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HEXAGA-II-120, -60, -30 Two-dimensional Multi-group Neutron Diffusion Programmes for a Uniform Triangular Mesh with Arbitrary Group Scattering

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H E X A G A - II - 120, -60, -30
TWO-DIMENSIONAL MULTI-GROUP NEUTRON DIFFUSION PROGRAMMES FOR A UNIFORM TRIANGULAR MESH WITH ARBITRARY GROUP SCATTERING

by

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Summary

This report presents the AGA two-sweep iterative methods belonging to the family of factorization techniques in their practical application in the HEXAGA-II two-dimensional programme to obtain the numerical solution to the multi-group, time-independent, (real and/or adjoint) neutron diffusion equations for a fine uniform triangular mesh. An arbitrary group scattering model is permitted.

The report written for the users provides the description of input and output. The use of HEXAGA-II is illustrated by two sample reactor problems.

HEXAGA II - Ein Rechenprogramm für die IBM-Anlage/370-168 zur Lösung der Multigruppen-Neutronen-Diffusionsgleichung in 2 Raumdimensionen für regelmäßige Dreiecksmaschengitter mit beliebiger Neutronenstreuung über die Energiegruppen

Zusammenfassung

Der Bericht enthält die Beschreibung der "AGA Two Sweep Iterative Methods", die zur Familie der Faktorisierungsverfahren gehören, und ihre Anwendung im Rechenprogramm HEXAGA-II für zwei Raumdimensionen. HEXAGA-II liefert die numerische Lösung der zeitunabhängigen Multigruppen-Neutronendiffusionsgleichungen für feine, regelmäßige Dreiecksmaschengitter für den reellen und den adjungierten Neutronenfluß. Im Rahmen des betrachteten Modells können die Neutronen beliebig über die Energiegruppen gestreut werden.

Der Bericht ist für die Benutzer von HEXAGA-II zusammengestellt und enthält die Beschreibungen der Programm-Ein- und Ausgabe. Zwei Sample Probleme für Reaktorberechnungen sollen die Anwendung von HEXAGA-II verdeutlichen.

Streszczenie

W raporcie przedstawiono dwuprzebiegowe metody iteracyjne AGA, należące do rodziny technik faktoryzacyjnych, w ich praktycznym zastosowaniu w dwuwymiarowym programie HEXAGA-II dostarczającym numerycznego rozwiązania wielogrupowych, czasowo niezależnych (rzeczywistych i/albo sprzężonych) równań dyfuzji neutronów w drobnej jednorodnej siatce trójkątnej. Możliwe jest stosowanie dowolnego modelu rozpraszania neutronów.
Raport ten, przeznaczony dla użytkowników, zawiera opis inputu i outputu. Użycie programu HEXAGA-II jest zilustrowane dwoma przykładami problemów reaktorowych.

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I. INTRODUCTION

This report contains the description of numerical methods utilized in two-dimensional multi-group neutron diffusion programmes HEXAGA-II-120, -60 and -30 and their user's manual.

All the three programmes written in FORTRAN-IV with dynamic storage allocation are implemented recently on IBM-370/168 and CDC-CYBER-73 computers for real and/or adjoint calculations with a uniform triangular mesh. They are an extension of the former version of HEXAGA-II /3/ in which the domain of solution is an arbitrary 120^o-parallelogram. In the present versions of HEXAGA-II called by HEXAGA-II-120, -60 and -30 the last numbers -120, -60 and -30 are related to the domain of solution which are 120^o-parallelogram, 60^o-triangle and 30^o-triangle, respectively. In HEXAGA-II-120 arbitrary logarithmic boundary conditions can be used on each of four external boundaries. In HEXAGA-II-60 and -30 the triangular domain of solution corresponds to the part of the reactor for which the solution has the 60-degree and 30-degree symmetry. Thus, logarithmic boundary conditions can be used only on the side of triangle corresponding to the outer boundary of a reactor and on two remaining sides of triangle the null flux derivative is used in a boundary condition. Despite of the different geometries the same input/output is used for all programmes and specified for the part of the reactor being 120^o-parallelogram /or rhombus/. However, the number of unknowns representing a discrete numerical solution is approximately decreased by factor 2 in HEXAGA-II-60 and 4 in HEXAGA-II-30 with respect to those in HEXAGA-II-120. This reduces storage requirements and CPU time. In all versions of HEXAGA-II there exist the input check of 60-degree and 30-degree symmetry of solution and if required symmetry is not satistied in HEXAGA-II-60 or -30 for a given reactor problem, programme is stopped with printing information about a mesh point in which an expected symmetry did not occur.

In order to simplify the preparation of the HEXAGA-II input data, which in the case of preparation by hand for reactor problems with a fine refinement of mesh is too much time-consuming, three auxiliary subprogrammes INPREP-II, HEXI-22 and HEXI-23 have been written. The first of them, INPREP-II provides the same picture of a hexagonal mesh as this printed in the HEXAGA-II output but without the specification of material composition numbers representing particular hexagons in the layout of mesh and these numbers can be written by user according to the material arrangement of a given reactor problem /see Appendix/. Two remaining subprogrammes HEXI-22 and HEXI-23 serve to producing the new HEXAGA-II input data for a given reactor problem in which the mesh step of uniform triangular mesh is decreased by factor 2 in the case of use HEXI-22 and by factor 3 for HEXI-23. Both subprogrammes use the same input as the HEXAGA-II input without introducing any additional input information. Thus, preparing the HEXAGA-II input by hand for a given reactor problem which can be described by the minimal number of mesh points and using an arbitrary combination of output/input from HEXI-22 and HEXI-23 we can produce the HEXAGA-II input data for arrangements of mesh points for this problem with the mesh step decreased by the following factors: 2,3,4,8,9,12 etc. /see Appendix/.

In HEXAGA-II the group equations are approximated for a uniform 60-degree triangular mesh using a seven-point difference formula at the points of intersection of the triangular mesh lines, where the smallest homogeneous diffusion region has the form of a triangle *). The obtained linear system of finite difference equations is solved by means of the AGA two-sweep iterative method proposed recently by the author for multidimensional critical reactor calculations /1, 4/. The application of the AGA method, which belongs to the family of factorization methods, leads to increasing the rate of convergence for inner spatial flux interations. In order to accelerate the rate of inner convergence in HEXAGA-II even further, two independent techniques based on a successive overrelaxation process are applied: the AGA Single and Double SOR methods /1, 4/. It turned out that the latter method is especially effective for solving large reactor problems with a fine mesh and when the method is not specified by the user the programme uses the AGA Double SOR method.

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*) It should be mentioned that the new version of the programme called HEXAGA-II-0 is under development in which the seven-point formula couples the points of the mesh coinciding with the centers of seven uniform hexagons. Thus, the smallest homogeneous diffusion region has the form of a hexagon representing an individual fuel element or hexagonal fuel assembly.

The solution of multi-group neutron diffusion equations called the outer iterations is carried out by the power method accelerated by means of usual relaxation. The strategy of inner-outer iterations realized in HEXAGA-II consists of a fixed number of inner iterations for all neutron groups in a given outer iteration and for the majority of problems a few /2 or 3/ inner iterations per outer iteration provides the minimum CPU time and costs. It should be mentioned that another technique for the acceleration of outer iterations in HEXAGA-II is presently under development.

A four-energy group problem with about 20000 mesh points representing a model of the SNR 300 reactor as a typical fast reactor requires about 6 minutes of CPU time and 1000 k core storage on the IBM-370/168 computer with the following convergence criteria: $\varepsilon_{k_{eff}} \leq 10^{-6}$ and $\varepsilon_{\phi} \leq 10^{-5}$.

II. THE MATHEMATICAL MODEL

1. The Multi-Group Neutron Diffusion Equation

HEXAGA-II provides an approximation to the solution of the following multi-group, time independent, neutron diffusion equations

$$-\nabla D_g(\underline{x})\nabla\phi_g(\underline{x}) + \Sigma_g^T(\underline{x})\phi_g(\underline{x}) = S_g(\underline{x}) \qquad (1)$$

$$S_g(\underline{x}) = \frac{\chi_g}{k_{eff}} \sum_{g'=1}^{G} \nu\Sigma_{g'}^F(\underline{x})\phi_g(\underline{x}) + \sum_{\substack{g'=1 \\ g'\neq g}}^{G} \Sigma_{g'\rightarrow g}^S(\underline{x})\phi_{g'}(\underline{x}) \qquad (1a)$$

for g = 1,2, ..., G

where g - group index

$\underline{x}$ - spatial point

∇ - gradient operator

ϕ_g - neutron flux

D_g - diffusion coefficient

Σ_g^T - macroscopic total removal cross section

$\nu\Sigma_g^F$ - macroscopic fission production cross section

$\Sigma_{g'\rightarrow g}^S$ - macroscopic scattering cross section from group g' to group g

χ_g - value of fission spectrum

k_{eff} - effective multiplication factor

These equations are supplemented by group-dependent logarithmic boundary conditions at the external boundaries of the reactor

$$\frac{1}{\phi_g(\underline{x})} \frac{\partial\phi_g(\underline{x})}{\partial n} = -\frac{\alpha_g(\underline{x})}{D_g(\underline{x})} \qquad (2)$$

where α_g is a non-negative constant and the derivative is taken normal to the boundary outward to the reactor.

The adjoint solution required for supplementary perturbation calculations is made in HEXAGA-II with a little extra effort devoted to the algorithm for the real solution. In fact, it is only necessary to transpose the scattering matrix and invert the order in which the group equations are solved, interchanging the roles of the fission spectrum fractions, χ_g, and the fission production cross section terms $\nu\Sigma_g^F$, in each equation.

As the real system is defined by Eqs. (1 and 1a) the corresponding adjoint system can be written in the following form

$$-\nabla D_g(\underline{x})\nabla\phi_g^*(\underline{x}) + \Sigma_g^T(\underline{x})\phi_g^*(\underline{x}) = S_g^*(\underline{x}) \qquad (1^*)$$

$$S_g^*(\underline{x}) = \frac{1}{k_{eff}} \sum_{g'=1}^{G} \nu\Sigma_g^F(\underline{x})\, \chi_{g'}\phi_{g'}(\underline{x}) + \sum_{\substack{g'=1 \\ g'\neq g}}^{G} \Sigma_{g\to g'}^S(\underline{x})\phi_{g'}^*(\underline{x}) \qquad (1^*a)$$

for g = G, G-1, ..., 1
where ϕ_g^* is adjoint neutron flux.

2. The Geometrical Representation

The solution is approximated over a parallelogram area that is composed of uniform triangular elementary subregions. The uniform grid of mesh lines is imposed upon this parallelogram area (see Fig. 1). The constant distance between mesh lines is chosen such that the boundaries of the area and the interfaces determining subregions (containing elementary triangles with the same material compositions) coincide exactly with the mesh lines. Both axes x and v in the assumed oblique coordinate system coincide with the boundary lines of the parallelogram area of the solution.

The discrete solution of Eq. (1) (and/or Eq. (1^*)) consists of the effective multiplication factor and of values approximating (real and/or adjoint) neutron flux and fission sources at the points of intersections of the mesh lines called mesh points.

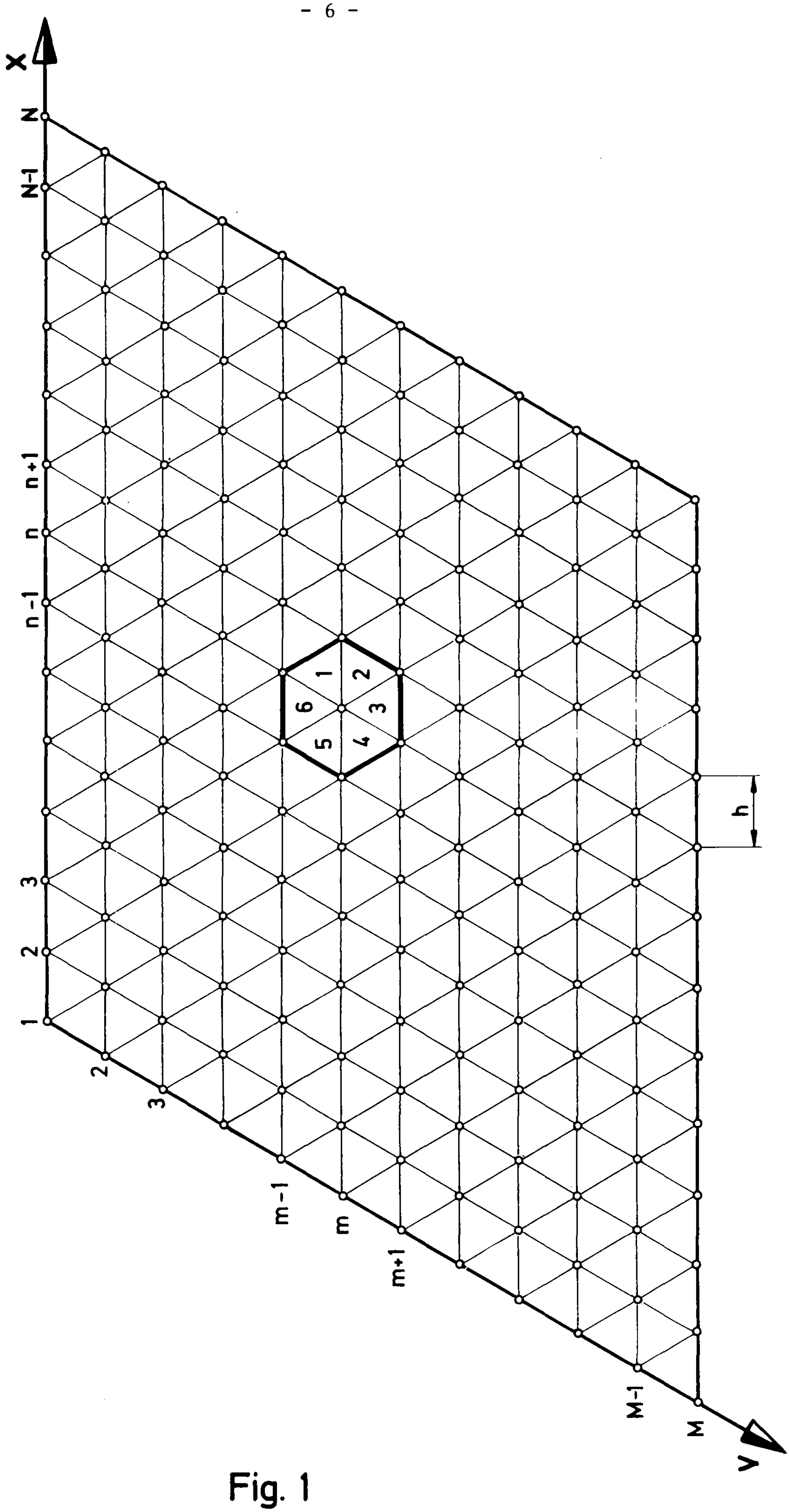


Fig. 1

3. Difference Equations

To obtain a solution, Eq. (1) is approximated by seven-point difference equations at mesh points. Consider the mesh point (m,n) at the intersection of two mesh lines m and n, as illustrated in Fig. 1. It is assumed that the smallest homogeneous diffusion region has the form of a triangle representing one material composition. Therefore, the following difference expression for a given group, g, is used at the corner point between six different triangles numbered from 1 to 6, as in Fig. 1.

$$k_n^m \phi_n^m = c_n^m + e_n^m \phi_{n-1}^m + l_n^m \phi_{n-1}^{m-1} + g_n^m \phi_n^{m-1} + \phi_{n+1}^{m+1} + u_n^m \phi_n^{m+1} + w_n^m \phi_{n+1}^m \qquad (3)$$

where $k_n^m = \frac{2}{a} \sum_{i=1}^{6} (D_i + \frac{h^2}{4} \Sigma_i^T)$

$$e_n^m = \frac{1}{a} (D_4 + D_5)$$

$$l_n^m = \frac{1}{a} (D_5 + D_6)$$

$$g_n^m = \frac{1}{a} (D_6 + D_1)$$

$$u_n^m = \frac{1}{a} (D_3 + D_4)$$

$$w_n^m = \frac{1}{a} (D_1 + D_2)$$

$$c_n^m = \frac{6h^2}{a} \{ \frac{\chi_g}{k_{eff}} \sum_{g'=1}^{G} \left[(\sum_{i=1}^{6} \nu\Sigma_i^F)_{g'} (\phi_n^m)_{g'} \right] + \sum_{\substack{g'=1 \\ g' \neq g}}^{G} \left[(\sum_{i=1}^{6} \Sigma_{g' \to g, i}^S)_{g'} (\phi_n^m)_{g'} \right] \}$$

$a = D_2 + D_3$

h - is spacing of the uniform triangular mesh.

Eq. (3) is normalized such that the coefficient with ϕ_{n+1}^{m+1} equals unity. Similar difference equations are used at the mesh points lying on the external boundaries; the term $\frac{2\sqrt{3}}{a}$ h α_n^m is added to k_n^m, where α_n^m is defined by Eq. (2), whereas the other coefficients of the difference equations (Eq. (3)) are calculated with appropriate modifications.

III. THE METHOD OF SOLUTION

A new approach to the numerical solution of the multidimensional neutron diffusion equation has recently been proposed by the author /1,4/. The method of solution used in HEXAGA-II is an application of this so-called AGA two-sweep iterative method.

Accepting the conventional scheme of fission source iterations one must repeatedly solve the inhomogeneous two-dimensional difference equations for G groups

$$A_g \phi_g = c_g, \qquad g = 1,2,\dots G \qquad (4)$$

where A_g is a non-singular matrix sxs and s is equal to the total number of mesh points, that is, s = MxN. In this matrix notation, the matrix A_g contains the difference coefficients of Eq. (3), the components of the vector c_g are the coefficients, c_n^m, of Eq. (3) and ϕ_g is the solution vector in a given group, g. Thus, the discrete solution of Eq. (1) consists of a series of outer iterations, each of them running over all energy groups. The fission sources are recalculated before each outer iteration, and the scattering sources before each group calculation. In each energy group, the inner iterations to solve Eq. (4) can be repeated I times. In HEXAGA-II the value of I, specified in the input, is fixed for all energy groups in a given outer iteration.

To solve Eq. (4), the AGA two-sweep iterative method is employed with the application of either the Single SOR or Double SOR process /1,4/. It will be described in the next sections of this Chapter.

1. A General Iteration Scheme

The non-singular sxs matrix A_g of Eq. (4) can be expressed in the following form (suppressing index g)

$$A = M - N \qquad (5)$$

where M and N are also sxs matrices. If M is non-singular, we say that this expression represents a splitting of A, and associated with this splitting is an iterative method

$$M\phi^{(j+1)} = N\phi^{(j)} + c, \quad j \geq 0 \tag{6}$$

$$\phi^{(j+1)} = M^{-1}N\phi^{(j)} + M^{-1}c, \quad j \geq 0 \tag{7}$$

where j denotes the iteration index and a guess is made of the inital vector $\phi^{(0)}$. The above equations represent the general scheme of the iterative method and $M^{-1}N$ is the iteration matrix associated with this method.

Particular iterative methods differ in the choice of the matrices M and N. For a given iterative method, $\phi^{(j+1)}$ tends to ϕ (the exact solution of Eq. (4)) with $j \to \infty$ for all $\phi^{(0)}$ if, and only if, the spectral radius $\rho(M^{-1}N)$ of the iteration matrix $M^{-1}N$ is less than unity /2/. Moreover, the smaller the spectral radius of the iteration matrix, the better is the convergence asymptotically of a given iterative method.
Let us define the sxs matrix $A = (a_{i,j})$ of Eq. (4) as a sum of the following sxs matrices

$$A = K - L - U \tag{8}$$

where

$$K = (k_{i,j}) = \text{diag}\,\{A_g\} \geq 0, \qquad k_{i,j} = \begin{cases} a_{i,j} & \text{for } i = j \\ 0 & \text{for } i \neq j \end{cases}$$

$$L = (l_{i,j}) \geq 0 \qquad l_{i,j} = \begin{cases} -a_{i,j} & \text{for } i > j \\ 0 & \text{for } i < j \end{cases}$$

$$U = (u_{i,j}) \geq 0 \qquad u_{i,j} = \begin{cases} 0 & \text{for } i \geq j \\ -a_{i,j} & \text{for } i < j \end{cases}$$

Thus, K, L and U are diagonal, strictly lower triangular and strictly upper triangular matrices, respectively.

Referring to Eq. (3) we have the following interpretation of the matrix A: The coefficients k_n^m are the entries of the positive main diagonal of K; e_n^m, l_n^m and g_n^m are respectively the entries of the three non-negative diagonals of L; and u_n^m, w_n^m and units are respectively the entries of the three non-negative diagonals of U. For the above interpretation of the matrix A it was assumed that the numbering of mesh points in the mesh grid shown in Fig. 1 increases successively along every mesh line in the axial direction x, and successively from a given mesh line to the next one in the axial direction of v. Since A is an irreducibly diagonally dominant matrix satisfying the definition (8), $A^{-1} > 0$ /2/.

With the above definition of A the classical iterative methods are represented by the following splittings.

a) The point Jacobi method

$$A = M_J - N_J, \quad M_J = K \text{ and } N_J = L + U$$

$$\mathcal{B} = K^{-1}(L+U) \geq 0 \tag{9}$$

b) The point Gauss-Seidel method

$$A = M_G - N_G, \quad M_G = K - L \text{ and } N_G = U$$

$$\mathcal{L}_1 = (I-K^{-1}L)^{-1}K^{-1}U \geq 0 \tag{10}$$

where $\mathcal{B}$ and $\mathcal{L}_1$ are iteration matrices, respectively, in these methods.

2. The AGA Two-Sweep Iterative Method

The non-singular sxs matrix A of Eq. (4) can be expressed as follows:

$$A = K - P - (L+H) - (U+Q) + P + H + Q \tag{11}$$

on the assumption that P, H and Q are diagonal, strictly lower triangular and strictly upper triangular non-negative sxs matrices, respectively.

We assume that the diagonal matrices $K = (k_{i,j})$ and $P = (p_{i,j})$ satisfy the following condition

$$K \geq P \geq 0 \tag{12}$$

where $k_{i,j} > p_{i,j} \geq 0$ for all $1 \leq i \leq s$, so that

$$D = K - P \geq 0 \tag{13}$$

is a non-singular non-negative matrix and Eq. (11) can be written equivalently as

$$A = D - (L+H) - (U+Q) + P + H + Q \tag{14}$$

We apply the following identity

$$D - (L+H) - (U+Q) \equiv [I - (L+H)D^{-1}]D[I - D^{-1}(U+Q)] - (L+H)D^{-1}(U+Q) \tag{15}$$

with the following required relation

$$(L+H)D^{-1}(U+Q) = P + H + Q + T \tag{16}$$

where P is the main diagonal of $(L+H)D^{-1}(U+Q)$, that is

$$P = \text{diag}\ \{(L+H)D^{-1}(U+Q)\} \tag{17}$$

and H + Q + T has zero entries on the main diagonal and its off-main diagonal entries are those of $(L+H)D^{-1}(U+Q)$.

Using the above relations we get

$$A = \left[I - (L+H)D^{-1}\right]D\left[I - D^{-1}(U+Q)\right] - T \equiv M_A - N_A \tag{18}$$

where

$$M_A = \left[I - (L+H)D^{-1}\right]D\left[I - D^{-1}(U+Q)\right] \text{ and } N_A = T \tag{19}$$

The iterative method associated with this splitting can be written as follows

$$\phi^{(j+1)} = \left[I - D^{-1}(U+Q)\right]^{-1}D^{-1}\left[I - (L+H)D^{-1}\right]^{-1}T\phi^{(j)} + \\ + \left[I - D^{-1}(U+Q)\right]^{-1}D^{-1}\left[I - (L+H)D^{-1}\right]^{-1}c, \quad j \geq 0 \tag{20}$$

and

$$\mathcal{A}_1 = \left[I - D^{-1}(U+Q)\right]^{-1}D^{-1}\left[I - (L+H)D^{-1}\right]^{-1} T \geq 0 \tag{21}$$

is the iteration matrix for this method.

This method can easily be implemented by applying the two-sweep procedure (for any initial vector $\phi^{(0)}$) which eliminates the calculation procedure for the inversion of triangular matrices. Let us multiply (20) on the left by $\left[I-D^{-1}(U+Q)\right]$ and shift $D^{-1}(U+Q)\phi$ on the right hand-side; we obtain

$$\phi^{(j+1)} = D^{-1}\{(U+Q)\phi^{(j+1)} + \left[I - (L+H)D^{-1}\right]^{-1}(T\phi^{(j)}+c)\}.$$

Denoting

$$\beta^{(j+1)} = \left[I - (L+H)D^{-1}\right]^{-1}(T\phi^{(j)}+c)$$

and again multiplying this expression on the left by $\left[I-(L+H)D^{-1}\right]$ we finally have

$$\left.\begin{aligned} \beta^{(j+1)} &= (L+H)D^{-1}\beta^{(j+1)} + T\phi^{(j)} + c, \\ \phi^{(j+1)} &= D^{-1}\left[(U+Q)\phi^{(j+1)} + \beta^{(j+1)}\right], \ j \geq 0 \end{aligned}\right\} \qquad (22)$$

Since $(L+H)D^{-1}$ and $D^{-1}(U+Q)$ are lower and upper strictly triangular matrices, respectively, successive components of $\beta^{(j+1)}$ can be calculated recursively for increasing indices in the forward elimination sweep and successive components of $\phi^{(j+1)}$ can be calculated recursively for decreasing indices in the backward substitution sweep.

This method is called the AGA two-sweep iterative method and the matrix $\mathcal{A}_1$, defined in Eq. (21), the AGA matrix associated with the matrix A of Eq. (4).

The AGA method represented by Eqs. (22) is a general form of the two-sweep iterative methods. Special versions of the AGA method differ in the choice of the matrices H and Q, where D, P and T are the resultant matrices.

Finally, it should be mentioned that when A is an irreducibly diagonally dominant matrix satisfying Def. (8), the following inequality (proved in Reference 1 and 4) is valid

$$0 < \rho\ (\mathcal{A}_1) < \rho\ (\mathcal{L}_1) < 1 \qquad (23)$$

Moreover, Beauwens /5/ proved that in this case matrix D has always positive diagonal entries.

The application of the successive overrelaxation process in the AGA method and a certain choice of the relaxation factor reduces the spectral radius of the iteration matrix, which in many cases results in a considerable acceleration of convergence. A process of this kind can be applied to one or both sweeps simultaneously. Both cases are described in the next sections.

3. The AGA Single Successive Overrelaxation Two-Sweep Iterative Method (the AGA Single SOR Method)

Using the overrelaxation process to the backward substitution sweep, we directly obtain from the two-sweep Equations (22).

$$\left.\begin{aligned} \beta^{(j+1)} &= (L+H)D^{-1}\beta^{(j+1)} + T\phi^{(j)} + c \\ \phi^{(j+1)} &= \omega D^{-1}\left[(U+Q)\phi^{(j+1)} + \beta^{(j+1)}\right] - (\omega-1)\phi^{(j)}, \quad j \geq 0 \end{aligned}\right\} \qquad (24)$$

and by analogy to Eq. (20)

$$\phi^{(j+1)} = \left[I - \omega D^{-1}(U+Q)\right]^{-1}\{\omega D^{-1}\left[I - (L+H)D^{-1}\right]^{-1}T - (\omega-1)I\}\phi^{(j)} +$$

$$+ \omega\left[I - \omega D^{-1}(U+Q)\right]^{-1}D^{-1}\left[I - (L+H)D^{-1}\right]^{-1}c, \quad j \geq 0 \qquad (25)$$

for any initial vector $\phi^{(0)}$.

For brevity's sake we shall call this method the <u>AGA single SOR method</u> and the matrix,

$$\mathcal{A}_{\omega} = \left[I - \omega D^{-1}(U+Q)\right]^{-1}\{\omega D^{-1}\left[I - (L+H)D^{-1}\right]^{-1}T - (\omega-1)I\}, \qquad (26)$$

the <u>AGA single SOR matrix.</u> Assuming $\omega = 1$ we see that this method reduces exactly to the AGA method expressed by Eq. (20) and $\mathcal{A}_{\omega=1} = \mathcal{A}_1$.

The question now arises whether there exists any value of the relaxation factor, ω, which minimizes the spectral radius $\rho(\mathcal{A}_{\omega})$. It has been proved /1,4/ that $\omega=1$ minimizes $\rho(\mathcal{A}_{\omega})$ for the range $0 < \omega \leq 1$. This suggests that the use of ω greater than unity would decrease the spectral radius $\rho(\mathcal{A}_{\omega})$. Unfortunately, there is no exact formula for an optimum value of ω which gives the minimum of $\rho(\mathcal{A}_{\omega})$ in the general case. However, it has been observed experimentally that there is an optimum value, $\bar{\omega}$, greater than unity, and the following inequality is fulfilled:

$$1 < \bar{\omega} < \omega_{max} < 2 \tag{27}$$

where ω_{max} is the value of ω for which the spectral radius of $\mathcal{R}_{\omega_{max}}$ equals unity.

It was observed in many numerical examples that in the case of a triangular geometry, $\omega_{max} \approx 1.33$.

4. The AGA Double Successive Overrelaxation Two-Sweep Iterative Method (the AGA Double SOR Method)

We can use the overrelaxation process simultaneously to both sweep equations of AGA method Eqs. (22), that is

$$\left.\begin{aligned} \beta^{(j+1)} &= \Omega_\beta\left[(L+H)D^{-1}\beta^{(j+1)} + T\phi^{(j)} + c\right] - (\Omega_\beta - 1)\beta^{(j)} \\ \phi^{(j+1)} &= \Omega_\phi D^{-1}\left[(U+Q)\phi^{(j+1)} + \beta^{(j+1)}\right] - (\Omega_\phi - 1)\phi^{(j)}, \quad j \geq 0 \end{aligned}\right\} \tag{28}$$

for any initial vectors $\phi^{(0)}$ and $\beta^{(0)}$.

The above equations can be condensed to the following iteration scheme

$$\phi^{(j+1)} = \mathcal{H}_{\Omega_\beta\Omega_\phi}\phi^{(j)} - \mathcal{N}_{\Omega_\beta\Omega_\phi}\phi^{(j-1)} + m, \quad j > 0 \tag{29}$$

where the iteration matrices $\mathcal{H}_{\Omega_\beta\Omega_\phi}$ and $\mathcal{N}_{\Omega_\beta\Omega_\phi}$ and the vector m have the following form

$$\begin{aligned} \mathcal{H}_{\Omega_\beta\Omega_\phi} &= \left[I - \Omega_\phi D^{-1}(U+Q)\right]^{-1}\{D^{-1}\left[I - \Omega_\beta(L+H)D^{-1}\right]^{-1}\left[\Omega_\beta\Omega_\phi T \right. \\ &\quad \left. - (\Omega_\beta - 1)D\left[I - \Omega_\phi D^{-1}(U+Q)\right]\right] - (\Omega_\phi - 1)I\} \end{aligned} \tag{30}$$

$$\mathcal{N}_{\Omega_\beta\Omega_\phi} = (\Omega_\beta - 1)(\Omega_\phi - 1)\left[I - \Omega_\phi D^{-1}(U+Q)\right]^{-1}D^{-1}\left[I - \Omega_\beta(L+H)D^{-1}\right]^{-1} \tag{31}$$

$$m = \Omega_\beta\Omega_\phi\left[I - \Omega_\phi D^{-1}(U+Q)\right]^{-1}D^{-1}\left[I - \Omega_\beta(1+H)D^{-1}\right]^{-1}c \tag{32}$$

For brevity's sake we shall call this method the <u>AGA double SOR method.</u> With $\Omega_\beta = 1$, this method reduces to the AGA single SOR method; and

$$\mathcal{H}_{\Omega_\beta=1,\Omega_\phi} = \mathcal{A}_{\omega=\Omega_\phi} \text{ and } \mathcal{N}_{\Omega_\beta=1,\Omega_\phi} = 0.$$

In reactor calculations it was observed that this method, with the proper choice of relaxation parameters Ω_β and Ω_ϕ, converges faster than the AGA single SOR method and is more effective for large reactor problems with a fine mesh. The best results are obtained when the following relation holds:

$$\Omega_\beta = \Omega_\phi = \bar{\Omega} \approx 1 + \frac{(\bar{\omega}-1)}{2} \tag{33}$$

where $\bar{\omega}$ is the optimum relaxation factor in the AGA single SOR method.

It should be mentioned that a special subroutine for estimating a priori the optimum $\bar{\Omega}$ is included in HEXAGA-II. This estimate of $\bar{\Omega}$ is based on an empirical formula giving a good approximation of the optimum $\bar{\Omega}$ for the problems considered up to now (see Section 7 of this Chapter).

5. Derivation of Recursive Formulae Used in HEXAGA-II

In this section the derivation of the recursive formulae for the version of the AGA two-sweep iterative method taken in HEXAGA-II is shown.

We postulate the following formula for the backward substitution sweep at the mesh point (m,n) (see Fig. 1)

$$\phi_n^m = \frac{\beta_n^m + \phi_{n+1}^{m+1} + U_n^m \phi_n^{m+1} + W_n^m \phi_{n+1}^m}{D_n^m} \tag{34}$$

The corresponding formula at the mesh point (n-1,n-1) can be written as follows

$$\phi_{n-1}^{m-1} = \frac{\beta_{n-1}^{m-1} + \phi_n^m + U_{n-1}^{m-1}\phi_{n-1}^m + W_{n-1}^{m-1}\phi_n^{m-1}}{D_{n-1}^{m-1}}$$

Substituting this formula in the difference equation (3) we have

$$(k_n^m - \frac{l_n^m}{D_{n-1}^{m-1}}) \phi_n^m = c_n^m + \frac{l_n^m}{D_{n-1}^{m-1}} \beta_{n-1}^{m-1} + (e_n^m + \frac{l_n^m}{D_{n-1}^{m-1}} U_{n-1}^{m-1}) \phi_{m-1}^m +$$

$$+ (g_n^m + \frac{l_n^m}{D_{n-1}^{m-1}} W_{n-1}^{m-1}) \phi_n^{m-1} + \phi_{n+1}^{m+1} + u_n^m \phi_n^{m+1} + w_n^m \phi_{n+1}^m$$

Again writing the formulae for ϕ_{n-1}^m and ϕ_n^{m-1}, that is, at the mesh points (m,n-1) and (m-1,n) (according to Eq. (34) and substituting them in the last equation and introducing an iteration index, j, we finally obtain the following recursive formulae

$$\left.\begin{aligned} (\beta_n^m)^{(j+1)} &= c_n^m + L_n^m(\beta_{n-1}^{m-1})^{(j+1)} + E_n^m\left[(\beta_{n-1}^m)^{(j+1)} + U_{n-1}^m(\phi_{n-1}^{m+1})^{(j)}\right] + \\ &\quad + G_n^m\left[(\beta_n^{m-1})^{(j+1)} + W_n^{m-1}(\phi_{n+1}^{m-1})^{(j)}\right] \\ (\phi_n^m)^{(j+1)} &= \frac{(\beta_n^m)^{(j+1)} + (\phi_{n+1}^{m+1})^{(j+1)} + U_n^m(\phi_n^{m+1})^{(j+1)} + W_n^m(\phi_{n+1}^m)^{(j+1)}}{D_n^m} \qquad j \geq 0 \end{aligned}\right\} \quad (35)$$

where

$$L_n^m = l_n^m / D_{n-1}^{m-1}$$

$$E_n^m = (e_n^m + L_n^m U_{n-1}^{m-1}) / D_{n-1}^m$$

$$G_n^m = (g_n^m + L_n^m W_{n-1}^{m-1}) / D_n^{m-1}$$

$$D_n^m = k_n^m - L_n^m - E_n^m W_{n-1}^m - G_n^m U_n^{m-1}$$

$$U_n^m = u_n^m + E_n^m$$

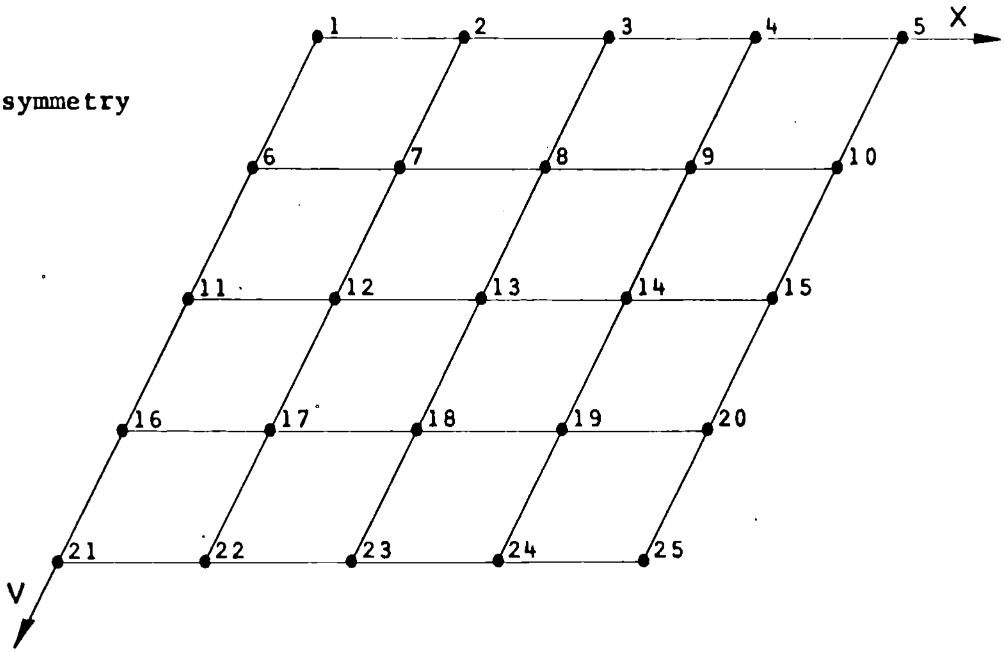
$$W_n^m = w_n^m + G_n^m$$

The above recursive formulae represent the version of the AGA two-sweep iterative method, defined by the two-sweep equations (22), which is taken in HEXAGA-II. Thus, for a given iteration j+1 and an energy group g the values of β are calculated recursively in the forward elimination sweep for successively increasing mesh indices m and n (m=1, n=1,2,...N; m=2, n=1,2,...N, etc.) using the values of ϕ from iteration j. With calculated values of β existing in all mesh points, the values of ϕ are calculated recursively in the backward substitution sweep for successively decreasing mesh indices m and n (m=M, n=N, N-1,...1; m=M-1, n=N,N-1,...1,etc.). The values of coefficients L, E, G, U and W are calculated (also recursively for successively increasing mesh indices m and n) only once for all mesh points and all energy groups and stored for the whole iteration process.

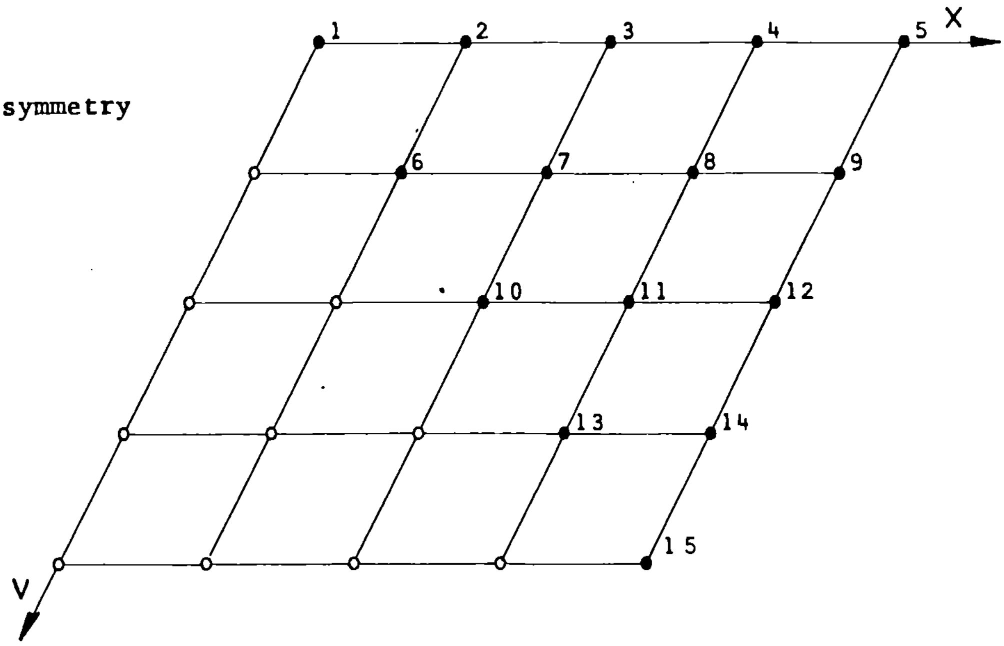
Similar recursive formulae can be derived in the same way for the mesh points belonging to outer boundaries. However, in this case some terms of Eqs. (35) must disappear according to a given outer boundary.

By relating Eq. (35) to the matrix notation of the AGA two-sweep iterative method defined by Eqs. (22) we can give the following interpretation of difference coefficients of Eqs. (35) under the assumption that the indices of the components of both vectors β and ϕ, i, are related to the mesh indices m and n by the following formula: i = (m-1)N + n (where N is the number of mesh points in x-direction, see Fig. 1). Thus, coefficients $L_n^m U_{n-1}^{m-1}$ and $L_n^m W_{n-1}^{m-1}$ are the respective entries of two non-negative subdiagonals of the matrix H coinciding with the non-negative subdiagonals of the matrix L. Coefficients E_n^m and G_n^m are the respective entries of two non-negative superdiagonals of the matrix Q coinciding with the non-negative superdiagonals of the matrix U. D_n^m are the entries of the diagonal matrix D, and terms $L_n^m + E_n^m W_{n-1}^m + G_n^m U_n^{m-1}$ are the entries of the diagonal matrix P. Coefficients $E_n^m U_{n-1}^m$ and $G_n^m W_n^{m-1}$ are the respective entries of two diagonals of the matrix T located symmetrically with respect to the main diagonal. The pictures of matrices A, H, Q and T (where non-zero entries are marked by crosses) are shown for the example in which M=N=5 for three versions of HEXAGA-II-120, -60 and -30. Black and numbered mesh points in the pictures of the point mesh denote these mesh points which are included in the domain of solution in particular versions of HEXAGA-II.

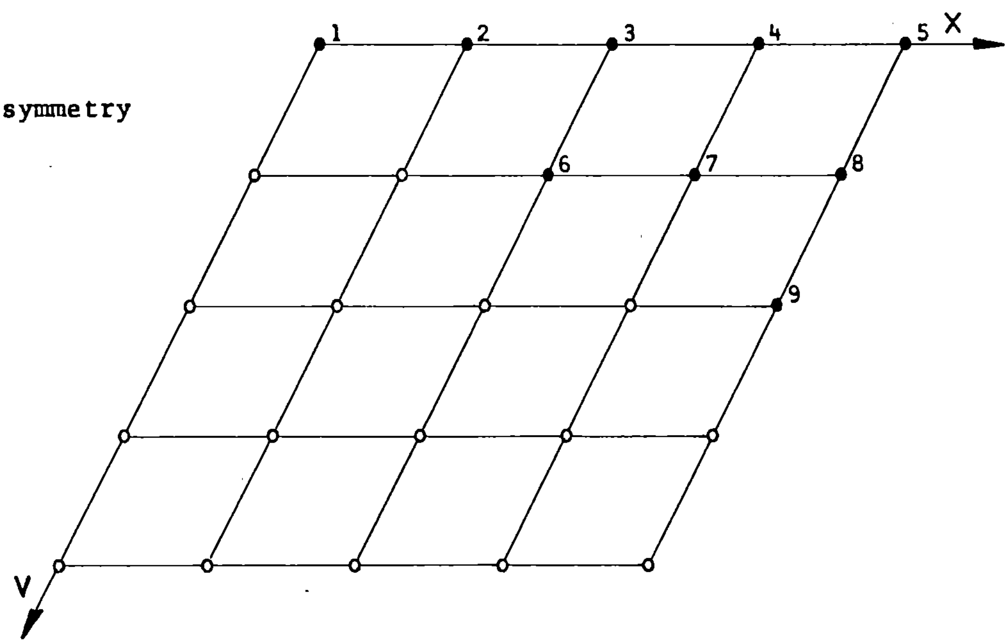
120° symmetry



60° symmetry

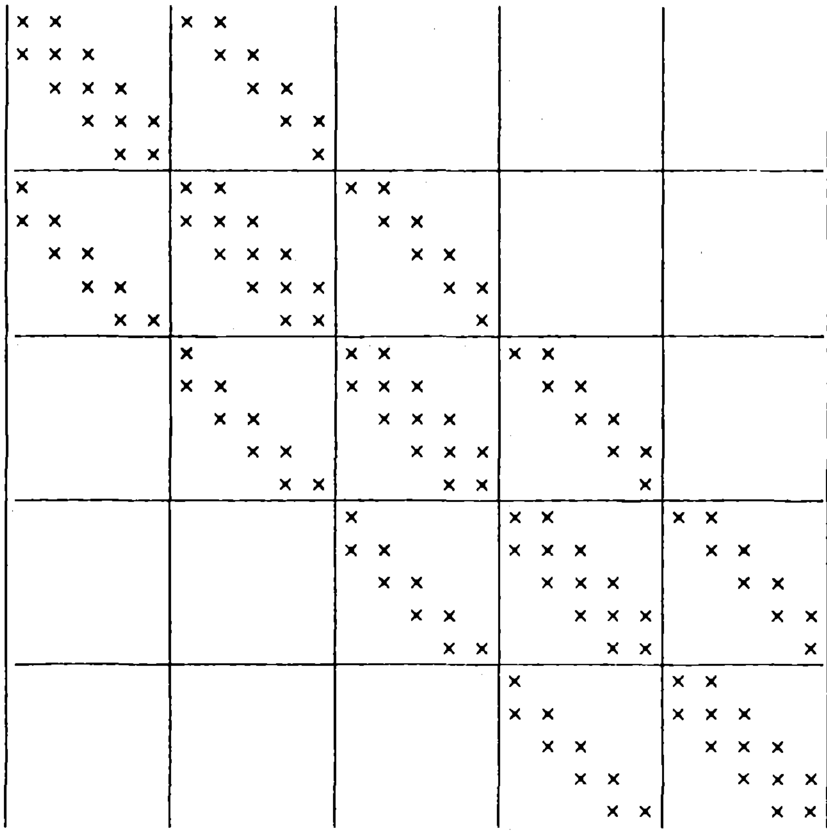


30° symmetry



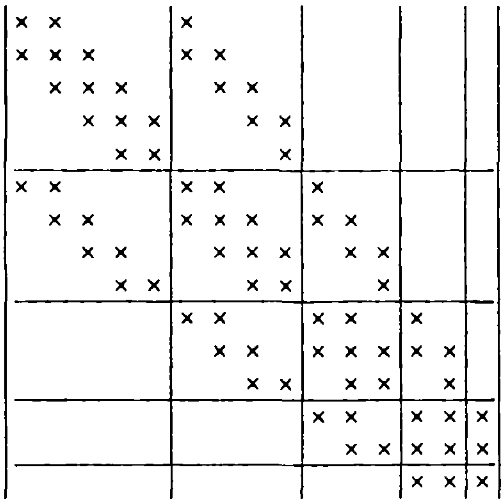
120° symmetry

A = K-L-U =



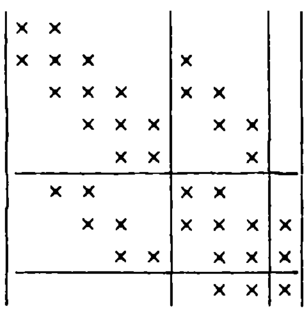
60° symmetry

A = K-L-U =



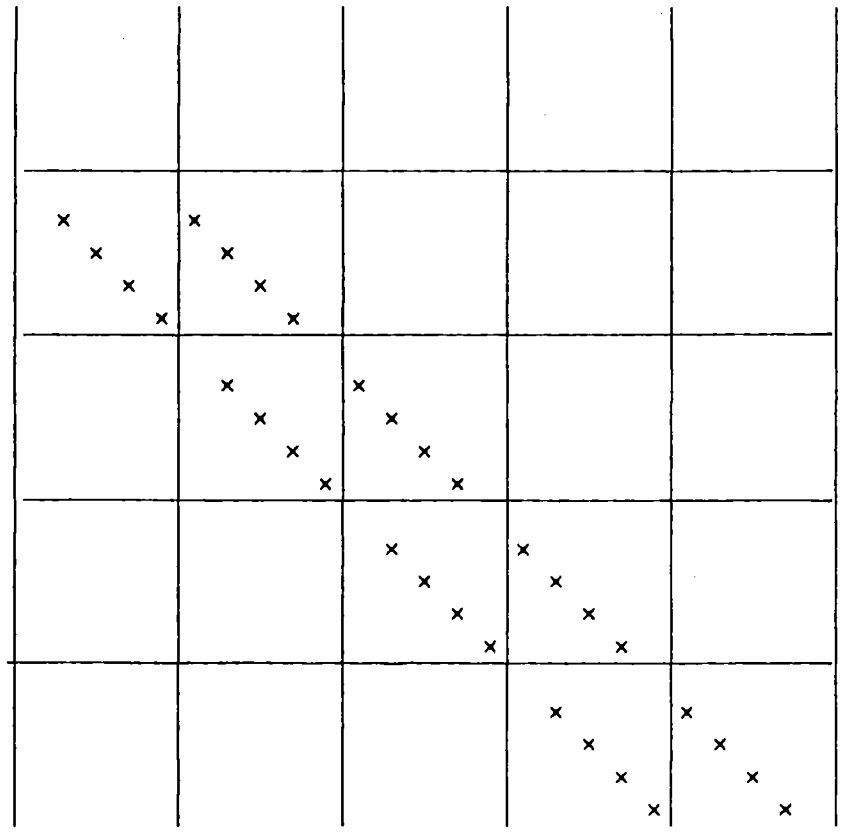
30° symmetry

A = K-L-U =



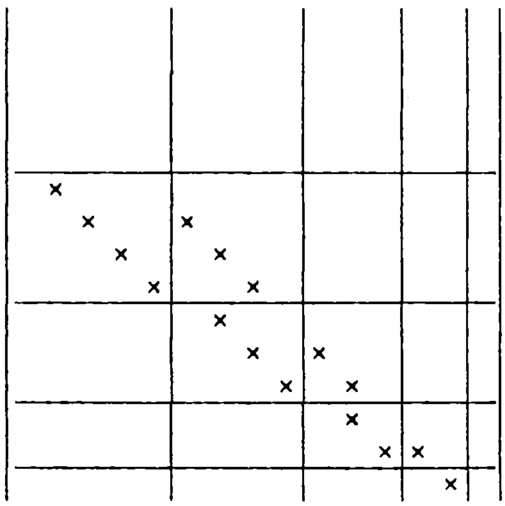
120^o symmetry

H =



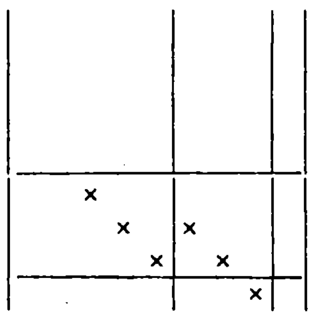
60^o symmetry

H =



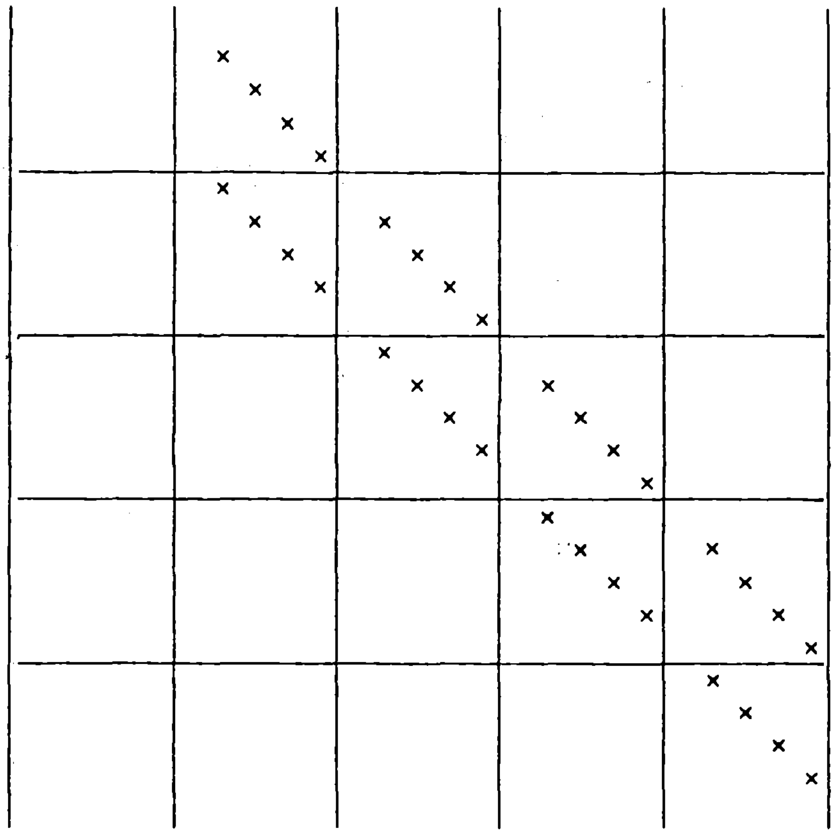
30^o symmetry

H =



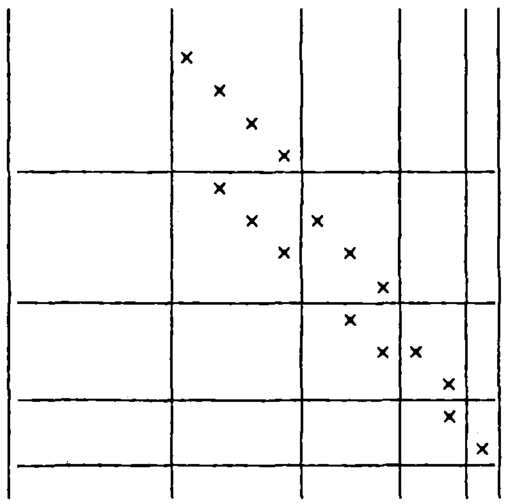
120° symmetry

$Q =$



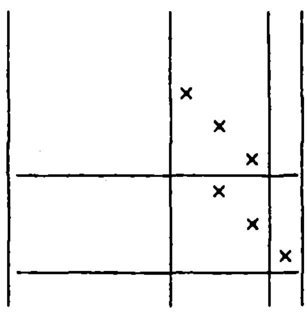
60° symmetry

$Q =$



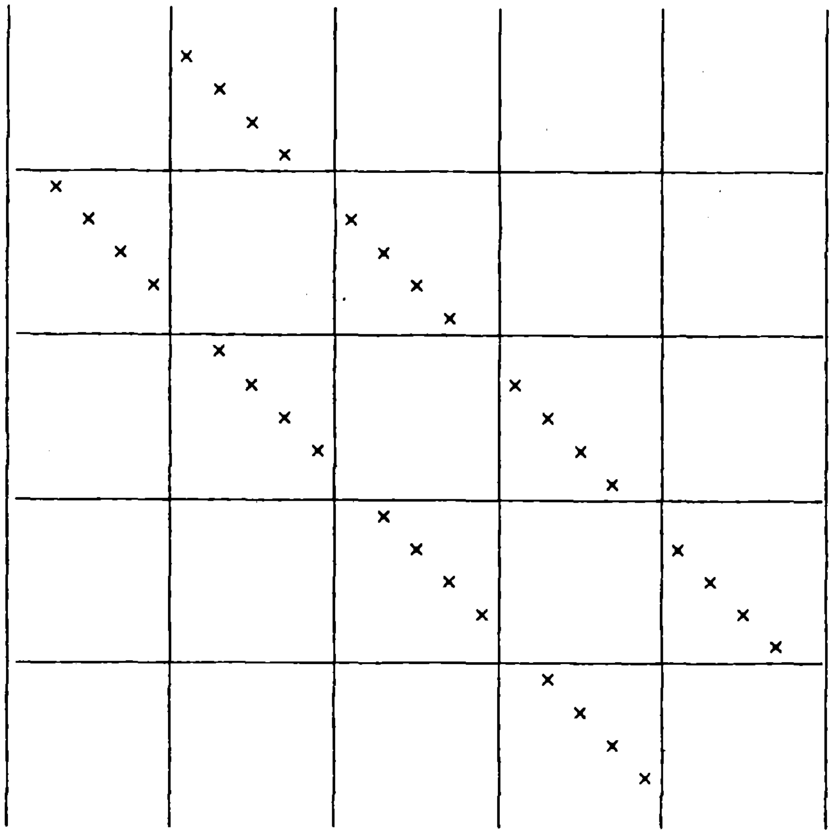
30° symmetry

$Q =$



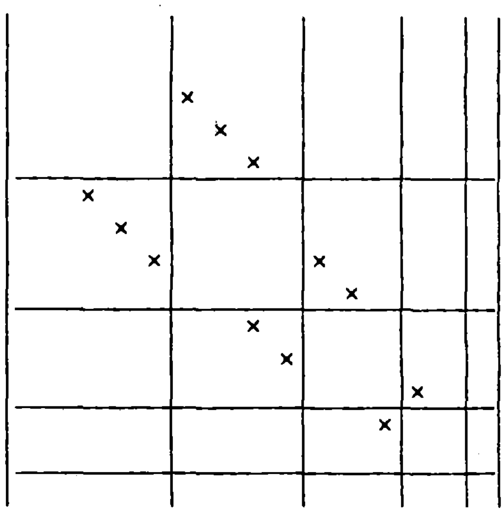
120° symmetry

T =



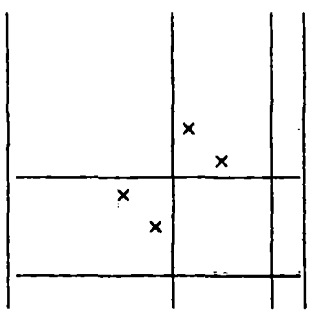
60° symmetry

T =



30° symmetry

T =



For the AGA single SOR and the AGA double SOR method, the corresponding recursive formulae have the following forms:

For the AGA single SOR method:

$$\left.\begin{aligned}
(\beta_n^m)^{(j+1)} &= c_n^m + L_n^m(\beta_{n-1}^{m-1})^{(j+1)} + E_n^m\left[(\beta_{n-1}^m)^{(j+1)} + U_{n-1}^m(\phi_{n-1}^{m+1})^{(j)}\right] + \\
&\quad + G_n^m\left[(\beta_n^{m-1})^{(j+1)} + W_n^{m-1}(\phi_{n+1}^{m-1})^{(j)}\right] \\
(\phi_n^m)^{(j+1)} &= \frac{\omega}{D_n^m}\left[(\beta_n^m)^{(j+1)} + (\phi_{n+1}^{m+1})^{(j+1)} + U_n^m(\phi_n^{m+1})^{(j+1)} + \right. \\
&\quad \left. + W_n^m(\phi_{n+1}^m)^{(j+1)}\right] - (\omega-1)\phi^{(j)}, \qquad j \geq 0
\end{aligned}\right\} \quad (36)$$

For the AGA double SOR method:

$$\left.\begin{aligned}
(\beta_n^m)^{(j+1)} &= \Omega_\beta\{c_n^m + L_n^m(\beta_{n-1}^{m-1})^{(j+1)} + E_n^m\left[(\beta_{n-1}^m)^{(j+1)} + U_{n-1}^m(\phi_{n-1}^{m+1})^{(j)}\right] + \\
&\quad + G_n^m\left[(\beta_n^{m-1})^{(j+1)} + W_n^{m-1}(\phi_{n+1}^{m-1})^{(j)}\right]\} - (\Omega_\beta-1)(\beta_n^m)^{(j)} \\
(\phi_n^m)^{(j+1)} &= \frac{\Omega_\phi}{D_n^m}\left[(\beta_n^m)^{(j+1)} + (\phi_{n+1}^{m+1})^{(j+1)} + U_n^m(\phi_n^{m+1})^{(j+1)} + \right. \\
&\quad \left. + W_n^m(\phi_{n+1}^m)^{(j+1)}\right] - (\Omega_\phi-1)(\phi_n^m)^{(j)}, \qquad j \geq 0
\end{aligned}\right\} \quad (37)$$

Finally, it should be mentioned that these methods require more arithmetic operations per mesh point compared with the point SOR method. In the case of HEXAGA-II, the AGA single SOR method needs 10 multiplications and 8 additions per mesh point; the AGA double SOR method needs 12 multiplications and 10 additions per mesh point whereas, in the point SOR method, these numbers are 8 and 7, respectively.

6. The Iteration Process

A special strategy of outer-inner iterations is used in HEXAGA-II, in which a number of inner iterations, I, given as an input value ($1 \leq I \leq 8$), are fixed for all energy groups, G, in a given outer iteration. The scattering sources are recalculated after each group calculation, that is, after I inner iterations each. The fission sources S_n^m and k_{eff} are recalculated after each outer iteration, j, that is,

$$(S_n^m)^{(j)} = \sum_{g=1}^{G} \left[\nu \Sigma_g^f (\phi_n^m)_g^{(j)} \right] \tag{38}$$

and in recent versions of HEXAGA-II the convergence rate of sources is accelerated by means of usual relaxation technique, as follows

$$(S_n^m)_*^{(j)} = \omega_s (S_n^m)^{(j)} - (\omega_s - 1)(S_n^m)^{(j-1)} \tag{38a}$$

and

$$k_{eff}^{(j)} = \int_V S_*^{(j)} dv \tag{39}$$

where ω_s is a relaxation factor specified in the input (it is recommended to use $\omega_s = 1.5$ for all cases) and the integration of sources is approximated by the trapezoidal method. For the next outer iteration, new sources are renormalized, as follows

$$(S_n^m)^{(j+1)} = \frac{1}{k_{eff}} (S_n^m)_*^{(j)} \tag{40}$$

To start the iteration process, a zero initial guess is made for vectors $\beta^{(0)}$ and $\phi^{(0)}$ (all components of both vectors $\beta^{(0)}$ and $\phi^{(0)}$ are set equal to zero in all energy groups). For the calculation of initial sources $S^{(0)}$ a flat flux ϕ, which is the same in all energy groups, is taken for the whole core region. It has been observed that such initial guesses for both vectors $\phi^{(0)}$, $\beta^{(0)}$ and $S^{(0)}$ minimize the number of outer iterations in most reactor problems.

The outer iteration index, j, coincides with the inner iteration index, I, only for I=1. For I>1, the inner iterations for spatial flux performed by the two-sweep equations (either Eqs. (36) or Eqs. (37) are repeated I times for every energy group, g (g=1,...G). Thus, for any convergent iteration process up to the outer iteration j_o the total number of inner iterations is equal to $j_o \cdot I \cdot G$. It has been observed in all problems considered up to now that using a few inner iterations per outer iteration ($1 \leq I \leq 3$) provides the minimum time of a central processor unit (CPU), and very often the best results are obtained for 2 or 3 inner iterations per outer iteration. In principle, the optimal number of inner iterations per outer iteration is determined by programme for a given problem, however, it can be also specified by user in the input (see explanation given in Chapter IV).

The iterative process continues until the following convergence criteria are fulfilled:

- Either the maximum number of outer iterations has been reached

$$j = j_{max},$$

- or the following inequalities are satisfied:

$$\left| \frac{k_{eff}^{(j+1)} - k_{eff}^{(j)}}{k_{eff}^{(j+1)}} \right| < \varepsilon_k \tag{42}$$

and

$$\left| \frac{\phi_{(I)}^{(j+1)} - \phi_{(I-1)}^{(j+1)}}{\phi_{(I)}^{(j+1)}} \right| < \varepsilon_\phi \tag{43}$$

for all energy-space mesh points, where values of j_{max}, I, ε_k and ε_ϕ are specified in the input data. In the case where I=1, $\phi_{(I-1)}^{(j+1)}$ is replaced by $\phi_{(I)}^{(j)}$.

7. The Estimate of Iteration Process Parameters

A special subroutine for estimating optimum relaxation factors, Ω_β and Ω_ϕ, and the number of inner iterations per outer iteration, I, before starting the iteration process is applied in HEXAGA-II. This estimate, which provides a good approximation of optimum relaxation factors, is based on an empirical formula derived from the analysis of numerical results obtained up to now. Since the AGA Single SOR method turned out to be less effective than the AGA Double SOR method, the latter is applied and the following relations hold in particular versions of HEXAGA-II:

HEXAGA-II-120

$$\bar{\Omega} = \Omega_\beta = \Omega_\phi = \frac{1.223295 - 1.126367\rho(\mathcal{A})}{1.080925 - \rho(\mathcal{A})} \tag{44}$$

HEXAGA-II-60

$$\bar{\Omega} = \Omega_\beta = \Omega_\phi = \frac{1.209731 - 1.132879\rho(\mathcal{A})}{1.064632 - \rho(\mathcal{A})} \tag{45}$$

HEXAGA-II-30

$$\bar{\Omega} = \Omega_\beta = \Omega_\phi = \frac{1.230149 - 1.110274\rho(\mathcal{A})}{1.100132 - \rho(\mathcal{A})} \tag{46}$$

where

$$\rho(\mathcal{A}) = \max_{1\le g\le G} \rho(\mathcal{A}_{g,\omega=1})$$

The values of I are determined by means of the following inequalities. In the case of HEXAGA-II-120 and -30

$$
\begin{aligned}
I = 1 &\text{ for } \qquad\quad \rho(\mathcal{A}) \le 0.80\\
2 &\text{ for } 0.80 < \rho(\mathcal{A}) \le 0.95\\
3 &\text{ for } 0.95 < \rho(\mathcal{A}) \le 0.99\\
4 &\text{ for } 0.99 < \rho(\mathcal{A}),
\end{aligned}
$$

and for HEXAGA-II-60

$$
\begin{aligned}
I = 1 &\text{ for } \qquad\quad \rho(\mathcal{A}) \le 0.80\\
2 &\text{ for } 0.80 < \rho(\mathcal{A}) \le 0.90\\
3 &\text{ for } 0.90 < \rho(\mathcal{A}) \le 0.97\\
4 &\text{ for } 0.97 < \rho(\mathcal{A}) \le 0.985\\
5 &\text{ for } 0.985 < \rho(\mathcal{A}) \le 0.992\\
6 &\text{ for } 0.992 < \rho(\mathcal{A}).
\end{aligned}
$$

The time of the estimate of $\bar{\Omega}$ by the programme amounts to a few per cent of the total time of calculations for a given reactor problem. It should be mentioned that there exist a possibility of using the values of Ω_β and Ω_ϕ (not necessary $\Omega_\beta = \Omega_\phi$) and I specified by user in the input with omitting the estimation of these parameters by the programme (see, explanations given in Chapters IV and VI.4).

Finally, it should be noted that the exact estimate of optimum relaxation factors is a very important problem and difficult to solve both in HEXAGA-II and in other diffusion programmes. Unfortunately, there are no theoretical considerations which would allow to predict these factors a priori for the AGA method. However, the above empirical formulae provide a good approximation of optimum relaxation factors for the majority of reactor problems. The values of $\bar{\Omega}$ evaluated by Eq. (45) are very close to the optimum value of Ω_{opt} for large reactor problems with 20000 - 40000 mesh points. For smaller problems these values of $\bar{\Omega}$ can sometimes be slightly underestimated which, in the effect, results in an increase in CPU time by about 10 to 20 percent. However, even with such underestimate of Ω_{opt}, CPU time is many times less than it would be if improper values of Ω had been used. Moreover, for the overestimated values of Ω_{opt} non-convergence can be obtained in HEXAGA-II.

IV. INPUT DESCRIPTION

The HEXAGA-II input data prepared mainly in the form of a card deck and the same for all versions of programme (-120, -60 and -30) consist of a series of input variables describing, for a given reactor problem, successively its size, the distribution of material compositions in the mesh, material composition group constants and parameters determining the iteration process. HEXAGA-II also offers the possibility of transmission of cross sections extracted from an SIGMN Block /6/ stored on an external file; this feature is due to G. Buckel of INR (Karlsruhe Nuclear Research Center).

Though HEXAGA-II is a code for a triangular geometry, the description of the material distribution inside the mesh is given in the input basically as for a hexagonal geometry. That is, six adjacent triangles are grouped in one hexagon. The layout of the reactor must be enclosed by a parallelogram. The left upper corner of this parallelogram is taken as the origin of an oblique coordinate system x - v (see Fig. 1). Now a mesh of regular hexagons is superimposed upon this parallelogram. The boundaries of the parallelogram cut some hexagons in pieces. These cut hexagons are also referred to as hexagons in the following text. As illustrated in Figs. 2, 3 and 4, there are three possibilities for choosing the location of hexagons relative to the origin of the coordinate system. These three arrangements of the hexagonal mesh will be called the 1st, 2nd and 3rd spatial models, corresponding to Figs. 2, 3 and 4, respectively.

In this hexagonal description of the triangular mesh we specify, line by line, from top to bottom, only the indices x and v of hexagon centers coinciding with mesh points of these lines. If there are ununiform hexagons, that is, hexagons containing more than one material composition, one has to create a new composition number for this type of material arrangement and to indicate this number in the input together with a specification of the material compositions corresponding to the six triangles.

To simplify the preparation of HEXAGA-II input data an auxiliary programme INPREP is available. It prints the arrangement of hexagons in the parallelogram mesh for any example considered and furnishes information

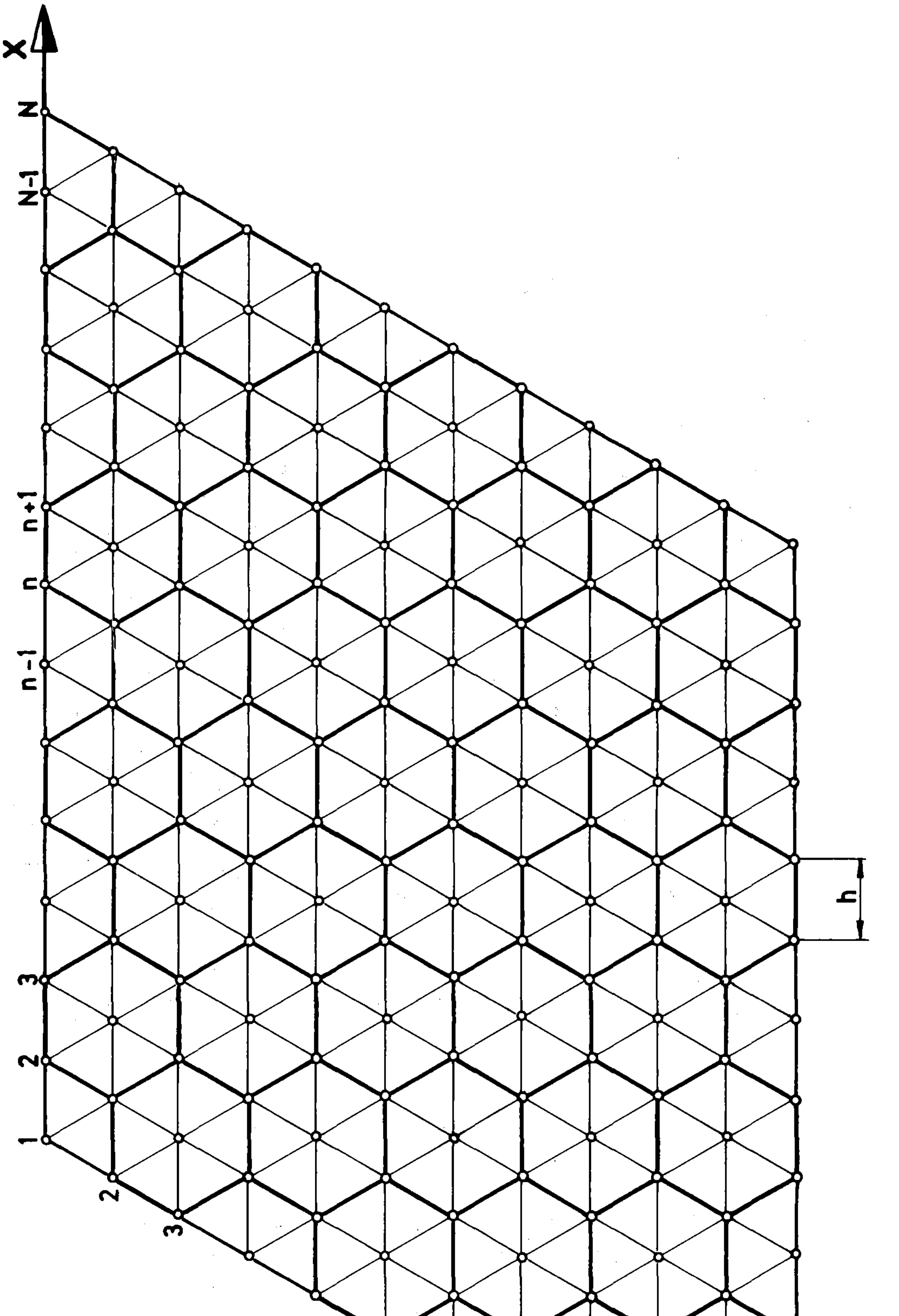


Fig. 2 1-st Spatial Model

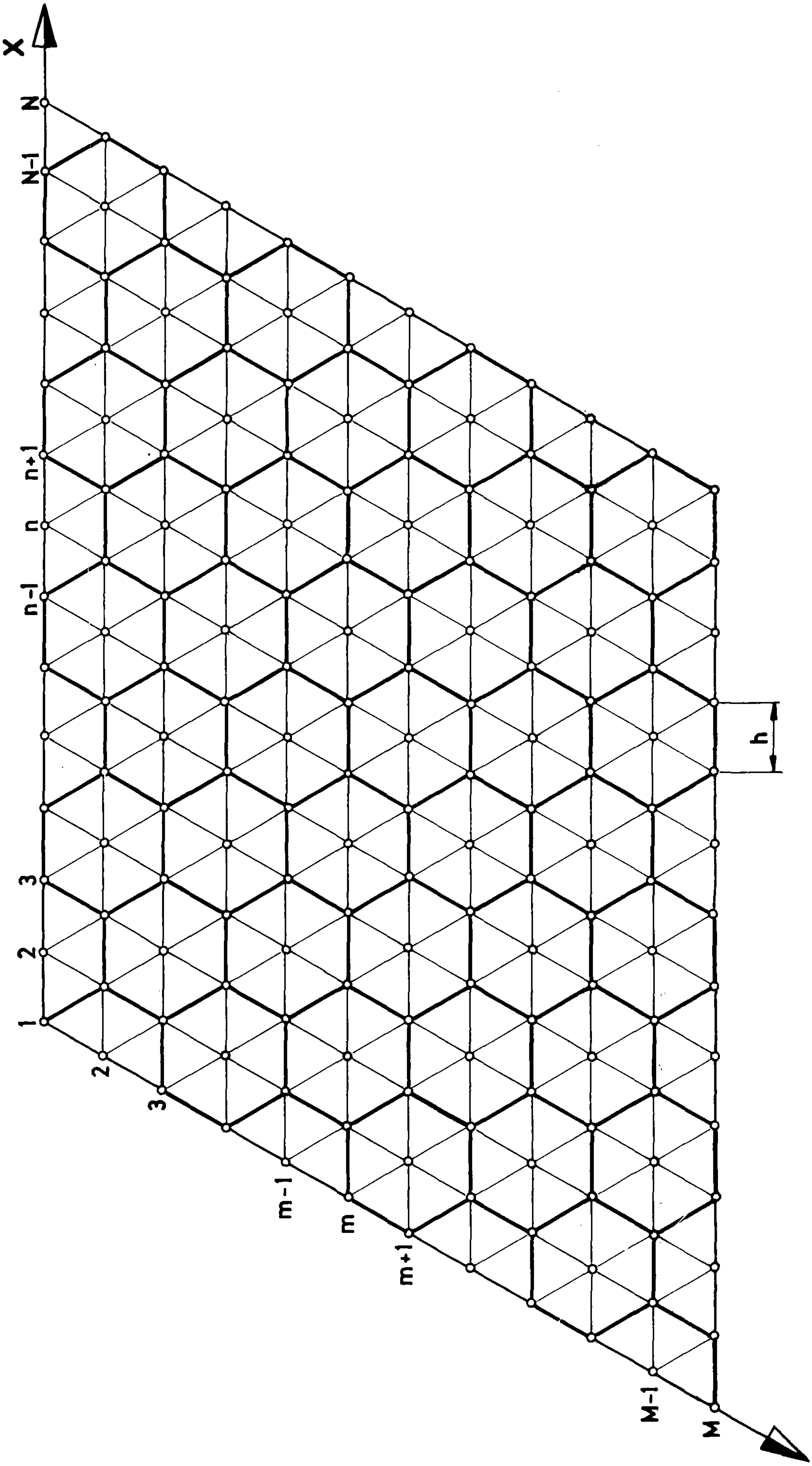


Fig.3 2-nd Spatial Model

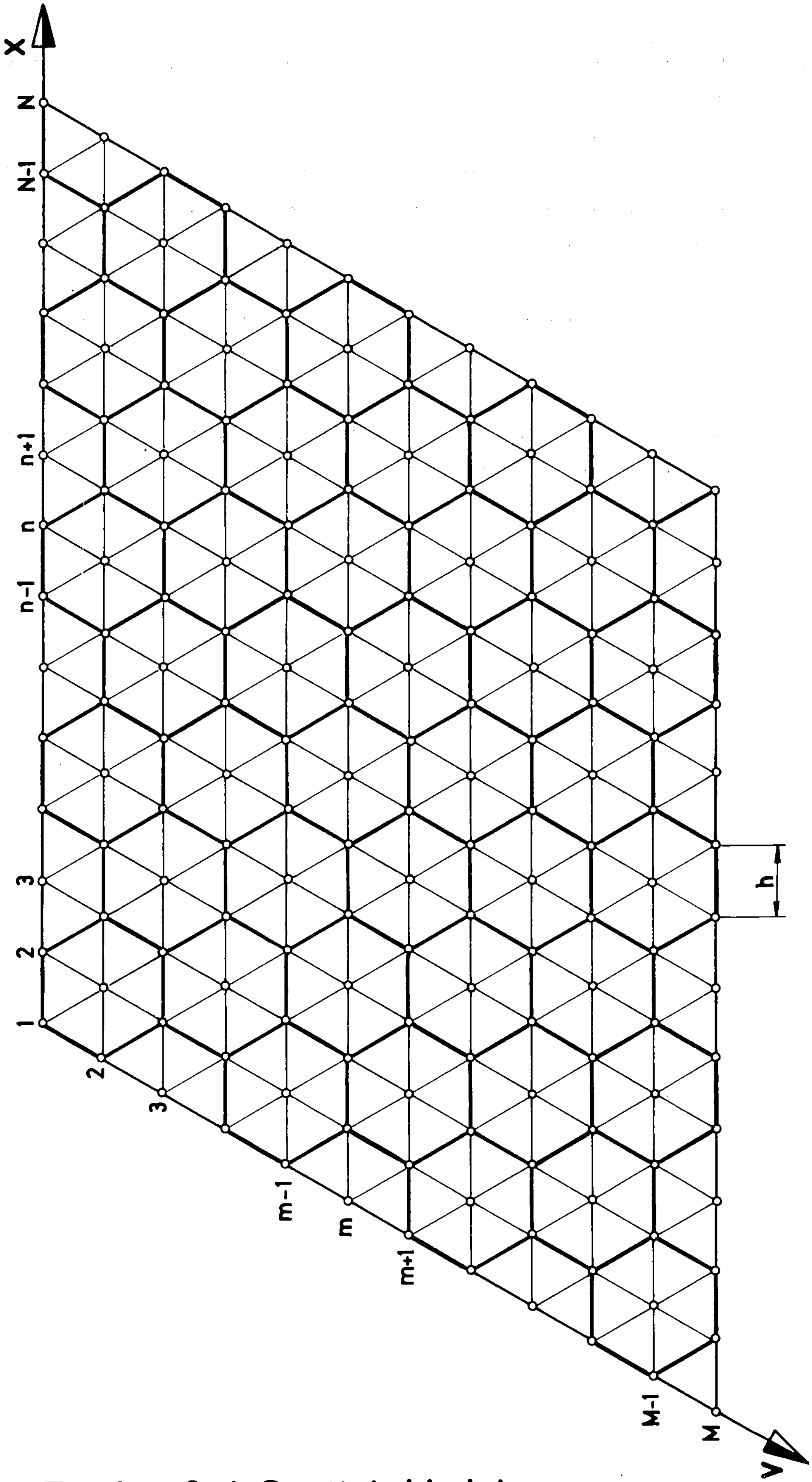


Fig. 4 3-d Spatial Model

about computer storage requirements. The use of this programme is described in Appendix.

It should be mentioned that there is the possibility with HEXAGA-II to calculate a sequence of reactor problems with optional forms of output and storage of results.

The two sample problems presented in this report provide a good illustration of the possibilities of HEXAGA-II input data.

In the table below, formats and the meaning of input variables together with comments on their use are described in the sequence in which they occur in particular cards (or card sets).

Input Card Description

Card (or Card set) number	Format	Name	Description
1/	(10A8)	Title card	(80 alphanumerical characters are permitted)
2/	(16I4,F11.5)	NOM	Spatial model number, 1 ≤ NOM ≤ 3, depending on the location of hexagons at the origin of the coordinate oblique system x - v; the value of NOM corresponds to one of the spatial model numbers represented in Figs. 2, 3 and 4.
		M	Number of mesh lines parallel to the axes x.
		N	Number of mesh lines parallel to the axes v.
			Note: In the case of using HEXAGA-II-60 or -30, M = N
		NOG	Number of energy groups, 2 ≤ NOG ≤ 40.
		MDS	Maximum number of energy groups throughout which neutrons are downscattered, 1 ≤ MDS ≤ NOG - 1.
		NOTHG	Number of thermal groups, 1 ≤ NOTHG ≤ NOG - 1.
		NOC	Number of different material compositions, NOC ≤ 999.
		NOFC	Number of different fissionable material compositions, NOFC ≤ NOC (if macroscopic cross sections are transferred from SIGMN block: NOFC = NOC).

NBASIC	Basic material composition number, $0 \leq NBASIC \leq NOC$. Dependent on the value of NBASIC, there are two possibilities for the description of the distribution of material compositions in the mesh (see explanations on card 3).
NOUH	Number of different kinds of uniform hexagons, $NOUH \leq NOC$
NOH	Number of all kinds of (uniform and non-uniform) hexagons, $NOH \geq NOUH$. Note: In a uniform hexagon, all triangles have the same material composition; in a non-uniform hexagon, triangles may have different material compositions. Hexagons cut by the outer boundaries are counted as full hexagons and their triangles lying outside outer boundary can be specified by an arbitrary material composition.
NLC	Left boundary condition indicator.
NTC	Top boundary condition indicator.
NRC	Right boundary condition indicator.
NBC	Bottom boundary condition indicator. These indicators may have one of the following values: 0 - corresponds to zero flux 1 - corresponds to zero current 2 - corresponds to a logarithmic derivative boundary condition where the parameter α of

Eq. (1a) is taken to be constant along the corresponding outer boundary.

3 - corresponds to a logarithmic derivative boundary condition, but the parameter α is given pointwise for the corresponding outer boundary.

Note: Parameters α, if any, are specified groupwise after the specification of group constants.
In the case of using HEXAGA-II-60 or -30, NLC = NTC = 1 and NRC = NBC.

NAD $0 \leq NAD \leq 2$

0 - real flux calculation only

1 - both real and adjoint flux calculations

2 - adjoint flux calculation only.

H Mesh width given in centimeters.

3/ The data specifying the location of material compositions in the hexagonal description of the mesh must be provided according to the value of NBASIC; if NBASIC = 0, continue with card set number 3/1'/.

3/1/ If $1 \leq NBASIC \leq NOC$, all hexagons must be uniform, NOH = NOUH = NOC.
Material composition NBASIC is assumed in all locations of the mesh that are not specified otherwise in the card subset below.
For j = 1, NOC - 1 the whole sequence from 3/1/1/ to 3/1/3/ must be indicated as follows

3/1/1/ (2I4) NSP Material composition number
$1 \leq NSP \leq NOC$ and $NSP \neq NBASIC$
given in an arbitrary order.

		NL	Number of mesh lines parallel to the x-axes which pass through centers of hexagons containing material composition NSP. For i = 1, ...NL 3/1/2/ and 3/1/3/ must be indicated.
3/1/2/	(2I4)	LNR	Index number of one of these NL mesh lines.
		NP	Number of points on this mesh line LNR coinciding with the centers of hexagons containing composition NSP.
3/1/3/	(20I4)	NCR(NP)	Array of the point indices (on the mesh line LNR) coinciding with the centers of hexagons containing composition NSP.

After completion of the material distribution, the input continues with card set 4.

3/1'/	(20I4)	If NBASIC = 0, all hexagons in the mesh are specified by their centers linewise from top to bottom. The input of each mesh line is treated as one card set. NOUH $\leq$ NOC. If NOH = NOUH, the hexagon composition numbers correspond to the material composition numbers NSP. If NOH > NOUH, new hexagon composition numbers NH (NH > NOC) have to be created for each type of non-uniform hexagon and each of them must be specified additionally in card set 3/1'/1/.
3/1'/1/	(6I4,I6)	If NOH > NOUH, the material composition numbers of six triangles (corresponding to the order of triangles shown in Fig. 1) for each non-uniform hexagon must be given followed by the newly

created hexagonal type of composition number NH, NH = NOUH + 1, NOUH + 2, . . . NOH.

4/		Group constant specifications must be provided for each material composition. Two possibilities are allowed: a) Input as a card deck or from an external file stored in the card image format. Mixing of these two input forms is allowed. b) Transmission of group constants from a SIGMN block /6/, stored on an external file. In this case, bucklings must be given according to 4/2'/-4/4'/.	
4/1/	(2I4)	INCS	Indicator for reading in group constants = 1 - group constants given as a card deck. < 0 - group constants given on an external file in card image format with data set reference number |INCS| and |INCS| > 1. = 0 - group constants must be transformed from SIGMN block.
		NSP	- material composition number, $1 \leq NSP \leq NOC$, if INCS $\neq$ 0 - data reference number of SIGMN block, if INCS = 0.
		If INCS = 0, turn to card sets 4/2'/...4/4'/.	
4/2/	(6E13.6)	DIF(NOG)	Array of diffusion coefficients D_g for all energy groups.

4/3/ SIGT (NOG) Array of macroscopic total removal cross sections Σ_g^T for all energy groups

$$\Sigma_g^T = \Sigma_g^A + \sum_{\substack{g=1 \\ g \neq g}}^{G} \Sigma_{g \to g'}^S + D_g B^2$$

where

Σ_g^A - macroscopic absorption cross section

$\Sigma_{g \to g'}^S$ -macroscopic scattering cross section from group g to g'.

B - transverse buckling

4/4/ If a given value of NSP corresponds to a fissionable material composition, that is, NSP $\leq$ NOFC, two arrays for $\nu\Sigma^F$ and χ must be specified. It should be noticed that all fissionable material compositions must be denoted by the numbers from 1 to NOFC. For NSP > NOFC, both arrays are omitted in the input. However, if a given material composition is in reality unfissionable but was declared a fissionable composition, zero values of $\nu\Sigma_g^F$ and values of χ with $\sum_1^G \chi_g = 1$ must be specified for all energy groups in the input.

4/4/1/ NUSIGF(NOG) Array of macroscopic production fission cross sections $\nu\Sigma_g^F$ for all energy groups.

4/4/2/ CHI(NOG) Array of fission source fractions χ_g for all energy groups.

4/5/ SIGDS(NOG-1,MDS) Array of macroscopic down-scattering cross sections $\Sigma_{g \to g'}^{ds}$, whose values for MDS > 1 are specified as follows:

4/5/1/ $\Sigma^{ds}_{1\to2}, \Sigma^{ds}_{1\to3}, \ldots\ldots \Sigma^{ds}_{1\to MDS+1}$

4/5/2/ $\Sigma^{ds}_{2\to3}, \Sigma^{ds}_{2\to4}, \ldots\ldots \Sigma^{ds}_{2\to MDS+2}$

4/5/NOG-2/ $\Sigma^{ds}_{NOG-2\to NOG-1}, \Sigma^{ds}_{NOG-2\to NOG}$

4/5/NOG-1/ $\Sigma^{ds}_{NOG-1\to NOG}$.

4/6/ If there is more than one thermal group, NOTHG > 1, we must provide the following triangular array:

SIGUS(NOTHG-1, NOTHG-1) Array of macroscopic upscattering cross sections $\Sigma^{us}_{g'\to g}$ whose values in a general case are specified as follows:

4/6/1/ $\Sigma^{us}_{I+1\to I}, \Sigma^{us}_{I+2\to I}, \ldots\ldots \Sigma^{us}_{NOG\to I}$

4/6/2/ $\Sigma^{us}_{I+2\to I+1}, \Sigma^{us}_{I+3\to I+1}, \ldots \Sigma^{us}_{NOG\to I+1}$

4/6/NOTHG-2/ $\Sigma^{us}_{NOG-1\to NOG-2}, \Sigma^{us}_{NOG\to NOG-2}$

4/6/NOTHG-1/ $\Sigma^{us}_{NOG\to NOG-1}$

where I = NOG - NOTHG + 1

Note: The above sequence of data beginning from 4/1/ must be repeated NOC times, that is, for each material composition. However, if |INCS| > 1, the data from 4/2/ to 4/6/ are omitted for this composition in the card deck, because they are stored on an external file with the data set number equal to |INCS|.

Turn to 5/

4/2'/	(I4)	IBUCK	Buckling indicator = 1 - uniform buckling = 2 - material dependent buckling = 3 - group dependent buckling = 4 - group and material dependent buckling.
4/3'/	(I4)	MX	= 1 for IBUCK = 1 = NOC for IBUCK = 2 or IBUCK = 4 = NOG for IBUCK = 3.
4/4'/	(6E13.6)	B2(MX)	Values of B^2.

Note: If IBUCK = 4, card 4/3'/ and 4/4'/ must be repeated NOG times.

5/ If at least one of the values of NLC, NTC, NRC and NBC is $\geq$ 2, we specify the parameters α of Eq. (1a) as follows:

If NLC = 2,

5/1/	(E11.5)	PARL	Parameter α constant along the left outer boundary.

If NLC = 3,

5/1'/	(7E11.5)	ALFAL(M)	Array of parameters α for all mesh points along the left outer boundary.

If NTC = 2,

5/2/	(E11.5)	PART	Parameter α constant along the top outer boundary.

If NTC = 3,

5/2'/	(7E11.5)	ALFAT(N)	Array of parameters α for all mesh points along the top outer boundary.

		If NRC = 2,	
5/3/	(E11.5)	PARR	Parameter α constant along the right outer boundary.
		IF NRC = 3,	
5/3'/	(7E11.5)	ALFAR(M)	Array of parameters α for all mesh points along the right outer boundary.
		If NBC = 2,	
5/4/	(E11.5)	PARB	Parameter α constant along the bottom outer boundary.
		If NBC = 3,	
5/4'/	(7E11.5)	ALFAB(N)	Array of parameters α for all mesh points along the bottom outer boundary.

Note: This sequence of data beginning from 5/1/, if it exists, must be repeated successively for all energy groups.

6/	(4I4, 2F8.4 2E9.1, 2I4, F8.4)	INIT	= 0 - fluxes and sources are not stored on an external file. = 1 - first fluxes and next sources are stored on the external file with data set reference number 21. = 2 - only fluxes are stored on the external file with data set reference number 21.
		MAXO	Maximum number of outer iterations,
		MAXI	Maximum number of inner iterations, $1 \leq MAXI \leq 8$.
		MINI	Minimum number of inner iterations, $1 \leq MINI \leq 8$.

Note: If MAXI = MINI = 1 the values of MAXI and MINI are recalculated by the programme with the assumption that MAXI = MINI. If MAXI = 1 and MINI > 1 the programme runs with the values of MAXI = MINI = 1. If MAXI = MINI > 1, the number of inner iterations equal to MAXI is performed in all outer iterations.
For MAXI > MINI, the following strategy is used: In the first MAXI - MINI outer iterations the number of inner iterations (fixed for all energy groups) is decreased by one from outer to outer iteration starting with MAXI. This is continued until the number of inner iterations reaches the value of MINI; then this number of inner iterations is fixed for the remaining outer iterations.

OMB — Relaxation factor Ω_β (see explanations given below for NOMEGA).

OMF — Relaxation factor Ω_ϕ (see explanations given below for NOMEGA).

EPS — Point convergence criterion for neutron flux (see Eq. (43)).

EPL — Convergence criterion for k_{eff} (see Eq. (42)).

NOMEGA	= 0 -	values of Ω_β and Ω_ϕ specified in the input are used in the iteration process.
	= 2 -	values of Ω_β and Ω_ϕ are calculated by programme for the iteration process independent of their values specified in the input.
NCON	= 0 -	fluxes and sources are printed without starting a new problem.
	= 1 -	fluxes and sources are printed and then reading of a new problem is started.
	= 2 -	printing of fluxes and sources is omitted in the output, but a new problem is started.
OMS		Relaxation factor ω_s for the acceleration of the convergence rate of sources, $1 \leq \omega_s < 2$. It is recommended to use $\omega_s = 1.5$ for all cases.

V. OUTPUT DESCRIPTION

The output of HEXAGA-II (for a printer with 132 characters per line) begins with the title information and the list of parameters describing a given reactor problem. Next, the picture of the reactor in the form of a parallelogram area is printed. The corners of hexagons are marked by stars and numbers printed inside each hexagon describe the type of material composition. Each type of material composition is specified for each type of hexagon behind the picture of the reactor. A table of group constants for all material compositions is included. If logarithmic boundary conditions are used, the values of the parameters α for all mesh points in each energy group are printed.

If optimum relaxation factors are estimated by the programme, the following information is printed: The preliminary estimate of the energy group in which the spectral radius reaches a maximum, the calculation of this spectral radius performed by the power method, and the values of Ω_β (OMEGAB) and Ω_ϕ (OMEGAF) evaluated by means of the empirical formula given in Chapter III.

During the iteration process, the values of relaxation factors Ω_β and Ω_ϕ, the eigenvalue k_{eff} and its relative error, and the maximum relative error of the neutron flux in inner iterations are printed for each outer iteration. The printing of neutron fluxes and sources is the last optional output information.

The sample problems presented in this report provide an illustration of the output form.

VI. PROGRAMMING INFORMATION

1. Description of the HEXAGA-II Programme

HEXAGA-II consists of six main subroutines

INPUT
MATREL
REORD
EIGEN
ITERAT
ADITER

wich are called by the main programme in the above sequence.

INPUT provides the description of problem to be solved and prints the distribution of material compositions in the parallelogram area represented by a hexagonal mesh.

In MATREL, coefficients of Eq. (3 and 35) are calculated, that is, the coefficients of difference equations, coefficients used with the calculation of scattering and fission terms, and coefficients of recursive formulae used in the two-sweep equations (35).

REORD reorders all records on external files in a sequence suitable for the iteration processes executed in EIGEN, ITERAT and ADITER.

EIGEN provides the estimate of the relaxation parameter based on the empirical formula (45) with the calculation of the spectral radius $\rho(\mathcal{H})$ by means of the power method.

In ITERAT, the real system of difference equations is solved by means of the AGA Double SOR two-sweep iteration method.

In ADITER, the adjoint system of difference equations is solved also by means of the AGA Double SOR two-sweep iteration method.

HEXAGA-II uses eight external files with dataset reference numbers 12, 13, 14, 15, 16, 17, 18 and 20 for real flux calculations and two auxiliary files 22 and 23 for adjoint flux calculations. In the case of storage of neutron fluxes and fission sources and/or adjoint fluxes, file 21 is used.

The above files used in ITERAT or ADITER serve as stores of the following data:

File 12 - coefficients used in the recurrence formulae of the AGA method (Eqs. (35)).

File 13 - coefficients used with the calculation of scattering terms and fission sources (vector c in Eq. 8).

File 14 - components of β (for former or current outer iteration).

File 15 - components of ϕ (for former or current outer iteration).

File 16 - components of β (for current or former outer iteration).

File 17 - components of ϕ (for current or former outer iteration).

File 18 - fission sources (for former or current outer iteration).

File 20 - fission sources (for current or former outer iteration).

Files 14, 16, 15, 17 and 18, 20 are used in the flip-flop form. In the case of adjoint calculations, the data stored on files 12 and 13 are reordered and restored on files 22 and 23, respectively.

2. Memory Requirements

HEXAGA-II is a module of the INR programme library NUSYS at the computer center of GfK, Karlsruhe. With a (mild) overlay structure, this module takes 60 K bytes of fast memory. Up to now it has been impossible to translate the source deck of HEXAGA-II with the FORTRAN IV H-Ext. Compiler (of the IBM/360-system) into a correctly working load module. So the above value corresponds to the version translated with the FORTRAN IV G1 Compiler. Without overlay the module occupies 90 K bytes of core region.

For any special case considered one has to take into account further storage requirements for

(a) dynamic storage: 36 time the number of mesh points in bytes,

(b) buffers: 16 buffers for real flux calculations,
20 buffers for adjoint flux calculations
2 additional buffers, if fluxes and/or sources have to be stored.
The sizes of the buffers depend (for the IBM/360 and IBM/370

systems, respectively) on the DCB subparameter BLKSIZE on the DD-(Data-Definition) cards for each file /7/ (see also sample problems).

3. External File Space Requirements

For data storage a space has to be reserved on particular external files. This space can be calculated for each file as follows:

File 12: $S_{12} = (24\times NOG+1)\times(M\times N+1)$

File 13: $S_{13} = 8\times NOG\times(M\times N+1) + 2\times MDS\times(2\times NOG-MDS-1)\times(M\times N+2\times M) + 2\times NOTHG\times(NOTHG-1)\times(M\times N+2\times M)$

File 14: $S_{14} = \max\{8\times NOG\times(M\times N+1);\ 2\times MDS\times(2\times NOG-MDS-1)\times(M\times N+2\times M)\}$

File 15: $S_{15} = \max\{8\times NOG\times(M\times N+1);\ 2\times NOTHG\times(NOTHG-1)\times(M\times N+2\times M)\}$

File 16: $S_{16} = \max\{4\times NOG\times(M\times M+1);\ 2\times MDS\times(2\times NOG-MDS-1)\times(M\times N+2\times M);\ 2\times NOTHG\times(NOTHG-1)\times(M\times N+2\times M)\}$

File 17: $S_{17} = S_{16}$

File 18: $S_{18} = 4\times(M\times N+1)$

File 20: $S_{20} = S_{18}$

File 21: $S_{21} = 4\times(2\times NOG+1)\times(M\times N+1)$

File 22: $S_{22} = S_{12}$

File 23: $S_{23} = S_{13}$

The values of S are expressed in bytes and M, N, NOG, MDS and NOTHG denote the number of mesh points in the x direction, the number of mesh points in the y direction (see Fig. 1), the number of energy groups, the maximum number of energy groups throughout which neutrons are downscattered and the number of thermal groups, respectively.

VII. NUMERICAL EXAMPLES

HEXAGA-II is illustrated by two four-group sample problems, B1 and B2, both based on a fast reactor problem similar to the prototype breeder reactor SNR-300.

Both sample problems represent the same physical configuration of the reactor and have the same group constants; they differ only in the step-size of the discretization mesh. The area of solution is restricted to one third of the reactor with the following boundary conditions: on the left and top boundaries the current is equal to zero, and on the right and bottom boundaries the logarithmic derivative boundary condition is taken.

In the sample problem B1 with the triangular mesh the step width equals 6.4665 cm, all hexagons are uniform and the total number of mesh points amounts to 324. In the sample problem B2 the mesh step corresponds to the mesh step of B1 divided by the factor of 2. This twofold decrease of the mesh step results in 1225 mesh points and the simultaneous appearance of some number of non-uniform hexagons in the mesh of B2.

Both sample problems are illustrated by job cards, external file specifications, input data sheets and the printout of the output.

1. Sample Problem B1

Real and adjoint flux calculations with the full printout of results. One inner iteration per outer iteration is assumed. In the case of using IBM/370-168 computer the following data were obtained:

CPU time: 42.4 sec
Total costs: 30.98 DM

DATENKARTEN

Programm HEXAGA-II SAMPLE PROBLEM B1 Datum ______ Name ___________ Blatt-Nr. _____

```
//        JØB CARD
// REGIØN=300K,TIME=2
/*FØRMAT PR,DDNAME=FT06F001,ØVFL=ØN
// EXEC FGG,LIB=NUSYS,NAME=HEXAGA
//SYSIN DD *
//G.FT12F001 DD UNIT=SYSDA,SPACE=(7294,5),DCB=(BLKSIZE=7294,RECFM=VBS)
//G.FT13F001 DD UNIT=SYSDA,SPACE=(7294,3),DCB=*.FT12F001
//G.FT14F001 DD UNIT=SYSDA,SPACE=(7294,2),DCB=*.FT12F001
//G.FT15F001 DD UNIT=SYSDA,SPACE=(7294,2),DCB=*.FT12F001
//G.FT16F001 DD UNIT=SYSDA,SPACE=(7294,2),DCB=*.FT12F001
//G.FT17F001 DD UNIT=SYSDA,SPACE=(7294,2),DCB=*.FT12F001
//G.FT18F001 DD UNIT=SYSDA,SPACE=(7294,1),DCB=*.FT12F001
//G.FT20F001 DD UNIT=SYSDA,SPACE=(7294,1),DCB=*.FT12F001
//G.FT21F001 DD UNIT=SYSDA,SPACE=(7294,5),DCB=*.FT12F001
//G.FT22F001 DD UNIT=SYSDA,SPACE=(7294,3),DCB=*.FT12F001
//G.SYSIN DD *
```

DATENKARTEN

Programm HEXAGA-II SAMPLE PROBLEM B1 Datum ______ Name ____________ Blatt-Nr. 1

INPUT DATA

```
1/
          SAMPLE PROBLEM B1
2/
   1  18  18   4   3   1   5   3   0   5   5   1   1   2   2   1    6.46650
3/1'/
   1   1   1   2   2   3
   1   1   1   2   3   3
   1   1   1   4   2   3
   1   1   5   1   2   3
   1   1   1   2   3   3
   1   1   1   2   2   3
   1   5   1   1   2   3
   1   1   1   2   3   3
   1   1   1   4   2   3
   2   1   1   2   2   3
   4   2   4   2   3   3
```

DATENKARTEN

Programm ________ Datum ________ Name ________ Blatt-Nr. 2

```
   2    2   2    2    2    3
   2    2   2    2    2    3
   2    2   2    2    3    3
   3    3   3    3    3    3
   3    3   3    3    3    3
   3    3   3    3    3    3
   3    3   3    3    3    3
4/
   1    1
  .287629E+01 .157085E+01 .722486E+00 .964199E+00
  .282040E-01 .527470E-02 .176120E-01 .265460E-01
  .118780E-01 .532520E-02 .104710E-01 .266110E-01
  .768000E+00 .232000E+00 0.          0.
  .235970E-01 .407910E-05 .444930E-07
  .161530E-02 .423090E-07
  .468380E-02
```

DATENKARTEN

Programm ______________ Datum ______ Name ____________ Blatt-Nr. 3

```
  1    2
.287654E+01 .157136E+01 .712708E+00 .942978E+00
.287820E-01 .604910E-02 .195100E-01 .337140E-01
.149430E-01 .768870E-02 .148090E-01 .381590E-01
.768000E+00 .232000E+00 0.          0.
.232620E-01 .464510E-05 .499680E-07
.157180E-02 .407240E-07
.434140E-02
  1    3
.228561E+01 .117193E+01 .632475E+00 .818357E+00
.359590E-01 .588550E-02 .160410E-01 .133490E-01
.774270E-02 .108250E-03 .297420E-03 .846870E-03
.768000E+00 .232000E+00 0.          0.
.320710E-01 .388800E-05 .450390E-07
.277760E-02 .900180E-07
.589710E-02
```

DATENKARTEN

Programm ______ Datum ______ Name ______ Blatt-Nr. 4

1 4			
.250307E+01	.131468E+01	.574277E+00	.615369E+00
.248140E-01	.164120E-01	.721220E-01	.168680E-00
.229460E-01	.103200E-05	.104890E-07	
.376870E-02	.703610E-11		
.868150E-02			
1 5			
.461642E+01	.290183E+01	.102118E+01	.172963E+01
.131590E-01	.145590E-02	.460010E-02	.786600E-03
.129420E-01	.687800E-06	.699030E-08	
.128710E-02	.436330E-11		
.345330E-02			
5/			
.46948E+00			
.46948E+00			
.46948E+00			

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DATENKARTEN

Programm ______ Datum ______ Name ______ Blatt-Nr. 5

```
         10        20        30        40        50        60        70        80
.46948E+00
.46948E+00
.46948E+00
.46948E+00
.46948E+00
6/
   0 100    1    1  1.0000    1.0000   1.0E-05   1.0E-06    2    0  1.0000
```

H E X A G A - II   WRITTEN BY ZBIGNIEW WOZNICKI,   FEB. 1975

SAMPLE PROBLEM B1

1 TYPE OF HEXAGONAL MESH ARRANGEMENT

324 MESH POINTS

4 NEUTRON GR.

1 THERMAL GR.

3 NEUTRON GR. THROUGHOUT WHICH NEUTRONS ARE DOWN-SCATTERED

5 MATERIAL COMP.

3 FISSIONABLE COMP.

6.4665 CM - MESH STEP

```
OUTER BOUNDARY COND:  LEFT   - FLUX DERIVATIVE EQUAL TO ZERO
                      TOP    - FLUX DERIVATIVE EQUAL TO ZERO
                      RIGHT  - LOGARITHMIC
                      BOTTOM - LOGARITHMIC
```

THE LOCATION OF HEXAGONS

```
                     1   3   5   7   9  11  13  15  17
                     / / / / / / / / / / / / / / / / / /

                1-   1 * * 1 * * 1 * * 2 * * 2 * * 3 * *
                 -  * * 1 * * 1 * * 1 * * 2 * * 3 * * 3
              3-   * 1 * * 1 * * 1 * * 4 * * 2 * * 3 *
               -  1 * * 1 * * 5 * * 1 * * 2 * * 3 * *
            5-   * * 1 * * 1 * * 1 * * 2 * * 3 * * 3
             -  * 1 * * 1 * * 1 * * 2 * * 2 * * 3 *
          7-   1 * * 5 * * 1 * * 1 * * 2 * * 3 * *
           -  * * 1 * * 1 * * 1 * * 2 * * 3 * * 3
        9-   * 1 * * 1 * * 1 * * 4 * * 2 * * 3 *
         -  2 * * 1 * * 1 * * 2 * * 2 * * 3 * *
     11-   * * 4 * * 2 * * 4 * * 2 * * 3 * * 3
       -  * 2 * * 2 * * 2 * * 2 * * 2 * * 3 *
   13-   2 * * 2 * * 2 * * 2 * * 2 * * 3 * *
     -  * * 2 * * 2 * * 2 * * 2 * * 3 * * 3
 15-   * 3 * * 3 * * 3 * * 3 * * 3 * * 3 *
   -  3 * * 3 * * 3 * * 3 * * 3 * * 3 * *
17-  * * 3 * * 3 * * 3 * * 3 * * 3 * * 3
 -  * 3 * * 3 * * 3 * * 3 * * 3 * * 3 *
```

THE MATERIAL SPECIFICATION OF HEXAGONS

```
       * * * * * * * *
      * *           * *
     *   *    T6   *   *
    *     *       *     *
   *       *     *       *
  *    T5   *   *   T1    *
 *           * *           *
* * * * * * *HNR* * * * * * *
 *           * *           *
  *    T4   *   *   T2    *
   *       *     *       *
    *     *       *     *
     *   *    T3   *   *
      * *           * *
       * * * * * * * *
```

HNR	T1	T2	T3	T4	T5	T6
1	1	1	1	1	1	1
2	2	2	2	2	2	2
3	3	3	3	3	3	3
4	4	4	4	4	4	4
5	5	5	5	5	5	5

MATERIAL SPECIFICATION

COMP	GR NR	DIF	SIGT	NUSIGF	CHI
1	G				
	1	2.87679E+00	2.82040E-02	1.18780E-02	7.68000E-01
	2	1.57085E+00	5.27470E-03	5.32520E-03	2.32000E-01
	3	7.22486E-01	1.76120E-02	1.04710E-02	0.0
	4	9.64199E-01	2.65460E-02	2.66110E-02	0.0

SIGDS

G	G-->G+1	G-->G+2	G-->G+3
1	2.35970E-02	4.07910E-06	4.44930E-08
2	1.61530E-03	4.23090E-08	
3	4.68380E-03		

COMP	GR NR	DIF	SIGT	NUSIGF	CHI
2	G				
	1	2.87654E+00	2.87820E-02	1.49430E-02	7.68000E-01
	2	1.57136E+00	6.04910E-03	7.68870E-03	2.32000E-01
	3	7.12708E-01	1.95100E-02	1.48090E-02	0.0
	4	9.42978E-01	3.37140E-02	3.81590E-02	0.0

SIGDS

G	G-->G+1	G-->G+2	G-->G+3
1	2.32620E-02	4.64510E-06	4.99680E-08
2	1.57180E-03	4.07240E-08	
3	4.34140E-03		

COMP	GR NR	DIF	SIGT	NUSIGF	CHI
3	G				
	1	2.28561E+00	3.59590E-02	7.74270E-03	7.68000E-01
	2	1.17193E+00	5.88550E-03	1.08250E-04	2.32000E-01
	3	6.32475E-01	1.60410E-02	2.97420E-04	0.0
	4	8.18357E-01	1.33490E-02	8.46870E-04	0.0

SIGDS

G	G-->G+1	G-->G+2	G-->G+3
1	3.20710E-02	3.88800E-06	4.50390E-08
2	2.77760E-03	9.00180E-08	
3	5.89710E-03		

COMP	GR NR	DIF	SIGT	NUSIGF	CHI
4	G				
	1	2.50307E+00	2.48140E-02	0.0	0.0
	2	1.31468E+00	1.64120E-02	0.0	0.0
	3	5.74277E-01	7.21220E-02	0.0	0.0
	4	6.15369E-01	1.68680E-01	0.0	0.0

SIGDS

G	G-->G+1	G-->G+2	G-->G+3
1	2.29460E-02	1.03200E-06	1.04890E-08
2	3.76870E-03	7.03610E-12	
3	8.68150E-03		

COMP	GR NR	DIF	SIGT	NUSIGF	CHI
5	G				
	1	4.61642E+00	1.31590E-02	0.0	0.0
	2	2.90183E+00	1.45590E-03	0.0	0.0
	3	1.02118E+00	4.60010E-03	0.0	0.0
	4	1.72963E+00	7.86600E-04	0.0	0.0

SIGDS

G	G-->G+1	G-->G+2	G-->G+3
1	1.29420E-02	6.87800E-07	6.99030E-09
2	1.28710E-03	4.36330E-12	
3	3.45330E-03		

LOGARITHMIC BOUNDARY CONDITION PARAMETERS

GR NR	PT NR	LEFT	TOP	RIGHT	BOTTOM
1					
	1			4.6948E-01	4.6948E-01
	2			4.6948E-01	4.6948E-01
	3			4.6948E-01	4.6948E-01
	4			4.6948E-01	4.6948E-01
	5			4.6948E-01	4.6948E-01
	6			4.6948E-01	4.6948E-01
	7			4.6948E-01	4.6948E-01
	8			4.6948E-01	4.6948E-01
	9			4.6948E-01	4.6948E-01
	10			4.6948E-01	4.6948E-01
	11			4.6948E-01	4.6948E-01
	12			4.6948E-01	4.6948E-01
	13			4.6948E-01	4.6948E-01
	14			4.6948E-01	4.6948E-01
	15			4.6948E-01	4.6948E-01
	16			4.6948E-01	4.6948E-01
	17			4.6948E-01	4.6948E-01
	18			4.6948E-01	4.6948E-01
2					
	1			4.6948E-01	4.6948E-01
	2			4.6948E-01	4.6948E-01
	3			4.6948E-01	4.6948E-01
	4			4.6948E-01	4.6948E-01
	5			4.6948E-01	4.6948E-01
	6			4.6948E-01	4.6948E-01
	7			4.6948E-01	4.6948E-01
	8			4.6948E-01	4.6948E-01
	9			4.6948E-01	4.6948E-01
	10			4.6948E-01	4.6948E-01
	11			4.6948E-01	4.6948E-01
	12			4.6948E-01	4.6948E-01
	13			4.6948E-01	4.6948E-01
	14			4.6948E-01	4.6948E-01
	15			4.6948E-01	4.6948E-01
	16			4.6948E-01	4.6948E-01
	17			4.6948E-01	4.6948E-01
	18			4.6948E-01	4.6948E-01
3					
	1			4.6948E-01	4.6948E-01
	2			4.6948E-01	4.6948E-01
	3			4.6948E-01	4.6948E-01
	4			4.6948E-01	4.6948E-01
	5			4.6948E-01	4.6948E-01
	6			4.6948E-01	4.6948E-01
	7			4.6948E-01	4.6948E-01
	8			4.6948E-01	4.6948E-01
	9			4.6948E-01	4.6948E-01
	10			4.6948E-01	4.6948E-01
	11			4.6948E-01	4.6948E-01
	12			4.6948E-01	4.6948E-01
	13			4.6948E-01	4.6948E-01
	14			4.6948E-01	4.6948E-01
	15			4.6948E-01	4.6948E-01
	16			4.6948E-01	4.6948E-01
	17			4.6948E-01	4.6948E-01
	18			4.6948E-01	4.6948E-01

4

1	4.6948E-01	4.6948E-01
2	4.6948E-01	4.6948E-01
3	4.6948E-01	4.6948E-01
4	4.6948E-01	4.6948E-01
5	4.6948E-01	4.6948E-01
6	4.6948E-01	4.6948E-01
7	4.6948E-01	4.6948E-01
8	4.6948E-01	4.6948E-01
9	4.6948E-01	4.6948E-01
10	4.6948E-01	4.6948E-01
11	4.6948E-01	4.6948E-01
12	4.6948E-01	4.6948E-01
13	4.6948E-01	4.6948E-01
14	4.6948E-01	4.6948E-01
15	4.6948E-01	4.6948E-01
16	4.6948E-01	4.6948E-01
17	4.6948E-01	4.6948E-01
18	4.6948E-01	4.6948E-01

THE ESTIMATION OF OPTIMUM OMEGA

NG	NORM
1	0.374871
2	0.589447
3	0.165770
4	0.166291

NG	IT	NI	ER	ER/ER
2	1	0.589447	0.967253	0.967253
2	2	0.645163	-0.094522	-0.097722
2	3	0.663563	-0.028520	0.301726
2	4	0.673531	-0.015021	0.526701
2	5	0.679565	-0.008959	0.596407
2	6	0.683284	-0.005472	0.610815
2	7	0.685576	-0.003354	0.612931
2	8	0.686981	-0.002048	0.610748
2	9	0.687834	-0.001240	0.605214
2	10	0.688350	-0.000751	0.605385
2	11	0.688659	-0.000447	0.595934
2	12	0.688841	-0.000264	0.590618
2	13	0.688949	-0.000155	0.588448
2	14	0.689010	-0.000089	0.570552

OMEGAB=1.1236   OMEGAF=1.1236

ITERATION PROCESS

FLUX CONV IN
INNER ITERS --> 1

IT NR	OMEGAB	OMEGAF	K-EFF	K-EFF CONV.	GR NR	
1	1.1236	1.1236	0.810501	5.1775E+02	1	1.00E+00
					2	1.00E+00
					3	1.00E+00
					4	1.00E+00
2	1.1236	1.1236	1.089722	2.5623E-01	1	3.84E+00
					2	5.04E-01
					3	6.27E-01
					4	9.67E-01
3	1.1236	1.1236	1.098463	7.9579E-03	1	5.58E-01
					2	2.67E-01
					3	3.59E-01
					4	5.34E-01
4	1.1236	1.1236	1.088725	8.9436E-03	1	3.11E-01
					2	1.98E-01
					3	2.74E-01
					4	3.41E-01
5	1.1236	1.1236	1.096784	7.3475E-03	1	1.29E-01
					2	1.28E-01
					3	7.06E-02
					4	6.01E-02
6	1.1236	1.1236	1.107114	9.3307E-03	1	5.99E-02
					2	5.54E-02
					3	3.99E-02
					4	3.27E-02
7	1.1236	1.1236	1.114005	6.1861E-03	1	3.45E-02
					2	2.86E-02
					3	2.25E-02
					4	1.75E-02
8	1.1236	1.1236	1.117773	3.3710E-03	1	1.93E-02
					2	1.53E-02
					3	1.12E-02
					4	8.79E-03
9	1.1236	1.1236	1.119725	1.7435E-03	1	1.09E-02
					2	7.91E-03
					3	5.83E-03
					4	4.47E-03
10	1.1236	1.1236	1.120701	8.7059E-04	1	5.28E-03
					2	4.04E-03
					3	2.91E-03
					4	2.50E-03
11	1.1236	1.1236	1.121181	4.2790E-04	1	2.96E-03
					2	2.05E-03
					3	1.50E-03
					4	1.14E-03
12	1.1236	1.1236	1.121419	2.1261E-04	1	1.48E-03
					2	1.06E-03
					3	7.64E-04

					4	5.54E-04
13	1.1236	1.1236	1.121544	1.1140E-04	1	7.45E-04
					2	5.34E-04
					3	3.87E-04
					4	2.91E-04
14	1.1236	1.1236	1.121609	5.7876E-05	1	3.78E-04
					2	2.74E-04
					3	1.99E-04
					4	1.44E-04
15	1.1236	1.1236	1.121638	2.6405E-05	1	1.89E-04
					2	1.36E-04
					3	9.73E-05
					4	7.06E-05
16	1.1236	1.1236	1.121654	1.3649E-05	1	9.35E-05
					2	7.10E-05
					3	5.17E-05
					4	3.96E-05
17	1.1236	1.1236	1.121664	9.3579E-06	1	4.58E-05
					2	3.56E-05
					3	2.63E-05
					4	2.10E-05
18	1.1236	1.1236	1.121667	2.5630E-06	1	2.38E-05
					2	1.76E-05
					3	1.24E-05
					4	1.05E-05
19	1.1236	1.1236	1.121671	3.4571E-06	1	1.14E-05
					2	9.89E-06
					3	7.57E-06
					4	7.93E-06
20	1.1236	1.1236	1.121671	0.0	1	7.63E-06
					2	5.72E-06
					3	4.77E-06
					4	5.72E-06

1 FLUX GROUP

	1	2	3	4	5	6	7	8	9	10
1	6.0389E-03	5.9802E-03	5.8052E-03	5.5235E-03	5.1729E-03	4.7955E-03	4.3816E-03	3.9027E-03	3.4129E-03	2.9999E-03
2	5.9802E-03	5.9802E-03	5.8622E-03	5.6242E-03	5.2775E-03	4.9030E-03	4.5417E-03	4.1198E-03	3.5986E-03	3.0240E-03
3	5.8052E-03	5.8622E-03	5.8052E-03	5.6242E-03	5.2906E-03	4.7717E-03	4.4820E-03	4.2475E-03	3.8134E-03	3.1849E-03
4	5.5235E-03	5.6242E-03	5.6242E-03	5.5235E-03	5.2775E-03	4.7717E-03	4.3663E-03	4.2354E-03	3.9897E-03	3.5568E-03
5	5.1729E-03	5.2775E-03	5.2906E-03	5.2775E-03	5.1730E-03	4.9030E-03	4.4820E-03	4.2354E-03	4.0517E-03	3.8064E-03
6	4.7955E-03	4.9030E-03	4.7717E-03	4.7717E-03	4.9030E-03	4.7955E-03	4.5417E-03	4.2475E-03	3.9897E-03	3.8064E-03
7	4.3816E-03	4.5417E-03	4.4820E-03	4.3663E-03	4.4820E-03	4.5417E-03	4.3816E-03	4.1199E-03	3.8134E-03	3.5568E-03
8	3.9027E-03	4.1199E-03	4.2475E-03	4.2354E-03	4.2354E-03	4.2475E-03	4.1199E-03	3.9027E-03	3.5986E-03	3.1849E-03
9	3.4129E-03	3.5986E-03	3.8134E-03	3.9897E-03	4.0517E-03	3.9897E-03	3.8134E-03	3.5986E-03	3.4129E-03	3.0240E-03
10	2.9999E-03	3.0240E-03	3.1849E-03	3.5568E-03	3.8064E-03	3.8064E-03	3.5568E-03	3.1849E-03	3.0240E-03	2.9999E-03
11	2.6448E-03	2.6463E-03	2.5418E-03	3.0045E-03	3.4400E-03	3.6054E-03	3.4400E-03	3.0045E-03	2.5418E-03	2.6463E-03
12	2.2679E-03	2.4164E-03	2.3936E-03	2.5779E-03	2.9805E-03	3.1949E-03	3.1949E-03	2.9805E-03	2.5779E-03	2.3936E-03
13	1.7338E-03	1.9836E-03	2.1191E-03	2.2431E-03	2.4511E-03	2.6368E-03	2.6981E-03	2.6368E-03	2.4511E-03	2.2431E-03
14	1.0224E-03	1.3551E-03	1.5801E-03	1.6503E-03	1.7841E-03	1.9672E-03	1.9775E-03	1.9775E-03	1.9672E-03	1.7841E-03
15	4.5877E-04	6.5171E-04	9.0733E-04	1.0053E-03	9.8341E-04	1.1755E-03	1.2258E-03	1.1198E-03	1.2258E-03	1.1755E-03
16	2.0518E-04	2.9707E-04	4.0202E-04	4.8596E-04	5.2392E-04	5.6770E-04	6.1450E-04	6.1528E-04	6.1528E-04	6.1450E-04
17	8.5646E-05	1.2853E-04	1.7582E-04	2.2029E-04	2.5213E-04	2.7493E-04	2.9564E-04	3.0739E-04	3.0939E-04	3.0739E-04
18	2.8717E-05	4.5696E-05	6.4646E-05	8.3772E-05	9.9835E-05	1.1162E-04	1.2086E-04	1.2761E-04	1.3061E-04	1.3061E-04

	11	12	13	14	15	16	17	18
1	2.6448E-03	2.2679E-03	1.7338E-03	1.0224E-03	4.5876E-04	2.0518E-04	8.5646E-05	2.8717E-05
2	2.6463E-03	2.4164E-03	1.9836E-03	1.3551E-03	6.5171E-04	2.9707E-04	1.2852E-04	4.5695E-05
3	2.5418E-03	2.3936E-03	2.1191E-03	1.5801E-03	9.0733E-04	4.0201E-04	1.7582E-04	6.4646E-05
4	3.0045E-03	2.5779E-03	2.2431E-03	1.6503E-03	1.0053E-03	4.8596E-04	2.2029E-04	8.3772E-05
5	3.4400E-03	2.9805E-03	2.4511E-03	1.7841E-03	9.8341E-04	5.2391E-04	2.5213E-04	9.9835E-05
6	3.6054E-03	3.1949E-03	2.6368E-03	1.9672E-03	1.1755E-03	5.6770E-04	2.7493E-04	1.1162E-04
7	3.4400E-03	3.1949E-03	2.6981E-03	1.9775E-03	1.2258E-03	6.1450E-04	2.9564E-04	1.2086E-04
8	3.0045E-03	2.9805E-03	2.6368E-03	1.9775E-03	1.1198E-03	6.1528E-04	3.0739E-04	1.2761E-04
9	2.5418E-03	2.5779E-03	2.4511E-03	1.9672E-03	1.2258E-03	6.1528E-04	3.0939E-04	1.3061E-04
10	2.6463E-03	2.3936E-03	2.2431E-03	1.7841E-03	1.1755E-03	6.1450E-04	3.0739E-04	1.3061E-04
11	2.6448E-03	2.4164E-03	2.1191E-03	1.6503E-03	9.8341E-04	5.6770E-04	2.9564E-04	1.2761E-04
12	2.4164E-03	2.2679E-03	1.9836E-03	1.5801E-03	1.0053E-03	5.2392E-04	2.7493E-04	1.2086E-04
13	2.1191E-03	1.9836E-03	1.7338E-03	1.3551E-03	9.0733E-04	4.8596E-04	2.5213E-04	1.1162E-04
14	1.6503E-03	1.5801E-03	1.3551E-03	1.0224E-03	6.5171E-04	4.0201E-04	2.2029E-04	9.9834E-05
15	9.8341E-04	1.0053E-03	9.0733E-04	6.5171E-04	4.5877E-04	2.9707E-04	1.7582E-04	8.3772E-05
16	5.6770E-04	5.2392E-04	4.8596E-04	4.0202E-04	2.9707E-04	2.0518E-04	1.2852E-04	6.4646E-05
17	2.9564E-04	2.7493E-04	2.5213E-04	2.2029E-04	1.7582E-04	1.2852E-04	8.5646E-05	4.5695E-05
18	1.2761E-04	1.2086E-04	1.1162E-04	9.9835E-05	8.3772E-05	6.4646E-05	4.5695E-05	2.8717E-05

2 FLUX GROUP

	1	2	3	4	5	6	7	8	9	10
1	3.0079E-02	2.9811E-02	2.9021E-02	2.7757E-02	2.6130E-02	2.4210E-02	2.1917E-02	1.9179E-02	1.6113E-02	1.3327E-02
2	2.9811E-02	2.9811E-02	2.9280E-02	2.8235E-02	2.6742E-02	2.5001E-02	2.2987E-02	2.0493E-02	1.7496E-02	1.4096E-02
3	2.9021E-02	2.9280E-02	2.9021E-02	2.8235E-02	2.6907E-02	2.5076E-02	2.3633E-02	2.1511E-02	1.8771E-02	1.5317E-02
4	2.7757E-02	2.8235E-02	2.8235E-02	2.7757E-02	2.6742E-02	2.5076E-02	2.3754E-02	2.2314E-02	1.9782E-02	1.6989E-02
5	2.6130E-02	2.6742E-02	2.6907E-02	2.6742E-02	2.6130E-02	2.5001E-02	2.3633E-02	2.2314E-02	2.0168E-02	1.7864E-02
6	2.4210E-02	2.5001E-02	2.5076E-02	2.5076E-02	2.5001E-02	2.4210E-02	2.2987E-02	2.1511E-02	1.9782E-02	1.7864E-02
7	2.1917E-02	2.2987E-02	2.3633E-02	2.3754E-02	2.3633E-02	2.2987E-02	2.1917E-02	2.0493E-02	1.8771E-02	1.6990E-02
8	1.9179E-02	2.0493E-02	2.1511E-02	2.2314E-02	2.2314E-02	2.1511E-02	2.0493E-02	1.9179E-02	1.7496E-02	1.5317E-02
9	1.6113E-02	1.7496E-02	1.8771E-02	1.9782E-02	2.0168E-02	1.9782E-02	1.8771E-02	1.7496E-02	1.6113E-02	1.4096E-02
10	1.3327E-02	1.4096E-02	1.5317E-02	1.6990E-02	1.7864E-02	1.7864E-02	1.6990E-02	1.5317E-02	1.4096E-02	1.3327E-02
11	1.1347E-02	1.1684E-02	1.1735E-02	1.3782E-02	1.5382E-02	1.5858E-02	1.5382E-02	1.3782E-02	1.1735E-02	1.1684E-02
12	9.7350E-03	1.0377E-02	1.0525E-02	1.1413E-02	1.2949E-02	1.3737E-02	1.3737E-02	1.2949E-02	1.1413E-02	1.0525E-02
13	7.9701E-03	8.7797E-03	9.3697E-03	9.9988E-03	1.0827E-02	1.1558E-02	1.1838E-02	1.1558E-02	1.0827E-02	9.9988E-03
14	6.0381E-03	6.9802E-03	7.5984E-03	8.2514E-03	8.8932E-03	9.3515E-03	9.7706E-03	9.7706E-03	9.3515E-03	8.8932E-03
15	3.8211E-03	4.7348E-03	5.6260E-03	6.1486E-03	6.4982E-03	7.1106E-03	7.3925E-03	7.3218E-03	7.3925E-03	7.1106E-03
16	2.1461E-03	2.8210E-03	3.4300E-03	3.9183E-03	4.2651E-03	4.5824E-03	4.8438E-03	4.9393E-03	4.9393E-03	4.8438E-03
17	9.4707E-04	1.3841E-03	1.7568E-03	2.0720E-03	2.3189E-03	2.5144E-03	2.6736E-03	2.7728E-03	2.8026E-03	2.7728E-03
18	2.0014E-04	3.5488E-04	4.8012E-04	5.8624E-04	6.7310E-04	7.4162E-04	7.9618E-04	8.3565E-04	8.5546E-04	8.5546E-04

	11	12	13	14	15	16	17	18
1	1.1347E-02	9.7350E-03	7.9701E-03	6.0381E-03	3.8211E-03	2.1461E-03	9.4707E-04	2.0014E-04
2	1.1684E-02	1.0377E-02	8.7797E-03	6.9802E-03	4.7348E-03	2.8210E-03	1.3841E-03	3.5488E-04
3	1.1735E-02	1.0525E-02	9.3697E-03	7.5984E-03	5.6259E-03	3.4300E-03	1.7568E-03	4.8011E-04
4	1.3782E-02	1.1413E-02	9.9988E-03	8.2514E-03	6.1486E-03	3.9183E-03	2.0720E-03	5.8624E-04
5	1.5382E-02	1.2949E-02	1.0827E-02	8.8932E-03	6.4982E-03	4.2651E-03	2.3189E-03	6.7310E-04
6	1.5858E-02	1.3737E-02	1.1558E-02	9.3515E-03	7.1106E-03	4.5824E-03	2.5144E-03	7.4162E-04
7	1.5382E-02	1.3737E-02	1.1838E-02	9.7706E-03	7.3925E-03	4.8438E-03	2.6736E-03	7.9618E-04
8	1.3782E-02	1.2949E-02	1.1558E-02	9.7706E-03	7.3217E-03	4.9393E-03	2.7728E-03	8.3564E-04
9	1.1735E-02	1.1413E-02	1.0827E-02	9.3515E-03	7.3925E-03	4.9393E-03	2.8026E-03	8.5546E-04
10	1.1684E-02	1.0525E-02	9.9938E-03	8.8932E-03	7.1106E-03	4.8438E-03	2.7728E-03	8.5546E-04
11	1.1347E-02	1.0377E-02	9.3697E-03	8.2514E-03	6.4982E-03	4.5824E-03	2.6736E-03	8.3564E-04
12	1.0377E-02	9.7350E-03	8.7797E-03	7.5984E-03	6.1486E-03	4.2651E-03	2.5144E-03	7.9618E-04
13	9.3697E-03	8.7797E-03	7.9701E-03	6.9802E-03	5.6260E-03	3.9183E-03	2.3189E-03	7.4162E-04
14	8.2514E-03	7.5984E-03	6.9802E-03	6.0381E-03	4.7348E-03	3.4300E-03	2.0720E-03	6.7310E-04
15	6.4982E-03	6.1486E-03	5.6260E-03	4.7348E-03	3.8211E-03	2.8210E-03	1.7568E-03	5.8624E-04
16	4.5824E-03	4.2651E-03	3.9183E-03	3.4300E-03	2.8210E-03	2.1461E-03	1.3841E-03	4.8011E-04
17	2.6736E-03	2.5144E-03	2.3189E-03	2.0720E-03	1.7568E-03	1.3841E-03	9.4707E-04	3.5488E-04
18	8.2564E-04	7.9618E-04	7.4162E-04	6.7310E-04	5.8624E-04	4.8011E-04	3.5488E-04	2.0014E-04

3 FLUX GROUP

	1	2	3	4	5	6	7	8	9	10
1	2.6806E-03	2.6604E-03	2.6024E-03	2.5129E-03	2.3885E-03	2.2101E-03	1.9674E-03	1.6652E-03	1.3042E-03	9.9360E-04
2	2.6603E-03	2.6603E-03	2.6217E-03	2.5526E-03	2.4647E-03	2.3322E-03	2.1115E-03	1.8194E-03	1.4678E-03	1.0242E-03
3	2.6024E-03	2.6217E-03	2.6024E-03	2.5526E-03	2.5025E-03	2.5160E-03	2.3605E-03	1.9829E-03	1.6286E-03	1.1546E-03
4	2.5129E-03	2.5526E-03	2.5526E-03	2.5129E-03	2.4647E-03	2.5160E-03	2.5556E-03	2.2123E-03	1.7790E-03	1.4242E-03
5	2.3885E-03	2.4647E-03	2.5025E-03	2.4647E-03	2.3885E-03	2.3322E-03	2.3605E-03	2.2123E-03	1.8421E-03	1.5285E-03
6	2.2101E-03	2.3322E-03	2.5160E-03	2.5160E-03	2.3322E-03	2.2101E-03	2.1115E-03	1.9829E-03	1.7790E-03	1.5285E-03
7	1.9674E-03	2.1115E-03	2.3605E-03	2.5556E-03	2.3605E-03	2.1115E-03	1.9674E-03	1.8194E-03	1.6286E-03	1.4242E-03
8	1.6652E-03	1.8194E-03	1.9829E-03	2.2123E-03	2.2123E-03	1.9829E-03	1.8194E-03	1.6652E-03	1.4678E-03	1.1546E-03
9	1.3043E-03	1.4678E-03	1.6286E-03	1.7790E-03	1.8421E-03	1.7790E-03	1.6286E-03	1.4678E-03	1.3042E-03	1.0242E-03
10	9.9360E-04	1.0242E-03	1.1546E-03	1.4242E-03	1.5285E-03	1.5285E-03	1.4242E-03	1.1546E-03	1.0242E-03	9.9359E-04
11	8.4756E-04	8.1134E-04	7.4796E-04	1.0067E-03	1.2414E-03	1.2877E-03	1.2414E-03	1.0067E-03	7.4795E-04	8.1133E-04
12	7.7151E-04	7.9108E-04	7.4033E-04	8.1163E-04	1.0106E-03	1.1013E-03	1.1013E-03	1.0106E-03	8.1163E-04	7.4032E-04
13	7.0777E-04	7.3435E-04	7.6328E-04	8.1079E-04	8.8432E-04	9.6091E-04	9.9517E-04	9.6091E-04	8.8431E-04	8.1079E-04
14	7.0122E-04	7.0862E-04	7.0944E-04	8.0730E-04	8.6602E-04	8.6568E-04	9.5837E-04	9.5837E-04	8.6568E-04	8.6602E-04
15	5.6244E-04	6.4552E-04	6.7561E-04	7.3385E-04	8.3246E-04	8.4046E-04	8.7602E-04	9.3711E-04	8.7602E-04	8.4047E-04
16	3.4585E-04	4.3928E-04	5.0839E-04	5.6415E-04	6.1887E-04	6.6220E-04	6.9101E-04	7.1369E-04	7.1369E-04	6.9101E-04
17	1.5063E-04	2.2118E-04	2.7391E-04	3.1568E-04	3.5045E-04	3.7954E-04	4.0181E-04	4.1663E-04	4.2220E-04	4.1663E-04
18	1.9054E-05	3.7609E-05	5.0388E-05	6.0256E-05	6.8245E-05	7.4847E-05	8.0140E-05	8.3956E-05	8.6022E-05	8.6022E-05

	11	12	13	14	15	16	17	18
1	8.4756E-04	7.7151E-04	7.0777E-04	7.0122E-04	5.6244E-04	3.4585E-04	1.5063E-04	1.9053E-05
2	8.1134E-04	7.9108E-04	7.3435E-04	7.0861E-04	6.4552E-04	4.3928E-04	2.2118E-04	3.7609E-05
3	7.4795E-04	7.4032E-04	7.6328E-04	7.0944E-04	6.7561E-04	5.0839E-04	2.7391E-04	5.0388E-05
4	1.0067E-03	8.1163E-04	8.1079E-04	8.0730E-04	7.3385E-04	5.6415E-04	3.1568E-04	6.0256E-05
5	1.2414E-03	1.0106E-03	8.8431E-04	8.6602E-04	8.3246E-04	6.1887E-04	3.5045E-04	6.8245E-05
6	1.2877E-03	1.1013E-03	9.6090E-04	8.6568E-04	8.4046E-04	6.6220E-04	3.7954E-04	7.4847E-05
7	1.2414E-03	1.1013E-03	9.9517E-04	9.5837E-04	8.7601E-04	6.9101E-04	4.0181E-04	8.0140E-05
8	1.0067E-03	1.0106E-03	9.6091E-04	9.5837E-04	9.3710E-04	7.1369E-04	4.1663E-04	8.3955E-05
9	7.4795E-04	8.1163E-04	8.8432E-04	8.6568E-04	8.7602E-04	7.1368E-04	4.2220E-04	8.6022E-05
10	8.1133E-04	7.4032E-04	8.1079E-04	8.6602E-04	8.4046E-04	6.9101E-04	4.1663E-04	8.6022E-05
11	8.4756E-04	7.9108E-04	7.6328E-04	8.0730E-04	8.3246E-04	6.6220E-04	4.0181E-04	8.3955E-05
12	7.9108E-04	7.7151E-04	7.3435E-04	7.0944E-04	7.3385E-04	6.1887E-04	3.7954E-04	8.0140E-05
13	7.6328E-04	7.3435E-04	7.0777E-04	7.0861E-04	6.7561E-04	5.6415E-04	3.5045E-04	7.4847E-05
14	8.0730E-04	7.0944E-04	7.0861E-04	7.0122E-04	6.4552E-04	5.0839E-04	3.1568E-04	6.8245E-05
15	8.3246E-04	7.3385E-04	6.7561E-04	6.4552E-04	5.6244E-04	4.3928E-04	2.7391E-04	6.0256E-05
16	6.6220E-04	6.1887E-04	5.6415E-04	5.0839E-04	4.3928E-04	3.4585E-04	2.2118E-04	5.0388E-05
17	4.0181E-04	3.7954E-04	3.5045E-04	3.1568E-04	2.7391E-04	2.2118E-04	1.5063E-04	3.7609E-05
18	8.3955E-05	8.0140E-05	7.4847E-05	6.8245E-05	6.0256E-05	5.0388E-05	3.7609E-05	1.9053E-05

4 FLUX GROUP

	1	2	3	4	5	6	7	8	9	10
1	4.6470E-04	4.6231E-04	4.5591E-04	4.4647E-04	4.2977E-04	3.9624E-04	3.4239E-04	2.7134E-04	1.8269E-04	1.1389E-04
2	4.6231E-04	4.6231E-04	4.5814E-04	4.5233E-04	4.4685E-04	4.2825E-04	3.7978E-04	3.0946E-04	2.2261E-04	1.0935E-04
3	4.5591E-04	4.5814E-04	4.5591E-04	4.5233E-04	4.5756E-04	4.8730E-04	4.5845E-04	3.5625E-04	2.6436E-04	1.3557E-04
4	4.4647E-04	4.5233E-04	4.5233E-04	4.4647E-04	4.4685E-04	4.8730E-04	5.0922E-04	4.2914E-04	3.0723E-04	2.1532E-04
5	4.2977E-04	4.4685E-04	4.5756E-04	4.4685E-04	4.2977E-04	4.2825E-04	4.5845E-04	4.2914E-04	3.2565E-04	2.4108E-04
6	3.9624E-04	4.2825E-04	4.8730E-04	4.8730E-04	4.2825E-04	3.9624E-04	3.7978E-04	3.5625E-04	3.0723E-04	2.4108E-04
7	3.4238E-04	3.7978E-04	4.5845E-04	5.0922E-04	4.5845E-04	3.7978E-04	3.4238E-04	3.0946E-04	2.6436E-04	2.1532E-04
8	2.7134E-04	3.0946E-04	3.5625E-04	4.2914E-04	4.2914E-04	3.5625E-04	3.0946E-04	2.7134E-04	2.2261E-04	1.3557E-04
9	1.8269E-04	2.2261E-04	2.6436E-04	3.0723E-04	3.2565E-04	3.0723E-04	2.6436E-04	2.2261E-04	1.8269E-04	1.0935E-04
10	1.1389E-04	1.0935E-04	1.3557E-04	2.1532E-04	2.4108E-04	2.4108E-04	2.1532E-04	1.3557E-04	1.0935E-04	1.1389E-04
11	9.7681E-05	7.6368E-05	5.3716E-05	1.0888E-04	1.7261E-04	1.8187E-04	1.7261E-04	1.0888E-04	5.3716E-05	7.6368E-05
12	1.0207E-04	9.5824E-05	7.2292E-05	8.1528E-05	1.2929E-04	1.4990E-04	1.4990E-04	1.2929E-04	8.1528E-05	7.2292E-05
13	1.1424E-04	1.0745E-04	1.0549E-04	1.1009E-04	1.2268E-04	1.3824E-04	1.4560E-04	1.3824E-04	1.2268E-04	1.1009E-04
14	1.5316E-04	1.3352E-04	1.2246E-04	1.4092E-04	1.5032E-04	1.4628E-04	1.6819E-04	1.6819E-04	1.4628E-04	1.5032E-04
15	1.5986E-04	1.6703E-04	1.5389E-04	1.6323E-04	1.9447E-04	1.8415E-04	1.9214E-04	2.1829E-04	1.9214E-04	1.8415E-04
16	1.1192E-04	1.3466E-04	1.4617E-04	1.5555E-04	1.7010E-04	1.8074E-04	1.8637E-04	1.9439E-04	1.9439E-04	1.8637E-04
17	5.2147E-05	7.4182E-05	8.8001E-05	9.7624E-05	1.0641E-04	1.1450E-04	1.2043E-04	1.2473E-04	1.2667E-04	1.2473E-04
18	7.9806E-06	1.4943E-05	1.9339E-05	2.2259E-05	2.4543E-05	2.6591E-05	2.8288E-05	2.9527E-05	3.0264E-05	3.0264E-05

	11	12	13	14	15	16	17	18
	9.7681E-05	1.0207E-04	1.1424E-04	1.5316E-04	1.5986E-04	1.1192E-04	5.2147E-05	7.9805E-06
2	7.6368E-05	9.5823E-05	1.0745E-04	1.3352E-04	1.6703E-04	1.3466E-04	7.4182E-05	1.4943E-05
3	5.3716E-05	7.2292E-05	1.0549E-04	1.2246E-04	1.5389E-04	1.4617E-04	8.8001E-05	1.9339E-05
4	1.0888E-04	8.1528E-05	1.1009E-04	1.4092E-04	1.6323E-04	1.5555E-04	9.7623E-05	2.2259E-05
5	1.7261E-04	1.2929E-04	1.2268E-04	1.5032E-04	1.9447E-04	1.7010E-04	1.0641E-04	2.4543E-05
6	1.8187E-04	1.4990E-04	1.3824E-04	1.4628E-04	1.8415E-04	1.8074E-04	1.1450E-04	2.6591E-05
7	1.7261E-04	1.4990E-04	1.4560E-04	1.6819E-04	1.9214E-04	1.8637E-04	1.2043E-04	2.8288E-05
8	1.0888E-04	1.2929E-04	1.3824E-04	1.6819E-04	2.1829E-04	1.9439E-04	1.2473E-04	2.9527E-05
9	5.3716E-05	8.1528E-05	1.2268E-04	1.4628E-04	1.9214E-04	1.9439E-04	1.2667E-04	3.0264E-05
10	7.6368E-05	7.2292E-05	1.1009E-04	1.5032E-04	1.8415E-04	1.8637E-04	1.2473E-04	3.0264E-05
11	9.7680E-05	9.5823E-05	1.0549E-04	1.4092E-04	1.9447E-04	1.8074E-04	1.2043E-04	2.9527E-05
12	9.5823E-05	1.0207E-04	1.0745E-04	1.2246E-04	1.6323E-04	1.7010E-04	1.1450E-04	2.8288E-05
13	1.0549E-04	1.0745E-04	1.1424E-04	1.3352E-04	1.5389E-04	1.5555E-04	1.0641E-04	2.6591E-05
14	1.4092E-04	1.2246E-04	1.3352E-04	1.5316E-04	1.6703E-04	1.4617E-04	9.7623E-05	2.4543E-05
15	1.9447E-04	1.6323E-04	1.5389E-04	1.6703E-04	1.5986E-04	1.3466E-04	8.8001E-05	2.2259E-05
16	1.8074E-04	1.7010E-04	1.5555E-04	1.4617E-04	1.3466E-04	1.1192E-04	7.4181E-05	1.9339E-05
17	1.2043E-04	1.1450E-04	1.0641E-04	9.7623E-05	8.8001E-05	7.4181E-05	5.2147E-05	1.4943E-05
18	2.9527E-05	2.8288E-05	2.6591E-05	2.4543E-05	2.2259E-05	1.9339E-05	1.4943E-05	7.9805E-06

SOURCES

	1	2	3	4	5	6	7	8	9	10
1	2.7234E-04	2.6994E-04	2.6288E-04	2.5161E-04	2.3704E-04	2.1957E-04	1.9847E-04	1.7315E-04	1.6364E-04	1.6636E-04
2	2.6994E-04	2.6994E-04	2.6520E-04	2.5592E-04	2.4279E-04	2.2719E-04	2.0858E-04	1.8535E-04	1.5720E-04	9.9177E-05
3	2.6288E-04	2.6520E-04	2.6288E-04	2.5592E-04	2.4451E-04	1.5302E-04	1.4400E-04	1.9524E-04	1.6934E-04	9.0061E-05
4	2.5161E-04	2.5592E-04	2.5592E-04	2.5161E-04	2.4279E-04	1.5302E-04	0.0	1.3581E-04	1.7954E-04	1.5336E-04
5	2.3704E-04	2.4279E-04	2.4451E-04	2.4279E-04	2.3704E-04	2.2719E-04	1.4400E-04	1.3581E-04	1.8348E-04	1.8386E-04
6	2.1957E-04	2.2719E-04	1.5302E-04	1.5302E-04	2.2719E-04	2.1957E-04	2.0858E-04	1.9524E-04	1.7954E-04	1.8386E-04
7	1.9847E-04	2.0858E-04	1.4400E-04	0.0	1.4400E-04	2.0858E-04	1.9847E-04	1.8535E-04	1.6934E-04	1.5336E-04
8	1.7315E-04	1.8535E-04	1.9524E-04	1.3581E-04	1.3581E-04	1.9524E-04	1.8535E-04	1.7315E-04	1.5720E-04	9.0061E-05
9	1.6364E-04	1.5720E-04	1.6934E-04	1.7954E-04	1.8348E-04	1.7954E-04	1.6934E-04	1.5720E-04	1.6364E-04	9.9177E-05
10	1.6636E-04	9.9177E-05	9.0061E-05	1.5336E-04	1.8386E-04	1.8386E-04	1.5336E-04	9.0061E-05	9.9177E-05	1.6636E-04
11	1.4304E-04	9.6206E-05	0.0	9.7483E-05	1.7655E-04	2.0182E-04	1.7655E-04	9.7483E-05	0.0	9.6206E-05
12	1.2406E-04	1.3127E-04	8.6943E-05	9.4266E-05	1.6400E-04	1.7539E-04	1.7539E-04	1.6400E-04	9.4266E-05	8.6943E-05
13	1.0203E-04	1.1212E-04	1.1904E-04	1.2660E-04	1.3765E-04	1.4778E-04	1.5163E-04	1.4778E-04	1.3765E-04	1.2660E-04
14	3.1916E-05	6.3529E-05	9.7212E-05	7.4968E-05	8.0786E-05	1.1970E-04	8.9121E-05	8.9121E-05	1.1970E-04	8.0786E-05
15	4.2684E-06	5.8920E-06	2.9541E-05	3.2335E-05	8.7299E-06	3.7422E-05	3.8964E-05	9.9263E-06	3.8964E-05	3.7422E-05
16	2.0186E-06	2.8502E-06	3.7590E-06	4.4863E-06	4.8463E-06	5.2416E-06	5.6456E-06	5.6755E-06	5.6755E-06	5.6456E-06
17	8.5461E-07	1.2736E-06	1.7075E-06	2.1065E-06	2.3975E-06	2.6108E-06	2.8000E-06	2.9098E-06	2.9317E-06	2.9098E-06
18	2.5644E-07	4.1606E-07	5.8387E-07	7.4886E-07	8.8693E-07	9.8927E-07	1.0697E-06	1.1285E-06	1.1551E-06	1.1551E-06

	11	12	13	14	15	16	17	18
1	1.4304E-04	1.2406E-04	1.0203E-04	3.1916E-05	4.2684E-06	2.0186E-06	8.5461E-07	2.5644E-07
2	9.6206E-05	1.3127E-04	1.1212E-04	6.3529E-05	5.8920E-06	2.8502E-06	1.2736E-06	4.1606E-07
3	0.0	8.6943E-05	1.1903E-04	9.7212E-05	2.9541E-05	3.7590E-06	1.7075E-06	5.8387E-07
4	9.7483E-05	9.4266E-05	1.2660E-04	7.4968E-05	3.2335E-05	4.4863E-06	2.1065E-06	7.4886E-07
5	1.7655E-04	1.6400E-04	1.3765E-04	8.0786E-05	8.7299E-06	4.8463E-06	2.3975E-06	8.8693E-07
6	2.0182E-04	1.7539E-04	1.4778E-04	1.1970E-04	3.7421E-05	5.2416E-06	2.6108E-06	9.8926E-07
7	1.7655E-04	1.7539E-04	1.5163E-04	8.9121E-05	3.8964E-05	5.6456E-06	2.8000E-06	1.0697E-06
8	9.7483E-05	1.6400E-04	1.4778E-04	8.9121E-05	9.9263E-06	5.6755E-06	2.9098E-06	1.1285E-06
9	0.0	9.4266E-05	1.3765E-04	1.1970E-04	3.8964E-05	5.6755E-06	2.9317E-06	1.1551E-06
10	9.6206E-05	8.6943E-05	1.2660E-04	8.0786E-05	3.7422E-05	5.6456E-06	2.9098E-06	1.1551E-06
11	1.4304E-04	1.3127E-04	1.1904E-04	7.4968E-05	8.7299E-06	5.2416E-06	2.8000E-06	1.1285E-06
12	1.3127E-04	1.2406E-04	1.1212E-04	9.7212E-05	3.2335E-05	4.8463E-06	2.6108E-06	1.0697E-06
13	1.1904E-04	1.1212E-04	1.0203E-04	6.3529E-05	2.9541E-05	4.4863E-06	2.3975E-06	9.8926E-07
14	7.4968E-05	9.7212E-05	6.3529E-05	3.1916E-05	5.8920E-06	3.7590E-06	2.1065E-06	8.8693E-07
15	8.7299E-06	3.2335E-05	2.9541E-05	5.8920E-06	4.2684E-06	2.8502E-06	1.7075E-06	7.4886E-07
16	5.2416E-06	4.8463E-06	4.4863E-06	3.7590E-06	2.8502E-06	2.0186E-06	1.2736E-06	5.8387E-07
17	2.8000E-06	2.6108E-06	2.3975E-06	2.1065E-06	1.7075E-06	1.2736E-06	8.5461E-07	4.1606E-07
18	1.1285E-06	1.0697E-06	9.8926E-07	8.8693E-07	7.4886E-07	5.8387E-07	4.1606E-07	2.5644E-07

ITERATION PROCESS (ADJOINT CALCULATIONS)

IT NR	OMEGAB	OMEGAF	K-EFF	K-EFF CONV.	GR NR	FLUX CONV IN INNER ITERS --> 1
1	1.1236	1.1236	0.675060	1.5502E+04	4	1.00E+00
					3	1.00E+00
					2	1.00E+00
					1	1.00E+00
2	1.1236	1.1236	1.019657	3.3795E-01	4	2.55E+00
					3	3.79E+00
					2	7.55E-01
					1	1.29E+00
3	1.1236	1.1236	1.087386	6.2286E-02	4	6.24E-01
					3	8.76E-01
					2	3.55E-01
					1	2.48E-01
4	1.1236	1.1236	1.088963	1.4477E-03	4	5.92E-01
					3	5.49E-01
					2	1.35E-01
					1	1.30E-01
5	1.1236	1.1236	1.094199	4.7858E-03	4	1.02E-01
					3	1.66E-01
					2	9.12E-02
					1	8.88E-02
6	1.1236	1.1236	1.104280	9.1285E-03	4	9.82E-02
					3	1.42E-01
					2	7.66E-02
					1	5.54E-02
7	1.1236	1.1236	1.112272	7.1860E-03	4	4.31E-02
					3	3.36E-02
					2	3.45E-02
					1	3.03E-02
8	1.1236	1.1236	1.116875	4.1208E-03	4	2.08E-02
					3	1.92E-02
					2	1.94E-02
					1	1.61E-02
9	1.1236	1.1236	1.119236	2.1098E-03	4	1.14E-02
					3	1.04E-02
					2	1.03E-02
					1	8.35E-03
10	1.1236	1.1236	1.120432	1.0674E-03	4	6.31E-03
					3	5.77E-03
					2	5.40E-03
					1	4.34E-03
11	1.1236	1.1236	1.121037	5.3936E-04	4	3.41E-03
					3	3.12E-03
					2	2.78E-03
					1	2.25E-03
12	1.1236	1.1236	1.121345	2.7472E-04	4	1.81E-03
					3	1.65E-03
					2	1.44E-03

					1	1.17E-03
13	1.1236	1.1236	1.121504	1.4204E-04	4	9.30E-04
					3	8.47E-04
					2	7.40E-04
					1	5.98E-04
14	1.1236	1.1236	1.121586	7.3135E-05	4	4.75E-04
					3	4.31E-04
					2	3.79E-04
					1	3.07E-04
15	1.1236	1.1236	1.121625	3.4869E-05	4	2.41E-04
					3	2.19E-04
					2	1.94E-04
					1	1.54E-04
16	1.1236	1.1236	1.121647	1.9610E-05	4	1.19E-04
					3	1.09E-04
					2	9.94E-05
					1	8.11E-05
17	1.1236	1.1236	1.121660	1.1921E-05	4	6.10E-05
					3	5.53E-05
					2	4.99E-05
					1	4.10E-05
18	1.1236	1.1236	1.121665	4.2915E-06	4	3.43E-05
					3	3.15E-05
					2	2.55E-05
					1	1.91E-05
19	1.1236	1.1236	1.121668	2.5630E-06	4	1.43E-05
					3	1.34E-05
					2	1.23E-05
					1	1.06E-05
20	1.1236	1.1236	1.121668	0.0	4	1.05E-05
					3	1.05E-05
					2	7.63E-06
					1	5.72E-06
21	1.1236	1.1236	1.121669	8.9407E-07	4	6.08E-06
					3	6.14E-06
					2	4.77E-06
					1	4.29E-06

4 ADJOINT FLUX GROUP

	1	2	3	4	5	6	7	8	9	10
1	2.1172E-04	2.0980E-04	2.0407E-04	1.9486E-04	1.8301E-04	1.6896E-04	1.5128E-04	1.2703E-04	9.6336E-05	7.5501E-05
2	2.0980E-04	2.0980E-04	2.0595E-04	1.9829E-04	1.8720E-04	1.7435E-04	1.5944E-04	1.3863E-04	1.0554E-04	5.0809E-05
3	2.0407E-04	2.0595E-04	2.0407E-04	1.9829E-04	1.8816E-04	1.7334E-04	1.6259E-04	1.4750E-04	1.2019E-04	5.5559E-05
4	1.9486E-04	1.9829E-04	1.9829E-04	1.9486E-04	1.8720E-04	1.7334E-04	1.6219E-04	1.5297E-04	1.3514E-04	1.0577E-04
5	1.8301E-04	1.8720E-04	1.8816E-04	1.8720E-04	1.8301E-04	1.7435E-04	1.6259E-04	1.5297E-04	1.4030E-04	1.2651E-04
6	1.6896E-04	1.7435E-04	1.7334E-04	1.7334E-04	1.7435E-04	1.6896E-04	1.5944E-04	1.4750E-04	1.3514E-04	1.2651E-04
7	1.5128E-04	1.5944E-04	1.6259E-04	1.6220E-04	1.6259E-04	1.5944E-04	1.5128E-04	1.3863E-04	1.2019E-04	1.0577E-04
8	1.2703E-04	1.3863E-04	1.4750E-04	1.5297E-04	1.5297E-04	1.4750E-04	1.3863E-04	1.2703E-04	1.0554E-04	5.5559E-05
9	9.6337E-05	1.0554E-04	1.2019E-04	1.3514E-04	1.4030E-04	1.3514E-04	1.2019E-04	1.0554E-04	9.6337E-05	5.0810E-05
10	7.5501E-05	5.0810E-05	5.5559E-05	1.0577E-04	1.2651E-04	1.2651E-04	1.0577E-04	5.5559E-05	5.0810E-05	7.5501E-05
11	7.2455E-05	4.3395E-05	1.2346E-05	5.2685E-05	1.0669E-04	1.1891E-04	1.0669E-04	5.2685E-05	1.2346E-05	4.3395E-05
12	7.1377E-05	6.8237E-05	3.9795E-05	4.4094E-05	8.7725E-05	1.0443E-04	1.0443E-04	8.7725E-05	4.4094E-05	3.9795E-05
13	5.8140E-05	6.4491E-05	6.3939E-05	6.4284E-05	7.4897E-05	8.6506E-05	9.0102E-05	8.6506E-05	7.4896E-05	6.4284E-05
14	3.3941E-05	4.5485E-05	5.2831E-05	5.2927E-05	5.7305E-05	6.5803E-05	6.6164E-05	6.6164E-05	6.5803E-05	5.7305E-05
15	1.4539E-05	2.1047E-05	3.0017E-05	3.2890E-05	3.1067E-05	3.8405E-05	4.0478E-05	3.6319E-05	4.0478E-05	3.8405E-05
16	6.1063E-06	9.1005E-06	1.2531E-05	1.5178E-05	1.6127E-05	1.7481E-05	1.9173E-05	1.9183E-05	1.9183E-05	1.9173E-05
17	2.1618E-06	3.4930E-06	4.8925E-06	6.1780E-06	7.0329E-06	7.6272E-06	8.2438E-06	8.6110E-06	8.6658E-06	8.6110E-06
18	3.2603E-07	6.4558E-07	9.5556E-07	1.2570E-06	1.4988E-06	1.6660E-06	1.8036E-06	1.9132E-06	1.9619E-06	1.9619E-06

	11	12	13	14	15	16	17	18
1	7.2454E-05	7.1377E-05	5.8140E-05	3.3941E-05	1.4539E-05	6.1063E-06	2.1618E-06	3.2603E-07
2	4.3395E-05	6.8237E-05	6.4491E-05	4.5485E-05	2.1047E-05	9.1005E-06	3.4930E-06	6.4558E-07
3	1.2346E-05	3.9795E-05	6.3939E-05	5.2831E-05	3.0017E-05	1.2531E-05	4.8925E-06	9.5555E-07
4	5.2685E-05	4.4094E-05	6.4284E-05	5.2926E-05	3.2890E-05	1.5178E-05	6.1780E-06	1.2570E-06
5	1.0669E-04	8.7725E-05	7.4896E-05	5.7305E-05	3.1067E-05	1.6127E-05	7.0329E-06	1.4988E-06
6	1.1891E-04	1.0443E-04	8.6506E-05	6.5803E-05	3.8405E-05	1.7481E-05	7.6271E-06	1.6660E-06
7	1.0669E-04	1.0443E-04	9.0102E-05	6.6163E-05	4.0478E-05	1.9173E-05	8.2438E-06	1.8036E-06
8	5.2685E-05	8.7725E-05	8.6506E-05	6.6163E-05	3.6319E-05	1.9183E-05	8.6110E-06	1.9132E-06
9	1.2346E-05	4.4094E-05	7.4896E-05	6.5803E-05	4.0478E-05	1.9183E-05	8.6657E-06	1.9619E-06
10	4.3395E-05	3.9795E-05	6.4284E-05	5.7305E-05	3.8405E-05	1.9173E-05	8.6110E-06	1.9619E-06
11	7.2454E-05	6.8236E-05	6.3939E-05	5.2926E-05	3.1067E-05	1.7481E-05	8.2438E-06	1.9132E-06
12	6.8236E-05	7.1377E-05	6.4491E-05	5.2831E-05	3.2890E-05	1.6127E-05	7.6271E-06	1.8036E-06
13	6.3939E-05	6.4491E-05	5.8140E-05	4.5485E-05	3.0017E-05	1.5178E-05	7.0329E-06	1.6660E-06
14	5.2926E-05	5.2831E-05	4.5485E-05	3.3941E-05	2.1047E-05	1.2531E-05	6.1780E-06	1.4988E-06
15	3.1067E-05	3.2890E-05	3.0017E-05	2.1047E-05	1.4539E-05	9.1004E-06	4.8925E-06	1.2570E-06
16	1.7481E-05	1.6127E-05	1.5178E-05	1.2531E-05	9.1004E-06	6.1062E-06	3.4930E-06	9.5555E-07
17	8.2438E-06	7.6271E-06	7.0329E-06	6.1780E-06	4.8925E-06	3.4930E-06	2.1618E-06	6.4558E-07
18	1.9132E-06	1.8036E-06	1.6660E-06	1.4988E-06	1.2570E-06	9.5555E-07	6.4558E-07	3.2603E-07

3 ADJOINT FLUX GROUP

	1	2	3	4	5	6	7	8	9	10
1	1.7942E-04	1.7778E-04	1.7291E-04	1.6506E-04	1.5485E-04	1.4261E-04	1.2718E-04	1.0653E-04	8.1623E-05	6.4420E-05
2	1.7778E-04	1.7778E-04	1.7450E-04	1.6800E-04	1.5858E-04	1.4743E-04	1.3432E-04	1.1645E-04	8.9876E-05	5.1379E-05
3	1.7291E-04	1.7450E-04	1.7291E-04	1.6800E-04	1.5951E-04	1.4736E-04	1.3720E-04	1.2401E-04	1.0180E-04	5.6815E-05
4	1.6506E-04	1.6800E-04	1.6800E-04	1.6506E-04	1.5858E-04	1.4736E-04	1.3687E-04	1.2819E-04	1.1361E-04	9.0464E-05
5	1.5485E-04	1.5858E-04	1.5951E-04	1.5858E-04	1.5485E-04	1.4743E-04	1.3720E-04	1.2819E-04	1.1782E-04	1.0630E-04
6	1.4261E-04	1.4743E-04	1.4736E-04	1.4736E-04	1.4743E-04	1.4261E-04	1.3432E-04	1.2401E-04	1.1361E-04	1.0630E-04
7	1.2718E-04	1.3432E-04	1.3720E-04	1.3687E-04	1.3720E-04	1.3432E-04	1.2718E-04	1.1645E-04	1.0180E-04	9.0464E-05
8	1.0653E-04	1.1645E-04	1.2401E-04	1.2819E-04	1.2819E-04	1.2401E-04	1.1645E-04	1.0653E-04	8.9876E-05	5.6815E-05
9	8.1623E-05	8.9876E-05	1.0180E-04	1.1361E-04	1.1782E-04	1.1361E-04	1.0180E-04	8.9876E-05	8.1623E-05	5.1379E-05
10	6.4420E-05	5.1380E-05	5.6816E-05	9.0464E-05	1.0630E-04	1.0630E-04	9.0464E-05	5.6815E-05	5.1379E-05	6.4420E-05
11	6.0796E-05	4.3487E-05	2.1713E-05	5.3534E-05	9.0238E-05	9.9819E-05	9.0238E-05	5.3534E-05	2.1713E-05	4.3487E-05
12	5.8990E-05	5.7251E-05	3.9971E-05	4.4419E-05	7.4429E-05	8.7615E-05	8.7615E-05	7.4429E-05	4.4419E-05	3.9970E-05
13	4.7707E-05	5.3113E-05	5.3091E-05	5.3901E-05	6.2616E-05	7.2122E-05	7.5205E-05	7.2122E-05	6.2615E-05	5.3900E-05
14	2.7655E-05	3.7011E-05	4.3088E-05	4.3242E-05	4.6945E-05	5.4112E-05	5.4572E-05	5.4572E-05	5.4112E-05	4.6945E-05
15	1.2168E-05	1.7466E-05	2.4331E-05	2.6718E-05	2.5807E-05	3.1333E-05	3.3135E-05	3.0357E-05	3.3135E-05	3.1333E-05
16	5.1548E-06	7.6596E-06	1.0449E-05	1.2601E-05	1.3475E-05	1.4628E-05	1.6007E-05	1.6112E-05	1.6112E-05	1.6007E-05
17	1.7873E-06	2.9151E-06	4.0742E-06	5.1295E-06	5.8446E-06	6.3535E-06	6.8709E-06	7.1883E-06	7.2462E-06	7.1883E-06
18	2.1380E-07	4.4450E-07	6.6039E-07	8.6761E-07	1.0341E-06	1.1509E-06	1.2477E-06	1.3252E-06	1.3608E-06	1.3608E-06

	11	12	13	14	15	16	17	18
1	6.0796E-05	5.8990E-05	4.7707E-05	2.7655E-05	1.2168E-05	5.1548E-06	1.7873E-06	2.1380E-07
2	4.3487E-05	5.7251E-05	5.3112E-05	3.7011E-05	1.7466E-05	7.6596E-06	2.9151E-06	4.4450E-07
3	2.1713E-05	3.9970E-05	5.3091E-05	4.3088E-05	2.4331E-05	1.0449E-05	4.0742E-06	6.6039E-07
4	5.3534E-05	4.4419E-05	5.3900E-05	4.3242E-05	2.6718E-05	1.2601E-05	5.1295E-06	8.6761E-07
5	9.0238E-05	7.4429E-05	6.2615E-05	4.6945E-05	2.5807E-05	1.3475E-05	5.8445E-06	1.0341E-06
6	9.9818E-05	8.7615E-05	7.2122E-05	5.4112E-05	3.1333E-05	1.4628E-05	6.3535E-06	1.1509E-06
7	9.0238E-05	8.7615E-05	7.5205E-05	5.4572E-05	3.3134E-05	1.6007E-05	6.8709E-06	1.2477E-06
8	5.3534E-05	7.4429E-05	7.2122E-05	5.4572E-05	3.0357E-05	1.6112E-05	7.1883E-06	1.3252E-06
9	2.1713E-05	4.4419E-05	6.2615E-05	5.4112E-05	3.3134E-05	1.6112E-05	7.2461E-06	1.3608E-06
10	4.3487E-05	3.9970E-05	5.3900E-05	4.6945E-05	3.1333E-05	1.6007E-05	7.1883E-06	1.3608E-06
11	6.0796E-05	5.7250E-05	5.3091E-05	4.3242E-05	2.5807E-05	1.4628E-05	6.8709E-06	1.3252E-06
12	5.7250E-05	5.8990E-05	5.3112E-05	4.3088E-05	2.6718E-05	1.3475E-05	6.3535E-06	1.2477E-06
13	5.3091E-05	5.3112E-05	4.7707E-05	3.7011E-05	2.4331E-05	1.2601E-05	5.8445E-06	1.1509E-06
14	4.3242E-05	4.3088E-05	3.7011E-05	2.7655E-05	1.7466E-05	1.0449E-05	5.1295E-06	1.0341E-06
15	2.5807E-05	2.6718E-05	2.4331E-05	1.7466E-05	1.2168E-05	7.6596E-06	4.0742E-06	8.6761E-07
16	1.4628E-05	1.3475E-05	1.2601E-05	1.0449E-05	7.6596E-06	5.1548E-06	2.9151E-06	6.6039E-07
17	6.8709E-06	6.3535E-06	5.8445E-06	5.1295E-06	4.0742E-06	2.9151E-06	1.7873E-06	4.4450E-07
18	1.3252E-06	1.2477E-06	1.1509E-06	1.0341E-06	8.6761E-07	6.6039E-07	4.4450E-07	2.1380E-07

2 ADJOINT FLUX GROUP

	1	2	3	4	5	6	7	8	9	10
1	2.1831E-04	2.1632E-04	2.1043E-04	2.0100E-04	1.8894E-04	1.7493E-04	1.5836E-04	1.3857E-04	1.1682E-04	9.7847E-05
2	2.1632E-04	2.1632E-04	2.1236E-04	2.0452E-04	1.9328E-04	1.8039E-04	1.6591E-04	1.4801E-04	1.2619E-04	1.0142E-04
3	2.1043E-04	2.1236E-04	2.1043E-04	2.0452E-04	1.9435E-04	1.7990E-04	1.6946E-04	1.5515E-04	1.3556E-04	1.0965E-04
4	2.0100E-04	2.0452E-04	2.0452E-04	2.0100E-04	1.9328E-04	1.7990E-04	1.6956E-04	1.6010E-04	1.4329E-04	1.2349E-04
5	1.8894E-04	1.9328E-04	1.9435E-04	1.9328E-04	1.8894E-04	1.8039E-04	1.6946E-04	1.6010E-04	1.4623E-04	1.3124E-04
6	1.7493E-04	1.8039E-04	1.7990E-04	1.7990E-04	1.8039E-04	1.7493E-04	1.6591E-04	1.5515E-04	1.4329E-04	1.3124E-04
7	1.5836E-04	1.6591E-04	1.6946E-04	1.6956E-04	1.6946E-04	1.6591E-04	1.5836E-04	1.4801E-04	1.3556E-04	1.2349E-04
8	1.3857E-04	1.4801E-04	1.5515E-04	1.6010E-04	1.6010E-04	1.5515E-04	1.4801E-04	1.3857E-04	1.2619E-04	1.0965E-04
9	1.1682E-04	1.2619E-04	1.3556E-04	1.4329E-04	1.4623E-04	1.4329E-04	1.3556E-04	1.2619E-04	1.1682E-04	1.0142E-04
10	9.7847E-05	1.0142E-04	1.0965E-04	1.2349E-04	1.3125E-04	1.3125E-04	1.2349E-04	1.0965E-04	1.0142E-04	9.7847E-05
11	8.4497E-05	8.5226E-05	8.2663E-05	1.0005E-04	1.1422E-04	1.1875E-04	1.1422E-04	1.0005E-04	8.2662E-05	8.5226E-05
12	7.3007E-05	7.7402E-05	7.6948E-05	8.3502E-05	9.6733E-05	1.0356E-04	1.0355E-04	9.6733E-05	8.3502E-05	7.6948E-05
13	5.8754E-05	6.5333E-05	6.9470E-05	7.3837E-05	8.0503E-05	8.6567E-05	8.8796E-05	8.6567E-05	8.0502E-05	7.3837E-05
14	4.1670E-05	4.9878E-05	5.5190E-05	5.9247E-05	6.3990E-05	6.8307E-05	7.0815E-05	7.0815E-05	6.8307E-05	6.3990E-05
15	2.4321E-05	3.1043E-05	3.8288E-05	4.1926E-05	4.3446E-05	4.8710E-05	5.0755E-05	4.9280E-05	5.0755E-05	4.8710E-05
16	1.2996E-05	1.7436E-05	2.1650E-05	2.5003E-05	2.7143E-05	2.9236E-05	3.1104E-05	3.1621E-05	3.1621E-05	3.1104E-05
17	5.5535E-06	8.2334E-06	1.0608E-05	1.2647E-05	1.4203E-05	1.5415E-05	1.6441E-05	1.7076E-05	1.7252E-05	1.7076E-05
18	1.1589E-06	2.0706E-06	2.8375E-06	3.5029E-06	4.0463E-06	4.4675E-06	4.8052E-06	5.0535E-06	5.1762E-06	5.1762E-06

	11	12	13	14	15	16	17	18
1	8.4496E-05	7.3007E-05	5.8753E-05	4.1669E-05	2.4321E-05	1.2996E-05	5.5535E-06	1.1589E-06
2	8.5226E-05	7.7402E-05	6.5333E-05	4.9878E-05	3.1043E-05	1.7436E-05	8.2334E-06	2.0706E-06
3	8.2662E-05	7.6948E-05	6.9469E-05	5.5189E-05	3.8288E-05	2.1650E-05	1.0608E-05	2.8375E-06
4	1.0005E-04	8.3502E-05	7.3837E-05	5.9247E-05	4.1926E-05	2.5003E-05	1.2647E-05	3.5029E-06
5	1.1422E-04	9.6733E-05	8.0502E-05	6.3990E-05	4.3446E-05	2.7143E-05	1.4203E-05	4.0463E-06
6	1.1875E-04	1.0355E-04	8.6567E-05	6.8306E-05	4.8709E-05	2.9236E-05	1.5415E-05	4.4675E-06
7	1.1422E-04	1.0355E-04	8.8796E-05	7.0814E-05	5.0755E-05	3.1104E-05	1.6441E-05	4.8052E-06
8	1.0005E-04	9.6733E-05	8.6567E-05	7.0814E-05	4.9280E-05	3.1621E-05	1.7076E-05	5.0535E-06
9	8.2662E-05	8.3502E-05	8.0502E-05	6.8306E-05	5.0755E-05	3.1621E-05	1.7252E-05	5.1762E-06
10	8.5226E-05	7.6948E-05	7.3837E-05	6.3990E-05	4.8709E-05	3.1104E-05	1.7076E-05	5.1762E-06
11	8.4496E-05	7.7402E-05	6.9469E-05	5.9247E-05	4.3446E-05	2.9236E-05	1.6441E-05	5.0535E-06
12	7.7402E-05	7.3007E-05	6.5333E-05	5.5189E-05	4.1926E-05	2.7143E-05	1.5415E-05	4.8052E-06
13	6.9469E-05	6.5333E-05	5.8753E-05	4.9878E-05	3.8288E-05	2.5003E-05	1.4203E-05	4.4675E-06
14	5.9247E-05	5.5189E-05	4.9878E-05	4.1669E-05	3.1043E-05	2.1650E-05	1.2647E-05	4.0462E-06
15	4.3446E-05	4.1926E-05	3.8288E-05	3.1043E-05	2.4321E-05	1.7436E-05	1.0608E-05	3.5029E-06
16	2.9236E-05	2.7143E-05	2.5003E-05	2.1650E-05	1.7436E-05	1.2996E-05	8.2333E-06	2.8375E-06
17	1.6441E-05	1.5415E-05	1.4203E-05	1.2647E-05	1.0608E-05	8.2333E-06	5.5535E-06	2.0706E-06
18	5.0535E-06	4.8052E-06	4.4675E-06	4.0463E-06	3.5029E-06	2.8375E-06	2.0706E-06	1.1589E-06

1 ADJOINT FLUX GROUP

	1	2	3	4	5	6	7	8	9	10
1	2.5228E-04	2.5001E-04	2.4329E-04	2.3256E-04	2.1893E-04	2.0339E-04	1.8566E-04	1.6532E-04	1.4357E-04	1.2300E-04
2	2.5001E-04	2.5001E-04	2.4549E-04	2.3656E-04	2.2380E-04	2.0925E-04	1.9344E-04	1.7482E-04	1.5334E-04	1.3053E-04
3	2.4329E-04	2.4549E-04	2.4329E-04	2.3656E-04	2.2499E-04	2.0864E-04	1.9638E-04	1.8153E-04	1.6203E-04	1.3921E-04
4	2.3256E-04	2.3656E-04	2.3656E-04	2.3256E-04	2.2380E-04	2.0864E-04	1.9592E-04	1.8535E-04	1.6846E-04	1.4875E-04
5	2.1893E-04	2.2380E-04	2.2499E-04	2.2380E-04	2.1893E-04	2.0925E-04	1.9638E-04	1.8535E-04	1.7084E-04	1.5455E-04
6	2.0339E-04	2.0925E-04	2.0864E-04	2.0864E-04	2.0925E-04	2.0339E-04	1.9344E-04	1.8153E-04	1.6846E-04	1.5455E-04
7	1.8566E-04	1.9344E-04	1.9638E-04	1.9592E-04	1.9638E-04	1.9344E-04	1.8566E-04	1.7482E-04	1.6203E-04	1.4875E-04
8	1.6532E-04	1.7482E-04	1.8153E-04	1.8535E-04	1.8535E-04	1.8153E-04	1.7482E-04	1.6532E-04	1.5334E-04	1.3921E-04
9	1.4357E-04	1.5334E-04	1.6203E-04	1.6846E-04	1.7084E-04	1.6846E-04	1.6203E-04	1.5334E-04	1.4357E-04	1.3053E-04
10	1.2300E-04	1.3053E-04	1.3921E-04	1.4875E-04	1.5455E-04	1.5455E-04	1.4875E-04	1.3921E-04	1.3053E-04	1.2300E-04
11	1.0513E-04	1.1087E-04	1.1509E-04	1.2692E-04	1.3623E-04	1.3957E-04	1.3623E-04	1.2692E-04	1.1509E-04	1.1087E-04
12	8.8585E-05	9.5724E-05	9.9867E-05	1.0716E-04	1.1680E-04	1.2202E-04	1.2202E-04	1.1680E-04	1.0716E-04	9.9866E-05
13	7.0838E-05	7.8981E-05	8.5152E-05	9.0999E-05	9.7450E-05	1.0269E-04	1.0464E-04	1.0269E-04	9.7450E-05	9.0998E-05
14	5.1742E-05	6.0815E-05	6.7174E-05	7.2684E-05	7.8050E-05	8.2150E-05	8.4859E-05	8.4859E-05	8.2150E-05	7.8049E-05
15	3.2359E-05	4.0213E-05	4.8103E-05	5.2764E-05	5.5550E-05	6.0777E-05	6.3050E-05	6.2199E-05	6.3049E-05	6.0777E-05
16	1.8522E-05	2.4106E-05	2.9295E-05	3.3509E-05	3.6472E-05	3.9139E-05	4.1322E-05	4.2084E-05	4.2083E-05	4.1321E-05
17	8.9743E-06	1.2582E-05	1.5834E-05	1.8644E-05	2.0862E-05	2.2610E-05	2.4016E-05	2.4886E-05	2.5146E-05	2.4886E-05
18	3.0743E-06	4.7521E-06	6.2772E-06	7.6215E-06	8.7390E-06	9.6252E-06	1.0325E-05	1.0826E-05	1.1077E-05	1.1077E-05

	11	12	13	14	15	16	17	18
1	1.0513E-04	8.8584E-05	7.0838E-05	5.1742E-05	3.2359E-05	1.8522E-05	8.9742E-06	3.0742E-06
2	1.1087E-04	9.5724E-05	7.8981E-05	6.0815E-05	4.0212E-05	2.4106E-05	1.2582E-05	4.7521E-06
3	1.1509E-04	9.9866E-05	8.5151E-05	6.7174E-05	4.8103E-05	2.9295E-05	1.5834E-05	6.2772E-06
4	1.2692E-04	1.0716E-04	9.0998E-05	7.2684E-05	5.2763E-05	3.3509E-05	1.8644E-05	7.6214E-06
5	1.3623E-04	1.1680E-04	9.7450E-05	7.8049E-05	5.5550E-05	3.6472E-05	2.0862E-05	8.7390E-06
6	1.3957E-04	1.2202E-04	1.0269E-04	8.2150E-05	6.0777E-05	3.9139E-05	2.2610E-05	9.6252E-06
7	1.3623E-04	1.2202E-04	1.0464E-04	8.4859E-05	6.3049E-05	4.1321E-05	2.4016E-05	1.0325E-05
8	1.2692E-04	1.1680E-04	1.0269E-04	8.4859E-05	6.2199E-05	4.2083E-05	2.4885E-05	1.0826E-05
9	1.1509E-04	1.0716E-04	9.7450E-05	8.2150E-05	6.3049E-05	4.2083E-05	2.5146E-05	1.1077E-05
10	1.1087E-04	9.9866E-05	9.0998E-05	7.8049E-05	6.0777E-05	4.1321E-05	2.4885E-05	1.1077E-05
11	1.0513E-04	9.5724E-05	8.5151E-05	7.2684E-05	5.5550E-05	3.9139E-05	2.4016E-05	1.0826E-05
12	9.5724E-05	8.8584E-05	7.8981E-05	6.7174E-05	5.2763E-05	3.6472E-05	2.2610E-05	1.0325E-05
13	8.5151E-05	7.8981E-05	7.0838E-05	6.0814E-05	4.8103E-05	3.3509E-05	2.0862E-05	9.6252E-06
14	7.2684E-05	6.7174E-05	6.0814E-05	5.1742E-05	4.0212E-05	2.9295E-05	1.8644E-05	8.7390E-06
15	5.5550E-05	5.2763E-05	4.8103E-05	4.0212E-05	3.2359E-05	2.4106E-05	1.5834E-05	7.6214E-06
16	3.9139E-05	3.6472E-05	3.3509E-05	2.9295E-05	2.4106E-05	1.8522E-05	1.2581E-05	6.2772E-06
17	2.4016E-05	2.2610E-05	2.0862E-05	1.8644E-05	1.5834E-05	1.2581E-05	8.9742E-06	4.7521E-06
18	1.0826E-05	1.0325E-05	9.6252E-06	8.7390E-06	7.6214E-06	6.2772E-06	4.7521E-06	3.0742E-06

2. Sample Problem B2

Only flux calculations without the printing of fluxes and sources. The following strategy is assumed in the iteration process: five inner iterations, in the first outer iteration, four inner iterations in the second outer iteration, three inner iterations in the third outer iteration, and two inner iterations in the next outer iteration. In the case of using IBM/370-168 computer the following data were obtained:

CPU time: 58.72 sec
Total costs: 41.53 DM

DATENKARTEN

Programm HEXAGA-II SAMPLE PROBLEM B2 Datum Name Blatt-Nr.

```
//.....   JØB CARD........,
// REGIØN=300K,TIME=1
/*FØRMAT PR,DDNAME=FT06F001,ØVFL=ØN
// EXEC FGG,LIB=NUSYS,NAME=HEXAGA
//SYSIN DD *
//G.FT12F001 DD UNIT=SYSDA,SPACE=(7294,17),DCB=(BLKSIZE=7294,RECFM=VBS)
//G.FT13F001 DD UNIT=SYSDA,SPACE=(7294,10),DCB=*.FT12F001
//G.FT14F001 DD UNIT=SYSDA,SPACE=(7294,6),DCB=*.FT12F001
//G.FT15F001 DD UNIT=SYSDA,SPACE=(7294,6),DCB=*.FT12F001
//G.FT16F001 DD UNIT=SYSDA,SPACE=(7294,5),DCB=*.FT12F001
//G.FT17F001 DD UNIT=SYSDA,SPACE=(7294,5),DCB=*.FT12F001
//G.FT18F001 DD UNIT=SYSDA,SPACE=(7294,1),DCB=*.FT12F001
//G.FT20F001 DD UNIT=SYSDA,SPACE=(7294,1),DCB=*.FT12F001
//G.SYSIN DD *
```

DATENKARTEN

Programm HEXAGA-II SAMPLE PROBLEM B2 Datum ______ Name ____________ Blatt-Nr. 1

INPUT DATA

```
1/
         SAMPLE PROBLEM B2
2/
  2  35  35  4  3  1  5  3  0  5  21  1  1  2  2  0  3.23325
3/11/
  1  1  1  1  1  9  2  2  2  3  3  3
  1  1  1  1  1  1  2  2  2  3  3  3
  1  1  1  1  1  1  17  2  20  3  3
  1  1  1  1  1  1  4  2  2  3  3  3
  1  1  1  1  6  1  11  4  2  2  3  3
  1  1  1  5  1  1  4  2  2  3  3
  1  1  1  8  5  1  1  16  2  21  3  3
  1  1  1  1  5  1  1  2  2  3  3  3
  1  1  1  1  7  1  12  2  20  3  3
  1  1  1  1  1  1  2  2  2  3  3  3
  1  1  6  1  1  1  9  2  2  2  3  3
```

DATENKARTEN

Programm ______________________ Datum ________ Name ______________ Blatt-Nr. 2

1	5	1	1	1	1	2	2	2	3	3	
1	6	5	1	1	1	1	2	2	21	3	3
1	1	5	1	1	1	1	2	2	3	3	3
1	1	7	1	1	1	13	2	20	3	3	
1	1	1	1	1	1	4	2	2	3	3	3
10	1	1	1	1	1	14	4	2	2	3	3
1	1	1	1	1	2	4	2	2	3	3	
2	15	1	10	1	13	2	16	2	21	3	3
2	4	1	2	1	4	2	2	2	3	3	3
18	4	12	2	14	4	2	2	20	3	3	
2	4	2	2	2	4	2	2	2	3	3	3
2	2	16	2	2	2	16	2	2	2	3	3
2	2	2	2	2	2	2	2	2	3	3	
2	2	2	2	2	2	2	2	2	21	3	3
2	2	2	2	2	2	2	2	2	3	3	3
19	2	19	2	19	2	19	2	21	3	3	

DATENKARTEN

Programm ______ Datum ______ Name ______ Blatt-Nr. 3

3	2	3	2	3	2	3	2	3	3	3	3
3	3	21	3	21	3	21	3	21	3	3	3
3	3	3	3	3	3	3	3	3	3	3	
3	3	3	3	3	3	3	3	3	3	3	3
3	3	3	3	3	3	3	3	3	3	3	3
3	3	3	3	3	3	3	3	3	3	3	
3	3	3	3	3	3	3	3	3	3	3	3
3	3	3	3	3	3	3	3	3	3	3	3
3/1'/1/											
1	1	5	5	1	1	6					
1	1	1	1	5	5	7					
5	5	1	1	1	1	8					
2	2	1	1	1	1	9					
1	1	2	2	1	1	10					
4	4	1	1	1	1	11					
2	2	2	2	1	1	12					

DATENKARTEN

Programm ______________ Datum ________ Name ____________ Blatt-Nr. 4

```
  2   2   4   4   1   1   13
  4   4   2   2   1   1   14
  1   1   4   4   1   1   15
  2   2   2   2   4   4   16
  2   2   4   4   2   2   17
  4   4   2   2   2   2   18
  2   2   3   3   2   2   19
  3   3   2   2   2   2   20
  3   3   3   3   2   2   21
4/
          THE SAME DATA AS IN SAMPLE PROBLEM 1
5/
          THE SAME DATA AS IN SAMPLE PROBLEM 1
6/
   0 100   5   2  1.0000  1.0000  1.0E-05  1.0E-06   2   2  1.0000
```

H E X A G A - II   WRITTEN BY ZBIGNIEW WOZNICKI,   FEB. 1975

SAMPLE PROBLEM B2

2 TYPE OF HEXAGONAL MESH ARRANGEMENT

1225 MESH POINTS

4 NEUTRON GR.

1 THERMAL GR.

3 NEUTRON GR. THROUGHOUT WHICH NEUTRONS ARE DOWN-SCATTERED

5 MATERIAL COMP.

3 FISSIONABLE COMP.

3.2332 CM - MESH STEP

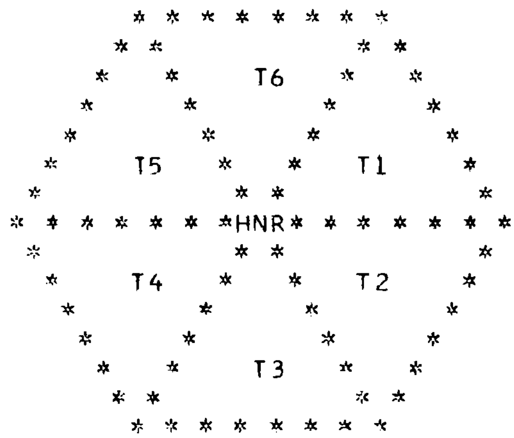
```
OUTER BOUNDARY COND:  LEFT    - FLUX DERIVATIVE EQUAL TO ZERO
                      TOP     - FLUX DERIVATIVE EQUAL TO ZERO
                      RIGHT   - LOGARITHMIC
                      BOTTOM  - LOGARITHMIC
```

THE LOCATION OF HEXAGONS

```
                                       1   3   5   7   9  11  13  15  17  19  21  23  25  27  29  31  33  35
                                      / / / / / / / / / / / / / / / / / / / / / / / / / / / / / / / / / / /

                                  1-   * 1 * * 1 * * 1 * * i * * 1 * * 9 * * 2 * * 2 * * 2 * * 3 * * 3 * * 3
                                  -  1 * * 1 * * 1 * * 1 * * 1 * * 1 * * 2 * * 2 * * 2 * * 3 * * 3 * * 3 *
                                3-  * * 1 * * 1 * * 1 * * 1 * * 1 * * 1 * *17 * * 2 * *20 * * 3 * * 3 * *
                                -  * 1 * * 1 * * 1 * * 1 * * 1 * * 1 * * 4 * * 2 * * 2 * * 3 * * 3 * * 3
                              5-  1 * * 1 * * 1 * * 1 * * 6 * * 1 * *11 * * 4 * * 2 * * 2 * * 3 * * 3 *
                              -  * * 1 * * 1 * * 1 * * 5 * * 1 * * 1 * * 4 * * 2 * * 2 * * 3 * * 3 * *
                            7-  * 1 * * 1 * * 1 * * 8 * * 5 * * 1 * * 1 * *16 * * 2 * *21 * * 3 * * 3
                            -  1 * * 1 * * 1 * * 1 * * 5 * * 1 * * 1 * * 2 * * 2 * * 3 * * 3 * * 3 *
                          9-  * * 1 * * 1 * * 1 * * 1 * * 7 * * 1 * *12 * * 2 * *20 * * 3 * * 3 * *
                          -  * 1 * * 1 * * 1 * * 1 * * 1 * * 1 * * 2 * * 2 * * 2 * * 3 * * 3 * * 3
                       11-  1 * * 1 * * 6 * * 1 * * 1 * * 1 * * 9 * * 2 * * 2 * * 2 * * 3 * * 3 *
                        -  * * 1 * * 5 * * 1 * * 1 * * 1 * * 1 * * 2 * * 2 * * 2 * * 3 * * 3 * *
                     13-  * 1 * * 8 * * 5 * * 1 * * 1 * * 1 * * 1 * * 2 * * 2 * *21 * * 3 * * 3
                      -  1 * * 1 * * 5 * * 1 * * 1 * * 1 * * 1 * * 2 * * 2 * * 3 * * 3 * * 3 *
                   15-  * * 1 * * 1 * * 7 * * 1 * * 1 * * 1 * *13 * * 2 * *20 * * 3 * * 3 * *
                    -  * 1 * * 1 * * 1 * * 1 * * 1 * * 1 * * 4 * * 2 * * 2 * * 3 * * 3 * * 3
                 17- 10 * * 1 * * 1 * * 1 * * 1 * * 1 * *14 * * 4 * * 2 * * 2 * * 3 * * 3 *
                  -  * * 1 * * 1 * * 1 * * 1 * * 1 * * 2 * * 4 * * 2 * * 2 * * 3 * * 3 * *
               19-  * 2 * *15 * * 1 * *10 * * 1 * *13 * * 2 * *16 * * 2 * *21 * * 3 * * 3
                -  2 * * 4 * * 1 * * 2 * * 1 * * 4 * * 2 * * 2 * * 2 * * 3 * * 3 * * 3 *
             21-  * *18 * * 4 * *12 * * 2 * *14 * * 4 * * 2 * * 2 * *20 * * 3 * * 3 * *
              -  * 2 * * 4 * * 2 * * 2 * * 2 * * 4 * * 2 * * 2 * * 2 * * 3 * * 3 * * 3
           23-  2 * * 2 * *16 * * 2 * * 2 * * 2 * *16 * * 2 * * 2 * * 2 * * 3 * * 3 *
            -  * * 2 * * 2 * * 2 * * 2 * * 2 * * 2 * * 2 * * 2 * * 2 * * 3 * * 3 * *
         25-  * 2 * * 2 * * 2 * * 2 * * 2 * * 2 * * 2 * * 2 * * 2 * *21 * * 3 * * 3
          -  2 * * 2 * * 2 * * 2 * * 2 * * 2 * * 2 * * 2 * * 2 * * 3 * * 3 * * 3 *
       27-  * *19 * * 2 * *19 * * 2 * *19 * * 2 * *19 * * 2 * *21 * * 3 * * 3 * *
        -  * 3 * * 2 * * 3 * * 2 * * 3 * * 2 * * 3 * * 2 * * 3 * * 3 * * 3 * * 3
     29-  3 * * 3 * *21 * * 3 * *21 * * 3 * *21 * * 3 * *21 * * 3 * * 3 * * 3 *
      -  * * 3 * * 3 * * 3 * * 3 * * 3 * * 3 * * 3 * * 3 * * 3 * * 3 * * 3 * *
   31-  * 3 * * 3 * * 3 * * 3 * * 3 * * 3 * * 3 * * 3 * * 3 * * 3 * * 3 * * 3
    -  3 * * 3 * * 3 * * 3 * * 3 * * 3 * * 3 * * 3 * * 3 * * 3 * * 3 * * 3 *
 33-  * * 3 * * 3 * * 3 * * 3 * * 3 * * 3 * * 3 * * 3 * * 3 * * 3 * * 3 * *
  -  * 3 * * 3 * * 3 * * 3 * * 3 * * 3 * * 3 * * 3 * * 3 * * 3 * * 3 * * 3
35-  3 * * 3 * * 3 * * 3 * * 3 * * 3 * * 3 * * 3 * * 3 * * 3 * * 3 * * 3 *
```

THE MATERIAL SPECIFICATION OF HEXAGONS



HNR	T1	T2	T3	T4	T5	T6
1	1	1	1	1	1	1
2	2	2	2	2	2	2
3	3	3	3	3	3	3
4	4	4	4	4	4	4
5	5	5	5	5	5	5
6	1	1	5	5	1	1
7	1	1	1	1	5	5
8	5	5	1	1	1	1
9	2	2	1	1	1	1
10	1	1	2	2	1	1
11	4	4	1	1	1	1
12	2	2	2	2	1	1
13	2	2	4	4	1	1
14	4	4	2	2	1	1
15	1	1	4	4	1	1
16	2	2	2	2	4	4
17	2	2	4	4	2	2
18	4	4	2	2	2	2
19	2	2	3	3	2	2
20	3	3	2	2	2	2
21	3	3	3	3	2	2

MATERIAL SPECIFICATION

COMP	GR NR	DIF	SIGT	NUSIGF	CHI
1	G				
	1	2.87679E+00	2.82040E-02	1.18780E-02	7.68000E-01
	2	1.57085E+00	5.27470E-03	5.32520E-03	2.32000E-01
	3	7.22486E-01	1.76120E-02	1.04710E-02	0.0
	4	9.64199E-01	2.65460E-02	2.66110E-02	0.0

SIGDS

G	G-->G+1	G-->G+2	G-->G+3
1	2.35970E-02	4.07910E-06	4.44930E-08
2	1.61530E-03	4.23090E-08	
3	4.68380E-03		

COMP	GR NR	DIF	SIGT	NUSIGF	CHI
2	G				
	1	2.87654E+00	2.87820E-02	1.49430E-02	7.68000E-01
	2	1.57136E+00	6.04910E-03	7.68870E-03	2.32000E-01
	3	7.12708E-01	1.95100E-02	1.48090E-02	0.0
	4	9.42978E-01	3.37140E-02	3.81590E-02	0.0

SIGDS

G	G-->G+1	G-->G+2	G-->G+3
1	2.32620E-02	4.64510E-06	4.99680E-08
2	1.57180E-03	4.07240E-08	
3	4.34140E-03		

COMP	GR NR	DIF	SIGT	NUSIGF	CHI
3	G				
	1	2.28561E+00	3.59590E-02	7.74270E-03	7.68000E-01
	2	1.17193E+00	5.88550E-03	1.08250E-04	2.32000E-01
	3	6.32475E-01	1.60410E-02	2.97420E-04	0.0
	4	8.18357E-01	1.33490E-02	8.46670E-04	0.0

SIGDS

G	G-->G+1	G-->G+2	G-->G+3
1	3.20710E-02	3.88800E-06	4.50390E-08
2	2.77760E-03	9.00180E-08	
3	5.89710E-03		

COMP	GR NR	DIF	SIGT	NUSIGF	CHI
4	G				
	1	2.50307E+00	2.48140E-02	0.0	0.0
	2	1.31468E+00	1.64120E-02	0.0	0.0
	3	5.74277E-01	7.21220E-02	0.0	0.0
	4	6.15369E-01	1.68680E-01	0.0	0.0

SIGDS

G	G-->G+1	G-->G+2	G-->G+3
1	2.29460E-02	1.03200E-06	1.04890E-08
2	3.76870E-03	7.03610E-12	
3	8.68150E-03		

COMP	GR NR	DIF	SIGT	NUSIGF	CHI
5	G				
	1	4.61642E+00	1.31590E-02	0.0	0.0
	2	2.90183E+00	1.45590E-03	0.0	0.0
	3	1.02118E+00	4.60010E-03	0.0	0.0
	4	1.72963E+00	7.86600E-04	0.0	0.0

SIGDS

G	G-->G+1	G-->G+2	G-->G+3
1	1.29420E-02	6.67600E-07	6.99030E-09
2	1.28710E-03	4.36330E-12	
3	3.45330E-03		

LOGARITHMIC BOUNDARY CONDITION PARAMETERS

GR NR	PT NR	LEFT	TOP	RIGHT	BOTTOM
1					
	1			4.6948E-01	4.6948E-01
	2			4.6948E-01	4.6948E-01
	3			4.6948E-01	4.6948E-01
	4			4.6948E-01	4.6948E-01
	5			4.6948E-01	4.6948E-01
	6			4.6948E-01	4.6948E-01
	7			4.6948E-01	4.6948E-01
	8			4.6948E-01	4.6948E-01
	9			4.6948E-01	4.6948E-01
	10			4.6948E-01	4.6948E-01
	11			4.6948E-01	4.6948E-01
	12			4.6948E-01	4.6948E-01
	13			4.6948E-01	4.6948E-01
	14			4.6948E-01	4.6948E-01
	15			4.6948E-01	4.6948E-01
	16			4.6948E-01	4.6948E-01
	17			4.6948E-01	4.6948E-01
	18			4.6948E-01	4.6948E-01
	19			4.6948E-01	4.6948E-01
	20			4.6948E-01	4.6948E-01
	21			4.6948E-01	4.6948E-01
	22			4.6948E-01	4.6948E-01
	23			4.6948E-01	4.6948E-01
	24			4.6948E-01	4.6948E-01
	25			4.6948E-01	4.6948E-01
	26			4.6948E-01	4.6948E-01
	27			4.6948E-01	4.6948E-01
	28			4.6948E-01	4.6948E-01
	29			4.6948E-01	4.6948E-01
	30			4.6948E-01	4.6948E-01
	31			4.6948E-01	4.6948E-01
	32			4.6948E-01	4.6948E-01
	33			4.6948E-01	4.6948E-01
	34			4.6948E-01	4.6948E-01
	35			4.6948E-01	4.6948E-01
2					
	1			4.6948E-01	4.6948E-01
	2			4.6948E-01	4.6948E-01
	3			4.6948E-01	4.6948E-01
	4			4.6948E-01	4.6948E-01
	5			4.6948E-01	4.6948E-01
	6			4.6948E-01	4.6948E-01
	7			4.6948E-01	4.6948E-01
	8			4.6948E-01	4.6948E-01
	9			4.6948E-01	4.6948E-01
	10			4.6948E-01	4.6948E-01
	11			4.6948E-01	4.6948E-01
	12			4.6948E-01	4.6948E-01
	13			4.6948E-01	4.6948E-01
	14			4.6948E-01	4.6948E-01
	15			4.6948E-01	4.6948E-01
	16			4.6948E-01	4.6948E-01
	17			4.6948E-01	4.6948E-01
	18			4.6948E-01	4.6948E-01
	19			4.6948E-01	4.6948E-01
	20			4.6948E-01	4.6948E-01
	21			4.6948E-01	4.6948E-01

	22	4.6948E-01	4.6948E-01
	23	4.6948E-01	4.6948E-01
	24	4.6948E-01	4.6948E-01
	25	4.6948E-01	4.6948E-01
	26	4.6948E-01	4.6948E-01
	27	4.6948E-01	4.6948E-01
	28	4.6948E-01	4.6948E-01
	29	4.6948E-01	4.6948E-01
	30	4.6948E-01	4.6948E-01
	31	4.6948E-01	4.6948E-01
	32	4.6948E-01	4.6948E-01
	33	4.6948E-01	4.6948E-01
	34	4.6948E-01	4.6948E-01
	35	4.6948E-01	4.6948E-01
3			
	1	4.6948E-01	4.6948E-01
	2	4.6948E-01	4.6948E-01
	3	4.6948E-01	4.6948E-01
	4	4.6948E-01	4.6948E-01
	5	4.6948E-01	4.6948E-01
	6	4.6948E-01	4.6948E-01
	7	4.6948E-01	4.6948E-01
	8	4.6948E-01	4.6948E-01
	9	4.6948E-01	4.6948E-01
	10	4.6948E-01	4.6948E-01
	11	4.6948E-01	4.6948E-01
	12	4.6948E-01	4.6948E-01
	13	4.6948E-01	4.6948E-01
	14	4.6948E-01	4.6948E-01
	15	4.6948E-01	4.6948E-01
	16	4.6948E-01	4.6948E-01
	17	4.6948E-01	4.6948E-01
	18	4.6948E-01	4.6948E-01
	19	4.6948E-01	4.6948E-01
	20	4.6948E-01	4.6948E-01
	21	4.6948E-01	4.6948E-01
	22	4.6948E-01	4.6948E-01
	23	4.6948E-01	4.6948E-01
	24	4.6948E-01	4.6948E-01
	25	4.6948E-01	4.6948E-01
	26	4.6948E-01	4.6948E-01
	27	4.6948E-01	4.6948E-01
	28	4.6948E-01	4.6948E-01
	29	4.6948E-01	4.6948E-01
	30	4.6948E-01	4.6948E-01
	31	4.6948E-01	4.6948E-01
	32	4.6948E-01	4.6948E-01
	33	4.6948E-01	4.6948E-01
	34	4.6948E-01	4.6948E-01
	35	4.6948E-01	4.6948E-01
4			
	1	4.6948E-01	4.6948E-01
	2	4.6948E-01	4.6948E-01
	3	4.6948E-01	4.6948E-01
	4	4.6948E-01	4.6948E-01
	5	4.6948E-01	4.6948E-01
	6	4.6948E-01	4.6948E-01
	7	4.6948E-01	4.6948E-01
	8	4.6948E-01	4.6948E-01
	9	4.6948E-01	4.6948E-01
	10	4.6948E-01	4.6948E-01
	11	4.6948E-01	4.6948E-01
	12	4.6948E-01	4.6948E-01
	13	4.6948E-01	4.6948E-01

14	4.6948E-01	4.6948E-01
15	4.6948E-01	4.6948E-01
16	4.6948E-01	4.6948E-01
17	4.6948E-01	4.6948E-01
18	4.6948E-01	4.6948E-01
19	4.6948E-01	4.6948E-01
20	4.6948E-01	4.6948E-01
21	4.6948E-01	4.6948E-01
22	4.6948E-01	4.6948E-01
23	4.6948E-01	4.6948E-01
24	4.6948E-01	4.6948E-01
25	4.6948E-01	4.6948E-01
26	4.6948E-01	4.6948E-01
27	4.6948E-01	4.6948E-01
28	4.6948E-01	4.6948E-01
29	4.6948E-01	4.6948E-01
30	4.6948E-01	4.6948E-01
31	4.6948E-01	4.6948E-01
32	4.6948E-01	4.6948E-01
33	4.6948E-01	4.6948E-01
34	4.6948E-01	4.6948E-01
35	4.6948E-01	4.6948E-01

THE ESTIMATION OF OPTIMUM OMEGA

NG	NORM
1	0.719727
2	0.836721
3	0.511508
4	0.509477

NG	IT	NI	ER	ER/ER
2	1	0.836721	0.976094	0.976094
2	2	0.867133	-0.036346	-0.037237
2	3	0.876614	-0.010933	0.300798
2	4	0.882126	-0.006288	0.575105
2	5	0.885935	-0.004317	0.686637
2	6	0.888813	-0.003247	0.752154
2	7	0.891101	-0.002574	0.792658
2	8	0.892983	-0.002111	0.820304
2	9	0.894562	-0.001768	0.837398
2	10	0.895904	-0.001499	0.847896
2	11	0.897055	-0.001285	0.856870
2	12	0.898047	-0.001105	0.860431
2	13	0.898902	-0.000952	0.861087
2	14	0.899643	-0.000824	0.865731
2	15	0.900285	-0.000713	0.865741
2	16	0.900840	-0.000616	0.863636
2	17	0.901321	-0.000533	0.865325
2	18	0.901739	-0.000463	0.869410
2	19	0.902099	-0.000399	0.860082
2	20	0.902412	-0.000346	0.868421
2	21	0.902683	-0.000299	0.865014
2	22	0.902916	-0.000258	0.863057
2	23	0.903119	-0.000224	0.867159
2	24	0.903293	-0.000192	0.855319
2	25	0.903445	-0.000168	0.875622
2	26	0.903576	-0.000144	0.857955
2	27	0.903689	-0.000125	0.867550
2	28	0.903786	-0.000107	0.854962
2	29	0.903870	-0.000093	0.875000

OMEGAB=1.1687   OMEGAF=1.1687

ITERATION PROCESS

IT NR	OMEGAB	OMEGAF	K-EFF	K-EFF CONV.	GR NR	FLUX CONV IN INNER ITERS --> 1	2	3	4	5
1	1.1687	1.1687	1.099779	3.8126E+02	1	1.00E+00	6.25E-01	2.33E-01	1.99E-01	1.89E-01
					2	1.00E+00	6.52E-01	3.72E-01	2.19E-01	1.02E-01
					3	1.00E+00	5.97E-01	4.57E-01	2.46E-01	9.63E-02
					4	1.00E+00	6.73E-01	3.86E-01	2.41E-01	1.36E-01
2	1.1687	1.1687	1.093054	6.1522E-03	1	4.64E+00	1.09E+00	4.12E-01	1.79E-01	
					2	4.61E-01	2.35E-01	1.26E-01	5.67E-02	
					3	8.95E-01	3.48E-01	1.40E-01	7.22E-02	
					4	4.21E-01	1.86E-01	8.01E-02	4.98E-02	
3	1.1687	1.1687	1.092194	7.8678E-04	1	2.92E-01	2.36E-01	1.40E-01		
					2	8.08E-02	6.54E-02	4.10E-02		
					3	2.59E-01	1.08E-01	5.40E-02		
					4	2.19E-01	1.16E-01	4.97E-02		
4	1.1687	1.1687	1.103693	1.0419E-02	1	1.14E-01	4.92E-02			
					2	4.17E-02	2.68E-02			
					3	7.11E-02	2.08E-02			
					4	7.98E-02	1.97E-02			
5	1.1687	1.1687	1.114928	1.0077E-02	1	6.14E-02	6.56E-02			
					2	2.98E-02	2.09E-02			
					3	4.80E-02	1.63E-02			
					4	4.35E-02	1.78E-02			
6	1.1687	1.1687	1.120794	5.2339E-03	1	2.40E-02	1.99E-02			
					2	1.65E-02	9.82E-03			
					3	2.45E-02	4.34E-03			
					4	1.97E-02	4.47E-03			
7	1.1687	1.1687	1.123072	2.0278E-03	1	1.26E-02	1.26E-02			
					2	7.90E-03	4.37E-03			
					3	1.14E-02	3.15E-03			
					4	9.63E-03	2.89E-03			
8	1.1687	1.1687	1.123827	6.7210E-04	1	6.27E-03	5.34E-03			
					2	3.48E-03	2.02E-03			
					3	4.71E-03	1.39E-03			
					4	3.57E-03	8.89E-04			
9	1.1687	1.1687	1.124104	2.4688E-04	1	2.81E-03	2.25E-03			
					2	1.48E-03	8.09E-04			
					3	2.01E-03	6.54E-04			
					4	1.65E-03	4.06E-04			
10	1.1687	1.1687	1.124236	1.1712E-04	1	1.34E-03	1.27E-03			
					2	6.22E-04	3.46E-04			
					3	8.58E-04	2.76E-04			
					4	6.91E-04	1.55E-04			
11	1.1687	1.1687	1.124329	8.2314E-05	1	8.64E-04	6.74E-04			
					2	2.72E-04	1.57E-04			
					3	3.70E-04	1.24E-04			
					4	3.00E-04	7.53E-05			
12	1.1687	1.1687	1.124377	4.3273E-05	1	5.42E-04	3.31E-04			
					2	1.17E-04	6.81E-05			
					3	1.45E-04	4.96E-05			

					4	1.15E-C4	3.72E-05
13	1.1687	1.1687	1.124383	5.1260E-06	1	3.12E-04	1.73E-04
					2	4.71E-C5	2.69E-05
					3	5.34E-05	2.96E-05
					4	4.77E-05	2.86E-05
14	1.1687	1.1687	1.124372	8.5831E-06	1	1.75E-04	8.89E-05
					2	2.57E-C5	1.72E-C5
					3	3.05E-05	1.72E-05
					4	2.19E-05	2.00E-05
15	1.1687	1.1687	1.124375	2.5630E-06	1	8.96E-05	5.69E-05
					2	1.72E-05	8.88E-06
					3	8.46E-06	4.65E-06
					4	1.02E-05	7.27E-06
16	1.1687	1.1687	1.124377	1.7285E-C6	1	4.01E-05	3.26E-05
					2	8.46E-06	6.68E-06
					3	7.33E-06	3.81E-06
					4	6.85E-06	2.98E-06
17	1.1687	1.1687	1.124378	8.94C7E-07	1	2.38E-05	1.44E-05
					2	5.72E-06	5.36E-06
					3	4.23E-C6	2.92E-06
					4	4.23E-06	1.97E-06
18	1.1687	1.1687	1.124378	C.0	1	1.24E-05	8.40E-06
					2	3.87E-06	3.99E-C6
					3	3.81E-C6	4.47E-06
					4	3.58E-C6	2.86E-06

3. Fine Mesh Problems

In this section all three versions of HEXAGA-II-120, -60 and -30 are illustrated by results of calculations for a series of problems (B1, 2, 3, 4, 6 and 8) derived from the reactor problem described in the previous sections of this Chapter. These problems differ only with the size of mesh step. B1 corresponds to the original problem (Section 1) with the mesh step equal to 6.4665 cm, B2-mesh step divided by factor 2 (Section 2), and in B3, B4, B6 and B8 these factors are 3, 4, 6 and 8, respectively. All results of calculations summarized in two tables given on the next pages are obtained with the values of $\bar{\Omega} = \Omega_\beta = \Omega_\phi$ estimated by the programme but without the acceleration of sources ($\omega_s = 1$) and for the following convergence criteria: $\varepsilon_\phi < 10^{-5}$ and $\varepsilon_{k_{eff}} < 10^{-6}$.

It is seen from the tables that HEXAGA-II-120 and -30 have the same behaviour of convergence whereas in the case of HEXAGA-II-60 the rate of convergence decreases stronger as the number of mesh points increases; this effect is rather difficult to explain. The increase of number of inner iterations per outer iteration above 4 or 5 (for HEXAGA-II-120 and -30) does not decrease the number of outer iterations which for this problem is equal to about 20 independently of the number of mesh points in particular examples. This means that a few inner iterations in all examples of this problem is equivalent to the case in which the direct method would be used for solving inner iterations. Moreover, it should be mentioned that HEXAGA-II is especially effective for problems with a large number of mesh points, CPU time per mesh point per inner iteration decreases more than ten times passing from B1 to B8. In addition, increasing the number of mesh points is accompanied by the reduction of costs per mesh point, for instance, in the case of HEXAGA-II-120 costs per mesh point equal to 0.051 DM for B1 reduce to 0.022 DM for B8 and for HEXAGA-II-30 from 0.157 DM to 0.021 respectively. In all problems it is observed the strong stability of k_{eff} independently of the number of inner iterations per outer iteration.

Problem	HEXAGA -II-	No. of mesh points	Core region	$\bar{\Omega}$	No. of inner per outer iter.	No. of outer iters	Total no. of inner iters	k_{eff}	CPU time in sec	Time per mesh pt. per inner iter. in msec	CPU costs in DM	Total costs in DM
B1	120	324	214	1.1411	1	21	84	1.121673	18.7	0.688	6.8	16.5
					2	20	160	1.121672	18.9	0.365	6.9	16.2
					3	24	288	1.121671	23.2	0.249	8.5	19.5
					4	24	384	1.121671	26.6	0.214	9.7	20.9
					5	24	480	1.121671	27.4	0.176	10.0	21.2
					6	24	576	1.121671	27.9	0.150	10.2	21.4
					7	24	672	1.121671	28.7	0.132	10.5	21.7
					8	24	768	1.121671	29.7	0.119	10.8	22.1
	60	171	196	1.1421	1	21	84	1.121672	19.2	1.336	7.0	16.0
					2	22	176	1.121671	22.0	0.732	8.1	17.5
					3	26	312	1.121672	26.5	0.497	9.7	20.7
					4	25	400	1.121671	26.1	0.381	9.5	20.2
					5	24	480	1.121669	25.2	0.307	9.2	19.5
					6	24	576	1.121669	24.9	0.253	9.1	19.4
					7	25	700	1.121670	27.4	0.229	10.0	20.7
					8	24	768	1.121670	26.5	0.202	9.7	20.0
	30	90	194	1.1287	1	17	68	1.121677	18.9	3.092	6.9	14.1
					2	23	184	1.121675	25.4	1.536	9.3	18.7
					3	24	288	1.121675	26.2	1.012	9.6	19.3
					4	24	384	1.121675	26.5	0.767	9.7	19.4
					5	24	480	1.121675	27.1	0.626	9.9	19.6
					6	24	576	1.121675	28.3	0.547	10.4	20.1
					7	24	672	1.121675	28.9	0.478	10.6	20.4
					8	24	768	1.121675	26.0	0.376	9.5	19.2
B2	120	1275	246	1.1590	1	33	132	1.124375	43.2	0.267	15.8	42.0
					2	22	176	1.124370	33.2	0.154	12.2	30.6
					3	26	312	1.124373	43.8	0.114	16.0	31.6
					4	23	368	1.124372	43.3	0.096	15.8	35.4
					5	23	460	1.124372	47.5	0.084	17.4	37.2
					6	24	576	1.124373	47.8	0.068	17.5	37.9
					7	24	672	1.124372	51.6	0.063	18.9	39.5
					8	24	768	1.124373	55.3	0.059	20.2	41.1
	60	630	212	1.1550	1	34	136	1.124372	38.4	0.448	14.0	33.4
					2	26	208	1.124371	31.1	0.237	11.4	26.7
					3	21	252	1.124371	27.0	0.170	9.9	22.7
					4	22	352	1.124371	29.6	0.133	10.8	24.3
					5	23	460	1.124370	33.3	0.115	12.2	26.2
					6	24	576	1.124370	36.7	0.101	13.4	28.1
					7	24	672	1.124370	38.5	0.091	14.1	28.9
					8	23	736	1.124368	39.3	0.085	14.4	28.7
	30	324	218	1.1520	1	30	120	1.124381	31.8	0.817	11.6	25.3
					2	22	176	1.124380	24.5	0.430	9.0	19.6
					3	21	252	1.124379	24.2	0.297	8.6	19.1
					4	22	352	1.124379	26.8	0.235	9.8	20.5
					5	23	460	1.124379	26.1	0.175	9.5	20.6
					6	24	576	1.124380	27.8	0.149	10.2	21.6
					7	24	672	1.124380	29.0	0.133	10.6	22.2
					8	24	736	1.124380	30.1	0.126	11.0	22.6
B3	120	2704	406	1.1720	1	44	176	1.124961	64.8	0.136	23.7	62.7
					2	28	224	1.124960	54.8	0.091	20.0	46.8
					3	23	276	1.124961	54.7	0.073	20.0	43.2
					4	21	336	1.124960	55.7	0.061	20.7	42.3
					5	20	400	1.124960	56.0	0.052	20.5	41.7
					6	21	504	1.124960	63.4	0.047	23.2	45.6
					7	21	588	1.124959	68.6	0.043	25.1	48.0
					8	23	736	1.124961	81.3	0.041	29.7	55.0
	60	1378	238	1.1655	1	58	240	1.124950	61.3	0.185	22.4	68.9
					2	35	280	1.124950	44.0	0.114	16.1	45.7
					3	26	312	1.124951	42.3	0.098	15.5	38.7
					4	23	388	1.124949	41.5	0.078	15.2	36.2
					5	22	440	1.124950	43.3	0.072	15.8	36.3
					6	22	528	1.124949	47.5	0.065	17.4	38.1
					7	24	672	1.124950	57.0	0.062	20.8	43.4
					8	23	736	1.124950	58.6	0.058	21.4	43.3
	30	702	220	1.1685	1	41	164	1.124977	50.4	0.438	18.4	42.3
					2	29	312	1.124977	36.6	0.167	13.4	30.9
					3	24	288	1.124976	32.5	0.161	11.9	26.9
					4	21	336	1.124975	29.3	0.124	10.7	24.2
					5	21	420	1.124975	32.9	0.112	12.0	25.6
					6	21	504	1.124974	34.9	0.099	12.8	26.5
					7	23	644	1.124976	39.9	0.088	14.6	29.5
					8	23	736	1.124975	42.0	0.081	15.3	30.4

Problem	HEXAGA -II-	No. of mesh points	Core region	$\bar{\Omega}$	No. of inner per outer iter.	No. of outer iters	Total no. of inner iters	k_{eff}	CPU time in sec	Time per mesh pt. per inner iter. in msec	CPU costs in DM	Total costs in DM
B4	120	4761	506	1.1795	1	59	236	1.125108	96.8	0.086	33.4	119.8
					2	33	264	1.125096	74.7	0.059	27.3	78.3
					3	25	300	1.125095	72.9	0.051	26.6	67.8
					4	23	368	1.125097	78.7	0.045	28.8	68.1
					5	21	420	1.125097	85.8	0.043	31.4	69.0
					6	21	504	1.125096	96.2	0.040	35.2	73.7
					7	19	532	1.125095	95.0	0.038	34.7	70.8
					8	20	640	1.125095	110.2	0.036	40.3	79.0
	60	2415	406	1.1720	1	80	320	1.125072	133.1	0.172	48.7	115.4
					2	48	384	1.125076	89.3	0.096	32.6	74.7
					3	31	372	1.125073	66.0	0.074	24.1	53.1
					4	28	448	1.125076	78.9	0.073	28.8	56.8
					5	24	480	1.125076	73.2	0.063	26.8	51.6
					6	23	552	1.125075	77.6	0.058	28.3	53.0
					7	21	588	1.125072	77.1	0.054	28.2	51.4
					8	21	672	1.125073	83.4	0.051	30.5	54.2
	30	1225	254	1.1775	1	57	228	1.125124	70.0	0.251	25.6	70.0
					2	33	354	1.125120	46.8	0.108	17.1	44.5
					3	26	312	1.125119	41.2	0.108	15.1	37.7
					4	23	388	1.125119	40.7	0.086	14.9	35.4
					5	20	400	1.125117	37.9	0.078	13.9	32.3
					6	20	480	1.125116	42.1	0.072	15.4	34.0
					7	20	560	1.125116	44.5	0.065	16.3	35.0
					8	21	672	1.125118	45.7	0.056	16.7	36.2
B6	120	10609	696	1.1867	1	84	336	1.125215	201.2	0.056	73.5	327.7
					2	44	352	1.125196	166.2	0.045	60.8	205.7
					3	33	396	1.125190	159.5	0.038	58.3	173.5
					4	28	448	1.125192	167.1	0.035	61.1	164.2
					5	24	480	1.125191	186.5	0.037	68.2	163.4
					6	22	528	1.125191	185.0	0.033	67.6	157.4
					7	21	578	1.125191	202.8	0.033	74.1	163.6
					8	19	608	1.125191	205.7	0.032	75.2	159.8
	60	5356	496	1.1785	1	135	540	1.125123	248.6	0.086	83.6	291.1
					2	77	616	1.125133	172.1	0.052	62.9	187.2
					3	50	600	1.125132	146.3	0.046	53.7	139.7
					4	41	656	1.125133	147.8	0.042	54.0	128.2
					5	33	660	1.125133	138.8	0.039	50.7	113.4
					6	29	736	1.125132	140.4	0.036	51.3	108.8
					7	26	728	1.125132	143.2	0.037	52.4	106.1
					8	24	736	1.125131	148.1	0.038	54.2	105.8
	30	2704	426	1.1858	1	80	320	1.125230	165.1	0.191	60.3	135.2
					2	44	352	1.125217	91.8	0.097	33.6	76.7
					3	32	384	1.125215	78.0	0.075	28.5	62.0
					4	29	464	1.125213	79.6	0.063	29.1	60.5
					5	23	460	1.125212	76.3	0.061	27.9	54.8
					6	21	504	1.125212	77.1	0.057	28.2	53.7
					7	20	560	1.125212	79.6	0.053	29.1	54.1
					8	19	608	1.125212	79.2	0.048	29.0	52.2
B8	120	18769	976	1.1900	1	114	456	1.125121	493.4	0.058	180.4	810.8
					2	59	472	1.125112	373.7	0.042	136.6	490.8
					3	40	480	1.125102	330.6	0.037	120.9	379.4
					4	36	556	1.125108	369.1	0.035	134.9	381.7
					5	29	580	1.125103	358.5	0.033	131.0	343.5
					6	25	600	1.125102	359.8	0.032	131.5	325.7
					7	25	700	1.125109	395.8	0.030	144.7	345.3
					8	22	704	1.125103	390.1	0.030	142.6	328.2
	60	9453	656	1.1818	1	207	828	1.125003	499.1	0.064	182.4	710.4
					2	114	912	1.125011	406.2	0.047	148.5	459.6
					3	72	864	1.125006	328.0	0.040	119.9	328.7
					4	58	828	1.125010	327.3	0.042	119.6	297.4
					5	45	900	1.125008	307.9	0.036	112.6	259.3
					6	41	984	1.125011	316.8	0.034	115.8	254.7
					7	34	952	1.125007	313.0	0.035	114.4	237.4
					8	34	1088	1.125014	335.7	0.033	122.7	248.5
	30	4761	466	1.1895	1	105	420	1.125151	156.2	0.078	57.1	203.2
					2	58	464	1.125148	126.6	0.057	46.3	133.2
					3	41	492	1.125146	113.8	0.049	41.6	107.1
					4	34	544	1.125147	112.8	0.044	41.2	98.4
					5	29	580	1.125142	113.6	0.041	41.5	92.8
					6	25	600	1.125144	112.6	0.039	41.2	87.5
					7	23	644	1.125143	115.6	0.038	42.3	86.5
					8	22	704	1.125141	121.5	0.036	44.4	88.0

VIII. APPENDIX:

1. Description of the INPREP Programme

The INPREP-II programme, written in FORTRAN IV and available in a card deck for IBM/370-168 computer, is intended as an auxiliary programme allowing to simplify considerably the preparation of that part of the HEXAGA-II input data which is concerned with the specification of material compositions inside a triangular mesh.

As input data INPREP-II uses only the first two cards of the HEXAGA-II input data, that is, card numbers 1/ and 2/ (see Chapter IV) where the value of NOH (number of all different hexagons) is ignored by the programme.

In the INPREP output, the picture of empty hexagonal mesh bounded by a parallelogram area of a given reactor problem is printed according to the value of NOM given in the input. In other words, INPREP-II provides the same picture of mesh (called "THE LOCATION OF HEXAGONS") as HEXAGA-II, but without the specification of material composition numbers representing particular hexagons in the mesh. However, these numbers can now be written by the user according to the material arrangement of a given reactor problem. With such specification of material compositions in the mesh prepared in advance it is possible in an easy way to prepare input cards for HEXAGA-II.

Moreover, INPREP-II in the output provides the specification of space (in bytes) which must be reserved on particular files used by HEXAGA-II.

The maximum CPU time amounts to a few seconds and a standard core region is sufficient (122 K). As an illustration of INPREP the output for sample problem B2, completed by hand writing, is presented.

I N P R E P - II   WRITTEN BY ZBIGNIEW WOZNICKI, FEB. 1975

SAMPLE PROBLEM B2

2 TYPE OF HEXAGONAL MESH ARRANGEMENT

1225 MESH POINTS

4 NEUTRON GR.

1 THERMAL GR.

3 NEUTRON GR. THROUGHOUT WHICH NEUTRONS ARE DOWN-SCATTERED

5 MATERIAL COMP.

3 FISSIONABLE COMP.

3.2332 CM - MESH STEP

OUTER BOUNDARY COND: LEFT - FLUX DERIVATIVE EQUAL TO ZERO
TOP - FLUX DERIVATIVE EQUAL TO ZERO
RIGHT - LOGARITHMIC
BOTTOM - LOGARITHMIC

THE DETERMINATION OF DISC SPACE

FILE NR	SPACE IN BYTES
12	117696
13	70336
14	39232
15	39232
16	31104
17	31104
18	4904
20	4904
21	44136
22	117696
23	70336

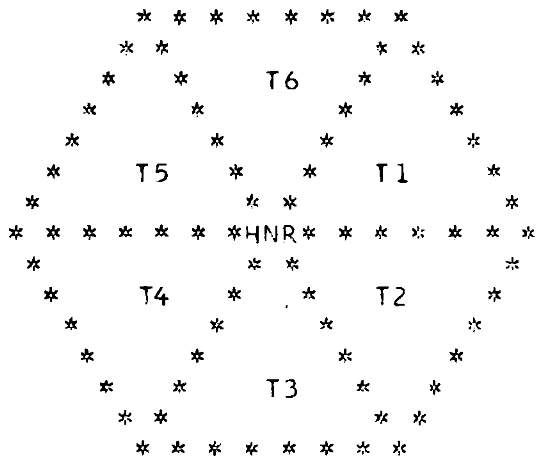
DIMENSION SPACE: 16520 BYTES

THE LOCATION OF HEXAGONS

1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31 33 35
/ /

1- * 1 * * 1 * * 1 * * 1 * * 1 * * 9 * * 2 * * 2 * * 2 * * 3 * * 3 * * 3
- 1 * * 1 * * 1 * * 1 * * 1 * * 1 * * 2 * * 2 * * 2 * * 3 * * 3 * * 3 *
3- * * 1 * * 1 * * 1 * * 1 * * 1 * * 1 * * 17 * * 2 * * 20 * * 3 * * 3 * *
- * 1 * * 1 * * 1 * * 1 * * 1 * * 1 * * 4 * * 2 * * 2 * * 3 * * 3 * * 3
5- 1 * * 1 * * 1 * * 1 * * 6 * * 1 * * 11 * * 4 * * 2 * * 2 * * 3 * * 3 *
- * * 1 * * 1 * * 1 * * 5 * * 1 * * 1 * * 4 * * 2 * * 2 * * 3 * * 3 * *
7- * 1 * * 1 * * 1 * * 8 * * 5 * * 1 * * 1 * * 16 * * 2 * * 21 * * 3 * * 3
- 1 * * 1 * * 1 * * 1 * * 5 * * 1 * * 1 * * 2 * * 2 * * 3 * * 3 * * 3 *
9- * * 1 * * 1 * * 1 * * 1 * * 7 * * 1 * * 12 * * 2 * * 20 * * 3 * * 3 * *
- * 1 * * 1 * * 1 * * 1 * * 1 * * 1 * * 2 * * 2 * * 2 * * 3 * * 3 * * 3
11- 1 * * 1 * * 6 * * 1 * * 1 * * 1 * * 9 * * 2 * * 2 * * 2 * * 3 * * 3 *
- * * 1 * * 5 * * 1 * * 1 * * 1 * * 1 * * 2 * * 2 * * 2 * * 3 * * 3 * *
13- * 1 * * 8 * * 5 * * 1 * * 1 * * 1 * * 1 * * 2 * * 2 * * 21 * * 3 * * 3
- 1 * * 1 * * 5 * * 1 * * 1 * * 1 * * 1 * * 2 * * 2 * * 3 * * 3 * * 3 *
15- * * 1 * * 1 * * 7 * * 1 * * 1 * * 1 * * 13 * * 2 * * 20 * * 3 * * 3 * *
- * 1 * * 1 * * 1 * * 1 * * 1 * * 1 * * 4 * * 2 * * 2 * * 3 * * 3 * * 3
17- 10 * * 1 * * 1 * * 1 * * 1 * * 1 * * 14 * * 4 * * 2 * * 2 * * 3 * * 3 *
- * * 1 * * 1 * * 1 * * 1 * * 1 * * 2 * * 4 * * 2 * * 2 * * 3 * * 3 * *
19- * 2 * * 15 * * 1 * * 10 * * 1 * * 19 * * 2 * * 16 * * 2 * * 21 * * 3 * * 3
- 2 * * 4 * * 1 * * 2 * * 1 * * 4 * * 2 * * 2 * * 2 * * 3 * * 3 * * 3 *
21- * * 18 * * 4 * * 12 * * 2 * * 14 * * 4 * * 2 * * 2 * * 20 * * 3 * * 3 * *
- * 2 * * 4 * * 2 * * 2 * * 2 * * 4 * * 2 * * 2 * * 2 * * 3 * * 3 * * 3
23- 2 * * 2 * * 16 * * 2 * * 2 * * 2 * * 16 * * 2 * * 2 * * 2 * * 3 * * 3 *
- * * 2 * * 2 * * 2 * * 2 * * 2 * * 2 * * 2 * * 2 * * 2 * * 3 * * 3 * *
25- * 2 * * 2 * * 2 * * 2 * * 2 * * 2 * * 2 * * 2 * * 2 * * 21 * * 3 * * 3
- 2 * * 2 * * 2 * * 2 * * 2 * * 2 * * 2 * * 2 * * 2 * * 3 * * 3 * * 3 *
27- * * 19 * * 2 * * 19 * * 2 * * 19 * * 2 * * 19 * * 2 * * 21 * * 3 * * 3 * *
- * 3 * * 2 * * 3 * * 2 * * 3 * * 2 * * 3 * * 2 * * 3 * * 3 * * 3 * * 3
29- 3 * * 3 * * 21 * * 3 * * 21 * * 3 * * 21 * * 3 * * 21 * * 3 * * 3 * * 3 *
- * * 3 * * 3 * * 3 * * 3 * * 3 * * 3 * * 3 * * 3 * * 3 * * 3 * * 3 * *
31- * 3 * * 3 * * 3 * * 3 * * 3 * * 3 * * 3 * * 3 * * 3 * * 3 * * 3 * * 3
- 3 * * 3 * * 3 * * 3 * * 3 * * 3 * * 3 * * 3 * * 3 * * 3 * * 3 * * 3 *
33- * * 3 * * 3 * * 3 * * 3 * * 3 * * 3 * * 3 * * 3 * * 3 * * 3 * * 3 * *
- * 3 * * 3 * * 3 * * 3 * * 3 * * 3 * * 3 * * 3 * * 3 * * 3 * * 3 * * 3
35- 3 * * 3 * * 3 * * 3 * * 3 * * 3 * * 3 * * 3 * * 3 * * 3 * * 3 * * 3 *

THE MATERIAL SPECIFICATION OF HEXAGONS



HNR	T1	T2	T3	T4	T5	T6
1	1	1	1	1	1	1
2	2	2	2	2	2	2
3	3	3	3	3	3	3
4	4	4	4	4	4	4
5	5	5	5	5	5	5
6	1	1	5	5	1	1
7	1	1	1	1	5	5
8	5	5	1	1	1	1
9	2	2	1	1	1	1
10	1	1	2	2	1	1
11	4	4	1	1	1	1
12	2	2	2	2	1	1
13	2	2	4	4	1	1
14	4	4	2	2	1	1
15	1	1	4	4	1	1
16	2	2	2	2	4	4
17	2	2	4	4	2	2
18	4	4	2	2	2	2
19	2	2	3	3	2	2
20	3	3	2	2	2	2
21	3	3	3	3	2	2

2. The Description of the HEXI-22 and HEXI-23 Programmes

As was mentioned early in order to simplify the preparation of the HEXAGA-II input data for reactor problems with a fine mesh refinement two auxiliary programmes HEXI-22 and HEXI-23 are available. Both programmes serve to reproducing the first part of the HEXAGA-II input data (concerned with the description of the material-geometrical configuration of point mesh) for a given reactor problem in which the step of uniform triangular mesh is decreased by factor 2 in the case of HEXI-22 and by factor 3 for HEXI-23. They use the same input data as the HEXAGA-II input data without introducing any additional input information. Each HEXI output can be used as a new HEXI input. Thus, having the HEXAGA-II input data describing a given reactor problem with the minimum number of mesh points and using an arbitrary combination of output/input from HEXI-22 and -23 we can produce the HEXAGA-II input data for arrangements of mesh points for this problem with the step of mesh decreased by the following factors: $2^i \cdot 3^k$ for arbitrary integers $i,k \geq 0$.

In principle, with the creation of a new HEXAGA-II input data all changes of data are concerned with the first part of HEXAGA-II input data describing the material-geometrical configuration of triangular mesh (card sets from 1/ to 3/). Therefore, HEXI-22 and -23 can be only used for producing the first part of the HEXAGA-II input data. However, if the second part of input data specifing group constants, logarithmic boundary parameters α and iteration strategy parameters (card sets from 4/ to 6/) are included to the HEXI input then these data are also reproduced by HEXI without any changes.

IX. REMARKS ON THE USE OF HEXAGA-II

Since HEXAGA-II is a programme based on a relatively new iterative method of solution and not experienced by many users, it seems reasonable to include some indications helpful for users.

In all versions of HEXAGA-II there exists the input check of 60- and 30-degree symmetry of solution and if required symmetry of solution is not satisfied in HEXAGA-II-60 or -30 for a given problem, programme is stopped with printing information about the first met mesh point at which an expected symmetry did not occur. It is possible to use HEXAGA-II-120 for problems with 60- and 30-degree symmetry and HEXAGA-II-60 for 30-degree symmetry, however, in this case recommendations for using the proper version of HEXAGA-II for next calculations of this problem are printed in the output.

In reactor problems solved by means of HEXAGA-II for the first time, it is recommended to use the iteration strategy selected by the programme putting in the input data MAXO = 50 or 100, MAXI = MINI = 1, NOMEGA = 2 and OMS = 1.5. With the above values of input parameters the programme finds the number of inner iterations per outer iteration and relaxation factors $\Omega_\beta = \Omega_\phi = \bar{\Omega}$ as a function of the spectral radius of iteration matrix. In reactor problems which can be solved by HEXAGA-II with 50 ÷ 100 outer iterations the iteration strategy selected by the programme is very often sufficient and close to the optimum. In subsequent calculations of a given problem and differing with small changes of material-geometrical configuration the estimate of $\bar{\Omega}$, MAXI and MINI (MAXI = MINI) by the programme can be avoided by putting in the input data: NOMEGA = 0 and the values of $\bar{\Omega}$, MAXI and MINI taken from previous calculations. Moreover, user can try to check or find the optimum iteration strategy by introducing insignificant changes of the values of $\bar{\Omega}$, MAXI and MINI in the relation to those used previously and the comparison of obtained results. However, it should be remembered that as was shown in Chapter VII.3. only a few (maximum 3 ÷ 5) inner iterations per outer iteration (considered as equivalent to the Gaussian direct method) provides the best iteration strategy.

In the reactor problem presented in Chapter VII it was observed that without the acceleration of convergence of sources ($\omega_s = 1$) about 20 outer iterations allow to calculate k_{eff} with the relative accuracy less than 10^{-6}. The application of the acceleration of sources does not provide a greater reduction of the number of outer iterations for this problem. However, in some problems, in which the ratio of k_{eff} to the next (greatest in moduli) eigenvalue is very close to unity, a very slow convergence of k_{eff} occurs and the acceleration of the power source method becomes an important problem. In HEXAGA-II outer iterations are accelerated by means of the usual relaxation method (see Chapter III.6.) where the value $\omega_s = 1.5$ (OMS in the input) is recommended for using in all problems. In one example, typical for a modular design of a large heterogeneous LMFBR, described by 1225 mesh points in 120-degree parallelogram using $\Omega_\beta = \Omega_\phi = \Omega \simeq 1.14$ estimated by the programme, $\omega_s = 1$ and the convergence criteria $\varepsilon_\phi \leq 10^{-5}$ and $\varepsilon_{k_{eff}} \leq 10^{-6}$ it was possible to obtain the solution after 340 outer iterations and only with the assumption of one inner iteration per outer iteration. The value of $\Omega = \Omega_\beta = \Omega_\phi$ found experimentally which minimizes the number of outer iterations to 82 is equal to 1.1825 (but with $\omega_s = 1$). It is a well known effect of influence of increased values of relaxation factor over the optimum value in inner iterations on the acceleration of convergence of outer iterations. The same result was obtained with using $\bar{\Omega} \simeq 1.13$ (as close to the optimum value) but with $\omega_s = 1.5$. It is interesting to notice that the above results could be obtained only with the assumption one inner/ outer iteration. Using 2 or more inner/outer iterations caused always a drastic decrease of the rate of convergence. In such problems, like this, it is recommended to use only one inner/outer iteration by putting in the input data MAXI = 1 and MINI = 2 and for estimating $\bar{\Omega}$ by the programme NOMEGA = 2 with $\omega_s = 1.5$ for all problems.

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