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K. Kobayashi
Institut für Neutronenphysik und Reaktortechnik
Projekt Nukleare Sicherheitsforschung

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A Code for the Solution of the Multigroup Neutron Transport Equation in x-y Geometry by a Spherical Harmonics Method of General Order

Keisuke Kobayashi*

*On leave from Department of Nuclear Engineering,
Kyoto University, Yoshida, Kyoto, Japan

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Abstract

The code PLXY solves the multigroup neutron transport equation by the spherical harmonics (P_L) method for two-dimensional x-y geometry allowing a general order (L) of approximation by the spherical harmonics functions. There exists no principal limit for the order L of the spherical harmonics expansion except the practical limitations for the size of the memory and the computation time of the available computer. Within the group anisotropic scattering cross-section is taken into account with higher order approximation, but the slowing-down cross-section and the external source as well as fission neutrons are presently for simplicity reasons assumed to be isotropic in the laboratory system. The explicit form of the equations, the discretization scheme for the mesh-edged finite difference solution scheme, a detailed explanation of the computer program and the format of the input data are given together with sample problems.

PLXY, Ein Rechenprogramm zur Lösung der Multigruppen-Neutronentransportgleichung in x-y Geometrie nach einer Kugelflächenfunktionsmethode beliebiger Ordnung

Zusammenfassung

Das Rechenprogramm PLXY löst die Multigruppen-Neutronen-Transport-Gleichung mit Hilfe der Kugelfunktions- (P_L-) Methode in zweidimensionaler Rechtecks- (xy-) Geometrie. Für die Ordnung L der Reihenentwicklung nach Kugelflächenfunktionen gibt es dabei keine prinzipielle obere Grenze außer den in der praktischen Anwendung auftretenden Beschränkungen bezüglich Speicherkapazität und Rechenzeit der verfügbaren Rechenanlage. In der zur Zeit existierenden Programmfassung wird aus Vereinfachungsgründen angenommen, daß in jeder Energiegruppe die externe Quelle, die Spaltneutronenverteilung und die Einstreuquellen aus anderen Energiegruppen eine isotrope Winkelverteilung im Laborsystem aufweisen; lediglich bei der Streuung innerhalb der gleichen Energiegruppe kann eine Anisotropie der Streuung durch die Verwendung höherer Momente des Streukerns berücksichtigt werden. Der Formalismus des Lösungsverfahrens und das Gleichungssystem zur Behandlung des Problems in der diskretisierten Form nach einem Finite-Differenzen Verfahren mit örtlichen Stützstellen an den Maschenrändern (mesh-edged) werden dargestellt. Außerdem wird das zugehörige Rechenprogramm einschließlich der benötigten Eingabegrößen beschrieben. Die Anwendung des Codes wird anhand einfacher Beispielprobleme verdeutlicht.

Preface

Most of the work in improving and implementing the PLXY code and in preparing the present report describing this code was done during a stay of the author at KfK in 1985.
In the final phase of testing the code, a peculiar problem was discovered for a particular case containing a low density region (approximately void) at the outer surface of the reactor configuration. This difficulty could not be solved before the author returned to his home institution, Kyoto University. Therefore, the publication of the report was postponed.

Although the problem appeared to be not too severe, it has taken some time to find the reason which caused the difficulties. To avoid possible misunderstanding and suspicion of potential users of the code, it should be emphasized that, due to the nature of the problem, the mentioned trouble was unimportant and of minor significance for most types of practical applications but was a certain challenge from a scientific point of view.

Detailed investigations showed that the difficulties were basically caused by using a too low order of the spherical harmonics expansion in the early test applications. If a sufficiently high order is used and if a refined spatial discretization scheme is applied (9-point difference formula at internal interfaces and external boundaries instead of 5-point difference formula usually applied at interior points), no difficulties were encountered any more even for this fairly crucial case which may be characterized as "void problem" and which initially prevented completion of the work at the intended date.

From the point of view of finding and checking suitable solution methods for complicated and severe numerical problems, it was no waste of time to be concerned with that particular case for a fairly long time. Dealing with it increased considerably the knowledge and experience of all who were involved in this study.

The code and the report were completed during a short stay of the author at KfK in 1990. The author thanks Professor Keßler, INR, for the opportunity to finish the work during the recent stay; he also gratefully acknowledges the support of Dr. Buckel and Dr. Kiefhaber and their continuous interest in the subject and appreciates their assistance and encouragement during the lengthy phase of investigations and their efforts which enabled the successful completion of the code and the report.

COMPUTER PROGRAM ABSTRACT

1. Name or Designation of Program: PLXY (VERSION 2)
   A Multigroup Neutron Transport Code in x-y Geometry by the Spherical Harmonics Method

2. Computer for which the Program is Designed:
   IBM/M3081, SIEMENS/M7890, and FACOM-M200 and compatibles

3. Nature of Physical Problem Solved:
   The stationary multigroup neutron transport equation is solved for two-dimensional x-y geometry by the spherical harmonics method allowing a general order of approximation. The adjoint equation can also be solved in the case of the criticality problem. Higher order scattering within the group is permitted, however, the slowing down scattering and external source are assumed in the present version to be isotropic.

4. Method of Solution:
   The angular flux is expanded into spherical harmonics functions, and the second order differential equations for the even moments of the angular flux are solved by the mesh edged finite difference approximation. The whole set of equations is solved by three iterative schemes, the inner iteration to solve the 9- or 5-point finite difference equations, the middle iteration to solve the equation for lower order moments to higher order and the source iteration method to solve multigroup problems. In the code, there is no limit for the order of the approximation L of the P_L approximation. In the reference version a 5-point mesh-edged discretization scheme is used inside homogeneous material regions whereas at the interfaces and outer boundaries a 9-point scheme is used.

5. Restrictions on the Complexity of the Problem:
   Variable dimensions are used for nearly all arrays so that the size of a problem is only restricted by the maximum region of the computer on economical viewpoints. At the outer boundary, either the reflective or the vacuum boundary conditions (zero-condition) can be specified. In case of vacuum boundary condition, a pure absorber of the thickness of several mean free paths should be added to the original configuration. In the present version, no up-scattering is considered. It is assumed that fission and external source neutrons and the slowing down neutrons are emitted with an isotropic distribution in the laboratory system.

6. Typical Running Time:
For a 4-energy group criticality problem with (16+16+8)x(16+16+8) mesh points, the CPU times are 2, 8, 16 and 27 sec by P1, P3, P5 and P7 approximations, respectively, with FACOM M230 computer.

7. Unusual Features of the Program:
Successive over relaxation method is used for the inner, middle and outer iterations, however, the acceleration factors must be specified by the user as input data. Only the even order moments of angular flux are available in the present version.

8. Related and Auxiliary Programs:
CROSS, the FORTRAN program to prepare a group cross section set for PLXY code from the group constants file SIGMN of KfK INR.

9. Status:
Tested.

10. References:

1.K. Kobayashi, H. Ohigawa and H. Yamagata, "The Spherical Harmonics Method for the Multigroup Transport Equation in x-y Geometry", Ann. Nucl. Energy, 13, 663 (1986)

2.K. Kobayashi, "PLXY, A Code for the Solution of the Multigroup Neutron Transport Equation in x-y Geometry by a Spherical Harmonics Method of General Order", KfK-4708, (1991).

11. Machine Requirements:
PLXY requires 164 K bytes plus dynamically allocated space for working arrays. Two files (Disk or Tape) are used.

12. Programming Language Used:
FORTRAN 77

13. Operating System/Monitor under which Program is Executed:
IBM OS-MVS and compatible systems

14. Any Other Programming or Operating Information:
None.

15. Name and Establishment of Authors:
K. Kobayashi, H. Ohigawa and H. Yamagata
Department of Nuclear Engineering, Kyoto University, Yoshida, Kyoto, Japan

16. Material Available:
Source Deck, Sample Problems, Sample Output and JCL are available from Institut für Neutronenphysik und Reaktortechnik, Kernforschungszentrum Karlsruhe.

Table of Contents

I. Introduction

Usually, the multigroup neutron transport equation is solved by the discrete ordinate method or S_N-method. The advantage of this method is that the equation is so simple, that computer programs of a general order N of approximation /1/ can be made without difficulties. However, the discrete ordinate method has a certain disadvantage, namely, the possible occurrence of the ray effect for problems in two- and three-dimensional geometries /2/. On the other hand, the spherical harmonics method (P_L-method) has the advantage that the ray effect does not occur. However, the spherical harmonics equations are very complicated and it has been difficult to make a computer code of general order L of approximation.

Fletcher has overcome this difficulty by making use of a computer program to derive the spherical harmonics equation and succeeded first in making a computer program of general order of P_L approximations /3, 4, 5/. However, he used an approximation that all higher order expansion coefficients of scattering cross-section take the same values as the first order's in order to make the equation simple.

A computer program of the spherical harmonics method for a general order of approximation is also developed by using the semi-discrete ordinate equation /6/. However, also in this code, the same approximation as Fletcher's for the scattering cross-section was used to make the code simple. Although this equation is fairly simple, the scattering cross section is given in the right-hand side of the equation, which must be recalculated during the iteration calculation, which makes the convergence rate slower when the scattering cross-section is large similar to the case of the discrete ordinate method.

This difficulty may be overcome by using the synthesis acceleration method developed by Morel /7/, McCoy and Larsen /8/, where the solution of the diffusion equation modified with some additional differential terms is made use of. However, it seems that their synthesis acceleration method works well at present, only if the scattering cross-section is isotropic or linear anisotropic.

In the present formulation, the higher order within-group scattering contribution is taken into account explicitly, and this term is incorporated in the left-hand side of the equation as in the case of the diffusion equation. Therefore, the convergence rate of the iteration calculation should be fast independent of the magnitude of the scattering cross-section. For simplicity, the slowing down, the fission and the external sources are assumed to be isotropic in the laboratory system. The resulting equation has the form of the second order differential equation for the spherical harmonics moments, whose left-hand side is similar to that of the diffusion equation. In the right-hand side of the equation, there are the differential terms of the higher and the lower order moments, which couple the equations of the different orders. These equations are solved from lower order to higher order moments by the successive over relaxation method.

For the numerical solution, the differential equations are approximated by the standard mesh edged finite difference equations. This approximation may use more computation time than the sophisticated nodal method, however, the solution will converge monotonically without difficulty and may, therefore, be used as a standard solution for comparison purposes, e.g. with results of codes using less accurate but more efficient solution algorithms. In some sample calculations, the present code gives more accurate results using even less computation time than the discrete ordinate method /9/.

The mathematical and numerical methods were already described in Ref. /9/. Then, in Chap. II, only a brief summary of the present spherical harmonics method is given. An explicit form of the finite difference equation is given in Appendix A.

In Chap. III, detailed descriptions for the code and input data preparations are given, and in Appendix B, sample problem input and output are shown.

II. Method of Solution

1. Spherical Harmonics Method

The details of the derivation of the spherical harmonics equation were presented in Ref. /9/. Here, a brief summary will be given.

The multigroup neutron transport equation which should be solved is

$$\Omega\nabla f_g(\mathbf{r},\Omega) + \Sigma_{tg} f_g(\mathbf{r},\Omega) = \int d\Omega' \Sigma_{sg}(\Omega \leftarrow \Omega') f_g(\mathbf{r},\Omega') + S_g(\mathbf{r},\Omega) \quad , \tag{1}$$

where Ω and g are a unit vector of the direction and group index, and Σ_{tg} and $\Sigma_{sg}(\Omega \leftarrow \Omega')$ are the total and the scattering cross-section from the direction Ω' to Ω in g-th group, respectively. The f and S are the angular flux and source term, respectively. Notations which are not explained here are the same as those used in Ref. /9/. In the source term S, the slowing down from other groups and fission source are included.

The flux and source terms are expressed as a sum of even and odd terms indicated by the suffixes "e" and "d" with respect to the angular direction. For simplicity, group index g will be omitted hereafter. The even and odd angular fluxes and scattering cross-section are expanded by the spherical harmonics functions as follows:

$$f^e(\mathbf{r},\Omega) = \frac{1}{4\pi} \sum_{\substack{\ell=0 \\ \text{even}}}^{L-1} (2\ell+1) \sum_{m=-\ell}^{\ell} f^e_{\ell m}(\mathbf{r}) Y_{\ell m}(\Omega) \quad , \tag{2}$$

$$f^d(\mathbf{r},\Omega) = \frac{1}{4\pi} \sum_{\substack{\ell=1 \\ \text{odd}}}^{L} (2\ell+1) \sum_{m=-\ell}^{\ell} f^d_{\ell m}(\mathbf{r}) Y_{\ell m}(\Omega) \quad , \tag{3}$$

$$\Sigma_{sg}(\Omega \leftarrow \Omega') = \frac{1}{4\pi} \sum_{\ell=0}^{\infty} (2\ell+1) \Sigma_{s\ell g} \sum_{m=-\ell}^{\ell} Y_{\ell m}(\Omega) Y^*_{\ell m}(\Omega') \quad , \tag{4}$$

Here, the spherical harmonics functions are defined as

$$Y_{\ell m}(\Omega) = Y_{\ell m}(\mu) e^{im\phi} \quad , \quad \mu = \cos\theta \tag{5}$$

$$Y_{\ell m}(\mu) = \left[\frac{(\ell-m)!}{(\ell+m)!}\right]^{1/2} P_{\ell m}(\mu) \ , \tag{6}$$

where $P_{\ell m}(\mu)$ is the associated Legendre function.

Using the expansions of Eqs. (2), the spherical harmonics equation can be written in the form,

$$g^{d}_{\ell m}(\mathbf{r}) + \Sigma_{\ell} f^{e}_{\ell m}(\mathbf{r}) = S^{e}_{\ell m}(\mathbf{r}) \tag{7a}$$

$$g^{e}_{\ell m}(\mathbf{r}) + \Sigma_{\ell} f^{d}_{\ell m}(\mathbf{r}) = S^{d}_{\ell m}(\mathbf{r}) \tag{7b}$$

where $S^{e}_{\ell m}(\mathbf{r})$ is the even moment of the source term $S(\mathbf{r})$ expanded similar to Eq. (2), $\Sigma_{\ell} = \Sigma_t - \Sigma_{s\ell}$, and

$$g^{a}_{\ell m}(\mathbf{r}) \equiv \int d\Omega Y^{*}_{\ell m}(\Omega)\, \Omega \nabla f^{a}(\mathbf{r}, \Omega), \quad a = e \ \text{ or } \ d \tag{8}$$

The cross section Σ_{ℓ} is assumed not to be zero. Using the recurrence relation for the spherical harmonics functions, $g^{a}_{\ell m}(\mathbf{r})$ can be expressed as

$$\begin{aligned} g^{a}_{\ell m}(\mathbf{r}) = \frac{1}{2\ell+1} \Big[& \partial_{-}\left(-\alpha_{\ell,m-1} f^{a}_{\ell-1,m-1} + \beta_{\ell,m-1} f^{a}_{\ell+1,m+1} \right) \\ & + \partial_{+}\left(\beta_{\ell,m+1} f^{a}_{\ell-1,m+1} - \alpha_{\ell,m+1} f^{a}_{\ell+1,m+1} \right) \\ & + \partial_{z}\left(\Gamma_{\ell m} f^{a}_{\ell-1,m} + \Gamma_{\ell+1,m} f^{a}_{\ell+1,m} \right) \Big], \quad a = e \ \text{ or } \ d \end{aligned} \tag{9}$$

where

$$\partial_{+} = \frac{\partial}{\partial x} + i\frac{\partial}{\partial y}, \quad \partial_{-} = \frac{\partial}{\partial x} - i\frac{\partial}{\partial y}, \quad \partial_{z} = \frac{\partial}{\partial z} \tag{10}$$

$$\alpha_{\ell m} = \frac{1}{2}\left[(\ell+m)(\ell+m+1)\right]^{1/2}, \quad \beta_{\ell m} = \alpha_{\ell,-m}, \quad \Gamma_{\ell m} = \left[(\ell+m)(\ell-m)\right]^{1/2}. \tag{11}$$

Solving Eq. (7b) for $f^d_{\ell m}(\mathbf{r})$ and substituting this into Eq. (7a) by using Eq. (9), we obtain the second order differential equation for the even moment $f^e_{\ell m}(\mathbf{r})$ in x - y - z geometry.

$$- \sum_{k,k'=-1}^{1}{}' \left[a^{k}_{\ell,m-1}\, a^{-k'}_{\ell+k,m}\, \partial_{-} \frac{1}{\Sigma_{\ell+k}} \partial_{+} + a^{-k}_{\ell,m+1}\, a^{k'}_{\ell+k,m}\, \partial_{+} \frac{1}{\Sigma_{\ell+k}} \partial_{-} \right.$$

$$\left. + \Gamma^{k}_{\ell m}\, \Gamma^{k'}_{\ell+k,m}\, \partial_{z} \frac{1}{\Sigma_{\ell+k}} \partial_{z} \right] f^{e}_{\ell+k+k',m}(\mathbf{r})$$

$$- \sum_{k,k'=-1}^{1}{}' \left(a^{k}_{\ell,m-1}\, a^{k'}_{\ell+k,m-2}\, \partial_{-} \frac{1}{\Sigma_{\ell+k}} \partial_{-} \right) f^{e}_{\ell+k+k',\,m-2}(\mathbf{r})$$

$$- \sum_{k,k'=-1}^{1}{}' \left(a^{-k}_{\ell,m+1}\, a^{-k'}_{\ell+k,m+2}\, \partial_{+} \frac{1}{\Sigma_{\ell+k}} \partial_{+} \right) f^{e}_{\ell+k+k',\,m+2}(\mathbf{r})$$

$$- \sum_{k,k'=-1}^{1}{}' \left(a^{k}_{\ell,m-1}\, \Gamma^{k'}_{\ell+k,m-1}\, \partial_{-} \frac{1}{\Sigma_{\ell+k}} \partial_{z} + \Gamma^{k}_{\ell m}\, a^{k'}_{\ell+k,m-1}\, \partial_{z} \frac{1}{\Sigma_{\ell+k}} \partial_{-} \right) f^{e}_{\ell+k+k',\,m-1}(\mathbf{r})$$

$$- \sum_{k,k'=-1}^{1}{}' \left(a^{-k}_{\ell,m+1}\, \Gamma^{k'}_{\ell+k,m+1}\, \partial_{+} \frac{1}{\Sigma_{\ell+k}} \partial_{z} + \Gamma^{k}_{\ell m}\, a^{-k'}_{\ell+k,m+1}\, \partial_{z} \frac{1}{\Sigma_{\ell+k}} \partial_{+} \right) f^{e}_{\ell+k+k',\,m+1}(\mathbf{r})$$

$$+ \Sigma_{\ell} f^{e}_{\ell m}(\mathbf{r}) = S^{e}_{\ell m}(\mathbf{r}) \qquad (12)$$

where $S^d_{\ell m}(\mathbf{r}) = 0$, i.e. all old terms of the coefficients of all sources (including external sources and slowing down group transfer neutrons) vanish,which means that an isotropic distribution of all sources is assumed, and

$$\alpha^{1}_{\ell m} = \beta_{\ell m}/(2\ \ell+1)\ ,\ \alpha^{-1}_{\ell m} = -\ \alpha_{\ell m}/(2\ \ell+1) \tag{13a}$$

$$\Gamma^{1}_{\ell m} = \Gamma_{\ell+1,m}/(2\ \ell+1)\ ,\ \Gamma^{-1}_{\ell m} = \Gamma_{\ell m}/(2\ \ell+1) \tag{13b}$$

The prime in the summation means that the summations over k and k' do not include the term $k = k' = 0$.

In the case of two-dimensional x - y geometry, the following relation holds due to the symmetry, with respect to the x - y plane:

$$f(\mathbf{r}, \theta, \phi) = f(\mathbf{r}, \pi-\theta, \phi)\ . \tag{14}$$

From this relation, we obtain the result that the moments vanish for $\ell + m$ = odd, so that the integer m of $f^{e}_{\ell m}(\mathbf{r})$ is restricted to even values. Therefore, the 4-th and 5-th terms of the left hand side of Eq. (12) vanish, since they include only moments with odd m.

Rewriting Eq. (12) in a real form by using Eqs. (10), (11), and(13), we obtain

$$
\begin{aligned}
&-\sum_{n=-1}^{1}{}' \left[\left(D^{\ell+n}_{xx} + D^{\ell+n}_{yy}\right) a^{no}_{\ell m} + D^{\ell+n}_{zz}\, c^{no}_{\ell m}\right] f^{ec}_{\ell m}(\mathbf{r}) + \Sigma_{\ell}\, f^{ec}_{\ell m}(\mathbf{r}) = S^{ec}_{\ell m}(\mathbf{r}) \\
&-\sum_{n=-1}^{1}{}' \left(D^{\ell+n}_{xx} + D^{\ell+n}_{yy}\right) b^{no}_{\ell m}\, f^{ec}_{\ell+2n,m}(\mathbf{r}) \\
&-\sum_{n=-1}^{1}{}' \left(D^{\ell+n}_{xx} - D^{\ell+n}_{yy}\right)\left(a^{n,-1}_{\ell m}\, f^{ec}_{\ell,m-2}(\mathbf{r}) + a^{n1}_{\ell m}\, f^{ec}_{\ell,m+2}(\mathbf{r}) - b^{n,-1}_{\ell m}\, f^{ec}_{\ell+2n,m-2}(\mathbf{r}) - b^{n1}_{\ell m}\, f^{ec}_{\ell+2n,m+2}(\mathbf{r})\right) \\
&+\sum_{n=-1}^{1}{}' \left(D^{\ell+n}_{xy} + D^{\ell+n}_{yx}\right)\left(a^{n,-1}_{\ell m}\, f^{es}_{\ell,m-2}(\mathbf{r}) - a^{n1}_{\ell m}\, f^{es}_{\ell,m+2}(\mathbf{r}) - b^{n,-1}_{\ell m}\, f^{es}_{\ell+2n,m-2}(\mathbf{r}) + b^{n1}_{\ell m}\, f^{es}_{\ell+2n,m+2}(\mathbf{r})\right) \\
&-\sum_{n=-1}^{1}{}' \left(D^{\ell+n}_{xy} - D^{\ell+n}_{yx}\right) a^{on}_{\ell m}\, f^{es}_{\ell m}(\mathbf{r})\ ,
\end{aligned}
$$

$$\text{for } m = 0, 2, \ldots, \ell \text{ and } \ell = 0, 2, 4, \ldots, L-1 \tag{15}$$

$$- \sum_{n=-1}^{1}{}' \left[\left(D_{xx}^{\ell+n} + D_{yy}^{\ell+n} \right) a_{\ell m}^{no} + D_{zz}^{\ell+n} c_{\ell m}^{no} \right] f_{\ell m}^{es}(\mathbf{r}) + \Sigma_\ell f_{\ell m}^{es}(\mathbf{r}) = S_{\ell m}^{es}(\mathbf{r})$$

$$- \sum_{n=-1}^{1}{}' \left(D_{xx}^{\ell+n} + D_{yy}^{\ell+n} \right) b_{\ell m}^{no} f_{\ell+2n,m}^{es}(\mathbf{r})$$

$$- \sum_{n=-1}^{1}{}' \left(D_{xx}^{\ell+n} - D_{yy}^{\ell+n} \right) \left(a_{\ell m}^{n,-1} f_{\ell,m-2}^{es}(\mathbf{r}) + a_{\ell m}^{n1} f_{\ell,m+2}^{es}(\mathbf{r}) - b_{\ell m}^{n,-1} f_{\ell+2n,m-2}^{es}(\mathbf{r}) - b_{\ell m}^{n1} f_{\ell+2n,m+2}^{es}(\mathbf{r}) \right)$$

$$- \sum_{n=-1}^{1}{}' \left(D_{xy}^{\ell+n} + D_{yx}^{\ell+n} \right) \left(a_{\ell m}^{n,-1} f_{\ell,m-2}^{ec}(\mathbf{r}) - a_{\ell m}^{n1} f_{\ell,m+2}^{ec}(\mathbf{r}) - b_{\ell m}^{n,-1} f_{\ell+2n,m-2}^{ec}(\mathbf{r}) + b_{\ell m}^{n1} f_{\ell+2n,m+2}^{ec}(\mathbf{r}) \right)$$

$$+ \sum_{n=-1}^{1}{}' \left(D_{xy}^{\ell+n} - D_{yx}^{\ell+n} \right) a_{\ell m}^{on} f_{\ell m}^{ec}(\mathbf{r}) \ ,$$

$$\text{for } m = 2, 4, \ldots, \ell \text{ and } \ell = 2, 4, \ldots, L-1 \tag{16}$$

where the prime in the summation means also that the summation over n does not include the term $n=0$, and

$$f_{\ell m}(\mathbf{r}) = f_{\ell m}^{c}(\mathbf{r}) - i\, f_{\ell m}^{s}(\mathbf{r}) \tag{17}$$

$$D_{xx}^{\ell} = \frac{\partial}{\partial x}\frac{1}{\Sigma_\ell}\frac{\partial}{\partial x}\ ,\ D_{yy}^{\ell} = \frac{\partial}{\partial y}\frac{1}{\Sigma_\ell}\frac{\partial}{\partial y}\ ,\ D_{zz}^{\ell} = \frac{\partial}{\partial z}\frac{1}{\Sigma_\ell}\frac{\partial}{\partial z} \tag{18}$$

$$D_{xy}^{\ell} = \frac{\partial}{\partial x}\frac{1}{\Sigma_\ell}\frac{\partial}{\partial x}\ ,\ D_{yx}^{\ell} = \frac{\partial}{\partial y}\frac{1}{\Sigma_\ell}\frac{\partial}{\partial x} \tag{19}$$

$$a_{\ell m}^{-1,0} = \frac{\alpha_{\ell,m-1}\alpha_{\ell-1,m}}{(2\ell-1)(2\ell+1)} + \frac{\beta_{\ell,m+1}\beta_{\ell-1,m}}{(2\ell-1)(2\ell+1)}\ ,\ a_{\ell m}^{1,0} = \frac{\alpha_{\ell,m+1}\alpha_{\ell+1,m}}{(2\ell+1)(2\ell+3)} + \frac{\beta_{\ell,m-1}\beta_{\ell+1,m}}{(2\ell+1)(2\ell+3)}\ ,$$

$$a_{\ell m}^{0,-1} = \frac{\alpha_{\ell,m-1}\alpha_{\ell-1,m}}{(2\ell-1)(2\ell+1)} - \frac{\beta_{\ell,m+1}\beta_{\ell-1,m}}{(2\ell-1)(2\ell+1)}\ ,\ a_{\ell m}^{0,1} = -\frac{\alpha_{\ell,m+1}\alpha_{\ell+1,m}}{(2\ell+1)(2\ell+3)} + \frac{\beta_{\ell,m-1}\beta_{\ell+1,m}}{(2\ell+1)(2\ell+3)}\ ,$$

$$a_{\ell m}^{1,-1} = \frac{\alpha_{\ell+1,m-2}\beta_{\ell,m-1}}{(2\ell+1)(2\ell+3)}\ ,\qquad a_{\ell m}^{1,1} = \frac{\alpha_{\ell,m+1}\beta_{\ell+1,m+2}}{(2\ell+1)(2\ell+3)}$$

$$a_{\ell m}^{-1,-1} = \frac{\alpha_{\ell,m+1}\beta_{\ell-1,m-2}}{(2\ell-1)(2\ell+1)}\ ,\qquad a_{\ell m}^{-1,1} = \frac{\alpha_{\ell-1,m+2}\beta_{\ell,m+1}}{(2\ell-1)(2\ell+1)} \tag{20}$$

$$b_{\ell m}^{-1,-1} = \frac{\alpha_{\ell,m-1}\alpha_{\ell-1,m-2}}{(2\ell-1)(2\ell+1)},\ b_{\ell m}^{-1,0} = \frac{2\alpha_{\ell,m-1}\beta_{\ell-1,m}}{(2\ell-1)(2\ell+1)},\ b_{\ell m}^{-1,1} = \frac{\beta_{\ell,m+1}\beta_{\ell-1,m+2}}{(2\ell-1)(2\ell+1)},$$

$$b_{\ell m}^{1,-1} = \frac{\beta_{\ell,m-1}\beta_{\ell+1,m+2}}{(2\ell+1)(2\ell+3)},\ b_{\ell m}^{1,0} = \frac{2\alpha_{\ell+1,m}\beta_{\ell,m-1}}{(2\ell+1)(2\ell+3)},\ b_{\ell m}^{1,1} = \frac{\alpha_{\ell,m+1}\alpha_{\ell+1,m+2}}{(2\ell+1)(2\ell+3)} \tag{21}$$

$$c_{\ell m}^{1,0} = \frac{\Gamma_{\ell+1,m}^{2}}{(2\ell+1)(2\ell+3)},\quad c_{\ell m}^{-1,0} = \frac{\Gamma_{\ell m}^{2}}{(2\ell-1)(2\ell+1)} \tag{22}$$

The difference of Eqs. (15) and (16) is in the sign at the front of the operator D_{xy} and D_{yx}, and the replacement of the suffixes "ec" and "es" by "es" and ec", respectively. Eqs. (15) and (16) can be regarded as the equations for moments $f^{ec}{}_{\ell m}(\mathbf{r})$ and $f^{es}{}_{\ell m}(\mathbf{r})$, respectively. Since $f^{es}{}_{\ell m}(\mathbf{r})$ vanishes for $\ell = m = 0$ from the definition of Eq. (2), Eq. (16) begins from $\ell = 2$ and $m = 2$, using the following relations for the moments,

$$f_{\ell,-m}^{ec}(\mathbf{r}) = f_{\ell m}^{ec}(\mathbf{r}),\quad f_{\ell,-m}^{es}(\mathbf{r}) = -f_{\ell m}^{es}(\mathbf{r}) \tag{23}$$

the moments with negative index m can be expressed by the ones with positive m.

If the system is homogeneous, finite and sufficiently long in z-direction, the moments may be approximated as

$$f_{\ell m}^{ea}(\mathbf{r}) \approx f_{\ell m}^{ea}(x,y)\cos B_z z \quad \text{for } a = c \text{ or } s \tag{24}$$

where B_z is a buckling which should be independent of the energy group. If there is an external source, it must have the same form as Eq. (24).
Substituting Eq. (24) into Eqs. (15) and (16), we obtain a set of two dimensional equations which includes a correction for the leakage in z-direction. The resulting equations are almost the same as Eqs. (15) and (16) , where the terms $D^{\ell+n}{}_{zz}$ are no longer present; instead of them the quantity Σ_ℓ has to be replaced by $\Sigma_{\ell m}$ defined as

$$\sum{}_{\ell m} = \Sigma_\ell + \sum_{n=-1}^{1}{}' c_{\ell m}^{no} \frac{1}{\Sigma_{\ell+n}} B_z^2 \tag{25}$$

2. Finite Difference Equation

In order to obtain finite difference equations in x-y geometry, the differential equations (15) and (16) must be integrated in a mesh box in x-y geometry. This can be done more easily by integrating Eq. (7a) over the mesh box with volume V to obtain

$$\int_S dS \int d\Omega \, Y^*_{\ell m}(\Omega)\, \mathbf{n}\Omega \, f^d_{\ell m}(\mathbf{r}, \Omega) + \int_V d\mathbf{r} \, \Sigma_\ell \, f^e_{\ell m}(\mathbf{r}) = \int_V d\mathbf{r} \, S^e_{\ell m}(\mathbf{r}) \qquad (26)$$

where vector **n** is an outward unit vector normal to the surface S. Here, Eq. (26) should be regarded as two dimensional equation in x-y geometry, and the cross section Σ_ℓ should be replaced by $\Sigma_{\ell m}$ of Eq. (25) to include the buckling leakage, if this is necessary. Correspondingly, V means the volume and S the surface of the mesh box shown in Fig. 1 (assuming unit extension in z-direction).

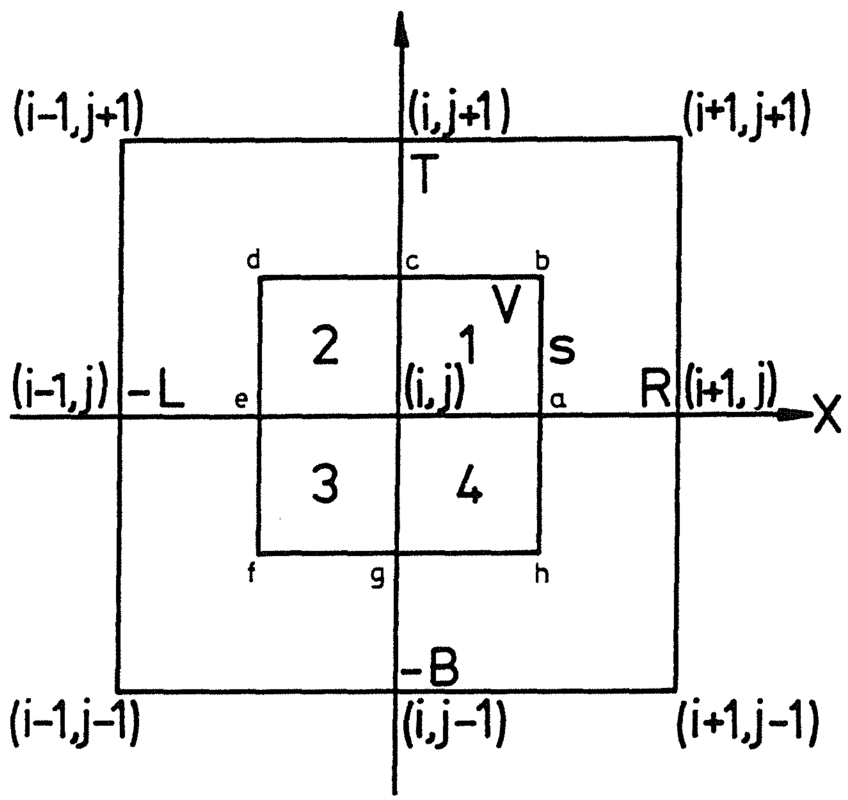


Fig.1 Mesh box in x-y geometry

Comparing Eq. (7a) with Eq. (26), we can see that the first term of the left hand side of Eq. (26) can be obtained by replacing the differential operators D^{ℓ}_{xx} etc. in Eqs. (15) and (16) by the corresponding operators $\hat{D}^{\ell}_{xx}$ etc. defined as follows:

$$\hat{D}^{\ell}_{xx} = \int_S dS\, n_x \frac{1}{\Sigma_\ell} \frac{\partial}{\partial x}, \quad \hat{D}^{\ell}_{yy} = \int_S dS\, n_y \frac{1}{\Sigma_\ell} \frac{\partial}{\partial y}, \tag{27}$$

$$\hat{D}^{\ell}_{xy} = \int_S dS\, n_x \frac{1}{\Sigma_\ell} \frac{\partial}{\partial y}, \quad \hat{D}^{\ell}_{yx} = \int_S dS\, n_y \frac{1}{\Sigma_\ell} \frac{\partial}{\partial x}, \tag{28}$$

Other terms in Eqs. (15) and (16) should be replaced by the following corresponding terms which define operator I):

$$I\Sigma_\ell f_{\ell m}(\mathbf{r}) = \int_V d\mathbf{r}\, \Sigma_\ell f_{\ell m}(\mathbf{r}), \quad IS_{\ell m}(\mathbf{r}) = \int_V d\mathbf{r}\, S_{\ell m}(\mathbf{r}) \tag{29}$$

In order to represent the terms appearing in the operators of Eqs. (27) ~ (29) by the related finite differences at discrete points, we expand the angular moments into Taylor series around the (i, j)-the mesh point as

$$f^{(q)}(x,y) = f^{(q)}_o + f^{(q)}_x x + f^{(q)}_y y + \frac{1}{2} f^{(q)}_{xx} x^2 + \frac{1}{2} f^{(q)}_{yy} y^2 + \frac{1}{2} f^{(q)}_{xy} xy + \frac{1}{2} f^{(q)}_{yx} yx + 0(\Delta^3) \tag{30}$$

Within a region of constant cross sections $f_{xy}(\mathbf{r}) = f_{yx}(\mathbf{r})$, but at interfaces between regions of different materials $f_{xy}(\mathbf{r}) \neq f_{yx}(\mathbf{r})$. The even moments $f_{\ell m}(\mathbf{r})$ are continuous, but their derivatives f_x, f_{xx}, etc. are not continuous when material properties change at internal boundaries between different regions.

Using the notations shown in Fig. 1, the term $\hat{D}_{xx}f$ can be written

$$\hat{D}_{xx} f = \int_h^b \frac{1}{\Sigma} \frac{\partial f}{\partial x} dy + \int_f^d \frac{1}{\Sigma} \frac{\partial f}{\partial x} dy + \int_d^b \frac{1}{\Sigma} \frac{\partial f}{\partial y} dx + \int_f^h \frac{1}{\Sigma} \frac{\partial f}{\partial y} dx\,. \tag{31}$$

In Eq. (30) and in some of the following equations, the indices or suffixes x, ℓ, m, ec, and es are sometimes omitted for simplicity reasons.

Setting $y = y_j$, $x = x_{i+1}$ or $x = x_{i-1}$ in Eq. (30), we obtain

$$\frac{1}{R}\left(f_{i+1,j} - f_{ij}\right) = f_x^{(q)} + \frac{R}{2} f_{xx}^{(q)} + 0(\Delta^2) \text{ , for } q = 1,4 \text{ .} \tag{32}$$

where $R = x_{i+1} - x_i$.

Using Eq. (32), we obtain

$$\int_h^b \frac{1}{\Sigma}\frac{\partial f}{\partial x}\,dy = \frac{1}{\Sigma^{(1)}}\int_a^b dy\left(f_x^{(1)} + f_{xx}^{(1)}x + f_{xy}^{(1)}y + 0\,(\Delta^2)\right)\Bigg|_{x=\frac{R}{2}}$$

$$+ \frac{1}{\Sigma^{(4)}}\int_h^a dy\left(f_x^{(4)} + f_{xx}^{(4)}x + f_{xy}^{(4)}y + 0(\Delta^2)\right)\Bigg|_{x=\frac{R}{2}}$$

$$= \frac{1}{2R}\left(\frac{T}{\Sigma^{(1)}} + \frac{B}{\Sigma^{(4)}}\right)\left(f_{i+1,j} - f_{ij}\right) + \frac{T^2}{8\Sigma^{(1)}} f_{xy}^{(1)} - \frac{B^2}{8\Sigma^{(4)}} f_{xy}^{(4)} + 0(\Delta^3) \text{ ,} \tag{33}$$

where $T = y_{j+1} - y_j$ and $B = y_j - y_{j-1}$.

Repeating similar calculations, we obtain the following results:

$$\hat{D}_{xx}^{\ell} = \overline{D}_{xx}^{\ell} + \delta_{xx}^{\ell} \text{ , } \hat{D}_{yy} = \overline{D}_{yy}^{\ell} + \delta_{yy}^{\ell} \tag{34}$$

$$\hat{D}_{xy}^{\ell} = \overline{D}_{xy}^{\ell} + \delta_{xy}^{\ell} \text{ , } \hat{D}_{yx}^{\ell} = \overline{D}_{yx}^{\ell} + \delta_{yx}^{\ell} \tag{35}$$

where

$$\overline{D}_{xx}^{\ell} = \frac{T}{2\Sigma^{(1)}}\left(f_x^{(1)} + \frac{R}{2} f_{xx}^{(1)}\right) - \frac{T}{2\Sigma^{(2)}}\left(f_x^{(2)} - \frac{L}{2} f_{xx}^{(2)}\right) - \frac{B}{2\Sigma^{(3)}}\left(f_x^{(3)} - \frac{L}{2} f_{xx}^{(3)}\right)$$

$$+ \frac{B}{2\Sigma^{(4)}}\left(f_x^{(4)} + \frac{R}{2} f_{xx}^{(4)}\right) = b^{\ell} f_{i-1,j} - (b^{\ell} + d^{\ell})\, f_{ij} + d^{\ell} f_{i+1,j} \tag{36}$$

$$\overline{D}_{yy} = \frac{R}{2\Sigma^{(1)}}\left(f_y^{(1)} + \frac{T}{2} f_{yy}^{(1)}\right) + \frac{L}{2\Sigma^{(2)}}\left(f_y^{(2)} + \frac{T}{2} f_{yy}^{(2)}\right) - \frac{L}{2\Sigma^{(3)}}\left(f_y^{(3)} - \frac{B}{2} f_{yy}^{(3)}\right)$$

$$- \frac{R}{2\Sigma^{(4)}}\left(f_y^{(4)} - \frac{B}{2} f_{yy}^{(4)}\right) = a^{\ell} f_{i,j-1} - (a^{\ell} + e^{\ell})\, f_{ij} + e^{\ell} f_{i,j+1} \tag{37}$$

$$\delta_{xx} f = \frac{T^2}{8}\left(\frac{1}{\Sigma^{(1)}} f_{xy}^{(1)} - \frac{1}{\Sigma^{(2)}} f_{xy}^{(2)}\right) + \frac{B^2}{8}\left(\frac{1}{\Sigma^{(3)}} f_{xy}^{(3)} - \frac{1}{\Sigma^{(4)}} f_{xy}^{(4)}\right) + 0\,(\Delta^3) \tag{38}$$

$$\delta_{yy} f = \frac{R^2}{8}\left(\frac{1}{\Sigma^{(1)}} f_{xy}^{(1)} - \frac{1}{\Sigma^{(4)}} f_{xy}^{(4)}\right) - \frac{L^2}{8}\left(\frac{1}{\Sigma^{(2)}} f_{xy}^{(2)} - \frac{1}{\Sigma^{(3)}} f_{xy}^{(3)}\right) + 0\,(\Delta^3) \tag{39}$$

$$\begin{aligned}\overline{D}_{xy} = {} & \frac{T}{2\Sigma^{(1)}}\left(f_y^{(1)} + \frac{T}{2} f_{yy}^{(1)} + \frac{R}{2} f_{xy}^{(1)}\right) + \frac{B}{2\Sigma^{(4)}}\left(f_y^{(4)} - \frac{B}{2} f_{yy}^{(4)} + \frac{R}{2} f_{xy}^{(4)}\right) \\ & - \frac{B}{2\Sigma^{(3)}}\left(f_y^{(3)} - \frac{B}{2} f_{yy}^{(3)} - \frac{L}{2} f_{xy}^{(3)}\right) - \frac{T}{2\Sigma^{(2)}}\left(f_y^{(2)} + \frac{T}{2} f_{yy}^{(2)} - \frac{L}{2} f_{xy}^{(2)}\right) + 0\,(\Delta^3)\end{aligned} \tag{40}$$

$$\begin{aligned}\overline{D}_{yx} = {} & \frac{R}{2\Sigma^{(1)}}\left(f_x^{(1)} + \frac{R}{2} f_{xx}^{(1)} + \frac{T}{2} f_{xy}^{(1)}\right) + \frac{L}{2\Sigma^{(2)}}\left(f_x^{(2)} - \frac{L}{4} f_{xx}^{(2)} + \frac{T}{2} f_{xy}^{(2)}\right) \\ & - \frac{L}{2\Sigma^{(3)}}\left(f_x^{(3)} - \frac{L}{2} f_{xx}^{(3)} - \frac{B}{2} f_{xy}^{(3)}\right) - \frac{R}{2\Sigma^{(4)}}\left(f_x^{(4)} + \frac{R}{2} f_{xx}^{(4)} - \frac{B}{2} f_{xy}^{(4)}\right)\end{aligned} \tag{41}$$

$$\delta_{xy} = \frac{T^2}{8}\left(-\frac{1}{\Sigma^{(1)}} f_{yy}^{(1)} + \frac{1}{\Sigma^{(2)}} f_{yy}^{(2)}\right) + \frac{B^2}{8}\left(-\frac{1}{\Sigma^{(3)}} f_{yy}^{(3)} + \frac{1}{\Sigma^{(4)}} f_{yy}^{(4)}\right) + 0\,(\Delta^3) \tag{42}$$

$$\delta_{yx} = \frac{R^2}{8}\left(-\frac{1}{\Sigma^{(1)}} f_{xx}^{(1)} + \frac{1}{\Sigma^{(4)}} f_{xx}^{(4)}\right) + \frac{L^2}{8}\left(\frac{1}{\Sigma^{(2)}} f_{xx}^{(2)} - \frac{1}{\Sigma^{(3)}} f_{xx}^{(3)}\right) + 0\,(\Delta^3) \tag{43}$$

$$a^{\ell} = a^{\ell+} + a^{\ell-}\ , \quad a^{\ell+} = \frac{R}{2B\Sigma_{\ell}^{(4)}}\ , \quad a^{\ell-} = \frac{L}{2B\Sigma_{\ell}^{(3)}}\ , \tag{44}$$

$$b^{\ell} = b^{\ell+} + b^{\ell-}\ , \quad b^{\ell+} = \frac{T}{2L\Sigma_{\ell}^{(2)}}\ , \quad b^{\ell-} = \frac{B}{2L\Sigma_{\ell}^{(3)}}\ , \tag{45}$$

$$d^{\ell} = d^{\ell+} + d^{\ell-}\ , \quad d^{\ell+} = \frac{T}{2R\Sigma_{\ell}^{(1)}}\ , \quad d^{\ell-} = \frac{B}{2R\Sigma_{\ell}^{(4)}}\ , \tag{46}$$

$$e^{\ell} = e^{\ell+} + e^{\ell-}\ , \quad e^{\ell+} = \frac{R}{2T\Sigma_{\ell}^{(1)}}\ , \quad e^{\ell-} = \frac{L}{2T\Sigma_{\ell}^{(2)}}\ , \tag{47}$$

$$(\overline{D}_{xy} + \overline{D}_{yx})f = \frac{1}{2\Sigma^{(3)}} f_{i-1,j-1} - \frac{1}{2\Sigma^{(4)}} f_{i+1,j-1} - \frac{1}{2\Sigma^{(2)}} f_{i-1,j+1} +$$

$$+ \frac{1}{2\Sigma^{(1)}} f_{i+1,j+1} + \frac{1}{2}\left(\frac{1}{\Sigma^{(2)}} + \frac{1}{\Sigma^{(4)}} - \frac{1}{\Sigma^{(1)}} - \frac{1}{\Sigma^{(3)}}\right) f_{ij} \tag{48}$$

$$(\overline{D}_{xy} - \overline{D}_{yx})f = \frac{1}{2}\left(\frac{1}{\Sigma^{(2)}} - \frac{1}{\Sigma^{(3)}}\right) f_{i-1,j} + \frac{1}{2}\left(\frac{1}{\Sigma^{(3)}} - \frac{1}{\Sigma^{(4)}}\right) f_{i,j-1}$$

$$+ \frac{1}{2}\left(\frac{1}{\Sigma^{(1)}} - \frac{1}{\Sigma^{(2)}}\right) f_{i,j+1} + \frac{1}{2}\left(\frac{1}{\Sigma^{(4)}} - \frac{1}{\Sigma^{(1)}}\right) f_{i+1,j} \tag{49}$$

and $L = x_i - x_{i-1}$.

Eqs. (29) become

$$I\Sigma_\ell f_{ij} = \frac{1}{4}\left(RT\Sigma_\ell^{(1)} + LT\Sigma_\ell^{(2)} + LB\Sigma_\ell^{(3)} + BR\Sigma_\ell^{(4)}\right) f_{ij} + 0\,(\Delta^3)\ , \tag{50}$$

$$IS = \frac{1}{4}\left(RTS^{(1)} + LTS^{(2)} + LBS^{(3)} + BRS^{(4)}\right) + 0\,(\Delta^3)\ . \tag{51}$$

In the case of the P_1 approximation, the terms of Eqs. (38) and (39) vanish at the material interface because of the continuity condition for the current, namely

$$\frac{1}{\Sigma_1^{(1)}} \frac{\partial f_{00}^{ec}}{\partial x} = \frac{1}{\Sigma_1^{(2)}} \frac{\partial f_{00}^{ec}}{\partial x}\ ,\ \frac{1}{\Sigma_1^{(3)}} \frac{\partial f_{00}^{ec}}{\partial x} = \frac{1}{\Sigma_1^{(4)}} \frac{\partial f_{00}^{ec}}{\partial x}\ , \tag{52}$$

However, in the general P_L approximation for $L \geq 3$, Eq. (52) does not hold, and then those terms of δ_{xy} , δ_{xx} etc. of Eqs. (38), (39), (42), and (43) do not vanish at the material interface.

Expressing the terms f_{xx}, f_{yy} and f_{xy} by the value at the mesh points, we obtain a corresponding difference equation which has an accuracy of $O(\Delta^3)$.

However, it is impossible to express the differential terms, for example $f^{(1)}{}_{xx}$, by the values at the mesh points only of the first quadrant. Therefore, we should try to eliminate the terms $f^{(q)}{}_{xx}$ and $f^{(q)}{}_{yy}$ by using the continuity condition at the material interface.

The continuity condition at the material interface $x = x_i$ can be obtained by integrating the spherical harmonics equation in the thin region from x_i-ε to $x_i + \varepsilon$ in x-direction and unit area in y-direction, where ε is a small positive value. Putting $n_x = 1$, $n_y = 0$ in Eq. (26), we obtain the continuity condition as

$$\sum_{n=-1}^{1}{}' \frac{1}{\Sigma_{\ell+n}} a_{\ell m}^{no} \frac{\partial f_{\ell m}^{ec}}{\partial x}\Bigg|_{x=x_i-\varepsilon}^{x=x_i+\varepsilon} = \sum_{n=-1}^{1}{}' \Bigg[\frac{1}{\Sigma_{\ell+n}} b_{\ell m}^{no} \frac{\partial f_{\ell+2n,m}^{ec}}{\partial x} + \frac{1}{\Sigma_{\ell+n}} \frac{\partial g_{\ell m}^{ec}}{\partial x}$$

$$- \frac{1}{\Sigma_{\ell+n}} \frac{\partial g_{\ell m}^{es}}{\partial y} + \frac{1}{\Sigma_{\ell+n}} a_{\ell m}^{on} \frac{\partial f_{\ell m}^{es}}{\partial y} \Bigg]\Bigg|_{x=x_i-\varepsilon}^{x=x_i+\varepsilon} \tag{53}$$

where

$$g_{\ell m}^{ec}(\mathbf{r}) = a_{\ell m}^{n,-1} f_{\ell,m-2}^{ec}(\mathbf{r}) + a_{\ell m}^{n1} f_{\ell,m+2}^{ec}(\mathbf{r}) - b_{\ell m}^{n,-1} f_{\ell+2n,m-2}^{ec}(\mathbf{r}) - b_{\ell m}^{n1} f_{\ell+2n,m+2}^{ec}(\mathbf{r})$$

$$g_{\ell m}^{es}(\mathbf{r}) = a_{\ell m}^{n,-1} f_{\ell,m-2}^{es}(\mathbf{r}) - a_{\ell m}^{n1} f_{\ell,m+2}^{es}(\mathbf{r}) - b_{\ell m}^{n,-1} f_{\ell+2n,m-2}^{es}(\mathbf{r}) + b_{\ell m}^{n1} f_{\ell+2n,m+2}^{es}(\mathbf{r})$$

Differentiating Eq. (53) with respect to y and multiplying by $T^2/8$ or $-B^2/8$, we obtain the following relation at $x = x_i$;

$$\sum_{n=-1}^{1}{}' \delta_{xx}^{(\ell+n)} a_{\ell m}^{no} f_{\ell m}^{ec} = \sum_{n=-1}^{1}{}' \Big(\delta_{xx}^{(\ell+n)} b_{\ell m}^{no} f_{\ell+2n,m}^{ec} + \delta_{xx}^{(\ell+n)} g_{\ell m}^{ec} + \delta_{xy}^{(\ell+n)} g_{\ell m}^{es}$$

$$- \delta_{xy}^{(\ell+n)} a_{\ell m}^{on} f_{\ell m}^{ec} \Big) \tag{56}$$

Similarly, we obtain the following continuity condition at $y = y_j$;

$$\sum_{n=-1}^{1}{}' \delta_{yy}^{(\ell+n)} a_{\ell m}^{no} f_{\ell m}^{ec} = \sum_{n=-1}^{1}{}' \Big(\delta_{yy}^{(\ell+n)} b_{\ell m}^{no} f_{\ell+2n,m}^{ec} - \delta_{yy}^{(\ell+n)} g_{\ell m}^{ec} + \delta_{yx}^{(\ell+n)} g_{\ell m}^{es}$$

$$+ \delta_{yx}^{(\ell+n)} a_{\ell m}^{on} f_{\ell m}^{ec} \Big) \tag{57}$$

Substituting the relations (34) and (35) into Eq. (15) and using the continuity conditions (56) and (57), the terms δ_{xy} f and δ_{yx} f can be eliminated, and we obtain

$$
\begin{aligned}
&- \sum_{n=-1}^{1}{}' \left(\bar{D}'^{\ell+n}_{xx} + \bar{D}'^{\ell+n}_{yy} \right) a^{no}_{\ell m}\, f^{ec}_{\ell m}(r) + I\Sigma_\ell\, f^{ec}_{\ell m}(r) = I S^{ec}_{\ell m}(r) \\
&- \sum_{n=-1}^{1}{}' \left(\bar{D}'^{\ell+n}_{xx} + \bar{D}'^{\ell+n}_{yy} \right) b^{no}_{\ell m}\, f^{ec}_{\ell+2n,m}(r) \\
&- \sum_{n=-1}^{1}{}' \left(\bar{D}'^{\ell+n}_{xx} - \bar{D}'^{\ell+n}_{yy} \right) g^{cc}_{\ell m}(r) + \sum_{n=-1}^{1}{}' \left(\bar{D}^{\ell+n}_{xy} + \bar{D}^{\ell+n}_{yx} \right) g^{cs}_{\ell m}(r) \\
&- \sum_{n=-1}^{1}{}' \left(\bar{D}^{\ell+n}_{xy} - \bar{D}^{\ell+n}_{yx} \right) a^{on}_{\ell m}\, f^{es}_{\ell m}(r)
\end{aligned}
\tag{58}
$$

where

$$
\bar{D}'^{\ell}_{xx} = \bar{D}^{\ell}_{xx} + 2\,\delta^{\ell}_{xx}\,, \quad \bar{D}'^{\ell}_{yy} = \bar{D}^{\ell}_{yy} + 2\,\delta^{\ell}_{yy}
\tag{59}
$$

Similarly, Eq. (16) can be rewritten such that the operators $D^{\ell+n}{}_{xx}$, $D^{\ell+n}{}_{yy}$, $D^{\ell+n}{}_{xy}$, and $D^{\ell+n}{}_{yx}$ are replaced by $\bar{D}'^{\ell+n}{}_{xx}$, $\bar{D}'^{\ell+n}{}_{yy}$, $\bar{D}^{\ell+n}{}_{xy}$, and $\bar{D}^{\ell+n}{}_{yx}$, respectively.

Eq. (58) has been used at the mesh point of the material boundary. At the mesh points inside the material boundary, Eqs. (38), (39), (42), and (43) vanish, if we choose the equal mesh widths, R = L and T = B. For this case, the operators $\bar{D}'^{\ell+n}{}_{xx}$ and $\bar{D}'^{\ell+n}{}_{yy}$ in Eq. (58) can be replaced by $\bar{D}^{\ell+n}{}_{xx}$ and $\bar{D}^{\ell+n}{}_{yy}$, respectively.

Using Eqs. (36) and (37), the operator $\bar{D}^{\ell}{}_{xx} \pm \bar{D}^{\ell}{}_{yy}$ becomes

$$
\left(\bar{D}^{\ell}_{xx} \pm \bar{D}^{\ell}_{yy} \right) f_{ij} = \pm\, a^{\ell} f_{i,j-1} + b^{\ell} f_{i-1,j} - \left(\pm a^{\ell} + b^{\ell} + d^{\ell} \pm e^{\ell} \right) f_{ij} + d^{\ell} f_{i+1,j} \pm e^{\ell} f_{i,j+1}\,.
\tag{60}
$$

which is used at the mesh points inside the material boundary. The plus and minus sign in Eq. (60) should be taken in the same order. The operator of the plus sign gives the 5-point difference equation inside of regions with constant material properties and equal mesh widths, which is the same form as the usual diffusion equation and can be solved easily by the three-point successive overrelaxation method. The term $(\bar{D}'^{\ell}{}_{xx} \pm \bar{D}'^{\ell}{}_{yy})$ f becomes

$$\left(\overline{D}'^{\ell}_{xx} \pm \overline{D}'^{\ell}_{yy}\right) f_{ij} = \frac{1}{2}\Big[(\pm a^{\ell} - b^{\ell-} - d^{\ell-}) f_{i,j-1} + (b^{\ell} \mp a^{\ell-} \mp e^{\ell-}) f_{i-1,j}$$

$$- (\pm a^{\ell} + b^{\ell} + d^{\ell} \pm e^{\ell}) f_{ij} + (d^{\ell} \mp a^{\ell+} \mp e^{\ell+}) f_{i+1,j} + (\pm e^{\ell} - b^{\ell+} - d^{\ell+}) f_{i,j+1}$$

$$+ (\pm a^{\ell-} + b^{\ell-}) f_{i-1,j-1} + (b^{\ell+} \pm e^{\ell-})\, f_{i-1,j+1}$$

$$+ (\pm a^{\ell+} + d^{\ell-}) f_{i+1,j-1} + (d^{\ell+} \pm e^{\ell+})\, f_{i+1,j+1}\Big] \tag{61}$$

which represents a 9-point difference form and has to be used at the mesh points at material interfaces and outside boundaries.*)

Eq. (61) together with Eq. (60) can be also solved by the line successive over-relaxation method. However, in this case, the terms $f_{i-1,j+1}$, $f_{i,j+1}$, $f_{i+1,j+1}$ etc. must be moved to the right hand side of the equation, which makes the convergence rate of the inner iteration slower.

For a reflective boundary, the following relations hold:

$$f^{ec}_{i,j+1} = f^{ec}_{i,j-1}\,,\; f^{es}_{i,j+1} = -\,f^{es}_{i,j-1}\,,\; f^{es}_{ij} = 0 \text{ at the reflective boundary } y = y_j \tag{62}$$

$$f^{ec}_{i+1,j} = f^{ec}_{i-1,j}\,,\; f^{es}_{i+1,j} = -\,f^{es}_{i-1,j}\,,\; f^{es}_{ij} = 0 \text{ at the reflective boundary } x = x_i \tag{63}$$

where $i = 1$ or I and $j = 1$ or J.

In the code, the coefficients are calculated by assuming the reflective boundary condition at the outermost boundary. Namely, Eqs. (62) and (63) are used at all outermost mesh points for the difference equations, whose explicit form is given in Appendix A.

In order to realize the vacuum boundary condition in the PLXY code, we add at the outside of the boundary a pure absorber of several mean free paths and set all moments of angular flux to zero. In this case, Eq. (58) etc. need not be solved for the outermost mesh points of the vacuum boundary, because they are known to be zero.

*) This 9-point mesh-edged discretization scheme is used as reference option in the standard version of PLXY at KfK.

3. Solution of Finite Difference Equation

1) For $f^{ec}{}_{\ell m}$ with the reflective boundary condition.

In the case of the reflective boundary condition at $x = x_1, x_I$ and $y = y_1, y_J$, the moments $f^{ec}{}_{\ell mij}$ for $i = 1, I$ and $j = 1, J$ are in general not equal to zero.

Using Eq. (60), for example, the finite difference equation for Eq. (58) can be written in a form,

$$a_{ij} f_{i,j-1} + b_{ij} f_{i-1,j} - c_{ij} f_{ij} + d_{ij} f_{i+1,j} + e_{ij} f_{ij} = q^c_{ij} \tag{64}$$

$$\text{for } i = 1 \sim I \text{ and } j = 1 \sim J$$

where

$$a_{ij} = \sum_{n=-1}^{1}{}' a^{\ell+n} a^{no}_{\ell m}, \; b_{ij} = \sum_{n=-1}^{1}{}' b^{\ell+n} a^{no}_{\ell m}, \; d_{ij} = \sum_{n=-1}^{1}{}' d^{\ell+n} a^{no}_{\ell m} \; e_{ij} = \sum_{n=-1}^{1}{}' e^{\ell+n} a^{no}_{\ell m},$$

$$c_{ij} = a_{ij} + b_{ij} + d_{ij} + e_{ij} + \Sigma_\ell \tag{65}$$

and

$$\begin{aligned} q^c_{ij} = &- S^{ec}_{ij} + \sum_{n=-1}^{1}{}' \left(\overline{D}'^{\ell+n}_{xx} + \overline{D}'^{\ell+n)}_{yy} \right) b^{no}_{\ell m} f^{ec}_{\ell+2n,m} \\ &+ \sum_{n=-1}^{1}{}' \left(\overline{D}'^{\ell+n}_{xx} - \overline{D}'^{\ell+n)}_{yy} \right) \left(a^{n,-1}_{\ell m} f^{ec}_{\ell,m+2} + a^{n1}_{\ell m} f^{ec}_{\ell,m+2} - b^{n,-1}_{\ell m} f^{ec}_{\ell+2n,m-2} - b^{n1}_{\ell m} f^{ec}_{\ell+2n,m+2} \right) \\ &- \sum_{n=-1}^{1}{}' \left(\overline{D}^{\ell+n}_{xy} + \overline{D}^{\ell+n}_{yx} \right) \left(a^{n,-1}_{\ell m} f^{es}_{\ell,m-2} - a^{n1}_{\ell m} f^{es}_{\ell,m+2} - b^{n,-1}_{\ell m} f^{es}_{\ell+2n,m-2} + b^{n1}_{\ell m} f^{es}_{\ell+2n,m+2} \right) \\ &+ \sum_{n=-1}^{1}{}' \left(\overline{D}^{\ell+n}_{xy} - \overline{D}^{\ell+n}_{yx} \right) a^{on}_{\ell m} f^{es}_{\ell m} \end{aligned} \tag{66}$$

For simplicity, suffixes ec and ℓm are omitted in Eq. (64). Equation (66) is written using the operator notations to express it in a simple form, and they can be calculated numerically by using subroutines for the finite difference expressions of Eqs. (48), (49), (50), (51), (60), and (61).

In the equation for $i = I$ of Eq. (60), for example, there is a moment for $i = I+1$, $f_{I+1,j}$, which can be replaced by $f_{I-1,j}$ using the reflective boundary condition of Eq. (63). Using the reflective boundary conditions Eqs. (62) and (63), Eq. (64) can be written in the form of the following 3-point equation,

$$-c_{1j} f_{1j} + d_{1j} f_{2j} = q^{c'}_{1j}$$

$$b_{ij} f_{i-1,j} - c_{ij} f_{ij} + d_{ij} f_{i+1,j} = q^{c'}_{1j} \ , \ \text{for } 2 \le i \le I-1$$

$$b_{Ij} f_{I-1,j} - c_{Ij} f_{Ij} = q^{c'}_{Ij} \ , \ \text{for } j = 1 \sim J \tag{67}$$

where

$$q^{c'}_{ij} = q^{c}_{ij} - a_{ij} f_{i,j-1} - e_{ij} f_{i,j+1} \ . \tag{68}$$

At the meshpoints of the material boundary, Eq. (61) should be used instead of Eq. (60).The explicit form of the coefficients is given in Appendix A. In the iteration method described in the next section, the right hand side $q^{c'}{}_{ij}$ of Eq. (67) are given values obtained from the previous iteration.

The 3-point difference equation (67) can be easily solved by the factorization method. First, we calculate lower triangular matrix elements ℓ_i, ℓ_{di} and upper triangular matrix elements u_i as

$$\ell_i = b_{ij} \ , \ i = 2, 3, \ldots, I$$

$$\ell_{di} = -c_{ij} - \ell_i u_{i-1} \ , \ i = 1, 2, \ldots, I, \text{ where } u_0 = 0$$

$$u_i = d_{ij} / \ell_{di} \ , \ i = 1, 2, \ldots, I-1 \ . \tag{69}$$

Then an auxiliary quantity g_i is calculated by

$$g_1 = q^{c'}_{1j} / \ell_{d1}$$

$$g_i = (q^{c'}_{ij} - \ell_i g_{i-1}) / \ell_{di} \ , \ i = 1, 2, \ldots, I, \text{ where } g_0 = 0 \ . \tag{70}$$

Using this auxiliary value g_i and the upper triangular matrix elements u_i, we can obtain the moment by

$$f_{ij} = g_i - u_i f_{i+1,j} \quad \text{for } i = I, I-1, \ldots, 1, \text{ where } f_{I+1,j} = 0 \quad . \tag{71}$$

2) For $f^{ec}{}_{\ell m}$ with the zero boundary condition.

If we use the zero boundary condition $f_{Ij} = 0$ at $x = x_I$, we need not use the equation $i = I$ of Eq. (67), and this condition is equivalent to put $d_{I-1,j} = 0$ in the equation for $i = I\text{-}1$ of Eq. (67), which results in $u_{I-1} = 0$ in Eq. (69). However, this $u_{I-1} = 0$ is equivalent to put $f_{Ij} = 0$ in Eq. (70) for $i = I\text{-}1$. All other values are the same as those for the reflective boundary condition.

If we use the zero boundary condition $f_{1j} = 0$ at $x = x_1$, this condition is equivalent to put $d_{1j} = q^{c'}{}_{1j} = 0$ for $i = 1$ in Eq. (67), which is equivalent to put simply $u_1 = 0$ and $g_1 = 0$ in Eqs. (69) and (70). If we use the zero boundary condition $f_{i1} = 0$ at $y = y_1$, Eqs. (64) should be solved for $j \geq 2$ with the boundary values of $f_{i1} = 0$.

Similarly, if we use the zero boundary condition $f_{iJ} = 0$ at $y = y_J$, Eqs. (64) should be solved for $j \leq J\text{-}1$ with boundary values of $f_{iJ} = 0$.

3) For $fes_{\ell m}$ with the reflective boundary condition.

In the case of the reflective boundary condition at $x = x_1, x_2$ and $y = y_1, y_J$, $fes_{\ell mij}$ for $i=1,I$ and $j=1,J$ vanish as shown in Eqs. (62) and (63). Using Eq. (60), the finite difference equation to Eq. (16) has the same form as Eq. (64), but its right hand side is given by the finite difference form of the right hand side of Eq. (16), and the equation for $i=2 \sim I\text{-}1$ and $j=2 \sim J\text{-}1$ should be used. Its 3-point difference form becomes

$$- c_{2j} f_{2j} + d_{2j} f_{3j} = q^{s'}_{2j} \; ,$$

$$b_{ij} f_{i-1,j} - c_{ij} f_{ij} + d_{ij} f_{i+1,j} = q^{s'}_{ij} \; , \quad \text{for } 3 \leq i \leq I-2$$

$$b_{I-1,j} f_{I-2,j} - c_{I-1,j} f_{I-1,j} = q^{s'}_{I-1,j} \; , \quad \text{for } j = 2 \sim J-1 \tag{72}$$

where

$$q^{s'}_{ij} = q^{s}_{ij} - a_{ij} f_{ij-1} - e_{ij} f_{ij+1} \quad . \tag{73}$$

The form of Eq. (72) is the same as Eq. (67), therefore, Eq. (72) can be solved using the similar equation as Eqs. (69) and (70).

In the case of zero boundary condition, we should also solve Eq. (72), namely, there is no difference between the finite difference equations for $f^{es}{}_{\ell m}$ with the reflective and the zero boundary conditions.

4. Iteration Method

In the code, the source term of Eq. (1) is assumed to be isotropic and takes the form:

$$S^{ec}_{oog}(\mathbf{r}) = \frac{\chi_g}{k} \sum_{g'=1}^{G} \nu\Sigma_{fg'} f^{ec}_{oog'}(\mathbf{r}) + \sum_{g'=1}^{g-1} \Sigma_s (g \leftarrow g') f^{ec}_{oog'}(\mathbf{r}) + Q^{ec}_{oog}(\mathbf{r}) \ , \tag{74}$$

where χ_g, k, $\nu\Sigma_{fg}$, $\Sigma_s (g \leftarrow g')$ and $Q^{ec}_{oog}(\mathbf{r})$ are the fission spectrum, criticality factor, fission cross-section multiplied by the number of fission neutrons, the isotropic scattering cross-section from g'-th group to g-th group, and isotropic external source, respectively (as in many other codes it is assumed in PLXY that a global fission spectrum can be used which is the same for all materials and, therefore, is not space- or region- or material-dependent). In the case of a source problem, $k = 1$.

The spherical harmonics equations (58) are solved using three iteration methods, a conventional fission source iteration or outer iteration, the middle and the inner iterations.

For the source iteration, the fission source F_{ij}

$$F_{ij} = \sum_{g=1}^{G} \nu\Sigma_{fg} f^{ec}_{oogij} \tag{75}$$

is normalized such that

$$\int_{\text{Reactor}} d\mathbf{r}\, F^{(s)}(\mathbf{r}) = k^{(s)} \tag{76}$$

in the case of criticality problems.

An acceleration method is used in the form

$$F^{(s+1)}_{ij} = F^{(s)}_{ij} + \alpha_o \left(F^{(s+1/2)}_{ij} - F^{(s)}_{ij} \right) \ , \tag{77}$$

where α_o is an appropriate acceleration factor, s the iteration index and $F^{(s+1/2)}$ is calculated from Eq. (75) using the solution $f^{ec(s+1/2)}_{oog}$ obtained from Eqs. (58) with the fission source $F_{ij}^{(s)}$. The $(s+1)$th criticality factor is calculated by

$$k^{(s+1)} = \frac{\int_{\text{Reactor}} dr \quad F^{(s+1/2)}(\mathbf{r})}{\int_{\text{Reactor}} dr \quad F^{(s)}(\mathbf{r})} \tag{78}$$

The outer iterations are terminated when the following convergence criteria are satisfied:

$$\frac{\left| k^{(s+1)} - k^{(s)} \right|}{k^{(s)}} < \varepsilon_k \tag{79}$$

and

$$\max_{i,j} \frac{\left| F_{ij}^{(s+1/2)} - F_{ij}^{(s)} \right|}{F_{ij}^{(s)}} < \varepsilon_o \tag{80}$$

where ε_k and ε_o are specified values.

For the given source term, Eqs. (64) are solved by the successive over relaxation method for the angular moments, which is called "middle iteration". Namely, first Eqs. (64) are solved for f^{ec}_{oo} and this solution is used in the right-hand side to obtain f^{ec}_{20} and so on. This middle iteration is accelerated by using an acceleration factor a_m by

$$f^{e\alpha(p+1)}_{\ell mij} = f^{e\alpha(p)}_{\ell mij} + a_m \left(f^{e\alpha(p+1/2)}_{\ell mij} - f^{e\alpha(p)}_{\ell mij} \right) , \quad \alpha = c \;\text{ or }\; s , \tag{81}$$

where p is the middle iteration index, $f^{(p+1/2)}_{\ell m}$ the (p + 1/2)-th solution of Eqs. (64) with the initial guess of $f^{(p)}_{\ell m}$. The middle iteration is terminated by the specified number of iterations or when the following error criterion is satisfied:

$$\max_{\ell,m} \max_{i,j} \left| \frac{f^{e\alpha(p+1/2)}_{\ell mij} - f^{e\alpha(p)}_{\ell mij}}{f^{ec(p)}_{ooij}} \right| < \varepsilon_M , \quad \alpha = c \;\text{ or }\; s . \tag{82}$$

This middle iteration converges fairly fast when Σ_t is not small as discussed in some detail in Ref. /9/.

The finite difference equations of Eqs. (64) are solved by the inner iteration of the line successive over relaxation method in the same form as Eq. (81) with an acceleration factor α_i. This inner iteration is also terminated by the specified maximum number or by the equation,

$$\max_{i,j} \left| \frac{f_{\ell mij}^{e\alpha(t+1/2)} - f_{\ell mij}^{e\alpha(t)}}{f_{ooij}^{ec(t)}} \right| < \varepsilon_I \ , \quad \alpha = c \text{ or } s \ . \tag{83}$$

where t is the inner iteration index.

During the inner iteration, the differential terms of the right-hand side of Eqs. (64) are kept constant. In Eqs. (82) and (83), the relative values of errors to the f^{ec}_{ooij} are used, because usually moments of higher order have small values, and then the values of their relative errors are not important.

5. Adjoint Equation

The second order differential equations (15) and (16) for one energy group are self-adjoint as shown in the following. Using the expansion for the angular flux of Eq. (3), Eq. (7a) can be written in the form:

$$-\int d\Omega Y^{*}_{\ell m}(\Omega)\Omega\nabla \frac{1}{4\pi}\sum_{\ell'=1}^{L-1}(2\ell'+1)\sum_{m=-\ell'}^{\ell'} Y_{\ell' m'}(\Omega) f^{d}_{\ell' m'}(\mathbf{r}) + \Sigma_{\ell} f^{e}_{\ell m}(\mathbf{r}) = S^{e}_{\ell m}(\mathbf{r}) \tag{84}$$

In the case of $S^{d}{}_{\ell m}(\mathbf{r}) = 0$, using Eq. (7b), Eq. (84) can be rewritten

$$-\sum_{\ell' m'}\sum_{\ell'' m''} C^{\ell' m'}_{\ell m}\nabla \frac{(2\ell'+1)}{\Sigma_{\ell'}} C^{\ell'' m''}_{\ell' m'}\nabla(2\ell''+1) f^{e}_{\ell'' m''}(\mathbf{r}) + \Sigma_{\ell} f^{e}_{\ell m}(\mathbf{r}) = S^{e}_{\ell m}(\mathbf{r}) \tag{85}$$

where

$$C^{\ell' m'}_{\ell m} = \frac{1}{4\pi}\int_{4\pi} d\Omega Y^{*}_{\ell m}(\Omega)\Omega Y_{\ell' m'}(\Omega). \tag{86}$$

If we define an operator $A_{\ell m, \ell' m'}$ as

$$A_{\ell m, \ell'' m''} = (2\ell+1)\sum_{\ell' m'} C^{\ell' m'}_{\ell m}\nabla \frac{(2\ell'+1)}{\Sigma_{\ell'}} C^{\ell'' m''}_{\ell' m'}\nabla(2\ell''+1) \tag{87}$$

the adjoint operator can be obtained by

$$(gAf) = \int d\mathbf{r}\sum_{\ell m}\sum_{\ell'' m''} g^{*}_{\ell m} A_{\ell m, \ell'' m''} f_{\ell'' m''}$$

$$= \int d\mathbf{r}\sum_{\ell m}\sum_{\ell'' m''} g^{*}_{\ell m}(2\ell+1)\sum_{\ell' m'} C^{\ell' m'}_{\ell m}\nabla \frac{(2\ell'+1)}{\Sigma_{\ell'}} C^{\ell'' m''}_{\ell' m'}\nabla(2\ell''+1) f_{\ell'' m''}$$

$$= \int d\mathbf{r}\sum_{\ell m}\sum_{\ell'' m''} f_{\ell'' m''}(2\ell''+1)\sum_{\ell' m'} C^{\ell'' m''}_{\ell' m'}\nabla \frac{(2\ell'+1)}{\Sigma_{\ell'}} C^{\ell' m'}_{\ell m}\nabla(2\ell+1) g^{*}_{\ell m}$$

$$= \left(\int d\mathbf{r}\sum_{\ell m}\sum_{\ell'' m''} f^{*}_{\ell'' m''}(2\ell''+1)\sum_{\ell' m'} C^{\ell' m'}_{\ell'' m''}\nabla \frac{(2\ell'+1)}{\Sigma_{\ell'}} C^{\ell m}_{\ell' m'}\nabla(2\ell+1) g_{\ell m}\right)^{*} \tag{88}$$

where **g** is an arbitrary vector whose elements satisfy similar boundary conditions as $f^e_{\ell m}(\mathbf{r})$, and asterisk * means to take conjugate complex quantity.
From Eq. (88), we can see that the operator $A_{\ell m,\ \ell'' m''}$ is self-adjoint, and then so is Eq. (85), the one group form of the spherical harmonics equation. Therefore, the multigroup adjoint equation can be obtained simply by rewriting the source term of Eq. (74) into the related adjoint form as is done in the case of diffusion equation:

$$S^{ec+}_{oog}(\mathbf{r}) = \frac{\nu\Sigma_{fg}}{k} \sum_{g'=1}^{G} \chi_{g'} f^{ec+}_{oog'}(\mathbf{r}) + \sum_{g'=g+1}^{G} \Sigma_s(g'\leftarrow g)\, f^{ec+}_{oog'}(\mathbf{r}) \ . \tag{89}$$

Using this source term, Eqs. (64) are solved from the lowest energy group G to the highest energy group. The corresponding boundary conditions, i.e. the vacuum or reflective conditions as in the case of the direct equation should be used.

III. Code Description

1. Nature of the Physical Problem Solved

1. Multigroup spherical harmonics equation is solved for two-dimensional x-y geometry.

2. There are no restrictions for the order L of P_L approximation, the number of energy groups, the number of regions and number of mesh points. They are restricted only by the total size of the arrays A and IA which can be used at the available computer environment.

3. Only down scattering is allowed.

4. Anisotropic scattering cross-section within the same energy group is taken into account up to the order L of the P_L approximation.

5. External source and slowing down cross-sections are assumed to be isotropic.

6. At the outermost boundaries, the reflective or zero-boundary conditions can be specified. Vacuum boundary condition can be simulated by putting a pure absorber material of several mean free paths and using zero boundary condition.

2. Outline of the Code

A diagram of the subroutines is shown in Fig. 2 and the flow in the program through subroutines is shown in the flow chart of Fig. 3 to Fig. 7. In the main program, the dimensions of the real and integer arrays A and IA are defined, which might be changed according to the memory requirement of the actual problem to be treated, and the subroutine SMAIN is called.

In the subroutine SMAIN are called the subroutines TIMEA, READIN, INIT etc. as shown in Fig. 3. In the TIMEA, the initial time is printed and in READIN, all input data are read. In the INITLZ, all initializations are made and the subroutine PL(L,RK) solves P_L approximation from P_1, P_3, ... to P_{L-2} with larger error criteria specified by the input value FECL and finally the P_L equation is solved with the specified error criterion, if IFADJ = 0 and IFP1 = 1.

When IFP1 $\neq$ 1, the P_L equation is solved directly using the input error criteria. When IFADJ = 1, an adjoint calculation is done as shown in Fig. 4. In that case, all cross-sections are inverted with respect to energy group numbering and the adjoint equation is solved using the same subroutine PL(L,RK) as that for the direct equation. After finishing the adjoint calculation, all cross-sections are again inverted with respect to energy groups to bring them in the original form. In Figs. 5, 6 and 7, details of the flow chart of the subroutines are shown.

Fig. 2 Diagram of Subroutines

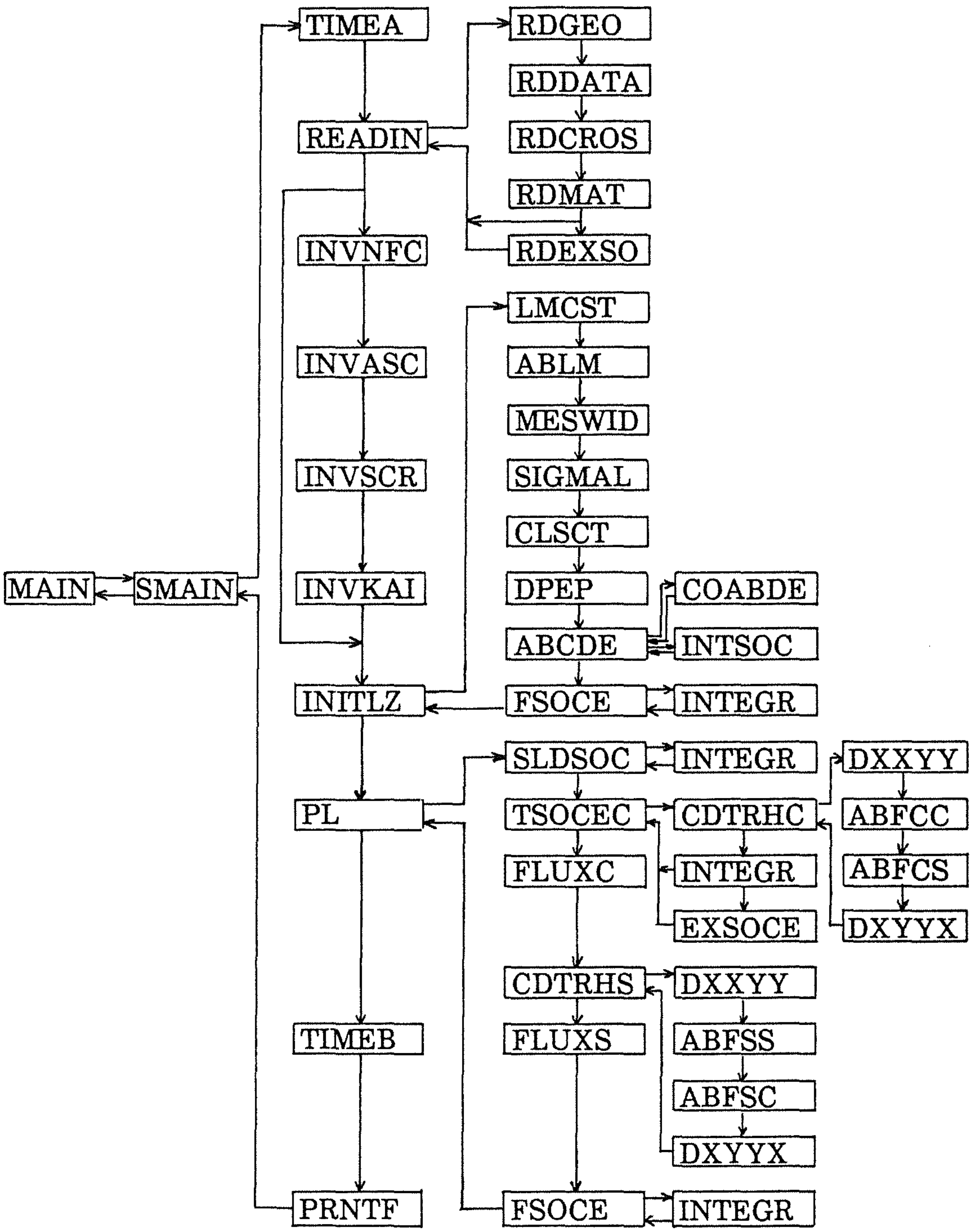


Fig. 3 Flow Chart for Subroutines

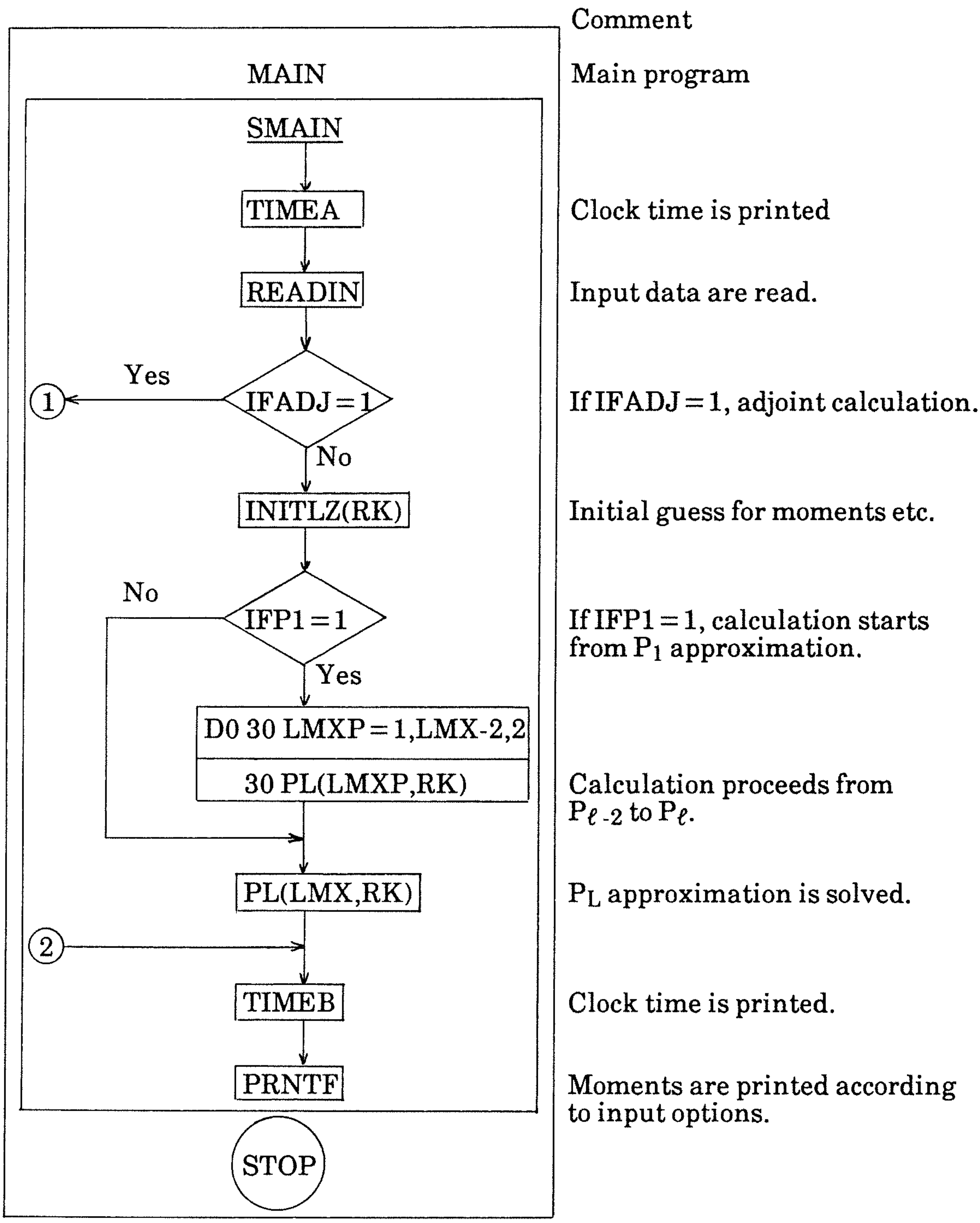
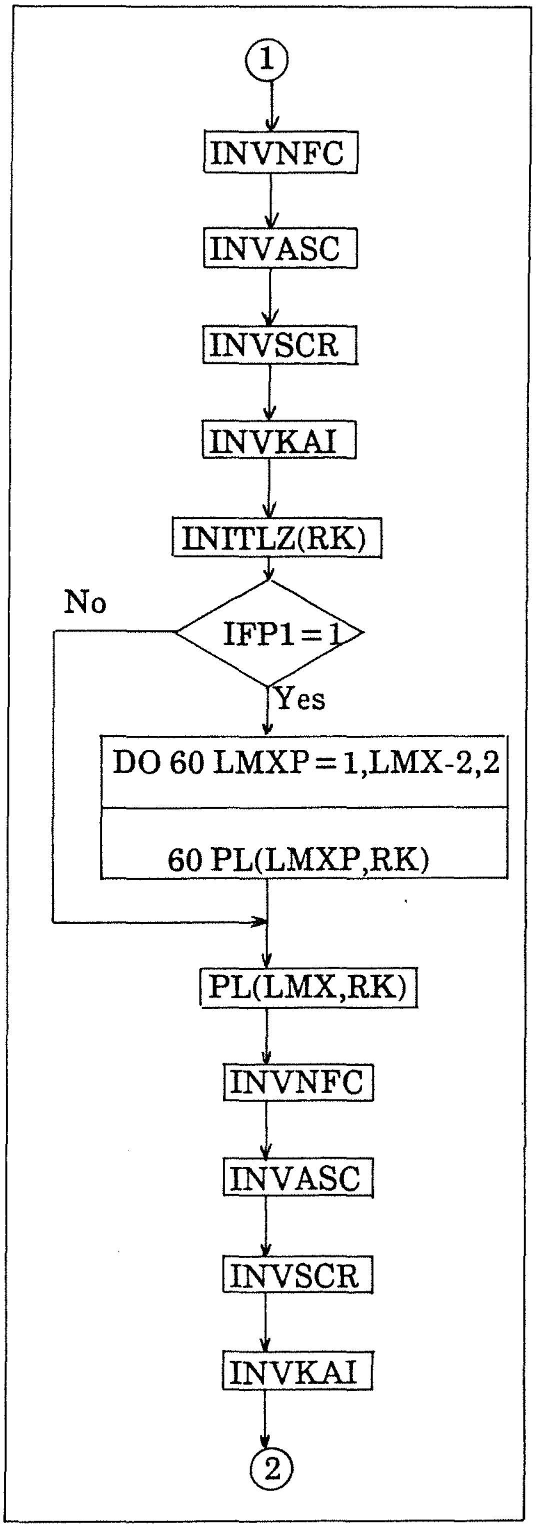


Fig. 4 Explanation of the Branch Indicated in Subroutine SMAIN (see Fig. 3)



Comment

Adjoint equation is solved.

Fission cross-section is inverted.

Anisotropic scattering cross-section is inverted.

Scattering matrix is inverted.

Fission spectrum is inverted.

Initial guess for moments etc.

If IFP1 = 1, calculation starts from P_1 approximation.

Calculation proceeds from $P_{\ell-2}$ to P_{ℓ}.

P_L approximation is solved.

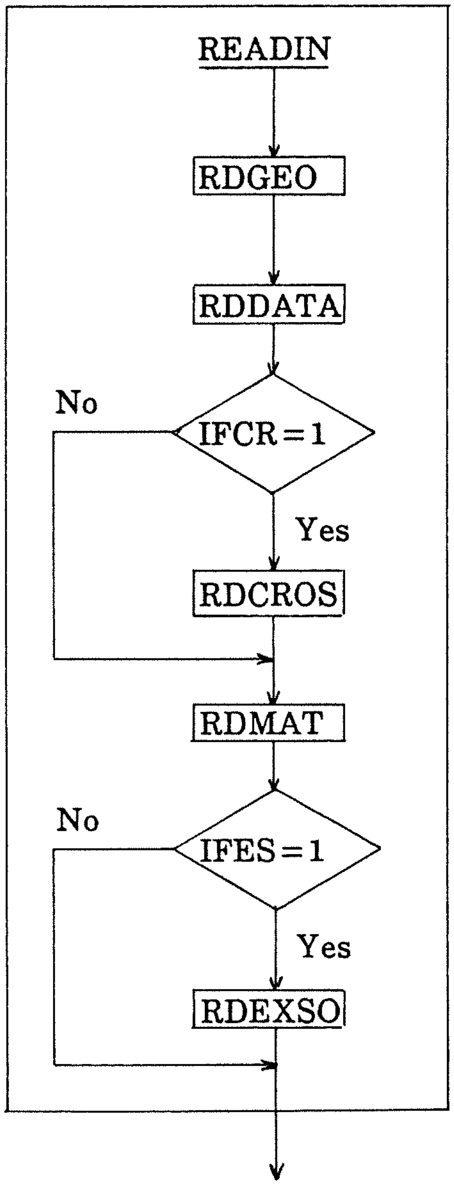
Fission cross-section is inverted again.

Anisotropic scattering cross-section is inverted again.

Scattering matrix is inverted again.

Fission spectrum is inverted again.

Fig. 5 Subroutine READIN Called in SMAIN



Data for the geometry are read.

Input specifications are read.

If IFCR $\neq$ 1, cross-sections are not read.

Cross-sections are read.

Material distributions are read.

If IFES $\neq$ 1, external source is not read.

External source distribution is read.

Fig. 6 Subroutine INITLZ Called in SMAIN

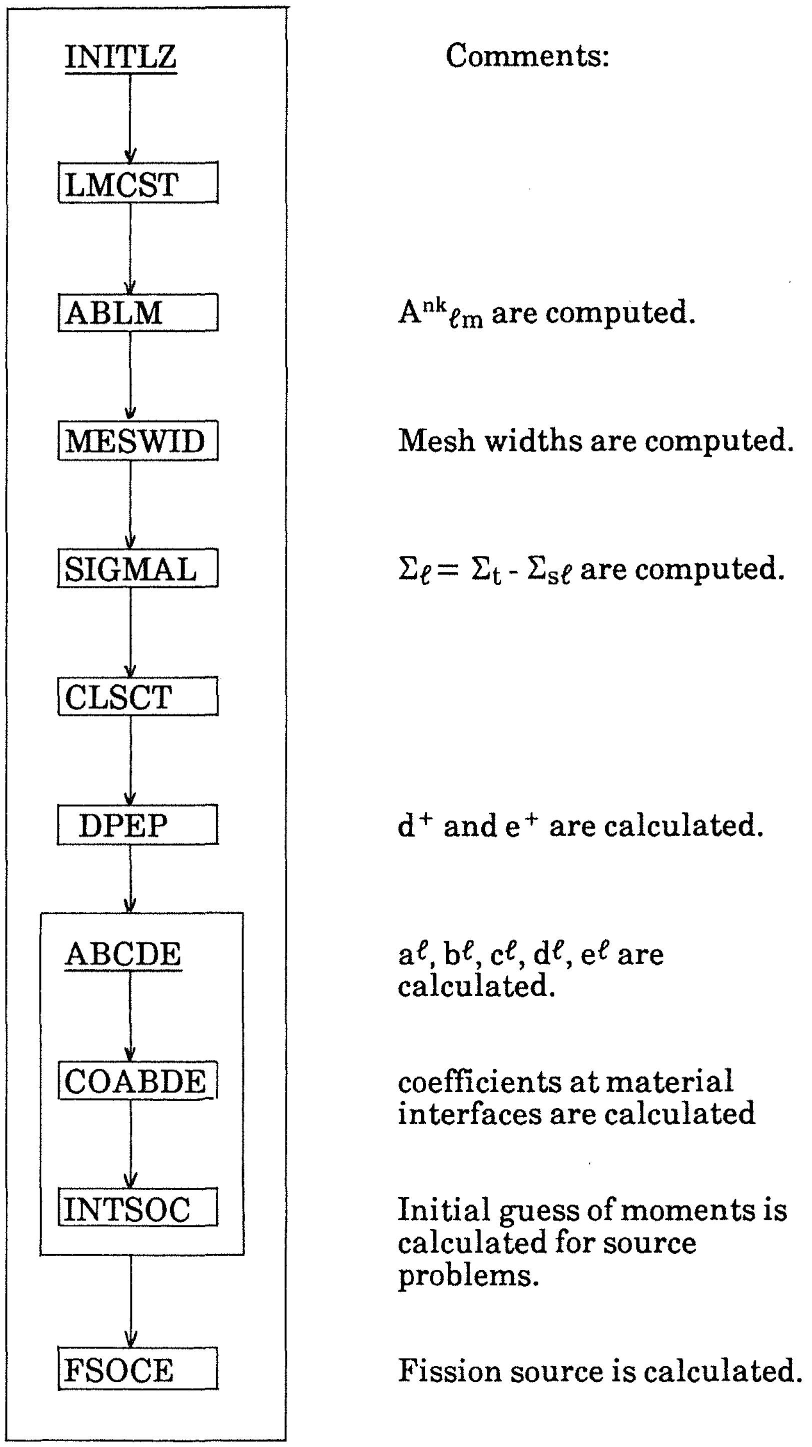
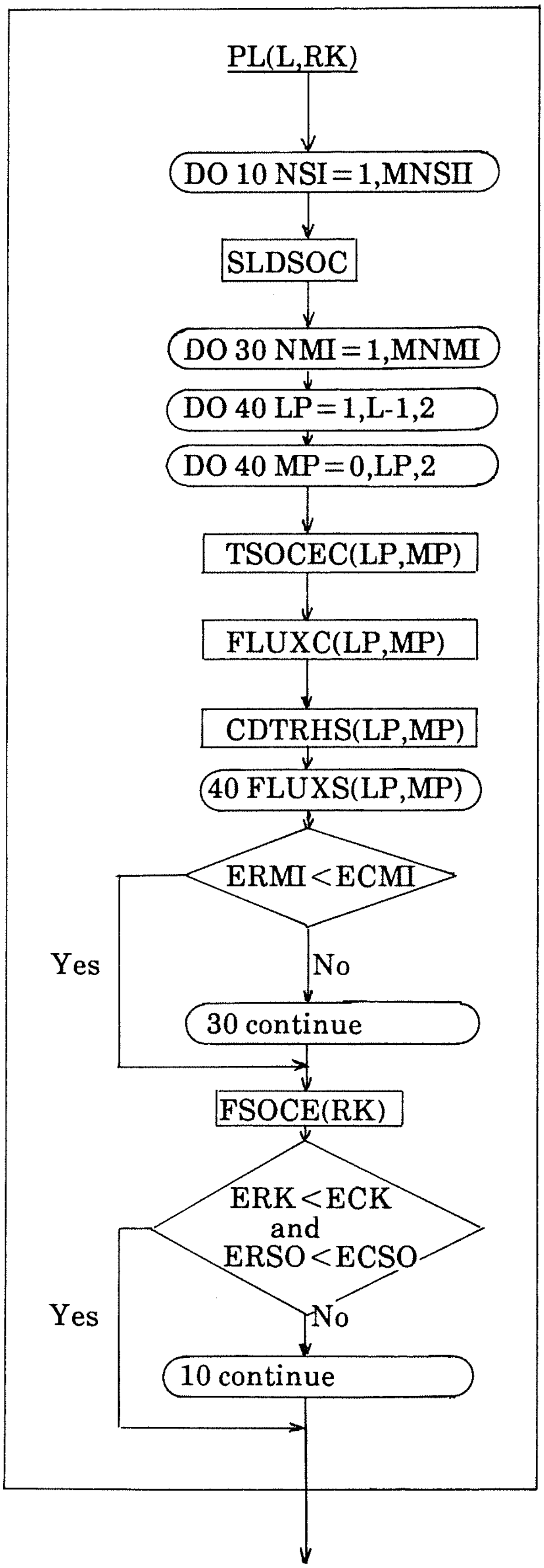


Fig. 7 Subroutine PL Called in SMAIN



Comment

Subroutine to solve P_L approximation of L-th order.

Source iteration starts.

Slowing down source is calculated.

Middle iteration starts.

Total source is calculated.

$f^{ec}_{\ell mij}$ are calculated.

Differential terms for $f^{es}_{\ell mij}$

$f^{es}_{\ell mij}$ are calculated.

ERMI is the error in middle iteration.

Fission source and criticality factor RK are recalculated.

3. Description of the Subroutines and Functions

1 ABCDE

Coefficients a^ℓ, b^ℓ, c^ℓ, d^ℓ and e^ℓ are calculated, where $c^\ell = a^\ell + b^\ell + d^\ell + e^\ell$.
Then the matrix elements of the upper and lower triangle to solve the three-point difference equation in x-direction are calculated. An initial guess for the angular moments is given and stored on disk 10 together with the coefficients needed to solve the three-point difference equations in x-direction.

Since the coefficients a^ℓ etc. are different for the inside and the interface of the region, indices NXX and NYY defined as in Fig. 8 are used.

Fig. 8 Indices NXX and NYY

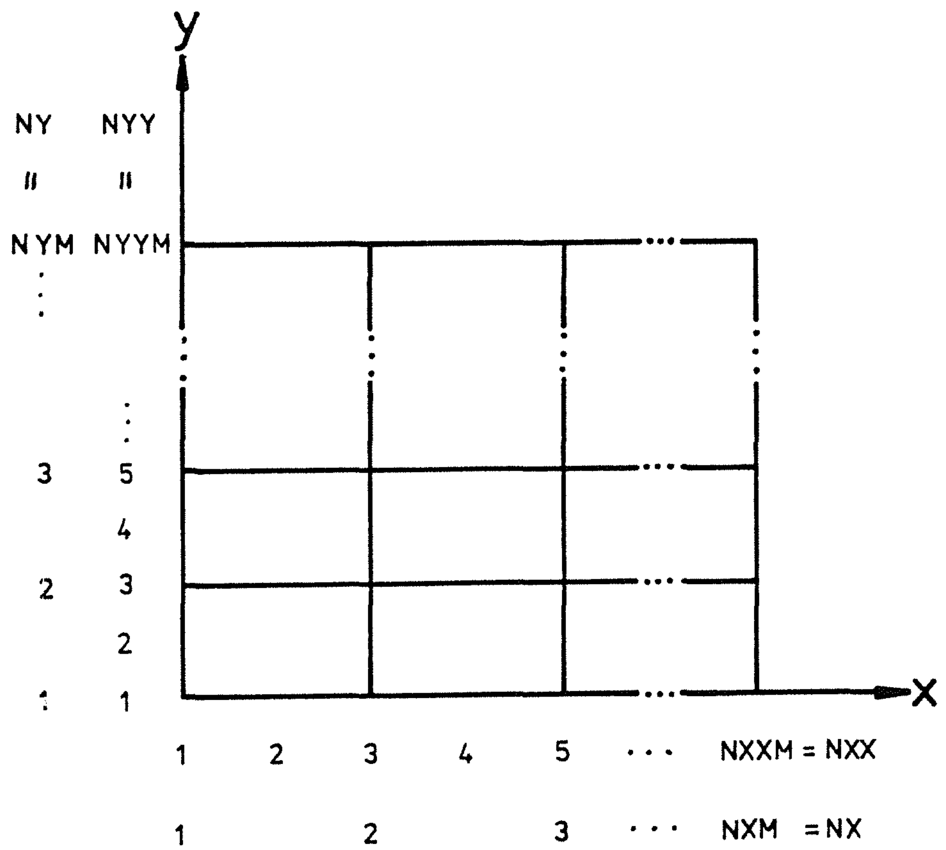


Fig. 8 Indices NX, NXX, NY and NYY

2 ABFCC

In this subroutine the following term

$$ABF(IX,IY) = a_{\ell m}^{n,-1} f^{ec}_{\ell,m-2,ij} + a_{\ell m}^{n1} f^{ec}_{\ell,m+2,ij} - b_{\ell m}^{n,-1} f^{ec}_{\ell+2n,m-2,ij} - b_{\ell m}^{n1} f^{ec}_{\ell+2n,m+2,ij}$$

is calculated for the differential terms of the right-hand side of Eq. (15), where IX = I, IY = J. Integers I1, I2, I3 and I4 used in the subroutine are equal to 1, if each of the terms $f^{ec}{}_{\ell,m-2}$, $f^{ec}{}_{\ell,m+2}$, $f^{ec}{}_{\ell+2n,m-2}$ and $f^{ec}{}_{\ell+2n,m+2}$ exists for the given indices ℓ, m and n, and they are equal to 0, if all of them do not exist. If I1 + I2 + I3 + I4 = 0, the integer ISKP = 0 and no calculation is made in the subroutine. In this case, the subroutine DXXYY is not called so that no contribution results from this differential term. The array ABF(IXM,IYM) is used also in other subroutines ABFCS, ABFSC, ABFSS, CDTRHC and CDTRHS.

3 ABFCS

The following term

$$ABF(IX,IY) = -a_{\ell m}^{n,-1} f^{es}_{\ell,m-2,ij} + a_{\ell m}^{n1} f^{es}_{\ell,m+2,ij} + b_{\ell m}^{n,-1} f^{es}_{\ell+2n,m-2,ij} - b_{\ell m}^{n1} f^{es}_{\ell+2n,m+2,ij}$$

is calculated for the differential term of the right-hand side of Eq. (15). The integers I1, I2, I3, I4 and ISKP play the same role as in subroutine ABFCC.

Using the relation $f^{es}{}_{\ell,-m} = - f^{es}{}_{\ell m}$, the integer m for $f^{es}{}_{\ell mij}$ = FES(IX,IY,LMS) is assumed to be positive.

4 ABFSC

The following term

$$ABF(IX,IY) = a_{\ell m}^{n,-1} f^{ec}_{\ell,m-2,ij} - a_{\ell m}^{n1} f^{ec}_{\ell,m+2,ij} - b_{\ell m}^{n,-1} f^{ec}_{\ell+2n,m-2,ij} + b_{\ell m}^{n1} f^{ec}_{\ell+2n,m+2,ij}$$

is calculated for the differential term of the right-hand side of Eq. (16). The structure of the subroutine is the same as the ABFCC. Eq. (16) is solved only for m ≥ 2, and in that case this term exists always. For this reason the integer ISKP is not meaningful in ABFSC and therefore this is not used in this subroutine.

5 ABFSS

The following term

$$ABF(IX,IY) = a^{n,-1}_{\ell m} f^{es}_{\ell,m-2,ij} + a^{n1}_{\ell m} f^{es}_{\ell,m+2,ij} - b^{n,-1}_{\ell m} f^{es}_{\ell+2n,m-2,ij} - b^{n1}_{\ell m} f^{es}_{\ell+2n,m+2,ij}$$

is calculated for the differential term of the right-hand side of Eq. (16). The structure of the program is the same as in ABFCC.

6 ABLM

The coefficients $a^{nk}{}_{\ell m}$ and $b^{nk}{}_{\ell m}$ appearing in Eqs. (20) and (21) are calculated and stored in the arrays ALM and BLM, respectively.

7 ALF

The constant $\alpha_{\ell m}$ defined by Eq. (11) is calculated.

8 BETA

The constant $\beta_{\ell m}$ defined by Eq. (11) is calculated.

9 CDTRHC

In order to calculate the differential terms of the right-hand side of Eq. (15) and to store the corresponding results in the array DTRH(IXM,IYM), the subroutines DXXYY, ABFCC, ABFCS, DXYYX and DXYYXM are called. Starting for the specified integers ℓ and m, by setting n = -1, then continuing with the following sequence:

1) ABF(IX,IY) = $b^{no}{}_{\ell m}\, f^{ec}{}_{\ell+2n,mij}$ is calculated.

2) Subroutine DXXYY(IFPM = 1) is called.

3) Subroutine ABFCC is called. If ISKP = 0, then skip to 5).

4) Subroutine DXXYY(IFPM = 0) is called.

5) Subroutine ABFCS is called. If ISKP = 0, then skip to 7).

6) Subroutine DXYYX is called.

7) Setting n = 1, the above procedure is repeated.

10 CDTRHS

In order to calculate the differential terms of the right-hand side of Eq. (16) and to store the corresponding results in the array DTRH(IXM,IYM), the subroutines DXXYY, ABFSS, ABFSC, DXYYX and DXYYXM are called. First, DTRH(IX,IY) is initialized with zero for all mesh points, and subsequently the values stored in this array are used by a similar procedure as in CDTRHC. Since $(\hat{D}^{\ell}_{xx} \pm \hat{D}^{\ell}_{yy}) f^{es}{}_{ij}$ and $(\hat{D}^{\ell}_{xy} + \hat{D}^{\ell}_{yx}) f^{ec}{}_{ij}$ should vanish at the outermost boundary as seen in Appendix A, DTRH(IX,IY) is set to zero for the outermost mesh points at the end of computation.

11 CLSCT

When the highest order of anisotropic scattering cross-section LSC is less than LMX, the order of the P_L approximation, the cross-section Σ_ℓ takes the same value Σ_t for LSC $+ 1 \leq \ell \leq$ LMX. The array LSCT(0:LHMX) which specifies the address of Σ_ℓ is calculated.

12 COABDE

The coefficients of the 9-point form of the difference equation (61) are calculated for material interfaces.

13 DPEP

The coefficients d^+ and e^+ of Eqs. (46) and (47) are calculated for each energy group and region.

14 DXXYY

The differential terms of Eq. (58), $(\bar{D}'^{\ell+n}{}_{xx} \pm \bar{D}'^{\ell+n}{}_{yy})$ ABF(IX,IY) are calculated.

When this subroutine is called in CDTRHC, the following calculations are done:

$$\mathrm{DTRH(IX,IY)} = \mathrm{DTRH(IX,IY)} + \sum_{n=-1}^{1}{}' \left(\overline{D}'^{\ell+n}_{xx} + \overline{D}'^{\ell+n}_{yy}\right) b^{no}_{\ell m} f^{ec}_{\ell+2n,mij}$$

$$+ \sum_{n=-1}^{1}{}' \left(\overline{D}'^{\ell+n}_{xx} - \overline{D}'^{\ell+n}_{yy}\right)\left(a^{n,-1}_{\ell m} f^{ec}_{\ell,m-2,ij} + a^{n1}_{\ell m} f^{ec}_{\ell,m+2,ij} -\right.$$

$$\left. - b^{n,-1}_{\ell m} f^{ec}_{\ell+2n,m-2,ij} - b^{n1}_{\ell m} f^{ec}_{\ell+2n,m+2,ij}\right)$$

and in CDTRHS,

$$\mathrm{DTRH(IX,IY)} = \mathrm{DTRH(IX,IY)} + \sum_{n=-1}^{1}{}' \left(\overline{D}'^{\ell+n}_{xx} + \overline{D}'^{\ell+n}_{yy}\right) b^{no}_{\ell m} f^{es}_{\ell+2n,mij}$$

$$+ \sum_{n=-1}^{1}{}' \left(\overline{D}'^{\ell+n}_{xx} - \overline{D}'^{\ell+n}_{yy}\right)\left(a^{n,-1}_{\ell m} f^{es}_{\ell,m-2,ij} + a^{n1}_{\ell m} f^{es}_{\ell,m+2,ij} -\right.$$

$$\left. - b^{n,-1}_{\ell m} f^{es}_{\ell+2n,m-2,ij} - b^{n1}_{\ell m} f^{es}_{\ell+2n,m+2,ij}\right)$$

If IFPM = 1, then the term $(\bar{D}'^{\ell+n}_{xx} + \bar{D}'^{\ell+n}_{yy}$, and if IFPM = 0, $(\bar{D}'^{\ell+n}_{xx} - \bar{D}'^{\ell+n}_{yy})$ is computed.

15 DXYYX

The differential term $(\bar{D}^{\ell+n}_{xy} + \bar{D}^{\ell+n}_{yx})$ABF(IX,IY) of Eq. (58) is calculated. When called in CDTRHC, the following terms are calculated:

$$\mathrm{DTRH(IX,IY)} = \mathrm{DTRH(IX,IY)} + \sum_{n=-1}^{1}{}' \left(\overline{D}^{\ell+n}_{xy} + \overline{D}^{\ell+n}_{yx}\right)\left(- a^{n,-1}_{\ell m} f^{es}_{\ell,m-2,ij} +\right.$$

$$\left. + a^{n1}_{\ell m} f^{es}_{\ell,m+2,ij} + b^{n,-1}_{\ell m} f^{es}_{\ell+2n,m-2,ij} - b^{n1}_{\ell m} f^{es}_{\ell+2n,m+2,ij}\right)$$

and in CDTRHS,

$$\mathrm{DTRH(IX,IY)} = \mathrm{DTRH(IX,IY)} + \sum_{n=-1}^{1}{}' \left(\overline{D}^{\ell+n}_{xy} + \overline{D}^{\ell+n}_{yx}\right)\left(a^{n,-1}_{\ell m} f^{ec}_{\ell,m-2,ij} -\right.$$

$$\left. - a^{n1}_{\ell m} f^{ec}_{\ell,m+2,ij} - b^{n,-1}_{\ell m} f^{ec}_{\ell+2n,m-2,ij} + b^{n1}_{\ell m} f^{ec}_{\ell+2n,m+2,ij}\right)$$

16 EXSOCE

The external source of the right-hand side of Eq. (58) is calculated in the form $ES = - Q_{ij} \Delta x_i \Delta y_j$ and added to the array SOCE(IX,IY). This value depends on the mesh points of the region. If the mesh point (i,j) is at the corner, at the boundary and at the interior of the region ES/4, ES/2 and ES is added to the array SOCE(IX,IY), respectively.

17 FLUXC

The moments $f^{ec}{}_{\ell mij}$ are calculated by the inner iteration of the successive over relaxation method solving the three-point difference equation in x-direction.

The coefficients of the difference equation are obtained by assuming the reflective boundary condition at the outermost boundary. The zero boundary conditions, however, are realized by omitting to solve the equations at those boundary mesh points. By this method, the vacuum boundary condition can be easily applied at all boundaries.

18 FLUXS

The moments $f^{es}{}_{\ell mij}$ are calculated by a similar inner iteration as in the FLUXC.

19 FSOCE

The fission source is calculated as

$$\mathrm{FSO(IX,IY)} = \sum_{g=1}^{G} v\Sigma_{fg} f^{ec}_{oogij}$$

by making use of the subroutine INTEGR, where corrections by factors of 1/4 or 1/2 are made at the corner or the inner boundary of regions, respectively.

The criticality factor k is calculated by

$$k = \sum_{ij} \sum_{g=1}^{G} v\Sigma_{fg} f^{ec}_{oogij} = \sum_{IY=1}^{IYM} \sum_{IX=1}^{IXM} \mathrm{FSO(IX,IY)}$$

20 INTSOC

For the source problem, the initial guess for the total flux is given in the form:

$$f^{ec}_{oogij} = \frac{S_{gij}}{\Sigma_{tg}}$$

The values at the corner and the other interfaces are calculated by multiplying 1/4 and 1/2, respectively, to get average values. All higher moments are put to zero at all mesh points.

21 INITLZ

Subroutines DPEP, ABCDE, FSOCE et al. are called to perform the initialization of the iteration calculations, namely, to calculate coefficients for the 5-point difference equation and the initial value of the moments. At internal material interfaces the 5-point discretization scheme is extended in subroutine COABDE to a more accurate 9-point discretization scheme (Actually this extension is applied at all coarse mesh boundaries, i.e. not only at external boundaries and internal material interfaces but also at such interfaces within a homogeneous region where the mesh size of the discretization grid is changed).

22 INTEGR

When this subroutine is called from FSOCE, the fission neutron production contribution

$$\nu\Sigma_{fg} f^{ec}_{oogij}$$

and when called from subroutine SLDSOC, the scattering contribution

$$\Sigma_{g\leftarrow g'} f^{ec}_{oog'}$$

are calculated for each quadrant of every mesh point and summed up for each mesh point. If the mesh points are at the corner of a region or at other boundaries of the region, factors of 1/4 or 1/2 are taken into account, respectively.

23 LMCST

The integer arrays LMCT(0:LHMX,0:LHMX) and LMST(LHMX,LHMX) are calculated.

24 INVASC

The anisotropic scattering cross-section ASC(NMT,0:LSC,IE) is inverted with respect to the energy group structure as ASC(NMT,0:LSC,NEG-IE + 1) for the adjoint calculation.

25 INVKAI

The fission spectrum RKAI(IE) is inverted with respect to the energy group structure as RKAI(NEG-IE + 1) for the adjoint calculation.

26 INVNFC

The production and total cross-sections are inverted with respect to the energy group structure for the adjoint calculation.

27 INVSCR

The within-group scattering matrix SCR(NMT,IE,JE) is inverted as SCR(NMT, NMT-JE + 1,NMT-IE + 1) for the adjoint calculation.

28 MESWID

The mesh width of each region is calculated.

29 PL

For the given order of approximation L = LMX and the error criteria of the inner, the middle and the source iterations, ECIN, ECMI and ECSO, the spherical harmonics equation is solved.

Printing of the errors during each iteration is controlled by the integer IFPRIN, IFPRMI and IFPRSO defined in this subroutine.

30 PRNTF

x and y coordinates, angular moments and the integrated total flux of each region are printed.

31 READIN

Subroutines RDGEO, RDCROS, RDMAT and RDEXSO to read input data are called and the addresses of arrays are calculated.

32 RDCROS

Total, production, scattering, anisotropic within-group scattering cross-sections, and fission spectrum are read.

33 RDDATA

The input data for the order L of the P_L-approximation, number of materials, number of energy groups, acceleration factors, error criteria etc. are read.

34 RDEXSO

The external neutron source distribution is read regionwise which is assumed to be constant in each region.

35 RDGEO

Number of mesh intervals and the coordinates of the boundaries for each region are read.

36 RDMAT

The table of the material distribution for the whole configuration is read.

37 SIGMAL

$\Sigma_\ell = \Sigma_t - \Sigma_{s\ell}$ is calculated and stored in SGL(NMT,0:LSC+1,NEG).

38 SLDSOC

The slowing down source

$$\mathrm{SLDS(IX,IY)} = \sum_{g'=1}^{g-1} \Sigma_{g \leftarrow g'} f^{ec}_{oog'ij}$$

is computed by making use of the subroutine INTEGR.

39 TIMEA (Entry TIMEB)

The CPU time is printed.

40 TSOCEC

The total sources, i.e. the differential term, the fission, the slowing down and the external source if it exists, are calculated, and summed up in the array SOCE(IXM,IYM). The computation proceeds as follows:

1) The array SOCE(IXM,IYM) is set to zero.
2) Subroutine CDTRHC is called and the differential term is stored in the array SOCE(IXM,IYM). If $(1,m) \neq (0,0)$, the computation is terminated here.
3) The fission source and the slowing down source are added to the SOCE(IXM,IYM) with a negative sign.
4) If the external source exists, it is added by calling the subroutine EXSOCE.

4. Description of Variables and their Meaning

1) Allocation of the Integer Array IA and the Real Array A

IA(1) ~ (43)	Integer constants
IA(50) ~ (57)	Pointer to integer arrays
IA(70) ~ (115)	Pointer to real arrays
IA(120) ~ IA(MIAUSE)	Area for integer arrays
A(1) ~ (18)	Real constants
A(20) ~ A(MAUSE)	Area for real arrays

After allocation of the arrays IA and A, integers MDA, IRESTA, MDIA and IRESIA are printed, which are the dimension of the real array A, the rest of the array A, the dimension of the integer array IA and the rest of the array IA, respectively.

2) Integer Constants

Integer	Meaning	Location in IA
MDA	Maximum dimension of the real array A.	1
MDIA	Maximum dimension of the integer array IA.	2
MAUSE	Used area of the real array A.	3
MIAUSE	Used area of the integer array IA.	4
IRESTA	Rest of real array A.	5
IRESIA	Rest of integer array IA.	6
NXM	Number of regions in x-direction.	11
NYM	Number of regions in y-direction.	12
IXM	Number of mesh points in x-direction.	13
IYM	Number of mesh points in y-direction.	14
IBCR	0/1 = Vacuum/Reflective condition at the right most boundary.	15
IBCL	0/1 = Vacuum/Reflective condition at the left most boundary	16
IBCT	0/1 = Vacuum/Reflective condition at the top boundary	17
IBCB	0/1 = Vacuum/Reflective condition at the bottom boundary.	18
IFCR	0/1/2 = Reading Cross-sections: No/Yes (from standard input unit) / from an external file on unit 22	19
IFES	0/1/2 = Reading external sources: No/Yes (in the form of a product of an energy and spatial distribution) / Detailed (with a general energy- and space-dependence)	20
IFP1	0/1 = Printout and accurate calculation of neutron fluxes only for final P_L approximation / Printout and accurate calculation of neutron fluxes for all $P_1, P_3, \ldots, P_{L-2}, P_L$ approximations	21
LMX	= L, Order of P_L approximation which must be odd.	22

LSC	Maximum order of scattering cross sections $\Sigma_{s\ell}$.	23
NMT	Number of materials.	24
NEG	Number of energy groups.	25
MNII	Maximum number of inner iterations.	26
MNMI	Maximum number of middle iterations.	27
MNSI	Maximum number of source iterations.	28
LPRT	Maximum order of angular moments to be printed out which should be even. When LPRT = -2, only the criticality factor, and LPRT = -1, the integrated total flux is printed.	29
LMTIME	CPU time in units of sec. to terminate all iteration calculations.	30
IFILE	File number of a disk unit to write out the coordinates and the total fluxes. If IFILE = 0, these data are not written.	31
LMCMX	= (L + 1)(L + 3)/8, Number of terms of $f^{ec}{}_{\ell m}$.	32
LMSMX	= $(L^2$-2)/8, Number of terms of $f^{es}{}_{\ell m}$. If L = 1, LMSMX is put to 1 to avoid reading or writing error into the disk.	33
IREC	Number of blocks to save arrays FEC, FES, RLC, RLOC, RUC, RLS, RLOS, RUS, AA and EE into disk.	34
NXXM	= 2*NXM + 1	35
NYYM	= 2*NYM + 1	36
NXM1	= NXM + 1	37
NYM1	= NYM + 1	38
LSC1	= LSC + 1	39
LHMX	= (LMX-1)/2	40
IFADJ	0/1 = Direct/Adjoint calculations. When LMX is negative, IFADJ is set to 1.	41
IBUCK	0/1/2/3 = No Buckling/Height H/Height H_0/Buckling B^2.	42
INTV	Interval to print iterations.	43

3) Real Constants

Real Constant	Meaning	Location in A
ACFI	Acceleration factor for the inner iteration.	1
ACFM	Acceleration factor for the middle iteration.	2
ACFS	Acceleration factor for the source iteration.	3
ECIN	Error criterion in absolute value for the inner iterations.	4
ECMI	Error criterion in absolute value for the middle iteration.	5
ECSO	Error criterion in absolute value for the source iteration.	6
ECK	Error criterion in relative value for the criticality factor.	7
FECL	Factor to make larger all error criteria for lower order calculations.	8
GUESS	Initial guess of the total flux for the source problem is generated in the program, when GUESS = -1.	9
ERIN1	Error of the inner iteration of the first time.	
ERIN	Error of the inner iteration of the last time.	
ERINMX	Maximum error of the inner iteration for NSI-th source iteration.	
ERMIC	Error of the middle iteration with sign for $f^{ec}{}_{\ell mij}$.	
ERMIS	Error of the middle iteration with the sign for $f^{es}{}_{\ell mij}$.	
ERMI	Maximum error of the middle iteration for each energy group.	
ERK	Error of the criticality factor.	
ERMIMX	Maximum error of the middle iteration of NSI-th source iteration.	
RK	Criticality constant.	
H	Height H, H_0 or Buckling B^2.	17
ZERO	$1 \cdot 10^{-8}$	18

4) Integer Array

Name of Array and (Dimensions)	Explanation of the Array	Pointer to Integer Array	Location in IA
NMIX(NX) (NXM)	Number of mesh intervals in NX-th region of x-direction	LNMIX	50
NMIY(NY) (NYM)	Number of mesh intervals in NY-th region of y-direction	LNMIY	51
MTT(NX,NY) (NXM,NYM)	Material table of index for NX and NY-th region	LMTT	52
LMCT(LM,MM) (0:LHMX, 0:LHMX)	=LMC, Address of $f^{ec}{}_{\ell m}$. Namely, (0,0)=1, (1,0)=2, (1,1)=3, (2,0)=4, (2,1)=5, ..., and FEC(IX,IY,LMC) = $f^{ec}{}_{\ell mij}$, where LH=ℓ/2, MH=m/2	LLMCT	53
LMST(LH,MH) (LHMX, LHMX)	=LMS, Address of $f^{es}{}_{\ell m}$. Namely, (1,1)=1, (2,1)=2, (2,2)=3, (3,1)=4, (3,2)=5, ..., and FES(IX,IY,LMS) = $f^{es}{}_{\ell mij}$, LH=ℓ/2, MH=m/2.	LLMST	54
MBX(NX) (NXM1)	Mesh index at the right boundary of the NX-th region in x-direction.	LMBX	55
MBY(NY) (NYM1)	Mesh index at the lower boundary of the NY-th region in y-direction.	LMBY	56
LSCT(LH) (0:LMX)	=LS, Address for the cross section Σ_ℓ. Namely, $\Sigma_{\ell g}$ = SGL(IM,LS,IE), where ℓ = LS and g=IE. For example, if LMX=5 and LSC=2, then LSCT(0)=0, (1)=1, (2)=2, (3)=3, (4)=3, (5)=3, because $\Sigma_3 = \Sigma_t$, $\Sigma_4 = \Sigma_t$ and $\Sigma_5 = \Sigma_t$.	LLSCT	57

5) Real Array

Name of Array and (Dimensions)	Explanation of the Array	Pointer to Real Array	Location in IA
RBX(NX) (NXM1)	Outer boundary of NX-th region in x-direction. Usually, RBX(1) = 0.	LRBX	70
RBY(NY) (NYM1)	Outer boundary of NY-th region in y-direction. Usually, RBY(1) = 0.	LRBY	71
DX(NX) (NXM)	Mesh width of NX-th region in x-direction.	LDX	72
DY(NY) (NYM)	Mesh width of NY-th region in y-direction.	LDY	73
RX(IX) (IXM)	x-coordinate of IX-th mesh point.	LRX	74
RY(IY) (IYM)	y-coordinate of IY-th mesh point.	LRY	75
TCR(IM,IE) (NMT,NEG)	$=\Sigma_{tg}$ of IM-th material, where IE = g.	LTCR	76
RNFC(IM,IE) (NMT,NEG)	$=\nu\Sigma_{fg}$ of IM-th material, where IE = g.	LRNFC	77
SCR(IM,IE,JE) (NMT,NEG,NEG)	$=\Sigma_{s0}(g \leftarrow g')$ of IM-th material, where IE = g and JE = g'.	LSCR	78
ASC(IM,L,IE) (NMT,0:LSC,NEG)	$=\Sigma_{s\ell g}$ of IM-th material, where $L=\ell$ and IE = g.	LASC	79
RKAI(IE) (NEG)	$=X_g$, where IE = g.	LRKAI	80
EXSSP(NEG)	energy distribution of external source.	LEXSSP	81
EXSO(NX,NY,IE) (NXM,NYM,NEG)	$=S_g$, external source in the NX and NY-th region for energy group IE.	LEXSO	82

ALM(LH,MH,N,K) (0:LHMX,0:LHMX, -1:1,-1:1)	$=a^{nk}{}_{\ell m}$, where LH $=\ell/2$, MH $=$ m/2, N $=$ n, K $=$ k and LH $\geq$ MH.	LALM	83
BLM(LH,MH,N,K) (0:LHMX,0:LHMX, -1:1,-1:1)	$=b^{nk}{}_{\ell m}$, where LH $=\ell/2$, MH $=$ m/2, N $=$ n, K $=$ k and LH $\geq$ MH.	LBLM	84
SGL(IM,L,IE) (NMT,0:LSC1, NEG)	$=\Sigma_{\ell g}$ of IM-th material, where L $=\ell$, IE $=$ g and IM is the material index.	LSGL	85
FEC(IX,IY,LMC) (IXM,IYM,LMCMX)	$=f^{ec}{}_{\ell mij}$, where IX $=$ i, IY $=$ j, LMC $=$ LMCT(LH,MH), LH $=\ell/2$ and MH $=$ m/2.	LFEC	86
FES(IX,IY,LMS) (IXM,IYM,LMSMX)	$=f^{es}{}_{\ell mij}$, where IX $=$ i, IY $=$ j, LMS $=$ LMST(LH,MH), LH $=\ell/2$ and LM $=$ m/s.	LFES	87
RLC(IX,NYY,LMC) (IXM,NYYM, LMCMX)	$=l_i$ for NYY-th region, which is the off diagonal element of lower triangular matrix used to calculate $f^{ec}{}_{\ell m}$.	LRLC	88
RLDC(IX,NYY,LMC) (IXM,NYYM, LMCMX)	$=l_{di}$ at i $=$ IX, LMC $=$ LMCT(LH,MH), LH $=\ell/2$ and MH $=$ m/s, which is the diagonal element of the lower triangular matrix obtained by the factorization method to the 3-point equation in x-direction, and is used to calculate $f^{ec}{}_{\ell m}$ in NYY-th region of y-direction.	LRLDC	89
RUC(IX,NYY,LMC) (IXM,NYYM, LMCMX)	$=u_i$ at i $=$ IX in NYY-th region, which is the off diagonal element of the upper triangular matrix to calculate $f^{ec}{}_{\ell m}$.	LRUC	90

RLS(IX,NYY,LMS)(IXM,NYYM,LMSMX)	$=l_i$ at $i=$IX for NYY-th region, the off diagonal element of the lower triangular matrix used to calculate $f^{es}{}_{\ell m}$.	LRLS	91
RLDS(IX,NYY,LMS)(IXM,NYYM,LMSMX)	$=l_{di}$ for NYY-th region at $i=$IX, the diagonal element of the lower triangular matrix used to calculate $f^{es}{}_{\ell m}$. LMS = LMST(LH,MH).	LRLDS	92
RUS(IX,NYY,LMS)(IXM,NYYM,LMSMX)	$=u_i$, the off diagonal element of the upper triangular element to calculate $f^{es}{}_{\ell mij}$, where IX $=i$.	LRUS	93
AA(NXX,NYY,LMC)(NXXM,NYYM,LMCMX)	$=\sum'^{1}_{n=-1} a^{\ell+n}\cdot a^{n0}{}_{\ell m}$ for NXX and NYY-th region	LAA	94
EE(NXX,NYY,LMC)(NXXM,NYYM,LMCMX)	$=\sum'^{1}_{n=-1} e^{\ell+n}\cdot a^{n0}{}_{\ell m}$ for NXX and NYY-th region	LEE	95
CDP(NX,NY,LS,IE)(NXM,NYM,0:LSC1,NEG)	$=d^{\ell+}{}_{g}$ of NX- and NY-th region, where IE $=g$ and L $=\ell$.	LCDP	96
CEP(NX,NY,LS,IE)(NXM,NYM,0:LSC1,NEG)	$=e^{\ell+}{}_{g}$ of NX- and NY-th region, where IE $=g$ and LS $=\ell$.	LCEP	97
COA(NXX,NXY,LS)(NXXM,NYYM,0:LSC1)	$=a^{\ell}$ for NXX- and NYY-th region, where LS $=\ell$.	LCOA	98
COB(NXX,NYY,LS)(NXXM,NYYM,0:LSC1)	$=b^{\ell}$ for NXX- and NYY-th region, where LS $=\ell$.	LCOB	99

COC(NXX,NYY,L) (NXXM,NYYM, 0:LSC1)	$=a^{\ell}+b^{\ell}+d^{\ell}+e^{\ell}$ for NXX- and NYY-th region, where $L=\ell$.	LCOC	100
COD(NXX,NYY,L) (NXXM,NYYM, 0:LSC1)	$=d^{\ell}$ for NXX- and NYY-th region.	LCOD	101
COE(NXX,NYY,L) (NXXM,NYYM, (0:LSC1)	$=e^{\ell}$ for NXX- and NYY-th region.	LCOE	102
COSL(NXX,NYY,L) (NXXM,NYYM, (0:LSC1)	= coefficient to calculate $f^{ec}{}_{\ell mij}$.	LCOSL	103
BB(NXX,NYY,LMC) (NXXM,NYYM, LMCMX)	$=\sum_{n=-1}^{1}{}' \ b^{\ell+n} \cdot a^{n0}{}_{\ell m}$	LBB	104
CC(NXX,NYY,LMC) (NXXM,NYYM, (LMCMX)	$=\sum_{n=-1}^{1}{}' \ c^{\ell+n} \cdot a^{n0}{}_{\ell m}$	LCC	105
DD(NXX,NYY,LMC) (NXXM,NYYM, LMCMX)	$=\sum_{n=-1}^{1}{}' \ d^{\ell+n} \cdot a^{n0}{}_{\ell m}$	LDD	106
FSO(IX,IY) (IXM,IYM)	= fission source	LFSO	107
TEMPM(IX,IY) (IXM,IYM)	Temporary memory used for FEC and FES in middle iteration.	LTEMPM	108
TEMPFS(IX,IY) (IXM,IYM)	Temporary memory used for FSO	LTEMPF	109

ABF(IX,IY) (IXM,IYM)	Used to calculate the differential terms of the right hand side, for example, $a^{n,-1}{}_{\ell m} f^{ec}{}_{\ell,m-2} + a^{n1}{}_{\ell m} f^{ec}{}_{\ell,m+2} -$ $- b^{n,-1}{}_{\ell m} f^{ec}{}_{\ell+2n,m-2} - b^{n1}{}_{\ell m} f^{ec}{}_{\ell+2n,m+2}$	LTEMP	110
TEMP(IX,IY) (IXM,IYM)	Temporary memory used for FEC and FES in inner iteration.	LTEMP	110
SLDS(IX,IY) (IXM,IYM)	$= \sum_{g'=1}^{g-1} \Sigma_s(g \leftarrow g') f^{ec}{}_{oog'\,ij}$ the slowing down source, where $i = IX$ and $j = JY$.	LSLDS	111
SOCE(IX,IY) (IXM,IYM)	Right hand side of Eq. (15) or Eq. (16).	LSOCE	112
DTRH(IX,IY) (IXM,IYM)	Differential terms of right hand side of Eq. (15) or Eq. (16).	LSOCE	112
TSOCE(IX) (IXM)	$=$ SOCE(IX,IY) $- a_{ij} f_{i,j-1} - e_{ij} f_{i,j+1}$, the source term of the 3-point finite difference equation.	LTSOCE	113
G(IX) (IXM)	$= g_i$, used to solve the 3-point finite difference equation.	LG	114
SGLB(IM,L,IE) (NMT,0:LSC1,NEG)	$= \Sigma_{s\ell g} - D_g B^2$ from IM-th material, where $L = \ell$ and $IE = g$.	LSGLB	115

5. Input Data Preparation

1) Input Description of PLXY Code

The input data is free format.

Introductory remark

When preparing the input, please note that each material interface has to be treated as a region boundary. Each region boundary for one coordinate direction is assumed to extend over the full length in the other (perpendicular) direction. Thus, the total number of regions equals NXM * NYM (see K2, K4 and the specification of the material distribution in K12).

Card (FORMAT)	Variables	Meaning
K1(18A4)	TITLE(18)	Information text
K2	NXM	Number of regions in x-direction
	NMIX(NX)	Number of mesh intervals of each region in x-direction. (NX = 1,2,...,NXM)
K3	RBX(NXP)	x-coordinates of each region. Usually, RBX(1) = 0. (NXP = 1,2,...,NXM + 1)
K4	NYM	Number of regions in y-direction
	NMIY(NY)	Number of mesh intervals of each region in y-direction. (NY = 1,2,...,NYM)
K5	RBY(NYP)	y-coordinates of each region, Usually, RBY(1) = 0. (NYP = 1,2,...,NYM + 1)
K6	IBCR	Boundary condition at right boundary 0/1 = 0./refl.
	IBCL	Boundary condition at left boundary 0/1 = 0./refl.
	IBCT	Boundary condition at top boundary 0/1 = 0./refl.
	IBCB	Boundary condition at bottom boundary 0/1 = 0./refl.

IFCR	Read cross sections or not 0/1/2 = No/Yes / Read from unit 22 instead of standard input unit
IFES	Source problem or not 0/1 = No/Yes
IFP1	Printout of fluxes P_1, P_3, ... P_L. 0/1 No/Yes Please note: In accordance with the printout of the fluxes for lower P_L orders, also the related accuracy parameters will be changed. For IFP1 = 1 the accuracy requirements for P_1, P_3, . . . are the same as for the final P_L calculation. For IFP1 = 0 they are usually less stringent by a factor FECL which usually has a value of 10.
LMX	Order of P_L approximation. LMX should be odd. LMX $>$ 0 direct calculation LMX $<$ 0 adjoint calculation
LSC	Maximum order of anisotropic scattering. $0 \leq$ LSC $\leq$ LMX
NMT	Number of materials
NEG	Number of energy groups
MNII	Maximum number of inner iterations
MNMI	Maximum number of middle iterations
MNSI	Maximum number of source iterations
LPRT	Maximum order of spherical harmonics moments of angular flux to be printed. LPRT should be even and $0 \leq$ LPRT $\leq$ LMX-1. When LPRT = -1, only integrated total flux and LPRT = -2, the criticality factor are printed.
LMTIME	CPU time in units of seconds to terminate the iteration calculation
IFILE	Identification number of disk memory to write out the coordinates and the total fluxes. When we use this option, the appropriate DD-control statement must be added in the Job-Control language.
IBUCK	Buckling correction, 0/1/2/3/4 = No/Height H including extrapolation length/Height H_0 excluding extrapolation length/ Global Buckling B^2 / Material dependent Buckling B^2
INTV	Intervals to print out iterations

K7	ACFI	Acceleration factor for inner iteration
	ACFM	Acceleration factor for middle iteration
	ACFS	Acceleration factor for source iteration
	ECIN	Error criterion in absolute value for inner iterations
	ECMI	Error criterion in absolute value for middle iterations. It is recommended to use the value ECMI = 10·ECIN
	ECSO	Error criterion in absolute value for source iterations
	ECK	Error criterion in relative value for criticality value
	FECL	For IFP1 = 0 this factor makes larger the error criteria for inner, middle and source iterations for the lower order P_L approximations $P_1, P_3, \dots, P_{L-2}$. For IFP1 = 1 the value of this factor is of no importance because the fluxes for all P_L approximations are determined with the nominal accuracy criteria.
	GUESS	= -1. The iteration starts with constant value of the total flux in the space.
	H	Height H, H_0 or Buckling B^2 for IBUCK = 1, 2 or 3, respectively, where H_0 is the geometrical height and H includes the extrapolation length in z-direction. (For simplicity reasons a global, group-independent value of the buckling, B^2, is assumed.) (or (H(IM), IM = 1, NMT) for IBUCK = 4; in this case H(IM) corresponds to the material dependent Buckling B^2.)

S1 Cards K8, K9 and K10 are read from the material index IM = 1 to NMT.

K8	TCR(IM,IE)	Total cross section Σ_t
	RNFC(IM,IE)	Fission cross section times the number of fission neutrons $\nu\Sigma_f$ in the order (IE = 1,NEG)
K9	SCR(IM,IE,JE)	Scattering cross section $\Sigma_s(g \leftarrow g')$, where g = IE and g' = JE in the order ((JE = 1,IE),IE = 1,NEG)

S2 Cards K10 are read only when there is anisotropic scattering, namely, LSC $\geq$ 1.

K10	ASC(IM,L,IE)	Anisotropic scattering cross section ASC(IM,L,IE) = $\Sigma_{s\ell g}$ for $\ell \geq 1$, where g = IE and ℓ = L in the order ((L = 1,LSC),IE = 1,NEG) (Presently anisotropic scattering is allowed only for within group scattering.)
K11	RKAI(IE)	Fission spectrum X_g in the order (IE = 1,NEG)
K12	MTT(NX,NY)	Material indices for each region in the order (((NX = 1,NXM),NY = 1,NYM)

(Please be aware that in the input, the data for the MTT-array have to be provided in the sequence from bottom to top of the reactor [and from left to right] whereas in the output listing, the material arrangement is printed so that it appears as considered usual by the user, such that the uppermost row - corresponding to the top line - is printed first, i.e. the printing sequence is reversed with respect to the input sequence.)

S3 K13 and K 14 are read in the case of a source problem, namely, if IFES $\neq$ 0

if IFES = 1:

K13 EXSSP(IE) Energy distribution for external source for (IE = 1,NEG)

K14	EXSO(NX,NY)	Source intensity EXSO(NX, NY) = $Sec_{00g}(r_p)$ which is assumed to be constant in each region, and is read in the order ((NX = 1,NXM), NY = 1,NYM)

if IFES = 2:

NEG cards with IE = 1, NEG are read with the following structure

K13	EXSO(NX,NY,IE)	External source for each region in group IE EXSO(NX, NY, IE) = $Sec_{00g}(r_p)$ which is assumed to be constant in each region, and is read in the order (((NX = 1,NXM), NY = 1, NYM), IE)

As input quantity for the source specification in PLXY, the strength of the source intensity per unit volume is used as can be seen from the above equation. The user should have in mind that the total strength of the source for the whole reactor configuration will depend on the boundary conditions, i.e. on the symmetry properties of the posed problem.

2) Comments to the Input Preparation

In the case of the 4-group criticality problem given in Ref. 9, the following values are found to be appropriate and are recommended for application in similar problems.

MNII = 10, MNMI = 10, MNSI = 100, ACFI = 1.5, ACFM = 1.1, ACFS = 1.4,
ECIN = 10^{-7}, ECMI = 10^{-6}, ECSO = 10^{-6}, ECK = 10^{-5}, FECL = 10, GUESS = -1.

In the error criteria described in Eqs. (79) ~ (83), the errors of the higher moments are related to the magnitude of the corresponding zeroth moment, i.e. to the scalar flux. This procedure is reasonable because the spherical harmonics functions have roughly an absolute magnitude of unity, so that the contribution of the higher moments to the angular flux is taken into account appropriately and in an efficient way. If we would have used, instead of the error criteria in Eqs. (82) and (83), relations for the relative errors of the higher moments, i.e. replacing the zeroth moment by the corresponding moments themselves, such a scheme would become inefficient and would lead to wasting of computing time. In accordance with usual experience, the error criterion for middle iteration ECMI should generally be chosen greater than that of the inner iteration ECII, for example, ECMI = 10·ECIN. If ECMI < ECIN, the convergence of the middle iteration is disturbed by the error of the inner iteration, and the middle iteration might not converge. Since errors are calculated from the difference of moments of successive iterations, it is necessary to use smaller error criteria to make the error from the exact solution sufficiently small, if the convergence rate of the iteration is very slow, for example, for fixed source problems of a nearly critical system or for so-called void problems, i.e. where at least one region of the reactor contains a region consisting of low density material.

6. Output Description

At the beginning of the computation, the dimensions of the integer and real arrays and the remaining ones are printed.

The abbreviations used in the output list have the following meaning:

FEC L=0 M=0	f^{ec}_{00}
FES L=2 M=2	f^{es}_{22}
NII	Maximum number of inner iteration
ERIN1	Error of first iteration of the inner iteration
ERIN	Error of the last inner iteration
ERMI	Error of the middle iteration
MNMI	Maximum number of middle iteration
NSI	Number of source iteration
RK	Criticality factor k

Most of the headlines in the output are self-descriptive; the meaning of most parameters is either self-explaining or may be deduced from the description of variables given in III.4 or is correlated to the characterization of the input data presented in III.5. For the various error criteria used to terminate the different iteration loops the reader is referred to K7 of the chapter III.6 on input data preparation and the associated comments given at the end of this chapter.

7. Sample Problems

For demonstration purposes, two sample problems are included in the present report. They are not too complicated so that the calculational effort remains acceptably small and their presentation (accepting some omissions for less important parts) is not too comprehensive and remains compatible with the size of the report.

The first sample problem characterized as "One group problem by Fletcher", was taken from the publication /4/. It is an external source problem with fairly small spatial dimensions and 90^0 symmetry (see Fig. 9). In fact this case has 45^0 symmetry, i.e. the solution is symmetric with respect to the diagonal.

In this sample problem we wanted to determine also rather accurate values for the fluxes in low order P_L approximations. Therefore, the input parameters IFP1 = 1 and FECL = 1.0 were chosen, whereas for efficiency reasons it is usual to specify IFP1 = 0 and FECL = 10.0 in order to reduce the output and to spend not too much time for the lower order cases where in general less stringent accuracy requirement are sufficient.

The second sample problem was taken from a fairly recent benchmark activity of Takeda et al. /10/. It deals with a "Small FBR Benchmark" configuration. For the present application, Model 2 with a Control Rod (CR) inserted in the core region of a small Fast Breeder Reactor (FBR) was chosen. It has also a 90^0 symmetry but since the control rod is positioned on the x-axis, the problem has no more a 45^0 symmetry.

IV. Numerical Examples and Discussion

In order to check the accuracy of the P_L equations, sample calculations were done for the one-group source problem given by Fletcher /4/ and the 4-group benchmark problem specified by Takeda et al. /10/ as Small FBR Benchmark. The geometry of Fletcher's problem is shown in Fig. 9. The system consists of a square of pure absorber and the constant external source is located at $0. \leq x < 1.2$ cm and $0. \leq y \leq 1.2$ cm whose strength is $s = 1/1.44$. Reflective boundary conditions are used at $x = 0.$ and $y = 0.$ and all moments are set to zero at $x = 7.0$ cm and $y = 7.0$ cm.
A mesh size of 0.1 cm is used for all intervals in the x- and y-direction. The total fluxes along the horizontal line at $y = 3.9$ cm are given in Table 1 for the P_1 - P_7 approximations together with the exact values taken from Table 2 of the related publication /9/ and the required CPU-time. Fig. 10 also taken from /9/ shows these total fluxes originally deduced from Table 2 of /9/ (but equivalent to Table 1 of this report because equivalent results are in nearly perfect agreement) together with the results of an S_N calculation with the finite difference discrete ordinates code TWOTRAN /11/.

Please note that in Fig. 10 (which is identical to Fig. 3 of /9/) the legend is slightly in error: in the legend the P_L orders P_5 and P_7 had to be interchanged (as obvious from Table 1 which is practically the same as Table 2 of /9/). The well-known ray effect which is typical for the results of discrete ordinate (S_N-) methods is evident from the S_8 curve shown in Fig. 10.

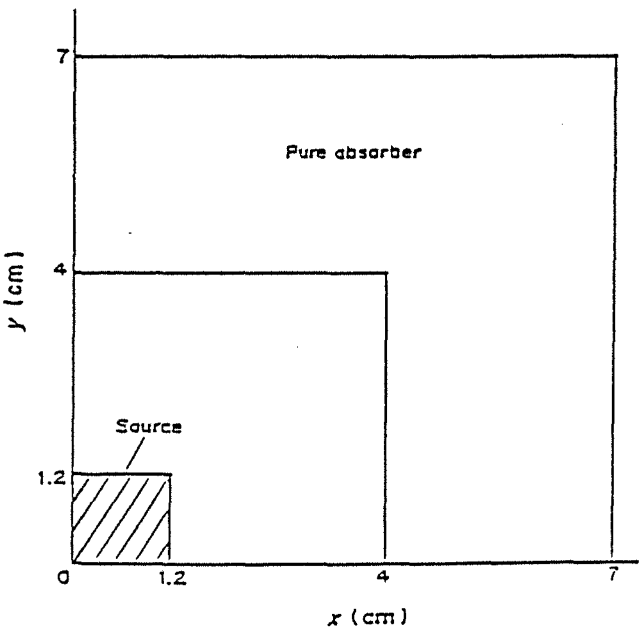


Fig. 9 Geometry of Fletcher's problem

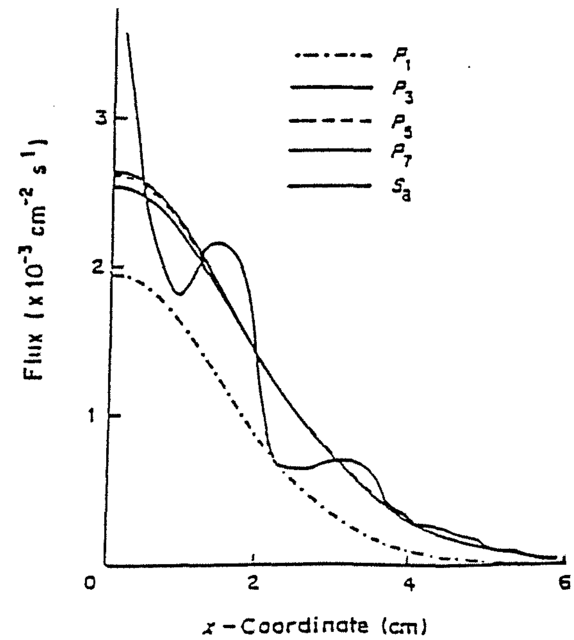


Fig. 10 Total flux along the line y = 3.9 cm for Fletcher's problem

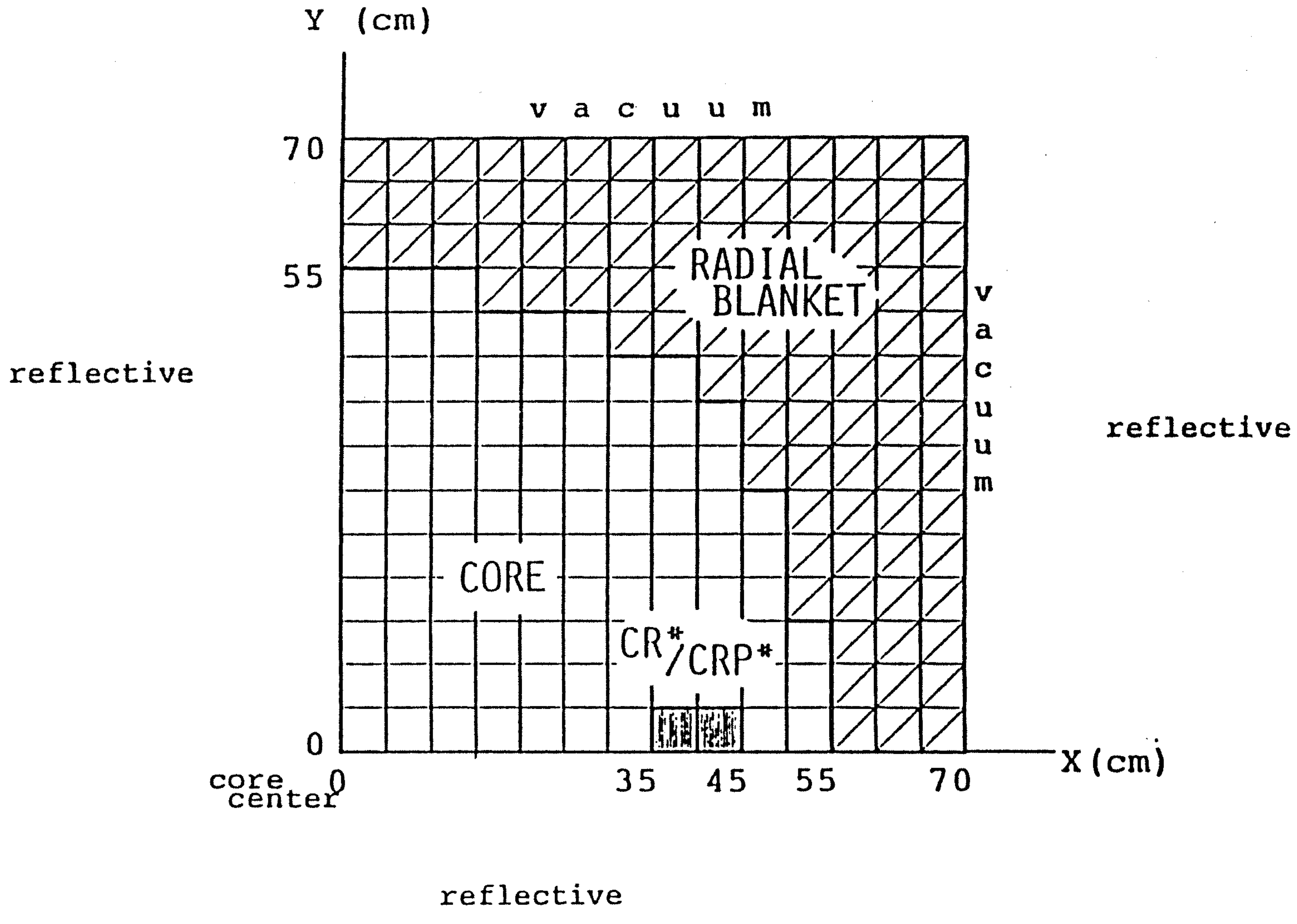
Table 1: Total flux along the line Y = 3.9 cm for Fletcher's problem
Results of PLXY for different PL-oders L

Distance (cm)	PL-Order P1	P3	P5	P7	Exact *)
0.1	1.9347E-03	2.5327E-03	2.6356E-03	2.6113E-03	2.6033E-03
0.3	1.9026E-03	2.5012E-03	2.6015E-03	2.5776E-03	2.5691E-03
0.5	1.8400E-03	2.4395E-03	2.5346E-03	2.5115E-03	2.5025E-03
0.7	1.7499E-03	2.3499E-03	2.4375E-03	2.4157E-03	2.4083E-03
0.9	1.6367E-03	2.2360E-03	2.3142E-03	2.2935E-03	2.2863E-03
1.1	1.5055E-03	2.1020E-03	2.1690E-03	2.1490E-03	2.1438E-03
1.3	1.3623E-03	1.9530E-03	2.0075E-03	1.9871E-03	1.9858E-03
1.5	1.2130E-03	1.7943E-03	1.8366E-03	1.8173E-03	1.8180E-03
1.7	1.0633E-03	1.6309E-03	1.6618E-03	1.6444E-03	1.6460E-03
1.9	9.1798E-04	1.4674E-03	1.4879E-03	1.4727E-03	1.4754E-03
2.1	7.8118E-04	1.3077E-03	1.3190E-03	1.3059E-03	1.3076E-03
2.3	6.5573E-04	1.1550E-03	1.1585E-03	1.1473E-03	1.1490E-03
2.5	5.4339E-04	1.0117E-03	1.0087E-03	9.9940E-04	1.0007E-03
2.7	4.4492E-04	8.7929E-04	8.7135E-04	8.6375E-04	8.6523E-04
2.9	3.6026E-04	7.5880E-04	7.4727E-04	7.4122E-04	7.4261E-04
3.1	2.8872E-04	6.5052E-04	6.3667E-04	6.3200E-04	6.3350E-04
3.3	2.2922E-04	5.5432E-04	5.3924E-04	5.3578E-04	5.3694E-04
3.5	1.8040E-04	4.6972E-04	4.5431E-04	4.5187E-04	4.5285E-04
3.7	1.4086E-04	3.9599E-04	3.8095E-04	3.7935E-04	3.8026E-04
3.9	1.0919E-04	3.3225E-04	3.1810E-04	3.1715E-04	3.1793E-04
CPU-Time (sec)	5	65	139	236	

*) Taken from Fletcher (Ref. /4/)

Fig. 11 taken from /10/ shows the geometrical and material arrangement for the Small FBR Benchmark. Please note that in PLXY the vacuum boundary condition is simulated by an additional external layer of absorber material with appropriate thickness and a sufficient absorption strength. For the Small FBR Sample Problem, therefore an extra region of 10 cm is added at the right and top boundary of the quarter section with an artificial absorber composition (specified as No. 6 and having only absorption and no scattering properties).

The dimensions are typical for such a configuration and the number of energy groups is representative of practical design calculations if the computational costs should be kept reasonably small. For a detailed analysis, e.g. of a similar critical assembly, the number of groups has to be increased by at least of factor of three, whereas the mesh size used here for the PLXY calculations (which is half of that originally specified in the benchmark description /10/ for reasons mentioned in the following) is probably not very different from that of realistic investigations. For preliminary studies even mesh sizes of about 5 cm are not unusual, so that a mesh size of 2.5 cm, as in the present PLXY calculation, is acceptable for most purposes and smaller intervals of about 1 cm thickness are only used if a fine resolution of the spatial distribution is aimed at or if the influence of the mesh size on overall quantities like the criticality value, k_{eff}, has been found to be fairly significant.



*CR : Control rod
CRP: Na filled control rod position

Fig. 11 Calculation Model of the Small FBR Sample Problem

With respect to the input data and the results of the "Small FBR Benchmark", the following remarks might be adequate:

(I) The present reference version of the PLXY code does not allow to have only one mesh interval per region. Therefore, it was impossible to comply with the original benchmark specifications /10/ which required to use a mesh size of 5 cm resulting in only one interval per region for all individual regions.

(II) For that reason at least two intervals per region were used in the PLXY input data and, correspondingly, the interval thickness was generally chosen as 2.5 cm.

(III) Due to this necessary mesh refinement, the results of the corresponding PLXY calculation are more accurate than those which would have been obtained with the originally specified coarser mesh grid. This aspect should be kept in mind when comparing the following PLXY results with those of other transport codes using a mesh grid which is in accordance with the original specifications.

(IV) This mesh refinement (although unintended but inevitable at the moment) is very favorable for the presented PLXY results because experience gained from additional calculations has shown that the results are rather sensitive to the magnitude of the mesh size, h; i.e. the error of integral quantities like k_{eff} depends roughly on the square of the mesh size, so that halving the mesh size reduces the error approximately by a factor of four. Although this rule is usually valid for most finite difference schemes, the proportionality factor for such a h^2-dependence is fairly large in the case of PLXY - at least if compared with the corresponding factor valid for S_N-results -.

(V) In case of the P_1 approximation, the PLXY code gives the same results as usual diffusion codes and the mesh size effect is also the same as for those diffusion codes using such standard finite difference methods as used in the PLXY code.

Acknowledgment

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Appendix A. Explicit Expression of the Differential Terms

Here, the explicit form of differential terms of Eqs. (15) and (16) is given, where the reflective boundary condition is used at the outer mesh points by extending the region with the same material. The mesh points i_a, j_a, i_b, and j_b designate the mesh points of the left, lower, right and top boundaries of a homogeneous region, respectively. The i_{max}, j_{max} and 1 designate the mesh points of the right, top and left or bottom boundaries, respectively.

In the code, the differential terms given below are valid for interior mesh points. For mesh points located at the external boundaries, these terms are divided by factors of 2 or 4, when two and three quarters of the mesh cell V are outside of the reactor, respectively, since the terms $\Sigma_\ell f$ and S(r) are integrated only inside of the reactor.

The equations without suffix ec or es hold for both cases of ec and es.

1. $i = i_a, \quad j = j_a$

a) $i_a \neq 1, \quad j_a \neq 1$

$$(\hat{D}^{\ell}_{xx} \pm \hat{D}^{\ell}_{yy}) f_{ij} = -(d^{\ell+} \pm e^{\ell+}) f_{ij} + d^{\ell+} f_{i+1,j} \pm e^{\ell+} f_{i,j+1} \tag{A-1}$$

$$(\hat{D}^{\ell}_{xy} + \hat{D}^{\ell}_{yx}) f_{ij} = \frac{1}{2\Sigma_{\ell}} f_{i+1,j+1} - \frac{1}{2\Sigma_{\ell}} f_{ij} \tag{A-2}$$

b) $i_a = 1, \quad j_a = 1$

$$(\hat{D}^{\ell}_{xx} \pm \hat{D}^{\ell}_{yy}) f^{ec}_{ij} = \{ -(d^{\ell+} + e^{\ell+}) f^{ec}_{ij} + d^{\ell+} f^{ec}_{i+1,j} \pm e^{\ell+} f^{ec}_{i,j+1} \} x4 \tag{A-3}$$

$$(\hat{D}^{\ell}_{xx} \pm \hat{D}^{\ell}_{yy}) f^{es}_{ij} = 0 \tag{A-4}$$

$$(\hat{D}^{\ell}_{xy} + \hat{D}^{\ell}_{yx}) f^{ec}_{ij} = 0 \tag{A-5}$$

$$(\hat{D}^{\ell}_{xy} + \hat{D}^{\ell}_{yx}) f^{es}_{ij} = \{ \frac{1}{2\Sigma_{\ell}} f^{es}_{i+1,j+1} - \frac{1}{2\Sigma_{\ell}} f^{es}_{ij} \} x4, \text{ where } f^{es}_{ij} = 0 \tag{A-6}$$

c) $i_a \neq 1, \quad j_a = 1$

$$(\hat{D}^{\ell}_{xx} \pm \hat{D}^{\ell}_{yy}) f^{ec}_{ij} = \{ -(d^{\ell+} + e^{\ell+}) f^{ec}_{ij} + d^{\ell+} f^{ec}_{ij} \pm e^{\ell+} f^{ec}_{i,j+1} \} x2 \tag{A-7}$$

$$(\hat{D}^{\ell}_{xx} \pm \hat{D}^{\ell}_{yy}) f^{es}_{ij} = 0 \tag{A-8}$$

$$(\hat{D}^{\ell}_{xy} + \hat{D}^{\ell}_{yx}) f^{ec}_{ij} = 0 \tag{A-9}$$

$$(\hat{D}_{xy} + \hat{D}_{yx}) f^{es}_{ij} = \{ \frac{1}{2\Sigma_{\ell}} f^{es}_{i+1,j+1} - \frac{1}{2\Sigma_{\ell}} f^{es}_{ij} \} x2, \text{ where } f^{es}_{ij} = 0 \tag{A-10}$$

d) $i_a = 1, \quad j_a \neq 1$

$$(\hat{D}^{\ell}_{xx} \pm \hat{D}^{\ell}_{yy}) f^{ec}_{ij} = \{ -(d^{\ell+} \pm e^{\ell+}) f^{ec}_{ij} + d^{\ell+} f^{ec}_{i+1,j} \pm e^{\ell+} f^{ec}_{i,j+1} \} x2 \tag{A-11}$$

$$(\hat{D}^{\ell}_{xx} \pm \hat{D}^{\ell}_{yy}) f^{es}_{ij} = 0 \qquad \text{(A-12)}$$

$$(\hat{D}^{\ell}_{xy} + \hat{D}^{\ell}_{yx}) f^{ec}_{ij} = 0 \qquad \text{(A-13)}$$

$$(\hat{D}^{\ell}_{xy} + \hat{D}^{\ell}_{yx}) f^{es}_{ij} = \{ \frac{1}{2\Sigma_{\ell}} f^{es}_{i+1,j+1} - \frac{1}{2\Sigma_{\ell}} f^{es}_{ij} \}x2, \text{ where } f^{es}_{ij} = 0 \qquad \text{(A-14)}$$

2. $i_a + 1 \le i \le i_b - 1, \quad j = j_a$

a) $j_a \ne 1$

$$(\hat{D}^{\ell}_{xx} \pm \hat{D}^{\ell}_{yy}) f_{ij} = d^{\ell+} f_{i-1,j} - 2(d^{\ell+} \pm e^{\ell+}) f_{ij} + d^{\ell+} f_{i+1,j} \pm 2e^{\ell+} f_{i,j+1} \qquad \text{(A-15)}$$

$$(\hat{D}^{\ell}_{xy} + \hat{D}^{\ell}_{yx}) f_{ij} = -\frac{1}{2\Sigma_{\ell}} f_{i-1,j+1} + \frac{1}{2\Sigma_{\ell}} f_{i+1,j+1} \qquad \text{(A-16)}$$

b) $j_a = 1$

$$(\hat{D}^{\ell}_{xx} \pm \hat{D}^{\ell}_{yy}) f^{ec}_{ij} = \{ d^{\ell+} f^{ec}_{i-1,j} - 2(d^{\ell+} \pm e^{\ell+}) f^{ec}_{ij} + d^{\ell+} f^{ec}_{i+1,j} \pm 2e^{\ell+} f^{ec}_{i,j+1} \}x2 \qquad \text{(A-17)}$$

$$(\hat{D}^{\ell}_{xx} \pm \hat{D}^{\ell}_{yy}) f^{es}_{ij} = 0 \qquad \text{(A-18)}$$

$$(\hat{D}^{\ell}_{xy} + \hat{D}^{\ell}_{yx}) f^{ec}_{ij} = 0 \qquad \text{(A-19)}$$

$$(\hat{D}^{\ell}_{xy} + \hat{D}^{\ell}_{yx}) f^{es}_{ij} = \{ -\frac{1}{2\Sigma_{\ell}} f^{es}_{i-1,j+1} + \frac{1}{2\Sigma_{\ell}} f^{es}_{i+1,j+1} \}x2 \qquad \text{(A-20)}$$

3. $i = i_b, \quad j = j_a$

a) $i_b \ne i_{max}, \quad j_a \ne 1$

$$(\hat{D}^{\ell}_{xx} \pm \hat{D}^{\ell}_{yy}) f_{ij} = d^{\ell+} f_{i-1,j} - (d^{\ell+} \pm e^{\ell+}) f_{ij} \pm e^{\ell+} f_{i,j+1} \qquad \text{(A-21)}$$

$$(\hat{D}^{\ell}_{xy} + \hat{D}^{\ell}_{yx}) f_{ij} = -\frac{1}{2\Sigma_{\ell}} f_{i-1,j+1} + \frac{1}{2\Sigma_{\ell}} f_{ij} \qquad \text{(A-22)}$$

b) $i_b \neq i_{max}, \quad j_a = 1$

$$(\hat{D}^{\ell}_{xx} \pm \hat{D}^{\ell}_{yy}) f^{ec}_{ij} = \{d^{\ell+} f^{ec}_{i-1,j} - (d^{\ell+} \pm e^{\ell+}) + f^{ec}_{ij} \pm e^{\ell+} f_{i,j+1}\} x2 \tag{A-23}$$

$$(\hat{D}^{\ell}_{xx} \pm \hat{D}^{\ell}_{yy}) f^{es}_{ij} = 0 \tag{A-24}$$

$$(\hat{D}^{\ell}_{xy} + \hat{D}^{\ell}_{yx}) f^{ec}_{ij} = 0 \tag{A-25}$$

$$(\hat{D}^{\ell}_{xy} + \hat{D}^{\ell}_{yx}) f^{es}_{ij} = \{-\frac{1}{2\Sigma_{\ell}} f^{es}_{i-1,j+1} + \frac{1}{2\Sigma_{\ell}} f^{es}_{ij}\} x2, \text{ where } f^{es}_{ij} = 0 \tag{A-26}$$

c) $i_b = i_{max}, \quad j_a = 1$

$$(\hat{D}^{\ell}_{xx} \pm \hat{D}^{\ell}_{yy}) f^{ec}_{ij} = \{d^{\ell+} f^{ec}_{i-1,j} - (d^{\ell+} \pm e^{\ell+}) f^{ec}_{ij} \pm e^{\ell+} f^{ec}_{i,j+1}\} x4 \tag{A-27}$$

$$(\hat{D}^{\ell}_{xx} \pm \hat{D}^{\ell}_{yy}) f^{es}_{ij} = 0 \tag{A-28}$$

$$(\hat{D}^{\ell}_{xy} + \hat{D}^{\ell}_{yx}) f^{ec}_{ij} = 0 \tag{A-29}$$

$$(\hat{D}^{\ell}_{xy} + \hat{D}^{\ell}_{yx}) f^{es}_{ij} = \{-\frac{1}{2\Sigma_{\ell}} f^{es}_{i-1,j+1} + \frac{1}{2\Sigma_{\ell}} f^{es}_{ij}\} x4, \text{ where } f^{es}_{ij} = 0 \tag{A-30}$$

d) $i_b = i_{max}, \quad j_a \neq 1$

$$(\hat{D}^{\ell}_{xx} \pm \hat{D}^{\ell}_{yy}) f^{ec}_{ij} = \{d^{\ell+} f^{ec}_{i-1,j} - (d^{\ell+} \pm e^{\ell+}) f^{ec}_{ij} \pm e^{\ell+} f^{ec}_{i,j+1}\} x2 \tag{A-31}$$

$$(\hat{D}^{\ell}_{xx} \pm \hat{D}^{\ell}_{yy}) f^{es}_{ij} = 0 \tag{A-32}$$

$$(\hat{D}^{\ell}_{xy} \pm \hat{D}^{\ell}_{yx}) f^{ec}_{ij} = 0 \tag{A-33}$$

$$(\hat{D}^{\ell}_{xy} + \hat{D}^{\ell}_{yx}) f^{es}_{ij} = \{-\frac{1}{2\Sigma_{\ell}} f^{es}_{i-1,j+1} + \frac{1}{2\Sigma_{\ell}} f^{es}_{ij}\} x2, \text{ where } f^{es}_{ij} = 0 \tag{A-34}$$

4. $i = i_a, \quad j_a + 1 \le j \le j_b - 1$

a) $i_a \neq 1$

$$(\hat{D}^{\ell}_{xx} \pm \hat{D}^{\ell}_{yy}) f_{ij} = \pm e^{\ell+} f_{i,j-1} - 2(d^{\ell+} \pm e^{\ell+}) f_{ij} + 2d^{\ell+} f_{i+1,j} \pm e^{\ell+} f_{i,j+1} \qquad \text{(A-35)}$$

$$(\hat{D}^{\ell}_{xy} + \hat{D}^{\ell}_{yx}) f_{ij} = -\frac{1}{2\Sigma_{\ell}} f_{i+1,j-1} + \frac{1}{2\Sigma_{\ell}} f_{i+1,j+1} \qquad \text{(A-36)}$$

b) $i_a = 1$

$$(\hat{D}^{\ell}_{xx} \pm \hat{D}^{\ell}_{yy}) f^{ec}_{ij} = \{\pm e^{\ell+} f^{ec}_{i,j-1} - 2(d^{\ell+} \pm e^{\ell+}) f^{ec}_{ij} + 2d^{\ell+} f^{ec}_{i+1,j} \pm e^{\ell+} f^{ec}_{i,j+1}\} x 2 \qquad \text{(A-37)}$$

$$(\hat{D}^{\ell}_{xx} \pm \hat{D}^{\ell}_{yy}) f^{es}_{ij} = 0 \qquad \text{(A-38)}$$

$$(\hat{D}^{\ell}_{xy} + \hat{D}^{\ell}_{yx}) f^{ec}_{ij} = 0 \qquad \text{(A-39)}$$

$$(\hat{D}^{\ell}_{xy} + \hat{D}^{\ell}_{yx}) f^{es}_{ij} = \{-\frac{1}{2\Sigma_{\ell}} f^{es}_{i+1,j-1} + \frac{1}{2\Sigma_{\ell}} f^{es}_{i+1,j+1}\} x 2 \qquad \text{(A-40)}$$

5. $i_a + 1 \le i \le i_b - 1, \quad j_a + 1 \le j \le j_b - 1$

$$(\hat{D}^{\ell}_{xx} \pm \hat{D}^{\ell}_{yy}) f_{ij} = 2\left[\pm e^{\ell+} f_{i,j-1} + d^{\ell+} f_{i-1,j} - 2(d^{\ell+} \pm e^{\ell+}) f_{ij} + d^{\ell+} f_{i+1,j} \pm e^{\ell+} f_{i,j+1}\right] \qquad \text{(A-41)}$$

$$(\hat{D}^{\ell}_{xy} + \hat{D}^{\ell}_{yx}) f_{ij} = \frac{1}{2\Sigma_{\ell}} f_{i-1,j-1} - \frac{1}{2\Sigma_{\ell}} f_{i+1,j-1} - \frac{1}{2\Sigma_{\ell}} f_{i-1,j+1} + \frac{1}{2\Sigma_{\ell}} f_{i+1,j+1} \qquad \text{(A-42)}$$

6. $i = i_b,\ \ j_a + 1 \le j \le j_b - 1$

a) $i_b \ne i_{max}$

$$(\hat{D}^{\ell}_{xx} \pm \hat{D}^{\ell}_{yy}) f_{ij} = \pm e^{\ell +} f_{i,j-1} + 2d^{\ell +} f_{i-1,j} - 2(d^{\ell +} \pm e^{\ell +}) f_{ij} \pm e^{\ell +} f_{i,j+1} \tag{A-43}$$

$$(\hat{D}^{\ell}_{xy} + \hat{D}^{\ell}_{yx}) f_{ij} = \frac{1}{2\Sigma_{\ell}} f_{i-1,j-1} - \frac{1}{2\Sigma_{\ell}} f_{i-1,j+1} \tag{A-44}$$

b) $i_b = i_{max}$

$$(\hat{D}^{\ell}_{xx} \pm \hat{D}^{\ell}_{yy}) f^{ec}_{ij} = \{ \pm e^{\ell +} f^{ec}_{i,j-1} + 2d^{\ell +} f^{ec}_{i-1,j} - 2(d^{\ell +} \pm e^{\ell +}) f^{ec}_{ij} \pm e^{\ell +} f^{ec}_{i,j+1} \} \times 2 \tag{A-45}$$

$$(\hat{D}^{\ell}_{xx} \pm \hat{D}^{\ell}_{yy}) f^{es}_{ij} = 0 \tag{A-46}$$

$$(\hat{D}^{\ell}_{xy} + \hat{D}^{\ell}_{yx}) f^{ec}_{ij} = 0 \tag{A-47}$$

$$(\hat{D}^{\ell}_{xy} + \hat{D}^{\ell}_{yx}) f^{es}_{ij} = \{ \frac{1}{2\Sigma_{\ell}} f^{es}_{i-1,j-1} - \frac{1}{2\Sigma_{\ell}} f^{es}_{i-1,j+1} \} \times 2 \tag{A-48}$$

7. $i = i_a,\ \ j = j_b$

a) $i_a \ne 1,\ \ j_a \ne j_{max}$

$$(\hat{D}^{\ell}_{xx} \pm \hat{D}^{\ell}_{yy}) f_{ij} = \pm e^{\ell +} f_{i,j-1} - (d^{\ell +} \pm e^{\ell +}) f_{ij} + d^{\ell +} f_{i+1,j} \tag{A-49}$$

$$(\hat{D}^{\ell}_{xy} + \hat{D}^{\ell}_{yx}) f_{ij} = -\frac{1}{2\Sigma_{\ell}} f_{i+1,j-1} + \frac{1}{2\Sigma_{\ell}} f_{ij} \tag{A-50}$$

b) $i_a = 1,\ \ j_b \ne j_{max}$

$$(\hat{D}^{\ell}_{xx} \pm \hat{D}^{\ell}_{yy}) f^{ec}_{ij} = \{ \pm e^{\ell +} f^{ec}_{i,j-1} - (d^{\ell +} \pm e^{\ell +}) f^{ec}_{ij} + d^{\ell +} f^{ec}_{i+1,j} \} \times 2 \tag{A-51}$$

$$(\hat{D}^{\ell}_{xx} \pm \hat{D}^{\ell}_{yy}) f^{es}_{ij} = 0 \tag{A-52}$$

$$(\hat{D}^{\ell}_{xy}+\hat{D}^{\ell}_{yx})\, f^{ec}_{ij}=0 \tag{A-53}$$

$$(\hat{D}^{\ell}_{xy}+\hat{D}^{\ell}_{yx})\, f^{es}_{ij}=\{-\frac{1}{2\Sigma_{\ell}} f^{es}_{i+1,j-1}+\frac{1}{2\Sigma_{\ell}} f^{es}_{ij}\}x2,\ \text{where}\ f^{es}_{ij}=0 \tag{A-54}$$

c) $i_a = 1,\quad j_b = j_{max}$

$$(\hat{D}^{\ell}_{xx}\pm\hat{D}^{\ell}_{yy})\, f^{ec}_{ij}=\{\pm e^{\ell+} f^{ec}_{i,j-1}-(d^{\ell+}\pm e^{\ell+})\, f^{ec}_{ij}+e^{\ell+} f_{i+1,j}\}\, x4 \tag{A-55}$$

$$(\hat{D}^{\ell}_{xx}\pm\hat{D}^{\ell}_{yy})\, f^{es}_{ij}=0 \tag{A-56}$$

$$(\hat{D}^{\ell}_{xy}+\hat{D}^{\ell}_{yx})\, f^{ec}_{ij}=0 \tag{A-57}$$

$$(\hat{D}^{\ell}_{xy}+\hat{D}^{\ell}_{yx})\, f^{es}_{ij}=\{-\frac{1}{2\Sigma_{\ell}} f^{es}_{i+1,j-1}+\frac{1}{2\Sigma_{\ell}} f^{es}_{ij}\}\, x4,\ \text{where}\ f^{es}_{ij}=0 \tag{A-58}$$

d) $i_a \neq 1,\quad j_b = j_{max}$

$$(\hat{D}^{\ell}_{xx}\pm\hat{D}^{\ell}_{yy})\, f^{ec}_{ij}=\{\pm e^{\ell+} f^{ec}_{i,j-1}-(d^{\ell+}\pm e^{\ell+})\, f^{ec}_{ij}+e^{\ell+} f^{ec}_{i+1,j}\}\, x2 \tag{A-59}$$

$$(\hat{D}^{\ell}_{xx}\pm\hat{D}^{\ell}_{yy})\, f^{es}_{ij}=0 \tag{A-60}$$

$$(\hat{D}^{\ell}_{xy}+\hat{D}^{\ell}_{yx})\, f^{ec}_{ij}=0 \tag{A-61}$$

$$(\hat{D}_{xy}+\hat{D}_{yx})\, f^{es}_{ij}=\{-\frac{1}{2\Sigma_{\ell}} f^{es}_{i+1,j-1}+\frac{1}{2\Sigma_{\ell}} f^{es}_{ij}\}x2,\ \text{where}\ f^{es}_{ij}=0 \tag{A-62}$$

8. $i_a + 1 \leq i \leq i_b - 1,\quad j = j_b$

a) $j_b \neq j_{max}$

$$(\hat{D}^{\ell}_{xx}\pm\hat{D}^{\ell}_{yy})\, f_{ij}=\pm 2e^{\ell+} f_{i,j-1}+d^{\ell+} f_{i-1,j}-2\,(d^{\ell+}\pm e^{\ell+})\, f_{ij}+d^{\ell+} f_{i+1,j} \tag{A-63}$$

$$(\hat{D}^{\ell}_{xy}+\hat{D}^{\ell}_{yx})\, f_{ij}=\frac{1}{2\Sigma_{\ell}} f_{i-1,j-1}-\frac{1}{2\Sigma_{\ell}} f_{i+1,j-1} \tag{A-64}$$

b) $j_b = j_{max}$

$$(\hat{D}^{\ell}_{xx} \pm \hat{D}^{\ell}_{yy}) f^{ec}_{ij} = \{\pm 2 e^{\ell +} f^{ec}_{i,j-1} + d^{\ell +} f^{ec}_{i-1,j} - 2(d^{\ell +} \pm e^{\ell +}) f^{ec}_{ij} + d^{\ell +} f_{i+1,j}\} x 2 \tag{A-65}$$

$$(\hat{D}^{\ell}_{xx} \pm \hat{D}^{\ell}_{yy}) f^{es}_{ij} = 0 \tag{A-66}$$

$$(\hat{D}^{\ell}_{xy} + \hat{D}^{\ell}_{yx}) f^{ec}_{ij} = 0 \tag{A-67}$$

$$(\hat{D}^{\ell}_{xy} + \hat{D}^{\ell}_{yx}) f^{es}_{ij} = \{ \frac{1}{2\Sigma_{\ell}} f^{es}_{i-1,j-1} - \frac{1}{2\Sigma_{\ell}} f^{es}_{i+1,j-1} \} x 2 \tag{A-68}$$

9. $i = i_b, \quad j = j_b$

a) $i_b \neq i_{max}, \quad j_b \neq j_{max}$

$$(\hat{D}^{\ell}_{xx} \pm \hat{D}^{\ell}_{yy}) f_{ij} = \pm e^{\ell +} f_{i,j-1} + d^{\ell +} f_{i-1,j} - (d^{\ell +} \pm e^{\ell +}) f_{ij} \tag{A-69}$$

$$(\hat{D}^{\ell}_{xy} + \hat{D}^{\ell}_{yx}) f_{ij} = \frac{1}{2\Sigma_{\ell}} f_{i-1,j-1} - \frac{1}{2\Sigma_{\ell}} f_{ij} \tag{A-70}$$

b) $i_b = i_{max}, \quad j_b \neq j_{max}$

$$(\hat{D}^{\ell}_{xx} \pm \hat{D}^{\ell}_{yy}) f^{ec}_{ij} = \{ \pm e^{\ell +} f^{ec}_{i,j-1} + d^{\ell +} f^{ec}_{i-1,j} - (d^{\ell +} \pm e^{\ell +}) f^{ec}_{ij}\} x 2 \tag{A-71}$$

$$(\hat{D}^{\ell}_{xx} \pm \hat{D}^{\ell}_{yy}) f^{es}_{ij} = 0 \tag{A-72}$$

$$(\hat{D}^{\ell}_{xy} + \hat{D}^{\ell}_{yx}) f^{ec}_{ij} = 0 \tag{A-73}$$

$$(\hat{D}^{\ell}_{xy} + \hat{D}^{\ell}_{yx}) f^{es}_{ij} = \{ \frac{1}{2\Sigma_{\ell}} f^{es}_{i-1,j-1} - \frac{1}{2\Sigma_{\ell}} f^{es}_{ij} \} x 2, \text{ where } f^{es}_{ij} = 0 \tag{A-74}$$

c) $i_b \neq i_{max}$, $j_b = j_{max}$

$$(\hat{D}^{\ell}_{xx} \pm \hat{D}^{\ell}_{yy}) f^{ec}_{ij} = \{\pm e^{\ell+} f^{ec}_{i,j-1} + d^{\ell+} f^{ec}_{i-1,j} - (d^{\ell+} \pm e^{\ell+}) f^{ec}_{ij}\} \times 2 \tag{A-75}$$

$$(\hat{D}^{\ell}_{xx} \pm \hat{D}^{\ell}_{yy}) f^{es}_{ij} = 0 \tag{A-76}$$

$$(\hat{D}^{\ell}_{xy} + \hat{D}^{\ell}_{yx}) f^{ec}_{ij} = 0 \tag{A-77}$$

$$(\hat{D}^{\ell}_{xy} + \hat{D}^{\ell}_{yx}) f^{es}_{ij} = \{\frac{1}{2\Sigma_{\ell}} f^{es}_{i-1,j-1} - \frac{1}{2\Sigma_{\ell}} f^{es}_{ij}\} \times 2, \text{ where } f^{es}_{ij} = 0 \tag{A-78}$$

d) $i_b = i_{max}$, $j_b = j_{max}$

$$(\hat{D}^{\ell}_{xx} \pm \hat{D}^{\ell}_{yy}) f^{ec}_{ij} = \{\pm e^{\ell+} f^{ec}_{i,j-1} + d^{\ell+} f^{ec}_{i-1,j} - (d^{\ell+} \pm e^{\ell+}) f^{ec}_{ij}\} \times 4 \tag{A-79}$$

$$(\hat{D}^{\ell}_{xx} \pm \hat{D}^{\ell}_{yy}) f^{es}_{ij} = 0 \tag{A-80}$$

$$(\hat{D}^{\ell}_{xy} + \hat{D}^{\ell}_{yx}) f^{ec}_{ij} = 0 \tag{A-81}$$

$$(\hat{D}^{\ell}_{xy} + \hat{D}^{\ell}_{yx}) f^{es}_{ij} = \{\frac{1}{2\Sigma_{\ell}} f^{es}_{i-1,j-1} - \frac{1}{2\Sigma_{\ell}} f^{es}_{ij}\} \times 4, \text{ where } f^{es}_{ij} = 0 \tag{A-82}$$

Appendix B. Input and Output of Sample Problems

In the following, representative parts of the PLXY output listings are reproduced for the two sample problems. In order to keep the size of the report within acceptable limits, the presentation of the output was restricted to those parts providing - in the opinion of the author - the most important information or illustrating relevant results or significant features of the code. If more detailed output listings would be needed, those interested in more comprehensive information should contact the author or the institute mentioned under item 16. of the Computer Program Abstract included here as first part of this report.

```
 ------------------------------------------------
 INPUT FOR ONE GROUP EXTERNAL SOURCE SAMPLE PROBLEM
 ------------------------------------------------

**********      BEGIN OF INPUT     ***************************

 ONE GROUP SOURCE PROBLEM BY FLETCHER
  2       12      58
  0.      1.2    7.0
  2       12      58
  0.      1.2    7.0
'RIGHT MOST BOUNDARY                    0/1=0./REF        IBCR='   0
'LEFT  MOST BOUNDARY                    0/1=0./REF        IBCL='   1
'TOP    BOUNDARY                        0/1=0./REF        IBCT='   0
'BOTTOM BOUNDARY                        0/1=0./REF        IBCB='   1
'READ CROSS SECTION               0/1/2=NO/CARD/SIGM      IFCR='   1
'READ EXTERNAL SOURCE 0/1/2=NO/NEG+ZONE/NEG*ZONE          IFES='   2
'PRINT FLUXES FOR ALL PL APPROXIMATIONS  0/1=NO/YES      IFP1='   1
'ORDER OF PL APPROXIMATION    +/-=DIRECT/ADJOINT          LMX='   7
'ORDER OF SCATTERING                                      LSC='   0
'NUMBER OF MATERIALS                                      NMT='   2
'NUMBER OF ENERGY GROUPS                                  NEG='   1
'MAXIMUM NUMBER OF INNER ITERATIONS                      MNII='  220
'MAXIMUM NUMBER OF MIDDLE ITERATIONS                     MNMI='  100
'MAXIMUM NUMBER OF SOURCE ITERATIONS                     MNSI='  100
'PRINT -2/-1/L=NO/INTEGRATED FLUX ONLY /UNTIL L          LPRT='   0
'TIME LIMIT (SEC)                                      LMTIME='  900
'STORE TOTAL FLUX IN FILE NUMBER IFILE (0=NO)           IFILE='   0
'BUCKLING 0/1/2/3/4=NO/H/HO/B**2/B**2 MAT. DEP.         IBUCK='   0
'INTERVAL TO PRINT ITERATIONS                            INTV='   1
'ACCELERATION FACTOR FOR INNER ITERATION                 ACFI='   1.300
'ACCELERATION FACTOR FOR MIDDLE ITERATION                ACFM='   1.1
'ACCELERATION FACTOR FOR SOURCE ITERATION                ACFS='   1.0
'ERROR CRITERION FOR INNER ITERATION                     ECIN='   5.E-8
'ERROR CRITERION FOR MIDDLE ITERATION                    ECMI='   1.E-6
'ERROR CRITERION FOR SOURCE ITERATION                    ECSO='   1.E-5
'ERROR CRITERION FOR CRITICALITY FACTOR                   ECK='   1.E-5
'FACTOR OF ERROR CRITERION FOR LOW ORDER APPR            FECL='   1.0
'GUESS FOR SOURCE PROBLEM (GUESS.GT.0.0)                GUESS='   0.
'HEIGHT H OR HO OR BUCKLING B**2 IN Z-DIRECTION              '   0.
   1.0   0.0
   0.0
   1.0   0.0
   0.0
   1.
   1   2
   2   2
   0.694444444  0.  0.  0.

**********      END OF INPUT     ******************************
```

```
 CALL CLOCKM    NO=  1     TIME=  0.005SEC    INTERVAL=  0.005SEC

SPHERICAL HARMONICS SOLUTION FOR X-Y GEOMETRY BY THE CODE PLXY OF VERSION 2 MADE AT 23.5.1985

ONE GROUP SOURCE PROBLEM BY FLETCHER

INPUT DATA FOR X-COORDINATES

    NO. OF REGIONS     2
    NO. OF INTERVALS FOR EACH REGION
   12 58

    BOUNDARY COORDINATES
         0.0000E+00  1.2000E+00  7.0000E+00

INPUT DATA FOR Y-COORDINATES

    NO. OF REGIONS     2
    NO. OF INTERVALS FOR EACH REGION
   12 58

    BOUNDARY COORDINATES
         0.0000E+00  1.2000E+00  7.0000E+00

RIGHT MOST BOUNDARY                        0/1=0./REF     IBCR=   0
LEFT  MOST BOUNDARY                        0/1=0./REF     IBCL=   1
TOP    BOUNDARY                            0/1=0./REF     IBCT=   0
BOTTOM BOUNDARY                            0/1=0./REF     IBCB=   1
READ CROSS SECTION                   0/1/2=NO/CARD/SIGM   IFCR=   1
READ EXTERNAL SOURCE 0/1/2=NO/NEG+ZONE/NEG*ZONE IFES=     2
PRINT FLUXES FOR ALL PL APPROX.    0/1=NO/YES             IFP1=   1
ORDER OF PL APPROXIMATION     +/-=DIRECT/ADJOINT  LMX=    7
ORDER OF SCATTERING                                        LSC=   0
NUMBER OF MATERIALS                                        NMT=   2
NUMBER OF ENERGY GROUPS                                    NEG=   1
MAXIMUM NUMBER OF INNER ITERATIONS                        MNII= 220
MAXIMUM NUMBER OF MIDDLE ITERATIONS                       MNMI= 100
MAXIMUM NUMBER OF SOURCE ITERATIONS                       MNSI= 100
MAXIMUM ORDER OF ANGULAR MOMENT TO PRINT                  LPRT=   0
(-2/-1/L=NO INTEGRATED FLUX/ONLY IT/UNTIL L)
TIME LIMIT                                              LMTIME= 900
STORE TOTAL FLUX IN FILE NUMBER IFILE (0=NO)              IFILE=   0
BUCKLING 0/1/2/3/4=NO/H/HO/B**2/B**2 MAT. DEP.            IBUCK=   0
INTERVAL TO PRINT ITERATIONS                              INTV=   1

ACCELERATION FACTOR FOR INNER ITERATION         ACFI=  1.30E+00
ACCELERATION FACTOR FOR MIDDLE ITERATION        ACFM=  1.10E+00
ACCELERATION FACTOR FOR SOURCE ITERATION        ACFS=  1.00E+00
ERROR CRITERION FOR INNER ITERATION             ECIN=  5.00E-08
ERROR CRITERION FOR MIDDLE ITERATION            ECMI=  1.00E-06
ERROR CRITERION FOR SOURCE ITERATION            ECSO=  1.00E-05
ERROR CRITERION FOR CRITICALITY FACTOR           ECK=  1.00E-05
FACTOR OF ERROR CRITERION FOR LOW ORDER APPR    FECL=  1.00E+00
GUESS FOR SOURCE PROBLEM (GUESS.GT.0.0)        GUESS=  0.00E+00
HEIGHT H OR HO OR BUCKLING B**2 IN Z-DIRECTION              0.0000E+00

USED AND REST OF ARRAYS A AND IA
          DEF        USED      REMAIN
REAL   1400000     136302    1263698
INTE      1200        173       1027
```

```
CROSS SECTION INPUT DATA

MATERIAL NUMBER  1
ENERGY    TOTAL        NU*FISSION
    1   1.0000E+00  0.0000E+00

ENERGY SCATTERING MATRIX
    1   0.0000E+00

ENERGY SCATTERING CROSS SECTIONS WITHIN GROUP FOR EACH ORDER L
       L=   0
    1    0.0000E+00

MATERIAL NUMBER  2
ENERGY    TOTAL        NU*FISSION
    1   1.0000E+00  0.0000E+00

ENERGY SCATTERING MATRIX
    1   0.0000E+00

ENERGY SCATTERING CROSS SECTIONS WITHIN GROUP FOR EACH ORDER L
       L=   0
    1    0.0000E+00


FISSION SPECTRUM
ENERGY
    1    1.0000E+00


MATERIAL DISTRIBUTION

 NY= 2      2  2
 NY= 1      1  2

 NX=        1  2

SPACE AND ENERGY DEPENDENT EXTERNAL SOURCE

IE= 1
NY= 2    0.000E+00 0.000E+00
NY= 1    6.944E-01 0.000E+00

NX=            1         2

SOURCE ITERATION. NSI=  1 STARTED
IE= 1
INNER IT. FEC L= 0 M= 0 NII=220 ERIN1= 1.9E+00 ERIN= 2.6E-05 ERMIC= 0.0E+00 IXEM= 70 IYEM= 65
SOURCE IT. NSI=  1 ENDED RK= 0.000000E+00 ERK=-2.0E+00 ERSO= 1.0E+00


SOURCE ITERATION. NSI=  2 STARTED
IE= 1
INNER IT. FEC L= 0 M= 0 NII=107 ERIN1= 2.5E-05 ERIN= 4.9E-08 ERMIC= 0.0E+00 IXEM= 70 IYEM= 65
SOURCE IT. NSI=  2 ENDED RK= 0.000000E+00 ERK=-2.0E+00 ERSO= 1.0E+00

PL CALCULATION L= 1 ENDED RK= 0.000000 ERK=-2.0E+00 NSI=  2 ERSO= 1.0E+00 ERMIMX= 0.0E+00 ERINMX= 4.9E-08
 CALL CLOCKM   NO=  2    TIME=  4.581SEC   INTERVAL=  4.576SEC
```

```
X-COORDINATES OF EACH MESH
 0.0000E+00  1.0000E-01  2.0000E-01  3.0000E-01  4.0000E-01  5.0000E-01  6.0000E-01  7.0000E-01  8.0000E-01  9.0000E-01
 1.0000E+00  1.1000E+00  1.2000E+00  1.3000E+00  1.4000E+00  1.5000E+00  1.6000E+00  1.7000E+00  1.8000E+00  1.9000E+00
 2.0000E+00  2.1000E+00  2.2000E+00  2.3000E+00  2.4000E+00  2.5000E+00  2.6000E+00  2.7000E+00  2.8000E+00  2.9000E+00
 3.0000E+00  3.1000E+00  3.2000E+00  3.3000E+00  3.4000E+00  3.5000E+00  3.6000E+00  3.7000E+00  3.8000E+00  3.9000E+00
 4.0000E+00  4.1000E+00  4.2000E+00  4.3000E+00  4.4000E+00  4.5000E+00  4.6000E+00  4.7000E+00  4.8000E+00  4.9000E+00
 5.0000E+00  5.1000E+00  5.2000E+00  5.3000E+00  5.4000E+00  5.5000E+00  5.6000E+00  5.7000E+00  5.8000E+00  5.9000E+00
 6.0000E+00  6.1000E+00  6.2000E+00  6.3000E+00  6.4000E+00  6.5000E+00  6.6000E+00  6.7000E+00  6.8000E+00  6.9000E+00
 7.0000E+00

   MULTIPLICATION FACTOR= 0.000000

    *** ANGULAR MOMENT ***

  ENERGY   1

 -- FEC --    L= 0  M= 0

... PART OF THE FOLLOWING OUTPUT WAS DELETED ...

 IY= 40 Y=  3.90E+00
  1.9387E-03  1.9347E-03  1.9226E-03  1.9026E-03  1.8749E-03  1.8400E-03  1.7981E-03  1.7499E-03  1.6959E-03  1.6367E-03
  1.5730E-03  1.5055E-03  1.4350E-03  1.3623E-03  1.2880E-03  1.2130E-03  1.1379E-03  1.0633E-03  9.8978E-04  9.1798E-04
  8.4832E-04  7.8118E-04  7.1690E-04  6.5573E-04  5.9785E-04  5.4339E-04  4.9240E-04  4.4492E-04  4.0089E-04  3.6026E-04
  3.2291E-04  2.8872E-04  2.5755E-04  2.2922E-04  2.0356E-04  1.8040E-04  1.5956E-04  1.4086E-04  1.2413E-04  1.0919E-04
  9.5891E-05  8.4078E-05  7.3608E-05  6.4347E-05  5.6173E-05  4.8971E-05  4.2637E-05  3.7075E-05  3.2199E-05  2.7931E-05
  2.4199E-05  2.0941E-05  1.8099E-05  1.5623E-05  1.3467E-05  1.1591E-05  9.9595E-06  8.5399E-06  7.3045E-06  6.2283E-06
  5.2893E-06  4.4678E-06  3.7465E-06  3.1097E-06  2.5437E-06  2.0359E-06  1.5749E-06  1.1503E-06  7.5230E-07  3.7182E-07
  0.0000E+00

... PART OF THE FOLLOWING OUTPUT WAS DELETED ...

  INTEGRATED TOTAL FLUX
            1           2
    2  1.6735E-01  7.0275E-02
    1  5.9497E-01  1.6735E-01


 SOURCE ITERATION. NSI=  1 STARTED

... PART OF THE FOLLOWING OUTPUT WAS DELETED ...

 SOURCE IT. NSI=  1 ENDED RK= 0.000000E+00 ERK=-2.0E+00 ERSO= 1.0E+00

 SOURCE ITERATION. NSI=  2 STARTED
 IE= 1
 INNER IT. FEC L= 0 M= 0 NII=  2 ERIN1= 8.3E-08 ERIN= 3.5E-08 ERMIC= 1.3E-07 IXEM= 70 IYEM=  1
 INNER IT. FEC L= 2 M= 0 NII=  1 ERIN1= 3.7E-08 ERIN= 3.7E-08 ERMIC= 4.9E-08 IXEM= 70 IYEM=  1
 INNER IT. FEC L= 2 M= 2 NII=  1 ERIN1= 2.2E-08 ERIN= 2.2E-08 ERMIC= 2.9E-08 IXEM= 70 IYEM=  1
 INNER IT. FES L= 2 M= 2 NII=  1 ERIN1= 9.0E-09 ERIN= 9.0E-09 ERMIS= 1.2E-08 IXEM= 57 IYEM= 57
 MIDDLE IT. NMI=  1 ENDED  ERMI=     1.26E-07
 MIDDLE IT. ENDED MNMI=  1 ERMI=     1.26E-07
 SOURCE IT. NSI=  2 ENDED RK= 0.000000E+00 ERK=-2.0E+00 ERSO= 1.0E+00

 PL CALCULATION L= 3 ENDED RK= 0.000000 ERK=-2.0E+00 NSI=  2 ERSO= 1.0E+00 ERMIMX= 1.3E-07 ERINMX= 3.7E-08
  CALL CLOCKM    NO=  3     TIME= 69.453SEC    INTERVAL= 64.872SEC

... PART OF THE FOLLOWING OUTPUT WAS DELETED ...


   MULTIPLICATION FACTOR= 0.000000
```

```
   *** ANGULAR MOMENT ***

  ENERGY   1

 -- FEC --    L= 0  M= 0

... PART OF THE FOLLOWING OUTPUT WAS DELETED ...

 IY= 40 Y=  3.90E+00
  2.5367E-03  2.5327E-03  2.5209E-03  2.5012E-03  2.4740E-03  2.4395E-03  2.3980E-03  2.3499E-03  2.2958E-03  2.2360E-03
  2.1712E-03  2.1020E-03  2.0290E-03  1.9530E-03  1.8745E-03  1.7943E-03  1.7129E-03  1.6309E-03  1.5489E-03  1.4674E-03
  1.3869E-03  1.3077E-03  1.2303E-03  1.1550E-03  1.0821E-03  1.0117E-03  9.4404E-04  8.7929E-04  8.1753E-04  7.5880E-04
  7.0313E-04  6.5052E-04  6.0093E-04  5.5432E-04  5.1061E-04  4.6972E-04  4.3155E-04  3.9599E-04  3.6293E-04  3.3225E-04
  3.0383E-04  2.7755E-04  2.5327E-04  2.3089E-04  2.1028E-04  1.9132E-04  1.7391E-04  1.5793E-04  1.4328E-04  1.2987E-04
  1.1759E-04  1.0637E-04  9.6108E-05  8.6736E-05  7.8175E-05  7.0356E-05  6.3212E-05  5.6681E-05  5.0703E-05  4.5221E-05
  4.0180E-05  3.5526E-05  3.1204E-05  2.7157E-05  2.3324E-05  1.9637E-05  1.6019E-05  1.2378E-05  8.5970E-06  4.5332E-06
  0.0000E+00

... PART OF THE FOLLOWING OUTPUT WAS DELETED ...

  INTEGRATED TOTAL FLUX
             1           2
    2  1.4623E-01  6.3919E-02
    1  6.4306E-01  1.4623E-01


 SOURCE ITERATION. NSI=   1 STARTED

... PART OF THE FOLLOWING OUTPUT WAS DELETED ...

 SOURCE IT. NSI=   1 ENDED RK= 0.000000E+00 ERK=-2.0E+00 ERSO= 1.0E+00

 SOURCE ITERATION. NSI=   2 STARTED
 IE= 1
 INNER IT. FEC L= 0 M= 0 NII=  3 ERIN1= 4.7E-07 ERIN= 4.6E-08 ERMIC= 6.8E-07 IXEM= 42 IYEM= 68
 INNER IT. FEC L= 2 M= 0 NII=  3 ERIN1= 3.1E-07 ERIN= 3.0E-08 ERMIC= 4.2E-07 IXEM= 52 IYEM= 68
 INNER IT. FEC L= 2 M= 2 NII=  2 ERIN1= 5.4E-08 ERIN= 1.8E-08 ERMIC= 8.2E-08 IXEM= 70 IYEM= 41
 INNER IT. FES L= 2 M= 2 NII=  1 ERIN1= 2.0E-08 ERIN= 2.0E-08 ERMIS= 2.5E-08 IXEM= 70 IYEM= 61
 INNER IT. FEC L= 4 M= 0 NII=  2 ERIN1= 5.9E-08 ERIN= 1.6E-08 ERMIC= 8.6E-08 IXEM= 43 IYEM= 69
 INNER IT. FEC L= 4 M= 2 NII=  2 ERIN1= 1.1E-07 ERIN= 3.0E-08 ERMIC= 1.5E-07 IXEM= 47 IYEM= 69
 INNER IT. FES L= 4 M= 2 NII=  1 ERIN1= 1.9E-08 ERIN= 1.9E-08 ERMIS= 2.5E-08 IXEM= 69 IYEM= 66
 INNER IT. FEC L= 4 M= 4 NII=  1 ERIN1= 1.8E-08 ERIN= 1.8E-08 ERMIC= 2.3E-08 IXEM= 57 IYEM= 70
 INNER IT. FES L= 4 M= 4 NII=  1 ERIN1= 1.5E-08 ERIN= 1.5E-08 ERMIS= 1.9E-08 IXEM= 70 IYEM= 57
 MIDDLE IT. NMI=  1 ENDED  ERMI=    6.77E-07
 MIDDLE IT. ENDED MNMI=  1 ERMI=    6.77E-07
 SOURCE IT. NSI=  2 ENDED RK= 0.000000E+00 ERK=-2.0E+00 ERSO= 1.0E+00

 PL CALCULATION L= 5 ENDED RK= 0.000000 ERK=-2.0E+00 NSI=  2 ERSO= 1.0E+00 ERMIMX= 6.8E-07 ERINMX= 4.6E-08
  CALL CLOCKM   NO=  4    TIME=207.923SEC    INTERVAL=138.470SEC

... PART OF THE FOLLOWING OUTPUT WAS DELETED ...

   MULTIPLICATION FACTOR= 0.000000
```

```
   *** ANGULAR MOMENT ***

  ENERGY  1

 -- FEC --    L= 0  M= 0

... PART OF THE FOLLOWING OUTPUT WAS DELETED ...

 IY= 40 Y=  3.90E+00
  2.6399E-03  2.6356E-03  2.6227E-03  2.6015E-03  2.5720E-03  2.5346E-03  2.4896E-03  2.4375E-03  2.3789E-03  2.3142E-03
  2.2440E-03  2.1690E-03  2.0898E-03  2.0075E-03  1.9228E-03  1.8366E-03  1.7494E-03  1.6618E-03  1.5745E-03  1.4879E-03
  1.4026E-03  1.3190E-03  1.2375E-03  1.1585E-03  1.0821E-03  1.0087E-03  9.3840E-04  8.7135E-04  8.0763E-04  7.4727E-04
  6.9029E-04  6.3667E-04  5.8634E-04  5.3924E-04  4.9527E-04  4.5431E-04  4.1625E-04  3.8095E-04  3.4828E-04  3.1810E-04
  2.9026E-04  2.6462E-04  2.4105E-04  2.1941E-04  1.9956E-04  1.8137E-04  1.6473E-04  1.4951E-04  1.3561E-04  1.2292E-04
  1.1133E-04  1.0076E-04  9.1113E-05  8.2307E-05  7.4262E-05  6.6902E-05  6.0156E-05  5.3955E-05  4.8234E-05  4.2930E-05
  3.7985E-05  3.3340E-05  2.8943E-05  2.4743E-05  2.0699E-05  1.6778E-05  1.2969E-05  9.2854E-06  5.7885E-06  2.6112E-06
  0.0000E+00

... PART OF THE FOLLOWING OUTPUT WAS DELETED ...

  INTEGRATED TOTAL FLUX
           1           2
    2  1.4171E-01  6.3975E-02
    1  6.5206E-01  1.4171E-01


 SOURCE ITERATION. NSI=  1 STARTED

... PART OF THE FOLLOWING OUTPUT WAS DELETED ...

 SOURCE IT. NSI=  1 ENDED RK= 0.000000E+00 ERK=-2.0E+00 ERSO= 1.0E+00

 SOURCE ITERATION. NSI=  2 STARTED
 IE= 1
 INNER IT. FEC L= 0 M= 0 NII=  3 ERIN1= 4.3E-07 ERIN= 4.2E-08 ERMIC= 5.8E-07 IXEM= 34 IYEM=  9
 INNER IT. FEC L= 2 M= 0 NII=  3 ERIN1= 4.3E-07 ERIN= 4.2E-08 ERMIC= 6.2E-07 IXEM= 36 IYEM= 68
 INNER IT. FEC L= 2 M= 2 NII=  2 ERIN1= 8.1E-08 ERIN= 2.5E-08 ERMIC= 1.0E-07 IXEM= 70 IYEM= 13
 INNER IT. FES L= 2 M= 2 NII=  1 ERIN1= 3.1E-08 ERIN= 3.1E-08 ERMIS= 4.0E-08 IXEM= 69 IYEM= 68
 INNER IT. FEC L= 4 M= 0 NII=  2 ERIN1= 1.3E-07 ERIN= 3.4E-08 ERMIC= 1.8E-07 IXEM= 61 IYEM= 69
 INNER IT. FEC L= 4 M= 2 NII=  3 ERIN1= 1.9E-07 ERIN= 1.6E-08 ERMIC= 2.4E-07 IXEM= 33 IYEM= 68
 INNER IT. FES L= 4 M= 2 NII=  1 ERIN1= 3.6E-08 ERIN= 3.6E-08 ERMIS= 4.7E-08 IXEM= 69 IYEM= 70
 INNER IT. FEC L= 4 M= 4 NII=  2 ERIN1= 5.6E-08 ERIN= 1.7E-08 ERMIC= 7.4E-08 IXEM= 70 IYEM=  1
 INNER IT. FES L= 4 M= 4 NII=  1 ERIN1= 2.1E-08 ERIN= 2.1E-08 ERMIS= 2.7E-08 IXEM= 70 IYEM= 12
 INNER IT. FEC L= 6 M= 0 NII=  1 ERIN1= 2.9E-08 ERIN= 2.9E-08 ERMIC= 3.8E-08 IXEM= 70 IYEM=  2
 INNER IT. FEC L= 6 M= 2 NII=  1 ERIN1= 4.2E-08 ERIN= 4.2E-08 ERMIC= 5.4E-08 IXEM= 70 IYEM=  4
 INNER IT. FES L= 6 M= 2 NII=  1 ERIN1= 8.7E-09 ERIN= 8.7E-09 ERMIS= 1.1E-08 IXEM= 70 IYEM= 70
 INNER IT. FEC L= 6 M= 4 NII=  2 ERIN1= 6.0E-08 ERIN= 2.2E-08 ERMIC= 8.0E-08 IXEM= 70 IYEM=  1
 INNER IT. FES L= 6 M= 4 NII=  1 ERIN1= 1.7E-08 ERIN= 1.7E-08 ERMIS= 2.2E-08 IXEM= 67 IYEM= 70
 INNER IT. FEC L= 6 M= 6 NII=  1 ERIN1= 3.9E-08 ERIN= 3.9E-08 ERMIC= 5.0E-08 IXEM= 70 IYEM=  1
 INNER IT. FES L= 6 M= 6 NII=  1 ERIN1= 1.7E-08 ERIN= 1.7E-08 ERMIS= 2.2E-08 IXEM= 70 IYEM= 66
 MIDDLE IT. NMI=  1 ENDED  ERMI=    6.25E-07
 MIDDLE IT. ENDED MNMI=  1 ERMI=    6.25E-07
 SOURCE IT. NSI=  2 ENDED RK= 0.000000E+00 ERK=-2.0E+00 ERSO= 1.0E+00

 PL CALCULATION L= 7 ENDED RK= 0.000000 ERK=-2.0E+00 NSI=  2 ERSO= 1.0E+00 ERMIMX= 6.2E-07 ERINMX= 4.2E-08
  CALL CLOCKM   NO=  5    TIME=443.179SEC   INTERVAL=235.256SEC
  CALL CLOCKM   NO=  6    TIME=443.179SEC   INTERVAL=  0.000SEC

... PART OF THE FOLLOWING OUTPUT WAS DELETED ...

   MULTIPLICATION FACTOR= 0.000000
```

*** ANGULAR MOMENT ***

ENERGY 1

-- FEC -- L= 0 M= 0

... PART OF THE FOLLOWING OUTPUT WAS DELETED ...

IY= 40 Y= 3.90E+00

2.6156E-03	2.6113E-03	2.5986E-03	2.5776E-03	2.5485E-03	2.5115E-03	2.4671E-03	2.4157E-03	2.3576E-03	2.2935E-03
2.2238E-03	2.1490E-03	2.0696E-03	1.9871E-03	1.9028E-03	1.8173E-03	1.7310E-03	1.6444E-03	1.5581E-03	1.4727E-03
1.3884E-03	1.3059E-03	1.2254E-03	1.1473E-03	1.0719E-03	9.9940E-04	9.2997E-04	8.6375E-04	8.0082E-04	7.4122E-04
6.8495E-04	6.3200E-04	5.8230E-04	5.3578E-04	4.9234E-04	4.5187E-04	4.1425E-04	3.7935E-04	3.4703E-04	3.1715E-04
2.8957E-04	2.6415E-04	2.4076E-04	2.1926E-04	1.9951E-04	1.8141E-04	1.6481E-04	1.4962E-04	1.3571E-04	1.2300E-04
1.1137E-04	1.0074E-04	9.1026E-05	8.2143E-05	7.4018E-05	6.6580E-05	5.9765E-05	5.3512E-05	4.7766E-05	4.2474E-05
3.7587E-05	3.3060E-05	2.8848E-05	2.4909E-05	2.1197E-05	1.7665E-05	1.4256E-05	1.0900E-05	7.5031E-06	3.9339E-06
0.0000E+00									

... PART OF THE FOLLOWING OUTPUT WAS DELETED ...

INTEGRATED TOTAL FLUX

	1	2
2	1.4021E-01	6.3899E-02
1	6.5512E-01	1.4021E-01

```
------------------------------------
INPUT FOR SMALL FBR SAMPLE PROBLEM
------------------------------------

**********      BEGIN OF INPUT      ***************************

 SMALL FBR CORE WITH CR, MODEL2
 9   6    6    2    2    2    2    2    6    4
 0.  15.  30.  35.  40.  45.  50.  55.  70.  80.
 9   2    4    6    4    2    2    2    6    4
 0.  5.   15.  30.  40.  45.  50.  55.  70.  80.
'RIGHT MOST BOUNDARY              0/1=0./REF          IBCR='   0
'LEFT MOST BOUNDARY               0/1=0./REF          IBCL='   1
'TOP        BOUNDARY              0/1=0./REF          IBCT='   0
'BOTTOM     BOUNDARY              0/1=0./REF          IBCB='   1
'READ CROSS SECTION           0/1/2=NO/CARD/SIGM      IFCR='   1
'READ EXTERNAL SOURCE 0/1/2=NO/NEG+ZONE/NEG*ZONE      IFES='   0
'PRINT FLUXES FOR ALL PL APPROXIMATIONS  0/1=NO/YES  IFP1='   1
'ORDER OF PL APPROXIMATION                           . LMX='   5
'ORDER OF SCATTERING                                   LSC='   0
'NUMBER OF MATERIALS                                   NMT='   6
'NUMBER OF ENERGY GROUPS                               NEG='   4
'MAXIMUM NUMBER OF INNER ITERATIONS                   MNII='   5
'MAXIMUM NUMBER OF MIDDLE ITERATIONS                  MNMI='   2
'MAXIMUM NUMBER OF SOURCE ITERATIONS                  MNSI=' 100
'PRINT -2/-1/L=NO/INTEGRATED FLUX ONLY /UNTIL L       LPRT='   0
'TIME LIMIT                                         LMTIME='  30
'STORE TOTAL FLUX IN FILE NUMBER IFILE (0=NO)        IFILE='   0
'BUCKLING 0/1/2/3/4/=NO/H/HO/B**2/B**2 MAT. DEP.     IBUCK='   3
'INTERVAL TO PRINT ITERATIONS                         INTV='   1
'ACCELERATION FACTOR FOR INNER ITERATION              ACFI='  1.2
'ACCELERATION FACTOR FOR MIDDLE ITERATION             ACFM='  1.1
'ACCELERATION FACTOR FOR SOURCE ITERATION             ACFS='  1.2
'ERROR CRITERION FOR INNER ITERATION                  ECIN='  5.D-6
'ERROR CRITERION FOR MIDDLE ITERATION                 ECMI='  5.D-5
'ERROR CRITERION FOR SOURCE ITERATION                 ECSO='  5.D-5
'ERROR CRITERION FOR CRITICALITY FACTOR                ECK='  5.D-5
'FACTOR OF ERROR CRITERION FOR LOW ORDER APPR         FECL='  1.00D+01
'GUESS FOR SOURCE PROBLEM (GUESS.GT.0.0)             GUESS='   0.0
'HEIGHT H OR HO OR BUCKLING B**2 IN Z-DIRECTION            '  4.7D-4
```

```
1.14568E-1  2.06063E-2
2.05177E-1  6.10571E-3
3.29381E-1  6.91403E-3
3.89810E-1  2.60689E-2
7.04326E-2  0.          0.          0.
3.47967E-2  1.95443E-1  0.          0.
1.88282E-3  6.20863E-3  3.20586E-1  0.
0.          7.07208E-7  9.92975E-4  3.62360E-1
1.19648E-1  1.89496E-2
2.42195E-1  1.75265E-4
3.56476E-1  2.06978E-4
3.79433E-1  1.13451E-3
6.91158E-2  0.          0.          0.
4.04132E-2  2.30626E-1  0.          0.
2.68621E-3  9.57027E-3  3.48414E-1  0.
0.          1.99571E-7  1.27195E-3  3.63631E-1
1.16493E-1  1.31770E-2
2.20521E-1  1.26026E-4
3.44544E-1  1.52380E-4
3.88356E-1  7.87302E-4
7.16044E-2  0.          0.          0.
3.73170E-2  2.10436E-1  0.          0.
2.21707E-3  8.59855E-3  3.37506E-1  0.
0.          6.68299E-7  1.68530E-3  3.74886E-1
6.58979E-2  0.
1.09810E-1  0.
1.86765E-1  0.
2.09933E-1  0.
4.74407E-2  0.          0.          0.
1.76894E-2  1.06142E-1  0.          0.
4.57012E-4  3.55466E-3  1.85304E-1  0.
0.          1.77599E-7  1.01280E-3  2.08858E-1
1.84333E-1  0.
3.66121E-1  0.
6.15527E-1  0.
1.09486     0.
1.34373E-1  0.          0.          0.
4.37775E-2  3.18582E-1  0.          0.
2.06054E-4  2.98432E-2  5.19591E-1  0.
0.          8.71188E-7  7.66209E-3  6.18265E-1
1.0         0.
1.0         0.
1.0         0.
1.0         0.
0.          0.          0.          0.
0.          0.          0.          0.
0.          0.          0.          0.
0.          0.          0.          0.
0.583319    0.405450    0.011231    0.

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

**********     END OF INPUT     ******************************
```

```
 CALL CLOCKM    NO=  1     TIME=  0.005SEC    INTERVAL=  0.005SEC

SPHERICAL HARMONICS SOLUTION FOR X-Y GEOMETRY BY THE CODE PLXY OF VERSION 2 MADE AT 23.5.1985

 SMALL FBR CORE WITH CR, MODEL2

INPUT DATA FOR X-COORDINATES

    NO. OF REGIONS      9
    NO. OF INTERVALS FOR EACH REGION
    6  6  2  2  2  2  2  6  4

    BOUNDARY COORDINATES
         0.0000E+00  1.5000E+01  3.0000E+01  3.5000E+01  4.0000E+01  4.5000E+01
         5.0000E+01  5.5000E+01  7.0000E+01  8.0000E+01

INPUT DATA FOR Y-COORDINATES

    NO. OF REGIONS      9
    NO. OF INTERVALS FOR EACH REGION
    2  4  6  4  2  2  2  6  4

    BOUNDARY COORDINATES
         0.0000E+00  5.0000E+00  1.5000E+01  3.0000E+01  4.0000E+01  4.5000E+01
         5.0000E+01  5.5000E+01  7.0000E+01  8.0000E+01

RIGHT MOST BOUNDARY                       0/1=0./REF     IBCR=   0
LEFT  MOST BOUNDARY                       0/1=0./REF     IBCL=   1
TOP    BOUNDARY                           0/1=0./REF     IBCT=   0
BOTTOM BOUNDARY                           0/1=0./REF     IBCB=   1
READ CROSS SECTION              0/1/2=NO/CARD/SIGM   IFCR=   1
READ EXTERNAL SOURCE 0/1/2=NO/NEG+ZONE/NEG*ZONE  IFES=   0
PRINT FLUXES FOR ALL PL APPROX.    0/1=NO/YES    IFP1=   1
ORDER OF PL APPROXIMATION     +/-=DIRECT/ADJOINT  LMX=   5
ORDER OF SCATTERING                                LSC=   0
NUMBER OF MATERIALS                                NMT=   6
NUMBER OF ENERGY GROUPS                            NEG=   4
MAXIMUM NUMBER OF INNER ITERATIONS                MNII=   5
MAXIMUM NUMBER OF MIDDLE ITERATIONS               MNMI=   2
MAXIMUM NUMBER OF SOURCE ITERATIONS               MNSI= 100
MAXIMUM ORDER OF ANGULAR MOMENT TO PRINT          LPRT=   0
(-2/-1/L=NO INTEGRATED FLUX/ONLY IT/UNTIL L)
TIME LIMIT                                      LMTIME=  30
STORE TOTAL FLUX IN FILE NUMBER IFILE (0=NO)     IFILE=   0
BUCKLING 0/1/2/3/4=NO/H/H0/B**2/B**2 MAT. DEP.   IBUCK=   3
INTERVAL TO PRINT ITERATIONS                      INTV=   1

ACCELERATION FACTOR FOR INNER ITERATION       ACFI=  1.20E+00
ACCELERATION FACTOR FOR MIDDLE ITERATION      ACFM=  1.10E+00
ACCELERATION FACTOR FOR SOURCE ITERATION      ACFS=  1.20E+00
ERROR CRITERION FOR INNER ITERATION           ECIN=  5.00E-06
ERROR CRITERION FOR MIDDLE ITERATION          ECMI=  5.00E-05
ERROR CRITERION FOR SOURCE ITERATION          ECSO=  5.00E-05
ERROR CRITERION FOR CRITICALITY FACTOR         ECK=  5.00E-05
FACTOR OF ERROR CRITERION FOR LOW ORDER APPR  FECL=  1.00E+01
GUESS FOR SOURCE PROBLEM (GUESS.GT.0.0)      GUESS=  0.00E+00
HEIGHT H OR H0 OR BUCKLING B**2 IN Z-DIRECTION          4.7000E-04

USED AND REST OF ARRAYS A AND IA
          DEF        USED     REMAIN
REAL   1400000      62954    1337046
INTE      1200        265        935
```

CROSS SECTION INPUT DATA

MATERIAL NUMBER 1

ENERGY	TOTAL	NU*FISSION
1	1.1457E-01	2.0606E-02
2	2.0518E-01	6.1057E-03
3	3.2938E-01	6.9140E-03
4	3.8981E-01	2.6069E-02

ENERGY SCATTERING MATRIX

1	7.0433E-02			
2	3.4797E-02	1.9544E-01		
3	1.8828E-03	6.2086E-03	3.2059E-01	
4	0.0000E+00	7.0721E-07	9.9297E-04	3.6236E-01

ENERGY SCATTERING CROSS SECTIONS WITHIN GROUP FOR EACH ORDER L

	L= 0
1	7.0433E-02
2	1.9544E-01
3	3.2059E-01
4	3.6236E-01

MATERIAL NUMBER 2

ENERGY	TOTAL	NU*FISSION
1	1.1965E-01	1.8950E-02
2	2.4219E-01	1.7526E-04
3	3.5648E-01	2.0698E-04
4	3.7943E-01	1.1345E-03

ENERGY SCATTERING MATRIX

1	6.9116E-02			
2	4.0413E-02	2.3063E-01		
3	2.6862E-03	9.5703E-03	3.4841E-01	
4	0.0000E+00	1.9957E-07	1.2719E-03	3.6363E-01

ENERGY SCATTERING CROSS SECTIONS WITHIN GROUP FOR EACH ORDER L

	L= 0
1	6.9116E-02
2	2.3063E-01
3	3.4841E-01
4	3.6363E-01

MATERIAL NUMBER 3

ENERGY	TOTAL	NU*FISSION
1	1.1649E-01	1.3177E-02
2	2.2052E-01	1.2603E-04
3	3.4454E-01	1.5238E-04
4	3.8836E-01	7.8730E-04

ENERGY SCATTERING MATRIX

1	7.1604E-02			
2	3.7317E-02	2.1044E-01		
3	2.2171E-03	8.5985E-03	3.3751E-01	
4	0.0000E+00	6.6830E-07	1.6853E-03	3.7489E-01

ENERGY SCATTERING CROSS SECTIONS WITHIN GROUP FOR EACH ORDER L

	L= 0
1	7.1604E-02
2	2.1044E-01
3	3.3751E-01
4	3.7489E-01

```
MATERIAL NUMBER  4
ENERGY   TOTAL       NU*FISSION
    1    6.5898E-02  0.0000E+00
    2    1.0981E-01  0.0000E+00
    3    1.8677E-01  0.0000E+00
    4    2.0993E-01  0.0000E+00

ENERGY SCATTERING MATRIX
    1    4.7441E-02
    2    1.7689E-02  1.0614E-01
    3    4.5701E-04  3.5547E-03  1.8530E-01
    4    0.0000E+00  1.7760E-07  1.0128E-03  2.0886E-01

ENERGY SCATTERING CROSS SECTIONS WITHIN GROUP FOR EACH ORDER L
       L=   0
    1     4.7441E-02
    2     1.0614E-01
    3     1.8530E-01
    4     2.0886E-01

MATERIAL NUMBER  5
ENERGY   TOTAL       NU*FISSION
    1    1.8433E-01  0.0000E+00
    2    3.6612E-01  0.0000E+00
    3    6.1553E-01  0.0000E+00
    4    1.0949E+00  0.0000E+00

ENERGY SCATTERING MATRIX
    1    1.3437E-01
    2    4.3777E-02  3.1858E-01
    3    2.0605E-04  2.9843E-02  5.1959E-01
    4    0.0000E+00  8.7119E-07  7.6621E-03  6.1826E-01

ENERGY SCATTERING CROSS SECTIONS WITHIN GROUP FOR EACH ORDER L
       L=   0
    1     1.3437E-01
    2     3.1858E-01
    3     5.1959E-01
    4     6.1826E-01

MATERIAL NUMBER  6
ENERGY   TOTAL       NU*FISSION
    1    1.0000E+00  0.0000E+00
    2    1.0000E+00  0.0000E+00
    3    1.0000E+00  0.0000E+00
    4    1.0000E+00  0.0000E+00

... THE ZEROS IN THE FOLLOWING OUTPUT WERE DELETED ...

FISSION SPECTRUM
ENERGY
    1     5.8332E-01
    2     4.0545E-01
    3     1.1231E-02
    4     0.0000E+00
```

```
MATERIAL DISTRIBUTION

 NY= 9      6  6  6  6  6  6  6  6  6
 NY= 8      2  2  2  2  2  2  2  2  6
 NY= 7      1  2  2  2  2  2  2  2  6
 NY= 6      1  1  2  2  2  2  2  2  6
 NY= 5      1  1  1  1  2  2  2  2  6
 NY= 4      1  1  1  1  1  2  2  2  6
 NY= 3      1  1  1  1  1  1  2  2  6
 NY= 2      1  1  1  1  1  1  1  2  6
 NY= 1      1  1  1  5  5  1  1  2  6

 NX=        1  2  3  4  5  6  7  8  9

SOURCE ITERATION. NSI=  1 STARTED
IE= 1
INNER IT. FEC L= 0 M= 0 NII=  5 ERIN1= 1.0E+00 ERIN= 3.8E+01 ERMIC= 0.0E+00 IXEM= 25 IYEM= 31
IE= 2
INNER IT. FEC L= 0 M= 0 NII=  5 ERIN1= 1.0E+00 ERIN= 5.7E+01 ERMIC= 0.0E+00 IXEM= 27 IYEM= 31
IE= 3
INNER IT. FEC L= 0 M= 0 NII=  5 ERIN1= 1.0E+00 ERIN= 8.9E+01 ERMIC= 0.0E+00 IXEM= 21 IYEM= 31
IE= 4
INNER IT. FEC L= 0 M= 0 NII=  5 ERIN1= 1.0E+00 ERIN= 2.5E+00 ERMIC= 0.0E+00 IXEM= 32 IYEM= 31
SOURCE IT. NSI=  1 ENDED RK= 6.810474E-01 ERK= 1.1E+00 ERSO= 9.7E-01
SOURCE ITERATION. NSI=  2 STARTED

... PART OF THE FOLLOWING OUTPUT WAS DELETED ...

SOURCE IT. NSI= 44 ENDED RK= 9.446144E-01 ERK= 6.2E-05 ERSO= 3.6E-05
SOURCE ITERATION. NSI= 45 STARTED
IE= 1
INNER IT. FEC L= 0 M= 0 NII=  4 ERIN1= 1.2E-05 ERIN= 4.8E-06 ERMIC= 0.0E+00 IXEM= 31 IYEM= 26
IE= 2
INNER IT. FEC L= 0 M= 0 NII=  4 ERIN1= 8.5E-06 ERIN= 4.6E-06 ERMIC= 0.0E+00 IXEM=  1 IYEM=  1
IE= 3
INNER IT. FEC L= 0 M= 0 NII=  4 ERIN1= 9.9E-06 ERIN= 4.7E-06 ERMIC= 0.0E+00 IXEM=  1 IYEM=  1
IE= 4
INNER IT. FEC L= 0 M= 0 NII=  3 ERIN1= 1.3E-05 ERIN= 4.8E-06 ERMIC= 0.0E+00 IXEM=  1 IYEM=  1
SOURCE IT. NSI= 45 ENDED RK= 9.446181E-01 ERK= 4.0E-05 ERSO= 2.5E-05

PL CALCULATION L= 1 ENDED RK= 0.944618 ERK= 4.0E-05 NSI= 45 ERSO= 2.5E-05 ERMIMX= 0.0E+00 ERINMX= 4.8E-06

... PART OF THE FOLLOWING OUTPUT WAS DELETED ...

SOURCE IT. NSI= 10 ENDED RK= 9.487150E-01 ERK= 3.2E-05 ERSO= 2.2E-05

PL CALCULATION L= 3 ENDED RK= 0.948715 ERK= 3.2E-05 NSI= 10 ERSO= 2.2E-05 ERMIMX= 4.0E-05 ERINMX= 5.0E-06

... PART OF THE FOLLOWING OUTPUT WAS DELETED ...

SOURCE IT. NSI=  8 ENDED RK= 9.488576E-01 ERK= 1.6E-05 ERSO= 1.3E-05

PL CALCULATION L= 5 ENDED RK= 0.948858 ERK= 1.6E-05 NSI=  8 ERSO= 1.3E-05 ERMIMX= 3.0E-05 ERINMX= 4.7E-06
 CALL CLOCKM   NO=  2    TIME= 28.467SEC    INTERVAL= 28.462SEC

X-COORDINATES OF EACH MESH
 0.0000E+00  2.5000E+00  5.0000E+00  7.5000E+00  1.0000E+01  1.2500E+01  1.5000E+01  1.7500E+01  2.0000E+01  2.2500E+01
 2.5000E+01  2.7500E+01  3.0000E+01  3.2500E+01  3.5000E+01  3.7500E+01  4.0000E+01  4.2500E+01  4.5000E+01  4.7500E+01
 5.0000E+01  5.2500E+01  5.5000E+01  5.7500E+01  6.0000E+01  6.2500E+01  6.5000E+01  6.7500E+01  7.0000E+01  7.2500E+01
 7.5000E+01  7.7500E+01  8.0000E+01

  MULTIPLICATION FACTOR= 0.948858
```

```
 *** ANGULAR MOMENT ***

ENERGY   1

-- FEC --    L= 0  M= 0
IY=   1 Y=  0.00E+00
 8.3569E-03  8.3336E-03  8.2636E-03  8.1473E-03  7.9848E-03  7.7765E-03  7.5227E-03  7.2233E-03  6.8784E-03  6.4875E-03
 6.0484E-03  5.5560E-03  4.9969E-03  4.3188E-03  3.4785E-03  2.5417E-03  2.0306E-03  1.7684E-03  1.7213E-03  1.7505E-03
 1.6374E-03  1.4091E-03  1.0759E-03  7.5106E-04  5.3803E-04  3.8470E-04  2.6591E-04  1.6640E-04  7.2602E-05  5.5858E-06
 5.0850E-07  4.9257E-08  0.0000E+00
IY=   2 Y=  2.50E+00
 8.3438E-03  8.3206E-03  8.2509E-03  8.1349E-03  7.9730E-03  7.7656E-03  7.5129E-03  7.2148E-03  6.8719E-03  6.4836E-03
 6.0483E-03  5.5617E-03  5.0128E-03  4.3563E-03  3.5560E-03  2.6472E-03  2.1356E-03  1.8635E-03  1.7866E-03  1.7926E-03
 1.6648E-03  1.4225E-03  1.0813E-03  7.5340E-04  5.3883E-04  3.8480E-04  2.6575E-04  1.6620E-04  7.2513E-05  5.5807E-06
 5.0791E-07  4.9181E-08  0.0000E+00
IY=   3 Y=  5.00E+00
 8.3047E-03  8.2816E-03  8.2126E-03  8.0979E-03  7.9377E-03  7.7325E-03  7.4828E-03  7.1891E-03  6.8517E-03  6.4709E-03
 6.0459E-03  5.5745E-03  5.0501E-03  4.4529E-03  3.7657E-03  3.0535E-03  2.5752E-03  2.2518E-03  2.0566E-03  1.9274E-03
 1.7266E-03  1.4538E-03  1.0945E-03  7.5877E-04  5.4037E-04  3.8474E-04  2.6515E-04  1.6561E-04  7.2231E-05  5.5547E-06
 5.0600E-07  4.9060E-08  0.0000E+00
IY=   4 Y=  7.50E+00
 8.2388E-03  8.2162E-03  8.1483E-03  8.0354E-03  7.8779E-03  7.6764E-03  7.4317E-03  7.1442E-03  6.8150E-03  6.4450E-03
 6.0349E-03  5.5845E-03  5.0924E-03  4.5666E-03  3.9944E-03  3.4448E-03  2.9985E-03  2.6254E-03  2.3328E-03  2.0777E-03
 1.7976E-03  1.4857E-03  1.1070E-03  7.6173E-04  5.3962E-04  3.8281E-04  2.6319E-04  1.6415E-04  7.1588E-05  5.5189E-06
 5.0332E-07  4.8843E-08  0.0000E+00
IY=   5 Y=  1.00E+01
 8.1466E-03  8.1244E-03  8.0579E-03  7.9474E-03  7.7935E-03  7.5968E-03  7.3583E-03  7.0788E-03  6.7598E-03  6.4030E-03
 6.0101E-03  5.5832E-03  5.1255E-03  4.6515E-03  4.1583E-03  3.6703E-03  3.2349E-03  2.8437E-03  2.4978E-03  2.1786E-03
 1.8488E-03  1.5001E-03  1.1058E-03  7.5699E-04  5.3431E-04  3.7808E-04  2.5949E-04  1.6167E-04  7.0474E-05  5.4398E-06
 4.9646E-07  4.8166E-08  0.0000E+00
IY=   6 Y=  1.25E+01
 8.0276E-03  8.0060E-03  7.9412E-03  7.8337E-03  7.6840E-03  7.4930E-03  7.2616E-03  6.9913E-03  6.6838E-03  6.3411E-03
 5.9661E-03  5.5617E-03  5.1335E-03  4.6918E-03  4.2389E-03  3.7920E-03  3.3715E-03  2.9712E-03  2.5944E-03  2.2320E-03
 1.8548E-03  1.4719E-03  1.0765E-03  7.3800E-04  5.2172E-04  3.6945E-04  2.5365E-04  1.5806E-04  6.8830E-05  5.3187E-06
 4.8618E-07  4.7230E-08  0.0000E+00
IY=   7 Y=  1.50E+01
 7.8818E-03  7.8608E-03  7.7980E-03  7.6938E-03  7.5488E-03  7.3640E-03  7.1406E-03  6.8801E-03  6.5845E-03  6.2563E-03
 5.8985E-03  5.5147E-03  5.1112E-03  4.6946E-03  4.2707E-03  3.8479E-03  3.4339E-03  3.0327E-03  2.6358E-03  2.2302E-03
 1.7824E-03  1.3539E-03  9.8630E-04  6.9246E-04  4.9641E-04  3.5415E-04  2.4422E-04  1.5265E-04  6.6598E-05  5.1434E-06
 4.7035E-07  4.5696E-08  0.0000E+00
IY=   8 Y=  1.75E+01
 7.7089E-03  7.6886E-03  7.6280E-03  7.5273E-03  7.3874E-03  7.2093E-03  6.9942E-03  6.7440E-03  6.4607E-03  6.1469E-03
 5.8058E-03  5.4409E-03  5.0576E-03  4.6615E-03  4.2571E-03  3.8501E-03  3.4458E-03  3.0427E-03  2.6351E-03  2.1953E-03
 1.6835E-03  1.2179E-03  8.8528E-04  6.4139E-04  4.6751E-04  3.3664E-04  2.3342E-04  1.4642E-04  6.3956E-05  4.9533E-06
 4.5379E-07  4.4145E-08  0.0000E+00
IY=   9 Y=  2.00E+01
 7.5091E-03  7.4896E-03  7.4311E-03  7.3342E-03  7.1996E-03  7.0284E-03  6.8219E-03  6.5820E-03  6.3107E-03  6.0108E-03
 5.6852E-03  5.3374E-03  4.9716E-03  4.5930E-03  4.2047E-03  3.8105E-03  3.4142E-03  3.0130E-03  2.5996E-03  2.1488E-03
 1.6186E-03  1.1426E-03  8.2624E-04  6.0396E-04  4.4298E-04  3.2029E-04  2.2268E-04  1.3991E-04  6.1077E-05  4.7331E-06
 4.3412E-07  4.2278E-08  0.0000E+00
IY=  10 Y=  2.25E+01
 7.2824E-03  7.2636E-03  7.2075E-03  7.1144E-03  6.9852E-03  6.8209E-03  6.6229E-03  6.3932E-03  6.1337E-03  5.8470E-03
 5.5360E-03  5.2038E-03  4.8540E-03  4.4905E-03  4.1162E-03  3.7336E-03  3.3449E-03  2.9481E-03  2.5340E-03  2.0814E-03
 1.5529E-03  1.0818E-03  7.7756E-04  5.6933E-04  4.1832E-04  3.0299E-04  2.1095E-04  1.3268E-04  5.7921E-05  4.4897E-06
 4.1202E-07  4.0145E-08  0.0000E+00
IY=  11 Y=  2.50E+01
 7.0292E-03  7.0112E-03  6.9573E-03  6.8680E-03  6.7441E-03  6.5867E-03  6.3972E-03  6.1774E-03  5.9293E-03  5.6552E-03
 5.3580E-03  5.0402E-03  4.7050E-03  4.3555E-03  3.9940E-03  3.6220E-03  3.2402E-03  2.8474E-03  2.4325E-03  1.9825E-03
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 1.4691E-03  1.0165E-03  7.2862E-04  5.3388E-04  3.9259E-04  2.8463E-04  1.9837E-04  1.2487E-04  5.4489E-05  4.2235E-06
 3.8771E-07  3.7789E-08  0.0000E+00
IY= 12 Y=  2.75E+01
 6.7498E-03  6.7326E-03  6.6809E-03  6.5954E-03  6.4768E-03  6.3261E-03  6.1448E-03  5.9346E-03  5.6974E-03  5.4355E-03
 5.1512E-03  4.8471E-03  4.5256E-03  4.1892E-03  3.8398E-03  3.4773E-03  3.0999E-03  2.7076E-03  2.2823E-03  1.8320E-03
 1.3518E-03  9.3619E-04  6.7197E-04  4.9437E-04  3.6449E-04  2.6478E-04  1.8484E-04  1.1650E-04  5.0824E-05  3.9378E-06
 3.6164E-07  3.5268E-08  0.0000E+00
IY= 13 Y=  3.00E+01
 6.4449E-03  6.4284E-03  6.3789E-03  6.2971E-03  6.1836E-03  6.0394E-03  5.8660E-03  5.6650E-03  5.4383E-03  5.1880E-03
 4.9161E-03  4.6249E-03  4.3164E-03  3.9925E-03  3.6546E-03  3.3017E-03  2.9276E-03  2.5205E-03  2.0470E-03  1.5797E-03
 1.1659E-03  8.3010E-04  6.0863E-04  4.5103E-04  3.3407E-04  2.4349E-04  1.7042E-04  1.0763E-04  4.6962E-05  3.6336E-06
 3.3338E-07  3.2486E-08  0.0000E+00
IY= 14 Y=  3.25E+01
 6.1152E-03  6.0994E-03  6.0521E-03  5.9737E-03  5.8650E-03  5.7271E-03  5.5612E-03  5.3689E-03  5.1522E-03  4.9129E-03
 4.6529E-03  4.3741E-03  4.0779E-03  3.7661E-03  3.4398E-03  3.0967E-03  2.7278E-03  2.3069E-03  1.7959E-03  1.3206E-03
 9.7529E-04  7.2127E-04  5.4275E-04  4.0638E-04  3.0285E-04  2.2174E-04  1.5573E-04  9.8592E-05  4.3011E-05  3.3254E-06
 3.0493E-07  2.9706E-08  0.0000E+00
IY= 15 Y=  3.50E+01
 5.7615E-03  5.7464E-03  5.7010E-03  5.6259E-03  5.5218E-03  5.3897E-03  5.2307E-03  5.0467E-03  4.8394E-03  4.6106E-03
 4.3619E-03  4.0945E-03  3.8101E-03  3.5100E-03  3.1952E-03  2.8624E-03  2.4991E-03  2.0869E-03  1.5923E-03  1.1430E-03
 8.4289E-04  6.3174E-04  4.7970E-04  3.6275E-04  2.7211E-04  2.0020E-04  1.4111E-04  8.9576E-05  3.9068E-05  3.0152E-06
 2.7634E-07  2.6924E-08  0.0000E+00
IY= 16 Y=  3.75E+01
 5.3847E-03  5.3701E-03  5.3266E-03  5.2544E-03  5.1544E-03  5.0274E-03  4.8747E-03  4.6981E-03  4.4996E-03  4.2805E-03
 4.0422E-03  3.7849E-03  3.5110E-03  3.2216E-03  2.9169E-03  2.5934E-03  2.2314E-03  1.8319E-03  1.3840E-03  9.8660E-04
 7.2822E-04  5.5138E-04  4.2208E-04  3.2141E-04  2.4245E-04  1.7919E-04  1.2676E-04  8.0679E-05  3.5169E-05  2.7082E-06
 2.4797E-07  2.4153E-08  0.0000E+00
IY= 17 Y=  4.00E+01
 4.9854E-03  4.9714E-03  4.9294E-03  4.8599E-03  4.7631E-03  4.6403E-03  4.4925E-03  4.3221E-03  4.1315E-03  3.9213E-03
 3.6919E-03  3.4411E-03  3.1732E-03  2.8928E-03  2.5952E-03  2.2735E-03  1.8836E-03  1.4879E-03  1.1274E-03  8.2456E-04
 6.2314E-04  4.7693E-04  3.6713E-04  2.8176E-04  2.1373E-04  1.5876E-04  1.1277E-04  7.1988E-05  3.1365E-05  2.4126E-06
 2.2062E-07  2.1475E-08  0.0000E+00
IY= 18 Y=  4.25E+01
 4.5645E-03  4.5509E-03  4.5103E-03  4.4426E-03  4.3482E-03  4.2272E-03  4.0819E-03  3.9155E-03  3.7314E-03  3.5303E-03
 3.3092E-03  3.0626E-03  2.7807E-03  2.4909E-03  2.2138E-03  1.9011E-03  1.5136E-03  1.1502E-03  8.7935E-04  6.7497E-04
 5.2592E-04  4.0780E-04  3.1646E-04  2.4446E-04  1.8659E-04  1.3929E-04  9.9368E-05  6.3634E-05  2.7724E-05  2.1228E-06
 1.9356E-07  1.8806E-08  0.0000E+00
IY= 19 Y=  4.50E+01
 4.1208E-03  4.1076E-03  4.0682E-03  4.0018E-03  3.9080E-03  3.7843E-03  3.6355E-03  3.4679E-03  3.2866E-03  3.0935E-03
 2.8789E-03  2.6272E-03  2.2961E-03  1.9650E-03  1.7046E-03  1.4532E-03  1.1634E-03  8.9276E-04  7.0358E-04  5.5520E-04
 4.3748E-04  3.4516E-04  2.7024E-04  2.1028E-04  1.6153E-04  1.2121E-04  8.6848E-05  5.5790E-05  2.4279E-05  1.8579E-06
 1.6928E-07  1.6443E-08  0.0000E+00
IY= 20 Y=  4.75E+01
 3.6520E-03  3.6395E-03  3.6018E-03  3.5372E-03  3.4430E-03  3.3131E-03  3.1373E-03  2.9450E-03  2.7661E-03  2.5848E-03
 2.3854E-03  2.1432E-03  1.7999E-03  1.4621E-03  1.2275E-03  1.0445E-03  8.6221E-04  6.9484E-04  5.6302E-04  4.5225E-04
 3.6245E-04  2.8865E-04  2.2857E-04  1.7907E-04  1.3834E-04  1.0435E-04  7.5100E-05  4.8414E-05  2.1071E-05  1.6016E-06
 1.4533E-07  1.4081E-08  0.0000E+00
IY= 21 Y=  5.00E+01
 3.1476E-03  3.1357E-03  3.0994E-03  3.0360E-03  2.9385E-03  2.7908E-03  2.5479E-03  2.2952E-03  2.1160E-03  1.9566E-03
 1.7926E-03  1.6033E-03  1.3473E-03  1.0979E-03  9.2720E-04  7.8408E-04  6.6025E-04  5.4896E-04  4.4982E-04  3.6739E-04
 2.9763E-04  2.3965E-04  1.9122E-04  1.5114E-04  1.1751E-04  8.9120E-05  6.4430E-05  4.1676E-05  1.8111E-05  1.3768E-06
 1.2484E-07  1.2094E-08  0.0000E+00
IY= 22 Y=  5.25E+01
 2.5843E-03  2.5735E-03  2.5399E-03  2.4802E-03  2.3853E-03  2.2324E-03  1.9605E-03  1.6845E-03  1.5150E-03  1.3816E-03
 1.2565E-03  1.1246E-03  9.7236E-04  8.2558E-04  7.0823E-04  6.0441E-04  5.1262E-04  4.3127E-04  3.5965E-04  2.9643E-04
 2.4274E-04  1.9706E-04  1.5861E-04  1.2610E-04  9.8652E-05  7.5217E-05  5.4634E-05  3.5474E-05  1.5417E-05  1.1616E-06
 1.0479E-07  1.0117E-08  0.0000E+00
IY= 23 Y=  5.50E+01
 1.9100E-03  1.9014E-03  1.8749E-03  1.8278E-03  1.7533E-03  1.6373E-03  1.4392E-03  1.2379E-03  1.1094E-03  1.0064E-03
 9.1276E-04  8.1800E-04  7.2236E-04  6.2968E-04  5.4372E-04  4.6894E-04  4.0014E-04  3.3884E-04  2.8497E-04  2.3760E-04
 1.9604E-04  1.6052E-04  1.3005E-04  1.0416E-04  8.1985E-05  6.2854E-05  4.5877E-05  2.9900E-05  1.2977E-05  9.7887E-07
 8.8234E-08  8.5171E-09  0.0000E+00
```

IY= 24 Y= 5.75E+01

1.3029E-03	1.2967E-03	1.2777E-03	1.2446E-03	1.1943E-03	1.1221E-03	1.0146E-03	9.0327E-04	8.1874E-04	7.4508E-04
6.7675E-04	6.0910E-04	5.4188E-04	4.7720E-04	4.1733E-04	3.6161E-04	3.1085E-04	2.6491E-04	2.2423E-04	1.8821E-04
1.5670E-04	1.2906E-04	1.0533E-04	8.4793E-05	6.7116E-05	5.1733E-05	3.7958E-05	2.4858E-05	1.0791E-05	8.0525E-07
7.2190E-08	6.9465E-09	0.0000E+00							

IY= 25 Y= 6.00E+01

9.1521E-04	9.1068E-04	8.9691E-04	8.7337E-04	8.3894E-04	7.9266E-04	7.2921E-04	6.6229E-04	6.0566E-04	5.5308E-04
5.0322E-04	4.5425E-04	4.0592E-04	3.5944E-04	3.1633E-04	2.7581E-04	2.3847E-04	2.0449E-04	1.7415E-04	1.4693E-04
1.2310E-04	1.0202E-04	8.3769E-05	6.7817E-05	5.3983E-05	4.1852E-05	3.0895E-05	2.0352E-05	8.8413E-06	6.5647E-07
5.8620E-08	5.6282E-09	0.0000E+00							

IY= 26 Y= 6.25E+01

6.4390E-04	6.4064E-04	6.3083E-04	6.1433E-04	5.9094E-04	5.6072E-04	5.2130E-04	4.7923E-04	4.4110E-04	4.0419E-04
3.6849E-04	3.3344E-04	2.9897E-04	2.6591E-04	2.3516E-04	2.0602E-04	1.7901E-04	1.5425E-04	1.3203E-04	1.1195E-04
9.4284E-05	7.8550E-05	6.4852E-05	5.2787E-05	4.2262E-05	3.2981E-05	2.4542E-05	1.6313E-05	7.1179E-06	5.2655E-07
4.6837E-08	4.4890E-09	0.0000E+00							

IY= 27 Y= 6.50E+01

4.3925E-04	4.3702E-04	4.3033E-04	4.1924E-04	4.0384E-04	3.8443E-04	3.5992E-04	3.3352E-04	3.0845E-04	2.8351E-04
2.5900E-04	2.3490E-04	2.1123E-04	1.8851E-04	1.6730E-04	1.4714E-04	1.2840E-04	1.1112E-04	9.5514E-05	8.1338E-05
6.8800E-05	5.7584E-05	4.7771E-05	3.9089E-05	3.1487E-05	2.4770E-05	1.8648E-05	1.2601E-05	5.5828E-06	4.1321E-07
3.6435E-08	3.4635E-09	0.0000E+00							

IY= 28 Y= 6.75E+01

2.7214E-04	2.7076E-04	2.6665E-04	2.5988E-04	2.5063E-04	2.3914E-04	2.2502E-04	2.0968E-04	1.9457E-04	1.7927E-04
1.6407E-04	1.4908E-04	1.3439E-04	1.2027E-04	1.0701E-04	9.4386E-05	8.2622E-05	7.1733E-05	6.1850E-05	5.2853E-05
4.4850E-05	3.7678E-05	3.1373E-05	2.5795E-05	2.0903E-05	1.6593E-05	1.2698E-05	8.8431E-06	4.1422E-06	3.1949E-07
2.8545E-08	2.7074E-09	0.0000E+00							

IY= 29 Y= 7.00E+01

1.1854E-04	1.1794E-04	1.1613E-04	1.1316E-04	1.0912E-04	1.0405E-04	9.8039E-05	9.1498E-05	8.4833E-05	7.8139E-05
7.1461E-05	6.4890E-05	5.8465E-05	5.2316E-05	4.6488E-05	4.0993E-05	3.5851E-05	3.1121E-05	2.6793E-05	2.2891E-05
1.9390E-05	1.6284E-05	1.3537E-05	1.1128E-05	9.0195E-06	7.1880E-06	5.5840E-06	4.1118E-06	2.2815E-06	1.9879E-07
1.9762E-08	1.9380E-09	0.0000E+00							

IY= 30 Y= 7.25E+01

9.1646E-06	9.1171E-06	8.9757E-06	8.7426E-06	8.4254E-06	8.0277E-06	7.5472E-06	7.0494E-06	6.5285E-06	6.0057E-06
5.4850E-06	4.9736E-06	4.4801E-06	3.9958E-06	3.5506E-06	3.1167E-06	2.7272E-06	2.3519E-06	2.0270E-06	1.7169E-06
1.4568E-06	1.2104E-06	1.0088E-06	8.1873E-07	6.6002E-07	5.2377E-07	4.0682E-07	3.1166E-07	1.9398E-07	6.1842E-08
8.3322E-09	9.8586E-10	0.0000E+00							

IY= 31 Y= 7.50E+01

8.3641E-07	8.3206E-07	8.1913E-07	7.9778E-07	7.6875E-07	7.3289E-07	6.8843E-07	6.4285E-07	5.9570E-07	5.4781E-07
5.0009E-07	4.5335E-07	4.0816E-07	3.6357E-07	3.2290E-07	2.8286E-07	2.4742E-07	2.1266E-07	1.8321E-07	1.5449E-07
1.3101E-07	1.0827E-07	9.0161E-08	7.2788E-08	5.8410E-08	4.6154E-08	3.5523E-08	2.7541E-08	1.9087E-08	8.1742E-09
2.2481E-09	3.6310E-10	0.0000E+00							

IY= 32 Y= 7.75E+01

8.1111E-08	8.0690E-08	7.9435E-08	7.7365E-08	7.4549E-08	7.1136E-08	6.6787E-08	6.2349E-08	5.7827E-08	5.3183E-08
4.8547E-08	4.4008E-08	3.9605E-08	3.5262E-08	3.1315E-08	2.7396E-08	2.3965E-08	2.0554E-08	1.7709E-08	1.4891E-08
1.2628E-08	1.0398E-08	8.6575E-09	6.9657E-09	5.5755E-09	4.3959E-09	3.3548E-09	2.5906E-09	1.8515E-09	9.5622E-10
3.5864E-10	8.9966E-11	0.0000E+00							

IY= 33 Y= 8.00E+01

0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
0.0000E+00	0.0000E+00	0.0000E+00							

INTEGRATED TOTAL FLUX

	1	2	3	4	5	6	7	8	9
9	2.4448E-03	1.7137E-03	3.8255E-04	2.9975E-04	2.2762E-04	1.6745E-04	1.1910E-04	1.6322E-04	5.4465E-06
8	1.6080E-01	1.0258E-01	2.1955E-02	1.6798E-02	1.2450E-02	8.9443E-03	6.2091E-03	7.9192E-03	1.6055E-04
7	1.7964E-01	1.0854E-01	2.1342E-02	1.5464E-02	1.1001E-02	7.5453E-03	5.0097E-03	5.9970E-03	1.1282E-04
6	2.6080E-01	1.8943E-01	3.7975E-02	2.7012E-02	1.7954E-02	1.1553E-02	7.3482E-03	8.4114E-03	1.5420E-04
5	3.2955E-01	2.6132E-01	6.1620E-02	4.6655E-02	2.9728E-02	1.7440E-02	1.0403E-02	1.1350E-02	2.0286E-04
4	8.3432E-01	6.8365E-01	1.7407E-01	1.4132E-01	1.0214E-01	5.9704E-02	3.2779E-02	3.3242E-02	5.7182E-04
3	1.5785E+00	1.2969E+00	3.3271E-01	2.7574E-01	2.1632E-01	1.5083E-01	8.3785E-02	7.6801E-02	1.2621E-03
2	1.1789E+00	9.4958E-01	2.3065E-01	1.8042E-01	1.3921E-01	1.0675E-01	7.2839E-02	6.6095E-02	1.0247E-03
1	6.0421E-01	4.8043E-01	1.0843E-01	7.0332E-02	4.9567E-02	4.4642E-02	3.5066E-02	3.3594E-02	5.2956E-04

ENERGY 2

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-- FEC --    L= 0  M= 0
IY=  1 Y=  0.00E+00
 4.5346E-02  4.5220E-02  4.4840E-02  4.4208E-02  4.3325E-02  4.2192E-02  4.0812E-02  3.9181E-02  3.7302E-02  3.5168E-02
 3.2770E-02  3.0082E-02  2.7044E-02  2.3393E-02  1.8774E-02  1.3164E-02  1.0295E-02  9.0242E-03  9.1740E-03  9.5880E-03
 9.2117E-03  8.3295E-03  7.1763E-03  5.7735E-03  4.5312E-03  3.4113E-03  2.3837E-03  1.4040E-03  3.5487E-04  2.4431E-05
 2.1343E-06  2.0177E-07  0.0000E+00
IY=  2 Y=  2.50E+00
 4.5275E-02  4.5149E-02  4.4770E-02  4.4140E-02  4.3261E-02  4.2133E-02  4.0758E-02  3.9135E-02  3.7266E-02  3.5147E-02
 3.2770E-02  3.0113E-02  2.7130E-02  2.3596E-02  1.9213E-02  1.3822E-02  1.0979E-02  9.6458E-03  9.5863E-03  9.8391E-03
 9.3660E-03  8.4099E-03  7.2162E-03  5.7945E-03  4.5412E-03  3.4154E-03  2.3850E-03  1.4041E-03  3.5484E-04  2.4428E-05
 2.1336E-06  2.0167E-07  0.0000E+00
IY=  3 Y=  5.00E+00
 4.5061E-02  4.4936E-02  4.4562E-02  4.3938E-02  4.3068E-02  4.1952E-02  4.0594E-02  3.8995E-02  3.7156E-02  3.5078E-02
 3.2758E-02  3.0184E-02  2.7335E-02  2.4117E-02  2.0399E-02  1.6411E-02  1.3793E-02  1.2116E-02  1.1174E-02  1.0602E-02
 9.7312E-03  8.6093E-03  7.3208E-03  5.8488E-03  4.5663E-03  3.4253E-03  2.3876E-03  1.4040E-03  3.5453E-04  2.4395E-05
 2.1308E-06  2.0140E-07  0.0000E+00
IY=  4 Y=  7.50E+00
 4.4703E-02  4.4580E-02  4.4211E-02  4.3598E-02  4.2742E-02  4.1647E-02  4.0315E-02  3.8751E-02  3.6957E-02  3.4940E-02
 3.2701E-02  3.0243E-02  2.7566E-02  2.4714E-02  2.1608E-02  1.8629E-02  1.6226E-02  1.4248E-02  1.2745E-02  1.1475E-02
 1.0168E-02  8.8500E-03  7.4502E-03  5.9069E-03  4.5889E-03  3.4305E-03  2.3858E-03  1.4008E-03  3.5355E-04  2.4344E-05
 2.1264E-06  2.0097E-07  0.0000E+00
IY=  5 Y=  1.00E+01
 4.4201E-02  4.4081E-02  4.3719E-02  4.3119E-02  4.2283E-02  4.1214E-02  3.9917E-02  3.8396E-02  3.6659E-02  3.4715E-02
 3.2573E-02  3.0245E-02  2.7751E-02  2.5171E-02  2.2499E-02  1.9872E-02  1.7544E-02  1.5482E-02  1.3706E-02  1.2111E-02
 1.0565E-02  9.0560E-03  7.5440E-03  5.9413E-03  4.5940E-03  3.4233E-03  2.3756E-03  1.3926E-03  3.5133E-04  2.4196E-05
 2.1128E-06  1.9959E-07  0.0000E+00
IY=  6 Y=  1.25E+01
 4.3554E-02  4.3436E-02  4.3085E-02  4.2501E-02  4.1687E-02  4.0649E-02  3.9392E-02  3.7922E-02  3.6249E-02  3.4384E-02
 3.2342E-02  3.0141E-02  2.7811E-02  2.5410E-02  2.2961E-02  2.0564E-02  1.8328E-02  1.6234E-02  1.4322E-02  1.2537E-02
 1.0808E-02  9.1537E-03  7.5676E-03  5.9275E-03  4.5684E-03  3.3962E-03  2.3529E-03  1.3778E-03  3.4738E-04  2.3928E-05
 2.0895E-06  1.9740E-07  0.0000E+00
IY=  7 Y=  1.50E+01
 4.2761E-02  4.2647E-02  4.2306E-02  4.1740E-02  4.0952E-02  3.9948E-02  3.8735E-02  3.7319E-02  3.5713E-02  3.3928E-02
 3.1984E-02  2.9899E-02  2.7709E-02  2.5450E-02  2.3165E-02  2.0906E-02  1.8719E-02  1.6640E-02  1.4659E-02  1.2768E-02
 1.0922E-02  9.0670E-03  7.3963E-03  5.8155E-03  4.4885E-03  3.3375E-03  2.3119E-03  1.3535E-03  3.4142E-04  2.3480E-05
 2.0499E-06  1.9361E-07  0.0000E+00
IY=  8 Y=  1.75E+01
 4.1821E-02  4.1711E-02  4.1381E-02  4.0835E-02  4.0075E-02  3.9108E-02  3.7940E-02  3.6582E-02  3.5043E-02  3.3339E-02
 3.1488E-02  2.9510E-02  2.7434E-02  2.5295E-02  2.3124E-02  2.0959E-02  1.8836E-02  1.6766E-02  1.4766E-02  1.2818E-02
 1.0897E-02  8.8698E-03  7.1420E-03  5.6573E-03  4.3767E-03  3.2575E-03  2.2572E-03  1.3215E-03  3.3346E-04  2.2982E-05
 2.0073E-06  1.8964E-07  0.0000E+00
IY=  9 Y=  2.00E+01
 4.0735E-02  4.0629E-02  4.0312E-02  3.9786E-02  3.9055E-02  3.8126E-02  3.7005E-02  3.5703E-02  3.4232E-02  3.2605E-02
 3.0840E-02  2.8959E-02  2.6984E-02  2.4946E-02  2.2869E-02  2.0781E-02  1.8712E-02  1.6671E-02  1.4673E-02  1.2701E-02
 1.0736E-02  8.6741E-03  6.9571E-03  5.5007E-03  4.2520E-03  3.1632E-03  2.1910E-03  1.2824E-03  3.2359E-04  2.2308E-05
 1.9488E-06  1.8412E-07  0.0000E+00
IY= 10 Y=  2.25E+01
 3.9504E-02  3.9403E-02  3.9098E-02  3.8593E-02  3.7892E-02  3.7000E-02  3.5927E-02  3.4681E-02  3.3275E-02  3.1722E-02
 3.0039E-02  2.8245E-02  2.6361E-02  2.4411E-02  2.2418E-02  2.0402E-02  1.8387E-02  1.6382E-02  1.4402E-02  1.2440E-02
 1.0482E-02  8.4240E-03  6.7287E-03  5.3108E-03  4.1006E-03  3.0488E-03  2.1111E-03  1.2355E-03  3.1181E-04  2.1500E-05
 1.8784E-06  1.7750E-07  0.0000E+00
IY= 11 Y=  2.50E+01
 3.8131E-02  3.8033E-02  3.7741E-02  3.7257E-02  3.6585E-02  3.5732E-02  3.4705E-02  3.3514E-02  3.2171E-02  3.0689E-02
 2.9083E-02  2.7371E-02  2.5571E-02  2.3703E-02  2.1787E-02  1.9840E-02  1.7881E-02  1.5922E-02  1.3974E-02  1.2034E-02
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 1.0105E-02  8.0953E-03  6.4532E-03  5.0859E-03  3.9236E-03  2.9158E-03  2.0187E-03  1.1813E-03  2.9817E-04  2.0563E-05
 1.7968E-06  1.6980E-07  0.0000E+00
IY= 12 Y=  2.75E+01
 3.6618E-02  3.6524E-02  3.6245E-02  3.5781E-02  3.5139E-02  3.4323E-02  3.3342E-02  3.2205E-02  3.0923E-02  2.9508E-02
 2.7976E-02  2.6342E-02  2.4621E-02  2.2832E-02  2.0991E-02  1.9112E-02  1.7212E-02  1.5297E-02  1.3377E-02  1.1475E-02
 9.6108E-03  7.6800E-03  6.1139E-03  4.8193E-03  3.7185E-03  2.7639E-03  1.9139E-03  1.1203E-03  2.8283E-04  1.9507E-05
 1.7050E-06  1.6117E-07  0.0000E+00
IY= 13 Y=  3.00E+01
 3.4969E-02  3.4880E-02  3.4613E-02  3.4170E-02  3.3556E-02  3.2777E-02  3.1841E-02  3.0756E-02  2.9533E-02  2.8184E-02
 2.6723E-02  2.5164E-02  2.3520E-02  2.1808E-02  2.0041E-02  1.8234E-02  1.6397E-02  1.4533E-02  1.2661E-02  1.0726E-02
 8.8935E-03  7.1490E-03  5.7208E-03  4.5154E-03  3.4881E-03  2.5948E-03  1.7981E-03  1.0532E-03  2.6602E-04  1.8324E-05
 1.6014E-06  1.5137E-07  0.0000E+00
IY= 14 Y=  3.25E+01
 3.3191E-02  3.3106E-02  3.2851E-02  3.2428E-02  3.1843E-02  3.1099E-02  3.0206E-02  2.9172E-02  2.8007E-02  2.6723E-02
 2.5330E-02  2.3844E-02  2.2276E-02  2.0640E-02  1.8951E-02  1.7216E-02  1.5449E-02  1.3644E-02  1.1800E-02  9.8039E-03
 8.0675E-03  6.5660E-03  5.2881E-03  4.1867E-03  3.2402E-03  2.4139E-03  1.6745E-03  9.8157E-04  2.4806E-04  1.7112E-05
 1.4958E-06  1.4143E-07  0.0000E+00
IY= 15 Y=  3.50E+01
 3.1291E-02  3.1209E-02  3.0966E-02  3.0563E-02  3.0004E-02  2.9296E-02  2.8445E-02  2.7461E-02  2.6352E-02  2.5130E-02
 2.3805E-02  2.2391E-02  2.0899E-02  1.9340E-02  1.7728E-02  1.6073E-02  1.4384E-02  1.2649E-02  1.0861E-02  8.9568E-03
 7.3601E-03  5.9999E-03  4.8405E-03  3.8435E-03  2.9811E-03  2.2247E-03  1.5453E-03  9.0675E-04  2.2929E-04  1.5819E-05
 1.3833E-06  1.3084E-07  0.0000E+00
IY= 16 Y=  3.75E+01
 2.9276E-02  2.9198E-02  2.8966E-02  2.8582E-02  2.8049E-02  2.7375E-02  2.6565E-02  2.5628E-02  2.4575E-02  2.3414E-02
 2.2156E-02  2.0813E-02  1.9397E-02  1.7918E-02  1.6388E-02  1.4811E-02  1.3199E-02  1.1558E-02  9.8836E-03  8.1086E-03
 6.6505E-03  5.4325E-03  4.3930E-03  3.4963E-03  2.7175E-03  2.0315E-03  1.4131E-03  8.3015E-04  2.1004E-04  1.4492E-05
 1.2678E-06  1.1997E-07  0.0000E+00
IY= 17 Y=  4.00E+01
 2.7156E-02  2.7082E-02  2.6860E-02  2.6494E-02  2.5987E-02  2.5344E-02  2.4574E-02  2.3684E-02  2.2684E-02  2.1584E-02
 2.0391E-02  1.9118E-02  1.7779E-02  1.6380E-02  1.4935E-02  1.3443E-02  1.1931E-02  1.0340E-02  8.7549E-03  7.2103E-03
 5.9481E-03  4.8694E-03  3.9471E-03  3.1496E-03  2.4535E-03  1.8377E-03  1.2803E-03  7.5313E-04  1.9067E-04  1.3160E-05
 1.1515E-06  1.0900E-07  0.0000E+00
IY= 18 Y=  4.25E+01
 2.4942E-02  2.4871E-02  2.4660E-02  2.4311E-02  2.3827E-02  2.3214E-02  2.2481E-02  2.1636E-02  2.0688E-02  1.9648E-02
 1.8524E-02  1.7317E-02  1.6042E-02  1.4720E-02  1.3367E-02  1.1973E-02  1.0526E-02  8.9460E-03  7.5482E-03  6.3172E-03
 5.2516E-03  4.3186E-03  3.5114E-03  2.8094E-03  2.1938E-03  1.6465E-03  1.1490E-03  6.7681E-04  1.7148E-04  1.1832E-05
 1.0354E-06  9.8029E-08  0.0000E+00
IY= 19 Y=  4.50E+01
 2.2646E-02  2.2579E-02  2.2378E-02  2.2045E-02  2.1582E-02  2.0995E-02  2.0296E-02  1.9492E-02  1.8596E-02  1.7616E-02
 1.6563E-02  1.5417E-02  1.4220E-02  1.2925E-02  1.1638E-02  1.0382E-02  9.0413E-03  7.6680E-03  6.5210E-03  5.4901E-03
 4.5825E-03  3.7887E-03  3.0916E-03  2.4812E-03  1.9424E-03  1.4610E-03  1.0213E-03  6.0242E-04  1.5271E-04  1.0552E-05
 9.2387E-07  8.7523E-08  0.0000E+00
IY= 20 Y=  4.75E+01
 2.0280E-02  2.0217E-02  2.0027E-02  1.9710E-02  1.9269E-02  1.8700E-02  1.8023E-02  1.7250E-02  1.6397E-02  1.5486E-02
 1.4508E-02  1.3446E-02  1.2258E-02  1.0913E-02  9.7306E-03  8.6399E-03  7.5516E-03  6.5090E-03  5.5701E-03  4.7184E-03
 3.9598E-03  3.2866E-03  2.6930E-03  2.1677E-03  1.7014E-03  1.2825E-03  8.9814E-04  5.3056E-04  1.3461E-04  9.2883E-06
 8.1316E-07  7.7038E-08  0.0000E+00
IY= 21 Y=  5.00E+01
 1.7856E-02  1.7796E-02  1.7619E-02  1.7318E-02  1.6899E-02  1.6334E-02  1.5676E-02  1.4902E-02  1.4076E-02  1.3243E-02
 1.2356E-02  1.1417E-02  1.0304E-02  9.1171E-03  8.1282E-03  7.1929E-03  6.3170E-03  5.4850E-03  4.7123E-03  4.0135E-03
 3.3826E-03  2.8198E-03  2.3183E-03  1.8727E-03  1.4738E-03  1.1134E-03  7.8111E-04  4.6208E-04  1.1729E-04  8.1126E-06
 7.1072E-07  6.7389E-08  0.0000E+00
IY= 22 Y=  5.25E+01
 1.5379E-02  1.5324E-02  1.5160E-02  1.4882E-02  1.4483E-02  1.3942E-02  1.3204E-02  1.2315E-02  1.1544E-02  1.0799E-02
 1.0040E-02  9.2498E-03  8.3887E-03  7.5212E-03  6.7189E-03  5.9581E-03  5.2404E-03  4.5686E-03  3.9453E-03  3.3728E-03
 2.8549E-03  2.3884E-03  1.9709E-03  1.5963E-03  1.2595E-03  9.5361E-04  6.7025E-04  3.9710E-04  1.0088E-04  6.9601E-06
 6.0957E-07  5.7786E-08  0.0000E+00
IY= 23 Y=  5.50E+01
 1.2835E-02  1.2787E-02  1.2643E-02  1.2399E-02  1.2041E-02  1.1568E-02  1.0845E-02  1.0026E-02  9.3754E-03  8.7395E-03
 8.1096E-03  7.4600E-03  6.7976E-03  6.1326E-03  5.4868E-03  4.8776E-03  4.2998E-03  3.7586E-03  3.2566E-03  2.7952E-03
 2.3738E-03  1.9932E-03  1.6495E-03  1.3402E-03  1.0601E-03  8.0428E-04  5.6631E-04  3.3599E-04  8.5390E-05  5.9108E-06
 5.1805E-07  4.9153E-08  0.0000E+00
```

IY= 24 Y= 5.75E+01

1.0094E-02	1.0055E-02	9.9362E-03	9.7359E-03	9.4462E-03	9.0679E-03	8.5576E-03	7.9995E-03	7.4844E-03	6.9728E-03
6.4639E-03	5.9475E-03	5.4259E-03	4.9096E-03	4.4074E-03	3.9249E-03	3.4681E-03	3.0392E-03	2.6408E-03	2.2731E-03
1.9370E-03	1.6307E-03	1.3537E-03	1.1023E-03	8.7383E-04	6.6432E-04	4.6861E-04	2.7853E-04	7.0830E-05	4.8851E-06
4.2804E-07	4.0606E-08	0.0000E+00							

IY= 25 Y= 6.00E+01

7.7838E-03	7.7526E-03	7.6584E-03	7.5005E-03	7.2758E-03	6.9880E-03	6.6240E-03	6.2232E-03	5.8299E-03	5.4324E-03
5.0348E-03	4.6344E-03	4.2329E-03	3.8365E-03	3.4512E-03	3.0799E-03	2.7273E-03	2.3953E-03	2.0864E-03	1.8002E-03
1.5380E-03	1.2980E-03	1.0802E-03	8.8151E-04	7.0031E-04	5.3347E-04	3.7705E-04	2.2458E-04	5.7154E-05	3.9406E-06
3.4535E-07	3.2789E-08	0.0000E+00							

IY= 26 Y= 6.25E+01

5.7809E-03	5.7573E-03	5.6863E-03	5.5679E-03	5.4017E-03	5.1915E-03	4.9339E-03	4.6505E-03	4.3625E-03	4.0679E-03
3.7712E-03	3.4730E-03	3.1752E-03	2.8819E-03	2.5967E-03	2.3214E-03	2.0594E-03	1.8121E-03	1.5815E-03	1.3674E-03
1.1707E-03	9.9015E-04	8.2568E-04	6.7517E-04	5.3745E-04	4.1027E-04	2.9071E-04	1.7372E-04	4.4303E-05	3.0558E-06
2.6798E-07	2.5491E-08	0.0000E+00							

IY= 27 Y= 6.50E+01

3.9981E-03	3.9817E-03	3.9323E-03	3.8504E-03	3.7365E-03	3.5935E-03	3.4216E-03	3.2319E-03	3.0353E-03	2.8325E-03
2.6272E-03	2.4209E-03	2.2152E-03	2.0128E-03	1.8158E-03	1.6256E-03	1.4444E-03	1.2730E-03	1.1128E-03	9.6375E-04
8.2655E-04	7.0029E-04	5.8499E-04	4.7921E-04	3.8221E-04	2.9251E-04	2.0811E-04	1.2523E-04	3.2240E-05	2.2355E-06
1.9639E-07	1.8724E-08	0.0000E+00							

IY= 28 Y= 6.75E+01

2.3364E-03	2.3268E-03	2.2980E-03	2.2504E-03	2.1845E-03	2.1023E-03	2.0045E-03	1.8962E-03	1.7826E-03	1.6647E-03
1.5450E-03	1.4245E-03	1.3045E-03	1.1863E-03	1.0713E-03	9.6020E-04	8.5417E-04	7.5380E-04	6.5980E-04	5.7225E-04
4.9142E-04	4.1699E-04	3.4879E-04	2.8624E-04	2.2879E-04	1.7567E-04	1.2586E-04	7.7023E-05	2.0649E-05	1.5068E-06
1.3632E-07	1.3164E-08	0.0000E+00							

IY= 29 Y= 7.00E+01

5.8879E-04	5.8636E-04	5.7910E-04	5.6711E-04	5.5064E-04	5.2999E-04	5.0577E-04	4.7896E-04	4.5041E-04	4.2084E-04
3.9067E-04	3.6032E-04	3.3011E-04	3.0036E-04	2.7137E-04	2.4338E-04	2.1663E-04	1.9131E-04	1.6754E-04	1.4542E-04
1.2494E-04	1.0609E-04	8.8782E-05	7.2896E-05	5.8307E-05	4.4862E-05	3.2445E-05	2.0682E-05	9.3224E-06	8.2685E-07
8.6899E-08	8.7029E-09	0.0000E+00							

IY= 30 Y= 7.25E+01

4.0565E-05	4.0398E-05	3.9898E-05	3.9072E-05	3.7938E-05	3.6515E-05	3.4793E-05	3.3006E-05	3.1045E-05	2.9008E-05
2.6930E-05	2.4839E-05	2.2767E-05	2.0708E-05	1.8732E-05	1.6782E-05	1.4968E-05	1.3192E-05	1.1589E-05	1.0028E-05
8.6500E-06	7.3149E-06	6.1511E-06	5.0241E-06	4.0169E-06	3.0918E-06	2.2476E-06	1.5072E-06	8.2598E-07	2.0747E-07
2.9257E-08	3.5636E-09	0.0000E+00							

IY= 31 Y= 7.50E+01

3.5408E-06	3.5261E-06	3.4826E-06	3.4106E-06	3.3120E-06	3.1890E-06	3.0384E-06	2.8830E-06	2.7130E-06	2.5356E-06
2.3544E-06	2.1721E-06	1.9912E-06	1.8113E-06	1.6391E-06	1.4685E-06	1.3106E-06	1.1549E-06	1.0153E-06	8.7829E-07
7.5826E-07	6.4094E-07	5.3943E-07	4.4047E-07	3.5218E-07	2.7123E-07	1.9751E-07	1.3632E-07	8.6760E-08	2.9239E-08
7.6450E-09	1.2490E-09	0.0000E+00							

IY= 32 Y= 7.75E+01

3.3430E-07	3.3292E-07	3.2882E-07	3.2204E-07	3.1274E-07	3.0127E-07	2.8702E-07	2.7244E-07	2.5648E-07	2.3979E-07
2.2270E-07	2.0552E-07	1.8845E-07	1.7145E-07	1.5522E-07	1.3907E-07	1.2421E-07	1.0945E-07	9.6303E-08	8.3283E-08
7.1983E-08	6.0813E-08	5.1240E-08	4.1823E-08	3.3468E-08	2.5819E-08	1.8845E-08	1.3168E-08	8.6873E-09	3.5593E-09
1.2483E-09	2.9782E-10	0.0000E+00							

IY= 33 Y= 8.00E+01

0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
0.0000E+00	0.0000E+00	0.0000E+00							

INTEGRATED TOTAL FLUX

	1	2	3	4	5	6	7	8	9
9	1.2087E-02	9.0611E-03	2.1624E-03	1.7534E-03	1.3794E-03	1.0494E-03	7.6627E-04	1.0023E-03	2.2100E-05
8	1.3085E+00	9.5801E-01	2.2571E-01	1.8118E-01	1.4094E-01	1.0594E-01	7.6397E-02	9.6301E-02	9.8184E-04
7	1.1006E+00	8.1564E-01	1.8987E-01	1.5019E-01	1.1519E-01	8.5053E-02	6.0243E-02	7.4127E-02	7.2763E-04
6	1.4623E+00	1.1512E+00	2.7501E-01	2.1781E-01	1.6434E-01	1.1897E-01	8.2881E-02	1.0012E-01	9.7008E-04
5	1.8059E+00	1.4617E+00	3.6700E-01	2.9824E-01	2.2531E-01	1.5949E-01	1.0888E-01	1.2909E-01	1.2347E-03
4	4.5346E+00	3.7315E+00	9.6175E-01	7.9884E-01	6.2820E-01	4.5133E-01	3.0272E-01	3.5053E-01	3.2942E-03
3	8.5631E+00	7.0377E+00	1.8094E+00	1.5085E+00	1.2084E+00	9.1568E-01	6.2936E-01	7.1756E-01	6.6672E-03
2	6.3963E+00	5.1481E+00	1.2489E+00	9.7704E-01	7.5853E-01	5.9741E-01	4.4870E-01	5.3870E-01	5.0359E-03
1	3.2784E+00	2.6041E+00	5.8694E-01	3.7200E-01	2.6004E-01	2.4521E-01	2.0957E-01	2.6685E-01	2.5517E-03

ENERGY 3

-- FEC -- L= 0 M= 0

IY= 1 Y= 0.00E+00									
2.8581E-02	2.8500E-02	2.8257E-02	2.7852E-02	2.7286E-02	2.6558E-02	2.5667E-02	2.4609E-02	2.3381E-02	2.1975E-02
2.0376E-02	1.8557E-02	1.6465E-02	1.3922E-02	1.0623E-02	6.8079E-03	5.1358E-03	4.6107E-03	5.2118E-03	5.9087E-03
6.0216E-03	5.7936E-03	5.4304E-03	4.8468E-03	4.0867E-03	3.2278E-03	2.3080E-03	1.3403E-03	2.5529E-04	1.7054E-05
1.4783E-06	1.3927E-07	0.0000E+00							
IY= 2 Y= 2.50E+00									
2.8537E-02	2.8456E-02	2.8214E-02	2.7811E-02	2.7247E-02	2.6522E-02	2.5635E-02	2.4583E-02	2.3364E-02	2.1970E-02
2.0388E-02	1.8596E-02	1.6552E-02	1.4093E-02	1.0954E-02	7.2961E-03	5.6439E-03	5.0682E-03	5.5278E-03	6.1047E-03
6.1430E-03	5.8635E-03	5.4715E-03	4.8728E-03	4.1026E-03	3.2372E-03	2.3132E-03	1.3427E-03	2.5571E-04	1.7082E-05
1.4803E-06	1.3944E-07	0.0000E+00							
IY= 3 Y= 5.00E+00									
2.8405E-02	2.8326E-02	2.8086E-02	2.7688E-02	2.7130E-02	2.6414E-02	2.5539E-02	2.4505E-02	2.3310E-02	2.1949E-02
2.0414E-02	1.8694E-02	1.6764E-02	1.4568E-02	1.2000E-02	9.3467E-03	7.7952E-03	6.9505E-03	6.7114E-03	6.6860E-03
6.4473E-03	6.0486E-03	5.5854E-03	4.9452E-03	4.1469E-03	3.2633E-03	2.3277E-03	1.3495E-03	2.5680E-04	1.7163E-05
1.4874E-06	1.4008E-07	0.0000E+00							
IY= 4 Y= 7.50E+00									
2.8185E-02	2.8107E-02	2.7872E-02	2.7480E-02	2.6933E-02	2.6232E-02	2.5377E-02	2.4368E-02	2.3208E-02	2.1895E-02
2.0428E-02	1.8805E-02	1.7024E-02	1.5129E-02	1.3076E-02	1.1164E-02	9.7199E-03	8.6348E-03	7.9233E-03	7.3907E-03
6.8422E-03	6.3012E-03	5.7478E-03	5.0454E-03	4.2074E-03	3.2982E-03	2.3465E-03	1.3582E-03	2.5831E-04	1.7254E-05
1.4947E-06	1.4072E-07	0.0000E+00							
IY= 5 Y= 1.00E+01									
2.7877E-02	2.7800E-02	2.7570E-02	2.7188E-02	2.6655E-02	2.5972E-02	2.5142E-02	2.4167E-02	2.3050E-02	2.1795E-02
2.0406E-02	1.8891E-02	1.7264E-02	1.5582E-02	1.3863E-02	1.2224E-02	1.0838E-02	9.6774E-03	8.7546E-03	7.9755E-03
7.2529E-03	6.5758E-03	5.9271E-03	5.1571E-03	4.2742E-03	3.3361E-03	2.3665E-03	1.3671E-03	2.5980E-04	1.7353E-05
1.5026E-06	1.4139E-07	0.0000E+00							
IY= 6 Y= 1.25E+01									
2.7479E-02	2.7405E-02	2.7181E-02	2.6811E-02	2.6294E-02	2.5633E-02	2.4832E-02	2.3895E-02	2.2826E-02	2.1632E-02
2.0322E-02	1.8910E-02	1.7416E-02	1.5886E-02	1.4349E-02	1.2879E-02	1.1555E-02	1.0371E-02	9.3488E-03	8.4423E-03
7.6132E-03	6.8411E-03	6.1059E-03	5.2632E-03	4.3348E-03	3.3687E-03	2.3824E-03	1.3736E-03	2.6085E-04	1.7422E-05
1.5080E-06	1.4185E-07	0.0000E+00							
IY= 7 Y= 1.50E+01									
2.6992E-02	2.6920E-02	2.6705E-02	2.6346E-02	2.5848E-02	2.5212E-02	2.4443E-02	2.3545E-02	2.2525E-02	2.1393E-02
2.0158E-02	1.8838E-02	1.7456E-02	1.6041E-02	1.4632E-02	1.3270E-02	1.1988E-02	1.0816E-02	9.7528E-03	8.8000E-03
7.9582E-03	7.1121E-03	6.2655E-03	5.3472E-03	4.3775E-03	3.3879E-03	2.3894E-03	1.3752E-03	2.6102E-04	1.7409E-05
1.5064E-06	1.4164E-07	0.0000E+00							
IY= 8 Y= 1.75E+01									
2.6416E-02	2.6347E-02	2.6139E-02	2.5795E-02	2.5316E-02	2.4706E-02	2.3970E-02	2.3113E-02	2.2144E-02	2.1071E-02
1.9907E-02	1.8669E-02	1.7376E-02	1.6057E-02	1.4738E-02	1.3449E-02	1.2219E-02	1.1062E-02	9.9957E-03	9.0365E-03
8.2169E-03	7.3296E-03	6.3763E-03	5.3965E-03	4.3949E-03	3.3893E-03	2.3845E-03	1.3702E-03	2.5997E-04	1.7368E-05
1.5030E-06	1.4132E-07	0.0000E+00							
IY= 9 Y= 2.00E+01									
2.5752E-02	2.5685E-02	2.5486E-02	2.5156E-02	2.4698E-02	2.4115E-02	2.3412E-02	2.2596E-02	2.1676E-02	2.0660E-02
1.9561E-02	1.8395E-02	1.7180E-02	1.5939E-02	1.4693E-02	1.3466E-02	1.2281E-02	1.1151E-02	1.0098E-02	9.1368E-03
8.3094E-03	7.4030E-03	6.4124E-03	5.3978E-03	4.3791E-03	3.3677E-03	2.3645E-03	1.3569E-03	2.5741E-04	1.7201E-05
1.4883E-06	1.3990E-07	0.0000E+00							
IY= 10 Y= 2.25E+01									
2.5001E-02	2.4937E-02	2.4747E-02	2.4431E-02	2.3994E-02	2.3438E-02	2.2769E-02	2.1993E-02	2.1120E-02	2.0157E-02
1.9119E-02	1.8018E-02	1.6872E-02	1.5698E-02	1.4518E-02	1.3347E-02	1.2208E-02	1.1112E-02	1.0080E-02	9.1275E-03
8.2968E-03	7.3782E-03	6.3724E-03	5.3474E-03	4.3269E-03	3.3205E-03	2.3278E-03	1.3345E-03	2.5316E-04	1.6921E-05
1.4641E-06	1.3762E-07	0.0000E+00							
IY= 11 Y= 2.50E+01									
2.4165E-02	2.4104E-02	2.3923E-02	2.3622E-02	2.3206E-02	2.2677E-02	2.2041E-02	2.1305E-02	2.0477E-02	1.9566E-02
1.8584E-02	1.7543E-02	1.6460E-02	1.5349E-02	1.4228E-02	1.3113E-02	1.2022E-02	1.0967E-02	9.9660E-03	9.0311E-03

8.1986E-03	7.2752E-03	6.2694E-03	5.2485E-03	4.2385E-03	3.2475E-03	2.2739E-03	1.3026E-03	2.4714E-04	1.6523E-05
1.4298E-06	1.3440E-07	0.0000E+00							
IY= 12 Y= 2.75E+01									
2.3248E-02	2.3190E-02	2.3018E-02	2.2732E-02	2.2337E-02	2.1835E-02	2.1232E-02	2.0535E-02	1.9751E-02	1.8889E-02
1.7961E-02	1.6978E-02	1.5953E-02	1.4902E-02	1.3839E-02	1.2780E-02	1.1743E-02	1.0736E-02	9.7813E-03	8.8779E-03
8.0409E-03	7.1077E-03	6.1093E-03	5.1042E-03	4.1154E-03	3.1493E-03	2.2032E-03	1.2614E-03	2.3940E-04	1.6008E-05
1.3856E-06	1.3028E-07	0.0000E+00							
IY= 13 Y= 3.00E+01									
2.2253E-02	2.2199E-02	2.2036E-02	2.1765E-02	2.1391E-02	2.0916E-02	2.0346E-02	1.9687E-02	1.8946E-02	1.8133E-02
1.7257E-02	1.6329E-02	1.5362E-02	1.4369E-02	1.3363E-02	1.2362E-02	1.1382E-02	1.0445E-02	9.5955E-03	8.7278E-03
7.8368E-03	6.8833E-03	5.8984E-03	4.9187E-03	3.9606E-03	3.0279E-03	2.1168E-03	1.2116E-03	2.3002E-04	1.5354E-05
1.3290E-06	1.2494E-07	0.0000E+00							
IY= 14 Y= 3.25E+01									
2.1188E-02	2.1136E-02	2.0982E-02	2.0727E-02	2.0374E-02	1.9926E-02	1.9389E-02	1.8768E-02	1.8071E-02	1.7305E-02
1.6481E-02	1.5607E-02	1.4697E-02	1.3762E-02	1.2815E-02	1.1871E-02	1.0950E-02	1.0084E-02	9.3265E-03	8.4816E-03
7.5560E-03	6.6029E-03	5.6415E-03	4.6973E-03	3.7782E-03	2.8863E-03	2.0168E-03	1.1540E-03	2.1920E-04	1.4666E-05
1.2699E-06	1.1944E-07	0.0000E+00							
IY= 15 Y= 3.50E+01									
2.0057E-02	2.0009E-02	1.9864E-02	1.9625E-02	1.9293E-02	1.8873E-02	1.8369E-02	1.7787E-02	1.7133E-02	1.6415E-02
1.5642E-02	1.4824E-02	1.3971E-02	1.3095E-02	1.2207E-02	1.1323E-02	1.0462E-02	9.6458E-03	8.9207E-03	8.1043E-03
7.1988E-03	6.2693E-03	5.3454E-03	4.4447E-03	3.5718E-03	2.7270E-03	1.9048E-03	1.0898E-03	2.0711E-04	1.3863E-05
1.2007E-06	1.1295E-07	0.0000E+00							
IY= 16 Y= 3.75E+01									
1.8870E-02	1.8825E-02	1.8690E-02	1.8466E-02	1.8157E-02	1.7765E-02	1.7296E-02	1.6753E-02	1.6143E-02	1.5473E-02
1.4753E-02	1.3992E-02	1.3198E-02	1.2383E-02	1.1557E-02	1.0733E-02	9.9365E-03	9.1728E-03	8.4624E-03	7.6571E-03
6.7807E-03	5.8919E-03	5.0161E-03	4.1664E-03	3.3458E-03	2.5533E-03	1.7831E-03	1.0201E-03	1.9397E-04	1.2987E-05
1.1254E-06	1.0592E-07	0.0000E+00							
IY= 17 Y= 4.00E+01									
1.7635E-02	1.7593E-02	1.7468E-02	1.7261E-02	1.6976E-02	1.6614E-02	1.6180E-02	1.5678E-02	1.5113E-02	1.4493E-02
1.3828E-02	1.3127E-02	1.2398E-02	1.1645E-02	1.0884E-02	1.0128E-02	9.4399E-03	8.7281E-03	7.9737E-03	7.1619E-03
6.3207E-03	5.4809E-03	4.6608E-03	3.8678E-03	3.1045E-03	2.3685E-03	1.6538E-03	9.4626E-04	1.8003E-04	1.2045E-05
1.0439E-06	9.8259E-08	0.0000E+00							
IY= 18 Y= 4.25E+01									
1.6363E-02	1.6325E-02	1.6210E-02	1.6021E-02	1.5760E-02	1.5431E-02	1.5036E-02	1.4578E-02	1.4060E-02	1.3490E-02
1.2879E-02	1.2240E-02	1.1593E-02	1.0920E-02	1.0210E-02	9.5148E-03	8.8884E-03	8.1827E-03	7.4146E-03	6.6241E-03
5.8275E-03	5.0457E-03	4.2864E-03	3.5552E-03	2.8526E-03	2.1760E-03	1.5193E-03	8.6937E-04	1.6550E-04	1.1088E-05
9.6136E-07	9.0532E-08	0.0000E+00							
IY= 19 Y= 4.50E+01									
1.5068E-02	1.5033E-02	1.4928E-02	1.4757E-02	1.4522E-02	1.4231E-02	1.3881E-02	1.3472E-02	1.3005E-02	1.2484E-02
1.1929E-02	1.1358E-02	1.0842E-02	1.0272E-02	9.6028E-03	8.9204E-03	8.2495E-03	7.5372E-03	6.7969E-03	6.0492E-03
5.3125E-03	4.5935E-03	3.8997E-03	3.2331E-03	2.5937E-03	1.9784E-03	1.3814E-03	7.9060E-04	1.5060E-04	1.0089E-05
8.7504E-07	8.2421E-08	0.0000E+00							
IY= 20 Y= 4.75E+01									
1.3762E-02	1.3731E-02	1.3636E-02	1.3482E-02	1.3275E-02	1.3021E-02	1.2740E-02	1.2402E-02	1.1981E-02	1.1506E-02
1.0996E-02	1.0482E-02	1.0028E-02	9.4967E-03	8.8699E-03	8.1997E-03	7.5206E-03	6.8342E-03	6.1404E-03	5.4546E-03
4.7828E-03	4.1324E-03	3.5063E-03	2.9065E-03	2.3315E-03	1.7785E-03	1.2420E-03	7.1095E-04	1.3551E-04	9.0846E-06
7.8821E-07	7.4275E-08	0.0000E+00							
IY= 21 Y= 5.00E+01									
1.2466E-02	1.2437E-02	1.2352E-02	1.2214E-02	1.2035E-02	1.1826E-02	1.1663E-02	1.1434E-02	1.1055E-02	1.0612E-02
1.0127E-02	9.6286E-03	9.1305E-03	8.5812E-03	7.9851E-03	7.3628E-03	6.7302E-03	6.0950E-03	5.4664E-03	4.8483E-03
4.2477E-03	3.6678E-03	3.1115E-03	2.5790E-03	2.0690E-03	1.5785E-03	1.1025E-03	6.3125E-04	1.2039E-04	8.0754E-06
7.0092E-07	6.6072E-08	0.0000E+00							
IY= 22 Y= 5.25E+01									
1.1203E-02	1.1177E-02	1.1100E-02	1.0977E-02	1.0817E-02	1.0643E-02	1.0514E-02	1.0311E-02	9.9707E-03	9.5601E-03
9.1059E-03	8.6239E-03	8.1205E-03	7.5931E-03	7.0410E-03	6.4779E-03	5.9093E-03	5.3433E-03	4.7851E-03	4.2407E-03
3.7130E-03	3.2055E-03	2.7191E-03	2.2539E-03	1.8085E-03	1.3800E-03	9.6410E-04	5.5215E-04	1.0537E-04	7.0676E-06
6.1359E-07	5.7857E-08	0.0000E+00							
IY= 23 Y= 5.50E+01									
1.0032E-02	1.0008E-02	9.9360E-03	9.8203E-03	9.6662E-03	9.4896E-03	9.2941E-03	9.0404E-03	8.7213E-03	8.3466E-03
7.9362E-03	7.4980E-03	7.0387E-03	6.5614E-03	6.0730E-03	5.5774E-03	5.0815E-03	4.5897E-03	4.1073E-03	3.6378E-03
3.1845E-03	2.7489E-03	2.3320E-03	1.9334E-03	1.5516E-03	1.1843E-03	8.2761E-04	4.7411E-04	9.0521E-05	6.0783E-06
5.2791E-07	4.9798E-08	0.0000E+00							

IY= 24 Y= 5.75E+01

8.6763E-03	8.6543E-03	8.5889E-03	8.4821E-03	8.3366E-03	8.1572E-03	7.9434E-03	7.6904E-03	7.3960E-03	7.0653E-03
6.7069E-03	6.3261E-03	5.9280E-03	5.5178E-03	5.0994E-03	4.6784E-03	4.2583E-03	3.8438E-03	3.4381E-03	3.0444E-03
2.6647E-03	2.3004E-03	1.9518E-03	1.6185E-03	1.2993E-03	9.9201E-04	6.9345E-04	3.9742E-04	7.5911E-05	5.0939E-06
4.4249E-07	4.1750E-08	0.0000E+00							

IY= 25 Y= 6.00E+01

7.1545E-03	7.1357E-03	7.0795E-03	6.9872E-03	6.8601E-03	6.7007E-03	6.5091E-03	6.2864E-03	6.0346E-03	5.7569E-03
5.4581E-03	5.1422E-03	4.8133E-03	4.4757E-03	4.1327E-03	3.7886E-03	3.4464E-03	3.1097E-03	2.7809E-03	2.4622E-03
2.1551E-03	1.8607E-03	1.5791E-03	1.3098E-03	1.0518E-03	8.0334E-04	5.6181E-04	3.2217E-04	6.1565E-05	4.1319E-06
3.5907E-07	3.3906E-08	0.0000E+00							

IY= 26 Y= 6.25E+01

5.5616E-03	5.5465E-03	5.5014E-03	5.4270E-03	5.3244E-03	5.1950E-03	5.0398E-03	4.8609E-03	4.6607E-03	4.4418E-03
4.2075E-03	3.9608E-03	3.7047E-03	3.4426E-03	3.1770E-03	2.9112E-03	2.6474E-03	2.3883E-03	2.1355E-03	1.8908E-03
1.6552E-03	1.4293E-03	1.2132E-03	1.0066E-03	8.0864E-04	6.1792E-04	4.3245E-04	2.4827E-04	4.7488E-05	3.1890E-06
2.7745E-07	2.6266E-08	0.0000E+00							

IY= 27 Y= 6.50E+01

3.9325E-03	3.9215E-03	3.8889E-03	3.8351E-03	3.7608E-03	3.6670E-03	3.5548E-03	3.4260E-03	3.2825E-03	3.1264E-03
2.9598E-03	2.7848E-03	2.6035E-03	2.4183E-03	2.2311E-03	2.0439E-03	1.8585E-03	1.6764E-03	1.4990E-03	1.3273E-03
1.1621E-03	1.0037E-03	8.5221E-04	7.0731E-04	5.6844E-04	4.3468E-04	3.0467E-04	1.7546E-04	3.3735E-05	2.2772E-06
1.9929E-07	1.8993E-08	0.0000E+00							

IY= 28 Y= 6.75E+01

2.2660E-03	2.2597E-03	2.2406E-03	2.2093E-03	2.1659E-03	2.1113E-03	2.0460E-03	1.9711E-03	1.8879E-03	1.7975E-03
1.7012E-03	1.6003E-03	1.4959E-03	1.3893E-03	1.2816E-03	1.1741E-03	1.0675E-03	9.6304E-04	8.6121E-04	7.6273E-04
6.6790E-04	5.7703E-04	4.9005E-04	4.0692E-04	3.2722E-04	2.5052E-04	1.7614E-04	1.0242E-04	2.0205E-05	1.4413E-06
1.3113E-07	1.2768E-08	0.0000E+00							

IY= 29 Y= 7.00E+01

4.2983E-04	4.2863E-04	4.2506E-04	4.1915E-04	4.1099E-04	4.0069E-04	3.8839E-04	3.7432E-04	3.5864E-04	3.4160E-04
3.2343E-04	3.0436E-04	2.8464E-04	2.6448E-04	2.4412E-04	2.2374E-04	2.0357E-04	1.8374E-04	1.6442E-04	1.4570E-04
1.2767E-04	1.1035E-04	9.3777E-05	7.7894E-05	6.2667E-05	4.8022E-05	3.3939E-05	2.0252E-05	8.3957E-06	7.5938E-07
8.1278E-08	8.2463E-09	0.0000E+00							

IY= 30 Y= 7.25E+01

2.8696E-05	2.8617E-05	2.8379E-05	2.7988E-05	2.7447E-05	2.6762E-05	2.5908E-05	2.5013E-05	2.3973E-05	2.2840E-05
2.1631E-05	2.0362E-05	1.9038E-05	1.7704E-05	1.6346E-05	1.4987E-05	1.3648E-05	1.2316E-05	1.1037E-05	9.7725E-06
8.5807E-06	7.4059E-06	6.3095E-06	5.2293E-06	4.2074E-06	3.2260E-06	2.2917E-06	1.4449E-06	7.6041E-07	1.7305E-07
2.5329E-08	3.1426E-09	0.0000E+00							

IY= 31 Y= 7.50E+01

2.4823E-06	2.4754E-06	2.4550E-06	2.4213E-06	2.3747E-06	2.3159E-06	2.2420E-06	2.1652E-06	2.0757E-06	1.9781E-06
1.8738E-06	1.7644E-06	1.6500E-06	1.5349E-06	1.4176E-06	1.3001E-06	1.1844E-06	1.0691E-06	9.5857E-07	8.4890E-07
7.4577E-07	6.4374E-07	5.4872E-07	4.5483E-07	3.6609E-07	2.8101E-07	2.0079E-07	1.3155E-07	8.1404E-08	2.5359E-08
6.5926E-09	1.0870E-09	0.0000E+00							

IY= 32 Y= 7.75E+01

2.3333E-07	2.3269E-07	2.3078E-07	2.2762E-07	2.2325E-07	2.1776E-07	2.1080E-07	2.0364E-07	1.9525E-07	1.8612E-07
1.7635E-07	1.6610E-07	1.5535E-07	1.4456E-07	1.3355E-07	1.2252E-07	1.1166E-07	1.0082E-07	9.0441E-08	8.0103E-08
7.0418E-08	6.0781E-08	5.1845E-08	4.2974E-08	3.4617E-08	2.6637E-08	1.9160E-08	1.2821E-08	8.2658E-09	3.1482E-09
1.0878E-09	2.5338E-10	0.0000E+00							

IY= 33 Y= 8.00E+01

0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
0.0000E+00	0.0000E+00	0.0000E+00							

INTEGRATED TOTAL FLUX

	1	2	3	4	5	6	7	8	9
9	8.9317E-03	7.3040E-03	1.8949E-03	1.6039E-03	1.3180E-03	1.0457E-03	7.9252E-04	1.0549E-03	1.9922E-05
8	1.1932E+00	9.8891E-01	2.5813E-01	2.1873E-01	1.7971E-01	1.4241E-01	1.0769E-01	1.4074E-01	1.0351E-03
7	8.2081E-01	7.0857E-01	1.8939E-01	1.6182E-01	1.3362E-01	1.0615E-01	8.0305E-02	1.0469E-01	7.5562E-04
6	1.0052E+00	8.6051E-01	2.3602E-01	2.0424E-01	1.7057E-01	1.3638E-01	1.0344E-01	1.3487E-01	9.7123E-04
5	1.1927E+00	1.0071E+00	2.7320E-01	2.3832E-01	2.0364E-01	1.6532E-01	1.2618E-01	1.6488E-01	1.1854E-03
4	2.9157E+00	2.4436E+00	6.5294E-01	5.6501E-01	4.8197E-01	4.0151E-01	3.1184E-01	4.1114E-01	2.9569E-03
3	5.4238E+00	4.4764E+00	1.1643E+00	9.8785E-01	8.2209E-01	6.7657E-01	5.4239E-01	7.3888E-01	5.3825E-03
2	4.0329E+00	3.2303E+00	7.7257E-01	5.9925E-01	4.7311E-01	3.9460E-01	3.2879E-01	4.8942E-01	3.7176E-03
1	2.0652E+00	1.6249E+00	3.5034E-01	2.0351E-01	1.4155E-01	1.5210E-01	1.4664E-01	2.3459E-01	1.8332E-03

ENERGY 4

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-- FEC --    L= 0  M= 0
IY=  1 Y=  0.00E+00
 9.7812E-04  9.7531E-04  9.6688E-04  9.5282E-04  9.3310E-04  9.0763E-04  8.7628E-04  8.3872E-04  7.9457E-04  7.4306E-04
 6.8283E-04  6.1145E-04  5.2433E-04  4.0991E-04  2.4334E-04  1.2173E-04  8.8138E-05  8.1127E-05  1.1660E-04  1.7862E-04
 2.0818E-04  2.2272E-04  2.3618E-04  2.3721E-04  2.1527E-04  1.7855E-04  1.3159E-04  7.7346E-05  1.4012E-05  9.2967E-07
 8.0451E-08  7.5763E-09  0.0000E+00
IY=  2 Y=  2.50E+00
 9.7664E-04  9.7384E-04  9.6545E-04  9.5145E-04  9.3181E-04  9.0646E-04  8.7529E-04  8.3798E-04  7.9421E-04  7.4326E-04
 6.8393E-04  6.1414E-04  5.3021E-04  4.1868E-04  2.5389E-04  1.3371E-04  1.0028E-04  9.2006E-05  1.2599E-04  1.8710E-04
 2.1437E-04  2.2636E-04  2.3852E-04  2.3892E-04  2.1647E-04  1.7936E-04  1.3209E-04  7.7604E-05  1.4057E-05  9.3266E-07
 8.0696E-08  7.5971E-09  0.0000E+00
IY=  3 Y=  5.00E+00
 9.7221E-04  9.6944E-04  9.6115E-04  9.4732E-04  9.2793E-04  9.0294E-04  8.7225E-04  8.3570E-04  7.9297E-04  7.4358E-04
 6.8665E-04  6.2076E-04  5.4346E-04  4.4925E-04  3.1512E-04  2.1339E-04  1.7585E-04  1.5992E-04  1.7819E-04  2.1552E-04
 2.2952E-04  2.3621E-04  2.4529E-04  2.4388E-04  2.1996E-04  1.8169E-04  1.3354E-04  7.8351E-05  1.4182E-05  9.4251E-07
 8.1549E-08  7.6774E-09  0.0000E+00
IY=  4 Y=  7.50E+00
 9.6478E-04  9.6207E-04  9.5393E-04  9.4036E-04  9.2138E-04  8.9695E-04  8.6706E-04  8.3157E-04  7.9036E-04  7.4317E-04
 6.8957E-04  6.2888E-04  5.6018E-04  4.8680E-04  4.0295E-04  3.2928E-04  2.8338E-04  2.5750E-04  2.5055E-04  2.5207E-04
 2.5028E-04  2.5059E-04  2.5568E-04  2.5151E-04  2.2529E-04  1.8521E-04  1.3569E-04  7.9457E-05  1.4376E-05  9.5384E-07
 8.2497E-08  7.7625E-09  0.0000E+00
IY=  5 Y=  1.00E+01
 9.5437E-04  9.5173E-04  9.4379E-04  9.3058E-04  9.1212E-04  8.8842E-04  8.5951E-04  8.2538E-04  7.8603E-04  7.4142E-04
 6.9152E-04  6.3636E-04  5.7625E-04  5.1416E-04  4.5012E-04  3.9172E-04  3.4764E-04  3.1544E-04  2.9565E-04  2.8322E-04
 2.7375E-04  2.6831E-04  2.6900E-04  2.6132E-04  2.3208E-04  1.8965E-04  1.3838E-04  8.0829E-05  1.4612E-05  9.6952E-07
 8.3811E-08  7.8820E-09  0.0000E+00
IY=  6 Y=  1.25E+01
 9.4097E-04  9.3841E-04  9.3072E-04  9.1793E-04  9.0009E-04  8.7724E-04  8.4946E-04  8.1684E-04  7.7949E-04  7.3754E-04
 6.9125E-04  6.4100E-04  5.8763E-04  5.3338E-04  4.7940E-04  4.2933E-04  3.8756E-04  3.5364E-04  3.2874E-04  3.1042E-04
 2.9794E-04  2.8973E-04  2.8566E-04  2.7294E-04  2.3982E-04  1.9457E-04  1.4130E-04  8.2294E-05  1.4865E-05  9.8630E-07
 8.5210E-08  8.0082E-09  0.0000E+00
IY=  7 Y=  1.50E+01
 9.2458E-04  9.2211E-04  9.1469E-04  9.0238E-04  8.8522E-04  8.6330E-04  8.3675E-04  8.0570E-04  7.7036E-04  7.3098E-04
 6.8798E-04  6.4191E-04  5.9387E-04  5.4506E-04  4.9729E-04  4.5265E-04  4.1275E-04  3.7941E-04  3.5299E-04  3.3462E-04
 3.2747E-04  3.2106E-04  3.0918E-04  2.8654E-04  2.4806E-04  1.9952E-04  1.4412E-04  8.3674E-05  1.5100E-05  1.0008E-06
 8.6438E-08  8.1197E-09  0.0000E+00
IY=  8 Y=  1.75E+01
 9.0520E-04  9.0282E-04  8.9571E-04  8.8390E-04  8.6748E-04  8.4655E-04  8.2126E-04  7.9182E-04  7.5847E-04  7.2155E-04
 6.8153E-04  6.3902E-04  5.9492E-04  5.5045E-04  5.0687E-04  4.6558E-04  4.2825E-04  3.9592E-04  3.7025E-04  3.5415E-04
 3.5402E-04  3.5136E-04  3.3135E-04  2.9889E-04  2.5528E-04  2.0370E-04  1.4641E-04  8.4748E-05  1.5283E-05  1.0143E-06
 8.7594E-08  8.2272E-09  0.0000E+00
IY=  9 Y=  2.00E+01
 8.8288E-04  8.8061E-04  8.7381E-04  8.6254E-04  8.4688E-04  8.2696E-04  8.0295E-04  7.7508E-04  7.4364E-04  7.0900E-04
 6.7163E-04  6.3216E-04  5.9138E-04  5.5029E-04  5.0999E-04  4.7157E-04  4.3651E-04  4.0593E-04  3.8173E-04  3.6697E-04
 3.6909E-04  3.6737E-04  3.4386E-04  3.0684E-04  2.6005E-04  2.0636E-04  1.4777E-04  8.5331E-05  1.5385E-05  1.0213E-06
 8.8170E-08  8.2777E-09  0.0000E+00
IY= 10 Y=  2.25E+01
 8.5770E-04  8.5554E-04  8.4907E-04  8.3834E-04  8.2346E-04  8.0456E-04  7.8182E-04  7.5550E-04  7.2589E-04  6.9337E-04
 6.5841E-04  6.2161E-04  5.8370E-04  5.4553E-04  5.0809E-04  4.7236E-04  4.3969E-04  4.1114E-04  3.8868E-04  3.7521E-04
 3.7805E-04  3.7608E-04  3.5056E-04  3.1103E-04  2.6230E-04  2.0732E-04  1.4802E-04  8.5320E-05  1.5383E-05  1.0215E-06
 8.8184E-08  8.2783E-09  0.0000E+00
IY= 11 Y=  2.50E+01
 8.2977E-04  8.2772E-04  8.2158E-04  8.1142E-04  7.9733E-04  7.7946E-04  7.5799E-04  7.3318E-04  7.0533E-04  6.7482E-04
 6.4211E-04  6.0776E-04  5.7245E-04  5.3696E-04  5.0223E-04  4.6921E-04  4.3922E-04  4.1320E-04  3.9321E-04  3.8130E-04
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 3.8381E-04  3.8057E-04  3.5328E-04  3.1200E-04  2.6208E-04  2.0649E-04  1.4708E-04  8.4658E-05  1.5268E-05  1.0142E-06
 8.7561E-08  8.2192E-09  0.0000E+00
IY= 12 Y=  2.75E+01
 7.9925E-04  7.9732E-04  7.9152E-04  7.8194E-04  7.6865E-04  7.5182E-04  7.3163E-04  7.0832E-04  6.8220E-04  6.5364E-04
 6.2309E-04  5.9108E-04  5.5824E-04  5.2534E-04  4.9329E-04  4.6316E-04  4.3641E-04  4.1381E-04  3.9821E-04  3.8916E-04
 3.8960E-04  3.8286E-04  3.5323E-04  3.1028E-04  2.5960E-04  2.0393E-04  1.4496E-04  8.3337E-05  1.5034E-05  9.9897E-07
 8.6265E-08  8.0994E-09  0.0000E+00
IY= 13 Y=  3.00E+01
 7.6637E-04  7.6455E-04  7.5911E-04  7.5012E-04  7.3767E-04  7.2190E-04  7.0300E-04  6.8122E-04  6.5684E-04  6.3022E-04
 6.0180E-04  5.7210E-04  5.4173E-04  5.1143E-04  4.8212E-04  4.5502E-04  4.3184E-04  4.1509E-04  4.1080E-04  4.0846E-04
 4.0168E-04  3.8477E-04  3.5050E-04  3.0604E-04  2.5500E-04  1.9973E-04  1.4170E-04  8.1374E-05  1.4685E-05  9.7372E-07
 8.4086E-08  7.8933E-09  0.0000E+00
IY= 14 Y=  3.25E+01
 7.3138E-04  7.2969E-04  7.2463E-04  7.1627E-04  7.0469E-04  6.9004E-04  6.7250E-04  6.5229E-04  6.2969E-04  6.0507E-04
 5.7884E-04  5.5151E-04  5.2368E-04  4.9607E-04  4.6963E-04  4.4564E-04  4.2606E-04  4.1528E-04  4.2151E-04  4.2533E-04
 4.1090E-04  3.8354E-04  3.4494E-04  2.9927E-04  2.4833E-04  1.9396E-04  1.3735E-04  7.8791E-05  1.4226E-05  9.4598E-07
 8.1721E-08  7.6749E-09  0.0000E+00
IY= 15 Y=  3.50E+01
 6.9468E-04  6.9312E-04  6.8847E-04  6.8078E-04  6.7015E-04  6.5671E-04  6.4061E-04  6.2208E-04  6.0137E-04  5.7886E-04
 5.5496E-04  5.3018E-04  5.0507E-04  4.8034E-04  4.5694E-04  4.3619E-04  4.2034E-04  4.1280E-04  4.2142E-04  4.2591E-04
 4.0801E-04  3.7661E-04  3.3621E-04  2.8998E-04  2.3967E-04  1.8670E-04  1.3198E-04  7.5638E-05  1.3663E-05  9.0898E-07
 7.8548E-08  7.3773E-09  0.0000E+00
IY= 16 Y=  3.75E+01
 6.5671E-04  6.5530E-04  6.5109E-04  6.4416E-04  6.3459E-04  6.2250E-04  6.0802E-04  5.9134E-04  5.7270E-04  5.5248E-04
 5.3114E-04  5.0924E-04  4.8720E-04  4.6568E-04  4.4566E-04  4.2838E-04  4.1704E-04  4.1249E-04  4.1912E-04  4.2003E-04
 3.9903E-04  3.6526E-04  3.2409E-04  2.7819E-04  2.2913E-04  1.7806E-04  1.2567E-04  7.1964E-05  1.3006E-05  8.6552E-07
 7.4818E-08  7.0301E-09  0.0000E+00
IY= 17 Y=  4.00E+01
 6.1805E-04  6.1681E-04  6.1312E-04  6.0705E-04  5.9871E-04  5.8821E-04  5.7563E-04  5.6108E-04  5.4475E-04  5.2709E-04
 5.0867E-04  4.9028E-04  4.7207E-04  4.5417E-04  4.3801E-04  4.2528E-04  4.2391E-04  4.2473E-04  4.2231E-04  4.1201E-04
 3.8561E-04  3.5023E-04  3.0903E-04  2.6412E-04  2.1688E-04  1.6818E-04  1.1853E-04  6.7828E-05  1.2265E-05  8.1491E-07
 7.0450E-08  6.6190E-09  0.0000E+00
IY= 18 Y=  4.25E+01
 5.7945E-04  5.7838E-04  5.7525E-04  5.7017E-04  5.6332E-04  5.5486E-04  5.4471E-04  5.3280E-04  5.1916E-04  5.0417E-04
 4.8880E-04  4.7433E-04  4.6265E-04  4.5105E-04  4.3721E-04  4.2829E-04  4.3256E-04  4.3455E-04  4.2210E-04  3.9950E-04
 3.6838E-04  3.3197E-04  2.9136E-04  2.4810E-04  2.0317E-04  1.5725E-04  1.1069E-04  6.3296E-05  1.1452E-05  7.6259E-07
 6.5956E-08  6.2002E-09  0.0000E+00
IY= 19 Y=  4.50E+01
 5.4190E-04  5.4103E-04  5.3851E-04  5.3458E-04  5.2957E-04  5.2389E-04  5.1709E-04  5.0864E-04  4.9828E-04  4.8618E-04
 4.7409E-04  4.6484E-04  4.6600E-04  4.6628E-04  4.5545E-04  4.4318E-04  4.3749E-04  4.2924E-04  4.0807E-04  3.8023E-04
 3.4748E-04  3.1075E-04  2.7146E-04  2.3034E-04  1.8817E-04  1.4539E-04  1.0223E-04  5.8428E-05  1.0577E-05  7.0356E-07
 6.0860E-08  5.7206E-09  0.0000E+00
IY= 20 Y=  4.75E+01
 5.0676E-04  5.0607E-04  5.0414E-04  5.0133E-04  4.9829E-04  4.9589E-04  4.9559E-04  4.9380E-04  4.8695E-04  4.7732E-04
 4.6746E-04  4.6165E-04  4.7066E-04  4.7815E-04  4.6884E-04  4.5141E-04  4.3338E-04  4.1248E-04  3.8604E-04  3.5603E-04
 3.2267E-04  2.8699E-04  2.4958E-04  2.1117E-04  1.7215E-04  1.3281E-04  9.3295E-05  5.3294E-05  9.6527E-06  6.4327E-07
 5.5669E-08  5.2359E-09  0.0000E+00
IY= 21 Y=  5.00E+01
 4.7601E-04  4.7549E-04  4.7409E-04  4.7237E-04  4.7153E-04  4.7392E-04  4.8695E-04  4.9829E-04  4.9581E-04  4.8755E-04
 4.7730E-04  4.6885E-04  4.6939E-04  4.6798E-04  4.5373E-04  4.3430E-04  4.1116E-04  3.8554E-04  3.5763E-04  3.2709E-04
 2.9473E-04  2.6087E-04  2.2612E-04  1.9080E-04  1.5525E-04  1.1963E-04  8.3965E-05  4.7947E-05  8.6893E-06  5.7863E-07
 5.0085E-08  4.7106E-09  0.0000E+00
IY= 22 Y=  5.25E+01
 4.5305E-04  4.5263E-04  4.5158E-04  4.5059E-04  4.5118E-04  4.5682E-04  4.7792E-04  4.9740E-04  4.9784E-04  4.9012E-04
 4.7871E-04  4.6631E-04  4.5509E-04  4.4186E-04  4.2351E-04  4.0205E-04  3.7790E-04  3.5166E-04  3.2371E-04  2.9447E-04
 2.6405E-04  2.3292E-04  2.0130E-04  1.6953E-04  1.3773E-04  1.0601E-04  7.4358E-05  4.2447E-05  7.6960E-06  5.1320E-07
 4.4438E-08  4.1816E-09  0.0000E+00
IY= 23 Y=  5.50E+01
 4.4695E-04  4.4652E-04  4.4539E-04  4.4415E-04  4.4397E-04  4.4721E-04  4.6016E-04  4.7131E-04  4.6932E-04  4.6077E-04
 4.4858E-04  4.3453E-04  4.1890E-04  4.0152E-04  3.8219E-04  3.6043E-04  3.3693E-04  3.1192E-04  2.8580E-04  2.5882E-04
 2.3133E-04  2.0345E-04  1.7548E-04  1.4752E-04  1.1970E-04  9.2058E-05  6.4536E-05  3.6832E-05  6.6816E-06  4.4537E-07
 3.8571E-08  3.6298E-09  0.0000E+00
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IY= 24 Y=  5.75E+01
 4.3047E-04  4.3000E-04  4.2872E-04  4.2698E-04  4.2541E-04  4.2483E-04  4.2657E-04  4.2663E-04  4.2115E-04  4.1167E-04
 3.9930E-04  3.8496E-04  3.6902E-04  3.5154E-04  3.3252E-04  3.1219E-04  2.9057E-04  2.6803E-04  2.4474E-04  2.2101E-04
 1.9699E-04  1.7292E-04  1.4888E-04  1.2501E-04  1.0135E-04  7.7889E-05  5.4581E-05  3.1148E-05  5.6524E-06  3.7713E-07
 3.2670E-08  3.0758E-09  0.0000E+00
IY= 25 Y=  6.00E+01
 3.8038E-04  3.7991E-04  3.7857E-04  3.7657E-04  3.7420E-04  3.7168E-04  3.6925E-04  3.6533E-04  3.5850E-04  3.4911E-04
 3.3758E-04  3.2435E-04  3.0975E-04  2.9393E-04  2.7698E-04  2.5913E-04  2.4044E-04  2.2118E-04  2.0148E-04  1.8156E-04
 1.6154E-04  1.4158E-04  1.2174E-04  1.0213E-04  8.2739E-05  6.3561E-05  4.4533E-05  2.5417E-05  4.6146E-06  3.0797E-07
 2.6692E-08  2.5148E-09  0.0000E+00
IY= 26 Y=  6.25E+01
 3.0990E-04  3.0947E-04  3.0823E-04  3.0626E-04  3.0370E-04  3.0058E-04  2.9693E-04  2.9207E-04  2.8544E-04  2.7714E-04
 2.6732E-04  2.5622E-04  2.4405E-04  2.3098E-04  2.1711E-04  2.0263E-04  1.8762E-04  1.7226E-04  1.5665E-04  1.4096E-04
 1.2525E-04  1.0966E-04  9.4214E-05  7.8984E-05  6.3959E-05  4.9126E-05  3.4425E-05  1.9661E-05  3.5728E-06  2.3861E-07
 2.0706E-08  1.9562E-09  0.0000E+00
IY= 27 Y=  6.50E+01
 2.2565E-04  2.2532E-04  2.2432E-04  2.2270E-04  2.2052E-04  2.1777E-04  2.1442E-04  2.1020E-04  2.0489E-04  1.9852E-04
 1.9114E-04  1.8290E-04  1.7392E-04  1.6433E-04  1.5421E-04  1.4371E-04  1.3287E-04  1.2184E-04  1.1068E-04  9.9492E-05
 8.8334E-05  7.7285E-05  6.6365E-05  5.5616E-05  4.5029E-05  3.4591E-05  2.4262E-05  1.3891E-05  2.5366E-06  1.7031E-07
 1.4876E-08  1.4161E-09  0.0000E+00
IY= 28 Y=  6.75E+01
 1.3158E-04  1.3137E-04  1.3076E-04  1.2975E-04  1.2837E-04  1.2661E-04  1.2445E-04  1.2178E-04  1.1852E-04  1.1469E-04
 1.1032E-04  1.0547E-04  1.0020E-04  9.4588E-05  8.8690E-05  8.2579E-05  7.6297E-05  6.9917E-05  6.3474E-05  5.7033E-05
 5.0616E-05  4.4272E-05  3.8007E-05  3.1849E-05  2.5790E-05  1.9826E-05  1.3941E-05  8.0497E-06  1.5058E-06  1.0692E-07
 9.7276E-09  9.4760E-10  0.0000E+00
IY= 29 Y=  7.00E+01
 2.3730E-05  2.3694E-05  2.3587E-05  2.3410E-05  2.3164E-05  2.2849E-05  2.2454E-05  2.1972E-05  2.1390E-05  2.0706E-05
 1.9927E-05  1.9060E-05  1.8117E-05  1.7111E-05  1.6053E-05  1.4954E-05  1.3825E-05  1.2675E-05  1.1515E-05  1.0351E-05
 9.1927E-06  8.0436E-06  6.9099E-06  5.7920E-06  4.6924E-06  3.6105E-06  2.5511E-06  1.5092E-06  6.1874E-07  5.6038E-08
 6.0106E-09  6.1058E-10  0.0000E+00
IY= 30 Y=  7.25E+01
 1.5731E-06  1.5708E-06  1.5638E-06  1.5523E-06  1.5364E-06  1.5157E-06  1.4880E-06  1.4583E-06  1.4202E-06  1.3753E-06
 1.3240E-06  1.2669E-06  1.2033E-06  1.1383E-06  1.0674E-06  9.9557E-07  9.2031E-07  8.4451E-07  7.6740E-07  6.9018E-07
 6.1334E-07  5.3668E-07  4.6149E-07  3.8664E-07  3.1331E-07  2.4124E-07  1.7135E-07  1.0719E-07  5.6120E-08  1.2584E-08
 1.8522E-09  2.3035E-10  0.0000E+00
IY= 31 Y=  7.50E+01
 1.3582E-07  1.3562E-07  1.3502E-07  1.3404E-07  1.3267E-07  1.3088E-07  1.2849E-07  1.2595E-07  1.2266E-07  1.1881E-07
 1.1441E-07  1.0951E-07  1.0403E-07  9.8440E-08  9.2335E-08  8.6151E-08  7.9659E-08  7.3123E-08  6.6467E-08  5.9797E-08
 5.3157E-08  4.6525E-08  4.0020E-08  3.3536E-08  2.7187E-08  2.0959E-08  1.4984E-08  9.7593E-09  6.0208E-09  1.8545E-09
 4.8221E-10  7.9588E-11  0.0000E+00
IY= 32 Y=  7.75E+01
 1.2757E-08  1.2738E-08  1.2683E-08  1.2591E-08  1.2462E-08  1.2294E-08  1.2067E-08  1.1831E-08  1.1521E-08  1.1161E-08
 1.0750E-08  1.0292E-08  9.7774E-09  9.2559E-09  8.6823E-09  8.1044E-09  7.4947E-09  6.8825E-09  6.2574E-09  5.6313E-09
 5.0075E-09  4.3837E-09  3.7721E-09  3.1616E-09  2.5650E-09  1.9826E-09  1.4281E-09  9.5160E-10  6.1214E-10  2.3079E-10
 7.9653E-11  1.8483E-11  0.0000E+00
IY= 33 Y=  8.00E+01
 0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
 0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
 0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
 0.0000E+00  0.0000E+00  0.0000E+00
```

INTEGRATED TOTAL FLUX

	1	2	3	4	5	6	7	8	9
9	5.0027E-04	4.4146E-04	1.2242E-04	1.0703E-04	9.0756E-05	7.4149E-05	5.7647E-05	7.8625E-05	1.4675E-06
8	6.3548E-02	5.9082E-02	1.6792E-02	1.4836E-02	1.2687E-02	1.0431E-02	8.1448E-03	1.0986E-02	7.7230E-05
7	3.4332E-02	3.5699E-02	1.0919E-02	9.9757E-03	8.7441E-03	7.3355E-03	5.8104E-03	7.9246E-03	5.5081E-05
6	3.7687E-02	3.6157E-02	1.1726E-02	1.1129E-02	1.0207E-02	8.8501E-03	7.1492E-03	9.8914E-03	6.9056E-05
5	4.2581E-02	3.7891E-02	1.1369E-02	1.0851E-02	1.0699E-02	9.8858E-03	8.2546E-03	1.1655E-02	8.1888E-05
4	1.0130E-01	8.6503E-02	2.4078E-02	2.1951E-02	2.0909E-02	2.0791E-02	1.8539E-02	2.7307E-02	1.9464E-04
3	1.8619E-01	1.5411E-01	4.0476E-02	3.5012E-02	3.0596E-02	2.8218E-02	2.7261E-02	4.4209E-02	3.2658E-04
2	1.3802E-01	1.0969E-01	2.5295E-02	1.8807E-02	1.5143E-02	1.4008E-02	1.3633E-02	2.6207E-02	2.0935E-04
1	7.0637E-02	5.4722E-02	1.0293E-02	4.2748E-03	2.9085E-03	4.6093E-03	5.7004E-03	1.2168E-02	1.0077E-04

Appendix C. CROSS, a FORTRAN Program to Create a Group Cross-Section Set for PLXY Code from SIGMN File of KfK-INR

A FORTRAN program CROSS creates a group cross-section file, namely, total and production cross-sections, scattering matrix and fission spectrum with the input format of PLXY code by reading SIGMN file of KfK-INR group constant data file.

1. Definition of Group Cross-Sections

In SIGMN file, the following group cross-sections are prepared.

$\Sigma_{ag} = \Sigma_{cg} + \Sigma_{fg}$;	Absorption cross-section due to capture and fission.
$\nu\Sigma_{fg}$;	Fission cross-section multiplied by the number of secondary neutrons.
$\Sigma_{el}(g'\leftarrow g)$;	Isotropic elastic scattering cross-section from group g to g'.
$\Sigma_{elg} = \sum_{g'} \Sigma_{el}(g'\leftarrow g)$;	Elastic scattering cross-section
$\Sigma_{el}(g'\leftarrow g)(1-\overline{\mu}_g)$;	Elastic scattering cross-section corrected 1st order anisotropic scattering
$\Sigma_{in}(g'\leftarrow g)$;	Inelastic scattering cross-section from group g to g'. Isotropic scattering is assumed.
$\Sigma_{ing} = \sum_{g'} \Sigma_{in}(g'\leftarrow g)$;	Inelastic scattering cross-section.
$\Sigma_{n2n}(g'\leftarrow g)$;	(n,2n) reaction matrix from group g to g'. (Factor 2 is not included.)
$\Sigma_{n2ng} = \sum_{g'} \Sigma_{n2n}(g'\leftarrow g)$;	(n, 2n) cross-section
$\Sigma_{sg} = \Sigma_{elg} + \Sigma_{ing}$;	Scattering cross-section
$\Sigma_{tg} = \Sigma_{ag} + \Sigma_{sg} + \Sigma_{n2ng}$;	Total cross-section

$$\Sigma_{rg} = \Sigma_{ag} + \sum_{g' \neq g} (\Sigma_{el}(g' \leftarrow g) + \Sigma_{in}(g' \leftarrow g) + \Sigma_{n,2n}(g' \leftarrow g)) - \Sigma_{n,2n}(g \leftarrow g) \;;$$

Removal cross-section. The last term corresponds to the generation of an additional neutron at the right hand side of the diffusion equation.

$\Sigma_{trg} = \Sigma_{ag} + \Sigma_{e\ell g}(1-\mu_g) + \Sigma_{ing} + \Sigma_{n,2ng})$; Transport cross-section

$$\frac{1}{\hat{\Sigma}_{trg}} = \frac{\left\langle \frac{\phi(E)}{\Sigma_{tr(E)}} \right\rangle_g}{<\phi(E)>_g} \;;\; D_g = \frac{1}{3\hat{\Sigma}_{trg}} \,,$$

$\hat{\Sigma}_{trg}$; Transport cross-section for the diffusion coefficient

χ_g ; Isotope independent fission spectrum

2. Output Group Cross-Sections

In CROSS code, the following cross-sections are read into array C using subroutines FILLC and FILTRA, and written onto a disk file SCRATCH.CNTL using subroutine FILPUN.

$\Sigma_{trg} = STR(g)$ for total cross-section, when KONTRA = 1 of ISN 8 in subroutine FILTRA

$\Sigma_{trg} = STRTR(g)$ for total cross-section, when KONTRA = 0 in subroutine FILTRA

$\nu\Sigma_{fg} = NUSF(g)$

$\Sigma_s(g' \leftarrow g) = SMTOT(g' \leftarrow g) = \Sigma_{el}(g' \leftarrow g) + \Sigma_{in}(g' \leftarrow g) + 2\Sigma_{n,2n}(g' \leftarrow g)$ for $g' \neq g$

$= \Sigma_{trg} - \Sigma_{rg}$ or $\hat{\Sigma}_{trg} - \Sigma_{rg}$ for $g' = g$

(its depends on the choice of the user in cross section preparation whether the first or the second of the above expressions is used to derive $\Sigma_s(g \leftarrow g)$)

$\chi_g = CHI(1, g)$

In PLXY code, cross-section Σ_ℓ is used in diffusion and removal terms, where $\Sigma_\ell = \Sigma_t - \Sigma_{s\ell}$. For example, $\Sigma_0 = \Sigma_t - \Sigma_{s0} = \Sigma_r$, $\Sigma_1 = \Sigma_t - \Sigma_{sl} = \Sigma_{tr}$, $\Sigma_2 = \Sigma_t - \Sigma_{s2} = \Sigma_t, \ldots$ If we use Σ_{tr} instead of Σ_t and assume that $\Sigma_{s1} = \Sigma_{s2} = \ldots = 0$, the above relations become $\Sigma_0 = \Sigma_r$, $\Sigma_1 = \Sigma_{tr}$, $\Sigma_2 = \Sigma_{tr}, \ldots$ Therefore, this assumption means that $\Sigma_{s1} = \Sigma_{s2} = \Sigma_{s3} = \ldots$, namely, it is assumed that all anisotropic components are equal to the first order component. In PLXY code, the removal cross-section is calculated as $\Sigma_{rg} = \Sigma_{tg} - \Sigma_s\,(g \leftarrow g)$. Therefore, this term gives just the removal cross-section corrected by $\Sigma_{n2n}\,(g \leftarrow g)$, that is consistent with the scattering in term which does not include the term of $g' = g$.

3. Input Data

The program CROSS reads the following data which should be given between the job control statements.

K1: MT, IGM, IHT, IDOWS, NMT

K2: (NMTA(J), J = 1, NMT)

Meaning of notations are as follows:

MT: Number of mixtures existing in SIGM file

IGM: Number of energy groups

IHT: Location of total cross-section in array C. Usually IHT = 6. Number of groups for upscattering IUPS = 0 is assumed in both subroutines, FILPUN of CROSS and RDCROS of PLXYA.

IDOWS: Number of downscattering groups

NMT: Number of mixtures to read from SIGMN file

NMTA(NMT): Mixture indices on SIGMN file which are written out into SCRATCH file. In PLXY code, the mixture index is assigned as 1,2,3, . . . , in the order of the reading the mixture of the SIGMN file.

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