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EXTERMINATOR – A MULTIGROUP CODE FOR SOLVING NEUTRON DIFFUSION EQUATIONS IN ONE AND TWO DIMENSIONS

T. B. Fowler
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Errata 2

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Page 25 - Delete lines 4 through 12 and insert the following:

Columns 13-24 SCATU(E12.8): The maximum number of groups for up-scatter. For example if the maximum up-scatter in a problem were from some group K to K − 5, then 5.0 would be specified. A zero for SCATU would specify no up-scatter.

Columns 25-36 SCATD(E12.8): The maximum number of groups for down-scatter. If the maximum down-scatter in a problem were from a group K to K + 5, then 5.0 would be specified. A zero specifies no down-scatter.

If both SCATU and SCATD are input 0 or left blank, the code assumes maximum up- and down-scatter.

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Page 4 - Add the following paragraph under The Five Point Difference Equations:

For points associated with a "rod region", the interior fluxes are not defined, but satisfy the logarithmic derivative condition

$$\frac{D}{\phi}\frac{d\phi}{dx} = -C_r \tag{1A}$$

along the boundaries of the region. C_r is a positive number and the derivative is taken normal to the boundary and in the direction of the rod region.

Page 27 -Change C to C_r in lines 5 and 19.

Page 32 -Delete first six sentences of paragraph beginning "No provision was made . . ."

Page 58 -Insert the following after line 4:

C_r Rod group constant.

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Reactor Division

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FEBRUARY 1965

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EXTERMINATOR — A MULTIGROUP CODE FOR SOLVING NEUTRON DIFFUSION EQUATIONS IN ONE AND TWO DIMENSIONS

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Abstract

The program described here solves the finite-difference analogs of the multigroup neutron diffusion equations in one and two dimensions, using an IBM-7090 computer. The co-ordinate systems permitted are rectangular (X-Y) and cylindrical (R-Z and R-θ). Scattering from any group to any other group is allowed. Outside boundary conditions are either symmetry, zero flux, or perodic, and internal control rod boundaries may be specified. The user may employ group-and material-dependent transverse bucklings where appropriate. Input cross sections may be macroscopic, microscopic, or both. Microscopic cross sections may be used from a previously made tape, from cards, or both. Eigenvalue, constant source, or poison search problems may be solved. Up to 50 groups, 500 materials, and 20,000 mesh points are allowed.

Acknowledgment

The authors of this report are listed in alphabetical order. While primary responsibility for the work described rests with the second writer, the effort has been a joint one and it is impossible to say where the contribution of one of us leaves off and that of another begins.

Introduction

The EXTERMINATOR code is designed to meet the need for a means of computing neutron flux distributions in two-dimensions. The equations upon which the program is based are finite-difference analogs of the multigroup neutron diffusion equations. The "Equipoise Method"[1] is employed to solve these equations with certain modifications made to accelerate convergence and insure stability. No mathematical proofs exist as yet concerning the range of validity of either the original method or the present modifications. Basically the method consists of sweeping the mesh using over- or under-relaxation to compute new fluxes from an eigenvalue estimate and the most recently computed fluxes wherever possible. At the end of a sweep of all mesh points and all groups, the eigenvalue is recomputed so that the number of neutrons produced equals the number lost. With this new eigenvalue, a new mesh sweep is started.

To accelerate convergence, the following innovations have been made:

1. Line relaxation may be used instead of point relaxation. With line relaxation, it is practical to solve one-dimensional problems even though the code was designed primarily for two-dimensional calculations. (In point relaxation, the fluxes at a given mesh point and group are computed from the fluxes at immediately neighboring mesh points and from those at the same mesh point in other groups. In line relaxation, the fluxes in a given group for an entire row or column are calculated from those of adjacent rows or columns and from those on the same line in other groups. In both cases the most recently obtained flux values are used in calculating new fluxes.)

2. Group rebalancing may be used at intervals until the rebalancing factors are within a specified range of 1.0. (Group rebalancing is a process for ensuring that a neutron balance is imposed on each group as well as on all the groups collectively.)

3. A search for an improved value of the "extrapolated Liebmann" coefficient[8] is made based upon the observed convergence behavior of the problem.

4. At appropriate times during the iteration process, an extrapolation of the fluxes is made; the extrapolation method is similar to the Aitken-δ^2 process.[9]

All of these procedures are fully automatic. The program may be said to "think for itself"; as will be seen, the techniques used are those which an experienced user of the program might employ to accelerate convergence if he could watch the progress of the computation.

Two new convergence criteria have been added to those which have been used in other Equipoise codes.[2,3,4] As before, the code calculates pointwise flux convergence and eigenvalue convergence. (Experience has shown that the former, while not foolproof, is the criterion least likely to mislead the user into thinking the problem has converged. The calculation of residues which was employed in some earlier work has been abandoned as worthless.) The first new convergence indicator which has been found is the calculation of eigenvalues on the basis of a neutron balance taken over each group. The neutron balances for each group are also reported. These eigenvalue estimates do not necessarily provide upper and lower estimates for the multiplication constant. They could all be made the same as a result of group-rebalancing, and therefore all on one side of the true answer. Nevertheless, they often bracket the answer, and usually provide a good indicator of the reliability of the eigenvalue. The second new criterion, which is reported at each iteration, is what is called the "absolute convergence". This quantity is the point-wise convergence divided by $1 - \sigma$, where σ is an estimate of the rate of error decay. Clearly, σ must be less than 1 in absolute value if the problem is to converge. Under certain assumptions, to be described later, the so-called "absolute convergence" is an estimate of the deviation from the true answer.

Besides the eigenvalue (multiplication constant) calculation, the program will also compute the flux distribution for a given k due to an arbitrary source distribution. Further, a direct poison search calculation can be done (in about the same amount of machine time as an eigenvalue calculation) which enables the user to determine a poison cross section in specified regions required to produce a given multiplication factor, k.

Cross sections may be specified macroscopically, microscopically, from cards and/or tapes, and material region specifications may overlay previously specified regions. The code therefore affords the user considerable flexibility and ease in input preparation, details of which may be found in the appropriate section below.

The rate of computation depends upon the problem and varies from 0.0018 to 0.0035 sec per point per iteration per group. EXTERMINATOR is faster than TWENTY GRAND[2] but not as fast as the two-group code EQUIPOISE-3[3]

Details of the Method

The Five Point Difference Equations

The difference-equation analogs of the neutron diffusion equations used in the present program are the same as those which have been used in the EQUIPOISE and TWENTY GRAND, programs[2,3,4] and will not be repeated in detail here. It is sufficient to note for present purposes that, regardless of the geometry employed, they take the form

$$a_{I,J,K}\,\phi_{I+1,J,K} + b_{I,J,K}\,\phi_{I-1,J,K} + c_{I,J,K}\,\phi_{I,J+1,K} + d_{I,J,K}\,\phi_{I,J-1,K} - \alpha'_{I,J,K}\,\phi_{I,J,K} + \chi_K \sum_{P=1}^{KMAX} \lambda\, f_{I,J,P}\,\phi_{I,J,P} + \sum_{\substack{P=1\\P\neq K}}^{KMAX} \alpha''_{I,J,P,K}\,\phi_{I,J,P} + S_{I,J,K} = 0 \qquad (1)$$

where $\alpha''_{I,J,P,K} = 0$ if $P = K$. In this equation, the subscripts I and J identify the mesh point in two dimensions and subscript K refers to the neutron energy group. In constant source distribution problems the value of λ is fixed at some pre-set level. In eigenvalue problems, λ is the eigenvalue and the last term in Eq. (1) is zero. (See the table of notation, page 58, for definitions of symbols.)

Basic Iterative Technique Employed

The five-point difference equations may be cast into matrix form

$$A\phi = \lambda M\phi \tag{2}$$

where A is a matrix with positive diagonal elements and all negative or zero off-diagonal elements. The sum of the elements of each column of A is greater than or equal to zero. M is a non-negative matrix. We may assume that the eigenvalue problem represented by Eq. (2) is irreducible and that A is non-singular. Because of the properties of A, A^{-1} is non-negative. It may then be concluded that the problem

$$\frac{1}{\lambda}\,\phi = A^{-1}M\,\phi \tag{3}$$

has a positive value of $1/\lambda$ equal to the spectral radius of $A^{-1}M$ and associated with it will be a unique all-positive vector ϕ.[8] It is this value of λ and the corresponding vector which we seek. Usually, this value of λ will be the eigenvalue of largest modulus, but exceptional cases may be cited where it is not. (For instance

$A = \begin{vmatrix} 1 & 0 \\ 0 & 1 \end{vmatrix}$ and M may be $\begin{vmatrix} 0 & 1 \\ 1 & 0 \end{vmatrix}$ in which case there will be two

values of λ of equal modulus.) The nature of the iterative procedure used here does not, however, depend upon the desired value of $1/\lambda$ being largest and is therefore capable of dealing with even these exceptional cases. The technique consists of partitioning the matrices so that the iterative procedure becomes

$$\phi_{n+1} = \beta(V - \beta L - \beta\lambda_n W)^{-1}\,(\lambda_n M - A)\phi_n + \phi_n \tag{4}$$

$$\lambda_n = \frac{e^T A\phi_n}{e^T M\phi_n} \quad . \tag{5}$$

The over-relaxation procedure described by Eq. (4) is used only when the percentage change from ϕ_n to ϕ_{n+1} is less than 0.1%. When the change is greater, an important modification, which we call the "exponential - β" method, is used to prevent negative fluxes from occurring. It is described more fully below.

These equations express the simple idea that the values of the fluxes most recently computed are to be used immediately for computation of new fluxes and that estimation of λ is done by adding up all equations like Eq. (1) and solving for λ. The value of λ will then be that which makes the algebraic sum of the imbalances in Eq. (1) zero. In that way, at the end of each sweep, we force the balance between neutron production and losses. We may further force a neutron balance on each group separately by the group rebalancing technique described later.

Eq. (4) and (5) are used whether the option of point or line relaxation is used. If point relaxation is used V, L, and W are matrices whose elements are point coefficients such as appear in Eq. (1). In line relaxation, the elements are instead submatrices corresponding to lines of points taken either horizontally or vertically at the user's option. The convergence of the procedure depends critically upon using an appropriate over-relaxation coefficient β.

Line Relaxation Method

The iterative technique is improved by the use of line relaxation. In the present program it may be carried out either by rows or columns of the mesh point network. One should choose the lines in the direction of <u>smallest</u> leakage. Thus, in R-θ geometry, relaxation by columns, i.e., along circles rather than radii, is much preferable. If one relaxes along columns, Eq. (1) becomes

$$a_{I,J,K}\,\phi_{I+1,J,K} + b_{I,J,K}\,\phi_{I-1,J,K} - \alpha'_{I,J,K}\,\phi_{I,J,K} + C_{I,J,K} = 0 \qquad (6)$$

where $C_{I,J,K}$ includes the most recently computed values of the fluxes $\phi_{I,J\pm1,K}$ and $\phi_{I,J,P}$. Solution of Eq. (6) involves the well-known problem

of inverting a tri-diagonal matrix. The technique used is based on the device of writing a recursion expression (the subscripts J and K are dropped for simplicity):

$$\phi_I = \frac{m_I + \phi_{I+1}}{q_I} \quad . \tag{7}$$

which is substituted into Eq. (6). It follows that

$$m_I = \frac{C_I}{a_I} + \frac{b_I \, m_{I-1}}{a_I \, q_{I-1}} \quad . \tag{8}$$

$$q_I = \frac{\alpha_I'}{a_I} - \frac{b_I}{a_I \, q_{I-1}} \quad . \tag{9}$$

Values of m_I and q_I are determined recursively, with m_2 and q_2 determined by boundary conditions at the top-end of the column of mesh points. Eq. (8) and (9) are used up to I = IMAX − 1. Then Eq. (7) is used to compute the fluxes starting with ϕ_{IMAX-1}, the computation depending upon the boundary conditions at the bottom-end of the column of mesh points. The boundary conditions may be zero flux, symmetry, or either or both ends of the column may terminate on a rod region. The following relations will hold according to the type of condition which exists at the ends:

Zero flux at top end ($\phi_1 = 0$) or rod at top end,

$$q_2 = \frac{\alpha_2'}{a_2} \; ; \; m_2 = \frac{C_2}{a_2} \quad . \tag{10}$$

Symmetry at top end ($\phi_1 = \phi_2$, symmetry axis must be midway between points 1 and 2)

$$q_2 = \frac{\alpha_2' - b_2}{a_2} \; ; \quad m_2 = \frac{C_2}{a_2} \quad . \tag{11}$$

Zero flux at bottom end ($\phi_{IMAX} = 0$) <u>or</u> rod at bottom end,

$$\phi_{IMAX-1} = \frac{m_{IMAX-1}}{q_{IMAX-1}} \quad . \tag{12}$$

Symmetry at bottom ($\phi_{IMAX-1} = \phi_{IMAX}$),

$$\phi_{IMAX-1} = \frac{m_{IMAX-1}}{q_{IMAX-1} - 1} \quad . \tag{13}$$

For the periodic boundary condition, a different method of line relaxation is used. Instead of Equation 7, the formula

$$\phi_I = \frac{m_I + \phi_{I+1} + n_I \, \phi_{IMAX-1}}{q_I}$$

is used. The constants m_I, n_I, and q_I are determined by recursion formulas like (8) and (19). The flux ϕ_{IMAX-1} is found by a back substitution process which leads to two simultaneous linear equations in ϕ_{IMAX-1} and ϕ_{IMAX}.

Group Rebalancing

At the user's option, group rebalancing may be employed at the end of each mesh sweep. This procedure consists of finding a set of numbers by which each group flux is multiplied (one multiplier to a group) which insure that a neutron balance is achieved in each energy group as well as over all groups. Group rebalancing is found to be useful primarily for those cell calculations in which the groups are poorly coupled, in which case a powerful accelerative effect may be obtained. Because of round off errors, rebalancing is discontinued when the group rebalancing factors are within a specified amount of unity. Further details of the group rebalancing method may be found elsewhere.[5,6]

Selection of Over-Relaxation Coefficient, β

The most critical feature in the program is the over-relaxation coefficient β. If it is too large or too small the iterative procedure

will either converge too slowly or not at all. There has not yet been found any proof that an over-relaxation coefficient can be found which will make the iterative procedure expressed by Eq. (4) and (5) converge in every case. Further, we have not yet discovered any rational method for obtaining an optimum value of β. Instead, the following empirical procedure is used which has proved highly successful in the most difficult cases which have come up in actual practice as well as for cases specially designed to offer awkward features. (It is curious to note that, with one or two exceptions, the most stringent tests of the method have been cases constructed by users in the ordinary course of their work. More has been learned from realistic problems than from any the authors have been able to devise as tests.)

The technique of β selection rests upon determining whether or not the problem appears to be converging. The problem is normally started with a $\beta = 1.9$. At the end of 20 iterations, the ratio of the pointwise flux convergence $\epsilon(\phi)$ at iteration 20 to that at iteration 10 is examined. If $|\epsilon_{10}(\phi)/\epsilon_{20}(\phi)| \geqslant 1.5$ the iterations continue with $\beta = 1.9$ for another 20 iterations. If this ratio is less than 1.5 and if

$$\left| \frac{\epsilon_n(\phi)}{\epsilon_{n-1}(\phi)} \left[1 + | \epsilon_{n-1}(\phi) | \right] \right| \geqslant 1.0$$

(an event we have nicknamed a "bump") 3 times or more between $n = 10$ and $n = 19$, β is reduced by 0.1. The iterations are then continued for 20 more iterations at the end of which the same tests are applied and β is reduced again if necessary. It is particularly to be noted that if the overall convergence rate equals or exceeds 1.5, β is left alone regardless of any "bumping" which may have occurred. If fewer than 3 "bumps" occur and the convergence rate is < 1.5, the fluxes are extrapolated by a technique described in the next section. If it appears necessary β may be reduced as low as 0.1. As a general rule, it is rarely necessary to reduce β below 1.

The philosophy behind the empirical procedure described is as follows. Let us suppose that Eq. (4) and (5) are linearized by writing $\phi_n = \bar{\phi} + E_n(\phi)$ and $\lambda_n = \bar{\lambda} + E_n(\lambda)$ where $\bar{\phi}$ and $\bar{\lambda}$ are the desired solution vector and

eigenvalue respectively and $E_n(\phi)$ and $E_n(\lambda)$ are the errors in these quantities at step n. Neglecting second order quantities, the resulting equations in $E(\phi)$ and $E(\lambda)$ as functions of $\bar{\phi}$ and $\bar{\lambda}$ may be written as an eigenvalue problem by writing $E_{n+1} = \mu E_n$. Assuming that the linearization process is justified, the μ's for this eigenvalue problem are asymptotically the decay rates for the modes of the original problem. It is easy to see that one solution to the new problem is $\mu = 1$, $E(\bar{\lambda}) = 0$ and $E(\phi) = \bar{\phi}$, and it is hoped that a β can be found which will make all other eigenvalues less than 1 in modulus. We have speculated that if β is too large the largest eigenvalue of modulus less than 1 is complex, and that a lower value of β would correspond to the point where the eigenvalue changes from imaginary to real. "Bumping" would certainly be produced by complex eigenvalues, and by cautiously reducing β, we hope to eliminate it and arrive at the optimum β. Regardless of the merits of these suppositions (and it is admitted that the arguments are no more than that, and may indeed present an erroneous picture), the basis of β selection is whether of not the case appears to be converging on the basis of the observed behavior $\epsilon(\phi)$. If $\epsilon(\phi)$ is not going down the problem is not converging, and if $\epsilon(\phi)$ is steadily being reduced then it seems safe to assume that the calculated fluxes are coming ever closer to the desired answer. There is more to be said on this point in the section on convergence criteria.

"Exponential-β" Over-Relaxation

A useful modification has been made in the over-relaxation scheme to prevent negative fluxes from appearing and, at the same time, permit the iterative procedure to go on in a smooth and consistent manner. The "extrapolated-Liebmann" scheme is:

$$\phi_{n+1} = \phi_n + \beta(\phi^*_{n+1} - \phi_n) \quad . \tag{14}$$

or what is the same thing:

$$\phi_{n+1} = \phi_n \left[1 + \beta \left(\frac{\phi^*_{n+1}}{\phi_n} - 1\right)\right] \quad . \tag{15}$$

where ϕ^*_{n+1} is the flux at a point calculated in either the point-or line-relaxation schemes before over-relaxation is applied. (In point relaxation, each point flux is over-relaxed as soon as it is computed; in line relaxation, all the fluxes on a line are computed and are then over-relaxed together.) If $(\phi^*_{n+1}/\phi_n) - 1$ is large and negative, ϕ_{n+1} may be negative. Also, if $(\phi^*_{n+1}/\phi_n) - 1$ is large and positive ϕ_{n+1} may be too wildly extrapolated. The expression Eq. (15) suggested exponential forms for extrapolation since $1 + X \simeq e^X$ if X is small. If $\phi^*_{n+1}/\phi_n - 1$ is negative, the program calculates ϕ_{n+1} as

$$\phi_{n+1} = \phi_n \, e^{-\beta \left| \frac{\phi^*_{n+1}}{\phi_n} - 1 \right|} \tag{16}$$

If $(\phi^*_{n+1}/\phi_n) - 1$ is positive, ϕ_{n+1} is calculated as

$$\phi_{n+1} = \phi_n \left(2 - e^{-\beta \left| \frac{\phi^*_{n+1}}{\phi_n} - 1 \right|} \right) \tag{17}$$

Thus ϕ_{n+1} can never be less than $e^{-\beta}\,\phi_n$ nor greater than $2\phi_n$ so that excessive extrapolation is avoided. As $(\phi_{n+1}/\phi_n) - 1$ becomes small, both expressions tend towards the original extrapolated Liebmann formula. In fact, the following formulas are used: Let

$$\beta \left| \frac{\phi^*_{n+1}}{\phi_n} - 1 \right| = A \quad .$$

Then

1. If $A > 0.1$, e^{-A} is calculated from the exponential subroutine.
2. If $0.001 < A < 0.1$, e^{-A} is calculated as $(1 - A/2)/(1 + A/2)$.
3. If $A < 0.001$, e^{-A} is calculated as $1 - A$.

Thus if $A < 0.001$, Eq. (16) becomes

$$\phi_{n+1} = \phi_n \, e^{-A} \simeq \phi_n(1 - A) = \phi_n\left[1 - \beta\left(1 - \frac{\phi^*_{n+1}}{\phi_n}\right)\right]$$

$$= \phi_n + \beta(\phi^*_{n+1} - \phi_n) \quad , \quad \phi^*_{n+1} < \phi_n \tag{18}$$

and Eq. (17) becomes

$$\phi_{n+1} = \phi_n(2 - e^{-A}) \simeq \phi_n(1 + A)$$

$$= \phi_n\left[1 + \beta\left(\frac{\phi^*_{n+1}}{\phi_n} - 1\right)\right] =$$

$$= \phi_n + \beta(\phi^*_{n+1} - \phi_n) \quad , \quad \phi^*_{n+1} > \phi_n \tag{19}$$

Extrapolation of Fluxes

It must first be pointed out that flux extrapolation has not been found necessary in the majority of cases we have tried. However, we have found that, like group rebalancing, it is a valuable technique for dealing with a minority of cases which are otherwise intractable. As has been said, it occurs automatically when the rate of decay of $\epsilon(\phi)$ is less than 1.5 and no "bumping" has occurred. After extrapolation, the calculation proceeds for 40 iterations before any attempt is made either to change β or to extrapolate again. Extrapolation usually produces a sudded rise in $\epsilon(\phi)$ followed by a rapid decay to a point well below the level of $\epsilon(\phi)$ before extrapolation.

The extrapolation procedure is closely related to the Aitken-δ^2 process.[9] It is assumed (admittedly incorrectly, in general) that the decay rate of the error is a real and unique quantity. That is, it is supposed that

$$\phi_n = \bar{\phi} + R\sigma^n \quad . \tag{20}$$

It is easy to show that

$$\bar{\phi} = \phi_n + \frac{\sigma}{1 - \sigma} (\phi_n - \phi_{n-1}) \quad . \tag{21}$$

The decay parameter σ is estimated by the code from successive values of $\epsilon_n(\phi)$ as follows. We observe from Eq. (20) that

$$\phi_n - \phi_{n-1} = R\sigma^{n-1} (\sigma - 1) \quad , \tag{22}$$

and

$$\phi_{n-1} - \phi_{n-2} = R\sigma^{n-2} (\sigma - 1) \quad . \tag{23}$$

Dividing Eq. (22) by Eq. (23) gives

$$\sigma = \frac{\phi_n - \phi_{n-1}}{\phi_{n-1} - \phi_{n-2}} \quad . \tag{24}$$

Now

$$\epsilon_n(\phi) = \left(\frac{\phi_n - \phi_{n-1}}{\phi_{n-1}}\right)_{max}$$

so that

$$\sigma = \frac{\epsilon_n(\phi)}{\epsilon_{n-1}(\phi)} \frac{\phi_{n-1}}{\phi_{n-2}} = \frac{\epsilon_n(\phi)}{\epsilon_{n-1}(\phi)} [1 + \epsilon_{n-1}(\phi)] \quad . \tag{25}$$

Originally, $|\sigma|$ was used to check for "bumps", but to make doubly certain that convergence was occurring, the criterion was modified to

$$\left| \frac{\epsilon_n(\phi)}{\epsilon_{n-1}(\phi)} \left[1 + \left| \epsilon_{n-1}(\phi) \right| \right] \right| \geqslant 1 \tag{26}$$

as noted previously.

The extrapolation procedure expressed by Eq. (21) is based on the nation that σ is real and unique, and significantly larger than any other decay eigenvalue. None of these assertions is necessarily true. Extrapolation nevertheless proves useful in certain cases; when it is used it is used with discretion. It cannot occur more than once every forty iterations. It cannot occur if $|\sigma| \geqslant 1$, for in such a case β is cut by 0.1 instead. If a given flux should extrapolate to a negative quantity, the original flux is used. If σ is positive and close to 1, $\sigma/(1 - \sigma)$ may be very large indeed.

Convergence Criteria

The program reports several convergence criteria. At each step, the following are reported

$$\epsilon_n(\phi) = \left(\frac{\phi_n - \phi_{n-1}}{\phi_{n-1}} \right)_{max} . \tag{27}$$

$$\epsilon_n(k) = \left| \frac{\lambda_n^{-1} - \lambda_{n-1}^{-1}}{\lambda_n^{-1}} \right| . \tag{28}$$

$$\text{"Absolute" convergence} = \frac{\epsilon_n(\phi)}{1 - \sigma} . \tag{29}$$

The latter criterion comes out of Eq. (21). Assuming that σ is close to 1, we note that

$$\frac{\bar{\phi} - \phi_n}{\phi_n} = \frac{\sigma}{1 - \sigma} \left(\frac{\phi_n - \phi_{n-1}}{\phi_n} \right) \approx \frac{\epsilon_n(\phi)}{1 - \sigma} \quad . \tag{30}$$

Thus, if a problem is converging very slowly ($1 - \sigma$ small) Eq. (29) will give a better idea of convergence that Eq. (27) even if $\epsilon_n(\phi)$ is small.

In addition, neutron balances are reported for each group so that the user can check productions against losses. Estimates of k, based on individual group balances, are also given. With these checks, pseudo-convergence is quite unlikely. The user is advised to make the required $\epsilon(k)$ about 10^{-6} and $\epsilon(\phi)$ about 10^{-4}. Further, at the conclusion of the calculation, the "absolute" convergence and the neutron balances should be checked.

In constant source and poison search calculations criterion Eq. (28) is replaced by an equivalent criterion. (See following section).

Constant Source and Poison Search Calculations

The program can be used to calculate the flux distribution due to an arbitrary source distribution for a given k(input). (The specified value of k(input) is normally 1.0.) The source is specified by <u>material</u> and <u>group</u> as a given number of neutrons per cubic centimeter per second. The computation is accelerated by a driving factor computed at the end of each mesh sweep.

$$(FA)_n = \frac{\text{Absorptions + Leakages} - [1/k(\text{input})]\ (\text{Fission Source})}{\text{Integrated Fixed Source}} \quad . \tag{31}$$

The fixed source distribution at the next mesh sweep is $(FA)_n$ times the specified source; in this way the source and flux levels move to match one another. The converged fluxes reported are normalized to the specified fixed source distribution. The eigenvalue convergence criterion (Eq. (28))

is replaced by a corresponding convergence criterion on the driving factor, namely

$$\left| \frac{(FA)_n}{(FA)_{n-1}} - 1 \right| \quad .$$

The other convergence criteria remain the same.

The poison search calculation is quite similar. The user may specify by material and group a cross section which is to be multiplied by a driving factor to be found, which will make the assembly just critical for a given k-effective. The driving factor is calculated as

$$(FA)_n = \frac{-[1/k(\text{input})]\ (\text{Fission Source}) + \text{Absorptions} + \text{Leakages}}{\text{Integrated Poison Absorptions}} \quad . \qquad (32)$$

$(FA)_n$ may be positive or negative at convergence. If negative, a poison has been used; if positive, a fission source has been added.

$$\left| (FA)_n/(FA)_{n-1} - 1 \right|$$

is reported in the output as well as the following quantity:

$$k(\text{effective}) = \frac{(\text{Fission Source})_n}{(\text{Absorp.})_n - (FA)_{n-1}\ (\text{Integrated Poison Absorp.})_n + (\text{Leak.})_n} \quad . \qquad (33)$$

As the calculation proceeds, k(effective) should approach k(input).

Procedure for the Use of the Code

Code Limitations

If IMAX = maximum number of rows

JMAX = maximum number of columns

KMAX = maximum number of groups

MMAX = maximum number of different compositions

NMAX = maximum number of nuclides

Then the calculations which may be made with EXTERMINATOR are restricted by the following limitations:

$3 \leq IMAX \leq 250$

$3 \leq JMAX \leq 250$

$1 \leq KMAX \leq 50$

$1 \leq MMAX \leq 400$

$9 \leq IMAX * JMAX \leq 20{,}000$

$3 \leq IMAX * KMAX \leq 2000$

$18 \leq JMAX * (5 + KMAX) \leq 2000$

$0 \leq MMAX * NMAX \leq 6300$

$1 \leq KMAX * MMAX \leq 1000$

$1 \leq KMAX ** 2 * MMAX \leq 10{,}000$

Running Time

The calculation rate varies from 0.0018 to 0.0035 sec per point per iteration per group. Using magnetic tapes with a density of 800 BPI, the running time of some typical problems were:

Points	Groups	Iter.	Time (min)	Rate
2500	2	100	15	0.0018
198	4	140	4	0.0022
1044	6	191	40	0.0020
1085	16	86	81	0.0032

Input

The input required for EXTERMINATOR is described below. The number formats are shown in FORTRAN nomenclature and are given in parentheses immediately following the input number symbol.

Line 1: Title Card

Columns 2-72 TITLE (12A6): The information punched in this card is printed at the top of each page of output.

Line 2: Control Card

Columns 1-3 ITMAX (I3): The maximum number of iterations a problem is allowed to run. If the number of iterations reaches this number before convergence, the case is terminated automatically with all output. Normally problems will reach convergence in fewer than 300 iterations.

Columns 4-6 ±IMAX (I3): Total number of rows in the mesh. The rows, which lie along radii in RZ and RΘ geometry, are numbered from top to bottom beginning with 1 and ending with |IMAX|. If IMAX is input positive, the calculation of the fluxes is done from left to right of the mesh along each row. If IMAX is input negative, the fluxes are calculated from top to bottom of the mesh along each column. Normally it makes no difference in which direction the calculation is done. However, when there is an appreciable difference in the mesh increments along the rows as opposed to the mesh increments along the columns, it is recommended that the balculation of the fluxes be done in the direction in which the buckling is smallest. IMAX should always be input negative for RΘ geometry problems and for problems which have a periodic boundary condition. If a negative IMAX is specified, the code limitations (page 17) should be altered by interchanging the symbols IMAX and JMAX, and a further restriction on the size of a problem is $|IMAX| * JMAX \leq 10{,}000$.

Columns 7-9 JMAX (I3): Total number of columns in the mesh. The columns are numbered from left to right beginning with 1 and ending with JMAX.

Columns 10-12 MMAX (I3): Total number of different compositions for which cross sections are to be supplied.

Columns 13-14 KMAX (I2): Total number of groups.

Columns 15-16 GI (I2): Geometry indicator. A zero for this number specifies XY geometry, +1 specifies RZ geometry, and −1 specifies Rθ geometry.

Columns 17-18 BI (I2): Buckling indicator. A zero for BI specifies a constant buckling and the value is written in columns 1–9 of line 5. If BI is +1, this specifies group dependent buckling and the group values are given on lines 5 +. A −1 for BI specifies composition-group dependent bucklings which are given with the macroscopic data on lines 9 +.

Columns 19-20 MI (I2): Cross section input indicator. If MI is 0, the code expects only macroscopic cross section data which is specified on lines 9 + and no nuclide densities or microscopic data should be written. If MI is +1, the code will expect macroscopic data (if any) plus microscopic cross sections from tape only (see Cross Sections for the format of this tape). Nuclide densities must be specified on lines 10 +. If MI is −1, the code will expect macroscopic data (if any) plus microscopic cross sections from cards only, and written on lines 11 +. Nuclide densities must be given. If this option is used, no previously made cross section tape should be used as it will be written on. If MI is +2, the code will expect macroscopic data (if any) plus microscopic cross sections from tape as well as cards; nuclide densities must be specified. For this option, the cross section tape is not altered by the microscopic data input from cards.

Columns 21-22 CS (I2): Problem type indicator. A zero for this number specifies an eigenvalue or k-effective problem. A +1 specifies a constant source problem in which case the desired k-effective is written on line 3 and the values of the source are input on lines 9 +. The code holds the specified k-effective constant and solves for the flux distribution. A −1 for CS specifies a poison search for the specified k-effective. For this calculation the code finds a factor FA with which to multiply all of the search cross sections (specified on lines 9 +) to obtain the specified k-effective.

For the constant source calculation, the neutron balance equation is

$$\sum \text{Leakage} + \sum \text{Absorption}$$

$$- \frac{1}{k(\text{input})} \sum \text{Fission Source} - \sum \text{Constant Source} = 0 \quad . \tag{34}$$

The k-effective reported in the output is the above equation solved for k(input). If all $\nu\Sigma f = 0$, then k-effective would be reported as 0. Otherwise k-effective output should approach k(input) at convergence.

For the search calculation, the balance equation is the same as shown above except that the constant source term is replaced by FA $\sum[(\text{Search } \Sigma)\ \phi]$. The reported k-effective is calculated as above. For a poison search (FA < 0), the true k-effective is reported. If FA is calculated to be positive, a fission source has been added and the k-effective reported in the output is not a true value since it is not applied to the last term in the above equation.

<u>Columns 23-24</u> FI(I2): Previous flux indicator. If this number is 0, the code supplies a flat initial flux guess. A +1 for this number informs the code to use the flux distribution on tape 5 as the initial guess. This tape 5 could have been saved from a previous calculation (for instance to continue a case from a previous run), or if this is not the first case in a series of stacked cases the tape will contain the final flux distribution from the preceeding case. To use this option however, the case must have the same number of rows and columns and the same boundary conditions as the previous case.

<u>Columns 25-26</u> AI(I2): Microscopic cross section edit option. If AI > 0, the microscopic cross sections from the cross section tape are included in the output. Any microscopic data that are input from cards are automatically edited.

<u>Columns 27-28</u> SI(I2): Output source indicator. If this number is 0, the source edit is skipped. If this number if +1, the output will include the source calculated as

$$\sum_K (\nu\Sigma_f\ \phi)_k$$

at the four quadrants of each mesh point. This source does not include any specified constant source.

Columns 29-30 GI(I2): Convergence indicator. If CI is 0, the calculation stops when

$$\left|\frac{(\mathrm{KEFF})_{n+1}}{(\mathrm{KEFF})_n} - 1\right| < \epsilon(k) \quad , \tag{35}$$

where n is the iteration number. If CI if +1, the calculation stops when the above condition is satisfied as well as the flux convergence condition

$$\left|\frac{\phi_{n+1}}{\phi_n} - 1\right|_{max} < \epsilon(\phi) \quad . \tag{36}$$

It is recommended that +1 always be specified for CI.

As noted under Convergence Criteria it is our practice to specify $\epsilon(k)$ and $\epsilon(\phi)$ as about 10^{-6} and 10^{-4} respectively. We have seen a few problems in which the flux convergence could not be reduced beyond a certain level because of round off error. One of these was a one-dimensional, 2 group problem with down scatter only in which the flux convergence "stuck" at 8.4×10^{-5}. The problem reached this level in 15 iterations and the flux convergence could not be made smaller no matter how many more iterations were run. However, the KEFF convergence was zero and the groups were well balanced indicating that the problem was well converged.

Columns 31-32 CY(I2): Rebalance cycle. The group fluxes are rebalanced at every CY^{th} iteration until the rebalancing factors are within EXTRA (see below) of unity, at which time the rebalancing procedure ceases. If a cell problem is being run and CY is zero, the code will set CY to 10. Since group rebalancing does not help most problems; we recommend a zero be input for CY except for cases in which the groups are not well coupled.

The code will not attempt to rebalance constant source or search problems, or problems in which there are mixed rod and non-rod groups specified for the same composition.

Columns 33-34, 35-36, 37-38, 39-40 LB(I2), TB(I2), RB(I2), BB(I2): Left, top, right, bottom boundary condition indicator. A 0 for any of these numbers specifies that boundary is a zero flux boundary. A +1 for any of these number specifies that a symmetry boundary exists midway between columns 1 and 2, rows 1 and 2, columns JMAX-1 and JMAX, or rows IMAX-1 and IMAX. Note that in Figure 1, which is for Rθ geometry, no point J = 1 is shown, this point being a purely fictitious convenience in Rθ and RZ geometry. The axis of the cylinder is supposed to lie half way between J = 1 and J = 2. Fluxes reported in the output for column J = 1 have merely been set equal to those at column J = 2 and may be ignored. No fluxes are calculated for the axis of symmetry itself.

One other boundary condition, the periodic boundary condition, is permitted. If both TB and BB are specified as −1, the code calculates a reactor in which the fluxes along the top row are equal to the fluxes along the bottom row. To use this boundary condition however, the reactor must be described in a somewhat pecular way which is best explained

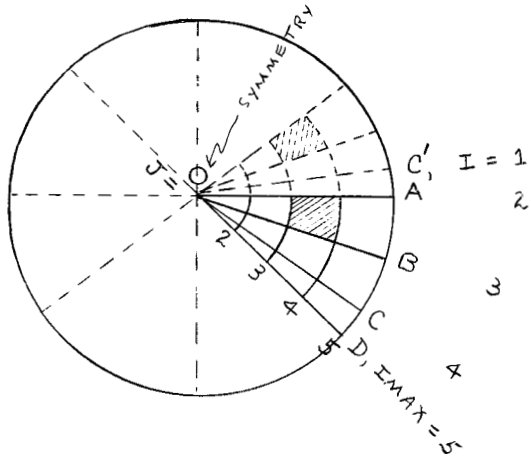

Figure 1. Illustration of Perodic Boundary Condition

with the use of figures. (The figures are drawn assuming RΘ geometry; however, this boundary condition is applicable in any geometry.)

With reference to Figure 1, suppose AOD, which repeats around the circle, is the reactor to be calculated. The fluxes along OA are equal to the fluxes along OD. The input to be written must be for the reactor C'OD; i.e., an extra row at the top, which is in the next cell and corresponds to C, must be included in the mesh. C' must be row 1 and D is row IMAX. The output for the above figure would include the fluxes for rows 1 through 4 and the neutron balance would be for rows 1 through 4; i.e., reactor C'OC.

Figure 2 represents a reactor which includes a full circle.

Suppose row OB is chosen as the top and bottom rows of the reactor. Then, to describe this reactor, OA would be rows 1 and 9 and OB would be rows 2 and 10. The fluxes would be output for rows 1 through 9; row 2 fluxes would be for OB and the fluxes for rows 1 and 9 would be the same. The neutron balance would be for reactor AOA.

When the periodic condition is specified, there must be a minimum of 5 rows in the mesh if the calculation is to be performed along columns, i.e., IMAX < 0.

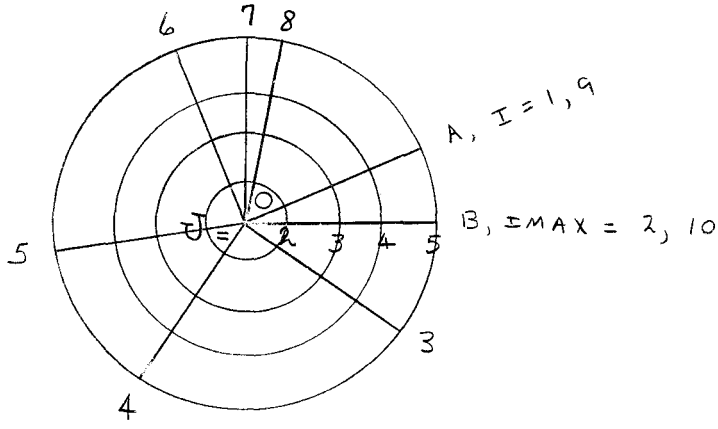

Figure 2. Full Circle Reactor

Columns 41-50 NORM. FACTOR (E10.7): Normalization factor. If this number is positive, all fluxes are multiplied by

$$\frac{\text{NORM. FACTOR}}{\sum_{I,J} V_{I,J} \sum_{K} (\nu\Sigma_f\phi)_{I,J,K}} \tag{37}$$

for output. If this number is input negative, the fluxes are multiplied by

$$\frac{|\text{NORM. FACTOR}|}{\sum_{I,J} V_{I,J} \sum_{K} (\Sigma_f\phi)_{I,J,K}} \quad . \tag{38}$$

If MI (columns 19-20) is input zero, specifying only macroscopic data, then NORM. FACTOR should be input positive. For constant source problems, the fluxes are normalized to the specified constant source. If NORM. FACTOR is input 0 or left blank, the code will use 1.0.

Columns 51-56 $\epsilon(k)$(E6.3): k-effective convergence criterion.

Columns 57-62 $\epsilon(\phi)$(E6.3): flux convergence criterion.

Columns 63-68 RI(E6.3): relaxation indicator. If RI is 0, the code will use line relaxation to solve for the flux distribution. If RI is 1.0, point relaxation is used. Even though the point relaxation calculation rate is slightly faster, it is recommended that line relaxation be used since problems solved by line relaxation usually converge in fewer iterations. For one-dimensional problems, line relaxation should always be used.

Columns 69-72 β(E4.3): extrapolated Liebmann coefficient. If this number is 0 or blank, the code will start with $\beta = 1.9$ (1.0 for one-dimensional problems using line relaxation) and adjust β during the course of the calculation. Otherwise the code will start with the input value. It is recommended that this number be input zero except for a continuation calculation in which case β should be given the value that the code was last using.

Line 3: Miscellaneous Data Card

Columns 1-12 ADDR(E12.8): A number which is added to the radius of each column of the mesh. Normally this number is input zero.

Columns 13-24 SCATU(E12.8): The maximum number of groups for up-scatter. For example if group K is allowed to scatter to group K-5, then 5.0 would be specified. If no microscopic data are to be used from tape and this number is 0 or blank, the code assumes maximum up-scattering to group 1 from any group.

Columns 25-36 SCATD(E12.8): The maximum number of groups for down-scatter. If this number is input 0 or left blank, and no microscopic data is to be used from tape, the code assumes maximum down-scattering to group KMAX from any group.

If microscopic data are to be used from tape, the numbers SCATU and SCATD are also read from the cross section tape. The numbers from tape will be used if both SCATU and SCATD are zero, otherwise the specified values will be used.

Columns 37-48 NMAX(E12.8): Largest nuclide number. If MI (control card) is not zero, NMAX must be at least as large as the largest nuclide number on the microscopic cross section tape or the microscopic cross section cards.

Columns 49-60 SKEFF(E12.8): k-effective for which the code is to search for a poison-search problem, or the k-effective the code is to assume in a constant source problem. (See CS above).

Columns 61-72 EXTRA(E12.8): Rebalancing convergence criterion. If the rebalancing option (CY control card) is being exercised, or if a cell problem is being run, the code stops rebalancing the groups when all rebalancing factors are within EXTRA of 1.0. Because of possible loss of significance in solving the KMAX by KMAX matrix for the re-balancing factors, it is recommended that a value of 0.01 be used for EXTRA for cases where KMAX $\geq$ 10. When KMAX $<$ 10, a number of the order of 0.001 should suffice.

Lines 4+: Fission Spectrum Cards

Columns 1-8, 9-16, 17-24, etc. χ(K)(9E8.4): The number of neutrons produced from fission that are born in group K; specified for groups 1, 2, 3, . . . , KMAX.

If microscopic data are to be used from tape, these numbers may be input as zeros in which case the fission spectrum is read from the cross section tape.

Line 5+: Buckling Cards

Columns 1-8, 9-16, 17-24, etc. B^2(CONST), or B^2(K)(9E8.4): The constant buckling or the group dependent buckling. If BI (control card) is 0, the constant buckling is specified in Columns 1-8. If BI = +1, the bucklings for groups 1, 2, 3, . . . , KMAX are specified. If BI = −1, these cards should not be included with the input deck.

Lines 6+: Mesh Specifications

Columns 1-6, 7-9; 10-15, 16-18; etc. Δ, ROW (8(E6.3,I3)): Specify a value of ΔY, ΔZ, or Δθ for XY, RZ, or Rθ geometry respectively and the row number up to which this value applies, going from the top to the bottom of the mesh. Use cm for XY or RZ geometry and radians for Rθ geometry. The last number on these cards should be IMAX.

Lines 7+: Mesh Specifications

Columns 1-6, 7-9; 10-15, 16-18; etc. Δ, COL (8(E6.3, I3)): Specify a value of ΔX, or ΔR for XY or RZ-Rθ geometry respectively and the column number up to which this value applies, going from the left to the right of the mesh. The last number on these cards should be JMAX.

Lines 8+: Composition Specifications

Columns 1-3 COMP. NO.(I3): Composition number. The compositions should be numbered from 1 to MMAX; however, they do not have to be specified in order.

Columns 4-6, 7-9, 10-12, 13-15 ROW 1(I3), ROW 2(I3), COL 1 (I3), COL 2 (I3): Top row, bottom row, left column, right column describing the mesh boundaries enclosing the composition specified above. A composition specification may overlay any number of previously specified compositions; the last one specified replacing previous specifications. Continue this specification in Columns 20-34, 39-53, and 58-72 using as many cards as necessary. If the last entry falls in Columns 58-72, one blank card must follow; otherwise no blank card is necessary.

Lines 9+: Macroscopic Data

Columns 1-5 M(I5): Composition number.

Columns 6-10 K(I5): Group number. The composition numbers and group numbers may be specified in any order.

Columns 11-20 D(E10.6): Diffusion coefficient for the composition and group specified above. If D is input zero, this specifies a rod group for this composition. The rod group constant C is input in the place of ΣA (below) and ΣR, $\nu\Sigma f$, S, and B^2 must be input zero. There are two restrictions which apply in specifying rod groups. 1). In a composition with rod groups, there should be no non-rod groups which have fissionable material, i.e., a value of $\nu\Sigma f$. 2). Except at the boundaries of the reactor, rod regions must have at least one internal mesh point.

Columns 21-30 ΣR(E10.6): Macroscopic removal cross section. If this number has a value, the scattering fractions specified below, $F(K \rightarrow L)$, are assumed to be fractions of ΣR scattering from group K to each group L. If ΣR is input as zero, the code assumes the scattering matrix below to be input as $\Sigma R(K \rightarrow L)$, the macroscopic values of the scattering cross sections specifying scattering from group K to each group L and will compute ΣR(total) and $F(K \rightarrow L)$.

Columns 31-40 ΣA(E10.6): Macroscopic absorption cross section, or C if D above is zero.

Columns 41-50 $\nu\Sigma f$(E10.6): ν times the macroscopic fission cross section.

Columns 51-60 S(E10.6): Constant source, input as neutrons per cm^3 per sec, for a constant source problem or a value of the macroscopic poison or fuel cross section for a search calculation. If CS (see control card) is 0, S may be ignored.

Columns 61-70 B^2(E10.6): Composition-group dependent buckling. B^2 may be ignored unless BI (see control card) is -1.

Following the above card, the scattering matrix for the composition and group specified in Columns 1-5 and 6-10 above is written.

Columns 1-10, 11-20, 21-30, etc. $F(K \rightarrow L)$ or $\Sigma R(K \rightarrow L)$ (7E10.0): The fractions of the ΣR specified above designating the scattering from group K (given above) to each group L, L = 1, 2, 3, . . ., KMAX; or the macroscopic removal cross section specifying the scattering from group K to each group L. There must be KMAX entries on these cards, and if the fractions are specified then sum must be 1.0.

Repeat the above set of cards (beginning with a new card specifying a composition number, group number, and macroscopic cross sections, followed by the scattering matrix) for as many compositions and groups as are to be input here. If less than MMAX and KMAX compositions and groups are to be specified, then a blank card must follow these data. Otherwise no blank card is included. If no macroscopic data are written, one blank card is needed.

Lines 10+: Nuclide Concentrations

If MI (see control card) is zero, these cards should not be included with the input deck.

For each composition for which nuclide concentrations are to be specified, the composition number is given on the first card followed by the nuclide numbers and concentrations on additional cards.

Columns 1-3 (first card) M(I3): Composition number.

Columns 1-3, 4-12; 13-15, 16-24, etc. (next cards) N, CONC. (6(I3, E9.5)): Nuclide number and concentration. A nuclide number and its concentration are specified for as many nuclides as are required for this composition. No nuclide number may exceed NMAX (see Miscellaneous Data Card).

A blank nuclide number signals the end of the concentrations for that composition and the code loops to find the next composition number. If the last concentration for a composition falls in Columns 64-72, a blank card must be inserted. A zero composition number (blank card) signals the end of the concentration specifications.

Lines 11+: Microscopic Data

These cards are present only if MI (control card) is −1 or +2.

For each nuclide and group for which microscopic cross sections are to be specified, the nuclide number and group number are given on the first card, σa, σf, σtr, and ν are given on the second card and the microscopic removal cross sections are given on additional cards.

Columns 1-3, 4-6 (first card) N, K(2I3): Nuclide number and group number. The nuclide number specified here must not be the same as any nuclide number that is on the microscopic cross section tape.

Columns 1-9, 10-18, 19-27, 28-36 (second card) σa, σf, σtr, ν(4E9.5): The microscopic absorption, fission, and transport cross sections, and ν for nuclide N and group K.

Columns 1-9, 10-18, etc. (next cards) $\sigma r(K \rightarrow L)$, L = 1, KMAX)(8E9.5): The microscopic scattering cross sections designating the scattering from group K to each group L. KMAX entries must be made.

A zero nuclide number (blank card) signals the end of this series of cards.

It should be noted that if ΣR (Input Form 3) is specified for a composition, then the $F(K \rightarrow L)$ values must be specified and no microscopic scattering cross section data will be used from tape or cards. The same holds true if $\Sigma R = 0$ and the $\Sigma R(K \rightarrow L)$ values are specified on Input Form 3. If ΣR is zero and the $F(K \rightarrow L)$ or $\Sigma R(K \rightarrow L)$ values are zero, then the scattering data are taken from tape and/or cards.

Output

The output for a problem consists of the following:

1. Reactor description
2. Material picture
3. Nuclide concentrations if input
4. Edit of microscopic cross section tape (optional) if microscopic data are specified
5. Macroscopic cross sections
6. Convergence levels at each iteration
7. Reaction rates for each nuclide, if microscopic data are specified
8. Complete neutron balance
9. Source (optional)
10. Group flux distributions

In the output of the convergence levels, the column of numbers headed by REL FLUX CONVR gives the pointwise flux convergence (Eq. (27)). The column of numbers headed by ABS FLUX CONVR is calculated from Eq. (29).

Cross Sections

Macroscopic Cross Sections

The macroscopic cross sections that EXTERMINATOR uses are calculated as follows, where M is the composition index, K is the group index, and N is the nuclide index.

$$D(M,K) = \frac{1}{\frac{1}{D'(M,K)} + \sum_N 3\sigma tr(N,K)\ CONC(N)} \quad . \tag{39}$$

$$\Sigma R(M,K) = \Sigma R'(M,K) + \sum_N CONC(N) \sum_L \sigma r(N,K \rightarrow L) \quad . \tag{40}$$

$$\Sigma A(M,K) = \Sigma A'(M,K) + \sum_N \sigma a(N,K)\ CONC(N) \quad . \tag{41}$$

$$\nu\Sigma f(M,K) = \nu\Sigma f'(M,K) + \sum_N \nu(N,K)\ \sigma f(N,K)\ CONC(N) \quad . \tag{42}$$

$$F(M,K \rightarrow L) = \Sigma R(M,K \rightarrow L)/\Sigma R(M,K) \quad . \tag{43}$$

The primes indicate input macroscopic values.

Microscopic Cross Section Tape Format

The code TONG[7] produces a microscopic cross section tape for EXTERMINATOR. However, any tape written with the following format may be used:

Record 1	Tape title (72 Hollerith)
Record 2	KMAX, NONUC, SCATD, SCATU

The next two records are repeated for NONUC nuclides.

Record 1	NUCNO, EXTA
Record 2	$\begin{cases} ((\sigma a(K),\ \sigma f(K),\ \sigma tr(K),\ \nu(K)),\ K = 1,\ KMAX), \\ ((\sigma r(K \rightarrow L),\ L = 1,\ KMAX),\ K = 1,\ KMAX) \end{cases}$

Next to last record NEG, EXTA

Last record (χ(K), K = 1, KMAX)

where KMAX in the total number of groups (columns 13-14 above)

NONUC is the number of nuclides for which cross sections are written on the tape

SCATD is the maximum number of groups for down scatter

SCATU is the maximum number of groups for up scatter

NUCNO is the nuclide number

EXTA is any number (Not used but must be written on tape)

NEG is a negative number (integer)

The cross sections and χ(K) are defined elsewhere.

If SCATD and SCATU are zero on the tape, values for these numbers are taken from the Miscellaneous Data Card (Line 3). Also if the χ(K) are zero on the tape, values are taken from the Fission Spectrum Cards (Lines 4+).

This tape is logical tape 13.

Code Operation

Data Transmission

IO Subroutines

EXTERMINATOR was programmed mostly in FORTRAN. However, FAP coded sub-routines are used to permit buffered tape operations during the iterative part of the calculation. To gain efficient use of tape operation and to be able to recover from tape errors, the tapes containing constants are duplicated. During the flux calculations, two tapes (one from each of two channels) are being read into core buffer regions, two tapes are being rewound, and calculations are being done with previously read data, all simultaneously. Since the "compute time" is approximately equal to the "tape time", EXTERMINATOR runs at computer speed plus a small fraction of the time required to read and write the fluxes. (An additional IO channel would eliminate this time).

Tape Errors

When tape errors are detected by the code, on-line comments to the operator are printed and the machine stops. These comments have the general form

LOGICAL TAPE I WILL NOT READ (WRITE), OPERATOR DO THE FOLLOWING - -

1. DETERMINE ACTUAL TAPE NO. OF LOGICAL TAPE I
2. CHANGE TAPE AND PUSH START

where I is a logical tape number.

No provision was made in the FAP coded IO sub-routines to skip bad spots on magnetic tape, or to skip noise records. To avoid having to change tapes excessively after a problem has been started, it is advantageous to start with a set of tapes that are free from bad spots. Our practice is to have the machine operator "scan" the tapes on units A4, A6, A7, B1, B3, and B7 (see Tapes below) from the console prior to running a problem. This is done by using the data channel console in manual and writing one continuous record with the "stop on error" switch down. In this way tapes with bad spots can be replaced. The amount of tape that should be scanned depends upon the size of the problem, however scanning each tape for approximately 30 seconds should suffice for most problems. The error recovery procedure programmed into EXTERMINATOR is such that after a problem has run at least 10 iterations, theoretically the worst that can happen is that the problem is terminated with tape 5 saved for a restart. However, we have had a few, as yet unexplained, tape errors that have caused the calculation to stop in such a way that no recovery was possible.

FORTRAN Monitor System

Chain Links

EXTERMINATOR is a "chain job" and runs under the FORTRAN-2 monitor system. The code consists of 6 chain links that are written on actual tape B2 at execution time. After an initial execute run, tape B2 may be saved and thereafter the code can be run with this tape mounted and a previously compiled two word program

```
CALL CHAIN (4, 2)
END
```

together with the case data.

The chain links comprising the code are:

INPT(4, 2)	reads input and calculates cross sections
CNST(5, 2)	generates group constants on tapes
FLUX(6, 2)	line relaxation flux and eigenvalue calculation
FLUX(66, 2)	point relaxation flux and eigenvalue calculation
BALN(7, 2)	computes and writes out neutron balance
POUT(8, 2)	writes out flux distribution

Tapes

In order to make the most efficient use of IO operations, an IOU sub-routine is included with each chain link which relates the actual and logical tape numbers as shown below. This correspondence should not be changed.

Logical No.	Actual No.	Use
1	A1	System
2	B2	Program
3	B3	Group constants
4	A4	Group constants
5	A5	Flux save tape
6	B6	Scratch
7	B7	Group constants
8	B1	Scratch
9	A3	Output
10	A2	Input
11	A6	Group constants
12	A7	Scratch
13	B5	Previously written microscopic cross section tape (optional)

Sense Switches

If sense switch 1 is depressed, the case will end normally as if convergence had been met. If sense switch 6 is depressed, the convergence and k-effective at each iteration are printed on line.

Restart

If logical tape 5 is saved from a run, a problem may be restarted by mounting this tape and specifying +1 for FI (columns 23-24 of the control card), all other data remaining the same.

Sample Problem

Figure 3 shows the diagram of the sample problem. Four groups were considered in RZ geometry. Figure 4 shows the input sheets filled out for the problem and Figure 5 gives the output. The problem requires about 7 minutes to run.

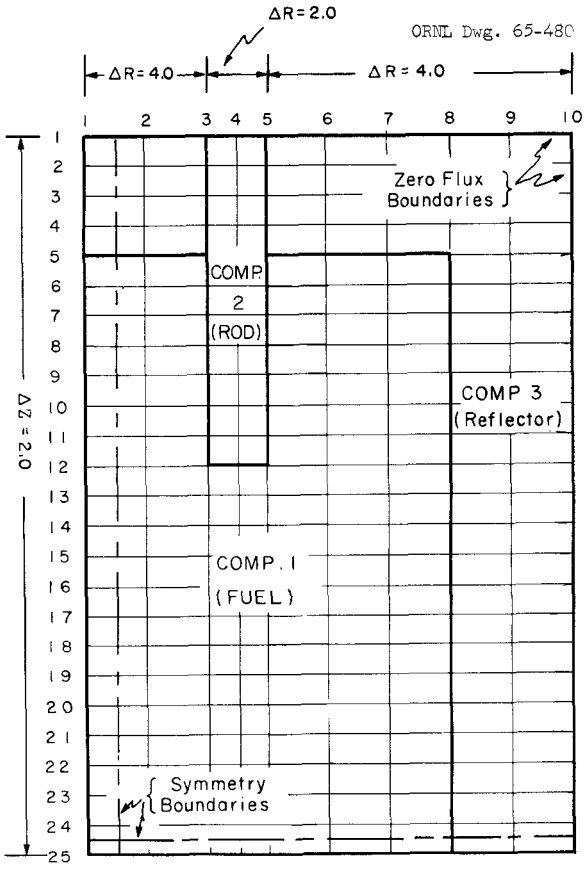

Fig. 3. Diagram of Sample Problem.

KEY PUNCHING INSTRUCTIONS:
Punch only those cards which have data in columns 73-80.

Figure 4.

EXTERMINATOR INPUT FORM-I

Request _____

1 TITLE	73–80
EXTERMINATOR SAMPLE PROBLEM	01

1 itmax	4 imax	7 jmax	10 nmax	13 kmax	15 GI	17 BI	19 MI	21 CS	23 EI	25 AI	27 SI	29 CI	31 CY	33 LB	35 IB	37 RB	39 JB	41 Norm. Factor	51 ε(k)	57 ε(φ)	63 RI	69 β	73
300	25	10		3	4	1	0	-1	0	0	0	1	1	0	1	0	0	1	11.0	+12	.00001	.00001			02

1 ADDR	13 SCATU	25 SCATD	37 NMAX	49 SKEFF	61 EXTRA	73–80
01.01	3.0	3.0	2.0			03

1 (X(k), k = 1, KMAX)	9	17	25	33	41	49	57	65	73–80
06	0.12	0.1	0.1						04

1 B^2 (CNST) - OR (B^2(k), k = 1, KMAX)	9	17	25	33	41	49	57	65	73–80
0.001									05

KEY PUNCHING INSTRUCTIONS:
Punch only those cards which have data in columns 73 - 80.

Figure 4.
(Contd)

EXTERMINATOR INPUT FORM - 2

REQUEST NO.

ΔY (1)	ROW (7)	ΔY (10)	ROW (16)	ΔY (19)	ROW (25)	ΔY (28)	ROW (34)	ΔY (37)	ROW (43)	ΔY (46)	ROW (52)	ΔY (55)	ROW (61)	ΔY (64)	ROW (70)	(73–80)
2.0	25															06

ΔX (1)	COL (7)	ΔX (10)	COL (16)	ΔX (19)	COL (25)	ΔX (28)	COL (34)	ΔX (37)	COL (43)	ΔX (46)	COL (52)	ΔX (55)	COL (61)	ΔX (64)	COL (70)	(73–80)
4.0	3	20	5	4.0	10											07

COMP. NO. (1)	ROW 1 (4)	ROW 2 (7)	COL 1 (10)	COL 2 (13)	COMP. NO. (20)	ROW 1 (23)	ROW 2 (26)	COL 1 (29)	COL 2 (32)	COMP. NO. (39)	ROW 1 (42)	ROW 2 (45)	COL 1 (48)	COL 2 (51)	COMP. NO. (58)	ROW 1 (61)	ROW 2 (64)	COL 1 (67)	COL 2 (70)	(73–80)
3	1	25	1	10	1	5	25	1	8	2	1	12	3	5						08

UCN-1336
(2 10-60)

Figure 4. (Contd)

EXTERMINATOR INPUT FORM-3 Macroscopic Data

KEYPUNCHING INSTRUCTIONS:
Punch only those cards having information in columns 73–80

REQUEST NO. _____

Specify Cards 1 and 2+ for Each Comp-Group
Card 1 → M, K, D, ΣR, ΣA, $\nu\Sigma f$, S, B → (2I5, 6E10.6) Cards 2+ → $\left\{ \begin{array}{l} F(K-L) \\ \Sigma R(K-L) \end{array} \right.$, L=1,KMAX, → (7E 10.6)

1	6	11	21	31	41	51	61	73	Card Number 80
2	1			0.2					09
0.0									10
2	2			0.2					11
0.0									12
2	3			0.2					13
0.0									14
2	4	1.0	0.0	0.0001					15
0.0									16
3	1	1.0	0.0001	0.00001					17
0.0		0.5	0.3	0.2					18
3	2	1.0	0.0002	0.00002					19
0.2		0.0	0.6	0.2					20
3	3	1.0	0.0003	0.0003					21
0.11		0.2	0.0	0.7					22
3	4	1.0	0.0	0.0004					23
0.00002		0.00008	0.0001	0.0					24
0.0									25

Figure 4. (Contd) **EXTERMINATOR INPUT FORM – 4 Nuclide Concentrations**

KEYPUNCHING INSTRUCTIONS:
Punch only those cards having information in columns 73–80

REQUEST NO. _____

Specify Cards 1 and 2+ for Each Comp
Card 1 → Comp. No.→(I3)
Card 2+ → Nuc. No., Conc. → 6(I3, E9.5)

1	4	13	16	25	28	37	40	49	52	61	64	Card Number 73–80
1												26
1	10-04	2	10-03									27
3												28
2	10-06											29
0												30

Figure 4. (Contd)

KEY PUNCHING INSTRUCTIONS:
Punch only those cards which have date in columns 73 - 80.

EXTERMINATOR INPUT FORM-5 Microscopic Data

Request _____

Specify card 1, card 2, and card 3+ for each nuc.-group

Card 1 → Nuc. no., grp. no., → (2I3)

Card 2 → σ_a, σf, σtr, ν → (4E9.5)

Card 3+ → (σscat(K→L), L=1, KMAX) → (8E9.5)

1	10	19	28	37	46	55	64	73	80
1 1								3	1
30.0	20.0	3333.3	2.0					3	2
0.0	10.0	5.0	2.5					3	3
1 1 2								3	4
60.0	40.0	3333.3	2.0					3	5
2.0	0.0	10.0	5.0					3	6
1 1 3								3	7
100.0	50.0	3333.3	2.0					3	8
1.0	2.0	0.0	20.0					3	9
1 1 4								4	0
300.0	200.0	3333.3	2.0					4	1
0.0	0.0	0.0	0.0					4	2
2 1 1								4	3
25.0	0.0	333.3	0.0					4	4
0.0	10.0	0.0	0.0					4	5

KEY PUNCHING INSTRUCTIONS:
Punch only those cards which have data in columns 73-80.

Figure 4. (Contd)

EXTERMINATOR INPUT FORM-5 Microscopic Data

Request _____

Specify card 1, card 2, and card 3+ for each nuc.-group

Card 1 → Nuc. no., grp. no., → (2I3)

Card 2 → σ_a, σf, σtr, ν → (4E9.5)

Card 3+ → (σscat(K→L), L=1, KMAX) →(8E9.5)

1	10	19	28	37	46	55	64	73–80
2 2								46
30.0	0.0	333.3	0 0					47
0.0	0.0	150						48
2 3								49
50.0	0.0	333 3						50
0 0	0.0	0 0	20 0					51
2 4								52
60 0	0.0	333 3	0.0					53
0.0	0.0	0 0	0.0					54
0								55

Figure 5

```
EXTERMINATOR SAMPLE PROBLEM

REACTOR SPECIFICATIONS

  25 ROWS    10 COLUMNS    4 GROUPS    3 COMP    RZ GEOM    B.C.(L,T,R,B) 1, 0, 0, 1    NORM FACTOR 10.000000E 11

FISSION-SOURCE CHI(K)
 0.6000  0.2000  0.1000  0.1000

MESH SPECIFICATIONS

   I  DELTA
   1  2.000  25

   J  DELTA
   1  4.000   3  2.000   5  4.000  10


DIMENSION SPECIFICATIONS

    I   DIST.
    2   2.000    3   4.000    4   6.000    5   8.000    6  10.000    7  12.000    8  14.000    9  16.000   10  18.000
   11  20.000   12  22.000   13  24.000   14  26.000   15  28.000   16  30.000   17  32.000   18  34.000   19  36.000
   20  38.000   21  40.000   22  42.000   23  44.000   24  46.000   25  48.000

    J   DIST.
    2   2.000    3   6.000    4   8.000    5  10.000    6  14.000    7  18.000    8  22.000    9  26.000   10  30.000
```

Figure 5. (Contd)

EXTERMINATOR SAMPLE PROBLEM

REACTOR MATERIAL PICTURE

J- \ I	1	2	3	4	5	6	7	8	9	10
1	3	3	2	2	3	3	3	3	3	
2	3	3	2	2	3	3	3	3	3	
3	3	3	2	2	3	3	3	3	3	
4	3	3	2	2	3	3	3	3	3	
5	1	1	2	2	1	1	1	3	3	
6	1	1	2	2	1	1	1	3	3	
7	1	1	2	2	1	1	1	3	3	
8	1	1	2	2	1	1	1	3	3	
9	1	1	2	2	1	1	1	3	3	
10	1	1	2	2	1	1	1	3	3	
11	1	1	2	2	1	1	1	3	3	
12	1	1	1	1	1	1	1	3	3	
13	1	1	1	1	1	1	1	3	3	
14	1	1	1	1	1	1	1	3	3	
15	1	1	1	1	1	1	1	3	3	
16	1	1	1	1	1	1	1	3	3	
17	1	1	1	1	1	1	1	3	3	
18	1	1	1	1	1	1	1	3	3	
19	1	1	1	1	1	1	1	3	3	
20	1	1	1	1	1	1	1	3	3	
21	1	1	1	1	1	1	1	3	3	
22	1	1	1	1	1	1	1	3	3	
23	1	1	1	1	1	1	1	3	3	
24	1	1	1	1	1	1	1	3	3	
25										

Figure 5. (Contd)

```
EXTERMINATOR SAMPLE PROBLEM

NUCLIDE CONCENTRATIONS FOR EACH COMPOSITION

 COMPOSITION  1

  NUC CONCENTRATION
    1 10.00000E-05     2 10.00000E-04    -0 -0.            -0 -0.            -0 -0.            -0 -0.

 COMPOSITION  3

  NUC CONCENTRATION
    2  1.00000E-06    -0 -0.            -0 -0.            -0 -0.            -0 -0.            -0 -0.

MICROSCOPIC CROSS SECTIONS LISTED AS
SIG AB, SIG FISS, SIG TR, NU, SIG SCAT(GRP K TO GRP KK, KK#1,KMAX)

 NUCLIDE   1

  GRP  CROSS SECTIONS
    1   3.00000E 01   2.00000E 01   3.33330E 03   2.00000E 00   0.            1.00000E 01   5.00000E 00   2.50000E 00

 NUCLIDE   1

  GRP  CROSS SECTIONS
    2   6.00000E 01   4.00000E 01   3.33330E 03   2.00000E 00   2.00000E 00   0.            1.00000E 01   5.00000E 00

 NUCLIDE   1

  GRP  CROSS SECTIONS
    3   1.00000E 02   5.00000E 01   3.33330E 03   2.00000E 00   1.00000E 00   2.00000E 00   0.            2.00000E 01

 NUCLIDE   1

  GRP  CROSS SECTIONS
    4   3.00000E 02   2.00000E 02   3.33330E 03   2.00000E 00   0.            0.            0.            0.

 NUCLIDE   2

  GRP  CROSS SECTIONS
    1   2.50000E 01   0.            3.33300E 02   0.            0.            1.00000E 01   0.            0.

 NUCLIDE   2

  GRP  CROSS SECTIONS
    2   3.00000E 01   0.            3.33300E 02   0.            0.            0.            1.50000E 01  -0.

 NUCLIDE   2

  GRP  CROSS SECTIONS
    3   5.00000E 01   0.            3.33300E 02  -0.            0.            0.            0.            2.00000E 01

 NUCLIDE   2
```

Figure 5. (Contd)

```
GRP  CROSS SECTIONS
  4   6.00000E 01   0.          3.33300E 02   0.          0.          0.          0.          0.
```

Figure 5. (Contd)

EXTERMINATOR SAMPLE PROBLEM

COMPOSITION SPECIFICATIONS

COMP	GRP	D	SIGR	SIGA	NUSIGF	SOURCE	BSQ
1	1	5.00028E-01	1.17500E-02	2.80000E-02	4.00000E-03	0.	10.00000E-04
	2	5.00028E-01	1.67000E-02	3.60000E-02	8.00000E-03	0.	10.00000E-04
	3	5.00028E-01	2.23000E-02	6.00000E-02	10.00000E-03	0.	10.00000E-04
	4	5.00028E-01	0.	9.00000E-02	4.00000E-02	0.	10.00000E-04
2	1	-0.	-0.	2.00000E-01	0.	-0.	10.00000E-04
	2	-0.	-0.	2.00000E-01	0.	-0.	10.00000E-04
	3	-0.	-0.	2.00000E-01	-0.	-0.	10.00000E-04
	4	1.00000E 00	0.	10.00000E-05	0.	-0.	10.00000E-04
3	1	9.99001E-01	10.00000E-04	1.25000E-04	0.	-0.	10.00000E-04
	2	9.99001E-01	2.00000E-03	2.30000E-04	0.	-0.	10.00000E-04
	3	9.99001E-01	3.00000E-03	3.05000E-03	-0.	-0.	10.00000E-04
	4	9.99001E-01	2.00000E-03	4.06000E-03	0.	-0.	10.00000E-04

FRACTION REMOVALS

COMP	GRP	TO GRP 1	2	3	4
1	1	0.	0.936	0.043	0.021
	2	0.012	0.	0.958	0.030
	3	0.004	0.009	0.	0.987
	4	-0.	-0.	-0.	-0.
2	1	-0.	-0.	-0.	-0.
	2	-0.	-0.	-0.	0.
	3	-0.	-0.	-0.	-0.
	4	-0.	-0.	-0.	-0.
3	1	0.	0.500	0.300	0.200
	2	0.200	0.	0.600	0.200
	3	0.100	0.200	0.	0.700
	4	0.100	0.400	0.500	0.

Figure 5. (Contd)

EXTERMINATOR SAMPLE PROBLEM

CONVERGENCE DATA AND K-EFFECTIVE EVERY ITERATION - BETA IS 1.9000E 00

IT NO	REL FLUX CONVR	ABS FLUX CONVR	KEFF CONVERGENCE	K - EFFECTIVE
1	-7.2773247E-01	-2.9637258E-01	6.4915666E 00	1.3348343E-01
2	8.8456467E-01	6.6461481E-01	1.3548557E-01	1.5440277E-01
3	6.6917846E-01	-1.5720060E 00	4.3237805E-02	1.6138051E-01
4	-5.5436568E-01	-2.3265374E-01	4.0754706E-02	1.6823696E-01
5	7.2444394E-01	4.5782672E-01	2.5050148E-02	1.7255960E-01
6	-4.7031817E-01	-2.2189730E-01	1.9060664E-02	1.7591261E-01
7	-4.9804958E-01	-1.1342857E 00	2.1624990E-02	1.7980080E-01
8	-3.5809656E-01	-5.6031491E-01	1.4453441E-02	1.8243766E-01
9	-3.3004976E-01	-8.0820926E-01	9.2912688E-03	1.8414863E-01
10	-3.2283138E-01	-9.3655223E-01	5.9491545E-03	1.8525071E-01
11	-3.1533926E-01	-9.3144948E-01	3.6426336E-03	1.8592798E-01
12	-3.2541441E-01	-1.1088725E 00	2.4450421E-03	1.8638370E-01
13	3.6825080E-01	2.0883169E-01	1.6218573E-03	1.8668647E-01
14	4.6581537E-01	-6.3744319E-01	1.7010048E-03	1.8700457E-01
15	5.3701046E-01	-7.7844507E-01	6.5877289E-04	1.8712784E-01
16	3.6759676E-01	-7.0527393E 00	4.8664212E-04	1.8703682E-01
17	-3.3055102E-01	-1.4824426E-01	1.1530817E-03	1.8682140E-01
18	-3.8509609E-01	-1.7497725E 00	1.6908348E-03	1.8650604E-01
19	2.1573913E-01	1.6046259E-01	2.0375848E-03	1.8612680E-01
20	2.8275827E-01	-4.7649955E-01	2.0104498E-03	1.8575335E-01
			BETA ADJUSTED TO	1.800000E 00
21	2.5562230E-01	-1.6011067E 00	1.1218786E-03	1.8554519E-01
22	-2.7395623E-01	-1.1679187E-01	7.0275366E-04	1.8541488E-01
23	-3.2418867E-01	-2.3019970E 00	1.1807680E-04	1.8543678E-01
24	-4.3914062E-01	-5.1934187E 00	3.6948919E-04	1.8550532E-01
25	6.5691754E-01	3.5721481E-01	3.2085180E-04	1.8544582E-01
26	6.5063207E-01	-1.0149254E 00	4.2502582E-04	1.8536703E-01
27	3.6893468E-01	5.7623601E 00	2.1649897E-04	1.8540717E-01
28	1.5086432E-01	3.4270450E-31	3.5858899E-04	1.8547368E-01
29	-1.3682268E-01	-6.6946940E-02	4.4411421E-04	1.8555609E-01
30	-8.7297976E-02	-1.9431476E-01	4.6352297E-04	1.8564214E-01
31	-1.3241754E-01	3.4445351E-01	5.2678585E-04	1.8573998E-01
32	-1.0771368E-01	-3.6603198E-01	5.2923709E-04	1.8583833E-01
33	-1.1865617E-01	-6.9521618E 00	2.6980788E-04	1.8588849E-01
34	-7.3700987E-02	-1.6284979E-01	8.0913305E-06	1.8588698E-01
35	-6.5346643E-02	-3.6567543E-01	1.7306209E-04	1.8585481E-01
36	3.1503439E-02	2.1717615E-02	2.0846725E-04	1.8581607E-01
37	-3.4654833E-02	-1.6234143E-02	1.3355911E-04	1.8579126E-01
38	2.3396850E-02	1.4164948E-02	6.7964196E-05	1.8577863E-01
39	3.8757697E-02	-5.5743008E-02	6.5252185E-05	1.8576651E-01
40	2.5749058E-02	8.3090663E-02	7.2777271E-05	1.8575299E-01
41	2.4303809E-02	7.6368432E-01	7.1227551E-05	1.8573976E-01
42	-2.3028836E-02	-1.1686389E-02	5.2526593E-05	1.8573000E-01
43	2.4391919E-02	1.1987389E-02	5.0216913E-05	1.8572067E-01
44	2.8716192E-02	-1.3939956E-01	2.8759241E-05	1.8571533E-01
45	-5.7105161E-02	-1.8749375E-02	2.2813678E-05	1.8571957E-01
46	4.5019999E-02	2.5823843E-02	4.9278140E-05	1.8572872E-01
47	-2.8201506E-02	-1.7044065E-02	3.6209822E-05	1.8573544E-01
48	2.7774155E-02	1.4191685E-02	3.3207238E-05	1.8574161E-01
49	1.5246987E-02	3.4987015E-02	5.8710575E-06	1.8574270E-01
50	-1.9245632E-02	-8.4355035E-03	2.6598573E-06	1.8574319E-01
51	-1.9346826E-02	-1.3732044E 00	1.8648803E-05	1.8574665E-01
52	-9.7837448E-03	-1.9409076E-02	1.5489757E-05	1.8574953E-01
53	7.4732006E-03	4.2549239E-03	8.2477927E-06	1.8575106E-01
54	4.7078580E-03	1.2886706E-02	4.3585896E-06	1.8575187E-01

Figure 5. (Contd)

55	-9.7271949E-03	-3.1624014E-03	2.0861626E-07	1.8575183E-01
56	-5.2198619E-03	-1.1139406E-02	3.1143427E-06	1.8575125E-01
57	4.0428787E-03	2.2834989E-03	9.9539757E-06	1.8574940E-01
58	4.2843968E-03	-6.6919133E-02	1.3425946E-05	1.8574691E-01
59	2.0548552E-03	3.9643650E-03	1.0386109E-05	1.8574498E-01
60	-1.9376203E-03	-9.9626472E-04	5.2005053E-06	1.8574401E-01
61	-2.1165535E-03	2.3457240E-02	2.2351742E-08	1.8574401E-01
62	1.5171915E-03	8.8450272E-04	1.8700957E-06	1.8574436E-01
63	1.5145093E-03	5.9772406E 00	7.3760748E-07	1.8574450E-01
64	1.2048781E-03	5.9283978E-03	1.7881393E-07	1.8574446E-01
65	-5.7467818E-04	-3.8894406E-04	1.3411045E-07	1.8574449E-01
66	-8.3690137E-04	1.8374908E-03	7.2270632E-07	1.8574462E-01
67	7.7119470E-04	4.0151397E-04	1.0579824E-06	1.8574482E-01
68	-4.5631826E-04	-2.8660338E-04	1.5795231E-06	1.8574511E-01
69	-7.0053339E-04	1.3106688E-03	2.3394823E-06	1.8574554E-01
70	-4.7957152E-04	-1.5181164E-03	1.9371510E-06	1.8574590E-01
71	3.2921135E-04	1.9524550E-04	5.3644180E-07	1.8574600E-01
72	2.2986531E-04	7.6230471E-04	2.0861626E-07	1.8574596E-01
73	3.2976270E-04	-7.5821341E-04	6.5565109E-07	1.8574584E-01
74	-6.1295927E-04	-2.1436625E-04	5.3644180E-07	1.8574574E-01
75	-5.1734596E-04	-3.3056461E-03	8.1956387E-08	1.8574575E-01
76	2.5564432E-04	1.7112659E-04	5.9604645E-08	1.8574574E-01
77	3.0942261E-04	-1.4687332E-03	3.1292439E-07	1.8574568E-01
78	1.1077523E-04	1.7257855E-04	2.9802322E-07	1.8574562E-01
79	-1.6420335E-04	-6.6145009E-05	3.8743019E-07	1.8574555E-01
80	1.2214482E-04	7.0047568E-05	2.9802322E-07	1.8574549E-01
81	2.1798909E-04	-2.7773015E-04	2.6822090E-07	1.8574544E-01
82	1.5240908E-04	5.0686716E-04	1.6391277E-07	1.8574541E-01
83	-7.0802867E-05	-4.8341849E-05	7.4505806E-08	1.8574543E-01
84	-8.5167587E-05	4.1996242E-04	2.2351742E-07	1.8574547E-01
85	-4.7042966E-05	-1.0507947E-04	2.1606684E-07	1.8574550E-01
86	8.2135201E-05	2.9912168E-05	2.0116568E-07	1.8574554E-01
87	6.4402819E-05	2.9839853E-04	0.	1.8574554E-01
88	-3.0383468E-05	-2.0643710E-05	4.4703484E-08	1.8574555E-01
89	-3.6031008E-05	1.9388252E-04	1.4901161E-08	1.8574555E-01
90	-2.6218593E-05	-9.6264925E-05	2.2351742E-08	1.8574555E-01
91	1.2770295E-05	8.5876274E-06	8.1956387E-08	1.8574557E-01
92	-1.3686717E-05	-6.6062735E-06	2.2351742E-08	1.8574557E-01
93	-2.2582710E-05	3.4745293E-05	0.	1.8574557E-01
94	1.1608005E-05	7.6670585E-06	1.4901161E-08	1.8574557E-01
95	1.3768673E-05	-7.3965544E-05	2.9802322E-08	1.8574556E-01
96	1.1608005E-05	7.3976475E-05	5.9604645E-08	1.8574555E-01
97	-9.2089176E-06	-5.1350823E-06	2.9802322E-08	1.8574554E-01

Figure 5. (Contd)

EXTERMINATOR SAMPLE PROBLEM

REACTION RATES FOR EACH NUCLIDE

NUC	ABS/TOT.LOSSES	FIS/TOT.LOSSES	CAP/TOT.LOSSES	PROD/TOT.PROD.	SUM(REGV*CONC)
1	1.4490923E-01	9.2872770E-02	5.2036465E-02	9.9999999E-01	2.2594303E 01
2	7.0777402E-01	0.	7.0777402E-01	0.	2.2623095E 02
TOTAL	8.5268325E-01	9.2872770E-02	7.5981048E-01	9.9999999E-01	

Figure 5. (Contd)

EXTERMINATOR SAMPLE PROBLEM

NEUTRON BALANCE

GROUP	ABSORPTIONS	OUT SCATTER	LFT LEAKAGE	TOP LEAKAGE	RIT LEAKAGE	BOT LEAKAGE	AXIAL LEAK	TOTAL LOSSES
1	2.039960E 12	8.301109E 11	0.	1.011313E 10	3.154882E 11	0.	4.443256E 10	3.240105E 12
2	1.159519E 12	5.289370E 11	0.	4.508508E 09	1.412785E 11	0.	1.983746E 10	1.854080E 12
3	7.429414E 11	2.738854E 11	0.	1.758495E 09	5.480051E 10	0.	7.680030E 09	1.081066E 12
4	7.940945E 11	2.408963E 09	0.	1.925640E 09	3.965086E 10	0.	5.720913E 09	8.438008E 11
TOTAL	4.736514E 12	1.635342E 12	0.	1.830577E 10	5.512181E 11	0.	7.767097E 10	7.019051E 12

GROUP	PRODUCTIONS	FISS SOURCE	CONST SOURCE	IN SCATTER	KEFFECTIVE	TOTAL GAINS
1	2.793496E 11	3.230226E 12	0.	9.878656E 09	1.857455E-01	3.240104E 12
2	2.493020E 11	1.076742E 12	0.	7.773383E 11	1.857455E-01	1.854080E 12
3	1.205968E 11	5.383709E 11	0.	5.426949E 11	1.857455E-01	1.081066E 12
4	3.507515E 11	5.383709E 11	0.	3.054298E 11	1.857455E-01	8.438007E 11
TOTAL	10.000000E 11	5.383709E 12	0.	1.635342E 12		7.019051E 12

COMPOSITION ABSORPTIONS

COMP 1 VOLUME 5.64858E 04

GRP	ABSORPTIONS	AVERAGE PHI
1	1.95545E 12	1.23637E 09
2	1.12186E 12	5.51692E 08
3	7.23581E 11	2.13500E 08
4	7.89191E 11	1.55239E 08

COMP 2 VOLUME 4.42336E 03

GRP	ABSORPTIONS	AVERAGE PHI
1	8.33225E 10	0.
2	3.66801E 10	0.
3	1.43234E 10	0.
4	1.32999E 07	3.00675E 07

COMP 3 VOLUME 7.19801E 04

GRP	ABSORPTIONS	AVERAGE PHI
1	1.19018E 09	1.32279E 08
2	9.79681E 08	5.91758E 07
3	5.03710E 09	2.29439E 07
4	4.89019E 09	1.67335E 07

Figure 5. (Contd)

EXTERMINATOR SAMPLE PROBLEM

POINT SOURCE AT EACH QUADRANT

(I, J)	TOP RIT	TOP LFT	BOT LFT	BOT RIT
(5, 2)	0.	0.	6.88601E 05	6.88601E 05
(5, 3)	0.	0.	5.93481E 05	0.
(5, 5)	0.	0.	0.	7.75777E 05
(5, 6)	0.	0.	9.84925E 05	9.84925E 05
(5, 7)	0.	0.	8.95273E 05	8.95273E 05
(5, 8)	0.	0.	6.16495E 05	0.
(6, 2)	1.21620E 06	1.21620E 06	1.21620E 06	1.21620E 06
(6, 3)	0.	9.27965E 05	9.27965E 05	0.
(6, 5)	1.19920E 06	0.	0.	1.19920E 06
(6, 6)	1.69009E 06	1.69009E 06	1.69009E 06	1.69009E 06
(6, 7)	1.51255E 06	1.51255E 06	1.51255E 06	1.51255E 06
(6, 8)	0.	8.87653E 05	8.87653E 05	0.
(7, 2)	1.91794E 06	1.91794E 06	1.91794E 06	1.91794E 06
(7, 3)	0.	1.37616E 06	1.37616E 06	0.
(7, 5)	1.73579E 06	0.	0.	1.73579E 06
(7, 6)	2.50056E 06	2.50056E 06	2.50056E 06	2.50056E 06
(7, 7)	2.20034E 06	2.20034E 06	2.20034E 06	2.20034E 06
(7, 8)	0.	1.21195E 06	1.21195E 06	0.
(8, 2)	2.90872E 06	2.90872E 06	2.90872E 06	2.90872E 06
(8, 3)	0.	2.00003E 06	2.00003E 06	0.
(8, 5)	2.42779E 06	0.	0.	2.42779E 06
(8, 6)	3.47884E 06	3.47884E 06	3.47884E 06	3.47884E 06
(8, 7)	3.00047E 06	3.00047E 06	3.00047E 06	3.00047E 06
(8, 8)	0.	1.59395E 06	1.59395E 06	0.
(9, 2)	4.35483E 06	4.35483E 06	4.35483E 06	4.35483E 06
(9, 3)	0.	2.90134E 06	2.90134E 06	0.
(9, 5)	3.35199E 06	0.	0.	3.35199E 06
(9, 6)	4.70120E 06	4.70120E 06	4.70120E 06	4.70120E 06
(9, 7)	3.95323E 06	3.95323E 06	3.95323E 06	3.95323E 06
(9, 8)	0.	2.04058E 06	2.04058E 06	0.
(10, 2)	6.49291E 06	6.49291E 06	6.49291E 06	6.49291E 06
(10, 3)	0.	4.26895E 06	4.26895E 06	0.
(10, 5)	4.65279E 06	0.	0.	4.65279E 06
(10, 6)	6.26265E 06	6.26265E 06	6.26265E 06	6.26265E 06
(10, 7)	5.09603E 06	5.09603E 06	5.09603E 06	5.09603E 06
(10, 8)	0.	2.55793E 06	2.55793E 06	0.
(11, 2)	9.63280E 06	9.63280E 06	9.63280E 06	9.63280E 06
(11, 3)	0.	6.51013E 06	6.51013E 06	0.
(11, 5)	6.64199E 06	0.	0.	6.64199E 06
(11, 6)	8.27501E 06	8.27501E 06	8.27501E 06	8.27501E 06
(11, 7)	6.45689E 06	6.45689E 06	6.45689E 06	6.45689E 06
(11, 8)	0.	3.14830E 06	3.14830E 06	0.
(12, 2)	1.40753E 07	1.40753E 07	1.40753E 07	1.40753E 07
(12, 3)	0.	1.06491E 07	1.06491E 07	1.06491E 07
(12, 4)	0.	0.	1.01438E 07	1.01438E 07
(12, 5)	1.00941E 07	0.	1.00941E 07	1.00941E 07
(12, 6)	1.08362E 07	1.08362E 07	1.08362E 07	1.08362E 07
(12, 7)	8.04071E 06	8.04071E 06	8.04071E 06	8.04071E 06
(12, 8)	0.	3.80730E 06	3.80730E 06	0.
(13, 2)	1.97133E 07	1.97133E 07	1.97133E 07	1.97133E 07
(13, 3)	1.73381E 07	1.73381E 07	1.73381E 07	1.73381E 07
(13, 4)	1.64465E 07	1.64465E 07	1.64465E 07	1.64465E 07
(13, 5)	1.56388E 07	1.56388E 07	1.56388E 07	1.56388E 07
(13, 6)	1.38988E 07	1.38988E 07	1.38988E 07	1.38988E 07
(13, 7)	9.81037E 06	9.81037E 06	9.81037E 06	9.81037E 06
(13, 8)	0.	4.52189E 06	4.52189E 06	0.

Figure 5. (Contd)

(14,	2)	2.56926E 07	2.56926E 07	2.56926E 07	2.56926E 07
(14,	3)	2.35442E 07	2.35442E 07	2.35442E 07	2.35442E 07
(14,	4)	2.22497E 07	2.22497E 07	2.22497E 07	2.22497E 07
(14,	5)	2.07779E 07	2.07779E 07	2.07779E 07	2.07779E 07
(14,	6)	1.71327E 07	1.71327E 07	1.71327E 07	1.71327E 07
(14,	7)	1.16850E 07	1.16850E 07	1.16850E 07	1.16850E 07
(14,	8)	0.	5.27135E 06	5.27135E 06	0.
(15,	2)	3.15765E 07	3.15765E 07	3.15765E 07	3.15765E 07
(15,	3)	2.92816E 07	2.92816E 07	2.92816E 07	2.92816E 07
(15,	4)	2.75880E 07	2.75880E 07	2.75880E 07	2.75880E 07
(15,	5)	2.55377E 07	2.55377E 07	2.55377E 07	2.55377E 07
(15,	6)	2.03499E 07	2.03499E 07	2.03499E 07	2.03499E 07
(15,	7)	1.35841E 07	1.35841E 07	1.35841E 07	1.35841E 07
(15,	8)	0.	6.03187E 06	6.03187E 06	0.
(16,	2)	3.71380E 07	3.71380E 07	3.71380E 07	3.71380E 07
(16,	3)	3.45449E 07	3.45449E 07	3.45449E 07	3.45449E 07
(16,	4)	3.24749E 07	3.24749E 07	3.24749E 07	3.24749E 07
(16,	5)	2.99189E 07	2.99189E 07	2.99189E 07	2.99189E 07
(16,	6)	2.34361E 07	2.34361E 07	2.34361E 07	2.34361E 07
(16,	7)	1.54395E 07	1.54395E 07	1.54395E 07	1.54395E 07
(16,	8)	0.	6.77998E 06	6.77998E 06	0.
(17,	2)	4.22525E 07	4.22525E 07	4.22525E 07	4.22525E 07
(17,	3)	3.93168E 07	3.93168E 07	3.93168E 07	3.93168E 07
(17,	4)	3.69037E 07	3.69037E 07	3.69037E 07	3.69037E 07
(17,	5)	3.39060E 07	3.39060E 07	3.39060E 07	3.39060E 07
(17,	6)	2.63156E 07	2.63156E 07	2.63156E 07	2.63156E 07
(17,	7)	1.71968E 07	1.71968E 07	1.71968E 07	1.71968E 07
(17,	8)	0.	7.49432E 06	7.49432E 06	0.
(18,	2)	4.68443E 07	4.68443E 07	4.68443E 07	4.68443E 07
(18,	3)	4.35730E 07	4.35730E 07	4.35730E 07	4.35730E 07
(18,	4)	4.08557E 07	4.08557E 07	4.08557E 07	4.08557E 07
(18,	5)	3.74750E 07	3.74750E 07	3.74750E 07	3.74750E 07
(18,	6)	2.89334E 07	2.89334E 07	2.89334E 07	2.89334E 07
(18,	7)	1.88129E 07	1.88129E 07	1.88129E 07	1.88129E 07
(18,	8)	0.	8.15636E 06	8.15636E 06	0.
(19,	2)	5.08618E 07	5.08618E 07	5.08618E 07	5.08618E 07
(19,	3)	4.72865E 07	4.72865E 07	4.72865E 07	4.72865E 07
(19,	4)	4.43063E 07	4.43063E 07	4.43063E 07	4.43063E 07
(19,	5)	4.05982E 07	4.05982E 07	4.05982E 07	4.05982E 07
(19,	6)	3.12476E 07	3.12476E 07	3.12476E 07	3.12476E 07
(19,	7)	2.02537E 07	2.02537E 07	2.02537E 07	2.02537E 07
(19,	8)	0.	8.75053E 06	8.75053E 06	0.
(20,	2)	5.42663E 07	5.42663E 07	5.42663E 07	5.42663E 07
(20,	3)	5.04301E 07	5.04301E 07	5.04301E 07	5.04301E 07
(20,	4)	4.72294E 07	4.72294E 07	4.72294E 07	4.72294E 07
(20,	5)	4.32487E 07	4.32487E 07	4.32487E 07	4.32487E 07
(20,	6)	3.32245E 07	3.32245E 07	3.32245E 07	3.32245E 07
(20,	7)	2.14920E 07	2.14920E 07	2.14920E 07	2.14920E 07
(20,	8)	0.	9.26401E 06	9.26401E 06	0.
(21,	2)	5.70269E 07	5.70269E 07	5.70269E 07	5.70269E 07
(21,	3)	5.29785E 07	5.29785E 07	5.29785E 07	5.29785E 07
(21,	4)	4.96008E 07	4.96008E 07	4.96008E 07	4.96008E 07
(21,	5)	4.54014E 07	4.54014E 07	4.54014E 07	4.54014E 07
(21,	6)	3.48374E 07	3.48374E 07	3.48374E 07	3.48374E 07
(21,	7)	2.25068E 07	2.25068E 07	2.25068E 07	2.25068E 07
(21,	8)	0.	9.68654E 06	9.68654E 06	0.
(22,	2)	5.91191E 07	5.91191E 07	5.91191E 07	5.91191E 07
(22,	3)	5.49101E 07	5.49101E 07	5.49101E 07	5.49101E 07
(22,	4)	5.13990E 07	5.13990E 07	5.13990E 07	5.13990E 07
(22,	5)	4.70353E 07	4.70353E 07	4.70353E 07	4.70353E 07

Figure 5. (Contd)

(22,	6)	3.60652E 07	3.60652E 07	3.60652E 07	3.60652E 07
(22,	7)	2.32816E 07	2.32816E 07	2.32816E 07	2.32816E 07
(22,	8)	0.	1.00102E 07	1.00102E 07	0.
(23,	2)	6.05244E 07	6.05244E 07	6.05244E 07	6.05244E 07
(23,	3)	5.62077E 07	5.62077E 07	5.62077E 07	5.62077E 07
(23,	4)	5.26075E 07	5.26075E 07	5.26075E 07	5.26075E 07
(23,	5)	4.81339E 07	4.81339E 07	4.81339E 07	4.81339E 07
(23,	6)	3.68924E 07	3.68924E 07	3.68924E 07	3.68924E 07
(23,	7)	2.38046E 07	2.38046E 07	2.38046E 07	2.38046E 07
(23,	8)	0.	1.02291E 07	1.02291E 07	0.
(24,	2)	6.12302E 07	6.12302E 07	6.12302E 07	6.12302E 07
(24,	3)	5.68595E 07	5.68595E 07	5.68595E 07	5.68595E 07
(24,	4)	5.32147E 07	5.32147E 07	5.32147E 07	5.32147E 07
(24,	5)	4.86861E 07	4.86861E 07	4.86861E 07	4.86861E 07
(24,	6)	3.73085E 07	3.73085E 07	3.73085E 07	3.73085E 07
(24,	7)	2.40680E 07	2.40680E 07	2.40680E 07	2.40680E 07
(24,	8)	0.	1.03395E 07	1.03395E 07	0.

Figure 5. (Contd)

EXTERMINATOR SAMPLE PROBLEM

NO.IT.# 97 K-EFF # 1.85746E-01 N.F./(TOT PROD)# 4.51341E 06

GROUP 1 FLUX

	1	2	3	4	5	6	7	8	9	10
1	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
2	5.193E 06	5.193E 06	2.983E 06	0.	8.286E 06	1.291E 07	1.271E 07	9.365E 06	4.872E 06	0.
3	1.153E 07	1.153E 07	6.537E 06	0.	1.713E 07	2.696E 07	2.640E 07	1.927E 07	1.006E 07	0.
4	2.045E 07	2.045E 07	1.128E 07	0.	2.697E 07	4.348E 07	4.214E 07	3.020E 07	1.590E 07	0.
5	3.409E 07	3.409E 07	1.785E 07	0.	3.782E 07	6.424E 07	6.121E 07	4.255E 07	2.283E 07	0.
6	7.036E 07	7.036E 07	3.372E 07	0.	6.175E 07	1.136E 08	1.048E 08	6.162E 07	3.154E 07	0.
7	1.161E 08	1.161E 08	5.415E 07	0.	9.116E 07	1.693E 08	1.530E 08	8.433E 07	4.203E 07	0.
8	1.806E 08	1.806E 08	8.359E 07	0.	1.287E 08	2.362E 08	2.089E 08	1.110E 08	5.439E 07	0.
9	2.765E 08	2.765E 08	1.296E 08	0.	1.796E 08	3.199E 08	2.754E 08	1.423E 08	6.874E 07	0.
10	4.220E 08	4.220E 08	2.080E 08	0.	2.558E 08	4.277E 08	3.554E 08	1.784E 08	8.513E 07	0.
11	6.423E 08	6.423E 08	3.570E 08	0.	3.862E 08	5.686E 08	4.508E 08	2.198E 08	1.035E 08	0.
12	9.625E 08	9.625E 08	6.809E 08	6.494E 08	6.502E 08	7.509E 08	5.623E 08	2.659E 08	1.238E 08	0.
13	1.369E 09	1.369E 09	1.190E 09	1.128E 09	1.074E 09	9.697E 08	6.869E 08	3.160E 08	1.455E 08	0.
14	1.795E 09	1.795E 09	1.641E 09	1.550E 09	1.449E 09	1.199E 09	8.188E 08	3.685E 08	1.682E 08	0.
15	2.212E 09	2.212E 09	2.050E 09	1.931E 09	1.788E 09	1.426E 09	9.523E 08	4.218E 08	1.911E 08	0.
16	2.604E 09	2.604E 09	2.422E 09	2.276E 09	2.097E 09	1.643E 09	1.083E 09	4.741E 08	2.137E 08	0.
17	2.963E 09	2.963E 09	2.757E 09	2.588E 09	2.378E 09	1.846E 09	1.206E 09	5.241E 08	2.353E 08	0.
18	3.286E 09	3.286E 09	3.056E 09	2.866E 09	2.629E 09	2.030E 09	1.319E 09	5.705E 08	2.554E 08	0.
19	3.568E 09	3.568E 09	3.317E 09	3.108E 09	2.848E 09	2.192E 09	1.420E 09	6.120E 08	2.736E 08	0.
20	3.807E 09	3.807E 09	3.538E 09	3.313E 09	3.034E 09	2.331E 09	1.507E 09	6.480E 08	2.892E 08	0.
21	4.001E 09	4.001E 09	3.717E 09	3.480E 09	3.185E 09	2.444E 09	1.578E 09	6.775E 08	3.022E 08	0.
22	4.147E 09	4.147E 09	3.852E 09	3.606E 09	3.300E 09	2.530E 09	1.633E 09	7.002E 08	3.121E 08	0.
23	4.246E 09	4.246E 09	3.943E 09	3.690E 09	3.377E 09	2.588E 09	1.669E 09	7.155E 08	3.188E 08	0.
24	4.295E 09	4.295E 09	3.989E 09	3.733E 09	3.415E 09	2.617E 09	1.688E 09	7.232E 08	3.222E 08	0.
25	4.295E 09	4.295E 09	3.989E 09	3.733E 09	3.415E 09	2.617E 09	1.688E 09	7.232E 08	3.222E 08	0.

Figure 5. (Contd)

EXTERMINATOR SAMPLE PROBLEM

NO.IT.# 97 K-EFF # 1.85746E-01 N.F./(TOT PROD)# 4.51341E 06

GROUP 2 FLUX

	1	2	3	4	5	6	7	8	9	10
1	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
2	2.229E 06	2.229E 06	1.277E 06	0.	3.679E 06	5.742E 06	5.669E 06	4.187E 06	2.181E 06	0.
3	4.943E 06	4.943E 06	2.788E 06	0.	7.591E 06	1.198E 07	1.177E 07	8.611E 06	4.502E 06	0.
4	8.755E 06	8.755E 06	4.781E 06	0.	1.191E 07	1.930E 07	1.878E 07	1.349E 07	7.115E 06	0.
5	1.459E 07	1.459E 07	7.491E 06	0.	1.660E 07	2.848E 07	2.726E 07	1.901E 07	1.022E 07	0.
6	3.030E 07	3.030E 07	1.411E 07	0.	2.692E 07	5.031E 07	4.665E 07	2.751E 07	1.411E 07	0.
7	5.030E 07	5.030E 07	2.283E 07	0.	3.975E 07	7.504E 07	6.811E 07	3.766E 07	1.881E 07	0.
8	7.867E 07	7.867E 07	3.555E 07	0.	5.617E 07	1.047E 08	9.302E 07	4.959E 07	2.434E 07	0.
9	1.211E 08	1.211E 08	5.567E 07	0.	7.858E 07	1.420E 08	1.227E 08	6.354E 07	3.076E 07	0.
10	1.858E 08	1.858E 08	9.032E 07	0.	1.123E 08	1.900E 08	1.584E 08	7.971E 07	3.810E 07	0.
11	2.842E 08	2.842E 08	1.568E 08	0.	1.704E 08	2.529E 08	2.010E 08	9.819E 07	4.635E 07	0.
12	4.276E 08	4.276E 08	3.019E 08	2.884E 08	2.885E 08	3.344E 08	2.508E 08	1.188E 08	5.543E 07	0.
13	6.096E 08	6.096E 08	5.293E 08	5.020E 08	4.782E 08	4.323E 08	3.065E 08	1.412E 08	6.515E 07	0.
14	8.004E 08	8.004E 08	7.313E 08	6.911E 08	6.457E 08	5.349E 08	3.654E 08	1.647E 08	7.530E 07	0.
15	9.868E 08	9.868E 08	9.143E 08	8.614E 08	7.976E 08	6.364E 08	4.251E 08	1.886E 08	8.558E 07	0.
16	1.162E 09	1.162E 09	1.081E 09	1.016E 09	9.360E 08	7.335E 08	4.833E 08	2.120E 08	9.570E 07	0.
17	1.323E 09	1.323E 09	1.231E 09	1.155E 09	1.061E 09	8.239E 08	5.384E 08	2.343E 08	1.054E 08	0.
18	1.467E 09	1.467E 09	1.364E 09	1.279E 09	1.173E 09	9.059E 08	5.890E 08	2.551E 08	1.144E 08	0.
19	1.593E 09	1.593E 09	1.481E 09	1.387E 09	1.271E 09	9.785E 08	6.341E 08	2.737E 08	1.225E 08	0.
20	1.699E 09	1.699E 09	1.579E 09	1.479E 09	1.354E 09	1.040E 09	6.729E 08	2.897E 08	1.295E 08	0.
21	1.786E 09	1.786E 09	1.659E 09	1.553E 09	1.422E 09	1.091E 09	7.047E 08	3.029E 08	1.353E 08	0.
22	1.851E 09	1.851E 09	1.720E 09	1.610E 09	1.473E 09	1.129E 09	7.290E 08	3.131E 08	1.398E 08	0.
23	1.895E 09	1.895E 09	1.760E 09	1.647E 09	1.507E 09	1.155E 09	7.453E 08	3.199E 08	1.428E 08	0.
24	1.917E 09	1.917E 09	1.781E 09	1.666E 09	1.525E 09	1.168E 09	7.536E 08	3.234E 08	1.443E 08	0.
25	1.917E 09	1.917E 09	1.781E 09	1.666E 09	1.525E 09	1.168E 09	7.536E 08	3.234E 08	1.443E 08	0.

Figure 5. (Contd)

EXTERMINATOR SAMPLE PROBLEM

NO.IT.# 97 K-EFF # 1.85746E-01 N.F./(TOT PROD)# 4.51341E 06

GROUP 3 FLUX

	1	2	3	4	5	6	7	8	9	10
1	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
2	9.022E 05	9.022E 05	5.215E 05	0.	1.442E 06	2.242E 06	2.208E 06	1.629E 06	8.489E 05	0.
3	1.994E 06	1.994E 06	1.136E 06	0.	2.975E 06	4.676E 06	4.581E 06	3.350E 06	1.751E 06	0.
4	3.513E 06	3.513E 06	1.944E 06	0.	4.670E 06	7.525E 06	7.302E 06	5.246E 06	2.767E 06	0.
5	5.820E 06	5.820E 06	3.044E 06	0.	6.520E 06	1.109E 07	1.059E 07	7.382E 06	3.971E 06	0.
6	1.197E 07	1.197E 07	5.702E 06	0.	1.059E 07	1.955E 07	1.808E 07	1.068E 07	5.482E 06	0.
7	1.978E 07	1.978E 07	9.167E 06	0.	1.562E 07	2.914E 07	2.639E 07	1.461E 07	7.303E 06	0.
8	3.084E 07	3.084E 07	1.419E 07	0.	2.205E 07	4.066E 07	3.603E 07	1.923E 07	9.449E 06	0.
9	4.732E 07	4.732E 07	2.209E 07	0.	3.081E 07	5.510E 07	4.752E 07	2.463E 07	1.194E 07	0.
10	7.242E 07	7.242E 07	3.559E 07	0.	4.393E 07	7.369E 07	6.133E 07	3.090E 07	1.479E 07	0.
11	1.105E 08	1.105E 08	6.130E 07	0.	6.642E 07	9.801E 07	7.782E 07	3.805E 07	1.799E 07	0.
12	1.658E 08	1.658E 08	1.173E 08	1.119E 08	1.120E 08	1.295E 08	9.707E 07	4.605E 07	2.150E 07	0.
13	2.361E 08	2.361E 08	2.051E 08	1.945E 08	1.853E 08	1.673E 08	1.186E 08	5.472E 07	2.528E 07	0.
14	3.098E 08	3.098E 08	2.831E 08	2.675E 08	2.500E 08	2.070E 08	1.414E 08	6.382E 07	2.921E 07	0.
15	3.818E 08	3.818E 08	3.538E 08	3.333E 08	3.086E 08	2.462E 08	1.645E 08	7.305E 07	3.319E 07	0.
16	4.495E 08	4.495E 08	4.181E 08	3.930E 08	3.621E 08	2.838E 08	1.870E 08	8.212E 07	3.712E 07	0.
17	5.117E 08	5.117E 08	4.761E 08	4.469E 08	4.106E 08	3.187E 08	2.083E 08	9.078E 07	4.088E 07	0.
18	5.674E 08	5.674E 08	5.277E 08	4.948E 08	4.539E 08	3.505E 08	2.279E 08	9.881E 07	4.437E 07	0.
19	6.161E 08	6.161E 08	5.728E 08	5.367E 08	4.918E 08	3.785E 08	2.453E 08	1.060E 08	4.751E 07	0.
20	6.573E 08	6.573E 08	6.109E 08	5.721E 08	5.239E 08	4.025E 08	2.603E 08	1.122E 08	5.024E 07	0.
21	6.908E 08	6.908E 08	6.417E 08	6.008E 08	5.500E 08	4.220E 08	2.726E 08	1.174E 08	5.248E 07	0.
22	7.161E 08	7.161E 08	6.651E 08	6.226E 08	5.698E 08	4.369E 08	2.820E 08	1.213E 08	5.421E 07	0.
23	7.332E 08	7.332E 08	6.809E 08	6.373E 08	5.831E 08	4.469E 08	2.884E 08	1.239E 08	5.537E 07	0.
24	7.417E 08	7.417E 08	6.888E 08	6.446E 08	5.898E 08	4.519E 08	2.916E 08	1.253E 08	5.596E 07	0.
25	7.417E 08	7.417E 08	6.888E 08	6.446E 08	5.898E 08	4.519E 08	2.916E 08	1.253E 08	5.596E 07	0.

Figure 5. (Contd)

EXTERMINATOR SAMPLE PROBLEM

NO. IT.# 97 K-EFF # 1.85746E-01 N.F./(TOT PROD)# 4.51341E 06

GROUP 4 FLUX

	1	2	3	4	5	6	7	8	9	10
1	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
2	2.430E 06	2.430E 06	2.544E 06	2.545E 06	2.469E 06	2.221E 06	1.824E 06	1.262E 06	6.424E 05	0.
3	4.857E 06	4.857E 06	5.157E 06	5.189E 06	5.023E 06	4.527E 06	3.730E 06	2.572E 06	1.319E 06	0.
4	7.238E 06	7.238E 06	7.901E 06	8.069E 06	7.742E 06	7.003E 06	5.806E 06	3.978E 06	2.068E 06	0.
5	9.432E 06	9.432E 06	1.079E 07	1.150E 07	1.066E 07	9.731E 06	8.163E 06	5.510E 06	2.943E 06	0.
6	1.432E 07	1.432E 07	1.558E 07	1.654E 07	1.577E 07	1.594E 07	1.348E 07	7.858E 06	4.035E 06	0.
7	2.133E 07	2.133E 07	2.213E 07	2.336E 07	2.242E 07	2.329E 07	1.949E 07	1.068E 07	5.350E 06	0.
8	3.121E 07	3.121E 07	3.098E 07	3.242E 07	3.108E 07	3.223E 07	2.651E 07	1.402E 07	6.901E 06	0.
9	4.518E 07	4.518E 07	4.292E 07	4.437E 07	4.242E 07	4.337E 07	3.487E 07	1.792E 07	8.700E 06	0.
10	6.486E 07	6.486E 07	5.896E 07	6.000E 07	5.730E 07	5.737E 07	4.486E 07	2.244E 07	1.076E 07	0.
11	9.214E 07	9.214E 07	8.038E 07	7.983E 07	7.676E 07	7.495E 07	5.668E 07	2.758E 07	1.306E 07	0.
12	1.287E 08	1.287E 08	1.084E 08	1.030E 08	1.016E 08	9.657E 07	7.037E 07	3.331E 07	1.559E 07	0.
13	1.750E 08	1.750E 08	1.574E 08	1.493E 08	1.416E 08	1.222E 08	8.562E 07	3.952E 07	1.830E 07	0.
14	2.252E 08	2.252E 08	2.075E 08	1.961E 08	1.830E 08	1.497E 08	1.018E 08	4.603E 07	2.113E 07	0.
15	2.754E 08	2.754E 08	2.558E 08	2.410E 08	2.230E 08	1.773E 08	1.182E 08	5.265E 07	2.400E 07	0.
16	3.233E 08	3.233E 08	3.008E 08	2.828E 08	2.605E 08	2.039E 08	1.343E 08	5.916E 07	2.682E 07	0.
17	3.675E 08	3.675E 08	3.420E 08	3.210E 08	2.949E 08	2.289E 08	1.496E 08	6.538E 07	2.953E 07	0.
18	4.073E 08	4.073E 08	3.789E 08	3.553E 08	3.259E 08	2.516E 08	1.636E 08	7.115E 07	3.205E 07	0.
19	4.422E 08	4.422E 08	4.111E 08	3.852E 08	3.530E 08	2.717E 08	1.761E 08	7.632E 07	3.431E 07	0.
20	4.718E 08	4.718E 08	4.384E 08	4.106E 08	3.760E 08	2.889E 08	1.869E 08	8.080E 07	3.628E 07	0.
21	4.958E 08	4.958E 08	4.606E 08	4.312E 08	3.947E 08	3.029E 08	1.957E 08	8.448E 07	3.790E 07	0.
22	5.139E 08	5.139E 08	4.774E 08	4.468E 08	4.089E 08	3.136E 08	2.025E 08	8.731E 07	3.914E 07	0.
23	5.262E 08	5.262E 08	4.886E 08	4.573E 08	4.185E 08	3.207E 08	2.070E 08	8.921E 07	3.998E 07	0.
24	5.323E 08	5.323E 08	4.943E 08	4.626E 08	4.233E 08	3.244E 08	2.093E 08	9.018E 07	4.041E 07	0.
25	5.323E 08	5.323E 08	4.943E 08	4.626E 08	4.233E 08	3.244E 08	2.093E 08	9.018E 07	4.041E 07	0.

Notation

A	In Eq. (2) the matrix whose elements are constants involving absorption, leakage, and group-to-group scattering properties.
C	In Eq. (6) a quantity involving the properties of lines and groups other than the one considered.
$E_n(\phi)$	$\phi_n - \bar{\phi}$
$E_n(\lambda)$	$\lambda_n - \bar{\lambda}$
e^T	In Eq. (5), a row matrix all of whose elements are 1 and having as many elements as there are fluxes to be calculated.
FA	A driving factor defined by Eq. (31) or Eq. (32).
$f_{I,J,P}$	In Eq. (1), the product of the volume of a mesh quadrant and the $\nu\Sigma_f$ appropriate to the group and the quadrant.
k	The effective multiplication constant = $1/\lambda$.
L	In Eq. (4), a matrix whose elements are zero except for those below the diagonal which are the negative of the corresponding elements of A.
M	In Eq. (2), the matrix whose elements are constants involving fission properties.
m, q	In Eq. (7), calculated constants used to determine fluxes by the line relaxation method.
R	In Eq. (14), an arbitrary constant.
V	A diagonal matrix composed of the diagonal elements of M.
W	A matrix whose elements are zero except for those below the diagonal which are the same as the corresponding elements of M.
$S_{I,J,P}$	In Eq. (1), a number equal to the input source strength in neutrons per cubic centimeter per second times the appropriate quadrant volume.
a,b,c,d	In Eq. (1), constants involving diffusion properties and quadrant surface areas; subscripted I,J,K.
α'	In Eq. (1), a constant involving quadrant volumes and absorption and removal cross sections; subscripted I,J,K.
α''	In Eq (1), a constant involving quadrant volumes and in-scattering cross sections from groups other than the one considered; subscripted I,J,P,K.

β In Eq. (4), the over-relaxation coefficient. In point relaxation, it is applied to the computation of each new flux as soon as it is calculated. In line relaxation, all the fluxes on a line are calculated, and then the fluxes of that line are all over-relaxed simultaneously.

λ The eigenvalue of the problem, equal to $1/k$; λ_n is the estimate of λ at iteration n.

$\bar{\lambda}$ The exact eigenvalue of the problem, the smallest positive eigenvalue of Eq. (2).

μ In the linearized form of the iteration problem, the decay rate of the error $(\bar{\phi} - \phi_n)$ or $(\bar{\lambda} - \bar{\lambda}_n)$.

ϕ, $\bar{\phi}$, ϕ^* Neutron flux; $\bar{\phi}$ is the neutron flux associated with $\bar{\lambda}$; ϕ^* is the calculated neutron flux before over-relaxation.

σ The estimated largest error decay rate.

χ_K The fraction of fission neutrons which appear in group K.

Subscripts

I, J Integers denoting row and column positions respectively of a mesh point.

K Group number

P A dummy index in Eq. (1), denoting group number.

n Iteration number; this appears also as an exponent in Eqs. (14), (16), and (17).

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