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A REVISION OF MUTUAL, A COMPUTER CODE FOR ANALYSING NUCLEAR CRITICALITY SAFETY ON ARRAY SYSTEM

October 1989

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A Revision of MUTUAL, A Computer Code for Analysing Nuclear Criticality Safety on Array System

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MUTUAL is a computer code for analysing nuclear criticality safety on array system. Its original version was published in 1986. It has been revised in the following three aspects: (1) the input format has been changed from the original BOX-type to the absolute coordinate type; (2) the eigen equation has been changed to obtain the maximum eigenvalue from that to obtain the minimum; (3) subroutines to calculate solid angles have been improved to correctly take into account the contribution to the solid angles from imaginary units. This report is a user's manual of the revised MUTUAL code.

Keywords: Criticality Safety, Array, Effective Multiplication Factor, Solid Angle Method, Shadow, Reflection, Computer Code, MUTUAL, Revision

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配列体系の臨界安全解析コード MUTUALの改訂

日本原子力研究所東海研究所燃料安全工学部
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（1989年9月12日受理）

MUTUALは配列体系の臨界安全解析コードである。その原版は1986年に公開された。以下の3点においてMUTUALを改訂した。(1)入力形式をボックス型から絶対座標型に変更した。(2)固有値方程式を最小固有値を求めるものから最大固有値を求めるものに変更した。(3)立体角を計算するサブルーチンで，鏡像ユニットからの寄与分が正しく取入れられるように改めた。この報告書は，改訂後のMUTUALの使用手引書である。

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1. Introduction

A computer code MUTUAL was developed to analyse nuclear criticality safety on array system, and was published in 1986[1]. This code has merits over the solid angle method[2] that 1) the effective multiplication factor is obtained, 2) the theoretical base is clear, 3) effects from shadowed units and reflector can be easily taken into account. The computational CPU-time of MUTUAL by FACOM M380 is less than a few seconds, which is roughly 2 orders shorter than that of KENO-IV[3], a typical Monte Carlo code, to obtain a reliable result. For these reasons, MUTUAL has been introduced in the Criticality Safety Handbook of Japan which was published in 1988[4].

Some difficulties, however, have been pointed out in using MUTUAL:

(1) BOX-type input form[5] is not easily handle, especially when applied to mixtures of various types of unit.

(2) The subroutine EJERBES[6] adopted in MUTUAL for obtaining the minimum eigenvalue is not easy to be introduced in computer system other than JAERI's.

Also an error is found in the subroutine SOLIDA which has a role to transmit reflector albedo to the main routine.

The original MUTUAL code has therefore been revised in the following three aspects: (1) the input format has been changed from the original BOX-type to the absolute coordinate type; (2) the eigenvalue equation has been changed to obtain from the minimum to the maximum eigenvalue; (3) the subroutines SOLIDA, SOLID2 and SOLID3 have been improved to correctly take into account contributions to the solid angle from image units;

Like the original manual, the basic equation expressing the neutron balance among fissile units is shown in Chapter 2. The logical flow of the program is summarized in Chapter 3. Limitations of the program as well as input and output data informations are explained in Chapter 4. Sample inputs and outputs are shown in the last Chapter.

2. Theory

2.1 Derivation of Eigenvalue Equation

The neutron balance equation of the array system which consists of nuclear fuel units is represented as follows. The neutron balance for unit i is expressed as,

$$\int_{Ai}(D_i\nabla\phi_i\cdot e_i)dA_i - \int_{Vi}\Sigma_{ai}\phi_i dV + \frac{1}{\lambda}\int_{Vi}\nu\Sigma_{fi}\phi_i dV + t_{1i} + \cdots + t_{ni} = 0 \quad (1)$$

where $t_{ji} = -\int_{Vj}D_j\nabla^2\phi_j dV\cdot\int(e_i\cdot e_r)dA_i/4\pi r^2$,

$\int_{Ai}(D_i\nabla\phi_i\cdot e_i)dA_i$: neutron leakage from unit i,

$\int_{Vi}\Sigma_{ai}\phi_i dV$: neutron absorption in unit i,

$\int_{Vi}\nu\Sigma_{fi}\phi_i dV$: neutron production in unit i,

λ : eigenvalues whose maximum corresponds to the effective multiplication factor of the system,

r : distance between the center of unit j and the dA_i surface,

e_r : unit vector directing from the center of unit j to the dA_i surface,

e_i : unit vector perpendicular to the dA_i surface,

dA_i : differential area on the surface of unit i.

The equation (1) can be represented as a matrix form by using the following three approximations.

(i) Even if there were neutron interactions among units, the neutron flux distribution in each unit is assumed to be as the same as that without interaction. Namely, neutron leakage from unit i in an array system is approximated as follows in terms of the buckling B_i^2 of unit i, in isolation from the other units:

$$\int_{Ai}(D_i\nabla\phi_i\cdot e_i)dA_i = \int_{Vi}D_i\nabla^2\phi_i dV_i \simeq -\int_{Vi}D_iB_i^2\phi_i dV_i \ . \quad (2)$$

(ii) Neutrons are assumed to be emitted isotropically from the center of each unit; the transportation probability t_{ji} from unit j to unit i is approximated as,

$$t_{ji} \simeq \int_{Vj}D_jB_j^2\phi_j dV_j\omega_{ji} \ , \quad (3)$$

where ω_{ji} is a fractional solid angle defined by a quatient of Ω_{ji}, a solid angle subtended at the center of unit j by unit i, devided by 4π.

(iii) All neutrons emitted from other units into a specific unit are assumed to be absorbed in it.

It should be noticed that the effective multiplication factor of the system is underestimated by the assumptions (i) and (ii), whereas is overestimated by the assumption (iii).

Under the above approximations, the neutron balance equation (1) can be rewritten as,

$$(-D + T + \frac{1}{\lambda}P)\phi = 0, \tag{4}$$

where

$$D = \begin{bmatrix} d_1 & & 0 \\ & \ddots & \\ 0 & & d_n \end{bmatrix}, \quad T = \begin{bmatrix} T_{11} & \cdots & \\ & \ddots & \\ \cdots & & T_{nn} \end{bmatrix}, \quad P = \begin{bmatrix} P_1 & & 0 \\ & \ddots & \\ 0 & & P_n \end{bmatrix}, \quad \phi = \begin{bmatrix} \phi_1 \\ \vdots \\ \phi_n \end{bmatrix},$$

$d_i = \{(DB^2)_i + \Sigma_{ai}\}V_i$: neutron destruction operator for unit i,

$T_{ij} = (DB^2)_j V_j \omega_{ji}$: neutron transportation operator from unit j to unit i,

$P_i = \nu\Sigma_{fi}V_i$: neutron production operator for unit i,

ϕ_i : averaged neutron flux for unit i,

And matrices K and I are respectively defined as follows:

$$PD^{-1} \equiv K = \begin{bmatrix} k_1 & & 0 \\ & \ddots & \\ 0 & & k_n \end{bmatrix}, \quad I = \begin{bmatrix} 1 & & 0 \\ & \ddots & \\ 0 & & 1 \end{bmatrix}, \tag{5}$$

where k_i is the effective multiplication factor of an isolated unit i.

The following equation is derived from Eq.(4).

$$\frac{1}{\lambda}(PD^{-1})(D\phi) = (I - TD^{-1})(D\phi) \tag{6}$$

The above equation can be rewritten with the matrix K and a matrix A as

$$(I - A)^{-1}K(D\phi) = \lambda(D\phi) \tag{7}$$

Equation (7) is the eigenvalue equation to be solved, where the matrix A is defined by TD^{-1} and its element a_{ij} can be represented as follows using the relation $M^2 = D/\Sigma_a$,

$$a_{ij} = \frac{T_{ij}}{d_j} = \frac{(M^2B^2)_j \omega_{ji}}{1+(M^2B^2)_i} \tag{8}$$

The multiplication factor of the array system is obtained by solving Eq.(7) as the maximum eigenvalue of the matrix $(I-A)^{-1}K$.

2.2 Calculation of Solid Angle

The solid angle subtended at the center of unit j by unit i is equal to an area of the image of unit i on the unit sphere from the viewpoint of the center of unit j. As an example, the calculation method for cylindrical unit is being explained. The diameter and height of cylindrical unit i is expressed as D and H, respectively. And the distance from the center of unit j to the surface of unit i is defined as L. Using the spherical coordinate whose origin is set to the center of unit j, the solid angle is obtained by integrating $\sin\theta d\theta d\phi$ over the area surrounded by a curve J in Fig. 1, defined by the following relation:

$$\tan\theta = \{(2(L+D/2))/H\}\{\sin\phi \pm \sqrt{((D/2)/(L+D/2))^2-\cos^2\phi}\} \tag{9}$$

Calculating the solid angle with this curve is disadvantageous with respect to computing time, because numerical integration must be performed. To reduce computing time, and to obtain an evaluation on safety-side, solid angle is assumed to be obtained by integrating $\sin\theta d\theta d\phi$ over the rectangular ABCD in Fig. 1.

2.3 Calculation of Partially Shadowed Area

The effect of "shadow" caused by other units is considered in calculating a solid angle as shown in Fig. 2. That is, in calculating the solid angle at unit j subtended by unit i if the unit k is between the two units, the unit k causes a "shadow" on the unit j, the corresponding solid angle is subtracted. Therefore, the solid angle corresponding to the area S=EFGH shown in Fig. 1 is subtracted from the area ABCD. This relation is expressed as

$$\Omega'_{ji} = \Omega_{ji} - \iint_S \sin\theta d\theta d\phi$$

2.4 Consideration of Neutron Reflection by Wall

If the specific unit is surrounded by the wall, the contribution of neutron reflection by the wall is considered. In this case, image units are added to the system in order to take into account the effect of neutron reflection. The transportation operator t'_{ji} from the image unit j' of the unit j to the unit i is given as

$$t'_{ji} = (DB^2)_j V_j \phi_j \beta' \omega'_{ji}$$

where β' is albedo of the wall. If there are walls in many sides, the operators are added with respect to every direction. The total transportation operator t'_{ji} can be written as

$$t'_{ji} = t_{ji} + \text{Sum } t_{j'i}$$
$$= (DB^2)_j V_j \phi_j (\omega_{ji} + \beta' \omega_{j'i} + \beta'' \omega_{j''i} + \cdots)$$

Therefore in calculating t_{ji} in Eq.(7), the solid angle fraction

$$\omega'_{ji} = \omega_{ji} + \beta' \omega_{j'i} + \beta'' \omega_{j''i} + \cdots$$

should be the substitute for ω_{ji} as shown in Fig. 3.

2.5 Reaction Rates

Various quantities of reaction rates, which are optional outputs, are explained hereafter. As shown in Eq.(7), the eigenvector has been defined as a quantity of neutron destruction, i.e., leakage plus absorption. Therefore, reaction rates of unit i can be written as follows with element i of the eigenvector,

$$X_i = D_i \phi_i = \{(DB^2)_i + \Sigma_{ai}\} V_i \phi_i ,$$

$$A_i = \Sigma_{ai} V_i \phi_i = X_i / \{1 + (M^2 B^2)_i\} ,$$

$$L_{out,i} = (DB^2)_i V_i \phi_i = A_i (M^2 B^2)_i ,$$

$$L_{in,i} = \underset{j}{\text{Sum}} (\omega_{ji} L_{out,j}) ,$$

$$L_{net,i} = L_{out,i} - L_{in,i} ,$$

$$F_i = k_{\infty,i} A_i / k_{eff} ,$$

where A_i : absorption in unit i,

$L_{out,i}$: leakage from unit i,

$L_{in,i}$: leakage into unit i from all other units,

$L_{net,i}$: net leakage for unit i,

F_i : fission in unit i,

$k_{\infty i}$: infinite-medium multiplication factor of unit i,

k_{eff} : effective multiplication factor of the array system.

Absolute value of each quantity is normalized as,

$$\mathrm{Sum}_i(A_i + L_{net,i}) = 1.$$

2.6 Indices of Neutron interaction

The following three index parameters are also calculated to measure an amplitude of the neutron interaction.

i) the maximum solid angle fraction among two units, max ω_{ji}

ω_{ji} : a solid angle subtended at the center of unit j by unit i

ii) difference between the neutron leakage rate of the single unit and that in the array system η

$$\eta = \frac{\sum_i \eta_i F_i}{\sum_i F_i}$$

η_i : η value of unit i

F_i : fission rate of unit i

and

$$\eta_i = \frac{L_i}{A_i} - \frac{L_{i,A}}{A_{i,A}}$$

$$= \frac{1}{k_i}\frac{F_i}{A_i} - \frac{1}{k_A}\frac{F_{i,A}}{A_{i,A}}$$

$$= k_{\infty,i}\left(\frac{1}{k_i} - \frac{1}{k_A}\right)$$

where

$$k_{\infty,i} \equiv \frac{F_i}{A_i} \simeq \frac{F_{i,A}}{A_{i,A}}$$

L_i : neutron leakage from unit i

A_i : neutron absorption in unit i

$L_{i,A}$: neutron net leakage from unit i in array system

$A_{i,A}$: neutron absorption in unit i in array system

k_i : effective multiplication factor of unit i

k_A : effective multiplication factor of array system

iii) ratio of the neutron leakage from the other unit and the fission neutron

$$\theta = \frac{\sum_i \left(\sum_j L_j \omega_{ji} / F_i\right) L_{i,out}}{\sum_i L_{i,out}}$$

where L_j : neutron leakage from unit j

ω_{ji} : solid angle fraction subtended at the center of unit j by unit i

F_i : neutron fission of unit i

$L_{i,out}$: neutron leakage from unit i to out of the system

$$L_{i,out} = L_i \left(1 - \sum_j \omega_{ij}\right)$$

3. Structure of Program

3.1 Logical Program Flow

3.1.1 Reat Input Data

Input data are read by subroutine CRDIN. Subroutine GTYPE1 deals with geometrical data. All input data are echoed back.

3.1.2 Check, Edit and Print Input Data

Input data are edited and printed out by subroutine CRDPRT. The geometrical configuration of units is checked by subroutine GEOCHK.

3.1.3 Calculation of Solid Angle

At first, direction vector is calculated from the center of a specific unit to other units. The coordinates of the center of each unit are given by input data. Subroutine RELATV calculates relative coordinates of the centers of two units. The center of the specific unit is assumed to be the origin of the spherical coordinate system to describe the location. The coordinate of a shadow on the unit sphere projected by the specific unit is calculated. Then subroutines CUBOID and CYLNDR are respectively used for a cuboid and a cylinder. The subroutine which calculates the solid angle from the coordinate as mentioned above is SOLID2 for a cylinder and SOLID3 for a cuboid. If there is a reflector, the location of the image unit is calculated by subroutine SOLIDA. Subroutine SOLIDA controlls the subroutines and prints out the calculated solid angles.

3.1.4 Calculation of Eigenvalue and Eigenvector

Subroutine EIGEN calculates the coefficient matrix for the eigenvalue equation and solves the equation in subroutine MULMS.

3.2 Tree Structure of Program

The tree structure of MUTUAL is shown in Fig. 4.

3.3 Alphabetical Subroutine Summary

The following is a list of subroutine summaries. The symbol (F) after the subroutine name indicates that it is a function routine.

ANORM (F)

ANORM calculates a distance between two points.

BDYCHK

This subroutine examines whether a face of each unit crosses the boundary box or not.

CRDIN

This subroutine reads the input data.

CRDIN2

CRDIN2 calculates the rest of the three nuclear data, i.e. the infinite multiplication factor k_∞, effective multiplication factor k_{eff} and leakage ratio M^2B^2, from the other two which have been input.

CRDPRT

This subroutine edits and prints input data and control subroutines which check the data.

CUBCHK

CUBCHK checks geometrical data for cuboids.

CYLCHK (entry name of subroutine CUBOID)

This procedure checks geometrical data for cylinders.

CUBCUB

This subroutine examines whether two cuboidal units are separate.

CUBCYL

This subroutine examines whether a cuboidal unit and a cylindrical unit are separate.

CYLCYL

This subroutine examines whether two cylindrical units are separate.

CUBOID

This subroutine calculates the coordinate points of a shadow on unit sphere projected by a cuboid.

CYLNDR

This subroutine calculates the coordinate points of a shadow on the unit sphere projected by a cylinder.

DAYTIM

DAYTIM gets data and time with library routine DATE and TIME.

DOMEG1

This subroutine gets the overlapped part with respect to ϕ coordinate in two integral regions in calculating "shadow" between two units.

DOMEG2 (entry name DOMEG1)

This subroutine gets the overlapped part with respect to θ coordinate as subroutine DOMEG1.

DOMEG3

This subroutine calculates a "shadow" for a cuboid.

DTLIST

This subroutine echoes back the input data.

EDIT1

This subroutine evaluates criticality safety of the system with the method described in CEA-R-3114[7], and prints out the result.

EDIT2

This subroutine calculates and prints out reaction rates.

EIGEN

This subroutine calculates the coefficient matrix from the solid angle between units and nuclear constant data, and calls subroutine MULMS to solve the eigenvalue equation.

CEOCHK

This subroutine controls the subroutines CUBCHK, BDYCHK, CUBCUB, CUBCYL, CYLCHK and CYLCYL for geometrical examinations.

GTYPE1

This subroutine processes geometrical data.

HEADER

This subroutine prints out the problem title with data and time.

MAIN

MAIN program defines the maximum number of units and controls the whole flow of computation.

MULMS

This subroutine solves the eigenvalue equation by the power method. The iteration for the power method is judged to be converged when the relation below is satisfied:

$$\underset{i}{\mathrm{Mix}} \left| \psi_i^{n} - \psi_i^{n-1} \right| / \psi_i^{n-1} \leqq \varepsilon \ ,$$

where ψ_i^{n} is the i-th element of n-th trial function of $D\phi$. The maximum number of iterations and ε are set 100 and 10^{-5}, respectively in the subroutine.

MULM

This subroutine calculates $(1-A)^{-1}K\psi^{n}$, where ψ^{n} is the n-th trial function of $D\psi$. The inverse of the matrix $(1-A)^{-1}$ is calculated by the power method. The convergence criterion is set as same as subroutine MULMS.

NOTEQ (F)

This function is equivalent to the relational operator ".NE." (in FORTRAN) for single precision real type variables.

EQUAL (entry name of NOTEQ)

This function is equivalent to the relational operator ".EQ." (in FORTRAN) for single precision real type variables.

DNOTEQ (entry name of NOTEQ)

This function is equivalent to the relational operator ".NE." (in FORTRAN) for double precision real type variables.

DEQUAL (entry name of NOTEQ)

This function is equivalent to the relational operator ".EQ." (in FORTRAN) for double precision real type variables.

OMCYL1 (F)

This function calculates a solid angle with θ and ϕ coordinates.

OMCYL2 (F)

This function calculates the solid angle of overlapped part in two integral regions.

RCLEAR

This subroutine sets single precision real type array eqaul to a constant value.

DCLEAR (entry name of RCLEAR)

This procedure sets double precision real type array equal to a constant value.

ICLEAR (entry name of RCLEAR)

This procedure sets an integer type array equal to a constant value.

CCLEAR (entry name of RCLEAR)

This procedure sets character type array equal to a constant value.

RELATV

This subroutine calculates relative coordinates of two space-points.

SOLIDA

This subroutine controls subroutines which are used to calculate solid angles.

SOLID2

This subroutine calculates a solid angle with coordinate of a shadow on unit sphere projected by a cylinder.

SOLID3

This subroutine calculates a solid angle with coordinate of a shadow

on unit sphere projected by a cuboid.

SORT

This subroutine performs quick sorting for single precision real type arrays.

SORTD

This subroutine performs quick sorting for double precision real type arrays.

DATE

This subroutine gets the running date.

TIME

This subroutine gets the running time.

4. Program Usage

4.1 Limitations

4.1.1 Limitations of Available Geometry Shape and Location

Cylinder, cube and cuboid are available as a geometrical shape of a unit. Cylinder should be so located as their center lines parallel to the z-axis. Cube and cuboid should be located so that any edge of them parallel to either x-, y- or z-axis.

4.1.2 Dimension of Array

Dimension of arrays in the code is determined by PARAMETER statement in MAIN routine. The present value of the maximum number of units in the system is 100. Therefore, the value in the statement must be changed, when the array size is short of capacity.

4.2 Input Data Instructions

Card 1 Title Card (A80)

TITLE Contains title only. When the first column is blank, the reaction rates explained in Section 3.5 are not calculated.

Card 2 Unit Number Card (13)

NUNIT Number of units

Card 3 Unit Shape and Location Card (I3, 1X, A8, 3E12.5)

1 ID Unit identification number arbitrarily chosen by the user.

2 CT1 Geometrical shape, which must be chosen among "CUBE", "CUBOID" and "CYLINDER".

3 ALOC(1) x-coordinate of the center of unit [cm].

4 ALOC(2) y-coordinate of the center of unit [cm].

5 ALOC(3) z-coordinate of the center of unit [cm].

Card 4 Dimension Card for Unit (12X, 3E12.5)

1 LPARAM(1) Length for CUBE, length in x-direction for CUBOID and diameter for CYLINDER [cm].

2 LPARAM(2) Length in y-direction for CUBOID and height for CYLINDER [cm].

3 LPARAM(3) Length in z-direction for CUBOID [cm].

Card 5 Nuclear Constant Data Card for Unit (12X, 3E12.5)

1 SQMK(1) M^2B^2 for the unit.

2 SQMK(2) Effective multiplication factor k_{eff} for the unit.

3 SQMK(3) Infinite multiplication factor k_{inf} for the unit.

NOTE 1: Only two of SQMK must be input. The other one is calculated automatically from the input data.

NOTE 2: Card 3 ~ Card 5 should be repeated NUNIT (Cf. Card 2) times.

Card 6 Boundary Location Card (4X, A8, 3E12.5)

1 CT2 Must be "BOUNDARY".

2 SALOC(1) x-coordinate of the center of a cuboidal box forming boundary [cm].

3 SALOC(2) y-coordinate of the center of a cuboidal box forming boundary [cm].

4 SALOC(3) z-coordinate of the center of a cuboidal box forming boundary [cm].

Card 7 Boundary Dimension Card (12X, 3E12.5)

1 SGPARM(1) Length in x-direction of the boundary box [cm].

2 SGPARM(2) Length in y-direction of the boundary box [cm].

3 SGPARM(3) Length in z-direction of the boundary box [cm].

Card 8 Reflector Constand Card (6E12.5)
The value of the reflector constant is the specular albedo, that is, the fractional return for that face.

1 BETA(1) Reflector constant for +x-face of the boundary box.

2 BETA(2) Reflector constant for -x-face of the boundary box.

3 BETA(3) Reflector constant for +y-face of the boundary box.

4 BETA(4) Reflector constant for -y-face of the boundary box.

5 BETA(5) Reflector constant for +z-face of the boundary box.

6 BETA(6) Reflector constant for -z-face of the boundary box.

Card 9 End Card (A10)

CT3 Must be either "END CASE" or "END MUTUAL". "END CASE" enables MUTUAL to start reading following cards and calculating for a new case. "END MUTUAL" terminates the

calculations.

4.3 Output Data Informations

A sequential number is assigned automatically to each unit in the order of input. This number as well as the identification number given by user, geometrical shape, size, coordinates of the center of unit and nuclear constant data are printed out. Calculated fractional solid angles of units subtended by each other are printed out using the assinged numbers. Then, a relative error in each iteration step to solve the eigenvalue equation and the corresponding eigenvalue are printed out. The final result obtained is the effective multiplciation factor (k_{eff}) of the system.

Neutron balances for each unit, i.e. absorption, fission, out-leakage, in-leakage and net leakage are optionally printed out. "Out-leakage" means a quantity of neutrons escaping from the specific unit. "In-leakage" means that reaching the specific unit from the all others.

The three index parameters shown in 2.6 are also optionally printed out to measure an amplitude of the neutron interaction.

5. Sample Input and Output

Input data for a sample problem is shown in Fig. 5. This problem is a 3×3×2 array of identical cuboids. The result is shown in Fig. 6, and its JCL is shown in Fig. 7.

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2) "Nuclear Safety Guide, TID-7016, Revision 2", NUREG/CR-0095, ORNL/NUREG/CSD-6, Oak Ridge National Laboratory (1978).
3) L.M. PETRIE and N.F. CROSS, "KENO IV-An Improved Monte Carlo Criticality Program", ORNL-4938, Oak Ridge National Laboratory(1975).
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5) Yoshitaka NAITO, Masahiko YOKOTA and Koh NAKANO, "MULTI-KENO: A Monte Carlo Code for Criticality Safety Analysis", JAERI-M 83-049 (1983).
6) Toichiro FUJIMURA and Tsuneo TSUTSUI, "EISPACK-J: Subprogram Package for Solving Eigenvalue Problems", JAERI-M 8253(1979).
7) "Guide de Criticité", CEA-R-3114, Centre d'Études Nucléaires de Saclay (1967).

5. Sample Input and Output

Input data for a sample problem is shown in Fig. 5. This problem is a 3×3×2 array of identical cuboids. The result is shown in Fig. 6, and its JCL is shown in Fig. 7.

Acknowledgements

The authors wish to express their thanks to Mr. M. Ishitobi of MMC for his valuable suggestion on the change of input forms and also to Dr. Y. Nomura of JAERI for his careful reading of the manuscript.

References

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7) "Guide de Criticité", CEA-R-3114, Centre d'Études Nucléaires de Saclay (1967).

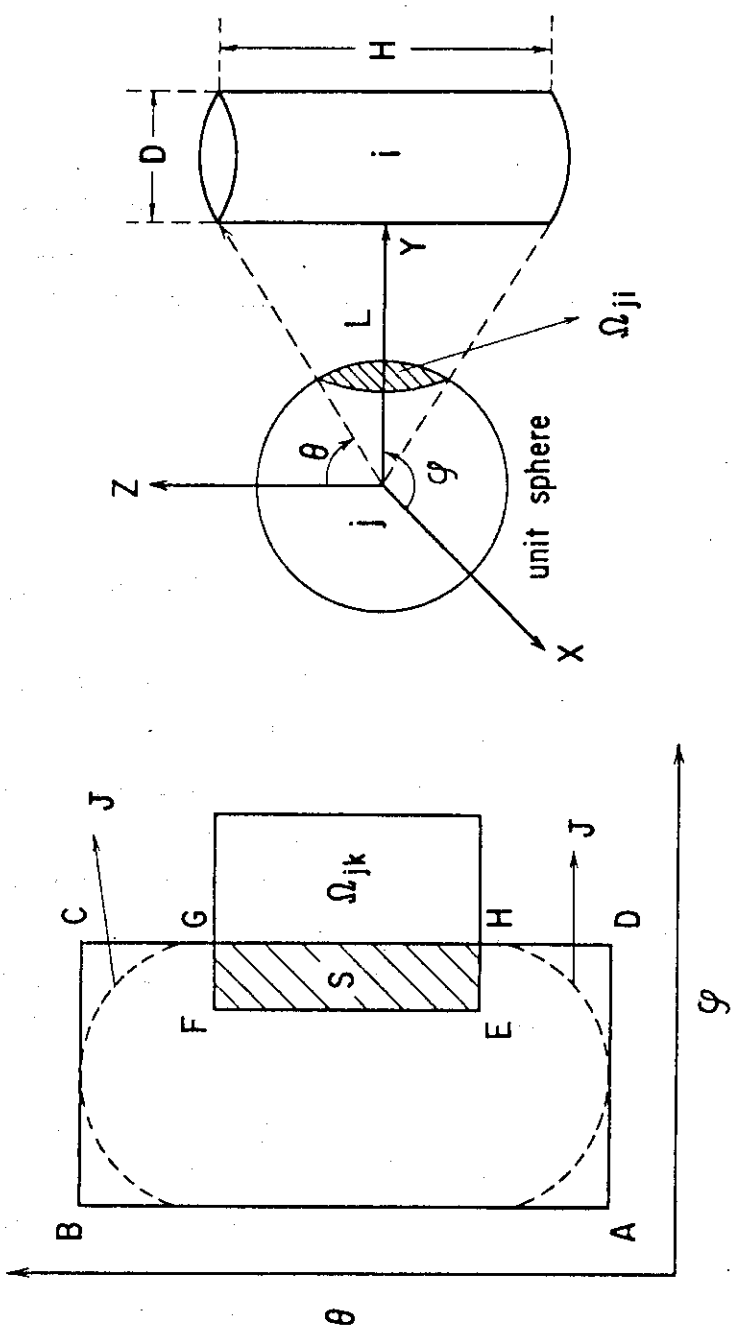


Fig. 1 Calculation Method of Solid Angle

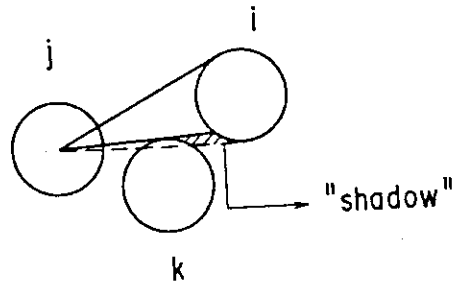


Fig. 2 Effect of "shadow"

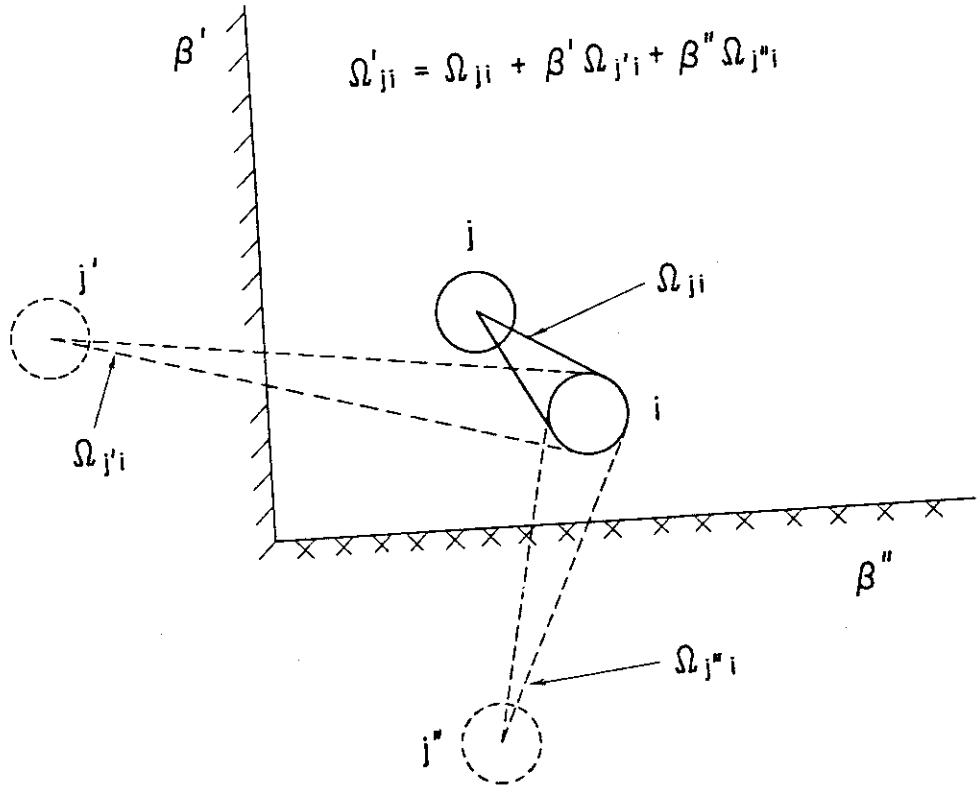
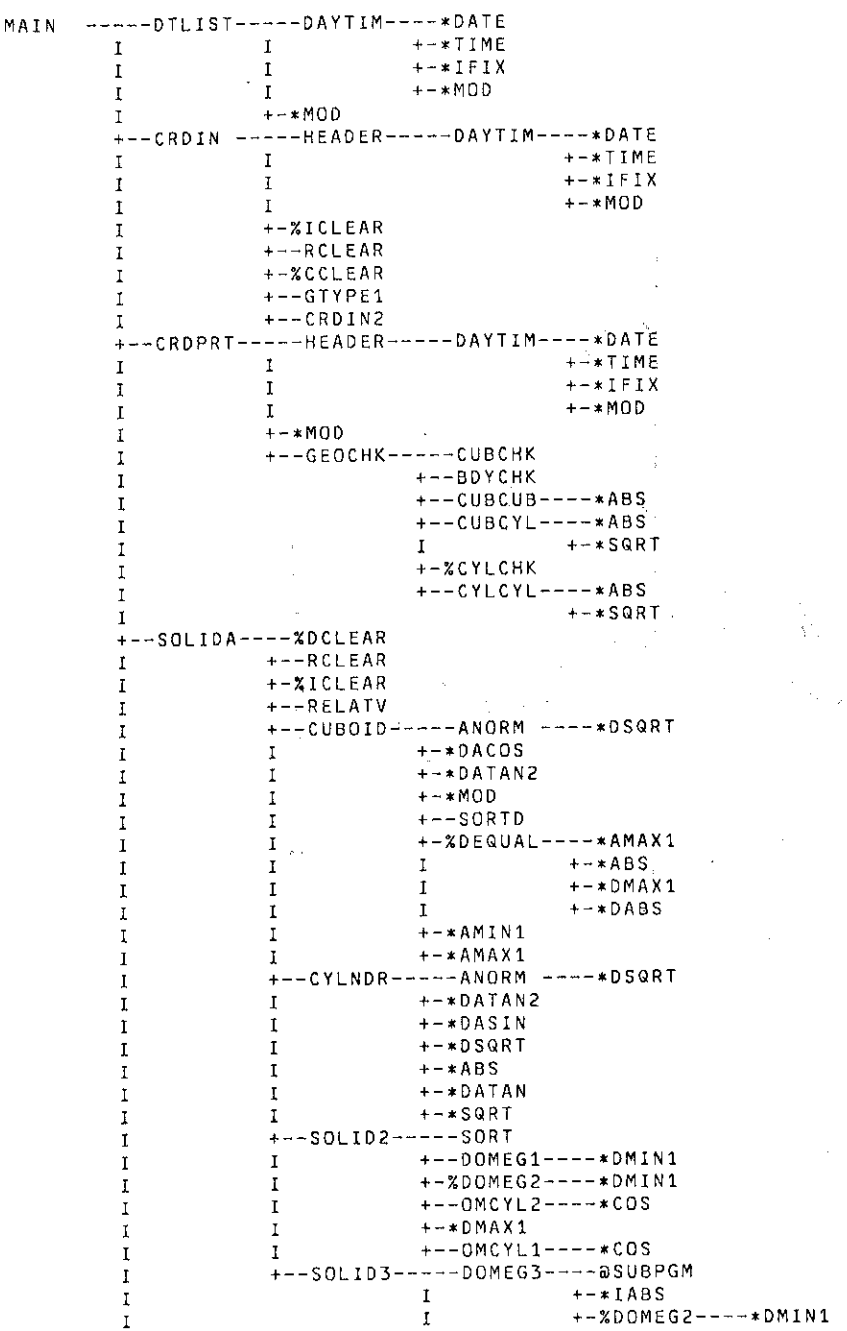
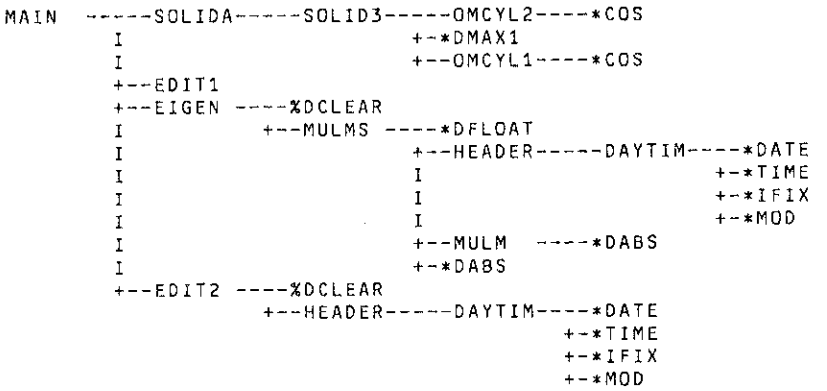


Fig. 3 Effect of Wall





Note * : library routine

% : entry name

@ : external procedure name

Fig. 4 The Structure of Program

```
                    **********************
                    *                    *     DSN = J3755.SAMPLE.DATA(MUTUAL)    PAGE    1
                    *   INPUT DATA LIST  *
                    *                    *     DATE  89/05/09  TIME  11:49:00
                    **********************
    ....*....1....*....2....*....3....*....4....*....5....*....6....*....7....*....8
** CUBOID 3X3X2 (50CM) 20GU/L H/U=1.0 (21.8CM,21.8CM,100CM) **
18
 1 CUBOID          0.      0.      0.
                  21.8     21.8   100.0
                           0.70878 1.469
 2 CUBOID          0.     71.8     0.
                  21.8     21.8   100.0
                           0.70878 1.469
 3 CUBOID          0.     143.6     0.
                  21.8     21.8   100.0
                           0.70878 1.469
 4 CUBOID         71.8      0.      0.
                  21.8     21.8   100.0
                           0.70878 1.469
 5 CUBOID         71.8     71.8     0.
                  21.8     21.8   100.0
                           0.70878 1.469
 6 CUBOID         71.8     143.6     0.
                  21.8     21.8   100.0
                           0.70878 1.469
 7 CUBOID        143.6      0.      0.
                  21.8     21.8   100.0
                           0.70878 1.469
 8 CUBOID        143.6     71.8     0.
                  21.8     21.8   100.0
                           0.70878 1.469
 9 CUBOID        143.6     143.6     0.
                  21.8     21.8   100.0
                           0.70878 1.469
10 CUBOID          0.      0.    150.0
                  21.8     21.8   100.0
                           0.70878 1.469
11 CUBOID          0.     71.8   150.0
                  21.8     21.8   100.0
                           0.70878 1.469
12 CUBOID          0.     143.6   150.0
                  21.8     21.8   100.0
                           0.70878 1.469
13 CUBOID         71.8      0.    150.0
                  21.8     21.8   100.0
                           0.70878 1.469
14 CUBOID         71.8     71.8   150.0
                  21.8     21.8   100.0
                           0.70878 1.469
15 CUBOID         71.8     143.6   150.0
                  21.8     21.8   100.0
                           0.70878 1.469
16 CUBOID        143.6      0.    150.0
                  21.8     21.8   100.0
                           0.70878 1.469
    ....*....1....*....2....*....3....*....4....*....5....*....6....*....7....*....8

***  CONTINUED  ***
```

Fig. 5 Sample Input Data

```
                ************************
                *                      *     DSN = J3755.SAMPLE.DATA(MUTUAL)      PAGE   2
                *   INPUT DATA LIST    *
                *                      *     DATE  89/05/09  TIME  11:49:00
                ************************

     . ....*....1....*....2....*....3....*....4....*....5....*....6....*....7....*....8 .
51   .  17 CUBOID          143.6         71.8        150.0                               .   51
52   .                      21.8         21.8        100.0                               .   52
53   .                                 0.70878        1.469                               .   53
54   .  18 CUBOID          143.6         143.6       150.0                               .   54
55   .                      21.8         21.8        100.0                               .   55
56   .                                 0.70878        1.469                               .   56
57   .     BOUNDARY         71.8         71.8         75.0                               .   57
58   .                     200.0         200.0       400.0                               .   58
59   .           0.0         0.0          0.0          0.0          0.0          0.0       .   59
60   . END MUTUAL                                                                         .   60
     . ....*....1....*....2....*....3....*....4....*....5....*....6....*....7....*....8 .

     ***  INPUT DATA END  ***
```

Fig. 5 Sample Input Data (cont'd)

```
** CUBOID 3X3X2 (50CM) 20GU/L H/U=1.0 (21.8CM,21.8CM,100CM) **          DATE  89/05/09  TIME  11:49:02

NO. OF UNITS      :    18


BOUNDARY CONDITON

                              X              Y              Z
CENTER POSITION       :   71.8000        71.8000        75.0000

GEOMETRICAL                  LX             LY             LZ
 PARAMETER            :  200.000         200.000        400.000

                             +X             -X             +Y             -Y             +Z             -Z
ALBEDO CONDITION      :    0.0            0.0            0.0            0.0            0.0            0.0


UNIT SQ NO.           :    1   ( ID =   1 )

GEOMETRY TYPE         :   CUBOID

                              X              Y              Z
CENTER POSITION       :    0.0            0.0            0.0

GEOMETRICAL                  LX             LY             LZ
 PARAMETER            :  21.800          21.800         100.000
                            M2B2           K-EFF          K-INF
NUCLEAR DATA          :  1.07257E+00     7.08780E-01    1.46900E+00


UNIT SQ NO.           :    2   ( ID =   2 )

GEOMETRY TYPE         :   CUBOID

                              X              Y              Z
CENTER POSITION       :    0.0           71.8000         0.0

GEOMETRICAL                  LX             LY             LZ
 PARAMETER            :  21.800          21.800         100.000
                            M2B2           K-EFF          K-INF
NUCLEAR DATA          :  1.07257E+00     7.08780E-01    1.46900E+00


UNIT SQ NO.           :    3   ( ID =   3 )

GEOMETRY TYPE         :   CUBOID

                              X              Y              Z
CENTER POSITION       :    0.0           143.6000        0.0

GEOMETRICAL                  LX             LY             LZ
 PARAMETER            :  21.800          21.800         100.000
                            M2B2           K-EFF          K-INF
NUCLEAR DATA          :  1.07257E+00     7.08780E-01    1.46900E+00
```

Fig. 6 Sample Output Data

```
** CUBOID 3X3X2 (50CM) 20GU/L H/U=1.0 (21.8CM,21.8CM,100CM) **        DATE  89/05/09  TIME  11:49:02
UNIT SQ NO.          :    4   ( ID =   4 )

GEOMETRY TYPE        :   CUBOID

                           X              Y              Z
CENTER POSITION      :   71.8000         0.0            0.0

GEOMETRICAL                LX             LY             LZ
 PARAMETER           :    21.800         21.800         100.000
                           M2B2           K-EFF          K-INF
NUCLEAR DATA         :  1.07257E+00    7.08780E-01    1.46900E+00


UNIT SQ NO.          :    5   ( ID =   5 )

GEOMETRY TYPE        :   CUBOID

                           X              Y              Z
CENTER POSITION      :   71.8000        71.8000         0.0

GEOMETRICAL                LX             LY             LZ
 PARAMETER           :    21.800         21.800         100.000
                           M2B2           K-EFF          K-INF
NUCLEAR DATA         :  1.07257E+00    7.08780E-01    1.46900E+00


UNIT SQ NO.          :    6   ( ID =   6 )

GEOMETRY TYPE        :   CUBOID

                           X              Y              Z
CENTER POSITION      :   71.8000        143.6000        0.0

GEOMETRICAL                LX             LY             LZ
 PARAMETER           :    21.800         21.800         100.000
                           M2B2           K-EFF          K-INF
NUCLEAR DATA         :  1.07257E+00    7.08780E-01    1.46900E+00


UNIT SQ NO.          :    7   ( ID =   7 )

GEOMETRY TYPE        :   CUBOID

                           X              Y              Z
CENTER POSITION      :   143.6000        0.0            0.0

GEOMETRICAL                LX             LY             LZ
 PARAMETER           :    21.800         21.800         100.000
                           M2B2           K-EFF          K-INF
NUCLEAR DATA         :  1.07257E+00    7.08780E-01    1.46900E+00
```

Fig. 6 Sample Output Data (cont'd)

```
** CUBOID 3X3X2 (50CM) 20GU/L H/U=1.0 (21.8CM,21.8CM,100CM) **        DATE  89/05/09  TIME  11:49:02
UNIT SQ NO.          :    8   ( ID =   8 )

GEOMETRY TYPE        :   CUBOID

                           X              Y              Z
CENTER POSITION      :  143.6000        71.8000        0.0

GEOMETRICAL                LX             LY             LZ
 PARAMETER           :    21.800         21.800         100.000
                           M2B2           K-EFF          K-INF
NUCLEAR DATA         :  1.07257E+00    7.08780E-01    1.46900E+00


UNIT SQ NO.          :    9   ( ID =   9 )

GEOMETRY TYPE        :   CUBOID

                           X              Y              Z
CENTER POSITION      :  143.6000        143.6000       0.0

GEOMETRICAL                LX             LY             LZ
 PARAMETER           :    21.800         21.800         100.000
                           M2B2           K-EFF          K-INF
NUCLEAR DATA         :  1.07257E+00    7.08780E-01    1.46900E+00


UNIT SQ NO.          :   10   ( ID =  10 )

GEOMETRY TYPE        :   CUBOID

                           X              Y              Z
CENTER POSITION      :    0.0            0.0            150.0000

GEOMETRICAL                LX             LY             LZ
 PARAMETER           :    21.800         21.800         100.000
                           M2B2           K-EFF          K-INF
NUCLEAR DATA         :  1.07257E+00    7.08780E-01    1.46900E+00


UNIT SQ NO.          :   11   ( ID =  11 )

GEOMETRY TYPE        :   CUBOID

                           X              Y              Z
CENTER POSITION      :    0.0            71.8000        150.0000

GEOMETRICAL                LX             LY             LZ
 PARAMETER           :    21.800         21.800         100.000
                           M2B2           K-EFF          K-INF
NUCLEAR DATA         :  1.07257E+00    7.08780E-01    1.46900E+00
```

Fig. 6 Sample Output Data (cont'd)

```
** CUBOID 3X3X2 (50CM) 20GU/L H/U=1.0 (21.8CM,21.8CM,100CM) **        DATE  89/05/09  TIME  11:49:02
UNIT SQ NO.          :   12   ( ID =  12 )

GEOMETRY TYPE        :   CUBOID

                           X              Y              Z
CENTER POSITION      :   0.0            143.6000       150.0000

GEOMETRICAL                LX             LY             LZ
 PARAMETER           :   21.800         21.800         100.000
                          M2B2           K-EFF          K-INF
NUCLEAR DATA         :   1.07257E+00    7.08780E-01    1.46900E+00


UNIT SQ NO.          :   13   ( ID =  13 )

GEOMETRY TYPE        :   CUBOID

                           X              Y              Z
CENTER POSITION      :   71.8000        0.0            150.0000

GEOMETRICAL                LX             LY             LZ
 PARAMETER           :   21.800         21.800         100.000
                          M2B2           K-EFF          K-INF
NUCLEAR DATA         :   1.07257E+00    7.08780E-01    1.46900E+00


UNIT SQ NO.          :   14   ( ID =  14 )

GEOMETRY TYPE        :   CUBOID

                           X              Y              Z
CENTER POSITION      :   71.8000        71.8000        150.0000

GEOMETRICAL                LX             LY             LZ
 PARAMETER           :   21.800         21.800         100.000
                          M2B2           K-EFF          K-INF
NUCLEAR DATA         :   1.07257E+00    7.08780E-01    1.46900E+00


UNIT SQ NO.          :   15   ( ID =  15 )

GEOMETRY TYPE        :   CUBOID

                           X              Y              Z
CENTER POSITION      :   71.8000        143.6000       150.0000

GEOMETRICAL                LX             LY             LZ
 PARAMETER           :   21.800         21.800         100.000
                          M2B2           K-EFF          K-INF
NUCLEAR DATA         :   1.07257E+00    7.08780E-01    1.46900E+00
```

Fig. 6 Sample Output Data (cont'd)

```
** CUBOID 3X3X2 (50CM) 20GU/L H/U=1.0 (21.8CM,21.8CM,100CM) **        DATE  89/05/09  TIME  11:49:02
UNIT SQ NO.          :   16   ( ID =  16 )

GEOMETRY TYPE        :   CUBOID

                         X              Y              Z
CENTER POSITION      :   143.6000       0.0            150.0000

                         LX             LY             LZ
GEOMETRICAL
 PARAMETER           :   21.800         21.800         100.000
                         M2B2           K-EFF          K-INF
NUCLEAR DATA         :   1.07257E+00    7.08780E-01    1.46900E+00


UNIT SQ NO.          :   17   ( ID =  17 )

GEOMETRY TYPE        :   CUBOID

                         X              Y              Z
CENTER POSITION      :   143.6000       71.8000        150.0000

                         LX             LY             LZ
GEOMETRICAL
 PARAMETER           :   21.800         21.800         100.000
                         M2B2           K-EFF          K-INF
NUCLEAR DATA         :   1.07257E+00    7.08780E-01    1.46900E+00


UNIT SQ NO.          :   18   ( ID =  18 )

GEOMETRY TYPE        :   CUBOID

                         X              Y              Z
CENTER POSITION      :   143.6000       143.6000       150.0000

                         LX             LY             LZ
GEOMETRICAL
 PARAMETER           :   21.800         21.800         100.000
                         M2B2           K-EFF          K-INF
NUCLEAR DATA         :   1.07257E+00    7.08780E-01    1.46900E+00
```

Fig. 6 Sample Output Data (cont'd)

SOLID ANGLE FRACTION

FROM / TO UNIT / UNIT	1 (1)	2 (2)	3 (3)	4 (4)	5 (5)	6 (6)	7 (7)	8 (8)	9 (9)	10 (10)
	11 (11)	12 (12)	13 (13)	14 (14)	15 (15)	16 (16)	17 (17)	18 (18)		
1 (1)	0.0	3.5435D-02	0.0	3.5435D-02	2.4078D-02	9.3760D-03	0.0	9.3760D-03	0.0	3.2686D-03
	5.2830D-03	1.8176D-03	5.2830D-03	6.4405D-03	4.5154D-03	1.8176D-03	4.5154D-03	1.7820D-03		
2 (2)	3.5435D-02	0.0	3.5435D-02	2.4078D-02	3.5435D-02	2.4078D-02	9.3760D-03	0.0	9.3760D-03	5.2830D-03
	3.2686D-03	5.2830D-03	6.4405D-03	5.2830D-03	6.4405D-03	4.5154D-03	1.8176D-03	4.5154D-03		
3 (3)	0.0	3.5435D-02	0.0	9.3760D-03	2.4078D-02	3.5435D-02	0.0	9.3760D-03	0.0	1.8176D-03
	5.2830D-03	3.2686D-03	4.5154D-03	6.4405D-03	5.2830D-03	1.7820D-03	4.5154D-03	1.8176D-03		
4 (4)	3.5435D-02	2.4078D-02	9.3760D-03	0.0	3.5435D-02	0.0	3.5435D-02	2.4078D-02	9.3760D-03	5.2830D-03
	6.4405D-03	4.5154D-03	3.2686D-03	5.2830D-03	1.8176D-03	5.2830D-03	6.4405D-03	4.5154D-03		
5 (5)	2.4078D-02	3.5435D-02	2.4078D-02	3.5435D-02	0.0	3.5435D-02	2.4078D-02	3.5435D-02	2.4078D-02	6.4405D-03
	5.2830D-03	6.4405D-03	5.2830D-03	3.2686D-03	5.2830D-03	6.4405D-03	5.2830D-03	6.4405D-03		
6 (6)	9.3760D-03	2.4078D-02	3.5435D-02	0.0	3.5435D-02	0.0	9.3760D-03	2.4078D-02	3.5435D-02	4.5154D-03
	6.4405D-03	5.2830D-03	1.8176D-03	5.2830D-03	3.2686D-03	4.5154D-03	6.4405D-03	5.2830D-03		
7 (7)	0.0	9.3760D-03	0.0	3.5435D-02	2.4078D-02	9.3760D-03	0.0	3.5435D-02	0.0	1.8176D-03
	4.5154D-03	1.7820D-03	5.2830D-03	6.4405D-03	4.5154D-03	3.2686D-03	5.2830D-03	1.8176D-03		
8 (8)	9.3760D-03	0.0	9.3760D-03	2.4078D-02	3.5435D-02	2.4078D-02	3.5435D-02	0.0	3.5435D-02	4.5154D-03
	1.8176D-03	4.5154D-03	6.4405D-03	5.2830D-03	6.4405D-03	5.2830D-03	3.2686D-03	5.2830D-03		
9 (9)	0.0	9.3760D-03	0.0	9.3760D-03	2.4078D-02	3.5435D-02	0.0	3.5435D-02	0.0	1.7820D-03
	4.5154D-03	1.8176D-03	4.5154D-03	6.4405D-03	5.2830D-03	1.8176D-03	5.2830D-03	3.2686D-03		
10 (10)	3.2686D-03	5.2830D-03	1.8176D-03	5.2830D-03	6.4405D-03	4.5154D-03	1.8176D-03	4.5154D-03	1.7820D-03	0.0
	3.5435D-02	0.0	3.5435D-02	2.4078D-02	9.3760D-03	0.0	9.3760D-03	0.0		
11 (11)	5.2830D-03	3.2686D-03	5.2830D-03	6.4405D-03	5.2830D-03	6.4405D-03	4.5154D-03	1.8176D-03	4.5154D-03	3.5435D-02
	0.0	3.5435D-02	2.4078D-02	3.5435D-02	2.4078D-02	9.3760D-03	0.0	9.3760D-03		
12 (12)	1.8176D-03	5.2830D-03	3.2686D-03	4.5154D-03	6.4405D-03	5.2830D-03	1.7820D-03	4.5154D-03	1.8176D-03	0.0
	3.5435D-02	0.0	9.3760D-03	2.4078D-02	3.5435D-02	0.0	9.3760D-03	0.0		
13 (13)	5.2830D-03	6.4405D-03	4.5154D-03	3.2686D-03	5.2830D-03	1.8176D-03	5.2830D-03	6.4405D-03	4.5154D-03	3.5435D-02
	2.4078D-02	9.3760D-03	0.0	3.5435D-02	0.0	3.5435D-02	2.4078D-02	9.3760D-03		
14 (14)	6.4405D-03	5.2830D-03	6.4405D-03	5.2830D-03	3.2686D-03	5.2830D-03	6.4405D-03	5.2830D-03	6.4405D-03	2.4078D-02
	3.5435D-02	2.4078D-02	3.5435D-02	0.0	3.5435D-02	2.4078D-02	3.5435D-02	2.4078D-02		
15 (15)	4.5154D-03	6.4405D-03	5.2830D-03	1.8176D-03	5.2830D-03	3.2686D-03	4.5154D-03	6.4405D-03	5.2830D-03	9.3760D-03
	2.4078D-02	3.5435D-02	0.0	3.5435D-02	0.0	9.3760D-03	2.4078D-02	3.5435D-02		
16 (16)	1.8176D-03	4.5154D-03	1.7820D-03	5.2830D-03	6.4405D-03	4.5154D-03	3.2686D-03	5.2830D-03	1.8176D-03	0.0
	9.3760D-03	0.0	3.5435D-02	2.4078D-02	9.3760D-03	0.0	3.5435D-02	0.0		
17 (17)	4.5154D-03	1.8176D-03	4.5154D-03	6.4405D-03	5.2830D-03	6.4405D-03	5.2830D-03	3.2686D-03	5.2830D-03	9.3760D-03
	0.0	9.3760D-03	2.4078D-02	3.5435D-02	2.4078D-02	3.5435D-02	0.0	3.5435D-02		
18 (18)	1.7820D-03	4.5154D-03	1.8176D-03	4.5154D-03	6.4405D-03	5.2830D-03	1.8176D-03	5.2830D-03	3.2686D-03	0.0
	9.3760D-03	0.0	9.3760D-03	2.4078D-02	3.5435D-02	0.0	3.5435D-02	0.0		
TOTAL	1.4842D-01	2.1606D-01	1.4842D-01	2.1606D-01	2.8821D-01	2.1606D-01	1.4842D-01	2.1606D-01	1.4842D-01	1.4842D-01
	2.1606D-01	1.4842D-01	2.1606D-01	2.8821D-01	2.1606D-01	1.4842D-01	2.1606D-01	1.4842D-01		

Fig. 6 Sample Output Data (cont'd)

FIRST EVALUATION OF CRITICALITY ** TEST **

UNIT	(ID)	KEFF	OMEGA	1-KEFF	CRITICALITY
1	1	7.0878E-01	1.4842D-01	2.9122E-01	SUBCRITICAL
2	2	7.0878E-01	2.1606D-01	2.9122E-01	SUBCRITICAL
3	3	7.0878E-01	1.4842D-01	2.9122E-01	SUBCRITICAL
4	4	7.0878E-01	2.1606D-01	2.9122E-01	SUBCRITICAL
5	5	7.0878E-01	2.8821D-01	2.9122E-01	SUBCRITICAL
6	6	7.0878E-01	2.1606D-01	2.9122E-01	SUBCRITICAL
7	7	7.0878E-01	1.4842D-01	2.9122E-01	SUBCRITICAL
8	8	7.0878E-01	2.1606D-01	2.9122E-01	SUBCRITICAL
9	9	7.0878E-01	1.4842D-01	2.9122E-01	SUBCRITICAL
10	10	7.0878E-01	1.4842D-01	2.9122E-01	SUBCRITICAL
11	11	7.0878E-01	2.1606D-01	2.9122E-01	SUBCRITICAL
12	12	7.0878E-01	1.4842D-01	2.9122E-01	SUBCRITICAL
13	13	7.0878E-01	2.1606D-01	2.9122E-01	SUBCRITICAL
14	14	7.0878E-01	2.8821D-01	2.9122E-01	SUBCRITICAL
15	15	7.0878E-01	2.1606D-01	2.9122E-01	SUBCRITICAL
16	16	7.0878E-01	1.4842D-01	2.9122E-01	SUBCRITICAL
17	17	7.0878E-01	2.1606D-01	2.9122E-01	SUBCRITICAL
18	18	7.0878E-01	1.4842D-01	2.9122E-01	SUBCRITICAL

Fig. 6 Sample Output Data (cont'd)

FIRST EVALUATION OF CRITICALITY ** TEST **

UNIT	(ID)	KEFF	OMEGA	1-KEFF	CRITICALITY
1	1	7.0878E-01	1.4842D-01	2.9122E-01	SUBCRITICAL
2	2	7.0878E-01	2.1606D-01	2.9122E-01	SUBCRITICAL
3	3	7.0878E-01	1.4842D-01	2.9122E-01	SUBCRITICAL
4	4	7.0878E-01	2.1606D-01	2.9122E-01	SUBCRITICAL
5	5	7.0878E-01	2.8821D-01	2.9122E-01	SUBCRITICAL
6	6	7.0878E-01	2.1606D-01	2.9122E-01	SUBCRITICAL
7	7	7.0878E-01	1.4842D-01	2.9122E-01	SUBCRITICAL
8	8	7.0878E-01	2.1606D-01	2.9122E-01	SUBCRITICAL
9	9	7.0878E-01	1.4842D-01	2.9122E-01	SUBCRITICAL
10	10	7.0878E-01	1.4842D-01	2.9122E-01	SUBCRITICAL
11	11	7.0878E-01	2.1606D-01	2.9122E-01	SUBCRITICAL
12	12	7.0878E-01	1.4842D-01	2.9122E-01	SUBCRITICAL
13	13	7.0878E-01	2.1606D-01	2.9122E-01	SUBCRITICAL
14	14	7.0878E-01	2.8821D-01	2.9122E-01	SUBCRITICAL
15	15	7.0878E-01	2.1606D-01	2.9122E-01	SUBCRITICAL
16	16	7.0878E-01	1.4842D-01	2.9122E-01	SUBCRITICAL
17	17	7.0878E-01	2.1606D-01	2.9122E-01	SUBCRITICAL
18	18	7.0878E-01	1.4842D-01	2.9122E-01	SUBCRITICAL

** CUBOID 3X3X2 (50CM) 20GU/L H/U=1.0 (21.8CM,21.8CM,100CM) ** DATE 89/05/09 TIME 11:49:02

ITERATION LIMIT = 100TIMES CRITERIA = 0.1000D-04

OUTER ITERATION COUNT	RELATIVE ERROR	KEFF	INNER ITERATION COUNT	RELATIVE ERROR
1	4.5575D-02	7.8837D-01	6	1.5424D-06
2	3.8567D-02	7.8880D-01	6	1.6381D-06
3	3.2798D-02	7.8917D-01	6	1.4328D-06
4	2.8005D-02	7.8949D-01	6	1.3189D-06
5	2.3992D-02	7.8978D-01	6	1.5012D-06
6	2.0612D-02	7.9003D-01	6	1.3998D-06
7	1.7749D-02	7.9024D-01	6	1.3059D-06
8	1.5313D-02	7.9043D-01	6	1.2868D-06
9	1.3234D-02	7.9059D-01	6	1.5353D-06
10	1.1453D-02	7.9074D-01	6	1.3590D-06
11	9.9235D-03	7.9086D-01	6	1.4355D-06
12	8.6072D-03	7.9097D-01	6	1.3595D-06
13	7.4722D-03	7.9106D-01	6	1.3506D-06
14	6.4919D-03	7.9114D-01	6	1.2765D-06
15	5.6437D-03	7.9121D-01	6	1.2016D-06
16	4.9094D-03	7.9128D-01	6	1.5786D-06
17	4.2725D-03	7.9133D-01	6	1.2651D-06
18	3.7199D-03	7.9138D-01	6	1.3431D-06
19	3.2400D-03	7.9142D-01	6	1.2140D-06
20	2.8228D-03	7.9145D-01	6	1.2625D-06
21	2.4602D-03	7.9148D-01	6	1.1830D-06
22	2.1446D-03	7.9151D-01	6	1.2391D-06
23	1.8700D-03	7.9153D-01	6	1.3397D-06
24	1.6306D-03	7.9155D-01	6	1.4180D-06
25	1.4223D-03	7.9157D-01	6	1.2601D-06

Fig. 6 Sample Output Data (cont'd)

26	1.2409D-03	7.9158D-01	6	1.4776D-06
27	1.0824D-03	7.9160D-01	6	1.2596D-06
28	9.4458D-04	7.9161D-01	6	1.2903D-06
29	8.2423D-04	7.9162D-01	6	1.2892D-06
30	7.1933D-04	7.9163D-01	6	1.4109D-06
31	6.2775D-04	7.9163D-01	6	1.2275D-06
32	5.4784D-04	7.9164D-01	6	1.3375D-06
33	4.7831D-04	7.9165D-01	6	1.4161D-06
34	4.1747D-04	7.9165D-01	6	1.2243D-06
35	3.6442D-04	7.9166D-01	6	1.2851D-06
36	3.1812D-04	7.9166D-01	6	1.3372D-06
37	2.7771D-04	7.9166D-01	6	1.2585D-06
38	2.4252D-04	7.9167D-01	6	1.2840D-06
39	2.1166D-04	7.9167D-01	6	1.2585D-06
40	1.8490D-04	7.9167D-01	6	1.3371D-06
41	1.6134D-04	7.9167D-01	6	1.3370D-06
42	1.4091D-04	7.9167D-01	6	1.4053D-06
43	1.2303D-04	7.9168D-01	6	1.2299D-06
44	1.0741D-04	7.9168D-01	6	1.2828D-06
45	9.3801D-05	7.9168D-01	6	1.2300D-06
46	8.1888D-05	7.9168D-01	6	1.2583D-06
47	7.1487D-05	7.9168D-01	6	1.2824D-06
48	6.2604D-05	7.9168D-01	6	1.4045D-06
49	5.4616D-05	7.9168D-01	6	1.5876D-06
50	4.7658D-05	7.9168D-01	6	1.2822D-06
51	4.1512D-05	7.9168D-01	6	1.3369D-06
52	3.6317D-05	7.9168D-01	6	1.2211D-06
53	3.1685D-05	7.9168D-01	6	1.3369D-06
54	2.7702D-05	7.9168D-01	6	1.2303D-06
55	2.4222D-05	7.9168D-01	6	1.2303D-06
56	2.1173D-05	7.9168D-01	6	1.2303D-06
57	1.8468D-05	7.9168D-01	6	1.2820D-06
58	1.6125D-05	7.9168D-01	6	1.2583D-06
59	1.4120D-05	7.9168D-01	6	1.2583D-06
60	1.2321D-05	7.9168D-01	6	1.2819D-06
61	1.0828D-05	7.9168D-01	6	1.5261D-06
62	9.4848D-06	7.9168D-01	6	1.4650D-06

*** PROBLEM CONVERGED ***

SECOND EVALUATION OF CRITICALITY

KEFF OF SYSTEM CRITICALITY

0.7917 SUBCRITICAL

Fig. 6 Sample Output Data (cont'd)

```
** CUBOID 3X3X2 (50CM) 20GU/L H/U=1.0 (21.8CM,21.8CM,100CM) **          DATE  89/05/09  TIME  11:49:02

TOTAL ABSORPTION      5.3893D-01
TOTAL NET LEAKAGE     4.6107D-01
TOTAL FISSION         1.0000D+00
WEIGHTED ETA          2.1704D-01
MAXIMUM OMEGA         3.5435D-02
WEIGHTED THETA        1.1697D-01
```

Fig. 6 Sample Output Data (cont'd)

```
//JCLG JOB                                                                  00010000
//JCLG EXEC JCLG                                                            00020000
//SYSIN DD DATA,DLM='++'                                                    00030000
// JUSER 12513755,HI.OKUNO,0943.01                                          00040000
   T.0 W.0 I.2 C.0                                                          00050001
  OPTP PASSWORD=                                                            00060002
//*********************<<J3755.JCL.CNTL(MUTUAL)>>************************** 00070005
// EXEC FORT77,SO=J3755.MUTUALR,Q='.FORT77',A='ELM(*)',                     00080003
//      B=NOMAP,LCT=62,                                                     00090000
//      RGN=768K,OBJS='30,10'                                               00100000
// EXEC LKED77                                                              00110000
// EXEC GO                                                                  00120000
//SYSIN    DD  DSN=J3755.SAMPLE.DATA(MUTUAL),DISP=SHR,LABEL=(,,,IN)        00130001
++                                                                          00140004
//                                                                          00150000
```

Fig. 7 Sample JCL