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VENTURE: A Code Block for Solving Multigroup Neutronics Problems Applying the Finite-Difference Diffusion-Theory Approximation to Neutron Transport

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OAK RIDGE NATIONAL LABORATORY
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NEUTRON PHYSICS*

VENTURE: A CODE BLOCK FOR SOLVING MULTIGROUP NEUTRONICS PROBLEMS APPLYING THE FINITE-DIFFERENCE DIFFUSION-THEORY APPROXIMATION TO NEUTRON TRANSPORT

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OCTOBER 1975

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*This effort began in the ORNL Reactor Division.

**Member of the Computer Sciences Division, Union Carbide Nuclear Division.

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ABSTRACT

This report documents the computer code block VENTURE designed to solve multigroup neutronics problems with application of the finite-difference diffusion-theory approximation to neutron transport (or alternatively simple P_1) in up to three-dimensional geometry. It uses and generates interface data files adopted in the cooperative effort sponsored by the Reactor Physics Branch of the Division of Reactor Research and Development of the U.S. Energy Research and Development Administration. Several different data handling procedures have been incorporated to provide considerable flexibility; it should be possible to solve a wide variety of problems on a variety of computer configurations relatively efficiently. Also, it should be straightforward to improve the efficiency for a particular computer and small range of problem type by changing one of the programmed data handling procedures. 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 more common orthogonal coordinate systems arising in reactor analysis applications have been treated in from one through three dimensions. These include the slab, the cylinder, Θ-R, Θ-R-Z, and hexagonal and triagonal coordinate systems in two and three dimensions. Only the mesh-centered finite difference formulation has been programmed. There is provision for the more common boundary conditions including the repeating boundary, 180° rotational symmetry, and the 90° slab and the 60° and 120° triangle rotational symmetry conditions.

A variety of types of problems may be solved: the usual eigenvalue problem, a direct criticality search on the buckling, on a reciprocal velocity absorber (prompt mode), or on nuclide concentrations, or an indirect criticality search on nuclide concentrations, or on dimensions. First-order perturbation analysis capability is available at the macroscopic cross section level.

COMPUTER CODE ABSTRACT

1. Program Identification: VENTURE, A Code Block for Solving Multigroup Neutronics Problems Applying the Finite-Difference Diffusion or a Simple P_1 Theory Approximation to Neutron Transport.

2. Function: This code solves usual neutronics eigenvalue, adjoint, fixed source, and criticality search (direct and indirect) problems, treating up to three geometric dimensions, maps power density and does first order perturbation analysis at the macroscopic cross section level.

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 difference equation is mesh centered point. Advanced capability is incorporated, as to treat direction-dependent diffusion coefficients and zone-dependent fission source distribution functions. Macroscopic nuclear properties are calculated from microscopic cross sections and zone and sub-zone nuclide concentrations.

4. Related material: Standard interface file specifications adopted in the ERDA Reactor Physics code coordination effort are used for external files. Input data is supplied by a code-dependent external file generated by a separate processor. Other codes meeting interface specifications will couple directly with this one.

5. Restrictions: This code is quite thoroughly variably dimensioned. Generally the larger the problem, the more Input/Output required for iteration. The 1000 space point one-dimensional problem has been solved within 50,000 word total fast computer memory.

6. Computer: This code has been run on IBM computers including the 360/91, the 360/75, and 360/195, and on the CDC-7600 computer after the required conversion step.

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 200 space energy points per second of central processor time on an IBM 360/91; this rate falls off approximately as $(10/N)^{0.7}$ where N is the average number of points in one dimension, less when the amount of data I/O is low, and more when it is high, excepting one-dimensional problems. Thermal reactor lattice and cell problems normally require more time by perhaps a factor of two. Problems involving significant upscatter (multi-thermal-group treatment) require additional computer time by a factor of two or three.

8. Programming Languages: The programming is basically in the ASA 1966 FORTRAN language excepting certain extensions, especially those required for unindexed block data transfers and direct access. Known limitations of manufacturer's current compilers are not exceeded: for example, arrays are limited to three dimensions, dummy arguments in subroutines to sixty, and subscripted subscripts are not used. Certain standard routines developed in the ERDA Reactor Physics code coordination effort are used, as for input data processing and data file managing; locally implemented procedures are needed as to make available elapsed computer time for executing certain user options. Local system routines used to allocate memory and to set up the direct access file specifications dynamically would require replacement. The source deck consists of about 30,000 statements (VENTURE proper).

9. Operating System: The basic OS-360 IBM operating system has been used under HASP with a FORTRAN IV, H level compiler version 20.1. Access capability in the modular sense is essential.

10. Machine Requirements: A 32,000 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. The programming

is included for three-level hierarchy data storage of efficient use of an extended slow memory for large three-dimensional problems when such a memory is available. Typically the code uses 27 logical I/O units.

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12. References:

a. D. R. Vondy, et. al., "VENTURE: A Code Block for Solving Multigroup Neutronics Problems Applying the Finite-Difference Diffusion-Theory Approximation to Neutron Transport: ERDA Report, Oak Ridge National Laboratory, ORNL-5062 (1975).

b. B. M. Carmichael, "Standard Interface Files and Procedures for Reactor Physics Codes, Version III," AEC Report LA-5486-MS (February 1974, revised!)

13. Material Available: The package being submitted to the Argonne Code Center includes Fortran card images for a driver code, the VENTURE neutronics code block, a cross section processor code block, a reaction rate calculation code block, and four special input data processors. Assembly language decks of locally used routines are included and copies of the documenting report.

Section 001: General Discussion

The code block VENTURE is designed to solve multi-neutron-energy-group, multi-dimensional neutronics problems. The finite-difference diffusion or a simple P_1 theory approximation to neutron transport is applied. Usual eigenvalue problems may be solved to determine the multiplication factor and the neutron flux distribution. The adjoint problem may be solved. Fixed source problems are treated and a variety of criticality search problems. Perturbation results based on macroscopic cross sections are produced by option.

The code treats scattering from one energy group to any other, including upscattering, internal black absorber zones, and a variety of boundary conditions including periodic and the more important rotational symmetry conditions.

The method of solution implemented is an iteration process.

The loose-leaf form of this report with sections in short blocks was chosen to facilitate updating to account for revisions.

Background

The procedures implemented in the VENTURE code represent a background of effort which can be traced back to the late 1950's, to the work of M. L. Tobias[a] and others. Over this period of time a large number of problems have been solved in routine reactor analysis effort at ORNL and at other installations by the methods which were evolving during this period. It seems noteworthy that although theoretical considerations have played a role, this has been primarily an engineering development directed at economical solution of problems encountered in analysis. The previous code programmed in this effort was CITATION.[b]

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[a] See ORNL-4078 for example.

[b] T. B. Fowler, D. R. Vondy, and G. W. Cunningham, "Nuclear Reactor Core Analysis Code: CITATION," ORNL-TM-2496, Revision 2, Oak Ridge National Laboratory (July 1971).

Many individuals have worked on developing and implementing procedures for solving diffusion theory neutronics problems, especially at the AEC National Laboratories,[a] but also in private companies[b] and in other countries.[c] We are aware of much of this work, and acknowledge that published information and discussions with several individuals have made direct contributions to this effort.

The Procedure of Calculation

A flow chart for the code is presented in Fig. 001-1. This shows the general flow through the procedures of calculation.

An inner, outer iteration scheme is used to solve problems. New flux values are calculated from finite-difference, neutron balance equations for a row of points simultaneously, and each new value is driven in the direction of the change from the old value. This procedure is continued over the space problem at one energy; it is repeated for a number of inner iterations, and the calculation proceeds to the next energy. At each energy the inscattering source and the fission source are determined. After a complete sweep of the problem, the eigenvalue is estimated either from an overall neutron balance, summed neutron balance equations, or from the source ratio, and the calculation is continued to satisfy specified convergence criteria. For an indirect criticality search, an additional outer iterative loop is required to adjust the desired parameters, nuclide concentrations or dimensions, to effect a desired solution.

If there is one main feature which stands out in the VENTURE code, it is the direct search procedure. As carried over from the CITATION code, an iteration procedure is implemented to move the iterate flux estimate

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[a] See WAPD-TM-678, BNWL-1264, ANL-7716, and LASL-4396.

[b] See GA-6540.

[c] See AEEW-R682, TRG-229(R).

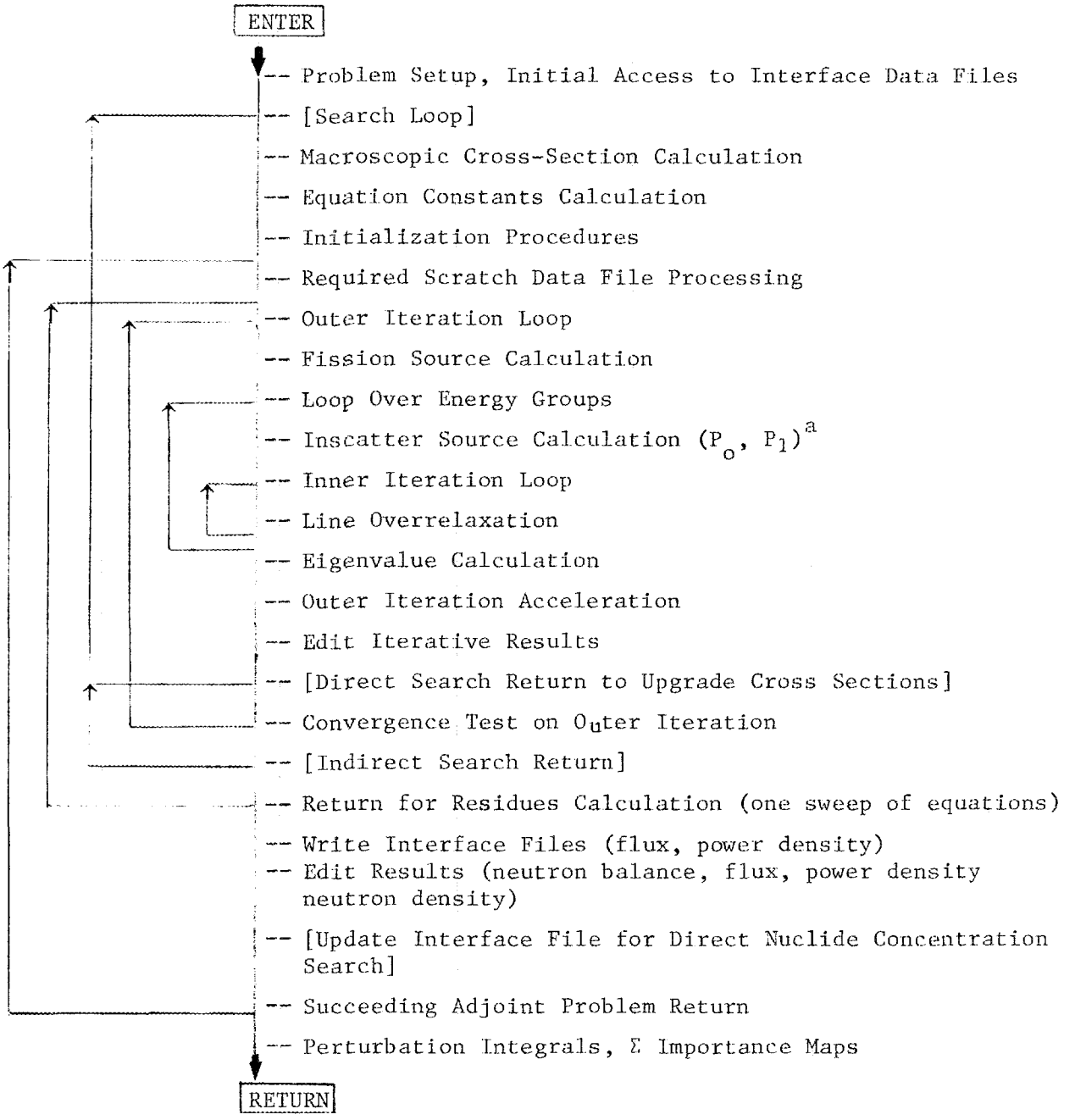

Fig. 001-1. User flow chart, VENTURE finite-difference diffusion theory neutronics code block.

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[a]The inscatter source calculation is normally done outside the inner iteration loop, however in one data handling mode this source is calculated inside the inner iteration loop to minimize I/O operations.

directly toward a solution by determining the eigenvalue of the problem when certain parameters are adjusted. Perhaps only the analyst who has experienced the frustrations of and relatively high cost of obtaining solutions by indirect methods can fully appreciate the utility of this direct search capability.

For a direct criticality search problem, the relative buckling, reciprocal velocity loss term, or relative change in the search nuclide concentrations is treated as the eigenvalue of the problem. No outer iteration loop is required.

The calculation of macroscopic cross sections, using the nuclide densities and microscopic cross sections and of equation constants is done in the head end of the code. As shown in the flow chart of Fig. 001-1, returns are made to this part of the program for recalculation of this macroscopic data to account for the effects from adjustments to the parameters in a criticality search problem. To initiate a succeeding adjoint problem which involves no changes in the parameters for a regular problem which has been solved, the data for the regular problem is simply reprocessed, and the procedure for the regular problem is used.

Alternative Procedures and Large Problems

The code contains parallel procedures involving different ways of handling data involving varying degrees of data transfer between memory and auxiliary storage within a flexible, basic iterative procedure. Automatic selection between these allows effective application on different computer hardware configurations to solve a variety of problem sizes. Still, modifications may well be required to most effectively use a particular facility, especially if it has a hierarchy of auxiliary storage devices which have quite different data transfer rates. The necessary changes should not be extremely hard to make if a preferred structuring can be identified.

The VENTURE code represents a considerable extension over the CITATION code in the size of problems which may be treated. One thousand point one-dimensional problems have been solved, and the extent in the other two dimensions is not limited. However, selection of a practical problem requires consideration of the cost of the calculation and justification of the expenditure in computer time. On many computers, especially so the IBM 360/91, the extra cost associated with the increased amount of data Input/Output required to solve the larger problems is indeed significant. Also, adequate on-line auxiliary storage is required for a problem to be solved, which increases directly with the number of space-energy points considered.

Standard Interfacing

This code block was programmed specifically to operate (interface) with other programs developed under rules established in a cooperative effort between several installations, an effort sponsored by the Reactor Physics Branch of the Division of Reactor Research and Development of the U.S. Energy Research and Development Administration. For example, all user input data is processed by a separate block of coding; this neutronics code block only interfaces data files. It uses microscopic cross sections supplied in a standard interface format from any source; other code blocks are being programmed elsewhere to generate this data, and yet others to use the results from the neutronics calculation. This coupling between major code blocks is effected by satisfying hard interface data file specifications.

We believe this code block satisfies the primary objective of this effort: development of a neutronics code which uses standard interface data files; one which can be converted from one computer to run on another relatively easily and permit effective and efficient utilization of computers having a variety of hardware configurations.

Programming

The programming is all done in the Fortran language. Basically, ASA 1966 standard Fortran generally implemented was used with a few extensions; data are transferred in blocks of mixed data type and direct access is used, for example. Known limits on the major computers using current manufacturer's compilers have quite generally not been exceeded. For example, the maximum number of dimensions of any variable is three, the number of arguments in subroutine statements is limited to sixty, and subscripts are not subscripted. Both short and long word storage of data are used for effective execution on IBM 360, 370 series computers (very low accuracy is associated with use of short words, single precision, carrying less than the equivalence of seven significant decimal digits), but this was done in such a way that conversion to such a machine as a CDC-7600 should not be too difficult if the comment instructions for this conversion included in this program are followed. However, special local system routines have been used to allocate memory and to set up direct access file specifications dynamically.

Status

This documentation covers the first release version of a new code. Our experience in documenting major codes under active development, development which must appreciably lead publication, has been that (1) initial documentation tends to be inaccurate, (2) the effort required to provide some anticipated capabilities must be deferred to satisfy other requirements found to be more important (and projections of satisfying programming goals tend to be over-optimistic), and (3) feed-back from production use by other than the originators is essential to the process of development of accurate documentation readily understood by the casual user. Nevertheless, a reasonably amount of effort has been expended in the attempt to produce good documentation. At the time of formal release, this code and auxiliary ones to it will represent a direct effort at ORNL of about eight man years.

A major code block is generally not free of bugs, especially when complicated options tend to have overlapping control. Still we have used an unusually large number of test problems for which reliable solutions are available. This testing gives us confidence that most problems will be properly solved. Part of this confidence comes from the nature of the effort, a straightforward extension of capability which has had wide application on a production basis.

The VENTURE and related codes are in routine production use locally and via remote terminal from other installations. Production use has contributed directly by feedback to the developed capability and reliability. Some of the individuals involved are E. J. Allen in the Reactor Division, S. C. Crick at General Electric (Sunnyvale), and D. Lancaster at Westinghouse (Madison). Testing of an early version of the code at LASL by G. E. Bosler and R. D. Odell on a CDC-7600 computer also made contribution. The code has yet to be used directly in conjunction with other code blocks for repeated solution of problems in depletion and fuel management analysis. Therefore, the provisions for control and repeat calculations may be incomplete.

The operation of the interfaced code blocks in a modular system locally is yet in a stage of development. Testing has been done with relatively crude programming to process the required input data instructions and to convert available cross sections into a standard nuclide-ordered interface file and then into an energy-group ordered file.

END OF SECTION

COMPUTER REQUIREMENTS

In the following discussion, information is presented which may be needed by a user for effective application of the code. The required files must be made available, and there must be adequate space allocated on each logical unit for the data carried on it. It is expected that much of the user burden regarding allocation of space can be relieved by use of a reference job control procedure available to the operating system; however, especially for solving large problems, it will be necessary to change the allocations by overriding those provided in the job control procedure. This procedure will also generally relieve the user of supplying a subroutine overlay structure; an overlay structure is not needed when the code is used as a load module.

VENTURE as a Module

The VENTURE code block is a module for solving neutron transport problems by application of diffusion theory. It is structured for use in a modular code system; other modules which serve the same role may parallel it in a system. The code does not read user input cards. Data supplied to it must be in well-defined interface data files. Results from the code are placed on other interface data files on demand for subsequent use. The code contains routines to produce elaborate edits of results on demand and always edits key results.

Locally the code is used under a resident driver as discussed in detail in Appendix C. The code is placed in executable load module form with an incorporated overlay structure, assembled. It is available on disc which may or may not be on-line. A catalogued procedure stored on disc contains basic job control instructions with provision for changing the space allocations and data blocking factors. Changes to the program, to the Fortran language compiler instructions, can not be done simply because reloading is necessary; such changes are therefore not allowed generally by the local user community. The code is used on a production basis locally and remotely from other installations via remote terminal. Therefore, modifications must be carefully assessed and proofed prior to general use.

Other modules are in use in this system. These include a standard input data processor to generate interface data files, a cross section data file processor, and a code to produce reaction rates and related results. Special input data processors are also in use which generate data files. New modules will be phased into the system as they become available and are made compatible; for example, depletion capability should soon be available.

Machine Time Requirements and Charging

Of primary concern here are central processor (cp) time, clock time, and costing. Clock time is quite dependent on what tasks are being performed; it increases with the number of Input/Output operations performed during any task, execution of a job, or computation. If a large fraction of the memory available for computation is used by a job, then the multitasking system cannot achieve overlap of calculation and data transfer.

A reference rate of fast reactor problem solution is 200 space-energy points per second IBM-360/91 cp time. This rate falls off approximately as $(10/N)^{0.7}$ where N is the average number of points in one dimension, less when the amount of data transfer is low and more when it is high, excepting one-dimensional problems. Certain types of problems require more time, especially when upscattering is treated or the problem is for a large thermal reactor or a cell with reflecting boundaries. Relative cp time for the IBM-360/195 is about half that for the /91, and the IBM-360/75 cp time is about four times that of the /91. Current local charge rates are given in Appendix D.

Memory Requirements

Memory requirements for the code block are discussed here. Separate storage is required to satisfy four requirements:

1. Program (machine instructions and variables not variably dimensioned) — The storage is minimized by an effective overlay scheme.

2. Library Routines — These are provided by the system and range from arithmetic functions to the data Input/Output package.

3. Buffer Area — This storage is required to allow data to be transferred in blocks, and is most important where large amounts of data are accessed repeatedly, as at the heart of an iterative procedure. Careful allocation of the buffer storage is important for effective machine utilization. The best allocation depends on the problem and the available facility, so user experience must be a guide to reasonable allocation. Generally, the larger the problem, the more data which must be transmitted and the larger the buffers required. However, if a large allocation of buffers causes degrading of the mode of data handling during iteration, the performance can be expected to be degraded. A special situation exists when extended slow memory is used for buffer storage of data being transferred.

4. Variably Dimensioned Data — Most data arrays in the code are variably dimensioned. The amount of storage required depends on an involved combination of the primary variables of a problem, the options exercised, and the mode of data handling selected.

There are six data handling modes programmed[a] and the one selected by the code depends upon the available core storage. A user-supplied input number is the dimension of the container array in which all problem dependent variables are stored. The modes of data handling are:

1. Data stored for all groups, all planes ("all-stored" mode).
2. Data stored for one group, all planes ("mesh-stored" mode).
3. Data stored for one group, several planes (3-D problems only) ("plane-stored" mode)[b]
4. Data stored for one group, several rows (2-D problems only) ("row-stored" mode).

---

[a]See Section 225 for details.

[b]After determining the number of inner iterations to be done for a given problem, the code normally will store as many planes of data there are inner iterations (to minimize I/O) providing enough core storage is available. This built-in procedure may be overriden by option.

5. Data stored for one group, one row ("one-row-stored" mode).
6. Data stored for one group, several planes (or one plane for 2-D problems) in extended slow core and moved by smaller blocks into fast core ("multi-level data transfer" mode).

The code edits a table of data storage requirements for all the applicable data handling modes when a job is executed, and automatically selects that mode involving the least amount of data input/output unless overridden by user control.

Basic Requirements (IBM short word, 4-byte)

Program	28,400
Library Routines	8,200
Buffer Area	5,000-30,000
Minimum Data	5,000

When operated under a resident driver, about 11,000 additional words of memory are required, the amount depending primarily on the system library routines used by it.

Continued effort on this code will probably introduce additional alternatives further complicating data storage requirements. Still, automated selection between alternatives minimizes the burden on the user. It is hoped that added coding can be incorporated within a simple overlay scheme such that the storage required for program will not increase much.

Auxiliary Storage

In solving a large problem, this code may well tax available capability for fast access storage. A 2.5×10^6 space-energy point problem requires 5×10^6 short-word (2.5×10^6 long-word) storage for one set of the flux values. Not only must three sets of these be stored, but one or two copies of the equation constants, each requiring about four times as much space as one set of flux values. Not only must this storage be available, generally on disc units, but also separated between control channels for efficient data transfer. When one disc unit is inadequate to hold a file, the data must span two or more units. Details of the files are discussed in Section 204.

To exercise control over the interface data files, a user must have information about these; refer to Section 204.

END OF SECTION

Programming Information

In the following sections, the information needed for a comprehensive understanding of the program is presented. This information is directed at the programmer making modification to the code or converting it from one computer to another, and is intended only to supplement the source deck FORTRAN listing which contains informative comments. Primary data arrays are defined on comment lines and conversion notes are included.

The source language is FORTRAN, primarily the standard ASA 1966 FORTRAN. However, block transfer of data of mixed type is done without indexing in the guise of the REAL type, and the direct access mode of data transfer is used. Local system routines are used to allocate memory and to define the direct access files and access parameters dynamically, and also to obtain time and computer model; the functions of these routines would have to be satisfied or requirements and associated capability by-passed.

END OF SECTION

Section 201-1 Information About Subroutines

Here principal information is provided about the subroutines. Where practical, they are grouped into sets to identify those which are used together to perform some well-defined function.

VENTURE SUBROUTINES

THE ACCESS, CONTROL, AND GENERAL PURPOSE ROUTINES

```
MAIN   ENTRY POINT TO THE VENTURE NEUTRONICS CODE BLOCK
            CALLS ERRSET, TIMER, DOPC, IONO, VENT, DRIV
IONO   ASSIGNS INPUT/OUTPUT UNIT NUMBERS
VENT   ACCESSES CODE BLOCK CONTROL INFORMATION
            CALLS SKER, FERR
DRIV   PASSES INFORMATION TO THE CONTROLLER ROUTINE
       ALLOCATES CORE STORAGE
            CALLS GETCOR, ROXX, ROXY, DIFF, DOPC, FRECOR
DIFF   CONTROLS THE CALCULATION
            CALLS CORE, MAC1, CON1, PHIA, ORLX, COMC, LCAL, FLXR,
                  FXSR, BSQV, AJNT, PROS, DOPC, OUTR, DSDF, DCID,
                  DINS, AJDS, FLRD, ADN1, EDIT, SAV1, PERT, TIMER
CORE   DETERMINES STORAGE REQUIREMENTS AND DATA HANDLING MODES
            CALLS CORI, CORP, GNAM, CORD, CORB, DDSP, DASU, SKER, FERR
CORI   OBTAIN FILE SPECIFICATION RECORD FROM INTERFACE FILES NDXSRF,
       ZNATDN, GRUPXS, AND GEODST
            CALLS SKER
DASU   SETUP DIRECT ACCESS FILES
            CALLS DOPC, FERR
TIMER  SERVICE ROUTINE FOR COMPUTER TIME ETC.
STOR   SERVICE ROUTINE FOR MOVING DATA IN MAIN MEMORY
SKER   FILE MANAGEMENT RELATED ERROR MESSAGES
FERR   ALL OTHER FATAL ERROR MESSAGES
```

THE INPUT/OUTPUT ROUTINES

```
DOPC   INITIALIZES, OPENS, AND CLOSES DATA FILES
         ENTRY ROXY   COMMUNICATES DATA ARRAYS
            CALLS SEEK, RITE, DEFILE, CLOSDA, (FBSAM AND ENTRIES)
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, (FBSAM AND ENTRIES)
SEEK   INTERFACE DATA FILES MANAGER
            CALLS RITE, REED
CRIT   ASSEMBLY LANGUAGE ROUTINE FOR CORE TO EXTENDED CORE DATA
       TRANSFER (SEE SECTION 203 FOR THE FORTRAN EQUIVALENT)
         ENTRY CRED   EXTENDED CORE TO CORE DATA TRANSFER
DEFILE ASSEMBLY LANGUAGE ROUTINE TO EXECUTE THE FORTRAN DEFINE FILE
       STATEMENT USING PROBLEM DEPENDENT VARIABLES (OPENS DIRECT
       ACCESS FILES) - ACCESSES SYSTEM ROUTINE INCEDIOS
CLOSDA ASSEMBLY LANGUAGE ROUTINE TO CLOSE DIRECT ACCESS FILES
FBSAM  LOCAL I/O ROUTINE USED ALONG WITH THE IBM I/O PACKAGE TO
       PRODUCE SPECIAL CAPABILITY - NOT USED IN THE CODE AS RELEASED
```

(CONT)

THE CALCULATION OF MACROSCOPIC CROSS SECTIONS

MAC1 CONTROLS MACROSCOPIC CROSS SECTION CALCULATION
CALLS MACA, MACB, MAC2, SCAL, MAC3, MAC5, CHDM, MAC4, MAC6, SKER, FERR
MACA INITIAL PROCESSING OF GROUPXS
CALLS STOR
MACB CHECK NAMES AND CLASSES ON NDXSEF AND GRUPXS FOR AGREEMENT
MAC2 CALCULATE MACROSCOPIC PRINCIPAL CROSS SECTIONS
SCAL LOCATES POSITION OF SCATTERING RECORDS ON GRUPXS
MAC3 CALCULATE MACROSCOPIC SCATTERING CROSS SECTIONS
MAC5 ADJUST DIFFUSION CONSTANT AND SCATTERING DATA FOR P1 CALC.
CHDM CHECK DIMENSION SEARCH DATA
CALLS SKER
MAC4 CALCULATE MACROSCOPIC SEARCH DATA
MAC6 EDIT MACROSCOPIC CROSS SECTIONS

THE CALCULATION OF EQUATION CONSTANTS

CON1 CONTROLS EQUATION CONSTANTS CALCULATION
CALLS MSH0, NRCF, MSH1, CON2, GEOQ, CON3, MSH3, CKCT, CON4, CON5, CON7, CON9, STOR, SKER, FERR
MSH0 SETUP COARSE MESH PARAMETERS FOR 1D AND 2D CASES
NRCF CONVERT REGION ASSIGNMENTS BY COARSE MESH TO FINE MESH
MSH1 CALCULATE FINE MESH DISTANCES
CON2 SETUP BOUNDARY CONSTANTS AND BUCKLING
GEOQ CHANGE FROM 3D TO 2D CASE
CON3 RESTRUCTURE MACROSCOPIC DATA AND ZERO ROD CROSS SECTIONS
CALLS NROD, STOR
MSH3 EDIT FINE MESH DISTANCES
CKCT SETUP INDEXING FOR DIFFUSION CONSTANTS
CON4 CALCULATES LEAKAGE CONSTANTS
CALLS NROD, BNDY
CON5 CALCULATES LEAKAGE CONSTANTS (TRIAGONAL)
CALLS NROD, BNDY
CON7 CALCULATES LEAKAGE CONSTANTS (HEXAGONAL)
CALLS NROD, BNDY
CON9 CALCULATE ZONE VOLUMES FROM REGION VOLUMES AND DETERMINE ZONE WITH MAXIMUM NU*SIGF*VOL
CALLS NROD
NROD FUNCTION TO DETERMINE INTERNAL BLACK ABSORBER ZONES
BNDY FUNCTION TO CALCULATE NON-RETURN LEAKAGE CONSTANT

THE INITIALIZATION PROCESS

PHIA CONTROLS FLUX INITIALIZATION
CALLS PHI1, PHI2, PHI3, FERR
PHI1 INITIAL FLUX IS CONSTANT
CALLS NROD

(CONT)

PHI2 INITIAL FLUX IS A FUNCTION OF SPACE AND ENERGY
CALLS EDBN, SDEN, NROD
EDBN CALCULATE ENERGY DISTRIBUTION FUNCTION
SDBN CALCULATE SPATIAL DISTRIBUTION FUNCTIONS
PHI3 PROCESS INITIAL FLUX FROM FLUX INTERFACE (MAY BE EXPANDED TO NEW MESH EXCEPT FOR TRIAGONAL AND HEXAGONAL GEOMETRIES)
CALLS PHI4, PHI5 ,PHI6, NRCD, SKER
PHI4 1D FLUX EXPANSION
PHI5 2D FLUX EXPANSION
CALLS PBND, PC2D
PHI6 3D FLUX EXPANSION
CALLS PBND, PC2D, PC3D
PBND FUNCTION TO DETERMINE ARTIFICIAL FLUX POINT
PC2D FUNCTION TO DETERMINE ARTIFICIAL CORNER POINT - 2D
PC3D FUNCTION TO DETERMINE ARTIFICIAL CORNER POINT - 3D
CALLS PC2D
ORLX CONTROLS OVERRELAXATION PARAMETER INITIALIZATION
CALLS BATG, CON6, FERR
BATG CALCULATE OVERRELAXATION COEFFICIENTS AND INNER ITERATIONS
CALLS LUCK, NROD
LUCK FUNCTION TO DETERMINE MESH DEPENDENT PARAMETER FOR LAMBDA
CON6 PREPARE MACROSCOPIC CROSS SECTIONS AND OTHER DATA FOR ITERATIVE PROCESS

THE ITERATIVE PROCESS

COMC UTILITY ROUTINE
LCAL CALCULATES STARTING ADDRESSES IN DATA ARRAY
CALLS FERR
FLXR OBTAINES INITIAL FLUX
FXSR OBTAINS A FIXED SOURCE
CALLS SKER
BSQV SEARCH CALCULATION UTILITY ROUTINE
AJNT SETS UP INPUT/OUTPUT FILES FOR THE ADJOINT PROBLEM
CALLS REV1
REV1 PROCESSES SCATTERING DATA FOR ADJOINT PROBLEM
PROS SETS UP INPUT/OUTPUT FILES
CALLS ZIO3
ZIO3 PROCESSES PRINCIPAL CROSS SECTIONS
DSDF CALCULATES INDIRECT NUCLIDE SEARCH CHANGE EIGENVALUE
DCID CONTROLS SEARCH CALCULATION EXIT OPTIONS
DIMS CALCULATES DIMENSION SEARCH CHANGE FACTOR
ADJS CONTROLS DIMENSION SEARCH CHANGES
CALLS DIM1, DIM2, DIM3
DIM1 READS COARSE MESH MODIFIERS FROM SEARCH INTERFACE FILE
DIM2 CONTROLS COARSE MESH AND VOLUME CHANGES - WRITES NEW GEODST
CALLS CMES, CRGV
DIM3 CONTROLS CHANGE ZONE VOLUMES - WRITES NEW NDXSRF INTERFACE
CALLS ZVRV
ZVRV CHANGES ZONE VOLUMES
FLRD READS GEODST FOR FINAL EDIT OF MESH - DIMENSION SEARCH
CALLS FLMH

(CONT)

```
CMES   CHANGES COURSE MESH
CRGV   CALCULATE REGION VOLS FROM POINT VCIS
            CALLS CHVL
CHVL   CHANGES REGION VOLUMNS
FLMH   EDITS FINAL MESH - DIMENSION SEARCH
OUTR   OUTER ITERATION CONTROLLER
            CALLS DOIN, ZINS, FSOR, SSOR, FLUX, PSOR, JUSB, BALC, XTRP
                  , WRES, RRES, PREC, MUEX, CHBF, CHB1, CHB2, ETR1
                  , ETR2, ATED, SGDA, FERR
BALC   NEUTRON BALANCE CALCULATION
ZINS   CALCULATES THE DIRECT SEARCH PROBLEM EIGENVALUE
CHBF   CHEBYSHEV ACCELERATION ROUTINE
CHB1   CHEBYSHEV ACCELERATION ROUTINE
CHB2   CHEBYSHEV ACCELERATION ROUTINE
XTRP   ASSESSES FLUX CONVERGENCE
            CALLS FFGG
JUSB   OVERRELAXATION COEFFICIENT CONTROL
ATED   EDITS ITERATION DATA
FFGG   CALCULATES FLUX EXTRAPOLATION FACTORS
RDUE   RESIDUE ESTIMATE OF THE MULTIPLICATION FACTOR
RELX  SOLVES FOR THE FLUX VALUES ALONG A ROW AND OVERRELAXES THEM
FSOR   FISSION SOURCE CALCULATION CONTROLLER
            CALLS FOU1, FOU2, FOU3, FOU4, FOU5, FOU6
SSOR   SCATTERING SOURCE CALCULATION CONTROL
            CALLS SOU1, SOU2, SOU3, SOU4, SOU5, SOU6
PSOR   P-1 SCATTERING SOURCE CALCULATION CONTROL
            CALLS POU1, POU2, POU3, POU4, POU5
FLUX   INNER ITERATION CONTROL
            CALLS INR1, INR2, INR3, INR4, INR5, INR6
MUEX   EXTRAPOLATION PARAMETER PROCESSING
ETR1   SINGLE ERROR MODE FLUX EXTRAPOLATION
ETR2   DOUBLE ERROR MODE FLUX EXTRAPOLATION
SGDA   SAVES AND RETRIVES DATA DURING DIRECT NUCLIDE SEARCH
DOIN   FLUX CALCULATION UTILITY ROUTINE
RRES   READS RESTART FILE
WRES   WRITES RESTART FILE
PREC   CALCULATES ONE-DIMENSIONAL SWEEP PARAMETERS
ADN1   CONTROLLER FOR UPDATING ATOMIC DENSITIES
            CALLS ADN2, ADN3, FERR, SKER
ADN2   UPDATES ATOMIC DENSITIES
ADN3   EDITS ATOM DENSITIES
INR1   INNER ITERATION CONTROL (1 ROW STORED MODE)
            CALLS LOU1, RDUE, RELX, LEK1
LOU1   IN-LEAKAGE CALCULATION
FOU1   FISSION SOURCE CALCULATION
SOU1   SCATTERING SOURCE CALCULATION
POU1   P-1 SCATTERING SOURCE CALCULATION
LEK1   OUT-LEAKAGE CALCULATION

INR2   INNER ITERATION CONTROL (ALL DATA STORED MODE)
            CALLS LOU2, RDUE, RELX, LEK2
FOU2   FISSION SOURCE CALCULATION
LOU2   IN-LEAKAGE CALCULATION
SOU2   SCATTERING SOURCE CALCULATION
```

(CONT)

POU2 P-1 SCATTERING SOURCE CALCULATION
LEK2 OUT-LEAKAGE CALCULATION

INR3 INNER ITERATION CONTROL (SPACE PROBLEM DATA STORED MODE)
CALLS LOU3, RDUE, RELX, IEK3
LOU3 IN-LEAKAGE CALCULATION
FOU3 FISSION SOURCE CALCULATION
SOU3 SCATTERING SOURCE CALCULATION
POU3 P-1 SCATTERING SOURCE CALCULATION
LEK3 OUT-LEAKAGE CALCULATION

INR4 INNER ITERATION CONTROL (MULTIPLE PLANE DATA STORED MODE)
CALLS LOU4, QDUE, QELX, IEK4, SOUX, J1C4
LOU4 IN-LEAKAGE CALCULATION
FOU4 FISSION SOURCE CALCULATION
SOU4 SCATTERING SOURCE CALCULATION
SOUX SCATTERING SOURCE CALCULATION
POU4 P-1 SCATTERING SOURCE CALCULATION
LEK4 OUT-LEAKAGE CALCULATION
J1C4 DEL DOT J CALCULATION
QDUE ACCESSES RESIDUE CALCULATION
CALLS RDUE
QELX ACCESSES FLUX CALCULATION
CALLS RELX

INR5 INNER ITERATION CONTROL (MULTI-ROW STORED MODE)
CALLS LOU5, RDUE, RELX, IEK5, J1C5
LOU5 IN-LEAKAGE CALCULATION
FOU5 FISSION SOURCE CALCULATION
SOU5 SCATTERING SOURCE CALCULATION
POU5 P-1 SCATTERING SOURCE CALCULATION
J1C5 DEL DOT J CALCULATION

INR6 CONTROLLER ROUTINE FOR THE SPECIAL ONE-DIMENSIONAL PROCEDURE
FOU6 FISSION SOURCE CALCULATION
SOU6 SCATTERING SOURCE CALCULATION
DELX LINE RELAXATION WITHOUT OVERRELAXATION

INRX INNER ITERATION CONTROL (MULTI-LEVEL DATA TRANSFER MODE)
CALLS LOUX, RDUE, RELX, IEKX, SOUZ, J1CX
LOUX IN-LEAKAGE CALCULATION
FOUX FISSION SOURCE CALCULATION
SOUY SCATTERING SOURCE CALCULATION
SOUZ SCATTERING SOURCE CALCULATION
POUX P-1 SCATTERING SOURCE CALCULATION
LEKX OUT-LEAKAGE CALCULATION
J1CX DEL DOT J CALCULATION

(CONT)

THE EDIT ROUTINES

EDIT CONTROLS EDITS
  CALLS NBAL, PNDN, FLXW, PERT, BSQS, FISS
CORP EDIT PROBLEM DESCRIPTION
GNAM EDIT GEOMETRY AND CHECK FOR VALIDITY
CORD EDIT MAJOR PROBLEM PARAMETERS
CORB EDIT BOUNDARY INDICATORS AND CHECK FOR VALIDITY
DDSP EDIT SYMBOLIC PARAMETERS FOR DISK SPACE (IBM 360 JCL)
POUT PRINTS FLUX, POWER DENSITY, NEUTRON DENSITY
NBAL PRINTS NEUTRON BALANCE
  CALLS SOBL, SKER
SOBL CALCULATES NEUTRON BALANCE SCATTERING DATA
FISS WRITES FISSION SOURCE INTERFACE (FISSOR)
  CALLS SKER
BSQS CALCULATES BUCKLINGS IN 3-D PROBLEMS
PNDN CALCULATES POWER AND NEUTRON DENSITY
  CALLS POUT, SKER
FLXW WRITES FLUX INTERFACE DATA FILE
  CALLS POUT, SKER
SAV1 SPECIAL DATA OUTPUT IN BCD FORM
  CALLS SAV2, SAV4, SAV6
SAV2 SPECIAL DATA OUTPUT IN BCD FORM (GEODST)
  CALLS SAV3
SAV3 SPECIAL DATA OUTPUT IN BCD FORM (GEODST)
SAV4 SPECIAL DATA OUTPUT IN BCD FORM (PWDINT)
  CALLS SAV5
SAV5 SPECIAL DATA OUTPUT IN BCD FORM (PWDINT)
SAV6 SPECIAL DATA OUTPUT IN BCD FORM (RTFLUX)
  CALLS SAV7
SAV7 SPECIAL DATA OUTPUT IN BCD FORM (RTFLUX)

THE PERTURBATION ROUTINES

PERT PERTURBATION CONTROL
  CALLS DAFA,LIFE,TUFY,PERO,MAPS,RTUB,QOUT,SKER
DAFA SETS UP INPUT/OUTPUT FILES FOR PERTURBATION CALCULATION
LIFE CALCULATES BASIC PERTURBATION INTEGRALS
TUFY CALCULATES TRANSPORT PERTURBATION INTEGRALS
  CALLS BBB1,BBB2
BBB1 PERTURBATION UTILITY ROUTINE
BBB2 PERTURBATION UTILITY ROUTINE
PERO EDITS PERTURBATION INTEGRALS
MAPS CALCULATES SPACE POINT IMPORTANCE MAPS
  CALLS PMAP
PMAP CONTROLS EDIT OF IMPORTANCE MAPS
  CALLS QOUT
QOUT EDITS SPACE POINT IMPORTANCE MAPS
RTUB WRITES INTERFACE FILE PERTUB
  CALLS SKER
MRPT CALCULATES CHANGE IN KEFF DUE TO SIGMAS

(CONT)

SPECIAL ROUTINES

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
ERRSET SUPPLIES THE LEVEL OF ERROR STOPS TO THE SYSTEM

LABEL COMMON BLOCKS

CNTRL
VCTRL
MGMTIO
IOUNT
AFLUY
AOSUB
LIMTS
ADRES
FSWAP

END OF SECTION 201

Section 203-1: Transferring Data

To facilitate any changes which might be required to the method of data transfer between memory and auxiliary storage, the routines REED and RITE with known functions have been used. REED transfers data from auxiliary storage into memory, RITE moves data from memory onto auxiliary storage. These transfers are made in blocks (arrays) of data, always under the guise of 4-byte IBM floating point numbers.

Sequential Access

A record is kept of the access position of each logical unit. Upon any request for a data transfer operation, the access position for that unit is checked with the reference record number provided. If properly positioned, the transfer is made with a Fortran READ or WRITE statement. If not properly positioned, repositioning is done to a higher record number or a rewind is done and repositioning done from the start. (The backspace capability is not used; trouble with this technique has simply caused us an inordinate amount of trouble locally and on conversion to distant facilities, and has been a costly penalty in analysis effort on projects.) Thus for transfers which are made sequentially, the tasks are performed directly.

It is noted that the technique implemented may discourage carrying an access position from one routine to another. This practice is generally deemed to be undesirable, that is, to read to some point in a data file in one routine and then continue reading in another routine, because it restrains sequencing routes. The access position data is carried in an array in a labeled common block in the service routines and not accessed in the coding or tinkered with.

REWIND capability is provided. Also there is protection against reading data which has not been written, especially useful for the debugging phase of program development. An END OF FILE may be placed on the unit (after it has been written) with a special call, and then rewind done. The position flags for the units accessed sequentially are initially set to zero; an attempt to get data before it has been written will cause an error message edit.

Direct Access

It is true that all data transfers could be made in either the direct access mode or the sequential access mode by repositioning. However, we find generally that when data is moved sequentially, sequential access is the most efficient. The multiple repositioning associated with accessing records out of order is a serious penalty when sequential access is used on many systems. The solution to this problem with storage on disk units is to carry a record accounting in the operating system and transmit a single positioning order, the direct access mode. In the direct access by record mode, only fixed length, unformatted records are moved.

To allow both sequential and direct access modes of operation in a program requires identification of the mode for each logical unit. This could be done by (1) using different routines or set flags in the program, (2) defining a range of logical units for one type of access, or (3) providing flags. We reject (1) as inhibiting interchange, and (2) as an undesirable and not a sufficiently general scheme. The scheme selected allows use of a local adaptation of the IBM system routines to be used.

For efficient execution, parameters such as record length must be made problem dependent. This is done with routines adapted locally which must be accessed prior to use of the auxiliary unit to open it.

Core-to-Core

An implementation was adopted which allows data files to be stored in memory (extended core) if space allows. In this mode, the data is simply moved from one location to another directly.

Asynchronous Operations

The routines provide for asynchronous operations to allow overlap of input/output operations with calculation. Special routines are required on a computer to provide this capability locally.

Multi-level I/O Hierarchy

Capability in the routines provides for storage of data in an extended (slow) core and input/output with both disc and memory. This

capability admits simulation and testing of the mode on a machine lacking extended core by use of memory. It also provides a useful mode of operation for a large memory machine, since the core-to-extended-core transfers are simply movement of data between memory locations.

The Input/Output Routines

We expect compromises to be made in the cooperative interinstallation effort on the scheme used to admit a variety of input/output techniques to be used in a code. The code uses a preliminary implementation of the input/output service routines which are listed along with their functions in section 201. A listing of documenting comments for these managing routines is presented in Figure 203-1; the concerned programmer should refer to the Fortran listing of the routines actually distributed.

FIGURE 203-1. DATA INPUT/OUTPUT SERVICE ROUTINES

(THESE COMMENT CARDS ARE PRIMARY DOCUMENTATION AT TIME OF PUBLICATION, SEE THE FORTRAN LISTING OF THE PROGIAM TRANSMITTED FOR DETAILS)

```
CDOPC ROUTINE FOR OPENING AND CLOSING AUXILIARY FILES
C        MODIFIED 3-1-75 ORNL VERSION                                  DOPC  20
C                                                                      DOPC  30
      SUBROUTINE DOPC(ITASK,LU,NR,LR,ILR,IPSOK)                        DOPC  40
C                                                                      DOPC  50
      COMMON/MGMTIO/HONOR(100),NVERS(100),NEDUM(100),IMODD(100), NDF,  DOPC  60
     * NIO,INPT,IOUT,JOUT,IAV(11),IEMA                                 DOPC  70
C     SEE ROUTINE SEEK FOR CONTENTS OF COMMON/MGMTIO/                  DOPC  80
C                                                                      DOPC  90
      DIMENSION KK(1), IPSOK(1)                                        DOPC 100
C                                                                      DOPC 110
      REAL*8 DD,HONOR                                                  DOPC 120
C                                                                      DOPC 130
C     THE FOLLOWING ARE REQUIRED FOR A MODULE IN THE LOCAL SYSTEM      DOPC 140
C       1- INITIALIZE WITH A CALL TO DOPC                              DOPC 150
C       2- ALLOCATE STORAGE                                            DOPC 160
C       3- COMMUNICATE STORAGE LOCATIONS WITH CALLS TO RCXX AND ROXY   DOPC 170
C       4- OPEN NECESSARY FILES (NOT REQUIRED FOR SEQUENTIAL FORTRAN)  DOPC 180
C          WITH CALLS TO DOPC                                          DOPC 190
C       5- CLOSE FILES AS DESIRED WITH CALLS TO DOPC                   DOPC 200
C       6- DETERMINE INTERFACE FILE UNITS WITH CALLS TO SEEK           DOPC 210
C       7- WRAP UP WITH A CLOSE CALL TO DOPC                           DOPC 220
C     (STAND ALONE OPERATION MAY USE SEEK, REED, AND RITE WITH         DOPC 230
C      SEQUENTIAL OPERATION WITHOUT THESE OTHER REQUIREMENTS)          DOPC 240
C                                                                      DOPC 250
C     DOPC DOES NOT ALTER THE ARGUMENTS COMMUNICATED, SO SUBSEQUENT USE DOPC 260
C     IS POSSIBLE WITH ONLY THE DESIRED CHANGES                        DOPC 270
C     NOTE THAT ARRAY KK IS RESERVED TO STORE CONTROL INFORMATION, SO  DOPC 280
C       IT MUST BE PROPERLY COMMUNICATED AND NOT TAMPERED WITH         DOPC 290
C                                                                      DOPC 300
C                        ARGUMENT USE                                  DOPC 310
C                        -------- ---                                  DOPC 320
C     ROLE OF ARGUMENTS                                                DOPC 330
C     ---- -- ---------                                                DOPC 340
C     ITASK         OPTION ON JOB TO BE DONE                           DOPC 350
C                     0 -INITIALIZATION, USUALLY REQUIRED, STORAGE ARRAYSDOPC 360
C                        NOT YET AVAILABLE                             DOPC 370
C                        RETURNS IPSOK(1) = INPT  INPUT UNIT           DOPC 380
C                                IPSOK(2) = IOUT  OUTPUT UNIT          DOPC 390
C                                IPSOK(3) = JOUT  CONDENSED OUTPUT UNIT DOPC 400
C                                OTHER VALUES OF IPSOK NOT USED OR SET DOPC 410
C                     1- OPEN SCRATCH DATA FILE                        DOPC 420
C                     2 -CLOSE SCRATCH DATA FILE                       DOPC 430
C                         (CLOSING FILES STORED IN EXTENDED CORE MAY BESTDOPC 440
C                         BE DONE IN REVERSE ORDED FROM OPENING)       DOPC 450
C                     3 -WRAP UP, CLOSE ALL FILES BEFORE LEAVING A MODULEDOPC 460
C     LU            LOGICAL UNIT NUMBER                                DOPC 470
C     NR            NUMBER OF LOGICAL RECORDS IN THE FILE              DOPC 480
C     LR            LOGICAL RECORD LENGTH (REQUIRED FOR FIXED LENGTH   DOPC 490
```

(CONT)

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C                       RECORDS, OTHERWISE MAXIMUM REQUIRED), WORDS        DOPC 500
C      ILR            LENGTH OF THE DATA FILE, WORDS                       DOPC 510
C      IPSOK(1)       MODE OF DATA ACCESS                                  DOPC 520
C                       0- SEQUENTIAL                                       DOPC 530
C                       1- SEQUENTIAL, RECORD LENGTHS STORED                DOPC 540
C                       2- RANDOM ACCESS BY RECORD, FIXED LENGTH RECORDS    DOPC 550
C                       3- RANDOM ACCESS BY RECORD, FIXED LENGTH RECORDS    DOPC 560
C                          RAMDOM WRITE REQUIRED WHICH MAY REQUIRE PREWRITEDOPC 570
C      IPSOK(2)       REFERENCE TECHNIQUE OF DATA TRANSFER                 DOPC 580
C                       0- MANUFACTURERS FORTRAN                            DOPC 590
C                          IPSOK(1) OPTION 1 = OPTION 0, 3 = 2  (IBM)       DOPC 595
C                       1- LOCAL ADAPTATION OF THE SYSTEM ROUTINES          DOPC 600
C                       2- DEFAULT THE FILE TO EXTENDED CORE                DOPC 610
C      IPSOK(3)       DEBUG MESSAGE EDIT LEVEL, EDITS DONE IF .GT. 0       DOPC 620
C      IPSOK(4)       RETURN ERROR FLAG, TASK COMPLETED ONLY IF 0          DOPC 630
C      IPSOK(5)       RELATIVE POSITION IN EXTENDED CORE DATA CONTAINER    DOPC 640
C                       ARRAY X WHERE THE FILE STARTS (IPSOK(2) = 2 ONLY)  DOPC 650
C      IPSOK(6)       RESERVED FOR SPECIAL OPTIONS IN LOCAL TRANSFER SCHEMEDOPC 660
C                       .LT.0 IS USED FOR TRACK OVERFLOW ON THE DISC        DOPC 665
C      IPSOK(7)       MAXIMUM BLOCK SIZE OF LOCAL TRANSFER SCHEME          DOPC 670
C      IPSOK(8-10)    RESERVED                                             DOPC 680
C          PRIMARY INPUT/OUTPUT CONTROL PARAMETERS                         DOPC 690
C          ---------------------------------------                         DOPC 700
C (NAMES USED HERE FOR DESCRIPTION ONLY, NOT PROGRAM VARIABLES)            DOPC 710
C      L  IS THE LOGICAL UNIT NUMBER                                       DOPC 720
C      N  IS THE LOCATION OF THE CONTROL DATA IN THE KK ARRAY (IF NEEDED)DOPC 730
C      J  IS THE FILE LOCATION WITHIN THE EXTENDED CORE DATA ARRAY X       DOPC 740
C      NP IS THE NUMBER OF PHYSICAL RECORDS PER LOGICAL RECORD             DOPC 750
C      MR IS THE NEXT POSITION IN THE FILE BY RECORD COUNT                 DOPC 760
C      NW IS THE NEXT POSITION IN THE FILE BY WORD COUNT                   DOPC 770
C      M  IS THE MAXIMUM RECORD COUNT WRITTEN                              DOPC 780
C      IP IS A FLAG INDICATING POSITION FOR MULTIPLE PHYSICAL RECORDS      DOPC 790
C      IL IS THE LENGTH OF THE PREVIOUS RECORD WRITTEN                     DOPC 800
C      NL IS 1820 WITHOUT TRACK OVERFLOW, 8188 WITH IT (2314 DISC)         DOPC 805
C                                                                          DOPC 810
C   IPSOK                                                                  DOPC 820
C  (1)  (2) IMODD(L) NEDUM(L) KK(N) KK(N+1) KK(N+2) KK(N+3) KK(N+4) MORE DOPC 830
C  ------- -------- -------- ----- ------- ------- ------- ------- ---- DOPC 840
C  0,1  0      0        MR    NONE                                       DOPC 850
C  2,3  0      1        NP    NONE                                       DOPC 860
C       1      N        MR      2      IP      M      NR    IPSOK(1) YES DOPC 870
C  0    2      N        NW      5      NR      J      MR     IL          DOPC 880
C  1    2      N        NW      4      NR      J      MR     IL      YES DOPC 890
C  2,3  2      N        LR      3      NR      J      MR     -           DOPC 900
C                                STORAGE REQUIREMENTS                    DOPC 910
C                        KK CONTROL ARRAY          X DATA CONTAINER      DOPC 920
C                        -- ------- -----          - ---- ---------      DOPC 930
C       0                        -                        -             DOPC 940
C 0,2,3 1                50 + 5*((LR-1)/NL)               -             DOPC 950
C  1    1                50 + 5*((LR-1)/NL) + NR          -             DOPC 960
C 0,2,3 2                5                                ILR            DOPC 970
C  1    2                5 + NR                           ILR            DOPC 980
C                                                                        DOPC 990
```

(CONT)

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C                SERVICE ROUTINES USED AND ENTRY POINTS                 DOPC1000
C                ------- -------- ---- --- ----- ------                 DOPC1005
C     DOPC          HANDLE FILE OPENING, ETC                            DOPC1010
C           BOXY                                                        DOPC1020
C     RITE          DATA TRANSFER                                       DOPC1030
C           REED BOXX                                                   DOPC1040
C     CRIT          CORE, EXTENDED CORE DATA TRANSFER                   DOPC1050
C           CRED                                                        DOPC1060
C     SEEK          MANAGE INTERFACE DATA FILES                         DOPC1070
C     FBSAM         LOCAL DATA TRANSFER SCHEME USING SYSTEM ROUTINES    DOPC1080
C           FREW FDISP FREAD FWRITE FPNTSP FORSPC FBKSPC FPNTR FCHECK   DOPC1090
C           (PLANS ARE TO SPLIT UP THIS LARGE ROUTINE)                  DOPC1095
C     DEFILE        IBM FORTRAN DIRECT ACCESS FILE OPENING              DOPC1100
C     CLOSDA        CLOSE FORTRAN DIRECT ACCESS FILES                   DOPC1110
C                                                                       DOPC1120


CRITE DATA TRANSFER ROUTINE, ORNL VERSION
C        MODIFIED 34-1-75                                               RITE  20
      SUBROUTINE RITE(LUN,IREC,ARRAY,NWDS,MODE)                         RITE  30
C                                                                       RITE  40
      COMMON/MGMTID/HONOR(100),NVERS(100),NEDUM(100),IMODD(100), NDF,   RITE  50
     * NIO,INPT,IOUT,JOUT,IAV(11),IEMA                                  RITE  60
C                                                                       RITE  70
      DIMENSION ARRAY(NWDS), X(1), KK(1)                                RITE  80
C                                                                       RITE  90
      REAL*8 HONOR                                                      RITE 100
C                                                                       RITE 110
C     THIS ROUTINE PACKAGES THE PROCEDURES FOR TRANSFER OF DATA BETWEEN RITE 120
C     MEMORY AND DISK AND MEMORY - MEMORY (PSEUDO EXTENDED CORE)        RITE 130
C                                                                       RITE 140
C     ON SOME COMPUTERS IT WILL BE NECESSARY TO COMMUNICATE THE         RITE 150
C       STARTING ADDRESSES OF ARRAYS KK AND X IN SOME OTHER MANNER      RITE 160
C                                                                       RITE 170
C     LUN       LOGICAL UNIT NUMBER OF THE FILE                         RITE 180
C     IREC      RECORD NUMBER TO BE ADDRESSED                           RITE 190
C     ARRAY     REFERENCE ARRAY IN CORE TO PROVIDE LOCATION FOR TRANSFER RITE 200
C     NWDS      LENGTH OF THE ARRAY THE BE TRANSFERRED                  RITE 210
C                   IF 0, REQIND ONLY                                   RITE 220
C                   IF .LT. 0, END FILE AND REQIND ONLY                 RITE 230
C     MODE      USED FOR ASYNCHRONOUS OPERATIONS                        RITE 240
C                 0- NO                                                 RITE 250
C                 1- TRANSFER OPERATION                                 RITE 260
C                 2- CHECK PREVIOUS TRANSFER COMPLETION, REQUIRED AS A  RITE 270
C                    SPECIAL OR EXTRA CALL PRIOR TO USE OF THE DATA,    RITE 280
C                    EXCEPT WHEN PROTECTION IS PROVIDED BY A SUBSEQUENT RITE 290
C                    CALL FOR ADDITIONAL DATA TRANSFER PRIOR TO USE     RITE 300
      IO = 0                                                            RITE 310
      GO TO 101                                                         RITE 320
C                                                                       RITE 330
C     VARIABLE LENGTH DATA BLOCKS COMMUNICATED HERE (ON SOME OF THE     RITE 340
C       SYSTEMS, THIS WON'T WORK - A FIXED COMMON BLOCK CAN BE USED)    RITE 350
      ENTRY BOXX ( N , M , X , L , KK )                                 RITE 360
```

(CONT)

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C     M          LENGTH OF THE EXTENDED CORE DATA CONTAINER ARRAY X        RITE 380
C     X          EXTENDED CORE DATA CONTAINER ARRAY                        RITE 390
C     L          LENGTH OF THE KK CONTROL ARRAY                            RITE 400
C     KK         CONTROL ARRAY                                             RITE 410
C     KK(1)          LENGTH OF THE CONTROL ARRAY                           RITE 420
C     KK(2)          SIZE OF THE EXTENDED CORE DATA CONTAINER ARRAY        RITE 430
C     KK(3)          USE OF THE SPACE FOR CONTROL DATA                     RITE 440
C     KK(4)          AMOUNT OF THE EXTENDED CORE DATA ARRAY USED           RITE 450
C     KK(5)          LARGEST USE OF THE EXTENDED CORE DATA ARRAY           RITE 460


CSEEK UTILITY ROUTINE FOR MANAGING INTERFACE DATA FILES                    SEEK  10
C        MODIFIED 3-1-75 ORNL VERSION                                      SEEK  20
C                                                                          SEEK  30
      SUBROUTINE SEEK(HNAME,IVERS,NREF,NOP)                                SEEK  40
C                                                                          SEEK  50
      COMMON/MGMTIO/HONOR(100),NVERS(100),NEDUM(100),IMODD(100), NDF,      SEEK  60
     * NIO,INPT,IOUT,JOUT,IAV(11),IEMA                                     SEEK  70
C                                                                          SEEK  80
      DIMENSION FNAME(15)                                                  SEEK  90
C                                                                          SEEK 100
      REAL*8 HNAME,HONOR,BLANK,CHANGE,PURGE,CONTRL,FNAME                   SEEK 110
C                                                                          SEEK 120
      DATA FNAME/6HCONTRL,6HGRUPXS,6HGEODST,6HNDXSRF,6HZNATDN, 6HSEARCH,SEEK 130
     *  6HRSTRTR,6HRTFLUX,6HATFLUX,6HRZFLUX, 6HPWDINT,6HCXSPRR,6HISOTXS,SEEK 140
     *  6HISOTXS,6HFIXSRC/                                                SEEK 150
      DATA CHANGE/6HCHANGE/                                                SEEK 160
      DATA BLANK/6H      /,PURGE/6HPURGE /,CONTRL/6HCONTRL/                SEEK 170
C                                                                          SEEK 180
C     FILE MANAGEMENT SUBROUTINE FOR STANDARD INTERFACE FILES              SEEK 190
C       ALLOWING ONLY ONE FILE TO A LOGICAL UNIT                           SEEK 200
C                                                                          SEEK 210
C     HNAME          FILE NAME (EXCEPTIONS NOTED BELOW)                    SEEK 220
C     IVERS          FILE VERSION NUMBER (EXCEPTIONS NOTED BELOW)          SEEK 230
C     NREF           LOGICAL UNIT NUMBER OR ERROR RETURN CONDITION         SEEK 240
C                    (EXCEPTIONS NOTED BELOW)                              SEEK 250
C     NOP            OPTION NUMBER (EXCEPTIONS NOTED BELOW)                SEEK 260
C     HONOR(I)       FILE NAME IN CATALOG, I IS LOGICAL UNIT NUMBER        SEEK 270
C     FNAME          CATALOG FILE NAMES FOR INITIALIZATION                 SEEK 280
C     NVERS(I)       FILE VERSION IN CATALOG                               SEEK 290
C     NEDUM(I)       DATA FOR I/O TASK (RECORD POSITION FOR SEQUENTIAL)    SEEK 300
C     IMODD(I)       TECHNIQUE OF DATA TRANSFER INDICATOR (SEQUENTIAL, 0)  SEEK 310
C     IAV            STORAGE ALLOWED FOR DIRECT ACCESS PARAMETERS          SEEK 320
C     NDF            NUMBER OF FILES IN CATALOG                            SEEK 330
C     NIO            LAST LOGICAL UNIT NUMBER ASSIGNED                     SEEK 340
C     INPT           USER DATA INPUT LOGICAL UNIT                          SEEK 350
C     IOUT           USER OUTPUT DATA LOGICAL UNIT                         SEEK 360
C     JOUT           USER CONDENSED (TERMINAL) OUTPUT LOGICAL UNIT         SEEK 370
C     IEMA           USED FOR ENTRY PROTECTION IN DOPC                     SEEK 380
C                                                                          SEEK 390
C                 PRIMARY CONTROL OPTIONS                                  SEEK 400
C                                                                          SEEK 410
C     HNAME = 'CHANGE'   INTERCHANGE FILE NAMES AND VERSION NUMBERS        SEEK 420
```

(CONT)

```
C                INPUT - HNAME,IVERS,NREF,NOP                                SEEK 430
C                IF IVERS EQ 0, THE NAMES AND VERSION NUMBERS ASSOCIATED     SEEK 440
C                    WITH CATALOG POSITIONS NREF AND NOP WILL BE             SEEK 450
C                    INTERCHANGED                                            SEEK 460
C                IF IVERS GT 0, THE NAMES AND VERSION NUMBERS ASSOCIATED     SEEK 470
C                    LOGICAL UNIT NUMBERS NREF AND NOP WILL BE               SEEK 480
C                    INTERCHANGED                                            SEEK 490
C                NREF WILL BE RETURNED ZERO FOR ERROR CONDITION              SEEK 500
C      NOP = 0,1     LOCATE FILE PRIOR TO READING, WRITING                   SEEK 510
C                INPUT - HNAME,IVERS,NOP                                     SEEK 520
C                IF IVERS EQ 0, RETURNS VERSION NUMBER AND LOGICAL           SEEK 530
C                    UNIT NUMBER OF THE LATEST VERSION                       SEEK 540
C                IF IVERS EQ N, RETURNS LOGICAL UNIT NUMBER FOR              SEEK 550
C                    VERSION N                                               SEEK 560
C                NREF WILL BE RETURNED ZERO FOR ERROR CONDITION              SEEK 570
C      NOP = 2       CREATE A NEW FILE VERSION PRIOR TO WRITING              SEEK 580
C                    WILL INITIALIZE CONTRL IF NOT IN TABLE POSITION 1       SEEK 590
C                INPUT - HNAME,NOP                                           SEEK 600
C                RETURNS NEW VERSION NUMBER AND LOGICAL UNIT NUMBER          SEEK 610
C                    AND ADDS NEW DATA TO CATALOG                            SEEK 620
C                NREF WILL BE RETURNED ZERO FOR ERROR CONDITION              SEEK 630
C      NOP = 3       CATALOG INITIALIZATION, PUTS DATA ON UNIT ICAT          SEEK 640
C                IF NREF .GT.0, IT IS THE NUMBER OF FILES FROM THE LIST      SEEK 650
C      NOP = 4       PURGING OPTION                                          SEEK 660
C                INPUT - HNAME,IVERS,NOP                                     SEEK 670
C                IF HNAME EQ 'PURGE ', ALL FILE REFERENCES WILL BE           SEEK 680
C                    DELETED EXCEPT FOR CONTRL                               SEEK 690
C                IF HNAME NE 'PURGE ' AND IVERS EQ 0, ALL VERSIONS           SEEK 700
C                    OF THE FILE WILL BE DELETED                             SEEK 710
C                IF HNAME NE 'PURGE ' AND IVERS EQ N, ONLY VERSION N         SEEK 720
C                    OF THE FILE WILL BE DELETED                             SEEK 730
C      NOP = 5       EXTRACT CONTENTS OF CATALOG                             SEEK 740
C                INPUT - IVERS,NREF,NOP                                      SEEK 750
C                IF IVERS EQ 0, NREF WILL BE TREATED AS THE POSITION         SEEK 760
C                    IN THE CATALOG AND THE ASSOCIATED FILE NAME,            SEEK 770
C                    VERSION NUMBER, AND LOGICAL UNIT NUMBER                 SEEK 780
C                    WILL BE RETURNED                                        SEEK 790
C                IF IVERS GT 0, NREF WILL BE TREATED AS THE LOGICAL          SEEK 800
C                    UNIT NUMBER AND THE ASSOCIATED FILE NAME,               SEEK 810
C                    VERSION NUMBER, AND CATALOG POSITION                    SEEK 820
C                    WILL BE RETURNED                                        SEEK 830
C                NREF WILL BE RETURNED ZERO FOR ERROR CONDITION              SEEK 840
C      NOP = 6,7     NOT USED                                                SEEK 850
C      NOP = 8       READ CONTENTS OF CATALOG (SAVED IN LAST MODULE          SEEK 860
C                    EXECUTED)                                               SEEK 870
C      NOP = 9       WRITE CONTENTS OF CATALOG (FOR USE BY NEXT MODULE       SEEK 880
C                    TO BE EXECUTED)                                         SEEK 890
C      NOP = 10      EDIT CONTENTS OF CATALOG                                SEEK 900
C                IF NREF.GT.0, WRITES JOUT INSTEAD OF IOUT                   SEEK 910
C      NOP = 11     RETURN UTILITY UNIT NUMBERS                              SEEK 920
C                                                                            SEEK 930
C      **********  REQUEST  ***********  **********  RESPONSE  **********SEEK 940
C       HNAME   IVERS    NREF     NOP      HNAME   IVERS    NREF     NOP   SEEK 950
C        CHANGE  0        IT1      IT2      CHANGE  0        IT1      IT2  SEEK 960
```

(CONT)

```
C                                                CHANGE  0       0=E     IT2  SEEK 970
C       CHANGE  M       LU1     LU2              CHANGE  M       LU1     LU2  SEEK 980
C                                                CHANGE  M       0=E     LU2  SEEK 990
C       H       0       -       0                H       NL      LU      0    SEEK1000
C                                                H       0       0=E     0    SEEK1010
C       H       N       -       0                H       N       LU      0    SEEK1020
C                                                H       N       0=E     0    SEEK1030
C       H       0       -       1                H       NL      LU      1    SEEK1040
C                                                H       0       0=E     1    SEEK1050
C       H       N       -       1                H       N       LU      1    SEEK1060
C                                                H       N       0=E     1    SEEK1070
C       H       -       -       2                H       NN      LU      2    SEEK1080
C                                                H       -       0=E     2    SEEK1090
C       -       -       -       3                -       -       INIT    3    SEEK1100
C       PURGE   -       -       4                PURGE   -       -       4    SEEK1110
C       H       0       -       4                H       0       -       4    SEEK1120
C       H       N       -       4                H       N       -       4    SEEK1130
C       -       0       IT      5                H       N       LU      5    SEEK1140
C                                                -       0       0=E     5    SEEK1150
C       -       M       LU      5                H       N       IT      5    SEEK1160
C                                                -       M       0=E     5    SEEK1170
C       H       N       LU      6                H       N       LU      6    SEEK1180
C       -       -       -       7                -       -       -       7    SEEK1190
C       -       -       -       8                -       -       -       8    SEEK1200
C       -       -       -       9                -       -       -       9    SEEK1210
C       -       -       -       10               -       -       -       10   SEEK1220
C       -       -       -       11               INPT    IOUT    JOUT         SEEK1230
C                                                                             SEEK1240
C     H             FILE NAME                                                 SEEK1250
C     N             VERSION NUMBER                                            SEEK1260
C     NL            LAST VERSION NUMBER                                       SEEK1270
C     NN            NEW VERSION NUMBER                                        SEEK1280
C     LU,LU1,LU2    LOGICAL UNIT NUMBER                                       SEEK1290
C     IT,IT1,IT2    TABLE POSITION                                            SEEK1300
C     M             GREATER THAN ZERO                                         SEEK1310
C     0=E           ERROR                                                     SEEK1320
C     -             NOT USED (BUT HNAME MUST NOT BE 'CHANGE')                 SEEK1330
C     ***************************************************************SEEK1340
```

```
CCRIT  BASIC ROUTINE FOR MEMORY, EXTENDED CORE DATA TRANSFERS
C      A MUCH FASTER ASSEMBLER LANGUAGE VERSION OF THIS IS IN USE
C
       SUBROUTINE CRIT(X,Y,N,J)
C
       DIMENSION X(1), Y(1)
C
C      USE OF ARGUMENTS
C      --- -- ---------
C      X       DATA ARRAY IN MEMORY
C      Y       DATA ARRAY IN EXTENDED (SLOW OR PARTITIONED) CORE
C      N       LENGTH OF DATA STRING TO BE MOVED, SHORT WORDS, MIXED TYPE
C                ALLOWED
C      J       SYSTEM FLAG ON SOME SYSTEMS, NOT USED LOCALLY
C
C      ENTRY FOR EXTENDED CORE TO MEMORY TRANSFER
C
       ENTRY CRED (Y,X,N,J)
C
       DO 101 I=1,N
       Y(I)=X(I)
  101  CONTINUE
       RETURN
       END
```

END OF SECTION 203

Section 204: Input/Output File Requirements

In this discussion, the data files which must be resident on auxiliary storage devices are identified as Standard Interface files[a] or scratch files. It is assumed that the scratch files are each assigned a logical unit number in the range 21-65 and units 1-9 are reserved for special purposes. Our normal logical devices are unit 5 input and unit 6 output. Unit 4 is used to contain a collection of the results for export (BCD, tape). Assignments may be simply changed at the front end of the code.

Standard Interface Data Files Used

GRUPXS — Group ordered microscopic cross sections
GEODST — Geometry description
NDXSRF — Nuclide to cross section referencing data
ZNATDN — Zone nuclide atomic densities
SEARCH — Search data (required only for search)
FIXSRC — Fixed source (required for a fixed source problem only)
RTFLUX — Total neutron flux (if supplied)
ATFLUX — Total adjoint neutron flux (if supplied)

Standard Interface Data Files Generated by Option

RTFLUX — Total neutron flux
ATFLUX — Total adjoint flux
RZFLUX — Zone average total neutron flux
PWDINT — Point power density
GEODST — Geometry description upon dimension search
NDXSRF — Nuclide to cross section referencing data upon dimension search
ZNATDN — Zone nuclide atomic densities upon concentration search
FIXSRC — Special fixed source result

Scratch Data Files by Unit Number

21	Macroscopic scattering cross sections
22	Principal macroscopic cross sections
23 (Direct access)[b]	Equation coupling constants in space
24 (Direct access)	Total neutron flux
27 (Direct access)	Flux Copy
28 (Direct access)	Flux copy

[a] Version III Specifications, LASL report, LA-5486-MS revised.

[b] Unless noted otherwise, files are accessed sequentially; by direct access is meant write and read of disc files at random by record.

29 (Direct access)	$\nabla \cdot J$ times volume (current in the P_1 sense)
40 (Direct access)	Equation constants
41	Fixed source
42	Fission source
43	Total source
44	Neutron balance data
45	Miscellaneous[a]
46	Miscellaneous
47	Search data, misc.
48	Miscellaneous
49	Point volume data
50, 51, 52	Cross section data
53	Mesh data

Certain files contain a large fraction of the data to be stored. Note that the product of the record length and number of records is the total amount of data to be stored in a file.

Let J = points in a row

I = number of rows in a plane

L = number of planes

K = number of groups

W = 1 for long-word machines, 2 for short word

R = 0 for one-dimensional, 2 for two-dimensional, 4 for three-dimensional cases

H = 1 for hexagonal, 0 otherwise

M = number of zones (m refers to zone)

A record on units 23 and 40 contain the following data for a row or a plane of points: total loss terms including leakage, regions, element volumes, left leakage constants, top and bottom leakage constants, front and back leakage constants, extra leakage constants for hexagonal geometry data terminated as appropriate for few-dimension problems.

The primary cross sections are carried on units 21 and 22 as follows, where M refers to the number of zones and K to the number of groups, N to the number of black absorber zones, and I the number of dimensions.

---

[a]By miscellaneous is meant that these files are generally used to store different information at different stages of a calculation, but the required storage space is usually not large relative to those for which requirements are given in detail.

Units	Record Length (Words)	Number of Records	Notes
23	[3 + W(1+2H)](J+1) + RJ	ILK	Needed only for the "row-stored" model(see Section 103), and/or for perturbation calculations.
24,27,28,29	WJI	LK	
40	(R+W)JI + (2+H)JI + (1+H)(J+L) + H	LK	For "plane-stored" mode only.
40	(3+W+H)JIL + (1+H)(J+I)L + JI + HL	K	For "mesh-stored" mode only.
40	{[3 + W(1+2H)](J+1) + RJ} I	LK	For the "multilevel data transfer mode only.
41	WJI	L	
42	WJI	L	
43	WJI	L	
44	WMK	2	
45	WJI	L	
46[a]	WJI	L	
47	WMK	1	
48	WMK	K	
49	WJ	IL	
50-53	Variable but small	Variable	

[a]For the case when the initial fluxes are read from the standard interface RTFLUX, number of records is LK.

Unit	Record Length	Number of Records	Contents
21	M[N(k)]	K	Inscattering $\Sigma_s^0(k' \rightarrow k,m)$; for the P_1 calculation, the data for each k follows the Σ_s^0 data in a separate record, increasing the number of records to 2K, $D(k,m)\Sigma_s^1(k' \rightarrow k,m)$
22	MK	1	Fission source distribution $\chi(m,k)$
	MK	1	Sink term $\Sigma_a(m,k) + D_\perp B_\perp^2(m,k)$
	MK	1	Buckling loss $D_\perp B_\perp^2(m,k)$
	MK	1	Production $\nu\Sigma_f(m,k)$
	MK	1	Search production $\nu\Sigma_p(m,k)$
	MK	1	Search absorption $\Sigma_q(m,k)$
	MK	1	Energy per unit flux W(m,k)
	MK	1	Reciprocal velocity Z(m,k)
	2K	1	Inscatter range, location of in-group term N(k),NJ(k)
	N	1	Black absorber zone list, if N > 0
	M	1	Zone volumes V(m)
	K	1	Number of inner iterations, if I > 1
	K	1	Spectral radius, if I > 1
	K	1	Overrelaxation factors, if I > 1
	MK	1	Removal cross sections (only with P_1 treatment)
	MK	1 to 4	Diffusion coefficients by zone, as well as the coordinate-direction dependent values when available from GRUPXS except with P_1 treatment
	2J+2I +2L+3	1	Distances to flux points and fine mesh interval interfaces.
	7K	1	External and internal boundary condition constants.
	MK	1	$\Sigma a(m,k)$ fissile
	MK	1	$\Sigma c(m,k)$ fertile

It should be noted that microscopic cross sections are used in a group-ordered form. A processor code block is required to recast the data into this form from a reference broad-energy-group library in the nuclide-ordered format defined by the specification for file ISOTXS.

Code-Dependent Data Files

Figure 204-1 shows the content of special interface files CONTRL, PERTUB, RSTRTR, and FISSOR. Also shown are the contents of the BCD file on unit 4 used to transfer data to other installations.

CONTRL is a file containing all the necessary control information needed by VENTURE for a calculation (see Section 403).

PERTUB is generated by option by the code and contains the basic perturbation integrals.

RSTRTR is a restart file which is written by option and may be supplied to the code to continue a previous calculation.

FISSOR is a fission source interface file written on option.

FIGURE 204-1. SPECIAL DATA FILE SPECIFICATIONS

```
C*********************************************************************
C                        REVISED 11/26/74
C
CF          CONTRL
CE          CODE-BLOCK-DEPENDENT DATA UNDER CONTROL OF THE DRIVER
C
C*********************************************************************


C---------------------------------------------------------------------
CS          FILE STRUCTURE
CS
CS             RECORD TYPE                          PRESENT IF
CS             ==============================       ===============
CS             FILE IDENTIFICATION                  ALWAYS FIRST
C
CN          THE FOLLOWING ARE CONTROL DATA RECORDS, ONE FOR EACH CODE
CN          BLOCK, AND EACH CONTAINING 201 WORDS(101*MULT+100)
C
CS             PROINS RECORD                        ALWAYS
CS             DVRINS RECORD                        ALWAYS
CS             XCPINS RECORD                        AS NEEDED
CS             DTNINS RECORD                        AS NEEDED
CS             RRTINS RECORD                        AS NEEDED
CS             BLANK  RECORD                        ALWAYS LAST
CS
CN          RECORDS FOR OTHER CODE-BLOCKS MAY ALSO BE PRESENT
CN          AND ORDER OF RECORDS NOT SPECIFIED
CS
C---------------------------------------------------------------------


C---------------------------------------------------------------------
CR          FILE IDENTIFICATION
C
CL     HNAME,(HUSE(I),I=1,2),IVERS
C
CW     3*MULT + 1
C
CD     HNAME          HOLLERITH FILE NAME - CONTRL - (A6)
CD     HUSE           HOLLERITH USER IDENTIFICATION (A6)
CD     IVERS          FILE VERSION NUMBER
CD     MULT           DOUBLE PRECISION PARAMETER
CD                        1 - A6 WORD IS SINGLE WORD
CD                        2 - A6 WORD IS DOUBLE PRECISION WORD
C
C---------------------------------------------------------------------
```

(CONT)

```
C-----------------------------------------------------------------------
CR          OVERALL PROBLEM INFORMATION AND INSTRUCTIONS
C
CL     PROINS, (XX(I),I=1,100), (IX(I),I=1,100)
C
CW     101*MULT + 100
C
CD     PROINS          OVERALL PROBLEM DATA IDENTIFIER (6HPROINS)
CD     XX(1-24)        PROBLEM OR CASE TITLE (A6)
CD     XX(25)          USER LABEL FOR PERMANENT DATA FILES (A6)
CD     XX(26)          USER LABEL FOR TEMPORARY DATA FILES (A6)
CD     XX(27-100)      RESERVED
CD     IX(1-100)       RESERVED
C
C-----------------------------------------------------------------------
```

```
C-----------------------------------------------------------------------
CR          DRIVER INSTRUCTIONS
C
CL     DVRINS, (XX(I),I=1,100), (IX(I),I=1,100)
C
CW     101*MULT + 100
C
CD     DVRINS          DRIVER DATA IDENTIFIER (6HDVRINS)
CD     XX(1-100)       RESERVED
CD     IX(1)           PRIMARY MEMORY ALLOCATION, WORDS
CD     IX(2)           RESERVED FOR SECONDARY MEMORY ALLOCATION, WORDS
CD     IX(3)           RESERVED FOR TERTIARY MEMORY ALLOCATION, WORDS
CD     IX(4)           MAXIMUM BLOCK SIZE FOR DIRECT ACCESS DATA FILES,
CD                         WORDS
CD     IX(5)           TOTAL PROCESSOR TIME ALLOWED FOR THE RUN, MINUTES
CD     IX(6)           RESERVED
CD     IX(7)           RESERVED
CD     IX(8)           RESERVED
CD     IX(9)           RESERVED
CD     IX(10)          RESERVED
CD     IX(11)          STAND-ALONE FLAG -
CD                         0 - MODULES ARE ACCESSED IN A TRUE MODULAR SENSE
CD                         1 - MODULES ARE ACCESSED AS IF EACH IS A
CD                             STAND-ALONE CODE
CD     IX(12)          RESERVED
CD     IX(13)          IF.GT.0 THE SEEK TABLES ARE INITILIZED PRIOR TO ANY
CD                         ACCESS OF THE STANDARD INPUT MODULE
CD     IX(14)          RESERVED
CD     IX(15)          RESERVED
CD     IX(16-100)      RESERVED
C
C-----------------------------------------------------------------------
```

(CONT)

```
C-----------------------------------------------------------------------
CR          CROSS SECTION PROCESSOR INSTRUCTIONS
C
CN     THIS DATA REQUIRED BY THE CROSS SECTION PROCESSOR
C
CL     XCPINS, (XX(I),I=1,100), (IX(I),I=1,100)
C
CW     101*MULT + 100
C
CD     XCPINS          CROSS SECTION PROCESSOR DATA IDENTIFIER (6HXCPINS)
CD     XX(1-100)       RESERVED
CD     IX(1-2)         RESERVED
CD     IX(3)           OPTION ON INPUT CROSS SECTION FILE PROCESSING
CD                         0 - NO PROCESSING REQUIRED
CD                         1 - GENERATE NEW NUCLIDE-ORDERED FILE FROM
CD                               THE FILE OR FILES HAVING FORMAT IX(5)
CD                               (REQUIRES INTERFACE FILE CXSPRR FOR
CD                               ADDITIONAL INFORMATION)
CD     IX(4)           OPTION TO GENERATE A GROUP-ORDERED FILE FROM
CD                         A NUCLIDE-ORDERED FILE
CD                         0 - NO
CD                         1 - YES
CD     IX(5)           FORMAT OF INPUT CROSS SECTIONS FOR IX(3) EQ 1
CD                         0 - NUCLIDE-ORDERED FILE
CD                         1 - CITATION CROSS SECTION SETS
CD                         2 - MERGE TWO NUCLIDE-ORDERED FILES
CD     IX(6)           OPTION ON PRINCIPAL CROSS SECTION DATA
CD                         FOR IX(4) EQ 1
CD                         0 - RETAIN ALL DATA
CD                         1 - REDEFINE (N,GAMMA) CROSS SECTION TO BE
CD                               THE CAPTURE CROSS SECTION = (N,GAMMA) +
CD                               (N,ALPHA) + (N,P) + (N,D) + (N,T) - (N,2N)
CD     IX(7)           OPTION ON SCATTERING DATA FOR IX(4) EQ 1
CD                         0 - RETAIN ALL DATA
CD                         1 - RETAIN THE TOTAL SCATTERING ONLY
CD     IX(8)           OPTION ON SCATTERING ORDER FOR IX(4) EQ 1
CD                         0 - RETAIN ALL DATA
CD                         N - RETAIN ORDERS UP TO (N-1) ONLY
CD     IX(9)           OPTION ON SCATTERING RECORD BLOCKING FACTOR
CD                         FOR IX(4) EQ 1
CD                         0 - NSBLOK = 1
CD                         N - NSBLOK = N, IF (NISO/N)*N EQ NISO,
CD                               OTHERWISE NSBLOK = NISO
CD                               WHERE NISO IS THE NUMBER OF NUCLIDES
CD     IX(10)          OPTION TO COMPUTE THE TOTAL SCATTERING MATRIX
CD                         FROM THE COMPONENTS FOR IX(4) EQ 1
CD                         TOTAL = ELASTIC + INELASTIC + N2N
CD                         (THIS MUST BE DONE IF THE GRUPXS FILE IS TO BE
CD                          USED BY VENTURE AND THERE IS NO TOTAL
CD                          SCATTERING DATA PRESENT)
CD                         0 - NO
CD                         1 - YES
CD     IX(11)          OPTION TO CREATE ISOTOPE MIXTURES AFTER PROCESSING
CD                         SPECIFIED BY IX(3) AND IX(5), IF ANY
```

(CONT)

```
CD                          0 - NO
CD                          1 - YES (REQUIRES INTERFACE FILE CXSERR FOR
CD                                 ADDITIONAL INFORMATION)
CD     IX(12-22)        RESERVED
CD     IX(23)           OPTION TO EDIT LATEST NUCLIDE-ORDERED FILE
CD                          0 - NO
CD                          1 - YES
CD     IX(24)           OPTION TO EDIT GROUP-ORDERED FILE
CD                          0 - NO
CD                          1 - YES
CD     IX(25-100)       RESERVED
C
C-----------------------------------------------------------------------
```

```
C-----------------------------------------------------------------------
CR            NEUTRONICS INSTRUCTIONS
C
CN     THIS DATA REQUIRED BY THE VENTURE CODE BLOCK
C
CL     DTNINS, (XX(I),I=1,100), (IX(I),I=1,100)
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
C
CN            NOTE THAT VARIABLES NOT DEFINED ARE RESERVED FOR LATER USE
C
CD     XX(4)               POWER LEVEL OF REACTOR, WATTS THERMAL
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) - XX(100)    RESERVED
C
CD     IX(1)               INDICATOR THAT THE CODE BLOCK HAS INPUT DATA
```

(CONT)

```
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      IX(3)             REFERENCE COUNT ON PROBLEMS (CYCLE NUMBER)
CD      IX(4)             NEUTRONICS OPTIONS
CD                             1- FINITE-DIFFERENCE DIFFUSION THEORY
CD                             2- FINITE-DIFFERENCE SIMPLE P1 APPROXIMATION
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)             OPTIONS ON GAMMA HEATING
CD                                (NOT IMPLEMENTED)
CD      IX(8)             OPTION TO FORCE DATA HANDLING MODE (FOR TESTING)
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)             OPTIONS ON FLUX INITIALIZATION
CD                             0  SET ALL FLUX VALUES EQUAL
CD                             1   USE AUTOMATED PROCEDURE
CD                             2- USE AVAILABLE 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
CD                           NOT SATISFIED, AND SECOND SEARCH IS TO BE DONE
CD      IX(12)            SPECIFIES THAT A 2-D PROBLEM IS TO BE SOLVED FOR
CD                            THIS PLANE OF A 3-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 COORDINATE DIRECTION (USUALLY 0)
CD      IX(14)            DITTO, SECOND COORDINATE DIRECTION
CD      IX(15)            DITTO, THIRD COORDINATE DIRECTION
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
```

(CONT)

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CD     IX(20)              CONSTRAINT ON OUTER ITERATIONS(MAX ALLOWED)
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     IX(22)              NEGATIVE FLUX OPTION (NORMALLY 0)
CD                              0- NOT ALLOWED NOR ACCEPTABLE IN SOLUTION
CD                              1- ALLOWED AND ACCEPTABLE SOLUTION
CD     IX(23)              OVERRELAXATION OPTIONS (ON INNER ITERATIONS)
CD                           0- USE AUTOMATED PROCEDURE
CD                           1- NO CHEBYSHEV - MAKE NUMBER OF INNERS A
CD                                MULTIPLE OF THE NUMBER OF PLANE(OR ROWS)
CD                                STORED
CD                           2- FIX THE NUMBER OF INNER ITERATIONS
CD                                (SAME AT EACH GROUP)
CD                           3- FIX NUMBER OF INNERS, NO CHEBYSHEV
CD                           4- FIX NUMBER OF INNERS, USE ONE COEFFICIENT
CD                           5- FIX NUMBER OF INNERS, USE ONE COEFFICIENT,
CD                              NO CHEBYSHEV
CD     IX(24)              INNERITERATION SWEEP ORDER
CD                            0- NORMAL
CD                            1- SIGMA-1 (AVAILABLE IN CERTAIN DATA
CD                                  HANDLING MODES ONLY)
CD     IX(25)              OUTER ITERATION CHEBYCHEV ACCELERATION OPTIONS
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     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
CN         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
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(CONT)

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CD     IX(35)              OPTION TO EDIT SCALAR NEUTRON FLUX BY POINT
CD     IX(37)              OPTION TO EDIT ZONE-AVERAGE SCALAR FLUX
CD     IX(38)              OPTION TO EDIT POWER DENSITY MAP BY INTERVAL
CD     IX(39)              OPTION TO EDIT POWER DENSITY TRAVERSES THRU PEAK
CD     IX(40)              OPTION TO EDIT NEUTRON DENSITY MAP (1/V FLUX
CD                            WEIGHTING)
CD     IX(41)              OPTION TO EDIT NEUTRON DENSITY TRAVERSES
CD     IX(42)              OPTION TO EDIT SCALAR ADJOINT FLUX
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
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)              ALSO EDIT SENSITIVITY RESULTS FOR THE CHANGE,
CD                           IX(45) AND IX(46) .NE.0
CD     IX(51)              OPTION TO WRITE THE POINT SCALAR FLUX FILE
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(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 POWER DENSITY FILE
CD     IX(55)              OPTION TO WRITE A NEW FIXED SOURCE FILE
CD                         CALCULATED FROM CONVERSION RATIO DATA
CD     IX(58)              OPTION TO WRITE SCALAR ADJOINT FLUX FILE
CD                           APPLICABLE ONLY IF AN ADJOINT PROBLEM WAS DONE
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
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(CONT)

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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
C
C-----------------------------------------------------------------------
C-----------------------------------------------------------------------
CR           REACTION RATE MODULE INSTRUCTIONS
C
CL     RRTINS, (XX(I),I=1,100), (IX(I),I=1,100)
C
CW     101*MULT + 100
C
CD     RRTINS          REACTION RATE MODULE DATA IDENTIFIER (6HRRTINS)
CD
CC     NOTE- UNDEFINED DATA ARE RESERVED FOR FUTURE USE.
CC     NOTE- THE VALUE OF ZERO IS A DEFAULT MEANING THAT THE OPTION TO
CC           PERFORM THE TASK IS NOT EXERCISED.  CONSIDERABLE DATA
CC           HANDLING MAY BE INVOLVED AND MUCH PAPER PRINTED, SO CARE
CC           SHOULD BE TAKEN TO OBTAIN ONLY THOSE RESULTS NEEDED.
CC     NOTE- QUITE GENERALLY THE FILES -NDXSRF- AND -ZNATDN- ARE NEEDED
CC           AND USUALLY -GRUPXS-
C
CD     XX(1)           DESIRED POWER LEVEL IF NON-ZERO (USUALLY NEW)
CD     XX(3)           WEIGHTING FACTOR DISCUSSED BELOW
CD     XX(4)           WEIGHTING FACTOR DISCUSSED BELOW
C
CD     IX(3)           OPTION TO EDIT PROGRAMMER INFORMATION FOR DEBUGGING
CD     IX(6)           OPTION TO COMPUTE AND EDIT REACTION RATES,
CD                         INVENTORIES, AND POWER PRODUCTION
CC     NOTE- INDEPENDENT OF THE OPTIONS WHICH FOLLOW, SUMMARY TABLES
CC           ARE ALWAYS EDITED ON THIS OPTION
CD     IX(9)           OPTION TO EDIT BY ZONE AND SUBZONE FOR EACH UNIQUE
CD                         NUCLIDE NAME
CD                         1 - YES (WILL BE DONE ONLY IF THERE ARE
CD                                  SUBZONES)
CC     NOTE- IN THIS EDIT, ZONE RESULTS EXCLUDE SUBZONE CONTRIBUTIONS
CD     IX(10)          OPTION TO EDIT BY ZONE FOR EACH UNIQUE NUCLIDE NAME
CD                         NOTE - ZONES WILL INCLUDE SUBZONE CONTRIBUTIONS
CD     IX(11)          OPTION TO EDIT BY ZONE CLASS FOR EACH UNIQUE
CD                         NUCLIDE NAME
CD     IX(12)          OPTION TO EDIT SUMMARY TABLES BY UNIQUE NUCLIDE NAME
CD     IX(14)          OPTION TO WEIGHT SUMMARY REACTION RATES BY NUCLIDE
CD                         ENERGY GENERATION
CD                         1- FISSION ENERGY ONLY
CD                         2- FISSION PLUS CAPTURE ENERGY
CD     IX(15)          OPTION FOR ADDITIONAL RESULTS WITH ALTERNATIVE
CD                         WEIGHTINGS (SUMMARY TABLES ONLY)
CD                         1- BY NET NEUTRON PRODUCTION (GENERATION MINUS
CD                            ABSORPTION)
```

(CONT)

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CD                          2- BY CAPTURE RATE IF FERTILE AND ABSORPTION
CD                             RATE IF FISSILE
CD     IX(16)           REPEAT THE CALCULATIONS OF REACTION RATES INDICATED
CD                          ABOVE (IX(6).GT.0) USING FLUX, ADJOINT WEIGHTING
CD                          REQUIRING FILE -PERTUB-
CD     IX(21)           OPTION TO EDIT REACTION RATE MAPS USING FILE -RTFLUX
CD                          .GT.0- SPECIFIES A PLANE OF A 3-D PROBLEM OR
CD                                 A ROW OF A 2-D PROBLEM
CD                          -1-    THE PLANE OR ROW IS TO CONTAIN THE
CD                                 LOCATION OF MAXIMUM POWER DENSITY
CD     IX(22)           MAP PRINCIPAL REACTION RATES FOR FISSILE NUCLIDES
CD                          1- ABSORPTION
CD                          2- ABSORPTION AND PRODUCTION
CD                          3- CAPTURE AND FISSION
CD                          4- CAPTURE, FISSION AND PRODUCTION PER
CD                             ABSORPTION
CD     IX(23)           MAP PRINCIPAL REACTION RATES FOR FERTILE NUCLIDES
CD                          1- CAPTURE
CD                          2- ABSORPTION ONLY
CD     IX(24)           MAP ABSORPTION RATES FOR NUCLIDES OF THIS CLASS
CD     IX(26)           REPEAT THE MAPPING WITH WEIGHTING ON ADJOINT FLUX
CD                          USING FILE -PERTUB
CD     IX(31)           OPTION TO EDIT REACTIVITY COEFFICIENTS FOR UNIT
CD                          CHANGES IN FISSILE NUCLIDE CONCENTRATIONS
CD     IX(32)           OPTION TO EDIT REACTIVITY COEFFICIENTS FOR UNIT
CD                          CHANGES IN FERTILE NUCLIDE CONCENTRATIONS
CD     IX(33)           OPTION TO EDIT REACTIVITY COEFFICIENTS FOR UNIT
CD                          CHANGES IN NUCLIDE CONCENTRATIONS OF THIS CLASS
CD     IX(35)           OPTION TO EDIT REACTIVITY COEFFICIENTS FOR A CHANGE
CD                          IN NUCLIDE CONCENTRATIONS BY ZONE (FROM THE
CD                          NEXT-TO-LATEST VERSION OF FILE -ZNATDN- TO THE
CD                          LATEST) AND CHANGE IN MICROSCOPIC CROSS SECTIONS
CD                          FILE -GRUPXS- SAME ORDER
CD                          1- ONLY CONCENTRATION CHANGES
CD                          2- ONLY CROSS SECTION CHANGES
CD                          3- DO ONLY BOTH TOGETHER
CD                          4- DO EACH AND BOTH TOGETHER
CD     IX(37)           OPTION TO PRODUCE DELAYED NEUTRON PROPERTIES WITH
CD                          FLUX, ADJOINT WEIGHTING USING FILE -PERTUB- AND
CD                          -DLAYXS-
CD     IX(41)           OPTION TO COLLAPSE CROSS SECTIONS IN ENERGY, FILE
CD                          -ISOTXS-TO-ISOTXS- USING THE ENERGY STRUCTURE
CD                          GIVEN AS GROUP LOWER BOUNDS DESCENDING EV, DATA
CD                          IN ARRAY XX STARTING AT XX(21) TERMINATING WITH
CD                          A ZERO ENTRY FOR THE LAST GROUP
CD                          1- PRODUCE MACROSCOPIC CROSS SECTIONS FOR PSEUDO
CD                             DENSITY UNITY FOR EACH ZONE, FLUX WEIGHTED
CD                          2- PRODUCE ONE-TO-ONE NUCLIDE DATA ONLY FOR THE
CD                             ONES HAVING NON-ZERO CONCENTRATIONS WITH FLUX
CD                             WEIGHTING USING FILE -RZFLUX-
CD                          3- SAME AS 2 EXCEPT FLUX, ADJOINT WEIGHTING
CD                             REQUIRING FILE -PERTUB-
CD     IX(51)           OPTION TO GENERATE A DISTRIBUTED NEUTRON SOURCE FILE
CD                          -FIXSRC- USING FLUX FROM -RTFLUX-
```

(CONT)

```
CD                          1- TOTAL PRODUCTIONS FROM FISSION MUITIPLIED BY
CD                             XX(3) NORMALIZED TO A TOTAL OF XX(3)*XX(4)
CD                             IF XX(4) IS NON ZERO, XX(3) SET TO UNITY IF 0
CD                          2- TOTAL DELAYED NEUTRON SOURCE USING FILE
CD                             -DLAYXS-
CD                          3- ASYMPTOTIC DELAYED NEUTRON SOURCE USING THE
CD                             FAMILY OF LONGEST HALF LIFE (ASSUMES DISTINCT
CD                             ONE APPLIES) USING FILE -DLAYXS-
CD     IX(52)          OPTION TO GENERATE A ZONE-GROUP DISTRIBUTED SOURCE
CD                          FILE -FIXSRC- USING ZONE AVERAGE FLUX FILE
CD                          -RZFLUX- (SEE OPTIONS IMMEDIATELY ABOVE)
CD     IX(61)          OPTION TO GENERATE A PSEUDO ZONE-GROUP SOURCE FILE
CD                          -FIXSRC- REQUIRED FOR A NEUTRONICS CALCULATION
CD                          OF A SENSITIVITY WEIGHTING FACTOR
CD                          1- CONVERSION (BREEDING) RATIO
C-----------------------------------------------------------------------------
C-----------------------------------------------------------------------------
CB            CLOSURE
C
CL     BLANK1, (XX(I),I=1,100), (IX(I),I=1,100)
C
C
CD     BLANK1          END OF FILE IDENTIFIER (6H      ) OR (6HBLANK )
C
C-----------------------------------------------------------------------------

CEOF
```

(CONT)

```
C*****************************************************************
C                        REVISED 11/26/74
C
CF          PERTUB
CE          PERTURBATION DATA - REGULAR AND ADJOINT FLUX INTEGRALS
C
C*****************************************************************


C-----------------------------------------------------------------
CR          FILE IDENTIFICATION
C
CL     HNAME,(HUSE(I),I=1,2),IVERS
C
CW     3*MULT+1
C
CD     HNAME                HOLLERITH FILE NAME - PERTUB - (A6)
CD     HUSE                 HOLLERITH USER IDENTIFICATION - (A6)
CD     IVERS                FILE VERSION NUMBER
CD     MULT                 DOUBLE PRECISION PARAMETER
CD                              1 - A6 WORD IS SINGLE PRECISION WORD
CD                              2 - A6 WORD IS DOUBLE PRECISION WORD
C
C-----------------------------------------------------------------


C-----------------------------------------------------------------
CR           SINGLE VALUE DATA
C
CL     BIGDAD,XK,CR,X1,NZONE,NGROUP,IND,N1,N2,N3,N4
C
CD     BIGDAD               BIG-DADDY NORMALIZATION FACTOR
CD                             INTEGRAL  ADJOINT*CHI*FORWARD*NUSIGF/K
CD     XK                   MULTIPLICATION FACTOR (K-EFF)
CD     CR                   PRIMITIVE FISSILE CONVERSION RATIO
CD     X1                   RESERVED FOR FUTURE USE
CD     NZONE                NUMBER OF GEOMETRIC ZONES
CD     NGROUP               NUMBER OF NEUTRON ENERGY GROUPS
CD     IND                  OPTION FOR INCLUDING TRANSPORT INTEGRALS
CD     N1                   FLAG ON PROBLEM TYPES -
CD                            0- MEANING NO PROBLEMS WERE SOLVED, OR THEY
CD                               WERE EIGENVALUE PROBLEMS
CD                            1  IS ADDED TO THIS IF A FIXED SOURCE FORWARD
CD                               PROBLEM WAS SOLVED
CD                            10 IS ADDED TO THIS IF A FIXED SOURCE ADJOINT
CD                               PROBLEM WAS SOLVED
C      N2                  RESERVED FOR FUTURE USE
C      N3                  RESERVED FOR FUTURE USE
C      N4                  RESERVED FOR FUTURE USE
C
CW     11
C
C-----------------------------------------------------------------
```

(CONT)

```
C-----------------------------------------------------------------------
CR          INTEGRALS FOR PRODUCTION MACRO
C
CL     ((T(M,K),M=1,NZONE),K=1,NGROUP)
C
CW     NZONE*NGROUP
C
CD     T                    FLUX(K)*CHI(KK)*ADJOINT(KK), INTEGRAI OVER KK
CD                             AND VOLUME, DIVIDED BY THE MULTIPLICATION
CD                              FACTOR, VOLUME INTEGRALS
C
C-----------------------------------------------------------------------


C-----------------------------------------------------------------------
CR         FLUX, ADJOINT VOLUME INTEGRALS
C
CL     ((S(M,KK),M=1,NZONE),KK=1,NGROUP)-----NOTE STRUCTURE BELOW-----
C
CW     NZONE*NGROUP
C
C      DO 1 K = 1,NGROUP
     1 READ(N)    *LIST AS ABOVE*
C
CD     S                    FLUX(KK)*ADJOINT(K) VOLUME INTEGRALS
CD                               (INTO GROUP K)
C
C-----------------------------------------------------------------------


C-----------------------------------------------------------------------
CR          INTEGRALS FOR TRANSPORT
C
CC          PRESENT ONLY IF IND.GT.0
C
CL     ((D(M,K),M=1,NZONE),K=1,NGROUP)
C
CW     NZONE*NGROUP
C
CD     D                    FLUX(K)*ADJOINT(K)  VOLUME INTEGRALS
C-----------------------------------------------------------------------

CEOF
```

(CONT)

```
C*********************************************************************
C                        REVISED 11/26/74
C
CF          RSTRTR
C
CE          CODE-BLOCK-DEPENDENT RESTART DATA SAVED FOR RECOVERY
C
C*********************************************************************


C- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
CR          IDENTIFICATION
C
CL    HNAME,(HUSE(I),I=1,2),IVERS
C
CW    3*MULT + 1
C
CD    HNAME                HOLLERITH FILE NAME - RSTRTR - (A6)
CD    HUSE(I)              HOLLERITH USER IDENTIFICATION(2A6)
CD    IVERS                FILE VERSION NUMBER
CD    MULT            DOUBLE PRECISION PARAMETER
CD                         1 - A6 WORD IS SINGLE WORD
CD                         2 - A6 WORD IS DOUBLE PRECISION WORD
CD                           VERSION 1 RESERVED FOR VENTURE
C
C- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -


C- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
CR          SPECIFICATIONS
C
CL    NFI1,NFI2,NFI3,N1,N2,N3,N4,N5,NR1,NR2,L2
C
CW    11
C
CD    NFI1 - NFI3          FILE IDENTIFICATION FLAGS
CD    N1 - N5              RESERVED
CD    NR1                  NUMBER OF RECORDS OF TYPE 1 DATA
CD    NR2                  NUMBER OF RECORDS OF TYPE 2 DATA
CD    L2                   LENGTH OF ALL RECORDS OF TYPE 2 DATA
C
C- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -


C- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
CR          RECORD LENGTHS OF TYPE 1 DATA
C
CL    (NWIR(J),J=1,NR1)
C
CD    NWIR(J)              NUMBER OF WORDS IN TYPE 1 DATA RECORD RECORD J
C
CW    NR1
C
C- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
```

(CONT)

```
C- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
CR          RESTART DATA RECORDS, TYPE 1
C
CL     (DARS(I),I=1,M)
C
CW     M, WHICH IS NWIR(J) FOR RECORD SEQUENCE J
C
CS     DO 1 J=1,NR1
CS   1 READ(N)        *LIST ABOVE*
C
CD     DARS(I)            CODE DEPENDENT RESTART, RECOVERY DATA ARRAY
C
C- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -


C- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
CR          RESTART DATA RECORDS, TYPE 2
C
CL     (DARS(I),I=1,L2)
C
CW     L2
C
CS     DO 2 J=1,NR2
CS   2 READ(N) *LIST ABOVE*
C
CD     DARS(I)            CODE DEPENDENT RECOVERY DATA ARRAY TYPE 2
C- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

CEOF
```

```
C*********************************************************************
C                        REVISED 11/26/74
C
CF          FISSOR
C
CE          FISSION SOURCE BY INTERVAL AND DISTRIBUTION FUNCTION
C
C*********************************************************************


C---------------------------------------------------------------------
CR          FILE IDENTIFICATION
C
CL    HNAME,(HUSE(I),I=1,2),IVERS
C
CW    1,3*MULT
C
CD    HNAME              HOLLERITH FILE NAME - FISSOR - (A6)
CD    HUSE               HOLLERITH USER IDENTIFICATION (A6)
CD    IVERS              FILE VERSION NUMBER
CD    MULT               DOUBLE PRECISION PARAMETER
CD                            1- A6 WORD IS SINGLE WORD
CD                            2- A6 WORD IS DOUBLE PRECISION WORD
C
C---------------------------------------------------------------------


C---------------------------------------------------------------------
CR          SPECIFICATIONS
C
CL    TIME, POWER, KEFF, IM, JM, KM, NCY, NG, NZ
C
CW    9
C
CD    TIME               REFERENCE REAL TIME, DAYS
CD    POWER              POWER LEVEL FOR ACTUAL NEUTRONICS PROBLEM,
CD                            WATTS THERMAL
CD    KEFF               MULTIPLICATION FACTOR
CD    IM                 NUMBER OF FIRST DIMENSION FINE INTERVALS
CD    JM                 NUMBER OF SECOND DIMENSION FINE INTERVALS
CD    KM                 NUMBER OF THIRD DIMENSION FINE INTERVALS
CD    NCY                REFERENCE COUNT (CYCLE NUMBER)
CD    NG                 NUMBER OF ENERGY GROUPS
CD    NZ                 NUMBER OF ZONES
C
C---------------------------------------------------------------------


C---------------------------------------------------------------------
C           FISSION SOURCE DISTRIBUTION FUNCTION
C
CL          ((CHIM(N,K),N=1,NZ),K=1,NG)
C
CW          NG*NZ
```

(CONT)

```
CD          CHIM(N,K)    SOURCE OF NEUTRONS IN GROUP K, ZONE N
C
C-----------------------------------------------------------------------


C-----------------------------------------------------------------------
CR          FISSION SOURCE VALUES
C
CL     ((PFS(I,J),I=1,IM),J=1,JM)------NOTE STRUCTURE BELOW-----
C
CW     IM*JM
C
CS     DO 1 K=1,KM
CS   1 READ(N) *LIST AS ABOVE*
C
C      PFS                  FISSION SOURCE BY INTERVAL, NEUTRONS/SEC/CC
C
C-----------------------------------------------------------------------

CEOF
```

```
C*C*C*C*C*C*C*C*C*C*C*C*C*C*C*C*C*C*C*C*C*C*C*C*C*C*C*C*C*C*C*C*C*C*C*C*C*C*C*C*C*C*C
C
C         THE FOLLOWING DOCUMENTS HOW A SPECIAL FILE IS WRITTEN IN BCD
C         FOR TRANSMISSION OF THE MAIN RESULTS FROM A NEUTRONCIS PROBLEM
C         TO ANOTHER INSTALLATION IN A SINGLE FILE, COMPLETE WITH THE
C         ESSENTIAL DOCUMENTING INFORMATION
C
C***************** DEFINITIONS ****************************************
C     IGOM          GEOMETRY
C     NZONE         NUMBER OF ZONES
C     NREG          NUMBER OF REGIONS
C     NZCL          NUMBER OF ZONE CLASSIFICATIONS
C     NCINTI        NUMBER OF FIRST DIMENSION COARSE MESH INTERVALS
C     NCINTJ        NUMBER OF SECOND DIMENSION COARSE MESH INTERVALS
C     NCINTK        NUMBER OF THIRD DIMENSION COARSE MESH INTERVALS
C     NINTI,IM      NUMBER OF FIRST DIMENSION FINE MESH INTERVALS
C     NINTJ,JM      NUMBER OF SECOND DIMENSION FINE MESH INTERVALS
C     NINTK,KM      NUMBER OF THIRD DIMENSION FINE MESH INTERVALS
C     IMBI          FIRST BOUNDARY INDICATOR ON FIRST DIMENSION
C     IMER          LAST BOUNDARY INDICATOR ON FIRST DIMENSION
C     JMBI          FIRST BOUNDARY INDICATOR ON SECOND DIMENSION
C     JMER          LAST BOUNDARY INDICATOR ON SECOND DIMENSION
C     KMEF          FIRST BOUNDARY INDICATOR ON THIRD DIMENSION
C     KMER          LAST BOUNDARY INDICATOR ON THIRD DIMENSION
C     NBS           NUMBER OF BUCKLING SPECIFICATIONS
C     NBCS          NUMBER OF CONSTANTS FOR EXTERNAL BOUNDARIES
C     NIBCS         NUMBER OF CONSTANTS FOR INTERNAL BOUNDARIES
C     NZBBB         NUMBER OF ZONES WHICH ARE BLACK ABSORBERS
C     NTRIAG        TRIAGONAL GEOMETRY OPTION
C     NRASS         REGION ASSIGNMENT OPTION
C     NGCP          NOT USED
C     XMESH         COARSE MESH BOUNDARIES, FIRST DIMENSION
C     YMESH         COARSE MESH BOUNDARIES, SECOND DIMENSION
C     ZMESH         COARSE MESH BOUNDARIES, THIRD DIMENSION
C     IFINTS        NUMBER OF FINE MESH INTERVALS PER COARSE MESH
C                     INTERVAL, FIRST DIMENSION
C     JFINTS        NUMBER OF FINE MESH INTERVALS PER COARSE MESH
C                     INTERVAL, SECOND DIMENSION
C     KFINTS        NUMBER OF FINE MESH INTERVALS PER COARSE MESH
C                     INTERVAL, THIRD DIMENSION
C     VOLR          REGION VOLUMES
C     BSQ           BUCKLING VALUES
C     BNDC          BOUNDARY CONSTANTS
C     BNCI          INTERNAL BLACK BOUNDARY CONSTANTS
C     NZHBB         ZONE NUMBERS WITH BLACK ABSORBER CONDITIONS
C     NZC           ZONE CLASSIFICATIONS
C     NZNR          ZONE NUMBER ASSIGNED TO EACH REGION
C     MR            REGION ASSIGNMENTS TO MESH INTERVALS
C                     IF NRASS EQ 0  COARSE MESH
C                     IF NRASS EQ 1  FINE MESH (ALWAYS THIS OPTION)
C     TIME          REFERENCE REAL TIME
C     POWER         POWER LEVEL
C     VOI           VOLUME OVER WHICH POWER WAS DETERMINED
C     NCY           REFERENCE COUNT (CYCLE NUMBER)
```

(CONT)

```
C     PWR            POWER DENSITY
C     NDIM           NUMBER OF DIMENSIONS
C     NGROUP         NUMBER OF ENERGY GROUPS
C     ITER           OUTER ITERATION NUMBER AT WHICH FLUX WAS WRITTEN
C     EFFK           EFFECTIVE MULTIPLICATION FACTOR
C     FREG           REGULAR TOTAL FLUX
C*********************************************************************
C
C*********************************************************************
C
      READ(ISAV,1001)    (TITLE(I),I=1,24)
C
C*********************************************************************
C
C     START INTERFACE GECDST
C
      READ(ISAV,1002)    IGOM,NZONE,NREG,NZCL,NCINTI,NCINTJ,NCINTK,
     *                   NINTI,NINTJ,NINTK,IMBL,IMBR,JMBT,JMBB,KMBF,
     *                   KMBB,NBS,NBCS,NIBCS,NZWBB,NTRIAG,NRASS,
     *                   (NGOP(I),I=1,5)
      NCBNDI = NCINTI + 1
      READ(ISAV,1003)    (XMESH(I),I=1,NCBNDI)
      NCBNDJ = NCINTJ + 1
      READ(ISAV,1003)    (YMESH(J),J=1,NCBNDJ)
      NCBNDK = NCINTK + 1
      READ(ISAV,1003)    (ZMESH(K),K=1,NCBNDK)
      READ(ISAV,1002)    (IFINTS(I),I=1,NCINTI)
      READ(ISAV,1002)    (JFINTS(J),J=1,NCINTJ)
      READ(ISAV,1002)    (KFINTS(K),K=1,NCINTK)
      READ(ISAV,1003)    (VOLR(L),L=1,NREG)
      READ(ISAV,1003)    (BSQ(N),N=1,NBS)
      READ(ISAV,1003)    (BNDC(N),N=1,NBCS)
      READ(ISAV,1003)    (BNCI(N),N=1,NIBCS)
      IF(NZWBB.LE.0) GO TO 100
      READ(ISAV,1002)    (NZHBB(N),N=1,NZWBB)
  100 CONTINUE
      READ(ISAV,1002)    (NZC(M),M=1,NZONE)
      READ(ISAV,1002)    (NZNR(L),L=1,NREG)
      IF(NRASS.GT.0) GO TO 101
      II = NCINTI
      JJ = NCINTJ
      KK = NCINTK
      GO TO 102
  101 CONTINUE
      II = NINTI
      JJ = NINTJ
      KK = NINTK
  102 CONTINUE
      DO 103 K=1,KK
      DO 104 J=1,JJ
      READ(ISAV,1002)    (MR(I),I=1,II)
  104 CONTINUE
  103 CONTINUE
```

(CONT)

```
C     END INTERFACE GEODST
C
C*********************************************************************
C
C     START INTERFACE PWDINT
C
      READ(ISAV,1004)    TIME,POWER,VOL,IM,JM,KM,NCY
C     IM = NINTI
C     JM = NINTJ
C     KM = NINTK
      DO 105 K=1,KM
      DO 106 J=1,JM
      READ(ISAV,1003)    (PWR(I),I=1,IM)
  106 CONTINUE
  105 CONTINUE
C
C     END INTERFACE PWDINT
C
C*********************************************************************
C
C     START INTERFACE RTFLUX
C
      READ(ISAV,1005)    NDIM,NGROUP,NINTI,NINTJ,NINTK,ITER,EFFK,POWER
      DO 107 K=1,NINTK
      DO 108 N=1,NGROUP
      DO 109 J=1,NINTJ
      READ(ISAV,1003)    (FREG(I),I=1,NINTI)
  109 CONTINUE
  108 CONTINUE
  107 CONTINUE
C
C     END INTERFACE RTFLUX
C
C*********************************************************************
C
 1001 FORMAT(12A6)
 1002 FORMAT(12I6)
 1003 FORMAT(6E12.5)
 1004 FORMAT(3E12.5,4I6)
 1005 FORMAT(6I6,2E12.5)
C
C*********************************************************************
CEND OF THE FILE
C*C*C*C*C*C*C*C*C*C*C*C*C*C*C*C*C*C*C*C*C*C*C*C*C*C*C*C*C*C*C*C*C*C*C*C*C
```

END OF SECTION 204

Section 205: Overlay of Blocks of Program

For effective use of the computer memory, groups of subroutines must be brought from auxiliary storage when needed and laid over others no longer needed in core. Shown in Fig. 205-1 is a listing of the cards which are recommended for execution on an IBM machine to provide overlay instructions to the loader. The main program resides in memory along with any subroutines (and label common) not assigned to an overlay level. Control to the lowest level must be resident for return through the calling routines without input of program. Thus the specifications identify groups of subroutines along any access sequence, control passing to level D, then level E, etc. Blocks of program assigned ("inserted" at) the same level share storage; the storage requirement for program is the sum of the maximum requirements at each level.

When the code is used as a load module or a job control procedure is used as available to the system, a suitable overlay structure is made available and need not be supplied.

FIGURE 205-1. PROGRAM OVERLAY STRUCTURE

THE FOLLOWING LISTING SHOWS THE COMMUNICATION THROUGH THE ROUTINES WITH TWO LEVELS OF OVERLAY, D AND E. IN ADDITION, THE FOLLOWING ROUTINES (AND LABEL COMMON BLOCKS) ARE IN THE ROOT SEGMENT.

MAIN,DRIV,DIFF,SKER,FERE,STOR,NRCD,LOPC,SEEK,RITE,CRIT,TIMER,DEFILE
CLOSDA

```
OVERLAY LEVELD
INSERT VENT,IONO,CORE,CORI,CORP,GNAM,COFD,CORB,DDSP,DASU
OVERLAY LEVELD
INSERT GETCOR,FREECOR
OVERLAY LEVELD
INSERT MAC1,MAC2,MAC3,MAC4,MAC5,MAC6,MACA,MACB,CHDM,SCAL
OVERLAY LEVELD
INSERT CON1,MSH0,NRCF,MSH1,CON2,CON3,CNCT,CON4,CON5,CON7,CON9,BNDY
INSERT MSH3,GEOQ
OVERLAY LEVELD
INSERT PHIA,PHI1,PHI2,PHI3,PHI4,PHI5,PHI6,FBND,PC2D,PC3D,EDBN,SDBN
OVERLAY LEVELD
INSERT CRLX,BATG,IUCK,CCN6
OVERLAY LEVELD
INSERT ADN1,ADN2,ADN3,DCID,DSDF,DIMS,AJDS,DIM1,DIM2,CMES,CHVL,DIM3
INSERT ZVRV,CHGV,ELRD,FLMH
OVERLAY LEVELD
INSERT COMC,LCAL,FLXR,FXSR,BSQV,AJNT,REV1,FBOS,ZIO3,SAV1,SAV2,SAV3
INSERT SAV4,SAV5,SAV6,SAV7
OVERLAY LEVELD
INSERT OUTR,BALC,ZINS,CHBF,CHB1,CHB2,XTBP,JUSB,ATED,FFGG,RDUE,RELX
INSERT FSOR,SSOR,PSOR,FLUX
OVERLAY LEVELE
INSERT MUEX,ETR1,ETR2,SGDA
OVERLAY LEVELE
INSERT DOIN,RRES,WRES,PREC
OVERLAY LEVELE
INSERT FOU1,SOU1,POU1,INR1,IOU1,LEK1
OVERLAY LEVELE
INSERT FOU2,SOU2,POU2,INR2,IOU2,LEK2
OVERLAY LEVELE
INSERT FOU3,SOU3,POU3,INR3,IOU3,LEK3
OVERLAY LEVELE
INSERT FOU4,SOU4,POU4,INR4,IOU4,LEK4,QDUE,QELX,SOUX,J1C4
OVERLAY LEVELE
INSERT FOU5,SOU5,POU5,INR5,IOU5,LEK5,J1C5
OVERLAY LEVELE
INSERT FOU6,SOU6,INR6,DELX
OVERLAY LEVELE
INSERT FOUX,SOUY,POUX,INRX,IOUX,LEKX,SOUZ,J1CX
OVERLAY LEVELD
INSERT EDIT,POUT,NBAL,SOBL,FISS,FLXW,ESQS,ENDN
OVERLAY LEVELD
INSERT PERT,DAFA,LIFE,PERC,MAPS,PMAP,QCUT,FIUB,TUFY,BBB1,BBB2,MRPT
ENTRY MAIN
```

END OF SECTION 205

Section 220-1: Conversion to Other Computers

The reference code is programmed for an IBM machine. We anticipate a second version of the code being made available for certain other machines, especially for the CDC-7600. This discussion addresses aspects of the programming which must receive attention in converting between machines. Comment lines within the source deck identify specific problem areas.

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

The following are basic changes required for a long-word machine:

1. Remove all REAL*8 statements.
2. Supply single precision library functions, e.g., SQRT and EXP instead of DSQRT and DEXP.
3. Change all references to "Double Precision," as in function definition statements.
4. Change LX(39) to 1 from 2.
5. Change the apostrophes which delimit alphanumeric strings in FORMAT and DATA statements.

6. 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

7. Satisfy the data access requirements including the dynamic opening of the files with parameters which are problem dependent.
8. Provide local capability to allocate memory dynamically, or fix the container array allocation and communication of it.
9. Provide the necessary overlay structure.
10. Correct any discrepancies missed by the IBM compiler (and please report this information back to us).

Local system routines would be needed to satisfy items 6, 7, and 8 above on an IBM machine.

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 should be carried on disk. Some of the data is used frequently, so it needs to be carried in even a small memory; suggestions for partitioning the data are given in the source program on comment lines.

END OF SECTION

Section 225: The Data Handling Strategy

Utilization of a specific computer facility can be improved by carefully tailoring the procedure of calculation. Of critical importance in solving large problems are the details of transferring data to and from memory using auxiliary storage within any hierarchy. The available fast memory and slow memory must be allocated carefully, and judicious choices must be made between alternatives in blocking the data and transferring it between the individual storage devices. Modifications to the procedures employed in this code may be found desirable. However, the capability of a particular facility in regard to rates of data transfer and storage capacity must be well understood as well as the strategy employed in this code if a modification is to produce improvement. A description is given in this section of the strategy used in handling data.

Consider an internal point for one energy group in a three-dimensional multigroup problem. It is located on a row of points, several of these rows make up a plane of points, and the third dimension involves a series of planes. The points are carefully arranged so that in the usual orthogonal coordinate systems, each internal point has six nearest neighbors, two on the row, two on a column in the plane, and two in the adjacent planes. Space coupling yields equation constants relating the flux at the reference point with values at nearest neighbor locations. Given the pointwise fission and inscattering source values, and removal terms for absorption and outscattering, this space problem is partially resolved by inner iteration, recalculation of the individual flux values by applying the equations repeatedly over the mesh in an ordered fashion.

During each outer iteration the fission source is recalculated, and for the space problem at each energy group the scattering source is recalculated. Thus, at any space point location, fission or scattering at any energy may produce a source at any other energy. A full scattering matrix is allowed which permits scattering from any group to any other group; however, often there is only downscatter. Thus, the calculation proceeds from the highest energy downward. Source neutrons may be produced by fission at any energy, but these are summed to give a single

space array of the total fission source with distribution of this into the individual groups.

In one of the modes of data handling, the flux values are stored on a direct access device in successive blocks for each energy group, with the values for each plane in an individual direct access record. Thus, the data is carried in the order desired and in blocks as needed for the inner iteration process at one energy. Then for the source calculation, they may be accessed one plane at a time over energy groups by skipping down through the file. The individual records may be accessed directly with a single repositioning of the disk head using the capability of the operating system to account for where the records are located. Upon reading or writing flux values, they are processed sequentially when possible to minimize the amount of disk head movement.

With one of the calculational procedures, one plane of flux data must be transferred into memory and the next operation involves writing out another plane of newly calculated flux data, not on adjacent planes. To realize efficient data handling, the last iterate and the present iterate flux values are carried in different files. This permits sequential reading and writing. A third file is also carred because the outer iteration acceleration schemes need three successive iterate sets of the fluxes, and the calculation proceeds by alternating between the three direct access flux files.

The equation constants for space coupling and total loss are stored on disc as needed when initially calculated from nuclide concentrations and microscopic cross sections. This is a direct access file which permits efficient access of the data during iteration with the particular scheme mode of data handling selected.

The macroscopic scattering cross sections are blocked for all compositions and energy groups by inscattering group. Thus, the inscattering source calculation is done by sequential processing of this data, one read for each energy group each outer iteration.

The primary data handling modes in the code are described below in the order of increasing amount of data transfer required.

All Stored Mode

For small problems, all the equation constants, one set of flux values and the necessary source values are stored in the computer memory. The calculation proceeds with very little data transfer.

Space Stored Mode

For problems of moderate size, the equation constants, the flux values and the necessary source values are stored in the computer memory for the space problem at one energy. Inner iteration is done with minimum data transfer, but reading the scattering data and flux values is required for the source calculation.

Multi-row Stored Mode

For two-dimensional calculations, in this mode the space problem at one energy is further partitioned to reduce the memory requirement. Data for several rows of fluxes are stored and inner iteration proceeds with the minimum amount of data transfer for a given problem using the avaialbe memory. This mode of data handling is a subset of that described in more detail below.

Multi-plane Stored Mode and Multi-Level Data Transfer Mode

In these modes data for several planes of a three-dimensional problem are stored in fast memory or slow memory. Consider the array of mesh points normal to rows for an arbitrary number of columns and planes:

Column	1	2	3	4	5
Plane					
1	.	.	.	.	.
2	.	.	.	.	.
3	.	.	.	.	.
4	.	.	.	.	.
5	.	.	.	.	.
6	.	.	.	.	.

Each dot represents a row of points for which new inner iteration iterate estimates of the flux values will be obtained simultaneously. The calculation proceeds in such a way that the latest values are always used in the calculation. That is, using the first subscript to refer to column and the second to plane, after fluxes for row $a_{1,1}$ are obtained, fluxes for rows $a_{1,2}$ and $a_{2,1}$ may be calculated. Considering that the calculation proceeds in order across the columns on each plane using the latest values of the fluxes obtained for the plane above and the column to the left, the process may be described as follows:

Plane	Iteration
1	1
2	1
1	2
3	1
2	2
1	3
4	1
3	2
2	3
1	4

The procedure is as follows after it develops to the stage where n planes of data are stored:

Plane	Iteration
m	1
m-1	2
m-2	3
m-3	4
.	.
.	.
.	.
m-n-1	n-2
m-n	n-1
m-n+1	n

Completion of the procedure is as follows, where M is the total number of planes:

Plane	Iteration
:	:
M	n-3
M-1	n-2
M-2	n-1
M-3	n
M	n-2
M-1	n-1
M-2	n
M	n-1
M-1	n
M	n

Storing the equation constants and source values for n planes and the flux values for n+2 planes, n inner iterations are done each full sweep with one access of equation constants, one access of old flux values, and one transfer of new flux values for each plane of the problem. If more inner iterations are done than the available storage allows in one sweep, the process is repeated. The amount of data transfer is minimized relative to computation for that problem which is too large to be handled in the more efficient modes above. Equation constants and also flux values are each separately blocked into one record for each plane.

In the "multi-level data transfer" mode, data is moved from slow memory into fast memory in small blocks as needed.

One Row Stored Mode

To handle the largest possible problem in the minimum amount of memory, and yet solve for new values of the fluxes along a row, this mode of data handling treats only one row at a time. It applies only to the three-dimensional problem (the space stored mode satisfies one-dimensional problem requirements and the multi-row stored mode satisfies two-dimensional problem requirements). Data is stored to calculate one row of fluxes at a time and the required flux values for five rows is stored. Calculations

on local computers in this mode show it to be very inefficient in total time and have an extreme data input/output penalty.

Input/Output Operations

The number of data Input/Output operations is approximated for three-dimensional problems by the following equation:

Let I = the average number of inner iterations in each group,

L = the number of planes treated simultaneously $\leq I$,

N = the number of outer iterations,

G = the number of groups,

B = the average actual scattering bandwidth in groups,

P = the number of planes,

R = the number of rows,

Θ = the number of data Input/Output operations, disc-memory;

$$\Theta \simeq AG\left(500 + (N+2)\begin{cases} [2] & \text{, all stored mode} \\ [8+B] & \text{space stored} \\ 4 + P[4(\frac{I+1}{L}) + B] & \text{multiplane stored} \\ 4 + PR[4I + 4 + B] & \text{one row stored} \end{cases}\right)$$

Where A is the average physical block size of the records, 1 for small problems but increasing with problem size. There is a direct dependence on the scattering band width not shown and Chebyshev acceleration adds 4 inside the square brackets. Typically $N \simeq 3PR/I$.

Our attempts to seek near optimum selection of the mode of data handling as dependent on problem size and local charging algorithms have not been successful. Generally at ORNL, it pays to use a large amount of memory to minimize data input/output provided job turnaround is satisfactory.

END OF SECTION

Application Information

In the following sections, application information is supplied which is directed to the needs of the program user. He is referred to the introductory section of this report for a broad coverage of the function of this neutronics code block, and to the later sections for the calculation algorithms. A user flow chart is presented in Figure 001-1 on page 001-3. Specific program considerations are given in Section 401. The discussion (disclaimer) on input data is in 403, error checking is covered in 405, and restart and recovery in Section 410. Section 440 addresses edited results and 450 the selected sample problems.

Section 401: Program Considerations

Application of this code will generally be more reliable the more intimately familiar the user is with its contents. In this section, certain specific aspects are addressed.

1) Major program options are covered in Section 204. Generally, these provide unique functions with minimum interaction. Automated selection between procedures is provided as default, but reasonable care must be taken to obtain desired edits without excess and to control generation of interface data files.

2) There are few constraints on the range of values of the variables:

   a) Data used together can not vary by more than perhaps $10^{\pm 6}$ and carry significance (atom density times cross section for the contributions to a macroscopic cross section from two nuclides),

   b) Data outside of $10^{\pm 40}$ can be expected to produce chaos (power level for example), and

   c) Large step changes in the mesh spacing, say by a factor of 100, may cause difficulty in converging the iterative procedure to effect an acceptable solution.

3) All major data arrays are variably dimensioned and storage allocation done dynamically. Problems have been solved which contained over 1000 points on a line and over 100 energy groups have been treated.

4) The larger the problem measured in terms of space-energy points, the more storage required or the more data which must be moved from auxiliary storage during the calculation. Several data handling modes are provided by parallel coding which require increasingly less core space and more data handling. Automatic selection of the mode of data handling is done to effect efficient computer use. Actual storage requirements are a complicated function of the variables (the nature of the problem and its size) and the mode of data handling; these requirements are edited each execution to provide

information which may be collected as background by a user for reference.

5) The constants to which values are assigned within the code are generally limited to those covered by equations in the 700 series of Sections. Of course constants like pi are assigned values to machine significance.

6) It is assumed that dimensions are in centimeters, nuclide concentrations are in atoms/barn-cm, and microscopic cross sections are in barns/atom. Quite generally the product of nuclide concentration and microscopic cross section must yield a macroscopic value having units of cm^{-1} for consistency.

7) Man-machine interaction during execution is not allowed.

8) No special forms of output are available, just printed pages, and a large stack of paper will be produced for a large problem if many of the edit options are exercised.

9) The programming has been done in a way to avoid underflows, overflows, and divide by zero. We recommend that the operating systems be allowed to detect such occurences and terminate a calculation. Should such an event occur, the cause should be traced by study of the program and rectified; it is probably due to inadequate data or possibly inconsistent instructions.

END OF SECTION

Section 403: Input Data

The VENTURE code block does not read data from cards. All data for a calculation must be provided through the standard interface files and the special interface file CONTRL described in Section 204.

To supply the required interfacing data, a separate data processor must be used. The agreement reached in the code coordination effort was that all input data would be processed by a standard free-form input data processor. Although the LASL standard input processor[a] is in service at ORNL, it is yet under development, so four special input porcessors have been implemented and are in use locally and are included with this first issue of the VENTURE code package. Appendix C describes how these special input processors are used under the local driver. A separate document acompanying this code describes the punched card input required by these processors. Alternatively, the standard input processor can be used to generate the required interface files from cards including the file named CONTRL. The special input file required for general use of the associated code block for processing microscopic cross section files can not be generated by known versions of the standard input data processor.

---

[a] J. C. Vigil, et.al., "Service Modules for Version II Standard Interface Data Files," USAEC report, Los Alamos Scientific Laboratory, LA-5367-MS (1973) (Upgraded to Version III.)

END OF SECTION

Section 405: Error Checking

An error discovered in the process of calculation is normally fatal and its cause is identified by an error message. Also, certain warning messages are printed, as to indicate lack of convergence if the maximum number of iterations or the allowed time is exceeded.

The fatal errors are of three types: those encountered in processing standard interface data files (error number 666), other interpreted errors (error number 555), and system detected errors. Hopefully the information printed will adquately describe the cause and corrective action can be taken.

For arithmetic operations where necessary, checks are made for overflows, underflows, and divide by zero. In a normal run, these types of errors should not occur; if one does occur, it is deemed fatal, and the cause should be traced and corrective action taken.

END OF SECTION

Section 407-1 Implied Capability and Limited Implementation

The interface data files used by the VENTURE code are those drawn up in an inter-installation effort. We have attempted to keep the coding up to date with the specifications through the period when these were being modified to satisfy requirements. We believe this implementation is a reasonable one in that the records are properly read and written, at least compatible with the locally implemented input data processor. Still certain of these specifications imply capability which is rather general and only a sub-set of possible alternatives has been implemented. This section addresses this subject to identify what is actually avail-ble for application. The qualifications are given for each of the files for which restrictions apply.

Files ISOTXS and GRUPXS

The fission-source data by nuclide may be in the form of $\nu\sigma_f(g) \cdot \chi\ (g \rightarrow g')$. The macroscopic data is recast into the separable form $\nu\Sigma_f(g)$, $\chi(g)$ without carrying the full group to group dependence. Both the production term ($\nu\Sigma_f$) and the distribution function (χ) are made zone dependent.

Only simple blocking of the scattering data is assumed, not certain possibilities which could lead to only partially filled data blocks.

In applying the P_l data it is assumed that the Legendre coefficient $2n + 1$ is contained in the data and is not multiplied in anywhere along the process of calculation.

File GEODST

At the time this is written, 30° and 90° triangular and (Θ-R-α) geometries have not implemented; we expect that a later release version will treat these. The user is cautioned to refer to the figures in Section 702 for actual orientations implemented; no other options are available. Thus hexagonal geometry is treated as shown in the figure with the X and Y coordinates at 60° and limitations of the implementation usually require full core treatment when hexagonal assemblies are involved because usual symmetry conditions can bet be readily represented accurately.

The repeating (periodic) boundary with the opposite face is allowed only for the first boundary condition (IMBL), no others. The rotational symmetry condition (repeating, periodic, with the next adjacent face or along the face is allowed only for the right boundary of the first dimension (IMBR) causing the point of rotation to be remote from the origin. No option which causes the geometry to be reduced to a triangle has been implemented; a triangular flux array would impact many of the interfacing data files, and a resolution of the difficulty has not been addressed. To blank out a volume of a problem, a material can be assigned to it along with the internal black absorber condition which applies the non-return boundary condition at the internal surfaces of this material.

File Search

The direct criticality search procedure is implemented for NMAXNP = 0. In this calculation, changes in macroscopic scattering and transport properties are ignored causing the result obtained to have some degree of uncertainty, unless NRCH (1) is made >0 to cause these to be updated periodically at a computation cost penalty. If NRCH (2) is >0, a secondary search will be done when constraints are not satisfied unless overridden by IX (11) in the DTNINS record in the CONTRL file; it is possible for the data to present a never-ending calculation, so care must be exercised in specifying more than one set of search data, the instructions for use, and the constraints for acceptable solutions.

END OF SECTION

Section 410: Restart and Recovery Procedures

A simple scheme is used to save the data required and to access it for restart of a neutronics calculation. On user request, a restart data file (RSTRTR described in Section 204) is generated periodically and also after a successful exit is made from the iteration procedure. Thus continuation is allowed only from some well-defined state of the calculation. This successful exit can occur only if 1) the convergence criteria specified are satisfied, 2) the limiting number of outer iterations is reached, or 3) the permitted machine central processor time or allowed total (clock) time is exceeded. The data is saved periodically on a cycle of processor time specified in the CONTRL file input data.

The restart procedure is designed to effect the continuation of the iterative process terminated at some point in a previous computer run. The general procedure consists of recalculation of cross sections and equation constants from the data in the normal user input for the new computer run. Then the data saved from the prior run is accessed and the calculation continued. Certain initialization procedures are bypassed, as of the flux and the overrelaxation coefficients. Some changes in the input data are allowed, some will be ignored, and others will cause abort; generally, no change is admissible which would cause changes in the locations of data in memory.

The data saved for restart consists of one iterate set of flux values and the principal data used in the iterative procedure. This data is sufficient for continuing the iterative procedure, but not always sufficient to duplicate the process; acceleration schemes requiring more than one iterate flux set will establish only after the necessary information has been accumulated.

For a usual restart, the following are necessary (see file CONTRL in Section 204):

1. The special restart data file must be available from a previous computer run (normally on tape for short-term storage).

2. Restart must be specified in the user input control data.
3. The number of outer iterations will often have to be increased to allow the desired convergence level to be satisfied.
4. Complete data file requirements must be satisfied normally requiring a full user input data deck (the same as for the original run), except that when such interface data files as GRUPXS have been generated and saved by other code blocks, they, of course, need not be regenerated.

Input data which can not be changed because the data storage locations would be altered include the following; note that the saved iterate flux values will be used for the restart case:

1. Number of dimensions and energy groups.
2. Number of mesh points along each coordinate and the number of material composition zones.
3. The mode of data handling during the iterative process, and normally the number of inner iterations which alters the use of data storage.
4. Basic problem type should not be changed (as from P_1 to P_0, eigenvalue problem to search or adjoint or fixed source).

Generally the previous procedure will be continued. Thus, the overrelaxation coefficients will be saved and used. However, such basic control options as of use or not of Chebyshev acceleration on outer iterations may be changed.

Although it might be better to start the problem over, the following are allowed changes for restart:

1. Nuclide assignments and concentrations.
2. Microscopic cross section.
3. The geometry (if both are orthogonal, not if one is hexagonal or triagonal).

4. Boundary conditions excluding any change in the assignment of internal black absorber points.

5. The meshpoint spacing and the assignment of points to regions and regions to zones.

Thus if a modest change is desired in any of the above data, it may be made.

Note also that any problem may be started from an existing data file of the flux values, RTFLUX, provided that the data in this file maps properly in space and energy. Remapping in space is allowed; it is assumed that a regular expansion of the mesh points was done and a simple linear interpolation of flux values is made. This allows a many-point problem to be initialized from a coarse solution.

END OF SECTION

Section 440: Edited Results

This is a general discussion about the information edited which documents each calculation done by an access of the code block. This discussion is ordered in the way results appear in the output. Brief, descriptive headings identify output results. Major edits are under control of the user.

Problem Details

Certain details of the problem description are contained in the interface data files and are not edited by this code block. The documenting edits would be done when these interface files are generated with user input or if a listing is made of the file contents.

Some of this information includes:

1. The geometric description including the locations of mesh points and material interfaces and zone volumes.
2. Boundary conditions.
3. Nuclide concentrations and associations with cross section data.
4. Microscopic cross sections.
5. Criticality search specifications.

Preparatory Information

The following information may be produced before the actual neutronics problem is addressed:

1. Assessment of storage requirements.
2. Selected mode of data handling.
3. Macroscopic cross sections on option.
4. Certain problem documenting information.
5. The type of neutronics problem and information about the method of solution.

Iterative Results

Each outer iteration, information is extracted about the iterative process and may be edited:

1. The calculation mode.
2. Assessment of inner iteration convergence.
3. Assessment of outer iteration convergence.
4. The maximum relative flux change from one outer iteration to the next.
5. Estimates of the eigenvalue of the outer iteration error vector which dominates asymptotically.
6. Outer iteration acceleration factors.
7. Actual eigenvalue used in the calculation.
8. Estimate of the eigenvalue of the problem (the multiplication factor or the search problem eigenvalue or the rebalancing factor for fixed source problems), generally determined from an overall neutron balance.

In addition, information about the inner iteration behavior may be obtained as a higher level of edit.

Summary

Upon termination of the neutronics calculation, a summary of the results is edited:

1. Number of outer iterations done.
2. The terminal calculation mode.
3. Terminal maximum relative flux change.
4. Estimate of the eigenvalue of the outer iteration error vector which dominates asymptotically.
5. Information about acceleration parameters.
6. The eigenvalue of the problem, often the multiplication factor.

7. Reliability estimates of the multiplication factor.
8. Power level normalization.
9. Fraction neutron loss to the search parameter for certain criticality search problems.
10. Gross neutron balance (external leakage, losses, production source).

Results from the Calculation

Edits of the following are available to the analyst:

1. Neutron balance data by energy group and zone.[a]
2. Gross neutron balance data by energy group.
3. Point neutron flux values.
4. Peak power density.
5. Power density map over space.
6. Power density traverses through the peak.
7. Neutron density map over space (given group velocity data).
8. Neutron density traverses through the peak.
9. Adjoint neutron flux values when calculated.
10. Calculated axial buckling values by traversed zone and group when requested on one or two planes.
11. Certain perturbation information given solutions for both a regular problem and an adjoint problem (neutron lifetime given group velocity data) at the macroscopic cross section level (microscopic data is not reaccessed).

Other Results

Other results may be produced by other modules in the system, such as integrated reaction rates and interpretation (as in a fuel conversion ratio calculation) by the reaction rate module.

[a]An estimate of the primitive conversion ratio is also available when the fissile and fertile nuclides are identified.

END OF SECTION

Section 450-1: Sample Problems

A separate report is to be issued covering a number of sample problems since a few are inadequate to check conversion to another computer type than used in the development.

Three sample problems are presented here. The first two were taken from the set of problems for which reliable answers are known and were reported in ORNL-TM-3793, "Job Stream of Cases for the Computer Code CITATION." Thus, the descriptions for these problems in the form of input data for this older code are available as well as the results. A third problem involves both a nuclide search and a dimension search for a fast reactor.

Table 450-1 shows a list of the input for these problems as three "stacked" cases. The input data are processed by the LASL standard input processor.[a] Table 450-2 displays input data for two of the cases in the form required by the special processors.

Table 450-3 displays selected printout from the computer run. Since this code is under continuous development, the output shown may not agree one-to-one with numbers produced by the code as issued. However, the end results should be in very close agreement.

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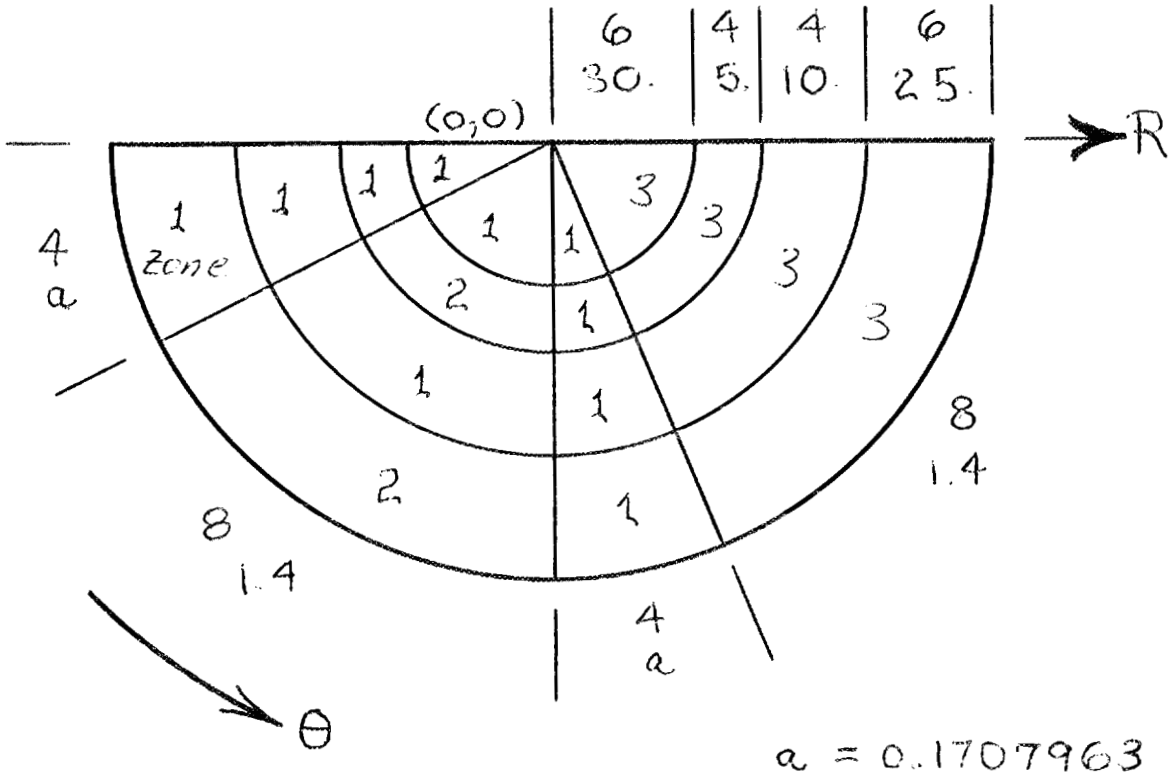
[a]Ibid., p. 403-1.

VENTURE Sample Problem 1

"Periodic Boundary in Theta-R Geometry, Case A4 with Black Absorber
24X20X3 Group, 1440 Points Stream of CITATION Cases ORNL 72"

This is an eigenvalue problem in ΘR geometry which is a 180° segment. Due to symmetry conditions, the problem can be solved with reflecting boundaries by reorientation (see Case A1 in the reference report). As oriented, the repeating, periodic boundary condition is required to account for net leakage across the surface, testing this below. Along coordinates, the number of internal mesh intervals is shown for each coarse interval and the spacing in centimeters.



COARSE MESH SKETCH OF VENTURE SAMPLE PROBLEM 1.

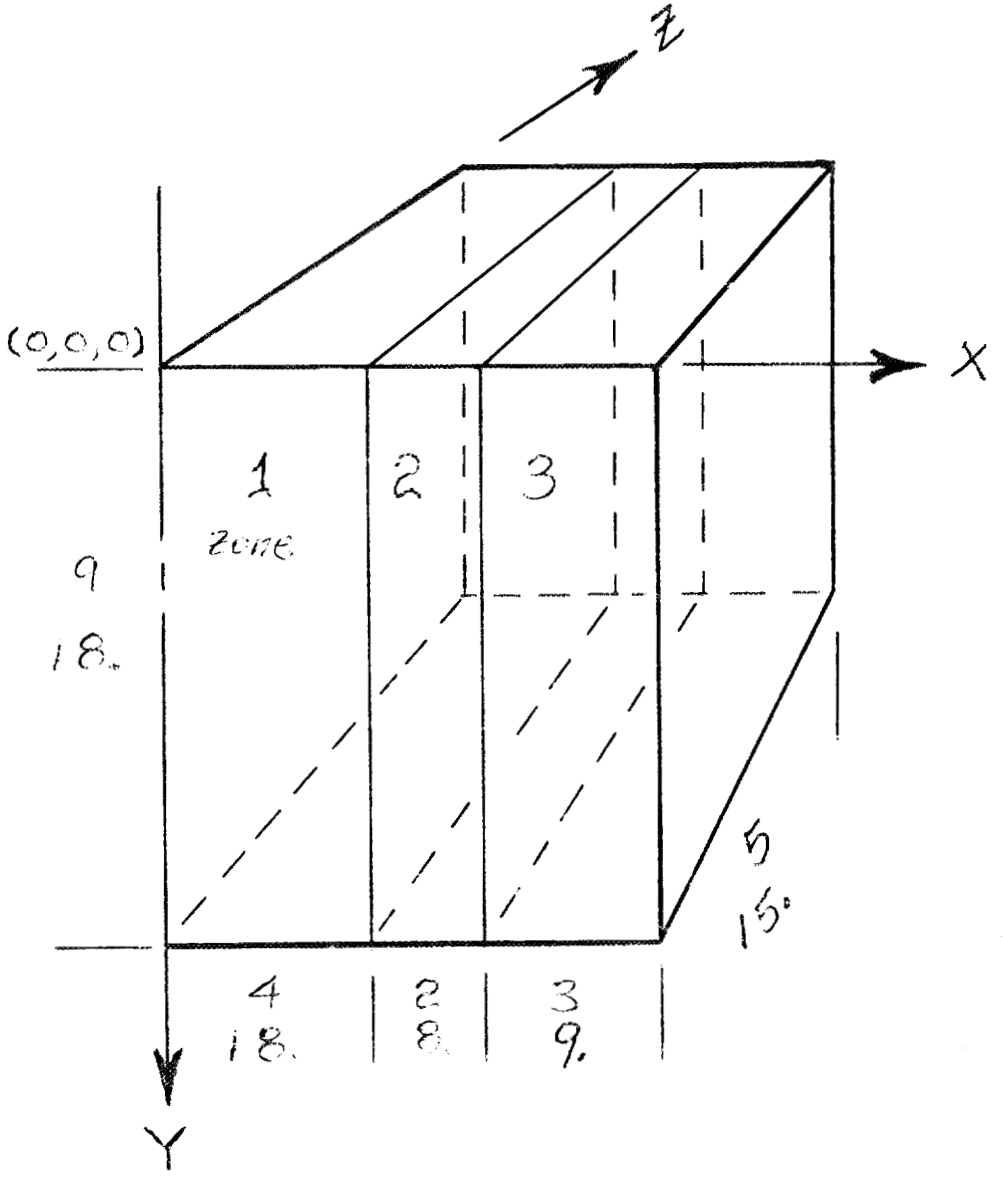
Note that the macroscopic cross sections are provided in pseudo microscopic form to generate an ISOTXS cross-section file. The normal neutron flux eigenvalue problem was solved and then the adjoint problem using k_{eff} from the normal problem. The problem was solved with all data stored in the computer memory which minimizes input/output of data between memory and disc.

VENTURE Sample Problem 2.

"3-D (X,Y,Z) Buckling Search (Old Whirlaway Case)

9x9x5x2 Group, 810 Points Stream of CITATION Cases ORNL 72"

This problem treats one-quarter of a reactor and involves three zones of different compositions. Again macroscopic cross sections are presented as pseudo microscopic, but here in the group-ordered file GRUPXS requiring no processing prior to use in the VENTURE code block. The problem is artificial in that the solution requested is the eigenvalue of a buckling search, not usually directly applicable to a three-dimensional problem. However there is simply a neutron loss rate equal to $DB_{\underline{1}}^2$ over the problem. The eignevalue problem was solved in the multiplane stored mode of data handling and also the following adjoint problem. Perturbation calculations are also done and space point importance maps are printed.

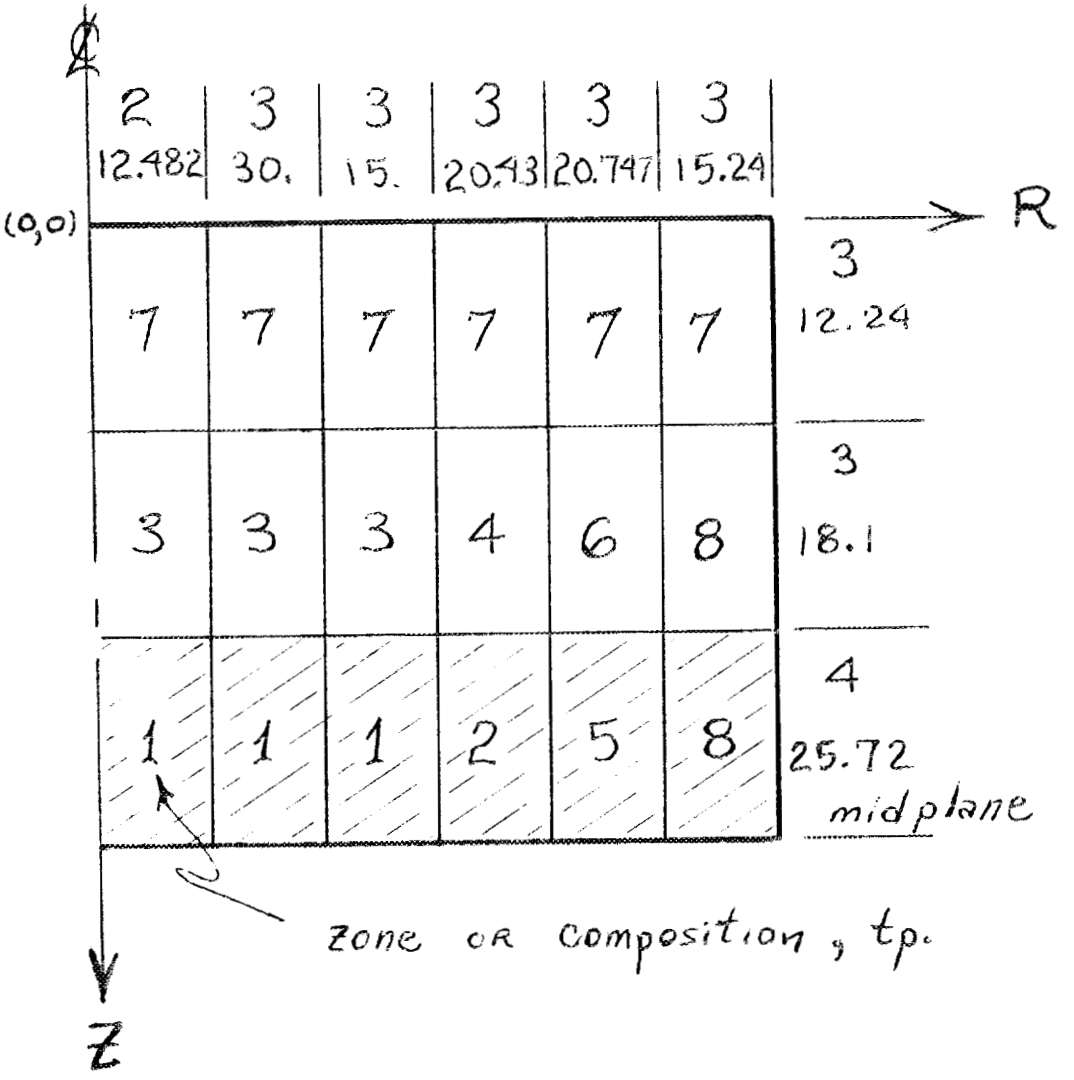


COARSE MESH SKETCH OF VENTURE SAMPLE PROBLEM 2.

VENTURE Sample Problem 3.

"2-D 17 x 10 - 5 GROUP SEARCH PROBLEM
PRIMARY SEARCH = NUCLIDE (DIRECT) - SECONDARY SEARCH = DIMENSION"

This problem treats two-dimensional (R,Z) geometry. The input instructions for the problem first instruct the code to do a direct nuclide criticality search for a multiplication factor of 1.01 by adding a mixture of heavy metal (^{238}U, ^{239}Pu, ^{240}Pu). The solution is found to be 197% addition of material, exceeding the amount of material allowed to attain the desired multiplication factor. The input instructions further specify that all of the available material (100%) should be added and that a secondary search be done to attain the desired state. This second search is a dimension search in which the widths and heights of specific course mesh intervals, the shaded area shown in the sketch below, are to be adjusted. The requirements for the desired state are determined and the adjoint problem is solved and perturbation calculation done. In addition, nuclide reaction rates are produced and printed. The geometric description of the problem is shown below.



COARSE MESH SKETCH OF VENTURE SAMPLE PROBLEM 3.

TABLE 450-1. INPUT FOR SAMPLE PROBLEMS IN THE LASL STANDARD INPUT PROCESSOR FORMAT.

```
//UIDXYZZZ JOB (CHARG,,,99,9000,,1),'ADRES,NAME COL 38-57',CLASS=Y,
// TYPRUN=HOLD,
// MSGLEVEL=(1,1)
/*ROUTE  PRINT LOCAL
//STEP EXEC VENTUREX,
// NB1=1,NB2=1,B1=3520,B2=15360,NX=2,NS=50,N1=100,
// N2=4,N3=13,N4=1,N5=6,N6=10,N7=1,N8=1,N9=2,N10=2,N11=3,N12=5,N13=2,
// N14=1,N15=10,
// PARM.FORT='NODECK,NOLIST,SOURCE,XREF,MAP',
// REGION.GO=310K
//FORT.SYSIN DD *
/*
//LKED.BVDRIVER DD UNIT=2314,VOLUME=SER=ZX2222,DISP=SHR,
// DSNAME=TBF.BOLD.VENTURE.DRIVER
//LKED.SYSIN DD *
 INCLUDE BVDRIVER
/*
//GO.XXXXXXXX DD UNIT=2314,VOL=SER=ZX2222,DISP=SHR,
// DSNAME=TBF.BOLD.VENTURE
//GO.FT99F001 DD *
*****************BOLD VENTURE RUN - SAMPLE PROBLEMS******************
015000                    3                                        1
  1  6  7  1  7  1  6  7  9  0
OV CONTRL
1D PROINS  /
* PERIODIC BOUNDARY IN THETA-R GEOMETRY, CASE A4 WITH BLACK ABSORBER   *
* 24X20X3 GROUP, 1440 POINTS  FWRD. + ADJ.                             *
*GWCRUN* *GWCRUN*  0.0 74R 0 100R
1D DVRINS  0.0 100R  15000  0  99R
1D XCPINS  0.0 100R  0 0 0 1 0 18R  1 1  0 76R
1D DTNINS  0.0 3R  1.0 3R  0.0 1.6 0.0 0.0 1.0-6 1.0-5  0.0 88R
   0 3R 1 0 1 0 13R 50 0 8R 1 1 1 1 1 0 67R
1D *      *  0.0 100R 0 100R
OV ISOTXS
1D  3  3  0  1  0  1  1  1
2D  /
*CITATION MACROS TO MICROS                                             *
*ZONE1* *ZONE2* *ZONE3*  0.6 0.4 0.0  0.0 3R 0.0 4R  0 3 6
4D (*ZONE1*) 3R  0.0 1.0 0.0 4R 0 1 1 0 5R 1 1 0
  0  1  1 2 2  1 1 1
5D  1.987677-1  3.833180-1  9.962149-1  0.0 3R
    0.0  2.864-2  1.132-1   0.0  8.0-14 1.0-12
    0.0  9.4375+10  1.088+11  0.6  0.4  0.0
7D  0.0  0.0  4.378-2  0.0  4.295-2
4D (*ZONE2*)  3R  0.0 6R 0 8R  1  1  0
  0  1  1 2 2  1 1 1
5D  1.8205-1  2.745745-1  3.333333-1  0.0 3R
    1.3-2  8.0-3  0.0
7D  0.0  0.0  4.3-3  0.0  2.5-3
4D (*ZONE3*) 3R  0.0 6R  0 8R 1 1 0
  0  1  1 2 2  1 1 1
```

(CONT)

```
5D  2.438430-1  3.261580-1  5.048977-1  0.0 3R
    0.0  2.9-3  7.16-3
7D  0.0  0.0  2.016-2  0.0  1.392-2
OV GEODST
1D /
  8  3 16  1  4  4  1 24 20  1  3  3  1  2  1  1  /
  1  6  3  1  0  1  0 5R  /
3D /
          0.0  1.707963-1     1.570796     1.741593     3.141593
          0.0   30.0  35.0  45.0  70.0
  4  8  4  8  /
  6  4  4  6  /
5D  /
  7.685832+1        6.3+2  7.685832+1        6.3+2  2.775439+1      2.275+2
  2.775439+1      2.275+2  6.831851+1        5.6+2  6.831851+1        5.6+2
  2.455197+2     2.0125+3  2.455197+2     2.0125+3
       1.C-3 /
  0.0 3R 0.4692  0.0 2R   0.0 2R  0.4692 /
  2       1 1 1 /
  1 4R  2  1  2  1 5R  3  4R
7D  /
 (1 4R  2 8R  3 4R  4 8R) 6R  /
 (5 4R  6 8R  7 4R  8 8R) 4R  /
 (9 4R 10 8R 11 4R 12 8R) 4R  /
(13 4R 14 8R 15 4R 16 8R) 6R  /
OV NDXSRF
1D /
  3  1  3  3  3  0
2D /
  (*ZONE1* *ZONE2* *ZONE3*) 2R  0.0 6R  0  3R  3  0  0  C
  (1 2 3) 2R
3D /
  3.125352+3  5.550879+1  4.516035+3  1.0 3R  1 3R
OV ZNATDN
1D /
  0.0  0  3  3  1
2D /
  1.0 0.0 0.0 0.0 1.0 0.0 0.0 0.0 1.0
    STOP
ENDINPUT
OV CONTRL
1D PROINS /
* 3-D (X,Y,Z) BUCKLING SEARCH (OLD WHIRLAWAY CASE) - 9X9X5X2            *
* RUNNING IN THE PLANE STORED MODE - 4 PLANES STORED                     *
*      * *      *  0.0 74R  0 100R
1D DVRINS  0.0 100R  5000  0 99R
1D XCPINS  0.0 100R  0 23R  1  C 76R
1D DTNINS  0.0  1.0  0.0  10.0  1.0 2R  0.09  0.0 3R  1.C-6  1.0-5
  0.0 88R
  0 3R  1  4  1  0 13R  50  0 8R  1 5R  0  1  0  1 6R  0 2R 5 1 1 0 3R
  1  0  1  1  0 2R  0  1  2  0  2  4  0 38R
1D *      *  0.0 100R  0 100R
OV GRUPXS
1D /
```

(CONT)

```
  2  3  0  1  0  1  18  0  0  0  1  1  0  0
2D /
* GRUPXS CROSS SECTIONS FOR VENTURE SAMPLE PROBLEM                    *
  (*ZONE1* *ZONE2* *ZONE3*)
  1.0  0.0  0.0 2R  0.0 3R
4D /
  (*       *) 3R  (*CITNXS*) 3R  (*       *) 3R /
  0.0 3R  6.25-11 2.5-11 0.0  0.0 3R  0.0 3R  0.0 3R  0.0 3R  0.0 3R /
  0 3R  0  1  1 2R  0  0 7R
5D /
  2.222222-1  1.960784-1  2.777778-1 /
  0.0 3R /
  4.0-4  5.0-4  5.2-4 /
  8.0-4  2.0-4  0.0 /
  5.0  2.0  0.0/
  1.0 2R  0.0 /
5D /
  2.777778-1  2.949854-1  3.831418-1 /
  0.0 3R /
  1.55-3  3.8-3  8.0-3 /
  3.15-3  2.5-3  0.0 /
  20.0  10.0  0.0 /
  0.0 3R
7D /
  1 3R  1 3R
8D /
  0.0 3R
7D /
  2 3R  1 3R
8D /
  0.0  3.3-3  0.0  5.2-3  0.0  6.7-3
0V GEODST
1D /
  14  3  3  1  3  1  1  9  9  5  1  0  0  1  0  0  1  6  1  0  0  1
  0 5R /
4D /
  0.0  8.0  16.0  25.0
  0.0  18.0
  0.0  15.0
  4  2  3 /
  9 /
  5 /
5D /
  2160.0  2160.0  2430.0 /
  0.0109045 /
  0.0  1.0+30  1.0+30  0.0  1.0+30  1.0+30 /
  0.4692 /
  1 3R /
  1  2  3 /
7D /
 (1 4R  2 2R  3 3R) 9R /
7D /
 (1 4R  2 2R  3 3R) 9R /
7D /
```

(CONT)

```
 (1 4R  2 2R  3 3R) 9R /
7D /
 (1 4R  2 2R  3 3R) 9R /
7D /
 (1 4R  2 2R  3 3R) 9R /
OV NDXSRF
1D /
  3  1  3  3  3  0
2D /
  (*ZONE1* *ZONE2* *ZONE3*) 2R  0.0 6R  0 3R  3  0  0  0
  (1  2  3) 2R
3D /
  2160.0  2160.0  2430.0 /
  1.0  1.0  1.0 /
  1  1  1
OV ZNATDN
1D /
  0.0  0  3  3  1
2D /
  1.0  0.0 2R /
  0.0  1.0  0.0 /
  0.0  0.0  1.0
STOP
ENDINPUT
 OV CONTRI
1D PROINS /
* 2-D  17X10 - 5 GROUP SEARCH PROBLEM                                    *
* PRIMARY SEARCH = NUCLIDE(DIRECT) - SECONDARY SEARCH = DIMENSION        *
*      * *      *  0.0 74R  0 100R
1D DVRINS  0.0 100R  10000  0 99R
1D XCPINS  0.0 100R  0 3R  1  0 18R  1  1  0 76R
1D DTNINS /
0.0 3R  2345.0  1.0  0.5  0.0 4R  1.0E-6  5.0E-5  0.0 88R /
 0 3R  1 3R  0 3R  7  0 9R  35  0 8R  1  1  0  1  1  0  1  0  0  1 5R
  0  0  5  1  1  0 3R  1  0  1  1  0 3R  1  2  0 41R
1D RRTINS  0.0 100R  0 5R  1  0  0  0  1  1  1  0  1  0 86R
1D *      *  0.0 100R  0 100R
OV ISOTXS
1D /
 5 15 0 4 0 1 1 1
2D /
* 5 GROUP LMFBR CROSS SECTION SET.                                       *
  *O-16  * *NA-23 * *CR-N  * *MN-55 * *FE-N  * *NI-N  * *MO-N  *
  *TA-181* *U-235 * *U-238 * *PU-239* *PU-240* *PU-241* *PU-242*
  *SSFP  *
 0.755037 0.238025 0.006938  0.0 2R /
 2579.927 891.3213 324.5034 109.3773 41.77161 /
 1.49182E+7 8.2085E+5 6.73795E+4 9118.816 748.5188 1.0E-4 /
 0 3 6 9 12 15 18 21 24 27 30 33 36 39 42
4D /
  *O-16  * *CITNXS* *O-16  * /
 15.86200 0.0 5R /
 0 0 0  0 5R 1 1 0 0 1 /
  1  2  3  2  2 /
```

(CONT)

```
 1 5R
5D /
 2.001419E+00 3.538190E+00 3.530899E+00 3.586479E+00 3.802440E+00
 0.0 0.0 0.0 0.0 0.0
 6.058659E-03 0.0 0.0 0.0 4.388488E-16
7D /
 2.166470E+00 3.647599E+00 4.272870E-01 3.463120E+00 1.759329E-01
 1.122229E-07 3.562880E+00 1.304229E-01 3.677589E+00 8.492589E-02
4D /
  *NA-23 * *CITNXS* *NA-23 * /
 22.78600 0.0 5R /
 6 1 1  0 5R 1 1 0 0 1 /
  1  2  3  2  2 /
 1 5R
5D /
 2.036969E+00 3.538750E+00 4.970710E+00 1.154060E+01 3.192539E+00
 0.0 0.0 0.0 0.0 0.0
 1.786468E-03 5.146489E-04 1.094200E-03 1.207110E-02 5.816218E-03
 1.541630E-06 0.0 0.0 0.0 0.0
 2.000000E+00 0.0 0.0 0.0 0.0
 7.550370E-01 2.380250E-01 6.937999E-03 0.0 0.0
7D /
 2.622210E+00 3.743600E+00 4.186479E-01 4.857280E+00 1.324430E-01
 1.452600E-04 1.609309E+01 1.414840E-01 3.054230E+00 5.449740E-02
4D /
  *CR-N  * *CITNXS* *CR-N  * /
 52.01000 0.0 5R /
 5 0 0  0 5R 1 1 0 0 1 /
  1  2  3  4  5 /
 1 5R
5D /
 1.895960E+00 2.847699E+00 4.099540E+00 1.258560E+01 4.485060E+00
 0.0 0.0 0.0 0.0 0.0
 3.482590E-03 4.594687E-03 7.548548E-03 1.374699E-01 1.257820E-01
7D /
 2.654610E+00 3.672379E+00 2.405180E-01 4.268359E+00 3.898390E-02
 6.128579E-03 1.243190E+01 1.094289E-01 0.0 4.783079E-04
 4.296340E+00 3.122900E-02 0.0 0.0 2.785960E-05
4D /
  *MN-55 * *CITNXS* *MN-55 * /
 54.46600 0.0 5R /
 5 1 1  0 5R 1 1 0 0 1 /
  1  2  3  4  2 /
 1 5R
5D /
 2.591649E+00 5.235530E+00 1.456410E+01 6.231160E+01 1.002660E+02
 0.0 0.0 0.0 0.0 0.0
 4.334409E-03 1.134890E-02 5.448210E-02 3.652869E-01 3.209069E+00
 1.073100E-04 0.0 0.0 0.0 0.0
 2.000000E+00 0.0 0.0 0.0 0.0
 7.550370E-01 2.380250E-01 6.937999E-03 0.0 0.0
7D /
 2.974719E+00 5.436890E+00 4.263680E-01 1.396750E+01 1.851780E-01
 1.911900E-02 7.817009E+01 4.328420E-01 5.918168E-03 5.526468E-04
```

(CONT)

```
 1.468200E+02 1.011980E-01
4D /
  *FE-N   * *CITNXS* *FE-N   * /
 55.84500 0.0 5R /
 5 0 0  0 5R 1 1 0 0 1 /
  1  2  3  4  2 /
 1 5R
5D /
 2.168090E+00 3.482690E+00 6.566119E+00 9.031090E+00 1.055570E+01
 0.0 0.0 0.0 0.0 0.0
 2.519850E-03 5.252499E-03 1.946380E-02 5.074910E-02 2.056830E-02
7D /
 2.565539E+00 3.926530E+00 3.419320E-01 7.636379E+00 3.941110E-02
 1.161280E-02 8.834049E+00 8.631974E-02 0.0 5.354248E-04
 1.047090E+01 6.575638E-02
4D /
  *NI-N   * *CITNXS* *NI-N   * /
 58.70500 0.0 5R /
 5 0 0  0 5R 1 1 0 0 1 /
  1  2  3  4  5 /
 1 5R
5D /
 2.299829E+00 4.373010E+00 1.716609E+01 1.579460E+01 1.633490E+01
 0.0 0.0 0.0 0.0 0.0
 7.411516E-02 9.023577E-03 1.714480E-02 1.964660E-02 3.636980E-02
7D /
 2.735749E+00 4.621889E+00 2.409970E-01 1.836949E+01 1.592640E-01
 5.383287E-03 1.589590E+01 9.364969E-02 0.0 5.395960E-04
 1.617560E+01 9.805179E-02 0.0 0.0 4.569250E-06
4D /
  *MO-N   * *CITNXS* *MO-N   * /
 95.06600 0.0 5R /
 5 1 1  0 5R 1 1 0 0 1 /
  1  2  3  3  4 /
 1 5R
5D /
 3.663779E+00 7.085640E+00 7.328959E+00 7.271429E+00 1.323520E+01
 0.0 0.0 0.0 0.0 0.0
 2.366135E-02 6.210750E-02 2.112700E-01 1.518339E+00 3.248449E+00
 1.485650E-03 0.0 0.0 0.0 0.0
 2.000000E+00 0.0 0.0 0.0 0.0
 7.550370E-01 2.380250E-01 6.937999E-03 0.0 0.0
7D /
 4.577000E+00 8.479199E+00 8.577590E-01 7.315180E+00 7.333905E-02
 1.588170E-02 5.658710E+00 3.783630E-02 8.116618E-04 9.642159E+00
 2.030290E-02 0.0 2.710729E-05
4D /
  *TA-181* *CITNXS* *TA-181* /
 179.3900 0.0 5R /
 7 1 1  0 5R 1 1 0 0 1 /
  1  2  3  3  2 /
 1 5R
5D /
 4.137730E+00 6.666160E+00 1.075010E+01 1.687169E+01 2.470959E+01
```

(CONT)

```
 0.0 0.0 0.0 0.0 0.0
 7.648069E-02 2.887599E-01 8.258290E-01 3.224420E+00 6.866340E+00
 3.773690E-03 0.0 0.0 0.0 0.0
 2.000000E+00 0.0 0.0 0.0 0.0
 7.550370E-01 2.380250E-01 6.937999E-03 0.0 0.0
7D /
 5.053289E+00 7.277980E+00 1.300570E+00 1.042640E+01 1.379640E-01
 2.069130E-02 1.451040E+01 7.560796E-02 1.500330E-03 2.003560E+01
 3.956910E-02
4D /
  *U-235 * *CITNXS* *U-235 * /
 233.0250 3.148100E-11  0.0 4R /
 1 1 1  0 5R 1 1 0 0 1 /
  1  2  3  3  3 /
 1 5R
5D /
 4.760500E+00 8.222549E+00 1.359530E+01 1.914319E+01 3.180229E+01
 0.0 0.0 0.0 0.0 0.0
 6.753063E-02 2.953396E-01 8.323002E-01 2.340739E+00 6.114193E+00
 1.276409E+00 1.422770E+00 2.397539E+00 5.349660E+00 1.433350E+01
 2.667859E+00 2.457879E+00 2.433379E+00 2.430380E+00 2.430070E+00
 7.550370E-01 2.380250E-01 6.937999E-03 0.0 0.0
7D /
 4.856970E+00 7.983669E+00 7.749810E-01 1.061980E+01 1.128620E-01
 6.262079E-03 1.135630E+01 3.006150E-02 6.019380E-04 1.172910E+01
 1.911250E-02 2.076550E-05
4D /
  *U-238 * *CITNXS* *U-238 * /
 236.0060 3.162500E-11  0.0 4R /
 2 1 1  0 5R 1 1 0 0 1 /
  1  2  3  4  3 /
 1 5R
5D /
 4.846760E+00 8.571039E+00 1.344970E+01 1.768149E+01 1.890230E+01
 0.0 0.0 0.0 0.0 0.0
 8.457595E-02 1.702173E-01 4.804530E-01 9.735650E-01 1.381539E+00
 3.346020E-01 2.376520E-04 0.0 0.0 0.0
 2.786519E+00 2.466439E+00 0.0 0.0 0.0
 7.550370E-01 2.380250E-01 6.937999E-03 0.0 0.0
7D /
 4.988910E+00 1.002520E+01 1.818430E+00 1.325670E+01 1.357570E-01
 4.470190E-02 1.698059E+01 4.110790E-02 5.152000E-04 2.062660E-04
 1.838379E+01 1.897440E-02 3.887150E-04
4D /
  *PU-239* *CITNXS* *PU-239* /
 236.9990 3.258600E-11  0.0 4R /
 1 1 1  0 5R 1 1 0 0 1 /
  1  2  3  3  2 /
 1 5R
5D /
 4.954309E+00 8.718180E+00 1.417930E+01 1.948119E+01 3.271959E+01
 0.0 0.0 0.0 0.0 0.0
 1.869965E-02 1.703405E-01 5.475597E-01 1.758830E+00 5.105810E+00
 1.883070E+00 1.544629E+00 1.793650E+00 3.520470E+00 9.376289E+00
```

(CONT)

```
 3.159670E+00 2.903930E+00 2.874129E+00 2.870489E+00 2.870060E+00
 7.550370E-01 2.380250E-01 6.937999E-03 0.0 0.0
7D /
 4.755099E+00 8.660600E+00 6.977440E-01 1.152080E+01 5.938330E-02
 1.403890E-02 1.228110E+01 5.996540E-02 1.393650E-04 1.321710E+01
 2.247640E-02
4D /
  *PU-240* *CITNXS* *PU-240* /
 237.9900 3.282700E-11  0.0 4R /
 2 1 1  0 5R 1 1 0 0 1 /
  1  2  3  4  3 /
 1 5R
5D /
 5.054469E+00 8.604670E+00 1.371420E+01 1.888170E+01 2.418489E+01
 0.0 0.0 0.0 0.0 0.0
 9.490967E-02 2.099380E-01 5.826710E-01 1.765706E+00 5.535801E+00
 1.543460E+00 2.327840E-01 1.008230E-01 8.248240E-02 5.786900E-02
 3.146529E+00 2.935940E+00 2.874260E+00 2.870649E+00 2.870070E+00
 7.550370E-01 2.380250E-01 6.937999E-03 0.0 0.0
7D /
 4.944110E+00 1.004100E+01 9.152250E-01 1.332420E+01 9.741586E-02
 1.617920E-02 1.696700E+01 3.657120E-02 4.508259E-05 1.091320E-04
 1.921140E+01 3.237760E-02 1.642760E-05
4D /
  *PU-241* *CITNXS* *PU-241* /
 238.9780 3.305100E-11  0.0 4R /
 1 1 1  0 5R 1 1 0 0 1 /
  1  2  3  4  3 /
 1 5R
5D /
 5.104230E+00 8.643849E+00 1.269630E+01 1.976459E+01 3.767090E+01
 0.0 0.0 0.0 0.0 0.0
 2.668953E-02 2.172995E-01 6.064100E-01 1.668990E+00 5.614212E+00
 1.703650E+00 1.869960E+00 3.036860E+00 6.653950E+00 1.995859E+01
 3.256940E+00 3.005619E+00 2.973280E+00 2.969489E+00 2.969060E+00
 7.550370E-01 2.380250E-01 6.937999E-03 0.0 0.0
7D /
 4.529670E+00 7.873819E+00 1.165449E+00 9.113990E+00 3.188040E-01
 7.122946E-02 1.127190E+01 4.141530E-02 5.656999E-03 2.550660E-04
 1.299900E+01 2.077500E-02 1.391030E-03
4D /
  *PU-242* *CITNXS* *PU-242* /
 240.1450 3.276200E-11  0.0 4R /
 3 1 1  0 5R 1 1 0 0 1 /
  1  2  3  2  3 /
 1 5R
5D /
 4.493779E+00 7.721160E+00 1.416950E+01 2.093379E+01 2.866119E+01
 0.0 0.0 0.0 0.0 0.0
 4.164982E-02 1.358470E-01 4.516167E-01 1.535060E+00 5.900109E+00
 1.453540E+00 1.398230E-01 4.632320E-02 0.0 0.0
 3.122800E+00 2.885630E+00 2.812289E+00 0.0 0.0
 7.550370E-01 2.380250E-01 6.937999E-03 0.0 0.0
7D /
```

(CONT)

```
 5.051700E+00 9.356939E+00 6.037650E-01 1.433580E+01 1.291580E-01
 1.092240E-02 1.935210E+01 4.589510E-02 2.431760E+01 3.522350E-02
 6.624369E-05
4D /
  *SSFP   * *CITNXS* *SSFP   * /
 161.0000 0.0 5R /
 4 0 0  0 5R 1 1 0 0 1 /
  1  1  1  1  1 /
 1 5R
5D /
 3.563750E-02 1.371830E-01 3.716339E-01 9.294800E-01 3.085389E+00
 0.0 0.0 0.0 0.0 0.0
 3.680390E-02 1.409680E-01 3.771360E-01 9.283320E-01 3.130919E+00
7D /
 0.0 0.0 0.0 0.0 0.0
0V GEODST
1D /
 7 8 18 1 6 3 1 17 10 1 1 2 2 1 2 2 1 6 1 0 0 1 0 5R
3D /
0.0 12.482 42.482 57.482 77.912 98.659 113.899 /
 0.0 12.24 30.34 56.06 /
 2 3 5R /
 3 3 4
5D /
 5991.004 63406.07 57658.88 106365.1 140865.9 124564.3 8859.246
 93762.25 85263.5 157288.2 208306.6 184200.5 12588.94 133235.6
 121159.0 223505.7 296002.6 261747.9 /
 0.0 /
 0.0 0.4692 2R  0.0  0.4692 2R /
 0.4692 /
 1 8R /
 7 6R  3 3R  4 6 8  1 3R  2 5 8 /
7D /
 (1 1  2 3R  3 3R  4 3R  5 3R  6 3R) 3R /
 (7 7  8 3R  9 3R  10 3R  11 3R  12 3R) 3R /
 (13 13  14 3R  15 3R  16 3R  17 3R  18 3R) 4R /
0V NDXSRF
1D /
  15  4  14  15  8  4
2D /
 (*O-16  * *NA-23 * *CR-N  * *MN-55 * *FE-N  * *NI-N  * *MO-N  *
  *TA-181* *U-235 * *U-238 * *PU-239* *PU-240* *PU-241* *PU-242*
  *SSFP   * ) 2R /
 0.0 15R /
 15.862 22.786 52.01 54.466 55.845 58.705 95.066 179.39 233.025
 236.006 236.999 237.990 238.978 240.145 161.0 /
 0 6  5 5R  7 1 2 1 2 1 3 4 /
 (14  0 3R) 3R  7  0 3R /
 1 2 3 4 5 6 7 8 10 11 12 13 14 15 /
 (1 2 3 4 5 6 7 8 9 10 11 12 13 15) 2R /
 2 3 4 5 6 7 8  0 7R /
 1 2 3 4 5 6 7 8 0 9 10 11 12 13 14 /
 (1 2 3 4 5 6 7 8 9 10 11 12 13 0 14) 2R /
 0 1 2 3 4 5 6 7  0 7R /
```

(CONT)

```
3D /
 266983.6 223505.7 187884.9 157288.2 296002.6 208306.6 498851.2
 445948.4 /
 1.0 0.0  1.C 6R /
 55876.42 4R /
 1 0  3 4R 4 4 /
 2 4R /
 2 4R /
0V ZNATDN
1D /
 0.0  0  12  14  1
2D /
 1.804800E-02 8.218598E-03 2.945900E-03 4.325500E-04 1.134900E-02
 2.078700E-03 5.186498E-04 5.261999E-05 7.179096E-03 9.960700E-04
 2.896199E-04 2.796900E-05 7.217899E-06 5.223998E-04
 0.0 14R  1.804800E-02 /
 8.218598E-03 2.945900E-03 4.325500E-04 1.134900E-02 2.078700E-03
 5.186498E-04 5.261999E-05 2.124799E-05 8.596398E-03 1.841500E-04
 6.197200E-06 9.999999E-16 4.515100E-05 1.804800E-02 8.218598E-03
 2.945900E-03 4.325500E-04 1.134900E-02 2.078700E-03 5.186498E-04
 5.261999E-05 2.124799E-05 8.596398E-03 1.841500E-04 6.197200E-06
 9.999999E-16 4.515100E-05 1.8048C0E-02 8.218598E-03 2.945900E-03
 4.325500E-04 1.134900E-02 2.078700E-03 5.186498E-04 5.261999E-05
 2.124799E-05 8.596398E-03 1.841500E-04 6.197200E-06 9.999999E-16
 4.515100E-05 1.804800E-02 8.218598E-03 2.945900E-03 4.325500E-04
 1.134900E-02 2.078700E-03 5.186498E-04 5.261999E-05 2.124799E-05
 8.596398E-03 1.841500E-04 6.197200E-06 9.999999E-16 4.515100E-05
 4.359998E-03 1.149600E-02 1.688000E-03 4.428800E-02 8.111998E-03
 2.024000E-03 9.999999E-16 /
  0.0 7R                   4.359998E-03 1.149600E-02 1.688000E-03
 4.428800E-02 8.111998E-03 2.024000E-03 9.999999E-16
 0.0 7R  1.804800E-02 /
 8.218598E-03 2.945900E-03 4.325500E-04 1.134900E-02 2.078700E-03
 5.186498E-04 5.261999E-05 2.124799E-05 8.596398E-03 1.841500E-04
 6.197200E-06 9.999999E-16 4.515100E-05 1.804800E-02 8.218598E-03
 2.945900E-03 4.325500E-04 1.134900E-02 2.078700E-03 5.186498E-04
 5.261999E-05 2.124799E-05 8.596398E-03 1.841500E-04 6.197200E-06
 9.999999E-16 4.515100E-05 1.804800E-02 8.218598E-03 2.945900E-03
 4.325500E-04 1.134900E-02 2.078700E-03 5.186498E-04 5.261999E-05
 2.124799E-05 8.596398E-03 1.8415C0E-04 6.197200E-06 9.999999E-16
 4.515100E-05 1.804800E-02 8.218598E-03 2.945900E-03 4.325500E-04
 1.134900E-02 2.078700E-03 5.186498E-04 5.261999E-05 2.124799E-05
 8.596398E-03 1.841500E-04 6.197200E-06 9.999999E-16 4.515100E-05
0V SEARCH
1D /
  7  2  0 18R /
2D /
 1.01  0.0  0.00005  0.001  0.0 6R /
  9  0  0  0 3R  3  1  2  0  0  0  8  0 17R /
5D /
  1  2 /
*U-238 *  *PU-240*  *PU-239* /
 0.0001  C.0C02  0.0003
1D /
```

(CONT)

```
  8   2   0 18R /
2D /
 1.01   0.0   0.00005   0.001   0.0 6R /
  5   0   7   6   3   1   0   0   2   0   0   0   0 18R /
3D /
 1.0   1.0   1.0   1.0   0.0   0.0 /
 0.0   0.0   0.5 /
 0.0
1D /
 -10   0 19R/
STOP
ENDINPUT
/*
//
```

TABLE 450-2. INPUT FOR SAMPLE PROBLEMS IN THE SPECIAL INPUT PROCESSORS FORMAT.

```
//UIDXYZZZ JOB (CHARG,,,99,9000,,1),'ADRES,NAME COL 38-57',CLASS=Y,
// TYPRUN=HOLD,
// MSGLEVEL=(1,1)
/*ROUTE  PRINT LOCAL
//STEP EXEC VENTUREX,
// NB1=1,NB2=1,B1=3520,B2=15360,NX=2,NS=50,N1=100,
// N2=4,N3=13,N4=1,N5=6,N6=10,N7=1,N8=1,N9=2,N10=2,N11=3,N12=5,N13=2,
// N14=1,N15=10,
// PARM.FORT='NODECK,NOLIST,ID,OPT=2,NOSOURCE,NOXREF,NOMAP',
// REGION.GO=310K
//FORT.SYSIN DD *
/*
//LKED.BVDRIVER DD UNIT=2314,VOLUME=SER=ZX2222,DISP=SHR,
// DSNAME=TBF.BOLD.VENTURE.DRIVER
//LKED.SYSIN DD *
 INCLUDE BVDRIVER
/*
//GO.XXXXXXXX DD UNIT=2314,VOL=SER=ZX2222,DISP=SHR,
// DSNAME=TBF.BOLD.VENTURE
//GO.FT99F001 DD *
 VENTURE SAMPLE PROBLEM RUN - USING THE SPECIAL INPUT PROCESSORS.
 15000
  2  2  6  2  7  2  2  6  2  7  0
DCMACR
  3
CITATION MACROS TO MICROS.
008
  3  1  0
     1      1        1.677          0.0          0.0
         0.0      0.04378          0.0
     1      2       0.8696      0.02864      0.00755              0.8      -13
         0.0          0.0      0.04295
     1      3       0.3346       0.1132       0.1088              1.0      -12
         0.0          0.0          0.0
     2      1        1.831        0.013          0.0
         0.0       0.0043          0.0
     2      2        1.214        0.008          0.0
         0.0          0.0       0.0025
     2      3  1.0
         0.0          0.0          0.0
     3      1        1.367          0.0          0.0
         0.0      0.02016          0.0
     3      2        1.022       0.0029          0.0
         0.0          0.0      0.01392
     3      3       0.6602      0.00716          0.0
         0.0          0.0          0.0
     0
         0.6          0.4          0.0
ENDINPUT
DCRSPR
        1  1  1
```

(CONT)

```
                3
ZONE 1
ZONE 2
ZONE 3
ENDINPUT
DVENTR
001
 0.0
                                        1.6
 0.0
            1
  1  1
003
  8  3  3  1  2  1  1  1  0  3  1
 0.001
 0.0          0.0          0.4692
  2
004
  4 .1707963  8       1.4  4 .1707963  8       1.4
  6      30.0  4       5.0  4      10.0  6      25.0
005
  1  1  1  1
  2  1  2  1
  1  1  1  1
  3  3  3  3
012
  0
  1  3  1  1 1.0
  0
013
  3
  3
ZONE 1ZONE 2ZONE 3
020
  1  1
ZONE 1 1.C
  2  2
ZONE 2 1.C
  3  3
ZONE 3 1.C
  0
ENDINPUT
DCMACR
  3
CITATION MACROS TO MICROS.
008
  2  1  0
     1     1          1.5       0.0012       0.004                5.      -14
         C.0       0.0033
     1     2          1.2       0.0047       0.063                1.96875-13
         0.0          0.0
     2     1          1.7       0.0007       0.0004                  5.  -15
         C.0       0.0052
     2     2         1.13       0.0063       0.025                6.25   -14
```

(CONT)

```
          0.0          0.0
     3      1          1.2      0.00052          0.0
          0.0       0.0067
     3      2         0.87        0.008          0.0
          0.0          0.0
     0
          1.0
ENDINPUT
DCRSPR
         1  1  1                                                                  1
                3
ZONE1
ZONE2
ZONE3
ENDINPUT
DVENTR
001
                                          10.0
 0.0
                                          0.09
     4      1      0        0      0 50
  1  1  1  1  1  1  1  1  0  0  1  1  2  4  1  1  1  1  C  2  1  5
003
 14  1  0  0  1  0  0  1  0  0  0
 0.0109045
004
  4       8.0  2       8.0  3       9.0
  9      18.0
  5      15.0
005
  1  1  1
006
   2
   5   6   1   9   1   5
   3
   7   9   1   9   1   5
   0
012
  0
  1  3  1  1 1.0
  0
013
  3
  3
ZONE1 ZONE2 ZONE3
020
  1  1
ZONE1  1.0
  2  2
ZONE2  1.0
  3  3
ZONE3  1.0
  0
ENDINPUT
```

TABLE 450-3 SELECTED PRINTOUT FOR SAMPLE PROBLEMS

```
***********BEGINNING BOLD VENTURE RUN - DRIVER INPUT FOLLOWS

*******************BOLD VENTURE RUN - SAMPLE PROBLEMS******************
 15000     0     0     0     3     0     0     0     0  0  0  0  1  0  0
  1  6  7  1  7  1  6  7  9

***STAND-ALONE OPERATION NOT REQUESTED.


*************************ACCESSING MODULE NUMBER  1 - MODULE NAME = LASLINPT - ON XXXXXXXX*************************
ELAPSED CPU TIME =   0.032 MINUTES  -  ELAPSED CLOCK TIME =   1.250 MINUTES


*************************ACCESSING MODULE NUMBER  6 - MODULE NAME = VENSIGPR - ON XXXXXXXX*************************
ELAPSED CPU TIME =   0.044 MINUTES  -  ELAPSED CLOCK TIME =   2.001 MINUTES


*************************ACCESSING MODULE NUMBER  7 - MODULE NAME = VENCALCU - ON XXXXXXXX*************************
ELAPSED CPU TIME =   0.469 MINUTES  -  ELAPSED CLOCK TIME =   4.938 MINUTES


*************************ACCESSING MODULE NUMBER  1 - MODULE NAME = LASLINPT - ON XXXXXXXX*************************
ELAPSED CPU TIME =   0.503 MINUTES  -  ELAPSED CLOCK TIME =   5.849 MINUTES


*************************ACCESSING MODULE NUMBER  7 - MODULE NAME = VENCALCU - ON XXXXXXXX*************************
ELAPSED CPU TIME =   1.079 MINUTES  -  ELAPSED CLOCK TIME =  20.646 MINUTES


*************************ACCESSING MODULE NUMBER  1 - MODULE NAME = LASLINPT - ON XXXXXXXX*************************
ELAPSED CPU TIME =   1.171 MINUTES  -  ELAPSED CLOCK TIME =  21.815 MINUTES


*************************ACCESSING MODULE NUMBER  6 - MODULE NAME = VENSIGPR - ON XXXXXXXX*************************
ELAPSED CPU TIME =   1.204 MINUTES  -  ELAPSED CLOCK TIME =  22.434 MINUTES


*************************ACCESSING MODULE NUMBER  7 - MODULE NAME = VENCALCU - ON XXXXXXXX*************************
ELAPSED CPU TIME =   1.886 MINUTES  -  ELAPSED CLOCK TIME =  32.323 MINUTES


*************************ACCESSING MODULE NUMBER  9 - MODULE NAME = VENRRATE - ON XXXXXXXX*************************
ELAPSED CPU TIME =   1.899 MINUTES  -  ELAPSED CLOCK TIME =  32.463 MINUTES


*********************NORMAL END OF BOLD VENTURE RUN
```

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LISTING OF INTERFACE FILE GROUPXS COMPLETED


 PERIODIC BOUNDARY IN THETA-R GEOMETRY, CASE A4 WITH BLACK ABSORBER
 24X20X3 GROUP, 1440 POINTS  FWRD. + ADJ.

*********START EXECUTING NEUTRONICS CODE BLOCK*********

*** WARNING *** UNIT   13  WILL BE READ BUT IT MAY NOT HAVE BEEN WRITTEN

*** WARNING *** UNIT   14  WILL BE READ BUT IT MAY NOT HAVE BEEN WRITTEN

*** WARNING *** UNIT   12  WILL BE READ BUT IT MAY NOT HAVE BEEN WRITTEN

SOLUTION BY FINITE-DIFFERENCE DIFFUSION THEORY
EIGENVALUE PROBLEM
A REGULAR ADJOINT WILL FOLLOW FORWARD PROBLEM
GEOMETRY NO.  8   2-D THETA-R
NUMBER OF ENERGY GROUPS                                  3
NUMBER OF UPSCATTER GROUPS (MAX)                         0
NUMBER OF DOWNSCATTER GROUPS (MAX)                       1
NUMBER OF INTERVALS IN DIMENSION 1 (COLUMNS)            24
NUMBER OF INTERVALS IN DIMENSION 2 (ROWS)               20
NUMBER OF INTERVALS IN DIMENSION 3 (PLANES)              1
NUMBER OF ZONES                                          3
NUMBER OF REGIONS                                       16
NUMBER OF BLACK ABSORBER ZONES                           1
BOUNDARY INDICATORS-   LEFT  3  RIGHT  3
                        TOP  1 BOTTOM  2


                                   MEMORY REQUIREMENTS FOR DATA STORAGE

                                        TOTAL                A          B          C          D
                                   MINIMUM   MAXIMUM
STORAGE AVAILABLE                    15000
MACRO CALCULATION                      187
EQUATION CONSTANTS CALCULATION
          CORE CONTAINED OR SPACE STORED      2908      2908
          PLANE STORED                        3868      3868
          ROW STORED                           944       944
          MULTI-LEVEL PLANE STORED            4344      4344
INITIAL FLUX                                  1733      1733
INITIAL OVERRELAXATION PARAMETERS              446
ITERATIVE PROCESS
          CORE CONTAINED                     14693                11652       987        90      1964
          SPACE STORED                        6830                 5804       987        39         0
        1 PLANES STORED                       8750                 7724       987        39         0
        1 PLANE STORED                        8750                 7724       987        39         0
       20 ROWS STORED                         6490                 5464       987        39         0
        1 ROW STORED                          1026                    0       987        39         0
        1 MULTI-LEVEL PLANES STORED          11146                 2880       987        39      7240
PERTURBATION CALCULATION                      1453

DATA WILL BE STORED FOR ALL GROUPS, ALL SPACE

MEMORY LOCATIONS RESERVED FOR DATA STORAGE---     15000
MAX MEMORY LOCATIONS REQUIRED FOR THIS PROB--     14693
MEMORY LOCATIONS NOT USED-------------------        307
```

A FLUX - EIGENVALUE PROBLEM FOLLOWS
4 INNERS MIN, 4 INNERS MAX - CHEBYCHEV BETA ON OUTERS
PROC=0,1,2,3,4-NORMAL,CHEBYSHEV,SEBEX,DEBEX,SEMEXP. ICVR=0,1-YES,NO INNERS CONVR. OCVR=0,1-YES,NO OUTERS CONVR.

ITER	PROC	ICVR	OCVR	FLUX CHANGE	MU-BAR	MU-1	MU-LOSS	ACCELERATION PARAMETERS		K-USED	K-CALC
1	0	1	1	1.11185E 01	0.0	0.0	0.0	0.0	0.0	1.0000000	0.6117370
2	0	1	1	4.57657E 01	0.26916	49.88192	0.00824	0.36829	0.0	0.6117370	0.5981128
3	0	1	0	2.29547E 00	0.46010	2.34562	-0.41740	0.46810	0.07637	0.5981128	0.5996553
4	0	0	1	8.39545E-01	0.50349	1.20529	0.74234	1.15759	-0.06073	0.5996553	0.6036770
5	0	0	0	4.03528E-01	0.62640	0.88418	-0.27035	-4.65745	2.39972	0.6036770	0.6058796
6	0	0	0	2.29934E-01	0.60738	0.79974	0.87386	1.37122	0.11571	0.6058796	0.6072123
7	0	0	0	1.61821E-01	0.74065	0.86559	0.74574	-0.49570	1.34467	0.6072123	0.6082762
8	0	0	0	1.17395E-01	0.75268	0.84286	0.84844	3.28997	-0.17417	0.6082762	0.6090899
9	0	0	0	8.69035E-02	0.75948	0.82717	0.84303	6.30109	-2.30093	0.6090899	0.6097103
10	0	0	0	6.61617E-02	0.77394	0.82749	0.81234	-7.29758	7.65315	0.6097103	0.6101905
11	0	0	0	5.13342E-02	0.78393	0.82723	0.80287	9.27144	-4.17446	0.6101905	0.6105658
12	0	0	0	4.03435E-02	0.79267	0.82624	0.79755	15.37752	-8.69125	0.6105658	0.6108607
13	2	0	0	8.75744E-02	0.79756	0.82181	0.79451	1.74796	0.0	0.6108607	0.6110931
14	0	0	0	1.59820E-03	0.0	0.0	0.0	0.0	0.0	0.6120140	0.6119999
15	0	0	0	1.24294E-03	0.82966	0.77895	0.53556	0.04515	0.04762	0.6119999	0.6119943
16	0	0	0	-8.03728E-04	0.62334	0.66376	0.56436	1.63755	0.03191	0.6119943	0.6119893
17	0	0	0	-5.18251E-04	0.64136	0.64425	0.63029	1.59114	0.11704	0.6119893	0.6119860
18	0	0	0	-3.59531E-04	0.68219	0.69338	0.65059	-6.29957	4.80035	0.6119860	0.6119837
19	0	0	0	-2.55561E-04	0.69800	0.71056	0.70959	3.48292	-0.75952	0.6119837	0.6119821
20	0	0	0	-1.84808E-04	0.71135	0.72296	0.74120	7.71933	-3.50580	0.6119821	0.6119808
21	0	0	0	-1.35933E-04	0.72715	0.73540	0.77468	28.04617	-17.06681	0.6119808	0.6119799
22	0	0	0	-1.01555E-04	0.74014	0.74699	0.80449	8.97870	-4.24545	0.6119799	0.6119791
23	0	0	0	-7.69585E-05	0.75515	0.75773	0.83185	36.62278	-23.38958	0.6119791	0.6119786
24	0	0	0	-5.90265E-05	0.76523	0.76693	0.85566	7.84135	-3.31761	0.6119786	0.6119781
25	0	0	0	-4.56016E-05	0.77468	0.77252	0.87623	15.91920	-9.16658	0.6119781	0.6119778
26	2	0	0	-9.09698E-05	0.78039	0.77995	0.89415	1.55758	0.0	0.6119778	0.6119775
27	0	1	0	-3.43386E-06	0.0	0.0	0.0	0.0	0.0	0.6119765	0.6119765
28	0	0	0	-2.52042E-06	0.75111	0.73399	0.86604	0.09231	0.08723	0.6119765	0.6119765

FINAL CALCULATED KEFFECTIVE 0.6119765
MULTIPLICATION RELIABILITY ESTIMATORS
BY THE SUM OF THE SQUARES OF THE RESIDUES---------- 0.6119763
UPPER AND LOWER BOUNDS ESTIMATES BY MAX REL FLUX CHANGE---------- 0.6119781 0.6119750
UPPER AND LOWER BOUNDS ESTIMATES OVER ALL SIGNIFICANT POINTS------- 0.6119865 0.6119692

FINAL GROUP OVERRELAXATION COEFFICIENTS AND NUMBER OF INNER ITERATIONS
1.60083E 00 1.60083E 00 1.63716E 00
4 4 4

CPU AND CLOCK MINUTES REQUIRED FOR THIS EIGENVALUE PROBLEM ARE 0.210 0.540

LEAKAGE 3.17834E 09 TOTAL LOSSES 1.73671E 11 TOTAL PRODUCTIONS 1.06283E 11 REACTOR POWER(WATTS) 1.00000D 00

BOUNDARY NEUTRON LEAKAGE

GRP	LFT LEAKAGE	RIT LEAKAGE	TOP LEAKAGE	BOT LEAKAGE	FNT LEAKAGE	BAK LEAKAGE
1	-2.32807D 08	2.32807D 08	0.0	6.02186D 08	0.0	0.0
2	-1.21548D 08	1.21548D 08	0.0	1.12112D 09	0.0	0.0
3	-1.37647D 08	1.37647D 08	0.0	1.45503D 09	0.0	0.0
SUM	-4.92002E 08	4.92002E 08	0.0	3.17834E 09	0.0	0.0

GROUP NEUTRON BALANCE FOR EACH ZONE

ZONE	GRP	ABSORPTIONS	B**2 LOSSES	1/V LOSS	OUT-SCATTER	IN-SCATTER	P1 IN-SCATTER	SOURCE	POWER(WATTS)	AVERAGE FLUX
1	1	0.0	3.54166E 09	0.0	9.24590E 10	0.0	0.0	1.04203E 11	0.0	6.75735E 08
1	2	6.24662E 10	1.89667E 09	0.0	9.36774E 10	9.24590E 10	0.0	6.94685E 10	1.74457E-01	6.97870E 08

1	3	9.34480E 10	2.76217E 08	0.0	0.0	9.36774E 10	0.0	0.0	8.25513E-01	2.64136E 08
SUM		1.55914E 11	5.71454E 09	0.0	1.86136E 11	1.86136E 11	0.0	1.73671E 11	1.00000E 00	
2	1	3.91168E 08	5.50946E 07	0.0	1.29387E 08	0.0	0.0	0.0	0.0	5.42075E 08
2	2	2.50769E 08	3.80541E 07	0.0	7.83652E 07	1.29387E 08	0.0	0.0	0.0	5.64705E 08
2	3	1.05904E 09	0.0	0.0	0.0	7.83652E 07	0.0	0.0	0.0	0.0
SUM		1.70098E 09	9.31488E 07	0.0	2.07752E 08	2.07752E 08	0.0	0.0	0.0	
3	1	0.0	4.46060E 08	0.0	6.57832E 09	0.0	0.0	0.0	0.0	7.22549E 07
3	2	1.48017E 09	5.21633E 08	0.0	7.10482E 09	6.57832E 09	0.0	0.0	0.0	1.13021E 08
3	3	4.23207E 09	3.90225E 08	0.0	0.0	7.10482E 09	0.0	0.0	0.0	1.30883E 08
SUM		5.71224E 09	1.35752E 09	0.0	1.36831E 10	1.36831E 10	0.0	0.0	0.0	

OVERALL NEUTRON BALANCE

GRP	ABSORPTIONS	B**2 LOSSES	1/V LOSS	OUT-SCATTER	IN-SCATTER	P1 IN-SCATTER	SOURCE	POWER(WATTS)
1	3.91168E 08	4.04281E 09	0.0	9.91667E 10	0.0	0.0	1.04203E 11	0.0
2	6.41971E 10	2.45636E 09	0.0	1.00861E 11	9.91667E 10	0.0	6.94685E 10	1.74487E-01
3	9.87391E 10	6.66442E 08	0.0	0.0	1.00861E 11	0.0	0.0	8.25513E-01
SUM	1.63327E 11	7.16560E 09	0.0	2.00027E 11	2.00027E 11	0.0	1.73671E 11	1.00000E 00

ZONE VOLUMES FOLLOW. TOTAL VOLUME 7.69688E 03
3.12534E 03 5.55088E 01 4.51603E 03

THE MAXIMUM POWER DENSITY IS AT PLANE 1, ROW 1, AND COLUMN 21 AND IS 5.20035080D-04 WATTS/CC.

THE MAXIMUM NEUTRON DENSITY IS AT PLANE 1, ROW 1, AND COLUMN 21 AND IS 2.67765488D 09 NEUTRONS/CC.
ELAPSED CPU AND CLOCK MINUTES ARE 0.264 2.396

ADJOINT PROBLEM FOLLOWS

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

PROC=0,1,2,3,4-NORMAL,CHEBYSHEV,SEMEX,DEMEX,SEMEXF. ICVR=0,1-YES,NO INNERS CONVR. OCVR=0,1-YES,NO OUTERS CONVR.

ITER	PROC	ICVR	OCVR	FLUX CHANGE	MU-BAR	MU-1	MU-LOSS	ACCELERATION	PARAMETERS
1	0	1	1	1.00698D 02	0.0	0.0	0.0	0.0	0.0
2	0	1	1	6.89702D 01	2.04735	69.65509	-0.00568	-1.00664	-0.99800
3	0	1	1	3.59923D 00	0.24005	3.65141	23.75185	-0.62578	-1.39888
4	0	0	0	2.79476D-01	0.10253	0.35713	0.10914	0.28357	-0.04800
5	0	0	0	1.05296D-01	0.48947	0.48206	0.04993	-0.10450	0.06201
6	0	0	0	-9.16561D-02	0.87637	0.84955	6.58155	13.02532	-0.70374
7	0	0	0	-5.28908D-02	0.57802	0.52417	0.67851	1.13383	0.70582
8	0	0	0	-3.77056D-02	0.70711	0.67519	0.69468	1.20800	0.48396
9	0	0	0	-2.88417D-02	0.76035	0.73608	0.76260	4.88816	-0.99251
10	3	0	0	-1.06677D-01	0.76921	0.74984	0.78672	4.23234	-0.44197
11	0	1	0	-3.09497D-04	0.0	0.0	0.0	0.0	0.0
12	0	0	1	7.11842D-04	2.46468	3.01168	-2.24260	0.00318	0.03143
13	0	0	0	-6.74366D-04	0.96678	1.07925	-6.00145	44.50342	0.86102
14	0	0	0	-5.69408D-04	0.84255	0.84379	0.90719	5.63744	-1.31169
15	3	0	0	-2.44563D-03	0.81548	0.81464	0.85227	5.44210	-1.17277
16	0	1	0	-2.53359D-05	0.0	0.0	0.0	0.0	0.0
17	0	0	1	-3.98985D-05	1.64023	1.57474	0.91736	0.03424	0.09447
18	0	0	0	-2.42238D-05	0.59307	0.60711	0.39798	1.60275	0.15154
19	0	0	0	-1.57944D-05	0.64666	0.65201	0.77361	1.58063	0.12848
20	0	0	0	-1.13196D-05	0.70679	0.71668	0.79550	16.20968	-7.40489
21	0	0	0	-8.96726D-06	0.78754	0.79218	0.88313	-24.70450	14.55037

MULTIPLICATION RELIABILITY ESTIMATORS

BY THE SUM OF THE SQUARES OF THE RESIDUES---------- 0.6119764

UPPER AND LOWER BOUNDS ESTIMATES BY MAX REL FLUX CHANGE---------- 0.6119820 0.6119710

UPPER AND LOWER BOUNDS ESTIMATES OVER ALL SIGNIFICANT POINTS------- 0.6120046 0.6119739

FINAL GROUP OVERRELAXATION COEFFICIENTS AND NUMBER OF INNER ITERATIONS

1.68399E 00 1.62282E 00 1.60000E 00

4 4 4

CPU AND CLOCK MINUTES REQUIRED FOR THIS EIGENVALUE PROBLEM ARE 0.159 0.468

TOTAL CPU TIME IS 0.423 MINUTES AND TOTAL CLOCK TIME IS 2.874 MINUTES

```
***CARD INPUT USED TO CREATE VERSION   1 OF FILE ZNATDN ON UNIT  14 ***

  0.0  0  3  3  1                                                                    CARD      86
20 /                                                                                 CARD      87
  1.0  0.0 23 /                                                                      CARD      88
  0.0  1.0  0.0 /                                                                    CARD      89
  0.0  0.0  1.0                                                                      CARD      90
STOP                                                                                 CARD      91

****NORMAL END OF STANDARD FILE CARD INPUT****

*** WARNING *** UNIT   10  WILL BE READ BUT IT MAY NOT HAVE BEEN WRITTEN


 3-D (X,Y,Z) BUCKLING SEARCH (OLD WHIRLAWAY CASE) - 9X9X5X2
 RUNNING IN THE PLANE STORED MODE - 4 PLANES STORED

**********START EXECUTING NEUTRONICS CODE BLOCK**********

*** WARNING *** UNIT   13  WILL BE READ BUT IT MAY NOT HAVE BEEN WRITTEN

*** WARNING *** UNIT   14  WILL BE READ BUT IT MAY NOT HAVE BEEN WRITTEN

*** WARNING *** UNIT   11  WILL BE READ BUT IT MAY NOT HAVE BEEN WRITTEN

*** WARNING *** UNIT   12  WILL BE READ BUT IT MAY NOT HAVE BEEN WRITTEN

SOLUTION BY FINITE-DIFFERENCE DIFFUSION THEORY
DIRECT BUCKLING SEARCH PROBLEM
A REGULAR ADJOINT WILL FOLLOW FORWARD PROBLEM
PERTURBATION RESULTS ARE REQUESTED
GEOMETRY NO. 14   3-D X-Y-Z
NUMBER OF ENERGY GROUPS                                  2
NUMBER OF UPSCATTER GROUPS (MAX)                         0
NUMBER OF DOWNSCATTER GROUPS (MAX)                       1
NUMBER OF INTERVALS IN DIMENSION 1 (COLUMNS)             9
NUMBER OF INTERVALS IN DIMENSION 2 (ROWS)                9
NUMBER OF INTERVALS IN DIMENSION 3 (PLANES)              5
NUMBER OF ZONES                                          3
NUMBER OF REGIONS                                        3
NUMBER OF BLACK ABSORBER ZONES                           0
BOUNDARY INDICATORS-   LEFT  1  RIGHT  0
                        TOP  0 BOTTOM  1
                      FRONT  0   REAR  0


                                        MEMORY REQUIREMENTS FOR DATA STORAGE

                                              TOTAL                A         B         C         D
                                          MINIMUM   MAXIMUM
STORAGE AVAILABLE                            5000
MACRO CALCULATION                             181
EQUATION CONSTANTS CALCULATION
          CORE CONTAINED OR SPACE STORED     2678      2840
          PLANE STORED                       1148      1330
          ROW STORED                          482       644
          MULTI-LEVEL PLANE STORED           1220      1382
INITIAL FLUX                                  397       721
INITIAL OVERRELAXATION PARAMETERS             249
ITERATIVE PROCESS
          CORE CONTAINED                     11139                8442      447       54      2196
```

```
        SPACE STORED                          5922                5436       447        39         0
      4 PLANES STORED                         4932                4446       447        39         0
      1 PLANE STORED                          1962                1476       447        39         0
      9 ROWS STORED                           1602                1116       447        39         0
      1 ROW STORED                             486                   0       447        39         0
      3 MULTI-LEVEL PLANES STORED             4482                 486       447        39      3510
PERTURBATION CALCULATION                       830

DATA WILL BE STORED FOR 1 GROUP,    4 PLANES

MEMORY LOCATIONS RESERVED FOR DATA STORAGE---     5000
MAX MEMORY LOCATIONS REQUIRED FOR THIS PROB--     4932
MEMORY LOCATIONS NOT USED-------------------        68

DD PARAMETERS FOLLOW FOR  B1 = 3520  AND  B2 =  10368
N2=   3  N3=  13  N4=   1  N5=   3  N6=  10  N7=   1  N8=   1  N9=   2  N10=   2  N11=   3  N12=   5  N13=   2  N14=   1  N15=  10

REQUIRED DISK STORAGE SPACE FOR FLUX(UNITS 24,27,28) IS      10560 BYTES.
                            FOR CONSTANTS(UNIT 40) IS--      31104 BYTES.
                            FOR CONSTANTS(UNIT 23) IS--      45760 BYTES.
REQUIRED TOTAL DISK STORAGE SPACE IS-------------------    5632640 BYTES.

THE REGION SIZE FOR SMALL PROBLEMS IN THE ALL-STORED MODE IS APPROXIMATELY   220K BYTES.
THE REGION SIZE FOR LARGE PROBLEMS IN THE PLANE-STORED MODE IS APPROXIMATELY 350K BYTES.

                    DIRECT ACCESS DATASET REQUIREMENTS

                    MAXIMUM PHYSICAL RECORD IS     7200 WORDS

    UNIT      NUMBER OF     LOGICAL RECORD  PHYSICAL REC     NUMBER OF      PHYSICAL RECORD
   NUMBER  LOGICAL RECORDS  LENGTH (WORDS)  /LOGICAL REC  PHYSICAL RECORDS  LENGTH (WORDS)
     23            90             82              1            90              84
     24            10            162              1            10             164
     27            10            162              1            10             164
     28            10            162              1            10             164
     25            90             18              1            90              20
     26            90             18              1            90              20
     40            10            666              1            10             668

STORAGE FOR MACRO CALCULATION
SUPPLIED    5000
REQUIRED     182


*** WARNING *** NUCLIDE NAMES OR CLASSES ON NDXSRF AND GRUPXS DO NOT COMPARE

CROSS SECTION          UNIQUE                          ABSOLUTE                          CLASS
    ORDER NO.  NDXSRF          GRUPXS        NDXSRF          GRUPXS       NDXSRF          GRUPXS
            1  ZONE1   NOT EQ  ZONE1   OR  ZONE1   NOT EQ        OR        0  NOT EQ        0
            2  ZONE2   NOT EQ  ZONE2   OR  ZONE2   NOT EQ        OR        0  NOT EQ        0
            3  ZONE3   NOT EQ  ZONE3   OR  ZONE3   NOT EQ        OR        0  NOT EQ        0

        3 NUCLIDES HAVE ERRORS


PRINCIPAL MACROSCOPIC CROSS SECTIONS

GROUP    1
ZONE   D             SIGA          SIGNF         SIGWF         SIGAS         SIGNFS
    1  1.500001E 00  1.200000E-03  3.999997E-03  5.000000E-14  0.0           0.0
    2  1.700001E 00  6.999997E-04  3.999998E-04  4.999998E-15  0.0           0.0
    3  1.200000E 00  5.199998E-04  0.0           0.0           0.0           0.0

GROUP    2
```

```
ZONE   D              SIGA          SIGNF         SIGWF         SIGAS         SIGNFS
    1  1.200000E 00  4.699998E-03  6.299996E-02  1.968750E-13  0.0           0.0
    2  1.129999E 00  6.299999E-03  2.499999E-02  6.249997E-14  0.0           0.0
    3  8.700005E-01  7.999998E-03  0.0           0.0           0.0           0.0

FISSION SPECTRUM CONSTANT FOR ALL ZONES
  1.000000E 00  0.0

1/V CONSTANT FOR ALL ZONES
  1.000000E 00  1.000000E 00

ZONE VOLUMES
  2.160000E 03  2.160000E 03  2.430000E 03


SCATTERING MACROSCOPIC CROSS SECTIONS

GROUP    1  MBAND    1  MJJ    1
TPO
  0.0           0.0           0.0

GROUP    2  MBAND    2  MJJ    1
TPO
  0.0           3.299999E-03  0.0           5.199999E-03  0.0           6.699998E-03

SCATTERING REMOVAL
GROUP    1
  3.299999D-03  5.199999D-03  6.699998D-03
GROUP    2
  0.0           0.0           0.0

FINE MESH DESCRIPTION - POINT IS LOCATED AT THE CENTROID OF THE VOLUME ELEMENT
DISTANCE TO POINT - DIMENSION 1 (LEFT TO RIGHT)
    1   1.0000    2   3.0000    3   5.0000    4   7.0000    5  10.0000    6  14.0000    7  17.5000    8  20.5000
    9  23.5000
DISTANCE TO BOUNDARY
    1   0.0       2   2.0000    3   4.0000    4   6.0000    5   8.0000    6  12.0000    7  16.0000    8  19.0000
    9  22.0000   10  25.0000
DISTANCE TO POINT - DIMENSION 2 (TOP TO BOTTOM)
    1   1.0000    2   3.0000    3   5.0000    4   7.0000    5   9.0000    6  11.0000    7  13.0000    8  15.0000
    9  17.0000
DISTANCE TO BOUNDARY
    1   0.0       2   2.0000    3   4.0000    4   6.0000    5   8.0000    6  10.0000    7  12.0000    8  14.0000
    9  16.0000   10  18.0000
DISTANCE TO POINT - DIMENSION 3 (FRONT TO REAR)
    1   1.5000    2   4.5000    3   7.5000    4  10.5000    5  13.5000
DISTANCE TO BOUNDARY
    1   0.0       2   3.0000    3   6.0000    4   9.0000    5  12.0000    6  15.0000

SEARCH LIMITING FACTORS - SP1 =  -1.275115E 00 SP2 =  -5.591301E 01  SA =   8.287418E-02 SNF =   0.0

REFERENCE ZONE FOR INITIALIZATION WILL BE     1

SUM OF REGION VOLUMES FROM GEODST                    6.750000D 03
SUM OF REGION VOLUMES COMPUTED FROM POINT VOLUMES    6.750000D 03
SUM OF ZONE VOLUMES (FROM COMPUTED REGION VOLUMES)   6.750000D 03
SUM OF ZONE VOLUMES  FROM NDXSRF                     6.750000D 03

INITIAL FLUX IS CONSTANT

ENERGY DEPENDENT OVERRELAXATION COEFFICIENTS CALCULATED
SPACE POINT AT COLUMN =      2 ROW =      8 PLANE =      3 ZONE =      1
K =  1 FK =   9.887511E-01 T1 =   2.225029E 01 TD =   2.200000E 01 NREC =   26
K =  2 FK =   9.880189E-01 T1 =   1.781342E 01 TD =   1.759999E 01 NREC =   71
RHOMIN =   8.709983E-01  OF =   6.558495E-01  RHOMAX =   8.716438E-01
```

A FLUX - EIGENVALUE PROBLEM FOLLOWS
4 INNERS MIN, 4 INNERS MAX - CHEBYCHEV BETA ON OUTERS
PROC=0,1,2,3,4-NORMAL,CHEBYSHEV,SEMEX,DEMEX,SEMEIP. ICVR=0,1-YES,NO INNERS CONVR. OCVR=0,1-YES,NO OUTERS CONVR.

ITER	PROC	ICVR	OCVR	FLUX CHANGE	MU-BAR	MU-1	MU-LOSS	ACCELERATION	PARAMETERS	K	SEARCH FACTOR	S.P.-CALC
1	0	1	1	1.88527D 02	0.0	0.0	0.0	0.0	0.0	0.0392559	0.0	0.0
2	0	0	0	6.93373D 00	0.04751	6.97051	-0.49042	0.04988	0.0	0.0473716	0.0	-2.93226D 00
3	0	1	0	-6.87272D-01	0.13169	0.03887	0.38399	0.05430	0.00422	0.0510834	-1.02009D-01	-2.68403D 00
4	0	1	0	-5.93891D-01	0.27024	0.27024	0.55468	0.51089	-0.01556	0.0534178	-1.93817D-01	-2.54868D 00
5	0	0	0	-4.62221D-01	0.63278	0.31607	0.61720	7.64134	-0.80477	0.0547367	-2.76444D-01	-2.50470D 00
6	0	0	0	-4.39348D-01	0.66142	0.51117	0.66538	2.02354	-0.04084	0.0558181	-3.50808D-01	-2.47718D 00
7	0	0	0	-4.23539D-01	0.67789	0.54048	0.68938	4.02775	-1.21016	0.0567724	-4.17736D-01	-2.45634D 00
8	3	0	0	-1.69361D 00	0.68942	0.55832	0.70301	5.07283	-1.94418	0.0576390	-4.77971D-01	-2.43883D 00
9	0	0	1	-5.24877D-01	0.0	0.0	0.0	0.0	0.0	0.0595500	-5.86395D-01	-2.38318D 00
10	0	0	0	-4.98750D-01	0.45147	0.45147	0.03958	1.41250	-0.35036	0.0610089	-7.59872D-01	-2.41973D 00
11	0	0	1	-4.44416D-01	0.80177	0.44664	0.68097	-0.39578	0.72448	0.0643751	-9.68045D-01	-2.37357D 00
12	0	0	0	-4.23087D-01	0.33712	0.52892	0.71469	0.27944	0.61432	0.0656083	-1.02009D 00	-2.33919D 00
13	0	0	0	-4.18793D-01	0.41534	0.57106	0.75635	0.48340	0.06749	0.0657149	-1.02009D 00	-2.33175D 00
14	0	0	0	-4.18218D-01	0.75305	0.58041	0.77820	-2.65551	1.00082	0.0657259	-1.02009D 00	-2.33080D 00
15	0	0	1	-3.33978D-01	3.26820	0.46460	0.61998	-1.32980	0.76825	0.0716560	-1.33887D 00	-2.26069D 00
16	0	0	0	-2.60960D-01	0.52041	0.52041	0.68378	-1.72126	-1.93930	0.0736800	-1.40581D 00	-2.21003D 00
17	0	0	0	-2.22092D-01	0.89848	0.62897	0.74389	2.15278	0.73780	0.0754211	-1.47610D 00	-2.18092D 00
18	0	0	0	-1.89370D-01	0.73805	0.66329	0.76217	2.51652	0.69773	0.0771829	-1.54990D 00	-2.15776D 00
19	0	0	1	-1.60088D-01	0.71563	0.68528	0.75996	2.97643	-0.36851	0.0791058	-1.62740D 00	-2.13361D 00
20	0	0	1	-1.17809D-01	0.72600	0.61805	0.69508	1.69480	0.65836	0.0812920	-1.70877D 00	-2.10459D 00
21	0	0	0	-8.48549D-02	0.62105	0.63542	0.69087	-0.57686	2.22473	0.0836162	-1.79420D 00	-2.07764D 00
22	0	0	0	-5.59081D-02	0.60296	0.60296	0.60464	1.86016	-0.22222	0.0861498	-1.88391D 00	-2.05061D 00
23	0	0	1	3.19740D-02	2.16360	8.75674	0.38274	-0.95028	1.60649	0.0889513	-1.97810D 00	-2.02230D 00
24	0	0	0	2.45483D-02	0.61966	0.79231	0.05168	-4.18719	-4.11337	0.0904446	-2.02230D 00	-2.00382D 00
25	0	0	0	-7.70180D-03	0.34797	0.47840	0.36088	0.97153	-0.46514	0.0900960	-2.00382D 00	-1.99981D 00
26	0	0	0	-2.71324D-03	0.37623	0.34957	0.15581	0.50196	0.03369	0.0900031	-1.99981D 00	-1.99968D 00
27	0	0	0	6.16356D-04	0.22445	0.25314	-0.10719	-0.48485	0.36218	0.0899932	-1.99968D 00	-1.99996D 00
28	0	0	1	3.48428D-04	0.32805	0.56565	0.18988	0.14797	0.06617	0.0899988	-1.99996D 00	-2.00001D 00
29	0	0	0	8.07635D-05	0.27490	0.23187	-1.12762	0.24613	0.04708	0.0900003	-2.00001D 00	-2.00000D 00
30	0	0	1	-1.81915D-05	0.33527	0.54151	0.63498	0.06959	0.10957	0.0900002	-2.00000D 00	-1.99999D 00
31	0	0	0	-7.81513D-06	0.43365	0.42960	0.34791	2.72263	-0.55901	0.0900000	-1.99999D 00	-1.99999D 00

FINAL CALCULATED KEFFECTIVE 0.0900000
MULTIPLICATION RELIABILITY ESTIMATORS
BY THE SUM OF THE SQUARES OF THE RESIDUES---------- 0.0900000
UPPER AND LOWER BOUNDS ESTIMATES BY MAX REL FLUX CHANGE---------- 0.0900007 0.0899993
UPPER AND LOWER BOUNDS ESTIMATES OVER ALL SIGNIFICANT POINTS------- 0.0900009 0.0899985

FINAL GROUP OVERRELAXATION COEFFICIENTS AND NUMBER OF INNER ITERATIONS
1.23448E 00 1.22139E 00
4 4

CPU AND CLOCK MINUTES REQUIRED FOR THIS EIGENVALUE PROBLEM ARE 0.324 8.039

LEAKAGE 1.83970E 13 TOTAL LOSSES 1.47888E 13 TOTAL PRODUCTIONS 1.33100E 12 REACTOR POWER(WATTS) 1.00000D 01

BUCKLINGS WERE MULTIPLIED BY -9.9998609D-01, FRACTION LOSS TO SEARCH PARAMETER -0.2660146

BOUNDARY NEUTRON LEAKAGE

GRP	LFT LEAKAGE	RIT LEAKAGE	TOP LEAKAGE	BOT LEAKAGE	FNT LEAKAGE	BAK LEAKAGE
1	0.0	2.99385D 11	2.59557D 12	0.0	7.25090D 12	7.25090D 12
2	0.0	4.54990D 10	1.44948D 11	0.0	4.04924D 11	4.04924D 11
SUM	0.0	3.44884E 11	2.74052E 12	0.0	7.65582E 12	7.65582E 12

GROUP NEUTRON BALANCE FOR EACH ZONE

ZONE	GRP	ABSORPTIONS	B**2 LOSSES	1/V LOSS	OUT-SCATTER	IN-SCATTER	P1 IN-SCATTER	SOURCE	POWER(WATTS)	AVERAGE FLUX
1	1	1.82956E 11	-2.49377E 12	0.0	5.03129E 11	0.0	0.0	1.29073E 13	7.62316E 00	7.05848E 10
1	2	4.11661E 10	-1.14610E 11	0.0	0.0	5.03129E 11	0.0	0.0	1.72438E 00	4.05497E 09
SUM		2.24123E 11	-2.60838E 12	0.0	5.03129E 11	5.03129E 11	0.0	1.29073E 13	9.34754E 00	
2	1	4.00925E 10	-1.06174E 12	0.0	2.97833E 11	0.0	0.0	1.88159E 12	2.86378E-01	2.65165E 10
2	2	3.69012E 10	-7.21733E 10	0.0	0.0	2.97833E 11	0.0	0.0	3.66083E-01	2.71172E 09
SUM		7.69937E 10	-1.13391E 12	0.0	2.97833E 11	2.97833E 11	0.0	1.88159E 12	6.52461E-01	
3	1	6.77399E 09	-1.70459E 11	0.0	8.72797E 10	0.0	0.0	0.0	0.0	5.36083E 09
3	2	1.79551E 10	-2.12921E 10	0.0	0.0	8.72797E 10	0.0	0.0	0.0	9.23618E 08
SUM		2.47291E 10	-1.91751E 11	0.0	8.72797E 10	8.72797E 10	0.0	0.0	0.0	

OVERALL NEUTRON BALANCE

GRP	ABSORPTIONS	B**2 LOSSES	1/V LOSS	OUT-SCATTER	IN-SCATTER	P1 IN-SCATTER	SOURCE	POWER(WATTS)
1	2.29823E 11	-3.72597E 12	0.0	8.88241E 11	0.0	0.0	1.47888E 13	7.90954E 00
2	9.60224E 10	-2.08075E 11	0.0	0.0	8.88241E 11	0.0	0.0	2.09046E 00
SUM	3.25845E 11	-3.93404E 12	0.0	8.88241E 11	8.88241E 11	0.0	1.47888E 13	1.00000E 01

ZONE AVERAGE FLUXES BY GROUP

GROUP 1
7.05848E 10 2.65165E 10 5.36083E 09

GROUP 2
4.05497E 09 2.71172E 09 9.23618E 08

ZONE VOLUMES FOLLOW. TOTAL VOLUME 6.75000E 03
2.16000E 03 2.16000E 03 2.43000E 03

ZONE AVERAGE FLUX INTERFACE FILE RZFLUX HAS BEEN WRITTEN ON CLD UNIT NUMBER 19

BUCKLINGS CALCULATED ALONG PLANE 2 FOLLOW

ZONE BUCKLINGS FOR GROUP 1
4.24406E-02 4.24406E-02 4.24406E-02

ZONE BUCKLINGS FOR GROUP 2
4.24406E-02 4.24407E-02 4.24406E-02

ZONE AVERAGE BUCKLINGS FOR EACH GROUP
4.24406E-02 4.24406E-02

ZONE AVERAGE DIFFUSION COEFFICIENTS FOR EACH GROUP
1.53388E 00 1.13175E 00

GROSS BUCKLING 4.24406E-02

BUCKLINGS CALCULATED ALONG PLANE 4 FOLLOW

ZONE BUCKLINGS FOR GROUP 1
4.24407E-02 4.24407E-02 4.24407E-02

ZONE BUCKLINGS FOR GROUP 2
4.24406E-02 4.24407E-02 4.24407E-02

ZONE AVERAGE BUCKLINGS FOR EACH GROUP
4.24407E-02 4.24407E-02

ZONE AVERAGE DIFFUSION COEFFICIENTS FOR EACH GROUP
1.53388E 00 1.13175E 00

THE MAXIMUM NEUTRON DENSITY IS AT PLANE 3, ROW 9, AND COLUMN 1 AND IS 2.05613367D 11 NEUTRONS/CC.

POINT POWER DISTRIBUTION (WATTS/CC)

PLANE NUMBER 1

	1	2	3	4	5	6	7	8	9
1	3.198D-04	3.046D-04	2.747D-04	2.309D-04	2.402D-05	1.542D-05	0.0	0.0	0.0
2	9.497D-04	9.046D-04	8.158D-04	6.857D-04	7.132D-05	4.580D-05	0.0	0.0	0.0
3	1.551D-03	1.477D-03	1.332D-03	1.120D-03	1.165D-04	7.478D-05	0.0	0.0	0.0
4	2.105D-03	2.005D-03	1.808D-03	1.520D-03	1.581D-04	1.015D-04	0.0	0.0	0.0
5	2.595D-03	2.471D-03	2.229D-03	1.873D-03	1.949D-04	1.251D-04	0.0	0.0	0.0
6	3.006D-03	2.863D-03	2.582D-03	2.170D-03	2.257D-04	1.449D-04	0.0	0.0	0.0
7	3.325D-03	3.168D-03	2.857D-03	2.401D-03	2.498D-04	1.604D-04	0.0	0.0	0.0
8	3.544D-03	3.376D-03	3.045D-03	2.559D-03	2.662D-04	1.709D-04	0.0	0.0	0.0
9	3.655D-03	3.482D-03	3.140D-03	2.639D-03	2.745D-04	1.763D-04	0.0	0.0	0.0

PLANE NUMBER 2

	1	2	3	4	5	6	7	8	9
1	8.372D-04	7.975D-04	7.193D-04	6.045D-04	6.288D-05	4.037D-05	0.0	0.0	0.0
2	2.486D-03	2.368D-03	2.136D-03	1.795D-03	1.867D-04	1.199D-04	0.0	0.0	0.0
3	4.060D-03	3.867D-03	3.488D-03	2.931D-03	3.049D-04	1.958D-04	0.0	0.0	0.0
4	5.510D-03	5.249D-03	4.733D-03	3.979D-03	4.138D-04	2.657D-04	0.0	0.0	0.0
5	6.793D-03	6.470D-03	5.835D-03	4.905D-03	5.102D-04	3.276D-04	0.0	0.0	0.0
6	7.869D-03	7.496D-03	6.760D-03	5.682D-03	5.910D-04	3.795D-04	0.0	0.0	0.0
7	8.706D-03	8.293D-03	7.479D-03	6.286D-03	6.539D-04	4.198D-04	0.0	0.0	0.0
8	9.279D-03	8.839D-03	7.971D-03	6.700D-03	6.969D-04	4.474D-04	0.0	0.0	0.0
9	9.570D-03	9.116D-03	8.221D-03	6.910D-03	7.187D-04	4.615D-04	0.0	0.0	0.0

PLANE NUMBER 3

	1	2	3	4	5	6	7	8	9
1	1.035D-03	9.858D-04	8.891D-04	7.473D-04	7.772D-05	4.990D-05	0.0	0.0	0.0
2	3.073D-03	2.927D-03	2.640D-03	2.219D-03	2.308D-04	1.482D-04	0.0	0.0	0.0
3	5.018D-03	4.780D-03	4.311D-03	3.623D-03	3.769D-04	2.420D-04	0.0	0.0	0.0
4	6.811D-03	6.488D-03	5.851D-03	4.918D-03	5.115D-04	3.284D-04	0.0	0.0	0.0
5	8.396D-03	7.998D-03	7.213D-03	6.063D-03	6.306D-04	4.049D-04	0.0	0.0	0.0
6	9.726D-03	9.265D-03	8.356D-03	7.023D-03	7.305D-04	4.690D-04	0.0	0.0	0.0
7	1.076D-02	1.025D-02	9.245D-03	7.771D-03	8.082D-04	5.189D-04	0.0	0.0	0.0
8	1.147D-02	1.093D-02	9.853D-03	8.282D-03	8.614D-04	5.531D-04	0.0	0.0	0.0
9	1.183D-02	1.127D-02	1.016D-02	8.541D-03	8.884D-04	5.704D-04	0.0	0.0	0.0

PLANE NUMBER 4

	1	2	3	4	5	6	7	8	9
1	8.372D-04	7.975D-04	7.193D-04	6.045D-04	6.288D-05	4.037D-05	0.0	0.0	0.0
2	2.486D-03	2.368D-03	2.136D-03	1.795D-03	1.867D-04	1.199D-04	0.0	0.0	0.0
3	4.060D-03	3.867D-03	3.488D-03	2.931D-03	3.049D-04	1.958D-04	0.0	0.0	0.0
4	5.510D-03	5.249D-03	4.733D-03	3.979D-03	4.138D-04	2.657D-04	0.0	0.0	0.0
5	6.793D-03	6.470D-03	5.835D-03	4.905D-03	5.102D-04	3.276D-04	0.0	0.0	0.0
6	7.869D-03	7.496D-03	6.760D-03	5.682D-03	5.910D-04	3.795D-04	0.0	0.0	0.0
7	8.706D-03	8.293D-03	7.479D-03	6.286D-03	6.539D-04	4.198D-04	0.0	0.0	0.0
8	9.279D-03	8.839D-03	7.971D-03	6.700D-03	6.969D-04	4.474D-04	0.0	0.0	0.0
9	9.570D-03	9.116D-03	8.221D-03	6.910D-03	7.187D-04	4.615D-04	0.0	0.0	0.0

PLANE NUMBER 5

	1	2	3	4	5	6	7	8	9
1	3.198D-04	3.046D-04	2.747D-04	2.309D-04	2.402D-05	1.542D-05	0.0	0.0	0.0
2	9.497D-04	9.046D-04	8.158D-04	6.857D-04	7.132D-05	4.580D-05	0.0	0.0	0.0
3	1.551D-03	1.477D-03	1.332D-03	1.120D-03	1.165D-04	7.478D-05	0.0	0.0	0.0
4	2.105D-03	2.005D-03	1.808D-03	1.520D-03	1.581D-04	1.015D-04	0.0	0.0	0.0
5	2.595D-03	2.471D-03	2.229D-03	1.873D-03	1.949D-04	1.251D-04	0.0	0.0	0.0
6	3.006D-03	2.863D-03	2.582D-03	2.170D-03	2.257D-04	1.449D-04	0.0	0.0	0.0
7	3.325D-03	3.168D-03	2.857D-03	2.401D-03	2.498D-04	1.604D-04	0.0	0.0	0.0
8	3.544D-03	3.376D-03	3.045D-03	2.559D-03	2.662D-04	1.709D-04	0.0	0.0	0.0
9	3.655D-03	3.482D-03	3.140D-03	2.639D-03	2.745D-04	1.763D-04	0.0	0.0	0.0

THE RELATIVE POWER DENSITY TRAVERSE LEFT-TO-RIGHT IS

ADJOINT PROBLEM FOLLOWS

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

PROC=0,1,2,3,4-NORMAL,CHEBYSHEV,SEMEX,DEMEX,SEMEXP. ICVR=0,1-YES,NO INNERS CONVR. OCVR=0,1-YES,NO OUTERS CONVR.

ITER	PROC	ICVR	OCVR	FLUX CHANGE	MU-BAR	MU-1	MU-LOSS	ACCELERATION PARAMETERS	
1	0	1	1	1.83088D 01	0.0	0.0	0.0	0.0	0.0
2	0	0	1	1.64111D 00	0.34307	1.73075	0.00420	-1.06744	-1.07363
3	0	0	1	7.07084D-01	0.42714	1.13794	-2.26613	0.59082	0.04632
4	0	1	0	1.75557D-01	0.30374	0.42384	0.17774	0.01550	0.21843
5	0	0	0	1.73447D-02	0.17322	0.11614	0.41792	0.95229	-0.26790
6	0	0	1	6.29468D-03	0.22743	0.36921	0.37263	0.14043	0.02492
7	0	0	0	2.16919D-03	0.34712	0.34678	0.35773	1.79825	-0.24343
8	2	0	0	8.59071D-04	0.35149	0.34786	0.35776	0.14096	0.0
9	0	0	0	1.31799D-05	0.0	0.0	0.0	0.0	0.0
10	0	0	0	4.53367D-06	0.30975	0.34395	0.37779	0.01517	0.01060

MULTIPLICATION RELIABILITY ESTIMATORS

BY THE SUM OF THE SQUARES OF THE RESIDUES---------- 0.0900000

UPPER AND LOWER BOUNDS ESTIMATES BY MAX REL FLUX CHANGE---------- 0.0900004 0.0899996

UPPER AND LOWER BOUNDS ESTIMATES OVER ALL SIGNIFICANT POINTS------- 0.0900037 0.0899989

FINAL GROUP OVERRELAXATION COEFFICIENTS AND NUMBER OF INNER ITERATIONS

1.44714E 00 1.43015E 00

4 4

CPU AND CLOCK MINUTES REQUIRED FOR THIS EIGENVALUE PROBLEM ARE 0.099 1.833

PERTURBATION RESULTS---DELTA-K/(K*DELTA-S) WHERE S REPRESENTS MACRO. CROSS SECTIONS. BIG DADDY = 4.354622D-13

ZONE	GRP	SIGA,SIGR,DB**2	B**2	NU*SIGF	DIFF. COEF.
1	1	-1.104552E 01	-1.656628E 01	1.227280E 02	-5.922500E-01
	2	-6.721984E 00	-8.066374E 00	7.000963E 00	-3.475163E-01
2	1	-2.113982E 00	-3.593772E 00	2.348869E 01	-1.445178E-01
	2	-1.962777E 00	-2.217937E 00	2.345307E 00	-1.184282E-01
3	1	-1.873071E-01	-2.247685E-01	2.081191E 00	-2.000709E-02
	2	-1.937938E-01	-1.686007E-01	3.451992E-01	-1.991298E-02

GRP. TO GRP. DELTA-K/(K*DELTA-SIGS) FOR ALL ZONES 1,2,3,.... - (THE IN-GROUP TERMS MAKE NO CONTRIBUTION.)

1	1	1.104552E 01	2.113982E 00	1.873071E-01
2	1	6.300865E-01	2.110776E-01	3.106793E-02
1	2	1.178734E 02	1.977754E 01	1.175526E 00
2	2	6.721984E 00	1.962777E 00	1.937938E-01

PROMPT-NEUTRON LIFETIME IS 2.22254D 01 SEC.

THE FOLLOWING ARE CHANGES IN KEFFECTIVE DUE TO 100 PERCENT CHANGE IN MACROSCOPIC CROSS SECTIONS.
(DIVIDE BY 100 TO GET THE EFFECT OF A 1 PERCENT CHANGE).

FOR INSCATTER

GRP. TO GRP.		FOR ALL ZONES		
1	1	0.0	0.0	0.0
2	1	0.0	0.0	0.0
1	2	3.889819E-01	1.028432E-01	7.876035E-03
2	2	0.0	0.0	0.0

SUM OF ALL INSCATTER IS 4.997011E-01

ZONE	GRP	REMOVAL
1	1	-3.645019E-02
	2	0.0
2	1	-1.099270E-02
	2	0.0
3	1	-1.254957E-03
	2	0.0

SUM IS -4.869785E-02

ZONE	GRP	ABSORPTIONS	SCATTERING	FISSION SOURCE	TRANSPORT
1	1	-1.325460E-02	3.525317E-01	4.909115E-01	4.441877E-01
	2	-3.159329E-02	0.0	4.410602E-01	2.085097E-01
2	1	-1.479781E-03	9.185052E-02	9.395473E-03	1.231802E-01
	2	-1.236549E-02	0.0	5.863265E-02	6.691188E-02
3	1	-9.739940E-05	6.621074E-03	0.0	1.200425E-02
	2	-1.550350E-03	0.0	0.0	8.662149E-03

SUMS OVER GROUPS

ZONE				
1	-4.484789E-02	3.525317E-01	9.319717E-01	6.526974E-01
2	-1.384527E-02	9.185052E-02	6.802809E-02	1.900921E-01
3	-1.647750E-03	6.621074E-03	0.0	2.066640E-02

SUMS OVER ZONES

GRP				
1	-1.483178E-02	4.510033E-01	5.003069E-01	5.793721E-01

```
        2    -4.550913E-02   0.0             4.996928E-01   2.840837E-01

TOTAL SUMS
             -6.034091E-02   4.510033E-01   9.999997E-01   8.634558E-01

TOTAL SUM IS  2.25412E 00


THE FOLLOWING ARE UNCERTAINTY ASSOCIATED WITH A 100 PERCENT UNCERTAINTY IN THE DATA (UNCORRELATED), BUT NET
SCATTERING IN THE ABOVE TABLE TREATED AS AN ENTITY.

SUMS OVER GROUPS
 ZONE
   1          3.426106E-02   3.525317E-01   6.599455E-01   4.906924E-01
   2          1.245372E-02   9.185052E-02   5.938065E-02   1.401805E-01
   3          1.553406E-03   6.621074E-03   0.0            1.480320E-02

SUMS OVER ZONES
       GRP
        1     1.333730E-02   3.643610E-01   4.910013E-01   4.611074E-01
        2     3.396240E-02   0.0            4.449403E-01   2.191541E-01

TOTAL SUMS
              3.648737E-02   3.643610E-01   6.626116E-01   5.105374E-01

TOTAL SUM IS  9.13123E-01


*****************************************************************************************
NORMALIZATION OF IMPORTANCE MAPS IS TO UNIT FISSION SOURCE IMPORTANCE FOR THE ACTUAL PROBLEM.     *
MULTIPLY BY THE FRACTION OF THE CORE TREATED IF THE VALUES ARE TO BE MADE RELATIVE TO THE         *
TOTAL, BUT TAKE CARE TO UNDERSTAND THAT THIS IS APPROPRIATE IN A SPECIFIC SITUATION.              *
*****************************************************************************************
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MACRO. ABSORP. CROSS SECTION IMPORTANCE MAP (SIGA/K)(DELTA K/DELTA SIGA).

PLANE NUMBER 1

	1	2	3	4	5	6	7	8	9
1	7.353D-08	6.758D-08	5.678D-08	4.308D-08	2.654D-08	1.065D-08	4.571D-09	1.217D-09	1.141D-10
2	6.484D-07	5.960D-07	5.007D-07	3.799D-07	2.341D-07	9.396D-08	4.031D-08	1.073D-08	1.006D-09
3	1.729D-06	1.589D-06	1.335D-06	1.013D-06	6.241D-07	2.505D-07	1.075D-07	2.861D-08	2.682D-09
4	3.185D-06	2.927D-06	2.459D-06	1.866D-06	1.150D-06	4.615D-07	1.980D-07	5.271D-08	4.941D-09
5	4.840D-06	4.448D-06	3.738D-06	2.836D-06	1.747D-06	7.013D-07	3.009D-07	8.011D-08	7.509D-09
6	6.495D-06	5.970D-06	5.016D-06	3.806D-06	2.345D-06	9.412D-07	4.038D-07	1.075D-07	1.008D-08
7	7.951D-06	7.308D-06	6.140D-06	4.659D-06	2.870D-06	1.152D-06	4.943D-07	1.316D-07	1.234D-08
8	9.031D-06	8.301D-06	6.974D-06	5.292D-06	3.260D-06	1.309D-06	5.615D-07	1.495D-07	1.401D-08
9	9.606D-06	8.829D-06	7.418D-06	5.628D-06	3.468D-06	1.392D-06	5.972D-07	1.590D-07	1.490D-08

PLANE NUMBER 2

	1	2	3	4	5	6	7	8	9
1	5.040D-07	4.632D-07	3.892D-07	2.953D-07	1.819D-07	7.303D-08	3.133D-08	8.341D-09	7.819D-10
2	4.444D-06	4.085D-06	3.432D-06	2.604D-06	1.604D-06	6.440D-07	2.763D-07	7.356D-08	6.896D-09
3	1.185D-05	1.089D-05	9.151D-06	6.943D-06	4.277D-06	1.717D-06	7.367D-07	1.961D-07	1.839D-08
4	2.183D-05	2.006D-05	1.686D-05	1.279D-05	7.879D-06	3.163D-06	1.357D-06	3.613D-07	3.387D-08
5	3.317D-05	3.049D-05	2.562D-05	1.944D-05	1.197D-05	4.807D-06	2.062D-06	5.491D-07	5.147D-08
6	4.452D-05	4.092D-05	3.438D-05	2.608D-05	1.607D-05	6.451D-06	2.768D-06	7.368D-07	6.907D-08
7	5.450D-05	5.009D-05	4.208D-05	3.193D-05	1.967D-05	7.897D-06	3.388D-06	9.020D-07	8.455D-08
8	6.190D-05	5.689D-05	4.780D-05	3.627D-05	2.234D-05	8.970D-06	3.848D-06	1.025D-06	9.604D-08
9	6.584D-05	6.052D-05	5.085D-05	3.858D-05	2.377D-05	9.541D-06	4.093D-06	1.090D-06	1.022D-07

PLANE NUMBER 3

	1	2	3	4	5	6	7	8	9
1	7.700D-07	7.077D-07	5.946D-07	4.512D-07	2.779D-07	1.116D-07	4.787D-08	1.274D-08	1.195D-09
2	6.790D-06	6.241D-06	5.244D-06	3.979D-06	2.451D-06	9.839D-07	4.222D-07	1.124D-07	1.054D-08
3	1.810D-05	1.664D-05	1.398D-05	1.061D-05	6.535D-06	2.623D-06	1.126D-06	2.997D-07	2.809D-08
4	3.335D-05	3.065D-05	2.575D-05	1.954D-05	1.204D-05	4.832D-06	2.073D-06	5.520D-07	5.174D-08
5	5.068D-05	4.658D-05	3.914D-05	2.970D-05	1.830D-05	7.344D-06	3.151D-06	8.389D-07	7.864D-08
6	6.802D-05	6.252D-05	5.253D-05	3.985D-05	2.455D-05	9.856D-06	4.229D-06	1.126D-06	1.055D-07
7	8.326D-05	7.653D-05	6.430D-05	4.879D-05	3.006D-05	1.207D-05	5.176D-06	1.378D-06	1.292D-07
8	9.458D-05	8.693D-05	7.304D-05	5.541D-05	3.414D-05	1.370D-05	5.880D-06	1.565D-06	1.467D-07
9	1.006D-04	9.246D-05	7.769D-05	5.894D-05	3.631D-05	1.458D-05	6.254D-06	1.665D-06	1.561D-07

PLANE NUMBER 4

	1	2	3	4	5	6	7	8	9
1	5.040D-07	4.632D-07	3.892D-07	2.953D-07	1.819D-07	7.303D-08	3.133D-08	8.341D-09	7.819D-10
2	4.444D-06	4.085D-06	3.432D-06	2.604D-06	1.604D-06	6.440D-07	2.763D-07	7.356D-08	6.896D-09
3	1.185D-05	1.089D-05	9.151D-06	6.943D-06	4.277D-06	1.717D-06	7.367D-07	1.961D-07	1.839D-08
4	2.183D-05	2.006D-05	1.686D-05	1.279D-05	7.879D-06	3.163D-06	1.357D-06	3.613D-07	3.387D-08
5	3.317D-05	3.049D-05	2.562D-05	1.944D-05	1.197D-05	4.807D-06	2.062D-06	5.491D-07	5.147D-08
6	4.452D-05	4.092D-05	3.438D-05	2.608D-05	1.607D-05	6.451D-06	2.768D-06	7.368D-07	6.907D-08
7	5.450D-05	5.009D-05	4.208D-05	3.193D-05	1.967D-05	7.897D-06	3.388D-06	9.020D-07	8.455D-08
8	6.190D-05	5.689D-05	4.780D-05	3.627D-05	2.234D-05	8.970D-06	3.848D-06	1.025D-06	9.604D-08
9	6.584D-05	6.052D-05	5.085D-05	3.858D-05	2.377D-05	9.541D-06	4.093D-06	1.090D-06	1.022D-07

PLANE NUMBER 5

	1	2	3	4	5	6	7	8	9
1	7.353D-08	6.758D-08	5.678D-08	4.308D-08	2.654D-08	1.065D-08	4.571D-09	1.217D-09	1.141D-10
2	6.484D-07	5.960D-07	5.007D-07	3.799D-07	2.341D-07	9.396D-08	4.031D-08	1.073D-08	1.006D-09
3	1.729D-06	1.589D-06	1.335D-06	1.013D-06	6.241D-07	2.505D-07	1.075D-07	2.861D-08	2.682D-09
4	3.185D-06	2.927D-06	2.459D-06	1.866D-06	1.150D-06	4.615D-07	1.980D-07	5.271D-08	4.941D-09
5	4.840D-06	4.448D-06	3.738D-06	2.836D-06	1.747D-06	7.013D-07	3.009D-07	8.011D-08	7.509D-09
6	6.495D-06	5.970D-06	5.016D-06	3.806D-06	2.345D-06	9.412D-07	4.038D-07	1.075D-07	1.008D-08
7	7.951D-06	7.308D-06	6.140D-06	4.659D-06	2.870D-06	1.152D-06	4.943D-07	1.316D-07	1.234D-08
8	9.031D-06	8.301D-06	6.974D-06	5.292D-06	3.260D-06	1.309D-06	5.615D-07	1.495D-07	1.401D-08
9	9.606D-06	8.829D-06	7.418D-06	5.628D-06	3.468D-06	1.392D-06	5.972D-07	1.590D-07	1.490D-08

```
SCAT SUB-BLOCK     1
   3.677588E 00   8.492583E-02   3.054230E 00   5.449738E-02   4.296340E 00   3.122898E-02   0.0            0.0
   2.785958E-05   1.468200E 02   1.011978E-01   1.047090E 01   6.575632E-02   1.617558E 01   9.805173E-02   0.0
   0.             4.569246E-06   9.642159E 00   2.030289E-02   0.0            2.710728E-05   2.003558E 01   3.956908E-02
   1.172910E 01   1.911249E-02   2.076548E-05   1.838379E 01   1.897439E-02   3.887147E-04   1.321710E 01   2.247639E-02
   1.921140E 01   3.237759E-02   1.642758E-05   1.299899E 01   2.077499E-02   1.391029E-03   2.431760E 01   3.522348E-02
   6.624368E-05   0.0


LISTING OF INTERFACE FILE GROUPXS COMPLETED


 2-D  17X10 - 5 GROUP SEARCH PROBLEM
 PRIMARY SEARCH = NUCLIDE(DIRECT) - SECONDARY SEARCH = DIMENSION

**********START EXECUTING NEUTRONICS CODE BLOCK**********

*** WARNING *** UNIT   13  WILL BE READ BUT IT MAY NOT HAVE BEEN WRITTEN

*** WARNING *** UNIT   14  WILL BE READ BUT IT MAY NOT HAVE BEEN WRITTEN

*** WARNING *** UNIT   12  WILL BE READ BUT IT MAY NOT HAVE BEEN WRITTEN

*** WARNING *** UNIT   15  WILL BE READ BUT IT MAY NOT HAVE BEEN WRITTEN

SOLUTION BY FINITE-DIFFERENCE DIFFUSION THEORY
SEARCH PROBLEM
     DIRECT CONCENTRATION SEARCH
A REGULAR ADJOINT WILL FOLLOW FORWARD PROBLEM
PERTURBATION RESULTS ARE REQUESTED
GEOMETRY NO.  7   2-D R-Z
NUMBER OF ENERGY GROUPS                          5
NUMBER OF UPSCATTER GROUPS (MAX)                 0
NUMBER OF DOWNSCATTER GROUPS (MAX)               4
NUMBER OF INTERVALS IN DIMENSION 1 (COLUMNS)    17
NUMBER OF INTERVALS IN DIMENSION 2 (ROWS)       10
NUMBER OF INTERVALS IN DIMENSION 3 (PLANES)      1
NUMBER OF ZONES                                  8
NUMBER OF REGIONS                               18
NUMBER OF BLACK ABSORBER ZONES                   0
BOUNDARY INDICATORS-   LEFT  1  RIGHT  2
                        TOP  2 BOTTOM  1


                                    MEMORY REQUIREMENTS FOR DATA STORAGE

                                          TOTAL                A          B          C          D
                                       MINIMUM   MAXIMUM
STORAGE AVAILABLE                        10000
MACRO CALCULATION                          968
EQUATION CONSTANTS CALCULATION
          CORE CONTAINED OR SPACE STORED  1396      1396
          PLANE STORED                    1736      1736
          ROW STORED                       705       705
          MULTI-LEVEL PLANE STORED        1889      1889
INITIAL FLUX                               774       774
INITIAL OVERRELAXATION PARAMETERS          490
ITERATIVE PROCESS
          CORE CONTAINED                  8221                6255       779        480        707
          SPACE STORED                    3046                2067       779        200          0
        1 PLANES STORED                   3727                2748       779        200          0
        1 PLANE STORED                    3727                2748       779        200          0
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      10 ROWS STORED                          2961                1982       779       200         0
       1 ROW STORED                            979                   0       779       200         0
       1 MULTI-LEVEL PLANES STORED            4559                1020       779       200      2560
PERTURBATION CALCULATION                       934

DATA WILL BE STORED FOR ALL GROUPS, ALL SPACE

MEMORY LOCATIONS RESERVED FOR DATA STORAGE---    10000
MAX MEMORY LOCATIONS REQUIRED FOR THIS PROB--     8221
MEMORY LOCATIONS NOT USED-------------------      1779

DD PARAMETERS FOLLOW FOR  B1 = 3520  AND  B2 =   5440
N2=   3  N3=  12  N4=   1  N5=   6  N6=  10  N7=   1  N8=   1  N9=   1  N10=   1  N11=   1  N12=   4  N13=   1  N14=   1  N15=  10

REQUIRED DISK STORAGE SPACE FOR FLUX(UNITS 24,27,28) IS      10560 BYTES.
                            FOR CONSTANTS(UNIT 40) IS--      32640 BYTES.
                            FOR CONSTANTS(UNIT 23) IS--      42240 BYTES.
REQUIRED TOTAL DISK STORAGE SPACE IS-------------------    5546880 BYTES.

THE REGION SIZE FOR SMALL PROBLEMS IN THE ALL-STORED MODE IS APPROXIMATELY   240K BYTES.
THE REGION SIZE FOR LARGE PROBLEMS IN THE PLANE-STORED MODE IS APPROXIMATELY 370K BYTES.

                    DIRECT ACCESS DATASET REQUIREMENTS

                    MAXIMUM PHYSICAL RECORD IS     7200 WORDS

    UNIT      NUMBER OF      LOGICAL RECORD  PHYSICAL REC     NUMBER OF      PHYSICAL RECORD
   NUMBER  LOGICAL RECORDS  LENGTH (WORDS)  /LOGICAL REC  PHYSICAL RECORDS  LENGTH (WORDS)
     23            50            120              1             50              120
     24             5            340              1              5              340
     27             5            340              1              5              340
     28             5            340              1              5              340
     25            50             34              1             50               36
     26            50             34              1             50               36
     40             5            707              1              5              708

STORAGE FOR MACRO CALCULATION
SUPPLIED   10000
REQUIRED     969


STORAGE FOR SEARCH MACRO CALCULATION
SUPPLIED   10000
REQUIRED     857


PRINCIPAL MACROSCOPIC CROSS SECTIONS

GROUP    1
ZONE   D              SIGA           SIGNF          SIGWF          SIGAS          SIGNFS
    1  2.516465E 00  5.792666E-03  1.421664E-02  1.536809E-13  9.401215E-04  2.849508E-03
    2  2.491580E 00  4.330136E-03  9.215195E-03  1.034325E-13  0.0           0.0
    3  2.491576E 00  4.330140E-03  9.215225E-03  1.034326E-13  0.0           0.0
    4  2.491576E 00  4.330140E-03  9.215225E-03  1.034326E-13  0.0           0.0
    5  2.491576E 00  4.330140E-03  9.215225E-03  1.034326E-13  0.0           0.0
    6  2.491576E 00  4.330140E-03  9.215225E-03  1.034326E-13  0.0           0.0
    7  2.121200E 00  8.190463E-04  6.389623E-06  0.0           0.0           0.0
    8  2.121200E 00  8.190463E-04  6.389623E-06  0.0           0.0           0.0

GROUP    2
ZONE   D              SIGA           SIGNF          SIGWF          SIGAS          SIGNFS
    1  1.453617E 00  3.342617E-03  4.837800E-03  5.416419E-14  6.200797E-04  1.484710E-03
    2  1.438300E 00  1.975165E-03  9.110016E-04  1.033252E-14  0.0           0.0
    3  1.438299E 00  1.975170E-03  9.110027E-04  1.033252E-14  0.0           0.0
```

4	1.438299E 00	1.975170E-03	9.110027E-04	1.033252E-14	0.0	0.0
5	1.438299E 00	1.975170E-03	9.110027E-04	1.033252E-14	0.0	0.0
6	1.438299E 00	1.975170E-03	9.110027E-04	1.033252E-14	0.0	0.0
7	1.276845E 00	5.057480E-04	0.0	0.0	0.0	0.0
8	1.276845E 00	5.057480E-04	0.0	0.0	0.0	0.0

GROUP 3

ZONE	D	SIGA	SIGNF	SIGWF	SIGAS	SIGNFS
1	9.447532E-01	6.746028E-03	5.472325E-03	6.199490E-14	8.871062E-04	1.604511E-03
2	9.359486E-01	5.115528E-03	1.075083E-03	1.238740E-14	0.0	0.0
3	9.359536E-01	5.115535E-03	1.075084E-03	1.238741E-14	0.0	0.0
4	9.359536E-01	5.115535E-03	1.075084E-03	1.238741E-14	0.0	0.0
5	9.359536E-01	5.115535E-03	1.075084E-03	1.238741E-14	0.0	0.0
6	9.359536E-01	5.115535E-03	1.075084E-03	1.238741E-14	0.0	0.0
7	6.192686E-01	1.612214E-03	0.0	0.0	0.0	0.0
8	6.192686E-01	1.612214E-03	0.0	0.0	0.0	0.0

GROUP 4

ZONE	D	SIGA	SIGNF	SIGWF	SIGAS	SIGNFS
1	6.452593E-01	1.574807E-02	1.068695E-02	1.212021E-13	2.050783E-03	3.078995E-03
2	6.413477E-01	1.179417E-02	2.138645E-03	2.472050E-14	0.0	0.0
3	6.413473E-01	1.179422E-02	2.138647E-03	2.472052E-14	0.0	0.0
4	6.413473E-01	1.179422E-02	2.138647E-03	2.472052E-14	0.0	0.0
5	6.413473E-01	1.179422E-02	2.138647E-03	2.472052E-14	0.0	0.0
6	6.413473E-01	1.179422E-02	2.138647E-03	2.472052E-14	0.0	0.0
7	3.954161E-01	7.729638E-03	0.0	0.0	0.0	0.0
8	3.954161E-01	7.729638E-03	0.0	0.0	0.0	0.0

GROUP 5

ZONE	D	SIGA	SIGNF	SIGWF	SIGAS	SIGNFS
1	6.781518E-01	3.251838E-02	2.851023E-02	3.233347E-13	5.601514E-03	8.106362E-03
2	6.903558E-01	1.931511E-02	5.696688E-03	6.586382E-14	0.0	0.0
3	6.903527E-01	1.931519E-02	5.696688E-03	6.586387E-14	0.0	0.0
4	6.903527E-01	1.931519E-02	5.696688E-03	6.586387E-14	0.0	0.0
5	6.903527E-01	1.931519E-02	5.696688E-03	6.586387E-14	0.0	0.0
6	6.903527E-01	1.931519E-02	5.696688E-03	6.586387E-14	0.0	0.0
7	3.869154E-01	1.466906E-02	0.0	0.0	0.0	0.0
8	3.869154E-01	1.466906E-02	0.0	0.0	0.0	0.0

FISSION SPECTRUM CONSTANT FOR ALL ZONES

7.550370E-01	2.380250E-01	6.937999E-03	0.0	0.0

1/V CONSTANT FOR ALL ZONES

3.876078E-04	1.121930E-03	3.081634E-03	9.142663E-03	2.393971E-02

ZONE VOLUMES

2.669836E 05	2.235057E 05	1.878849E 05	1.572882E 05	2.960026E 05	2.083066E 05	4.988512E 05	4.459434E 05

SCATTERING MACROSCOPIC CROSS SECTIONS

GROUP 1 MBAND 1 MJJ 1

TPO

0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

GROUP 2 MBAND 2 MJJ 1

TPO

0.0	3.099186E-02	0.0	3.272266E-02	0.0	3.272273E-02	0.0	3.272273E-02
0.0	3.272273E-02	0.0	3.272273E-02	0.0	2.414452E-02	0.0	2.414452E-02

GROUP 3 MBAND 3 MJJ 1

TPO

0.0	6.354101E-03	5.214883E-04	0.0	6.463207E-03	5.669191E-04	0.0	6.463237E-03
5.669224E-04	0.0	6.463237E-03	5.669224E-04	0.0	6.463237E-03	5.669224E-04	0.0
6.463237E-03	5.669224E-04	0.0	4.524011E-03	6.934805E-04	0.0	4.524011E-03	6.934805E-04

```
GROUP    4  MBAND    4  MJJ    1
TPO
  0.0            5.591076E-03  7.068575E-06  1.036582E-05  0.0           5.589414E-03  7.527391E-06  1.062008E-05
  0.0            5.589440E-03  7.527407E-06  1.062010E-05  0.0           5.589440E-03  7.527407E-06  1.062010E-05
  0.0            5.589440E-03  7.527407E-06  1.062010E-05  0.0           5.589440E-03  7.527407E-06  1.062010E-05
  0.0            7.264681E-03  1.163266E-05  3.452154E-05  0.0           7.264681E-03  1.163266E-05  3.452154E-05

GROUP    5  MBAND    5  MJJ    1
TPO
  0.0            3.247920E-03  2.834759E-06  1.405918E-08  9.156958E-08  0.0           3.246953E-03  3.342082E-06
  1.405917E-08   9.156952E-08  0.0           3.246958E-03  3.342087E-06  1.405918E-08  9.156958E-08  0.0
  3.246958E-03   3.342087E-06  1.405918E-08  9.156958E-08  0.0           3.246958E-03  3.342087E-06  1.405918E-08
  9.156958E-08   0.0           3.246958E-03  3.342087E-06  1.405918E-08  9.156958E-08  0.0           4.516136E-03
  0.0            5.486510E-08  3.573390E-07  0.0           4.516136E-03  0.0           5.486510E-08  3.573390E-07

SCATTERING REMOVAL
GROUP    1
  3.152382D-02   3.330036D-02  3.330038D-02  3.330038D-02  3.330038D-02  3.330038D-02  2.487289D-02  2.487289D-02
GROUP    2
  6.361208D-03   6.470796D-03  6.470800D-03  6.470800D-03  6.470800D-03  6.470800D-03  4.535699D-03  4.535699D-03
GROUP    3
  5.593935D-03   5.592799D-03  5.592802D-03  5.592802D-03  5.592802D-03  5.592802D-03  7.264688D-03  7.264688D-03
GROUP    4
  3.247921D-03   3.246958D-03  3.246959D-03  3.246959D-03  3.246959D-03  3.246959D-03  4.516141D-03  4.516141D-03
GROUP    5
  0.0            0.0           0.0           0.0           0.0           0.0           0.0           0.0

FINE MESH DESCRIPTION - POINT IS LOCATED AT THE CENTROID OF THE VOLUME ELEMENT
DISTANCE TO POINT - DIMENSION 1 (LEFT TO RIGHT)
    1   6.2410     2  10.8097     3  20.7514     4  31.3091     5  39.1139     6  45.3280     7  50.5416     8  55.2654
    9  61.3612    10  68.4633    11  74.8950    12  81.7364    13  88.8928    14  95.5146    15 101.3582    16 106.5518
   17 111.5037
DISTANCE TO BOUNDARY
    1   0.0        2   8.8261     3  12.4820     4  26.5601     5  35.4271     6  42.4820     7  48.0056     8  52.9562
    9  57.4820    10  65.0093    11  71.7513    12  77.9120    13  85.3896    14  92.2632    15  98.6590    16 103.9875
   17 109.0559    18 113.8990
DISTANCE TO POINT - DIMENSION 2 (TOP TO BOTTOM)
    1   2.0400     2   6.1200     3  10.2000     4  15.2567     5  21.2900     6  27.3233     7  33.5550     8  39.9850
    9  46.4150    10  52.8450
DISTANCE TO BOUNDARY
    1   0.0        2   4.0800     3   8.1600     4  12.2400     5  18.2733     6  24.3067     7  30.3400     8  36.7700
    9  43.2000    10  49.6300    11  56.0600

SEARCH LIMITING FACTORS - SP1 =  -5.805285E 00 SP2 =  -1.039481E 01  SA =   1.009960E-02 SNF =   1.712408E-02

REFERENCE ZONE FOR INITIALIZATION WILL BE     1

SUM OF REGION VOLUMES FROM GEODST                    2.284771D 06
SUM OF REGION VOLUMES COMPUTED FROM POINT VOLUMES    2.284769D 06
SUM OF ZONE VOLUMES (FROM COMPUTED REGION VOLUMES)   2.284769D 06
SUM OF ZONE VOLUMES  FROM NDXSRF                     2.284771D 06

INITIAL FLUX IS CONSTANT

ENERGY DEPENDENT OVERRELAXATION COEFFICIENTS CALCULATED
SPACE POINT AT COLUMN =     2 ROW =     9 PLANE =     1 ZONE =     1
K =  1 FK =   8.977555E-01 TI =   5.743311E 02 TD =   5.156069E 02 NREC =    9
K =  2 FK =   9.512308E-01 TI =   3.131077E 02 TD =   2.978376E 02 NREC =   19
K =  3 FK =   9.088309E-01 TI =   2.129929E 02 TD =   1.935745E 02 NREC =   29
K =  4 FK =   8.155953E-01 TI =   1.621023E 02 TD =   1.322099E 02 NREC =   39
K =  5 FK =   7.308475E-01 TI =   1.901209E 02 TD =   1.389494E 02 NREC =   49
RHOMIN =   7.148064E-01  QF =   8.518455E-01  RHOMAX =   9.303526E-01
 NBJ =  1  XJ =   9.957342E-01
 NBI =  2  XI =   9.876884E-01
NBKB =  0 XKB =   0.0
```

A FLUX - EIGENVALUE PROBLEM FOLLOWS
4 INNERS MIN, 4 INNERS MAX - CHEBYCHEV BETA ON OUTERS
PROC=0,1,2,3,4-NORMAL,CHEBYSHEV,SEMEX,DEMEX,SEMEXF. ICVR=0,1-YES,NO INNERS CONVR. OCVR=0,1-YES,NO OUTERS CONVR.

ITER	PROC	ICVR	OCVR	FLUX CHANGE	MU-BAR	MU-1	MU-LOSS	ACCELERATION PARAMETERS		K	SEARCH FACTOR	S.F.-CALC
1	0	1	1	4.39584D 01	0.0	0.0	0.0	0.0	0.0	0.6308038	0.0	0.0
2	0	1	1	1.73189D 02	0.16135	177.12836	-0.36335	0.19240	0.0	0.6631133	0.0	4.87592D 00
3	0	1	1	2.23747D 02	0.61604	225.03884	0.50934	0.30551	0.09595	0.7846156	4.87592D-01	3.27543D 00
4	0	1	0	1.66452D 01	0.23920	16.71962	0.44247	0.23130	0.10144	0.8353485	7.66376D-01	2.85926D 00
5	0	1	0	1.21354D 00	0.13122	1.28645	0.63724	0.36150	-0.05749	0.8749117	9.75665D-01	2.56544D 00
6	0	1	0	-5.36175D-01	0.32908	0.18254	0.66317	-0.04917	0.05468	0.9009923	1.13464D 00	2.40926D 00
7	0	1	0	-3.35712D-01	0.30461	0.29041	0.71951	0.41587	0.00756	0.9201270	1.26210D 00	2.31082D 00
8	0	1	0	-2.42356D-01	0.47692	0.47956	0.75279	-0.53152	0.33070	0.9348861	1.36698D 00	2.24334D 00
9	0	1	1	-1.86592D-01	0.78966	0.58332	0.69068	-13.68420	3.34435	0.9571706	1.54225D 00	2.16059D 00
10	0	1	1	-1.35801D-01	0.79475	0.59200	0.50286	3.91107	-0.03009	0.9868479	1.78959D 00	2.06232D 00
11	0	0	0	-8.06977D-02	0.77327	0.51354	0.16970	0.09795	2.90814	1.0126222	2.00778D 00	1.97670D 00
12	0	0	0	-3.95251D-02	0.53861	0.45027	-0.00937	-1.66329	4.45432	1.0097924	1.97670D 00	1.97915D 00
13	0	1	0	-1.43415D-02	0.28348	0.34850	-0.71923	2.04299	-1.37790	1.0102849	1.97915D 00	1.97577D 00
14	0	1	0	-4.51417D-03	0.33370	0.31025	0.01587	0.34723	0.04049	1.0100230	1.97577D 00	1.97549D 00
15	0	0	0	-1.85055D-03	0.48145	0.40809	13.22873	-27.91890	7.49186	1.0100522	1.97549D 00	1.97487D 00
16	0	0	0	-8.89167D-04	0.51781	0.47960	0.51769	1.27472	-0.08993	1.0100169	1.97487D 00	1.97466D 00
17	0	0	0	-4.84501D-04	0.57054	0.54441	1.07105	9.78893	-3.90170	1.0100131	1.97466D 00	1.97450D 00
18	2	0	0	-4.04437D-04	0.56723	0.56589	0.87333	0.47438	0.0	1.0100091	1.97450D 00	1.97442D 00
19	0	0	0	-1.38112D-05	0.0	0.0	0.0	0.0	0.0	1.0099992	1.97430D 00	1.97430D 00
20	0	0	1	-1.46603D-05	0.66847	1.06147	1.04674	0.02121	0.02968	1.0099998	1.97430D 00	1.97430D 00

**********SEARCH EIGENVALUE RANGE VIOLATED - CALCULATED 1.97430D 00 USING 1.00000D 00
DENSITIES UPDATED FOR DIRECT SEARCH WITH CHANGE EIGENVALUE 1.00000E 00
PROCEEDING WITH SECONDARY SEARCH

STORAGE FOR MACRO CALCULATION
SUPPLIED 10000
REQUIRED 969

PRINCIPAL MACROSCOPIC CROSS SECTIONS

GROUP 1

ZONE	D	SIGA	SIGNF	SIGWF	SIGAS	SIGNFS
1	2.461064E 00	6.732788E-03	1.706615E-02	1.832810E-13	0.0	0.0
2	2.491580E 00	4.330136E-03	9.215195E-03	1.034325E-13	0.0	0.0
3	2.491576E 00	4.330140E-03	9.215225E-03	1.034326E-13	0.0	0.0
4	2.491576E 00	4.330140E-03	9.215225E-03	1.034326E-13	0.0	0.0
5	2.491576E 00	4.330140E-03	9.215225E-03	1.034326E-13	0.0	0.0
6	2.491576E 00	4.330140E-03	9.215225E-03	1.034326E-13	0.0	0.0
7	2.121200E 00	8.190463E-04	6.389623E-06	0.0	0.0	0.0
8	2.121200E 00	8.190463E-04	6.389623E-06	0.0	0.0	0.0

GROUP 2

ZONE	D	SIGA	SIGNF	SIGWF	SIGAS	SIGNFS
1	1.421424E 00	3.962696E-03	6.322514E-03	7.079309E-14	0.0	0.0
2	1.438300E 00	1.975165E-03	9.110016E-04	1.033252E-14	0.0	0.0
3	1.438299E 00	1.975170E-03	9.110027E-04	1.033252E-14	0.0	0.0
4	1.438299E 00	1.975170E-03	9.110027E-04	1.033252E-14	0.0	0.0
5	1.438299E 00	1.975170E-03	9.110027E-04	1.033252E-14	0.0	0.0
6	1.438299E 00	1.975170E-03	9.110027E-04	1.033252E-14	0.0	0.0
7	1.276845E 00	5.057480E-04	0.0	0.0	0.0	0.0
8	1.276845E 00	5.057480E-04	0.0	0.0	0.0	0.0

A FLUX - EIGENVALUE PROBLEM FOLLOWS
4 INNERS MIN, 4 INNERS MAX - CHEBYCHEV BETA ON OUTERS
PROC=0,1,2,3,4-NORMAL,CHEBYSHEV,SEMEX,DEMEX,SEMEXF. ICVR=0,1-YES,NO INNERS CONVR. OCVR=0,1-YES,NO OUTERS CONVR.

ITER	PROC	ICVR	OCVR	FLUX CHANGE	MU-BAR	MU-1	MU-LOSS	ACCELERATION	PARAMETERS	K-USED	K-CALC
1	0	1	1	-3.45672D-01	0.0	0.0	0.0	0.0	0.0	1.0099993	0.8991243
2	0	1	0	-3.38280D-01	0.77246	0.64033	-0.00229	3.39489	0.0	0.8991243	0.9082068
3	0	1	0	2.02772D-01	0.51560	1.08538	-1.06718	0.23692	1.36078	0.9082068	0.9029371
4	0	1	0	1.15040D-01	0.69823	0.68238	-0.02058	0.76114	0.49871	0.9029371	0.9047852
5	0	1	0	3.39959D-02	0.28830	0.32951	-0.94526	-0.05744	0.76164	0.9047852	0.9045303
6	0	1	0	7.86578D-03	0.21490	0.23924	0.09460	0.43653	-0.05178	0.9045303	0.9045002
7	0	1	0	2.68429D-03	0.28570	0.34395	-0.10868	0.07224	0.06408	0.9045002	0.9044780
8	2	1	0	8.84050D-04	0.29320	0.30184	4.91728	0.09405	0.0	0.9044780	0.9044677
9	0	1	0	9.83934D-05	0.0	0.0	0.0	0.0	0.0	0.9044647	0.9044611
10	0	1	0	6.71309D-05	0.73424	0.68234	1.02446	-0.23510	0.14693	0.9044611	0.9044591

NOTE RELAXED FLUX CHANGE ON FIRST PASS OF INDIRECT SEARCH

FINAL CALCULATED KEFFECTIVE 0.9044591
MULTIPLICATION RELIABILITY ESTIMATORS
BY THE SUM OF THE SQUARES OF THE RESIDUES---------- 0.9044544
UPPER AND LOWER BOUNDS ESTIMATES BY MAX REL FLUX CHANGE---------- 0.9045199 0.9043984
UPPER AND LOWER BOUNDS ESTIMATES OVER ALL SIGNIFICANT POINTS------- 1.3166812 0.8060398

FINAL GROUP OVERRELAXATION COEFFICIENTS AND NUMBER OF INNER ITERATIONS
1.41483E 00 1.51558E 00 1.42057E 00 1.50744E 00 1.36862E 00
4 4 4 4 4

CPU AND CLOCK MINUTES REQUIRED FOR THIS EIGENVALUE PROBLEM ARE 0.050 0.151

COURSE MESH CHANGE EIGENVALUE IS 3.96143D-01

REFERENCE ZONE FOR INITIALIZATION WILL BE 1

SUM OF REGION VOLUMES FROM GEODST 4.026185D 06
SUM OF REGION VOLUMES COMPUTED FROM POINT VOLUMES 4.026186D 06
SUM OF ZONE VOLUMES (FROM COMPUTED REGION VOLUMES) 4.026186D 06
SUM OF ZONE VOLUMES FROM NDXSRF 4.026185D 06
NBJ = 1 XJ = 9.957342E-01
NBI = 2 XI = 9.876884E-01
NBKB = 0 XKB = 0.0
AMDAL = 9.834930E-01 AMDAG = 9.780514E-01
RHO 8.822106E-01 8.920235E-01 8.837236E-01 8.667389E-01 8.518495E-01
BETA 1.359753E 00 1.377421E 00 1.362389E 00 1.334435E 00 1.312519E 00
NINR 4 4 4 4 4
ELAPSED CPU AND CLOCK MINUTES ARE 0.238 4.730

A FLUX - EIGENVALUE PROBLEM FOLLOWS
4 INNERS MIN, 4 INNERS MAX - CHEBYCHEV BETA ON OUTERS
PROC=0,1,2,3,4-NORMAL,CHEBYSHEV,SEMEX,DEMEX,SEMEXP. ICVR=0,1-YES,NO INNERS CONVR. OCVR=0,1-YES,NO OUTERS CONVR.

ITER	PROC	ICVR	OCVR	FLUX CHANGE	MU-BAR	MU-1	MU-LOSS	ACCELERATION PARAMETERS		K-USED	K-CALC
1	0	1	1	-6.56041D-01	0.0	0.0	0.0	0.0	0.0	1.0099993	0.9813170
2	0	1	0	-6.52608D-01	0.68794	0.34216	-0.00089	2.20452	0.0	0.9813170	0.9979253
3	0	1	0	-3.71184D-01	0.36470	0.19759	-0.53856	1.44775	-1.22361	0.9979253	1.0009653
4	0	1	0	-1.84109D-01	0.35004	0.31190	0.11541	0.58697	-0.01807	1.0009653	1.0034464
5	0	1	0	-8.19281D-02	0.36183	0.36307	0.67919	0.20665	0.12384	1.0034464	1.0045596
6	0	1	0	-3.90581D-02	0.52818	0.43768	0.57106	-1.37320	0.66681	1.0045596	1.0051981
7	0	1	0	-2.09909D-02	0.60009	0.51644	0.56597	2.06629	-0.25328	1.0051981	1.0055898
8	0	1	0	-1.24828D-02	0.64120	0.58219	0.56545	3.20116	-0.76136	1.0055898	1.0058419
9	3	1	0	-2.89719D-02	0.66738	0.62929	0.52235	3.89562	-1.25347	1.0058419	1.0060096
10	0	0	0	-4.00046D-04	0.0	0.0	0.0	0.0	0.0	1.0063469	1.0063577
11	0	1	0	-3.65113D-04	0.86405	0.91231	1.01505	0.03355	0.05288	1.0063577	1.0063645
12	0	1	0	-2.32967D-04	0.65818	0.63784	0.95896	1.90839	0.03720	1.0063645	1.0063693
13	0	1	1	-2.28554D-04	1.04162	0.98083	1.03349	0.96660	2.08314	1.0063693	1.0063729
14	0	1	0	-1.79763D-04	0.72448	0.78634	0.98197	2.95474	2.24249	1.0063729	1.0063753
15	0	1	0	-1.27671D-04	0.67144	0.71009	1.00386	2.56424	-0.44984	1.0063753	1.0063772
16	0	1	0	-7.46370D-05	0.56230	0.58453	0.98644	-20.20024	19.21754	1.0063772	1.0063784
17	0	1	0	-4.73355D-05	0.60731	0.63416	1.00248	0.94596	0.30297	1.0063784	1.0063793
18	0	1	0	-3.61640D-05	0.64772	0.76396	0.98426	5.49334	-1.99112	1.0063793	1.0063799

FINAL CALCULATED KEFFECTIVE 1.0063799
MULTIPLICATION RELIABILITY ESTIMATORS
BY THE SUM OF THE SQUARES OF THE RESIDUES---------- 1.0063777
UPPER AND LOWER BOUNDS ESTIMATES BY MAX REL FLUX CHANGE---------- 1.0064163 1.0063435
UPPER AND LOWER BOUNDS ESTIMATES OVER ALL SIGNIFICANT POINTS------- 1.0342586 0.8622427

FINAL GROUP OVERRELAXATION COEFFICIENTS AND NUMBER OF INNER ITERATIONS
1.35984E 00 1.48133E 00 1.47074E 00 1.41101E 00 1.35004E 00
4 4 4 4 4

CPU AND CLOCK MINUTES REQUIRED FOR THIS EIGENVALUE PROBLEM ARE 0.083 0.212

COURSE MESH CHANGE EIGENVALUE IS 4.10210D-01

REFERENCE ZONE FOR INITIALIZATION WILL BE 1

SUM OF REGION VOLUMES FROM GEODST 4.099473D 06
SUM OF REGION VOLUMES COMPUTED FROM POINT VOLUMES 4.099473D 06
SUM OF ZONE VOLUMES (FROM COMPUTED REGION VOLUMES) 4.099473D 06
SUM OF ZONE VOLUMES FROM NDISAP 4.099473D 06
NBJ = 1 XJ = 9.957342E-01
NBI = 2 XI = 9.876884E-01
NBKB = 0 XKB = 0.0
AMDAL = 9.834930E-01 AMDAG = 9.780514E-01
RHO 8.811952E-01 8.907340E-01 8.826643E-01 8.662054E-01 8.518495E-01
BETA 1.358002E 00 1.375019E 00 1.360540E 00 1.333617E 00 1.312519E 00
NINR 4 4 4 4 4
ELAPSED CPU AND CLOCK MINUTES ARE 0.344 5.774

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A FLUX - EIGENVALUE PROBLEM FOLLOWS
      4 INNERS MIN,  4 INNERS MAX - NO CHEBYCHEV BETA
PROC=0,1,2,3,4-NORMAL,CHEBYSHEV,SEMEX,DEMEX,SEMEXF.   ICVR=0,1-YES,NO INNERS CONVR.   OCVR=0,1-YES,NO OUTERS CONVR.
ITER  PROC  ICVR  OCVR   FLUX CHANGE     MU-BAR    MU-1   MU-LOSS   ACCELERATION PARAMETERS                K-USED    K-CALC
  1    0     1     1   -2.33305D-05    0.0       0.0      0.0          0.0        0.0                   1.0099993  1.0099992

FINAL CALCULATED KEFFECTIVE   1.0099992
MULTIPLICATION RELIABILITY ESTIMATORS
BY THE SUM OF THE SQUARES OF THE RESIDUES-------------------------   1.0099969
UPPER AND LOWER BOUNDS ESTIMATES BY MAX REL FLUX CHANGE------------   1.0100228   1.0099756
UPPER AND LOWER BOUNDS ESTIMATES OVER ALL SIGNIFICANT POINTS-------   1.0179673   0.9030859

FINAL GROUP OVERRELAXATION COEFFICIENTS AND NUMBER OF INNER ITERATIONS
  1.30808E 00  1.52964E 00  1.51943E 00  1.40940E 00  1.34975E 00
  4  4  4  4  4

CPU AND CLOCK MINUTES REQUIRED FOR THIS EIGENVALUE PROBLEM ARE  0.007   0.045

FINAL COURSE MESH INTERVAL BOUNDARIES
XMESH  0.0            1.765121D 01  6.007519D 01  8.128719D 01  1.101779D 02  1.309249D 02  1.461649D 02
YMESH  0.0            1.224000D 01  3.034000D 01  6.138575D 01
ZMESH  0.0            1.000000D 00

DISTANCES TO FINE MESH INTERFACES
1/XX    1    0.0       2   12.4813    3   17.6512    4   37.5595    5   50.0986    6   60.0752    7   67.8863
1/XX    8   74.8871    9   81.2872   10   91.9318   11  101.4658   12  110.1779   13  117.5013   14  124.3943
1/XX   15  130.9249   16  136.1945   17  141.2677   18  146.1649
2/YY    1    0.0       2    4.0800    3    8.1600    4   12.2400    5   18.2733    6   24.3067    7   30.3400
2/YY    8   38.1014    9   45.8629   10   53.6243   11   61.3857
3/ZZ    1    0.0       2    1.0000

DISTANCES TO FLUX POINTS
1/X     1    8.8256    2   15.2864    3   29.3452    4   44.2752    5   55.3123    6   64.0999    7   71.4725
1/X     8   78.1527    9   86.7729   10   96.8163   11  105.9115   12  113.8985   13  120.9969   14  127.7014
1/X    15  133.5857   16  138.7543   17  143.7372
2/Y     1    2.0400    2    6.1200    3   10.2000    4   15.2567    5   21.2900    6   27.3233    7   34.2207
2/Y     8   41.9822    9   49.7436   10   57.5050
3/Z     1    0.5000

    LEAKAGE  7.47046E 12  TOTAL LOSSES  1.04243E 14  TOTAL PRODUCTIONS  1.05285E 14  REACTOR POWER(WATTS)  2.34500D 03

PRIMITIVE FISSILE CONVERSION RATIO IS  1.23325E 00, ESTIMATE FOR CRITICAL SYSTEM IS  1.26298D 00
FISSILE DESTRUCTION PER UNIT ENERGY (ATOMS/WATT-SEC) IS  2.99027D 10

BOUNDARY NEUTRON LEAKAGE

GRP  LFT LEAKAGE  RIT LEAKAGE  TOP LEAKAGE  BOT LEAKAGE  FNT LEAKAGE  BAK LEAKAGE
 1   0.0          2.90586D 10  4.94740D 11  0.0          0.0          0.0
 2   0.0          3.64114D 11  4.11278D 12  0.0          0.0          0.0
 3   0.0          1.51484D 11  1.53639D 12  0.0          0.0          0.0
 4   0.0          6.20007D 10  5.67395D 11  0.0          0.0          0.0
 5   0.0          1.67725D 10  1.35721D 11  0.0          0.0          0.0

SUM  0.0          6.23430E 11  6.84702E 12  0.0          0.0          0.0

GROUP NEUTRON BALANCE FOR EACH ZONE

ZONE GRP  ABSORPTIONS  B**2 LOSSES    1/V LOSS   OUT-SCATTER  IN-SCATTER  P1 IN-SCATTER   SOURCE     POWER(WATTS)  AVERAGE FLUX
  1   1  1.07638E 13  0.0          0.0          5.13344E 13  0.0          0.0          7.13496E 13  2.93012E 02  2.48069E 09
  1   2  2.30175E 13  0.0          0.0          3.72454E 13  5.04649E 13  0.0          2.24929E 13  4.11205E 02  9.01306E 09
  1   3  2.07127E 13  0.0          0.0          1.52591E 13  3.80564E 13  0.0          6.55628E 11  2.17600E 02  4.21054E 09
```

1	4	1.27916E 13	0.0	0.0	2.34507E 12	1.53096E 13	0.0	0.0	1.12228E 02	1.11516E 09
1	5	2.43420E 12	0.0	0.0	0.0	2.35310E 12	0.0	0.0	2.65244E 01	9.90852E 07
SUM		6.97198E 13	0.0	0.0	1.06184E 14	1.06184E 14	0.0	9.44981E 13	1.06057E 03	
2	1	5.58662E 11	0.0	0.0	4.25630E 12	0.0	0.0	2.36688E 12	1.33446E 01	2.39138E 08
2	2	1.71329E 12	0.0	0.0	5.61284E 12	4.22178E 12	0.0	7.46156E 11	8.96261E 00	1.60779E 09
2	3	2.80928E 12	0.0	0.0	3.07136E 12	5.67944E 12	0.0	2.17491E 10	6.80276E 00	1.01790E 09
2	4	2.32775E 12	0.0	0.0	6.40833E 11	3.07742E 12	0.0	0.0	4.87895E 00	3.65821E 08
2	5	5.91656E 11	0.0	0.0	0.0	6.42692E 11	0.0	0.0	2.01753E 00	5.67771E 07
SUM		8.00064E 12	0.0	0.0	1.36213E 13	1.36213E 13	0.0	3.13478E 12	3.60064E 01	
3	1	9.63483E 11	0.0	0.0	7.40954E 12	0.0	0.0	3.76174E 12	2.30144E 01	5.92202E 08
3	2	2.67771E 12	0.0	0.0	8.77234E 12	7.28101E 12	0.0	1.18589E 12	1.40077E 01	3.60817E 09
3	3	4.16134E 12	0.0	0.0	4.54957E 12	8.88826E 12	0.0	3.45665E 10	1.00768E 01	2.16506E 09
3	4	3.40080E 12	0.0	0.0	9.36243E 11	4.55942E 12	0.0	0.0	7.12803E 00	7.67432E 08
3	5	8.65678E 11	0.0	0.0	0.0	9.39001E 11	0.0	0.0	2.95192E 00	1.19285E 08
SUM		1.20690E 13	0.0	0.0	2.16677E 13	2.16677E 13	0.0	4.98219E 12	5.71788E 01	
4	1	1.23854E 11	0.0	0.0	9.52483E 11	0.0	0.0	6.53539E 11	2.95846E 00	9.09352E 07
4	2	4.75646E 11	0.0	0.0	1.55824E 12	9.35961E 11	0.0	2.06028E 11	2.48820E 00	7.65603E 08
4	3	8.62782E 11	0.0	0.0	9.43275E 11	1.57264E 12	0.0	6.00534E 09	2.08925E 00	5.36209E 08
4	4	7.86862E 11	0.0	0.0	2.16624E 11	9.44827E 11	0.0	0.0	1.64925E 00	2.12106E 08
4	5	2.28056E 11	0.0	0.0	0.0	2.17193E 11	0.0	0.0	7.77661E-01	3.75377E 07
SUM		2.47720E 12	0.0	0.0	3.67062E 12	3.67062E 12	0.0	8.65573E 11	9.96282E 00	
5	1	6.77230E 10	0.0	0.0	5.20814E 11	0.0	0.0	4.33505E 11	1.61768E 00	3.20571E 07
5	2	3.11075E 11	0.0	0.0	1.01910E 12	5.11780E 11	0.0	1.36662E 11	1.62730E 00	3.22813E 08
5	3	6.21795E 11	0.0	0.0	6.79805E 11	1.02678E 12	0.0	3.98346E 09	1.50569E 00	2.49142E 08
5	4	5.96051E 11	0.0	0.0	1.64093E 11	6.80750E 11	0.0	0.0	1.24931E 00	1.03587E 08
5	5	1.81503E 11	0.0	0.0	0.0	1.64503E 11	0.0	0.0	6.18918E-01	1.92609E 07
SUM		1.77815E 12	0.0	0.0	2.38381E 12	2.38381E 12	0.0	5.74150E 11	6.61890E 00	
6	1	2.05190E 10	0.0	0.0	1.57798E 11	0.0	0.0	1.41494E 11	4.90130E-01	1.66598E 07
6	2	9.93946E 10	0.0	0.0	3.25623E 11	1.55061E 11	0.0	4.46059E 10	5.19954E-01	1.76918E 08
6	3	2.04554E 11	0.0	0.0	2.23638E 11	3.27930E 11	0.0	1.30018E 09	4.95334E-01	1.40583E 08
6	4	2.05039E 11	0.0	0.0	5.64473E 10	2.23933E 11	0.0	0.0	4.29758E-01	6.11197E 07
6	5	6.64347E 10	0.0	0.0	0.0	5.65821E 10	0.0	0.0	2.26539E-01	1.20923E 07
SUM		5.95941E 11	0.0	0.0	7.63506E 11	7.63507E 11	0.0	1.87400E 11	2.16171E 00	
7	1	2.98628E 10	0.0	0.0	9.06875E 11	0.0	0.0	1.74158E 08	0.0	4.43817E 07
7	2	1.81797E 11	0.0	0.0	1.63040E 12	8.80319E 11	0.0	5.49032E 07	0.0	4.37557E 08
7	3	3.71995E 11	0.0	0.0	1.67622E 12	1.65149E 12	0.0	1.60033E 06	0.0	2.80865E 08
7	4	8.81739E 11	0.0	0.0	5.15167E 11	1.68166E 12	0.0	0.0	0.0	1.38856E 08
7	5	3.81766E 11	0.0	0.0	0.0	5.15199E 11	0.0	0.0	0.0	3.16795E 07
SUM		1.84716E 12	0.0	0.0	4.72867E 12	4.72867E 12	0.0	2.30662E 08	0.0	
8	1	2.46245E 09	0.0	0.0	7.47811E 10	0.0	0.0	1.43611E 07	0.0	4.61132E 06
8	2	2.19035E 10	0.0	0.0	1.96437E 11	7.25913E 10	0.0	4.52734E 06	0.0	6.64261E 07
8	3	5.24522E 10	0.0	0.0	2.36351E 11	1.98016E 11	0.0	1.31964E 05	0.0	4.98999E 07
8	4	1.39387E 11	0.0	0.0	8.14383E 10	2.36959E 11	0.0	0.0	0.0	2.76580E 07
8	5	6.79329E 10	0.0	0.0	0.0	8.14417E 10	0.0	0.0	0.0	7.10293E 06
SUM		2.84138E 11	0.0	0.0	5.89007E 11	5.89007E 11	0.0	1.90204E 07	0.0	

OVERALL NEUTRON BALANCE

GRP	ABSORPTIONS	B**2 LOSSES	1/V LOSS	OUT-SCATTER	IN-SCATTER	P1 IN-SCATTER	SOURCE	POWER(WATTS)
1	1.25303E 13	0.0	0.0	6.56529E 13	0.0	0.0	7.87068E 13	3.34437E 02
2	2.84983E 13	0.0	0.0	5.63603E 13	6.45233E 13	0.0	2.48123E 13	4.38810E 02
3	2.97968E 13	0.0	0.0	2.66393E 13	5.74009E 13	0.0	7.23234E 11	2.38570E 02
4	2.11292E 13	0.0	0.0	4.95591E 12	2.67145E 13	0.0	0.0	1.27563E 02
5	4.81722E 12	0.0	0.0	0.0	4.96971E 12	0.0	0.0	3.31169E 01
SUM	9.67719E 13	0.0	0.0	1.53609E 14	1.53609E 14	0.0	1.04242E 14	1.17250E 03

ZONE VOLUMES FOLLOW. TOTAL VOLUME 4.12005E 06

POINT NEUTRON DENSITY (NEUTRONS/CC)

	1	2	3	4	5	6	7	8	9	10	11
1	6.413D 06	6.261D 06	5.800D 06	4.834D 06	3.975D 06	3.248D 06	2.643D 06	2.125D 06	1.517D 06	9.744D 05	6.232D 05
2	1.415D 07	1.382D 07	1.280D 07	1.067D 07	8.772D 06	7.168D 06	5.833D 06	4.690D 06	3.349D 06	2.152D 06	1.377D 06
3	2.113D 07	2.063D 07	1.911D 07	1.593D 07	1.309D 07	1.069D 07	8.695D 06	6.985D 06	4.983D 06	3.197D 06	2.042D 06
4	2.653D 07	2.590D 07	2.399D 07	1.999D 07	1.642D 07	1.340D 07	1.088D 07	8.732D 06	6.219D 06	3.978D 06	2.533D 06
5	3.390D 07	3.310D 07	3.065D 07	2.553D 07	2.095D 07	1.706D 07	1.382D 07	1.106D 07	7.871D 06	5.003D 06	3.164D 06
6	4.164D 07	4.065D 07	3.764D 07	3.133D 07	2.568D 07	2.087D 07	1.686D 07	1.347D 07	9.696D 06	6.142D 06	3.856D 06
7	4.809D 07	4.695D 07	4.347D 07	3.616D 07	2.960D 07	2.398D 07	1.929D 07	1.541D 07	1.175D 07	7.456D 06	4.648D 06
8	5.776D 07	5.638D 07	5.220D 07	4.340D 07	3.549D 07	2.869D 07	2.301D 07	1.833D 07	1.395D 07	8.799D 06	5.444D 06
9	6.556D 07	6.399D 07	5.925D 07	4.925D 07	4.024D 07	3.250D 07	2.602D 07	2.067D 07	1.565D 07	9.815D 06	6.040D 06
10	6.978D 07	6.812D 07	6.306D 07	5.241D 07	4.281D 07	3.456D 07	2.765D 07	2.194D 07	1.657D 07	1.036D 07	6.359D 06

	12	13	14	15	16	17
1	4.098D 05	2.748D 05	1.820D 05	1.180D 05	6.992D 04	2.851D 04
2	9.059D 05	6.089D 05	4.062D 05	2.647D 05	1.570D 05	6.363D 04
3	1.343D 06	9.049D 05	6.120D 05	4.037D 05	2.405D 05	9.740D 04
4	1.663D 06	1.125D 06	7.814D 05	5.634D 05	3.383D 05	1.374D 05
5	2.067D 06	1.396D 06	9.778D 05	7.282D 05	4.434D 05	1.810D 05
6	2.504D 06	1.684D 06	1.180D 06	8.845D 05	5.411D 05	2.213D 05
7	2.998D 06	2.007D 06	1.402D 06	1.052D 06	6.436D 05	2.634D 05
8	3.488D 06	2.323D 06	1.617D 06	1.211D 06	7.405D 05	3.030D 05
9	3.853D 06	2.556D 06	1.775D 06	1.327D 06	8.108D 05	3.316D 05
10	4.047D 06	2.680D 06	1.858D 06	1.388D 06	8.478D 05	3.467D 05

THE RELATIVE NEUTRON DENSITY TRAVERSE LEFT-TO-RIGHT IS

1.00000D 00 9.76171D-01 9.03722D-01 7.51070D-01 6.13532D-01 4.95273D-01 3.96231D-01 3.14407D-01 2.37410D-01
1.48467D-01 9.11240D-02 5.80017D-02 3.84098D-02 2.66270D-02 1.98940D-02 1.21492D-02 4.96804D-03

THE RELATIVE NEUTRON DENSITY TRAVERSE TOP-TO-BOTTOM IS

9.19048D-02 2.02830D-01 3.02861D-01 3.80211D-01 4.85794D-01 5.96689D-01 6.89213D-01 8.27669D-01 9.39425D-01
1.00000D 00

POWER DENSITY INTERFACE FILE PWDINT HAS BEEN WRITTEN ON CLD UNIT NUMBER 20
ELAPSED CPU AND CLOCK MINUTES ARE 0.540 8.230

ADJOINT PROBLEM FOLLOWS

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

PROC=0,1,2,3,4-NORMAL,CHEBYSHEV,SEMEX,DEMEX,SEMEXF. ICVR=0,1-YES,NO INNERS CONVR. OCVR=0,1-YES,NO OUTERS CONVR.

ITER	PROC	ICVR	OCVR	FLUX CHANGE	MU-BAR	MU-1	BU-LOSS	ACCELERATION	PARAMETERS
1	0	1	1	1.10537E 01	0.0	0.0	0.0	0.0	0.0
2	0	1	1	2.22643E 01	0.18977	24.27845	0.16567	0.23457	0.00030
3	0	1	1	1.17634E 00	0.46319	1.22917	0.36686	0.31533	0.06884
4	0	1	0	2.46281E-01	0.34592	0.45564	0.29510	0.43314	0.05403
5	0	1	0	1.16761E-01	0.42794	0.59086	0.49792	0.27558	0.14295
6	0	1	0	4.74083E-02	0.40834	0.45344	0.46842	0.56502	0.05538
7	0	1	0	2.07106E-02	0.46216	0.45757	0.49230	-0.18891	0.38908
8	0	1	0	1.03258E-02	0.53616	0.50890	0.52539	5.17769	-1.60296
9	0	1	0	5.71247E-03	0.58829	0.55894	0.56448	2.83604	-0.66965
10	0	1	0	3.10582E-03	0.54904	0.54680	0.58211	0.62042	0.38475
11	0	1	0	1.95479E-03	0.68078	0.63135	0.65888	-0.17336	0.89624
12	0	1	0	1.15745E-03	0.65229	0.61377	0.66458	1.59322	0.20964
13	0	1	0	8.26442E-04	0.70766	0.69100	0.67916	0.32915	1.14701
14	0	1	0	5.16794E-04	0.65213	0.62584	0.67836	0.85497	0.85863
15	0	1	0	3.64485E-04	0.71866	0.70564	0.68702	0.73527	0.95943
16	0	1	0	2.30699E-04	0.65368	0.63318	0.68021	0.90293	0.87100
17	0	1	0	1.64065E-04	0.72567	0.71133	0.68062	0.81793	0.94619
18	0	1	0	1.04058E-04	0.65598	0.63435	0.66818	0.93184	0.88721
19	0	1	0	7.39888E-05	0.72887	0.71111	0.65279	0.87883	0.93545
20	0	0	0	4.65495E-05	0.65831	0.62919	0.62292	0.94605	0.90070

MULTIPLICATION RELIABILITY ESTIMATORS

BY THE SUM OF THE SQUARES OF THE RESIDUES---------- 1.0099978

UPPER AND LOWER BOUNDS ESTIMATES BY MAX REL FLUX CHANGE---------- 1.0100462 1.0099522

UPPER AND LOWER BOUNDS ESTIMATES OVER ALL SIGNIFICANT POINTS------- 1.1422228 0.9607270

FINAL GROUP OVERRELAXATION COEFFICIENTS AND NUMBER OF INNER ITERATIONS

1.01254E 00 1.13343E 00 1.31006E 00 1.37440E 00 1.30754E 00

4 4 4 4 4

CPU AND CLOCK MINUTES REQUIRED FOR THIS EIGENVALUE PROBLEM ARE 0.089 0.274

PERTURBATION RESULTS---DELTA-K/(K*DELTA-S) WHERE S REPRESENTS MACRO. CROSS SECTIONS. BIG DADDY = 1.602643D-14

ZONE	GRP	SIGA,SIGB,DE**2	E**2	NU*SIGF	DIFF. COEF.
1	1	-1.733594E 01	-4.266487E 01	1.643028E 01	-1.574874E-02
	2	-5.177007E 01	-7.358720E 01	5.921547E 01	-4.100100E-02
	3	-2.055157E 01	-1.896771E 01	2.741916E 01	-1.521269E-02
	4	-5.361814E 00	-3.385131E 00	7.194737E 00	-3.112444E-03
	5	-5.786453E-01	-3.796322E-01	6.286305E-01	8.171450E-06
2	1	-2.915685E-01	-7.264663E-01	2.712585E-01	-2.274908E-03
	2	-1.401424E 00	-2.015670E 00	1.717649E 00	-6.606407E-03
	3	-5.539811E-01	-5.184985E-01	1.054751E 00	-2.494422E-03
	4	-1.461643E-01	-9.374219E-02	3.704297E-01	-5.176924E-04
	5	-2.572950E-02	-1.776251E-02	5.574585E-02	-3.363760E-06
3	1	-1.064336E 00	-2.651874E 00	9.942851E-01	-6.073251E-03
	2	-4.820757E 00	-6.933689E 00	5.813602E 00	-1.755509E-02
	3	-1.938077E 00	-1.813950E 00	3.417872E 00	-6.429154E-03
	4	-5.091047E-01	-3.265128E-01	1.184841E 00	-1.140644E-03
	5	-8.742809E-02	-6.035625E-02	1.783169E-01	8.293100E-05
4	1	-3.145789E-02	-7.837969E-02	2.903055E-02	-2.152601E-04
	2	-1.844627E-01	-2.653126E-01	2.330878E-01	-9.658439E-04
	3	-7.114768E-02	-6.659091E-02	1.595866E-01	-3.788001E-04
	4	-1.901373E-02	-1.219441E-02	6.186677E-02	-9.322961E-05
	5	-3.959838E-03	-2.733686E-03	1.068389E-02	-1.353695E-05
5	1	-6.876983E-03	-1.713453E-02	6.282955E-03	-3.872756E-05
	2	-4.743828E-02	-6.823039E-02	6.238211E-02	-2.378826E-04
	3	-1.732884E-02	-1.621899E-02	4.768598E-02	-8.803485E-05
	4	-4.957959E-03	-3.179775E-03	1.959488E-02	-2.227434E-05
	5	-1.181433E-03	-8.156050E-04	3.585361E-03	-4.321853E-06
6	1	-1.178609E-03	-2.936595E-03	1.074532E-03	-7.451595E-06
	2	-8.466057E-03	-1.217673E-02	1.123333E-02	-4.827984E-05
	3	-3.065760E-03	-2.869409E-03	8.849878E-03	-1.764583E-05
	4	-9.150812E-04	-5.888848E-04	3.791588E-03	-4.684193E-06
	5	-2.334669E-04	-1.611744E-04	7.355860E-04	-9.735986E-07
7	1	-5.116918E-02	-1.085400E-01	4.724531E-02	-7.224965E-04
	2	-3.534281E-01	-4.512728E-01	4.447567E-01	-4.659232E-03
	3	-1.213173E-01	-7.512796E-02	2.865543E-01	-2.322912E-03
	4	-3.167672E-02	-1.252548E-02	1.390289E-01	-5.940928E-04
	5	-6.606478E-03	-2.556148E-03	3.086748E-02	-9.476377E-05
8	1	-3.175903E-04	-6.736727E-04	2.896755E-04	-4.462997E-06
	2	-3.078468E-03	-3.930725E-03	4.070520E-03	-3.506249E-05
	3	-9.295819E-04	-5.756607E-04	3.131417E-03	-1.566127E-05
	4	-2.777381E-04	-1.098221E-04	1.716123E-03	-4.679143E-06
	5	-7.034405E-05	-2.721719E-05	4.334108E-04	-9.487464E-07

GRP. TO GRP. DELTA-K/(K*DELTA-SIGS) FOR ALL ZONES 1,2,3,.... - (THE IN-GROUP TERMS MAKE NO CONTRIBUTION.)

1	1	1.733594E 01	2.915685E-01	1.064336E 00	3.145789E-02	6.876983E-03	1.178609E-03	5.116918E-02	3.175903E-04
2	1	6.248277E 01	1.847520E 00	6.226563E 00	2.526662E-01	6.826398E-02	1.232191E-02	4.818048E-01	4.463539E-03
3	1	2.893359E 01	1.134905E 00	3.661585E 00	1.730407E-01	5.219952E-02	9.707734E-03	3.103107E-01	3.432850E-03
4	1	7.592558E 00	3.986893E-01	1.269693E 00	6.711602E-02	2.145055E-02	4.159287E-03	1.505732E-01	1.883613E-03
5	1	6.634621E-01	6.002117E-02	1.911700E-01	1.158923E-02	3.925145E-03	8.069647E-04	3.343929E-02	4.752208E-04
1	2	1.436706E 01	2.218574E-01	8.261295E-01	2.301408E-02	4.779015E-03	8.099785E-04	3.757762E-02	2.192332E-04
2	2	5.177007E 01	1.401424E 00	4.820757E 00	1.844627E-01	4.743828E-02	8.466057E-03	3.534281E-01	3.078468E-03
3	2	2.396721E 01	8.594033E-01	2.831500E 00	1.261907E-01	3.625659E-02	6.669018E-03	2.280515E-01	2.370968E-03
4	2	6.287696E 00	3.015068E-01	9.805232E-01	4.890154E-02	1.489552E-02	2.856752E-03	1.105915E-01	1.300604E-03

1	-1.228035E-01	-1.076065E-01	2.923992E-01	3.087604E-02
2	-2.180938E-01	-6.157886E-02	3.815306E-01	5.041294E-02
3	-1.702864E-01	-4.397895E-03	1.990814E-01	1.214698E-02
4	-1.037028E-01	4.505917E-03	1.025507E-01	1.671213E-03
5	-2.444530E-02	0.0	2.443714E-02	-5.128416E-06

TOTAL SUMS

-6.393316E-01	-1.690766E-01	9.999989E-01	9.510124E-02

TOTAL SUM IS 2.86692E-01

THE FOLLOWING ARE UNCERTAINTY ASSOCIATED WITH A 100 PERCENT UNCERTAINTY IN THE DATA (UNCORRELATED), BUT NET SCATTERING IN THE ABOVE TABLE TREATED AS AN ENTITY.

SUMS OVER GROUPS

ZONE				
1	2.998545E-01	1.074304E-01	5.165114E-01	3.570628E-02
2	4.528333E-03	4.043814E-03	3.272813E-03	5.656328E-03
3	1.578303E-02	1.292362E-02	1.153070E-02	1.502714E-02
4	5.830154E-04	6.051455E-04	4.090425E-04	7.659663E-04
5	1.465074E-04	1.778613E-04	1.066936E-04	1.826042E-04
6	2.623815E-05	3.256575E-05	1.940652E-05	3.690859E-05
7	3.759048E-04	9.257735E-04	3.018795E-07	3.156998E-03
8	3.226660E-06	9.405206E-06	1.850918E-09	2.340690E-05

SUMS OVER ZONES

GRP				
1	1.168170E-01	9.680521E-02	2.805621E-01	2.101176E-02
2	2.053889E-01	4.826982E-02	3.744310E-01	3.225600E-02
3	1.572120E-01	2.731410E-03	1.940789E-01	7.761944E-03
4	9.563893E-02	4.151016E-03	9.907794E-02	1.068367E-03
5	2.212837E-02	0.0	2.304297E-02	3.447123E-05

TOTAL SUMS

3.003040E-01	1.082861E-01	5.166502E-01	3.928527E-02

TOTAL SUM IS 6.08588E-01

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NORMALIZATION OF IMPORTANCE MAPS IS TO UNIT FISSION SOURCE IMPORTANCE FOR THE ACTUAL PROBLEM.     *
MULTIPLY BY THE FRACTION OF THE CORE TREATED IF THE VALUES ARE TO BE MADE RELATIVE TO THE         *
TOTAL, BUT TAKE CARE TO UNDERSTAND THAT THIS IS APPROPRIATE IN A SPECIFIC SITUATION.              *
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1/V (NEUTRON IMPORTANCE) MAP (1/V/K)(DELTA K/DELTA 1/V).

	1	2	3	4	5	6	7	8	9	10	11
1	1.781D-09	1.698D-09	1.456D-09	1.010D-09	6.789D-10	4.479D-10	2.906D-10	1.817D-10	8.626D-11	3.278D-11	1.253D-11
2	8.538D-09	8.138D-09	6.980D-09	4.839D-09	3.253D-09	2.145D-09	1.388D-09	8.644D-10	4.060D-10	1.527D-10	5.803D-11
3	2.303D-08	2.195D-08	1.883D-08	1.305D-08	8.770D-09	5.774D-09	3.728D-09	2.308D-09	1.068D-09	3.965D-10	1.494D-10
4	4.955D-08	4.723D-08	4.051D-08	2.807D-08	1.884D-08	1.238D-08	7.966D-09	4.899D-09	2.226D-09	8.121D-10	3.027D-10
5	1.029D-07	9.807D-08	8.410D-08	5.823D-08	3.902D-08	2.554D-08	1.628D-08	9.829D-09	4.220D-09	1.461D-09	5.264D-10
6	2.047D-07	1.951D-07	1.672D-07	1.157D-07	7.740D-08	5.046D-08	3.191D-08	1.889D-08	7.445D-09	2.407D-09	8.301D-10
7	4.065D-07	3.874D-07	3.321D-07	2.296D-07	1.534D-07	9.967D-08	6.270D-08	3.672D-08	1.287D-08	3.840D-09	1.263D-09
8	6.466D-07	6.161D-07	5.281D-07	3.648D-07	2.432D-07	1.575D-07	9.852D-08	5.715D-08	1.959D-08	5.616D-09	1.786D-09
9	8.545D-07	8.143D-07	6.979D-07	4.819D-07	3.209D-07	2.074D-07	1.293D-07	7.462D-08	2.535D-08	7.144D-09	2.234D-09
10	9.750D-07	9.290D-07	7.962D-07	5.496D-07	3.658D-07	2.362D-07	1.470D-07	8.468D-08	2.867D-08	8.026D-09	2.491D-09

	12	13	14	15	16	17
1	5.147D-12	2.205D-12	9.080D-13	3.519D-13	1.197D-13	2.386D-14
2	2.378D-11	1.019D-11	4.201D-12	1.565D-12	5.092D-13	9.508D-14
3	6.102D-11	2.624D-11	1.098D-11	3.889D-12	1.214D-12	2.181D-13
4	1.230D-10	5.310D-11	2.318D-11	8.638D-12	2.560D-12	4.441D-13
5	2.096D-10	8.964D-11	3.943D-11	1.540D-11	4.609D-12	7.949D-13
6	3.223D-10	1.358D-10	5.944D-11	2.341D-11	7.035D-12	1.212D-12
7	4.769D-10	1.975D-10	8.558D-11	3.368D-11	1.011D-11	1.741D-12
8	6.590D-10	2.685D-10	1.151D-10	4.513D-11	1.352D-11	2.323D-12
9	8.128D-10	3.277D-10	1.395D-10	5.453D-11	1.630D-11	2.796D-12
10	9.011D-10	3.616D-10	1.534D-10	5.984D-11	1.786D-11	3.062D-12

PERTURBATION INTERFACE FILE PERTUB HAS BEEN WRITTEN ON NEW UNIT NUMBER 37

TOTAL CPU TIME IS 0.680 MINUTES AND TOTAL CLOCK TIME IS 9.812 MINUTES

START EXECUTING REACTION RATE MODULE

CASE TITLE - 2-D 17X10 - 5 GROUP SEARCH PROBLEM
PRIMARY SEARCH = NUCLIDE(DIRECT) - SECONDARY SEARCH = DIMENSION

MAXIMUM ARRAY SIZE USED FOR INITIAL PROCESSING IS 684

STORAGE REQUIRED FOR BASIC DATA IS 570

STORAGE SUPPLIED IS 10000
MAXIMUM STORAGE REQUIRED IS 2027
MINIMUM STORAGE REQUIRED IS 1270

MODZSZ = 0 MODZ = 0 MODZC = 0

INTERFACE FILE RZFLUX
TIME = 0.0 POWER = 1.172500E 03
VOL = 4.120052E 06 EFFK = 1.009998E 00
EIVS = 0.0 DKDS = 0.0
TNL = 1.042425E 14 TNA = 9.677209E 13
TNSL = 7.470456E 12 TNBL = 0.0
TNBAL = 0.0 TNCRA = 0.0
FC = 5.000000E-0' CRTF = 1.000000E 00
X3 = 0.0 X4 = 0.0
ITPS = 1 NZONE = 8
NGROUP= 5 NCY = 0

REACTION RATE AND POWER PRODUCTION BY ZONE
REACTION RATES HAVE UNITS OF EVENTS/SEC

ZONE 1 ZONE CLASS 1

POS. RRT.	POS. SIG.	IDENTIFIER UNIQUE	IDENTIFIER ABSOLUTE	CLASS	INVENTORY (KGS)	ABSORPTION	FISSION	PRODUCTION	CAPTURE(N,G)	FISS. POWER (WATTS)	CAPT. POWER (WATTS)
1	1	O-16	O-16	0	3.063401E 02	1.748130E 11	0.0	0.0	1.748130E 11	0.0	0.0
2	2	NA-23	NA-23	6	2.003930E 02	1.468137E 11	2.025563E 07	4.051128E 07	1.467935E 11	0.0	0.0
3	3	CR-N	CR-N	5	1.639540E 02	4.700704E 11	0.0	0.0	4.700704E 11	0.0	0.0
4	4	MN-55	MN-55	5	2.521034E 01	2.977251E 11	7.420698E 07	1.484140E 08	2.976510E 11	0.0	0.0
5	5	FE-N	FE-N	5	6.782012E 02	1.420200E 12	0.0	0.0	1.420200E 12	0.0	0.0
6	6	NI-N	NI-N	5	1.305822E 02	4.861382E 11	0.0	0.0	4.861382E 11	0.0	0.0
7	7	MO-N	MO-N	5	5.276143E 01	1.178824E 12	1.231854E 09	2.463707E 09	1.177592E 12	0.0	0.0
8	8	TA-181	TA-181	7	1.010103E 01	3.579345E 11	3.174574E 08	6.349148E 08	3.576171E 11	0.0	0.0
10	10	U-238	U-238	2	1.838305E 03	2.731005E 13	3.903854E 12	1.087494E 13	2.340621E 13	1.234594E 02	0.0
11	11	PU-239	PU-239	1	3.286941E 02	3.120111E 13	2.589345E 13	7.592477E 13	5.307675E 12	8.437642E 02	0.0
12	12	PU-240	PU-240	2	1.246909E 02	4.274846E 12	2.034970E 12	6.218705E 12	2.239874E 12	6.680200E 01	0.0
13	13	PU-241	PU-241	1	7.152403E 00	9.059380E 11	7.798450E 11	2.349471E 12	1.260935E 11	2.577466E 01	0.0
14	14	PU-242	PU-242	3	1.854817E 00	4.924585E 10	2.354224E 10	7.184568E 10	2.570365E 10	7.712907E-01	0.0
15	15	SSFP	SSFP	4	9.000073E 01	1.446066E 12	0.0	0.0	1.446066E 12	0.0	0.0

ZONE 2 ZONE CLASS 1

POS. RRT.	POS. SIG.	IDENTIFIER UNIQUE	IDENTIFIER ABSOLUTE	CLASS	INVENTORY (KGS)	ABSORPTION	FISSION	PRODUCTION	CAPTURE(N,G)	FISS. POWER (WATTS)	CAPT. POWER (WATTS)
1	1	O-16	O-16	0	2.564529E 02	1.410755E 10	0.0	0.0	1.410755E 10	0.0	0.0
2	2	NA-23	NA-23	6	1.677592E 02	3.154756E 10	1.634648E 06	3.269293E 06	3.154592E 10	0.0	0.0
3	3	CR-N	CR-N	5	1.372542E 02	1.165537E 11	0.0	0.0	1.165537E 11	0.0	0.0
4	4	MN-55	MN-55	5	2.110484E 01	9.115160E 10	5.988564E 06	1.197714E 07	9.114563E 10	0.0	0.0
5	5	FE-N	FE-N	5	5.677561E 02	2.975269E 11	0.0	0.0	2.975269E 11	0.0	0.0
6	6	NI-N	NI-N	5	1.093170E 02	6.609486E 10	0.0	0.0	6.609486E 10	0.0	0.0
7	7	MO-N	MO-N	5	4.416920E 01	2.968288E 11	9.941165E 07	1.988234E 08	2.967294E 11	0.0	0.0
8	8	TA-181	TA-181	7	8.456093E 00	8.214295E 10	2.561909E 07	5.123814E 07	8.211733E 10	0.0	0.0
9	9	U-235	U-235	1	4.435482E 00	1.185974E 11	8.946149E 10	2.190583E 11	2.913593E 10	2.816338E 00	0.0
10	10	U-238	U-238	2	1.817440E 03	6.019636E 12	3.728726E 11	1.038450E 12	5.646758E 12	1.179210E 01	0.0
11	11	PU-239	PU-239	1	3.909656E 01	8.294522E 11	6.536993E 11	1.899496E 12	1.757526E 11	2.130145E 01	0.0
12	12	PU-240	PU-240	2	1.321218E 00	9.338327E 09	2.940405E 09	8.864252E 09	6.397923E 09	9.652460E-02	0.0
13	13	PU-241	PU-241	1	2.140813E-10	6.460514E 00	5.434189E 00	1.626462E 01	1.026324E 00	1.796054E-10	0.0
15	15	SSFP	SSFP	4	6.511993E 00	2.768937E 10	0.0	0.0	2.768937E 10	0.0	0.0

ZONE 3 ZONE CLASS 1

POS. RRT.	POS. SIG.	IDENTIFIER UNIQUE	IDENTIFIER ABSOLUTE	CLASS	INVENTORY (KGS)	ABSORPTION	FISSION	PRODUCTION	CAPTURE(N,G)	FISS. POWER (WATTS)	CAPT. POWER (WATTS)
1	1	O-16	O-16	0	1.785995E 02	2.433028E 10	0.0	0.0	2.433028E 10	0.0	0.0
2	2	NA-23	NA-23	6	1.168312E 02	4.706748E 10	2.819156E 06	5.638312E 06	4.706466E 10	0.0	0.0
3	3	CR-N	CR-N	5	9.558687E 01	1.721006E 11	0.0	0.0	1.721006E 11	0.0	0.0
4	4	MN-55	MN-55	5	1.469789E 01	1.340243E 11	1.032804E 07	2.065608E 07	1.340140E 11	0.0	0.0
5	5	FE-N	FE-N	5	3.953982E 02	4.434012E 11	0.0	0.0	4.434012E 11	0.0	0.0
6	6	NI-N	NI-N	5	7.613077E 01	1.038642E 11	0.0	0.0	1.038642E 11	0.0	0.0
7	7	MO-N	MO-N	5	3.076045E 01	4.382850E 11	1.714479E 08	3.428956E 08	4.381137E 11	0.0	0.0
8	8	TA-181	TA-181	7	5.889006E 00	1.220043E 11	4.418334E 07	8.836669E 07	1.219601E 11	0.0	0.0
9	9	U-235	U-235	1	3.088970E 00	1.782605E 11	1.348846E 11	3.305009E 11	4.337632E 10	4.246302E 00	0.0
10	10	U-238	U-238	2	1.265706E 03	9.093502E 12	6.427794E 11	1.790230E 12	8.450721E 12	2.032790E 01	0.0
11	11	PU-239	PU-239	1	2.722772E 01	1.256627E 12	9.957798E 11	2.896456E 12	2.608476E 11	3.244847E 01	0.0
12	12	PU-240	PU-240	2	9.201263E-01	1.428054E 10	4.755751E 09	1.436876E 10	9.524785E 09	1.561171E-01	0.0
13	13	PU-241	PU-241	1	1.490909E-10	9.724371E 00	8.197686E 00	2.455246E 01	1.526689E 00	2.709417E-10	0.0
15	15	SSFP	SSFP	4	4.535096E 00	4.127199E 10	0.0	0.0	4.127199E 10	0.0	0.0

ZONE 4 ZONE CLASS 1

POS. RRT.	POS. SIG.	IDENTIFIER UNIQUE	IDENTIFIER ABSOLUTE	CLASS	INVENTORY (KGS)	ABSORPTION	FISSION	PRODUCTION	CAPTURE(N,G)	FISS. POWER (WATTS)	CAPT. POWER (WATTS)
1	1	O-16	O-16	0	1.495147E 02	3.127612E 09	0.0	0.0	3.127612E 09	0.0	0.0
2	2	NA-23	NA-23	6	9.780537E 01	1.013669E 10	3.623972E 05	7.247941E 05	1.013832E 10	0.0	0.0
3	3	CR-N	CR-N	5	8.002066E 01	3.869653E 10	0.0	0.0	3.869653E 10	0.0	0.0

6	6	NI-N	NI-N	5	5.155432E 02	1.374282E 10	0.0	0.0	1.374282E 10	0.0	0.0
7	7	MO-N	MO-N	5	2.083040E 02	1.053742E 11	9.040503E 06	1.808099E 07	1.053652E 11	0.0	0.0
8	8	TA-181	TA-181	7	1.942050E-10	1.295583E-01	1.134572E-05	2.269144E-05	1.295469E-01	0.0	0.0

REACTION RATE AND POWER PRODUCTION BY ZONE CLASS
REACTION RATES HAVE UNITS OF EVENTS/SEC

ZONE CLASS 1

POS. RRT.	POS. SIG.	IDENTIFIER UNIQUE	IDENTIFIER ABSOLUTE	CLASS	INVENTORY (KGS)	ABSORPTION	FISSION	PRODUCTION	CAPTURE(N,G)	FISS. POWER (WATTS)	CAPT. POWER (WATTS)
1	1	O-16	O-16	0	1.258021E 03	2.186067E 11	0.0	0.0	2.186067E 11	0.0	0.0
2	2	NA-23	NA-23	6	1.068005E 03	2.557479E 11	2.559525E 07	5.119056E 07	2.557222E 11	0.0	0.0
3	3	CR-N	CR-N	5	2.136170E 03	1.135099E 12	0.0	0.0	1.135099E 12	0.0	0.0
4	4	MN-55	MN-55	5	3.284717E 02	8.682017E 11	9.994610E 07	1.998923E 08	8.681018E 11	0.0	0.0
5	5	FE-N	FE-N	5	6.836340E 03	2.995385E 12	0.0	0.0	2.995385E 12	0.0	0.0
6	6	NI-N	NI-N	5	1.701387E 03	8.111121E 11	0.0	0.0	8.111121E 11	0.0	0.0
7	7	MO-N	MO-N	5	6.874412E 02	2.885502E 12	1.659129E 09	3.318259E 09	2.883842E 12	0.0	0.0
8	8	TA-181	TA-181	7	4.148103E 01	6.152016E 11	3.969856E 08	7.939717E 08	6.148047E 11	0.0	0.0
9	9	U-235	U-235	1	1.645981E 01	3.700026E 11	2.788675E 11	6.826038E 11	9.113508E 10	8.779033E 00	0.0
10	10	U-238	U-238	2	8.532711E 03	4.604025E 13	5.061308E 12	1.409847E 13	4.097897E 13	1.600640E 02	0.0
11	11	PU-239	PU-239	1	4.737786E 02	3.378493E 13	2.792640E 13	8.183169E 13	5.858587E 12	9.100098E 02	0.0
12	12	PU-240	PU-240	2	1.295939E 02	4.303985E 12	2.044064E 12	6.246126E 12	2.259917E 12	6.710056E 01	0.0
13	13	PU-241	PU-241	1	7.152403E 00	9.059380E 11	7.798450E 11	2.349471E 12	1.260935E 11	2.577466E 01	0.0
14	14	PU-242	PU-242	3	1.854817E 00	4.924585E 10	2.354224E 10	7.184568E 10	2.570365E 10	7.712907E-01	0.0
15	15	SSFP	SSFP	4	1.141663E 02	1.532711E 12	0.0	0.0	1.532711E 12	0.0	0.0

TOTAL REACTION RATE AND POWER PRODUCTION BY ABSOLUTE ISOTOPE FOR WHOLE REACTOR
REACTION RATES HAVE UNITS OF EVENTS/SEC

POS.	IDENTIFIER ABSOLUTE	INVENTORY (KGS)	ABSORPTION	FISSION	PRODUCTION	CAPTURE(N,G)	FISS. POWER (WATTS)	CAPT. POWER (WATTS)
1	C-16	2.516042E 03	4.372133E 11	0.0	0.0	4.372133E 11	0.0	0.0
2	NA-23	2.132009E 03	5.114958E 11	5.119050E 07	1.023811E 08	5.114444E 11	0.0	0.0
3	CR-N	4.272340E 03	2.270198E 12	0.0	0.0	2.270198E 12	0.0	0.0
4	MN-55	6.569434E 02	1.736403E 12	1.998922E 06	3.997844E 08	1.736203E 12	0.0	0.0
5	FE-N	1.767268E 04	5.990771E 12	0.0	0.0	5.990771E 12	0.0	0.0
6	NI-N	3.402774E 03	1.622224E 12	0.0	0.0	1.622224E 12	0.0	0.0
7	MO-N	1.374882E 03	5.771004E 12	3.318258E 09	6.636515E 09	5.767684E 12	0.0	0.0
8	TA-181	8.296207E 01	1.230402E 12	7.939712E 08	1.587943E 09	1.229608E 12	0.0	0.0
9	U-235	3.291962E 01	7.400052E 11	5.577351E 11	1.365607E 12	1.822702E 11	1.755806E 01	0.0
10	U-238	1.716542E 04	9.208051E 13	1.012262E 13	2.819693E 13	8.195794E 13	3.201279E 02	0.0
11	PU-239	9.475571E 02	6.756987E 13	5.585279E 13	1.636634E 14	1.171717E 13	1.820020E 03	0.0
12	PU-240	2.591875E 02	8.607970E 12	4.088127E 12	1.249225E 13	4.519834E 12	1.342011E 02	0.0
13	PU-241	1.430481E 01	1.811875E 12	1.559690E 12	4.698942E 12	2.521870E 11	5.154932E 01	0.0
14	PU-242	3.709635E 00	9.849170E 10	4.708449E 10	1.436914E 11	5.140729E 10	1.542581E 00	0.0
15	SSEP	2.283326E 02	3.065422E 12	0.0	0.0	3.065422E 12	0.0	0.0
	TOTALS		1.935438E 14	7.223241E 13	2.105695E 14	1.213116E 14	2.344998E 03	0.0

2-D 17X10 - 5 GROUP SEARCH PROBLEM
PRIMARY SEARCH = NUCLIDE(DIRECT) - SECONDARY SEARCH = DIMENSION
SUMMARY TABLE OF NEUTRON LOSSES FLUX WEIGHTED
NORMALIZED WITH 2.084652E 14 K-EFFECTIVE IS 1.009998

ZONE CLASS ID.	FISSILE 1	FERTILE 2	C. ACTINIDE 3	FISSION PROD 4	STRUCTURAL 5	COOLANT 6	CONTROL ROD 7	OTHER 0
1	0.3363391	0.4829526	0.0004724	0.0147033	0.0834140	0.0024534	0.0059016	0.0020971
SUM	0.3363391	0.4829526	0.0004724	0.0147033	0.0834140	0.0024534	0.0059016	0.0020971

SUMMARY TABLE OF OTHER INFORMATION

ZONE CLASS ID.	ABSORPTION LOSSES	FISSILE INVENTORY (KGS)	CONVERSION RATIO	FISSION POWER (WATTS)	TOTAL POWER (WATTS)
1	0.9283334	9.947813E 02	1.23325	2.344998E 03	2.344998E 03
SUM	0.9283334	9.947813E 02	1.23325	2.344998E 03	2.344998E 03
OTHER LOSSES	0.0716666				
TOTAL LOSSES	1.000000				

A BETTER ESTIMATE OF THE FUEL CONVERSION RATIO FOR A CRITICAL SYSTEM IS 1.26298
(BUT NOT MADE CRITICAL BY CHANGING CONTROL ABSORPTIONS OR LEAKAGE)

FISSILE CONSUMPTION/UNIT ENERGY GENERATION IS 1.176778E-14 KGS/WATT-SEC
FISSILE CONSUMPTION RATE IS 2.759544E-11 KGS/SEC

PRIMITIVE DOUBLING TIME (YEARS) OF THE ABOVE FISSILE INVENTORY (ONE PLANT) IS**********

NOTE - CONVERSION RATIO = (CAPTURE IN FERTILE)/(ABSORPTION IN FISSILE)

ENERGY PRODUCING UNIQUE ISOTOPES -- EQUIVALENT FUEL
BASED ON FISSION POWER

POS.	IDENTIFIER UNIQUE	IDENTIFIER ABSOLUTE	AMOUNT (KGS)	DESTRUCTION RATE (KGS/SEC)	WEIGHT	WEIGHTED ABSORPTION (ATOM/SEC)	UNWEIGHTED CAPTURE (ATOM/SEC)
1	O-16	O-16	2.516042E 03	1.151524E-14	C.0	0.0	4.372133E 11
2	NA-23	NA-23	2.132009E 03	1.935227E-14	C.0	0.0	5.114444E 11
3	CR-N	CR-N	4.272340E 03	1.960525E-13	C.0	0.0	2.270198E 12
4	MN-55	MN-55	6.569434E 02	1.570354E-13	C.0	0.0	1.736203E 12
5	FE-N	FE-N	1.767268E 04	5.555057E-13	C.0	0.0	5.990771E 12
6	NI-N	NI-N	3.402774E 03	1.581275E-13	C.0	0.0	1.622224E 12
7	MO-N	MO-N	1.374882E 03	9.109571E-13	C.0	0.0	5.767684E 12
8	TA-181	TA-181	8.296207E 01	3.664942E-13	C.0	0.0	1.229608E 12
9	U-235	U-235	3.291962E 01	2.863249E-13	2.776842E-01	2.054877E 11	1.822702E 11
10	U-238	U-238	1.716542E 04	3.608382E-11	9.709533E-03	8.940588E 11	8.195794E 13
11	PU-239	PU-239	9.475571E 02	2.659017E-11	1.000000E 00	6.756987E 13	1.171717E 13
12	PU-240	PU-240	2.591875E 02	3.401584E-12	2.695699E-01	2.320449E 12	4.519834E 12
13	PU-241	PU-241	1.430481E 01	7.189653E-13	1.876162E 00	3.399370E 12	2.521870E 11
14	PU-242	PU-242	3.709635E 00	3.927308E-14	2.164941E-01	2.132287E 10	5.140729E 10
15	SSFP	SSFP	2.283326E 02	8.194791E-13	C.0	0.0	3.065422E 12
	TOTAL				3.649619D 00	7.441056D 13	

WEIGHTED EQUIVALENT FUEL CONSUMPTION/UNIT ENERGY GENERATION IS 1.249229E-14 KGS/WATT-SEC (BASED ON PU-239)
CORRESPONDING CONSUMPTION RATE IS 2.929440D-11 KGS/SEC

END OF REACTION RATE MODULE - MAX ARRAY SIZE USED IS 2027 WORDS

Mathematical Formulations

Presented in this part of the documentation of the VENTURE code block are the mathematical equations programmed along with background material and certain displays to convey the nature of some of the formulations. Relatively simple approximations have generally been used; these tend to become more sophisticated with development and as experience in application grows. As with any of the more active programs, modifications must be made to extend the capability. The originators plan to upgrade the coverage of the programmed equations as appropriate; others who introduce changes are urged to do the same to keep the users fully informed about the version of the code in local use, and to notify us of the changes they have found to be desirable to make.

END OF SECTION

Section 701: The Discrete-Energy Group Diffusion Equation

Presented here is the basic equation which accounts for the various reactions of neutrons with material in a macroscopic sense, scattering and the diffusion approximation to neutron transport. Quite generally, an accounting of the neutrons in a system at one location and at one energy may be done in the form

$$\frac{1}{v}\frac{\partial N}{\partial t} = \text{Sources} - \text{Losses} - \text{Net Transport Loss} \ , \qquad (701\text{-}1)$$

where v is the neutron velocity, and $\frac{\partial N}{\partial t}$ is the time rate of change of the neutron density. We are not concerned here with the dynamic problem, but rather with a steady-state condition or static approximation to the neutron density. For a steady-state condition, it is necessary that the rate at which neutrons are added is equal to the rate at which they are removed, locally, and therefore over the whole system treated. At any location there may be generation of neutrons through the fission process and other sources not related to neutron reactions, in-scattering to any energy from other energies, removal by absorption or outscattering, and transport in and transport out.

The neutron density in an operating reactor is at steady state on the average due to natural reactivity compensation and control. In a large fraction of the neutronics problems solved, it is the intent to approximate this condition. Any problem describing a geometry, nuclide concentrations and cross sections, may represent a situation far from a steady state. The neutron population would actually rise or fall, and a steady-state solution only approximates the neutron distribution.

To effect this steady-state condition, the multiplication factor is introduced. The rate at which source neutrons are generated from fission is divided by the multiplication factor causing the loss rate to equal this adjusted source rate, a pseudo steady-state condition. The multiplication factor is defined as

$$k_e = \frac{\text{neutron generation rate}}{\text{neutron loss rate}} \ . \qquad (701\text{-}2)$$

A critical condition is one at steady state for which k_e is unity. The pseudo steady-state equation with the diffusion approximation to transport for the neutron flux at geometric location r and energy E using usual macroscopic nuclear properties is expressed as

$$- \nabla D_{r,E} \nabla \phi_{r,E} + (\Sigma_{a,r,E} + \Sigma_{s,r,E} + D_{r,E} B^2_{\perp E}) \phi_{r,E}$$

$$= \int_{E'} \left(\Sigma_{r,E'\to E} + \frac{1}{k_e} \chi_{r,E} (\nu\Sigma)_{f,r,E'}\right) \phi_{r,E'} dE' \ . \qquad (701\text{-}3)$$

The continuous energy spectrum is divided into discrete energy groups, and usually a simplification is made in the transport term,

$$- D_{r,g} \nabla^2 \phi_{r,g} + \left(\Sigma_{a,r,g} + \sum_n \Sigma_{s,r,g\to n} + D_{r,g} B^2_{\perp g}\right) \phi_{r,g}$$

$$= \sum_n \left(\Sigma_{s,r,n\to g} + \frac{1}{k_e} \chi_{r,g} (\nu\Sigma)_{f,r,n}\right) \phi_{r,n} \ . \qquad (701\text{-}4)$$

Where

∇^2 = the Laplacian geometric operator, $\frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2} + \frac{\partial^2}{\partial z^2}$ in slab geometry, cm^{-2},

$\phi_{r,g}$ = the neutron flux at location r and in energy group g, $n/sec\text{-}cm^2$,

$\Sigma_{a,r,g}$ = the macroscopic cross section for absorption, normally weighted over a representative flux energy spectrum, cm^{-1},

$\Sigma_{s,r,g\to n}$ = the macroscopic cross section for scattering of neutrons from energy group g to energy group n[a] (a set of these makes up a scattering kernel), cm^{-1},

$D_{r,g}$ = the diffusion coefficient, normally one-third of the reciprocal of the transport cross section,[b] cm,

$B^2_{\perp g}$ = the buckling term to account for the effect of the Laplacian operator (leakage) in one or more orthogonal coordinates treated explicitly, cm^{-2},

---

[a]The in-group term g→g is excluded from the calculation.

[b]Coordinate-direction dependence is permitted without effect on the value of D used for the buckling loss.

$\nu\Sigma_{f,r,g}$ = the macroscopic production cross section (ν is the number of neutrons produced by a fission and Σ_f is the cross section for fission), cm^{-1},

$\chi_{r,g}$ = the distribution function for source neutrons (normally $\sum_g \chi_{r,g} = 1.0$, but provision is made for it not),

k_e = the effective multiplication factor, the ratio of the rate of production of neutrons to the rate of loss of neutrons from all causes, an unknown to be determined.

Eq. 701-4 is called the usual neutron flux eigenvalue problem in this report. There is no provision in the above expression for fixed, external sources. The level of the neutron flux is not defined by the equation above. It can be whatever the investigator wants; however, there is no account made of temperature effects associated with changes in the power density on the nuclear properties, so the equation is appropriate to the extent that the macroscopic properties are representative.

The multiplication factor is an extremely useful measure of the degree a calculated system deviates from critical. The more positive the value of $(k_e - 1)$, the faster the flux level would increase; the more negative, the faster it would decrease. The effectiveness of control rods is directly measured by the decrease in k_e associated with rod insertion.

The difficulty associated with determining critical conditions and associated high cost of computation to support analysis effort have directly caused extensive application of this usual flux eigenvalue formulation in analysis of reactors. It is important to recognize, however, that the conditions estimated for a system which is not critical only approximate the real situation of reactor operation.

A Simple P_1 Treatment

A first order correction to diffusion theory is possible by application of the consistent P_1 equations. These are examined here for the usual eigenvalue problem in the form

$$\nabla\cdot J + \Sigma_t\phi = \frac{1}{k}\chi\int\nu\Sigma_f\phi dE' + \int\Sigma_s{}^0\phi dE' \;;$$
$$\nabla\phi + 3\Sigma_t J = \int\Sigma_s{}^1 J dE' \;, \tag{701-5}$$

where the equations are for a point in space and energy, the integrals run over the energy range of interest, J is the current, ϕ is the scalar flux, $\Sigma_s{}^0$ is the in-scattering cross section, and $\Sigma_s{}^1$ is its first moment.

The diffusion theory approximation of the neutron current gives

$$J = -D\nabla\phi \;; \tag{701-6}$$

$$-\nabla D\nabla\phi + \Sigma_t\phi = \frac{1}{k}\chi\int\nu\Sigma_f\phi dE' + \int\Sigma_s{}^0\phi dE' \;, \tag{701-7}$$

In one-dimension, J has only one direction component but the integral over direction is required in general. For the one-dimensional case,

$$D = \frac{1}{3\left\{\Sigma_t - \frac{1}{3J}\int\Sigma_s{}^1 J dE'\right\}} \;, \tag{701-8}$$

or a common approximation

$$D \cong \frac{1}{3\left\{\Sigma_a + (1-\bar{\mu}_0)\Sigma_s{}^0\right\}} \;.$$

In a simple P_1 form, the equations may be cast as

$$-\frac{1}{3\Sigma_t}\nabla^2\phi + \Sigma_t\phi = \frac{1}{k}\chi\int\nu\Sigma_f\phi dE' + \int\Sigma_s{}^0\phi dE' - \frac{1}{3\Sigma_t}\int\Sigma_s{}^1\nabla\cdot J dE' \;, \tag{701-9}$$

and the $\nabla\cdot J$ term is given by

$$\nabla\cdot J = \frac{1}{k}\chi\int\nu\Sigma_f\phi dE' + \int\Sigma_s{}^0\phi dE' - \Sigma_t\phi \;. \tag{701-10}$$

In multi-group form the P_1 equations chosen for implementation, with in-group corrections, are

$$- D(n,r)\ \nabla^2\phi(n,r) + \Sigma_r(n,r)\ \phi(n,r) = S(n,r)$$

$$- D(n,r)\sum_{m\neq n}\Sigma_s{}^1(m\rightarrow n)\ \nabla\cdot J(m)$$

where

$$S(n,r) = \frac{1}{k}\chi(n,r)\sum_m \nu\Sigma_f(m,r)\phi(m,r) + \sum_{\substack{m\\ m\neq n}}\Sigma_s{}^0(m\rightarrow n,r)\phi(m,r) \ ,$$

$$\nabla\cdot J(n,r) = S(n,r) - \Sigma_r(n,r)\phi(n,r) \ ,$$

$$D(n,r) = \frac{1}{3\left[\Sigma_t(n,r) - \frac{1}{3}\ \Sigma_s{}^1(n\rightarrow n,r)\right]} \ ,$$

$$\Sigma_r(n,r) = \Sigma_t(n,r) - \Sigma_s{}^0(n\rightarrow n,\ r) \ ,$$

where the argument r refers to space and n and m to energy.

We note that if the finite-difference equations are summed, the P_1 scattering term does not cancel out, so an overall neutron balance does not result. This may restrict practical application. The apparent advantage of the scheme is that the diffusion coefficient to be used is obtained directly at each energy without requiring some weighting on what happens at other energies.

If one examines the spherical harmonics equations for P_1 truncation, there is one more first-order equation than coordinates treated; for example, four equations treat three space coordinates. As implemented, a simple equation for the net current is used along with a second order equation for the flux. There is a piece of information lost, even if only one coordinate is treated. That is, the in-group correction is the same regardless of the direction of the net current at another energy. In

fact, anisotropic scattering at one energy has a direct effect on the angular flux at the energy scattered into. This effect can only be accounted for by applying a better formulation. The utility of the programmed equations remains to be demonstrated.

A remark is in order about the representation of boundary conditions. The simple P_1 approximation is programmed to use only the usual diffusion theory boundary conditions. Reflected, periodic and rotational symmetry conditions require no special attention: the approximations are consistent with the formulation for internal points. The extrapolated or non-return boundary condition may require special attention. The leakage of neutrons in this approximation is not simply related to the scalar flux derivative. As is usual in the application of diffusion theory, the representation of conditions near a control rod should be tested against a higher-order transport approximation; a best value for the extrapolation distance must be established by test, and this test should be with the P_1 formulation implemented, not regular diffusion theory. As is usual with the application of diffusion theory, external boundaries should be located sufficiently remote from the core proper that the actual leakage which will be calculated will not have much effect on the flux distribution in the core. The estimate of surface leakage is probably not especially improved by the programmed equations; rather, careful attention to what will result from the formulation is may be necessary.

We look forward to learning about the results of experience with application given sufficient detailed information to permit thorough assessment. Meanwhile, a superior treatment is sought to bridge the gap between diffusion theory and a more explicit representation of transport theory which can be applied at a reasonable cost of computation.

END OF SECTION

Section 702: Finite Difference Representation of the Laplacian Operator

The Laplacian operator is to be represented in a finite-difference form. First, the finite-difference mesh will be examined. The equations will be developed for the three-dimensional slab; for fewer dimensions, the extent in the untreated orthogonal directions is considered to be infinite and contributions from these simply drop out of the equations.

Consider a traverse in space direction r. A region is traversed between r_1 and r_2 boundaries or material interfaces. Input data specifies the number of mesh points to be located between r_1 and r_2 and the spacing $\Delta = r_2 - r_1$ across the region.

Figure 702-1 presents a three-dimensional sketch showing the flux location at mesh point (i,j,m) and the surrounding six flux locations, nearest neighbors. The finite-difference volume about mesh point (i,j,m) is $(x_i - x_{i-1})\ (y_j - y_{j-1})\ (z_m - z_{m-1})$ where these are locations of the surfaces of the finite-difference element.

Neutron leakage from (i,j,m) to (i,j,m-1), $L(z_{m-1})$, through the front face of area $(x_i - x_{i-1})\ (y_j - y_{j-1})$ is approximated as follows. Let A_1 equal the unknown flux at the interface. Leakage out is given by approximating the flux slope at the surface by the average within the element (between the central point and the surface),

$$L(z_{m-1}) = D_{i,j,m}\ [\phi_{i,j,m} - A_1\ ]\left[\frac{(y_j - y_{j-1})\ (x_i - x_{i-1})}{\left(\frac{z_m - z_{m-1}}{2}\right)}\right],$$

where $D_{i,j,m}$ is the diffusion constant at (i,j,m). Similarly for inward leakage from the adjacent finite element,

$$-\ L(z_{m-1}) = D_{i,j,m-1}\ [\phi_{i,j,m-1} - A_1\ ]\left[\frac{(y_j - y_{j-1})\ (x_i - x_{i-1})}{\left(\frac{z_{m-1} - z_{m-2}}{2}\right)}\right].$$

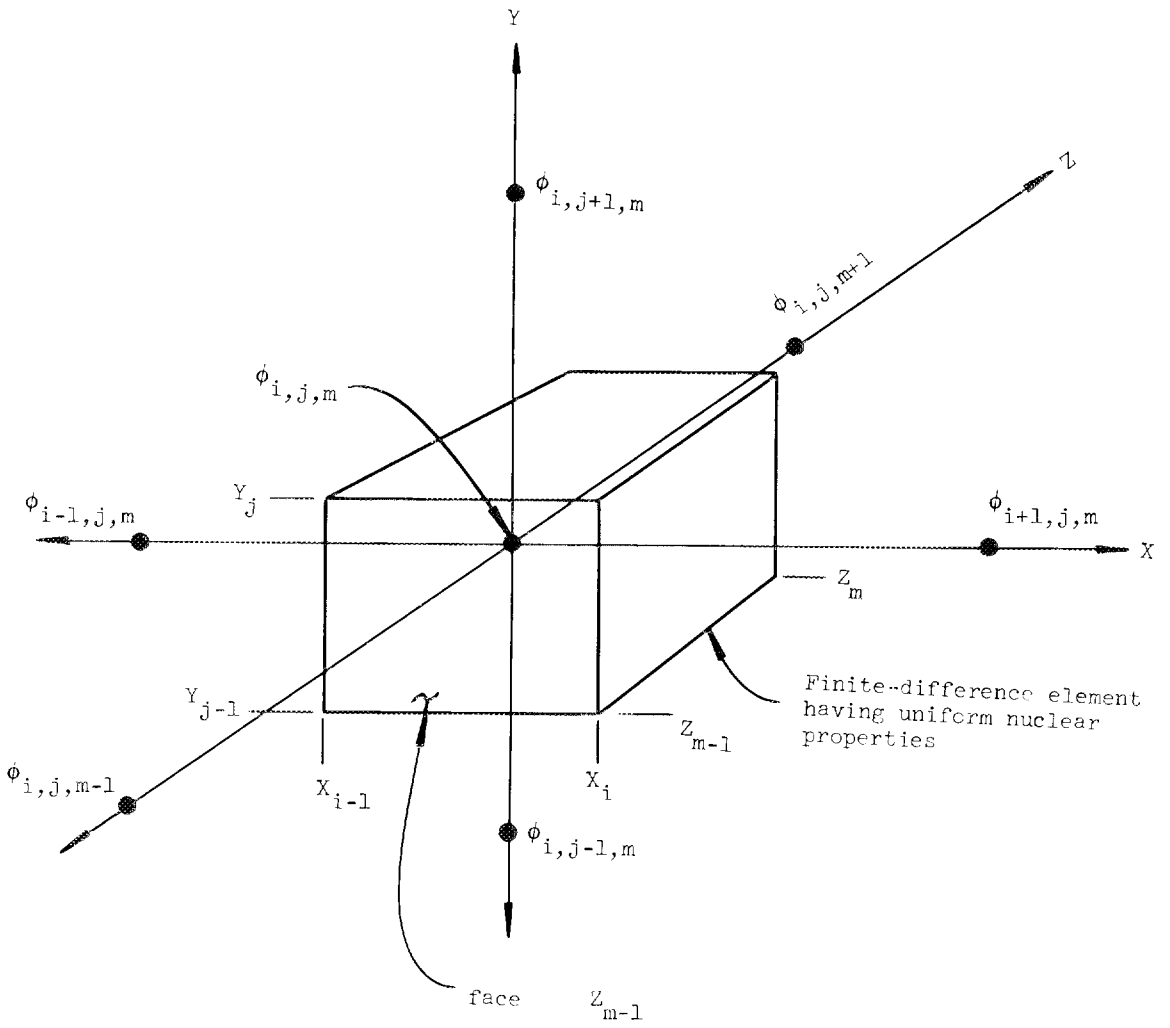

Fig. 702-1. The Seven-Point Finite Difference Mesh.

Eliminating A_1 from the equations gives

$$L(z_{m-1}) = \left[\frac{2(y_j - y_{j-1})\ (x_i - x_{i-1})}{\dfrac{z_m - z_{m-1}}{D_{i,j,m}} + \dfrac{z_{m-1} - z_{m-2})}{D_{i,j,m-1}}}\right] [\phi_{i,j,m} - \phi_{i,j,m-1}] \ . \quad (702\text{-}1)$$

Since the term which multiplies the flux difference is simply some constant, Eq. 702-1 reduces to the form

$$L(z_{m-1}) = C_{i,j,m,m}\ [\phi_{i,j,m} - \phi_{i,j,m-1}] \ . \quad (702\text{-}2)$$

It may be noted that within a region having uniform nuclear properties and uniform mesh spacing,

$$C_{i,j,m,m-1} = \frac{(y_j - y_{j-1})(x_i - x_{i-1})\ D_{i,j,m}}{(z_m - z_{m-1})}, \text{ internal, slab geometry.}$$

Provision is incorporated for the diffusion constant D to depend on coordinate direction; value of D simply depends on the particular coordinate treated and the assigned transport cross section.

The leakage from the whole element is given by

$$L(z_m) + L(z_{m-1}) + L(x_i) + L(x_{i-1}) + L(y_j) + L(y_{j-1}) =$$

$$\phi_{i,j,m}\ [C_{i,j,m,m+1} + C_{i,j,m,m-1} + C_{i,j,m,i+1} + C_{i,j,m,i-1} + C_{i,j,m,j+1}$$

$$+ C_{i,j,m,j-1}] - C_{i,j,m,m+1}\ \phi_{i,j,m+1} - C_{i,j,m,m-1}\ \phi_{i,j,m-1}$$

$$- C_{i,j,m,i+1}\ \phi_{i+1,j,m} - C_{i,j,m,i-1}\ \phi_{i-1,j,m}$$

$$- C_{i,j,m,j+1}\ \phi_{i,j+1,m} - C_{i,j,m,j-1}\ \phi_{i,j-1,j} \ . \quad (702\text{-}3)$$

For a zero gradient boundary condition, the associated $C_{i,j,m,m-1}$ constant is set to zero.

For an extrapolated boundary condition, external or internal black boundary, the flux slope within the finite-difference element is extended. The boundary condition to be satisfied at the element surface is

$$-\frac{D}{\phi_s}\frac{\partial\phi}{\partial x}\bigg|_s = C_s \ , \qquad (702\text{-}4)$$

where C_s is a specified constant.[a]

Let ϕ_i be the internal flux, ϕ_s be the boundary flux, and Δ be the distance to the boundary from the internal point.

A linear approximation of the flux within the element gives

$$-\frac{\partial\phi}{\partial x} = \frac{\phi_i - \phi_s}{\Delta} \ ,$$

or

$$-\frac{D_i}{\phi_s}\frac{\partial\phi}{\partial x}\bigg|_s = \frac{D_i}{\Delta\phi_s}\left(\phi_i - \phi_s\right) = C_s \ .$$

Representing the normal area by A_n, the boundary leakage from one face of an element volume is given by

$$L_{s,n} = -D_i\, A_n \frac{\partial\phi}{\partial x}\bigg|_b = \frac{A_n\phi_i}{\left(\frac{1}{C_s} + \frac{\Delta}{D_i}\right)} \ , \qquad (702\text{-}5)$$

which gives the required constant for Eq. 702-3. Of course, the external leakage is considered lost from the system, but leakage into an internal black absorber is accounted for as an absorption in the region.

---

[a] A default value of 0.4692 is used for C_s. Suitable group-dependent values which will reproduce the leakage condition must come from appropriate neutron transport calculations for a specific situation. An approximation which may be useful is $C_s \simeq 0.4692/(1 - \bar{\mu} + \frac{\Sigma_a}{\Sigma_s})$. There is also a correction for a curved surface; multiply C_s by something like (R+.5)/(R+1.) for a black sphere to reduce it as R decreases.

An alternative formulation for the extrapolated boundary condition is possible. Consider Eq. 702-4. Direct integration yields

$$\phi \propto e^{-C_s x/D} , \qquad (702\text{-}6)$$

and the leakage constant is given by

$$L_{s,n} = - D_i A \frac{\partial \phi}{\partial x}\Big|_b = A_n C_s \phi_i e^{-C_s \Delta/D_i} \qquad (702\text{-}7)$$

This assumes an exponential shape of the flux between the internal point and the surface, rather than linear. At the time this is written, it is intended to offer the choice between the two as a user option, or adopt the better of the two if it can be identified.

The repeating boundary condition causes flux values at opposite ends of a row to be coupled so that the row is a closed loop. For 90° rotational symmetry, coupling is from the right-hand edge column to the bottom edge row. Similarly, 120° rotational symmetry is treated for the triangular mesh problem. In all such problems, the appropriate physical boundaries abut and the adjacent point flux values couple as across any internal interface. For 180° rotational symmetry, the right-hand edge column couples with itself inverted.

For curvilinear geometries, the surface areas of the finite-difference element faces must be used which lead to somewhat more involved equations than above. The finite-difference element is illustrated in Fig. 702-2.

For the special treatment of hexagonal and triagonal finite-difference elements, leakages across the individual volume element faces are formulated in the same manner as for slab geometry. The three-dimensional problem in hexagonal geometry involves eight nearest neighbors, six on the plane of the hexagons. In triangular geometry there are five nearest neighbors, three on the plane of the triangle. The hexagonal formulation is a high-order approximation to the situation (which may allow a relatively coarse mesh). The triangular formulation is of low-order and somewhat less reliable, especially since the next ring of points beyond the nearest neighbors are relatively close but not considered.

The mesh-point layout for the various geometries treated is indicated in the compact display in Table 702-1.

The special boundary conditions considered are shown in Fig. 702-3. These are for two-dimensional problems or on planes of three-dimensional problems. Note that the coordinate axes in triangular geometry are at either 120° or 60°. Fig. 702-4 shows the orientations for triangular geometry in detail, and Fig. 702-5 the layout for hexagonal geometry.

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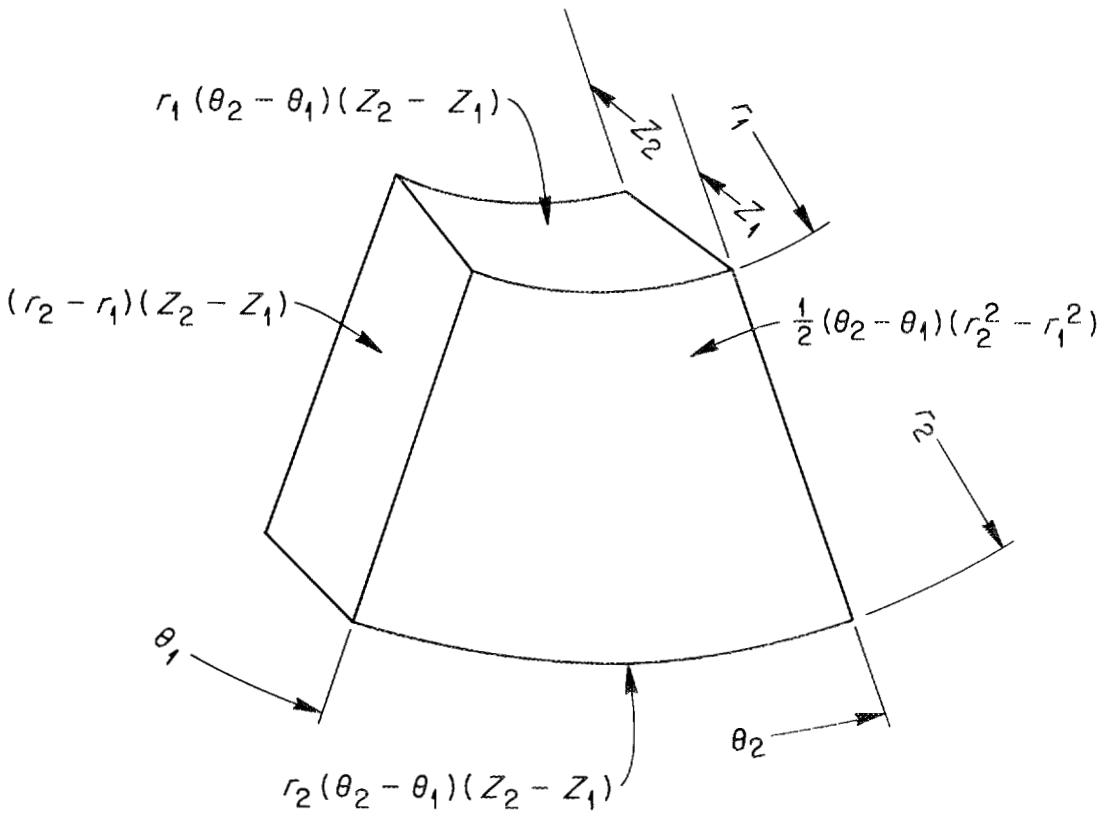


NOTE: θ IS IN RADIANS; WHEN THE CIRCLE IS CLOSED, θ SPANS 2π RADIANS

Figure 702-2. Cylindrical Finite-Difference Element

Table 702-1. Layout of Meshpoints.[a]

System	Slab	Cylinder	Cylinder	Sphere	Hexagonal[b]	Triagonal[c]
Reference	$X\ Y\ Z$	$\theta\ R\ Z$	$R\ Z$	R	$X\ Y\ Z$	$X\ Y\ Z$
Geometry	X-Y-Z	θ-R-Z	R-Z	R	H-Z	T-Z
Specified region dimensions	Δ_x Δ_y Δ_z	Δ_r Δ_θ Δ_z	Δ_r Δ_z	Δ_r	Δ_x $\Delta_y = \Delta_x$ Δ_z	Δ_x $\Delta_y = \Delta_x$ Δ_z
Specified internal mesh points	J_x, I_y, M_z	J_r, I_z, M_θ	J_r, I_z	J_r	J_x, I_y, M_z	J_x, I_x, M_z
Volume of region	$\Delta_x\Delta_y\Delta_z$	$\frac{\Delta_z\Delta_\theta}{2}(r_2^2-r_1^2)$	$\pi\Delta_z(r_2^2-r_1^2)$	$\frac{4\pi}{3}(r_2^3-r_1^3)$	$\Delta_x\Delta_y\Delta_z\frac{\sqrt{3}}{2}$	$\Delta_x\Delta_y\Delta_z\frac{\sqrt{3}}{2}$

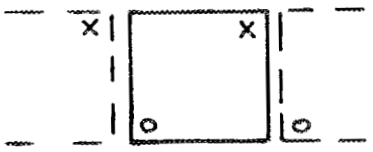
[a]Volume about each mesh point = volume of region ÷ number of internal points; mesh point locations are at finite-difference centroids.

[b]On a plane the Y coordinate is rotated 60° from the X coordinate.

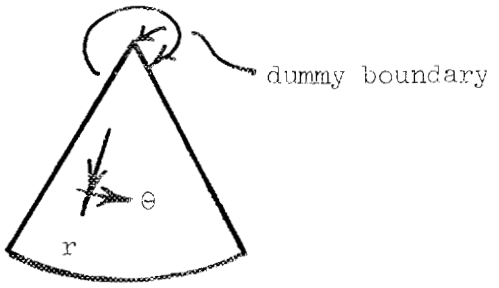
[c]On a plane, the Y coordinate is rotated 120° from the X coordinate in one option, 60° in another option, or 30° or 90° as special cases (shown in Figure 702-4).

Special boundary conditions are keyed to the right-hand or third side indexed clockwise beginning with the left side. The coordinate axis intersect at the upper left hand corner in all cases.

REPEATING OR PERIODIC BOUNDARY

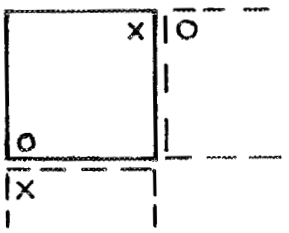


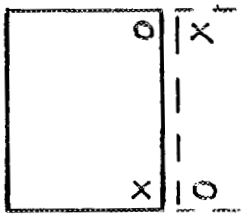
SLAB



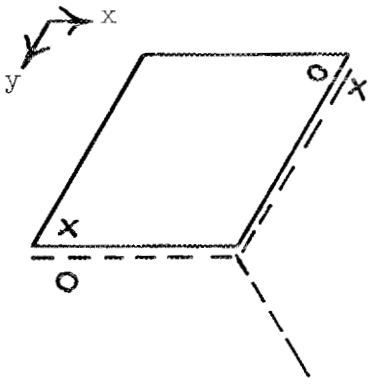
CYLINDER

90° AND 180° ROTATIONAL SYMMETRY

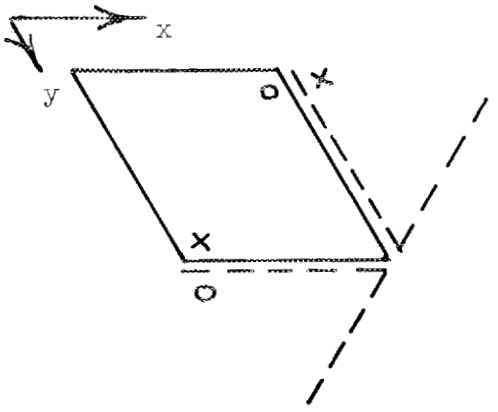




120° AND 60° ROTATIONAL SYMMETRY



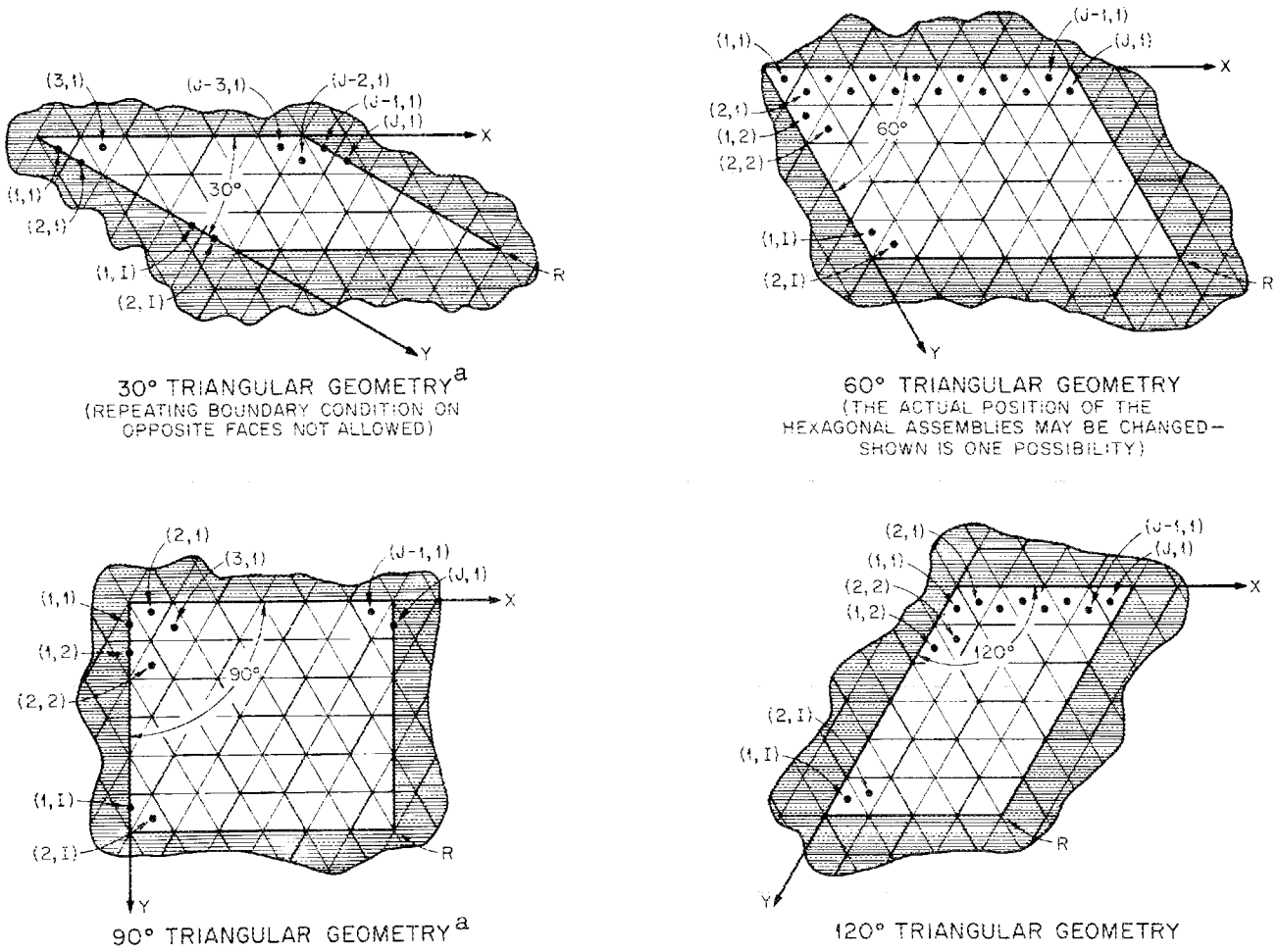
Triangular, 120° Coordinates



Triangular, 60° Coordinates

Fig. 702-3. Special Boundary Conditions.

ORNL-DWG 74-6654



R = ROTATIONAL SYMMETRY ABOUT THIS POINT ALLOWED

[a]Not implemented in first release version.

Fig. 702-4. Orientation for Triangular Geometry

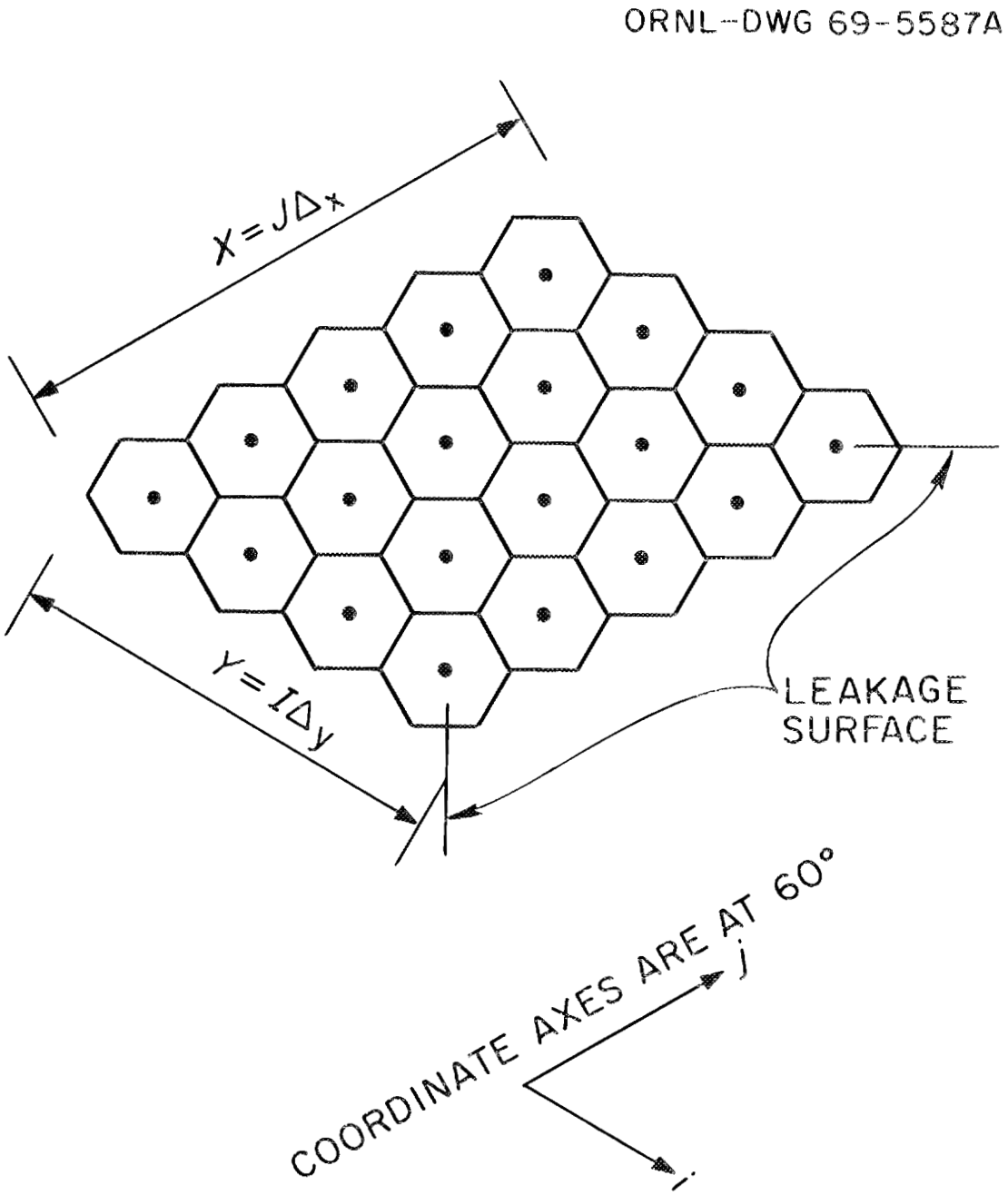


Figure 702-5. The Layout of Hexagonal Geometry.

Accuracy

It is well-known that the finite-difference approximation to the Laplacian operator is accurate to the order of the mesh spacing squared. We recognize that the accuracy of the mesh point centered approximation is slightly lower than that obtained with mesh points located on material interfaces. Of course they are identical within a homogeneous medium with uniform spacing. With mesh centered points, reaction rates are properly located (rather than smearing abutting materials within the finite-difference volume element), a gain with this approximation; this makes such approximations as that of simple P_1 more realistic.

Still the analyst wants to know how accurate are integral quantities (k) as well as estimates of local properties (power density). We believe that experience is the best guide here. It is possible to increase the number of mesh points and solve the new fine-mesh problem, which normally improves the estimate of both integral and local quantities, but not necessarily. Care must be taken in allocation of mesh points and in selecting an energy group structure to get the best results. Generally it is desirable to increase the number of points in each direction (not just in one), and within each zone of uniform composition. About the same mean free neutron path length between adjacent points is desirable in all directions; therefore increasing of the number of mesh points should be done with this objective — decreasing large steps in the spacing.

Regarding local properties, it is a fallacy to believe that use of a very small finite-difference volume at one location will cause the estimate of local properties to have a high accuracy. We recommend against use of large changes in mesh spacing. Further, the interpretation of local quantities should be of mesh-average properties rather than local at the actual mesh point site.

Finite-Difference Approximation error

The solution obtained by application of a finite-difference formulation is not precise; an error is associated with the approximation. This error may be larger than a casual user may anticipate. It is more serious regarding certain specific results than others, and has a dependence on the actual problem not readily predicted.

Some information is available from simple problems for which explicit solutions are available. Consider the one-group bare homogeneous cube in three dimensions, half-length L. The precise and finite-difference solutions for the flux are separable in space, the precise solution being $\phi(x,y,z) \propto \cos(\pi x/2L) \cos(\pi y/2L) \cos(\pi z/2L)$ with reflection at the start of each coordinate and zero flux at the extreme. Normalizing the flux such that its volume integral is unity,

$$\phi(x,y,z) = \left(\frac{\pi}{2L}\right)^3 \cos\left(\frac{\pi x}{2L}\right) \cos\left(\frac{\pi y}{2L}\right) \cos\left(\frac{\pi z}{2L}\right) .$$

The leakage rate at one surface is, typically,

$$-D \int_y \int_z \left.\frac{\partial\phi(x,y,z)}{\partial x}\right|_{x=L} dy\, dz = D\left(\frac{\pi}{2L}\right)^2 ,$$

and

$$k_e = \frac{\nu\Sigma_f}{\Sigma_a + 3D\left(\frac{\pi}{2L}\right)^2} ,$$

containing the familiar buckling term, $B_e = 3\,(\pi/2L)^2$.

The result for a finite-difference formulation depends on the location of the mesh points. Generally,

$$k_n = \frac{\nu\Sigma_f}{\Sigma_a + DB_n^2} ,$$

and

$$B_n^2 = \frac{-\int \left.\frac{\partial\phi}{\partial n}\right|_s ds}{\iiint \phi \, dx \, dy \, dz}$$

where the numerator is a surface integral of the normal derivative. For the situation here, assume the same representation along each coordinate,

$$B_n^2 = \frac{-3 \left.\frac{\partial\phi}{\partial x}\right|_{x=L}}{\int \phi \, dx} .$$

Consider mesh centered points. Given N internal points along each coordinate space L/N, the end points located L/2N from boundaries, the solution is

$$\phi(n,j,i) = A \cos\left[\frac{\pi}{4N}(2n-1)\right] \cos\left[\frac{\pi}{4N}(2j-1)\right] \cos\left[\frac{\pi}{4N}(2i-1)\right] .$$

The surface leakage at x = L is estimated by assuming zero flux at x = L,

$$-\left.\frac{\partial\phi}{\partial x}\right|_s \simeq -\left.\frac{\Delta\phi}{\Delta x}\right|_s \simeq \left(\frac{2N}{L}\right)\phi(N,j,i)$$

$$= A\left(\frac{2N}{L}\right)\cos\left[\frac{\pi}{4N}(2N-1)\right] \cos\left[\frac{\pi}{4N}(2j-1)\right] \cos\left[\frac{\pi}{4N}(2i-1)\right]$$

$$= A\left(\frac{2N}{L}\right)\left\{\cos\left(\frac{\pi}{2}\right)\cos\left(\frac{\pi}{4N}\right) + \sin\left(\frac{\pi}{2}\right)\sin\left(\frac{\pi}{4N}\right)\right\}$$

$$\times \cos\left[\frac{\pi}{4N}(2j-1)\right] \cos\left[\frac{\pi}{4N}(2i-1)\right]$$

$$= A\left(\frac{2N}{L}\right)\sin\left(\frac{\pi}{4N}\right)\cos\left[\frac{\pi}{4N}(2j-1)\right] \cos\left[\frac{\pi}{4N}(2i-1)\right] .$$

The integrated flux is obtained as the sum

$$\int \phi \, dx \simeq A \sum_{n} \phi(n,j,i) \left[\frac{L}{N} \right]$$

$$= A\left(\frac{L}{N}\right)\cos\left[\frac{\pi}{4N}(2j-1)\right]\cos\left[\frac{\pi}{4N}(2i-1)\right]\sum_{n=1}^{N}\cos\left[\frac{\pi}{4N}(2n-1)\right]$$

$$= A\left(\frac{L}{N}\right)\cos\left[\frac{\pi}{4N}(2j-1)\right]\cos\left[\frac{\pi}{4N}(2i-1)\right]\frac{\cos\left(\frac{\pi}{4}\right)\sin\left(\frac{\pi}{4}\right)}{\sin\left(\frac{\pi}{4N}\right)}$$

$$= A\left(\frac{L}{2N}\right)\frac{\cos\left[\frac{\pi}{4N}(2j-1)\right]\cos\left[\frac{\pi}{4N}(2i-1)\right]}{\sin\left(\frac{\pi}{4N}\right)} ;$$

$$B_N^2 = \frac{3\left(\frac{2N}{L}\right)\left[\sin\left(\frac{\pi}{4N}\right)\right]^2}{\left(\frac{L}{2N}\right)} ,$$

$$B_N^2 = 3\left\{\left(\frac{2N}{L}\right)\sin\left(\frac{\pi}{4N}\right)\right\}^2 .$$

Note that for large N, $\sin(\pi/4N) \to \pi/4N$, $B_\infty^2 \to 3\,(\pi/2L)^2$, the precise result.

The more general solution for a different number of mesh points along each coordinate follows directly,

$$B_{N,J,I}^2 = \left\{\frac{2N}{L}\sin\left(\frac{\pi}{4N}\right)\right\}^2 + \left\{\frac{2J}{L}\sin\left(\frac{\pi}{4J}\right)\right\}^2 + \left\{\frac{2I}{L}\sin\left(\frac{\pi}{4I}\right)\right\}^2 .$$

Comparing the finite-difference solution to the precise one, the expressions for the flux are identical except for normalization. This aspect limits the generality of this assessment.

The error associated with any point flux value is given by comparing normalized results. Normalizing to the same loss rate, absorption plus leakage, yields

$$\iiint [\Sigma_a + DB_e^2]\ \phi(x,y,z)\ dx\ dy\ dz \simeq$$

$$\sum_{n,j,i} \left[\Sigma_a + DB^2_{N,J,I}\right]\left[\frac{L^3}{NJI}\right] \phi(n,j,i) \ ,$$

and the right hand side is easily obtained by the product of averages along each coordinate. This leads to the relative error

$$\frac{\phi(n,j,i) - \phi\ (x,y,z)}{\phi(x,y,z)} = \left(\frac{4}{\pi}\right)^3 NJI\ \sin\left(\frac{\pi}{4N}\right) \sin\ \left(\frac{\pi}{4J}\right) \sin\left(\frac{\pi}{4I}\right)$$

$$\times \left[\frac{1 + \frac{D}{\Sigma_a} B_e^2}{1 + \frac{D}{\Sigma_a} B^2_{N,J,I}}\right] - 1$$

$$\simeq \frac{-\frac{1}{6}\left[1 + \frac{D}{\Sigma_a}\left(\frac{\pi}{2L}\right)^2\right]\left[\left(\frac{\pi}{4N}\right)^2 + \left(\frac{\pi}{4J}\right)^2 + \left(\frac{\pi}{4I}\right)^2\right]}{1 + \frac{D}{\Sigma_a}\left(\frac{\pi}{2L}\right)^2 \left[3 - \frac{1}{3}\left\{\left(\frac{\pi}{4N}\right)^2 + \left(\frac{\pi}{4J}\right)^2 + \left(\frac{\pi}{4I}\right)^2\right\}\right]} \ .$$

Thus the error in a point flux value depends on the problem, and it depends on the mesh, each coordinate making an independent contribution. Except for a small number of points, the error decreases as the sum of the reciprocals of the squares of the numbers of mesh points along each coordinate. Doubling the number of points along each of the coordinates would be expected to reduce the error by a factor of 4.

Consider the error in an integral quantity, namely the multiplication factor. Since

$$k_{N,J,I} = \frac{\nu\Sigma_f}{\Sigma_a + DB^2_{N,J,I}} ,$$

the error is given by

$$\frac{k_{N,J,I} - k_e}{k_e} = \frac{\frac{D}{\Sigma_a}\left(B_e^2 - B^2_{N,J,I}\right)}{1 + \frac{D}{\Sigma_a} B^2_{N,J,I}}$$

$$\simeq \frac{\frac{D}{3\Sigma_a}\left[\left(\frac{\pi}{4N}\right)^2 + \left(\frac{\pi}{4J}\right)^2 + \left(\frac{\pi}{4I}\right)^2\right]}{1 + \frac{D}{\Sigma}\left(\frac{\pi}{2L}\right)^2\left[3 - \frac{1}{3}\left\{\left(\frac{\pi}{4N}\right)^2 + \left(\frac{\pi}{4J}\right)^2 + \left(\frac{\pi}{4I}\right)^2\right\}\right]} ,$$

a similar variation to that obtained above.

The Leakage Operator Error

Consider the finite-difference approximation to the leakage operator. If the flux and derivatives were known at a point, the flux at a neighboring point is given by a Taylor expansion as

$$\phi(\Delta) = \phi(0) + \Delta \left.\frac{\partial\phi}{\partial x}\right|_0 + \frac{\Delta^2}{2}\left.\frac{\partial^2\phi}{\partial x^2}\right|_0 + \frac{\Delta^3}{6}\left.\frac{\partial^3\phi}{\partial x^3}\right|_0 + \frac{\Delta^4}{24}\left.\frac{\partial^4\phi}{\partial x^4}\right|_0 + \ldots ,$$

$$\phi(-\Delta) = \phi(0) - \Delta \left.\frac{\partial\phi}{\partial x}\right|_0 + \frac{\Delta^2}{L}\left.\frac{\partial^2\phi}{\partial x^2}\right|_0 - \frac{\Delta^3}{6}\left.\frac{\partial^3\phi}{\partial x^3}\right|_0 + \frac{\Delta^4}{24}\left.\frac{\partial^4\phi}{\partial x^4}\right|_0 - \ldots ,$$

where Δ is the mesh spacing. Summing these gives the central difference approximation for the Laplace operator,

$$\frac{\partial^2\phi}{\partial x^2} = \frac{\phi(\Delta) + \phi(-\Delta) - 2\phi(0)}{\Delta^2} - \frac{\Delta^2}{12}\left.\frac{\partial^4\phi}{\partial x^4}\right|_0 + \ldots .$$

Thus the error from dropping the higher terms is to the order of the mesh spacing squared, so the error is expected to vary inversely as the square of the number of mesh points.

Application

Consider that a calculation produced a result V_1 with a mesh of N_1, J_1, and I_1 points. A second result V_2 is obtained with N_2, J_2, and I_2 points. We expect that

$$\frac{V_1 - V_\infty}{V_2 - V_\infty} = \frac{\alpha_1}{\alpha_2} ;$$

$$V_\infty = \frac{\alpha_1 V_2 - \alpha_2 V_1}{\alpha_1 - \alpha_2} ,$$

where

$$\alpha_n = \left[\frac{1}{N_n^2} + \frac{1}{J_n^2} + \frac{1}{I_n^2}\right],$$

applicable to one, two or three dimensions (drop terms not applicable).

These results show that the errors in the point flux values and in the multiplication factor are inversely proportional to the square of the number of mesh points along each coordinate. Given two solutions,

$$\frac{V(N) - V(\infty)}{V(M) - V(\infty)} = \left(\frac{M}{N}\right)^2 ;$$

$$V(\infty) = \frac{V(N) - \left(\frac{M}{N}\right)^2 V(M)}{1 - \left(\frac{M}{N}\right)^2} ,$$

where V(N) is the result with N mesh points, V(∞) is the extrapolation to approximate the result for a continuum. Note that N and M are the number of points along one coordinate, not the total points. The equations apply to one, two, or three dimensional problems.

Changes made locally or to less than all coordinates treated should not be expected to produce reliable extrapolation and error assessment, not is error assessment of a coarse mesh result reliable. The reliability of such extrapolation in application to the general multi-group, complicated geometry problem is unknown. Extrapolation of integral quantities should be more reliable than of point properties; the points may be at different locations and an extreme (such as the maximum power density) may move from one location to another. For reliable assessment, it is recommended that a uniform increase in mesh points be made along all coordinate directions in each zone.

An illustration of application is given here. Explicit solutions are known for bare homogeneous problems. The results from extrapolation of answers for successive meshes are shown below for a particular seven-group three-dimensional case:

Space Mesh (M)	k(M)	$\left(\frac{M}{N}\right)^2$	k (∞)
6 x 2 x 4	0.7400339	-	-
12 x 4 x 8	0.7280397	4	0.7240416
24 x 8 x 16	0.7250360	4	0.7240348
48 x 16 x 32	0.7242847	4	0.7240343
96 x 32 x 64	0.7240969	4	0.7240343
144 x 48 x 96	0.7240621	2.25	0.7240343
∞ (continuum)	0.7240343		

Of course the problems soved in analysis usually have geometric and composition complexities, an integral quantity such as the multiplication factor may be monotonic with increasing mesh only above some mesh size, and extrapolation of coarse results is unreliable due to higher order error contamination.

END OF SECTION

Section 704: Calculation of Macroscopic Cross Sections, Normalization and Edits

This code is designed to use microscopic data for individual nuclides to take into account changes in the concentrations of the nuclides. It may be practical in some situations to use a pseudo non-depleting nuclide concentration of relative density and associated macroscopic cross sections.

The basic equations used for calculation of macroscopic cross sections are shown below. For sub-zone concentrations, the effective zone concentration of each nuclide is taken as the sub-zone concentration times the ratio of the sub-zone volume to the zone volume. It is assumed that nuclide densities are in atoms/barn-cm and microscopic cross sections in barns in calculating reaction rates, depletion, and determining mass balances.

Consider some zone within which each nuclide has a uniform, smeared concentration N. The usual cross sections are calculated as follows with indexes a-absorption, f-fission, tr-transport, s-scattering, and g and k-energy groups, z-zone, and n-nuclide,

$$\Sigma_{a,g,z} = \sum_n N_{n,z}\, \sigma_{a,n,g} ,$$

$$\Sigma_{f,g,z} = \sum_n N_{n,z}\, \sigma_{f,n,g} ,$$

$$\nu\, \Sigma_{f,g,z} = \sum_n N_{n,z}\, \nu\, \sigma_{f,n,g} ,$$

$$\Sigma_{tr,g,z} = \sum_n N_{n,z}\, \sigma_{tr,n,g} ,$$

where

$$\nu\, \sigma_{f,n,g} = \nu_{n,g}\, \sigma_{f,n,g} ,$$

and

$$N_{n,z} = M_{n,z} q_z + \sum_{sz} M_{n,sz} \frac{V_{sz}}{V_z} ,$$

where $M_{n,z}$ is the concentration of nuclide n in zone z, q_z is the volume fraction, $M_{n,sz}$ is a subzone concentration and V_{sz} and V_z are the subzone and zone volumes respectively;

$$D_{g,z} = \frac{1}{3\ \Sigma_{tr,g,z}} ,$$

$$\Sigma_{s,g\to k} = \sum_n N_{n,z}\ \sigma_{s,g\to k} \ . \qquad (704\text{-}1)$$

For the diffusion-approximation calculations, each $\Sigma_{s,g\to g}$ is set to zero to avoid slowing the rate of convergence of the iterative process.

The equations used to determine reaction rates are as follows. The reactor thermal power level, P, is determined by

$$P = \frac{C_1}{C_2} \sum_z V_z \sum_n N_{n,z} \left\{ X_n \sum_g \bar{\phi}_{g,z}\ \sigma_{f,n,g} + Y_n \sum_g \bar{\phi}_{g,z}\ \sigma_{c,n,g} \right\} , \qquad (704\text{-}2)$$

where X_n is the nuclide thermal energy watt-sec per fission, Y_n is per capture, C_1 is the specified fraction useful power, C_2 is the specified fraction of the core treated and the flux level is adjusted such that the calculated P is that value specified in watts. The values of $\bar{\phi}_{g,z}$ are simply volume weighted over zones at each energy,

$$\bar{\phi}_{g,z} = \frac{\sum_{i \in z} \phi_{i,g}\ V_i}{\sum_{i \in z} V_i} , \qquad (704\text{-}3)$$

where i refers to a mesh point (and its associated elemental volume).

Given the microscopic type of energy data, not group dependent,

$$W_{g,z} = \sum_n N_{n,z}\ (X_n\ \sigma_{f,n,g} + Y_n\ \sigma_{c,n,g}) , \qquad (704\text{-}4)$$

then

$$P = \frac{C_1}{C_2} \sum_t V_z \sum_g W_{g,z}\ \bar{\phi}_{g,z} \ . \qquad (704\text{-}5)$$

That is, the normalization of the results of a calculation is to a desired thermal power level based on the sum of contributions associated with fission and capture.

Edited results are based on the flux level required to satisfy the desired power level. Point flux and zone average flux values are discussed above.

The local power density is given by

$$H_i = \sum_g W_{g,z} \; \phi_{i,g} \; , \qquad (704\text{-}6)$$

where i is contained in z. For traverses, the maximum value of H_i is found and values along each of the coordinate directions edited.

The local neutron density is given by

$$N_i = \sum_g \frac{1}{v_{g,z}} \; \phi_{i,g} \; , \qquad (704\text{-}7)$$

where $v_{g,z}$ is the group neutron velocity associated with point i.

When an edit of the "Reference Fissile Conversion Ratio" is found, it is the ratio of the rate of capture (n,α) in the defined fertile nuclides divided by the rate of absorption in the defined fissile nuclides.

END OF SECTION

Section 705: Types of Problems Solved

The procedures implemented in the VENTURE code block are oriented at resolution of any of a wide variety of basic problem types. These are described in this section with the equations cast in matrix form. We start with the usual neutron flux eigenvalue problem (see Eq. 701-2).

The Usual Eigenvalue Problem

The usual neutron flux eigenvalue problem may be cast in the form

$$A\ \phi = \frac{1}{k_e} \chi F\ \phi\ , \qquad (705\text{-}1)$$

Where A is the transport, scattering coupling, and loss operator; F is the fission source, a row operator; χ is the source distribution function, a column operator[a]; ϕ is the neutron flux vector; and k_e is the multiplication factor to be determined which effects a pseudo steady-state condition.

Eq. 705-1 has the solution

$$\phi = \frac{1}{k_e} A^{-1} \chi\ F\ \phi \qquad (705\text{-}2)$$

where A^{-1} is the inverse of A, $A^{-1}A = I$. For many problems of interest it is not practical to invert A. Given n space-energy points, A is an nxn square matrix containing n^2 entries. So an interative procedure is used which takes advantage of the sparceness of both A and F.

Eq. 705-2 may also be expressed as

$$(A^{-1}\chi F - k_e\ I)\ \phi\ , \qquad (705\text{-}3)$$

---

[a] χF could be a matrix, not separable.

indicating that k_e is an eigenvalue of $A^{-1}\chi F$. We hope that any flux eigenvalue problem to be treated has a unique, most positive eigenvalue in the set of all of them, $k_e = k_1 > k_2 > \ldots$. The requirements under which this is the situation have been studied.[b,c] Physically, it is required that each point in the space-energy system be coupled to every other point through the coupling coefficients (in both A and χF). Further, the solution vector ϕ is unique and each component $\geqslant 0$, but only if χF is all positive and the diagonal terms of A dominate along columns; it is sufficient that all macroscopic cross sections be positive given the necessary coupling, but not absolutely necessary.

The Fixed Source Problem

The fixed source problem is expressed as

$$A\,\phi = \chi F\,\phi + S\ , \qquad (705\text{-}4)$$

not an eigenvalue problem. Occasionally F = 0, as for deep penetration shielding problems, especially applicable to extending a solution for a fueled region to a remote location by an auxiliary calculation. In reactor core analysis, fixed source problems have been used mostly to play computation games. However, there are special situations which require this formulation, as for analysis of the start-up condition with a source inserted in the reactor.

For usual situations there is a neutron density distribution associated with a fixed source problem, and the level of this density is higher the larger the magnitude of the source. A prime objective of a fixed source calculation is to determine the neutron flux level associated with the source.

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[b] G. Birkhoff and R. S. Varga, "Reactor Criticality and Nonnegative Matrices," *J. Soc. Ind. App. Math 6*, p. 354 (1958).

[c] R. Froehlich, "positivity Theorems for the Discrete Form of the Multigroup Diffusion Equations," NS&E *34*, p. 57 (1968).

When F is non-zero, there is a sensible solution to Eq. 705-4 only if the related problem

$$A\ \phi = \frac{1}{k_e} \chi F\ \phi$$

is subcritical, $k_e < 1$, when $S = 0$. Otherwise, the flux level would keep increasing, even without the fixed source, and the usual procedures for resolving fixed source problems generally fail.

The Adjoint Flux Problem

The adjoint flux eigenvalue problem is expressed as

$$A^t \phi^* = \frac{1}{k_e} (\chi F)^t \phi^*, \qquad (705\text{-}5)$$

where the superscript t refers to the transpose of elements about the diagonal (interchange of rows and columns). In diffusion-theory representation, transposing A involves

(1) no changes in the total removal (absorption + outscattering + DB^2) terms on the diagonal,

(2) no change in the diffusion coupling due to symmetry about the diagonal, but

(3) change in the group-to-group transfer or scattering terms, $\Sigma(g \to n)$ to $\Sigma(n \to g)$; inscattering no longer cancels removal if the equations are summed.

Transposing χF causes the contribution to group g by the distribution function $\chi(g)$ of neutrons produced in fission in group n from the reaction due to cross section $\nu\Sigma_f(n)$, namely $\chi(g)\nu\Sigma_f(n)$, for the usual problem to be reversed for the adjoint problem, namely $\nu\Sigma(g)\chi(n)$, or $F^t\chi^t$, if (χF) is separable.

The eigenvalue of the adjoint problem is the same as that of the regular problem, k_e. Thus it is common practice to use the result from the regular problem in the process of solution of the adjoint problem when they are treated in succession. However, it sometimes is of more interest to solve the perturbed adjoint problem for more precise analysis of perturbations when a specific perturbation is of interest. In this case the perturbation changes k_e requiring that it be determined as an unknown.

The adjoint fixed source problem is of special utility in analysis of the effect of perturbations to the system on some specific local effect. The problem to be solved is

$$A^t\phi^* = F^t\chi^t\phi^* + S^*, \qquad (705\text{-}6)$$

and the appropriate source, S^* must be supplied for this adjoint problem. As noted before, the system must be subcritical.

When an adjoint problem is of the eigenvalue type and directly follows a regular problem, in the same code block access, then the result for k_e from the regular problem is used. It is thus assumed that these eigenvalue problems are for the same system. When an adjoint eigenvalue problem is of the eigenvalue type and directly follows a regular problem in which a criticality search was done, it is again assumed that these eigenvalue problems are for the same system, namely the result of the criticality search. This is true even for the 1/v search and the 1/v loss terms are included in the adjoint problem.

When an adjoint problem is of the fixed source type, it is assumed to be for the system initially presented, except when a regular problem is run first and adjustments are made in nuclide concentrations or dimensions.

An adjoint problem may be solved in an access to the code block without first solving a regular problem. This problem may be an eigenvalue problem, or a fixed source problem for which there may or may not be a transposed fission source.

Criticality Searches

The primary application of a code block designed to solve neutronics eigenvalue problems is analysis of reactor core conditions. To hold a reactor at a desired power level, it must be maintained at a near critical condition. Therefore, it is incumbent on analysis effort to determine representative conditions near this required state of operation. The type of problem to be solved has been named the criticality search; adjustments are to be made in certain parameters of the problem to establish a desired state of criticality.

Establishing the positions of individual control rods represented discretely in a finite-difference mesh which satisfy the critical condition and minimize the peak power density is one of the most difficult problems formulated in reactor analysis. This problem has only been solved by indirect methods.

The criticality search problem may be expressed in a general formulation as

$$(A - \frac{1}{k_e}\chi F)\phi = B\phi \ , \qquad (705\text{-}7)$$

where k_e is the multiplication factor to be satisfied, a specified number often unity, and B is the search operator. This problem is to be solved given a specified way in which the components of B are to be changed to effect the solution.

There may be constraints on acceptable solutions; a mathematical solution may not have a realistic physical interpretation. A system containing no fissile material cannot be made critical unless fissile material is added to it. A mathematical solution which involves negative nuclide concentrations or ones which exceed physical limitations is usually not acceptable.

A unique solution to the general search problem is not assured. There are often two different mixtures of D_2O and H_2O which will satisfy critical conditions in a wide lattice thermal reactor. There are often three different concentrations of the same mixture of plutonium isotopes which will satisfy critical conditions (mathematically) in a water-cooled core. The analyst is often seeking only one of these possible solutions. He is cautioned about the difficulties associated with the general criticality search problem. The automated procedures seek a mathematical solution, try to determine those situations where such a solution does not exist, and make key tests on a solution to determine if it is realistic in a physical sense, and discontinue further calculation if it is not. Quite generally, it is assumed that the initial state of the system is relatively close to the desired solution. When it is so, many of the difficulties are avoided. Beware the results when large changes to the initial conditions were required to effect a solution.

The sophistication of the treatment in a code such as VENTURE increases with development. At the time this documentation will be published, it should contain the basic capabilities described herein. An extension over simple procedures has been incorporated. Consider that concentrations of nuclides have been adjusted in accordance to specifications, but the problem solution is found to be unacceptable. Let us say it took more of the described fuel as makeup than is available. Adding the alloted amount of this fuel, and then searching on a secondary fuel mixture is possible.

The basic criticality search problems treated in the VENTURE code are described below. For several of these, Eq. 705-7 is recast in the form

$$(A - \frac{1}{k_e}\chi F)\phi = \lambda(\frac{1}{k_e}\chi P - Q)\phi \ , \qquad (705\text{-}8)$$

where χP is the neutron source operator generally associated with search on fissile nuclide concentrations, similar to but often more sparse than χF, Q is a diagonal matrix representing loss only, and λ is the eigenvalue of the search problem to be determined. For such problems a procedure is available which iterates directly toward a solution.

The Direct Buckling Search

In Eq. 705-8, P = 0, and Q contains the contributions from buckling loss terms as specified, $DB_{\perp}^{2}V$. The local value of the diffusion coefficient D is used, the local volume V, and the buckling $B_{\perp}$ which may be energy group and position dependent. The value of λ, an eigenvalue, is to be determined; it is a relative magnitude of the buckling. That is, all the values of $B_{\perp}$ are adjusted proportionally ($\lambda B_{\perp}$) to effect a solution. As programed, λ-1 is determined during the iterative procedure.

The Direct Reciprocal Velocity Search

For this problem, P = 0, and only the diagonal elements of Q contain the product of the reciprocal of the velocity and the local volume, loss terms. The eigenvalue λ is a multiplier on the reciprocal velocity sink term which effects a solution. If λ is negative, a distributed source has been added to the system.

This calculation determines the prompt mode time constant. The dynamic neutron balance is considered in the form

$$\frac{\partial X}{\partial t} = \frac{1}{v}\frac{\partial \phi}{\partial t} = \text{sources} - \text{losses} \ , \qquad (705\text{-}9)$$

where χ is the neutron density and v is the neutron velocity. The asymptotic neutron flux mode is formulated by assuming that

$$\phi = Ce^{-\alpha t} ,$$

$$\frac{\partial \phi}{\partial t} = - \alpha C e^{-\alpha t}$$

Substitution of these into Eq. 705-9 leads to the form of Eq. 705-8, $P = 0$, with λ identified as α, a time constant usually associated with a prompt neutron mode (no contribution from delayed neutrons), and Q is v^{-1}. A suitable value of k_e must be specified and the results properly interpreted, but coverage of these important details is beyond the scope of this document. It is often necessary to solve another problem first to obtain the desired results, either to establish suitable conditions, as by adjusting some of the parameters, or to establish the value of k_e for the system.

The Direct Nuclide Concentration Search

The direct search technique may often be usefully applied to problems of determining nuclide concentration changes, the nuclide concentration search. Desired conditions may often be satisfied with little more calculational effort than required to solve the corresponding usual eigenvalue problem. It is assumed that the nuclides for which concentration changes are to be made make primary contribution to the macroscopic absorption and production cross sections, and only secondarily affect the scattering and transport terms. Thus application is to heavy metals or control absorber, not to moderator.

The concentrations of certain nuclides are to be changed in the system as necessary to satisfy a desired value of k_e. Given specifications for these concentration changes, a common multiplier is desired such that at solution the actual change made in the concentration of nuclide n at location r is given by

$$\Delta N_r(k_e) = \lambda \, \Delta N_r(0) \ , \qquad (705\text{-}10)$$

where the argument (0) refers to the initial specification, and λ is a common multiplier, an eigenvalue to be determined. Consider the following which are effectively macroscopic properties:

$$\Sigma_{p,r,g} = \sum_n \Delta N_{n,r}(0) \ \sigma_{a,n} \ ,$$

$$\Sigma_{q,r,g} = \sum_n \Delta N_{n,r}(0) \ \nu \ \sigma_{f,n} \ ,$$

where sums are over the search nuclides.[a] Given an iterate estimate of the neutron flux, an overall neutron balance may be formulated as

$$\frac{1}{k_e} P_t - A_t - L_t = \lambda [A_s - \frac{1}{k_e} P_s] \ ,$$

where P_t is the summed neutron production rate for the system; A_t is the summed loss rate, absorption and buckling, for the system; L_t is the surface leakage, and

$$A_s = \sum_r V_r \sum_g \Sigma_{p,r,g} \ \phi_{r,g} \ ,$$

$$P_s = \sum_r V_r \sum_g \Sigma_{q,r,g} \ \phi_{r,g} \ ,$$

V_r being the region volume, and $\phi_{r,g}$ is region average neutron flux in group g.

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[a] Account for volume fractions, and for volume ratios in the case of subzone search, is not shown.

Solving the above equation for the unknown eigenvalue gives

$$\lambda = \frac{\frac{1}{k_e} P_t - A_t - L_t}{A_s - \frac{1}{k_e} P_s} . \qquad (705\text{-}11)$$

Thus from an overall neutron balance, an estimate is made of the eigenvalue of the nuclide concentration search problem. With this estimate, the usual iterative procedure may be applied; account is taken of the contributions from the search nuclides using the macroscopic absorption and production cross sections associated with the changes.

To account for small changes in the scattering and transport properties, the nuclide concentrations are updated at convenient points in the iteration cycle, and the macroscopic cross sections and equation constants are recalculated at this point in the calculation.

The Indirect Search

The conventional way that the nuclide search problem has been solved is by solution of a series of usual eigenvalue problems with estimates of the required changes to the search nuclide concentrations introduced after each eigenvalue problem. First the usual eigenvalue problem is solved (for k_e) for the conditions presented. A change is made in the nuclide concentrations according to user specifications, and this new eigenvalue problem is solved. Based on these results, the nuclide concentrations are further adjusted, and the process continued to an apparent solution, subject to acceptance by the analyst.

The dimension search problem is done in the same manner. Changes are made in the geometric mesh spacing to effect a desired solution.

END OF SECTION

Section 716: The Iteration Procedures

Introduction

This section documents the iterative procedures implemented in the VENTURE code. An attempt is made to provide the user with the information he needs for practical use of the code and to choose between the programmed options available, for experimentation or selective application.

The procedures of calculation must be considered rather complicated when viewed by the analyst wanting results and not much concerned about how they are obtained. In solving large problems, computation cost is an important consideration; there is incentive to reduce the cost by applying an effective procedure. The overall strategy involves:

1. Initialization (see Section 718),
2. Inner iteration with overrelaxation to accelerate the fixed source problem at each energy,
3. Outer iteration with acceleration,
4. Convergence tests, and
5. Reliability checks (see Section 720).

The following discussion addresses the individual procedures. Introductory material is given first to orient the reader.

Inner iteration involves successive recalculation of the flux values. Given the fission and inscattering source, the coupling (neutron balance) equations are solved by an ordered sweep through the space mesh at one energy. This is expressed in matrix form as

$$\phi_{t,n} = M\,\phi_{t-1,n} + S_n \quad ,$$

a set of coupled linear equations where $\phi_{t,n}$ represents the point flux values for inner iteration t, outer iteration n, M is the operator (coupling terms) and S_n represents the point source terms. Latest point values of the fluxes are used as they become available and new values are obtained for a block of points simultaneously. The newly calculated values are driven by overrelaxation which involves using the changes in the point flux values to drive the fluxes in the directions of individual changes from the previous iterate values. Thus, M above is appreciably

altered from just a simple coupling operator; it may depend on n and t. The number of inner iterations carried out on one space problem each outer iteration is a key variable.

Outer iteration on an eigenvalue problem may be viewed as solving the matrix equation

$$\phi_n = (E + \frac{1}{k_{n-1}} \chi F) \phi_{n-1} \quad ,$$

a set of coupled equations where ϕ_n represents the point flux values for outer iteration n, E is a space, energy coupling operator, F contains the terms for neutron production from fission and χ is the into-group distribution function, and k_{n-1} is the estimate of the multiplification factor. It is noted that inner iteration causes E to have a complicated form.

Each outer iteration there is full sweep yielding latest estimates of the point flux values ϕ_n, and a new estimate of the eigenvalue of the problem, k_n, is obtained. The calculation starts with the first or highest energy group for usual problems and proceeds downward, following the primary direction of neutron scattering. For adjoint problems, the sweep is reversed.

The same steps are carried out within each outer iteration. This is necessary to permit effective acceleration of the outer iteration process. Two acceleration schemes are used, Chebyshev acceleration applied repeatedly and asymptotic extrapolation done only occasionally.

The Chebyshev acceleration process involves acceleration each outer iteration of the calculated flux values given the iterate estimates for the two previous outer iterations. The objective is to beat down the contributions from all the error vectors having eigenvalues over a specific range. Practical considerations include selection of the stage of the calculation to initiate the process, identifying the eigenvalue spectrum range, identifying when the procedure is not effective and when it can be expected to not be effective.

Asymptotic single-error-mode extrapolation is based on the assumption that a single error vector dominates asymptotically, the others having

decayed away. Two succeeding outer iteration sets of flux values are extrapolated to an apparent solution. An asymptotic double-error-mode extrapolation procedure is also implemented which uses three succeeding iterate sets of the flux values. Practical considerations include identifying when the iterative behavior indicates extrapolation will be effective and estimating suitable extrapolation factors. Extrapolation may be done when the Chebyshev process is being applied.

The primary criteria selected to identify that an iterative process is convergent, is the maximum relative flux change between successive iterations. This quantity is used in the implemented procedures to evaluate the behaviors of the inner iteration and the outer iteration processes. Also the ratio of the sums of the magnitudes of the flux changes is used on outer iterations.

Remarks on Optimum Strategy

If the optimum number of inner iterations is very few, perhaps even one, a relatively straight-forward and effective procedure can be identified and applied. If the optimum number of inner iterations is large, a different relatively straight-forward and effective procedure can be identified. The two procedures are quite different and there is no smooth transition from one to the other which is needed when a modest number of inner iterations should be the optimum. Furthermore, an initial commitment to set data handling procedures makes it very difficult to shift the strategy during the calculation as information becomes available about the iterative behavior.

The objective is effecting an acceptable solution to a problem at a minimum cost of computation to the project. Considering the large number of variables involved, including the available computer environment and local cost allocation, pre-selection of an optimum strategy is simply not possible.

The procedures implemented admit selection between a number of alternatives. A strategy is selected which depends on the particular problem to be solved and this strategy undergoes modest changes as information about the iterative behavior becomes available. The automatic selection of a strategy allows application with minimum burden

to the user; however, it involves compromises and can hardly be expected to represent the optimum in any given situation for a particular problem. Principal alternatives for basic selection between procedures are under the control of user-input options. For those problems for which the iterative behavior is predictable from past experience, input control is available and exercising this control is desirable. However, a note of caution is in order. Only a limited background of experience with the actual procedures implemented is available to the authors; it takes time to accumulate experience. Past experience with similar procedures but yet different in detail, may not be applicable nor trustworthy. Further, the overhead of handling the large amount of data for the larger problems and associated penalty must be considered in applying the procedures or attempting to modify them.

Before discussing the details of the procedures, an overview of the iteration strategy is presented.

An Overview of the Iteration Strategy

The general procedure of solution employed is one of iteration. For the usual eigenvalue problem, the equation to be solved is

$$A\phi = \frac{1}{k_e} \chi F \phi \quad . \tag{716-1}$$

With special partitioning of the matrix A,

$$[D - J - L - U]\ \phi = [S + T + \frac{1}{k_e} \chi F]\ \phi \quad , \tag{716-2}$$

where

D = the main diagonal term (loss due to absorption, buckling, outscatter),

J contains the coupling terms for a block of points (as along a row in space at one energy) for which the flux values are determined simultaneously precisely given the current values of the other fluxes,

L = the lower triangular matrix containing coupling terms in space,

U = the upper triangular matrix containing coupling terms in space (excluding any appearing in J),

S = the downscattering source matrix (group-to-group scattering terms at a point,

T = the upscattering source matrix (group-to-group scattering terms at a point,

F = the fission source component (from all groups at a space point contributing to the total at that point, a row matrix operator),

χ = the source distribution (from the total to all groups at a point, a column matrix operator), and

k_e = the unknown multiplication factor, a constant for any problem to be determined.

To illustrate how an iterative procedure is formulated, let us put the term $D\phi$ on one side of the equation, Eq. (716-2), and the remaining on the other, giving

$$D\phi = [J + L + U + S + T + \frac{1}{k_e} \chi F] \phi.$$

If a set of fluxes is available for iterate n, namely ϕ_n, then a simple iterative scheme is expressed as

$$\phi_{n+1} = D^{-1} [J + L + U + S + T + \frac{1}{k_n} \chi F] \phi_n \quad , \qquad (716\text{-}3)$$

where the inverse D^{-1} is of a diagonal, the reciprocals of terms in D. An estimate of k_e is required, k_n, and a continuing iterative process may proceed. The above with all positive entries and $\phi_n > 0$ produces $\phi_{n+1} > 0$; only with $\phi > 0$ can a unique and most positive value of k be assured. Eq. (716-3) does not even admit the use of newly calculated ϕ values, so it represents a rather crude procedure.

With downward sweep in energy and simple sweeps carrying the simultaneous solution for rows across the space problem, use of newly calculated fluxes causes them to contribute through the matrices J, L, and S, or

$$[D - J - L - S]\ \phi_{n+1} = [U + T + \frac{1}{k_n}\ \chi F]\ \phi_n \quad ;$$

$$\phi_{n+1} = [D - J - L - S]^{-1}\ [U + T + \frac{1}{k_n}\ \chi F]\ \phi_n \quad . \qquad (716\text{-}4)$$

The inverse shown would generally be impractical to obtain. It is not needed, however, but rather is a consequence of the process and the partitioning of the coupling terms.

Overrelaxation is used as discussed later in detail. The basic equation is

$$X_{i,n} = X_{i,n-1} + \beta(X^*_{i,n} - X_{i,n-1}), \ , \qquad (716\text{-}5)$$

where $X_{i,n-1}$ is a component of ϕ_{n-1} obtained from iteration n-1, $X^*_{i,n}$ is the newly calculated value for iterative sweep n, β is the overrelaxation factor, and $X_{i,n}$ is the overrelaxed value used thereafter for this sweep of the equations. Note that $\beta = 1$ causes the newly calculated value to be used; overrelaxation is done for $1 < \beta < 2$. A fixed value of β may be used, or a different overrelaxation coefficient may be used for the space problem at each energy. Also, the value of β used may be iteration dependent. This flexibility is shown in the equations by representing the overrelaxation process with a matrix B_n containing only the values of β on the main diagonal, the subscript n indicating the values may be changed during the iterative history. Overrelaxation changes Eq. (716-4) to

$$\phi_{n+1} = \left\{D - B_n[J + L + S]\right\}^{-1} \left\{(I - B_n)D + B_n[L + T + \frac{1}{k_n}\ \chi F]\right\} \phi_n \ . \qquad (716\text{-}6)$$

Inner iteration may be done. For many types of problems, additional calculational effort shows advantage to reduce the error associated with the space problem at each energy. Thus, several sweeps may be made of the space problem at each energy. Considering a fixed

number of inner iterations, Eq. (716-6) becomes

$$\phi_{n+1} = \left\{ [R_n V_n]^t + \left[\sum_{i=1}^{t} R_n^i \right] B_n \left[T + \frac{1}{k_n} \chi F \right] \right\} \phi_n \quad , \tag{716-7}$$

where

$$R_n = \left\{ D - B_n \left[J + L + S \right] \right\}^{-1}$$

$$V_n = [I - B_n] D + B_n U \quad ,$$

and t refers to the number of inner iterations. Eq. (716-7) would have to be altered if either the number of inner iterations is different for the space problems at each energy or if B_n is varied during inner iteration.

Equation (716-7) also applies to the direct search problem with rearrangement of the terms and inclusion of the estimate of the eigenvalue of the search problem. Acceleration on outer iteration adds further complexity not shown.

Latest Iterate Estimates of the Flux Values

New values of the fluxes are obtained each inner iteration by applying the basic finite-difference neutron balance equations for the volume elements. Substitution of the leakage terms of Eq. (702-3) into Eq. (701-4) yields an equation for each point equating the loss rate with the source rate in the form.

$$a_i X_{i,t} = S_{i,t} + b_i X_{i-1,t} + b_{i+1} X_{i+1,t} \quad , \tag{716-8}$$

Where i refers to a mesh point along a row, t refers to inner iteration, S_i is the summed fission and scattering source plus the contributions from nearest neighbor points on adjacent rows, a_i is the loss constant, and b_i is the coupling coefficient between nearest neighbors along the row.

Line relaxation involves a forward, backward sweep to solve the tri-diagonal matrix yielding new flux values simultaneously for all the points along the row. To satisfy the recursion for the backward sweep

$$X_{i,t} = g_i \left\{ X_{i+1,t} + \frac{f_i}{b_{i+1}} \right\} \quad . \tag{716-9}$$

requires a forward sweep

$$f_i = s_{i,t} + g_{i-1} f_{i-1} \quad ,$$

and a previously done forward sweep,

$$g_i = b_{i+1} \left[\frac{1}{a_i - b_i g_{i-1}} \right] ,$$

with the amount of division minimized.

An alternative procedure[a] is attractive to reduce the amount of computation during iteration. To solve the system of equations

$$A\phi = S$$

a new set of operators is desired such that

$$CV^T VC\phi = S \ .$$

The elements of these operators are obtained as follows. Let a_i be the diagonal terms of A and b_i the off-diagonal terms, coupling point i with i-1. Then, an initial calculation is done giving

$$f_1 = a_1^{\frac{1}{2}}$$

$$f_i = \left[a_i - \left(\frac{b_i}{f_{i-1}} \right)^2 \right]^{\frac{1}{2}} , \quad 1 < i \leqslant I$$

$$v_i = \frac{b_{i+1}}{f_i f_{i+1}} \quad , \text{ elements of } V, \ 1 \leqslant i \leqslant I - 1$$

$$c_i = \frac{1}{f_i} \quad , \text{ elements of } C \quad .$$

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[a]Cuthill, E. H. and Varga, R. S., "A Method of Normalized Block Iteration," J Assoc. Comput. Mach., 6, (1959).

The forward-backward sweep equations solved during iteration are:

$$
\begin{aligned}
x_i &= c_i s_i \\
y_1 &= x_1 \\
y_i &= x_i - v_{i-1} y_{i-1} \\
z_I &= y_I \\
z_i &= y_i - v_i z_{i+1} \\
\phi_i &= c_i z_i
\end{aligned}
\qquad (716\text{-}10)
$$

It may be noted that the new values C_i and V_i must be made available, but that the original elements a_i and b_i and intermediate values f_i are not later required. This scheme is not applicable when the direct criticality search procedure is used (unless the new values of a_i are used each outer iteration and the precalculation of C and V is redone).

The direct inversion scheme requires ten arithmetic operations including two divisions, while the modified procedure involves at most six with no divisions during iteration. The reduction is a smaller fraction of the total calculation involving overrelaxation and summing the individual source terms which increases as the number of dimensions is increased.

For the repeating boundary condition, leakage from one end feeds back to the other end, and a term must be added to Eq. (716-9),

$$X_{i,t} = \left(\frac{f_i}{b_{i+1}} + X_{i+1,t} + h_i \, X_{I,t-1} \, g_i \right) \quad , \qquad (716\text{-}11)$$

where I refers to one of the flux values. The unknowns are obtained from this recursion relationship.

The calculations are done in such a way that a zero value of $X_{i,t}$ indicates that the associated point lies in a black absorber region.

Clearly the whole point of solving for several point fluxes simultaneously is to invest calculational effort where it will accelerate the iterative process. We seek ways of resolving more points or different blocks of points which will accelerate problems.

A special situation is presented by rotational symmetry boundary conditions: a point on one row couples with a point on another row. The newest iterate value of the flux is used in this coupling, but half of the time this is a previous iteration value. Thus, the rate of convergence might be expected to be slower than without this coupling.

Sweep Order

By "normal ordering" is meant that new flux values are obtained at each point each inner iteration by a sweep across the space mesh at one energy. This sweep starts on the first plane at the first row, then the next row on the plane is done, and so on across the plane, then the first row on the second plane, and so on across the planes. With I inner iterations, the flux at each point is calculated I times with I successive sweeps.

With σ_1 ordering, new values are first obtained for alternate points or along alternate rows, then for the others. Consider the two-dimensional problem with simultaneous solution for point values along each row. Looking at the ends of the rows,

. x . x . x . x . x

the odd ones shown as a dot would be treated first (in any order) and then those shown as an x would be treated. Spacial coupling by the finite-difference equations relates only nearest neighbors, so there are no direct couplings between any . rows or between x rows. The neutron leakage contribution (space coupling) is calculated from the nearest x values when a . point is treated; therefore, this leakage contribution is obtained from the same iterate nearest neighbors. (With normal ordering, the adjacent points have values one iteration apart for the sweep row.)

In three dimensions, we look again at the ends of the rows and find

. x . x . x

x . x . x .

. x . x . x

Again with coupling only between nearest neighbors, the . points do not couple and are swept first in any order, then the x points. This ordering applies to all coordinate systems treated.

The σ_1 order of sweeping the mesh imposes rather severe data handling requirements, especially for large problems treated in an small computer memory. Therefore, application is quite selective.

Inner Iteration and Overrelaxation

Overrelaxation is a simple but powerful scheme for accelerating the rate of convergence of the iterative process. The theory is not well developed for optimizing the overall strategy to maximize the rate of convergence of a multigroup eigenvalue problem. However, the behavior of the fixed source problem involving the simple coupled finite difference equations, the space problem at one energy, is well known; the following discussion is directed at this inner iteration process.

Consider calculation of new values of the fluxes each inner iteration using only the old values. If we examine the eigenvalues of the iteration matrix, there is the same number of them as points or flux values to be determined, all less than unity. These contribute to the error in the sense of the difference between the answer and the current estimate of the flux at each point for iteration t,

$$X_{i,\infty} - X_{i,t} = \sum_j A_{i,j}\, \rho_j^{\,t}. \qquad (716\text{-}12)$$

Thus, there is a contribution to the error from each error vector having an associated eigenvalue ρ_j which depends on the value of $A_{i,j}$ and the iteration number. The values of ρ_j depend only on the equation constants, not on the source values. The values of $A_{i,j}$ depend on the initial state of the problem, both the fixed source values and the initial flux values. Since $\rho_j^{\,t} \to 0$ as $t \to \infty$, $\rho_j < 1.0$, each contribution to the error dies away; the smaller the value of ρ_j, the more rapid its contribution decays.

Asymptotically as $t \to \infty$, the contribution from the largest ρ_j dominates. Eliminating the constant $A_{i,j}$ from the recursion equations yields information about the asymptotic behavior,

$$\frac{X_{i,\infty} - X_{i,t}}{X_{i,\infty} - X_{i,t-1}} = \rho = \frac{X_{i,t} - X_{i,t-1}}{X_{i,t-1} - X_{i,t-2}} \quad ;$$

$$\frac{X_{i,\infty} - X_{i,t}}{X_{i,t} - X_{i,t-1}} = \frac{\rho}{1.0 - \rho} \quad .$$

That is, asymptotically, the absolute error is reduced by ρ each iteration as is the iterate change. However, the ratio of the absolute error to the iterate change depends on the reciprocal of $1.0 - \rho$.

Quite generally the more unknowns in a given problem (the more space points used), the larger the value of ρ, the slower the rate of convergence, and the larger the ratio of the absolute error to the iterate change.

Use of the latest values as they become available in a consistently ordered process accelerates the rate of convergence. The effect is squaring the eigenvalues giving the asymptotic behavior

$$\frac{X_{i,\infty} - X_{i,t}}{X_{i,\infty} - X_{i,t-1}} = \rho^2 \quad ;$$

$$\frac{X_{i,\infty} - X_{i,t}}{X_{i,t} - X_{i,t-1}} = \frac{\rho^2}{1.0 - \rho^2} \quad .$$

Note that for $\rho = 0.9$, $\rho^2 = 0.81$, a significant improvement. The ratio of absolute error to iterative change decreases from 9 to 4.3. Of primary concern here is not this situation, but rather that where ρ approaches unity, having a value of 0.99 or even larger.

For certain problems, the value of ρ is larger than usual; one of these is the situation involving rotational symmetry for which old values of the fluxes along the coupled boundary are used since new ones are not yet available.

With overrelaxation, the iterate flux estimates are driven in the direction of the calculated change by the equation

$$X_{i,t} = X_{i,t}^{*} + \beta_t (X_{i,t}^{*} - X_{i,t-1}) \quad . \qquad (716\text{-}13)$$

Here $X_{i,t}^*$ is the newly calculated value and β_t is the overrelaxation coefficient. For the fixed source problem, there is an optimum value of β_t, given by[a]

$$\beta_{opt} = \frac{2.0}{1.0 + \sqrt{1.0 - \rho^2}} \quad . \tag{716-14}$$

The eigenvalues of the overrelaxation process occur in pairs. Shown in Fig. (716-1) is the dependence of the dominating eigenvalues of the overrelaxation process on the value of β_t, $1 < \beta_t < 2$, for the situation where ρ^2 is 0.99. Considering only this fixed source problem (not the overall eigenvalue problem), the objective is to effect the minimum dominating eigenvalue of the process. This occurs when the optimum value of β_t is used. For $\beta_t < \beta_{opt}$, the pair of eigenvalues are real, one relatively large, the other small. For $\beta_t > \beta_{opt}$, the pair of eigenvalues are complex conjugate. The error vectors associated with these eigenvalues are not independent, but have a rather complicated dependence on the iteration number.

The importance of the use of an overrelaxation coefficient near the optimum is evident from Fig. 716-1. Indeed, it is preferable that the value used be too large rather than too small because the convergence property is not degraded as much. It should be noted that asymptotically, the absolute error reduction is a factor of 0.82 each iteration with optimum overrelaxation compared with 0.99 without overrelaxation. Each iteration done with optimum overrelaxation is the equivalent of 20 iterations without it. Clearly, the amount of calculation required to do overrelaxation returns a large dividend justifying its use, and a reasonable amount of calculation can be justified to determine near optimum requirements. However, a convergent process is indicated for $1 < \beta < 2$.

New values can be obtained of the fluxes for a block of points simultaneously. Thus, when line relaxation is done as discussed previously,

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[a]S. P. Frankel, Convergence Rates of Iterative Treatments of Partial Differential Equations, Math. Tables Other Aid Comp. 4 (1950).

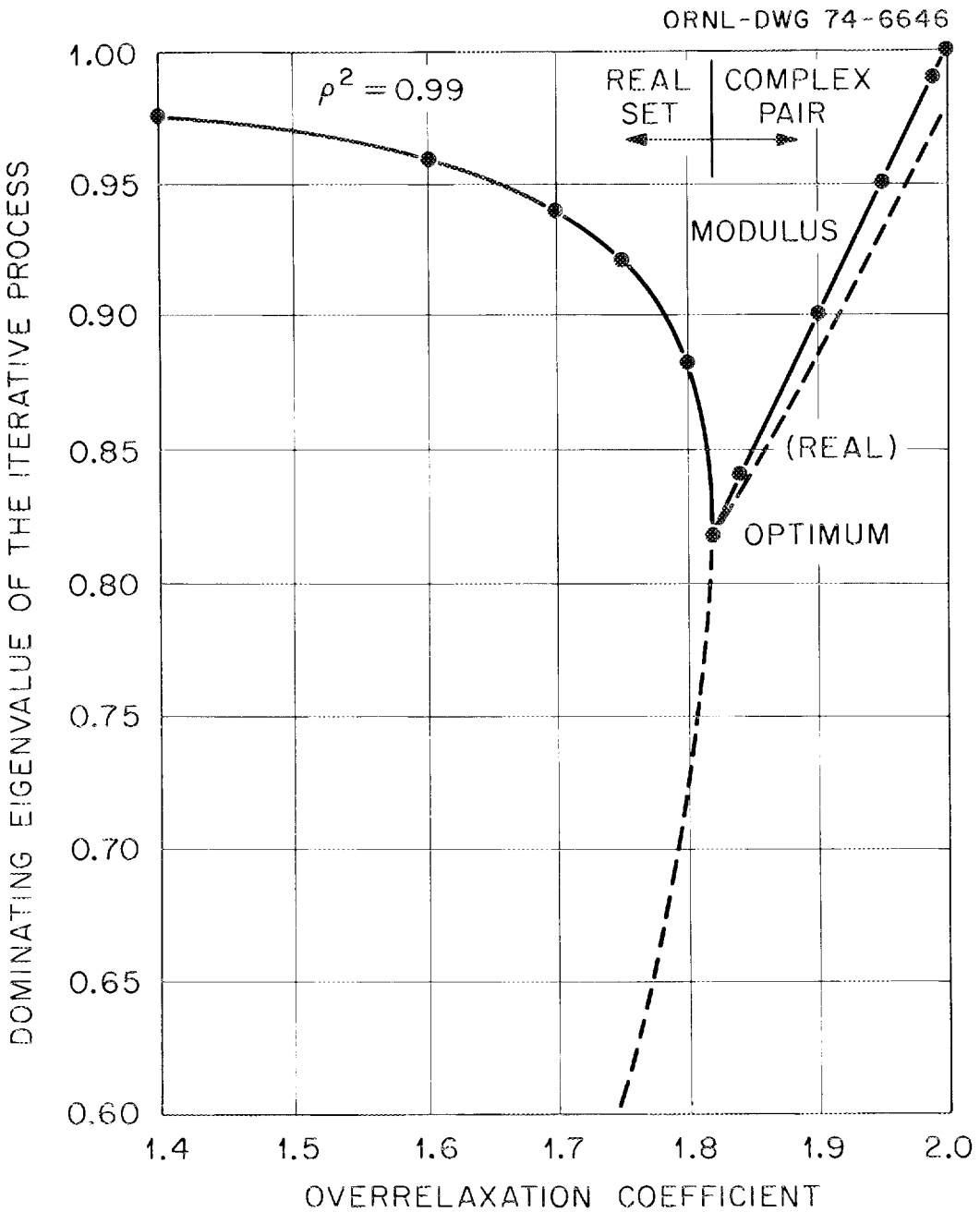

Fig. 716-1. Dominating Eigenvalue Dependence on the Overrelaxation Coefficient.

these values are overrelaxed simultaneously.

It is of interest to compare asymptotic rates of convergence for a reference problem. For the two-dimensional square mesh with even mesh point spacing, homogeneous, and no sink term, the asymptotic rates of convergence for various schemes are shown below as dependent on the number of mesh points on one side.

Mesh Points	β_{opt}	Asymptotic Rate of Convergence			
		Use Old Values	Use New Values	Point Overrelax	Line Overrelax[a]
10	1.560	0.041	0.081	0.58	0.82
50	1.884	0.0019	0.0038	0.12	0.17
100	1.940	0.00048	0.00097	0.062	0.088

During the early iterative progress of a problem, large changes in the flux values are associated with initial error vectors which may cause Eq. (716-13) to produce unacceptable negative values. We restrain the process by restricting the result in a manner which dampens out excessive driving, requiring

$$0.5\ X_{i,t}^{*} < X_{i,t} < X_{i,t}^{*} + X_{i,t-1} \quad ; \qquad (716\text{-}15)$$

$X_{i,t}^{*}$ is the newly calculated value and $X_{i,t}$ is the restrained overrelaxed value. The nature of restrained overrelaxation is shown in Fig. (716-2). When the iterative progress reaches a stage where the calculated changes are small, no restraint is required. Therefore, the restraint applies only during the early history when bad initial error vectors dominate ($|\varepsilon_n| > 0.01$, see later discussion).

For those special situations where negative flux values are acceptable and expected, the application of Eq. (716-15) must be prevented by user option. Further, if a change in sign occurs with the new estimate, Eq. (716-13) causes extreme driving, so the newly calculated value is used rather than the overrelaxed value.

The overrelaxation factors may be adjusted by applying the recursion relationships involving the Chebyshev polynominals. This procedure causes large values of the overrelaxation coefficient to be used in the early

[a]This scheme is the only one implemented; the numbers of mesh points along each coordinate are for a full slab, divide by two for half slab.

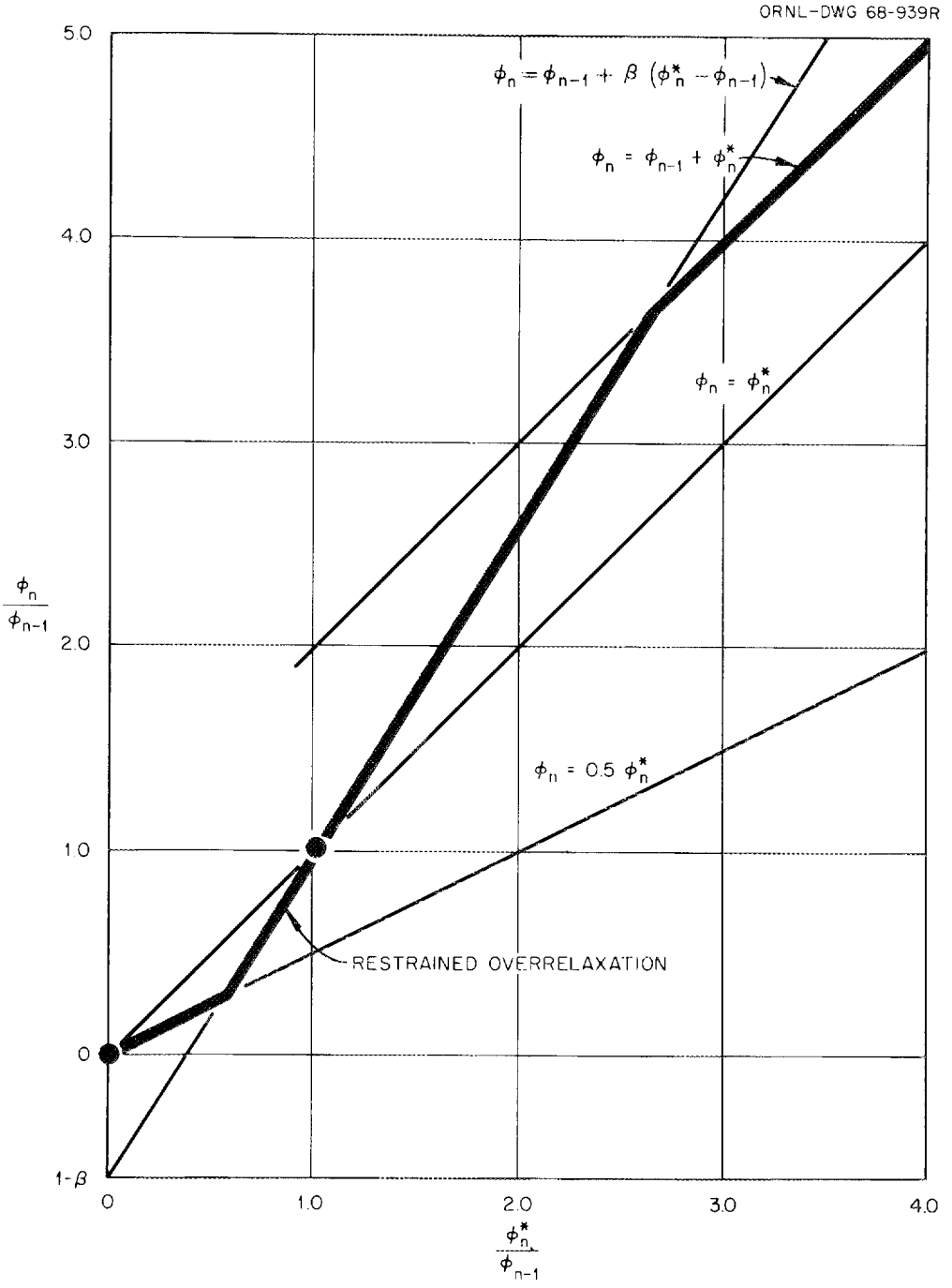

Fig. 716-2. Restrained Overrelaxation.

history, the value decreasing each outer iteration approaching an asymptotic value. The objective of this procedure is to drive out bad error vectors. Experience has shown that hard driving during the early history, in an orderly way, causes the estimate of the problem eigenvalue (the multiplication factor) to move most rapidly toward the answer.

The procedure consists of applying the following equations for the space problem at energy group g,

$$\beta_t(g) = \begin{cases} 1.0, & t = 1 \\ \dfrac{2.0}{2.0 - \rho^2(g)}, & t = 2 \\ \dfrac{4.0}{4.0 - \rho^2(g)\ \beta_{t-1}(g)}, & t > 2 \end{cases} \quad . \tag{716-16}$$

In Eq. (716-16), t refers to inner iteration with normal sweeps. With σ_1 ordering, t refers to each sweep on alternate points, so $\beta_t(g)$ is adjusted midway through the inner iteration process; this is the so-called cyclic Chebyshev procedure.[a]

Experience has shown little advantage, if any, of adjusting the coefficients during inner iteration except with σ_1 ordered sweeps, and then only when a relatively large number of inner iterations are done.

A two-dimensional fixed source, homogeneous, no sink, uniform mesh problem was solved by line overrelaxation with optimum coefficients, and the reduction in the absolute error was determined from the known analytical solution. The number of iterations required to reduce the absolute error the same amount in each case is shown below.

Scheme / Mesh Size (Points)	Iterations Required			
	40x40	40x80	80x40	80x80
Normal Ordering	60	86	73	122
Normal Ordering, Chebyshev	55	87	72	120
σ_1 Ordering	47	60	60	98
σ_1 Ordering, Chebyshev	41	52	53	81

[a] Hageman, L. A., "The Estimation of Acceleration Parameters for the Chebyshev Polynominal and the Successive Overrelaxation Iteration Methods," USAEC Report (BAPL) WARD-TM-1038, June 1972.

The advantage from the σ_1 ordering is clearly demonstrated; it shows the largest gain for the rectangular mesh with line relaxation along the short rows. When the application of Chebyshev polynominals was done on a cycle, it was found that the optimum was a many iteration cycle; use of a short cycle showed no advantage over not applying these factors. Thus, only when enough inner iterations are done for the overrelaxation coefficient to reach the asymptotic value, can advantage be expected in applying the Chebyshev polynominals during the inner iteration process.

When few inner iterations are done, adjustments are made on outer iteration n,

$$\beta_{t,n}(g) = \begin{cases} 1.0, \ t = 1, \ n = 1 \\ \dfrac{2.0}{2.0 - \rho^2(g)}, \ t > 1, \ n = 1 \\ \dfrac{4.0}{4.0 - \rho^2(g), \beta_{T,n-1}(g)}, \ n > 1, \\ \beta_{T,n-1}(g), \ \ n > 20; \end{cases} \tag{716-17}$$

Where T refers to the number of inner iterations. That is, the values are basically adjusted on outer iteration. Application of the procedure is done only during the early iterations, and is discontinued after any procedure for acceleration of the outer iteration process is initiated. Also, overrelaxation is not done the first inner iteration following asymptotic acceleration in this mode of calculation.

When $\beta > \beta_{opt}$, the iterative behavior has a marked difference than when $\beta_t < \beta_{opt}$. A direct measure of the behavior is obtained from the iterate values of the maximum relative flux change. Let $a_{i,t} = \dfrac{X_{i,t}}{X_{i,t-1}}$ where $X_{i,t}$ is the flux value at location i after overrelaxation is done at iteration t, and

$$r_t = \max(a_{i,t}),$$

$$s_t = \min(a_{i,t}),$$

over the space problem of interest. The maximum relative flux change is determined from this information with the sign retained to indicate if the flux at that location is rising (positive) or falling (negative),

$$\varepsilon_t = |\max| \ (r_t - 1.0, s_t - 1.0). \tag{716-18}$$

Thus, $\varepsilon_t = |\max| \ \dfrac{X_{i,t} - X_{i,t-1}}{X_{i,t-1}}$, retaining the negative sign if the iterate value is descending. Quite generally, the process is deemed to be convergent only if $|\varepsilon_t| < |\varepsilon_{t-1}|$. When $\beta_t > \beta_{opt}$, this criterion may be satisfied for one or even several iterations, but will eventually be violated.

A special condition exists when the changes in the flux values are so small that they lose significance. In this situation, arbitrarily if $|\varepsilon_t| < 10^{-10}$, the number of inner iterations is adjusted to

$$I_{n+1}(g) = \frac{4.0 + I_n(g)}{2.0} \quad ,$$

reducing it, but not to less than 4. In the multirow or multiplane modes of data handling, the number of inner iterations may be a multiple of the rows or planes stored; in this case, the number of inner iterations is arbitrarily reduced when $|\varepsilon_t| < 10^{-10}$ by the number of rows or planes stored, down to a minimum of the number of planes stored. Upon such reduction, the inner iteration process is judged to be convergent for purposes of analyzing behavior.

Estimates are made of the dominating eigenvalue of the process from the maximum and minimum flux ratios. We assume that asymptotically,

$$\lambda_t = \frac{X_{i,t} - X_{i,t-1}}{X_{i,t-1} - X_{i,t-2}} \tag{716-19}$$

Given

$$\lambda_{t,1} = \left(\frac{r_t - 1.0}{r_{t-1} - 1.0}\right) r_{t-1} \quad , \text{ and}$$

$$\lambda_{t,2} = \left(\frac{s_t - 1.0}{s_{t-1} - 1.0}\right) s_{t-1} \quad ,$$

The estimate of λ is

$$\lambda_t = \sqrt{\lambda_{t,1}\ \lambda_{t,2}} \tag{716-20}$$

which is essentially the average of the two values when they are not greatly different. In the event that all flux values are falling, both r_t and S_t will have values less than unity, or if they are all rising, they will both be greater than unity. A change from this condition (or to it) causes the value of r_t or s_t to swing about unity resulting in a negative value for the estimate of λ. We assume that the iterate estimates are moving toward a solution, $\lambda > 0$, and arbitrarily set

$$\lambda_t = \max\ (\lambda_{t,1}, \lambda_{t,2})$$

if either is negative.

The inner iteration process is deemed convergent and not over-accelerated if $|\varepsilon_T| < |\varepsilon_{T-1}| < |\varepsilon_{T-2}|$, where T refers to the last iteration done each outer iteration. If convergent, an asymptotic behavior is deemed to have established if

$$\lambda_{T,n} < 1.0 \qquad \text{, and}$$

$$0.95 < \frac{1.0 - \lambda_{T,n}}{1.0 - \lambda_{T,n-1}} < 1.05 \qquad ,$$

where the subscript T refers to the last inner iteration for that outer iteration. In this event, a new estimate is made of the spectral radius,[a]

$$\rho_n{}^2(g) = \frac{1.0}{\lambda_{T,n}} \left[1.0 - \left(\frac{1.0 - \lambda_{T,n}}{\beta_{T,n}(g)} \right) \right]^2 \tag{716-21}$$

The overrelaxation coefficient is recalculated with Eq. (716-4), but only if the asymptotic single error mode extrapolation criteria discussed later

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[a]D. M. Young, "Iterative Methods for Solving Partial Difference Equations of Elliptic Type," Harvard University Dissertation (1950).

are satisfied, indicating that an asymptotic behavior of the outer iteration has established, and only if $\beta_{T,n}(g) - 1.0 < \lambda_{T,n}$, and the adjusted value is constrained to

$$\beta_{T,n+1}(g) \leq \frac{4.0\beta_{T,n}(g)}{2.0 + \beta_{T,n}(g)} \quad . \tag{716-22}$$

If the inner iteration process is deemed to be non-convergent, the overrelaxation coefficient is arbitrarily decreased

$$\beta_{T,n+1}(g) = \max\left[\beta_{T,n}(g) - 0.05,\ 1.0\right] \quad . \tag{716-23}$$

When $\beta(g)$ is changed, the associated value of $\rho(g)$ is recalculated to make them consistent. If any $\beta(g)$ is decreased, this coefficient is not permitted to be increased later. Reduction in $\beta(g)$ is allowed no more frequently than every other outer iteration, but when in use, the scheme of applying Chebyshev polynominals is continued.

When the number of inner iterations done at any group is less than 4, the criteria for inner iteration convergence are not applied. Rather the behavior of the outer iteration process is examined, and information from it is used in Eq. (716-21) as discussed later.

We note that the optimum overrelaxation coefficient for a one-group fixed source problem may not be the optimum for the multigroup eigenvalue problem; experience shows that the latter is often smaller.

Outer Iteration Strategy

Here we discuss assessment of the behavior of the outer iteration process and delays imposed on adjusting the parameters of the individual procedures. When the flux values for successive iterations are available at the same time (as when the Chebyshev process is applied), behavior of the outer iteration process is assessed directly.

Let $a_{i,n} = \dfrac{X_{i,n}}{X_{i,n-1}}$

where $X_{i,n}$ is one of the flux values (component of ϕ_n), and

$$r_n = \max\ (a_{i,n})$$
$$s_n = \min\ (a_{i,n}). \tag{716-24}$$

$$\varepsilon_n = |\max|\ (r_n - 1.0,\ s_n - 1.0) \quad . \tag{716-25}$$

The process is deemed to be convergent only if $|\varepsilon_n| < |\varepsilon_{n-1}|$. Otherwise, the procedure in use is causing excessive changes in the flux values and the parameters must be altered.

When succeeding outer iterate flux values are not readily available, the maximum relative flux change is estimated by a bound. Given the values of r_t and s_t for the inner iteration, at each energy group, the estimate is

$$r_n = \max \prod_{t=1}^{n} r_t$$
$$s_n = \min \prod_{t=1}^{n} s_t \tag{716-26}$$

over the individual energy groups. Quite generally the values obtained from Eq. (716-26) are wider bounds than the values from Eq. (716-25).

The dominating eigenvalue of the outer iteration process is estimated. We assume that

$$\mu = \frac{X_{i,n} - X_{i,n-1}}{X_{i,n-1} - X_{i,n-2}} \tag{716-27}$$

Given

$$\mu_{n,1} = \left(\frac{r_n - 1.0}{r_{n-1} - 1.0}\right) r_{n-1}, \quad \text{, and}$$

$$\mu_{n,2} = \left(\frac{1.0 - s_n}{1.0 - s_{n-1}}\right) s_{n-1}$$

The estimate of this dominant eigenvalue is

$$\mu_n = \sqrt{\mu_{n,1}\ \mu_{n,2}} \tag{716-28}$$

If either of the two estimates of this eigenvalue is negative, arbitrarily they are all set equal to the positive one.

Other estimates of μ have also been used, for example

$$\mu_{n,3} = \sqrt{\frac{\sum_i (X_{i,n} - X_{i,n-1})^2}{\sum_i (X_{i,n-1} - X_{i,n-2})^2}} \quad \text{, and} \tag{716-29}$$

$$\mu_{n,4} = \frac{\sum_i \left| X_{i,n} - X_{i,n-1} \right|}{\sum_i \left| X_{i,n-1} - X_{i,n-2} \right|} \quad . \tag{716-30}$$

It is not practical to obtain $\mu_{n,3}$ in this code which allows the source and flux values to float to an arbitrary level making it likely that the numbers would exceed machine range. The value $\mu_{n,4}$ is now being used and reported when easily calculated without data access.

An independent estimate is made of the dominant eigenvalue of the outer iteration process. The total neutron loss (absorption plus leakage) is calculated each iteration, L_n. The asymptotic eigenvalue of the iteration process is estimated by

$$\gamma_n = \frac{L_n - L_{n-1}}{L_{n-1} - L_{n-2}} \tag{716-31}$$

Equation (716-31) is, unfortunately, only reliable when most of the flux values are either rising or falling, restricting effective use.

When successive outer iteration values of the fluxes are not readily available, the test for a convergent process is modified. If $|\varepsilon_n| > |\varepsilon_{n-1}|$, it is deemed not convergent. If $|\varepsilon_n| < |\varepsilon_{n-1}|$, the process is deemed convergent if $|\varepsilon_n| < 0.1$ and

$$|k_n - k_{n-1}| < |k_{n-1} - k_{n-2}| \qquad \text{or}$$

$$\frac{k_n - k_{n-1}}{k_n - k_{n-2}} < 2 \quad ,$$

or regardless of the value of ϵ_n,

$$\mu_n < 1.0 \text{ and either}$$

$$0.9 < \frac{1 - \mu_n}{1 - \gamma_n} < 1.1 \text{ or}$$

$$0.1 < \frac{\mu_{n,a}}{\mu_n} < 1.5 \quad ,$$

Where $\mu_{n,a}$ is $\mu_{n,1}$ or $\mu_{n,2}$, the one associated with the maximum relative flux change. This qualification on a convergent process does not apply when only one inner iteration is done each outer iteration.

Together, the individual procedures act in a complicated way on the overall process which displays interaction effects. Certain delays and cycles are incorporated as found desirable from the behavior of representative test problems. These are discussed here. With line relaxation on rows, for a problem containing R rows and P planes, R + P - 1 sweeps are required for the most remote boundary condition to propagate across the space problem. Typically, there is a change in the iterative behavior when this number of inner iterations have been done. However, it has been found that the behavior should be assessed earlier.

Let R = Number of rows

P = Number of planes

T = Number of inner iterations (minimum)

$$a = \sqrt{\frac{R + P - 1}{T}}$$

$$J = \max\left[\frac{21a - 9}{a + 1}, 5\right] \qquad (716\text{-}32)$$

$$L = \max\left[\frac{R + P}{T} + 1.99, 10\right]$$

$$K = \min\,[L, 2J]$$

$$M = \max [J + 2, K]$$

$$N = M + 1$$

where

- J is the initial delay in accessing convergence behavior,
- M is the initial delay in applying extrapolation arbitrarily,
- K is the delay between arbitrary extrapolations,
- N is the initial delay on initiation of the Chebyshev acceleration procedure.

Asymptotic extrapolation is delayed 5 iterations whenever any action is taken which would disrupt the outer iteration process preventing an approach to an asymptotic error mode. Extrapolation itself or adjustment of the acceleration parameters cause such delay.

Chebyshev acceleration may be initiated sooner than N above when the asymptotic single error mode extrapolation criteria are satisified; a minimum cycle of 5 iterations is imposed as discussed later on restart of the Chebyshev acceleration process, extended by 3 iterations from that iteration when any of the overrelaxation coefficients are reduced. When initiated or restarted after asymptotic extrapolation or after the estimated eigenvalue spectrum range has been decreased, start of the process is delayed one iteration.

Testing to reduce the overrelaxation coefficients is permitted only 3 iterations following restart of the Chebyshev acceleration process or 4 iterations following asymptotic extrapolation when inner iteration behavior is examined (requires ≥ 4 inner iterations), or 5 iterations after these events otherwise, and 5 iterations after any prior reduction has been done.

When the minimum number of inner iterations done at any group is less than 4, non-convergence of the outer iteration process is used as criterion for reducing the overrelaxation factors. However, if the number of inner iterations done at any group is 4 or more and this inner iteration process is deemed convergent, that overrelaxation coefficient is not reduced the first time reduction of these coefficients is done based on outer iteration behavior.

The overrelaxation factors at groups for which the number of inner iterations is less than 4 may be increased when the others are. However, μ_n for the outer iteration process (Eq. 716-29) is used in place of λ_t in Eq. (716-21), or the max (μ_n, μ_2) when Chebyshev acceleration is done.

When the minimum number of inner iterations is 4 or more and Chebyshev acceleration is not being done and after the outer iteration count satisfies the set delays, if the outer iteration process is deemed to be not convergent, all of the overrelaxation coefficients are arbitrarily reduced using Eq. (716-23). This can occur no more frequently than every other outer iteration. Note that once reduced, an overrelaxation coefficient will not be increased later, except if they are all reduced simultaneously.

The continuing discussion addresses acceleration of the outer iteration process.

Chebyshev Acceleration on Outer Iterations

We outline here in general the procedure implemented for accelerating the outer iterations using the Chebyshev polynominals. This procedure has been selected from information about experience of others[a] in applying the technique with rather drastic modifications introduced based on our own experience with iterative procedures. A number of options are incorporated to facilitate testing. The automatic application of use of the Chebyshev acceleration procedure is made problem-dependent; it is not always automatically applied, but can always be applied at the whim of the user.

When Chebyshev acceleration is initiated (or reinitiated) the equation applied (pointwise) is

$$\phi_N = \phi_N^* + f_N\,(\phi_N^* - \phi_{N-1}) \quad , \tag{716-33}$$

and each outer iteration after this one,

$$\phi_n = \phi_n^* + f_n(\phi_n^* - \phi_{n-1}) + g_n(\phi_{n-1} - \phi_{n-2}). \tag{716-34}$$

However, if $|\varepsilon_n| > 0.1$, the result is constrained to

$$0.25\phi_n^* < \phi_n < 4.0\phi_n^* \quad .$$

[a] E. L. Wachspress, Iterative Solution of Elliptic Equations, Prentice-Hall, Inc., N. J. (1966).

Here n refers to outer iteration, N is the outer iteration when the process is initiated, ϕ_n^* is the newly calculated flux, ϕ_n the accelerated flux, and f_n and g_n are acceleration parameters. The latter are determined as follows. The Chebyshev polynominal recursion is used in the form

$$T_{N-1}(b) = 1.0$$

$$T_N(b) = b$$

$$T_n(b) = 2.0\ b\ T_{n-1}(b) - T_{n-2}(b),\ n > 1,\ \text{or}$$

$$\frac{T_{n-1}(b)}{T_n(b)} = \frac{1}{2.0\ b - \left[\dfrac{T_{n-2}(b)}{T_{n-1}(b)}\right]} \tag{716-35}$$

Note that $\dfrac{T_{n-1}(b)}{T_n(b)} \to b - \sqrt{b^2 - 1}$ as $n \to \infty$,

where

$$b = \frac{2.0 - (\mu_2 + \mu_1)}{(\mu_2 - \mu_1)} \quad , \tag{716-36}$$

and μ_1 and μ_2 are the lower and upper bounds of the eigenvalue spectrum, respectively. Given the above recursion, the acceleration parameters are determined from

$$f_N = \frac{\mu_2 + \mu_1}{2.0 - (\mu_2 + \mu_1)} \tag{716-37}$$

$$f_n = \frac{4.0}{(\mu_2 - \mu_1)} \left[\frac{T_{n-1}(b)}{T_n(b)}\right] - 1.0 \quad ,$$

$$g_n = 2.0b \left[\frac{T_{n-1}(b)}{T_n(b)}\right] - 1.0;\ \text{or} \tag{716-38}$$

$$f_n = \left(\frac{4.0}{\mu_2 - \mu_1}\right)^2 \left[\frac{1.0}{\left(\dfrac{8.0b}{\mu_2 - \mu_1}\right) - 1.0 - f_{n-1}}\right] - 1.0 \quad ,$$

$$g_n = (1.0 + f_n)\ [1.0 - 0.5\ (\mu_2 + \mu_1)] - 1.0 \quad . \tag{716-39}$$

Consider the acceleration Eq. (716-34). The new estimate of the flux is obtained by applying the iteration matrix

$$\phi_n^* = M\phi_{n-1} \quad ,$$

$$\phi_n = [(1 + f_n)\, M - f_n]\, \phi_{n-1} + g_n\, (\phi_{n-1} - \phi_{n-2})$$

Define the error $E_n = \phi_\infty - \phi_n$, and since $M\phi_\infty$ returns ϕ_∞

$$E_n = [(1 + f_n)\, M - f_n]\, E_{n-1} + g_n\, (E_{n-1} - E_{n-2}) \quad .$$

Consider that asymptotically f_n and g_n become constants, and assume that an error vector dominates,

$$E_n = \sum_i A_i\, \mu_i^{\,n} \to A\mu^n \quad ,$$

and that this error vector must be driven by the dominant one of the iteration matrix,

$$M \to \lambda \quad .$$

These assumptions lead to

$$\mu^2 - [(1 + f_n)\lambda - f_n]\, \mu + g_n(1 - \mu) = 0.$$

Given an estimate for μ when the Chebyshev process is in use, an estimate of the dominant eigenvalue of the iteration matrix (and hence the upper limit of the spectrum of eigenvalues needed to select the Chebyshev parameters) is given by

$$\lambda = \frac{\mu^2 + \mu f_n + g_n(1 - \mu)}{\mu(1 + f_n)} \quad . \tag{716-40}$$

We seek the smallest value of μ for maximum acceleration,

$$\mu = \tfrac{1}{2}\{[(1 + f)\lambda - f + g] \pm \sqrt{[(1 + f)\lambda - f + g]^2 - 4g}\,\} \quad .$$

Note that for $f = g = 0$, $\mu = \lambda$ as it should with no acceleration.

The values of f and g are related through the polynominal equations for Chebyshev acceleration by

$$g_n = f_n - \left(\frac{\lambda + a}{2}\right)\left(1 + f_n\right) \quad ,$$

where a is the lower limit of the spectrum. Assuming that λ is known,

$$\mu = \frac{1}{2}\left\{\left(\frac{\lambda - a}{2}\right)(1 + f) \pm \sqrt{\left[\left(\frac{\lambda - a}{2}\right)(1 + f)\right]^2 - 4f + 2(\lambda + a)(1 + f)}\right\}$$

The largest value of μ can be reduced to a point by increasing f, but further increase in f causes it to have an imaginary component. This occurs when

$$\left[\left(\frac{\lambda - a}{2}\right)(1 + f)\right]^2 - 4f + 2(\lambda + a)(1 + f) = 0 \qquad \text{, and}$$

$$\mu = \left(\frac{\lambda - a}{4}\right)(1 + f) \qquad \text{, or from above,}$$

$$1 + f = \frac{4}{(\lambda - a)^2}\left[2 - (\lambda + a) - 2\sqrt{(1 - a)(1 - \lambda)}\right] \qquad ,$$

the smallest value selected, and

$$\mu = \frac{1}{(\lambda - a)}\left[2 - (\lambda + a) - 2\sqrt{(1 - a)(1 - \lambda)}\right] \qquad . \qquad (716\text{-}41)$$

Asymptotically, we expect optimum Chebyshev acceleration of an iterative process having a dominant eigenvalue λ to have a dominant eigenvalue μ. An estimate of μ from the behavior of a problem may be compared with this value to assess effectiveness. Note that if μ were known and the lower limit were zero,

$$\lambda = \frac{4\mu}{1 + 2\mu + \mu^2} \qquad .$$

It is of interest to examine the gain in the rate of error reduction with Chebyshev acceleration (asymptotic optimum). Values of μ and λ are compared on the following page (a = 0). In practice we have found that theoretical gains are not realized in typical application, possibly due to the actual distribution density of the eigenvalues.

No Acceleration (λ)	Optimum Acceleration (μ)
0.25	0.0718
0.50	0.1716
0.75	0.3333
0.85	0.4417
0.95	0.6345
0.99	0.8182

If the basic iterative process reduces the absolute error by 5% each outer iteration, the Chebyshev process optimumally reduces this absolute error 36.5% each outer iteration asymptotically, an impressive gain.

The automated procedure for starting the Chebyshev acceleration process consists of:

1. Requiring the outer iteration process be convergent,
2. Requiring the inner iteration processes be convergent for two successive outer iterations,
3. Requiring the maximum number of inner iterations be $\geqslant 5$ (overridden by user option),
4. The outer iteration count must exceed the imposed initial delay (see Eq. 716-31).

One exception to 3 is that the procedure is applied when a problem has upscattering. Another exception is the one-dimensional problem for which the procedure is applied automatically after an outer iteration count of 10 when the iteration process is convergent.

Limits for the eigenvalue spectrum are selected automatically. Initially μ_1 is set to zero and

$$\mu_2 = \max\,[\min\,(0.9,\ X),\ 0.5]$$

where $X = \dfrac{G}{2.0 - G}$ for one-dimensional problems, G is the number of energy groups, otherwise[a]

$$X = \max\,\beta_o(g) - 1.0 \qquad .$$

[a]We expect to use an estimate from the multigroup equations for one point involving weighting of the space-dependent properties.

An attempt is made to obtain a better estimate of this eigenvalue from the iterative behavior as discussed later. When non-zero values of these eigenvalues are supplied as input data, they are used, overriding the above procedure.

After starting or restarting the process, a set minimum delay is imposed. Then if the outer iteration behavior does not satisfy the criteria for a convergent process, the procedure is restarted with a reduced value for the estimate of the eigenvalue spectrum limit,

$$\mu_2 = \min\,[0.98,\ \max\,(\mu_{2,0}{}^2,\ 0.75\ \mu_{2,0})] \quad , \qquad (716\text{-}42)$$

where $\mu_{2,0}$ refers to the value in current use. Equation (716-42) is applied a maximum of three times (each time only if the behavior does not satisfy convergence criteria when tested), and then Chebyshev acceleration is discontinued if the behavior is still not convergent. The process will later be restarted if the single-error-mode extrapolation criteria are satisfied. Whenever the upper limit of the eigenvalue spectrum μ_2 is reduced, the old value of μ_2 is saved as an upper limit for μ_2, gradually increased thereafter.

The maximum relative flux change, ε_m for iteration m, is saved whenever the procedure is restarted. After the set delay, if $|\varepsilon_n| > 1.5\ |\varepsilon_m|$, the process is deemed to be ineffective, Eq. (716-42) is used, and the procedure restarted, but only if $|\varepsilon_n| > \mu_2\ |\varepsilon_{n-1}|$.

Given a convergent process when Chebyshev acceleration is in use, the behavior is examined after a maximum delay of 15 iterations, or if $f_n/f_{n-1} < 0.999$. Either single- or double-error-mode asymptotic extrapolation may then be done as discussed later, and then the process is always restarted. Also, when the asymptotic single-error-mode extrapolation criteria are satisfied, μ_2 is reset to λ from Eq. (716-40).

This new value is used and the process restarted if

$$0.95 < \frac{1.0 - \mu_{2,n}}{1.0 - \mu_{2,n-1}} < 1.05 \quad ,$$

provided

$$\mu_{2,0} < \mu_{2,n} < 0.99999$$

be limited to $\mu_2 < \frac{B - 1.0 + \mu_{2,0}}{B}$, where $B = \max\,[1.4,\ \ln\,(2 + \sqrt{I})]$ where I is the minimum number of inner iterations done, except that B is defaulted to 2.0 for one-dimensional problems. Restart is not done when only a small change in μ_2 occurs,

$$0.99 < \frac{1.0 - \mu_{2,n}}{1.0 - \mu_{2,0}} < 1.01 \quad .$$

This last test is not applied when asymptotic extrapolation is done causing restart, normally allowing μ_2 to be adjusted. Also, if the test on successive iterate estimates of $\mu_{2,n}$ fails, then the new value used is

$$\mu_2 = \tfrac{1}{2}(\mu_{2,n} + \mu_{2,0}) \quad . \tag{716-43}$$

Asymptotic Extrapolation

When the iterative behavior of a problem indicates that an asymptotic mode has established, an extrapolation is done on sets of the outer iteration flux values.

Consider the outer iteration problem in the form

$$\phi_{n+1} = (G_n + \frac{1}{k_n}\chi F)\phi_n \quad . \tag{716-44}$$

or in the alternative form

$$\phi_{n+1} = (G_n + \frac{1}{k_e}\chi F)\phi_n + \left(\frac{k_e - k_n}{k_n k_e}\right)\chi F\phi_n \quad . \tag{716-45}$$

Note that an error from the estimated value of the multiplication factor enters the problem directly.

This iterative process may be expressed as

$$\phi_{n+1} = M_n\phi_n \quad , \tag{716-46}$$

where M_n is the iteration matrix. M_n depends on the latest estimate of the problem eigenvalue, the multiplication factor for the usual type of eigenvalue problem or the eigenvalue of the direct search problem. For a process which converges to a solution, the largest eigenvalue of M must tend to unity; the operation $M_\infty\phi_\infty$ must return ϕ_∞.

It is assumed that the outer iteration flux vector can be expanded into a set of linearly independent error vectors,

$$\phi_\infty - \phi_n = \sum_j \left[\prod_{\ell=m}^{n} \mu_{\ell,j} \right] A_j + 0_{i,n} \quad . \tag{716-47}$$

$0_{i,n}$ is a residual error (associated with the eigenvalue estimate), hopefully small and decreasing as n increases. The A_j is diagonal, a constant for each component of ϕ associated with some previous state of the problem), and the $\mu_{\ell,j}$ represent eigenvalues of the error vectors, eigenvalues of the iteration matrix M_n.

The single error mode extrapolation procedure is based on one error vector dominating, asymptotically

$$X_{i,\infty} - X_{i,n} = a_i \mu^n \quad , \tag{716-48}$$

where a_i is a constant and μ the eigenvalue of the dominating error vector. This recursion relationship yields the expression for the eigenvalue

$$\mu = \frac{X_{i,n} - X_{i,n-1}}{X_{i,n-1} - X_{i,n-2}} \quad , \tag{716-49}$$

and the extrapolation equation

$$X_{i,\infty} = X_{i,n} + b(X_{i,n} - X_{i,n-1}) \quad . \tag{716-50}$$

where

$$b = \frac{\mu}{1 - \mu} \quad .$$

Alternatively, iterate values spaced two iterations apart may be used by properly determining the extrapolation factor. At the time this is written, we use

$$X_{i,\infty} = X_{i,n} + g(X_{i,n} - X_{i,n-2}) \quad , \tag{716-51}$$

where

$$g = \frac{\mu^2}{1 - \mu^2}$$

The dependence of the extrapolation factor (for Eq. (716-50) is shown in Fig. (716-3).

Thus, the asymptotic single-error mode extrapolation procedure uses information from three succeeding outer iteration flux values to give a single factor applied to the most recent flux values and those from two outer iterations back to drive the iterate estimates toward an apparent solution. The scheme is used to eliminate an error vector which dominates asymptotically, or one which dominates at any stage of the calculation.

Of critical importance are (1) determining when one error vector dominates, and (2) producing a good estimate of the eigenvalue of the dominating error vector.

The single-error mode process is restrained. A maximum value for b of 75 is used. Until $|\varepsilon_{n-1}| < 0.01$, an imposed restraint (preventing negative flux values) is

$$0.25 < \frac{X_{i,\infty}}{X_{i,n}} < 4.0 \quad ,$$

when the minimum number of inner iterations < 4, or

$$0.1 < \frac{X_{i,\infty}}{X_{i,n}} < 10. \quad .$$

otherwise.

The asymptotic two-error-mode extrapolation procedure procedure is less clearly defined. Basically, it is assumed that the composite error vector is given by

$$X_{i,\infty} - X_{i,n} = b_n(X_{i,n} - X_{i,n-1}) + q_n(X_{i,n-1} - X_{i,n-2}) \quad . \qquad (716\text{-}52)$$

This recursion relationship leads to the equation

$$\mu_n(1.0 + b_n + \frac{q_n}{\mu_n}) = b_{n-1} + \frac{q_{n-1}}{\mu_{n-1}} \quad , \qquad (716\text{-}53)$$

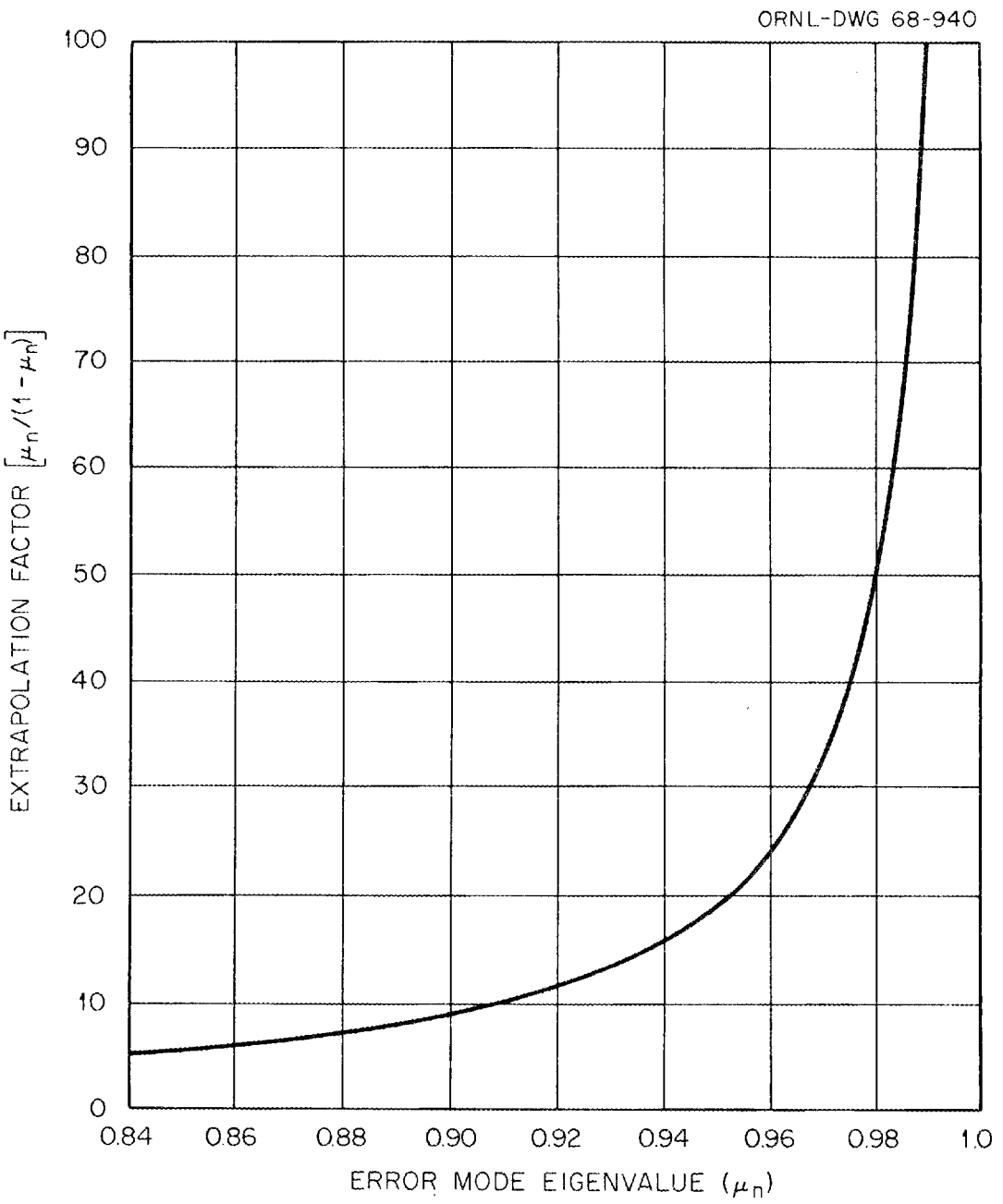

Fig. 716-3. Dependence of the Extrapolation Factor on the Single Error Eigenvalue.

where μ_n is defined above. At some stage in the calculation, it is assumed that the individual error vectors contribute in such a way that the values of b_n and q_n are nearly independent of the outer iteration n. When so independent,

$$q_n = \frac{\mu_{n-1}\mu_{n-2}\,(\mu_n - \mu_{n-1})}{\mu_{n-2}(1.0 - \mu_{n-1})^2 - \mu_{n-1}(1.0 - \mu_n)(1.0 - \mu_{n-2})} \quad ;$$

$$b_n = \frac{\mu_n - b_n \left[\dfrac{1.0 - \mu_{n-1}}{\mu_{n-1}}\right]}{1.0 - \mu_n} \quad . \qquad (716\text{-}54)$$

Note that a test for significance can be made on the denominator of the equation for q_n. In any event, $q_n = 0$ defaults the equations to those for the single-error mode.

The asymptotic two error mode extrapolation equation is

$$X_{i,\infty} = X_{i,n} + b_n(X_{i,n} - X_{i,n-1}) + q_n(X_{i,n-1} - X_{i,n-2}) \quad , \qquad (716\text{-}55)$$

applied to each flux value. An attractive feature of this procedure is that the eigenvalues of the two dominating error vectors may be a complex conjugate set. The rather indefinite state of the contributions from the individual error vectors which are required for the procedure to be effective is a distinct disadvantage.

The criteria which are used to assess error vector dominance include that the outer iteration process be convergent, $|\varepsilon_n| < 10$, and $\mu_{n,a} < 10$. An asymptotic single-error mode is judged to have established when

$$\mu_n < 0.99999 \quad ,$$

$$|\mu_n - \mu_{n-1}| < |\mu_{n-1} - \mu_{n-2}| \quad ,$$

$$0.5 < \frac{1.0 - \mu_{n-1}}{1.0 - \mu_{n-2}} < 1.5 \quad ,$$

$$0.95 < \frac{b_n}{b_{n-1}} < 1.05 \quad ,$$

where

$$b_n = \frac{\mu_n}{1.0 - \mu_n} \quad ,$$

and that either $0.75 < \frac{1.0 - \mu_n}{1.0 - \mu_{n,a}} < 1.25$, or $0.90 < \frac{1.0 - \mu_n}{1.0 - \gamma_n} < 1.10$,

and $0.1 < \frac{\mu_{n,a}}{\mu_n} < 1.5$ when Equation (716-27) is used, where $\mu_{n,a}$ is that value of $\mu_{n,1}$ or $\mu_{n,2}$ associated with the maximum relative flux change.

First priority is given to the double-error mode procedure, applied when the following criteria are satisfied, using values from Eq. (716-54),

$$\mu_n < 0.99999$$

$$b_n + q_n > 0 \quad ,$$

$$0.8 < \frac{b_n + q_n}{b_{n-1} + q_{n-1}} < 1.2 \quad ,$$

$$|b_n| < 1000 \quad ,$$

$$b_n b_{n-1} > 0 \quad ,$$

$$q_n q_{n-1} > 0 \quad ,$$

$$|q_{n-1}| < |b_n| \quad ,$$

$$|q_n| < |b_n| \quad ,$$

$$q_n < 0 \quad .$$

In addition, a new value for b_n is obtained from

$$b_n' = \frac{1}{\mu_n} \left\{ b_{n-1} + \frac{q_{n-1}}{n-1} - q_n - \mu_n \right\} \tag{716-56}$$

and the extrapolation is done only if

$$0.9 < \frac{b_n'}{b_n} < 1.1 \quad .$$

Then b_n' is used instead of b_n. Default is to the single-error mode procedure, applied when its criteria are satisfied.

The same restraints are applied to the flux values as for the single-error-mode process, but now only when $|\varepsilon_{n-1}| > 0.001$.

Extrapolation is allowed only after the initial set delay in outer iteration count, and after the set delay following any major change in the process, as when extrapolation is done, or parameters are changed as discussed earlier. Otherwise, the procedure involves a continuous check on the iterative behavior for conditions allowing extrapolation. Upon extrapolation, the overrelaxation coefficients are not permitted to be adjusted for the set delay of 5 outer iterations; when the Chebyshev acceleration process is used, it is restarted whenever extrapolation is done.

Superimposed on the above procedure is an arbitrary scheme. A fixed delay initially (and after asymptotic extrapolation is done) is imposed, see Eq. (716-32), then the procedure is further delayed until the outer iteration process is convergent and the inner iteration processes are convergent for two succeeding outer iterations. When the Chebyshev acceleration process is to be done, the above fixed initial delay is not imposed, and the procedure is applied only at that stage of the calculation when Chebyshev acceleration is initiated, convergent processes required.

Equation (716-30) is applied to the space problem at each group, as well as to the overall problem, producing estimates of $\mu_n(g)$. If all $\mu_n(g) < 0.99999$, extrapolation is done in the singe-error-mode sense, applying Eq. (716-51), constrained such that $b < 75$. If the Chebyshev acceleration procedure is to be initiated, the new estimate of the upper limit of the eigenvalue spectrum, unless user supplied, is $\mu_2 = \min(0.9, \mu_n)$.

At the time the first asymptotic extrapolation is done, the number of inner iterations at each group are recalculated if the minimum is $\geqslant 4$. The adjustments are made to attempt to get the same error reduction for each space problem. Considering that the rate of error reduction (asymptotically) each inner iteration is approximately $\mu_n(g) \frac{1}{I(g)}$, the number of inner iterations is recalculated for each group as (truncated)

$$I_{n+1}(g) = \frac{XI_n(g)}{\ell n \mu_n(g)} + 0.5 \quad , \tag{716-57}$$

restrained to

$$4 < I_{n+1}(g) < \max I_n(g) \quad ,$$

where

$$X = \left[\max I_n(g)\right] \ell n \left[\max \left\{\mu_n(g)^{\frac{1}{I_n(g)}}\right\}\right]$$

and $\mu_n(g)$ is determined at each group by Eq. (716-30).

If any $\mu_n(g) > 0.99999$, extrapolation is not done and the overrelaxation coefficient for that group is reduced.

It is possible to do simultaneous Chebyshev acceleration and extrapolation, by redefining the Chebyshev acceleration parameters to

$$f_n' = b + (1.0 - b)\ f_n \quad ,$$

$$g_n' = (1.0 + b)\ g_n + q \quad .$$

Experience has shown that effective extrapolation is possible only when the Chebyshev process is under-accelerated, as expected theoretically.

Estimating the Eigenvalue

After each outer iteration, each full sweep of the mesh points, the eigenvalue is estimated from an overall neutron balance.[a] If the point neutron balance equations are summed, the scattering and internal leakage terms cancel leaving only production, surface leakage and absorption (plus buckling and internal black absorber loss) terms. Therefore, for the usual eigenvalue problem,

$$k_n = \frac{P_n}{L_n} \tag{716-58}$$

[a]Except as noted later.

where P_n refers to the total neutron production rate, and L_n to the neutron absorption rate plus the surface leakage rate, each determined for outer iteration n. This estimate of the multiplication factor is used the next outer iteration except when outer iteration acceleration is done.

In the event that the sum of the distribution function for source neutrons is not unity for one or more zones, then the totals must be applied to the total production rate,

$$P_n = \sum_z V_z \left(\sum_g \nu\Sigma_{f,z,g} \bar{\phi}_{z,g} \right) \sum_{g'} \chi_{z,g'} \quad . \qquad (716\text{-}59)$$

Calculations of the losses to internal black absorber regions, in-leakage from adjacent regions, presents a bit of a problem. To avoid a significant cost in computer time, this contribution to the overall neutron balance is approximated as a calculation proceeds, which involves use of all the latest point flux values available, but some point flux values have not yet been recalculated for the last inner iteration. The effect of this approximation has been found to be insignificant for usual situations where the total black absorber contribution is a small part of the total neutron losses.

For the adjoint eigenvalue problem, the scattering terms do not cancel. Therefore, the overall neutron balance equation is greatly complicated, and it would be expensive in computer time to apply an overall neutron balance. So when the associated adjoint problem is solved after a regular problem, the available estimate of k_e from the latter is used. When done alone, the simple estimate from source ratios is used,

$$k_n = \frac{k_{n-1} P_n}{P_{n-1}} \quad . \qquad (716\text{-}60)$$

This formulation is also used when solving the consistent P_1 equations and when Chebyshev acceleration is being done (without criticality search) using the accelerated flux values.

For other types of eigenvalue problems, the direct searches, the overall neutron balance yields an estimate of the eigenvalue,

$$\lambda_n = \frac{L_n - \frac{1}{k_e} P_n}{\left(\frac{1}{k_e} \Delta P_n - \Delta A_n\right)} \quad , \qquad (716\text{-}61)$$

where the new terms ΔP_n and ΔA_n are productions and losses associated with the changes introduced through the search parameter. Generally a λ of zero means none of the material to be adjusted is added to the system; the exception is the buckling search where the specified buckling term is initially included in the equation constants, so the search is done on the changes to it, zero λ meaning no change.

To avoid trouble with initial error modes, a change which is less than that indicated by Eq. (716-61) is introduced during the early iterations. Let λ^* be the value calculated from Eq. (716-60) and λ_{n-1} be the value used the previous iteration; the formulation used is

$$\lambda_n = \lambda_{n-1} + C_n \, (\lambda^* - \lambda_{n-1}) \quad , \qquad (716\text{-}62)$$

where C_n is initialized at a small value, say 0.1, and is doubled after each time it is used until it exceeds unity, after which the estimate of λ given by Eq. (716-61) is used directly. In the event that the system has a very low multiplication factor, Eq. (716-61) tends to be an overestimate; therefore, if $k_n/k_e < 0.5$, where k_n is determined from Eq. (716-58), the factor C_n of Eq. (716-62) is not increased, nor is it increased during the first few iterations if $0.95 < k_n/k_e < 1.05$. Other techniques have been used, as to dampen oscillatory behavior. However, it is quite important that asymptotic extrapolation be allowed; this requires that the detailed treatment of each iteration be identical, after the early history, or extraneous error vectors will be introduced.

Special care must often be taken when the iterate estimate of the search problem eigenvalue is negative. This causes a negative contribution to be added to the absorption at a point, decreasing the diagonal dominance. Thus, for a subcritical system, one having an associated k_e

considerably less than unity, the solution for a desired k_e of unity of a reciprocal velocity search involves a negative value of λ. At solution the negative absorption contribution from the $\lambda(1/v)$ term may exceed that from the sum of outscatter and absorption, even at solution. During the iterative process, if not controlled, negative point flux values could be obtained. The technique used for control is to determine those values of λ which cause the total removal term with and without the diffusion coupling terms to be zero. Then the iterate estimate of λ is allowed to move only slowly from one value to the other, and no negative point flux can be obtained.

The Indirect Search

Consider that the results are available for two succeeding problems, namely, the multiplication factors associated with two conditions representing different contributions from the search parameters. Then use is made of the formulation

$$\lambda = \frac{C_1 k}{C_2 - k} \tag{716-63}$$

where C_1 and C_2 are constants to evaluate, k is the multiplication factor, and λ is the search problem eigenvalue. Equation (716-63) is assumed to fail if $|C_2| > 10^4$ as calculated, or if the estimated search eigenvalue exceeds either of the first two values. In this event, a linear approximation is used which gives the new estimate,

$$\lambda_{i+1} = \lambda_i + (k_e - k_i) \Bigg/ \left[\frac{k_i - k_{i-1}}{\lambda_i - \lambda_{i-1}}\right] \quad , \tag{716-64}$$

where k_e is the desired value of the multiplication factor, often unity, and i refers to the index on the eigenvalue problem loop.

A third eigenvalue problem is then solved. Given three states and the associated values for the multiplication factors, the formulation used is

$$\lambda = C_3 + \frac{C_1 k}{C_2 - k} \quad , \tag{716-65}$$

where C_1, C_2, and C_3 are constants to evaluate. Again significant results are required, or Eq. (716-64) is used in default.

To allow old results to be used, an estimate is made of the change in multiplication factor with change in the search eigenvalue

$$\lambda \frac{\partial k}{\partial \lambda} \simeq \lambda_i \left(\frac{k_i - k_{i-1}}{\lambda_i - \lambda_{i-1}} \right) \quad . \tag{716-66}$$

and the last significant value of this derivative (calculated during the process of an indirect search) could be made available if another search problem of the same type were solved.

The Fixed Source Problem

A special aspect must be considered if the procedure for solving fixed source problems is to be effective. Given a fixed source, there is an associated neutron flux level, provided there is a solution. This solution may be far away from the conditions used to initialize the problem. Quite generally, that error contribution which is hardest to remove is associated with the flux level being far from solution.

To remove this major error contribution, the source is scaled during the iterative calculation. After each outer iteration, an overall neutron balance is used to estimate the required level of the fixed source,

$$\begin{aligned} P_n + h_n S_o &= L_n \quad , \\ h_n &= \frac{L_n - P_n}{S_o} \quad , \end{aligned} \tag{716-67}$$

where P_n is the fission source rate, L_n is the loss rate, and S_o is the total fixed source. The factor h_n determined above is a multiplier on the total source,

$$S_{n+1} = \begin{cases} S_o, & n = 0 \\ h_n S_o, & n > 0 \end{cases} \tag{716-68}$$

and therefore on the individual components of it.

Upon completion of the problem, the solution flux values are scaled to give the solution associated with the specified fixed source. This procedure applies in any situation where there is no feedback into the problem. Note that the procedure allows the source to go negative if so calculated as necessary. The result of a calculation may be that a negative source is required for the situation presented, and this is generally deemed not acceptable.

For the fixed source adjoint problem, L_n in Eq. (716-67) is replaced by a constant to fix the total source based on initial conditions,

$$L_n = P_o + \frac{S_o}{10.}\left|\frac{P_o}{S_o}\right| \quad . \tag{716-69}$$

Outer Iteration Acceleration Estimates

When acceleration is done (on an outer iteration, Chebyshev or extrapolation), a new estimate is obtained of the problem eigenvalue. The neutron production rate and the neutron loss rate (absorption plus surface leakage) for the overall neutron balance are accelerated individually, given by the general form,

$$\begin{aligned} P_n &= P_n^* + f_n(P_n^* - P_{n-1}) + g_n(P_{n-1} - P_{n-2}) \quad , \\ L_n &= L_n^* + f_n(L_n^* - L_{n-1}) + g_n(L_{n-1} - L_{n-2}) \quad , \end{aligned} \tag{716-70}$$

where f_n and g_n are the parameters used to accelerate the flux (b and q in the case of extrapolation). The accelerated values are arbitrarily left at the calculated values if the acceleration would produce a change of more than 10% in the production rate. Acceleration of these quantities causes the current estimate of the eigenvalue of the problem to be modified in applying the equations discussed above. However, a restraint is added when Chebyshev acceleration is done to prevent oscillation behavior. The accelerated value of the eigenvalue of a problem (the multiplification factor or the search problem eigenvalue) is not used if it does not represent forward driving from the neutron balance values if

$$\frac{k_n - k_n^*}{k_n^* - k_{n-1}^*} < 0 \quad ,$$

k_n^* is used and the last term in Eq. (716-70) is eliminated the next iteration. Once this is done, extrapolation is not done on k thereafter. (The automated procedure causes k to be determined from total source ratios when Chebyshev acceleration is done.)

END OF SECTION

Section 718: Initialization

Prior to iteration on the neutronics problem, values for the flux must be assigned at each point in space and energy. Certain parameters are required for the iteration procedures. The initialization procedures are discussed here.

An existing set of the flux values may be available for use. It could be the solution for a similar problem. Situations are known for which seemingly small changes in a system cause the solution for another problem to be a poor starting point, as when control rods are repositioned. However, considerable reduction in computation time is associated with use of the previous solution to start each problem for discrete step depletion calculations. The capability is incorporated to perform a linear interpolation of the flux values when a finer meshpoint description is presented; this expansion from a coarse-mesh result is appropriate only if the number of meshpoints has been increased regularly along any one coordinate (for example, doubled across the board, or each two replaced by three).

To effect a reasonable initialization, the basic procedure selected is use of a cosine flux distribution along each coordinate direction, and satisfaction of the point neutronics problem for the macroscopic cross sections of the zone located at the point where the boundary conditions indicate the flux is near maximum,

$$\phi(g,r) = A(g)\ B(x)\ C(y)\ D(z) \quad , \qquad (718\text{-}1)$$

where $\phi(g,r)$ is the flux guess for energy group g and space location r, A(g) is determined from

$$T(g)\ A(g) = X(g) + \sum_{g'} S(g')\ A(g') \quad , \qquad (718\text{-}2)$$

where T(g) is the loss term for the group including a buckling loss associated with $B_{\perp}^2 = 0.01$; $\chi(g)$ is the fission source distribution (i.e., a unit source distributed), and S(g) is the inscattering cross section. B(x), C(y), and D(z) are determined for the individual coordinate directions by the relationship, typically

$$B(x) = \cos\left[\frac{0.8\pi\ (X - X_o)}{2L}\right] \quad . \qquad (718\text{-}3)$$

Values of X_o and L depend on the boundary conditions for that space coordinate as shown on the following page:

Boundary Conditions (left, Right)	L	X_o
Reflected, Reflected*	(Not used)	(Not used)
Reflected, Extrapolated**	width	0
Extrapolated, Reflected	width	width
Extrapolated, Extrapolated	half-width	half-width

*or repeated
**non-return or zero flux

Of course, at the user's whim, all flux values are initialized at a constant or a data file supplied will be used. It is planned to implement a more sophisticated initialization procedure to reduce the cost of solving the larger problems.

The adjoint flux values are initialized at those values available for an associated regular problem; point values over space for all energy groups are set equal to the point values over space for the first energy group of the regular problem.

The overrelaxation coefficients are initialized at values dependent on an estimate of the next-to-largest, in magnitude, eigenvalue of the iteration matrix, $\rho(g)$.

$$\beta_o(g) = \frac{2}{1.0 + \sqrt{1.0 - \rho(g)^2}} \quad . \tag{718-4}$$

Along each coordinate direction, an "ideal" eigenvalue is determined for a uniform mesh homogeneous problem,

$$\lambda_j = \cos\left\{\frac{\pi}{\alpha_j N_j}\right\} \quad , \tag{718-5}$$

where j refers to a coordinate direction; N_j is the number of mesh intervals; and α_i depends on the boundary conditions: 1.0 for zero flux or non-return (extrapolated) boundaries associated with this coordinate, 2.0 if one boundary is reflected, or 3.0 if both are reflected, but λ_j is then set max (λ_j, 0.995) except for the first coordinate direction.

For line overrelaxation along the first coordinate direction, the "ideal" eigenvalue is estimated as

$$\lambda_L = \frac{\sum_{j=2}^{J} \rho_j}{J - \rho_1} \tag{718-6}$$

where J is the number of coordinates, 2 or 3. Note that for the one-dimensional problem with line relaxation, $\lambda_L = 0$, the optimum overrelaxation coefficient is unity, and overrelaxation is not done.

Based on experience with problems involving from few to many energy groups, λ_L is arbitrarily reduced as follows. The number of inner iterations is estimated at

$$\beta_L = \frac{2.0}{1.0 + \sqrt{1.0 - \lambda_L^2}} \quad ,$$

$$X = \min \left\{ 30, \max \left[1.0, \frac{-A}{\ln(\beta_L - 1.0)} \right] \right\} \quad ,$$

where A is 1.5 without upscatter, 0.8 with upscatter; if $X \leqslant 4$, it is set to 4 without upscatter or one if $\rho_L < 0.9$ or with upscatter. If the number of inner iterations is specified in the user input, this value is used. Then, the eigenvalue λ is adjusted:

$$b = \max \left\{ 1.0, \min \left[5.0, \frac{G + 4X + 10}{4X + 11} \right] \right\} \quad ,$$

where G is the number of groups, and

$$\lambda_G = \lambda_L^{\,b} \quad . \tag{718-7}$$

To allow for dependence on the relative magnitudes of the leakage constants and the total loss term in the finite-difference formulation, an internal mesh point location is selected where the product of the volume and $\nu\Sigma_f$ is largest, and the estimate of the eigenvalue is adjusted by

$$\rho(g) = \max \left[0.75, \lambda_G \left\{ \frac{1.0}{1.0 + \frac{C_{R,i}(g)}{\sum_s C_{s,i}(g)}} \right\} \right] \quad , \tag{718-8}$$

where $C_{R,i}(g)$ is the total loss constant (the finite-difference-element volume times the total cross section for outscatter and absorption plus the buckling loss term, mesh point i, and $C_{s,i}(g)$ refers to the leakage constant associated with a surface of the element for that energy group.

The eigenvalue estimates obtained from Eq. (718-8) are arbitrarily adjusted as follows

$$a = \min\left\{\rho(g)\right\} \quad ,$$

$$b = 1.0 - \sqrt{1.0 - \lambda_G} \quad ,$$

$$c = \max \rho(g) \quad ,$$

$$f = \begin{cases} c, & c > b \quad , \\ \frac{1}{2}(\lambda_G + b), & c \leq b \quad , \end{cases}$$

Then only if a < b,

$$\rho(g) = b + \left[\frac{f - b}{c - a}\right]\left[\rho(g) - a\right] \quad . \qquad (718\text{-}9)$$

The number of inner iterations required to effect a particular error reduction is estimated. Consider that a number of inner iterations has been specified; this number is used for the group m where $\rho(m)$ is a maximum and the number of iterations at each of the other groups is calculated (unless the specified number is ≤ 4) as

$$I(g) = \max\left[4, \min\left\{30, 1 + N \frac{\ln\left[\beta_o(m) - 1.0\right]}{\ln\left[\beta_o(g) - 1.0\right]}\right\}\right] \quad , \qquad (718\text{-}10)$$

(except that all I(g) are set to unity if max $\rho(g) < 0.9$), and used unless overridden by user option. When a value of N is not supplied, the value used is

$$N = \max\left\{4,\ 1.0 - \frac{A}{\ln[\beta_o(m) - 1.0]}\right\} \quad , \qquad (718\text{-}11)$$

where A is 1.5 without upscatter. With upscatter A is 0.8 and if the maximum number of inner iterations for any group is 4, they are all set to unity.

In the multirow and multiplane modes of data handling, there is a maximum number of inner iterations which can be done for a given amount of data transfer. By user option, the number of iterations done at each energy is arbitrarily rounded up to cause the maximum amount of calculation relative to data transfer, but this is not the automated procedure and may not be superior to the automated procedure.

It is planned to perform iterations on a one-dimensional problem selected from the mesh. The multi-group result can be used for initialization of the flux and inner and outer iteration information developed which may improve the starting points for both processes for the whole problem to be solved. Evaluation of the potential of the Chebyshev process (over single-error-mode extrapolation) appears possible.

END OF SECTION

Section 720: Reliability of Solution

A solution obtained by an iterative process is generally not entirely converged. It is uneconomical to satisfy tight convergence criteria. Therefore, the user relaxes the criteria to the extent possible which will still cause the result to satisfy the particular needs. Unfortunately, a simple measure of the reliability of a solution is not directly available from the iterative results. A satisfactory measure of reliability is, however, of critical importance.

If the inner iterations were continued enough times, the flux ϕ_{n+1} in Eq. (716-1) would satisfy the relationship in Eq. (720-1) provided there were no upscatter:

$$\phi_{n+1} = R\phi_{n+1} + \frac{1}{k_n} \chi F \phi_n \quad , \text{ or} \tag{720-1}$$

$$(I - R)\ \phi_{n+1} = A\ \phi_{n+1} = \frac{1}{k_n} \chi F\ \phi_n \quad .$$

The process could now be written as

$$\Psi_n = \chi F \phi_n \quad ,$$

$$\Psi_{n+1} = \frac{1}{k_n} M\ \Psi_n \quad .$$

Under this condition, bounds on k_e can be identified and calculated as simply the maximum and minimum ratios of the source, components of Ψ, between outer iterations, times k_n. Use has been made of these bounds, especially in the PDQ series of codes.[a] Unfortunately, the bounded range tends to be wide at low levels of convergence, and relaxation of the inner iteration convergence destroys the proof that the estimates are bounds. Only with a relatively large number of inner iterations does one have

[a] Cadwell, W. R., WAPD-TM-179

assurance that bounds have been identified. The optimum number of inner iterations for problem solution, considered here to minimize the computation cost, may be far fewer that are required to insure that bounds on the eigenvalue are established. Thus, we seek an alternative measure of reliability.

The Maximum Relative Flux Change

The iterative process, Eq. (716-1), may be described as

$$\phi_{n+1} = M_n \phi_n \quad , \tag{720-2}$$

where the flux vector from outer iteration n is operated on by the iteration matrix M_n to generate the new estimate. The iteration matrix M is iteration dependent because it contains the latest estimate of k_e. Bounds on the largest eigenvalue or spectral radius of M can be calculated.[a] Consider the set of components of the flux vector ϕ to be X_i, and the elements of M to be a_{ij}. Now consider the new matrix formed of the elements

$$b_{ij} = a_{ij} \frac{X_j}{X_i} \quad .$$

The new matrix is the result of performing the operation $P^{-1}MP$; therefore, it is similar to the matrix M and has the same eigenvalues. The spectral radius of this new matrix is bound by the maximum and the minimum of sums along columns or rows. The sum along a row is simply the ratio of flux values at one point between outer iterations. Therefore

$$\min \left(\frac{X_{i,n}}{X_{i,n-1}} \right) \leq \rho(M_n) \leq \text{maximum} \left(\frac{X_{i,n}}{X_{i,n-1}} \right) \quad . \tag{720-3}$$

Since $\rho(M_n)$ must tend to unity, an indication that the iterative process is convergent is that

$$\left| \varepsilon_{\phi,n} \right| < \left| \varepsilon_{\phi,n-1} \right| \quad , \tag{720-4}$$

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[a]Due to M. L. Tobias, unpublished.

where

$$\varepsilon_{\phi,n} = \left|\max\right| \frac{X_{i,n} - X_{i,n-1}}{X_{i,n-1}} \quad . \tag{720-5}$$

Further, $\rho(M_n)$ is bounded by $1 \pm |\varepsilon_{\phi,n}|$. There is not a one to one correspondence between bounds on k_n and on $\rho(M_n)$ because of the way k_n appears in M. However, a reasonable estimate of the probable uncertainty in k_n is

$$k_n \left(1 \pm |\varepsilon_{\phi,n}|\right) \quad . \tag{720-6}$$

Ocassionally, a result falls outside of this range, so it should be interpreted as an approximate bound, perhaps two standard deviations. Increasing the number of inner iterations generally increases the reliability of this bound, excluding the upscattering problem.

The VENTURE code tests $\varepsilon_{\phi,n}$ against a specified convergence criterion as the primary way an acceptable solution is identified and the iteration process is discontinued. Thus, if the estimated k is desired to within 0.01 percent, the criterion on the convergence of the point fluxes should be 0.0001. Quite generally a value of 0.00005 is recommended for wide use, a smaller value when necessary, and a larger value for situations where a lower degree of convergence is acceptable.

At the time this is written, it appears that the penalty associated with reaccess and/or storing away a copy of the iterate flux set for each iteration as necessary to determine the maximum relative point flux change is not justified. As an alternative, each re-evaluated point flux may be tested and the maximum for that inner iteration determined. Thus, at one energy g, outer iteration n and inner iteration m, we calculate

$$r_{g,n,m} = \max\left(\frac{X_{i,n,m}}{X_{i,n,m-1}}\right) \quad , \text{ and}$$

$$S_{g,n,m} = \min\left(\frac{X_{i,n,m}}{X_{i,n,m-1}}\right) \quad ;$$

by group g for outer iteration n, inner iteration m.

Then over the inner iterations, taking

$$p_{g,n} = \prod_m r_{g,n,m} \quad , \text{ and}$$

$$q_{g,n} = \prod_m s_{g,n,m} \quad ,$$

and finding the maximum over all g,

$$w_n = |\max| \; (p_{q,n} - 1, \; q_{g,n} - 1) \quad ,$$

$$|w_n| \geqslant |\varepsilon_{\phi,n}| \quad .$$

Thus the convergence property tested by $\varepsilon_{\phi,n}$ is also tested by w_n. Experience with its use indicates that $|w_n| >> |\varepsilon_{\phi,n}|$ during the early iterative history, but usually approaches its value by that stage of the calculation when the convergence level is low enough to terminate the process.

It should be noted that the discussion above is directed at the reliability of a solution regarding the error due to lack of convergence of the iterative process, not the error associated with the finite-difference approximations, the use of diffusion theory, or the discrete energy group representation.

The Residues Estimate

An independent measure of reliability is also available unless overridden by user. The value of the multiplication factor is determined which minimizes the sum of the squares of the residues of the point neutron balance equations cast in the form of actual reaction rates. The residue R_i is defined as

$$R_i = \frac{1}{k_r} F_i + S_i - T_i \quad , \qquad (720\text{-}7)$$

where R_i is the residue which would be zero if the problem were completely converged, F_i is the associated fission source, S_i is the in-scattering plus in-leakage term, and T_i is the total removal and out-leakage term. Each of the above terms is evaluated with the solution flux vector components. Summing equations and determining

$$\frac{\partial}{\partial k_r}\sum_i R_i^2 = 2\sum_i R_i \frac{\partial R_i}{\partial k_r} = 0 \quad ,$$

$$k_r = \frac{\sum_i F_i^2}{\sum_i F_i(T_i - S_i)} \quad . \tag{720-8}$$

Experience has shown the residues estimate of the multiplication constant to be quite useful, especially when a problem solved has an unfamiliar iterative behavior. If the residues estimate differs markedly from the value used in the iterative process, then the problem is not converged.

The analyst wants to know the best estimate of the multiplication factor for a problem, especially of concern when convergence criteria has been relaxed. Results from a wide range of problems indicate that the residues estimate is often not superior to that from the neutron balance used in the calculation. We suggest simply averaging the two values.

In some situations, even the residues estimate of k_e will not reflect lack of convergence, one case being that where over much of the system the flux is quite flat. The point neutron balance equations are used at each space-energy point having fission source to yield independent bounds on k_e

$$\frac{1}{k_b} F_i + S_i = T_i$$

$$k_b = \frac{F_i}{T_i - S_i} \quad , \tag{720-9}$$

and maximum and minimum values of k_b are determined as bounds. Unfortunately, in most situations there are locations where the magnitude of F_i is small relative to S_i, due either to small values of the macroscopic production cross sections ($\nu\Sigma_f$) or a small distribution factor, causing the bound estimates to be uselessly wide. For more useful estimates we restrict the test to locations and energy groups where $F_i/S_i > .00001$ if $S_i > 0$. Since S_i is zero for the first energy group, all of the first-group equations are considered. A user must rely on experience in assessing the results of such tests.

The Absolute Error

The responsible analyst must have some concern for the absolute error possible in a reported solution associated with lack of convergence of the iterative process. Certainly the iterative change in any integral quantity must be small if the absolute error is small. However, the multiplication factor calculated for two successive iterations may be nearly the same and yet differ considerably from a proper solution.

An indication of the absolute error is available from reported estimates of the eigenvalue of the overall iterative process which dominates asymptotic. See Section 716 for further discussion. When in this asymptotic mode, this eigenvalue μ is related to the iterate point flux values by

$$\mu = \frac{X_n - X_{n-1}}{X_{n-1} - X_{n-2}} \quad , \tag{720-10}$$

where n refers to outer iteration, and

$$\mu = \frac{X_\infty - X_n}{X_\infty - X_{n-1}} \quad . \tag{720-11}$$

Thus, μ is a direct measure of the absolute error reduction each iteration. Further

$$\frac{X_\infty - X_n}{X_n - X_{n-1}} = \frac{\mu}{1 - \mu} \quad ; \tag{720-12}$$

that is, an estimate of the ratio of the absolute error to the iterative change is given directly. Given the maximum relative flux change, ε_n, the absolute error in the local flux is

$$\frac{X_\infty - X_n}{X_\infty} \simeq \frac{X_\infty - X_n}{X_n} \simeq \left(\frac{\mu}{1 - \mu}\right) \varepsilon_n \quad . \tag{720-13}$$

Since the procedure of calculation attempts to make use of this information and apply asymptotic extrapolation, reported values of μ each iteration have limited utility. However, asymptotic extrapolation is only done when it appears that an asymptotic mode has developed. Thus, the estimate of μ at that point in the calculation is of interest, especially so if the extrapolation was effective as indicated by subsequent values of ε_n being considerably smaller than before extrapolation. In applying Eq. (720-13), the largest eigenvalue of the iterative process should be used, not a smaller one associated with the dominating error contribution at any stage of the calculation, nor any unusually large estimate of it. Note that we recommend use of the factor ε_n, which makes a primary contribution in Eq. (720-13), as the primary user control for termination of the iterative process. Tests on the iterate estimates of the eigenvalue of the problem (the multiplication factor or search problem eigenvalue) are unreliable at best, especially when acceleration schemes are used.

END OF SECTION

Section 721: Perturbation

Discussion

The equations used to estimate the effect of small changes are discussed here. First order perturbation theory is applied which is precise only in the limit of zero change. The adjoint flux is used which requires solution of this special problem. The fact that finite-difference equations must be dealt with rather than a continuum introduces complexity.

The following discussion contains an introduction cast in simple terms. This is intended to help the reader who desires to understand the subject from a practical standpoint. Then the actual equations used in the code are presented. A theoretical analysis has been presented.[a]

Consider a neutron balance associated with the finite-difference volume about a mesh point for a one-energy-group, one-dimensional slab geometry problem. With usual terminology,

Source = Removal + Leakage, or

$$\frac{1}{k}\,\nu\Sigma_{f,i}\,V_i\,\phi_i = \Sigma_i V_i \phi_i + D_i A_i \left[\left(\frac{\phi_i - \phi_{i-1}}{\Delta_{i/2}}\right) + \left(\frac{\phi_i - \phi_{i+1}}{\Delta_{i+1/2}}\right)\right] , \qquad (721\text{-}1)$$

where i refers to a location, V refers to volume, A to the leakage surface, and Δ to mesh spacing. Let $\Delta_{i+1} = \Delta_i$.

A change in the nuclear properties would change the flux distribution and also the multiplication factor. Let us neglect the change in flux and consider the partial derivative of terms of Eq. 721-1 with respect to Σ_i. This operation gives

$$\nu\,\Sigma_{f,i}\,V_i\,\phi_i\,\frac{\partial\left(\frac{1}{k}\right)}{\partial\,\Sigma_i} = V_i\,\phi_i \quad .$$

Considering change in Σ_i only at certain points within some material m and summing equations gives

$$\frac{\partial\left(\frac{1}{k}\right)}{\partial\,\Sigma_m}\sum_i \nu\,\Sigma_{f,i}\,V_i\,\phi_i = \sum_{i\epsilon m} V_i\phi_i \quad .$$

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[a] Melvin Tobias, T. B. Fowler and D. R. Vondy, "First-Order Perturbation Theory as used in the Multigroup Diffusion Code EXTERMINATOR-2," USAEC Report, ORNL-TM-1741 (January 1967).

Since $$\partial\left(\frac{1}{k}\right) = -\frac{1}{k^2}\,\partial k \quad ,$$

$$\frac{1}{k}\frac{\partial k}{\partial \Sigma_m} = \frac{-\sum\limits_{i\epsilon m} V_i\,\phi_i}{\frac{1}{k}\sum\limits_i \nu\,\Sigma_{f,i}\,V_i\,\phi_i} \quad .$$

If we simply accept that Eq. 721-1 may be multiplied through by a weighting factor, namely the adjoint flux, ϕ_i^*, which will cause both $\phi_i\phi_i^*$ and the flux slope in the leakage terms to be invariant, increasing the accuracy, then the result becomes

$$\frac{1}{k}\frac{\partial k}{\partial \Sigma_m} = \frac{-\sum\limits_{i\epsilon m} V_i\,\phi_i\phi_i^*}{\frac{1}{k}\sum\limits_i \nu\,\Sigma_{f,i}\,V_i\,\phi_i\,\phi_i^*} \quad . \tag{721-2}$$

This expresses the change in the multiplication factor associated with a unit change in the cross section. Similarly

$$\frac{1}{k}\frac{\partial k}{\partial D_m} = \frac{-\sum\limits_{i\epsilon m} \frac{2\,A_i}{\Delta_i}\left[(\phi_i - \phi_{i-1}) + (\phi_i - \phi_{i-1})\right]\phi_i^*}{\frac{1}{k}\sum\limits_i \nu\,\Sigma_{f,i}\,V_i\,\phi_i\,\phi_i^*} \quad . \tag{721-3}$$

Also,

$$\frac{1}{k}\frac{\partial k}{\partial(\nu\,\Sigma_{f,m})} = \frac{-\sum\limits_{i\epsilon m} V_i\,\phi_i\,\phi_i^*}{\sum\limits_i \nu\,\Sigma_{f,i}\,V_i\,\phi_i\,\phi_i^*} \quad , \tag{721-4}$$

where the region of interest m must be for $\nu\,\Sigma_{f,i} \neq 0$. Complications associated with material interfaces have been avoided here, and the equations must be extended to consider more than one group and other dimensions, and to treat the trans-group scattering.

Once the changes due to changes in macroscopic cross sections have been determined, the effects of nuclide density changes may be obtained, but not in the VENTURE code. Adding contributions gives

$$\frac{\partial k}{\partial N_b} = \sum_m \left\{ \left[\sum_j \frac{\partial k}{\partial \Sigma_{j,m}} \frac{d\,\Sigma_{j,m}}{d\,N_{b,m}} \right] + \frac{\partial k}{\partial D_m} \frac{d\,D_m}{d\,N_{b,m}} + \frac{\partial k}{\partial(\nu\,\Sigma_{f,m})} \frac{d\,(\nu\,\Sigma_{f,m})}{dN_{b,m}} \right\} , \qquad (721\text{-}5)$$

where $N_{b,m}$ is the density of a nuclide in region m and index j is over appropriate cross sections.

Since
$$\Sigma_{j,m} = \sum_b N_{b,m}\,\sigma_{j,b,m} , \quad \frac{d\,\Sigma_{j,m}}{d\,N_{b,m}} = \sigma_{j,b,m} ;$$

$$D_m = \frac{1}{\sum_b 3\,N_{b,m}\,\sigma_{tr,b,m}} , \quad \frac{d\,D_m}{d\,N_{b,m}} = -\,3D_m^2\,\sigma_{tr,b,m};$$

$$\nu\,\Sigma_{f,m} = \sum_b N_{b,m}\,\nu\,\sigma_{f,b,m}, \quad \frac{d\,(\nu\,\Sigma_{f,m})}{d\,N_{b,m}} = \nu\,\sigma_{f,b,m} ;$$

$$\frac{\partial k}{k\partial N_b} = \sum_m \left\{ \left[\sum_j \left(\frac{\partial k}{k\partial \Sigma_{j,m}}\right) \sigma_{j,b,m} \right] + \left(\frac{\partial k}{k\partial D_m}\right)\left(-\,3\,D_m\,\sigma_{tr,b,m}\right) + \left[\frac{\partial k}{k\partial(\nu\,\Sigma_{f,m})}\right] \nu\,\sigma_{f,b,m} \right\} . \qquad (721\text{-}6)$$

This does assume consistent treatment over the individual zones of material. The estimate of the effect of an actual change, decreasing in accuracy as the amount of change increases, is then $\frac{\Delta k}{k\Delta N_b} \simeq \frac{\partial k}{k\partial N_b}$. (721-7)

The Perturbation Equations

Within region m, the change in multiplication factor relative to change in a macroscopic property is calculated as

$$\frac{\partial k}{k \partial X_{m,n}} = \frac{\sum_{i \varepsilon m} G_i(n)}{\frac{1}{k}\sum_i V_i \sum_g \chi(m,g)\ \sigma^*_{i,g} \sum_n \nu\ \Sigma_{f,n}\ \phi_{i,n}} \quad , \tag{721-8}$$

where $X_{m,n}$ refers to a macroscopic property in region m,i refers to a space point in geometric space and g and n to energy groups. G_i is defined below. It is assumed in this discussion that $\sum_g \chi(m,g) = 1$.

$X = \Sigma_a(n),\ \Sigma_r(n) = \sum_g \Sigma(n \to g)$, or $D(n)B^2(n)$

$$- G_i\ (n) = V_i\ \phi_{i,n}\ \phi^*_{i,n} \tag{721-9}$$

$X = \Sigma(g \to n)$

$$G_i(n) = V_i\ \phi_{i,g}\ \phi^*_{i,n} \tag{721-10}$$

$X = D(n)$

$$G_i(n) = \sum_j A_j \begin{cases} \left[\frac{1}{\Delta_i + \Delta_j}\right] \phi^*_{i,n} \left[\phi_{i,n} - \phi_{j,n}\right] \text{ , internal,} \\ \frac{1}{\Delta_i}\left[\frac{1}{1 + \frac{\Delta_j\ D_i(n)}{\Delta_i\ D_j(n)}}\right]^2 \left[\phi^*_{i,n} - \phi^*_{j,n}\right]\left[\phi_{i,n} - \phi_{j,n}\right] \text{ , at} \\ \text{material interfaces, or} \\ \frac{1}{\Delta_i}\left[\frac{1}{1 - \frac{D_i(n)}{\Delta_i C_s(n)}}\right] \phi^*_{i,n}\ \phi_{i,n} \text{ , adjacent to} \\ \text{any black boundary.} \end{cases} \tag{721-11}$$

Here j refers to each of the nearest neighboring mesh points, A_j is the normal leakage area, and Δ_i is the distance from a point to the appropriate interface between mesh points. $C_s(n)$ is the internal or external black boundary constant (see section 702). At reflecting boundaries there is zero contribution.

$\underline{X = \nu\ \Sigma_f(n)}$

$$G_i(n) = \frac{V_i}{k}\ \phi_{i,n} \sum_g X(m,g)\ \phi^*_{i,g} \quad . \tag{721-12}$$

Calculation of a temperature or power coefficient of reactivity would be done directly from the partial derivatives discussed above using additional data,

$$\frac{\partial k}{\partial P} = \sum_\ell \left[\frac{\partial k}{\partial X_\ell}\right] \frac{dX_\ell}{dP} \quad ,$$

where X_ℓ refers to each contributing macroscopic property including cross sections and diffusion constants. To consider the general situation, discrete changes would have to be considered. Thus resonance calculations may be done at two temperatures representing some desired change, and the generated microscopic data used in the form:

$$\frac{1}{k}\frac{\partial k}{\partial P} = \sum_\ell \frac{\partial k}{\partial X_\ell}\left[X_\ell(P_1) - X_\ell(P_2)\right] \quad , \tag{721-13}$$

where $X_\ell(P_1)$ refers to a macroscopic cross section determined from initial nuclide densities and the originally specified microscopic cross sections; $X_\ell(P_2)$ refers to the altered value due to specified changes in nuclide densities and new microscopic data.

Importance maps over space may be obtained. "Importance" is used here to mean the contribution to the multiplication factor per unit volume from some factor, namely

$$I_i\ (c) = \frac{\sum_{\ell} X_{\ell,i}\ (c)\ \phi_i\ \phi_i^*}{\frac{1}{k}\sum_i \nu\ \Sigma_{f,i}\ V_i\ \phi_i\ \phi_i^*}\ , \qquad (721\text{-}14)$$

for the one-group situation treated above, where i represents a mesh point location and the contribution from component c to the macroscopic cross section X on a unit volume basis is shown to be given the flux times adjoint weighting.

Prompt Neutron Lifetime

For the estimate of the prompt neutron lifetime, the weighting is of reciprocal neutron velocity, Eq. 721-15 applies

$$\ell = \frac{\sum_n \sum_i \frac{V_i}{v(n)}\ \phi_{i,n}^*\ \phi_{i,n}}{\frac{1}{K}\sum_i V_i \sum_g \chi(m,g)\ \phi_{i,g}^* \sum_n \nu\ \Sigma_{f,n}\ \phi_{i,n}} \qquad (721\text{-}15)$$

Results Produced

Given forward and adjoint flux solutions, the derivatives of k with respect to each macroscopic (zone) cross section are calculated and edited, Eqs. 721-9 through 721-12 above. No calculations are done which require reaccess of microscopic data or nuclide concentrations. The basic zone integrals, $V_i \phi_i \phi_i^*$, are written on an interface data file for further use. On option, pointwise importance maps are edited of $V\Sigma_f$, Σ_a, and $V\Sigma_f - \Sigma_a$.

To produce additional information at the macroscopic cross-section level, the effects of relative changes in the cross sections are calculated. Consider

$$\Delta k = \sum \frac{\partial k}{\partial \Sigma}\ (f\Sigma) = f \sum \frac{\partial k}{\partial \Sigma}\ (\Sigma) \qquad (721\text{-}16)$$

where f represents a fractional change, set to unity for the calculations (100% change). The contributions to Δk are determined for neutron production, absorption, scattering and transport and the total for the common value of f unity. These results are edited by option to reflect energy, zone dependence, summed over zones to yield energy dependence, summed over energy to yield zone dependence, and totals are generated.

Additional information is produced to indicate the effect of uncertainties at the macroscopic cross-section level. Consider that in an uncertainty sense,

$$\delta k = \left\{ \sum \left[\frac{\partial k}{\partial \Sigma} (f\Sigma) \right]^2 \right\}^{\frac{1}{2}} = f \left\{ \sum \left[\frac{\partial k}{\partial \Sigma} (\Sigma) \right]^2 \right\}^{\frac{1}{2}} \qquad (721\text{-}17)$$

and again f is set at unity. The results are obtained for individual contributions, summed over zones, energy, zones and energy, and individual components added, by user option.

Conclusion and Glossary

We expect this code block and its documentation to improve with time. Feed-back of information from analysts applying the procedures to general situations and quite special problems allows upgrading the capability; it also permits the documentation to be improved, removal of errors and inconsistencies and expansion of the coverage to further address and clarify troublesome areas. Keep us posted!

The capability contained in the VENTURE code block is a direct reflection of experience in nuclear reactor analysis and the requirements found over a period of years at ORNL. Several analysts have made direct contributions. Methods in use have undergone a continuing improvement which has been in part a trial-and-error process, but also benefitted from the direct contributions of several individuals, and we particularly acknowledge those of M. L. Tobias.

A glossary follows which is intended to convey an intended meaning of certain terms used in this report.

Glossary

Absolute Convergence. The difference between an estimated or iterate value of dependent variable and its value at solution divided by the latter, giving a direct error measure.

Acceleration. The iterate estimate of the flux values are driven in some manner toward an apparent solution.

Adjoint Solution. As opposed to the direct, forward or normal solution of the differential equations expressing a neutron balance, these equations are recast in the true adjoint form appropriate to perturbation theory (matrix elements are transposed about the main diagonal).

Blunder. That which produced an error, more often having human source than machine.

Convergence Criterion. The specified maximum relative change between iterations of a dependent variable used to terminate an interative process.

Convergence Level (Relative Convergence Level). The relative change from one iteration to the next of the iterate value of a dependent variable, generally the maximum of a set when several variables are involved such as point flux, is termed the convergence level.

Convergence Rate Plot. A graph of the logarithm of the convergence level as dependent on iteration number, which is asymptotically linear for a wide variety of problems as a solution is approached but fluctuates about some value when further resolution is not possible due to limited signficant figures carried in digital calculations.

Discrete Formulation. A differential and/or integral equation involving continuous functions is recast into a finite-difference representation by discretization of some or all of the independent variables. Thus the neutron population is divided into groups, each associated with an energy range over which there is no energy dependence.

Direct Search. The search eigenvalue problem is iterated directly toward a desired solution without using the conventional approach of solving each of a series of problems for the multiplication factor.

Eigenvalue. Root of the determinate of a matrix, often used as the most positive root. Given a set of N equations for N unknown neutron flux values, there remains one unknown in a multiplying system; this unknown multiplication factor is termed the eigenvalue of the problem and an additional equation must be used to supply a complete set of equations.

Extrapolation. This term is reserved herein to mean that occasionally a complete iterate set of flux values are driven to a new extrapolated set for use in the next iteration; driving is generally in the direction of the individual changes between the last two iterations and is based on the iterative behavior over three or more previous iterations.

Fission Source Distribution Function. In the discrete, multi-energy-group representation, neutrons produced from the fission reactions at one geometric location are summed and the total is then distributed in energy by this distributon function.

Flux. Neutron flux is neutron density times speed. Since flux times cross section gives reaction rate, flux is total track length per unit volume.

Foot-Draggers Disease. This expression is reserved for the situation where either a poor arrangment of the terms in equations or the ordered sweep of the equations causes slow rate of convergence (per Tobias).

Inner-Iteration. Several sweeps are made of only part of the whole problem, generally over geometric space at one energy; the process is continued until a set number of inner-iterations on this partitioned iterative problem is reached, at which time the calculation proceeds to the next partitioned problem for iteration. Only after a complete

sweep has been made of all the space-energy mesh points is an outer-iteration completed and a new estimate made of the eigenvalue of the problem for use in the next sweep.

Line Relaxation. The equations for the flux values along a row of points at one energy are solved simultaneously (a forward-backward sweep to solve a tri-diagonal matrix with simple coupling); source terms are held fixed as are flux values along adjacent rows.

Material. A material is considered to be homogeneous and have nuclear properties which are proportional to individual nuclide densities and additive in the usual sense. See Zone.

Outer-Iteration. A complete sweep of the mesh points; that is, the equations for each unknown flux value have been solved, individually, at least once (more than once with inner-iteration).

Overrelaxation. The newly calculated value of each dependent variable is driven in the direction of the change between iterations to accelerate the iterative process, and these overrelaxed, iterate values of the flux are used at latest values during an inner- or outer-iteration.

Predominant Error Mode. Contributions to the error in iterate flux estimate are dominated by one or two error vectors, usually those having the largest eigenvalues. Contributions from the others have decayed and therefore have but little influence on the changes in point flux values with iteration; they tend to move in a single mode.

Production Cross Section. This is used to mean the product of the cross section for fission and the number of neutrons produced by the fission reaction, either in a macroscopic or a microscopic sense, e.g., $\nu \Sigma_f = \nu (\Sigma_f)$.

Rate of Convergence. A measure of the rate of approach to a solution: often the reciprocal of the number of iterations (computer mesh sweeps) required to reduce the relative flux change by a factor of e or to reduce the absolute error by a factor of e.

Region. A volume containing mesh points which are located at the geometric centroids of finite-difference volume elements of equal volume.

Removal Cross Section (Σ_t). This is used as the sum of all cross sections for removal of neutrons from the energy of interest including absorption (sink) and out-of-energy scatter.

Residue. The equation used for solution of an unknown (point neutron balance) is rearranged with all terms on one side and the result obtained by use of current iterate estimates of the unknowns is called here the residue of the equation for the iterate set. Weighting is arbitrarily on true volumetric reactions.

Slab Geometry. This refers to the cartesian coordinate system with orthogonal axes (one-dimensional slab geometry has symmetry in two dimensions as would be the situation if conditions were uniform over all space in these dimensions).

Time, Machine. The machine time reported to resolve a problem by iteration is the total time required for the calculation but generally excludes that for auxiliary operations of reading data, setting up the problems, and processing results. Both the amount of time the central processer is active and the total (clock) time are measured.

Zone. A volume, consisting of one or more Regions, within which macroscopic nuclear properties are constant. A zone may contain material (have nuclide concentrations) and additionally contain one or more subzones of material having specified volumes (each having nuclide concentrations).

Appendix A: CROSS-SECTION PROCESSOR CODE BLOCK

Presented herein is primary documentation of a code block designed to process microscopic cross-section data. For example, it will convert a nuclide-ordered ISOTXS file to a group-ordered GRUPXS file as would usually be required before the VENTURE neutronics code could be used. Locally we call this code block CasSandraPiC. The following items are covered:

A1. Code Block Specifications

A2. Tasks Performed and Order of Performance

A3. Computer Requirements

A4. Use of Logical Data Storage Units and Interface Files

A5. Code Structure and Subroutine Referencing

A6. File Specifications, VERSION-III for cross sections excluding an extended blocking of the principal cross sections in GRUPXS, and the special code block dependent interface file CXSPRR

Code Block Specification

Code Block - Broad Group Microscopic Cross Section Processor

Basic Functions -

1. Convert a microscopic library order by nuclide to a microscopic library ordered by group — going from one standard interface format to another. As an option, a second nuclide-ordered library consistent with the group-ordered file may be generated.

2. Provides selectivity to eliminate extraneous data.

3. Provides flexibility to collect data for isotopes or other mixtures as desired.

4. Provides for adding libraries (files) together, as well as selecting data from two or more nuclide-ordered files.

(not done) 5. Provides for basic integrals (reaction rates) over energy of principal cross sections to test data.

6. Provides for condensation of such data as $\chi\nu\sigma_f(g \rightarrow g')$ for simple treatment.

7. Provides for user input of data to override that in the library in short, select data blocks as well as full data for additional nuclides.

8. Provides at least elementary capability for converting data from old formats.

Energy Groups - 1 to 1,000, but fully variably dimensioned.

Nuclides - 1 to 500, but fully variably dimensioned.

Legendre Order - Provision through order 20.

Library Protection and Recovery

Care and some sacrifice in efficiency is to be taken to protect libraries. Reasonable tests are to be made to insure integrity of data. Full recovery is normally possible when old libraries are preserved and the nature of failure is made known. Even the possibility of misunderstanding of procedures on the part of the production user is to be taken into account.

Edits - Not under user option:

1. Description of what was done by the code block when accessed, and associated data storage use.

2. Integrals over energy (reaction rates) when these calculations are requested.

Under user option:

Full edits of final interface data files.

Special Input Data Requirements - See interface file CONTRL, record XCPINS (Section 204):

1. Control options for selection of procedures and data file handling.

2. Edit control.

3. Input data control.

4. Select data to override that in the library.

5. Nuclide data for adding to the library.

6. A broad-group neutron flux spectrum for integrals and for condensing such data as $\chi\nu\sigma_f(g\rightarrow g')$.

Data Conversion -

Initially only simple CITATION cross-section data, elementary 1DX,[a] and basic LASL S_n[a] forms of data are to be converted to the nuclide-ordered standard interface data file as needed at several installations to support methods development effort.

Programming Note -

It is noted that direct-access techniques must be used to permit efficient data processing.

Interface Data Files -

Used	Generated
ISOTXS	GRUPXS (ISOTXS)

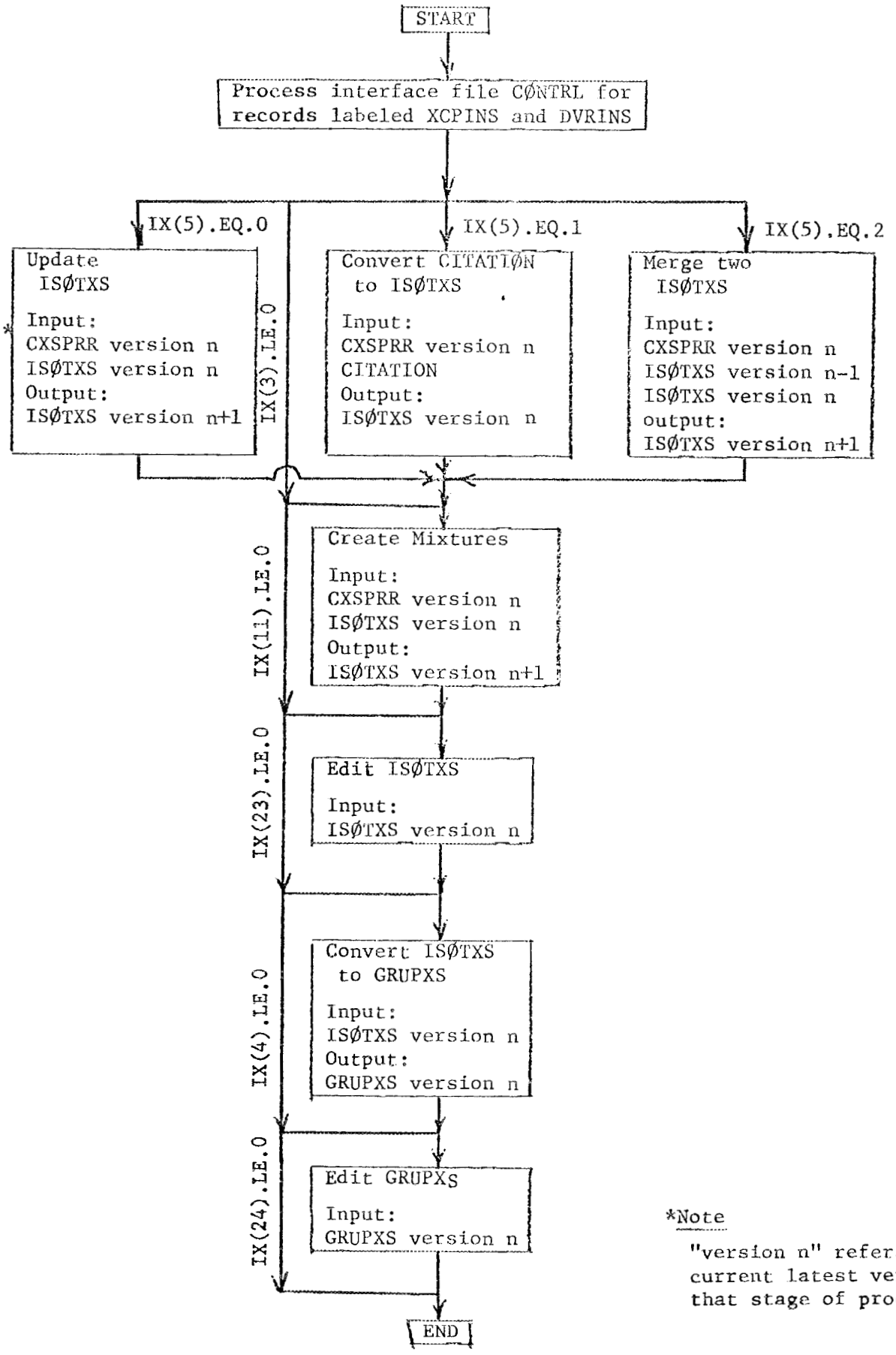
[a]Not done.

Tasks Performed

A primary function of the code is to convert a nuclide-ordered cross-section interface file (ISOTXS) to a group-ordered cross-section interface file (GRUPXS).

Additional functions include creating a nuclide-ordered file from the ORNL CITATION code cross-section format, updating an existing nuclide-ordered file, or merging two existing nuclide-ordered files. Each of these functions may, on option, eliminate selected nuclides or replace certain data (for example, Hollerith names) for a nuclide.

The capability for creating nuclide mixtures is also available. It is possible to generate a complete set of macroscopic data in the nuclide-ordered format. Any nuclide used in a mixture will be excluded from the resulting interface file.



*Note

"version n" refers to the current latest version at that stage of processing.

Computer Requirements

The requirements of this code on an IBM-360/370 machine are given here.

Allocation to	Core Storage (4-byte words) Without Overlay	With Overlay
Program	33K	14K
System Routines	7K	7K
Data	10K	10K
Typical Buffers	9K	9K
Total	59K	40K

Use of Logical Data Storage Units and Interface Files

The use of logical units and interface files for each task is presented here. Unit numbers shown are for stand-alone operation as implemented.

Always Required

ITRL (A)	CØNTRL	10 (stand-alone unit, typical)

ISØTXS to ISØTXS (Update)

IØUT	standard output	6
ICXS (A)	CXSPRR	30
ICIT (A)	input ISØTXS	32
ISØT (B)	output ISØTXS	34
ISCR	scratch	45

CITATIØN to ISØTXS (Create)

IØUT	standard output	6
ICXS (A)	CXSPRR	30
ICIT	CITATIØN	8
ISØT (D)	output ISØTXS	32
ISCR	scratch	45

ISØTXS + ISØTXS to ISØTXS (Merge)

IØUT	standard output	6
ICXS (A)	CXSPRR	30
ICIT (C)	primary input ISØTXS	31
IØTH (A)	secondary input ISØTXS	32
ISØT (B)	output ISØTXS	34
ISCR	scratch	45

ISØTXS to ISØTXS (Create Mixtures)

IØUT	standard output	6
ICXS (A)	CXSPRR	30
ICIT (A)	input ISØTXS	32 or 34
ISØT (B)	output ISØTXS	34 or 35
ISCR	scratch	45
ISC2	scratch	46
IDA3	scratch (direct access)	23

EDIT ISØTXS

IØUT	standard output	6
ISØT (A)	ISOTXS	32 or 34 or 35

ISØTXS to GRUPXS

IØUT	standard output	6
ISØT (A)	ISØTXS	32 or 34 or 35
IGRU (D)	GRUPXS	11
ISCR	scratch	45
IDA1	scratch (direct access)	27
IDA2	scratch (direct access)	24

EDIT GRUPXS

IØUT	standard output	6
IGRU (A)	GRUPXS	11

Notes:

(A) Asks SEEK for latest version to read.

(B) Asks SEEK for a new version to write.

(C) Asks SEEK for the next to the latest version to read.

(D) Asks SEEK for the latest version to write, if none available, asks SEEK for a new version to write.

INFORMATION ABOUT SUBROUTINES

```
C*********************************************************************
C
C     CROSS SECTION PROCESSOR SUBROUTINE CROSS-REFERENCING
C
C  SUBROUTINE ****************  CALLED SUBROUTINE  *********************
C
C     CHOL
C     CTI1     CTI2     CTI3     REED     SEEK
C     CTI2     CHOL     HCHK     ISTR     REED     RITE     RSTI
C     CTI3     REED
C     GXS1     GXS2     REED     SEEK
C     GXS2     REED     XLEI
C     HCHK
C     ITI1     ITI2     REED     SEEK
C     ITI2     HCHK     ISTR     NPCR     REED     RITE     RSTI
C     IXS1     IXS2     REED     SEEK
C     IXS2     ISTR     REED     XLEI
C     MAIN     DOPC     XSCI     XSCU
C     MIXC     REED
C     MIX1     MIX2     REED     SEEK
C     MIX2     DOPC     HCHK     ISTR     MIXC     MIX3     MIX4     MIX5
C              NPCR     REED     RITE     XORD
C     MIX3     ISTR     NPCR     REED     RITE     RSTI     XORD
C     MIX4     ISTR     REED     RITE     RSTI
C     MIX5     NPCR     REED     RITE     STOR     XORD
C     M2I1     M2I2     REED     SEEK
C     M2I2     HCHK     ISTR     NPCR     REED     RITE     RSTI
C     NPCR
C     TRLR     CTI1     GXS1     ITI1     IXS1     MIX1     M2I1     XSC1
C     XLEI
C     XORD
C     XSCI     FERR     REED     SEEK     SKER
C     XSCU     DOPC     ROXX     ROXY     TRLR     FRECOR   GETCOR
C     XSC1     DOPC     REED     SEEK     XSC2
C     XSC2     REED     RITE     RSTI     STOR     XORD     XSC3     XSC4
C              XSC5
C     XSC3     ISTR     REED     RITE
C     XSC4     HCHK     REED     RITE     XORD
C     XSC5     ISTR     REED     RITE     RSTI
C
C*********************************************************************

C*********************************************************************
C
C     CROSS SECTION PROCESSOR SUBROUTINE CROSS-REFERENCING
C
C  SUBROUTINE **************  CALLED FROM SUBROUTINE  ****************
C
C     CHOL     CTI2
C     CTI1     TRLR
C     CTI2     CTI1
C     CTI3     CTI1
```

(CONT)

```
C     DOPC     MAIN     MIX2     XSCU     XSC1
C     FEEB     XSCI
C     FRECOR   XSCU
C     GETCOR   XSCU
C     GXS1     TRIB
C     GXS2     GXS1
C     HCEK     CTI2     ITI2     MIX2     M2I2     XSC4
C     ISTB     CTI2     ITI2     IXS2     MIX2     MIX3     MIX4     M2I2
C              XSC3     XSC5
C     ITI1     TRIB
C     ITI2     ITI1
C     IXS1     TRIB
C     IXS2     IXS1
C     MAIN
C     MIXC     MIX2
C     MIX1     TRIB
C     MIX2     MIX1
C     MIX3     MIX2
C     MIX4     MIX2
C     MIX5     MIX2
C     M2I1     TRIB
C     M2I2     M2I1
C     NPCR     ITI2     MIX2     MIX3     MIX5     M2I2
C     REED     CTI1     CTI2     CTI3     GXS1     GXS2     ITI1     ITI2
C              IXS1     IXS2     MIXC     MIX1     MIX2     MIX3     MIX4
C              MIX5     M2I1     M2I2     XSCI     XSC1     XSC2     XSC3
C              XSC4     XSC5
C     RITE     CTI2     ITI2     MIX2     MIX3     MIX4     MIX5     M2I2
C              XSC2     XSC3     XSC4     XSC5
C     ROXX     XSCU
C     ROXY     XSCU
C     RSTI     CTI2     ITI2     MIX3     MIX4     M2I2     XSC2     XSC5
C     SEEK     CTI1     GXS1     ITI1     IXS1     MIX1     M2I1     XSCI
C              XSC1
C     SKER     XSCI
C     STCR     MIX5     XSC2
C     TRIB     XSCU
C     XLEI     GXS2     IXS2
C     XORD     MIX2     MIX3     MIX5     XSC2     XSC4
C     XSCI     MAIN
C     XSCU     MAIN
C     XSC1     TRIB
C     XSC2     XSC1
C     XSC3     XSC2
C     XSC4     XSC2
C     XSC5     XSC2
C*****************************************************************
```

```
C*********************************************************************
C
C     SIMPLE OVERLAY STRUCTURE FOR CROSS SECTION PROCESSOR
C
C                              MAIN
C                              XSCI
C                              XSCU
C                              TRIB
C                              HCBK
C                              NPCR
C                              XORD
C                              XLEI
C                              DOPC(BOXY)        LIBRARY
C                              RITE(BEED,BOXX)   LIBRARY
C                              SEEK              LIBRARY
C                              STOR              LIBRARY
C                              ISTR              LIBRARY
C                              RSTI              LIBRARY
C                              SKER              LIBRARY
C                              FEER              LIBRARY
C                              GETCOR            LIBRARY
C                              FRECOR            LIBRARY
C                              DEFILE            LIBRARY
C                              CLOSDA            LIBRARY
C                               *
C                               *
C      ***********************************************
C      *       *       *       *       *       *       *
C     ITI1    CTI1    M2I1    MIX1    IXS1    XSC1    GXS1
C     ITI2    CTI2    M2I2    MIX2    IXS2    XSC2    GXS2
C             CTI3            MIX3            XSC3
C             CHCI            MIXC            XSC4
C                             MIX4            XSC5
C                             MIX5
C*********************************************************************
C*********************************************************************
C     NON-STANDARD SUBROUTINE USAGE IN CROSS SECTION PROCESSOR
C
C     DEFILE        (CALLED FROM DOPC) ASSEMBLER LANGUAGE ROUTINE
C                   USED TO OPEN DIRECT ACCESS FILES - REPLACES THE
C                   IBM DEFINE FILE STATEMENT
C     CLOSDA        (CALLED FROM DOPC) ASSEMBLER LANGUAGE ROUTINE
C                   USED TO CLOSE DIRECT ACCESS FILES OPENED
C                   WITH DEFIIF
C     GETCOR/FRECOR(CALLED FROM XSCU) ASSEMBLER LANGUAGE ROUTINES
C                   USED TO DYNAMICALLY ALLOCATE AND RELEASE MAIN
C                   CORE STORAGE
C     CHCL          (CALLED FROM CTI2) NON-STANDARD FORTRAN ROUTINE
C                   USED TO CONVERT FOUR CHARACTER SINGLE PRECISION
C                   HOLLERITH WORDS TO SIX CHARACTER DOUBLE PRECISION
C                   HOLLERITH WORDS. USED ONLY IN CONVERSION OF
C                   CITATION CROSS SECTIONS TO ISOTXS
C
C*********************************************************************
```

(CONT)

INTERFACE DATA FILE SPECIFICATIONS

```
C*********************************************************************
C                        PREPARED 10/18/73                            -
C                                                                     -
CF          CXSPFB                                                    -
CE          DATA FOR CROSS SECTION PROCESSOR                          -
C                                                                     -
CN          SEE INTERFACE FILE CONTROL, RECORD XCFINS, FOR REFERENCES -
CN          TO ARRAY IX                                               -
C                                                                     -
C*********************************************************************

C---------------------------------------------------------------------
CS          FILE STRUCTURE                                            -
CS                                                                    -
CS             RECORD TYPE                          PRESENT IF        -
CS             ==========================           ==============    -
CS             FILE IDENTIFICATION                  ALWAYS            -
CS             FILE CONTROL                         ALWAYS            -
CS             CITATION SET NUMBERS                 NCF(1) GT 0       -
CS             NEUTRON ENERGY SPECTRUM              NOP(3) GT 0       -
CS             TRANSPORT MULTIPLIERS                NOP(4) GT 0       -
CS                                                                    -
CS          ******(REPEAT FROM 1 TO NOP(5))                           -
CS          *  ISOTOPE DATA                         NCF(5) GT 0       -
CS          ******                                                    -
CS                                                                    -
CS          ******(REPEAT FROM 1 TO NOP(6))                           -
CS          *  ISOTOPE NAMES IN MIXTURE             NOP(6) GT 0       -
CS          *  ISOTOPE DENSITIES IN MIXTURE         NCF(6) GT 0       -
CS          ******                                                    -
CS                                                                    -
CS          ******(REPEAT FROM 1 TO NOP(6))                           -
CS          *  MIXTURE DATA                         NCF(6) GT 0       -
CS          ******                                                    -
C                                                                     -
C---------------------------------------------------------------------

C---------------------------------------------------------------------
CR          FILE IDENTIFICATION                                       -
C                                                                     -
CI     HNAME,(HUSE(I),I=1,2),IVERS                                    -
C                                                                     -
CW     3*MUIT + 1                                                     -
C                                                                     -
CD     HNAME          HOLLERITH FILE NAME - CXSPRR - (A6)             -
CD     HUSE           HOLLERITH USER IDENTIFICATION (A6)              -
CD     IVERS          FILE VERSION NUMBER                             -
CD     MUIT           DOUBLE PRECISION PARAMETER                      -
CD                        1 - A6 WORD IS SINGLE WORD                  -
CD                        2 - A6 WORD IS DOUBLE PRECISION WORD        -
C                                                                     -
C---------------------------------------------------------------------
```

(CONT)

```
C-----------------------------------------------------------------------
CB          FILE CONTROL                                               -
C                                                                      -
CL    (NOP(I),I=1,24)                                                  -
C                                                                      -
CW    24                                                               -
C                                                                      -
CD    NOP(1)          NUMBER OF CITATION CROSS SECTION SETS TO PROCESS -
CD                        (IF NOP(1) EQ 0 AND IX(3) EQ 1 AND IX(5) EQ 1, -
CD                        SET ONE WILL BE PROCESSED)                   -
CD    NOP(2)          SCATTERING BLOCKING FACTOR FOR NUCLIDE-ORDERED   -
CD                        FILE CREATED FROM CITATION CROSS SECTIONS    -
CD                        0 - NSBLOK = 1                               -
CD                        N - NSBLOK = N, IF (NGROUP/N)*N EQ NGROUP,   -
CD                              OTHERWISE NSBLOK = 1                   -
CD    NOP(3)          OPTION TO INPUT A NEUTRON ENERGY SPECTRUM        -
CD                        0 - NO                                       -
CD                        N - YES (N SHOULD BE EQUAL TO THE NUMBER OF  -
CD                              ENERGY GROUPS ON THE CROSS SECTION FILE) -
CD    NOP(4)          OPTION TO CREATE PSEUDO DIRECTION DEPENDENT      -
CD                        TRANSPORT DATA                               -
CD                        0 - NO                                       -
CD                        1 - YES                                      -
CD    NOP(5)          OPTION TO INPUT OVERRIDE DATA FOR ISOTOPES       -
CD                        0 - NO                                       -
CD                        N - YES (N IS THE NUMBER OF RECORDS OF DATA) -
CD    NOP(6)          NUMBER OF MIXTURES (REQUIRED IF IX(11) EQ 1)     -
CD    NOP(7)          MAXIMUM NUMBER OF ISOTOPES IN ANY MIXTURE        -
CD                        (REQUIRED IF IX(11) EQ 1)                    -
CD    NOP(8-9)        RESERVED                                         -
CD    NOP(10)         OPTION ON USE OF THE OVERRIDE DATA FOR ISOTOPES  -
CD                        WHEN NOP(5) GT 0  (APPLICABLE ONLY WHEN      -
CD                        IX(3) EQ 1 AND IX(5) EQ 0)                   -
CD                        0 - DATA CORRESPONDS WITH THE ORDER OF       -
CD                              ISOTOPES IN THE FILE                   -
CD                        1 - DATA IDENTIFIES ISOTOPES TO BE SELECTED  -
CD                              BY UNIQUE ISOTOPE LABEL                -
CD    NOP(11-23)      RESERVED                                         -
CD    NOP(24)         OPTION ON EDIT DURING CITATION CROSS SECTION     -
CD                        PROCESSING                                   -
CD                        0 - NO                                       -
CD                        1 - YES                                      -
C                                                                      -
C-----------------------------------------------------------------------
```

```
C-----------------------------------------------------------------------
CR          CITATION CROSS SECTION SET NUMBERS                         -
C                                                                      -
CC          PRESENT IF NOP(1) GT 0                                     -
C                                                                      -
CL    (ISET(I),I=1,NOP1)                                               -
C                                                                      -
CW    NOP1 = NOP(1)                                                    -
C                                                                      -
CD    ISET          SET NUMBERS IN ASCENDING ORDER OF APPEARANCE       -
CD                      IN LIBRARY                                     -
C                                                                      -
C-----------------------------------------------------------------------

C-----------------------------------------------------------------------
CR          NEUTRON ENERGY SPECTRUM                                    -
C                                                                      -
CC          PRESENT IF NOP(3) GT 0                                     -
C                                                                      -
CL    (WGT(I),I=1,NOP3)                                                -
C                                                                      -
CW    NOP3 = NOP(3)                                                    -
C                                                                      -
CD    WGT           SPECTRUM FOR WEIGHTING IN MIXTURE CALCULATION      -
C                                                                      -
C-----------------------------------------------------------------------

C-----------------------------------------------------------------------
CR          MULTIPLIERS FOR TRANSPORT CROSS SECTION                    -
C                                                                      -
CC          PRESENT IF NOP(4) GT 0                                     -
C                                                                      -
CL    (TRMCD(I),I=1,3)                                                 -
C                                                                      -
CW    3                                                                -
C                                                                      -
CD    TRMCD         MULTIPLIER FOR EACH COORDINATE DIRECTION           -
CD                      STRED(I) = TRMCD(I)*STRPI(1) FOR EACH ENERGY   -
C                                                                      -
C-----------------------------------------------------------------------

C-----------------------------------------------------------------------
CR          ISOTOPE DATA                                               -
C                                                                      -
CC          PRESENT IF NOP(5) GT 0                                     -
CC          THERE MUST BE NOP(5) RECORDS                               -
C                                                                      -
CN          WHEN NOP(10) EQ 0,                                         -
CN          THIS DATA MAY BE USED WHEN IX(3) EQ 1 TO CONTROL THE       -
CN          PROCESSING OF THE INPUT CROSS SECTIONS. THE ORDER          -
CN          OF THESE RECORDS MUST BE ONE-TO-ONE WITH THE ORDER         -
CN          OF THE ISOTOPES IN THE INPUT CROSS SECTIONS. FOR EACH      -
CN          ISOTOPE READ FROM THE INPUT CROSS SECTIONS, ONE RECORD     -
CN          IS READ FROM THIS DATA                                     -
```

(CONT)

```
CN              A) IF HISCNM EQ 6HDELETE, THE DATA FOR THIS ISOTOPE      -
CN                 IS NOT WRITTEN ON THE NEW NUCLIDE-ORDERED FILE        -
CN              B) IF HISCNM NE 6HDELETE, THE DATA FOR THIS ISOTOPE      -
CN                 WILL BE COPIED TO THE NEW NUCLIDE-ORDERED FILE        -
CN                 (NON-BLANK OR NON-ZERO DATA WILL REPLACE THE          -
CN                 DATA ON THE NEW FILE)                                 -
CN              C) IF AFTER READING NOP(5) RECORDS, THERE ARE ISOTOPES   -
CN                 REMAINING IN THE INPUT CROSS SECTIONS, THOSE          -
CN                 REMAINING WILL BE DELETED FROM THE NEW FILE           -
CN                                                                       -
CN           WHEN NOP(10) EQ 1,                                          -
CN           THIS DATA MAY BE USED WHEN IX(3) EQ 1 AND IX(5) EQ 0 TO     -
CN           CONTROL THE CONTENT OF THE NEW ISOTXS FILE. THE ORDER       -
CN           OF THE RECORDS IS NOT SPECIFIED SINCE THE UNIQUE LABEL      -
CN           (HISONM) IS USED TO IDENTIFY ISOTOPES TO BE COPIED TO       -
CN           THE NEW FILE. NON-BLANK OR NON-ZERO VALUES FOR THE          -
CN           REST OF THE DATA WILL BE PUT ON THE NEW FILE.               -
CN           THE UNIQUE LABEL CAN NOT BE CHANGED WHEN USING THIS OPTION.-
CN                                                                       -
CN           IF THIS DATA IS NOT PRESENT, ALL ISOTOPES ON THE INPUT      -
CN           CROSS SECTIONS WILL BE COPIED TO THE NEW FILE               -
C                                                                        -
CL     HISONM,HABSID,HMAT,AMASS,EFISS,ECAPT,KBR,(IOP(I),I=1,3)           -
C                                                                        -
CW     3*MULT + 7                                                        -
C                                                                        -
CD     HISONM          HOLLERITH ISOTOPE LABEL (UNIQUE)   (A6)           -
CD     HABSID          HOLLERITH ISOTOPE LABEL (ABSOLUTE)   (A6)         -
CD     HMAT            HOLLERITH ISOTOPE LABEL (REFERENCE)   (A6)        -
CD     AMASS           GRAM ATOMIC WEIGHT                                -
CD     EFISS           TOTAL THERMAL ENERGY YIELD/FISSION (W.SEC/FISS)   -
CD     ECAPT           TOTAL THERMAL ENERGY YIELD/CAPTURE(N,GAMMA)       -
CD                         (W.SEC/CAPT)                                  -
CD     KBR             ISOTOPE CLASSIFICATION                            -
CD     IOP             RESERVED                                          -
C-----------------------------------------------------------------------

C-----------------------------------------------------------------------
CR           ISOTOPE NAMES IN MIXTURE                                    -
C                                                                        -
CC           PRESENT IF NOP(6) GT 0                                      -
CC           THIS RECORD AND THE RECORD FOLLOWING APPEAR IN PAIRS        -
CC           THERE MUST BE NOP(6) PAIRS                                  -
C                                                                        -
CL     (HISOMX(I),I=1,NOP7)                                              -
C                                                                        -
CW     MULT*NOP7 = MULT*NOP(7)                                           -
C                                                                        -
CD     HISOMX          UNIQUE NAME OF ISOTOPE TO BE INCLUDED IN MIXTURE  -
CD                         (BLANK NAMES ARE IGNORED)                     -
C                                                                        -
CN           ANY ISOTOPE INCLUDED IN A MIXTURE WILL BE DELETED FROM THE -
CN              NEW FILE                                                 -
C-----------------------------------------------------------------------
```

(CONT)

```
C-----------------------------------------------------------------------
CR          ISOTOPE DENSITIES IN MIXTURE                               -
C                                                                      -
CC          PRESENT IF NOP(6) GT 0                                     -
C                                                                      -
CL     (RDENS(I),I=1,NOP7)                                             -
C                                                                      -
CW     NOP7 = NOP(7)                                                   -
C                                                                      -
CD     RDENS          DENSITY OF ISOTOPE TO BE INCLUDED IN MIXTURE    -
C-----------------------------------------------------------------------

C-----------------------------------------------------------------------
CR          MIXTURE DATA                                               -
C                                                                      -
CC          PRESENT IF NOP(6) GT 0                                     -
CC          THERE MUST BE NOP(6) RECORDS                               -
C                                                                      -
CL     HISONM,HABSID,HMAT,AMASS,EFISS,ECAPT,KBR,(IOP(I),I=1,3)         -
C                                                                      -
CW     3*MULT + 7                                                      -
C                                                                      -
CD     HISONM         HOLLERITH MIXTURE LABEL (UNIQUE)  (A6)          -
CD     HABSID         HOLLERITH MIXTURE LABEL (ABSOLUTE)  (A6)        -
CD     HMAT           HOLLERITH MIXTURE LABEL (REFERENCE)  (A6)       -
CD     AMASS          GRAM ATOMIC WEIGHT                              -
CD     EFISS          TOTAL THERMAL ENERGY YIELD/FISSION (W.SEC/FISS) -
CD     ECAPT          TOTAL THERMAL ENERGY YIELD/CAPTURE(N,GAMMA)     -
CD                        (W.SEC/CAPT)                                 -
CD     KBR            MIXTURE CLASSIFICATION                          -
CD     IOP            RESERVED                                        -
C                                                                      -
CN          NON-BLANK DATA SHOULD BE SUPPLIED FOR LABELS               -
CN          AND NON-ZERO DATA FOR KBR                                  -
CN          AMASS, EFISS, AND ECAPT ARE CALCULATED FOR MIXTURE BUT     -
CN          MAY BE REPLACED BY NON-ZERO ENTRIES                        -
C                                                                      -
C-----------------------------------------------------------------------

CEOF
```

END OF APPENDIX A

Appendix B: CODE BLOCK TO CALCULATE REACTION RATES, ETC.

This code block produces reaction rate integrals by nuclide, certain summary tables, and such auxiliary results as the primitive fuel conversion (breeding) ratio. It is compatible with the VENTURE code and operational locally as a separate module in the code system requiring less than 50K words total memory usually. File communication is compatible with VENTURE. Basic control parameters are indicated in the specifications for the CONTRL file in the body of this report.

It is intended that this code block perform a variety of tasks on demand, independent of the neutronics model applied, using cross sections and nuclide concentrations from the files used by the neutronics codes and flux data produced by neutronics codes, and perhaps generate a new interface data file. A preliminary list of the tasks follows, but only the first is implemented in this release version:

1. Calculate by zone (and sub-zone) average neutron, nuclide reaction rates and integrated summary tables using interface data files with user control over edit levels
    a. Using files NDXSRF, ZNATDN, RZFLUX and GRUPXS.
    b. Repeat with flux, adjoint weighting on option using file PERTUB.
2. Edit selected maps of individual reaction rates (traverse or on a plane)
3. Basic cross section collapse capability in energy and space
4. Basic pertrubation analysis capability considering nuclide concentration changes and/or microscopic cross section changes and weighting of delayed neutron data
5. Generation of a fixed source file, as of prompt or delayed neutron generation rate

The code structure and subroutine referencing start on page B1-1. The module should be simple to implement on a specific computer. An overlay structure will not be needed for this first release version.

INFORMATION ABOUT SUBROUTINES

```
C*********************************************************************
C
C     REACTION RATE MODULE SUBROUTINE CROSS-REFERENCING
C
C  SUBROUTINE ****************  CALLED SUBROUTINE  **********************
C
C     MAIN     DOPC     RRCI     RRDS
C     RRCI     FERR     REED     SEEK     SKER
C     RRDS     DOPC     ROXX     ROXY     RRT1     FRECOR   GETCOR
C     RRTA     REED     RITE
C     RRTB     REED     RITE
C     RRTC     REED     RITE
C     RRTD     REED
C     RRTE     RITE
C     RRTF
C     RRTG     REED     RITE
C     RRTH     REED
C     RRTI     REED     RITE
C     RRTJ     REED
C     RRTK     REED
C     RRTL
C     RRTM
C     RRTN
C     RRTO     REED
C     RRTP
C     RRTS     DOPC     FERR
C     RRTT     RITE
C     RRT1     FERR     REED     RRTA     RRTB     RRTC     RRTD     RRTE
C              RRTF     RRTG     RRTH     RRTI     RRTJ     RRTK     RRTL
C              RRT1     RRTN     RRTO     RRTP     RRTS     RRTT     RRT2
C              RRT3     RRT4     RRT5     RRT6     RRT7     RRT8     RRT9
C              SEEK     SKER     STOR
C     RRT2
C     RRT3     REED     RITE     SEEK     SKER
C     RRT4
C     RRT5
C     RRT6     REED     RITE
C     RRT7     REED     RITE
C     RRT8
C     RRT9     REED     RITE     SEEK     SKER
C
C*********************************************************************
```

(CONT)

```
C*********************************************************************
C
C     REACTION RATE MODULE SUBROUTINE CROSS-REFERENCING
C
C  SUBROUTINE **************  CALLED FROM SUBROUTINE  ******************
C
C     DOPC     MAIN     RRDS     RRTS
C     FERR     RRCI     RRTS     RRT1
C     FRECOR   RRDS
C     GETCOR   RRDS
C     REED     RRCI     RRTA     RRTB     RRTC     RRTD     RRTG     RRTH
C              RRTI     RRTJ     RRTK     RRTO     RRT1     RRT3     RRT6
C              RRT7     RRT9
C     RITE     RRTA     RRTB     RRTC     RRTE     RRTG     RRTI     RRTT
C              RRT3     RRT6     RRT7     RRT9
C     ROXX     RRDS
C     ROXY     RRDS
C     RRCI     MAIN
C     RRDS     MAIN
C     RRTA     RRT1
C     RRTB     RRT1
C     RRTC     RRT1
C     RRTD     RRT1
C     RRTE     RRT1
C     RRTF     RRT1
C     RRTG     RRT1
C     RRTH     RRT1
C     RRTI     RRT1
C     RRTJ     RRT1
C     RRTK     RRT1
C     RRTL     RRT1
C     RRTM     RRT1
C     RRTN     RRT1
C     RRTO     RRT1
C     RRTP     RRT1
C     RRTS     RRT1
C     RRTT     RRT1
C     RRT1     RRDS
C     RRT2     RRT1
C     RRT3     RRT1
C     RRT4     RRT1
C     RRT5     RRT1
C     RRT6     RRT1
C     RRT7     RRT1
C     RRT8     RRT1
C     RRT9     RRT1
C     SEEK     RRCI     RRT1     RRT3     RRT9
C     SKER     RRCI     RRT1     RRT3     RRT9
C     STOR     RRT1
C
C*********************************************************************
```

(CONT)

```
C*********************************************************************
C
C     SIMPLE OVERLAY STRUCTURE FOR REACTION RATE MODULE
C     MODULE MAY BE USED WITHOUT OVERLAY AT THIS TIME
C
C                              MAIN
C                              RRCI
C                              RRDS
C                              RRT1
C                              DOPC(BOXY)        LIBRARY
C                              RITE(BEEI,BOXX)   LIBRARY
C                              SEEK              LIBRARY
C                              STOR              LIBRARY
C                              SKER              LIBRARY
C                              FERR              LIBRARY
C                              GETCOR            LIBRARY
C                              FRECOR            LIBRARY
C                              DEFILE            LIBRARY
C                              CLOSDA            LIBRARY
C                               *
C                               *
C      ***************************************
C      *       *       *       *       *       *
C     RRT2    RRT3    RRTA    RRTG    RRTI    RRTO
C     RRT5    RRT9    RRTE    RRTH    RRTJ    RRTP
C     RRT7    RRTI    RRTC            RRT6
C     RRT4            RRTD            RRTK
C     RRTF            RRTF            RRTL
C     RRTS                            RRTM
C                                     RRTN
C                                     RRTR
C
C*********************************************************************

C*********************************************************************
C
C     NON-STANDARD SUBROUTINE USAGE IN REACTION RATE MODULE
C
C     DEFILE        (CALLED FROM DOPC) ASSEMBLER LANGUAGE ROUTINE
C                   USED TO OPEN DIRECT ACCESS FILES - REPLACES THE
C                   IBM DEFINE FILE STATEMENT
C     CLOSDA        (CALLED FROM DOPC) ASSEMBLER LANGUAGE ROUTINE
C                   USED TO CLOSE DIRECT ACCESS FILES OPENED
C                   WITH DEFILE
C     GETCOR/FRECOR(CALLED FROM RRDS) ASSEMBLER LANGUAGE ROUTINES
C                   USED TO DYNAMICALLY ALLOCATE AND RELEASE MAIN
C                   CORE STORAGE
C
C*********************************************************************
```

END OF APPENDIX B

Appendix C: LOCAL USE OF THE VENTURE AND RELATED CODES

The VENTURE code is structured as a module for use in a computation system along with other codes. Locally, a standard input processor, the cross section processing code (Appendix A), the reaction rate code (Appendix B), and special input data processors are used. Typically, microscopic cross section data must be converted from a nuclide ordered file, ISOTXS, to one in which the data is ordered by neutron group, GRUPXS, by the cross section processor. To produce such information as integral reaction rates by nuclide, the reaction rate module must be used.

For any implementation of the VENTURE code, some scheme of access must be used. A stand-alone version of selected code blocks can easily be implemented, although there would be obvious limitations, especially regarding extensions. A primary objective of this effort was to produce codes which could readily be introduced into a system for computation basically compatible with general inter-installation ground rules. Thus these codes do not read user input data upon access, rather files containing the necessary data and instructions must have been generated prior to the code access. Data interfacing between codes is through well-defined data files.

For production application locally, a driver code is used to access the code blocks as instructed by the user. This section of the documentation describes the code set and a simple driver used routinely and its input data requirements. Also discussed are detailed instructions on running VENTURE locally on the IBM-360/91 and IBM-360/195 computers. The driver routines are shown at the end of this Appendix in Table C-6.

The Code Set

BOLD VENTURE is the name of a partitioned data set for the IBM-360 computers which contain independent nuclear codes stored as separate load modules. Any of these may be brought into memory by a suitable driver and executed. The sequence of execution is limited only by data communication requirements. The scheme and form of user data input to the implemented

driver was chosen to allow general application of VENTURE and associated codes on a production basis, locally and via remote terminals. Additional code blocks are being phased into the set and the driver functions expanded to add sophistication and provide interface data file management capability.

Driver Input Instructions

Input to the driver consists of a Title card, an Option card, and Path cards specifying the order in which the various code members are to be executed. The contents of these cards are described here.

The Title Card (Format 12A6):

This is the run title card and is printed along with other edited output from each code accessed.

The Option Card (Format 9I6,6I3):

In the following description of each individual number, the card columns are shown in parenthesis following each name and any default values are shown in parenthesis following the description.

IP1(1-6)-Memory allocation of the primary container array for the variably dimensional data of each code, 4-byte words, (040000).

IP2(7-12)-Memory allocation of secondary container array (000000).

IP3(13-18)-Memory allocation of a tertiary container array (000000).

IP4(19-24)-Maximum block size for direct access data files, 4-byte words, (7200).

IP5(25-30)-Total computer central processor time allowed for the run (tested prior to any code access), minutes (5).

IP6(31-36)-

IP7(37-42)-

IP8(43-48)-

IP9(49-54)-

IP10(55-57)-

IP11(58-60)-Stand-alone flag

0-codes are accessed in a true modular code set environment, recommended.

1-codes are accessed as if each were a stand-alone code.

IP12(61-63)-

IP13(64-66)-If >0, the SEEK tables will be initilized prior to each access of the standard input processor code.

IP14(67-69)-Debug flag, if >0, the SEEK tables will be printed after each code access.

IP15(70-72)-

The Path Cards (Format 24I3):

Each code in the set is assigned an integer number and they are accessed by the driver in the order in which their identifying number appears on these cards. A maximum of 96 entries may be specified. This referencing, which must be known to the user, is assigned as follows:

1 - The standard input data processor [a] which generates the Standard Interface data files (see Section 204).

2 - Special processors discussed below.

6 - The cross section processor code.

7 - The VENTURE neutronics code.

9 - The reaction rate calculation code.

A blank entry signals the end of this data. For example, to instruct the driver to access the general input processor, the cross section code, VENTURE, and finally the reaction rate code, a card would be punched 1 6·7 9 0.

Special processors are allowed in the BOLD VENTURE code set. These codes may read user input in any format (described elsewhere) and write various standard interface files for use by the other codes. The driver is instructed to access a special processor by an interger 2 on the path card, and the particular processor is identified by a name (Format A6) in the input data stream. Following this special identification card must be any input data required by that processor. The following names

[a] Ibid., p.403-1.

identify special processors which are in production use:

DCMACR - Reads CITATION format macroscopic cross sections and writes a pseudo CITATION format microscopic cross section file.

DCRSPR - Reads input data to generate the files CONTRL (Section 204) and CXSPRR (Appendix A) required by the cross section processor code.

DVENTR - Reads input data to generate the necessary interface files required by VENTURE (see Section 104), excluding cross sections (ISOTXS or GRUPXS file required).

DUTLIN - Reads input data to generate the file CONTRL required by the reaction rate code.

As an example of the use of two special processors, consider that the the standard input processor is to read input data to generate an ISOTXS file, use the special processor DCRSPR to produce a GRUPXS file, use the special processor DVENTR to write the files needed by VENTURE, and finally execute VENTURE. The Path card supplied to the driver would contain 1 2 6 2 7 0, and the input stream would contain:

1. Driver instructions
2. ISOTXS data to be read by the standard input processor
3. The DCRSPR card followed by input for this processor
4. The DVENTR card followed by input for this processor

Running VENTURE on the IBM-360/91 (ORNL)

The first part of this discussion describes running VENTURE on the IBM-360/91 computer located at the ORNL site. A discussion of running VENTURE on the IBM-360/195 computer located at the ORDGP site starts on page C-22.

Job Control Cards

The IBM-360 Job Control Language is quite powerful, but complicated and therefore difficult to use. Most of the job control cards required to run VENTURE are stored in a procedure library and referred to as a "catalogued procedure." They are retrieved and altered automatically at run time. To execute the code, Figure C-1 shows a typical set of job control cards required in addition to those stored. The numbers at the right-hand side are not punched on the cards, but refer to the noted

discussion following. Also, no blank cards are permitted; the ones shown are for clarity only. The user should read the notes carefully to understand how to use the VENTURE code.

Note:

(1) The parameters UID, X, Y, ZZZ, CHARG, and the contents of columns 38-57 are job and user dependent and are described below.

UID - This is the users' identification and is assigned by the computer dispatcher (see Services below).

X - Any one digit number or letter.

Y - This is the job "class" (two places on the card) and is either D, E, F, or G as shown in the following table.

Class	CP Time Limit (min)	Region Size[a]	Tapes Required
D	> 5	> 540K	No
E	≤ 5	≤ 540K	Yes
F	> 5	> 540K	Yes
G	≤ 0.5	≤ 270K	Yes

The operating system automatically terminates class E and class G jobs if they exceed the CP time shown. Class D and F jobs are terminated at the discretion of the computer operator if they exceed either CP time or estimated wall clock time (see Estimated Time below).

ZZZ - This is the expected CP time in minutes and is discussed below under Estimated Time.

CHARG - This is the users' charge number (see Services below).

Col. 38-57 - This is the users' address and name and specifies where the job output is to be sent. If the job is submitted through the PDP-10 by a remote terminal, columns 38-40 may be used to direct the output to the remote terminal printer. This parameter is GEC for the G.E. terminal

[a]See Note (4) below.

FIGURE C-1. CONTROL CARDS FOR RUNNING VENTURE ON THE 360/91.

```
                                                                          NOTE
//UIDXYZZZ JOB (CHARG,,,99,9000,,1),'ADRES,NAME COL 38-57',CLASS=Y,        (1)
// TYPRUN=HOLD,
// MSGLEVEL=(1,1)
/*ROUTE  PRINT LOCAL                                                      (2)
//STEP EXEC VENTUREX,
// NB1=1,NB2=1,B1=3520,B2=32000,NX=50,NS=50,N1=100,                        (3)
// N2=1,N3=1,N4=1,N5=1,N6=1,N7=1,N8=1,N9=1,N10=1,N11=1,N12=1,N13=1,        (3)
// N14=1,N15=1,N16=1,                                                      (3)
// PARM.FORT='NODECK,NOLIST,NOSOURCE,NOMAP,NOXREF',
// REGION.GO=88BK                                                          (4)
//FORT.SYSIN DD *
/*
//LKED.BVDRIVER DD UNIT=2314,VOLUME=SER=ZX2222,DISP=SHR,
// DSNAME=TBF.BOLD.VENTURE.DRIVER
//LKED.SYSIN DD *
 INCLUDE BVDRIVER
/*
//GO.FT11F001 DD UNIT=TAPE9,VOLUME=SER=11,LABEL=(,NL),DISP=OLD,           (5)
// DCB=(RECFM=VBS,LRECL=X,BLKSIZE=3520)                                    (5)
//GO.XXXXXXXX DD UNIT=2314,VOL=SER=ZX2222,DISP=SHR,
// DSNAME=TBF.BOLD.VENTURE
//GO.FT04F001 DD UNIT=TAPE7,VOLUME=SER=04,LABEL=(,NL),DISP=OLD,           (6)
// DCB=(DEN=2,TRTCH=ET,RECFM=FBS,LRECL=80,BLKSIZE=3200)                    (6)
//GO.FT16F001 DD UNIT=TAPE9,VOLUME=SER=16,LABEL=(,NL),DISP=OLD,           (7)
// DCB=(RECFM=VBS,LRECL=X,BLKSIZE=3520)                                    (7)
//GO.FT99F001 DD *
                                                                          (8)
***************VENTURE RUN NUMBER 1 - 1/1/75***************             (9)
AAAAAA                        ZZZ                                         (9)
  2  7  2  7  0                                                           (9)

DVENTR                                                                    (9)
COMMENT*****VENTURE CASE INPUT DATA GOES HERE.                            (10)
ENDINPUT                                                                  (11)

DVENTR                                                                    (9)
COMMENT*****VENTURE CASE INPUT DATA GOES HERE.                            (10)
ENDINPUT                                                                  (11)
/*
//
```

located at Sunnyvale, California. (See also note (2) below). A typical card might be

```
//SCC1F040 JOB (00001,,,99,9000,,1),'GECSUNNYVALE S.CRICK',CLASS-F,
```

where a fictitious charge number is shown.

(2) This card is optional. If it is present, it specifies that the job output is to be printed at the computer and overrides the destination specified by columns 32-40 on the first card. For remote terminals connected directly to the IBM 360/91, this card may be used to direct the job output to that remote terminal. It would have the form

/*ROUTE PRINT REMOTEn

where n is the remote terminal number.

(3) These parameters are problem dependent and are discussed under Problem Dependent Parameters below.

(4) The parameter BBB (maximum 1536) specifies the maximum number of bytes of core storage (in K = 1024 bytes) allowed for the job. For running VENTURE

BBB≅4(AAAAAA)/1000+300

where AAAAAA is the size of the VENTURE data container array (see note 9 below). It is important that this number not be much larger than that required for the job. (See discussion in last paragraph under Comments below.)

(5) Any cards included here are optional. They identify logical I/O unit numbers and override those defined in the catalogued procedure (Figure C-4). If included, the cards must be placed in the deck so that the logical unit numbers are in ascending order. SeeeSection 204-1 for a complete description of the I/O units required to run VENTURE.

Logical unit number 11 is the GRUPXS interface data set. It may previously have been written, or it may be written during this run depending upon instructions to the driver program (see note 9 below).

If these cards are not present, logical unit 11 is defined as a scratch disk in the catalogued procedure, and the GRUPXS interface data set if made this run would not be saved. The cards shown define this data set as a non-labeled 9=track binary tape. If the GRUPXS interface data set had previously been written and saved on a disk, the cards might have the following forms, where disk is used, not generally available.

```
//GO.FT11F001 DD UNIT=2314,VOLUME=SER=ZX1111,DISP=(SHR,KEEP),
// DCB=(RECFM=VBS,LRECL=X,BLKSIZE=3500,BUFNO=1),
// DSNAME=TBF.GE.MACROS.X17GR
```

Here the data set resides on a 2314 disk unit, number ZX1111, and the data set name is as shown on the last card. If a GRUPX file is generated in the run and is to be saved, it generally will be a magnetic tape.

(6), (7) Any cards included here are optional. They identify logical I/O unit numbers that supplement those defined in the catalogued procedure (Figure C-4).

(6) This pair of cards is optional. They describe a data set, logical 4, as a magnetic tape which is written by VENTURE (user option) at the end of a run. If written, this data set will contain formatted data described in Section 204.[a] The cards shown define this data set as a non-labeled 7-track BCD tape, 800 BPI, even parity, each logical records 80 characters long, blocked at 3200 characters per block (actual record length).

(7) Logical unit number 16 is reserved to contain data for restart, the RSTRTR file. This data set is required if the restart data is to be written or read for a restart case (user options). This pair of cards defines this unit as a 9-track binary tape which it generally will be.

---

[a] If more than one stacked case is being run, this data would only be saved for the last case.

(8) No blank cards are allowed in the input stream (except in the input data decks). The blanks shown here are for clarity only.

(9) These cards are driver instruction cards and are described in Appendix C. In this example it is assumed that a GRUPXS file exists (see note 5 above). The number AAAAAA is the size of the VENTURE data container array.

(10) VENTURE case input data. This input data is described in the document INPUT DATA REQUIREMENTS FOR VENTURE.

(11) A card with ENDINPUT, punched in columns 1-8, is required following the input data for each input processor, including that for the stan-card input processor.

Problem-Dependent Parameters

Certain parameters specifying disk space and block size (in bytes) which appear on the cards defining logical data sets are problem dependent.

These parameters are shown in NB1, NB2, B1, B2, NX, NS, and N1 through N15 in the catalogued procedure, Figure C-4. They are specified at run time by assigning values, note (3) in Figure C-1.

B1 and B2 are the size (limited to 32000) of core memory blocks into which data are read. The larger this block size the fewer are the I/O requests required to read a particular data set. B2 defines the block size of the data sets which are read most often during the iterative part of the calculation. NB1 and NB2 (permissible values of 1 or 2) specify the number of buffers (number of blocks or size B1 or B2) of core memory into which data will be stored.

We recommend specifying NB1 = 1, NB2 = 1, B1 = 3520, and B2 = 32000, NX = 2, NS = 50, and N1 = 100. These values will be adequate for most practical problems. We find advantage in using only one buffer which minimizes core memory requirements. For small problems, it may be desirable to set B2 to something smaller than 32000 to minimize core memory. It is recommended that B1 and B2 not be set smaller than 3520. Values for parameters N2 through N15 are calculated as follows:

Let C = number of columns in the mesh

R = number of rows in the mesh

P = number of planes in the mesh

G = number of energy groups

Z = number of zones

and NN = [(110+1.1L)N]/B + 1

where NN is the value assigned to N2 through N16, and L, N, and B are given in Figure C-2. A value of 100 is recommended for N1.

If NN times B exceeds about 14,500,000 (unlikely except for N3 and N5), special clean disks must be used for the data set; in this case, contact the authors for details.

For a "plane-stored" non-hexagonal problem with 48 columns, 22-rows, 16 planes, and 6 groups, N2=257, N3=1210, N4=310, N5=113, N6=10, N7=5, N8=5, N9=100, N10=43, N11=54, N12=1, N13=1, N14=1, N15=1, and N16=1. Larger values could be used for these parameters, but computer resources will be wasted, and run costs likely increased.

Estimated Time

The central processor (CP) time and wall clock times (see Job Card below) depend upon the problem size and the data handling mode of calculation. Large "fast-reactor," three-dimensional problems running in the "plane-stored" mode are solved at a rate of about 100 space-energy points per second CP time. Wall clock time is roughly a factor of 6 to 10 more than the CP time for problems running in the "plane-stored" mode when other jobs are running concurrently in the 360/91 computer. A 48x22x16x6 group problem (101,376 space energy points) with 4 inner, 27 outer interations required 12.5 minutes CP time and 86 minutes wall clock time. A 48x22x16x17 group problem (287,232 space energy points) required 60 minutes CP time and 7 hours wall clock time. Reflected "thermal-reactor" problems usually require somewhat longer to solve.

For problems which run in the "all-stored" mode or "mesh-stored" mode, the wall clock time is much less relative to the CP time.

Figure C-2. Determining the Values of L, N, and B

For	L	N	B	Remarks
N2	8CR 8C	PG RPG	B1 B1	Normally. If perturbation calculations are to be done.
N3	----- 36C+4 44C+12	 RPB	 B1	Set N3=1 except for the "row-stored" mode (see Section 103), or if perturbation calculations are to be done. Non-hexagonal geometry. Hexagonal geometry.
N4	----- 8CR 4Z	 PG G	 B1	Set N4=1 except for fixed source problems. Fixed source by point and group. Fixed source by zone and group.
N5	----- 4(8CR+C+R) 4(9CR+2C+2R)	 PG	 B2	Set N5=1 for the "row-stored" mode only. Non-hexagonal geometry. Hexagonal geometry.
N6				Set N6=10.
N7	8CR	P	B2	
N8	8CR	P	B2	
N9	8CR	P	B1	
N10	8CR	P PG	 B1	Normally. If initial flux guess is to be read from RTFLUX interface and to be expanded.
N11	8C	RP	B1	
N12				Set N12=1.
N13	----- 8CR	 P	 B1	Set N13=1 unless the power density interface PWDINT will be written. For writing the interface PWDINT.
N14	----- 8CR	 PG	 B1	Set N14=1 unless the P_1 calculation is to be done. For the P_1 calculation:
N15				Set N15=10.
N16	----- 8CR	 PG	 B1	Normally N16=1. If the standard flux interfaces RTFLUX and/or ATFLUX are to be written on scratch disk.

Job Submission Form

A job submission form must accompany each job submitted. This form is either sent to the dispatcher with the job deck, or called in to the dispatcher for jobs submitted from remote terminals. (See Services below for phone numbers, etc.) Figure C-3 shows a job submission form that might go with the job shown in Figure C-1.

At the top of the card following 360/ is written the job class (see note (1) above) and the number of bytes of core storage required (see note (4) above) for the job; for instance, F-500K. The Job Number, Charge, and Maximum Execution Time are explained in note (1) above. The columns under TAPES REQUIRED are described as follows (there are three 9-track tapes and two 7-track tapes available on the 360/91).

Log No.	- The tape logical number. The tapes must be listed here in the same order as they appear in the job control language. Those overriding the ones in the catalogued procedure must be specified first followed by those that are not in the procedure.
Reel Number	- The number assigned to the tape. The POOL specifies that a free tape is to be used. If a previously checked-out tape were to be used, the tape number would be written as shown for logical 16 where NNNN is some number.
Special Handling	- Any appropriate comment.
Save	- If checked, the tape will be saved.
Saved Reel Number	- If POOL and SAVE are written, the tape will be checked out to the user and the reel number recorded here by the dispatcher.
File Protect	- (Before mounting, after dismounting) If Y is checked this means the tape cannot be written on. If N is checked, this means the tape can be written on.
7 or 9 track	- Generally formatted tapes which may be read by other computers than the IBM-360 are designated as 7 track. Binary tapes are normally 9 track.

Figure C-3. Typical Job Submission Form

JOB NUMBER: UIDXYZZZ

360/ Y-BBBK **JOB CARD** [X] 91 [ ] 75 [ ] EITHER

PHONE: (Phone)

NAME: (Name)

BUILDING / ROOM / PLANT: (Location)

CHARGE: CHARG

MAXIMUM EXECUTION TIME
[ ] 360/75
[X] 360/91 ZZZ MINUTES

DUMP ON OPERATOR CANCELLATION [ ] YES [X] NO

CANCELLATION BY OPERATOR
[ ] EXCEEDED TIME [ ] OTHER

CONSOLE ERROR MESSAGE(S)

UCN-7662 (3 7-69)

TAPES REQUIRED

LOG NO	REEL NUMBER	SPECIAL HANDLING	SAVE	SAVED REEL NUMBER	FILE PROTECT BEFORE Y	FILE PROTECT BEFORE N	FILE PROTECT AFTER Y	FILE PROTECT AFTER N	7 OR 9 TRACK
4	POOL	[illegible]	X			X	X		7
11	POOL		X			X	X		9
16	K-NOWN		X			X	X		9

REMARKS:
I/O BOUND.
APPROX. 4 HOURS
WALL CLOCK TIME.

DISKS

IDENT.
ZX2222

One mountable disk is required for running VENTURE. It is numbered ZX2222 and must be written as shown in the figure.

In the remarks columns, write I/O Bound and show the expected wall clock time. For small problems running in the "all stored" or "mesh-stored" mode, this is not necessary.

Comments

For the user who is not familiar with running VENTURE on the IBM-360/91 computer at ORNL, some comments may be useful.

Several jobs normally are executing in the computer at the same time, each competing for the computer resources. Because of this, it is important that any job not require more of the computer resources than necessary. That is why the region size of a job should be as small as possible (see note (4) above). Likewise, that is why the parameters N2 through N15 (see Problem-Dependent Parameters above) should not be larger than necessary.

Probably, the best overall strategy for running large three-dimensional problems on the 360/91 with VENTURE is to specify the size of the data container array such that the code runs in the "plane-stored" mode, storing about three to five planes of data (see Section 103: Memory Requirements). Normally, the number of inner iterations is also the number of planes stored. In this mode, I/O is minimized during the iterative procedure and the core region size is small enough so that other jobs may run concurrently. For a problem with 48 columns, 22 rows, and 16 planes, the data container array of 66000 allows 4 planes of data to be stored and the region size is about 500K. (The number of planes stored is independent of the number of energy groups.) A 48x44x32 mesh problem with 4 planes stored requires an array size of 120,000 and a region size of about 750K; and 50x50x50 mesh problem required 110,000 work array size to store 3 planes of data requiring a region size of about 710K bytes.

We suggest that a new user of VENTURE run a first case for only one iteration (specified by input) to not only check out the job control cards, input data, etc., but also to obtain the container data array requirements for all modes and the region size requirements. This first run should be made to do all the calculations (i.e., neutron balance) that the production run will do.

Catalogued Procedure

Figure C-4 shows the catalogued job control cards that are used by a VENTURE run in addition to those included in the input streams.

Services

Given here is information which might be required by a user. For a complete description of the ORNL computer facilites (hardware and software) refer to the ORNL Programmers Manual.

A. The Dispatcher (Telephone Number 3-0205)

The Dispatcher of the ORNL Computing Center is the primary interface between the Center and the public, and in this sense is the "receptionist" for the Center, answering and routing phone calls, answering questions concerning the Computing Center and directing customers to specific individuals. Other duties are:

a. Logging jobs into and out of the Computer Center.
b. Preparing and recording the recorded status report periodically.
c. Coordinating the activities of any couriers assigned to the Center.
d. Issuing the Jobname initials which are required for use of the IBM/360 computers.

FIGURE C-4. CATALOGUED JOB CONTROL CARDS.

```
//VENTUREX PROC CLSIZE=270K,LKSIZE=150K,GOSIZE=540K,GOTIME=,                C
// NB1=1,NB2=1,B1=3520,B2=32000,NX=2,NS=50,N1=100,
// N2=1,N3=1,N4=1,N5=1,N6=1,N7=1,N8=1,N9=1,N10=1,N11=1,N12=1,N13=1,
// N14=1,N15=1,N16=1
//FORT    EXEC  PGM=IEKAA00,REGION=&CLSIZE
//SYSLIN    DD  DSN=&&LOADSET,UNIT=SYSDA,SPACE=(800,(400,20),RLSE),         C
//              DISP=(MOD,PASS),DCB=(RECFM=FB,LRECL=80,BLKSIZE=800)
//SYSPRINT  DD  SYSOUT=A,DCB=BLKSIZE=1100
//SYSPUNCH  DD  SYSOUT=B
//SYSUT2    DD  UNIT=SYSDA,SPACE=(1024,(30,10))
//LKED    EXEC  PGM=IEWL,PARM='OVLY',REGION=&LKSIZE,                         C
//              COND=(5,LT,FORT)
//SYSLIB    DD  DSN=SYS1.FORTLIB,DISP=SHR
//          DD  DSN=SYS1.LOGLIB,DISP=SHR
//SYSLIN    DD  DSN=&&LOADSET,DISP=(OLD,DELETE)
//          DD  DDNAME=SYSIN
//SYSLMOD   DD  DSN=&&FJOBLIB(BOLDV),UNIT=SYSDA,DISP=(NEW,PASS),            C
//              SPACE=(3072,(50,10,1),RLSE)
//SYSPRINT  DD  SYSOUT=A,DCB=BLKSIZE=605
//SYSUT1    DD  UNIT=(SYSDA,SEP=(SYSLIN,SYSLMOD)),SPACE=(3072,(50,10))
//GO      EXEC  PGM=BOLDV,COND=((5,LT,FORT),(5,LT,LKED)),                   C
//              REGION=&GOSIZE,TIME=&GOTIME
//STEPLIB   DD  DSN=&&FJOBLIB,DISP=(OLD,DELETE)
//FT01F001  DD  SYSOUT=A,DCB=(RECFM=VBA,LRECL=137,BLKSIZE=1100)
//FT02F001  DD  SYSOUT=A,DCB=(RECFM=VBA,LRECL=137,BLKSIZE=1100)
//FT03F001  DD UNIT=SYSDA,SPACE=(80,(10)),DCB=(RECFM=F,BLKSIZE=80)
//FT05F001  DD UNIT=SYSDA,SPACE=(80,(4000,1000)),
//              DCB=(RECFM=F,BUFNO=1,LRECL=80,BLKSIZE=80)
//FT06F001  DD  SYSOUT=A,DCB=(RECFM=VBA,LRECL=137,BLKSIZE=1100)
//FT08F001  DD UNIT=SYSDA,SPACE=(&B1,(&N1,2)),
//              DCB=(RECFM=VBST,LRECL=X,BUFNO=&NB1,BLKSIZE=&B1)
//FT09F001  DD UNIT=SYSDA,SPACE=(&B1,(&NS,1)),
//              DCB=(RECFM=VBST,LRECL=X,BUFNO=&NB1,BLKSIZE=&B1)
//FT10F001  DD UNIT=SYSDA,SPACE=(&B1,(&NS,1)),
//              DCB=(RECFM=VBST,LRECL=X,BUFNO=&NB1,BLKSIZE=&B1)
//FT11F001  DD UNIT=SYSDA,SPACE=(&B1,(&N1,&NX)),
//              DCB=(RECFM=VBST,LRECL=X,BUFNO=&NB1,BLKSIZE=&B1)
//FT12F001  DD UNIT=SYSDA,SPACE=(&B1,(&N1,&NX)),
//              DCB=(RECFM=VBST,LRECL=X,BUFNO=&NB1,BLKSIZE=&B1)
//FT13F001  DD UNIT=SYSDA,SPACE=(&B1,(&N1,2)),
//              DCB=(RECFM=VBST,LRECL=X,BUFNO=&NB1,BLKSIZE=&B1)
//FT14F001  DD UNIT=SYSDA,SPACE=(&B1,(&NS,1)),
//              DCB=(RECFM=VBST,LRECL=X,BUFNO=&NB1,BLKSIZE=&B1)
//FT15F001  DD UNIT=SYSDA,SPACE=(&B1,(&NS,1)),
//              DCB=(RECFM=VBST,LRECL=X,BUFNO=&NB1,BLKSIZE=&B1)
//FT17F001  DD UNIT=SYSDA,SPACE=(&B1,(&N16)),
//              DCB=(RECFM=VBST,LRECL=X,BUFNO=&NB1,BLKSIZE=&B1)
//FT18F001  DD UNIT=SYSDA,SPACE=(&B1,(&N16)),
//              DCB=(RECFM=VBST,LRECL=X,BUFNO=&NB1,BLKSIZE=&B1)
//FT19F001  DD UNIT=SYSDA,SPACE=(&B1,(&NS,1)),
//              DCB=(RECFM=VBST,LRECL=X,BUFNO=&NB1,BLKSIZE=&B1)
//FT20F001  DD UNIT=SYSDA,SPACE=(&B1,(&N13)),
```

(CONT)

```
//                DCB=(RECFM=VBST,LRECL=X,BUFNO=&NB1,BLKSIZE=&B1)
//FT21F001 DD UNIT=SYSDA,SPACE=(&B1,(&N1,2)),
//                DCB=(RECFM=VBST,LRECL=X,BUFNO=&NB1,BLKSIZE=&B1)
//FT22F001 DD UNIT=SYSDA,SPACE=(&B1,(&NS,1)),
//                DCB=(RECFM=VBST,LRECL=X,BUFNO=&NB1,BLKSIZE=&B1)
//FT23F001 DD UNIT=SYSDA,SPACE=(&B1,(&N3)),
//                DCB=(RECFM=FT,BUFNO=&NB1)
//FT24F001 DD UNIT=SYSDA,SPACE=(&B1,(&N2)),
//                DCB=(RECFM=FT,BUFNO=&NB2)
//FT25F001 DD UNIT=SYSDA,SPACE=(&B1,(&N12)),
//                DCB=(RECFM=FT,BUFNO=&NB1)
//FT26F001 DD UNIT=SYSDA,SPACE=(&B1,(&N12)),
//                DCB=(RECFM=FT,BUFNO=&NB1)
//FT27F001 DD UNIT=SYSDA,SPACE=(&B1,(&N2)),
//                DCB=(RECFM=FT,BUFNO=&NB2)
//FT28F001 DD UNIT=SYSDA,SPACE=(&B1,(&N2)),
//                DCB=(RECFM=FT,BUFNO=&NB2)
//FT29F001 DD UNIT=SYSDA,SPACE=(&B1,(&N14)),
//                DCB=(RECFM=FT,BUFNO=&NB2)
//FT30F001 DD UNIT=SYSDA,SPACE=(&B1,(&N1,2)),
//                DCB=(RECFM=VBST,LRECL=X,BUFNO=&NB1,BLKSIZE=&B1)
//FT31F001 DD UNIT=SYSDA,SPACE=(&B1,(&N1,&NX)),
//                DCB=(RECFM=VBST,LRECL=X,BUFNO=&NB1,BLKSIZE=&B1)
//FT32F001 DD UNIT=SYSDA,SPACE=(&B1,(&N1,2)),
//                DCB=(RECFM=VBST,LRECL=X,BUFNO=&NB1,BLKSIZE=&B1)
//FT33F001 DD UNIT=SYSDA,SPACE=(&B1,(&N4)),
//                DCB=(RECFM=VBST,LRECL=X,BUFNO=&NB1,BLKSIZE=&B1)
//FT34F001 DD UNIT=SYSDA,SPACE=(&B1,(&N1,&NX)),
//                DCB=(RECFM=VBST,LRECL=X,BUFNO=&NB1,BLKSIZE=&B1)
//FT35F001 DD UNIT=SYSDA,SPACE=(&B1,(&N1,2)),
//                DCB=(RECFM=VBST,LRECL=X,BUFNO=&NB1,BLKSIZE=&B1)
//FT36F001 DD UNIT=SYSDA,SPACE=(&B1,(&N6,2)),
//                DCB=(RECFM=VBST,LRECL=X,BUFNO=&NB1,BLKSIZE=&B1)
//FT37F001 DD UNIT=SYSDA,SPACE=(&B1,(&N15,2)),
//                DCB=(RECFM=VBST,LRECL=X,BUFNO=&NB1,BLKSIZE=&B1)
//FT38F001 DD UNIT=SYSDA,SPACE=(&B1,(&N15,2)),
//                DCB=(RECFM=VBST,LRECL=X,BUFNO=&NB1,BLKSIZE=&B1)
//FT39F001 DD UNIT=SYSDA,SPACE=(&B1,(&N15,2)),
//                DCB=(RECFM=VBST,LRECL=X,BUFNO=&NB1,BLKSIZE=&B1)
//FT40F001 DD UNIT=SYSDA,SPACE=(&B2,(&N5)),
//                DCB=(RECFM=FT,BUFNO=&NB2)
//FT41F001 DD UNIT=SYSDA,SPACE=(&B1,(&N4)),
//                DCB=(RECFM=VBST,LRECL=X,BUFNO=&NB1,BLKSIZE=&B1)
//FT42F001 DD UNIT=SYSDA,SPACE=(&B2,(&N7)),
//                DCB=(RECFM=VBST,LRECL=X,BUFNO=&NB2,BLKSIZE=&B2)
//FT43F001 DD UNIT=SYSDA,SPACE=(&B2,(&N8)),
//                DCB=(RECFM=VBST,LRECL=X,BUFNO=&NB2,BLKSIZE=&B2)
//FT44F001 DD UNIT=SYSDA,SPACE=(&B1,(&NS,1)),
//                DCB=(RECFM=VBST,LRECL=X,BUFNO=&NB1,BLKSIZE=&B1)
//FT45F001 DD UNIT=SYSDA,SPACE=(&B1,(&N9)),
//                DCB=(RECFM=VBST,LRECL=X,BUFNO=&NB1,BLKSIZE=&B1)
//FT46F001 DD UNIT=SYSDA,SPACE=(&B1,(&N10)),
//                DCB=(RECFM=VBST,LRECL=X,BUFNO=&NB1,BLKSIZE=&B1)
//FT47F001 DD UNIT=SYSDA,SPACE=(&B1,(&NS,1)),
```

(CONT)

```
//                DCB=(RECFM=VBST,LRECL=X,BUFNO=&NB1,BLKSIZE=&B1)
//FT48F001 DD UNIT=SYSDA,SPACE=(&B1,(&N1,2)),
//                DCB=(RECFM=VBST,LRECL=X,BUFNO=&NB1,BLKSIZE=&B1)
//FT49F001 DD UNIT=SYSDA,SPACE=(&B1,(&N11)),
//                DCB=(RECFM=VBST,LRECL=X,BUFNO=&NB1,BLKSIZE=&B1)
//FT50F001 DD UNIT=SYSDA,SPACE=(&B1,(&N1,2)),
//                DCB=(RECFM=VBST,LRECL=X,BUFNO=&NB1,BLKSIZE=&B1)
//FT51F001 DD UNIT=SYSDA,SPACE=(&B1,(&NS,1)),
//                DCB=(RECFM=VBST,LRECL=X,BUFNO=&NB1,BLKSIZE=&B1)
//FT52F001 DD UNIT=SYSDA,SPACE=(&B1,(&NS,1)),
//                DCB=(RECFM=VBST,LRECL=X,BUFNO=&NB1,BLKSIZE=&B1)
//FT53F001 DD UNIT=SYSDA,SPACE=(&B1,(&NS,1)),
//                DCB=(RECFM=VBST,LRECL=X,BUFNO=&NB1,BLKSIZE=&B1)
//VENTUREX PEND
```

e. Filling out Job Submission Forms called in by telephone.

f. Routing or mailing job output, which may include magnetic tapes, to remote users.

B. Charge Numbers

All services performed by the ORNL Computing Center are billed to a five-digit Charge Number (sometimes called a "request" number). These numbers are assigned by the Tape Librarian (telephone number 3-1214) upon request of individual users. With each request for a Charge number, each requestor must be prepared to supply a valid departmental account. Billing for services is done on a monthly basis by Central Accounting. Monthly charges are made to each departmental account; thus, if it is desired to keep more detailed accounts of computing costs, several Charge numbers (perhaps one for each project) should be opened against the one departmental account. As many Charge numbers as desired may be opened. Charge numbers may be closed (discontinued) at any time by the user who opened it (or his supervision) by notifying the Dispatcher; however, the closing will not become effective until the end of the month during which notification was received.

C. Programming Assistance

The Systems Programming Department maintains a Programming Assistance group (telephone number 3-1177) who are available for consultation and trouble-shooting. The people manning this office are experienced programmers and can answer most questions concerning error messages, compilers, operating systems, etc. They cannot write programs for users but are there for advice and counsel. Regular office hours are kept (8:30-11:30 a.m.; 12:30-4:00 p.m.). However, for usual problems in running codes, the authors should normally be contacted.

D. Tape Librarian (Telephone Number 3-1214)

Many users of the computers will wish to save information on magnetic tape for varying periods of time. Each user is responsible for so notifying the Computing Center via his Job Submission Form if a magnetic tape is

to be saved. The Tape Librarian is responsible for maintaining appropriate records associated with saved magnetic tapes. Among the duties of the Tape Librarian are:

a. Updating, on a daily basis, the records of tapes assigned to users.

b. Processing those tapes which are returned to the pool, including necessary revisions to the records.

c. Publishing a bi-weekly report of all tapes assigned and sending copies to all users. Each user is notified of those tapes assigned to him and requested to inform the librarian of any tapes which can be returned to the pool.

d. Filling other requests for tapes or information pertaining to same.

e. Issuing job request numbers (the 5-digit number which is used for billing and which must be on all work submitted to the Computing Center, and maintaining associated records.

Note: The Tape Librarian always has a recent listing of assigned tapes listed both in order of tape number and in alphabetical order of user. However, the assignee always has the burden of keeping records on tape contents.

E. Recorded Status Message

The Computing Center maintains an automatic telephone answering device which has a recorded message describing the current status of the equipment, what jobs are currently being run, status of the work backlog, and other pieces of information deemed to be of interest to users of Computing Center services. Messages are updated periodically throughout the day. The telephone number of the device is 3-1817.

Running VENTURE on the IBM-360/195

The following discussion describes how to run the VENTURE code on the IBM-360/195 located at the ORDGP site. The user should understand the first part of this section since the only differences from running on the IBM-360/91 located at the ORNL site will be discussed here. Both computers are operated by the Computer Sciences Division (not under ORNL).

Job Control Cards

Figure C-5 shows a typical set of job control cards required. Reference should be made to Figure C-1 and the corresponding notes since only differences are discussed here. Reference numbers refer to note numbers in Figure C-5.

Note:

(1) This card is required for a job stream supplied from a terminal connected to the 360/91. It causes the job stream to be passed on to the PDP-10 computer (REMOTE5). (Note that the REMOTE5 begins in column 16.) This card would not be used if the terminal is connected with the PDP-10.

(2) This card causes the job stream to be passed on to the 360/195 by the PDP-10. (Neither of these first two cards is required if the terminal is connected directly with the 360/195.)

(3) Note the differences between this card and the one in Figure 105-1. Here the eight character job number is ZZZ(unless otherwise assigned), UID(user identification), NN(any two digit integer). The CHARG number is the same as that used on the 360/91 at X-10, and columns 25-44 contain the same information as columns 38-57 shown in Figure 105-1. All VENTURE runs on the 360/195 are CLASS=A.

(4) The BBB here has the same meaning as described in Figure 105-1, but is now limited to a maximum of 1650.

(5) The only variable on this card is TT which is the limit on lines of printed output in thousands, i.e., 50 would allow 50,000 lines to be printed. The job is terminated if the number of lines exceeds the limit.

FIRURE C-5. CONTROL CARDS FOR RUNNING VENTURE ON THE 360/195.

```
                                                                        NOTE
/*RELAY        REMOTE3                                                   (1)
95                                                                      (2)
//ZZZUIDNN JOB (CHARG),'ADRES,NAME COL 25-44',CLASS=A,                   (3)
// REGION=BBBK,                                                         (4)
// MSGLEVEL=(1,1)
//*MAIN HOLD=YES,LINES=(TT,C)                                           (5)
//STEP EXEC VENTUREX,
// NB1=1,NB2=1,B1=3520,B2=32000,NX=50,NS=50,N1=100,
// N2=1,N3=1,N4=1,N5=1,N6=1,N7=1,N8=1,N9=1,N10=1,N11=1,N12=1,N13=1,
// N14=1,N15=1,N16=1,
// PARM.FORT='NODECK,NOLIST,NOSOURCE,NOMAP,NOXREF',
// GOTIME=MM                                                            (6)
//FORT.SYSIN DD *
/*
//LKED.BVDRIVER DD UNIT=2314,VOLUME=SER=XXXA72,DISP=SHR,                (7)
// DSNAME=TBF.BOLD.VENTURE.DRIVER
//LKED.SYSIN DD *
 INCLUDE BVDRIVER
/*
//GO.FT11F001 DD UNIT=TAPE9,VOLUME=SER=TAPENO,LABEL=(,NL),DISP=WWW,     (8)
// DCB=(RECFM=VBS,LRECL=X,BLKSIZE=3520)
//GO.XXXXXXXX DD UNIT=2314,VOL=SER=XXXA72,DISP=SHR,                     (7)
// DSNAME=TBF.BOLD.VENTURE
//GO.FT04F001 DD UNIT=TAPE7,VOLUME=SER=TAPENO,LABEL=(,NL),DISP=WWW,     (8)
// DCB=(DEN=2,TRTCH=ET,RECFM=FBS,LRECL=80,BLKSIZE=3200)
//GO.FT16F001 DD UNIT=TAPE9,VOLUME=SER=TAPENO,LABEL=(,NL),DISP=WWW,     (8)
// DCB=(RECFM=VBS,LRECL=X,BLKSIZE=3520)
//GO.FT99F001 DD *

***************VENTURE RUN NUMBER 1 - 1/1/75***************
AAAAAA                        ZZZ
  1  2  6  2  7  0

COMMENT*****THE ISOTXS CARDS (TO BE READ BY THE GENERAL INPUT
            PROCESSOR) MIGHT GO HERE.
ENDINPUT

DCRSPR
COMMENT*****THE CROSS SECTION PROCESSOR INPUT GOES HERE.
ENDINPUT

DVENTR
COMMENT*****VENTURE CASE INPUT DATA GOES HERE.
ENDINPUT
/*
//
```

(6) The variable MM on this card is the CPU time allowed for the run in minutes, and if exceeded, the job is terminated by the operating system. Note that the 360/195 CPU is about twice as fast as the 360/91 CPU. This should be considered when specifying any time limits in the driver input or the VENTURE input.

(7) The XXXA72 (on 2 cards) is changed from ZX2222.

(8) There are two differences in tape DD cards.

(A) The variable TAPENO in the VOLUME=SER=TAPENO field is different. For the 360/195, TAPENO is the identifying number on the tape. Where VOLUME=SER=11 would be specified for the 360/91, VOLUME=SER=X12345 or VOLUME=SER=012345 might be specified for the 360/195. This means that the user will have to check out any new tapes in advance of submitting a job requiring a new tape. (See Operating Procedure and Services below)

(B) If a tape is to be written, the variable WWW in DISP=WWW field must be NEW. OLD is used to mean to protect a tape, so when specified, the ring will be removed from the tape before mounting so that it cannot be written. (WWW is always OLD for the 360/91.)

If any NN times B (see Problem Dependent Parameters, page c-9) exceeds about 25,000,000 (unlikely except for N3 and N5), special clean disks must be used for the data set; in this case, contact the authors for details.

Operating Procedure and Services

All services for the 360/195 have the telephone extension 3-3625.

The operators are informed by the computer about tapes and disks to be mounted, and the region size for a job, so no job card is needed as for the 360/91. The operators do not have access to the CPU time that a job has used; and, therefore, the only information they will need for a job from the user is the expected clock time a job will require. After a job has been submitted, the user should call the shift supervisor and give the job number and the expected clock time.

Tapes may be checked out by calling the Tape Librarian. The information required is a name for the tape, the number of tracks (7 or 9), and the user's charge number. Always specify Non-Labeled for the tape label. The user should keep a log of the tape name, use, and number. Each tape at ORDGP is assigned a six-digit number. (Tapes at ORNL have an X as the first character of the tape number.) Any tapes in the ORNL library that are to be used on the 360/195 at ORDGP should be sent to the 360/195 tape librarian by so instructing the tape librarian at ORNL (telephone extension 3-1214).

Arrangements should be made with the Program Control-Technical Applications Department to examine the output from jobs, inform the user if the job failed, or to report numbers from the output, and to mail the output to the user.

FIGURE C-6. THE DRIVER ROUTINES.

```
  MAIN    DRIVER CONTROL
               CALLS ABND, SEAK, UTL1, WRAP, FLINK, TIMER, CLRPL8
  UTL1    UTILITY ROUTINE
               CALLS SEAK, TRAN
  SEAK    DATA FILES INITILIZATION
               CALLS TRAN
  WRAP    WRAPUP AT END OF RUN
               CALLS SEAK
  TRAN    INPUT/OUTPUT ROUTINE
  ABND    PRINTS ABNORMAL TERMINATION MESSAGES
  TIMER   CALCULATES TIMES, ETC.
               CALLS IDAY, TIME, MODEL, ICLOCK, ITTIME, JOBNUM
  ITTIME  ASSEMBLY LANGUAGE ROUTINE TO RETURN CLOCK TIME
  CLRPL8  ASSEMBLY LANGUAGE ROUTINE TO INITILIZE A SECTION OF THE IBM
          OPERATING SYSTEM
  FLINK   ASSEMBLY LANGUAGE ROUTINE TO EVOLK THE IBM OPERATING SYSTEM
          LINK MACRO
IHCUATBL  THE IBM INPUT/OUTPUT TABLE DEFINING THE FUNCTION OF THE
          LOGICAL UNIT NUMBERS 1 THROUGH 99
```

END OF APPENDIX C

Appendix D: LOCAL COMPUTER FACILITIES

The present hardware at the ORNL and ORGDP sites are described here. First, current charge rates are listed.

Approximate Local Computer Charge

A fixed rate schedule is now in effect, subject to change, as shown in the following list. These rates exclude capital cost recovery charged users when appropriate.

	Basic Rate
IBM 360/195 CPU Time (per hr.)	$250.00
IBM 370/155 CPU Time (per hr.)	50.00
IBM 360/75 CPU Time (per hr.)	30.00
IBM 360/91 CPU Time (per hr.)	150.00
IBM 360/91, 360/195, 360/75, 370/155 Input/Output (per unit)	.0004
IBM 360/91, 360/195, 360/75, 370/155 (per line printed, per card punched)	.0008
IBM 1401 CPU Time (per hr.)	25.00
IBM 360/30 CPU Time (per hr.)	30.00
PDP-10 Misc. Service (per hr.)	40.00
PDP-10 Kilo Core (per hr.)	15.00
PDP-10 Connect Time (per hr.)	6.00
PDP-10 Disk Space (per block per month)	.075
Teleprocessing CPU (per hr.)	110.00
Teleprocessing Connect Time (per hr.)	6.00
TSO CPU Time (per hr.)	30.00
TSO Disk Space (per track per month)	.75
TSO Connect Time (per hr.)	6.00

The Computer Facility at the ORNL Site

Hardware

The Computer facility at the ORNL site consists of an IBM 360/91 and and IBM 360/75 accessed through a PDP-10. The disc storage devices are shared which is not indicated in the following discussion.

A brief description of the equipment configuration for each computer system follows. Some of the terms used are defined here:

a. byte = 8 binary digits and is the smallest addressable unit of memory in the IBM computers
b. K = 1,024
c. ns = nanosecond = 1/1,000,000,000 second
d. μs = microsecond = 1/1,000,000 second
e. b.p.i. = bits per inch

The 360/91 Computer System is made up of the following components:

Quantity	Type	Description
1	2091	Central Processing Unit — basic cycle time is 60 ns.
1	2395	Processor Storage — capacity of 2,048K bytes of which 1,536K is available to the user.
2	2301	Drum storage — used for the operating system; not available to users.
2	2314	Direct Access Storage Facility — auxiliary storage device with a total capacity of 233,408,000 bytes spread over eight removable disk packs. One pack can store 29,170,000 bytes.
4	2401	Magnetic Tape Units — two are 9-track units recording data at 800 b.p.i. Two are 7-track units recording data at 200 b.p.i., 556 b.p.i., or 800 b.p.i.
1	2501	Card Reader — 1,000 cards/minute.

Quantity	Type	Description
1	2540	Card Read/Punch — 1,000 cards/minute reading; 300 cards/minute punching.
3	1403	Printers — 132 characters/line; up to 1,100 lines/minute.
2	2701	Data Adaptor — interfaces to high-speed remote terminals. (NRL, WSAO)
-	-	Various control units for the above auxiliary storage and input/output devices.

The facility is illustrated in Fig. D-1.

The 360/75 Computer System is made up of the following components:

Quantity	Type	Description
1	2075	Central Processing Unit — basic cycle time is 200 ns.
2	2365	Processor Storage — total capacity of 512K bytes with 750 ns access time.
2	2361	Large Core Storage — total capacity of 2,048K bytes with average of 4 μs access time.
1	2314	Direct Access Storage Facility — auxiliary storage of up to 233,408,000 bytes spread over eight removable disk packs. One pack can store 29,170,000 bytes.
8	2311	Disk Units — auxiliary storage of 7,250,000 bytes on each unit.
5	2402 and 2403	Magnetic Tape Units — three are 9-track units recording data at 800 b.p.i. and two are 7-track units recording data at 200 b.p.i., 556 b.p.i., or 800 b.p.i.
1	2540	Card Read/Punch — 1,000 cards/minute reading, 300 cards/minute punching.
1	2520	Card Punch — 500 cards/minute.

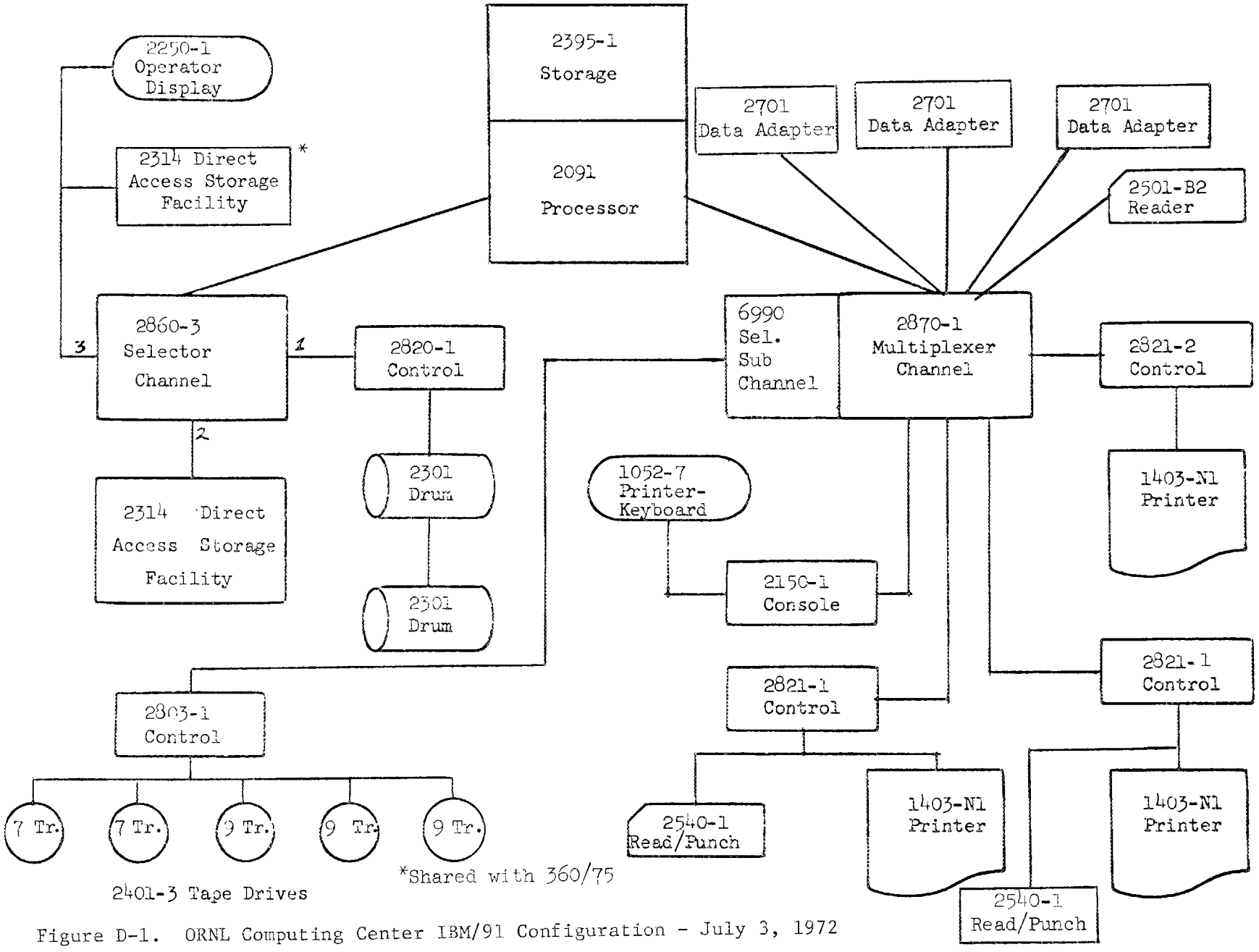


Figure D-1. ORNL Computing Center IBM/91 Configuration - July 3, 1972

Quantity	Type	Description
2	1403	Printers — 132 characters/line, up to 1,100 lines/minute
3	2701	Data Adaptors — interfaces to high-speed remote terminals. (Y-12, ORIC, NRL)
1	2702	Terminal Adaptor — interfaces to low-speed remote terminals.
-	-	Various control units for the above auxiliary storage devices and input/output devices.
1	2321	Data Cell Drive — auxiliary storage of up to 400,000,000 bytes spread over ten removable data cells. One data cell can store 40,000,000 bytes.
1	2914	Switching Unit
1	CCI-7012	Multiplexor (RECON system).
1		Bolt-Beranek-Newman Data Set Control Unit.

The facility is illustrated in Fig. D-2.

The PDP-10 system is made up of the following major components:

Quantity	Type	Description
1	KA10	Central Processor — basic cycle time is 200 nsec.
5	MA10	16K bank core memory, 1 μsec (36 bit word).
3	TU55	DEC tapes.
1	CR10	Card Reader, 1000 cards/minute.
1	CP10	Card Punch, 200-365 cards/minute.
1	LP10C	Line Printer, 1000 lines/minute.
2	TU30A	IBM — 9-track compatible tape.
1	RD10	Swapping Disk; 2,204,000 bytes.
14	RP02	Disk Pack Drive — 23,385,600 bytes per drive.

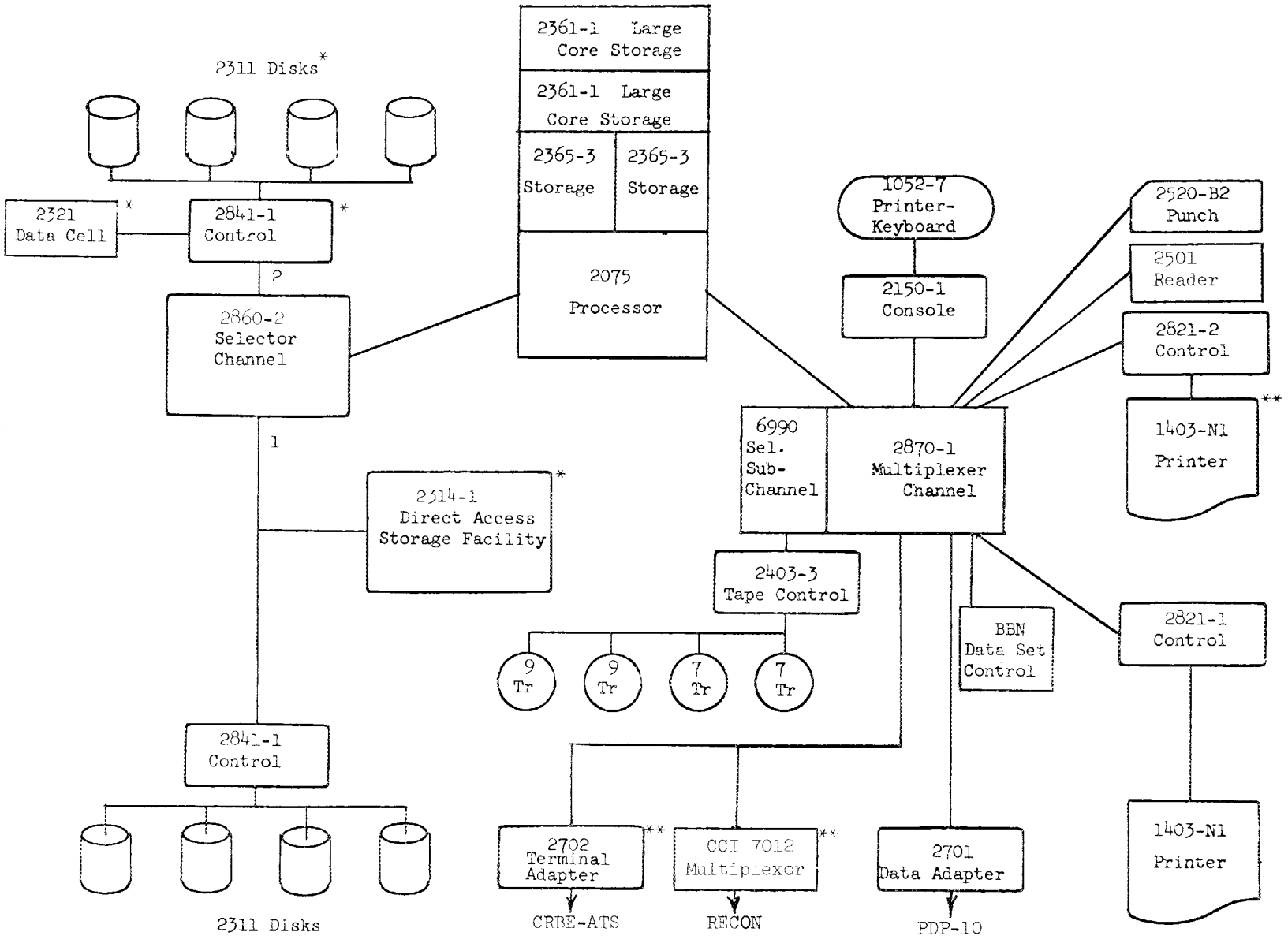


Figure D-2. ORNL Computing Center IBM/75 Configuration - July 3, 1972

Quantity	Type	Description
1	DC10	(2) 8-line Communication Groups (one with dial-up feature.
1	PDP-15/10	Computer for communications control (16K 18 bit words, basic cycle time is 800 nsec).
4	PDP-15/10	Computers for graphical CRT interaction.
4	VT15	CRT Display Unit

Software

A HASP-MVT manager is used to supervise each of the computers. The IBM OS/360 operating system with version 21 of the IBM FORTRAN IV H-Level compiler and the IBM linkage editor are used. Data stored in the LCS on the IBM-360/75 machine may be directly selected in the same sense as data is addressable in fast memory. Even though the cycle time of the LCS is slow compared to that of the fast core (4 μs vs 0.75 μs), we have found that problems using all data stored in the LCS run only about 15% slower than they do using data stored exclusively in fast core.

Computer Facility Use

The IBM-360/91 and IBM/360/75 computers are operated under "MVT" multi-job tasking.

A loaded machine language program is stored on a disk. The program is called into fast core with control cards when a job is started and once control is transferred to the program, it has full control until the job is completed. The operator has no way of on-line control over program instructions (other than abortion). Machine CP time used on any job is available for programmed instructions to allow some user control of machine time use. Alternatively, a program may be loaded from the version of the code consisting of hex cards for each routine, and the user may provide FORTRAN or machine language subroutines which override those on the disk. Thus a user may easily replace instructions with

others more appropriate to his problem provided these are carefully presented in a form consistent with the rest of the program.

On Precision

Although some calculations are done with 4-byte words which give nearly 7 decimal digits significance, most are done in "double precision," as frequently required to obtain significant results, using 8 bytes which gives just over 17 decimal digits significance. The significance indicated here is that carried in calculations. (There is also round-off from decimal to binary representation which may cause simple sums to indicate greater loss in significance than actually occurs in calculations.) Many calculations can be done quite adequately with less than 7 decimal digits significance, but often subtractions which cause loss of several digits significance produce poor results. One example of difficulty is that which occurs when two iterate sets of flux values are to be extrapolated, and this extrapolation is based on the change in values. Loss of significance in differences becomes serious even at relatively small loss of significance in the individual values. It is especially bad because round-off is done at the hexadecimal number level on the IBM machines rather than the binary number level.

The Computer Facility at the ORDGP Site

Hardware

The computer facility at the ORDGP plant site consists of an IBM-360/195 primary computer driven by an IBM-370/155. The equipment is illustrated in Fig. D-3. Not shown is remote entry available from the ORNL Computing Center. The 3330 disc units have 10^8 byte storage capacity, but dedication of space reduces availability to 40×10^6 bytes, 10^7 short words.

Software

An ASP-MVT manager supervises the intercoupled computers in a multitasking mode allowing several tasks or jobs to be resident simultaneously and execution to pass from one to another. Each computer has its equivalent of an IBM OS/360 operating system. The IBM FORTRAN IV H-level version 21 compiler and linkage editor are used.

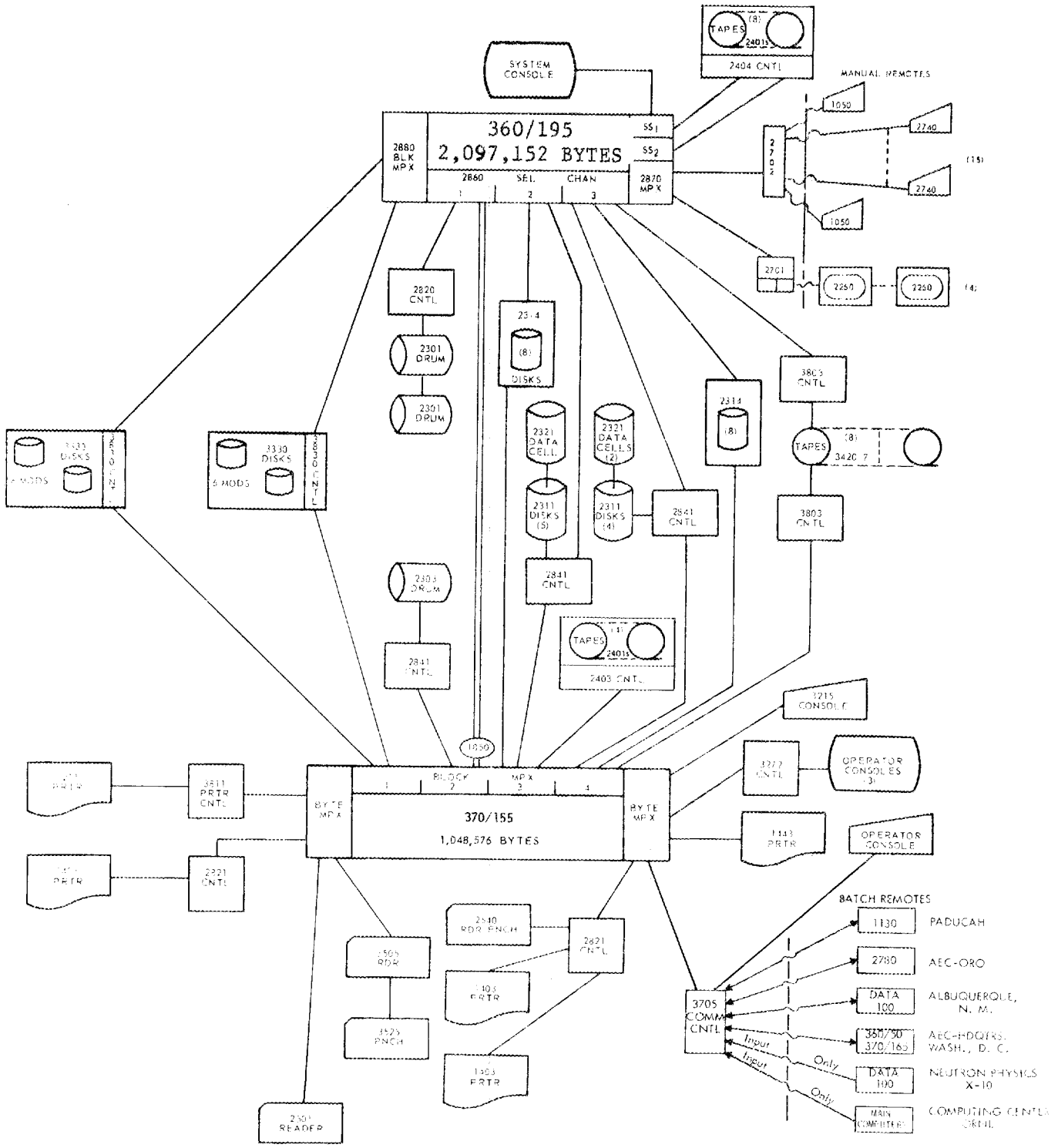


Fig. D-3. ORDGP Computer Facility

Central Processing Units

360/195 - Main Processor (2,097,152 bytes)

370/155 - Support and Main Processor (1,048,576 bytes)

Channels

360/195 - Three Selector Channels
One Block Multiplexor Channel
One Multiplexor Channel

370/155 - Four Block Multiplexor Channels
Two Byte Multiplexor Channels

I/C Devices

Shared - One 3330 8 Spindle Disk Drive
One 3330 6 Spindle Disk Drice
Two 2314 8 Spindle Disk Drives
Four 2311 Disk Drives
Three 2321 Data Cell Drives
Eight 3400 Tape Drives (Dual 800-1600 bpi)

360/195 - Five 2420 9 track Tape Drives
Two 2400 7 track Tape Drives

370/155 - One 2400 9 track Tape Drive
Three 2400 7 track Tape Drives
One 3211 Printer
Two 1403-N1 Printers
One 3505 Card Reader
One 2501 Card Reader
One 2540 Card Reader/Punch
One 3525 Card Punch

Remote JOB Entry

370/155 - IBM 1130 Computer (Paducah)
IBM 3780 Terminal (Paducah)
IBM 2780 Terminal (ERDA-ORO)
IBM 360/50 - 370/165 (ERDA-HDQ)
PDP-11 (Goodyear Atomics Corp.)
IBM 360/50 (Y-12)
IBM 360/50 (Air Research)
360/75, 360/91, PDP-Complex (ORNL Computing Center)
Input only

Teleprocessing Terminals

360/195 - Twelve 2740 Terminals
Three 1050 Terminals
Four 2260 Terminals

Operator Consoles

360/195 - One 2250 Console (CRT)

370/155 - Three 3275 Consoles (CRT)
One 3215 Console
One 1443 Printer

In addition, a 2540 card reader/punch and/or one or two 1403 printers which are normally on-line to the 360/30 can be switched to the 370/155.

The Computer Sciences Division Computer Network

Figure D-4 shows the network of computers presently in operation at the ORNL, ORGDP, and the Y-12 sites, which obsoletes the connections shown in the previous figures.

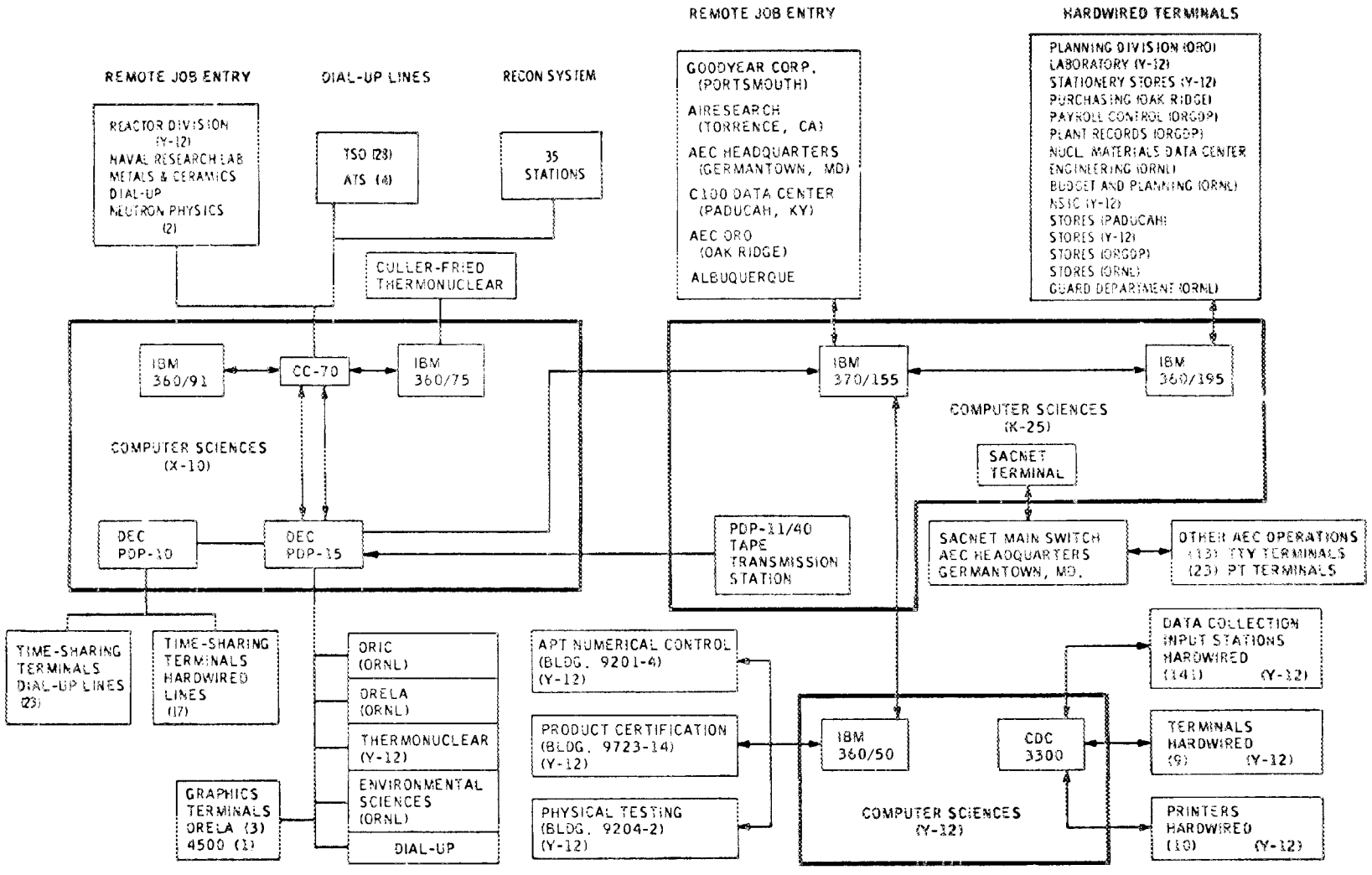


Fig. D-4. Computer Sciences Division Computer Network

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