L)+6.0*R2(L)+6.0*R3(L))
C
  200  CONTINUE
C
```

```
C
  351 CONTINUE
C
      IF (NCOUNT .EQ. 1) GO TO 312
C
      DO 210 L=1,NUMEL
      LL=ITYPE(L)
      IF(LL .NE. 0) GO TO 210
      N1=ELNOD(L,1)
      N2=ELNOD(L,2)
      N3=ELNOD(L,3)
      DO 88 J=1,3
      DO 90 N=1,3
      ALFA(N,J)=PSIIV(N1)*CM(L,N,J,1)+PSIIV(N2)*CM(L,N,J,2)
     1   +PSIIV(N3)*CM(L,N,J,3)
   90 CONTINUE
   88 CONTINUE
      DO 150 K=1,3
      KK=ELNOD(L,K)
      DO 180 I=1,3
      II=ELNOD(L,I)
      BIGC(KK,II)=BIGC(KK,II)+ALFA(K,I)*ZOMEGA(L)
  180 CONTINUE
  150 CONTINUE
  210 CONTINUE
C
C        INSERTION OF BOUNDARY POINTS
      DO 285 I=1,NUPBP
      II=IUPBP(I)
      DO 291 J=1,NUMSNP
      BIGC(J,II)=0
      BIGC(II,J)=0
  291 CONTINUE
  285 CONTINUE
C
C
      DO 310 I=1,NUMSNP
      DO 310 J=1,NUMSNP
      BIGCC(I,J)=0
      PART(I,J)=0
      DO 300 K=1,NUMSNP
      BIGCC(I,J)=BIGCC(I,J)+(BIGAB(K,J)-BIGC(K,J))*BIGA(I,K)
      PART(I,J)=PART(I,J)+(BIGAB(K,J)-2.*BIGC(K,J))*BIGA(I,K)
 300  CONTINUE
  310 CONTINUE
C
C
C
```

```
  312 CONTINUE
C
C
C         **************************************************************
C         * SOLVE NON-LINEAR FLUX EQUATIONS WITH SUBROUTINE DVOGER *
C         **************************************************************
C
 350  CALL DVOGER(YVETTE,PSI,T,NUMSNP,MTH,MAXDER,JSTART,H,HMIN,HMAX,EPS,
     1   YMAX,ERROR,PW,IER)
C
C
      IF(IER.EQ.0) GO TO 3540
      JSTART=-1
      H=HMIN*.1
      HMIN=H*.1
      GO TO 350
C
 3540 CONTINUE
      JSTART=1
      IF((T-PTIME)/PTIME .LT. STAR)   GO TO 352
      PTIME= T
      WRITE(5,3510)T,H,JSTART,IER
 3510 FORMAT(//2X,'T=',G12.6,2X,'H=',G12.6,2X,'JSTART=',I4,2X,'IER=',I4)
      WRITE (6,354)
  354 FORMAT(/(5(4X,'NODE',7X,'PSI',4X)))
C
C
      DO 355 I=1,NUF
      I1=I+NUF
      I2=I+2*NUF
      I3=I+3*NUF
      I4=I+4*NUF
      WRITE(6,356) (I,PSI(1,I),I1,PSI(1,I1),I2,PSI(1,I2),I3,PSI(1,I3),I4
     1,PSI(1,I4))
  355 CONTINUE
  356 FORMAT(5(4X,I3,3X,1PE12.4))
C
      NIT= 1 + NIT
      IF (NIT .GT. 400)   GO TO 377
  377 CONTINUE
C
      DO 360 I=1,NUMSNP
      S(I)=PSI(2,I)/H
  360 CONTINUE
C
      WRITE(6,357)
  357 FORMAT(/(5(4X,'NODE',7X,'DPSI',3X)))
      DO 359 I=1,NUF
```

```
      I1=I+NUF
      I2=I+2*NUF
      I3=I+3*NUF
      I4=I+4*NUF
      WRITE(6,356)(I,S(I),I1,S(I1),I2,S(I2),I3,S(I3),I4,S(I4))
  359 CONTINUE
  362 CONTINUE
C
      DO 27 MN=1,NUMSNP
      PSIIV(MN)=PSI(1,MN)
      DO 28 I=1,NUMSNP
      BIGC(MN,I)=.0
   28 CONTINUE
   27 CONTINUE
C
      IF (T .LT. TF) GO TO 351
C
C
      STOP
      END
```

```
      SUBROUTINE PEPSI (NUMEL,NUMSNP,R1,R2,R3,AREA,ELNOD,
     1    BIGA,BIGAB,VLMBDA)
C
C*****************************************************************************
C
C     PEPSI CALCULATES THE BIGA MATRIX AND PART OF THE BIGAB
C*****************************************************************************
C
      INTEGER*4 ELNOD
C
      DIMENSION  R1(NJMEL),R2(NUMEL),R3(NUMEL),BIGA(NUMSNP,NUMSNP),
     1    BIGAB(NUMSVP,NUMSNP),AMATRX(3,3),
     2    VLMBDA(NUMEL),AREA(NUMEL),ELNOD(NUMEL,3)
C
      PI=3.1415927
C
C CALCULATE THE 3X3 D(I,J) MATRIX FOR ELEMENT L
C
      DO 200 L=1,NUMEL
      COEFFA=(PI/30.0)*AREA(L)
C
      AMATRX(1,1)=COEFFA    *(6.0*R1(L)+2.0*R2(L)+2.0*R3(L))
      AMATRX(1,2)=COEFFA    *(2.0*R1(L)+2.0*R2(L)+R3(L))
      AMATRX(1,3)=COEFFA    *(2.0*R1(L)+R2(L)+2.0*R3(L))
      AMATRX(2,1)=AMATRX(1,2)
      AMATRX(2,2)=COEFFA    *(2.0*R1(L)+6.0*R2(L)+2.0*R3(L))
      AMATRX(2,3)=COEFFA    *(R1(L)+2.0*R2(L)+2.0*R3(L))
      AMATRX(3,1)=AMATRX(1,3)
      AMATRX(3,2)=AMATRX(2,3)
      AMATRX(3,3)=COEFFA    *(2.0*R1(L)+2.0*R2(L)+6.0*R3(L))
C
C-----------------------------------------------------------------------------
C STORE ELEMENT MATRIX, AMATRX, INTO SYSTEM MATRIX, BIGA
C-----------------------------------------------------------------------------
C
      DO 20 K=1,3
      KK=ELNOD(L,K)
      DO 10 I=1,3
      II=ELNOD(L,I)
      BIGA(KK,II)=BIGA(KK,II)+AMATRX(K,I)
      BIGAB(KK,II)=BIGAB(KK,II)+VLMBDA(L)*AMATRX(K,I)
   10 CONTINUE
   20 CONTINUE
C
  200 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE CRJISE (NUMEL,NUMSNP,      R1,R2,R3,AREA,ELNOD,BIGAB,
     1   A,B,VD)
C    *                                                              *
C
C     CRUISE CALCULATES THE BIGAB MATRIX
C-----------------------------------------------------------------------
C
      INTEGER*4 ELNOD
C
      DIMENSION R1(NJMEL),R2(NUMEL),R3(NUMEL),AREA(NUMEL),
     1   BIGAB(NUMSVP,NUMSNP),BMATRX(3,3),
     2   ELNOD(NUMEL,3),A(NUMEL,3),B(NUMEL,3),VD(NUMEL)
C
      PI=3.1415927
C
C
C CALCULATE THE 3X3 B(I,J) MATRIX FJR ELEMENT L
C-----------------------------------------------------------------------
C
      DO 200 L=1,NUMEL
C
      COEFFB=PI*VD(L)/(6.0*AREA(L))
C
      BMATRX(1,1)=COEFFB    *(-R1(L)*(2.0*B(L,1)**2+2.0*A(L,1)**2)-R2(L)*
     1(B(L,1)*B(L,2)+B(L,1)**2+A(L,1)*A(L,2)+A(L,1)**2)-R3(L)*(B(L,1)*
     2B(L,3)+B(L,1)**2+A(L,1)*A(L,3)+A(L,1)**2)+2.0*AREA(L)*B(L,1))
C
      BMATRX(1,2)=COEFFB    *(-R1(L)*(2.0*B(L,1)*B(L,2)+2.0*A(L,1)*
     1A(L,2))-R2(L)*(B(L,2)**2+B(L,1)*B(L,2)+A(L,2)**2+A(L,1)*A(L,2))-
     2R3(L)*(B(L,2)*B(L,3)+B(L,1)*B(L,2)+A(L,2)*A(L,3)+A(L,1)*A(L,2))+
     32.0*AREA(L)*B(L,2))
C
      BMATRX(1,3)=CJEFFB    *(-R1(L)*(2.0*B(L,1)*B(L,3)+2.0*A(L,1)*
     1A(L,3))-R2(L)*(B(L,2)*B(L,3)+B(L,1)*B(L,3)+A(L,2)*A(L,3)+A(L,1)*
     2A(L,3))-R3(L)*(B(L,3)**2+B(L,1)*B(L,3)+A(L,3)**2+A(L,1)*A(L,3))+
     32.0*AREA(L)*B(L,3))
C
      BMATRX(2,1)=BMATRX(1,2)
C
      BMATRX(2,2)=COEFFB    *(-R1(L)*(B(L,2)**2+B(L,1)*B(L,2)+A(L,2)**2+
     1A(L,1)*A(L,2))-R2(L)*(2.0*B(L,2)**2+2.0*A(L,2)**2)-R3(L)*(B(L,3)*
     2B(L,2)+B(L,2)**2+A(L,3)*A(L,2)+A(L,2)**2)+2.0*AREA(L)*B(L,2))
C
      BMATRX(2,3)=CJEFFB    *(-R1(L)*(B(L,2)*B(L,3)+B(L,1)*B(L,3)+A(L,2)*
     1A(L,3)+A(L,1)*A(L,3))-R2(L)*(2.0*B(L,2)*B(L,3)+2.0*A(L,2)*A(L,3))-
     2R3(L)*(B(L,3)**2+B(L,2)*B(L,3)+A(L,3)**2+A(L,2)*A(L,3))+
     32.0*AREA(L)*B(L,3))
C
```

```
      BMATRX(3,1)=BMATRX(1,3)
C
      BMATRX(3,2)=BMATRX(2,3)
C
      BMATRX(3,3)=COEFFB    *(-R1(L)*(B(L,3)**2+B(L,1)*B(L,3)+A(L,3)**2+
     1A(L,1)*A(L,3))-R2(L)*(B(L,3)**2+B(L,2)*B(L,3)+A(L,3)**2+A(L,2)*
     2A(L,3))-R3(L)*(2.0*B(L,3)**2+2.0*A(L,3)**2)+2.0*AREA(L)*B(L,3))
C
C
C STORE ELEMENT MATRIX, AMATRX, INTO SYSTEM MATRIX, BIGA
C-----------------------------------------------------------------------------
C
      DO 20 K=1,3
      KK=ELNOD(L,K)
      DO 10 I=1,3
      II=ELNOD(L,I)
      BIGAB(KK,II)=BIGAB(KK,II)+BMATRX(K,I)
   10 CONTINUE
   20 CONTINUE
C
  200 CONTINUE
C
      RETURN
C
      END
```

```
      SUBROUTINE YVET(NUMEL,NUMEQ,NUMSNP,       IUPBP,PSIIV,NUPBP,BIGC,
     1    ITYPE,ELNOD,CM,BIGA,BIGAB,        BIGCC,PART,NWK,PSI,PW,DPSI,
     2    PDPSI,PV,NCOUNT,ZOMEGA,WP)
C
C
      INTEGER*4 ELNOD
C
      DIMENSION PART(132,132),BIGA(132,132),BIGAB(132,132),BIGC(132,132)
     1    ,BIGCC(132,132),ALFA(3,3),ITYPE(220)     ,ELNOD(220,3),IUPBP(22),
     5    ZOMEGA(220),WP(132,132)                  ,CM(220,3,3,3),DPSI(132)
     6    ,PSIIV(132),PDPSI(132),PW(20000),PSI(8,132),PV(132)
      PI=3.1415927
      RETURN
C
C
C*************************************************************************
C
          ENTRY YVETTE(PSI,T,MQ,DPSI,WP,IND)
C
C YVETTE IS AN EXTERNAL SUBROUTINE REQUIRED BY SUBROUTINE DVOGER
C
C
C
      DO 15 I=1,NUMSNP
      PV(I)=PSI(1,I)
   15 CONTINUE
      DO 50 I=1,NUPBP
      J=IUPBP(I)
      PV(J)=0.
   50 CONTINUE
      IF (NCOUNT .NE. 1) GO TO 05
C
      DO 27 MM=1,NUMSNP
      PSIIV(MM)=PV(MM)
      DO 28 I=1,NUMSNP
      BIGC(MM,I)=0.
   28 CONTINUE
   27 CONTINUE
      DO 210 L=1,NUMEL
      LL=ITYPE(L)
      IF(LL .NE. 0) GO TO 210
      N1=ELNOD(L,1)
      N2=ELNOD(L,2)
      N3=ELNOD(L,3)
      DO 86   J=1,3
      DO 90  N=1,3
      ALFA(N,J)=PSIIV(N1)*CM(L,N,J,1)+PSIIV(N2)*CM(L,N,J,2)
     1    +PSIIV(N3)*CM(L,N,J,3)
   90 CONTINUE
```

```
   86 CONTINUE
      DO 150 K=1,3
      KK=ELNOD(L,K)
      DO 280 I=1,3
      II=ELNOD(L,I)
C
      BIGC(KK,II)=BIGC(KK,II)+ALFA(K,I)*ZOMEGA(L)
  280 CONTINUE
  150 CONTINUE
  210 CONTINUE
C
C          INSRRTION OF BOUNDARY POINTS
      DO 285 I=1,NUP3P
      II=IUPBP(I)
      DO 281 J=1,NUMSNP
      BIGC(J,II)=0.
      BIGC(II,J)=0.
  281 CONTINUE
  285 CONTINUE
      DO 311 I=1,NUMSNP
      DO 310 J=1,NUMSNP
      BIGCC(I,J)=0.
      PART(I,J)=.0
      DO 300 K=1,NUMSNP
      BIGCC(I,J)=BIGCC(I,J)+(BIGAB(K,J)- BIGC(K,J))*BIGA(I,K)
      PART(I,J)=PART(I,J)+(BIGAB(K,J)-2.*BIGC(K,J))*BIGA(I,K)
  300 CONTINUE
  310 CONTINUE
  311 CONTINUE
C
   05 CONTINUE
C
C
      IF (IND .EQ. 1) GO TJ 205
C
      DO 81 K=1,NUMSNP
      DPSI(K)=0.
      IF(K.GT.NUMEQ)GO TO 81
      DO 80 I=1,NUMSNP
      DPSI(K)=DPSI(K)+BIGCC(K,I)*PV(I)
   80 CONTINUE
   81 CONTINUE
      IF(T.GT.0.0) RETURN
      WRITE(6,60)T
   60 FORMAT(/2X,'FRJM YVETTE',5X,'T=',G20.10)
      WRITE(6,65)(DPSI(K),K=1,NJMSNP)
      WRITE(6,65)(PSI(1,K),K=1,NUMSNP)
   65 FORMAT(10(1X,E11.5))
```

```
C
      RETURN
  205 CONTINUE
C
C        WHEN MTH = 1 COMPUTE THE JACOBIAN
C
      DO 900 K=1,NUMSNP
      DO 880 L=1,NUMSNP
      WP(K,L)=PART(K,L)
  880 CONTINUE
  900 CONTINUE
      RETURN
      END
```

```
C     ******************************************************************
C     *                                                                *
C     *  FINITE ELEMENT SOLUTION OF NONLINEAR REACTOR DYNAMICS         *
C     *  IN TWO DIMENSIONAL SPACE    (COMPACT VERSION)                 *
C     *                                                                *
C     *                                                                *
C     *                                                                *
C     * THE FOLLOWING VARIABLES ARE DIMENSIONED WITH RESPECT           *
C     * TO THE NUMBER OF ELEMENTS IN THE SYSTEM, NUMEL:                *
C     *                                                                *
C     * R1(NUMEL)            R2(NUMEL)            R3(NUMEL)            *
C     * Z1(NUMEL)            Z2(NUMEL)            Z3(NUMEL)            *
C     * A(3,NUMEL)           B(3,NUMEL)           AREA(NUMEL)          *
C     * A12(NUMEL)           A23(NUMEL)           A31(NUMEL)           *
C     * GAMMA(NUMEL)         DELTA(NUMEL)                              *
C     * ELEMNT(NUMEL)        ELNOD(3,NUMEL)                            *
C     *                                                                *
C     * THE FOLLOWING VARIABLES ARE DIMENSIONED WITH RESPECT           *
C     * TO THE NUMBER OF SYSTEM NODAL POINTS, NUMSNP:                  *
C     *                                                                *
C     * BAGB(NUMSNP,NCMPK)          BAGAB(NUMSNP,NCMPK)                *
C     * SCRAPC(NUMSNP,NCC)                                             *
C     * ERROR(NUMSNP)                                                  *
C     * R(NUMSNP)                    Z(NUMSNP)                         *
C     * SYSNOD(NUMSNP)              PSI(8,NUMSNP)                      *
C     *                                                                *
C     *                                                                *
C     * ITYPE DENOTES THE KIND OF ELEMENT MATERIAL, 0 FOR FUEL         *
C     *       ELEMENT, NONZERO FOR CORE ELEMENT                        *
C     * NFULEL DENOTES THE NUMBER OF FUEL ELEMENTS                     *
C     * NUMEL DENOTES THE NUMBER OF ELEMENTS                           *
C     * NBP IS THE NUMBER OF BOUNDARY POINTS                           *
C     * NUMSNP IS THE NUMBER OF SYSTEM NODAL POINTS                    *
C     * NCOUNT DENOTES NUMBER OF INTEGRATIONS BEFORE EACH OUTPUT*
C     *                                                                *
C     * NCMPK=MAX(NEIGHBORS OF A NODAL+1)                               *
C     * NCC=NCMPK*(NCMPK+1)/2                                          *
C     * NPROB EQUAL 1 FOR THE LINEAR PROBLEM                           *
C     * NPROB=0 FOR THE NON LINEAR PROBLEM                             *
C     * NTYPE=0 FOR THE PSI SQUARE TERM                                *
C     * JPLOT=0 FOR NO PLOTTING                                        *
C     * JPLOT=1 FOR PLOTTING                                           *
C     * IRUN IDENTIFIES PUNCHED CARD OUTPUT                            *
C     * NDE= NUMBER OF NON ZERO DIFFERENTIAL EQUATIONS                 *
C     * WS= 12*NDE+4*NL                                                *
C     * NL= NUMBER OF ALGEBRAIC EQUATIONS                              *
C     *                                                                *
C     ******************************************************************
```

```
C
C--------- DECLARATION STATEMENTS ------------------------------------------
C
C
      IMPLICIT REAL*4 (A-H,O-Z), INTEGER*4 (I-N)
C
      INTEGER*2 NAME
      INTEGER*4 SYSNOD,ELEMNT,ELNOD,RHO
C
      COMMON/NUMB/ELNOD(220,3),NUMEL,NUMSNP,NFULEL,NELROW,NBP,IBP(30)
     1,NPROB,NTYPE,ITYPE(220)
      COMMON/CMCL/BAGA(132,7),BAGAB(132,7),SCRAPC(132,28),NDE,NCMPK,
     1NAME(132,7)
C
      COMMON/SOLVE/PI,VDF,VDC,VLMBDA,ZOMEGA,VSMAAC,SCALE
C
      COMMON R1(220),R2(220),R3(220),A(220,3),B(220,3),AREA(220),Z1(220)
     1,Z2(220),Z3(220),A12(220),A23(220),A31(220),GAMMA(220),DELTA(220)
C
      DIMENSION PSTART(132),R(132),Z(132),TPLOT(20)
      DIMENSION PSI(8,132),ERROR(132),YMAX(132)
      DIMENSION SYSNOD(132),ELEMNT(220),TITLE(20)
      DIMENSION Y(7,132),WS(1430)
      DIMENSION ICORE(70)
C
      CALL ERRSET(207,256,0,1,1,209)
C


      READ(5,998) TITLE
      WRITE(6,999) TITLE
  998 FORMAT(20A4)
  999 FORMAT(1H1,18X,20A4)
C
      READ(5,10) NUMEL,NBP,NUMSNP,NFULEL,NELROW,MXEVAL,NCOUNT,NCMPK
      READ(5,10) NDE,NL
      WRITE(6,997) NDE,NL
  997 FORMAT(//2X,'NDE=',I10//2X,'NL=',I10)
      READ(5,200)(IBP(I),I=1,NBP)
   10 FORMAT(8I10)
  200 FORMAT(16I5)
C
C
C*************************************************************************
C GENERAL PROBLEM DATA
C*************************************************************************
C
      WRITE(6,11) NUMEL,  NBP,NUMSNP,NFULEL,NELROW,MXEVAL,NCOUNT,NCMPK
```

```
   11 FORMAT(//2X,'# OF ELEMENTS=',I5//2X,'# OF SYSTEM BOUNDARY POINTS=
     1',I5//2X,'# OF SYSTEM NODAL POINTS=',I5//2X,'# OF FUEL ELEMENTS=',
     2I5//2X,'# OF ELEMENTS IN A ROW=',I5//2X,'MAX. # OF EVALUATIONS=',I
     35//2X,'NCOUNT=',I5//2X,'NCMPK=',I5)
      WRITE(6,10) (I3P(I),I=1,NBP)
C
      READ(5,15)VELOCT,DSUBF,DSUBC,SGMAAF,SGMAAC,SGMAF,FISFAC,HBAR
      READ(5,15) ZNU,ALPHA,RMSEPS,AFUEL,TSTART,TEND,PINITV,SCALE
      READ(5,15) HMIN,HMAX
      WRITE(6,19) HMIN,HMAX
   19 FORMAT(//2X,'HMIN=',G12.6/2X,'HMAX=',G12.6)
C
      IF(TSTART.GT.0.) READ(5,13) (PSTART(I),I=1,NUMSNP)
      IF(TSTART.GT.0.) WRITE(6,13) (PSTART(I),I=1,NUMSNP)
   13 FORMAT(5G15.5)
C
      READ(5,10) MTH,MAXDER,NPROB,NTYPE,JPLOT,NPLOT,IRUN
      WRITE(6,12) NPROB,NTYPE,JPLOT,NPLOT,IRUN
   12 FORMAT(/2X,'NPROB=',I5/2X,'NTYPE=',I5/2X,'JPLOT=',I5/2X,'NPLOT=',I
     15/2X,'IRUN=',I5)
      IF(JPLOT.EQ.1) READ(5,13) (TPLOT(I),I=1,NPLOT)
      IF(JPLOT.EQ.1) WRITE(6,13) (TPLOT(I),I=1,NPLOT)
      IF(JPLOT.EQ.1) ITPC=1
C
      WRITE(6,16)VELOCT,DSUBF,DSUBC,SGMAAF,SGMAAC,SGMAF,FISFAC,HBAR,ZNU,
     1ALPHA,RMSEPS,AFUEL,TSTART,TEND,PINITV,SCALE
   16 FORMAT(//5X,'NUCLEAR DATA'/2X,'VELOCT=',G12.6/2X,'DSUBF=',G12.6/2X
     1,'DSUBC=',G12.6/2X,'SGMAAF=',G12.6/2X,'SGMAAC=',G12.6/2X,'SGMAF=',
     2G12.6/2X,'FISFAC=',G12.6/2X,'HBAR=',G12.6/2X,'ZNU=',G12.6/2X,
     3    'ALPHA=',G12.6/2X,'RMSEPS=',G12.6/2X,'AFUEL=',G12.6/2X,/2X,
     4    'TSTART=',G12.6/2X,'TEND=',G12.6/2X,'PINITV=',G12.6,/2X,
     5    'SCALE=',E10.5)
C
   15 FORMAT(8G10.5)
C
C     CALCULATE PHYSICAL CONSTANTS FROM NUCLEAR DATA
C
      ICOUNT=0
      ZLMBDA=ZNU*SGMAF/SGMAAF-1.
      VDF=VELOCT*DSUBF
      VDC=VELOCT*DSUBC
      VLMBDA=VELOCT*ZLMBDA*SGMAAF
      ZOMEGA=2.*VELOCT*SGMAAF*ALPHA*FISFAC*SGMAF/(HBAR*(AFUEL**2.))*SCAL
     1E
      IF(NTYPE.EQ.0) ZOMEGA=ZOMEGA*(AFUEL**2)/2.
      VSMAAC=VELOCT*SGMAAC
      PI= 3.1415927
C
```

AD-A035 862   NAVAL POSTGRADUATE SCHOOL MONTEREY CALIF   F/G 18/11
A COMPARISON OF INTEGRATION METHODS FOR THE SOLUTION OF NONLINE--ETC(U)
DEC 76   R C SHELDRICK

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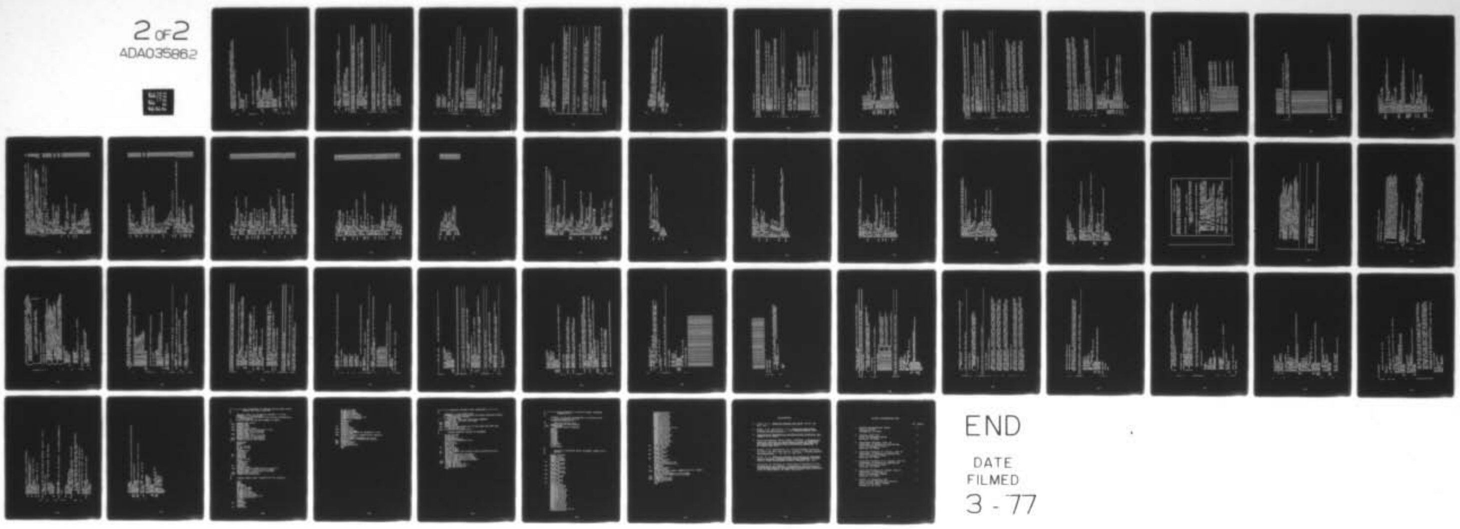
2 OF 2
ADA035862



END
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3 - 77

```
      WRITE(6,17)ZLMBDA,VDF,VDC,VLMBDA,ZOMEGA,VSMAAC,VELOCT
   17 FORMAT(//5X,'PHYSICAL CONSTANTS'/2X,'ZLMBDA=',G12.6/2X,'VDF=',
     1G12.6/2X,'VDC=',G12.6/2X,'VLMBDA=',G12.6/2X,'ZOMEGA=',G12.6/2X,
     2'VSMAAC=',G12.6/2X,'VELOCT=',G12.6)
C
C
      DO 50 I=1,NUMSNP
      Y(1,I)=0.
      Y(2,I)=0.
   50 CONTINUE

      Y(1,1)=PINITV

C
C
C
C        NODAL NEIGHBOR CONNECTIVITY
C
C
      DO 18 I=1,NUMSNP
      READ(5,111)(NAME(I,J),J=1,NCMPK)
      WRITE(6,111)   (NAME(I,J),J=1,NCMPK)
   18 CONTINUE
  111 FORMAT(9(2X,I3))
      DO 172 KK=1,NUMSNP
      DO 171 II=1,NCMPK
      BAGA(KK,II)=0.
      BAGAB(KK,II)=0.
      DO 174 J=II,NCMPK
      JJ=(II-1)*(2*NCMPK-II)/2+J
      SCRAPC(KK,JJ)=0.
  174 CONTINUE
  171 CONTINUE
  172 CONTINUE
C
      WRITE(6,8)
    8 FORMAT ('1','NUCLEAR DATA'///)
C
C
C
      NSNPSQ= NUMSNP * NUMSNP
C
C--------- GEOMETRY OF SYSTEM NODAL POINTS ---------------------------------------
C
      WRITE(6,40)
   40 FORMAT   (///1X,'GEOMETRY OF SYSTEM NODAL POINTS'///)
C
      READ(5,41) (SYSNOD(I),R(I),Z(I),I=1,NUMSNP)
```

```
 41   FORMAT(5X,I5,2F15.5)
C
      WRITE      (6,60) (SYSNOD(I),R(I),Z(I),I=1,NUMSNP)
   60 FORMAT (1X,'SYSTEM NODAL POINT NO. ',I3,5X,'R COORD.= ',F10.6,5X,'
     1Z COORD.= ',F10.6)
C
      IF(JPLOT.EQ.0) GO TO 72
      WRITE(7,7000) IRUN,HBAR,NUMSNP
 7000 FORMAT(' RUN NUMBER=',I3,F10.5,I5)
      WRITE(7,7001) (R(I),Z(I),I=1,NUMSNP)
 7001 FORMAT(4E15.6)
C
C***********************************************************************************
C CORRESPONDENCE TABLE BETWEEN SYSTEM AND ELEMENT NODAL POINTS
C***********************************************************************************
C
   72 WRITE(6,73)
   73 FORMAT(//2X,'CONNECTIVITY MATRIX',//,' EL #',33X,'TYPE'//)
      DO 75 I=1,NUMEL
      READ(5,76) ELEMNT(I),ELNOD(I,1),ELNOD(I,2),ELNOD(I,3),ITYPE(I)
      WRITE(6,77) ELEMNT(I),ELNOD(I,1),ELNOD(I,2),ELNOD(I,3),ITYPE(I)
   75 CONTINUE
   76 FORMAT (5I10)
   77 FORMAT (2X,I3,4I10)
C
C
C
C***********************************************************************************
C CALCULATE GEOMETRY FOR EACH ELEMENT
C***********************************************************************************
C
      WRITE(6,110)
  110 FORMAT (1X///1X,'GEOMETRY CALCULATIONS FOR EACH ELEMENT')
C
C-----------------------------------------------------------------------------------
C LOAD SYSTEM NODE COORDINATES (R,Z) INTO
C ELEMENT NODE COORDINATES (R1,R2,R3,Z1,Z2,Z3)
C-----------------------------------------------------------------------------------
C
      WRITE(6,95)
   95 FORMAT (1X///1X,'ELEMENT',5X,'R1',9X,'Z1',9X,'R2',9X,'Z2',9X,'R3',
     19X,'Z3'/)
C
      DO 100 I=1,NUMEL
C
      J=ELNOD(I,1)
      R1(I)=R(J)
      Z1(I)=Z(J)
```

```
C
      K=ELNOD(I,2)
      R2(I)=R(K)
      Z2(I)=Z(K)
C
      L=ELNOD(I,3)
      R3(I)=R(L)
      Z3(I)=Z(L)
C
      WRITE     (6,105) I,R1(I),Z1(I),R2(I),Z2(I),R3(I),Z3(I)
  105 FORMAT (1X,2X,I3,4X,7(F10.6,1X))
C
  100 CONTINUE
C
C-----------------------------------------------------------------------
C COMPUTE A1,A2,A3,B1,B2,B3,AREA FOR EACH ELEMENT
C-----------------------------------------------------------------------
C
      WRITE     (6,120)
  120 FORMAT (1X///1X,'ELEMENT',5X,'A1',9X,'A2',9X,'A3',9X,'B1',9X,'B2',
     19X,'B3',8X,'AREA'/)
C
      DO 140 I=1,NUMEL
      A(I,1)=R3(I)-R2(I)
      A(I,2)=R1(I)-R3(I)
      A(I,3)=R2(I)-R1(I)
      B(I,1)=Z2(I)-Z3(I)
      B(I,2)=Z3(I)-Z1(I)
      B(I,3)=Z1(I)-Z2(I)
      AREA(I)=0.5*(A(I,2)*B(I,1)-A(I,1)*B(I,2))
C
      WRITE(6,130) I,A(I,1),A(I,2),A(I,3),B(I,1),B(I,2),B(I,3),
     1AREA(I)
  140 CONTINUE
C
  130 FORMAT (1X,2X,I3,4X,7(F10.6,1X))
C
C-----------------------------------------------------------------------
C COMPUTE A12,A23,A31,GAMMA,DELTA FOR EACH ELEMENT
C-----------------------------------------------------------------------
C
      WRITE     (6,150)
  150 FORMAT ('1','ELEMENT',5X,'A12',8X,'A23',8X,'A31',6X,'GAMMA',7X,'DE
     1LTA'/)
C
      DO 170 L=1,NUMEL
      A12(L)=0.5*    (R1(L)*Z2(L)-R2(L)*Z1(L))
      A23(L)=0.5*    (R2(L)*Z3(L)-R3(L)*Z2(L))
```

```
      A31(L)=0.5*    (R3(L)*Z1(L)-R1(L)*Z3(L))
      ZX=Z3(L)-Z2(L)
      IF(ZX.EQ.0.) WRITE(6,161) ZX
      IF(ZX.EQ.0.) GO TO 170
      GAMMA(L)=(R3(L)-R2(L))/(Z3(L)-Z2(L))
      DELTA(L)=R3(L)-GAMMA(L)*Z3(L)
  170 CONTINUE
C
      WRITE       (6,160) L,A12(L),A23(L),A31(L),GAMMA(L),DELTA(L)
  160 FORMAT (1X,2X,I2,4X,5(F10.4,1X))
  161 FORMAT(//2X,'ZX=',G12.6)
C
C
C
C
C
C*****************************************************************************
C    CALCULATION OF THE SYSTEM INFLUENCE MATRICES FOR THE FIELD EQUATION IN
C         PEPSI(CONSTANT TERM), CRUISE(DEL SQJARE TERM), AND PSISQ (OR MOE)
C         FOR THE NON LINEAR TERM.
C*****************************************************************************
C
C
C-----------------------------------------------------------------------------
C PEPSI CALCULATES THE D-MATRIX MULTIPLYING THE D(CY)/DT TERM
C-----------------------------------------------------------------------------
C
      CALL PEPSI
C
C
C-----------------------------------------------------------------------------
C CRUISE CALCULATES THE SYSTEM MATRIX, BIGA, ASSOCIATED WITH THE
C 'DEL SQUARE' TERM. IT THEN COMBINES BIGA WITH BIGB, THE SYSTEM MATRIX
C ASSOCIATED WITH THE CONSTANT TERM, INTO THE SYSTEM MATRIX, BIGAB.
C-----------------------------------------------------------------------------
C
      CALL CRUISE
C
C-----------------------------------------------------------------------------
C  PSISQ CALCULATES THE SYSTEM MATRIX ASSOCIATED WITH THE NON LINEAR PSI**2 TERM
C
C  MOE CALCULATES THE SYSTEM MATRIX ASSOCIATED WITH THE NON LINEAR INTEGRAL TERM
C-----------------------------------------------------------------------------
C
C
      IF(NPROB.EQ.1) GO TO 199
      IF(NTYPE.EQ.0) CALL PSISQ
  199 CONTINUE
```

```
C
C
      JSKF=0
      WRITE(6,317)
      WRITE(6,318) TSTART,TEND,MAXDER,JSKF,HMIN,HMAX,RMSEPS
  317 FORMAT(//5X,'INITIAL ARGUMENTS',//)
  318 FORMAT(2X,'TSTART=',G12.6/2X,'TEND=',G12.6/2X,'MAXDER=',I5/2X,
     1'JSKF=',I5/2X,'HMIN=',G12.6/2X,'HMAX=',G12.6/2X,'RMSEPS=',G12.6)
C
      H = HMIN*1000.
      CALL SDESOL(Y,YL,TSTART,TEND,NDE,NL,NDE,JSKF,MAXDER,1,H,HMIN,HMAX,
     1RMSEPS,WS)
 9998 WRITE(6,9997) JSKF
 9997 FORMAT(//2X,'JSKF=',I5)
C
 9999 STOP
      END
```

```
      SUBROUTINE PEPSI
C
C*****************************************************************************
C PEPSI CALCULATES THE A-MATRIX MULTIPLYING THE D(CY)/DT TERM
C*****************************************************************************
C
      INTEGER*2 NAME
      INTEGER*4 SYSNOD,ELEMNT,ELNOD,RHO
C
      COMMON/NUMB/ELNOD(220,3),NUMEL,NUMSNP,NFULEL,NELROW,NBP,IBP(30)
     1,NPROB,NTYPE,ITYPE(220)
      COMMON/CMCL/BAGA(132,7),BAGAB(132,7),SCRAPC(132,28),NDE,NCMPK,
     1NAME(132,7)
      COMMON/SOLVE/PI,VDF,VDC,VLMBDA,ZOMEGA,VSMAAC,SCALE
C
      COMMON R1(220),R2(220),R3(220),A(220,3),B(220,3),AREA(220),Z1(220)
     1,Z2(220),Z3(220),A12(220),A23(220),A31(220),GAMMA(220),DELTA(220)
C
      DIMENSION AMATRX(3,3)
C
C-----------------------------------------------------------------------------
C CALCULATE THE 3X3 D(I,J) MATRIX FOR ELEMENT L
C-----------------------------------------------------------------------------
C
C
      DO 200 L=1,NUMEL
      LL=ITYPE(L)
      COEFFA= (PI/30.0) * AREA(L)
C
      CC=-VSMAAC
      IF(LL .EQ.0) CC=VLMBDA
C
      AMATRX(1,1)=COEFFA    *(6.0*R1(L)+2.0*R2(L)+2.0*R3(L))
      AMATRX(1,2)=COEFFA    *(2.0*R1(L)+2.0*R2(L)+R3(L))
      AMATRX(1,3)=COEFFA    *(2.0*R1(L)+R2(L)+2.0*R3(L))
      AMATRX(2,1)=AMATRX(1,2)
      AMATRX(2,2)=COEFFA    *(2.0*R1(L)+6.0*R2(L)+2.0*R3(L))
      AMATRX(2,3)=COEFFA    *(R1(L)+2.0*R2(L)+2.0*R3(L))
      AMATRX(3,1)=AMATRX(1,3)
      AMATRX(3,2)=AMATRX(2,3)
      AMATRX(3,3)=COEFFA    *(2.0*R1(L)+2.0*R2(L)+6.0*R3(L))
C
   35 FORMAT(2X,3E20.10)
C     WRITE(6,35) ((AMATRX(I,J),J=1,3),I=1,3)
C-----------------------------------------------------------------------------
C STORE ELEMENT MATRIX, AMATRX, INTO SYSTEM MATRIX, BIGA
C-----------------------------------------------------------------------------
C
```

```
C
      DO 7050 K=1,3
      KK=ELNOD(L,K)
      DO 7040 I=1,3
      II=ELNOD(L,I)
      DO 7035 M=1,NCMPK
      KKM=NAME(KK,M)
      IF(KKM.EQ.II) GO TO 7032
 7035 CONTINUE
 7032       BAGAB(KK,  M)=BAGAB(KK,  M)+CC*AMATRX(K,I)
      BAGA(KK,  M)=BAGA(KK,  M)+AMATRX(K,I)
 7040 CONTINUE
 7050 CONTINUE
  200 CONTINUE
 8074 FORMAT(1P3E15.4)
      WRITE(6,8071)
 8071 FORMAT(//2X,'BAGA MATRIX FROM PEPSI')
      WRITE(6,8072) ((BAGA(I,J),J=1,NCMPK),I=1,NUMSNP)
      WRITE(6,8073)
C     WRITE(7,8076) ((BAGA(I,J),J=1,NCMPK),I=1,NUMSNP)
 8076 FORMAT(1P7E11.4)
 8073 FORMAT(//2X,'BAGAB MATRIX FROM PEPSI')
      WRITE(6,8072)(( BAGAB(I,J),J=1,NCMPK),I=1,NUMSNP)
 8072 FORMAT(1P7E15.4)
C
      RETURN
      END
```

```
      SUBROUTINE CRJISE
C***********************************************************************
C CRUISE CALCULATES THE SYSTEM MATRIX, BIGB, ASSOCIATED WITH THE
C 'DEL SQUARE' TERM.
C***********************************************************************
C
      INTEGER*2 NAME
      INTEGER*4 SYSNJD,ELEMNT,ELNOD,RHO
C
      COMMON/NUMB/ELNOD(220,3),NUMEL,NUMSNP,NFULEL,NELROW,NBP,IBP(30)
     1,NPROB,NTYPE,ITYPE(220)
      COMMON/CMCL/BAGA(132,7),BAGAB(132,7),SCRAPC(132,28),NDE,NCMPK,
     1NAME(132,7)
      COMMON/SOLVE/PI,VDF,VDC,VLMBDA,ZOMEGA,VSMAAC,SCALE
C
      COMMON R1(220),R2(220),R3(220),A(220,3),B(220,3),AREA(220),Z1(220)
     1,Z2(220),Z3(220),A12(220),A23(220),A31(220),GAMMA(220),DELTA(220)
C
      DIMENSION BMATRX(3,3)
C
C-----------------------------------------------------------------------
C CALCULATE THE 3X3 B(I,J) MATRIX FOR ELEMENT L
C-----------------------------------------------------------------------
C
C
      DO 200 L=1,NUMEL
      LL=ITYPE(L)
C
      COEFFB= PI / (6.0 * AREA(L) )
      CC=VDF
      IF(LL.NE.0) CC=VDC
C
      BMATRX(1,1)=COEFFB   *(-R1(L)*(2.0*B(L,1)**2+2.0*A(L,1)**2)-R2(L)*
     1(B(L,1)*B(L,2)+B(L,1)**2+A(L,1)*A(L,2)+A(L,1)**2)-R3(L)*(B(L,1)*
     2B(L,3)+B(L,1)**2+A(L,1)*A(L,3)+A(L,1)**2)+2.0*AREA(L)*B(L,1))
C
      BMATRX(1,2)=COEFFB   *(-R1(L)*(2.0*B(L,1)*B(L,2)+2.0*A(L,1)*
     1A(L,2))-R2(L)*(B(L,2)**2+B(L,1)*B(L,2)+A(L,2)**2+A(L,1)*A(L,2))-
     2R3(L)*(B(L,2)*B(L,3)+B(L,1)*B(L,2)+A(L,2)*A(L,3)+A(L,1)*A(L,2))+
     32.0*AREA(L)*B(L,2))
C
      BMATRX(1,3)=COEFFB   *(-R1(L)*(2.0*B(L,1)*B(L,3)+2.0*A(L,1)*
     1A(L,3))-R2(L)*(B(L,2)*B(L,3)+B(L,1)*B(L,3)+A(L,2)*A(L,3)+A(L,1)*
     2A(L,3))-R3(L)*(B(L,3)**2+B(L,1)*B(L,3)+A(L,3)**2+A(L,1)*A(L,3))+
     32.0*AREA(L)*B(L,3))
C
      BMATRX(2,1)=BMATRX(1,2)
C
```

```
      BMATRX(2,2)=COEFFB    *(-R1(L)*(B(L,2)**2+B(L,1)*B(L,2)+A(L,2)**2+
     1A(L,1)*A(L,2))-R2(L)*(2.0*B(L,2)**2+2.0*A(L,2)**2)-R3(L)*(B(L,3)*
     2B(L,2)+B(L,2)**2+A(L,3)*A(L,2)+A(L,2)**2)+2.0*AREA(L)*B(L,2))
C
      BMATRX(2,3)=COEFFB    *(-R1(L)*(B(L,2)*B(L,3)+B(L,1)*B(L,3)+A(L,2)*
     1A(L,3)+A(L,1)*A(L,3))-R2(L)*(2.0*B(L,2)*B(L,3)+2.0*A(L,2)*A(L,3))-
     2R3(L)*(B(L,3)**2+B(L,2)*B(L,3)+A(L,3)**2+A(L,2)*A(L,3))+
     32.0*AREA(L)*B(L,3))
C
      BMATRX(3,1)=BMATRX(1,3)
C
      BMATRX(3,2)=BMATRX(2,3)
C
      BMATRX(3,3)=COEFFB    *(-R1(L)*(B(L,3)**2+B(L,1)*B(L,3)+A(L,3)**2+
     1A(L,1)*A(L,3))-R2(L)*(B(L,3)**2+B(L,2)*B(L,3)+A(L,3)**2+A(L,2)*
     2A(L,3))-R3(L)*(2.0*B(L,3)**2+2.0*A(L,3)**2)+2.0*AREA(L)*B(L,3))
C     WRITE(6,35) ((BMATRX(I,J),J=1,3),I=1,3)
   35 FORMAT(2X,3E20.10)
C
C
C-----------------------------------------------------------------------
      DO 7050 K=1,3
      KK=ELNOD(L,K)
      DO 7040 I=1,3
      II=ELNOD(L,I)
      DO 7035 M=1,NCMPK
      KKM=NAME(KK,M)
      IF(KKM.EQ.II) GO TO 7032
 7035 CONTINUE
 7032       BAGAB(KK,  M)=BAGAB(KK,  M)+CC*BMATRX(K,I)
 7040 CONTINUE
 7050 CONTINUE
  200 CONTINUE
 8074 FORMAT(1P3E15.4)
      WRITE(6,8073)
 8073 FORMAT(//2X,'BAGAB MATRIX FROM CRUISE')
      WRITE(6,8072)(( BAGAB(I,J),J=1,NCMPK),I=1,NUMSNP)
 8072 FORMAT(1P7E15.4)
C     WRITE(7,8076) ((BAGAB(I,J),J=1,NCMPK),I=1,NUMSNP)
 8076 FORMAT(1P7E11.4)
C
      RETURN
C
      END
```

```
      SUBROUTINE PSISQ
C
C     THIS SUBROUTINE CALCULATES THE NON LINEAR PSI SQUARE TERM
C
      INTEGER*2 NAME
      INTEGER*4 SYSNOD,ELEMNT,ELNOD,RHO
C
      COMMON/NUMB/ELNOD(220,3),NUMEL,NUMSNP,NFULEL,NELROW,NBP,IBP(30)
     1,NPROB,NTYPE,ITYPE(220)
      COMMON/CMCL/BAGA(132,7),BAGAB(132,7),SCRAPC(132,28),NDE,NCMPK,
     1NAME(132,7)
      COMMON/SOLVE/PI,VDF,VDC,VLMBDA,ZOMEGA,VSMAAC,SCALE
C
      COMMON R1(220),R2(220),R3(220),A(220,3),B(220,3),AREA(220),Z1(220)
     1,Z2(220),Z3(220),A12(220),A23(220),A31(220),GAMMA(220),DELTA(220)
C
      DIMENSION CMATRX(3,9),CM(3,3,3)
C
C
C
      NCC=(NCMPK+1)*NCMPK/2
      DO 200 L=1,NUMEL
      LL=ITYPE(L)
      IF(LL.NE.0) GO TO 200
C
      CC=PI*AREA(L)/180.
C
      CMATRX(1,1)=CC*(24.*R1(L)+6.0*R2(L)+6.0*R3(L))
      CMATRX(1,2)=CC*(6.0*R1(L)+4.0*R2(L)+2.0*R3(L))
      CMATRX(1,3)=CC*(6.0*R1(L)+2.0*R2(L)+4.0*R3(L))
      CMATRX(1,4)=CMATRX(1,2)
      CMATRX(1,5)=CC*(4.0*R1(L)+6.0*R2(L)+2.0*R3(L))
      CMATRX(1,6)=CC*(2.0*R1(L)+2.0*R2(L)+2.0*R3(L))
      CMATRX(1,7)=CMATRX(1,3)
      CMATRX(1,8)=CMATRX(1,6)
      CMATRX(1,9)=CC*(4.0*R1(L)+2.0*R2(L)+6.0*R3(L))
      CMATRX(2,1)=CMATRX(1,2)
      CMATRX(2,2)=CMATRX(1,5)
      CMATRX(2,3)=CMATRX(1,6)
      CMATRX(2,4)=CMATRX(1,5)
      CMATRX(2,5)=CC*(6.0*R1(L)+24.*R2(L)+6.0*R3(L))
      CMATRX(2,6)=CC*(2.0*R1(L)+6.0*R2(L)+4.0*R3(L))
      CMATRX(2,7)=CMATRX(1,6)
      CMATRX(2,8)=CMATRX(2,6)
      CMATRX(2,9)=CC*(2.0*R1(L)+4.0*R2(L)+6.0*R3(L))
      CMATRX(3,1)=CMATRX(1,3)
      CMATRX(3,2)=CMATRX(1,6)
      CMATRX(3,3)=CMATRX(1,9)
```

```
      CMATRX(3,4)=CMATRX(1,6)
      CMATRX(3,5)=CMATRX(2,6)
      CMATRX(3,6)=CMATRX(2,9)
      CMATRX(3,7)=CMATRX(1,9)
      CMATRX(3,8)=CMATRX(2,9)
      CMATRX(3,9)=CC*(6.0*R1(L)+6.0*R2(L)+24.*R3(L))
C
C     IF(L.EQ.1) WRITE(6,888) ((I,J,CMATRX(I,J),J=1,9),I=1,3)
C     IF(L.EQ.1) WRITE(6,888) ((I,J,CMATRX(I,J),J=1,9),I=1,3)
  888 FORMAT(2X,'I=',I5,5X,'J=',I5,5X,'CMATRX=',1PE12.4)
C
      CM(1,1,1)=CMATRX(1,1)
      CM(1,1,2)=CMATRX(1,2)
      CM(1,1,3)=CMATRX(1,3)
      CM(1,2,1)=CMATRX(1,4)
      CM(1,2,2)=CMATRX(1,5)
      CM(1,2,3)=CMATRX(1,6)
      CM(1,3,1)=CMATRX(1,7)
      CM(1,3,2)=CMATRX(1,8)
      CM(1,3,3)=CMATRX(1,9)
      CM(2,1,1)=CMATRX(2,1)
      CM(2,1,2)=CMATRX(2,2)
      CM(2,1,3)=CMATRX(2,3)
      CM(2,2,1)=CMATRX(2,4)
      CM(2,2,2)=CMATRX(2,5)
      CM(2,2,3)=CMATRX(2,6)
      CM(2,3,1)=CMATRX(2,7)
      CM(2,3,2)=CMATRX(2,8)
      CM(2,3,3)=CMATRX(2,9)
      CM(3,1,1)=CMATRX(3,1)
      CM(3,1,2)=CMATRX(3,2)
      CM(3,1,3)=CMATRX(3,3)
      CM(3,2,1)=CMATRX(3,4)
      CM(3,2,2)=CMATRX(3,5)
      CM(3,2,3)=CMATRX(3,6)
      CM(3,3,1)=CMATRX(3,7)
      CM(3,3,2)=CMATRX(3,8)
      CM(3,3,3)=CMATRX(3,9)
C
C     IF(L.EQ.1) WRITE(6,889) (((K,I,J,CM(K,I,J),K=1,3),I=1,3),J=1,3)
  889 FORMAT(2X,'K=',I5,5X,'I=',I5,5X,'J=',I5,5X,'CM=',1PE12.4)
C
C
C
      DO 8050 K=1,3
      KK=ELNOD(L,K)
      DO 8040 I=1,3
      II=ELNOD(L,I)
```

```
      DO 8035 M=1,NCMPK
      KKM=NAME(KK,M)
      IF(KKM.EQ.0) GO TO 8032
      IF(KKM.EQ.II) GO TO 8032
 8035 CONTINUE
 8032 DO 8030 J=I,3
      IF(I.EQ.J) KMN=(M-1)*(2*NCMPK-M)/2+M
      IF(I.EQ.J) SCRAPC(KK,KMN)=SCRAPC(KK,KMN)+CM(K,I,J)
      IF(I.EQ.J) GO TO 8030
      JJ=ELNOD(L,J)
      DO 8020 N=1,NCMPK
      KKN=NAME(KK,N)
      IF(KKN.EQ.JJ) GO TO 8015
      IF(KKN.EQ.0) GO TO 8015
 8020 CONTINUE
 8015 MX=MAX0(M,N)
      MN=MIN0(M,N)
      KMN=(MN-1)*(NCMPK*2-MN)/2+MX
      SCRAPC(KK,KMN)=SCRAPC(KK,KMN)+CM(K,I,J)
      IF(I.NE.J) SCRAPC(KK,KMN)=SCRAPC(KK,KMN)+CM(K,I,J)
 8030 CONTINUE
 8040 CONTINUE
 8050 CONTINUE
  200 CONTINUE
      DO 8060 I=1,NUMSNP
      DO 8060 J=1,NCC
      SCRAPC(I,J)=+ZOMEGA*SCRAPC(I,J)*(1.E+14)
 8060 CONTINUE
      WRITE(6,8074)
 8074 FORMAT('SCRAPC FROM PSISQ')
      DO 8080 K=1,NUMSNP
      WRITE(6,8075) (SCRAPC(K,L),L=1,NCC)
C     WRITE(7,8076) (SCRAPC(K,L),L=1,NCC)
 8080 CONTINUE
 8075 FORMAT(1P7E15.4)
 8076 FORMAT(1P7E11.4)
C
      RETURN
C
      END
```

```
      SUBROUTINE LDASUB(Y,YL,T,TEND, NY,NL,M1,JSTART,KFLAG,MAXOR, IPRT,
     1 H,HMIN,HMAX,   RMSEPS, SAVE,YLSV,YMAX,ER,ESV,F1,DY)
      DIMENSION Y(7,1),YL(1),SAVE(7,1),YMAX(1),ER(1),YLSV(1),F1(1),A(7),
     1 PERT(6,3),COF(21),ESV(1),DY(1)
      DATA PERT/4.,9.,16.,25.,36.,49.,9.,16.,25.,36.,49.,64.,1.,1.,
     1 .25,2.7889E-2,1.70569E-3,6.83929E-5/
      DATA KZILCH/0/
      DATA COF/-1., -1.5,-.5, -1.833333,-1.,-.1666667, -2.083333,
     1 -1.458333,-.4166667,-.04166667, -2.833333,-1.875,-.7083333,
     2 -.125,-.008333333, -2.45,-2.255556,-1.208333,-.2430556,
     3 -.02916667,-.001388889/
    1 FORMAT(2I5,I2,1P2E10.2,7E14.6/(32X,7E14.6))
    2 FORMAT(32X,1P7E14.6)
    3 FORMAT(           '1  N =',I3,'    NL =',I3,'   RMSEPS =',1PD9.2,
     1 '     TEND =',D9.2,'    H =',D9.2//)
    4 FORMAT('    NS    NW Q     H',8X,'T    ',8X,'Y(1,*) AND YL(*)'//)
      IF(JSTART.GT.0)GO TO 60
      N = NY + NL
      LCOPYY = 7*NY
      LCOPYL = NL
      EPS = SQRT(FLOAT(M1))*RMSEPS
      MAXDER = MAXOR
      IF(MAXDER.GT.5)MAXDER = 6
      IF(IPRT.LE.0)GO TO 10
      PRINT 3, N,NL,RMSEPS,TEND,H
      PRINT 4
   10 CONTINUE
      NS = 0
      NW = 0
      DO 20 J=1,NY
         YMAX(J) = AMAX1(1.,ABS(Y(1,J)))
   20    Y(2,J) = Y(2,J)*H
      NQ = 1
      BR = 1.
      ASSIGN 100 TO IRET
  170 K = NQ*(NQ - 1)/2
      CALL COPYZ(A(2),COF(K+1),NQ)
  230 K = NQ + 1
      IDOUB = NQ
      ENQ1 = .5/NQ
      ENQ2 = .5/K
      ENQ3 = .5/(NQ + 2)
      PEPSH = EPS**2
      E = PERT(NQ,1)*PEPSH
      EUP = PERT(NQ,2)*PEPSH
      EDWN = PERT(NQ,3)*PEPSH
      BND = (EPS*ENQ3)**2
      IWEVAL = 1
```

```
      GO TO IRET,(100,250,630,751)
   60 IF(H.EQ.HNEW)GO TO 100
      R = H/HNEW
      ASSIGN 100 TO IRET
      GO TO 800
   70 KFLAG = -2
   80 JSTART = NQ
      HNEW = H
      RETURN
   90 NS = NS + 1
      IF(IPRT.LE.0)GO TO 95
      PRINT 1,NS,NW,NQ,H,T    ,(Y(1,I),I=1,NY)
      IF(NL.GT.0)PRINT 2,(YL(I),I=1,NL)
   95 CONTINUE
      IF(KFLAG.LT.0)GO TO 80
      IF(T    .GE.TEND)GO TO 80
      JSTART = 1
  100 CALL COPYZ(SAVE,Y,LCOPYY)
      CALL COPYZ(YLSV,YL,LCOPYL)
      RACUM = 1.
      KFLAG = 1
      HOLD = H
      NQOLD = NQ
      TOLD = T
      KZILCH = 1
  250 T = T + H
      HINV = 1./H
      DO 260  J=2,K
         J3 = K+J-1
         DO 260  J1=J,K
            J2 = J3 - J1
            DO 260  I=1,NY
  260          Y(J2,I) = Y(J2,I) + Y(J2+1,I)
      DO 270  I=1,NY
  270    ER(I) = 0.
      CALL NXSTP(Y,YL,T,HINV,A(2),EPS,NY,NL,DY,F1,ER,YMAX,BND,BR,IWEVAL,
     1 KFLAG,NW,KRET)
      GO TO (490,440,780),KRET
  440 T = TOLD
      IF(IWEVAL)445,455,450
  445 IF(H.LE.HMIN*1.00001)GO TO 460
  450 RACUM = RACUM*.25
  455 CONTINUE
      GO TO 750
  460 KFLAG = -3
  470 CALL COPYZ(Y,SAVE,LCOPYY)
      CALL COPYZ(YL,YLSV,LCOPYL)
      H = HOLD
```

```
      NQ = NQOLD
      GO TO 90
  490 D = 0.
      DO 500 I=1,M1
         YM = AMAX1(ABS(Y(1,I)),YMAX(I))
  500    D = D + (E3(I)/YM)**2
      IWEVAL = 0
      IF(D.GT.E) GO TJ 540
      IF(K.LT.3)GO TJ 520
      DO 510 J=3,K
         DO 510 I=1,NY
  510       Y(J,I) = Y(J,I) + A(J)*ER(I)
  520 KFLAG = 1
      IDOUB = IDOUB - 1
      IF(IDOUB)550,525,700
  525 CALL COPYZ(ESV,ER,M1)
      GO TO 700
  540 IF(JSTART.GT.))GO TO 548
      DO 544 I=1,NY
  544    SAVE(2,I) = Y(2,I)
  548 KFLAG = KFLAG - 2
      IF(H.LE.HMIN) 3O TO 740
      T = TOLD
      IF(KFLAG.LE.-5)GO TO 720
  550 PR2 = (D/E)**ENQ2*1.2
      L = 0
      IF(NQ.LE.1)GO TO 570
      D = 0.
      DO 560 J=1,M1
         YM = AMAX1(ABS(Y(1,J)),YMAX(J))
  560    D = D + (Y(K,J)/YM)**2
      PR1 = (D/EDWN)**ENQ1*1.3
      IF(PR1.GE.PR2)GO TO 570
      PR2 = PR1
      L = -1
  570 IF(KFLAG.LT.0 .OR. NQ.GE.MAXDER)GO TO 590
      D = 0
      DO 580 J=1,M1
         YM = AMAX1(ABS(Y(1,J)),YMAX(J))
  580   D = D + ((E3(J) - ESV(J))/YM)**2
      PR1 = (D/EUP)**ENQ3*1.4
      IF(PR1.GE.P3R2)GO TO 590
      PR2 = PR1
      L = 1
  590 R = 1./AMAX1(P32,1.E~5)
      IF(KFLAG.LT.0 .OR. R.GE.1.1)GO TO 600
      IDOUB = 9
      GO TO 700
```

```
600 NEWQ = NQ + L
    K = NEWQ + 1
    IF(NEWQ.LE.NQ)GO TO 620
    R1 = A(NEWQ)/FLOAT(NEWQ)
    DO 610 J=1,NY
610    Y(K,J) = ER(J)*R1
620 CONTINUE
    IDOUB = NQ
    IF(NEWQ.EQ.NQ)GO TO 630
    NQ = NEWQ
    ASSIGN 630 TO IRET
    GO TO 170
630 IF(KFLAG.GT.0)GO TO 670
    RACUM = RACUM*R
    GO TO 750
670 R = AMAX1(AMIN1(HMAX/H,R),HMIN/H)
    H = H*R
    IWEVAL = 1
    ASSIGN 700 TO IRET
    GO TO 800
700 DO 710 I=1,M1
710    YMAX(I) = AMAX1(ABS(Y(1,I)),YMAX(I))
    GO TO 90
720 IF(NQ.EQ.1)GO TO 735
    NQ = 1
    IDOUB = 1
    ASSIGN 751 TO IRET
    GO TO 170
735 NQOLD = 1
    KFLAG = -4
    GO TO 470
740 KFLAG = -1
    GO TO 90
750 H = HOLD*RACUM
    H = AMAX1(HMIN,AMIN1(H,HMAX))
751 RACUM = H/HOLD
    R1 = 1.
    DO 760 J=2,K
       R1 = R1*RACUM
       DO 760 I=1,NY
760       Y(J,I) = SAVE(J,I)*R1
    DO 770 I=1,NY
770    Y(1,I) = SAVE(1,I)
    CALL COPYZ(YL,YLSV,LCOPYL)
    IWEVAL = 1
    GO TO 250
780 KFLAG = -5
    GO TO 80
```

```
800 R1 = 1.
    DO 810 J=2,K
        R1 = R1*R
        DO 810 I=1,NY
810     Y(J,I) = Y(J,I)*R1
    GO TO IRET,(100,700)
    ENTRY REDSUB
    IF(KZILCH.EQ.0)RETURN
    DO 910 I=1,NY
        Y(1,I) = SAVE(1,I)
910     Y(2,I) = SAVE(2,I)/HOLD
    CALL COPYZ(YL,YLSV,LCOPYL)
    T = TOLD
    RETURN
    END
```

```
      SUBROUTINE NXSTP(Y,YL,T,HINV,A2,EPS,NY,NL,DY,F1,ER,YMAX,BND,BR,
     1 IWEVAL,KFLAG,NW,KRET)
      DIMENSION Y(7,1),YL(1),DY(1),ER(1),F1(1),YMAX(1), PW(110,7)
      COMMON/CMCL/A(132,7),B(132,7),C(132,28),N,NNZ,K(132,7)
      INTEGER*2 K
      DATA  SPD,SPDM1/1.05,.05/
      KRET = 1
      DO 430 L=1,3
      CALL DIFFUN(Y,YL,T,HINV,DY)
         IF(IWEVAL.LT.1)GO TO 280
      NOIT = N**2
      EPSS = EPS**2
      EPSA2 = EPSS*.0001
         CALL JACMAT(Y,YL,T,HINV,A2,EPS,NY,NL,DY,F1,PW)
         KFLAG = 1
         IWEVAL = -1
         NW = NW + 1
  280 DO 281 I=1,NY
  281 F1(I) = DY(I)/PW(I,1)
      DO 287 IT = 1,NOIT
      RCH = 0.
      CH = 0.
      DO 285 I=1,NY
      FN = DY(I)
      DO 284 J=2,NNZ
      IF(K(I,J).LE.0.OR.K(I,J).GT.NY)GO TO 284
      FN = FN - PW(I,J)*F1(K(I,J))
  284 CONTINUE
      FN = FN/PW(I,1)
      FN = FN*SPD - SPDM1*F1(I)
      ACH = F1(I) - FN
      CH = CH + (ACH/YMAX(I))**2
      RCH = RCH + (ACH/AMAX1(ABS(FN),EPS))**2
  285 F1(I) = FN
      IF(RCH.LT.EPSS)GO TO 288
      IF(CH.LE.EPSA2)GO TO 288
  287 CONTINUE
      KRET = 3
      RETURN
  288 CONTINUE
         IF(NL.LE.0)GO TO 300
         DO 290 I=1,NL
  290       YL(I) = YL(I) - F1(I+NY)
  300    CONTINUE
         DEL=0.
          DO 420 I=1,NY
             Y(1,I) = Y(1,I) - F1(I)
             Y(2,I) = Y(2,I) + A2*F1(I)
```

```
          ER(I) = ER(I) + F1(I)
          DEL = DEL + (F1(I)/AMAX1(YMAX(I),ABS(Y(1,I))))**2
420       CONTINUE
        IF(L.GE.2)BR = AMAX1(.9*BR,DEL/DEL1)
        DEL1 = DEL
        IF(AMIN1(DEL,BR*DEL*2.).LE.BND)GO TO 450
430     CONTINUE
      KRET = 2
      RETURN
450   CONTINUE
      RETURN
      END
```

```
      SUBROUTINE SDESOL(Y,YL,T,TEND,   NY,NL,M,JSKF,MAXDER, IPRT,   H,
     1 HMIN,HMAX,EPS,W)
      DIMENSION Y(7,1),YL(1),W(1)
      IF(JSKF.NE.0)GO TO 200
      DO 110 I=1,NY
  110 Y(2,I) = 0.
      CALL DIFFUN(Y,YL,0.,1.,W)
      CALL DERVAL(W,KRETR)
      IF(KRETR.NE.0)GO TO 300
      DO 120 I=1,NY
  120 Y(2,I) = W(I)
      N = NY +  NL
      NSV = 1
      NSVL = 7*NY + 1
      NYMAX = NSVL + NL
      NER = NYMAX + N
      NESV = NER + NY
      NF1 = NESV + NY
      NDY = NF1 + N
  200 JS = JSKF
      CALL LDASUB(Y,YL,T,TEND,  NY,NL,M,JS,KF,MAXDER,  IPRT,  H,HMIN,
     1 HMAX,EPS,W,W(NSVL),W(NYMAX),W(NER),W(NESV),W(NF1),W(NDY))
      JSKF = ISIGN(JS*10 + IABS(KF),KF)
      RETURN
  300 JSKF = -6
      RETURN
      END
```

```
      SUBROUTINE DERVAL(DY,KERET)
      COMMON/CMCL/A(132,7),B(132,7),C(132,28),N,NNZ,K(132,7)
      INTEGER*2 K
      DIMENSION DY(1)
      DO 100 I=1,N
      DY(I+N) = -DY(I)
  100 DY(I) = -DY(I)/A(I,1)
      DO 200 L=1,500
      DO 180 I=1,N
      DYN = DY(I+N)
      E = 0.
      DO 150 J=2,NNZ
      IF(K(I,J).LE.0.OR.K(I,J).GT.N)GO TO 150
      DYN = DYN - A(I,J)*DY(K(I,J))
  150 CONTINUE
      DYN = DYN/A(I,1)
      E = AMAX1(ABS((DYN - DY(I))/DYN),E)
  180 DY(I) = DYN
      IF(E.LT.1.E-4)GO TO 300
  200 CONTINUE
      PRINT 1,E
      IF(E.LE.1.E-2)GO TO 300
      KERET = 1
      RETURN
  300 KERET = 0
      RETURN
    1 FORMAT('  AFTER 500 ITERATIONS, E =',1PE10.3)
      END
```

```
      SUBROUTINE JACMAT(Y,YL,T,HINV,A2,EPS,NY,NL,DY,F1,PW)
      COMMON/CMCL/A(132,7),B(132,7),C(132,28),N,NNZ,K(132,7)
      INTEGER*2 K,P
      DIMENSION Y(7,1),YL(1),F1(1 ),DY(1),PW(110,1)
      DIMENSION P(8,8)
      DATA  P/64*0/,INITP/0/
      IF(INITP.EQ.NNZ)GO TO 99
      INITP = NNZ
      DO 98 L=1,NNZ
      DO 98 M = L,NNZ
   98 P(L,M) = M + (L - 1)*(2*NNZ - L)/2
   99 CONTINUE
      AH =-A2*HINV
      DO 300 I=1,NY
      DO 300 J=1,NNZ
      PW(I,J) = AH*A(I,J) - B(I,J)
       DO 100 L=1,J
      IF(K(I,L).LE.0)GO TO 295
  100 PW(I,J) = PW(I,J) + C(I,P(L,J))*Y(1,K(I,L))
      DO 200 M=J,NNZ
      IF(K(I,M).LE.0)GO TO 295
  200 PW(I,J) = PW(I,J) + C(I,P(J,M))*Y(1,K(I,M))
  295 CONTINUE
  300 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE COPYZ(S,Y,L)
      DIMENSION S(1),Y(1)
      IF(L.LE.0)RETURN
      DO 100 J=1,L
  100 S(J) = Y(J)
      RETURN
      END


      SUBROUTINE DIFFUN(Y,YL,T,HINV,DY)
      COMMON/CMCL/A(132,7),B(132,7),C(132,28),N,NNZ,K(132,7)
      INTEGER*2 K
      DIMENSION Y(7,1),YL(1),DY(1)
      DO 400 I=1,N
      DY(I) = 0.
      DO 300 J=1,NNZ
      IF(K(I,J).LE.0)GO TO 310
      DY(I) = DY(I) + Y(2,K(I,J))*A(I,J)*HINV - B(I,J)*Y(1,K(I,J)) +
     1 C(I,J)*Y(1,K(I,J))*Y(1,K(I,1))
  300 CONTINUE
  310 L = NNZ
      DO 360 J1=2,NNZ
      IF(K(I,J1).LE.0)GO TO 400
      DO 350 J2=J1,NNZ
      L = L + 1
      IF(K(I,J2).LE.0)GO TO 350
      DY(I) = DY(I) + C(I,L)*Y(1,K(I,J1))*Y(1,K(I,J2))
  350 CONTINUE
  360 CONTINUE
  400 CONTINUE
      RETURN
      END
```

```
C
C     ******************************************************************
C     *                                                                *
C     *                  PROGRAM FED-2-COMPACT                         *
C     *                                                                *
C     * FINITE ELEMENT SOLUTION OF NON-LINEAR REACTOR                  *
C     * DYNAMICS IN TWO DIMENSIONAL SPACE WITH PRE-                    *
C     * MULTIPLICATION TO REDUCE THE NON-LINEARITY.                    *
C     *                                                                *
C     *                                                                *
C     * SOLUTION METHOD                                                *
C     *                1-CRANKO (INCLUDED)                             *
C     *                                                                *
C     *       1- CRANKO ROUTINE BASED ON CRANK-NICOLSON                *
C     *          FORMULATION AND SOLVED BY GAUSS-SEIDEL                *
C     *          ITERATION.                                            *
C     *                                                                *
C     *                                                                *
C     * INPUT PARAMETERS AND DIMENSIONING REQUIREMENTS.                *
C     *                                                                *
C     * SINGLE ITEMS                                                   *
C     *    NUMSNP IS THE NUMBER OF SYSTEM NODAL POINTS.                *
C     *    NUMEL  IS THE NUMBER OF TRIANGULAR ELEMENTS.                *
C     *    NUPBP  IS THE NUMBER OF EXTERIOR BOUNDARY PTS.              *
C     *    NUFULEL IS THE NUMBER OF ELEMENTS IN THE CORE.              *
C     *    ERRVAL IS THE CONVERGENCE CRITERIA FOR CRANKO               *
C     *    TO IS THE PROBLEM START TIME                                *
C     *    TF IS THE PROBLEM FINISH TIME                               *
C     *    H  IS THE FIRST ATTEMPTED TIME INTERVAL                     *
C     *    HMIN IS THE SMALLEST TIME INTERVAL                          *
C     *    HMAX IS THE LARGEST ALLOWED TIME INTERVAL                   *
C     *    LCON IS THE MAX NUMBER OF NODE CONTRIBUTORS                 *
C     *                                                                *
C     * THESE ARE THE INPUT REQUIREMENTS                               *
C     *    TITLE  NUMEL NUPBP NUMSNP NFUEL IUPBP                       *
C     *                 ZNU FISFAC HBAR           ERRVAL               *
C     *    AFUEL TO H TF HMIN HMAX V D SGA SGF ALPHA                   *
C     *    PSIIV SYSNOD R Z ELEMNT ELNOD ITYPE LCON MNOD               *
C     *                                                                *
C     * ITYPE=0  DENOTES CORE ELEMENTS                                 *
C     * ITYPE=1  DENOTES BLANKET ELEMENTS                              *
C     *                                                                *
C     *                                                                *
C     *                                                                *
C-----------------------------------------------------------------------
C
```

```
C
C
C
C      THESE ARE THE DIMENSIONING REQUIREMENTS.
C             PART(NUMSNP,LCON),BIGA(NUMSNP,LCON),
C      BIGAB(NJMSNP,LCON),BIGC(NUMSNP,LCON),BIGCC(NUMSNP,LCON),
C     MNOD(NUMSNP,MNOD),V(NUMEL),D(NUMEL),SGA(NUMEL),
C     SGF(NUMEL),ALPHA(NUMEL),PSIIV(NUMSNP),PDPSI(NUMSNP),
C     ZLMBDA(NUMEL),VLMBDA(NUMEL),ZOMEGA(NUMEL),
C                    SYSNOD(NUMSNP),R(NUMSNP),Z(NUMSNP),
C      ELEMNT(NUMEL),ELNOD(NUMEL,3),ITYPE(NUMEL),R1(NUMEL),
C      Z1(NUMEL),R2(NUMEL),Z2(NJMEL),R3(NJMEL),Z3(NUMEL)
C             A(NJMEL,3),B(NUMEL,3)
C      ERROR(NUMSNP),CM(NUMEL,3,3,3),ALFA(3,3),PSTEP(NUMSNP),
C     BIGD(NUMSNP,LCON),BIGE(NUMSNP,LCON),ESTR(NUMSNP),VD(NUMEL)
C     YMAX(NUMSNP),IUPBP(NUPBP),PSI(8,NUMSNP),DPSI(NUMSNP),
C     AREA(NUMEL),PV(NUMSNP),HOLD(NUMSNP)
C-------------------------------------------------------------------------------
C
C
C
C
C-------- DECLARATION STATEMENTS -----------------------------------------------
C
C     NONLINEAR SUPERCRITICAL REACTOR
C     PROMPT FEEDBACK
C     FULLY REFLECTED SYSTEM
C     SPACE-DEPENDENT NEUTRONIC PROPERTIES
C
C
C*******************************************************************************@
C
```

```
      INTEGER*4 SYSNOD,ELEMNT,ELNOD
C
      DIMENSION TITLE(20)
C
C
      DIMENSION PART(132,7),BIGA(132,7),BIGAB(132,7),BIGC(132,7),
     1   BIGCC(132,7),MNOD(132,7),V(220),D(220),SGA(220),SGF(220),
     2   ALPHA(220),PSIIV(132),PDPSI(132),ZLMBDA(220),VLMBDA(220),
     3   ZOMEGA(220),RHO(220),SYSNOD(132),R(132),Z(132),ELEMNT(220),
     4   ELNOD(220,3),ITYPE(220),R1(220),Z1(220),R2(220),Z2(220),
     5   R3(220),Z3(220),A(220,3),PW(2244),BATCH(400,4),ERROR(132),
     6   CM(220,3,3,3),PSTEP(132),BIGD(132,7),BIGE(132,7),ESTR(132),
     7   VD(220),YMAX(132),IUPBP(22),PSI(8,132),AREA(220),PV(132),
     8   B(220,3),ASTR(132,7),HOLD(132),WP(132,132)
C
C
      READ(5,998) TITLE
      READ(5,10) NUMEL,NUPBP,NUMSNP,NFULEL
  998 FORMAT(20A4)
   10 FORMAT(8I10)
C
      LCON=7
      CALL ERRSET(207,256,0,1,1,209)
C
C
C
C     *                                                              *
             CALL FEDMAN (NJMEL,NUPBP,NUMSNP,NFULEL,LCON     ,TITLE,
     1                    PART,BIGA,BIGAB,BIGC,BIGCC,MNOD,V,D,SGA,SGF,
     2   ALPHA,PSIIV,PDPSI,ZLMBDA,VLMBDA,ZOMEGA,     SYSNOD,R,Z,ELEMNT,
     3   ELNOD,ITYPE,R1,Z1,R2,Z2,R3,Z3,A,B,          ERROR,CM,ALFA,
     4   PSTEP,BIGD,BIGE,ASTR,ESTR,VD,YMAX,IJPBP,AREA,PV,HOLD)
C     *                                                              *
      STOP
      END
```

```
      SUBROUTINE FEDMAN (NJMEL,NJPBP,NUMSNP,NFULEL,LCON     ,TITLE,
     1                PART,BIGA,BIGAB,BIGC,BIGCC,MNOD,V,D,SGA,SGF,
     2   ALPHA,PSIIV,PDPSI,ZLMBDA,VLMBDA,ZOMEGA,     SYSNOD,R,Z,ELEMNT,
     3   ELNOD,ITYPE,R1,Z1,R2,Z2,R3,Z3,A,B,          ERROR,CM,ALFA,
     4   PSTEP,BIGD,BIGE,ASTR,ESTR,VD,YMAX,IJPBP,AREA,PV,HOLD)
C     *                                                            *
C     *                                                            *
C     *          FINITE ELEMENT SOLUTION OF NONLINEAR              *
C     *       REACTOR DYNAMICS IN TWO-DIMENTIONAL SPACE            *
C     *                                                            *
C     *                                                            *
      INTEGER*4 SYSNOD,ELEMNT,ELNOD
C
      DIMENSION TITLE(20)
C
      DIMENSION PART(NUMSNP,LCON),BIGA(NUMSNP,LCON),
     1    BIGAB(NUMSNP,LCON),BIGC(NUMSNP,LCON),BIGCC(NUMSNP,LCON),
     2   MNOD(NUMSNP,LCON),V(NUMEL),D(NUMEL),SGA(NUMEL),
     3   SGF(NUMEL),ALPHA(NUMEL),PSIIV(NUMSNP),PDPSI(NUMSNP)
      DIMENSION ZLMBDA(NUMEL),VLMBDA(NUMEL),ZOMEGA(NUMEL),
     1             SYSNOD(NUMSNP),R(NUMSNP),Z(NUMSNP),
     2    ELEMNT(NUMEL),ELNOD(NUMEL,3),ITYPE(NUMEL),R1(NUMEL),
     3    Z1(NUMEL),R2(NUMEL),Z2(NUMEL),R3(NJMEL),Z3(NUMEL)
      DIMENSION A(NUMEL,3),B(NUMEL,3),
     1    ERROR(NUMSNP),CM(NUMEL,3,3,3),ALFA(3,3),PSTEP(NUMSNP),
     2   BIGD(NUMSNP,LCON),BIGE(NUMSNP,LCON),ESTR(NUMSNP),VD(NUMEL),
     3   YMAX(NUMSNP),IUPBP(NUPBP),AREA(NUMEL),PV(NUMSNP),HOLD(NUMSNP)
C
      DO 05 I=1,NUMSNP
      ERROR(I)=0.
       PDPSI(I)=0.
      YMAX(I)=1.
   05 CONTINUE
C
C
      NUF=NUMSNP/5
      XNP=NUMSNP
      XNUF=XNP/5.
      IF ((XNUF-FLOAT(NUF)) .LT. 1.)  NUF=NUF+1
C
C
C GENERAL PROBLEM DATA
C
      READ(5,12) (IJPBP(I),I=1,NUPBP)
      READ(5,10) MTH,MAXDER,NCOUNT
   10 FORMAT(8I10)
   12 FORMAT(16I5)
C
```

```
      WRITE(6,11) NUMEL,NUPBP,NUMSNP,NFULEL
   11 FORMAT(//2X,'# OF ELEMENTS=',I5//2X,'# OF UPPER BDRY NODAL POINTS=
     1',I5//2X,'# OF SYSTEM NODAL POINTS=',I5//2X,'# OF FUEL ELEMENTS=',
     2I5)
C
      READ(5,15) ZNJ,FISFAC,HBAR,EPSVAL,ERRVAL,AFUEL
      READ(5,19)TO,H,TF,HMIN,HMAX
      READ(5,15) (V(I),I=1,NUMEL)
      READ(5,15) (D(I),I=1,NUMEL)
      READ(5,15) (SGA(I),I=1,NUMEL)
      READ(5,15) (SGF(I),I=1,NUMEL)
      READ(5,1000)(ALPHA(I),I=1,NUMEL)
      READ(5,18) (PSIIV(I),I=1,NUMSNP)
   15 FORMAT(8G10.5)
 1000 FORMAT(5F15.8)
C
C
C     CALCULATE PHYSICAL CONSTANTS FROM NUCLEAR DATA
C
      PI= 3.1415927
C
      DO 25 I=1,NUMEL
      VD(I)=V(I)*D(I)
      ZLMBDA(I)=ZNU*SGF(I)/SGA(I)-1.
      VLMBDA(I)=V(I)*ZLMBDA(I)*SGA(I)
      ZOMEGA(I)=V(I)*SGA(I)*ALPHA(I)*FISFAC*SGF(I)/HBAR
   25 CONTINUE
C
   18 FORMAT(5E15.4)
   19 FORMAT(2E20.4,4G10.5)
  998 FORMAT(20A4)
C
C
C--------- GEOMETRY OF SYSTEM NODAL POINTS ---------------------------------------
C
      WRITE(6,40)
   40 FORMAT   (///1X,'GEOMETRY OF SYSTEM NODAL POINTS'///)
C
      READ(5,41) (SYSNOD(I),R(I),Z(I),I=1,NUMSNP)
 41   FORMAT(5X,I5,2F15.5)
C
C
      WRITE      (6,60) (SYSNOD(I),R(I),Z(I),I=1,NUMSNP)
   60 FORMAT (1X,'SYSTEM NODAL POINT NO. ',I3,5X,'R COORD.= ',F10.6,5X,'
     1Z COORD.= ',F10.6)
C
C
C
```

```
C*************************************************************************
C CORRESPONDENCE TABLE BETWEEN SYSTEM AND ELEMENT NODAL POINTS
C************************************************************************@
C
C
      WRITE(6,73)
   73 FORMAT(//2X,'CONNECTIVITY MATRIX',//,' EL #',33X,'TYPE'//)
      DO 75 I=1,NUMEL
      READ(5,76) ELEMNT(I),ELNOD(I,1),ELNOD(I,2),ELNOD(I,3),ITYPE(I)
      WRITE(6,77) ELEMNT(I),ELNOD(I,1),ELNOD(I,2),ELNOD(I,3),ITYPE(I)
   75 CONTINUE
   76 FORMAT (5I10)
   77 FORMAT (2X,I3,4I10)
C
C     READ AND WRITE THE HEXAGONAL CONNECTIVITY MATRIX.
C     LCON IS THE MAX NR OF NODAL POINT CONTRIBUTORS.
      WRITE(6,1111)
 1111 FORMAT(//2X,'HEXAGONAL CONNECTIVITY MATRIX',//' EL #')
      DO 776 J=1,NUMSNP
      READ (5,777) (MNOD(J,K),K=1,LCON)
  776 CONTINUE
  777 FORMAT  (9(2X,I3))
      DO 775 J=1,NUMSNP
      WRITE (6,777) (MNOD(J,K),K=1,LCON)
  775 CONTINUE
C
C
C     WHEN REQUIRED THE INITIAL DERIVATIVES ARE READ IN HERE,
C     INSERTED AT THE END OF THE DATA DECK IN FORMAT 771
C     READ AND WRITE THE INITIAL DIRRIVATIVES OF THE NODE POINTS.
      WRITE(6,2222)
 2222 FORMAT(//2X,'INITIAL DERIVATIVES OF NODE POINTS')
C     READ (5,771) (PDPSI(J),J=1,NUMSNP)
  771 FORMAT (4E15.5)
      WRITE (6,771) (PDPSI(J),J=1,NUMSNP)
C
C
C
C************************************************************************@
C CALCULATE GEOMETRY FOR EACH ELEMENT
C************************************************************************@
C
      WRITE(6,110)
  110 FORMAT (1X///1X,'GEOMETRY CALCULATIONS FOR EACH ELEMENT')
C
C-------------------------------------------------------------------------
C LOAD SYSTEM NODE COORDINATES (R,Z) INTO
C ELEMENT NODE COORDINATES (R1,R2,R3,Z1,Z2,Z3)
```

```
C
      WRITE(6,95)
   95 FORMAT (1X///1X,'ELEMENT',5X,'R1',9X,'Z1',9X,'R2',9X,'Z2',9X,'R3',
     19X,'Z3'/)
C
      DO 100 I=1,NUMEL
C
      J=ELNOD(I,1)
      R1(I)=R(J)
      Z1(I)=Z(J)
C
      K=ELNOD(I,2)
      R2(I)=R(K)
      Z2(I)=Z(K)
C
      L=ELNOD(I,3)
      R3(I)=R(L)
      Z3(I)=Z(L)
C
      WRITE      (6,105) I,R1(I),Z1(I),R2(I),Z2(I),R3(I),Z3(I)
C
  100 CONTINUE
  105 FORMAT (3X,I3,3X,    7(F10.6,1X))
C
C COMPUTE A1,A2,A3,B1,B2,B3,AREA FOR EACH ELEMENT
C-----------------------------------------------------------------------------
C
      WRITE       (6,120)
 120  FORMAT(1X///1X,'ELEMENT',5X,'A1',11X,'A2',11X,'A3',11X,'B1',11X,
     1'B2',11X,'B3',10X,'AREA'/)
C
      DO 140 I=1,NUMEL
      A(I,1)=R3(I)-R2(I)
      A(I,2)=R1(I)-R3(I)
      A(I,3)=R2(I)-R1(I)
      B(I,1)=Z2(I)-Z3(I)
      B(I,2)=Z3(I)-Z1(I)
      B(I,3)=Z1(I)-Z2(I)
      AREA(I)=0.5*(A(I,2)*B(I,1)-A(I,1)*B(I,2))
C
      WRITE(6,130) I,A(I,1),A(I,2),A(I,3),B(I,1),B(I,2),B(I,3),
     1AREA(I)
  140 CONTINUE
C
  130 FORMAT (3X,I3,3X,    7(F12.7,1X))
C
C
C
```

```
C--------- ZERO THE BIGA,     BIGC AND BIGAB MATRICES---------------------
C
C
C
      DO 194  KK=1,NUMSNP
      DO 193 II=1,LCON
      BIGA(KK,II)=0.
      BIGAB(KK,II)=0.0
      BIGC(KK,II)=.0
      PART(KK,II)=.0
  193 CONTINUE
  194 CONTINUE
C
C
C*************************************************************************
C
C
C------------------------------------------------------------------------
C      PEPSI CALCULATES THE BIGA MATRIX AND PART OF THE BIGAB
C------------------------------------------------------------------------
C
      CALL PEPSI (NJMEL,NUMSNP,R1,R2,R3,AREA,ELNOD,LCON,MNOD,
     1     BIGA,BIGA3,VLMBDA)
C
  195 FORMAT(//5X,'BIGA MATRIX',//)
      WRITE(6,195)
      WRITE(6,778)((BIGA(I,J),J=1,LCON) ,I=1,NUMSNP)
  778 FORMAT(2X,7(E14.5))
      WRITE(6,196)
  196 FORMAT(//5X,'BIGAB MATRIX FROM PEPSI, NO DEL**2 CONTRIBUTION',//)
      WRITE(6,778) ((BIGAB(I,J),J=1,LCON),I=1,NUMSNP)
C
C
C------------------------------------------------------------------------
C      CRUISE CALCULATES THE BIGAB MATRIX
C------------------------------------------------------------------------
C
      CALL CRUISE (NJMEL,NUMSNP,LCON,R1,R2,R3,AREA,ELNOD,
     1     BIGAB,MNOD,A,B,VD)
C
      WRITE(6,197)
  197 FORMAT(//5X,'BIGAB MATRIX FROM CRUISE, WITH DEL**2 TERM',//)
      WRITE(5,778) ((BIGAB(I,J),J=1,LCON),I=1,NUMSNP)
C
C------------------------------------------------------------------------
C
      DO 255 I=1,NUPBP
      II=IJPBP(I)
```

```
      DO 251 J=1,NUMSNP
      BIGAB(II,1)=.0
      BIGA(II,1)=1.
      DO 241 MX=2,LCON
      BIGA(II,MX)=.0
      BIGAB(II,MX)=.0
  241 CONTINUE
  251 CONTINUE
  255 CONTINUE
  753 FORMAT (///10X,'AB AND A MATRICIES AFTER BOUNDRY POINTS'/)
C
C
      WRITE (6,753)
C
      WRITE(6,5555)
 5555 FORMAT(///10X,'AB AFTER BOUNDARY POINTS'/)
      WRITE(6,778) ((BIGAB(I,J),J=1,LCON),I=1,NUMSNP)
C
      WRITE(6,5556)
 5556 FORMAT(///10X,'A AFTER BOUNDARY POINTS'/)
      WRITE(6,778)((BIGA(I,J),J=1,LCON) ,I=1,NUMSNP)
C
C
C
C     WRITE OUT NUCLEAR DATA
C
      WRITE(6,3105) ZNU,FISFAC,HBAR,EPSVAL,ERRVAL,AFUEL
 3105 FORMAT(//5X,'NUCLEAR DATA'/2X,'ZNU=',G12.6/2X,'FISFAC=',G12.6/2X,
     1 'HBAR=',G12.6/2X,'EPSVAL=',G12.6/2X,'ERRVAL=',G12.6/2X,'AFUEL=',
     2 G12.6)
      WRITE(6,3110)
 3110 FORMAT(1H0,2X,'ELEM',6X,'D',8X,'SGA',9X,'SGF',8X,'ALPHA',9X,'VD',
     1 7X,'ZLMBDA',7X,'VLMBDA',7X,'ZOMEGA',8X,'V')
      DO 3115 I=1,NUMEL
      WRITE(6,3120) (I,D(I),SGA(I),SGF(I),ALPHA(I),VD(I),ZLMBDA(I),
     1 VLMBDA(I),ZOMEGA(I),V(I))
 3115 CONTINUE
 3120 FORMAT(2X,I4,10(1PE12.4))
C
C
C     WRITE THE INITIAL VALUES OF THE FLUX
      WRITE(6,4444)
 4444 FORMAT(//2X,'INITIAL FLUX VALUES')
      WRITE (6,771) (PSIIV(J),J=1,NUMSNP)
C
C
C     *************************************************************
C
```

```
C
C
      WRITE(6,999) TITLE
  999 FORMAT(1H1,20A4)
      IF (MTH .EQ. 5)  WRITE (6,35)
   35 FORMAT (10X,'THIS PGM UTILIZES CRANK-NICOLSON METHOD TO SET',
     1   'UP A SET OF SIMULTANEOUS LINEAR EQNS WHICH ARE THEN'
     2   ,/10X,'SOLVED BY SUCCESSIVE ITERATION WITH IMPROVEMENT.')
C
      IF (MTH .EQ. 5) GO TO 319
  319 CONTINUE
C
C
C     CONSTRUCT THE BIGC MATRIX ON THE ELEMENT LEVEL
C-----------------------------------------------------------------------
C
      DO 200 L=1,NUMEL
C
      DO 583 I=1,3
      DO 582 J=1,3
      DO 581 K=1,3
      CM(L,I,J,K) =0.
  581 CONTINUE
  582 CONTINUE
  583 CONTINUE
      LL=ITYPE(L)
      IF (LL .NE. 0) GO TO 200
C
      CC=PI*AREA(L)/180.
C
      CM(L,3,3,3)=CC*(6.0*R1(L)+6.0*R2(L)+24.*R3(L))
      CM(L,3,3,2)=CC*(2.0*R1(L)+4.0*R2(L)+6.0*R3(L))
      CM(L,3,3,1)=CC*(4.0*R1(L)+2.0*R2(L)+6.0*R3(L))
      CM(L,3,2,3)=CC*(2.0*R1(L)+4.0*R2(L)+6.0*R3(L))
      CM(L,3,2,2)=CC*(2.0*R1(L)+6.0*R2(L)+4.0*R3(L))
      CM(L,3,2,1)=CC*(2.0*R1(L)+2.0*R2(L)+2.0*R3(L))
      CM(L,3,1,3)=CC*(4.0*R1(L)+2.0*R2(L)+6.0*R3(L))
      CM(L,3,1,2)=CC*(2.0*R1(L)+2.0*R2(L)+2.0*R3(L))
      CM(L,3,1,1)=CC*(6.0*R1(L)+2.0*R2(L)+4.0*R3(L))
      CM(L,2,3,3)=CC*(2.0*R1(L)+4.0*R2(L)+6.0*R3(L))
      CM(L,2,3,2)=CC*(2.0*R1(L)+6.0*R2(L)+4.0*R3(L))
      CM(L,2,3,1)=CC*(2.0*R1(L)+2.0*R2(L)+2.0*R3(L))
      CM(L,2,2,3)=CC*(2.0*R1(L)+6.0*R2(L)+4.0*R3(L))
      CM(L,2,2,2)=CC*(6.0*R1(L)+24.*R2(L)+6.0*R3(L))
      CM(L,2,2,1)=CC*(4.0*R1(L)+6.0*R2(L)+2.0*R3(L))
      CM(L,2,1,3)=CC*(2.0*R1(L)+2.0*R2(L)+2.0*R3(L))
      CM(L,2,1,2)=CC*(4.0*R1(L)+6.0*R2(L)+2.0*R3(L))
      CM(L,2,1,1)=CC*(6.0*R1(L)+4.0*R2(L)+2.0*R3(L))
```

```
      CM(L,1,3,3)=CC*(4.0*R1(L)+2.0*R2(L)+6.0*R3(L))
      CM(L,1,3,2)=CC*(2.0*R1(L)+2.0*R2(L)+2.0*R3(L))
      CM(L,1,3,1)=CC*(6.0*R1(L)+2.0*R2(L)+4.0*R3(L))
      CM(L,1,2,3)=CC*(2.0*R1(L)+2.0*R2(L)+2.0*R3(L))
      CM(L,1,2,2)=CC*(4.0*R1(L)+6.0*R2(L)+2.0*R3(L))
      CM(L,1,2,1)=CC*(6.0*R1(L)+4.0*R2(L)+2.0*R3(L))
      CM(L,1,1,3)=CC*(6.0*R1(L)+2.0*R2(L)+4.0*R3(L))
      CM(L,1,1,2)=CC*(6.0*R1(L)+4.0*R2(L)+2.0*R3(L))
      CM(L,1,1,1)=CC*(24.*R1(L)+6.0*R2(L)+6.0*R3(L))
C
  200 CONTINUE
C
  151 CONTINUE
C
C
      IF (MTH .EQ. 5) CALL CRANKD (NUMEL,NUMSNP,NUPBP,LCON,H,TO,
     1     ERRVAL,EPSVAL,IUPBP,PSIIV,ITYPE,ELNOD,CM,MNOD,ZOMEGA,
     2 BIGAB,BIGA,                    PV,PSTEP,BIGD,BIGE,ASTR,ESTR,
     3   BIGC,BIGCC,HOLD,TF)
C
C
      STOP
      END
```

```
      SUBROUTINE PEPSI (NUMEL,NUMSNP,R1,R2,R3,AREA,ELNOD,LCON,MNOD,
     1    BIGA,BIGAB,VLMBDA)
C***********************************************************************
C     PEPSI CALCULATES THE BIGA MATRIX AND PART OF THE BIGAB
C***********************************************************************
      INTEGER*4 ELNOD
C
      DIMENSION  R1(NJMEL),R2(NUMEL),R3(NJMEL),BIGA(NUMSNP,LCON),
     1     BIGAB(NUMSNP,LCON),MNOD(NUMSNP,LCON),AMATRX(3,3),
     2    VLMBDA(NUMEL),AREA(NUMEL),ELNOD(NUMEL,3)
C
      PI=3.1415927
C
C CALCULATE THE 3X3 D(I,J) MATRIX FOR ELEMENT L
C
      DO 200 L=1,NUMEL
      COEFFA=(PI/30.0)*AREA(L)
      AMATRX(1,1)=COEFFA    *(6.0*R1(L)+2.0*R2(L)+2.0*R3(L))
      AMATRX(1,2)=COEFFA    *(2.0*R1(L)+2.0*R2(L)+R3(L))
      AMATRX(1,3)=COEFFA    *(2.0*R1(L)+R2(L)+2.0*R3(L))
      AMATRX(2,1)=AMATRX(1,2)
      AMATRX(2,2)=COEFFA    *(2.0*R1(L)+6.0*R2(L)+2.0*R3(L))
      AMATRX(2,3)=COEFFA    *(R1(L)+2.0*R2(L)+2.0*R3(L))
      AMATRX(3,1)=AMATRX(1,3)
      AMATRX(3,2)=AMATRX(2,3)
      AMATRX(3,3)=COEFFA    *(2.0*R1(L)+2.0*R2(L)+6.0*R3(L))
C
C-----------------------------------------------------------------------
C STORE ELEMENT MATRIX, AMATRX, INTO SYSTEM MATRIX, BIGA
C-----------------------------------------------------------------------
C
      DO 20 K=1,3
      KK=ELNOD(L,K)
      DO 10 I=1,3
      II=ELNOD(L,I)
      DO 91 MX=1,LCON
      NOW =MX
      MM     =MNOD(KK,MX)
      IF (MM      .EQ. II) GO TO 92
   91 CONTINUE
   92 CONTINUE
      BIGA(KK,NOW)=BIGA(KK,NOW)+AMATRX(K,I)
      BIGAB(KK,NOW)=BIGAB(KK,NOW)+VLMBDA(L)*AMATRX(K,I)
   10 CONTINUE
   20 CONTINUE
  200 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE CRJISE (NUMEL,NUMSNP,LCON,R1,R2,R3,AREA,ELNOD,BIGAB,
     1    MNOD,A,B,VD)
C     *                                                             *
C
C     CRUISE CALCULATES THE BIGAB MATRIX
C-----------------------------------------------------------------------
C
      INTEGER*4 ELNOD
C
      DIMENSION R1(NJMEL),R2(NUMEL),R3(NUMEL),AREA(NUMEL),
     1    MNOD(NUMSVP,LCON),BIGAB(NUMSNP,LCON),BMATRX(3,3),
     2   ELNOD(NUMEL,3),A(NUMEL,3),B(NUMEL,3),VD(NUMEL)
C
      PI=3.1415927
C
C
C CALCULATE THE 3X3 B(I,J) MATRIX FOR ELEMENT L
C-----------------------------------------------------------------------
C
      DO 200 L=1,NUMEL
C
      COEFFB=PI*VD(L)/(6.0*AREA(L))
C
      BMATRX(1,1)=COEFFB    *(-R1(L)*(2.0*B(L,1)**2+2.0*A(L,1)**2)-R2(L)*
     1(B(L,1)*B(L,2)+B(L,1)**2+A(L,1)*A(L,2)+A(L,1)**2)-R3(L)*(B(L,1)*
     2B(L,3)+B(L,1)**2+A(L,1)*A(L,3)+A(L,1)**2)+2.0*AREA(L)*B(L,1))
C
      BMATRX(1,2)=COEFFB    *(-R1(L)*(2.0*B(L,1)*B(L,2)+2.0*A(L,1)*
     1A(L,2))-R2(L)*(B(L,2)**2+B(L,1)*B(L,2)+A(L,2)**2+A(L,1)*A(L,2))-
     2R3(L)*(B(L,2)*B(L,3)+B(L,1)*B(L,2)+A(L,2)*A(L,3)+A(L,1)*A(L,2))+
     32.0*AREA(L)*B(L,2))
C
      BMATRX(1,3)=COEFFB    *(-R1(L)*(2.0*B(L,1)*B(L,3)+2.0*A(L,1)*
     1A(L,3))-R2(L)*(B(L,2)*B(L,3)+B(L,1)*B(L,3)+A(L,2)*A(L,3)+A(L,1)*
     2A(L,3))-R3(L)*(B(L,3)**2+B(L,1)*B(L,3)+A(L,3)**2+A(L,1)*A(L,3))+
     32.0*AREA(L)*B(L,3))
C
      BMATRX(2,1)=BMATRX(1,2)
C
      BMATRX(2,2)=CJEFFB    *(-R1(L)*(B(L,2)**2+B(L,1)*B(L,2)+A(L,2)**2+
     1A(L,1)*A(L,2))-R2(L)*(2.0*B(L,2)**2+2.0*A(L,2)**2)-R3(L)*(B(L,3)*
     2B(L,2)+B(L,2)**2+A(L,3)*A(L,2)+A(L,2)**2)+2.0*AREA(L)*B(L,2))
C
      BMATRX(2,3)=COEFFB    *(-R1(L)*(B(L,2)*B(L,3)+B(L,1)*B(L,3)+A(L,2)*
     1A(L,3)+A(L,1)*A(L,3))-R2(L)*(2.0*B(L,2)*B(L,3)+2.0*A(L,2)*A(L,3))-
     2R3(L)*(B(L,3)**2+B(L,2)*B(L,3)+A(L,3)**2+A(L,2)*A(L,3))+
     32.0*AREA(L)*B(L,3))
C
```

```
      BMATRX(3,1)=BMATRX(1,3)
C
      BMATRX(3,2)=BMATRX(2,3)
C
      BMATRX(3,3)=COEFFB   *(-R1(L)*(B(L,3)**2+B(L,1)*B(L,3)+A(L,3)**2+
     1A(L,1)*A(L,3))-R2(L)*(B(L,3)**2+B(L,2)*B(L,3)+A(L,3)**2+A(L,2)*
     2A(L,3))-R3(L)*(2.0*B(L,3)**2+2.0*A(L,3)**2)+2.0*AREA(L)*B(L,3))
C
C
C STORE ELEMENT MATRIX, AMATRX, INTO SYSTEM MATRIX, BIGA
C--------------------------------------------------------------------------------
C
      DO 20 K=1,3
      KK=ELNOD(L,K)
      DO 10 I=1,3
      II=ELNOD(L,I)
      DO 91 MX=1,LCON
      NOW =MX
      MM    =MNOD(KK,MX)
      IF (MM      .EQ. II) GO TO 92
   91 CONTINUE
   92 CONTINUE
      BIGAB(KK,NOW)=BIGAB(KK,NOW)+BMATRX(K,I)
   10 CONTINUE
   20 CONTINUE
C
  200 CONTINUE
C
      RETURN
C
      END
```

```
      SUBROUTINE CRANKO (NJMEL,NJMSNP,NUPBP,LCON,H,TO,ERRVAL,
     1     EPSVAL,IUPBP,PSIIV,ITYPE,ELNOD,CM,MNOD,ZOMEGA,BIGAB,BIGA,
     2   PV,PSTEP,BIGD,BIGE,ASTR,ESTR,
     3   BIGC,BIGCC,HOLD,TF)
C
C
C
      INTEGER*4 ELNOD
C
      DIMENSION IUPBP(NUPBP),PSIIV(NUMSNP),ITYPE(NUMEL),
     1     ELNOD(NUMEL,3),CM(NUMEL,3,3,3),MNOD(NUMSNP,LCON),
     2   ZOMEGA(NUMEL),BIGAB(NUMSNP,LCON),BIGA(NUMSNP,LCON),
     3   PSTEP(NUMSNP),ALFA(3,3),PV(NUMSNP)
      DIMENSION BIGD(NUMSNP,LCON),BIGE(NUMSNP,LCON),
     1     ASTR(NUMSNP,LCON),ESTR(NUMSNP),BIGC(NUMSNP,LCON),
     2   BIGCC(NUMSNP,LCON),HOLD(NUMSNP)
C
C
C        DLT IS THE MAX TIME INTERVAL ATTEMPTED FOR ONE STEP.
C        EPSN IS THE CONVERGENCE CRITERA FOR  SOLN AT TIME T=T+DT
C
C
C        INITIALIZATION
C
      DLT=H
      PTIME=H
      T=TO
      LRGE = 1
      EPSN=ERRVAL
      STAR=EPSVAL
      NIT=0
      NUMEQ=NUMSNP-NJPBP
      MIN=NUMSNP/4
C
C
      NUF=NUMSNP/5
      XNP=NUMSNP
      XNUF=XNP/5.
      IF ((XNUF-FLOAT(NUF)) .LT. 1.)   NUF=NUF+1
C
      DO 05 I=1,NUMSNP
      PV(I)=.0
   05 CONTINUE
C
C
C     BUILD THE BIGCC MATRIX
C
  351 CONTINUE
```

```
C
      DO 07 I=1,NUPBP
      J=IUPBP(I)
      PSIIV(J)=0.
   07 CONTINUE
      DO 09 I=1,NUMSNP
      PSTEP(I)=PSIIV(I)
   09 CONTINUE
C
      DO 210 L=1,NUMEL
      LL=ITYPE(L)
      IF(LL .NE. 0) GO TO 210
      N1=ELNOD(L,1)
      N2=ELNOD(L,2)
      N3=ELNOD(L,3)
      DO 88 J=1,3
      DO 90 N=1,3
      ALFA(N,J)=PSIIV(N1)*CM(L,N,J,1)+PSIIV(N2)*CM(L,N,J,2)
     1    +PSIIV(N3)*CM(L,N,J,3)
   90 CONTINUE
   88 CONTINUE
      DO 150 K=1,3
      KK=ELNOD(L,K)
      DO 180 I=1,3
      II=ELNOD(L,I)
      DO 91 MX=1,LCON
      NOW =MX
      MM     =MNOD(KK,MX)
      IF (MM      .EQ. II) GO TO 92
   91 CONTINUE
   92 CONTINUE
      BIGC(KK,NOW)=BIGC(KK,NOW)+ALFA(K,I)*ZOMEGA(L)
  180 CONTINUE
  150 CONTINUE
  210 CONTINUE
C
C         INSERTION OF BOUNDARY POINTS
      DO 185 I=1,NUPBP
      II=IUPBP(I)
      DO 191 MX=1,LCON
      BIGC(II,MX)=.0
  191 CONTINUE
  185 CONTINUE
C
C
      DO 310 I=1,NUMSNP
      DO 310 J=1,LCON
      BIGCC(I,J)=BIGAB(I,J)-BIGC(I,J)
```

```
  310 CONTINUE
C
C
C         BEGIN STEPING OUT IN TIME.
C
      STP = 4.
      ITRY=0
C
C         COMPUTE PSI BASED ON A TRIAL DT.
      DO 55 JQ=1,12
C
C         FIRST COMPJTE (2/DT)*A=ASTR, ASTR-C=D, ASTR+D=E
      DS=2./DLT
      DO 15 KA=1,NUMSNP
      DO 13 KB=1,LCON
      ASTR(KA,KB)=DS*BIGA(KA,KB)
      BIGD(KA,KB)=ASTR(KA,KB)-BIGCC(KA,KB)
      BIGE(KA,KB)=ASTR(KA,KB)+BIGCC(KA,KB)
   13 CONTINUE
   15 CONTINUE
C
      DO 19 KA=1,NUMSNP
      ESTR(KA)=0.
      DO 17 KB=1,LCON
      NAME = MNOD(KA,KB)
      ESTR(KA)=ESTR(KA)+BIGE(KA,KB)*PSIIV(NAME)
   17 CONTINUE
   19 CONTINUE
C
C         THE SYSTEM IS NOW IS THE FAMILIAR FJRM D(I,J)*PV(J)=ESTR(J)
C         AND MAY BE SJLVED USING ANY TECHNIQJE FOR LINEAR SIMULTANEOUS
C         EQNS.  HERE GAUSS-SEIDEL ITERATION IS USED.
C
C         ACCOMPLISH THE FIRST ITERATION BASED ON THE PV VALUE AT THE
C         LAST SUCCESSFUL TIME POINT.  SECOND AND SUCCESSIVE ITERATIONS
C         ARE BASED JN JPDATED VALUED OF PV.  A TEST FOR CONVERGENCE IS
C         MADE, AND FAILURE RESULTS IN ANOTHER ATTEMPT WITH A SMALLER DT
C
C         CREATION OF ESTR(I)=BIGE(I,J)*PSIIV(I)
C         PERFORMED ONCE ON EACH ATTEMPT TO FIND A PROPER TIME INTERVAL.
C
      DO 45 MTRY=1,NUMEQ
      KT=0
      DO 25 K=1,NUMEQ
      HOLD(K)=0.
      PV(K)=0.
      DO 20 L=2,LCON
      NAME = MNOD(K,L)
```

```
      HOLD(K)= HOLD(K) + BIGD(K,L)*PSTEP(NAME)
   20 CONTINUE
      PV(K)=(ESTR(K)-HOLD(K))/BIGD(K,1)
      PDIF=(PV(K)-PSTEP(K))/PV(K)
   24 CONTINUE
      IF (ABS(PDIF) .LT. EPSN) KT =KT+1
      PSTEP(K)=PV(K)
   25 CONTINUE
      IF (KT .GE. NJMEQ)  GO TJ 65
   45 CONTINUE
C
C
  291 FORMAT (//10X,'NO SOLN FJUND IN INTERVAL ',G10.4,'  PLUS ',
     1   G10.4)
      WRITE(6,291) T,DLT
C
C        PENALTY --- MAKE THE INTERVAL EVEN SMALLER.
      DLT=DLT/STP
      STP=STP+2.
      ITRY=ITRY+1
   55 CONTINUE
C
C
      WRITE(6,292)
  292 FORMAT(/10X,'A SOLN IS NOT POSSIBLE.  THE PROGRAM SURRENDERS.')
C
      STOP
C
C
   65 CONTINUE
      T=T + DLT
      ITRA=MTRY+NUMEQ*ITRY
      WRITE(6,350) T,DLT,ITRA
  350 FORMAT   (5X,'T= ',G12.6,4X,'DT= ',G12.6,4X,
     1    'ITERATIONS REQUIRED = ',I3)
C
C        IF THE SOLN REQUIRED LESS ITERATIONS THAN PREVIOUSLY,
C        INCREASE THE SIZE OF THE INITIAL TIΜE STEP.
      LRGE = ITRA
      IF(ITRA.LT.LRGE.OR.ITRA.LT.MIN) DLT=DLT*1.2
C
      IF ((T-PTIME)/PTIME .LT. STAR)  GO TO 377
      PTIME=T
      WRITE (6,354)
  354 FORMAT(/(5(4X,'NODE',7X,'PSI',4X)))
      DO 355 I=1,NUF
      I1=I+NUF
      I2=I+2*NUF
```

```
      I3=I+3*NUF
      I4=I+4*NUF
      WRITE(6,356) (I,PV(I),I1,PV(I1),I2,PV(I2),I3,PV(I3),I4,PV(I4))
  355 CONTINUE
  356 FORMAT(5(4X,I3,3X,1PE12.4))
      WRITE(6,357)
  357 FORMAT(/10X)
  700 FORMAT (//1X,'VALUES OF IPT-1, IPT-2, IPT-3'/)
C
      NIT= 1 + NIT
      IF (NIT .GT. 400)  GO TO 377
  377 CONTINUE
C
      DO 27 MN=1,NUMSNP
      PSIIV(MN)=PV(MN)
      DO 28 I=1,LCON
      BIGC(MN,I)=.0
   28 CONTINUE
   27 CONTINUE
      IF (T .LT. TF) GO TO 351
  778 FORMAT (2X,8(E14.5))
  399 FORMAT (10X,I4)
      WRITE (6,399) NIT
      WRITE (3) BATCH
      WRITE (4) BATCH
      STOP
      END
```

```
C-----------DATA GENERATOR TO PROVIDE SYSTEM NODAL POINT
C            RADIAL AND AXIAL POSITION
C
C
      IMPLICIT REAL * 4 (A-H,O-Z),INTEGER * 4 (I-N)
      INTEGER * 4 SYSNOD,ELNOD
      DIMENSION R(150),Z(150),X(150),Y(150),SYSNOD(150),
     1   ELNOD(220,3)
C     READ IN GRID VALUES AND NUMBER OF NODES
C
1     READ(5,100) NH,NV
100   FORMAT(2I5)
      WRITE(6,200)
200   FORMAT('1')
      WRITE(6,300) NH,NV
300   FORMAT(2X,'NH =',I5,5X,'NV =',I5)
      READ(5,400) (X(I),I=1,NH)
      READ(5,400) (Y(J),J=1,NV)
400   FORMAT(15F5.1)
      WRITE(6,500) (X(I),I=1,NH)
      WRITE(6,501) (Y(J),J=1,NV)
500   FORMAT(//2X,'R',5X,14F8.3)
501   FORMAT(//2X,'Z',5X,14F8.3)
C
      NVH=NV*NH
      NN=NV-1
      K=0
      DO 10 I=1,NH
      DO 20 J=1,NN
      K=K+1
      SYSNOD(K)=K
      R(K)=X(I)
      Z(K)=Y(J)
20    CONTINUE
10    CONTINUE
      K=NVH-NH
      DO 60 I=1,NH
      K=K+1
      SYSNOD(K)=K
      R(K)=X(I)
      Z(K)=Y(NV)
60    CONTINUE
      WRITE(6,700)
700   FORMAT(/////5X,'NODE',11X,'R',11X,'Z')
      WRITE(6,600) (I,R(I),Z(I),I=1,NVH)
      WRITE(7,601) (I,R(I),Z(I),I=1,NVH)
600   FORMAT(/5X,I5,2F15.5)
601   FORMAT(5X,I5,2F15.5)
C
C
C     COMPUTE NODAL POINT CONNECTIVITY OF ELEMENTS
C
      LL=1
      K=1
      MM=0
      NHH=NH-1
      NVV=NV-2
      DO 30 I=1,NHH
      DO 40 J=1,NVV
      ELNOD(K,1)=LL
      ELNOD(K+1,1)=LL
      ELNOD(K,2)=MM+NV
      ELNOD(K+1,2)=LL+NV
      ELNOD(K,3)=ELNOD(K+1,2)
      ELNOD(K+1,3)=LL+1
      LL=LL+1
      K=K+2
      MM=MM+1
40    CONTINUE
      LL=LL+1
      MM=MM+1
30    CONTINUE
```

```
      DO 70 I=1,NHH
      ELNOD(K,1)=NN
      ELNOD(K+1,1)=NN
      ELNOD(K,2)=NN+NV-1
      ELNOD(K+1,2)=LL+NV
      ELNOD(K,3)=ELNOD(K+1,2)
      ELNOD(K+1,3)=MM+NV
      K=K+2
      NN=NN+NV-1
      LL=LL+1
      MM=MM+1
      NEL=K-1
70    CONTINUE
      WRITE(5,750)
750   FORMAT('1')
      WRITE(6,800)NEL
800   FORMAT(5X,'NUMBER OF ELEMENTS =',I4)
      WRITE(6,950)
950   FORMAT(/////10X,'CONNECTIVITY MATRIX')
      DO 50 I=1,NEL
      WRITE(6,900)I,(ELNOD(I,J),J=1,3)
      WRITE(7,901) I,(ELNOD(I,J),J=1,3)
50    CONTINUE
900   FORMAT(/4I10)
901   FORMAT(4I10)
      IF(NV.EQ.12)STOP
      GO TO 1
      END
```

```
C-----------NUCLEAR PRJPERTY DATA GENERATOR------------
C
C
      INTEGER * 4 NEL,ELEM,ITYPE
      DIMENSION V(22J),ALPHA(220),SGF(220),SGA(220),D(220),
     1   ITYPE(220),ELEM(220)
 1    READ(5,100) NEL
C         IDENTIFY CORE AND REFLECTOR ELEMENTS
      READ(5,200) (ITYPE(I),I=1,NEL)
 100  FORMAT(2I10)
 200  FORMAT(16I5)
      WRITE(6,400)
 400  FORMAT('1',2X,'ELEM',6X,'D',8X,'SGA',9X,'SGF',8X,
     1   'ALPHA',8X,'V')
 300  FORMAT(2X,I4,5(1PE12.4))
C
C         ASSIGN PROPERTY VALUES TO ELEMENTS
C
      DO 30 I=1,NEL
      ELEM(I)=I
      V(I)=4.8E+07
      ALPHA(I)=1.0E-05
      IF(ITYPE(I).EQ.0)GO TO 10
      D(I)=1.2
      SGA(I)=.008
      SGF(I)=0
      GO TJ 20
 10   D(I)=0.913
      SGA(I)=0.014
      SGF(I)=0.008
 20   WRITE(6,300)(I,J(I),SGA(I),SGF(I),ALPHA(I),V(I))
 30   CONTINJE
      WRITE(7,500)(V(I),I=1,NEL)
      WRITE(7,500)(D(I),I=1,NEL)
      WRITE(7,500)(SJA(I),I=1,NEL)
      WRITE(7,500)(SGF(I),I=1,NEL)
      WRITE(7,600)(ALPHA(I),I=1,NEL)
 500  FORMAT(8G10.5)
 600  FORMAT(5F15.8)
      IF(NEL.EQ.64)GJ TO 1
      IF(NEL.EQ.112)GO TO 1
      IF(NEL.EQ.220)STOP
      END
```

```
C ----------DATA GENERATOR TO PROVIDE NODAL NEIGHBOR
C           CONNECTIVITY
C
C
C
      INTEGER * 4 NV,NVH,LCON,NN,MM,LL,JJ,MNOD,II,KK,
     1   IJ,IK,IM,IN,NH,LI,LJ,LK
      DIMENSION MNOD(132,7)
C
C        READ IN INITIAL DATA
  1   READ(5,200) NV,NVH,LCON,NH
 200  FORMAT(4I5)
C        COMPUTE MATRIX COUNTERS
      M=NV+1
      N=NV-1
      NN=2*N
      MM=3*N
      II=4*N
      KK=5*N
      IJ=6*N
      IK=7*N
      IM=8*N
      IN=9*N
      LK=10*N
      LI=NVH-NH
      LJ=LI+1
      LL=LI-NV+2
C
C
C        CALCULATE COMPACTED NODAL NEIGHBOR CONNECTIVITY
C        MATRIX
C
      DO 10 I=1,NVH
      MNOD(I,1)=I
      MNOD(I,2)=I+1
      MNOD(I,3)=N+I
      MNOD(I,4)=NV+I
 10   CONTINUE
      DO 20 I=2,NVH
      MNOD(I,5)=I-1
 20   CONTINUE
      DO 30 I=NV,NVH
      MNOD(I,6)=I-N
 30   CONTINUE
      DO 40 I=M,NVH
      MNOD(I,7)=I-NV
 40   CONTINUE
      DO 50 I=1,NV
      MNOD(I,7)=0
 50   CONTINUE
      DO 60 I=1,N
      MNOD(I,6)=0
 60   CONTINUE
      MNOD(1,5)=0
      MNOD(N,2)=LI+1
      MNOD(N,4)=LI+2
      MNOD(NV,5)=0
      MNOD(NN,2)=LI+2
      MNOD(NN,4)=LI+3
      MNOD(NN+1,5)=0
      MNOD(NN+1,7)=0
      MNOD(MM,2)=LI+3
      MNOD(MM,4)=LI+4
      MNOD(MM+1,5)=0
      MNOD(MM+1,7)=0
      MNOD(LI+1,5)=0
      MNOD(NVH,2)=0
      MNOD(II,2)=LI+4
      MNOD(II,4)=LI+5
      MNOD(II+1,5)=0
      MNOD(II+1,7)=0
      IF(NVH.EQ.45)GO TO 15
      MNOD(KK,2)=LI+5
```

```
      MNOD(KK,4)=LI+6
      MNOD(KK+1,5)=0
      MNOD(KK+1,7)=0
      MNOD(IJ,2)=LI+6
      MNOD(IJ,4)=LI+7
      MNOD(IJ+1,5)=0
      MNOD(IJ+1,7)=0
      MNOD(IK,2)=LI+7
      MNOD(IK,4)=LI+8
      MNOD(IK+1,5)=0
      MNOD(IK+1,7)=0
      IF(NVH.EQ.72)GO TO 15
      MNOD(IM,2)=LI+8
      MNOD(IM,4)=LI+9
      MNOD(IM+1,5)=0
      MNOD(IM+1,7)=0
      MNOD(LK,2)=LI+10
      MNOD(LK,4)=LI+11
      MNOD(LK+1,5)=0
      MNOD(LK+1,7)=0
      MNOD(IN,2)=LI+9
      MNOD(IN,4)=LI+10
      MNOD(IN+1,5)=0
      MNOD(IN+1,7)=0
15    DO 70 I=LJ,NVH
      MNOD(I,6)=0
      MNOD(I,7)=0
70    CONTINUE
      DO 80 I=LL,LI
      MNOD(I,3)=0
80    CONTINUE
      DO 85 I=LL,LJ
      MNOD(I,4)=0
85    CONTINUE
      DO 95 I=LJ,NVH
      MNOD(I,3)=N
      IF(I.EQ.NVH)GO TO 95
      MNOD(I+1,4)=MNOD(I,3)
      N=N+NV-1
95    CONTINUE
      MNOD(LI,2)=NVH
      WRITE(6,300)
300   FORMAT(5X,'HEXAGONAL CONNECTIVITY',/' NODE')
      DO 90 I=1,NVH
      WRITE(6,100)(MNOD(I,J),J=1,LCON)
      WRITE(7,101)(MNOD(I,J),J=1,LCON)
90    CONTINUE
100   FORMAT(/9(2X,I3))
101   FORMAT(9(2X,I3))
      IF(NV.EQ.12)STOP
      GO TO 1
      END
```

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