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Neutronics Code Vale for Two-Dimensional Triagonal (Hexagonal) and Three-Dimensional Geometries

D. R. Vondy
T. B. Fowler

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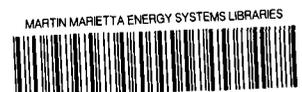
NEUTRONICS CODE VALE FOR TWO-DIMENSIONAL TRIAGONAL (HEXAGONAL)
AND THREE-DIMENSIONAL GEOMETRIES

D. R. Vondy
T. B. Fowler

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ABSTRACT

This report documents the computer code VALE designed to solve multigroup neutronics problems with the diffusion theory approximation to neutron transport for a triangular arrangement of mesh points on planes in two- and three-dimensional geometry. This code parallels the VENTURE neutronics code in the local computation system, making exposure and fuel management capabilities available. It uses and generates interface data files adopted in the cooperative effort sponsored by Reactor Physics RRT Division of the U.S. DOE. The programming in Fortran is straightforward, although data is transferred in blocks between auxiliary storage devices and main core, and direct access schemes are used. The size of problems which can be handled is essentially limited only by cost of calculation since the arrays are variably dimensioned. The memory requirement is held down while data transfer during iteration is increased only as necessary with problem size.

There is provision for the more common boundary conditions including the repeating boundary, 180° rotational symmetry, and the rotational symmetry conditions for the 30° , 60° , and 120° triangular grids on planes.

A variety of types of problems may be solved: the usual neutron flux eigenvalue problem, or a direct criticality search on the buckling, on a reciprocal velocity absorber (prompt mode), or on nuclide concentrations. The adjoint problem and fixed source problem may be solved, as well as the dominating higher harmonic, or the importance problem for an arbitrary fixed source.



COMPUTER CODE ABSTRACT

1. Program Identification: VALE, a code block for solving multigroup neutronics problems applying a discretized diffusion theory approximation to neutron transport.^a
2. Function: This code solves usual neutronics eigenvalue problems, and adjoint, higher harmonic fixed source, importance, and criticality search problems, treating up to three geometric dimensions. The code is used as a module of a local computation system.^{b,c}
3. Method of Solution: An inner, outer iteration procedure is used with several different data handling schemes programmed in parallel. Restrained line overrelaxation is used, and succeeding iterate flux sets may be accelerated by the Chebyshev process, and asymptotic extrapolation done when distinct error modes establish. Normally the eigenvalue of a problem is estimated each outer iteration from an overall neutron balance; however, source ratios are used in some situations. The reference formulation is mesh edge on planes of equally spaced mesh points, triangular geometry, on mesh centered planes. Macroscopic nuclear properties are calculated from nuclide concentrations and microscopic cross sections that may have a dependence on the local temperature.
4. Related Material: Standard interface data file specifications adopted in the U.S. DOE RRTD Reactor Physics code coordination effort are used with modest extensions.^d Input data must be read by a separate processor.
5. Restrictions: This code is quite thoroughly variably dimensioned. Generally the larger the problem, the more Input/Output required for iteration. Three-dimensional problems have been solved that contained more than 10^6 space, energy points.
6. Computer: This code has been run on IBM computers including the 3033, 360/91, and 360/195.

7. **Running Time:** Running time is directly related to problem size and inversely proportional to some measure of central processor and data transfer speeds. The basic rate of solution of eigenvalue problems is about 125 space energy points per second of central processor time on an IBM 3033. Thermal reactor lattice and cell problems normally require more time by perhaps a factor of two. Problems involving significant upscatter (multithermal-group treatment) require additional computer time, typically a factor of two or more.
8. **Programming Languages:** The programming is basically in the ASA 1966 FORTRAN language excepting certain extensions, especially those required for unindexed, mixed type block data transfers and direct access of data by record from disc. Known limitations of manufacturer's current compilers are not exceeded: for example, arrays are limited to three dimensions, dummy arguments in sub-routines to sixty. Special routines are used for certain functions including memory allocation, support of the data transfer procedures and to make available elapsed computer time for executing certain user options; these would require replacement for compatibility with a different operating system. The source deck consists of about 35,000 statements.
9. **Operating System:** The basic IBM MVT and MVS operating systems have been used with a FORTRAN IV, H level compiler version 21.8. Access capability of programs in the modular sense is essential to use the system of codes.
10. **Machine Requirements:** A 100,000 word core is needed, and preferably one much larger; auxiliary storage of the disc or drum type is essential, preferably several on different data channels. Typically the code uses 27 logical units.
11. **Authors:** D. R. Vondy
T. B. Fowler
Oak Ridge National Laboratory
P.O. Box X
Oak Ridge, Tennessee 37830

12. References:
- a. D. R. Vondy and T. B. Fowler, "Neutronics Code VALE for Two-Dimensional Triagonal (Hexagonal) and Three-Dimensional Geometries," ORNL-5792
 - b. D. R. Vondy, T. B. Fowler, and G. W. Cunningham, III, "The BOLD VENTURE Computation System for Nuclear Reactor Core Analysis, Version III," ORNL-5711 (1981).
 - c. D. R. Vondy, T. B. Fowler, G. W. Cunningham, III, and L. M. Petrie, "A Computation System for Nuclear Reactor Core Analysis," ERDA Report, ORNL-5158 (1977).
 - d. G. E. Bosler, R. D. O'Dell, and W. M. Resnik, "LA SIP-III, A Generalized Processor for Standard Interface Files," ERDA Report, LA-6280 MS (April 1976).
13. Material Available: The package submitted to the National Energy Software Center at ANL, DOE sponsored, includes Fortran card image source decks for the VALE neutronics code, assembly language routines for use on a compatible computer, and an input data deck for sample problems plus the edit from the computer run for these. Other released members of the computation system are available.

I. INTRODUCTION

The VENTURE¹ code was the latest in a series of diffusion theory neutronics codes implemented at ORNL. It applied the mesh centered neutron balance finite-difference formulation. We yet find that this formulation is often cost effective, especially in comparison with other difference formulations, including so-called higher order schemes like the linear finite-element, or the simpler schemes like the nodal approach when account must be taken of a large number of geometric differences. Still, in triangular geometry (used primarily to treat the plane through hexagonal assemblies), the use of only three nearest neighbors of a point for the neutron transport approximation is poor, sometimes seriously inaccurate. Locating the mesh points at the material junctures, mesh edge, places one point at each corner of a hexagonal fuel assembly and one in the center in the coarsest modeling, effectively 3 points per hex. Each point thus has six neighbors, and an improvement over the leakage approximation of the mesh centered formulation is expected. Indeed with the mesh centered formulation, the flux level at other points that lie nearby is not accounted for in the leakage approximation. With the mesh-edge location, typically 3 points/hex are used compared with 6 points/hex for the mesh centered formulation, and the extra computation cost of tighter coupling is offset by the fewer points required. Furthermore, it is often possible to model many situations with a 30° pie-shaped repeating section, thereby reducing the cost of calculations by a factor of two over that to treat a 60° section, especially important for three-dimension problems. Further gain comes about by discarding the requirement to treat a parallelogram thereby eliminating a large number of inactive points. Maximum advantage is taken of a uniform mesh point arrangement on planes (triangular), and with these located between interfaces axially (mesh centered planes), the calculational burden is minimized.

Some gain in accuracy is often possible with a parametric formulation that allows part of the absorption term to lie off the matrix diagonal (linear flux and linear finite element equation formulation methods), an

option implemented with a parametrized fractional off-diagonal term. Paying the cost penalty of a consistent source calculation is deemed necessary, but parallel procedures are used so that the base calculation is not penalized.

A secondary objective of this effort was to develop a code that could serve as the starting point to treat the non-uniform arrangement of mesh points at the apexes of triangles of uniform properties. This capability is much needed in analysis to treat several different classes of problems, especially those involving mixed geometries: a round rod in a hexagonal fuel assembly, a cylindrical pressure vessel around a core of hexagonal fuel assemblies, a bowed core, etc. The mesh centered formulation should not be used because distortion of the mesh causes nearest neighbors to change with the obvious consequence that the representation can have a very low accuracy. Effort toward this future goal indeed was the primary impetus for this work.

It is not unusual to find that in some applications many axial planes of points are required to reduce the associated error of discretization to an acceptable level. Thus an integral part of this work was to identify and implement a preferred coarse mesh formulation for the axial coordinate as an alternative to the finite-difference formulation. This effort is yet in progress at the time of preparation of this document.

We assume that certain reports are readily available and rely on them for much documentation, such as the user's guide to the system codes² and the VENTURE code report.¹ Here only specific aspects are covered, differences from VENTURE, and exceptions.

The VALE code is in routine production use locally and remotely via terminal in the local system of codes for computation.³ The input processor⁴ is used for primary user problem description input, although special processors also prove very useful.² Certain modifications to the interface data files were necessary, as to block the data for a plane of mesh points into a simple record (m points instead of rectangular ixj), and a new geometry file is defined, TRIGOM.²

In this computation system the codes are executed in an order prescribed by the user with instructions to a control module. Not every sequence of execution would be useful or even viable, but no restraints are imposed that would limit flexibility. Loops over the successive use of a series of codes is usual, and problems are solved that require such a continuing sequence of calculations to produce a converged solution. In this sense the VENTURE and the VALE neutronics codes serve the same role. Only one would be used in a specific application. VALE provides parallel capability to VENTURE, excluding the perturbation capability of the latter. It has the capability to perform criticality searches, solve regular and adjoint problems, the fundamental and the dominate higher harmonic, and importance problems given an arbitrary fixed source that may have negative components, treat equilibrium xenon and to apply a temperature correlation on microscopic cross sections. The other codes in this system are compatible except for the perturbation code that remains to be upgraded.

In the following the application information, problem definition, and programming information are discussed. A sample problem is described in the Appendix with the input data and computer printout displayed.

Approximately three man years went into implementing the VALE code.

II. APPLICATION INFORMATION

This section presents information about the code that is of special interest to the user.

A. Program Description

This code solves neutronics problems by applying the diffusion theory approximation to neutron transport.

It is a member of the local modular nuclear reactor computation system and does not read data from the user input stream. Information is supplied via standard interface data files, and results are printed and written on interface data files. A user's flow diagram is presented as Fig. 1 indicating the major tasks and the calculational path.

B. Program Considerations

Figure 2 lists the contents of the record DTNINS of the interface data file CONTRL showing the instructions to VALE and lists the programmed options. This record of the file CONTRL may be created with the input processor,⁴ or alternatively with the special processor DUTLIN.²

Figure 3 documents the contents of the special geometry file TRIGOM.

We found it necessary for the most efficient use of computer memory to avoid the requirement of a parallelepiped arrangement of mesh points. Instead of specifying I columns and J rows of mesh points on planes, giving IJ points, the number of points on a plane is specified and simple descriptions are given that identify the arrangements and relate neighbors on a 60° grid, equilateral arrangement of points. The special file TRIGOM is used to describe the geometry. Planes of mesh points are located between material interfaces, mesh centered.

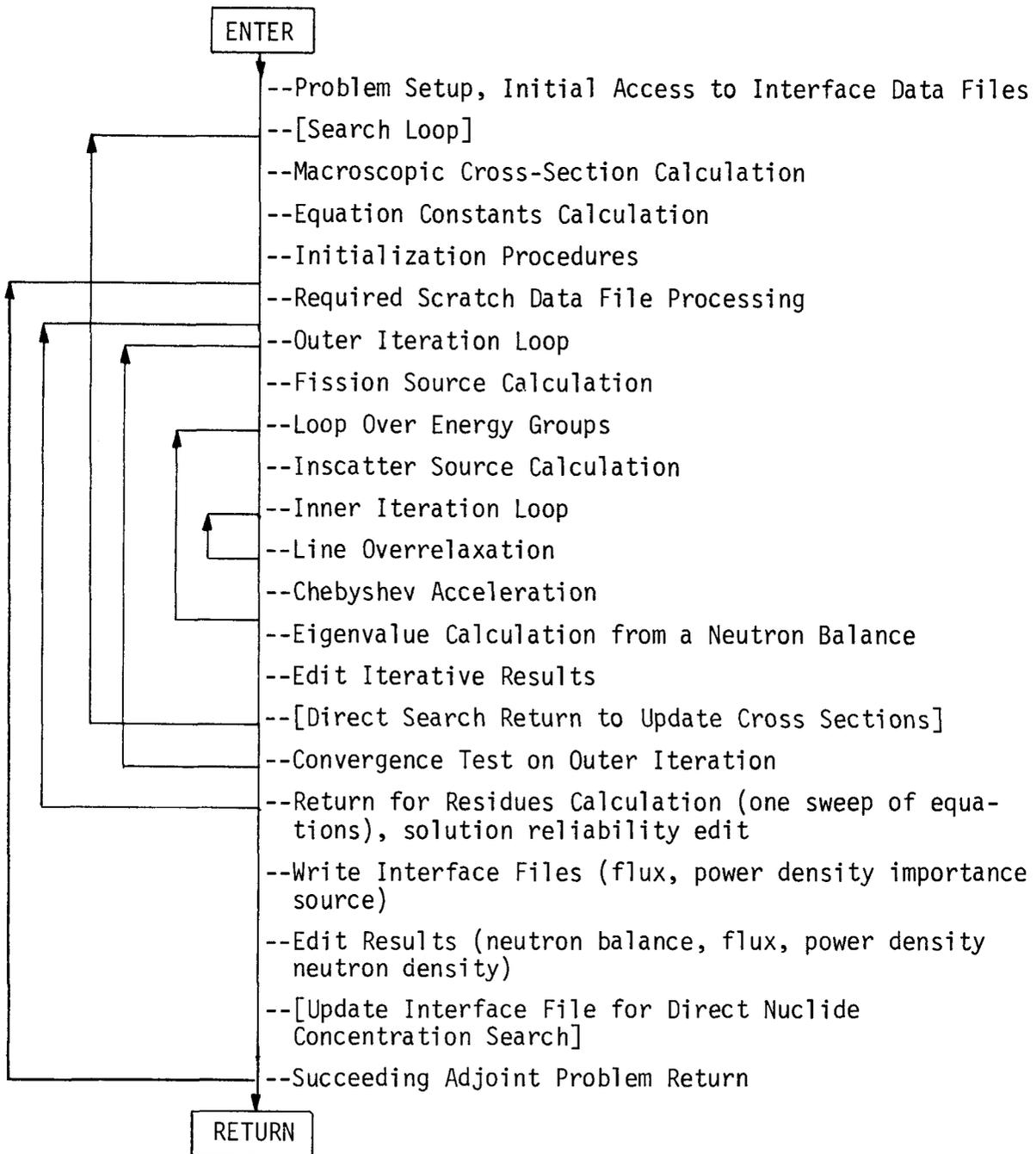


Fig. 1. User flow chart, VALE neutronics code.

```

C
CR          NEUTRONICS INSTRUCTIONS
C
CL          DTNINS, (XX(I),I=1,100), (IX(I),I=1,100)
C
CW          101*MULT + 100
C
CD          DTNINS          NEUTRONICS CONTROL IDENTIFIER, A(6)
CD          XX(1)          REFERENCE REAL TIME, DAYS
CD          XX(2)          MACHINE TIME ALLOWED FOR SOLUTION, MIN
CD                          (ITERATION TERMINATED IF TIME EXCEEDED)
CD          XX(3)          CYCLE TIME IN MINUTES TO WRITE RESTART DATA
CD                          NOT DONE IF 0, ALWAYS DONE AT END IF NON-ZERO
CD                          THIS OPTION IS IMPLIMENTED IN VENTURE ONLY.
CD                          AN EFFECTIVE RESTART PROCEDURE FOR VALE
CD                          (OR VENTRUE) IS TO FLAG IX(9)=2 AND ALSO
CD                          IX(16).GT.0 IF CHANGES IN THE PROBLEM
CD                          ARE MINOR
CD          XX(4)          POWER LEVEL OF REACTOR, WATTS THERMAL
CD                          IF 0, NORMALIZATION IS TO ONE SOURCE NEUTRON
CD                          (WATT-SEC/FISS DEFAULTED TO 3.2E-11 IF ZERO)
CD          XX(5)          ENERGY CONVERSION FACTOR, FISSION TO THERMAL
CD          XX(6)          FRACTION OF REACTOR TREATED
CD          XX(7)          SPECIFIED MULTIPLICATION FACTOR FOR SEARCH IF
CD                          NON-ZERO
CD          XX(8)          SPECIFIED OVERRELAXATION COEFFICIENT IF NON-ZERO
CD          XX(9)          ESTIMATE OF THE EIGENVALUE FOR CHEBYCHEV
CD                          ACCELERATION ON OUTER ITERATIONS
CD          XX(10)         ESTIMATE OF THE LOWER LIMIT OF THE SPECTRUM OF
CD                          EIGENVALUES FOR CHEBYCHEV ACCELERATION
CD          XX(11)         CONVERGENCE CRITERIA ON INTEGRAL QUANTITIES
CD                          MAXIMUM RELATIVE CHANGE ON OUTER ITERATION
CD          XX(12)         CONVERGENCE CRITERIA ON LOCAL OR POINT VARIABLES
CD                          MAXIMUM RELATIVE POINT FLUX CHANGE ON OUTER
CD                          ITERATION (.00005)
CD          XX(13)         CONSTANT BUCKLING VALUE WHICH OVERRIDES THE DATA
CD                          IN GEODST FILE IF NON-ZERO
CD          XX(14)         RESERVED
CD          XX(15)         RESERVED
CD          XX(16)         RESERVED
CD          XX(17)         RESERVED
CD          XX(18)         RESERVED
CD          XX(19)         LIMITING VALUE OF ANY DIFFUSION COEFFICIENT
CD                          IF NOT ZERO - DEFAULT 100.0
CD          XX(20)         PARAMETER FOR HIGHER ORDER VALE SOLUTIONa
CD                          1/6 = 0.1666666 - TAYLOR SERIES
CD                          7/36 = 0.194444 - LINEAR FLUX
CD                          1/4 = 0.25 - LINEAR FINITE ELEMENT
CD                          IF MADE NEGATIVE, THE HIGHER ORDER APPROXIMATION
CD                          IS NOT APPLIED TO THE SOURCE
CD          XX(21)         THE ZONE AND GROUP DIFFUSION COEFFICIENTS
CD                          THROUGH ZONE IX(43) (SEE BELOW) WILL BE
CD                          MULTIPLIED BY THIS NUMBER IF NOT ZERO
CD          XX(22)         THIS NUMBER WILL BE ADDED TO THE ZONE AND
CD                          GROUP DIFFUSION COEFFICIENTS THROUGH ZONE
CD                          IX(43) AFTER XX(21) IS APPLIED IF NOT ZERO
CD          XX(23)         XENON+IODINE YIELD FRACTON FOR EQUILIBRIUM
CD                          XENON - IF IX(69) GT 0
CD          XX(24)         'Q' FACTOR FOR POWER WEIGHTED REGULAR TIMES
CD                          ADJOINT FLUX

```

^aValue constrained at each group to ensure positive flux solution.

Fig. 2. Specifications for DTNINS Record in Interface File CONTRL.

CD XX(25) REFERENCE TEMPERATURE (DEGREES C) OF THE
 CD NEXT-TO-LATEST VERSION 'GRUPXS' CROSS SECTION
 CD INTERFACE FILE
 CD XX(26) REFERENCE TEMPERATURE (DEGREES C) OF THE
 CD LATEST VERSION 'GRUPXS' CROSS SECTION INTERFACE
 CD FILE
 CD XX(27) CORRELATION PARAMETER FOR THE ARCTANGENT
 CD DEPENDENCE OF CROSS SECTIONS ON ZONE
 CD TEMPERATURES (LINEAR CORRELATION IF 0.0)
 CD XX(28) FACTOR APPLIED TO SPACE INTERPOLATION SLOPE
 CD FOR SPACE-ENERGY REBALANCE. IF ZERO, NO
 CD SPACE INTERPOLATION IS DONE, FOR VENTURE ONLY
 CD XX(29) FACTOR APPLIED TO THE FINAL REBALANCE FACTORS
 CD FOR SPACE-ENERGY REBALANCE - DEFAULT 1.0
 CD FOR VALE, THIS IS A FACTOR APPLIED TO THE AXIAL
 CD DIFFUSION COEFFICIENTS FOR 3-D PROBLEMS IF
 CD NOT ZERO
 CD XX(30) XENON DECAY CONSTANT FOR EQUILIBRIUM XENON -
 CD IF IX(69) GT 0
 CD XX(31) - XX(100) RESERVED
 C
 CD IX(1) INDICATOR THAT THE CODE BLOCK HAS INPUT DATA
 CD NOT CONTAINED IN THE STANDARD INTERFACE FILES
 CD OTHER THAN THIS BLOCK OF DATA IF .GT.0
 CD IX(2) RESTART OPTIONS- RESTART USING DATA FROM AN
 CD OLD CASE IF .GT. 0, REQUIRES SPECIAL RESTART
 CD DATA FILE
 CD FOR VALE SEE XX(3)
 CD IX(3) REFERENCE COUNT ON PROBLEMS (CYCLE NUMBER)
 CD IX(4) FORMULATION OPTIONS
 C
 CD VENTURE, MESH CENTERED FINITE-DIFFERENCE
 CD 1 - DIFFUSION THEORY (FUNDAMENTAL)
 CD 2 - SIMPLE P1 APPROXIMATELY (FUNDAMENTAL)
 CD -1 - DIFFUSION THEORY SOLUTION FOR THE DOMINANT
 CD ALLOWED FIRST HARMONIC REQUIRING THE
 CD FUNDAMENTAL REGULAR AND ADJOINT FLUX FILES
 CD 'RTFLUX' AND 'ATFLUX'. THE FIRST ITERATE
 CD SOURCE DISTRIBUTION WILL BE SKEWED TO
 CD EXCITE ALL SPACIAL FLUX HARMONICS SO
 CD THAT THE DOMINANT WILL SURFACE.
 CD -2 - SAME AS -1 BUT THE FIRST ITERATE SOURCE
 CD WILL NOT BE SKEWED. USUALLY FOR THIS
 CD OPTION THE 'RTFLUX' FILE MUST EITHER BE A
 CD UNIFORM FLUX DISTRIBUTION (IN WHICH CASE
 CD THE SOLUTION MAY OR MAY NOT BE FOR THE
 CD DOMINANT HARMONIC) OR AN INITIAL ESTIMATE
 CD OF THE DOMINANT HARMONIC FLUX DISTRIBUTION
 CD (FOR EXAMPLE, A COSINE FROM -1 TO +1
 CD ALONG A COORDINATE WHILE PERHAPS UNIFORM
 CD IN OTHER DIRECTIONS) THAT WILL CAUSE THE
 CD DESIRED HARMONIC TO SURFACE. THIS MAY
 CD ESPECIALLY BE USEFUL TO ACCELERATE
 CD CONVERGENCE WHEN TWO OF THE SPACIAL
 CD HARMONIC EIGENVALUES ARE NEARLY EQUAL.
 CD -10 - SPECIAL DOMINANT HARMONIC SOLUTION (RZ)
 CD ADJUSTING THE TOTAL LOSS TERM TO ACCOUNT
 CD FOR THE AZIMUTHAL HARMONIC
 C
 CD VALE, MESH EDGE TRIANGULAR

Fig. 2. (CONTINUED)

```

CD      1 - DIFFUSION THEORY (FUNDAMENTAL)
CD     -1 - DIFFUSION THEORY (DOMINANT HARMONIC)
CD     -2 - SAME AS -1 BUT THE FIRST ITERATE SOURCE
CD           WILL NOT BE SKEWED
CD      3 - HIGHER ORDER (FUNDAMENTAL) - SEE IX(20)
CD     -3 - HIGHER ORDER (DOMINATE HARMONIC)
CD     -4 - SAME AS -3 BUT THE FIRST ITERATE SOURCE
CD           WILL NOT BE SKEWED
C
CD     VANCER, MESH EDGE (2- AND 3-D SLAB INFO SHOWN )
CD      1 - FINITE DIFFERENCE
CD      2 - LINEAR FINITE DIFFERENCE (8, 10 NEIGHBORS)
CD      3 - EXTENDED TAYLOR SERIES (8, 10 NEIGHBORS)
CD      4 - LINEAR FINITE ELEMENT (8, 10 NEIGHBORS)
CD      5 - SIMPLE TAYLOR SERIES (8, 10 NEIGHBORS)
CD      6 - USUAL FINITE DIFFERENCE (4, 6 NEIGHBORS)
CD      7 - COMPROMISE (8, 10 NEIGHBORS)
CD      8 - COMPROMISE (4, 6 NEIGHBORS)
CD      9 - COMPENSATED DIFFERENCE (4, 6 NEIGHBORS)
C
CD     IX (5)  TYPE OF PROBLEM
CD              0- DETERMINE SOURCE MULTIPLICATION FACTOR
CD              1- SEARCH PROBLEM (FILE OF SEARCH DATA IS
CD                  REQUIRED, SEE OPTION IX(10))
CD              2- FIXED SOURCE PROBLEM
CD              3- ADJOINT PROBLEM ONLY
CD              4- BUCKLING SEARCH
CD              5- PROMPT MODE ALPHA CALCULATION, 1/V SEARCH
CD     IX (6)  ADJOINT PROBLEM OPTIONS
CD              0 - NO ADJOINT PROBLEM TO BE DONE
CD              1 - EIGENVALUE TYPE PROBLEM
CD                  (NORMALLY FOLLOWING A FORWARD PROBLEM)
CD              2 - FIXED SOURCE TYPE PROBLEM
CD     IX (7)  RESERVED
CD     IX (8)  OPTION TO FORCE DATA HANDLING MODE (FOR TESTING)
CD              -1  OPTION TO TERMINATE IF MEMORY ALLOCATION
CD                  IS TOO SMALL FOR EFFICIENT EXECUTION (THE
CD                  SPACE PROBLEM CANNOT BE STORED IN TWO-
CD                  DIMENSIONS OR ENOUGH PLANES OF DATA CAN
CD                  NOT BE STORED TO AVOID EXCESS TRANSFER
CD                  IN THREE-DIMENSIONS)
CD              0- AUTOMATED TO MINIMIZE INPUT/OUTPUT
CD              1- BASE PROBLEM CORE CONTAINED
CD              2- SPACE PROBLEM AT EACH ENERGY CONTAINED
CD              3- ONE ROW CONTAINED IN CORE
CD              4- ONE OR MORE SPACE PLANES CONTAINED IN CORE
CD              5- MULTIPLE ROWS STORED FOR TWO DIMENSIONAL
CD              6- MULTI-LEVEL DATA TRANSFER
CD     IX (9)  FOR VALE, OPTIONS -1, 0, 2, AND 4 APPLY
CD              OPTIONS ON FLUX INITIALIZATION
CD              -1 SET ALL FLUX VALUES EQUAL
CD              0 AUTOMATED PROCEDURE
CD              1 POINT ENERGY MODEL, COSINE IN SPACE
CD              2 USE LATEST VERSION OF AVAILIABLE SCALAR
CD                  FLUX FILE
CD              3 USE NEXT-TO-LATEST VERSION OF AVAILIABLE
CD                  SCALAR FLUX FILE
CD     IX (10) IDENTIFIES SEARCH DATA IN SEARCH FILE, IX(5)=1
CD     IX (11) IDENTIFIES SECONDARY SEARCH DATA IN SEARCH FILE
CD                  TO BE USED IF CONSTRAINTS FOR FIRST SET ARE

```

Fig. 2. (CONTINUED)

CD NOT SATISFIED, AND SECOND SEARCH IS TO BE DONE
 CD IX(12) SPECIFIES THAT A 2-D (OR 1-D) PROBLEM IS TO BE
 CD SOLVED FOR THIS PLANE (OR ROW) OF A 3-D
 CD (OR 2-D) DESCRIPTION IF NON-ZERO
 CD IX(13) ORDER IN THE CROSS SECTION FILE OF THE DIRECTION
 CD DEPENDENT TRANSPORT CROSS SECTION TO BE USED
 CD FOR THE FIRST CORRDINATE DIRECTION (USUALLY 0)
 CD IX(14) DITTO, SECOND COORDINATE DIRECTION
 CD IX(15) DITTO, THIRD COORDINATE DIRECTION
 CD IX(16) INSTRUCTION NORMALLY EXERCISED BY CONTROL MODULE
 CD TO INFORM THE NEUTRONICS MODULE TO RECOVER
 CD DATA FOR INITIALIZATION FROM FILES RZFLUX AND
 CD RTFLUX
 CD IX(17) FORCE KEFF. CALC. BY SOURCE RATIO IF GT 0
 CD IX(18) FISSION SOURCE DISTRIBUTION FUNCTION OPTION
 CD 0- SET VALUES TO BE USED (SAME IN EACH ZONE)
 CD 1- REGION DEPENDENT VALUES TO BE USED
 CD IX(19) FISSION SOURCE DISTRIBUTION NORMALIZATION OPTION
 CD 0- LEAVE UNNORMALIZED
 CD 1- NORMALIZE EACH SET TO SUM TO UNITY
 CD IX(20) CONSTRAINT ON OUTER ITERATIONS (MAX ALLOWED)
 CD (SET BY THE CODE IF NOT SPECIFIED)
 CD IF SET = 969 INITIAL DATA PROCESSING IS DONE
 CD FOR CHECKING INTERFACE DATA FILES, MEMORY
 CD REQUIREMENTS, ETC. AND NO CALCULATIONS
 CD ARE DONE - EXCEPT IF IX(9) IS GREATER
 CD THAN 1, THE RESIDUES PASS IS MADE TO
 CD CALCULATE KEFFECTIVE ONLY
 CD IX(21) INNER ITERATION OPTION
 CD 0- USE AUTOMATED PROCEDURE (RECOMENDED)
 CD N- REFERENCE NUMBER OF INNERS = N
 CD SET BY THE CODE IF NOT SPECIFIED
 CD (IF 1 .LE. N .LE. 4, CHEBYSHEV ACCELERATION
 CD WILL NOT BE DONE ON OUTER ITERATIONS
 CD AS THE AUTOMATED PROCEDURE)
 CD FOR VALE, THIS IS ALSO THE NUMBER OF PLANES
 CD STORED FOR THE PLANE STORED MODE, IX(8)=4,
 CD (DEFAULT 4)
 CD IX(22) OPTION TO REESTIMATE OVERRELAXATION FACTORS BY
 CD L1 NORM FOR ZERO SOURCE PROBLEM, SPECIAL INNER
 CD ITERATIONS ARE DONE (MAKE LARGE TO OVERRIDE
 CD THE AUTOMATED PROCEDURE WHICH EMPLOYS THIS)
 CD IX(23) INITIALIZATION OPTIONS FOR PROCEDURES, CHOICE OF
 CD OVERRELAXITION COEFFICIENTS AND ITERATIONS
 CD -2 DONT DO ONE-DIMENSIONAL CALCULATION
 CD FOR INITIALIZATION
 CD -1 DONT USE 1-D OVERRELAXATION COEFFICIENTS
 CD 0- USE AUTOMATED PROCEDURE, SOLVES 1-D PROBLEM
 CD CHEBYSHEV COEFFICIENTS ON OUTER ITERATIONS
 CD IF THE NUMBER OF INNERS IS .LT. 5
 CD EXCEPT WHEN CHEBYSHEV FLUX ON OUTERS
 CD 1- SAME AS 0 BUT DO NOT CHEBYSHEV
 CD OVERRELAXATION COEFFICIRNTS
 CD 2- FIX THE NUMBER OF INNER ITERATIONS
 CD 3- FIX NUMBER OF INNERS, NO CHEBYSHEV
 CD 4- FIXED INNERS AND INITIAL COEFFICIENTS
 CD 5- FIXED INNERS AND COEFFICIENTS, NO CHEBYSHEV
 CD 6- SAME AS 4 BUT DONT USE 1-D COEFFICIENTS
 CD 7- SAME AS 5 BUT DONT USE 1-D COEFFICIENTS
 CD FOR VALE THE AUTOMATED OPTION 0 IS THE SAME
 CD AS VENTURE OPTION -2, AND THE ONLY OTHER
 CD OPTIONS ARE 2, 3, 4, AND 5
 CD IX(24) INNERITERATION SWEEP ORDER

Fig. 2. (CONTINUED)

```

CD          -1 NORMAL ORDERED
CD          0 AUTOMATED (SIGMA-1 IF AVAILABLE, USUALLY)
CD          1 SIGMA-1 ORDERED IF AVAILABLE
CD IX (25)  OUTER ITERATION CHEBYCHEV ACCELERATION OPTIONS
CD          .LT. 0 START AT THIS ITERATION
CD          0- USE AUTOMATED PROCEDURE
CD          1- APPLY ONLY AFTER THE FIRST EXTRAPOLATION
CD          2- APPLY CONTINUOUSLY FROM THE START
CD          3- DONT APPLY THE PROCESS
CD          .GT. 100- THE PROCESS IS STARTED AT ITERATION
CD          IX (25)-100 USING AN L1 NORM EIGENVALUE
CD          FOR THE AUTOMATED OPTION IN VENTURE, THE
CD          INITIALIZATION PROCEDURE DETERMINES WHEATHER
CD          CHEBYCHEV ACCELERATION IS TO BE DONE
CD          FOR VALE, THE AUTOMATED OPTION IS NOT TO APPLY
CD          THE CHEBYCHEV ACCELERATION, THEREFORE FOR
CD          PROBLEMS IN WHICH THIS ACCELERATION IS
CD          DEEMED TO BE EFFECTIVE A NON ZERO VALUE
CD          MUST BE SPECIFIED
CD IX (26)  ASYMPTOTIC OUTERITERITION EXTRAPOLATION OPTIONS
CD          -1 SINGLE ERROR MODE ONLY
CD          0- USE AUTOMATED PROCEDURE
CD          1- SINGLE ERROR MODE USING DATA FOR ALTERNATE
CD          ITERATIONS
CD          2- NOT ALLOWED
CD          3- WE ARE TRYING TO FIGURE OUT WHAT THIS DOES
CD IX (27)  FORCED DELAY IN ASYMPTOTIC EXTRAPOLATION
CD          N- NOT ALLOWED FOR THIS MANY OUTER ITERATIONS
CD          (IF NEGATIVE, A FORCED PROCEDURE MAY BE
CD          EXECUTED EARLIER)
C
C          EDITS GENERALLY ARE NOT DONE WHEN FLAG IS ZERO
C
CD IX (28)  OPTION FOR CONDENSED EDIT (TERMINAL) IF .GT. 1
CD IX (29)  OPTION TO EDIT THE PRINCIPAL MACROSCOPIC
CD          CROSS SECTIONS BY ZONE
CD IX (30)  OPTION TO EDIT THE MACROSCOPIC SCATTERING
CD          CROSS SECTIONS BY ZONE
CD IX (31)  OPTIONS ON ITERATION DATA EDITS
CD          -1- NO EDITS DURING ITERATION
CD          0, OR 1- PRIMARY OUTER ITERATION DATA ONLY
CD          2- GETS DETAILS EDITED FOR TESTING
CD          3- REQUESTS EXTENDED EDIT FOR DEBUGGING
CD IX (32)  OPTION TO EDIT OVERALL NEUTRON BALANCE BY GROUP
CD IX (33)  OPTION TO EDIT NEUTRON BALANCE BY ZONE
CD IX (34)  RESERVED
CD IX (35)  OPTION TO EDIT SCALAR NEUTRON FLUX BY POINT
CD IX (36)  RESERVED
CD IX (37)  OPTION TO EDIT ZONE-AVERAGE FLUX BY GROUP
CD          IF .GT. 1, ALSO EDIT THE ZONE, GROUP ADJOINT FLUX
CD IX (38)  OPTION TO EDIT POWER DENSITY MAP BY INTERVAL
CD IX (39)  OPTION TO EDIT POWER DENSITY TRAVERSES THRU PEAK
CD          THIS OPTION APPLIES ONLY TO VENTURE - NOT VALE
CD IX (40)  OPTION TO EDIT NEUTRON DENSITY MAP (1/V FLUX
CD          WEIGHTING)
CD IX (41)  OPTION TO EDIT NEUTRON DENSITY TRAVERSES
CD          THIS OPTION APPLIES ONLY TO VENTURE - NOT VALE
CD IX (42)  OPTION TO EDIT SCALAR ADJOINT FLUX
CD IX (43)  MAXIMUM ZONE NUMBER FOR WHICH XX(21) AND XX(22)

```

Fig. 2. (CONTINUED)

CD ARE TO BE APPLIED TO THE ZONE AND GROUP
 CD DIFFUSION COEFFICIENTS IF NOT ZERO
 CD IX(44) OPTION TO EDIT ATOMIC DENSITIES WHEN SEARCHING
 CD 0- NO EDIT
 CD 1- MINIMUM EDIT AT END
 CD 2- MAXIMUM EDIT DURING CALCULATION
 C
 CN OPTIONS IX(45) THROUGH IX(50) APPLY ONLY
 CN TO VENTURE - NOT VALE
 C
 CD IX(45) PERTURBATION OPTIONS - IF NEGATIVE, FILES RTFLUX
 CD AND ATFLUX ARE SUPPLIED AND NO NEUTRONICS
 CD CALCULATION IS DONE - OTHERWISE THE REGULAR
 CD AND/OR ADJOINT SOLUTION IS OBTAINED AS
 CD SPECIFIED ABOVE AND EITHER FLUX FILE NOT
 CD GENERATED MUST BE SUPPLIED
 CD 0- NO PERTURBATION CALCULATION
 CD 1- CALCULATE AND EDIT BASIC REGULAR*ADJOINT
 CD FLUX INTEGRALS EXCEPT TRANSPORT
 CD 2- ALSO CALCULATE AND EDIT TRANSPORT INTEGRALS
 CD (REQUIRED FOR COMPLETE PERTURBATION EFFECT)
 CD 3- ALSO EDIT MACROSCOPIC ABSORPTION CROSS
 CD SECTION SPACE POINT IMPORTANCE MAP
 CD 4- ALSO EDIT MACROSCOPIC PRODUCTION CROSS
 CD SECTION SPACE POINT IMPORTANCE MAP
 CD PLUS ABS-PROD MAP
 CD 5- ALSO EDIT 1/V SPACE POINT IMPORTANCE MAP
 CD IX(46) EDIT RESULTS FOR A 100 PERCENT CHANGE IN MACRO
 CD CROSS SECTIONS, ONLY IF IX(45).NE.0
 CD IX(47) OPTION TO WRITE POINT FLUX VALUES FOR EXPOSURE
 CD (EXERCISED ONLY IF IX(53) .GT. 0)
 CD .GT. 0 WRITE DATA FOR POINTS IN THIS ZONE
 CD -1 WRITE ONLY THE SPECTRUM FOR THE POINT WHERE
 CD THE POWER DENSITY IS A MAXIMUM INITIALLY
 CD -2 WRITE DATA FOR THE POINTS IN THE ZONE WHERE
 CD THE POWER DENSITY IS A MAXIMUM INITIALLY
 CD -3 WRITE ONLY THE SPECTRUM FOR THE POINT WHERE
 CD THE FIRST GROUP FLUX IS A MAXIMUM INITIALLY
 CD -4 WRITE DATA FOR THE POINTS IN THE ZONE WHERE
 CD THE FIRST GROUP FLUX IS A MAXIMUM INITIALLY
 C: .LT.-4 WRITE SPECTRUM FOR THIS MESH POINT
 CD IX(48) ANOTHER ZONE NUMBER FOR WHICH THE POINT FLUX
 CD VALUES ARE TO BE WRITTEN FOR EXPOSURE IF .GT. 0
 CD IX(49) OPTION TO EDIT THE DIRECT CONTRIBUTION TO CHANGE
 CD IN CONVERSION RATIO FROM UNIT CHANGE IN FERTILE
 CD CAPTURE AND FISSILE ABSORPTION (MACROSCOPIC)
 CD IX(50) OPTION TO WRITE SCALAR ADJOINT FLUX FILE AS
 CD THE PRODUCT OF THE REGULAR AND ADJOINT FLUX
 CD 0- NO
 CD 1- REWRITE THE LATEST VERSION OF AN OLD FILE
 CD (IF THERE IS NONE, WRITE A NEW ONE)
 CD 2- WRITE NEW FILE
 C
 CN OPTIONS ABOVE ARE TYPICAL FOR EACH FILE COVERED BELOW
 C
 CD IX(51) OPTION TO WRITE THE POINT SCALAR FLUX FILE
 CD IX(52) OPTION TO WRITE THE POINT FISSION SOURCE FILE
 CD IX(53) OPTION TO WRITE ZONE-AVERAGE SCALAR FLUX FILE
 CD IX(54) OPTION TO WRITE POINT POWER DENSITY FILE

Fig. 2. (CONTINUED)

CD IX(55) WRITE THE CONVERSION RATIO ADJOINT IMPORTANCE
 CD FIXED SOURCE FILE (ALWAYS ADDS A FILE OR TWO)
 CD .GT.0- WRITE COMBINED FILE (HAS NEGATIVE DATA)
 CD .LT.0- WRITE TWO FILES, ALL POSITIVE
 CD IX(56) OPTION TO WRITE THE ZONE POWER DENSITY FILE
 CD IX(57) OPTION TO WRITE THE ADJOINT ZONE AVERAGE FLUX
 CD FILE AZFLUX
 CD IX(58) OPTION TO WRITE SCALAR ADJOINT FLUX FILE
 CD APPLICABLE ONLY IF AN ADJOINT PROBLEM WAS DONE
 C
 CN OPTIONS IX(59) THROUGH IX(63) APPLY ONLY
 CN TO VENTURE - NOT VALE
 C
 CD IX(59) OPTION TO WRITE PERTURBATION INTEGRALS ON FILE
 CD PERTUB. IX(45) MUST BE NON-ZERO. TRANSPORT
 CD INTEGRALS ARE INCLUDED IF ABS(IX(45)) GT 2.
 CD IX(60) OPTION TO WRITE SPECIAL FORMATTED DATA FILE
 CD (LOGICAL 4) AT THE END OF A CASE - SEE SECTION 204
 CD OF THE VENTURE REPORT
 CD IX(61) A PLANE NUMBER AT WHICH ZONE AND GROUP BUCKLINGS
 CD ARE TO BE CALCULATED
 CD IX(62) A SECOND PLANE NUMBER FOR THE BUCKLING CALCULATION
 CD IX(63) OPTION TO WRITE A POINTWISE FIXED SOURCE FILE
 CD AS (DB**2) TIMES FLUX
 CD IX(64) WRITE A POINT POWER DENSITY ADJOINT IMPORTANCE
 CD FIXED SOURCE FILE (ALWAYS ADDS A FILE)
 CD 1 POINT WHERE POWER DENSITY IS MAX
 CD -M POINT IN ZONE ABS(M) WHERE POWER DENSITY
 CD IS MAX
 CD 2 POINT GIVEN BY IX(65-67) BELOW
 CD IX(65) COLUME NUMBER FOR IX(64)=2
 CD IX(66) ROW NUMBER FOR IX(64)=2
 CD IX(67) PLANE NUMBER FOR IX(64)=2
 CD IX(68) RESERVED
 CD IX(69) IF GT 0 EQUILIBRIUM XENON WILL BE ACCOUNTED FOR
 CD AND THIS IS THE ORDER NUMBER OF XENON IN THE
 CD NUCLIDE LIST (SET 1) IN SECTION 013 DVENTR
 CD IX(70) FORCE DATA TRANSFER IN INITIALIZATION (TO TEST
 CD PROCEDURES)
 CD IX(71) RESERVED
 CD IX(72) RESERVED
 CD IX(73) OVERRIDE DEFAULT OF FILES TO MEMORY (TO TEST
 CD PROCEDURES)
 C
 CN OPTIONS IX(74) THROUGH IX(77) APPLY ONLY
 CN TO VENTURE - NOT VALE
 C
 CD IX(74) SPACE-ENERGY REBALANCE WILL BE DONE OCCASIONALLY
 CD IF GT 0
 CD IX(75) THE NUMBER OF BOLCKS ALONG ROWS (LEFT-RIGHT)
 CD FOR REBALANCE - IX(74) .GT. 0
 CD IX(76) THE NUMBER OF BOLCKS ALONG COLS (TOP-BOTTOM)
 CD FOR REBALANCE - IX(74) .GT. 0
 CD IX(77) THE NUMBER OF BOLCKS ALONG PLANES (FORE-AFT)
 CD FOR REBALANCE - IX(74) .GT. 0
 CD IX(78) - IX(79) RESERVED
 CD IX(80) OPTION TO ACCOUNT FOR THE DEPENDENCE OF THE
 CD CROSS SECTIONS ON THE LOCAL TEMPERATURE, REQUIRES
 CD TWO 'GRUPXS' FILES, A 'ZNTMP' FILE, AND REFERENCE
 CD TEMPERATURES (SEE XX(25), XX(26), AND XX(27))
 CD 0- NO
 CD 1- YES
 CD IX(81) - IX(100) RESERVED
 C

Fig. 2. (CONTINUED)

```

C*****
C              REVISED 04/01/80
C
CF          TRIGOM
C
CE          TRIANGULAR GEOMETRY DESCRIPTION
C
C*****

C-----
CR          FILE IDENTIFICATION (NV)
C
CL          HNAME, (HUSE(I), I=1,2), IVERS
C
CW          1+3*MULT
C
CD          HNAME          HOLLERITH FILE NAME - TRIGOM - (A6)
CD          HUSE           HOLLERITH USER IDENTIFICATION (A6)
CD          IVERS          FILE VERSION NUMBER
C
CN          MULT           1 FOR LONG WORD, 2 FOR SHORT WORD MACHINES
C
C-----

C-----
CR          FILE REFERENCE INFORMATION (1D RECORD)
C
CL          IGOM, NZONE, NREG, NZCL, NCINTI, NCINTJ, NCINTK, NINTI, NINTJ, NINTK, IMB1,
CL          IMB2, JMB1, JMB2, KMB1, KMB2, NBS, NBCS, NIBCS, NZWBB, NTRIAG, NRASS,
CL          (NGOP(I), I=1,5)
C
CW          27
C
CD          IGOM           GEOMETRY 5- SPECIAL TRIANGONAL, TWO-DIMENSIONAL
CD                          19- SPECIAL TRIANGONAL-Z, THREE-DIMENSIONAL
CD          NZONE          NUMBER OF ZONES (EACH HOMOGENEOUS IN NEUTRONICS
CD                          PROBLEM)
CD          NREG           NOT DEFINED
CD          NZCL           NUMBER OF ZONE CLASSIFICATIONS (EDIT PURPOSES)
CD          NCINTI         NOT DEFINED
CD          NCINTJ         NOT DEFINED
CD          NCINTK         NUMBER OF THIRD DIMENSION COARSE MESH INTERVALS
CD                          NCINTK.EQ.1 FOR ONE AND TWO
CD                          DIMENSIONAL CASES.
CD                          A COARSE MESH INTERVAL IS DEFINED AS ONE
CD                          CONTAINING ONE OR MORE FINE MESH INTERVALS, EACH
CD                          OF WHICH CONTAINS THE SAME MATERIAL ZONE.
CD          NINTI          THE NUMBER OF POINTS ON A PLANE. POINTS ARE AT
CD                          THE INTERSECTIONS OF MESH LINES.
CD          NINTJ          NOT DEFINED
CD          NINTK          NUMBER OF THIRD DIMENSION FINE MESH INTERVALS
CD                          NINTK.EQ.1 FOR ONE AND TWO DIMENSIONAL
CD                          CASES.

```

Fig. 3. Contents of Geometry Description File TRIGOM.

```

CD      IMB1      FIRST BOUNDARY ON FIRST DIMENSION      -
CD      0- ZERO FLUX (DIFFUSION)                        -
CD      1- REFLECTED                                     -
CD      2- EXTRAPOLATED (DIFFUSION - DEL PHI           -
CD      /PHI ==-C/D WHERE C IS GIVEN AS BNDC           -
CD      BELOW AND D IS THE GROUP DIFFUSION            -
CD      CONSTANT, TRANSPORT - NO RETURN)              -
CD      3- NOT DEFINED                                   -
CD      4- REPEATING (PERIODIC) WITH NEXT              -
CD      ADJACENT FACE 60 OR 120 DEGREE                -
CD      ROTATION) .                                     -
CD      THE LEFT AND TOP BOUNDARIES ARE               -
CD      REPEATING.                                     -
CD      5- NOT DEFINED                                   -
CD      6- NOT DEFINED                                   -
C
CN      NOTE THAT FOR REPEATING BOUNDARIES, THE FIRST BOUNDARY IN -
CN      ORDER WHICH IS INVOLVED CARRIES THE DESIGNATOR DEFINING -
CN      THE REPEATING CONDITION.                       -
C
CD      IMB2      LAST BOUNDARY ON FIRST DIMENSION      -
CD      JMB1      FIRST BOUNDARY ON SECOND DIMENSION    -
CD      5- REPEATING ALONG THIS BOUNDARY - 180        -
CD      DEGREES. IF NPF EQUALS THE NUMBER OF          -
CD      POINTS ON THIS BOUNDARY, THEN THE FLUXE      -
CD      AT POINTS NPF/2 THROUGH NPF ARE EQUAL        -
CD      TO THE FLUXES AT POINTS 1 THROUGH NPF/2     -
CD      FOR THIS OPTION, IMB1=IMB2 AND                -
CD      NTRIAG=1.                                       -
CD      JMB2      LAST BOUNDARY ON SECOND DIMENSION    -
CD      KMB1      FIRST BOUNDARY ON THIRD DIMENSION    -
CD      KMB2      LAST BOUNDARY ON THIRD DIMENSION    -
CD      NBS       NUMBER OF BUCKLING SPECIFICATIONS   -
CD      1- SINGLE VALUE APPLIES EVERYWHERE           -
CD      .EQ.NZONE, ZONE-DEPENDENT                     -
CD      N*NZONE, DATA IS GIVEN OVER ALL ZONES FOR   -
CD      THE FIRST ENERGY GROUP, THEN FOR THE NEXT   -
CD      GROUP, TO END OF LIST - IF THERE ARE MORE    -
CD      GROUPS, LAST GROUP DATA GIVEN IS USED      -
CD      NBCS      NUMBER OF CONSTANTS FOR EXTERNAL BOUNDARIES -
CD      1- SINGLE VALUE USED EVERYWHERE              -
CD      6- INDIVIDUAL VALUES FOR EACH POSSIBLE      -
CD      SURFACE (BOUNDARY SPECS GIVE ACTUAL USE)     -
CD      N*6- SIX VALUES ARE GIVEN FOR THE FIRST    -
CD      ENERGY GROUP, THEN SIX FOR THE NEXT, TO    -
CD      THE END OF THE LIST - THE LAST GROUP DATA   -
CD      GIVEN APPLIES TO ALL ADDITIONAL GROUPS      -
CD      NIBCS     NUMBER OF CONSTANTS FOR INTERNAL BOUNDARIES -
CD      1- SINGLE VALUES USED EVERYWHERE           -
CD      .GT.1- VALUES ARE GIVEN BY ENERGY GROUP   -
CD      WITH NON-BLACK CONDITION INDICATED BY       -
CD      ZERO ENTRY - LAST VALUE APPLIES TO          -
CD      ADDITIONAL GROUPS                             -

```

Fig. 3. (CONTINUED)

```

CD   NZWBB          BLACK ABSORBER ZONE INDICATOR.          -
CD                               0- NO BLACK ZONES.          -
CD                               1- ONE BLACK ABSORBER ZONE.  -
CD   NTRIAG         MESH ORINTATION                          -
CD                               0- RHOMBUS WITH 120 DEGREES  -
CD                               CORNER (NPL.EQ.NPF BELOW).  -
CD                               1- TRAPEZOID (OR TRIANGLE)  -
CD                               WITH 60 DEGREES AT          -
CD                               UPPER LEFT AND UPPER RIGHT  -
CD                               CORNERS                     -
CD                               (NPL.LT.NPF).              -
CD                               2- TRIANGLE WITH 30 DEGREES  -
CD                               AT UPPER LEFT              -
CD                               CORNER AND 60 DEGREES AT   -
CD                               UPPER RIGHT                -
CD                               CORNER (NPL.LT.NPF).  IMB1  -
CD                               AND JMB2 MUST BE 1        -
CD                               AND NPF .GE. 3.           -
CD   NRASS          ZONE ASSIGNMENTS.                        -
CD                               0- TO COARSE MESH          -
CD                               1- TO FINE MESH            -
CD   NGOP           NOT DEFINED.                            -
C
C-----

```

```

C-----
CR           GEOMETRY DATA (2D RECORD)                      -
C
CL   (BSQ(N),N=1,NBS), (BNDC(N),N=1,NBCS), (BNCI(N),N=1,  -
CL   (NZHBB(N),N=1,NZWBB), (NZC(N),N=1,NZONE)              -
C
CW   NBS+NBCS+NIBCS+NZWBB+NZONE                            -
C
CD   BSQ           BUCKLING (B**2) VALUES (CM**-2)        -
CD   BNDC          BOUNDARY CONSTANTS (DEL PHI/PHI =-C/D)  -
CD   BNCI          INTERNAL BLACK BOUNDARY CONSTANTS        -
CD   NZHBB         ZONE NUMBER WITH BLACK ABSORBER         -
CD   NZC           ZONE CLASSIFICATIONS                     -
C
C-----

```

```

C-----
CR           REFERENCE MESHPOINT DATA (3D RECORD)          -
C
CL   MPO,NPF,NPL,NRP,MNP,NRS,NOS,NO3,MZA,MB,MC, (KFINTS(L),L=1,NCINTK) -
C
CW   NCINTK + 11                                           -
C
CD   MPO           MESHPOINT LOCATION OPTION                -
CD                               0- UNIFORM, EQUILATERAL    -
CD                               MESH ARRANGEMENT           -
CD                               (SIMPLE GEOMETRY DESCRIBED  -
CD                               BY DATA IN THIS           -
CD                               RECORD, MNP=6)             -
CD                               1- PARALLEL ROWS OF MESH   -
CD                               POINTS                     -
CD                               2- GENERAL ARRANGEMENT     -
CD   NPF           NUMBER OF POINTS ALONG FIRST (TOP) ROW  -
CD                               -- USED IF MPO = 0        -
C

```

Fig. 3. (CONTINUED)

```

CD   NPL           NUMBER OF POINTS ALONG LAST (BOTTOM) ROW           -
CD   -- USED IF MPO = 0. NPL MUST BE .EQ. OR .LT. NPF.             -
CD   FOR NPL.EQ.NPF, 120 DEGREES IS IN UPPER LEFT                 -
CD   CORNER. IF NPL.LT.NPF, THE UPPER LEFT CORNER                 -
CD   IS 30 OR 60 DEGREES (SEE NTRIAG ABOVE).                       -
CD   NRP           NUMBER OF ROWS OF POINTS                         -
CD   -- USED IF MPO .LT. 2                                         -
CD   MNP           REFERENCE OR MAXIMUM NUMBER OF NEIGHBOR POINTS ON A -
CD   PLANE                                                         -
CD   NRS           NUMBER OF ZONE ASSIGNMENTS ON EACH PLANE        -
CD   NOS           NOT DEFINED                                       -
CD   NO3           NOT DEFINED                                       -
CD   MZA           NOT DEFINED                                       -
CD   MB            NOT DEFINED                                       -
CD   MC            NOT DEFINED                                       -
CD   KFINTS       NUMBER OF FINE MESH INTERVALS PER COARSE MESH   -
CD   INTERVAL, THIRD DIMENSION                                     -
C
CN   MESHPOINTS HERE MAY BE INTERPRETED AS TRIANGLE CORNERS      -
C
C-----

```

```

C-----
CR   REFERENCE DATA (4D RECORD)                                   -
C
CL   PMESH,QMESH,X1,X2,X3,(ZMESH(K),K=1,NCBNDK)                   -
C
CW   MULT*(NCINTK+6)                                             -
C
CD   PMESH         LENGTH OF TRIANGLE LEG (MESHPOINT SPACING) IF FIXED -
CD   -- USED IF MPO = 0                                           -
CD   QMESH        NOT DEFINED                                       -
CD   X1           NOT DEFINED                                       -
CD   X2           NOT DEFINED                                       -
CD   X3           NOT DEFINED                                       -
CD   ZMESH        COARSE MESH BOUNDARIES, THIRD DIMENSION         -
CD   NCBNDK       NCINTK+1, NUMBER OF THIRD DIMENSION COARSE MESH -
CD   BOUNDARIES                                                 -
C
CN   NOTE THAT FOR TWO-DIMENSIONAL PROBLEMS, NCINTK=1, NCBNDK=2, -
CN   ALTHOUGH DATA FOR THE THIRD DIMENSION ARE NOT USED (IGOM=5) -
C
C-----

```

```

C-----
CR   MESHPOINT ARRANGEMENTS (5D RECORD)                           -
C
CC   PRESENT IF MPO.EQ.1                                         -
C
CL   (XMESH(I),I=1,NINTI),(YROW(J),J=1,NRP),(NMPR(J),J=1,NRP)   -
C
CW   MULT*(NINTI + NRP) + NRP                                     -

```

Fig. 3. (CONTINUED)

```

C
CD   XMesh          LOCATION OF EACH MESHPOINT ON A PLANE MEASURED FROM
CD                   REFERENCE ALONG X COORDINATE, CM
CD   YRow           ROW LOCATION MEASURED FROM REFERENCE ALONG Y
CD                   COORDINATE (NORMAL TO X), CM
CD   NMPR           NUMBER OF MESH POINTS ON THE ROW
C
C-----

```

```

C-----
CR           MESHPOINT ARRANGEMENTS (6D RECORD)
C
CC           PRESENT IF MPO.EQ.2
C
CL           ((XMesh(I,J),I=1,2),J=1,NINTI)
C
CW           2*MULT*NINTI
C
CD   XMesh(1,J)     LOCATION OF MESHPOINT MEASURED ALONG X COORDINATE
CD                   FROM REFERENCE (INCREASING ORDER FOR ANY Y), CM
CD   XMesh(2,J)     LOCATION OF MESHPOINT MEASURED ALONG Y COORDINATE
CD                   FROM REFERENCE, Y NORMAL TO X, (INCREASING), CM
C
C-----

```

THERE ARE NCINTK RECORDS WHICH FOLLOW IF NRASS IS 0
 NINTK RECORDS WHICH FOLLOW IF NRASS IS 1
 BUT ONLY ONE SET IF IGOM IS 5

```

C-----
CR           TRIANGLE ZONE ASSIGNMENTS (7D RECORD)
C
CC           ALWAYS PRESENT
C
CL           (MR(I),I=1,NRS)
C
CW           NRS
C
CD   MR            ZONE NUMBER ASSIGNMENT TO MESH INTERVAL
C
CN           CONSIDER THAT NEAR-NEIGHBOR POINTS HAVE A LINE OF COUPLING.
CN           COUPLING LINES FORM TRIANGLES. THE TRIANGLES LYING
CN           WHOLLY BELOW A LOCAL HORIZONTAL LINE ARE ASSIGNED ZONE
CN           NUMBERS THROUGH THE MESH STARTING WITH THE FIRST (TOP)
CN           HORIZONTAL ROW, INCREASING X GIVEN Y, THEN INCREASING Y
C
C-----

```

```

C*****
C
CEOF        TRIGOM
C
C*****

```

Fig. 3. (CONTINUED)

Other files that contain data by spacial mesh point have the data blocked as a given number of points on a plane. The usual interpretation of "the number of points...in each of three dimensions," L, M, and N would be a three-dimensional figure containing LMN points and relative positions simply related. In those files created and used by VALE, L is the number of points on each plane, M is 1, and N is the number of planes, so LMN is still the number of points. Other data in file TRIGOM must be used to obtain the full description of the two-dimensional mesh point arrangement. This is true of the flux data file RTFLUX, the adjoint flux ATFLUX, the fixed source FIXSRC, and the power density PWDINT.

C. System Control Requirements

The job control instructions required to execute VALE are nearly the same as for the VENTURE code and will not be repeated here. The user-supplied job control instructions are discussed in the Appendix. Note that VALE is module number 8 in the set while VENTURE is number 7.

Figure 4 shows the space requirements for the scratch I/O logical units. Generally the space for these units is specified by supplying override parameters in the job control instructions (see cataloged procedure in Ref. 2). It is not simple to define space requirements for all possible options. Therefore, values for these parameters will have to be determined and supplied, or override I/O control cards used to specify space for individual units.

D. An Input Data Processing Difficulty

The Special Processor DVENTR² was implemented to allow ready input of VENTURE data in a form convenient to the user, albeit inconvenient fixed field formats. A special advantage of this input is the generation of data for the geometry file GEODST, the cross section-nuclide concentration association file NDXSRF, and the zone density file ZNATDN. Otherwise if the data for the interface data files is supplied directly to the

Define N = Number of points on a plane.
 P = Number of planes.
 G = Number of groups.
 Z = Number of zones.
 W = Maximum scattering band width.
 D = 1 for long word computers, 2 for short word computers.
 T = 0 for two-dimensional, 1 for three-dimensional problems.
 S = 1 if criticality search, 0 if no search.
 F = 1 if fixed source problem, 0 if no fixed source.
 H = 1 if harmonic problem, 0 if fundamental.
 NB = Number of blocks, symbolic parameter, see Job Control Instructions, ref. 2.
 BS = Block size symbolic parameter.
 SEQ = Sequential file.
 DA = Direct access file.

| UNIT NUMBER | TYPE | NB | BS | NUMBER OF RECORDS | RECORD LENGTH |
|-------------|------|-----|----|----------------------------------|-----------------------------|
| 21 | SEQ | N1 | B1 | G plus 1 plus 2 | W*Z 2*G G*Z |
| 22,47 | SEQ | NS | B1 | 15 plus 2 plus 7 plus 5 | G*Z D*P D*G G |
| 24,25,27,28 | DA | N2 | B1 | G*P | D*N |
| 26 | DA | N2 | B1 | G*P | D*N*(S+H) |
| 40 | DA | N5 | B2 | G*P | D*2*N +D*2*N*T +D*N*S |
| 41 | SEQ | N4 | B1 | G*P | D*N*F |
| 44 | SEQ | NS | B1 | G | D*Z |
| 45 | SEQ | N9 | B1 | G | D*2*N*T +Z |
| 46 | SEQ | N10 | B1 | P | D*N |
| 48 | SEQ | N1 | B1 | P | D*N |
| 49 | SEQ | N11 | B1 | P | 2*N |
| 52,54 | SEQ | NS | B1 | P | D*N*H |

Fig. 4. Space Requirements for Scratch I/O Units.

Input Processor to take advantage of the free form format input, additional effort is normally required to generate the needed information.

The geometry file TRIGOM required by VALE must be generated with the Input Processor. The free form format input along with the flexible processing capability is especially useful to generate this file. Typically, we also supply the data for the Special Processor DVENTR to simplify the generation of other data files, using an abbreviated geometry description (slab) to produce the GEODST file that is not used, but also produced are ZNATDN, NDXSRF files, SEARCH file if desired, and the neutronics control instructions for VALE (or VENTURE!), record DTNINS and also two other records conveying core size and a problem title in the file CONTRL.



III. PROBLEM DEFINITION

This section presents the neutron flux, eigenvalue balance and related equations oriented toward the routine user. Some detail has been omitted since it would seem to cause confusion rather than convey useful information.

A. Discussion

This code solves the nuclear reactor neutronics problem. If there is any fixed neutron source, the neutron flux solution is a direct consequence whether or not there is any source from fission. Lacking a fixed source, there is a set of solutions each of which satisfies the equations and has a distinct eigenvalue; we normally seek that solution called the fundamental that has the most positive eigenvalue of any of the set (that is, the multiplication factor, k_{eff}), a solution that normally has all components of the neutron flux ≥ 0 representative of real conditions. The adjoint solution may be of interest which is the importance function for contributions to the multiplication. Since reactors operate at the critical state on the average, there is primary interest in this condition, $k_{\text{eff}} = 1$, so criticality search procedures to establish such a state may be of interest. Then the capability to solve for the dominant higher harmonic or importance for an arbitrary fixed source may be of interest.

The flux, eigenvalue problem is cast in matrix notation as

$$(A - \frac{1}{k} M) \phi = 0 \quad (1)$$

where A is the space coupling, energy scattering coupling, loss operator; M is the fission source, distribution operation; ϕ is the neutron flux; and k is the eigenvalue. We note the other problems solved: the adjoint problem,

$$(A^T - \frac{1}{k} M^T) \phi^* = 0, \quad (2)$$

the fixed source problem,

$$(A - M) \phi = S \quad (3)$$

and the importance problem

$$(A^T - M^T) \phi^* = S^* \quad (4)$$

Complicated solution techniques are used that are discussed elsewhere. Basically one applies an iteration procedure

$$\phi_m = B_m \phi_{m-1} \quad (5)$$

where B_m is the operator and m the outer iteration. The error may be expressed in matrix vector notation as

$$\epsilon_m = \phi_m - \phi_\infty \quad (6)$$

where ϕ_∞ is the true solution, unknown. Hopefully $\epsilon_m \rightarrow 0$ as m increases, and at termination ϵ_m is sufficiently small that the results are acceptable for the analysis task.

B. Solution Method

Problems are solved by iteration. At each energy new flux values are obtained at each space point in an inner iteration sweep. These new values are obtained from the neutron accounting equations for a discrete elemental volume given flux values at neighboring points. Acceleration techniques are applied that include the use of the latest values as they are obtained, simultaneous solution of a full row of points, overrelaxation that moves a value further in the calculated direction of change, and σ_1 ordering of the sweeps that accelerates propagation in comparison with normal ordering. Several inner iterations are done at each energy to reduce the discrepancy between the current flux estimates and the current distributed source of neutrons into this energy. Note that there is an optimum number of inner iterations in the sense of minimizing the cost of solution. With too few inner iterations, the outer iteration process

is more difficult to solve, while with too many there is waste of effort in moving the intermediate solutions toward the answer for the intermediate source.

An outer iteration consists of a full sweep over all energy (groups) involving inner iteration at each. Not only must the fission source be obtained at each location but also the in-scattering source, and the multiplication factor estimated. The fission source each outer iteration is divided by the multiplication factor to force a pseudo steady state condition admitting solution. Alternatively other types of problems may be solved such as a buckling or nuclide concentration search to establish a steady state condition.

Acceleration schemes are applied to the outer iterations. For these to be generally effective, the same procedure must be used each outer iteration, such as the same number of inner iterations at one energy. This allows simple error vectors to establish that then can be eliminated by asymptotic extrapolation or be suppressed by the application of the Chebyshev polynomials on demand.

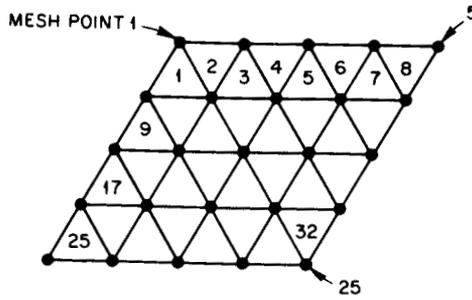
We rely on outer iteration convergence criteria to terminate the iteration process, specifically a bound on the maximum relative point flux change. At termination results are produced to test reliability of the solution and an estimate is made of the absolute error.

C. Geometry

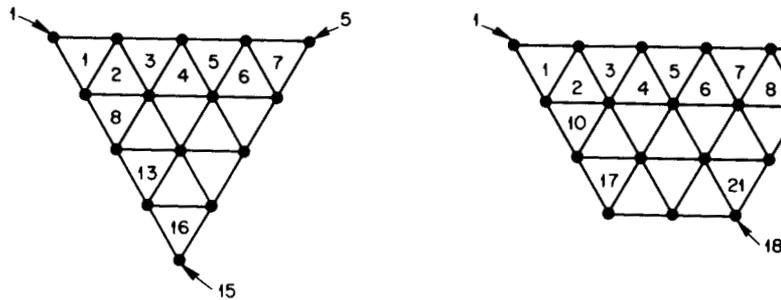
The mesh points are arranged on an equilateral triangular grid repeated on all planes. A parallelogram need not be described. For the three-dimensional problem the planes of mesh points are located mesh centered between interfaces for the axial finite-difference formulation.

Special routines are used for each of the 120° , 60° , and 30° mesh point arrangements illustrated in Fig. 5. Of concern to the user is the requirement to describe the desired problem accurately with as few mesh

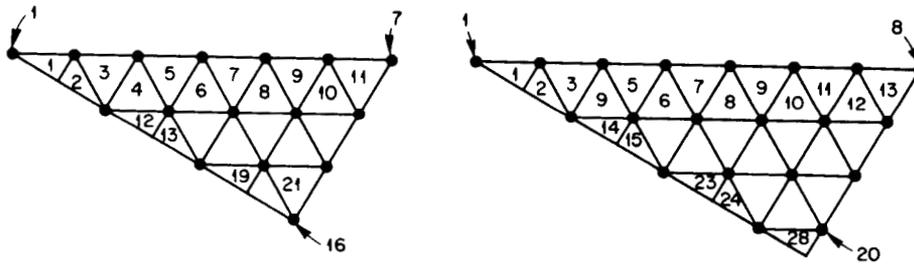
120° MESH POINT ARRANGEMENT



60° MESH POINT ARRANGEMENT



30° MESH POINT ARRANGEMENT



NOTES

1. MATERIAL REFERENCE ORDER NUMBER ASSIGNMENTS TO TRIANGLES ARE INDICATED; NOTE THE ALLOWANCE FOR TRUNCATION OF THE POINTS IN THE 60° ARRANGEMENT SO THAT AN EQUILATERAL FIGURE IS NOT NECESSARY.
2. ROTATIONAL SYMMETRY ALLOWED ABOUT MESH POINT 1 IN 120° AND 60° ARRANGEMENTS.
3. 180° ROTATIONAL SYMMETRY ABOUT THE TOP EDGE IS ALLOWED ONLY IN 60° MESH POINT ARRANGEMENT.

Fig. 5. Allowed Configurations-Mesh Points on Planes

points as necessary to obtain a reliable solution taking advantage of the available boundary conditions. Quite generally when there is 30° symmetry or repetition, it can be modeled directly as 30° at less than half the cost of representing it in a 60° section, and obviously far cheaper than as a full core. Of special utility is the repeating boundary condition. By 180° repeating boundary is meant that the two-dimensional figure may be rotated 180° and abutted to the original requiring special coupling along the top row of mesh points and materials:

$$\begin{array}{ccc} 0 & & + \\ \hline + & & 0 \end{array} \quad \swarrow \text{Top row}$$

By rotational symmetry about a point is meant that the given figure may be rotated clockwise and abutted to the original, or counterclockwise as well. There are few limitations in such application, but one is that there must be the same number of mesh points along the coupling lines.

D. Specific Equations

We display the finite-difference form of the equations in what follows. The two-dimensional equations are a simple subset of the three-dimensional equations with a unit axial length. These equations result from usual application of the diffusion theory approximation to neutron transport,

$$-\nabla \cdot D_g \nabla \phi_g + \Sigma_g \phi_g = S_g \quad , \quad (7)$$

at any spacial location, where D is the diffusion coefficient and Σ is the macroscopic cross section for removal of neutrons. S is the local source,

$$S_g = \frac{1}{k} \chi_g \sum_{g^1} V \Sigma_{f,g^1} \phi_{g^1} + \sum_{g^1} \Sigma_{g^1 \rightarrow g} \phi_{g^1} \quad , \quad (8)$$

the first term being the fission source and the last term the scattering source. With a fixed source, Eq. (8) would have such an added term and $k = 1$.

Referring to Fig. 6, a parameterized neutron balance equation can be written for a volume element on an arbitrary reference plane as

$$(IS)_g + (FS)_g + (SS)_g = [R_g + Q_g] \phi_{0,g} \quad (9)$$

with the following definitions.

$$(IS)_g = \text{IN-LEAKAGE SOURCE} = \frac{H}{T} [(\phi_{1,g} - \phi_{0,g})(E_{1,g} + E_{2,g}) + (\phi_{2,g} - \phi_{0,g})(E_{2,g} + E_{3,g}) \\ + (\phi_{3,g} - \phi_{0,g})(E_{3,g} + E_{4,g}) + (\phi_{4,g} - \phi_{0,g})(E_{4,g} + E_{5,g}) \\ + (\phi_{5,g} - \phi_{0,g})(E_{5,g} + E_{6,g}) + (\phi_{6,g} - \phi_{0,g})(E_{6,g} + E_{1,g})]$$

$$(FS)_g = \text{FISSION SOURCE} = \frac{\chi_g A \Delta}{k} \left(\sum_{\ell} \left\{ [(1-2\alpha)\phi_{0,\ell} \sum_{M=1}^6 \nu \Sigma_{f,M,\ell}] \right. \right. \\ \left. \left. + \alpha \left[\nu \Sigma_{f,1,\ell}(\phi_{6,\ell} + \phi_{1,\ell}) + \nu \Sigma_{f,2,\ell}(\phi_{1,\ell} + \phi_{2,\ell}) + \nu \Sigma_{f,3,\ell}(\phi_{2,\ell} + \phi_{3,\ell}) \right. \right. \right. \\ \left. \left. \left. + \nu \Sigma_{f,4,\ell}(\phi_{3,\ell} + \phi_{4,\ell}) + \nu \Sigma_{f,5,\ell}(\phi_{4,\ell} + \phi_{5,\ell}) + \nu \Sigma_{f,6,\ell}(\phi_{5,\ell} + \phi_{6,\ell}) \right] \right\} \right)$$

$$(SS)_g = \text{SCATTERING SOURCE} = A \Delta \left(\sum_{\ell} \left\{ [(1-2\alpha)\phi_{0,\ell} \sum_{M=1}^6 \Sigma_{S,M,\ell}] \right. \right. \\ \left. \left. + \alpha \left[\Sigma_{S,1,\ell}(\phi_{6,\ell} + \phi_{1,\ell}) + \Sigma_{S,2,\ell}(\phi_{1,\ell} + \phi_{2,\ell}) + \Sigma_{S,3,\ell}(\phi_{2,\ell} + \phi_{3,\ell}) \right. \right. \right. \\ \left. \left. \left. + \Sigma_{S,4,\ell}(\phi_{3,\ell} + \phi_{4,\ell}) + \Sigma_{S,5,\ell}(\phi_{4,\ell} + \phi_{5,\ell}) + \Sigma_{S,6,\ell}(\phi_{5,\ell} + \phi_{6,\ell}) \right] \right\} \right)$$

$$R_g = \text{REMOVAL LOSS} = A \Delta \sum_{M=1}^6 \Sigma_{R,M,g}$$

$$Q_g = \text{BOUNDARY LOSS} = \sum_B B_{B,g} \Delta T \phi_{B,g} + \sum_R \phi_{R,g} B_{R,g} + \sum_N \phi_{N,g} B_{N,g}$$

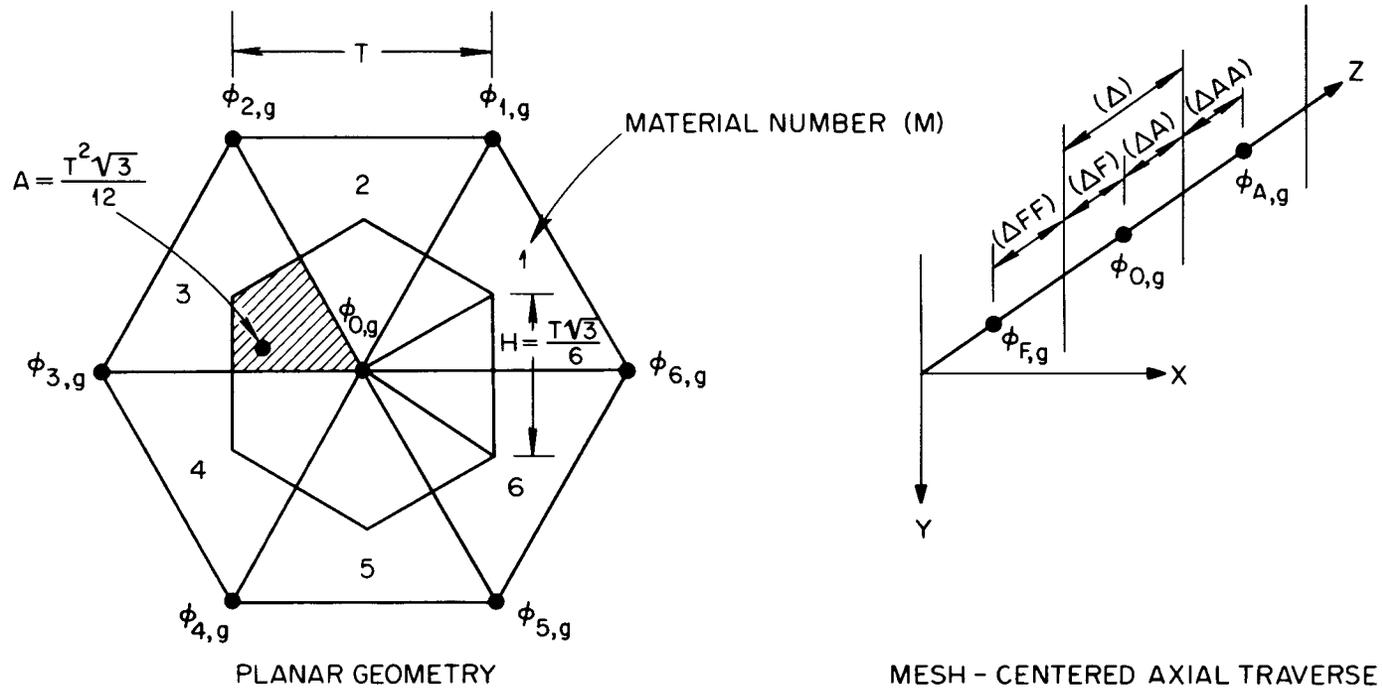


Fig. 6. Finite Difference Volume Element

$$L_{F,g} = \sum_{M=1}^6 \frac{A D_{M,F,g} D_{M,c,g}}{(\Delta FF) D_{M,c,g} + (\Delta F) D_{M,F,g}}, \text{ Fore Leakage Constant}$$

$$L_{A,g} = \sum_{M=1}^6 \frac{A D_{M,A,g} D_{M,c,g}}{(\Delta AA) D_{M,c,g} + (\Delta A) D_{M,A,g}}, \text{ Aft Leakage Constant}$$

$$B_{N,g} = \sum_{M=1}^6 \frac{C_{NA} D_{M,F,g}}{D_{M,F,g} + (\Delta F)(BC)}, \text{ Fore Boundary Leakage Constant}$$

$$B_{R,g} = \sum_{M=1}^6 \frac{C_{RA} D_{M,A,g}}{D_{M,A,g} + (\Delta A)(BC)}, \text{ Aft Boundary Leakage Constant}$$

$$E_{M,g} = D_{M,g} - 2\alpha A \Sigma_{R,M,g}$$

where α is the off-diagonal loss term parameter:^a

- 0 - Normal finite difference
- 1/6 - Taylor series formulation
- 7/36 - Linear flux formulation
- 1/4 - Linear finite element formulation

and the interpretation is:

- C = Boundary condition constant
- k = Multiplication factor
- χ = Fission spectrum
- ϕ = Flux
- D = Diffusion coefficient
- Σ_R = Removal cross section (absorption + out-scatter + buckling loss)
- Σ_S = Scattering cross section
- $\nu \Sigma_f$ = Neutron production, neutrons per fission times fission cross section.
- $\Delta A, \Delta AA, \Delta F, \Delta FF$ = Axial mesh spacing (see Fig. 6).

^aBut at each group the value of α is limited such that $E_{M,g} > 0$ for all M, a rather severe constraint that ensures no negative flux values will be calculated.

Subscripts:

- A = Aft material (to the rear)
- B = Boundary flux for left, right, top, bottom boundaries
- R = Boundary for aft boundary
- N = Boundary for fore boundary
- C = Center material
- F = Fore material (to the front)
- g or λ = Energy group
- i=1,6 = Mesh point reference to near neighbors on the plane
- M = Material

Solving Eq. (9) for $\phi_{0,g}$ gives the form used to calculate the new local flux estimate based on available iterate data for the other points:

$$\phi_{0,g} = \left[\begin{aligned} &\phi_{1,g}(E_{1,g}+E_{2,g}) + \phi_{2,g}(E_{2,g}+E_{3,g}) + \phi_{3,g}(E_{3,g}+E_{4,g}) \\ &+ \phi_{4,g}(E_{4,g}+E_{5,g}) + \phi_{5,g}(E_{5,g}+E_{6,g}) + \phi_{6,g}(E_{6,g}+E_{1,g}) \\ &+ \phi_{F,g}L_{F,g} + \phi_{A,g}L_{A,g} + (FS)_g + (SS)_g \end{aligned} \right] / \left[R_g + Q_g + 2 \sum_{M=1}^6 E_{M,g} \right] \quad (10)$$

E. Validation

When a new computer code applies unique equations, the developers face a major task in proving that the coding is free of major discrepancies. We claim to have done a reasonable amount of proof testing to assure a relatively high reliability of reported solutions. The solution procedures are not one-to-one with those in the VENTURE code, but enough so to allow the assumption of no gross procedural discrepancies. Fortunately the formulation for two dimensional triangular geometry allows a direct comparison of results with those generated in Germany^{5,6} and the US.⁷ The apparent error-free results obtained by extrapolating results for

two mesh point arrangements have been found to agree well with similar results produced by other codes including VENTURE. Elaborate testing has been done of the 30°, 60°, and 120° mesh point arrangements and optional boundary conditions by solving the same problem many different ways.

The analyst must of course carry responsibility for the reliability of application. He may well find that the considerable effort invested in validation and in producing reliability information to be quite valuable.

We present results for two documented benchmark problems in Tables 1 and 2 and Fig. 7 (Ref. 5 and 7). Note that the formulation of the VALE code is adequate compared to other finite-difference codes, the procedures are cost effective, and the results are reliable.

Additional results are reported here for the KFK problem. Shown below are results obtained for the formulations involving off-diagonal loss and source terms on planes with the coarsest modeling, three points per hex:

| Mesh Edge Formulation | α | k_{eff} |
|-------------------------|----------|-----------|
| Usual Finite Difference | 0 | 1.012487 |
| | 1/8 | 1.012585 |
| Taylor Series | 1/6 | 1.012625 |
| Linear Flux | 7/36 | 1.012626 |
| Linear Finite Element | 1/4 | 1.012644 |

Although the value of k_{eff} moves away from the apparent solution without a difference error, 1.0117, as α increases, it appears that this is due to a loss in the compensation of the error and that more accurate planar solutions are obtained. This is indicated by the peak power density results shown below:

| Formulation | Points per Hex | α | Relative Peak Power Density |
|-------------------------|-------------------|----------|--------------------------------|
| Mesh Centered (VENTURE) | 6 | -- | 0.9953 |
| | 24 | -- | 1.0038 |
| | 54 | -- | 1.0051 |
| | (∞) | | 1.006 |
| Mesh Edge (VALE) | 3 | 0 | 1.0113 |
| | 3 | 1/6 | 1.0089 |
| | 3 | 7/36 | 1.0086 |
| | 3 | 1/4 | 1.0079 |
| | 12 | 0 | 1.0079 |
| | 48 | 0 | 1.0073 |
| | (∞) | | 1.007 |

A cost benefit analysis would be required to justify the extra cost of using the off-diagonal formulation in a specific application. A relatively large error with the coarse mesh representation would certainly bear special consideration. In some applications it may prove more attractive to use more mesh points (increase the mesh points per hex from 3 to 12). The contribution from the off-diagonal term goes to zero as the mesh spacing is reduced. The evidence that we have accumulated indicates that the linear finite element formulation is usually but not always superior to the others that apply a smaller value of α . The constraint that is applied to the "higher order" formulation selects the largest value of α up to the specified value that leaves a positive diagonal term (after subtracting $2\alpha\Sigma\Delta^2$) at each group by testing over the macroscopic properties of all the zones. Such a constraint is deemed to be essential, even though rather severe.

Table 1. KFK Three-Dimensional Fast Breeder Reactor Benchmark Problem Results (Four Groups)

| Code | Code Source | Sector in Degrees | Mesh Points Per Hex | Mesh | Spacial Mesh Points | Outer Iterations | Inner Iterations Per Outer | Memory Used (bytes ^a) | Computer | Processor Time (min) | k _{eff} |
|-------------------|----------------|-------------------|---------------------|-----------|---------------------|------------------|----------------------------|-----------------------------------|-------------|----------------------|------------------|
| D3E | KFK,FRG | 30 | 3 | 90x19 | 1,710 | | | 300K | IBM 370/168 | 1.2 | 1.007256 |
| | | | 12 | 324x37 | 11,988 | | | 1200K | " | 10.0 | 1.010481 |
| | | | 27 | 702x55 | 38,610 | | | 1100K | " | 29.7 | 1.011139 |
| | | | (Extrapolate) | | | | | | | | 1.01166 |
| DIF3D | ANL | 60 | 6 | 34x17x18 | 10,409 | 15 | 10 | 1200K | IBM 360/195 | 1.0 | 1.016630 |
| | | | 24 | 68x34x36 | 83,232 | 18 | 18 | 1900K | " | 12.0 | 1.013038 |
| | | | 54 | 102x51x54 | 280,908 | 18 | 26 | 1900K | " | 58.0 | 1.012317 |
| | | | (Extrapolate) | | | | | | | | 1.01174 |
| VENTURE | ORNL | 60 | 6 | 34x17x18 | 10,404 | 18 | 4 | 458K | IBM 360/195 | 2.0 | 1.016660 |
| | | | 24 | 68x34x36 | 83,232 | 24 | 4 | 962K | " | 14.0 | 1.013068 |
| | | | 54 | 102x51x54 | 280,908 | 29 | 5 | 1678K | " | 62.0 | 1.012347 |
| | | | (Extrapolate) | | | | | | | | 1.01177 |
| VALE | ORNL | 30 | 3 | 90x18 | 1,620 | 19 | 4 | 290K | IBM-3033 | 0.8 | 1.012488 |
| | | | 12 | 324x36 | 11,664 | 21 | 4 | 420K | " | 4.75 | 1.011884 |
| | | | 48 | 1225x72 | 88,200 | 34 | 5,7,4,5 | 1450K | " | 47.8 | 1.011766 |
| | | | (Extrapolate) | | | | | | | | 1.01173 |
| VALE ^b | $\alpha = 1/4$ | 30 | 3 | 90x18 | 1,620 | 20 | 4 | 290K | " | 0.9 | 1.012644 |
| | | 30 | 3 | 90x18 | 1,620 | 20 | 4 | 290K | " | 0.9 | 1.012626 |

^a4 bytes per short word, data for the VALE runs estimated (virtual memory).

^bOff-diagonal loss term on planes instead of usual finite difference, with consistent source, $\alpha = 1/4$ for linear finite element, $\alpha = 7/36$ linear flux approximation.

Table 2. GA High Temperature Gas Cooled Reactor Benchmark Problem Results (Four Groups)

| Code | Mesh (planar x axial) | Space Points | Outer Iterations | Processor Time (min) | Peak Power Density | k_{eff} |
|----------------------|-----------------------------|-----------------|---------------------|----------------------------|--------------------------|-----------|
| VENTURE ^a | 38x19x8 | 5,776 | 30 | 1.9 | 1.6249 | 1.090687 |
| | 38x19x16 | 11,552 | 34 | 3.9 | 1.6102 | 1.090632 |
| | 38x19x24 | 17,328 | 34 | 6.1 | 1.5975 | 1.091075 |
| | 38x19x ∞ | | | | 1.587 | 1.09143 |
| VALE ^b | 300x8 | 2,400 | 40 | 1.8 | 1.5837 | 1.088212 |
| | 300x16 | 4,800 | 38 | 3.5 | 1.5767 | 1.088012 |
| | 300x24 | 7,200 | 39 | 5.5 | 1.5668 | 1.088400 |
| | 300x32 | 9,600 | 43 | 8.0 | 1.5628 | 1.088676 |
| | 1128x32 | 36,096 | 45 | 23.8 | 1.6216 | 1.089370 |
| | 300x ∞ | | | | 1.558 | 1.08903 |
| | ∞ | | | | 1.636 | 1.0898 |
| VALE ^c | $\alpha=1/4$ 300x16 | 4,800 | 33 | 3.3 | 1.6233 | 1.087444 |
| | $\alpha=7/36$ 300x16 | 4,800 | 34 | 3.4 | 1.6129 | 1.087545 |
| GATT ^d | 1201x31 | 37,231 | 79 | 115.2 | | 1.088504 |

^aIBM-3033, 60° Sector (1/6 of core).

^bIBM-3033, 60° Sector.

^cOff-diagonal loss term instead of usual finite difference, with consistent source, $\alpha = 1/4$ finite element, $\alpha = 7/36$ linear flux approximation, initialized with a cosine axial flux distribution.

^dUnivac 1110, full core model, General Atomic.

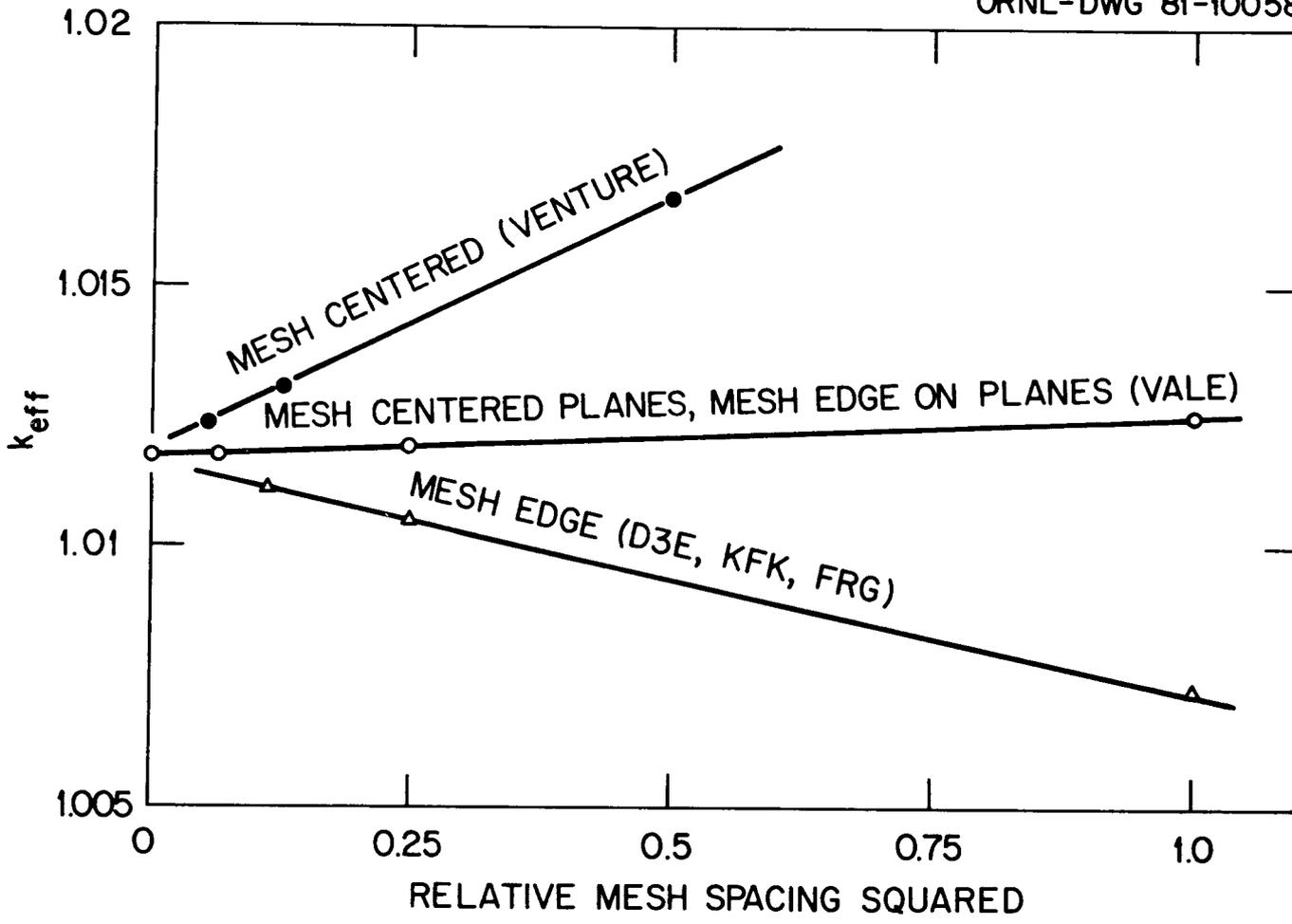


Fig. 7. Plot of K_{eff} vs Mesh for Three Differencing Methods

IV. PROGRAMMING INFORMATION

This section presents information of primary use to the individual implementing this code about the subroutines, program overlay, and local adaptation.

A. Source Program

Most of the programming in this code is FORTRAN language. However, some service routines are in machine dependent IBM ASSEMBLER language. Figure 8 lists the names of some of the special subroutines and their use. The source program consists of 214 routines totaling nearly 35,000 cards.

B. Program Implementation

This code is not a stand-alone code and must be implemented in a modular environment under compatible rules.

The data used in this code is variably dimensioned and therefore the core storage requirements are a function of the problem to be solved. On the IBM-360 model computers, the program plus system routines require approximately 100,000 words of core storage when the code is loaded with the recommended overlay structure shown in Fig. 9. The core storage for data is supplied by the user at run time. Depending upon the amount of storage available for data, the user chooses one of two modes of data storage. Information about disk storage requirements is included in the printout of each run.

C. Conversion to Other Computers

On an IBM machine, much of the calculation is done in double precision and certain data carried as long words. On long-word machines, this data should be carried as regular length and the associated double precision operations changed to single precision. This change is essential

DOPC INITIALIZES, OPENS, AND CLOSES DATA FILES
 ENTRY ROXY COMMUNICATES DATA ARRAYS
 CALLS SEEK, RITE, DEFILE, CLOSDA

RITE DATA TRANSFER MANAGER AND WRITES DATA (FORTRAN WRITE) -
 CALLED BY MOST ROUTINES
 ENTRY REED READS DATA (FORTRAN READ) - CALLED BY MOST
 ROUTINES
 ENTRY ROXX COMMUNICATES DATA ARRAYS
 CALLS CRIT, CRED

SEEK INTERFACE DATA FILES MANAGER
 CALLS RITE, REED

CRIT ASSEMBLY LANGUAGE ROUTINE FOR CORE TO CORE DATA TRANSFER
 ENTRY CRED CORE TO CORE DATA TRANSFER

GETCOR ASSEMBLY LANGUAGE ROUTINE TO ALLOCATE CORE DYNAMICALLY FOR
 THE VARIABLY DIMENSIONED ARRAYS AT RUN TIME

FRECOR ASSEMBLY LANGUAGE ROUTINE TO FREE CORE ALLOCATED BY GETCOR

DEFILE ASSEMBLY LANGUAGE ROUTINE TO EXECUTE THE FORTRAN DEFINE FILE
 STATEMENT USING PROBLEM DEPENDENT VARIABLES (OPENS DIRECT
 ACCESS FILES) - ACCESSES SYSTEM ROUTINE IHCEDIOS

CLOSDA ASSEMBLY LANGUAGE ROUTINE TO CLOSE DIRECT ACCESS FILES

Fig. 8. The Role of Special Subroutines.

THE FOLLOWING LISTS THE SUBROUTINES IN THE RECOMMENDED FOUR LEVELS OF OVERLAY, A, B, C, AND D. IN ADDITION THE FOLLOWING ROUTINES ARE IN THE ROOT SGHMENT.

MAIN, IONO, VENT, DRIV, DIFF, APLY, A122, FFGG, NROD, TIME, FERR, SKER, KEEP, RITE, SEEK, DOPC, CRIT, STOR, PRTH, PRTI, PRTR, PRTT, SERM, CMPH, CMPI, PRC2, PRC3, PRC4, PRC5, PRC6, PRC7, TIMER, GETCOR, FRECOR, DEFILE, CLOSDA

OVERLAY LEVELA

INSERT SGX0,SGX1,SGX2,SGX3,SCAL

OVERLAY LEVELA

INSERT CORE,CORI,CORP,CORD,CORB,DASU,DDSP

OVERLAY LEVELA

INSERT MAC1,VZT2,MACA,MACB,MAC2,MAC3,MAC5,CHDM,MAC4,MAC6

INSERT ADN1,ADN2,ADN3,DCID

OVERLAY LEVELA

INSERT CON1,NEW1,NEW2,CON2,CON3,NSH3,CKCT,NEW3

OVERLAY LEVELA

INSERT LIZE,LIZ1,LUCK,LIZ2,RCOV

OVERLAY LEVELA

INSERT INUX,INU1,INU2

OVERLAY LEVELA

INSERT COMC,PROS,ZIO3,RDSC,REV1,RSIG,RWR4,RWR8,RGFF,BSQV,FXSR,FSBP

INSERT CNST,PRC1,SP2X,FEFS,COER,IFTD,TWOS,HST2

OVERLAY LEVELB

INSERT T121,T122,T123,T601,T602,T603,T301,T302,T303

OVERLAY LEVELB

INSERT B121,B122,B123,B601,B602,B603,B301,B302,B303,DCON,DELZ,CYNC

INSERT ZRDC,ZRNC,ZQDC,DWMP

OVERLAY LEVELA

INSERT OUTR,CHBF,XTRP,JUSB,ATED,BHAV,NEWB,CHEV,OELX,RDUE,RELX,ZINS

INSERT FSOR,SSOR,FLUX,FS2D,SS2D,AJFS,AJSS,AJFF,FBAR,RLBL,HOFS,SGDA

INSERT D2SF,SFJA,FFJA,D2SS,SSJA

OVERLAY LEVELB

INSERT DOIN,MUEX,ETR1,ETR2

OVERLAY LEVELB

INSERT K121,K122,K123,H121,H122,H123

OVERLAY LEVELB

Fig. 9. Recommended Overlay Structure.

```
INSERT KTR1,KTR2,KTR3,HTR1,HTR2,HTR3
OVERLAY LEVELB
INSERT J121,J122,J123
OVERLAY LEVELB
INSERT JTR1,JTR2,JTR3
OVERLAY LEVELB
INSERT CRFS,SFRC
OVERLAY LEVELB
INSERT S121,S122,S123
OVERLAY LEVELB
INSERT STR1,STR2,STR3
OVERLAY LEVELB
INSERT HS21,HS22,HS23
OVERLAY LEVELB
INSERT HSR1,HSR2,HSR3
OVERLAY LEVELC
INSERT INSP,INPL,ADSR,ADFA
OVERLAY LEVELD
INSERT I121,I122,I123
OVERLAY LEVELD
INSERT I601,I602,I603
OVERLAY LEVELD
INSERT I301,I302,I303
OVERLAY LEVELA
INSERT EDIT,PBAR
OVERLAY LEVELB
INSERT NBAL,PFCR,SOBL,WZPD
OVERLAY LEVELB
INSERT RZFL,POUT,AOUT
OVERLAY LEVELB
INSERT PDPA,PDP1,PDP2,PDP3,PDP4,PDP5,PDP6,PDEN,WRC1,WRC2,WRC3,WRC4
INSERT WRC5,WRC6,WRC7
```

Fig. 9. (CONTINUED)

to minimize storage requirements. Alphanumeric characters are carried in the guise of real numbers (Hollerith) as A(6) requiring long-word storage on an IBM machine.

As a convenience for conversion to a long word computer, a multiplier is carried through the routines, MULT or NDP or LX(39), which must be 2 for an IBM machine and 1 for long-word machines. This multiplier adjusts the lengths of words for short-word storage and manipulations avoiding extensive reprogramming upon conversion.

The following changes are required for use on a long-word machine and should be done with a FORTRAN source deck processor:

1. Delete all REAL*8 statements.
2. Change library function references from double to single precision, e.g., SQRT and EXP instead of DSQRT and DEXP.
3. Change all references to "Double Precision," as in function definition statements.
4. Change the apostrophes which delimit alphanumeric strings in FORMAT and DATA statements.

Further requirements include:

1. Change LX(39) to 1 from 2.
2. Replace the subroutine TIMER to provide information from the local system,
 - ICLOCK -- gives cpu time
 - ITTIME -- gives clock time
 - MODEL -- gives computer model
 - IDAY -- gives alphanumeric: Month-Day-Year
 - JSTIME -- gives cpu time remaining
 - JOBNUM -- gives alphanumeric: Job number
 - IOLEFT -- gives the number of I/O's remaining
 - TIME -- gives alphanumeric: time of day

3. Satisfy the data access, transfer requirements including the dynamic opening of the files with parameters which are problem dependent and selective default of files to be resident by replacing the data handling service routines.
4. Provide local capability to allocate memory at run time, or fix the allocations for container arrays and communication.
5. Provide an equivalent program overlay structure.

Local system routines would be needed to satisfy items 2, 3, and 4 immediately above unless those supplied are compatible.

Note that the assembly language routines can only be used on compatible IBM machines (otherwise use the Fortran source decks). You must correct any discrepancies missed by the IBM compiler, and please report this information back to us.

The code is used locally as a module of a computation system. Effecting stand alone capability should not be hard using those modules needed including input data processing capability. It should be most attractive to implement an equivalent modular system, either one-to-one with that in use at ORNL, or adapt the modules into another system.

In converting this code, consideration should be given to data storage and transfer requirements. If large problems are to be solved, even a large extended core cannot contain a set of the flux values, so they must be carried on disc.

D. Limitations

Certain features of the standard interface data file specifications imply capability which is not available. Only the geometry options described herein are available. Quite generally, it has been assumed that the data is simply blocked in the files. No provision has been made to account for partially filled records, for example. At this time the other modules in this system can not process the geometry file TRIGOM and capability that would require this (perturbation, local exposure) is not available.

ACKNOWLEDGEMENTS

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APPENDIX: SAMPLE PROBLEM

The simple four group, three-dimensional problem used as a sample⁵ here was selected from the set we have treated primarily from convenience considerations. In what follows is a brief description of the problem. The input stream with job control information is shown in Fig. A1 and the computer printout showing results is presented as Fig. A2.

The problem is a three-dimensional model of a liquified metal cooled fast breeder reactor core. It treats only a 30° sector. The instructions to the control module cause the use of the Input Processor and the Special Processors for converting input data to interface files and the nuclide ordered cross sections of ISOTXS to the group ordered from GRUPXS. The printout from the computer follows the data processing and computational flow documenting the use of solution procedures and presenting results.

The first printout file is a condensed edit. Information is printed by the control module, first about the instructions it has received, then the module accesses, and finally a wrap-up showing the status of the interface data files. As each code is executed, it prints a limited amount of information in this file. Thus the file is a condensed history of the calculation. Note that the VALE code printed information about the iterative neutronics problem, the peak power density and the multiplication factor. Such auxiliary information as the primitive conversion ratio that would normally be printed is not available because macroscopic cross sections were used for benchmarking (pseudo microscopic).

We note that this three-dimensional problem requires less than two minutes IBM 3033 computer processor time to compute the regular and adjoint fluxes.

The problem is solved in the mode where all of the data for one group over space is stored in memory. The automated capability for defaulting scratch data files to memory when space allows is used for the first two files, the ones of most importance regarding the amount of use.

Point flux values are initially set equal over space and energy. Four inner iterations are used each outer iteration and preferred over-relaxation coefficients are calculated after a delay to propagate boundary conditions. Chebyshev acceleration is not used on outer iteration, but the dominant error vector is removed by asymptotic extrapolation accelerating convergence. The acceptable convergence level for termination is 5×10^{-5} maximum relative flux change on outer iteration. The dominant outer iteration error vector for the regular flux problem appears to play no significant role in the iterative solution, the error vector removed by extrapolation having an eigenvalue of only 0.61. After termination, an additional sweep of the equations produces the reliability data about the solution showing seven digit agreement between two independent estimates of the multiplication factor. Computer time is displayed with a breakdown into major computational tasks.

The neutron balance is printed on option. Special auxiliary calculations are always done to produce zone average and peak zone power densities, and maps are produced on option. Finally the adjoint problem in the reactivity sense is solved and related information printed.

```
//USERID   JOB (CHARG),'USER ADDRESS           ',MSGLEVEL=(1,1)
//STEP EXEC BOLDVENT,
// NB1=1,NB2=1,B1=3520,B2=32000,NX=50,NS=50,N1=100,
// N2=20,N3=10,N4=10,N5=10,N6=10,N7=10,N8=10,N9=10,N10=10,N11=10,
// N12=20,N13=10,N14=10,N15=10,N16=20,
// GOSIZE=500K
//GO.SYSIN DD *
```

```
=CONTROL1
      VALE RUN OF KFK LMFBR BENCHMARK PROBLEM.
41000                                0
  1  2  6  2  8  0
END
```

1

```
INPUT PROCESSOR DATA FOLLOWS.
OV TRIGOM
1D
$ IGOM $ 19
$ NZONE $ 6
$ NREG,NZCL,NCINTI,NCINTJ $ 0 0 0 0
$ NCINTK $ 4
$ POINTS $ 90
$ NINTJ,NINIK $ 0 18
$ LRFBFB $ 1 2 1 1 2 2
$ NBS $ 0
$ NBCS $ 1
$ NIBCS $ 1
$ NZWBB $ 0
$ NTRIAG $ 2
$ NRASS,NGOP $ 1 0 0 0 0 0
2D
$ BSQ(NBS) $
$ BNDC(NBCS) $ 0.4692
$ BNCI(NIBCS) $ 0.4692
$ NZHBB $
$ NZC(NZONE) $ 0 6R
3D
$ MPO $ 0
$ NPF $ 18
$ NPL $ 2
$ NRP $ 9
$ MNP $ 6
$ NRS $ 153
$ NOS,NO3,MZA,MB,MC $ 0 0 0 0 0
$ KFINTS $ 4 5 5 4
4D
$ PMESH $ 6.4665
$ QMESH,X1,X2,X3 $ 0.0 4R
$ZMESH $ 0.0 40.0 87.5 135.0 175.0
7D $ MR(NRS) $
  4 16R 4 9R 3 8R
  4 13R 5 3R 4 6R 3 7R
  4 1R 5 3R 4 6R 5 3R 4 6R 3 6R
  5 1R 4 6R 4 6R 3 8R
  4 1R 4 9R 3 7R
```

Fig. A1. Input Data for Sample Problem.

```

  4 7R 3 6R
  4 1R 3 8R
  3 5R
  3 1R
7D 153S
7D 153S
7D 153S
7D
  1 16R 2 9R 3 8R
  1 13R 5 3R 2 6R 3 7R
  1 1R 6 3R 1 6R 5 3R 2 6R 3 6R
  6 1R 1 6R 2 6R 3 8R
  1 1R 2 9R 3 7R
  2 7R 3 6R
  2 1R 3 8R
  3 5R
  3 1R
7D 153S
7D 153S
7D 153S
7D 153S
7D
  1 16R 2 9R 3 8R
  1 13R 6 3R 2 6R 3 7R
  1 1R 6 3R 1 6R 6 3R 2 6R 3 6R
  6 1R 1 6R 2 6R 3 8R
  1 1R 2 9R 3 7R
  2 7R 3 6R
  2 1R 3 8R
  3 5R
  3 1R
7D 153S
7D 153S
7D 153S
7D 153S
7D
  4 16R 4 9R 3 8R
  4 13R 6 3R 4 6R 3 7R
  4 1R 6 3R 4 6R 6 3R 4 6R 3 6R
  6 1R 4 6R 4 6R 3 8R
  4 1R 4 9R 3 7R
  4 7R 3 6R
  4 1R 3 8R
  3 5R
  3 1R
7D 153S
7D 153S
7D 153S
0V ISOTXS
1D
$NGROUP$ 4
$NISO $ 6
$MAXUP $ 0
$MAXDN $ 3
$MAXORD$ 0
$ICHIST$ 1
$NSCMAX$ 1
$NSBLOK$ 1

```

Fig. A1. (CONTINUED)

```

2D
$HSETID$
* KFK LMFBR BENCHMARK CROSS SECTIONS
$HISONM$ *M1 * *M2 * *M3 * *M4 * *M5 * *M6
$CHI $ 0.768 0.232 0.0 0.0
$VEL $ 1.7234E+9 4.0246E+8 7.9700E+7 3.1594E+7
$EMAX $ 1.05E+7 8.0E+5 1.0E+4 1.0E+3
$EMIN $ 1.0E-4
$LOCA $ 0 3 6 9 12 15
4D
$HABSID, HIDENT, HMAT$ *M1 * *KFKINR* *INCORE*
$AMASS, EFISS, ECAPT, TEMP, SIGPOI, ADENS$ 0.0 6R
$KBR, ICHI, IALF, INP, IN2N, IND, INT$ 1 0 1 0 5R
$LTOT, LTRN, ISTRPD, IDSCT, LORD$ 1 1 0 0 1
$JBAND, IJJ$ 1 2 3 4 1 4R
5D
$STRPL-M1$ 0.11587 0.21220 0.46137 0.34571
$STOTPL-M1$ 0.0 0.0 0.0 0.0
$SNGAM-M1$ 0.690577E-3 0.1830758E-2 0.92948E-2 0.173045E-1
$SFIS-M1$ 0.39123E-2 0.18286E-2 0.36334E-2 0.92415E-2
$SNUTOT-M1$ 3.03607 2.91217 2.88187 2.87951
7D
$SCAT-M1 1-1, 2-2 1-2, 3-3 2-3 1-3, 4-4 3-4 2-4 1-4$
0.0
0.0 0.23597E-1
0.0 0.16153E-2 0.40791E-5
0.0 0.46838E-2 0.42309E-7 0.44493E-7
4D
$HABSID, HIDENT, HMAT$ *M2 * *KFKINR* *OTCORE*
$AMASS, EFISS, ECAPT, TEMP, SIGPOI, ADENS$ 0.0 6R
$KBR, ICHI, IALF, INP, IN2N, IND, INT$ 1 0 1 0 5R
$LTOT, LTRN, ISTRPD, IDSCT, LORD$ 1 1 0 0 1
$JBAND, IJJ$ 1 2 3 4 1 4R
5D
$STRPL-M2$ 0.11588 0.21213 0.46770 0.35349
$STOTPL-M2$ 0.0 0.0 0.0 0.0
$SNGAM-M2$ 0.662205E-3 0.1839559E-2 0.100354E-1 0.20476E-1
$SFIS-M2$ 0.48531E-2 0.26377E-2 0.51332E-2 0.13238E-1
$SNUTOT-M2$ 3.07906 2.91492 2.88494 2.88253
7D
$SCAT-M2 1-1, 2-2 1-2, 3-3 2-3 1-3, 4-4 3-4 2-4 1-4$
0.0
0.0 0.23262E-1
0.0 0.15718E-2 0.46451E-5
0.0 0.43414E-2 0.40724E-7 0.49968E-7
4D
$HABSID, HIDENT, HMAT$ *M3 * *KFKINR* *RADBLK*
$AMASS, EFISS, ECAPT, TEMP, SIGPOI, ADENS$ 0.0 6R
$KBR, ICHI, IALF, INP, IN2N, IND, INT$ 2 0 1 0 5R
$LTOT, LTRN, ISTRPD, IDSCT, LORD$ 1 1 0 0 1
$JBAND, IJJ$ 1 2 3 4 1 4R
5D
$STRPL-M3$ 0.14584 0.28443 0.52703 0.40732
$STOTPL-M3$ 0.0 0.0 0.0 0.0
$SNGAM-M3$ 0.1115267E-2 0.3063463E-2 0.1002116E-1 0.1299948E-1
$SFIS-M3$ 0.27688E-2 0.44347E-4 0.12274E-3 0.34952E-3
$SNUTOT-M3$ 2.79641 2.44098 2.42317 2.42295

```

Fig. A1. (CONTINUED)

7D

\$SCAT-M3 1-1, 2-2 1-2, 3-3 2-3 1-3, 4-4 3-4 2-4 1-4\$
 0.0
 0.0 0.32071E-1
 0.0 0.27776E-2 0.38880E-5
 0.0 0.58971E-2 0.90018E-7 0.45039E-7

4D

\$HABSID, HIDENT, HMAT\$ *M4 * *KFKINR* *AXIBLK*
 \$AMASS, EFISS, ECAPT, TEMP, SIGPOI, ADENS\$ 0.0 6R
 \$KBR, ICHI, IALF, INP, IN2N, IND, INT\$ 2 0 1 0 5R
 \$LTOT, LTRN, ISTRPD, IDSCT, LORD\$ 1 1 0 0 1
 \$JBAND, IJJ\$ 1 2 3 4 1 4R

5D

\$STRPL-M4\$ 0.12270 0.23133 0.46274 0.33749
 \$STOTPL-M4\$ 0.0 0.0 0.0 0.0
 \$SSGAM-M4\$ 0.822777E-3 0.2170873E-2 0.7640834E-2 0.971851E-2
 \$SFIS-M4\$ 0.19453E-2 0.31065E-4 0.87566E-4 0.23769E-3
 \$SNUTOT-M4\$ 2.79026 2.44188 2.42309 2.42299

7D

\$SCAT-M4 1-1, 2-2 1-2, 3-3 2-3 1-3, 4-4 3-4 2-4 1-4\$
 0.0
 0.0 0.26322E-1
 0.0 0.22889E-2 0.28907E-5
 0.0 0.53536E-2 0.62133E-7 0.33248E-7

4D

\$HABSID, HIDENT, HMAT\$ *M5 * *KFKINR* *ABSREG*
 \$AMASS, EFISS, ECAPT, TEMP, SIGPOI, ADENS\$ 0.0 6R
 \$KBR, ICHI, IALF, INP, IN2N, IND, INT\$ 7 0 1 0 5R
 \$LTOT, LTRN, ISTRPD, IDSCT, LORD\$ 1 1 0 0 1
 \$JBAND, IJJ\$ 1 2 3 4 1 4R

5D

\$STRPL-M5\$ 0.13317 0.25355 0.58044 0.54168
 \$STOTPL-M5\$ 0.0 0.0 0.0 0.0
 \$SSGAM-M5\$ 0.1866958E-2 0.126433E-1 0.634405E-1 0.16868
 \$SFIS-M5\$ 0.0 0.0 0.0 0.0
 \$SNUTOT-M5\$ 0.0 0.0 0.0 0.0

7D

\$SCAT-M5 1-1, 2-2 1-2, 3-3 2-3 1-3, 4-4 3-4 2-4 1-4\$
 0.0
 0.0 0.22946E-1
 0.0 0.37687E-2 0.10320E-5
 0.0 0.86815E-2 0.70361E-11 0.10489E-7

4D

\$HABSID, HIDENT, HMAT\$ *M6 * *KFKINR* *POLREG*
 \$AMASS, EFISS, ECAPT, TEMP, SIGPOI, ADENS\$ 0.0 6R
 \$KBR, ICHI, IALF, INP, IN2N, IND, INT\$ 7 0 1 0 5R
 \$LTOT, LTRN, ISTRPD, IDSCT, LORD\$ 1 1 0 0 1
 \$JBAND, IJJ\$ 1 2 3 4 1 4R

5D

\$STRPL-M6\$ 0.72206E-1 0.11487 0.32642 0.19272
 \$STOTPL-M6\$ 0.0 0.0 0.0 0.0
 \$SSGAM-M6\$ 0.216305E-3 0.168800E-3 0.11468E-2 0.78660E-3
 \$SFIS-M6\$ 0.0 0.0 0.0 0.0
 \$SNUTOT-M6\$ 0.0 0.0 0.0 0.0

```

7D
$SCAT-M6 1-1, 2-2 1-2, 3-3 2-3 1-3, 4-4 3-4 2-4 1-4$
0.0
0.0 0.12942E-1
0.0 0.12871E-2 0.68780E-6
0.0 0.34533E-2 0.43633E-11 0.69903E-8
STOP
END

DCRSPR
1
END

DVENTR
001
0.0
0.0
0.0
1 1 0 1 0 0 0 0 0 0 0 0 2 25 1 0 0 1 1 0 0 0 0 0 0 0 0
002
0
0
0
0.0 0.25
0.0
003
1 1 1
004
1 67945.36 1 72245.70 1 171108.2 1 118055.6 1 11678.82 1 16839.22
0
005
1 2 3 4 5 6
012
0
1 6 1 0 0.0

013
6
6
M1 M2 M3 M4 M5 M6
020
1 1
M1 1.0
2 2
M2 1.0
3 3
M3 1.0
4 4
M4 1.0
5 5
M5 1.0
6 6
M6 1.0
0
END
/*
//

```

Fig. A1. (CONTINUED)

BOLD VENTURE VERS-4 RUN ON THE IEM-360/***. CONTROL MOD=CONTROL1, DATE=05-13-81, TIME=16.34.26, JOBNAME=TBPVALE .

INITIALIZATION, REFERENCE - REMAINING I/O= 9.99, CPU MIN= 3.18

RUN TITLE AND CONTROL MODULE DATA

VALE RUN OF KFK LMFBR BENCHMARK PROBLEM.
 41000 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0
 1 2 6 2 8

INITIAL I/O FILE MANAGEMENT TABLES
 FILE NAME SUPPLIED BY

| FILE NUMBER | SEEK | USER-EXIST | USER-STACK | VERSION | WRITTEN | USER IDENTIFICATION |
|-------------|--------|------------|------------|---------|---------|---------------------|
| 10 | CONTRL | | | 1 | 1 | TBPVALE 05-13-81 |

MODULES TO BE ACCESSED IN ORDER

1 2 6 2 8

READ DATA AND ACCESS MODULE 1 - REMAINING I/O= 9.97, CPU MIN= 3.18
 READ DATA FOR A SPECIAL PROCESSOR - REMAINING I/O= 9.91, CPU MIN= 3.16
 ACCESS PROCESSOR 'DCRSRP' - REMAINING I/O= 9.90, CPU MIN= 3.16
 READ INPUT DATA ONLY (LOOK-AHEAD) - REMAINING I/O= 9.88, CPU MIN= 3.15
 ACCESS MODULES 6 0 0 0 0 - REMAINING I/O= 9.87, CPU MIN= 3.15
 ACCESS PROCESSOR 'DVENTR' - REMAINING I/O= 9.41, CPU MIN= 3.14
 ACCESS MODULES 8 0 0 0 0 - REMAINING I/O= 9.38, CPU MIN= 3.13
 ITERATIONS, CONVERGENCE, SEARCH, PEAK POWER DENSITY, K - 19 -4.64948D-05 0.0 1.32199E-16 1.0124875
 PRIMITIVE CONVERSION RATIO, ALSO FOR CRITICAL SYSTEM, FUEL CONSUMPTION (ATOMS/WATT-SEC) - 0.26149 0.28163 0.0
 ADJOINT - ITERATIONS, CONVERGENCE, K - 18 -4.46605D-05 1.0124874

FINAL I/O FILE MANAGEMENT TABLES
 FILE NAME SUPPLIED BY

| FILE NUMBER | SEEK | USER-EXIST | USER-STACK | VERSION | WRITTEN | USER IDENTIFICATION |
|-------------|--------|------------|------------|---------|---------|---------------------|
| 10 | CONTRL | | | 1 | 1 | TBPVALE 05-13-81 |
| 11 | TRIGOM | | | 1 | 1 | TBPVALE 05-13-81 |
| 12 | ISOTXS | | | 1 | 1 | TBPVALE 05-13-81 |
| 13 | GRUPXS | | | 1 | 1 | ORNL N ADE |
| 14 | GEODST | | | 1 | 1 | TBPVALE 05-13-81 |
| 15 | NDXSRP | | | 1 | 1 | TBPVALE 05-13-81 |
| 16 | ZNATDN | | | 1 | 1 | TBPVALE 05-13-81 |
| 17 | RTFLUX | | | 1 | 1 | TBPVALE 05-13-81 |
| 18 | ATFLUX | | | 1 | 1 | TBPVALE 05-13-81 |

WRAP-UP NOW COMPLETE. -- DRIVER TO SEEK NEW CASE - REMAINING I/O= 7.54, CPU MIN= 1.33 - TIME=16.46.48

DVENTP - SPECIAL INPUT MODULE - JANUARY 17, 1979 - QUALITY ASSURANCE LEVEL 0

CASE TITLE - VALE RUN OF KFK LMFBR BENCHMARK PROBLEM.

MPARM 41000 0 0 0 0 0 0 0 0 0 0 0 0 1

INPUT SECTION 1

INPUT SECTION 2

RXX 0.0 0.0 0.0 0.0 0.0 0.0 0.0
 RXX 0.0 0.0 0.0 0.0 0.0 0.0 0.0
 RXX 0.0 0.0 0.0 0.0 0.0 0.0 0.0
 IXC 1 0 0 1 0 0 0 0 0 0 0 25 0 0 0 0 0 0 0 0 0 0 0 0
 IXC 1 1 0 1 0 0 0 0 0 0 0 2 1 0 0 1 1 0 0 0 0 0 0 0 0
 IXCN 0
 IXFN 0
 IXUN 0
 RIXN 0.0 2.500000E-01 0.0 0.0 0.0 0.0 0.0
 RIXN 0.0 0.0 0.0 0.0 0.0 0.0 0.0

DININS RECORD ADDED TO FILE CONTRL

Fig. A2. Selected Output from Sample Problem.

INPUT SECTION 3

1 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0
 GEOMETRY NO. 1 1-D SLAB
 BSQ 0.0
 INRB 1
 BNDC 0.0 0.0 9.999999E 29 9.999999E 29 9.999999E 29 9.999999E 29
 BNDI 4.692000E-01

INPUT SECTION 4

MEMORY REQUIRED 980
 XSHJ/XSHJ 1 1.000000D 00
 XSHI/XSHI 1 1.000000D 00
 XSHFB/XSHKB 1 1.000000D 00
 XMHSH 0.0 1.000000D 00 2.000000D 00 3.000000D 00 4.000000D 00 5.000000D 00 6.000000D 00
 XMHSH 0.0 1.000000D 00
 XMHSH 0.0 1.000000D 00
 GEOMETRY NO. 1
 J/XX 1 0.0 2 1.0000 3 2.0000 4 3.0000 5 4.0000 6 5.0000 7 6.0000
 I/YY 1 0.0 2 1.0000
 KB/ZZ 1 0.0 2 1.0000
 J/X 1 0.5000 2 1.5000 3 2.5000 4 3.5000 5 4.5000 6 5.5000
 I/Y 1 0.5000
 KB/Z 1 0.5000
 MEMORY REQUIRED 998

INPUT SECTION 5

ZONE INPUT BY REGION
 LAYER NUMBER 1
 1 2 3 4 5 6

INPUT SECTION 12

NSZ 0
 1 6 1 0 0.0
 0 0 0 0 0.0
 REGION VOL SUM 6.000000D 00 ZONE VOL SUM 6.000000D 00
 MEMORY REQUIRED 1052
 INTERFACE FILE GEODST HAS BEEN WRITTEN ON UNIT 14

INPUT SECTION 13

NNS 6
 MEMORY REQUIRED 1212
 TITLE FROM CROSS SECTION FILE / KFK IMPBR BENCHMARK CROSS SECTIONS
 NDXS(1) 6 FOR SET 1
 M1 M2 M3 M4 M5 M6

INPUT SECTION 20

NCPD 0 NCYS 0 TIMES 0.0
 1 1
 M1 1 1.000000E 00 0.0 0.0 0.0
 2 2
 M2 2 1.000000E 00 0.0 0.0 0.0
 3 3
 M3 3 1.000000E 00 0.0 0.0 0.0
 4 4
 M4 4 1.000000E 00 0.0 0.0 0.0
 5 5
 M5 5 1.000000E 00 0.0 0.0 0.0
 6 6
 M6 6 1.000000E 00 0.0 0.0 0.0
 0 0
 INTERFACE FILE NDXSRF HAS BEEN WRITTEN ON UNIT 15

Fig. A2. (CONTINUED)

VALE - NEUTRONICS MODULE - VERSION 1 - JANUARY 1, 1979 - QUALITY ASSURANCE LEVEL 0

RUN TITLE - VALE RUN OF KPK LMFBR BENCHMARK PROBLEM.

STORAGE REQUIRED FOR CROSS SECTION CHECK 120 WORDS

TITLE OF THE LATEST VERSION CROSS SECTION FILE
KPK LMFBR BENCHMARK CROSS SECTIONS

CROSS SECTION CHECK COMPLETED NORMALLY

REFERENCE REAL TIME FROM ZNATDN INTERFACE FILE = 0.0 DAYS

SOLUTION BY FINITE-DIFFERENCE DIFFUSION THEORY
EIGENVALUE PROBLEM
A REGULAR ADJACENT WILL FOLLOW FORWARD PROBLEM
GEOMETRY NUMBER 19 SPECIAL TRIANGONAL-Z, THREE-DIMENSIONAL
TRIANGONAL OPTION 2 30 DEGREES
NUMBER OF ENERGY GROUPS 4
NUMBER OF UPSCATTER GROUPS (MAX) 0
NUMBER OF DOWNSCATTER GROUPS (MAX) 3
NUMBER OF POINTS ON EACH PLANE 90
NUMBER OF ROWS OF POINTS ON EACH PLANE 9
NUMBER OF POINTS ON FIRST (TOP) ROW 18
NUMBER OF POINTS ON LAST (BOTTOM) ROW 2
NUMBER OF INTERVALS IN DIMENSION 3 (PLANES) 18
NUMBER OF ZONES 6
NUMBER OF BLACK ABSORBER ZONES 0
BOUNDARY INDICATORS- LEFT 1 RIGHT 2
TOP 1 BOTTOM 1
FRONT 2 REAR 2

MEMORY REQUIREMENTS FOR DATA STORAGE

| | WORDS |
|--------------------------------------|-------|
| STORAGE AVAILABLE | 41000 |
| MACRO CALCULATION | 282 |
| EQUATION CONSTANTS CALCULATION | 714 |
| INITIAL FLUX | 388 |
| ITERATIVE PPROCESS SPACE STORED MODE | 24512 |
| ITERATIVE PROCESS PLANE STORED MODE | 7232 |

DATA WILL BE STORED FOR 1 GROUP AND 18 PLANES FOR THE SPACE STORED MODE (24512)

| | |
|--|-------|
| MEMORY LOCATIONS RESERVED FOR DATA STORAGE--- | 41000 |
| MAX MEMORY LOCATIONS REQUIRED FOR THIS PROB--- | 24512 |
| MEMORY LOCATIONS NOT USED----- | 16488 |

THE ARRAY SIZES FOR STORING SCRATCH I/O DATA FILES IN MEMORY ARE AS FOLLOWS

| UNIT | DATA STORED | WORDS |
|------|--------------------------------|--------|
| 49 | POINT COMPOSITION NUMBERS----- | 27851 |
| 25 | WUSIGF BY POINT----- | 40815 |
| 24 | FLUX----- | 53777 |
| 27 | FLUX----- | 66738 |
| 28 | FLUX----- | 79699 |
| 40 | TOT.LOSS, COUPLING, SRCH.LOSS- | 131540 |

SPECIAL SCRATCH DATASET REQUIREMENTS
MAXIMUM PHYSICAL RECORD IS 7200 WORDS

| | | | | | | | | | |
|-------------------------------------|-----------|-----------|-----------------|------------|----|-----|-------|------|-------|
| RITE CONTAINER ARRAYS, CONTROL | 88 DATA | 16390 | | | | | | | |
| FILE 49 DEFAULTS TO CORE - NO.RECS, | REC.LNTH, | TOT.LNTH, | START LOC, | CORE LEFT. | 18 | 180 | 3240 | 1 | 13150 |
| FILE 25 DEFAULTS TO CORE - NO.RECS, | REC.LNTH, | TOT.LNTH, | START LOC, | CORE LEFT. | 72 | 180 | 12960 | 3241 | 190 |
| DIRECT ACCESS FILE 24 REQUIRES | 4 RECORDS | 3240 | WORDS IN LENGTH | | | | | | |
| DIRECT ACCESS FILE 27 REQUIRES | 4 RECORDS | 3240 | WORDS IN LENGTH | | | | | | |
| DIRECT ACCESS FILE 28 REQUIRES | 4 RECORDS | 3240 | WORDS IN LENGTH | | | | | | |
| DIRECT ACCESS FILE 40 REQUIRES | 4 RECORDS | 12960 | WORDS IN LENGTH | | | | | | |

DD PARAMETERS FOLLOW FOR B1 = 3520 AND B2 = 32000
N2= 19 N3= 10 N4= 10 N5= 4 N6= 10 N7= 3 N8= 3 N9= 1 N10= 5 N11= 2 N12= 10 N13= 10 N14= 10 N15= 10
N16= 19

FOR THE ASSIGNED DATA STORAGE, THE REQUIRED REGION SIZE IS APPROXIMATELY 464K BYTES

****(WATT.SEC/PISS) AND (WATT.SEC/CAPT) ARE ZERO ON GROUPS - DEFAULTING TO 3.2E-11

Fig. A2. (CONTINUED)

PRINCIPAL MACROSCOPIC CROSS SECTIONS

| GROUP 1 | | | | | | | | | |
|---|-----------------|------------------|--------------|--------------|----------------|-----------------|--|--|--|
| ZONE | D | SIGA | SIGNP | SIGWF | SEARCH SIGA | SEARCH SIGNP | | | |
| 1 | 2.876787E 00 | 4.602872E-03 | 1.187800E-02 | 1.251935E-13 | 0.0 | 0.0 | | | |
| 2 | 2.876539E 00 | 5.515300E-03 | 1.494297E-02 | 1.552991E-13 | 0.0 | 0.0 | | | |
| 3 | 2.285609E 00 | 3.884065E-03 | 7.742696E-03 | 8.860154E-14 | 0.0 | 0.0 | | | |
| 4 | 2.716653E 00 | 2.768076E-03 | 5.427886E-03 | 6.224952E-14 | 0.0 | 0.0 | | | |
| 5 | 2.503067E 00 | 1.866957E-03 | 0.0 | 0.0 | 0.0 | 0.0 | | | |
| 6 | 4.616424E 00 | 2.163049E-04 | 0.0 | 0.0 | 0.0 | 0.0 | | | |
| ZONE | FISSILE SIGA | FERTILE SIGNG | SIGNG | SIGP | | | | | |
| 1 | 4.602872E-03 | 0.0 | 6.905769E-04 | 3.912296E-03 | | | | | |
| 2 | 5.515300E-03 | 0.0 | 6.622048E-04 | 4.853096E-03 | | | | | |
| 3 | 0.0 | 1.115266E-03 | 1.115266E-03 | 2.768799E-03 | | | | | |
| 4 | 0.0 | 8.227767E-04 | 8.227767E-04 | 1.945299E-03 | | | | | |
| 5 | 0.0 | 0.0 | 1.866957E-03 | 0.0 | | | | | |
| 6 | 0.0 | 0.0 | 2.163049E-04 | 0.0 | | | | | |
| GROUP 2 | | | | | | | | | |
| ZONE | D | SIGA | SIGNP | SIGWF | SEARCH SIGA | SEARCH SIGNP | | | |
| 1 | 1.570845E 00 | 3.659356E-03 | 5.325187E-03 | 5.851515E-14 | 0.0 | 0.0 | | | |
| 2 | 1.571363E 00 | 4.477255E-03 | 7.688679E-03 | 8.440633E-14 | 0.0 | 0.0 | | | |
| 3 | 1.171934E 00 | 3.107809E-03 | 1.082501E-04 | 1.419103E-15 | 0.0 | 0.0 | | | |
| 4 | 1.440943E 00 | 2.201937E-03 | 7.585695E-05 | 9.940796E-16 | 0.0 | 0.0 | | | |
| 5 | 1.314665E 00 | 1.264329E-02 | 0.0 | 0.0 | 0.0 | 0.0 | | | |
| 6 | 2.901832E 00 | 1.688000E-04 | 0.0 | 0.0 | 0.0 | 0.0 | | | |
| ZONE | FISSILE SIGA | FERTILE SIGNG | SIGNG | SIGP | | | | | |
| 1 | 3.659356E-03 | 0.0 | 1.830757E-03 | 1.828599E-03 | | | | | |
| 2 | 4.477255E-03 | 0.0 | 1.839558E-03 | 2.637699E-03 | | | | | |
| 3 | 0.0 | 3.063462E-03 | 3.063462E-03 | 4.434698E-05 | | | | | |
| 4 | 0.0 | 2.170872E-03 | 2.170872E-03 | 3.106499E-05 | | | | | |
| 5 | 0.0 | 0.0 | 1.264329E-02 | 0.0 | | | | | |
| 6 | 0.0 | 0.0 | 1.688000E-04 | 0.0 | | | | | |
| GROUP 3 | | | | | | | | | |
| ZONE | D | SIGA | SIGNP | SIGWF | SEARCH SIGA | SEARCH SIGNP | | | |
| 1 | 7.224861E-01 | 1.292820E-02 | 1.047098E-02 | 1.162688E-13 | 0.0 | 0.0 | | | |
| 2 | 7.127080E-01 | 1.516859E-02 | 1.480896E-02 | 1.642623E-13 | 0.0 | 0.0 | | | |
| 3 | 6.324750E-01 | 1.014389E-02 | 2.974195E-04 | 3.927678E-15 | 0.0 | 0.0 | | | |
| 4 | 7.203470E-01 | 7.728394E-03 | 2.121802E-04 | 2.802111E-15 | 0.0 | 0.0 | | | |
| 5 | 5.742770E-01 | 6.344044E-02 | 0.0 | 0.0 | 0.0 | 0.0 | | | |
| 6 | 1.021179E 00 | 1.146800E-03 | 0.0 | 0.0 | 0.0 | 0.0 | | | |
| ZONE | FISSILE SIGA | FERTILE SIGNG | SIGNG | SIGP | | | | | |
| 1 | 1.292820E-02 | 0.0 | 9.294797E-03 | 3.633399E-03 | | | | | |
| 2 | 1.516859E-02 | 0.0 | 1.003539E-02 | 5.133197E-03 | | | | | |
| 3 | 0.0 | 1.002115E-02 | 1.002115E-02 | 1.227399E-04 | | | | | |
| 4 | 0.0 | 7.640831E-03 | 7.640831E-03 | 8.756598E-05 | | | | | |
| 5 | 0.0 | 0.0 | 6.344044E-02 | 0.0 | | | | | |
| 6 | 0.0 | 0.0 | 1.146800E-03 | 0.0 | | | | | |
| GROUP 4 | | | | | | | | | |
| ZONE | D | SIGA | SIGNP | SIGWF | SEARCH SIGA | SEARCH SIGNP | | | |
| 1 | 9.641998E-01 | 2.654599E-02 | 2.661097E-02 | 2.957278E-13 | 0.0 | 0.0 | | | |
| 2 | 9.429784E-01 | 3.371397E-02 | 3.815888E-02 | 4.236156E-13 | 0.0 | 0.0 | | | |
| 3 | 8.183579E-01 | 1.334899E-02 | 8.468688E-04 | 1.118463E-14 | 0.0 | 0.0 | | | |
| 4 | 9.876842E-01 | 9.956196E-03 | 5.759203E-04 | 7.606078E-15 | 0.0 | 0.0 | | | |
| 5 | 6.153698E-01 | 1.686800E-01 | 0.0 | 0.0 | 0.0 | 0.0 | | | |
| 6 | 1.729625E 00 | 7.865999E-04 | 0.0 | 0.0 | 0.0 | 0.0 | | | |
| ZONE | FISSILE SIGA | FERTILE SIGNG | SIGNG | SIGP | | | | | |
| 1 | 2.654599E-02 | 0.0 | 1.730449E-02 | 9.241495E-03 | | | | | |
| 2 | 3.371397E-02 | 0.0 | 2.047599E-02 | 1.323799E-02 | | | | | |
| 3 | 0.0 | 1.299947E-02 | 1.299947E-02 | 3.495198E-04 | | | | | |
| 4 | 0.0 | 9.718508E-03 | 9.718508E-03 | 2.376900E-04 | | | | | |
| 5 | 0.0 | 0.0 | 1.686800E-01 | 0.0 | | | | | |
| 6 | 0.0 | 0.0 | 7.865999E-04 | 0.0 | | | | | |
| FISSION SPECTRUM CONSTANT FOR ALL ZONES | | | | | | | | | |
| 7.679999E-01 2.320000E-01 0.0 0.0 | | | | | | | | | |
| 1/V CONSTANT FOR ALL ZONES | | | | | | | | | |
| 5.802485E-10 2.484720E-09 1.254705E-08 3.165160E-08 | | | | | | | | | |

Fig. A2. (CONTINUED)

ZONE NUMBER ASSIGNMENTS FOR EACH TRIANGLE - PLANE 6

```

1 1 1 1 1 1 1 1 1 1 1 1 1 1 2 2 2 2 2 2 2 2 3 3 3 3 3 3 3
  1 1 1 1 1 1 1 1 1 1 1 1 5 5 5 2 2 2 2 2 2 3 3 3 3 3 3 3
    1 6 6 6 1 1 1 1 1 1 1 5 5 5 2 2 2 2 2 2 3 3 3 3 3 3 3
      6 1 1 1 1 1 2 2 2 2 2 2 2 3 3 3 3 3 3 3 3 3
        1 2 2 2 2 2 2 2 2 2 3 3 3 3 3 3 3
          2 2 2 2 2 2 2 3 3 3 3 3
            2 3 3 3 3 3 3 3
              3 3 3 3 3
                3

```

ZONE NUMBER ASSIGNMENTS FOR EACH TRIANGLE - PLANE 7

```

1 1 1 1 1 1 1 1 1 1 1 1 1 1 2 2 2 2 2 2 2 2 3 3 3 3 3 3 3
  1 1 1 1 1 1 1 1 1 1 1 1 5 5 5 2 2 2 2 2 2 3 3 3 3 3 3 3
    1 6 6 6 1 1 1 1 1 1 5 5 5 2 2 2 2 2 2 3 3 3 3 3 3 3
      6 1 1 1 1 1 2 2 2 2 2 2 2 3 3 3 3 3 3 3 3
        1 2 2 2 2 2 2 2 2 2 3 3 3 3 3 3 3
          2 2 2 2 2 2 2 3 3 3 3 3 3
            2 3 3 3 3 3 3 3
              3 3 3 3 3
                3

```

ZONE NUMBER ASSIGNMENTS FOR EACH TRIANGLE - PLANE 8

```

1 1 1 1 1 1 1 1 1 1 1 1 1 1 2 2 2 2 2 2 2 2 3 3 3 3 3 3 3
  1 1 1 1 1 1 1 1 1 1 1 1 5 5 5 2 2 2 2 2 2 3 3 3 3 3 3 3
    1 6 6 6 1 1 1 1 1 1 5 5 5 2 2 2 2 2 2 3 3 3 3 3 3 3
      6 1 1 1 1 1 2 2 2 2 2 2 2 3 3 3 3 3 3 3
        1 2 2 2 2 2 2 2 2 2 3 3 3 3 3 3 3
          2 2 2 2 2 2 2 3 3 3 3 3 3
            2 3 3 3 3 3 3 3
              3 3 3 3 3
                3

```

ZONE NUMBER ASSIGNMENTS FOR EACH TRIANGLE - PLANE 9

```

1 1 1 1 1 1 1 1 1 1 1 1 1 1 2 2 2 2 2 2 2 2 3 3 3 3 3 3 3
  1 1 1 1 1 1 1 1 1 1 1 1 5 5 5 2 2 2 2 2 2 3 3 3 3 3 3 3
    1 6 6 6 1 1 1 1 1 1 5 5 5 2 2 2 2 2 2 3 3 3 3 3 3 3
      6 1 1 1 1 1 2 2 2 2 2 2 2 3 3 3 3 3 3 3
        1 2 2 2 2 2 2 2 2 2 3 3 3 3 3 3 3
          2 2 2 2 2 2 2 3 3 3 3 3 3
            2 3 3 3 3 3 3 3
              3 3 3 3 3
                3

```

ZONE NUMBER ASSIGNMENTS FOR EACH TRIANGLE - PLANE 10

```

1 1 1 1 1 1 1 1 1 1 1 1 1 1 2 2 2 2 2 2 2 2 3 3 3 3 3 3 3
  1 1 1 1 1 1 1 1 1 1 1 1 6 6 6 2 2 2 2 2 2 3 3 3 3 3 3 3
    1 6 6 6 1 1 1 1 1 1 6 6 6 2 2 2 2 2 2 3 3 3 3 3 3 3
      6 1 1 1 1 1 2 2 2 2 2 2 2 3 3 3 3 3 3 3
        1 2 2 2 2 2 2 2 2 2 3 3 3 3 3 3 3
          2 2 2 2 2 2 2 3 3 3 3 3 3
            2 3 3 3 3 3 3 3
              3 3 3 3 3
                3

```

ZONE NUMBER ASSIGNMENTS FOR EACH TRIANGLE - PLANE 11

```

1 1 1 1 1 1 1 1 1 1 1 1 1 1 2 2 2 2 2 2 2 2 3 3 3 3 3 3 3
  1 1 1 1 1 1 1 1 1 1 1 1 6 6 6 2 2 2 2 2 2 3 3 3 3 3 3 3
    1 6 6 6 1 1 1 1 1 1 6 6 6 2 2 2 2 2 2 3 3 3 3 3 3 3
      6 1 1 1 1 1 2 2 2 2 2 2 2 3 3 3 3 3 3 3
        1 2 2 2 2 2 2 2 2 2 3 3 3 3 3 3 3
          2 2 2 2 2 2 2 3 3 3 3 3 3
            2 3 3 3 3 3 3 3
              3 3 3 3 3
                3

```

Fig. A2. (CONTINUED)

ZONE NUMBER ASSIGNMENTS FOR EACH TRIANGLE - PLANE 12

```
1 1 1 1 1 1 1 1 1 1 1 1 1 1 2 2 2 2 2 2 2 2 3 3 3 3 3 3 3
1 1 1 1 1 1 1 1 1 1 1 1 6 6 6 2 2 2 2 2 2 3 3 3 3 3 3 3
1 6 6 6 1 1 1 1 1 1 6 6 6 2 2 2 2 2 2 3 3 3 3 3 3 3
6 1 1 1 1 1 1 2 2 2 2 2 2 3 3 3 3 3 3 3 3
1 2 2 2 2 2 2 2 2 3 3 3 3 3 3
2 2 2 2 2 2 3 3 3 3 3 3
2 3 3 3 3 3 3
3 3 3 3
3
```

ZONE NUMBER ASSIGNMENTS FOR EACH TRIANGLE - PLANE 13

```
1 1 1 1 1 1 1 1 1 1 1 1 1 1 2 2 2 2 2 2 2 2 3 3 3 3 3 3 3
1 1 1 1 1 1 1 1 1 1 1 1 6 6 6 2 2 2 2 2 2 3 3 3 3 3 3 3
1 6 6 6 1 1 1 1 1 1 6 6 6 2 2 2 2 2 2 3 3 3 3 3 3 3
6 1 1 1 1 1 1 2 2 2 2 2 2 3 3 3 3 3 3 3 3
1 2 2 2 2 2 2 2 2 3 3 3 3 3 3
2 2 2 2 2 2 3 3 3 3 3 3
2 3 3 3 3 3 3
3 3 3 3
3
```

ZONE NUMBER ASSIGNMENTS FOR EACH TRIANGLE - PLANE 14

```
1 1 1 1 1 1 1 1 1 1 1 1 1 1 2 2 2 2 2 2 2 2 3 3 3 3 3 3 3
1 1 1 1 1 1 1 1 1 1 1 1 6 6 6 2 2 2 2 2 2 3 3 3 3 3 3 3
1 6 6 6 1 1 1 1 1 1 6 6 6 2 2 2 2 2 2 3 3 3 3 3 3 3
6 1 1 1 1 1 1 2 2 2 2 2 2 3 3 3 3 3 3 3 3
1 2 2 2 2 2 2 2 2 3 3 3 3 3 3
2 2 2 2 2 2 3 3 3 3 3 3
2 3 3 3 3 3 3
3 3 3 3
3
```

ZONE NUMBER ASSIGNMENTS FOR EACH TRIANGLE - PLANE 15

```
4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 3 3 3 3 3 3 3
4 4 4 4 4 4 4 4 4 4 4 4 6 6 6 4 4 4 4 4 4 3 3 3 3 3 3 3
4 6 6 6 4 4 4 4 4 4 6 6 6 4 4 4 4 4 4 3 3 3 3 3 3 3
6 4 4 4 4 4 4 4 4 4 4 4 4 3 3 3 3 3 3 3 3
4 4 4 4 4 4 4 4 4 4 3 3 3 3 3 3
4 4 4 4 4 4 3 3 3 3 3 3
4 3 3 3 3 3 3 3
3 3 3 3
3
```

ZONE NUMBER ASSIGNMENTS FOR EACH TRIANGLE - PLANE 16

```
4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 3 3 3 3 3 3 3
4 4 4 4 4 4 4 4 4 4 4 4 6 6 6 4 4 4 4 4 4 3 3 3 3 3 3 3
4 6 6 6 4 4 4 4 4 4 6 6 6 4 4 4 4 4 4 3 3 3 3 3 3 3
6 4 4 4 4 4 4 4 4 4 4 4 4 4 3 3 3 3 3 3 3 3
4 4 4 4 4 4 4 4 4 4 3 3 3 3 3 3
4 4 4 4 4 4 3 3 3 3 3 3
4 3 3 3 3 3 3 3
3 3 3 3
3
```

ZONE NUMBER ASSIGNMENTS FOR EACH TRIANGLE - PLANE 17

```
4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 3 3 3 3 3 3 3
4 4 4 4 4 4 4 4 4 4 4 4 6 6 6 4 4 4 4 4 4 3 3 3 3 3 3 3
4 6 6 6 4 4 4 4 4 4 6 6 6 4 4 4 4 4 4 3 3 3 3 3 3 3
6 4 4 4 4 4 4 4 4 4 4 4 4 4 3 3 3 3 3 3 3 3
4 4 4 4 4 4 4 4 4 4 3 3 3 3 3 3
4 4 4 4 4 4 3 3 3 3 3 3
4 3 3 3 3 3 3 3
3 3 3 3
3
```

Fig. A2. (CONTINUED)

ZONE NUMBER ASSIGNMENTS FOR EACH TRIANGLE - PLANE 18

```

4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 3 3 3 3 3 3 3
4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 3 3 3 3 3 3 3
4 6 6 6 4 4 4 4 4 4 6 6 6 4 4 4 4 4 4 4 4 4 4 4 3 3 3 3 3 3
6 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 3 3 3 3 3 3 3
4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 3 3 3 3 3 3 3
4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 3 3 3 3 3 3 3
4 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3
3 3 3 3 3
3
    
```

ZONE VOLUMES - TOTAL = 4.578729691936D 05
 6.794536102419D 04 7.224570032951D 04 1.711082376225D 05 1.180556306136D 05 1.167881621868D 04
 1.683922338507D 04

*****NOTE - THE ZONE VOLUMES (VOLZ (M)) HAVE BEEN RE-WRITTEN ON THE INTERFACE FILE NDISRF*****

BUCKLING VALUE FOR ALL ZONES AND GROUPS IS 0.0

THERE ARE NO BLACK ABSORBER ZONES

| GROUP | BOUNDARY CONSTANTS | | | | | | | |
|-------|--------------------|-------------|-----|--------|-------------|-------------|-------------|--|
| | EXTERNAL | | | | INTERNAL | | | |
| | LEFT | RIGHT | TOP | BOTTOM | FRONT | REAR | INTERNAL | |
| | 1 | 2 | 1 | 2 | 1 | 2 | | |
| 1 | 0.0 | 4.69200E-01 | 0.0 | 0.0 | 4.69200E-01 | 4.69200E-01 | 4.69200E-01 | |
| 2 | 0.0 | 4.69200E-01 | 0.0 | 0.0 | 4.69200E-01 | 4.69200E-01 | 4.69200E-01 | |
| 3 | 0.0 | 4.69200E-01 | 0.0 | 0.0 | 4.69200E-01 | 4.69200E-01 | 4.69200E-01 | |
| 4 | 0.0 | 4.69200E-01 | 0.0 | 0.0 | 4.69200E-01 | 4.69200E-01 | 4.69200E-01 | |

THE MAXIMUM AND MINIMUM DIFFUSION COEFFICIENTS ARE 4.61642E 00 5.74277E-01

EQUILATERAL TRIANGLES ON PLANES - SIDE = 6.4665 TRIANGLE AREA = 1.81066918D 01

FINE MESH DESCRIPTION - POINT IS LOCATED AT THE CENTROID OF THE VOLUME ELEMENT
 DISTANCE TO POINT - DIMENSION 3 (FRONT TO REAR)
 1 5.0000 2 15.0000 3 25.0000 4 35.0000 5 44.7500 6 54.2500 7 63.7500 8 73.2500
 9 82.7500 10 92.2500 11 101.7500 12 111.2500 13 120.7500 14 130.2500 15 140.0000 16 150.0000
 17 160.0000 18 170.0000

FIXED OVERRELAXATION COEFFICIENT BEFORE ADJUSTMENT
 BETAC = 1.525229E 00 RHOC = 9.503188E-01
 ANDAL = 9.600536E-01 ANDAG = 9.503188E-01
 RHO 9.035851E-01 9.354420E-01 8.771367E-01 9.060164E-01
 BETA 1.400159E 00 1.477672E 00 1.351131E 00 1.405241E 00
 WINR 4 4 4 4

A FLUX - EIGENVALUE PROBLEM FOLLOWS
 4 INNERS MIN, 4 INNERS MAX - CHEBYCHEV BETA ON INNERS
 SIGMA-1 ORDERING

| ITER | PROC | ICVR | OCVR | FLUX CHANGE | MU-BAR | OTHER-MU | SEM-IND | ACCELERATION | PARAMETERS | SOURCE | K-CALC | K-USED |
|------|------|------|------|--------------|---------|----------|---------|--------------|------------|-------------|-----------|-----------|
| 1 | 0 | 0 | 0 | 1.150179D 01 | 0.0 | 0.0 | 1.00000 | 0.0 | 0.0 | 1.14321E 16 | 0.2872212 | 1.0000000 |
| 2 | 0 | 0 | 0 | 1.128189D 01 | 0.03438 | 0.0 | 1.00000 | 1.00000 | 0.0 | 7.35129E 15 | 0.8889516 | 1.0000000 |
| 3 | 0 | 0 | 0 | 1.555879D 00 | 0.12425 | 0.0 | 1.00000 | 0.14188 | 0.0 | 7.11876E 15 | 0.9360980 | 1.0000000 |
| 4 | 0 | 0 | 0 | -5.87576D-01 | 0.13557 | 0.0 | 1.00000 | 0.16193 | -0.00063 | 6.95688E 15 | 0.9787095 | 1.0000000 |

NEW OVERRELAXATION COEFFICIENTS CALCULATED
 1.42029 1.54880 1.32025 1.38239
 NEW INNERS CALCULATED

| | | | | | | | | | | | | |
|----|---|---|---|--------------|---------|-----|---------|----------|----------|-------------|-----------|-----------|
| 5 | 0 | 0 | 0 | -2.67544D-01 | 0.32650 | 0.0 | 1.00000 | -1.87828 | 0.24960 | 6.90486E 15 | 0.9943139 | 1.0000000 |
| 6 | 0 | 0 | 0 | -1.51536D-01 | 0.58807 | 0.0 | 1.00000 | 2.48632 | -0.21142 | 6.90250E 15 | 1.0030008 | 1.0014582 |
| 7 | 0 | 0 | 0 | -9.52072D-02 | 0.58346 | 0.0 | 1.00000 | 1.38715 | 0.00808 | 6.92319E 15 | 1.0073178 | 1.0073178 |
| 8 | 0 | 0 | 0 | -5.83816D-02 | 0.61063 | 0.0 | 1.00000 | -0.45449 | 1.10321 | 6.92865E 15 | 1.0093896 | 1.0093896 |
| 9 | 0 | 0 | 0 | -3.45646D-02 | 0.60209 | 0.0 | 1.00000 | 1.13078 | 0.23860 | 6.93172E 15 | 1.0106858 | 1.0106858 |
| 10 | 0 | 0 | 0 | -2.06096D-02 | 0.60854 | 0.0 | 1.00000 | 0.73970 | 0.48265 | 6.93328E 15 | 1.0111459 | 1.0111459 |
| 11 | 0 | 0 | 0 | -1.24254D-02 | 0.61214 | 0.0 | 1.00000 | 2.90430 | -0.79953 | 6.93414E 15 | 1.0118475 | 1.0118475 |
| 12 | 2 | 0 | 0 | -1.22116D-02 | 0.61608 | 0.0 | 0.0 | 0.61176 | 0.0 | 6.93462E 15 | 1.0121033 | 1.0121033 |
| 13 | 0 | 0 | 0 | 3.93185D-04 | 0.0 | 0.0 | 1.00000 | 0.0 | 0.0 | 6.93534E 15 | 1.0125062 | 1.0125062 |
| 14 | 0 | 0 | 0 | 2.82951D-04 | 0.76475 | 0.0 | 1.00000 | 0.02958 | 0.04484 | 6.93531E 15 | 1.0124992 | 1.0124992 |
| 15 | 0 | 0 | 0 | 2.00590D-04 | 0.75451 | 0.0 | 1.00000 | 3.07029 | 0.00251 | 6.93527E 15 | 1.0124932 | 1.0124932 |
| 16 | 0 | 0 | 0 | 1.43896D-04 | 0.70056 | 0.0 | 1.00000 | -2.45007 | 4.40793 | 6.93526E 15 | 1.0124907 | 1.0124907 |
| 17 | 0 | 0 | 0 | 9.76008D-05 | 0.68734 | 0.0 | 1.00000 | 2.88662 | -0.50342 | 6.93525E 15 | 1.0124893 | 1.0124893 |
| 18 | 0 | 0 | 0 | 6.65981D-05 | 0.68884 | 0.0 | 1.00000 | 1.97725 | 0.16177 | 6.93524E 15 | 1.0124886 | 1.0124886 |
| 19 | 0 | 0 | 0 | -4.64948D-05 | 0.69341 | 0.0 | 0.0 | -3.86805 | 4.16034 | 6.93524E 15 | 1.0124881 | 1.0124881 |

ESTIMATED ABSOLUTE POINT FLUX RELATIVE ERROR 1.05155D-04

FINAL CALCULATED KEFFECTIVE 1.0124879
 MULTIPLICATION RELIABILITY ESTIMATORS
 BY THE SUM OF THE SQUARES OF THE RESIDUES----- 1.0124881
 UPPER AND LOWER BOUNDS ESTIMATES BY MAX REL FLUX CHANGE----- 1.0125349 1.0124408
 UPPER AND LOWER BOUNDS ESTIMATES OVER ALL SIGNIFICANT POINTS----- 1.0162880 1.0086894

NUMBER OF INNER ITERATIONS, OUTER ITERATION ERROR EIGENVALUE, AND OVERRELAXATION COEFFICIENTS 4 6.93406D-01
 1.42029 1.54880 1.32025 1.38239

CPU AND CLOCK MINUTES REQUIRED FOR THIS EIGENVALUE PROBLEM ARE 0.818 4.002

Fig. A2. (CONTINUED)

| ITERATION TIMING STATISTICS | | | |
|-----------------------------|-------------|---------|--|
| CALCULATION | TIMER UNITS | SECONDS | |
| FISS-SOURCE | 310 | 3.10 | |
| SCAT-SOURCE | 242 | 2.42 | |
| IN-LEAKAGE | 1608 | 16.08 | |
| P-E SWEEP | 1211 | 12.11 | |
| CHEB. ACCL. | 0 | 0.0 | |
| OTHER | 1536 | 15.36 | |
| OVERALL | 4907 | 49.07 | |

TOTAL I/O REQUESTS = 701

LEAKAGE 1.36905E-01 TOTAL LOSSES 9.87666E-01 TOTAL PRODUCTIONS 1.00000E 00 REACTOR POWER (WATTS) 0.0

PRIMITIVE FISSILE CONVERSION RATIO IS 2.61494D-01, ESTIMATE FOR CRITICAL SYSTEM IS 2.81630D-01
 FISSILE DESTRUCTION PER UNIT ENERGY (ATOMS/WATT-SEC) IS 0.0

| BOUNDARY NEUTRON LEAKAGE | | | | | | | |
|--------------------------|------|-------------|-----|--------|-------------|-------------|--|
| GROUP | LEFT | RIGHT | TOP | BOTTOM | FRONT | BACK | |
| 1 | 0.0 | 1.19478D-02 | 0.0 | 0.0 | 7.30085D-04 | 1.26860D-03 | |
| 2 | 0.0 | 8.13733D-02 | 0.0 | 0.0 | 8.79006D-03 | 1.69685D-02 | |
| 3 | 0.0 | 8.39509D-03 | 0.0 | 0.0 | 8.07092D-04 | 1.80574D-03 | |
| 4 | 0.0 | 3.23636D-03 | 0.0 | 0.0 | 3.65435D-04 | 1.21739D-03 | |
| SUM | 0.0 | 1.04952E-01 | 0.0 | 0.0 | 1.06927E-02 | 2.12602E-02 | |

GROUP NEUTRON BALANCE FOR EACH ZONE

| ZONE | GROUP | ABSORPTIONS | B**2 LOSSES | 1/V LOSS | OUT-SCATTER | IN-SCATTER | SOURCE | POWER (WATTS) | AVERAGE FLUX |
|------|-------|-------------|-------------|----------|-------------|-------------|-------------|---------------|--------------|
| 1 | 1 | 5.57548E-02 | 0.0 | 0.0 | 2.85882E-01 | 0.0 | 3.99078E-01 | 1.51648E-12 | 1.7827E-04 |
| | 2 | 2.07799E-01 | 0.0 | 0.0 | 9.17284E-02 | 2.85832E-01 | 1.20555E-01 | 3.32283E-12 | 8.35757E-04 |
| | 3 | 6.72470E-02 | 0.0 | 0.0 | 2.43632E-02 | 9.17754E-02 | 0.0 | 6.04782E-13 | 7.65554E-05 |
| | 4 | 2.53206E-02 | 0.0 | 0.0 | 0.0 | 2.43661E-02 | 0.0 | 2.82077E-13 | 1.40383E-05 |
| | SUM | 3.56122E-01 | 0.0 | 0.0 | 4.01973E-01 | 4.01973E-01 | 5.19633E-01 | 5.72616E-12 | |
| 2 | 1 | 4.32258E-02 | 0.0 | 0.0 | 1.82351E-01 | 0.0 | 3.33691E-01 | 1.21715E-12 | 1.0848E-04 |
| | 2 | 1.51280E-01 | 0.0 | 0.0 | 5.31103E-02 | 1.82314E-01 | 1.00802E-01 | 2.85197E-12 | 4.67690E-04 |
| | 3 | 4.52905E-02 | 0.0 | 0.0 | 1.29626E-02 | 5.31453E-02 | 0.0 | 4.90456E-13 | 4.1328E-05 |
| | 4 | 1.66082E-02 | 0.0 | 0.0 | 0.0 | 1.29643E-02 | 0.0 | 2.08682E-13 | 6.81869E-06 |
| | SUM | 2.56405E-01 | 0.0 | 0.0 | 2.48424E-01 | 2.48424E-01 | 4.34493E-01 | 4.76826E-12 | |
| 3 | 1 | 9.43891E-03 | 0.0 | 0.0 | 7.79472E-02 | 0.0 | 1.67189E-02 | 2.15316E-13 | 1.4202E-05 |
| | 2 | 5.45647E-02 | 0.0 | 0.0 | 4.87687E-02 | 7.79377E-02 | 5.05051E-03 | 2.49156E-14 | 1.02605E-04 |
| | 3 | 2.46395E-02 | 0.0 | 0.0 | 1.43240E-02 | 4.87765E-02 | 0.0 | 9.54031E-15 | 1.41957E-05 |
| | 4 | 9.49340E-03 | 0.0 | 0.0 | 0.0 | 1.43257E-02 | 0.0 | 7.95417E-15 | 4.15626E-06 |
| | SUM | 9.81364E-02 | 0.0 | 0.0 | 1.41040E-01 | 1.41040E-01 | 2.17694E-02 | 2.57726E-13 | |
| 4 | 1 | 4.20691E-03 | 0.0 | 0.0 | 4.57146E-02 | 0.0 | 9.03964E-03 | 1.08100E-13 | 1.4709E-05 |
| | 2 | 3.86537E-02 | 0.0 | 0.0 | 4.01814E-02 | 4.57095E-02 | 2.73072E-03 | 1.74505E-14 | 1.48696E-04 |
| | 3 | 2.08968E-02 | 0.0 | 0.0 | 1.44756E-02 | 4.01853E-02 | 0.0 | 7.57664E-15 | 2.29036E-05 |
| | 4 | 1.01341E-02 | 0.0 | 0.0 | 0.0 | 1.44768E-02 | 0.0 | 7.74201E-15 | 8.62197E-06 |
| | SUM | 7.44916E-02 | 0.0 | 0.0 | 1.00372E-01 | 1.00372E-01 | 1.17704E-02 | 1.40869E-13 | |
| 5 | 1 | 1.21164E-03 | 0.0 | 0.0 | 1.48924E-02 | 0.0 | 0.0 | 0.0 | 5.55701E-05 |
| | 2 | 4.02428E-02 | 0.0 | 0.0 | 1.19955E-02 | 1.48918E-02 | 0.0 | 0.0 | 2.72539E-04 |
| | 3 | 1.56891E-02 | 0.0 | 0.0 | 2.14697E-03 | 1.19962E-02 | 0.0 | 0.0 | 2.11754E-05 |
| | 4 | 5.18516E-03 | 0.0 | 0.0 | 0.0 | 2.14697E-03 | 0.0 | 0.0 | 2.6320E-06 |
| | SUM | 6.23287E-02 | 0.0 | 0.0 | 2.90349E-02 | 2.90349E-02 | 0.0 | 0.0 | |
| 6 | 1 | 3.83916E-04 | 0.0 | 0.0 | 2.29718E-02 | 0.0 | 0.0 | 0.0 | 1.05402E-04 |
| | 2 | 1.54632E-03 | 0.0 | 0.0 | 1.17907E-02 | 2.29705E-02 | 0.0 | 0.0 | 5.44007E-04 |
| | 3 | 1.15364E-03 | 0.0 | 0.0 | 3.47389E-03 | 1.17919E-02 | 0.0 | 0.0 | 5.97392E-05 |
| | 4 | 1.93116E-04 | 0.0 | 0.0 | 0.0 | 3.47390E-03 | 0.0 | 0.0 | 1.45795E-05 |
| | SUM | 3.27699E-03 | 0.0 | 0.0 | 3.82363E-02 | 3.82363E-02 | 0.0 | 0.0 | |

OVERALL NEUTRON BALANCE

| GROUP | ABSORPTIONS | B**2 LOSSES | 1/V LOSS | OUT-SCATTER | IN-SCATTER | SOURCE | POWER (WATTS) |
|-------|-------------|-------------|----------|-------------|-------------|-------------|---------------|
| 1 | 1.14822E-01 | 0.0 | 0.0 | 6.29758E-01 | 0.0 | 7.58527E-01 | 3.05704E-12 |
| 2 | 4.94087E-01 | 0.0 | 0.0 | 2.57575E-01 | 6.29655E-01 | 2.29138E-01 | 6.21717E-12 |
| 3 | 1.74916E-01 | 0.0 | 0.0 | 7.17462E-02 | 2.57670E-01 | 0.0 | 1.11235E-12 |
| 4 | 6.69345E-02 | 0.0 | 0.0 | 0.0 | 7.17537E-02 | 0.0 | 5.06455E-13 |
| SUM | 8.50760E-01 | 0.0 | 0.0 | 9.59079E-01 | 9.59080E-01 | 9.87665E-01 | 1.08930E-11 |

ZONE VOLUMES FOLLOW. TOTAL VOLUME 4.57873E 05
 6.79454D 04 7.22457D 04 1.71108D 05 1.18056D 05 1.16788D 04 1.68392D 04

THE TOTAL FLUX INTERFACE FILE RTFLUX (VERSION 1) HAS BEEN WRITTEN ON UNIT NUMBER 17

Fig. A2. (CONTINUED)

THE AVERAGE POWER DENSITY FOR EACH TRIANGLE ON PLANE 1

| | | | | | | | | |
|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|
| 2.80260E-19 | 2.76951E-19 | 2.73679E-19 | 2.66958E-19 | 2.60670E-19 | 2.50691E-19 | 2.42672E-19 | 2.31310E-19 | 2.23816E-19 |
| 2.13472E-19 | 2.06737E-19 | 1.96832E-19 | 1.88335E-19 | 1.76433E-19 | 1.64899E-19 | 1.49810E-19 | 1.37950E-19 | 1.24563E-19 |
| 1.16921E-19 | 1.07797E-19 | 1.01791E-19 | 9.31966E-20 | 8.49505E-20 | 7.50948E-20 | 6.53181E-20 | 7.75785E-20 | 6.33151E-20 |
| 4.94839E-20 | 3.85220E-20 | 2.82776E-20 | 2.03530E-20 | 1.28151E-20 | 7.70595E-21 | 2.63508E-19 | 2.52429E-19 | 2.45900E-19 |
| 2.29004E-19 | 2.22433E-19 | 2.06680E-19 | 2.05213E-19 | 1.94729E-19 | 1.93084E-19 | 1.82429E-19 | 1.74276E-19 | 1.59274E-19 |
| 1.46341E-19 | 0.0 | 0.0 | 0.0 | 1.04797E-19 | 9.73457E-20 | 9.17516E-20 | 8.21173E-20 | 7.37067E-20 |
| 6.26096E-20 | 7.56948E-20 | 5.97980E-20 | 4.78505E-20 | 3.53185E-20 | 2.67074E-20 | 1.69745E-20 | 1.10067E-20 | 2.18638E-19 |
| 0.0 | 0.0 | 0.0 | 1.86073E-19 | 1.80567E-19 | 1.78569E-19 | 1.68329E-19 | 1.57187E-19 | 1.42897E-19 |
| 0.0 | 0.0 | 0.0 | 1.01773E-19 | 9.56310E-20 | 8.75815E-20 | 7.96618E-20 | 6.83200E-20 | 5.96784E-20 |
| 6.80574E-20 | 5.63406E-20 | 4.13512E-20 | 3.22766E-20 | 2.05407E-20 | 1.38496E-20 | 0.0 | 1.77213E-19 | 1.76444E-19 |
| 1.71781E-19 | 1.65664E-19 | 1.55388E-19 | 1.43763E-19 | 1.32388E-19 | 1.20294E-19 | 1.11639E-19 | 1.02404E-19 | 9.37780E-20 |
| 8.50980E-20 | 1.04063E-19 | 9.14344E-20 | 7.32334E-20 | 6.22626E-20 | 4.60239E-20 | 3.68294E-20 | 2.34814E-20 | 1.62673E-20 |
| 1.67887E-19 | 1.58988E-19 | 1.52606E-19 | 1.41485E-19 | 1.32891E-19 | 1.21221E-19 | 1.12063E-19 | 1.00197E-19 | 9.11485E-20 |
| 7.82358E-20 | 9.80369E-20 | 7.85933E-20 | 6.65080E-20 | 4.97007E-20 | 4.02774E-20 | 2.58070E-20 | 1.82055E-20 | 1.36745E-20 |
| 1.24464E-19 | 1.17533E-19 | 1.04135E-19 | 9.59570E-20 | 8.16456E-20 | 7.29731E-20 | 8.33684E-20 | 7.14188E-20 | 5.27721E-20 |
| 4.31394E-20 | 2.76419E-20 | 1.97328E-20 | 9.76679E-20 | 1.17480E-19 | 1.06292E-19 | 8.46316E-20 | 7.40796E-20 | 5.46738E-20 |
| 4.53161E-20 | 2.89564E-20 | 2.09150E-20 | 7.41586E-20 | 5.52127E-20 | 4.62800E-20 | 2.96170E-20 | 2.16512E-20 | 2.18666E-20 |

THE AVERAGE POWER DENSITY FOR EACH TRIANGLE ON PLANE 18

| | | | | | | | | |
|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|
| 3.77720E-19 | 3.77422E-19 | 3.77133E-19 | 3.77018E-19 | 3.76495E-19 | 3.77051E-19 | 3.75040E-19 | 3.74263E-19 | 3.67795E-19 |
| 3.62172E-19 | 3.50939E-19 | 3.41356E-19 | 3.29785E-19 | 3.20771E-19 | 3.11953E-19 | 3.06947E-19 | 2.97149E-19 | 2.88708E-19 |
| 2.68417E-19 | 2.47281E-19 | 2.18775E-19 | 1.93049E-19 | 1.67967E-19 | 1.43657E-19 | 1.21370E-19 | 1.40899E-19 | 1.12664E-19 |
| 8.64498E-20 | 6.63417E-20 | 4.81042E-20 | 3.42925E-20 | 2.14142E-20 | 1.27846E-20 | 3.77191E-19 | 3.79300E-19 | 3.79683E-19 |
| 3.87695E-19 | 3.84287E-19 | 3.88418E-19 | 3.72772E-19 | 3.64233E-19 | 3.44051E-19 | 3.32422E-19 | 3.20714E-19 | 3.14143E-19 |
| 3.09194E-19 | 0.0 | 0.0 | 0.0 | 2.51367E-19 | 2.20969E-19 | 1.91157E-19 | 1.63273E-19 | 1.40855E-19 |
| 1.15995E-19 | 1.37225E-19 | 1.06029E-19 | 8.34901E-20 | 6.06913E-20 | 4.54135E-20 | 2.85735E-20 | 1.83859E-20 | 3.95325E-19 |
| 0.0 | 0.0 | 0.0 | 3.72643E-19 | 3.51584E-19 | 3.31546E-19 | 3.16077E-19 | 3.10382E-19 | 3.00730E-19 |
| 0.0 | 0.0 | 0.0 | 2.39779E-19 | 2.14747E-19 | 1.78760E-19 | 1.57098E-19 | 1.28558E-19 | 1.09872E-19 |
| 1.21934E-19 | 9.94829E-20 | 7.15995E-20 | 5.53472E-20 | 3.47868E-20 | 2.32910E-20 | 0.0 | 3.63978E-19 | 3.46659E-19 |
| 3.19700E-19 | 3.09157E-19 | 2.90520E-19 | 2.87789E-19 | 2.68244E-19 | 2.65132E-19 | 2.35711E-19 | 2.21860E-19 | 1.86073E-19 |
| 1.60006E-19 | 1.94765E-19 | 1.69367E-19 | 1.31141E-19 | 1.10390E-19 | 7.97487E-20 | 6.34095E-20 | 3.98403E-20 | 2.74699E-20 |
| 3.10061E-19 | 2.88477E-19 | 2.79480E-19 | 2.58390E-19 | 2.49885E-19 | 2.25493E-19 | 2.14431E-19 | 1.85850E-19 | 1.71343E-19 |
| 1.41533E-19 | 1.77998E-19 | 1.38269E-19 | 1.16810E-19 | 8.53679E-20 | 6.90580E-20 | 4.35780E-20 | 3.06994E-20 | 2.46297E-20 |
| 2.22654E-19 | 2.10355E-19 | 1.84041E-19 | 1.70598E-19 | 1.42496E-19 | 1.27938E-19 | 1.43333E-19 | 1.23017E-19 | 8.92452E-20 |
| 7.30546E-20 | 4.61702E-20 | 3.30035E-20 | 1.70026E-20 | 2.02164E-19 | 1.82046E-19 | 1.43006E-19 | 1.25082E-19 | 9.10872E-20 |
| 7.55657E-20 | 4.77492E-20 | 3.45443E-20 | 1.24084E-19 | 9.14067E-20 | 7.63339E-20 | 4.84149E-20 | 3.53517E-20 | 3.55687E-20 |

THE MAXIMUM POWER DENSITY IS 1.3219946E-16 IN ZONE 1 ON PLANE 10 IN TRIANGLE 1

THE MAXIMUM POWER DENSITIES IN EACH ZONE ARE
 1.32199E-16 1.25595E-16 1.13598E-17 4.80826E-18 0.0 0.0

D.A. 40 RECORD LENGTH FROM CORE AND PROS 12960 12960

CCRE STORAGE REQUIRED IS 24509 WORDS
 ELAPSED CPU AND CLOCK MINUTES ARE 0.879 6.895

ADJOINT PROBLEM FOLLOWS

4 INNERS MIN, 4 INNERS MAX - CHEBYCHEV BETA ON INNERS

SIGMA-1 ORDERING

PROCEDURE=0,1,2,3,4-NORMAL,CHEBYTSHEV,SEMEX,DEMEX,SEMEXP. ICVPR=0,1-YES,NO INNERS CONVR. OCVR=0,1-YES,NO OUTERS CONVR.

| ITER | PROC | ICVPR | OCVPR | FLUX CHANGE | NO-BAR | OTHER-NU | SEM-LWD | ACCELERATION | PARAMETERS |
|------|------|-------|-------|--------------|----------|----------|---------|--------------|------------|
| 1 | 0 | 0 | 0 | 8.43099D 00 | 0.0 | 0.0 | 1.00000 | 0.0 | 0.0 |
| 2 | 0 | 1 | 0 | 2.30533D 01 | 14.26100 | 0.0 | 1.00000 | 1.00000 | 0.0 |
| 3 | 0 | 0 | 0 | -5.51999D-01 | 0.15880 | 0.0 | 1.00000 | 0.18878 | 0.0 |
| 4 | 0 | 0 | 0 | -2.47721D-01 | 0.35955 | 0.0 | 1.00000 | 0.23248 | 0.03953 |

NEW OVERRELAXATION COEFFICIENTS CALCULATED

1.38202 1.32180 1.54926 1.42048

NEW INNERS CALCULATED

| | 4 | 4 | 4 | 4 | | | | | |
|----|---|---|---|--------------|---------|-----|---------|-----------|-----------|
| 5 | 0 | 0 | 0 | -1.20019D-01 | 0.47669 | 0.0 | 1.00000 | 1.15953 | -0.07272 |
| 6 | 0 | 0 | 0 | 8.20862D-02 | 0.67670 | 0.0 | 1.00000 | 176.12717 | -51.25304 |
| 7 | 0 | 0 | 0 | 6.52367D-02 | 0.72846 | 0.0 | 1.00000 | 3.31684 | -0.36039 |
| 8 | 0 | 0 | 0 | 4.99517D-02 | 0.71259 | 0.0 | 1.00000 | 1.90917 | 0.43966 |
| 9 | 0 | 0 | 0 | 3.59727D-02 | 0.70643 | 0.0 | 1.00000 | 3.71112 | -0.94971 |
| 10 | 0 | 0 | 0 | 2.51127D-02 | 0.69288 | 0.0 | 1.00000 | -7.54331 | 7.24209 |
| 11 | 0 | 0 | 0 | 1.73196D-02 | 0.69064 | 0.0 | 1.00000 | 2.65701 | -0.29632 |
| 12 | 3 | 0 | 0 | 4.43064D-02 | 0.68957 | 0.0 | 0.0 | 3.81212 | -1.09034 |
| 13 | 0 | 0 | 0 | 2.75591D-04 | 0.0 | 0.0 | 1.00000 | 0.0 | 0.0 |
| 14 | 0 | 0 | 0 | 2.02093D-04 | 0.77035 | 0.0 | 1.00000 | 0.01884 | 0.02237 |
| 15 | 0 | 0 | 0 | 1.61785D-04 | 0.80025 | 0.0 | 1.00000 | 4.01290 | -0.00442 |
| 16 | 0 | 0 | 0 | 1.02440D-04 | 0.64723 | 0.0 | 1.00000 | -0.12297 | 2.76682 |
| 17 | 0 | 0 | 0 | 6.73080D-05 | 0.66683 | 0.0 | 1.00000 | 1.70768 | 0.17956 |
| 18 | 0 | 0 | 0 | -4.46605D-05 | 0.66573 | 0.0 | 1.00000 | 1.88700 | 0.06995 |

ESTIMATED ABSOLUTE POINT FLUX RELATIVE ERROR 9.92064D-05

MULTIPLICATION RELIABILITY ESTIMATORS

| | | |
|---|-----------|-----------|
| BY THE SUM OF THE SQUARES OF THE RESIDUES----- | 1.0124878 | |
| UPPER AND LOWER BOUNDS ESTIMATES BY MAX REL FLUX CHANGE----- | 1.0125331 | 1.0124426 |
| UPPER AND LOWER BOUNDS ESTIMATES OVER ALL SIGNIFICANT POINTS----- | 1.0124917 | 1.0124620 |

NUMBER OF INNER ITERATIONS, OUTER ITERATION ERROR EIGENVALUE, AND OVERRELAXATION COEFFICIENTS 4 6.89571D-01

1.38202 1.37949 1.54926 1.42048

CPU AND CLOCK MINUTES REQUIRED FOR THIS EIGENVALUE PROBLEM ARE 0.788 4.568

Fig. A2. (CONTINUED)

ITERATION TIMING STATISTICS

| CALCULATION | TIMER UNITS | SECONDS |
|-------------|-------------|---------|
| FISS-SOURCE | 33 | 0.33 |
| SCAT-SOURCE | 241 | 2.41 |
| IN-LEAKAGE | 1645 | 16.45 |
| P-E SWEEP | 1161 | 11.61 |
| CHEB. ACCL. | 0 | 0.0 |
| OTHR | 1648 | 16.48 |
| OVERALL | 4728 | 47.28 |

TOTAL I/O REQUESTS = 657

***** THE ADJOINT NEUTRON BALANCE DOES NOT INCLUDE BOUNDARY LEAKAGES OR INTERNAL BLACK ROD LOSSES *****

PRIMITIVE FISSILE CONVERSION RATIO IS 9.88953D-02, ESTIMATE FOR CRITICAL SYSTEM IS 1.13033D-01
 FISSILE DESTRUCTION PER UNIT ENERGY (ATOMS/WATT-SEC) IS 0.0

ADJOINT GROUP NEUTRON BALANCE FOR EACH ZONE

| ZONE | GROUP | ABSORPTIONS | B**2 | LOSSES | 1/V LOSS | OUT-SCATTER | IN-SCATTER | SOURCE | POWER(WATTS) | AVERAGE FLUX |
|------|-------|-------------|------|--------|----------|-------------|-------------|-------------|--------------|--------------|
| 1 | 4 | 1.69338E 14 | 0.0 | 0.0 | 0.0 | 2.98787E 13 | 0.0 | 0.0 | 1.88646E 03 | 9.38850E 10 |
| | 3 | 6.94698E 13 | 0.0 | 0.0 | 0.0 | 8.70175E 12 | 2.98782E 13 | 0.0 | 6.24772E 02 | 7.90858E 10 |
| | 2 | 2.27865E 13 | 0.0 | 0.0 | 0.0 | 1.46936E 14 | 8.68010E 12 | 7.90834E 13 | 3.64369E 02 | 9.16455E 10 |
| | 1 | 3.33088E 13 | 0.0 | 0.0 | 0.0 | 0.0 | 1.46959E 14 | 2.61793E 14 | 9.05966E 02 | 1.06505E 11 |
| | SUM | 2.94903E 14 | 0.0 | 0.0 | 0.0 | 1.85517E 14 | 1.85517E 14 | 3.40877E 14 | 3.78157E 03 | |
| 2 | 4 | 1.30133E 14 | 0.0 | 0.0 | 0.0 | 1.67577E 13 | 0.0 | 0.0 | 1.63511E 03 | 5.34274E 10 |
| | 3 | 4.91828E 13 | 0.0 | 0.0 | 0.0 | 5.11148E 12 | 1.67574E 13 | 0.0 | 5.32605E 02 | 4.48803E 10 |
| | 2 | 1.69549E 13 | 0.0 | 0.0 | 0.0 | 8.80908E 13 | 5.09657E 12 | 6.66584E 13 | 3.19638E 02 | 5.24165E 10 |
| | 1 | 2.45394E 13 | 0.0 | 0.0 | 0.0 | 0.0 | 8.81060E 13 | 2.20662E 14 | 6.90977E 02 | 6.15861E 10 |
| | SUM | 2.20810E 14 | 0.0 | 0.0 | 0.0 | 1.09960E 14 | 1.09960E 14 | 2.87320E 14 | 3.17833E 03 | |
| 3 | 4 | 1.55017E 13 | 0.0 | 0.0 | 0.0 | 6.84825E 12 | 0.0 | 0.0 | 1.29883E 01 | 6.78672E 09 |
| | 3 | 9.73153E 12 | 0.0 | 0.0 | 0.0 | 2.66842E 12 | 6.84809E 12 | 0.0 | 3.76802E 00 | 5.60668E 09 |
| | 2 | 5.29820E 12 | 0.0 | 0.0 | 0.0 | 5.46747E 13 | 2.66479E 12 | 4.41710E 12 | 2.41929E 00 | 9.96325E 09 |
| | 1 | 8.94112E 12 | 0.0 | 0.0 | 0.0 | 0.0 | 5.46785E 13 | 1.46221E 13 | 2.03961E 02 | 1.34535E 10 |
| | SUM | 3.94725E 13 | 0.0 | 0.0 | 0.0 | 6.41913E 13 | 6.41913E 13 | 1.90392E 13 | 2.23136E 02 | |
| 4 | 4 | 8.05467E 12 | 0.0 | 0.0 | 0.0 | 4.33119E 12 | 0.0 | 0.0 | 6.15340E 00 | 6.85280E 09 |
| | 3 | 5.34964E 12 | 0.0 | 0.0 | 0.0 | 1.58639E 12 | 4.33112E 12 | 0.0 | 1.93964E 00 | 5.86335E 09 |
| | 2 | 3.58937E 12 | 0.0 | 0.0 | 0.0 | 4.29074E 13 | 1.58444E 12 | 2.90766E 12 | 1.62045E 00 | 1.38079E 10 |
| | 1 | 6.09575E 12 | 0.0 | 0.0 | 0.0 | 0.0 | 4.29094E 13 | 9.62536E 12 | 1.37083E 02 | 1.86536E 10 |
| | SUM | 2.30894E 13 | 0.0 | 0.0 | 0.0 | 4.88250E 13 | 4.88250E 13 | 1.25330E 13 | 1.46797E 02 | |
| 5 | 4 | 2.19671E 13 | 0.0 | 0.0 | 0.0 | 1.13059E 12 | 0.0 | 0.0 | 0.0 | 1.11509E 10 |
| | 3 | 9.11042E 12 | 0.0 | 0.0 | 0.0 | 5.41355E 11 | 1.13059E 12 | 0.0 | 0.0 | 1.22963E 10 |
| | 2 | 4.20684E 12 | 0.0 | 0.0 | 0.0 | 7.63489E 12 | 5.41207E 11 | 0.0 | 0.0 | 2.84903E 10 |
| | 1 | 8.31542E 11 | 0.0 | 0.0 | 0.0 | 0.0 | 7.63504E 12 | 0.0 | 0.0 | 3.81374E 10 |
| | SUM | 3.61159E 13 | 0.0 | 0.0 | 0.0 | 9.30683E 12 | 9.30683E 12 | 0.0 | 0.0 | |
| 6 | 4 | 7.69591E 11 | 0.0 | 0.0 | 0.0 | 3.37863E 12 | 0.0 | 0.0 | 0.0 | 5.81011E 10 |
| | 3 | 9.43937E 11 | 0.0 | 0.0 | 0.0 | 1.05998E 12 | 3.37863E 12 | 0.0 | 0.0 | 4.88802E 10 |
| | 2 | 1.66619E 11 | 0.0 | 0.0 | 0.0 | 1.27748E 13 | 1.05942E 12 | 0.0 | 0.0 | 5.86181E 10 |
| | 1 | 2.49013E 11 | 0.0 | 0.0 | 0.0 | 0.0 | 1.27754E 13 | 0.0 | 0.0 | 6.83648E 10 |
| | SUM | 2.12916E 12 | 0.0 | 0.0 | 0.0 | 1.72134E 13 | 1.72134E 13 | 0.0 | 0.0 | |

ADJOINT OVERALL NEUTRON BALANCE

| GROUP | ABSORPTIONS | B**2 | LOSSES | 1/V LOSS | OUT-SCATTER | IN-SCATTER | SOURCE | POWER(WATTS) |
|-------|-------------|------|--------|----------|-------------|-------------|-------------|--------------|
| 4 | 3.45763E 14 | 0.0 | 0.0 | 0.0 | 6.23250E 13 | 0.0 | 0.0 | 3.54072E 03 |
| 3 | 1.43788E 14 | 0.0 | 0.0 | 0.0 | 1.96693E 13 | 6.23239E 13 | 0.0 | 1.16308E 03 |
| 2 | 5.30024E 13 | 0.0 | 0.0 | 0.0 | 3.53018E 14 | 1.96265E 13 | 1.53066E 14 | 6.88047E 02 |
| 1 | 7.39656E 13 | 0.0 | 0.0 | 0.0 | 0.0 | 3.53063E 14 | 5.06703E 14 | 1.93799E 03 |
| SUM | 6.16519E 14 | 0.0 | 0.0 | 0.0 | 4.35013E 14 | 4.35013E 14 | 6.59769E 14 | 7.32983E 03 |

ZONE VOLUMES FOLLOW. TOTAL VOLUME 4.57873E 05
 6.79454D 04 7.22457D 04 1.71108D 05 1.18056D 05 1.16788D 04 1.68392D 04

THE TOTAL FLUX INTERFACE FILE ATPLUX (VERSION 1) HAS BEEN WRITTEN ON UNIT NUMBER 18

THE ADJOINT AVERAGE POWER DENSITY FOR EACH TRIANGLE ON PLANE 18

| | | | | | | | | |
|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|
| 6.29181E-04 | 6.27272E-04 | 6.26274E-04 | 6.23784E-04 | 6.20821E-04 | 6.17560E-04 | 6.11968E-04 | 6.06159E-04 | 5.95082E-04 |
| 5.83326E-04 | 5.66131E-04 | 5.48903E-04 | 5.29559E-04 | 5.11073E-04 | 4.93011E-04 | 4.77027E-04 | 4.58152E-04 | 4.40201E-04 |
| 4.12178E-04 | 3.81787E-04 | 3.44193E-04 | 3.08349E-04 | 2.73356E-04 | 2.38632E-04 | 2.06289E-04 | 2.45498E-04 | 2.01909E-04 |
| 1.59690E-04 | 1.25809E-04 | 9.40335E-05 | 6.91627E-05 | 4.57601E-05 | 2.93650E-05 | 6.22668E-04 | 6.20787E-04 | 6.18601E-04 |
| 6.20574E-04 | 6.13723E-04 | 6.11402E-04 | 5.92082E-04 | 5.76297E-04 | 5.50313E-04 | 5.29540E-04 | 5.09644E-04 | 4.91373E-04 |
| 4.76818E-04 | 0.0 | 0.0 | 0.0 | 3.85287E-04 | 3.44840E-04 | 3.05497E-04 | 2.66531E-04 | 2.34660E-04 |
| 1.98376E-04 | 2.39883E-04 | 1.91315E-04 | 1.54710E-04 | 1.16160E-04 | 8.93639E-05 | 5.95611E-05 | 4.08282E-05 | 6.24734E-04 |
| 0.0 | 0.0 | 0.0 | 5.82368E-04 | 5.53202E-04 | 5.26358E-04 | 5.00563E-04 | 4.85473E-04 | 4.64519E-04 |
| 0.0 | 0.0 | 0.0 | 3.69985E-04 | 3.36589E-04 | 2.89026E-04 | 2.58312E-04 | 2.17634E-04 | 1.89568E-04 |
| 2.16776E-04 | 1.80754E-04 | 1.34956E-04 | 1.06967E-04 | 7.13162E-05 | 5.07058E-05 | 0.0 | 5.67173E-04 | 5.44776E-04 |
| 5.07846E-04 | 4.90476E-04 | 4.60853E-04 | 4.49986E-04 | 4.19599E-04 | 4.09341E-04 | 3.69712E-04 | 3.48480E-04 | 3.01137E-04 |
| 2.75080E-04 | 3.28395E-04 | 2.90316E-04 | 2.32541E-04 | 1.98978E-04 | 1.49152E-04 | 1.21153E-04 | 8.07966E-05 | 5.89490E-05 |
| 4.93312E-04 | 4.60728E-04 | 4.45639E-04 | 4.13101E-04 | 3.97928E-04 | 3.62006E-04 | 3.44048E-04 | 3.03504E-04 | 2.81825E-04 |
| 2.39227E-04 | 3.04831E-04 | 2.44773E-04 | 2.10561E-04 | 1.59192E-04 | 1.31345E-04 | 8.78811E-05 | 6.53321E-05 | 3.95652E-04 |
| 3.60192E-04 | 3.41718E-04 | 3.03331E-04 | 2.83075E-04 | 2.41990E-04 | 2.19821E-04 | 2.53341E-04 | 2.20927E-04 | 1.66159E-04 |
| 1.38635E-04 | 9.28623E-05 | 6.99554E-05 | 2.83418E-04 | 3.44045E-04 | 3.13888E-04 | 2.53967E-04 | 2.24996E-04 | 1.69685E-04 |
| 1.43261E-04 | 9.59549E-05 | 7.30804E-05 | 2.24202E-04 | 1.70472E-04 | 1.44924E-04 | 9.73237E-05 | 7.47785E-05 | 7.52703E-05 |

THE ADJOINT MAXIMUM POWER DENSITY IS 8.9770854E-02 IN ZONE 1 ON PLANE 10 IN TRIANGLE 1

THE ADJOINT MAXIMUM POWER DENSITIES IN EACH ZONE ARE
 8.97709E-02 8.72708E-02 7.03068E-03 4.38550E-03 0.0 0.0

DOPC USE OF CONTAINER ARRAYS, CONTROL 16, MAX DATA 16200

TOTAL CPU TIME IS 1.695 MINUTES AND TOTAL CLOCK TIME IS 11.719 MINUTES

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