

ANL-7847

ANL-7847

RETURN TO ANL (ICAF) LIBRARY.

# YN2D, A Flux-synthesis Program Based on Discontinuous Trial-function Formulation



U of C-ANL-USAEC

---

ARGONNE NATIONAL LABORATORY, ARGONNE, ILLINOIS

The facilities of Argonne National Laboratory are owned by the United States Government. Under the terms of a contract (W-31-109-Eng-38) between the U. S. Atomic Energy Commission, Argonne Universities Association and The University of Chicago, the University employs the staff and operates the Laboratory in accordance with policies and programs formulated, approved and reviewed by the Association.

#### MEMBERS OF ARGONNE UNIVERSITIES ASSOCIATION

The University of Arizona	Kansas State University	The Ohio State University
Carnegie-Mellon University	The University of Kansas	Ohio University
Case Western Reserve University	Loyola University	The Pennsylvania State University
The University of Chicago	Marquette University	Purdue University
University of Cincinnati	Michigan State University	Saint Louis University
Illinois Institute of Technology	The University of Michigan	Southern Illinois University
University of Illinois	University of Minnesota	The University of Texas at Austin
Indiana University	University of Missouri	Washington University
Iowa State University	Northwestern University	Wayne State University
The University of Iowa	University of Notre Dame	The University of Wisconsin

#### NOTICE

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Atomic Energy Commission, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately-owned rights.

Printed in the United States of America  
Available from  
National Technical Information Service  
U.S. Department of Commerce  
5285 Port Royal Road  
Springfield, Virginia 22151  
Price: Printed Copy \$3.00; Microfiche \$0.95

ARGONNE NATIONAL LABORATORY  
9700 South Cass Avenue  
Argonne, Illinois 60439

SYN2D, A Flux-synthesis Program Based on  
a Discontinuous Trial-function Formulation

Formulated by V. Luco\*

Analysis Done by G. K. Leaf\*\* and J. C. Stork†

Programmed by J. C. Stork

Documented by J. C. Stork, G. K. Leaf, and V. Luco

Applied Physics Division

June 1971

\*Applied Physics Division

\*\*Applied Mathematics Division

†Formerly Applied Mathematics Division. Now with Combustion  
Engineering, Inc., Windsor, Conn.



## TABLE OF CONTENTS

	<u>Page</u>
ABSTRACT . . . . .	9
I. INTRODUCTION . . . . .	9
II. USER'S GUIDE TO SYN2D. . . . .	11
A. Program Abstract . . . . .	11
1. Description of Capabilities . . . . .	11
2. ARC System Standard Paths Using This Module. . . . .	11
3. ARC System Data Sets Used by This Module. . . . .	11
B. Mathematical Formulation and Description of Solution . . . . .	11
1. Introduction . . . . .	11
2. The Variational Principle . . . . .	13
3. The Synthesis Assumptions and the Synthesis Equations . . . . .	21
4. Discrete Approximations and Method of Solution . . . . .	29
5. Output Edits . . . . .	37
6. Implementation of Particular Interface Conditions . . . . .	46
7. Integration Procedures and the Formation of Partial Integrals . . . . .	47
8. Other Geometries and Synthesis-region Configurations. . . . .	53
C. General Program Description. . . . .	61
1. Capabilities . . . . .	61
2. User Options. . . . .	64
3. Data Sets Used . . . . .	65
D. Description of Program Execution. . . . .	66
1. Catalogued Procedure Description . . . . .	66
2. Path Description . . . . .	71
E. Module-dependent Input to SYN2D . . . . .	72
F. Error Messages. . . . .	76
G. Sample Input and Output. . . . .	91
1. Input . . . . .	91
2. Output . . . . .	100
H. J2DTOLIB, A Generator Program for Synthesis Trial- function Libraries . . . . .	126
1. Introduction . . . . .	126
2. Input Data Sets . . . . .	126

## TABLE OF CONTENTS

	<u>Page</u>
3. Output Data Sets . . . . .	127
4. Scratch Data Sets Used. . . . .	127
5. Method of Operation. . . . .	127
6. Input-card Specifications (J2D Deck). . . . .	128
7. Sample Input. . . . .	128
8. Printed Output: Messages and Significance . . . . .	129
9. JCL and Program Listings . . . . .	131
III. PROGRAMMER'S DESCRIPTION OF SYN2D . . . . .	135
A. Description of Program Flow . . . . .	135
1. Overlay Structure . . . . .	135
2. Description of Program Structure and Flow . . . . .	136
B. Common-block Descriptions . . . . .	141
1. BCBLK . . . . .	141
2. BLKSTR . . . . .	143
3. HEADER . . . . .	143
4. NAMBLK . . . . .	144
5. SINGLE . . . . .	144
C. Dynamic Storage Array Allocation . . . . .	149
D. Subroutine Descriptions . . . . .	161
1. Subroutine BCONDS . . . . .	162
2. Subroutine CALC1 . . . . .	163
3. Subroutine CALC2 . . . . .	165
4. Subroutine CHECK . . . . .	167
5. Subroutine CLOSE . . . . .	168
6. Subroutine COFGEN. . . . .	169
7. Subroutine DIMSCT . . . . .	171
8. Subroutine DSRNCK . . . . .	172
9. Subroutine D2DCAL . . . . .	172
10. Subroutine D2DOUT . . . . .	173
11. Subroutine ERRMSG. . . . .	173
12. Subroutine FLOP. . . . .	174
13. Subroutine FLUXPR. . . . .	175
14. Subroutine FPRIME . . . . .	175
15. Subroutine GETBND. . . . .	176
16. Subroutine GETCHI . . . . .	178
17. Subroutine IAREA . . . . .	178
18. Subroutine IFXNRM. . . . .	179
19. Subroutine IFXVOL . . . . .	180

## TABLE OF CONTENTS

	<u>Page</u>
20. Subroutine IGPCAL . . . . .	180
21. Subroutine ILKCEL . . . . .	181
22. Subroutine IRGBAL . . . . .	183
23. Subroutine ITOBAL . . . . .	184
24. Function IVOL . . . . .	184
25. Subroutine LIB . . . . .	185
26. Subroutine MADD . . . . .	187
27. Subroutine MOVE . . . . .	187
28. Subroutine MSUB . . . . .	188
29. Subroutine MTGEN1 . . . . .	188
30. Subroutine MTGEN2 . . . . .	190
31. Subroutine NORM . . . . .	192
32. Subroutine NUMMLT . . . . .	193
33. Subroutine PAGHED . . . . .	193
34. Subroutine PCKSCT . . . . .	193
35. Subroutine PCOMP . . . . .	196
36. Subroutine PGEOM . . . . .	197
37. Subroutine PROCES . . . . .	197
38. Subroutine PRTBC . . . . .	199
39. Subroutine RBNDCC . . . . .	199
40. Subroutine RCDEP . . . . .	201
41. Subroutine RCOMP . . . . .	201
42. Subroutine RDELAY . . . . .	202
43. Subroutine RGEOM . . . . .	202
44. Subroutine RGROUP . . . . .	203
45. Subroutine RIEMAN . . . . .	206
46. Subroutine RKIN . . . . .	209
47. Subroutine RMESH . . . . .	210
48. Subroutine RRCALC . . . . .	211
49. Subroutine RSDEF . . . . .	212
50. Subroutine RVEL . . . . .	213
51. Subroutine RXSC01 . . . . .	214
52. Subroutine SINCAL . . . . .	214
53. Subroutine SINOUT . . . . .	217
54. Subroutine STORBC . . . . .	218
55. Subroutine SWEEP1 . . . . .	219
56. Subroutine SWEEP2 . . . . .	219
57. Program SYN2D . . . . .	220
58. Subroutine SYNCAL . . . . .	220
59. Subroutine SYNDEF . . . . .	221
60. Subroutine SYNGEN . . . . .	222
61. Subroutine SYNIN . . . . .	222
62. Subroutine SYNOUT . . . . .	223

## TABLE OF CONTENTS

	<u>Page</u>
63. Subroutine TWODPR . . . . .	223
64. Subroutine VALUES . . . . .	226
E. Data-set Usage . . . . .	227
1. Data Set A.SYN2D . . . . .	227
2. Data Set BC . . . . .	228
3. Data Set FA.TRIAL . . . . .	228
4. Data Set FR.D2 . . . . .	229
5. Data Set FR.PN . . . . .	229
6. Data Set FR.TG . . . . .	229
7. Data Set FR.TRIAL . . . . .	230
8. Data Set GEOM . . . . .	231
9. Data Set LIB.ADJT . . . . .	231
10. Data Set LIB.MIX . . . . .	233
11. Data Set LIB.PART . . . . .	233
12. Data Set LIB.REAL . . . . .	236
13. Data Set SCR001 . . . . .	237
14. Data Set SCR002 . . . . .	240
15. Data Set SCR003 . . . . .	241
16. Data Set SCR004 . . . . .	242
17. Data Set XS.C.MIN . . . . .	243
18. Data Set XS.ISO2 or XS.ISO . . . . .	243
19. Unnamed Scratch Data Sets . . . . .	243
ACKNOWLEDGMENTS . . . . .	244
REFERENCES . . . . .	245

LIST OF FIGURES

<u>No.</u>	<u>Title</u>	<u>Page</u>
1.	Schematic Representation of the Reactor . . . . .	14
2.	Typical Synthesis Region. . . . .	62
3.	Typical Two-dimensional xy Reactor Configuration. . . . .	127
4.	Diagrammatic Subroutine Calling Map. . . . .	142
5.	Bandwidth Structure . . . . .	195

LIST OF TABLES

TABLE NO.	TITLE	PAGE
1	General description of the material	1
2	Chemical composition of the material	2
3	Physical properties of the material	3
4	Mechanical properties of the material	4
5	Thermal properties of the material	5
6	Electrical properties of the material	6
7	Magnetic properties of the material	7
8	Optical properties of the material	8
9	Acoustic properties of the material	9
10	Biological properties of the material	10
11	Toxicological properties of the material	11
12	Environmental properties of the material	12
13	Summary of properties	13
14	References	14
15	Index	15

SYN2D, A Flux-synthesis Program Based on  
a Discontinuous Trial-function Formulation

ABSTRACT

This report presents the documentation of the SYN2D computer program. It consists of two sections. The first is intended for use by users of the program SYN2D; the second is provided for use by programmers and other individuals who wish to alter the program.

The SYN2D program performs two-dimensional criticality calculations using a single-channel discontinuous-trial-function flux-synthesis technique. It can handle rectangular or cylindrical coordinates, and it allows for zero flux, zero current, or logarithmic boundary conditions. The trial functions may or may not satisfy the boundary conditions.

The SYN2D program is structured as a module in the Argonne Reactor Computation (ARC) System and depends on the output of other ARC System computational modules for its input.

I. INTRODUCTION

The body of this report comprises two sections: Section II is intended for users of the program SYN2D; Section III is provided for programmers or other individuals who wish to alter the program.

The SYN2D program is structured as a module in the Argonne Reactor Computation (ARC) System, and depends on the output of other ARC System computational modules for its input. The ARC System has been executed on IBM system/360 computers, models 50, 75, 85, and 195, under the OS/360 operating system.

The ARC System consists of a library of computational modules for fast-reactor design calculations, along with a set of system modules and subroutines which provide an environment for the operation of the computational modules. The modules are used in a selected order by directive programs called "paths." Intermodule communication is through ARC system data sets. The data sets are defined such that output from one computational module can be used as input to others. This allows for the automation into a single run of what would normally be a sequence of runs.

ANL-7711<sup>1</sup> is the first volume of a series describing the ARC System. It describes the ARC System history and philosophy, the software environment in which the ARC System operates, the system modules and subroutines which make up the software environment, and the ARC System data sets. It also contains instructions on how to write, use, and maintain paths. The other ARC System computational modules used by the path for SYN2D are described in ANL-7713<sup>2</sup> and ANL-7714.<sup>3</sup>

## II. USER'S GUIDE TO SYN2D

### A. Program Abstract

#### 1. Description of Capabilities

This module uses a flux-synthesis technique to calculate an approximation to the two-dimensional multigroup diffusion equation.

The only capability presently available is a real homogenous k-effective calculation.

#### 2. ARC System Standard Paths Using This Module

STP008--Two-dimensional Synthesis Standard Path

ARC System Modules used by STP008

INHOMG (NUI001) Cross-section Homogenization  
Specifications

GNIP (NUI002) Neutronics Input Processor

HOMOG (NUC001) Cross-section Homogenization

SYN2D (AJC005) Two-dimensional Flux Synthesis

Catalogued Procedure Using This Standard Path

ARCSP008--Invokes the standard path STP008

#### 3. ARC System Data Sets Used by This Module

Upper interface--A.SYN2D, BC, FR.TG, FR.TRIAL, FA.TRIAL,  
GEOM, LIB.ADJT, LIB.MIX, LIB.PART,  
LIB.REAL, and XS.C.MIN

Lower interface--FR.D2, FR.PN, FR.TG, LIB.ADJT, LIB.MIX,  
LIB.PART, and LIB.REAL

### B. Mathematical Formulation and Description of Solution

#### 1. Introduction

The continuously increasing demand for more accurate descriptions of the neutron-flux distribution in complex reactor systems has been the driving force behind the development of approximate flux-synthesis techniques to calculate those neutron-flux distributions. Using these

techniques, one obtains a reasonably accurate picture of the neutron-flux distribution at a substantially lower cost than a comparable "exact" calculation using straight finite-difference approximations to the equations of the problem.

The idea of flux synthesis in reactor physics consists of assuming that the multidimensional neutron fluxes in the reactor, let us say  $\varphi(X_1, X_2, \dots, X_M)$ , can be represented with reasonable accuracy by a linear combination of a finite (and usually small) number of known functions  $\psi_i(X_1, \dots, X_S)$  of lower dimensionality ( $S \leq M$ ):

$$\varphi(X_1, X_2, \dots, X_M) \approx \sum_{i=1}^M \psi_i(X_1, \dots, X_S) C_i(X_{S+1}, \dots, X_M).$$

The functions of  $\psi_i(X_1, \dots, X_S)$  are known as the trial functions for the problem. The unknown coefficients  $C_i(X_{S+1}, \dots, X_M)$  of the linear combination are usually called the mixing functions.

The independent variables of the problem can be quite diverse: for example, the spatial coordinates  $x, y, z$ , or  $r, \theta, z$ , the time  $t$ , the neutron energy  $E$ , and the angle  $\Omega$  of the neutron motion. The breakdown into variables entering as arguments of the trial functions or of the mixing functions can also be made in various ways, selected according to the characteristics of the problem at hand. For example, in a three-dimensional, time-dependent, monoenergetic problem the synthesis assumption could be

$$\varphi(x, y, z, t) \approx \sum_{i=1}^M \psi_i(x, y, z) C_i(t)$$

or

$$\varphi(x, y, z, t) \approx \sum_{i=1}^M \psi_i(x, y) C_i(z, t).$$

In the first case, the mixing functions are time functions; in the second case, the problem of determining the mixing functions is two-dimensional. Another example: The two-dimensional flux  $\varphi(r, z)$  can be synthesized as follows:

$$\left. \begin{aligned} \varphi(r, z) &\approx \sum_{i=1}^M \psi_i(r) C_i(z) \\ \text{or} \\ \varphi(r, z) &\approx \sum_{i=1}^M \psi_i(z) C_i(r), \end{aligned} \right\} \quad (1)$$

and the choice between these two options will depend on which one of the expressions is more convenient in the reactor configuration being considered.

The object of a flux-synthesis calculational method is to specify some way of obtaining the mixing functions. Since the synthesis expansions are essentially approximations, the coefficient functions are determined not with the idea of actually obtaining the exact solution, but aiming at an optimum choice as judged with some arbitrarily chosen criterion. The degree of approximation to the real fluxes of these synthesis solutions depends largely on how good a choice of trial functions  $\psi_i$  has been made. There are a number of flux-synthesis methods, depending on both the type of trial functions used and the techniques prescribed to determine the mixing functions.

The most successful and commonly used synthesis techniques are the variational and weighted residual methods.

The earliest developments of these techniques were done using continuous sets of trial functions. This means that the same set of trial functions  $\psi_i(X_1, \dots, X_G)$  are used throughout the whole range of the variables  $X_1, \dots, X_M$ . In some cases, though, some of the trial functions  $\psi_i(X_1, \dots, X_G)$  used are important only over certain ranges of the variables and could be ignored at other locations in the reactor.

A synthesis method that allows one to do precisely this, that is, to expand the flux in different sets of trial functions at different locations in the reactor, is known as a discontinuous trial-function synthesis. Each set of trial functions is used to expand the flux in a partial volume of the reactor. These partial nonoverlapping volumes will be called synthesis regions. The surface between two synthesis regions will be called a synthesis interface. This report develops a variational method using as a basis the functional proposed by Buslik.<sup>4</sup> An alternative treatment of the discontinuities is introduced by a weighted-residuals method.<sup>5</sup>

The problem that will be used to illustrate the method proposed is the approximate solution of the static multigroup neutron diffusion equations in two-dimensional  $(r, z)$  cylindrical coordinates. The synthesis breakdown for the flux will be made as in Eq. 1. The method proposed can be easily adapted to other geometries and number of coordinates as well as to other synthesis expansions.

## 2. The Variational Principle

The equations for the multigroup problem to be considered are

$$\nabla \cdot (D_g \nabla \phi_g) - \Sigma_{rg} \phi_g + \sum_{g'=1}^{g-1} \Sigma_{g'g} \phi_{g'} + \lambda \chi_g \sum_{g'=1}^G (\nu \Sigma_f)_{g'} \phi_{g'} = 0, \quad g = 1, \dots, G, \quad (2)$$

where  $G$  is the number of energy groups, and the adjoint set

$$\nabla \cdot (D_g \nabla \phi_g^*) - \Sigma_{rg} \phi_g^* + \sum_{g'=g+1}^G \Sigma_{gg'} \phi_{g'}^* + \lambda (\nu \Sigma_f)_g \sum_{g'=1}^G \chi_{g'} \phi_{g'}^* = 0, \quad g = 1, \dots, G, \quad (3)$$

where  $k$ -effective is defined in the conventional manner, i.e.,  $k = 1/\lambda$ , with conditions

$$\text{and } \left. \begin{aligned} C_2 \phi_g &= -C_1 D_g \frac{\partial \phi_g}{\partial n} \\ B_2 \phi_g^* &= -B_1 D_g \frac{\partial \phi_g^*}{\partial n} \end{aligned} \right\} g = 1, \dots, G \quad (4)$$

at the outside reactor boundary  $S_0$ .  $C_j$  and  $B_j$  can vary on each outside reactor surface, with the usual meaning for the constant  $D$ ;  $\partial/\partial n$  indicates derivative with respect to the positive (meaning *outgoing*) normal vector at the outside reactor surfaces.

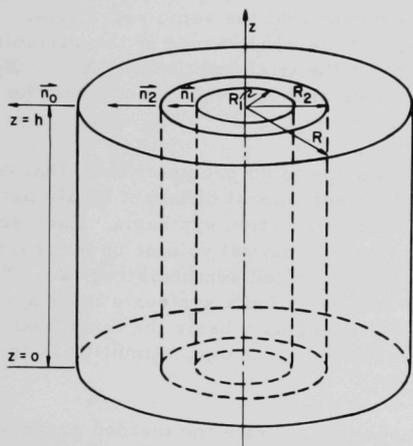


Fig. 1. Schematic Representation of the Reactor

The reactor geometry is represented in Fig. 1. The regions shown, limited by the radii  $R_1$ ,  $R_2$ , ...,  $R_i$ , ..., are synthesis regions where different sets of trial functions will be assumed. For a practical calculation, there may be quite a few of these regions. The trial functions used will be functions of the  $z$  coordinate, one set in each region, for both flux and adjoint. The cylindrical surfaces of radii  $R_i$  are the surfaces at which the trial function discontinuities occur;  $\theta$  symmetry is assumed throughout.

The variational functional to be used is

$$J \left[ u_g^k(r, z), u_g^{k*}(r, z), \alpha_g^k(z), \beta_g^k(z) \right] \equiv \sum_{k=1}^K \left\langle 2\pi \int_{V_k} \sum_{g=1}^G \left\{ \nabla u_g^{k*} \cdot D_g \nabla u_g^k + u_g^{k*} \left[ \Sigma_{rg} u_g^k - \sum_{g'=1}^{G-1} \Sigma_{g'g} u_{g'}^k - \lambda \chi_g \sum_{g'=1}^G (\nu \Sigma_f)_g u_{g'}^k \right] \right\} r \, dr \, dz \right\rangle \quad (5)$$

(Contd.)

$$\begin{aligned}
& - \sum_{k=1}^{K-1} \left\langle 2\pi R_k \int_0^h \sum_{g=1}^G \left\{ \alpha_g^k \left[ u_g^{(k+1)}(R_k, z) - u_g^k(R_k, z) \right] \right. \right. \\
& + \left. \left. \left[ u_g^{(k+1)*}(R_k, z) - u_g^{k*}(R_k, z) \right] \beta_g^k \right\} dz \right\rangle \\
& + \sum_{g=1}^G \left[ \sum_{k=1}^K \left\langle 2\pi \int_{R_{(k-1)}}^{R_k} \left\{ \alpha_{gk}^T u_g^{k*}(r, h) u_g^k(r, h) + (\alpha - 1) \left[ u_g^{k*}(r, h) D_g \frac{\partial u_g^k}{\partial z} \right]_{z=h} \right. \right. \right. \\
& + \left. \left. u_g^k(r, h) D_g \frac{\partial u_g^{k*}}{\partial z} \right]_{z=h} \right\} r dr + \eta 2\pi \int_{R_{(k-1)}}^{R_k} \left\{ \beta_{gk}^B u_g^{k*}(r, 0) u_g^k(r, 0) \right. \\
& + \left. (1 - \beta) \left[ u_g^{k*}(r, 0) D_g \frac{\partial u_g^k}{\partial z} \right]_{z=0} + u_g^k(r, 0) D_g \frac{\partial u_g^{k*}}{\partial z} \right]_{z=0} \right\} r dr \right\rangle \\
& + 2\pi R \theta \int_0^h \left\{ \gamma C_{gK}^R u_g^{K*}(R, z) u_g^K(R, z) + (\gamma - 1) \left[ u_g^{K*}(R, z) D_g \frac{\partial u_g^K}{\partial r} \right]_{r=R} \right. \\
& + \left. u_g^K(R, z) D_g \frac{\partial u_g^{K*}}{\partial r} \right]_{r=R} \Bigg\} dz + 2\pi \int_0^h \left. \frac{\partial u_{1*}}{\partial r} \right]_{r=0} \cdot \left. \frac{\partial u_{1g}}{\partial r} \right]_{r=0} dz \Bigg], \quad (\text{Contd.}) \quad (5)
\end{aligned}$$

where

$V_k$  is the volume between  $R_{k-1} \leq r \leq R_k$ ,  $0 \leq z \leq h$ ,

and

$u_g^{k*}(r, z)$  and  $u_g^k(r, z)$  are independent-variable functions defined in the  $k$ th synthesis region.

These will be identified later with  $\phi_g^{k*}(r, z)$  and  $\phi_g^k(r, z)$  when at their stationary values.  $\alpha_g^k(z)$ ,  $\beta_g^k(z)$  are functions of  $z$  only, defined at the cylindrical surfaces with radius  $R_k$ . There are  $K$  synthesis regions:

$$R_0 = 0$$

and

$$R_K \equiv R, \text{ the outside reactor radius,}$$

where  $\zeta$ ,  $\alpha$ ,  $\eta$ ,  $\beta$ ,  $\theta$ , and  $\gamma$  can take on the values 0 or 1. The choice of these six numbers gives the boundary conditions at the outside of the reactor. Note that  $\zeta$  and  $\alpha$ ,  $\beta$  and  $\eta$ , and  $\theta$  and  $\gamma$  can never be pairwise zero, but can change value with group or synthesis region. The numbers  $C_{gK}^B$ ,  $C_{gK}^T$ , and  $C_{gK}^R$  are nonzero if  $\eta$ ,  $\zeta$ , or  $\theta$  are nonzero, respectively.

The  $k$ -dependence of the parameters in the functional has not been emphasized, since the  $k$  boundaries may not be boundaries between different material compositions.

Which among the family of functions  $u_g^k(r, z)$ ,  $u_g^{k*}(r, z)$ ,  $\alpha_g^k(z)$ , and  $\beta_g^k(z)$  will make the functional  $J$  stationary? To find out the conditions to be satisfied by the  $u_g^k(r, z)$  and  $\beta_g^k$ , we transform the first term in the volume integrals in Eq. 5 in the following way, using Green's theorem:

$$\begin{aligned}
 \sum_{k=1}^K \sum_{g=1}^G 2\pi \int_{V_k} \nabla u_g^{k*} \cdot D_g \nabla u_g^k r \, dr \, dz &= - \sum_{k=1}^K \sum_{g=1}^G 2\pi \int_{V_k} u_g^{k*} \nabla \cdot (D_g \nabla u_g^k) r \, dr \, dz \\
 &+ \sum_{k=1}^{K-1} \sum_{g=1}^G \left\{ 2\pi R_k \int_0^h \left[ u_g^{k*}(R_k, z) D_g \frac{\partial u_g^k}{\partial r} \Big|_{r=R_k} \right. \right. \\
 &\left. \left. - u_g^{(k+1)*}(R_k, z) D_g \frac{\partial u_g^{(k+1)}}{\partial r} \Big|_{r=R_k} \right] dz \right\} \\
 &+ \sum_{k=1}^K \sum_{g=1}^G \left\{ 2\pi \int_{R_{(k-1)}}^{R_k} \left[ u_g^{k*}(r, h) D_g \frac{\partial u_g^k}{\partial z} \Big|_{z=h} - u_g^{k*}(r, 0) D_g \frac{\partial u_g^k}{\partial z} \Big|_{z=0} \right] r \, dr \right\} \\
 &+ 2\pi R \sum_{g=1}^G \int_0^h \left[ u_g^{K*}(R, z) D_g \frac{\partial u_g^K}{\partial r} \Big|_{r=R} \right] dz. \tag{6}
 \end{aligned}$$

Introducing this result into Eq. 5, we obtain

$$\begin{aligned}
 J \equiv \sum_{k=1}^K 2\pi \sum_{g=1}^G V_k \left\{ u_g^{k*} \left[ -\nabla \cdot (D_g \nabla u_g^k) + \Sigma_{rg} u_g^k - \sum_{g'=1}^{g-1} \Sigma_{g'g} u_{g'}^k \right. \right. \\
 \left. \left. - \lambda \chi_g \sum_{g'=1}^G (v \Sigma_f)_{g'} u_{g'}^k \right] r \, dr \, dz \right\} \tag{7}
 \end{aligned}$$

(Contd.)

$$\begin{aligned}
& + \sum_{k=1}^{K-1} \sum_{g=1}^G 2\pi R_k \int_0^h \left\{ \alpha_g^k \left[ u_g^{(k+1)}(R_k, z) - u_g^k(R_k, z) \right] \right. \\
& - u_g^{(k+1)*}(R_k, z) \left[ \beta_g^k(z) + D_g \frac{\partial u_g^{(k+1)}}{\partial r} \Big|_{r=R_k} \right] + u_g^{k*}(R_k, z) \left[ D_g \frac{\partial u_g^k}{\partial r} \Big|_{r=R_k} + \beta_g^k(z) \right] \Big\} dz \\
& + \sum_{k=1}^K \sum_{g=1}^G 2\pi \int_{R_{(k-1)}}^{R_k} \left\{ u_g^{k*}(r, h) \left[ \zeta \alpha C_{gk}^T u_g^k(r, h) + (\zeta(\alpha - 1) + 1) D_g \frac{\partial u_g^k}{\partial z} \Big|_{z=h} \right] \right. \\
& + \frac{\partial u_g^{k*}}{\partial z} \Big|_{z=h} \zeta(\alpha - 1) \left[ D_g u_g^k(r, h) \right] \\
& + u_g^{k*}(r, 0) \left[ \beta \eta C_{gk}^B u_g^k(r, 0) + (\eta(1 - \beta) - 1) D_g \frac{\partial u_g^k}{\partial z} \Big|_{z=0} \right] \\
& \left. + \frac{\partial u_g^{k*}}{\partial z} \Big|_{z=0} \eta(1 - \beta) \left[ D_g u_g^k(r, h) \right] \right\} r dr \\
& + \sum_{g=1}^G 2\pi \int_0^h \left\{ u_g^{k*}(R, z) R \left[ \theta \gamma C_{gK}^R u_g^k(R, z) + (\theta(\gamma - 1) + 1) D_g \frac{\partial u_g^k}{\partial r} \Big|_{r=R} \right] \right. \\
& \left. + \frac{\partial u_g^{k*}}{\partial r} \Big|_{r=R} R \theta(\gamma - 1) u_g^k(R, z) + \frac{\partial u_g^{1*}}{\partial r} \Big|_{r=0} \cdot \frac{\partial u_g^1}{\partial r} \Big|_{r=0} \right\} dz. \quad (\text{Contd.}) \quad (7)
\end{aligned}$$

Varying  $u_g^{k*}(r, z)$  and  $\alpha_g^k(z)$  arbitrarily in Eq. 7, the following necessary conditions for stationariness are obtained. Writing  $\varphi_g^k$  and  $j_g^k$  for the stationary values of  $u_g^k$  and  $\beta_g^k$ ,

$$-\nabla \cdot (D_g \nabla \varphi_g^k) + \Sigma_{rg} \varphi_g^k - \sum_{g'=1}^{g-1} \Sigma_{g'g} \varphi_{g'}^k - \lambda \chi_g \sum_{g'=1}^G (\nu \Sigma_f)_{g'} \varphi_{g'}^k = 0, \quad k = 1, \dots, K; \quad (8)$$

$$\left. \begin{aligned} \varphi_g^{(k+1)}(R_k, z) &= \varphi_g^k(R_k, z) \\ j_g^k(z) &= -D_g \frac{\partial \varphi_g^k}{\partial r} \Big|_{r=R_k} = -D_g \frac{\partial \varphi_g^{(k+1)}}{\partial r} \Big|_{r=R_k} \end{aligned} \right\}, \quad k = 1, \dots, K-1; \quad (9)$$

$$\left. \begin{aligned} \zeta C_{gk}^T \varphi_g^k(r, h) &= -\alpha D_g \frac{\partial \varphi_g^k}{\partial z} \Big|_{z=h} \\ \beta C_{gk}^B \varphi_g^k(r, 0) &= +\eta D_g \frac{\partial \varphi_g^k}{\partial z} \Big|_{z=0} \end{aligned} \right\}, \quad k = 1, \dots, K; \quad (11)$$

$$\theta C_{gK}^R \varphi_g^K(R, z) = -\gamma D_g \frac{\partial \varphi_g^K}{\partial r} \Big|_{r=R}; \quad (12)$$

$$\theta C_{gK}^R \varphi_g^K(R, z) = -\gamma D_g \frac{\partial \varphi_g^K}{\partial r} \Big|_{r=R}; \quad (13)$$

and

$$\frac{\partial \varphi_g^1}{\partial r} \Big|_{r=0} = 0, \quad (14)$$

with  $g = 1, \dots, G$  in all these equations. The functions  $\varphi_g^k$  and  $j_g^k$  thus determined provide the solution to the variational problem posed and at the same time clearly are the functions that give the solution to the neutron-diffusion problem formulated in Eqs. 2 and 4.

Even though the functional  $J$  admits discontinuous functions  $u_g^k$ , with finite jumps at the surfaces with radius  $R_k$ , the stationary "point" occurs for functions that are continuous across those boundaries. The Lagrange-multiplier functions  $\beta_{gk}^k(z)$  turn out to be (see Eq. 10) the values of the normal neutron currents at the boundaries between synthesis regions. Conditions 11, 12, and 13 are the usual conditions of zero incoming current at the reactor boundaries. Condition 14 is a natural condition to require when the flux is symmetric in  $\theta$ . Equations 11-13 give  $\varphi' = 0$ ,  $\varphi = 0$ ,  $D\varphi' + C\varphi = 0$  at the outside as desired.

†The actual boundary condition yielded is

$$\zeta \alpha C_{gk}^T \varphi_g^k + (\zeta(\alpha - 1) + 1) D_g \frac{\partial \varphi_g^k}{\partial z} \Big|_{z=h} = 0$$

instead of Eq. 11. This is, however, equivalent to Eq. 11 for all admissible values of  $\zeta$  and  $\alpha$ . The same comment applies to Eqs. 12 and 13.

To find out the necessary conditions for  $u_g^{k*}(r, z)$  and  $\alpha_g^k(z)$ , the sums in energy in the first summation of Eq. 5 are rearranged in order to take  $u_g^k$  as a common factor of the  $g'$  sums; the following transformation, the symmetric of Eq. 6, is then introduced:

$$\begin{aligned} \sum_{k=1}^K \sum_{g=1}^{G_k} \int_{V_k} \nabla u_g^{k*} \cdot D_g \nabla u_g^k r \, dr \, dz &= - \sum_{k=1}^K \sum_{g=1}^G \int_{V_k} u_g^k \nabla \cdot (D_g \nabla u_g^{k*}) r \, dr \, dz \\ &+ \sum_{k=1}^{K-1} \sum_{g=1}^G \left\{ 2\pi R_k \int_0^h \left[ u_g^k(R_k, z) D_g \frac{\partial u_g^{k*}}{\partial r} \Big|_{r=R_k} \right. \right. \\ &\left. \left. - u_g^{(k+1)}(R_k, z) D_g \frac{\partial u_g^{(k+1)*}}{\partial r} \Big|_{r=R_k} \right] dz \right\} \\ &+ \sum_{k=1}^K \sum_{g=1}^G \left\{ 2\pi \int_{R_{(k-1)}}^{R_k} \left[ u_g^k(r, h) D_g \frac{\partial u_g^{k*}}{\partial z} \Big|_{z=h} - u_g^k(r, 0) D_g \frac{\partial u_g^{k*}}{\partial z} \Big|_{z=0} \right] r \, dr \right\} \\ &+ 2\pi R \int_0^h \left[ u_g^k(R, z) D_g \frac{\partial u_g^{k*}}{\partial r} \Big|_{r=R} \right] dz. \end{aligned}$$

The new form of the functional J is

$$\begin{aligned} J \equiv \sum_{k=1}^K \sum_{g=1}^G 2\pi \int_{V_k} \left\{ u_g^k \left[ -\nabla \cdot (D_g \nabla u_g^{k*}) + \Sigma_{rg} u_g^{k*} - \sum_{g'=g+1}^G \Sigma_{gg'} u_{g'}^{k*} \right. \right. \\ \left. \left. - \lambda (\nu \Sigma_f)_g \sum_{g'=1}^G \chi_{g'} u_{g'}^{k*} \right] r \, dr \, dz \right\} + \sum_{k=1}^{K-1} \sum_{g=1}^G 2\pi R_k \int_0^h \left\{ \left[ u_g^{(k+1)*}(R_k, z) \right. \right. \\ \left. \left. - u_g^{k*}(R_k, z) \right] \beta_g^k - u_g^{(k+1)}(R_k, z) \left[ \alpha_g^k(z) + D_g \frac{\partial u_g^{(k+1)*}}{\partial r} \Big|_{r=R_k} \right] \right. \\ \left. + u_g^k(R_k, z) \left[ \alpha_g^k(z) + D_g \frac{\partial u_g^{k*}}{\partial r} \Big|_{r=R_k} \right] \right\} dz \end{aligned} \tag{15}$$

(Contd.)

$$\begin{aligned}
& + \sum_{k=1}^K \sum_{g=1}^G 2\pi \int_{R(k-1)}^{R_k} \left( u_g^k(r, h) \left\{ \zeta \alpha C_{gk}^T u_g^{k*}(r, h) + [\zeta(\alpha - 1) + 1] D_g \frac{\partial u_g^{k*}}{\partial z} \Big|_{z=h} \right\} \right. \\
& + \left. \frac{\partial u_g^k}{\partial z} \Big|_{z=h} \cdot \zeta(\alpha - 1) D_g u_g^{k*}(r, h) + u_g^k(r, 0) \left\{ \beta \eta C_{gk}^B u_g^{k*}(r, 0) \right. \right. \\
& + \left. \left. [\eta(1 - \beta) - 1] D_g \frac{\partial u_g^k}{\partial z} \Big|_{z=0} \right\} + \frac{\partial u_g^k}{\partial z} \Big|_{z=0} \cdot \eta(1 - \beta) D_g u_g^{k*}(r, h) \right) r \, dr \\
& + \sum_{g=1}^G 2\pi \int_0^h \left( u_g^K(R, z) R \left\{ \theta \gamma C_{gk}^R u_g^{K*}(R, z) + [\theta(\gamma - 1) + 1] D_g \frac{\partial u_g^{K*}}{\partial r} \Big|_{r=R} \right\} \right. \\
& + \left. \frac{\partial u_g^K}{\partial r} \Big|_{r=R} R \cdot \theta(\gamma - 1) u_g^{K*}(R, z) + \frac{\partial u_g^{1*}}{\partial r} \Big|_{r=0} \cdot \frac{\partial u_g^1}{\partial r} \Big|_{r=0} \right) dz. \quad (\text{Contd.}) \quad (15)
\end{aligned}$$

If  $u_g^k(r, z)$  and  $\beta_g^k(z)$  in Eq. 15 are arbitrarily varied, the following necessary conditions for stationariness follow:

$$-\nabla \cdot (D_g \nabla \varphi_g^{k*}) + \Sigma_{rg} \varphi_g^{k*} - \sum_{g'=g+1}^G \Sigma_{gg'} \varphi_{g'}^{k*} - \lambda (\nu \Sigma_f)_g \sum_{g'=1}^G \chi_{g'} \varphi_{g'}^{k*} = 0,$$

$$k = 1, \dots, K; \quad (16)$$

$$\varphi_g^{(k+1)*}(R_k, z) = \varphi_g^{k*}(R_k, z) \quad (17)$$

$$j_g^{k*}(z) = -D_g \frac{\partial \varphi_g^{(k+1)*}}{\partial r} \Big|_{r=R_k} = -D_g \frac{\partial \varphi_g^{k*}}{\partial r} \Big|_{r=R_k} \quad (18)$$

$$\zeta C_{gk} \varphi_g^{k*}(r, h) = -\alpha D_g \frac{\partial \varphi_g^{k*}}{\partial z} \Big|_{z=h}; \quad (19)$$

$$\eta C_{gk}^B \varphi_g^{k*}(r, 0) = +\beta D_g \frac{\partial \varphi_g^{k*}}{\partial z} \Big|_{z=0}; \quad (20)$$

$$\theta C_{gk}^R \varphi_g^{K*}(R, z) = -\gamma D_g \left. \frac{\partial \varphi_g^{K*}}{\partial r} \right|_{r=R}; \quad (21)$$

and

$$\left. \frac{\partial \varphi_g^{1*}}{\partial r} \right|_{r=0} = 0, \quad (22)$$

with  $g = 1, \dots, G$  in all these equations.

These sets of equations and conditions satisfy both the variational condition required and the adjoint diffusion Eqs. 3 and 4.

### 3. The Synthesis Assumptions and the Synthesis Equations

The following synthesis assumptions are now introduced:

$$\left. \begin{aligned} u_g^k(r, z) &= \sum_{n=1}^{N_g^k} H_{gn}^k(z) T_{gn}^k(r) \\ u_g^{k*}(r, z) &= \sum_{n=1}^{N_g^k} H_{gn}^{k*}(z) T_{gn}^{k*}(r) \end{aligned} \right\}, \quad \begin{aligned} k &= 1, \dots, K; \\ g &= 1, \dots, G. \end{aligned} \quad (23)$$

$$\left. \begin{aligned} u_g^k(r, z) &= \sum_{n=1}^{N_g^k} H_{gn}^k(z) T_{gn}^k(r) \\ u_g^{k*}(r, z) &= \sum_{n=1}^{N_g^k} H_{gn}^{k*}(z) T_{gn}^{k*}(r) \end{aligned} \right\} \quad (24)$$

Here  $H_{gn}^k(z)$  and  $H_{gn}^{k*}(z)$ , usually referred to as the trial functions, are known functions. The functions  $T_{gn}^k(r)$  and  $T_{gn}^{k*}(r)$  are unknown functions to be determined. The numbers  $N_{gn}^k$  of trial functions at each group and region do not have intrinsic limitations except the obvious one,  $N_{gn}^k \geq 1$ . The functions  $\beta_g^k(z)$  and  $\alpha_g^k(z)$  are also expanded:

$$\left. \beta_g^k(z) = \sum_{n=1}^{M_g^k} B_{gn}^k(z) b_{gn}^k \right\}, \quad \begin{aligned} k &= 1, \dots, K-1, \\ g &= 1, \dots, G. \end{aligned} \quad (25)$$

$$\left. \alpha_g^k(z) = \sum_{n=1}^{M_g^k} A_{gn}^k(z) a_{gn}^k \right\} \quad (26)$$

Here the mixing coefficients  $a_{gn}^k$  and  $b_{gn}^k$  are pure numbers. The numbers  $M_{gn}^k$  of trial functions for the normal currents at the interfaces have upper and lower bounds, as will be shown later (see Eq. 47).

The selection of trial functions  $H_{gn}^k(z)$ ,  $H_{gn}^{k*}(z)$  and  $B_{gn}^k(z)$ ,  $A_{gn}^k(z)$  has to be guided by whatever knowledge or intuition the user of the method has about the system to be calculated. The variational method, or any other similar method, can only combine these preselected flux shapes in some optimum way, but it will never achieve a good approximation to the actual fluxes of the system with a poor selection of trial functions.

From the variational point of view, assumptions 23-26 mean that the freedom of choice of independent-variable functions for functional 5 is now restricted to functions of the form given in those expansions. The problem is now restricted to finding functions with the forms of Eqs. 23-26 that will make stationary the value of the functional 5.

A variational problem like the one posed in connection with the functional in 5 is defined both by the functional used and by the set of admissible functions used with it. We are thus now treating a different variational problem from the initial one, because the set of admissible functions is severely restricted by the synthesis assumption.

The functional  $J'$  obtained by substituting the synthesis assumptions (Eqs. 23-26) into Eq. 5 is called the "reduced" functional. Its independent variable functions are now  $T_{gn}^k(r)$ ,  $T_{gn}^{k*}(r)$ ,  $a_{gn}^k$ , and  $b_{gn}^k$ . The corresponding necessary conditions for a stationary value, its Euler equations, are also of a lower dimensionality.

The functional  $J'$  is

$$\begin{aligned}
 J' [T_{gn}^k(r), T_{gn}^{k*}(r), b_{gn}^k, a_{gn}^k] &\equiv \sum_{g=1}^G \left\langle \sum_{k=1}^K \int_{R_{(k-1)}}^{R_k} 2\pi r dr \left( \frac{d\bar{T}_g^{k*}}{dr} [D_g^k] \frac{d\bar{T}_g^k}{dr} \right. \right. \\
 &+ \bar{T}_g^{k*} \left\{ [L_g^k] + [\Sigma_g^k] + [C_g^k] \right\} \bar{T}_g^k - \sum_{g'=1}^{g-1} \bar{T}_g^{k*} [\Sigma_{g',g}^k] \bar{T}_g^k, \\
 &+ \lambda \sum_{g'=1}^G \bar{T}_g^{k*} \left\{ [\chi_{g'}(\nu \Sigma_{f,g'})^k] \bar{T}_g^k \right\} \left. \right\rangle + \sum_{g=1}^G \left\langle \sum_{k=1}^{K-1} \left[ 2\pi R_k \bar{a}_g^k \left\{ [A_g^k] \bar{T}_g^k(R_k) \right. \right. \right. \\
 &- \left. \left. \left[ \bar{A}_g^{(k+1)} \right] \bar{T}_g^{(k+1)}(R_k) \right\} + \left\{ \bar{T}_g^{k*}(R_k) [B_g^k] - \bar{T}_g^{(k+1)*}(R_k) [\bar{B}_g^{(k+1)}] \bar{b}_g^k \right\} \cdot 2\pi R_k \right] \\
 &+ 2\pi \left\{ \theta \nu C_{gK}^R \bar{T}_g^{K*}(R) [W_g^K] \bar{T}_g^K(R) + \frac{d\bar{T}_g^{1*}}{dr} \Big|_{r=0} [W_g^1] \frac{d\bar{T}_g^1}{dr} \Big|_{r=0} \right. \\
 &\left. + R \theta (\nu - 1) \left[ \bar{T}_g^{K*} [D_g^K] \frac{d\bar{T}_g^K}{dr} \Big|_{r=R} + \bar{T}_g^K [D_g^K] \frac{d\bar{T}_g^{K*}}{dr} \Big|_{r=R} \right] \right\} \left. \right\rangle, \quad (27)
 \end{aligned}$$

where the following nomenclature has been adopted:  $\bar{T}_g^k$  and  $\bar{b}_g^k$  are column vectors with components  $T_{gn}^k(r)$  and  $b_{gn}^k$ ;  $\bar{T}_g^{k*}$  and  $\bar{a}_g^k$  are row vectors with components  $T_{gm}^{k*}(r)$  and  $a_{gm}^k$ . Left multiplication on a matrix implies a row vector, right multiplication a column vector.

$[D_g^k]$  is an  $N_g^k$  by  $N_g^k$  square matrix with elements defined by

$$\int_0^h D_g(r, z) H_{gm}^{k*}(z) H_{gn}^k(z) dz = D_{gk}^{mn}(r); \quad (28)$$

$[L_g^k]$  is an  $N_g^k$  by  $N_g^k$  square matrix with elements defined by

$$L_{gk}^{mn}(r) = \int_0^h D_g(r, z) \frac{dH_{gm}^{k*}(z)}{dz} \frac{dH_{gn}^k(z)}{dz} dz; \quad (29)$$

$[\Sigma_g^k]$  is an  $N_g^k$  by  $N_g^k$  square matrix with elements defined by

$$\int_0^h \Sigma_{rg}(r, z) H_{gm}^{k*}(z) H_{gn}^k(z) dz = \Sigma_{gk}^{mn}(r); \quad (30)$$

$[C_g^k]$  is an  $N_g^k$  by  $N_g^k$  square matrix with elements defined by

$$\begin{aligned} & \zeta \left\{ \alpha C_{gk}^T H_{gm}^{k*}(h) H_{gn}^k(h) + (\alpha - 1) D_g(r, h) \left[ H_{gm}^{k*}(h) H_{gn}^{k'} \Big|_{z=h} + H_{gm}^{k*'} \Big|_{z=h} H_{gn}^k(h) \right] \right\} \\ & + \eta \left\{ \beta C_{gk}^B H_{gm}^{k*}(0) H_{gn}^k(0) + (1 - \beta) D_g(r, 0) \left[ H_{gm}^{k*}(0) H_{gn}^{k'} \Big|_{z=0} \right. \right. \\ & \left. \left. + H_{gm}^{k*'} \Big|_{z=0} H_{gn}^k(0) \right] \right\} = C_{gk}^{mn}(r); \quad (31) \end{aligned}$$

$[\Sigma_{g'g}^k]$  is an  $N_{g'}^k$  by  $N_g^k$  rectangular matrix with elements defined by

$$\int_0^h \Sigma_{g'g}(r, z) H_{gm}^{k*}(z) H_{gn}^k(z) dz = \Sigma_{g'g, k}^{mn}(r); \quad (32)$$

$\{[\chi_g(\nu\Sigma_f)_g]^{k}\}$  is an  $N_g^k$  by  $N_g^k$ , rectangular matrix with elements defined by

$$\int_0^h (\chi_g \nu_{g'} \Sigma_{f_{g'}})(r, z) H_{gm}^{k*}(z) H_{gn}^k(z) dz = (\chi_g \nu_{g'} \Sigma_{f_{g'}})_{k}^{mn}(r); \quad (33)$$

$[W_g^k]$  is an  $N_g^k$  by  $N_g^k$  square matrix with elements defined by

$$\int_0^h H_{gm}^{k*}(z) H_{gn}^k(z) dz = W_{gk}^{mn}, \quad k = 1 \text{ and } K; \quad (34)$$

$[A_g^k]$  is an  $M_g^k$  by  $N_g^k$  rectangular matrix, and  $[\bar{A}_g^{(k+1)}]$  is an  $M_g^k$  by  $N_g^{(k+1)}$  rectangular matrix with elements defined by

$$\int_0^h A_{gm}^k(z) H_{gn}^k(z) dz = A_{gk}^{mn} \quad (35)$$

and

$$\int_0^h A_{gm}^k(z) H_{gn}^{(k+1)}(z) dz = \bar{A}_{g(k+1)}^{mn}, \text{ respectively}; \quad (36)$$

$[B_g^k]$  is an  $N_g^k$  by  $M_g^k$  rectangular matrix, and  $[\bar{B}_g^{(k+1)}]$  is an  $N_g^{(k+1)}$  by  $M_g^k$  rectangular matrix with elements defined by

$$\int_0^h H_{gm}^{k*}(z) B_{gn}^k(z) dz = B_{gk}^{mn} \quad (37)$$

and

$$\int_0^h H_{gm}^{(k+1)*}(z) B_{gn}^k(z) dz = \bar{B}_{g(k+1)}^{mn}, \text{ respectively}. \quad (38)$$

To obtain the Euler equations in  $\bar{T}_{gn}^k(r)$  and  $\beta_{gn}^k$  for this functional, it is convenient to transform Eq. 27 by integrating the double-gradient term by parts:

$$\begin{aligned}
& \sum_{g=1}^G \sum_{k=1}^K \int_{R_{(k-1)}}^{R_k} 2\pi r \, dr \frac{d\bar{T}_g^{k*}}{dr} [D_g^k] \frac{d\bar{T}_g^k}{dr} = \sum_{g=1}^G \left\langle \sum_{k=1}^K \int_{R_{(k-1)}}^{R_k} \right. \\
& - 2\pi \bar{T}_g^{k*} \frac{d}{dr} \left\{ r [D_g^k] \frac{d\bar{T}_g^k}{dr} \right\} dr + \sum_{k=1}^{K-1} 2\pi R_k \left\{ \bar{T}_g^{k*}(R_k) [D_g^k] \frac{d\bar{T}_g^k}{dr} \right|_{r=R_k} \\
& \left. - \bar{T}_g^{(k+1)*}(R_k) [D_g^{(k+1)}] \frac{d\bar{T}_g^{(k+1)}}{dr} \right|_{r=R_k} \right\} + 2\pi R \bar{T}_g^{K*}(R) [D_g^K] \frac{d\bar{T}_g^K}{dr} \bigg|_{r=R} \rangle. \quad (39)
\end{aligned}$$

Introducing Eq. 39 into Eq. 27 results in

$$\begin{aligned}
J' & \equiv \sum_{g=1}^G \left[ \sum_{k=1}^K \left\langle \int_{R_{(k-1)}}^{R_k} 2\pi r \, dr \bar{T}_g^{k*} \left( -\frac{1}{r} \frac{d}{dr} \left[ r [D_g^k] \frac{d\bar{T}_g^k}{dr} \right] + \{ [L_g^k] + [\Sigma_g^k] + [C_g^k] \} \bar{T}_g^k \right. \right. \right. \\
& \left. \left. - \sum_{g'=1}^{g-1} [\Sigma_{g'g}^k] \bar{T}_{g'}^k + \lambda \sum_{g'=1}^G \{ \chi_{g'}(\nu \Sigma_{g'}^{jk}) \} \bar{T}_{g'}^k \right\rangle \right. \\
& \left. + \sum_{k=1}^{K-1} \left\langle 2\pi R_k \bar{a}_g^k [A_g^k] \bar{T}_g^k(R_k) - [\bar{A}_g^{(k+1)}] \bar{T}_g^{(k+1)}(R_k) \right\} \right. \\
& \left. + 2\pi R_k \bar{T}_g^{k*}(R_k) \left\{ [D_g^k] \frac{d\bar{T}_g^k}{dr} \right|_{r=R_k} + [B_g^k] \bar{b}_g^k \right\} \\
& \left. - 2\pi R_k \bar{T}_g^{(k+1)*}(R_k) \left\{ [D_g^{(k+1)}] \frac{d\bar{T}_g^{(k+1)}}{dr} \right|_{r=R_k} + [\bar{B}_g^{(k+1)}] \bar{b}_g^k \right\rangle \right. \\
& \left. + 2\pi R \theta (\gamma - 1) \left[ \bar{T}_g^K [D_g^K] \frac{d\bar{T}_g^K}{dr} \right|_{r=R} + \bar{T}_g^K [D_g^K] \frac{d\bar{T}_g^{K*}}{dr} \right|_{r=R} \right] \\
& + 2\pi R \bar{T}_g^{K*}(R) \left\{ \gamma \theta C_{gKl}^R [W_g^K] \bar{T}_g^K(R) + [D_g^K] \frac{d\bar{T}_g^K}{dr} \right|_{r=R} \right\} \\
& + \frac{d\bar{T}_g^{1*}}{dr} \bigg|_{r=0} 2\pi \cdot [W_g^1] \frac{d\bar{T}_g^1}{dr} \bigg|_{r=0} \right]. \quad (40)
\end{aligned}$$

And now an arbitrary variation in the independent variable-functions  $T_{gm}^{k*}(r)$  and  $a_{gm}^k$  yields immediately the following conditions for stationariness for  $T_{gn}^k(r)$  and  $b_{gn}^k$ , now named  $\psi_{gn}^k(r)$  and  $j_{gn}^k$ . In the volumes  $V_k$ ,

$$\sum_{n=1}^{N_g^k} \left[ -\frac{d}{dr} \left( r D_{gk}^{mn} \frac{d\psi_{gn}^k}{dr} \right) + r \left( L_{gk}^{mn} + \Sigma_{gk}^{mn} + C_{gk}^{mn} \right) \psi_{gn}^k \right] - \sum_{n=1}^{N_{g'}^k} \left( \sum_{g'=1}^{g-1} r \Sigma_{g'gk}^{mn} \psi_{g'n}^k \right) + \lambda \sum_{g'=1}^G r \left\{ \left[ \chi_{g'}(\nu \Sigma_f)_{g'} \right]_{gk}^{mn} \right\} \psi_{g'n}^k = 0, \quad m = 1, 2, \dots, N_g^k, \quad k = 1, 2, \dots, K; \quad (41)$$

at the cylindrical surfaces with radii  $R_k$ ,

$$\sum_{n=1}^{N_g^k} A_{gk}^{mn} \psi_{gn}^k(R_k) = \sum_{n=1}^{N_{g^{(k+1)}}^k} \bar{A}_{g^{(k+1)}}^{mn} \psi_{gn}^{(k+1)}(R_k), \quad m = 1, 2, \dots, M_g^k; \quad (42)$$

$$\sum_{n=1}^{N_g^k} D_{gk}^{mn}(R_k) \frac{d\psi_{gn}^k}{dr} \Big|_{r=R_k} + \sum_{n=1}^{M_g^k} B_{gk}^{mn,k} \psi_{gn}^k = 0, \quad m = 1, 2, \dots, N_g^k; \quad (43)$$

$$\sum_{n=1}^{N_{g^{(k+1)}}^k} D_{g^{(k+1)}}^{mn}(R_k) \frac{d\psi_{gn}^{(k+1)}}{dr} \Big|_{r=R_k} + \sum_{n=1}^{M_g^k} \bar{B}_{g^{(k+1)}}^{mn,k} \psi_{gn}^k = 0, \quad m = 1, 2, \dots, N_{g^{(k+1)}}^k; \quad (44)$$

at the outer surface of the reactor,

$$\sum_{n=1}^{N_g^K} \left\{ \gamma D_{gK}^{mn}(R) \frac{d\psi_{gn}^K}{dr} \Big|_{r=R} + \theta C_{gK}^R W_{gK}^{mn} \psi_{gn}^K(R) \right\} = 0, \quad m = 1, \dots, N_g^K; \quad (45)$$

at  $r = 0$ ,

$$\sum_{n=1}^{N_g^1} \left\{ W_{g1}^{mn} \frac{d\psi_{gn}^1}{dr} \Big|_{r=0} \right\} = 0, \quad m = 1, 2, \dots, N_g^1; \quad (46)$$

and  $g = 1, 2, \dots, G$  in Eqs. 41-46.<sup>†</sup>

<sup>†</sup>Actually Eq. 45 is only technically correct. The possible boundary conditions at  $r = R$  are  $\theta = 0, \gamma = 1$ , implying  $\left[ D_{gK}^K \frac{d\psi_{gK}^K}{dr} \Big|_{r=R} \right] = 0$ , which in turn implies that  $\frac{d\psi_{gK}^K}{dr} \Big|_{r=R} = 0$  since, as we will show later,  $\left[ D_{gK}^K \right]^{-1}$  and  $\left[ W_{gK}^K \right]^{-1}$  exist;  $\theta = 1, \gamma = 0$ , implying  $\left[ D_{gK}^K \right] \psi_{gK}^K \Big|_{r=R} = 0$ , which in turn implies that  $\psi_{gK}^K \Big|_{r=R} = 0$ . Finally,  $\theta = 1, \gamma = 1$ , implying  $\left[ D_{gK}^K \right] \frac{d\psi_{gK}^K}{dr} \Big|_{r=R} + C_{gK}^R \psi_{gK}^K = 0$ . Eq. 45 with proper manipulation will yield this.

The systems of Eqs. 41-46 form a well-determined systems of equations with an equal number of unknowns and conditions. From the physical point of view, though, it is necessary to impose bounds on the numbers  $M_g^k$  of trial functions  $B_{gn}^k$  and  $A_{gn}^k$ . From the structure of the conditions, Eqs. 42-46, it is clearly necessary that

$$1 \leq M_g^k \leq N_g^k + N_g^{k+1} \quad (47)$$

if one is to avoid zero values for the fluxes and adjoints at the interface.

Finally, the approximate values of fluxes and currents are obtained by substituting the solutions  $\psi_{gn}^k(r)$  and  $j_{gn}^k$  of this system of differential equations into Eqs. 23 and 25. The finite-difference approximation (Section 4) to the system of Eqs. 41 with boundary and interface conditions (Eqs. 42-46), along with the additional assumptions

$$B_{gn}^k(z) = D_g^k(R_k, z) H_{gn}^k(z) \quad (48)$$

and

$$A_{gn}^k(z) = D_g^k(R_k, z) H_{gn}^{k*}(z), \quad (49)$$

is solved by SYN2D. These assumptions (Eqs. 48 and 49) reduce the choice of trial functions to those for the fluxes and adjoints, that is, the  $H_{gn}^k(z)$  and  $H_{gn}^{k*}(z)$ , eliminating the need for special expansion functions for the currents. They constitute an asymmetric weighting at the interfaces, as the weight functions are those corresponding to one side of the interface.

It is possible to establish a set of symmetric interface conditions instead of the set (Eqs. 42-44) [with assumptions (Eqs. 48 and 49)], by weighted residual methods as follows:

The desired conditions at the boundary between synthesis regions  $k$  and  $k+1$  are the equality of fluxes and the equality of currents. Using the approximations (Eqs. 23 and 24), we cannot exactly satisfy these equalities. In general, each one is satisfied to within an error, called residual:

$$\sum_{n=1}^{N_g} H_{gn}^k(z) \psi_{gn}^k(R_k) - \sum_{n=1}^{N_g} H_{gn}^{(k+1)}(z) \psi_{gn}^{(k+1)}(R_k) = \epsilon_1(z) \quad (50)$$

and

$$\sum_{n=1}^{N_g} D_g(R_k, z) H_{gn}^k(z) \frac{d\psi_{gn}^k}{dr} \Big|_{r=R_k} - \sum_{n=1}^{N_g} D_g(R_k, z) H_{gn}^{(k+1)}(z) \frac{d\psi_{gn}^{(k+1)}}{dr} \Big|_{r=R_k} = \epsilon_2(z). \quad (51)$$

One now proceeds to weight these residuals with some weight function and to equate the weighted residuals to zero. To obtain a well-posed problem, one has to create in this case  $2N_g$  weighted residual conditions. The weight functions to be used are

$$X_{gm}^{k*}(z) \equiv H_{gm}^{k*}(z) + H_{gm}^{(k+1)*}(z), \quad m = 1, \dots, N_g \quad (52)$$

and the weighted residual interface conditions obtained are

$$\sum_{n=1}^{N_g} \left[ \hat{V}_{gk}^{mn} \psi_{gn}^k(R_k) - \hat{W}_{g(k+1)}^{mn} \psi_{gn}^{(k+1)}(R_k) \right] = 0, \quad (53)$$

and

$$\sum_{n=1}^{N_g} \hat{K}_{gk}^{mn}(R_k) \left. \frac{d\psi_{gn}^k}{dr} \right|_{r=R_k} - \hat{L}_{g(k+1)}^{mn}(R_k) \left. \frac{d\psi_{gn}^{(k+1)}}{dr} \right|_{r=R_k} = 0, \quad m = 1, \dots, N_g, \quad (54)$$

where

$$\hat{V}_{gk}^{mn} = \int_0^h X_{gm}^{k*}(z) H_{gn}^k(z) dz, \quad (55)$$

$$\hat{W}_{g(k+1)}^{mn} = \int_0^h X_{gm}^{k*}(z) H_{gn}^{(k+1)}(z) dz, \quad (56)$$

$$\hat{K}_{gk}^{mn}(R_k) = \int_0^h D_g(R_k, z) X_{gm}^{k*}(z) H_{gn}^k(z) dz, \quad (57)$$

and

$$\hat{L}_{g(k+1)}^{mn}(R_k) = \int_0^h D_g(R_k, z) X_{gm}^{k*}(z) H_{gn}^{(k+1)}(z) dz. \quad (58)$$

The  $2N_g$  interface conditions (Eqs. 53 and 54), together with the equations and conditions (Eqs. 41, 45, and 46), form a well-posed system of differential equations. In this weighted residual option of the interface conditions, the essential restriction  $N_g^k = N_g^{(k+1)}$  for all  $k$  has been implicit. These symmetric weighted residual interface conditions have also been programmed in SYN2D as an alternative option.

#### 4. Discrete Approximations and Method of Solution

Rewriting synthesis Eqs. 41-46 in matrix form, using definitions 28-38, we obtain

$$-\frac{1}{r} \frac{d}{dr} r \left[ D_g^k \right] \frac{d\bar{\psi}_g^k}{dr} + \left[ \Sigma_{Rg}^k \right] \bar{\psi}_g^k = \sum_{g'=1}^{g-1} \left[ \Sigma_{g'g}^k \right] \bar{\psi}_{g'}^k + \lambda \sum_{g'=1}^G \left\{ \left[ \chi_{g'}(\nu \Sigma_f)_{g'} \right]^k \right\} \bar{\psi}_{g'}^k \quad (59)$$

with interface and boundary conditions

$$\left[ A_g^k \right] \bar{\psi}_g^k(R_k) = \left[ \bar{A}_g^{(k+1)} \right] \bar{\psi}_g^{(k+1)}(R_k), \quad (60)$$

$$\left[ D_g^k(R_k) \right] \frac{d\bar{\psi}_g^k}{dr} \Big|_{r=R_k} + \left[ B_g^k \right] \bar{j}_g^k = 0, \quad (61)$$

$$\left[ D_g^{(k+1)}(R_k) \right] \frac{d\bar{\psi}_g^{(k+1)}}{dr} \Big|_{r=R_k} + \left[ \bar{B}_g^{(k+1)} \right] \bar{j}_g^k = 0, \quad (62)$$

and

$$\nu \left[ D_g^K(R) \right] \frac{d\bar{\psi}_g^K}{dr} \Big|_{r=R} + \theta C_{gK}^R \left[ W_g^K \right] \bar{\psi}_g^K(R) = 0, \quad (63)$$

with  $k = 1, 2, \dots, K$ , and  $g = 1, 2, \dots, G$ ;  $\bar{\psi}_g^k$  and  $\bar{j}_g^k$  are column vectors with components  $\psi_{gn}^k$  and  $j_{gn}^k$ , respectively, and

$$\left[ \Sigma_{Rg}^k \right] \equiv \left[ L_g^k \right] + \left[ \Sigma_g^k \right] + \left[ C_g^k \right]. \quad (64)$$

With this notation it is seen that the system has the form of the usual one-dimensional multigroup equation where matrices now replace the usual scalar coefficients. This observation forms the basis for the derivation of a finite-difference approximation to the given system. Since most of the derivation is involved with the Laplacian term, it will suffice to consider the case of one group. Thus the group index is dropped.

Let the reactor domain be the interval  $[0, R]$ , and impose a mesh  $0 = \rho_0 < \rho_1 < \dots < \rho_I = R$  on this interval in such a manner that

- Any synthesis interface coincides with some mesh point  $\rho_i$ .
- Any region interface coincides with some mesh point  $\rho_i$ .

Then in any interval  $[\rho_{i-1}, \rho_i]$ , we can assume that we have a differential system of the form

$$-\frac{1}{r} \frac{d}{dr} \left( r D_i \frac{d\psi}{dr} \right) + (\Sigma R)_i \psi = f_i(r) \quad (65)$$

with interface conditions

$$A_{i-1} \psi(\rho_{i-1}^-) = \hat{A}_{i-1} \psi(\rho_{i-1}^+),$$

$$A_i \psi(\rho_i^-) = \hat{A}_i \psi(\rho_i^+),$$

$$D_{i-1} \psi'(\rho_{i-1}^-) + B_{i-1} j_{i-1} = 0,$$

$$\hat{D}_{i-1} \psi'(\rho_{i-1}^+) + \hat{B}_{i-1} j_{i-1} = 0,$$

$$D_i \psi'(\rho_i^-) + B_i j_i = 0,$$

and

$$\hat{D}_i \psi'(\rho_i^+) + \hat{B}_i j_i = 0,$$

where the vector and matrix notation has been dropped for simplicity. The relation between  $A_i$  and  $\hat{A}_i$ ,  $B_i$  and  $\hat{B}_i$ ,  $D_i$  and  $\hat{D}_i$  is the same as that which exists between  $[A_g^k]$  and  $[\hat{A}_g^{k+1}]$ ,  $[B_g^k]$  and  $[\hat{B}_g^{k+1}]$ , and  $[D_g^k(R_k)]$  and  $[D_g^{(k+1)}(R_k)]$ , where  $i$  now indicates mesh point  $\rho_i$ ;  $\rho_i^-$  and  $\rho_i^+$  indicate evaluation at point  $\rho_i$  using functions defined to the left or right of the point respectively;  $\psi'$  indicates derivative with respect to  $r$ . The dimension of  $\psi(r)$  is  $N_i$ , where  $N_i = N_k$  when the interval  $[\rho_{i-1}, \rho_i]$  lies in the  $k$ th synthesis region. Since each interval lies entirely within a region of constant composition, the coefficient matrices are constant over each interval. If  $\rho_i$  is a regular interface point in the sense that it does not separate two synthesis regions, then the dimension of  $\psi(r)$  does not change when passing from  $[\rho_{i-1}, \rho_i]$  to  $[\rho_i, \rho_{i+1}]$ . In this case, the interface conditions are defined by the matrix relationships

$$A_i = \hat{A}_i = I; \quad N_i \times N_i;$$

$$B_i = \hat{B}_i = I; \quad N_i \times N_i.$$

On the other hand, if  $\rho_i$  separates the  $k$ th synthesis region from the  $(k+1)$ st, then the interface matrices are defined by

$$A_i = A_k; \quad M_i \times N_i, \quad M_i = M_k, \quad N_i = N_k;$$

$$\hat{A}_i = \bar{A}_{k+1}; \quad M_i \times N_{i+1}, \quad N_{i+1} = N_{k+1};$$

$$B_i = B_k; \quad N_i \times M_i;$$

$$\hat{B}_i = \bar{B}_{k+1}; \quad N_{i+1} \times M_i.$$

To derive a finite-difference approximation, consider the following class of functions defined on the interval  $[r_i, r_{i+1}]$ , where  $r_i$  is the midpoint of the interval  $[\rho_{i-1}, \rho_i]$ :

$$\psi(r) = \begin{cases} \psi(r_i) + (r - r_i) \zeta, & r_i \leq r \leq \rho_i, \\ \psi(r_{i+1}) - (r_{i+1} - r) \xi, & \rho_i \leq r \leq r_{i+1}, \end{cases}$$

which satisfy the conditions

$$A_i \psi(\rho_i^-) = \hat{A}_i \psi(\rho_i^+),$$

$$D_i \psi'(\rho_i^-) + B_i j_i = 0,$$

and

$$\hat{D}_i \psi'(\rho_i^+) + \hat{B}_i j_i = 0.$$

Here  $\zeta$ ,  $\xi$ , and  $j_i$  are assumed to be given vectors having dimensions  $N_i$ ,  $N_{i+1}$ , and  $M_i$ , respectively.

If the interface conditions are applied to this class of functions,  $\zeta$ ,  $\xi$ , and  $j_i$  must satisfy the following system of equations:

$$\frac{1}{2} \delta_i A_i \zeta + \frac{1}{2} \delta_{i+1} \hat{A}_i \xi = \hat{A}_i \psi(r_{i+1}) - A_i \psi(r_i),$$

$$D_i \zeta + B_i j_i = 0,$$

and

$$\hat{D}_i \xi + \hat{B}_i j_i = 0,$$

where  $\delta_i$  denotes the length of the interval  $[\rho_{i-1}, \rho_i]$ .

Up to this point, no assumptions have been made concerning the nature or structure of the matrices  $A_i$ ,  $\hat{A}_i$ ,  $D_i$ ,  $\hat{D}_i$ ,  $B_i$ , and  $\hat{B}_i$ ; thus the question of existence of a solution to the above system is still open. In fact, the matter is not trivial, even in the case of a regular interface. In this case, the system reduces to the following system by eliminating the vector  $j_i$ :

$$\frac{1}{2} \delta_i \zeta + \frac{1}{2} \delta_{i+1} \xi = \psi(r_{i+1}) - \psi(r_i);$$

$$-D_i \zeta + \hat{D}_i \xi = 0.$$

This leads to the equation

$$[\frac{1}{2} \delta_i \hat{D}_i + \frac{1}{2} \delta_{i+1} D_i] \xi = D_i [\psi(r_{i+1}) - \psi(r_i)].$$

The question now arises whether the matrix

$$\Delta_i = \frac{1}{2}\delta_i\hat{D}_i + \frac{1}{2}\delta_{i+1}D_i$$

is invertible. If it is, then

$$D_i\zeta = \hat{D}_i\xi = \hat{D}_i\Delta_i^{-1}D_i[\psi(r_{i+1}) - \psi(r_i)].$$

The question of nonsingularity, although easy to characterize in terms of cross-grammians, is not easy to characterize in more physical terms. Thus, for example, consider the question of whether or not the matrix  $D_i$  is singular. Recall that these matrices have elements  $D^{mn}$  defined by

$$D^{mn} = \sum_{j=1}^J w_j H_m^*(j) H_n(j), \quad 1 \leq m, n \leq N.$$

Here we have dropped the  $i$  subscript since it is not pertinent. The weights  $w_j$  result from numerically approximating the corresponding integral; moreover,  $H_m^*(j)$  and  $H_n(j)$  are the numerical values of the trial functions. Define the vectors

$$H_m^* = \{H_m^*(j)\}_{j=1}^J \quad \text{and} \quad H_n = \{H_n(j)\}_{j=1}^J$$

for  $n = 1, 2, \dots, N$ . Let  $X$  be the  $J$ -dimensional Hilbert space defined by the inner product

$$\langle X, Y \rangle = \sum_{j=1}^J w_j X_j Y_j.$$

Then in this space  $X$  we are given two sets of vectors  $\{H_1, H_2, \dots, H_n\}$  and  $\{H_1^*, \dots, H_n^*\}$ , each set being linearly independent. The matrix  $D$  is then the cross-grammian of these two sets of vectors. Let  $M$  denote the subspace generated by the set  $\{H_n\}$  and  $N$  denote the subspace generated by the set  $\{H_m^*\}$ ; then the matrix  $D$  is nonsingular if  $M$  and  $N^\perp$  are disjoint. Note that since  $M$  and  $N$  have the same dimension, this last statement is equivalent to the statement that  $M$  and  $N^\perp$  span the space  $X$ . Also note that if  $\{H_m^*\}$  is the conjugate set (or basis) corresponding to the set  $\{H_n\}$ , then  $M = N$  and it is clear that the matrix  $D$  is nonsingular, and indeed it is a diagonal matrix in this case. This observation leads to the following result: The matrix  $D$ , which is the cross-grammian for the two sets of vectors, is nonsingular if, and only if, the two sets of vectors span the same space.

If the cross-grammian is nonsingular, then a conjugate set for the set  $\{H_n\}$  can be constructed from the set  $\{H_m\}$ . But the conjugate set for  $\{H_n\}$  spans the same space as  $\{H_n\}$ ; hence  $\{H_m^*\}$  also spans the same space. On the other hand, if the two sets of vectors span the same space, and if the cross-grammian were singular, there would exist a nonzero element in the space which was orthogonal to every element of the set  $\{H_n\}$ . This would contradict the fact that the space was generated by the linearly independent set  $\{H_n\}$ .

Although it is not hard to state criteria for the matrix  $D$  to be nonsingular, it is very difficult to give simple heuristic criteria by which the user can be guided in choosing trial functions.

Returning to the general system for  $\xi$ ,  $\zeta$ , and  $j_i$ , we find that if  $D_i$  and  $\hat{D}_i$  are nonsingular, then

$$\zeta = D_i^{-1} B_i j_i,$$

$$\xi = \hat{D}_i^{-1} \hat{B}_i j_i,$$

and

$$\left( \frac{1}{2} \delta_i A_i D_i^{-1} B_i + \frac{1}{2} \delta_{i+1} \hat{A}_i \hat{D}_i^{-1} \hat{B}_i \right) j_i = \hat{A}_i \psi(r_{i+1}) - A_i \psi(r_i).$$

If the  $M_i \times M_i$  dimensional matrix

$$\Omega_i = \frac{1}{2} \delta_i A_i D_i^{-1} B_i + \frac{1}{2} \delta_{i+1} \hat{A}_i \hat{D}_i^{-1} \hat{B}_i$$

has an inverse, then

$$D_i \zeta = B_i \Omega_i^{-1} [\hat{A}_i \psi(r_{i+1}) - A_i \psi(r_i)],$$

and

$$\hat{D}_i \xi = \hat{B}_i \Omega_i^{-1} [\hat{A}_i \psi(r_{i+1}) - A_i \psi(r_i)].$$

With the assumption of invertibility,  $\psi(r)$  has now been determined as a class of piecewise linear vector-valued functions which satisfy the given interface conditions.

Returning to the differential Eq. 65 and integrating it with respect to  $r$  over the interval  $[\rho_{i-1}, \rho_i]$  leads to the equation

$$-[\rho_i D_i \psi'(\rho_i^-) - \rho_{i-1} D_i \psi'(\rho_{i-1}^+)] + (\Sigma_R)_i \int_{\rho_{i-1}}^{\rho_i} \psi(r) r \, dr = \int_{\rho_{i-1}}^{\rho_i} f_i(r) r \, dr,$$

$$1 \leq i \leq I.$$

The solution to this system within the class of functions just constructed is required. Using the expressions for  $D_i \psi'(\rho_i^-)$  and  $D_i \psi'(\rho_{i-1}^+)$  just derived, we obtain the system

$$\begin{aligned}
 & -\{\rho_i B_i \Omega_i^{-1} [\hat{A}_i \psi(r_{i+1}) - A_i \psi(r_i)] - \rho_{i-1} \hat{B}_{i-1} \Omega_{i-1}^{-1} [\hat{A}_{i-1} \psi(r_i) - A_{i-1} \psi(r_{i-1})]\} \\
 & + (\Sigma_R)_i \int_{\rho_{i-1}}^{\rho_i} \psi(r) r \, dr = \int_{\rho_{i-1}}^{\rho_i} f_i(r) r \, dr. \tag{67}
 \end{aligned}$$

Integrating the functions in this class would result in a quadrature formula linking  $\psi(r_{i-1})$ ,  $\psi(r_i)$ , and  $\psi(r_{i+1})$ . However, the truncation error is of a higher order than that which results from the derivative terms. In addition, such a quadrature formula leads to nonsymmetric matrices, even in the case of regular interface conditions. For these reasons, the following quadrature formulas will be used:

$$\int_{\rho_{i-1}}^{\rho_i} \psi(r) r \, dr \approx \frac{1}{2}(\rho_i^2 - \rho_{i-1}^2) \psi(r_i) = V_i \psi(r_i);$$

$$\int_{\rho_{i-1}}^{\rho_i} f_i(r) r \, dr \approx V_i f_i(r_i).$$

With these approximations, the following matrices can be defined:

$$G_i = \rho_i B_i \Omega_i^{-1} \hat{A}_i; \quad N_i \times N_{i+1};$$

$$H_i = \rho_{i-1} \hat{B}_{i-1} \Omega_{i-1}^{-1} A_{i-1}; \quad N_i \times N_{i-1};$$

$$E_i = \rho_i B_i \Omega_i^{-1} A_i + \rho_{i-1} \hat{B}_{i-1} \Omega_{i-1}^{-1} \hat{A}_{i-1} + V_i \Sigma_{R_i},$$

for  $i = 1, 2, \dots, I$  with  $H_1 = 0$ ,  $G_I = 0$ , and

$$E_I = \rho_I D_I \left[ \gamma D_I + \frac{\theta}{2} C_{gK}^R \delta_I W_I \right]^{-1} \theta C_{gK}^R W_I \tag{68}$$

$$+ \rho_{I-1} \hat{B}_{I-1} \Omega_{I-1}^{-1} \hat{A}_{I-1} + V_I \Sigma_{R_I},$$

where

$$\delta_I = \rho_I - \rho_{I-1}$$

and

$$W_I = \begin{bmatrix} W_g^K \end{bmatrix}.$$

At a regular interface,  $N_i = N_{i+1}$  and  $A_i = \hat{A}_i = B_i = \hat{B}_i = I$ ; thus,  $H_{i+1} = G_i$ . However, in general,  $H_{i+1} \neq G_i$ ; therefore the matrices are not symmetric.

With the above matrices the differential system has been approximated by the following algebraic system:

$$\begin{bmatrix} E_1 & -G_1 & 0 & \dots & 0 \\ -H_2 & E_2 & -G_2 & \dots & 0 \\ \vdots & & & & \\ 0 & -H_3 & & & \\ \vdots & & & & -G_{I-1} \\ 0 & & -H_I & & E_I \end{bmatrix} \psi = f, \quad (69)$$

where  $\psi = [\psi_1, \psi_2, \dots, \psi_I]$  and  $\psi_i = \psi(r_i)$ .

In the multigroup case, there are  $G$  matrices of the above form which will be denoted by  $P_g$ . Letting

$$\Sigma^{g'} g = \text{diag}\{V_i \Sigma^{g'} g\}_{i=1}^I,$$

and

$$F^{g'} g = \text{diag}\{V_i F_i^{g'} g\}_{i=1}^I,$$

for  $1 \leq g, g' \leq G$  and defining  $\psi_g \equiv [\psi_{g1}, \psi_{g2}, \dots, \psi_{gI}]$ , the discrete approximation to the original differential equations system takes the form

$$P_g \psi_g = \sum_{g'=1}^{g-1} \Sigma^{g'} g \psi_{g'} + \lambda \sum_{g'=1}^G F^{g'} g \psi_{g'}, \quad 1 \leq g \leq G. \dagger \quad (70)$$

Since  $P_g^{-1} \geq 0$  and the matrices  $\Sigma^{g'} g$  and  $F^{g'} g$  are nonnegative, this system is solved for the dominant eigenvalue and eigenvector by the power technique. Thus, given any guess  $\psi^{(0)} > 0$  and  $\lambda^{(0)}$  for the dominant eigenvector and eigenvalue, the successive approximations are generated by the following scheme:

$$P_g \psi_g^{(n+1)} = \sum_{g'=1}^{g-1} \Sigma^{g'} g \psi_{g'}^{(n+1)} + \lambda^{(n)} \sum_{g'=1}^G F^{g'} g \psi_{g'}^{(n)}, \quad (71)$$

---

†Note that the desired  $k$ -effective is defined by the relation  $k = 1/\lambda$ .

and

$$\lambda^{(n)} = \lambda^{(n-1)} \frac{(\varphi^{(n)}, \varphi^{(n-1)})}{(\varphi^{(n)}, \varphi^{(n)})}, \quad (72)$$

where

$$(\varphi, \psi) = \sum_{g=1}^G \sum_{i=1}^I \sum_{\ell=1}^{N_i} \varphi_{\ell ig} \psi_{\ell ig}.$$

The generation of  $\psi_g^{(n+1)}$  thus involves the solution of the system

$$P_g \psi_g = f_g \quad (73)$$

for  $g = 1, 2, \dots, G$ . Since each matrix  $P_g$  is block tridiagonal, each system can be solved directly by factoring the matrix  $P_g$  using a variant of Choleski's method. For simplicity, the group index is dropped. Then  $P = LU$ , where  $L$  and  $U$  have the forms

$$L = \left[ \begin{array}{cccc} U_1 & 0 & \dots & 0 \\ -H_2 & U_2 & \dots & 0 \\ \vdots & \ddots & \ddots & \vdots \\ 0 & & -H_I & U_I \end{array} \right], \quad U = \left[ \begin{array}{cccc} I & -V_1 & 0 & \dots & 0 \\ 0 & I & -V_2 & \dots & 0 \\ \vdots & & \ddots & \ddots & \vdots \\ 0 & & & -V_{I-1} & \\ & & & & I \end{array} \right]. \quad (74)$$

This factorization leads to the following recursive relations for the matrices  $U_i$  and  $V_i$ :

$$\left. \begin{aligned} U_1 &= E_1, \quad U_1 V_1 = G_1, \\ H_i V_{i-1} + U_i &= E_i, \quad U_i V_i = G_i, \quad 2 \leq i \leq I \quad (G_I = 0). \end{aligned} \right\} \quad (75)$$

With this factorization, the single system  $P\psi = f$  is equivalent to the pair of equations

$$L\omega = f$$

and

$$U\varphi = \omega.$$

Hence,

$$\left. \begin{aligned} \omega_1 &= U_1^{-1} f_1; \\ \omega_i &= U_1^{-1} [f_i + H_i \omega_{i-1}], \quad 2 \leq i \leq I; \\ \bar{\Phi}_I &= \omega_I; \\ \bar{\Phi}_j &= \omega_j + V_j \bar{\Phi}_{j+1}, \quad I-1 \geq j \geq 1. \end{aligned} \right\} \quad (76)$$

The method requires the creation and storage of the matrices  $\{U_i^{-1}\}_{i=1}^I$ . However, these matrices can replace the matrices  $E_i$ , which are not needed in the actual solution.

### 5. Output Edits

Presently the printed output of the synthesis module is almost identical to the output of the two-dimensional diffusion-theory module, which is discussed below. Of interest here is the output that varies from the two-dimensional diffusion output in form and/or content.

Each page of the output is numbered and titled with a user-supplied heading.

The edits that may appear from this module may be divided into four sections: input, iterations, mixing functions, and output.

a. Input. The input section is divided into several parts. In the first part the code prints out the following items, which were user-input:

- (1) Maximum number of outer iterations (NMAX).
- (2) k-effective difference convergence criterion,  $\epsilon_k$ .
- (3) Normalized-flux difference convergence criterion,  $\epsilon_f$ ,

$$\left( \frac{\sum_{gin} |\bar{\Phi}_{gin}^{l+1} - \bar{\Phi}_{gin}^l| / GIN}{\sum_{gin} |\bar{\Phi}_{gin}^{(l+1)}|} \right) \leq \epsilon_f,$$

where G is the number of energy groups, I is the number of X-direction intervals, and N is the maximum number of real trial functions in any synthesis region.

- (4) Lambda-limits difference convergence criterion,  $\epsilon_\lambda$ ,  $|\bar{\lambda} - \underline{\lambda}| \leq \epsilon_\lambda$ , where

$$\bar{\lambda} = \max_{gin} w_{gin}, \quad \underline{\lambda} = \min_{gin} w_{gin} \quad \text{and} \quad w_{gin} = |\bar{\Phi}_{gin}^l / \bar{\Phi}_{gin}^{(l-1)}|.$$

- (5) Power-normalization factor for a burnup calculation,  $P_0$ , in watts (set to one if input is zero or blank).
- (6) Size of the POINTR core container allocated in double words, for both main and bulk core.
- (7) Interface condition to be used at each internal synthesis region boundary.
- (8) Indication of which trial functions will be used as adjoints; i.e., either SYN2D will use the real trial functions supplied, or the user will also supply adjoint trial functions.

The second part states the geometry type (RZ, ZR, or XY) and describes the mesh structure, region and composition assignments, and buckling, region half-heights, and extrapolation distances.

The third part displays the group-dependent macroscopic cross section for each composition defined. The diffusion coefficient shown was calculated from the transport cross section [ $D = 1/(3\Sigma_{tr})$ ].

The fourth part describes the type of boundary condition applied by space point and energy group.

Then the geometry type (XY, RZ, or ZR) and the internal synthesis boundary points, along with the number of refined regions and the time spent in the execution of the synthesis input processor, is printed. This is followed by an approximation to the condition number of  $D_{gk}(r)$ . This approximation is computed by taking the column norms of  $[D_{gk}(r)]$  and of  $[D_{gk}(r)]^{-1}$ . The product of these two norms is computed for all  $r$ , and the largest is printed out for each group, indicating which synthesis region is occurred in. Then the time required to compute all the calculated matrices is printed out.

b. Iteration History. Ten columns of monitoring information are printed out as the code iterates. This enables the user to study the convergence of the iterates and to observe where any problems might have occurred. The information printed out is in order as follows for each iteration:

- (1) The outer iteration number.
- (2) The number of inner iterations. (This is always zero, since no upscattering is handled.)
- (3) The last approximation to k-effective, i.e., the value obtained by the previous outer iteration.
- (4) The difference between (3) and the present k-effective computed in this iteration (see a(2)).

- (5) Lambda up  $\bar{\lambda}$  (see a(4)).
- (6) Lambda down  $\underline{\lambda}$  (see a(4)).
- (7) Lambda difference (see a(4)).
- (8) The sum of the absolute values of the new mixing functions, minus the old mixing functions.
- (9) The sum of the absolute values of the old mixing functions.
- (10) Normed quotient of (8) and (9) (see a(3)).

The iteration process stops when we exceed the number of outer iterations or when the number given by (4) is less than  $\epsilon_k$  and the number given by (7) is less than  $\epsilon_\lambda$  and the number given by (10) is less than  $\epsilon_f$ . The time for the iteration section is then printed out.

c. Mixing Functions. The calculated mixing functions for each group and the user-input real trial functions for each group and synthesis region are printed out. The time required to do this and calculate the re-constructed 2-D fluxes is also printed out.

d. Output. Five basic categories of output inventories appear: flux, flux integrals, fission integrals, power calculations, and balance calculations.

The following output section is the same as for the two-dimensional diffusion-theory module; however, synthesis cannot handle  $R\theta$  geometry, and external source calculation, or an adjoint problem. Items not applicable are indicated by an asterisk.

All inventories are based on weighted integrals of the flux as a function of three spatial variables and one energy variable, with the integrals extending over the dimensions of the reactor defined in a given problem.

The following shapes were assumed for the flux in each of the four geometries:

$$\left. \begin{aligned}
 (1) \text{ RZ or ZR: } \quad \varphi(r, z, \theta) &= \varphi(r, z), \\
 (2) \text{ XY finite: } \quad \varphi(x, y, z) &= \varphi(x, y) \cos \frac{\pi z}{2H_R}, \\
 \text{XY infinite: } \quad \varphi(x, y, z) &= \varphi(x, y);
 \end{aligned} \right\} \quad (77)$$

(Contd.)

$$\begin{aligned}
 (3) \quad R\theta \text{ finite:} \quad \varphi(r, z, \theta) &= \varphi(r, \theta) \cos \frac{\pi z}{2H_R}, \\
 R\theta \text{ infinite:} \quad \varphi(r, z, \theta) &= \varphi(r, \theta),
 \end{aligned}
 \left. \vphantom{\begin{aligned} (3) \quad R\theta \text{ finite:} \quad \varphi(r, z, \theta) &= \varphi(r, \theta) \cos \frac{\pi z}{2H_R}, \\ R\theta \text{ infinite:} \quad \varphi(r, z, \theta) &= \varphi(r, \theta), \end{aligned}} \right\} \begin{array}{l} \text{(Contd.)} \\ (77) \end{array}$$

where  $H_R$  is the region half-height plus the extrapolation distance.

Consider any macroscopic cross section  $\sigma^g(R)$ , where  $R$  denotes a particular region in the reactor. Using  $XY$  geometry as an example, a typical inventory might involve the numerical approximation to the following integral:

$$\begin{aligned}
 I_{R,g} &= \int_{x,y \in R} \int_{-(H_L)_R}^{(H_L)_R} \sigma^g(R) \varphi_g(x, y) \cos \frac{\pi z}{2H_R} \cdot dz \, dx \, dy \\
 &= \int_{xy \in R} \sigma^g(R) \varphi_g(x, y) \frac{4H_R}{\pi} \sin \frac{\pi(H_L)_R}{2H_R} \, dx \, dy \\
 &\approx W_R \sigma^g(R) \sum_{x,y \in R} \varphi_g(x, y) V_{x,y},
 \end{aligned}
 \left. \vphantom{\begin{aligned} I_{R,g} &= \int_{x,y \in R} \int_{-(H_L)_R}^{(H_L)_R} \sigma^g(R) \varphi_g(x, y) \cos \frac{\pi z}{2H_R} \cdot dz \, dx \, dy \\ &= \int_{xy \in R} \sigma^g(R) \varphi_g(x, y) \frac{4H_R}{\pi} \sin \frac{\pi(H_L)_R}{2H_R} \, dx \, dy \\ &\approx W_R \sigma^g(R) \sum_{x,y \in R} \varphi_g(x, y) V_{x,y}, \end{aligned}} \right\} (78)$$

where

$$W_R = \frac{4H_R}{\pi} \sin \frac{\pi(H_L)_R}{2H_R},$$

$V_{x,y}$  is the volume per unit height of a cell,

and

$(H_L)_R$  is the physical half-height of region  $R$ .

For each geometry type, the following table gives the physical volumes and integration weighting factor by region:

Geometry	$V_R$	$W_R$
RZ, ZR	$\sum_{x,y \in R} V_{x,y}$	1
XY finite	$2(H_L)_R \sum_{x,y \in R} V_{x,y}$	$\frac{4H_R}{\pi} \sin \frac{\pi(H_L)_R}{2H_R}$
XY infinite	$\sum_{x,y \in R} V_{x,y}$	1
R $\theta$ finite*	$2(H_L)_R \sum_{x,y \in R} V_{x,y}$	$\frac{4H_R}{\pi} \sin \frac{\pi(H_L)_R}{2H_R}$
R $\theta$ infinite*	$\sum_{x,y \in R} V_{x,y}$	1

The area associated with each side of the cell and values for each geometry are given below.

Geometry	$A_L$	$A_R$	$A_T$	$A_B$	Volume
XY	$\Delta y_j$	$\Delta y_j$	$\Delta x_i$	$\Delta x_i$	$\Delta x \Delta y$
R $\theta^*$	$R_{i-1} \Delta \theta_j$	$R_i \Delta \theta_j$	$\Delta R_i \cos \frac{\Delta \theta_j}{4}$	$\Delta R_i \cos \frac{\Delta \theta_j}{4}$	$\frac{\Delta \theta_j}{2} (R_{i+1}^2 - R_i^2)$
RZ	$2\pi R_{i-1} \Delta Z_j$	$2\pi R_i \Delta Z_j$	$\pi(R_i^2 - R_{i-1}^2)$	$\pi(R_i^2 - R_{i-1}^2)$	$\pi(R_{i+1}^2 - R_i^2) \Delta Z_j$

For a homogeneous calculation, the fluxes are normalized to one fission in the reactor. The normalization factor is calculated the following way:

$$\left. \begin{aligned}
 \psi_{r,g} &= \sum_{ij \in R} \varphi_{i,j,g}^{(\text{computed})} V_{ij} \\
 \text{and} \\
 N &= \sum_{g=1}^G \sum_{r=1}^R W_R (\sigma_f)_R^g \psi_{r,g}
 \end{aligned} \right\} \quad (79)$$

where  $N$  is the normalization factor.

For an inhomogeneous calculation, no normalization is involved.

We can now display the calculations made in each of the five categories.

(1) Neutron Flux.  $\varphi_{i,j,g} = \varphi_{i,j,g}^{(\text{computed})} / N.$

(2) Flux and Fission Integrals

a. Real or adjoint\* regional flux integrals by group

$$\bar{\Phi}_{R,G} = W_R \sum_{i,j \in R} \varphi_{ijg} V_{ij}.$$

b. Real power-normalized regional flux averages by group, where  $P_0$  (in watts) is an input parameter

$$\bar{\Phi}_{R,G} = \frac{\bar{\Phi}_{R,G}}{V_R} (3.1 \times 10^{10} \times P_0).$$

c. Removal by region and group

$$R_{R,G} = \left( \sigma_G^{\text{Rem}} + D_G^c B_R^2 + \frac{\alpha}{v_G} \right) \bar{\phi}_{R,G};$$

$$R_R = \sum_G R_{R,G}; \quad R_G = \sum_R R_{R,G}.$$

d. Absorption by region and by group

$$A_R = \sum_G (\Sigma_a)_{R,G} \bar{\phi}_{R,G};$$

$$A_G = \sum_R (\Sigma_a)_{R,G} \bar{\phi}_{R,G}.$$

e. Scattering by region and group

$$SS_{R,G} = \sum_{h=1}^G \sigma_{h \rightarrow g} \bar{\phi}_{R,h};$$

$$SS_R = \sum_G SS_{R,G}; \quad SS_G = \sum_R SS_{R,G}.$$

f. Fission source (real)

$$F_{R,G} = \chi_G \sum_{h=1}^G \sim \sigma_h^F \bar{\phi}_{R,h} \text{ for a } \chi\text{-vector};$$

$$F_{R,G} = \sum_{h=1}^G \chi^{h \rightarrow G} \sim \sigma_h^F \bar{\phi}_{R,h} \text{ for a } \chi\text{-matrix*}.$$

Fission source (adjoint\*)

$$F_{R,G} = \sim \sigma_G^F \sum_{h=1}^G \chi_h \bar{\phi}_{R,h} \text{ for a } \chi\text{-vector};$$

$$F_{R,G} = \sim \sigma_G^F \sum_{h=1}^G \chi^{h \rightarrow G} \bar{\phi}_{R,h} \text{ for a } \chi\text{-matrix*};$$

$$F_R = \sum_G F_{R,G}; \quad F_G = \sum_R F_{R,G}.$$

For an external source problem\*:

$$F(R,G) = \mu F(R,G).$$

g. Leakage

$$L_{R,G} = W_R \sum_{ij \in R} L_{i,j,g};$$

$$L_R = \sum_G L_{R,G}; \quad L_G = \sum_R L_{R,G}.$$

The net leakage from cell (i,j) is given by

$$L_{ijg} = J_L A_L + J_R A_R + J_T A_T + J_B A_B,$$

where J is the current, which may also be printed out by region and group, A is the area, and the subscripts L, R, T, and B indicate the left, right, top, and bottom.

For XY geometry:

Internal cell (i,j)

$$\left. \begin{aligned} J_R &= - \frac{D_{i,j,g} D_{i+1,j,g} (\varphi_{i+1,j,g} - \varphi_{i,j,g})}{\frac{1}{2}(\Delta x_i D_{i+1,j,g} + \Delta x_{i+1} D_{i,j,g})}; \\ J_L &= - \frac{D_{i,j,g} D_{i-1,j,g} (\varphi_{i,j,g} - \varphi_{i-1,j,g})}{\frac{1}{2}(\Delta x_i D_{i-1,j,g} + \Delta x_{i-1} D_{i,j,g})}; \\ J_T &= - \frac{D_{i,j,g} D_{i,j+1,g} (\varphi_{i,j+1,g} - \varphi_{i,j,g})}{\frac{1}{2}(\Delta y_j D_{i,j+1,g} + \Delta y_{j+1} D_{i,j,g})}; \\ J_B &= - \frac{D_{i,j,g} D_{i,j-1,g} (\varphi_{i,j,g} - \varphi_{i,j-1,g})}{\frac{1}{2}(\Delta y_j D_{i,j-1,g} + \Delta y_{j+1} D_{i,j,g})}. \end{aligned} \right\} \quad (80)$$

External cell (boundary condition  $A\varphi' + B\varphi = C$ )

$$\left. \begin{aligned} J_R &= -D_{i,j,g}(C - B\varphi_{i,j,g}) / (A + \frac{1}{2}\Delta x_i B); \\ J_L &= D_{i,j,g}(B\varphi_{i,j,g} - C) / (A + \frac{1}{2}\Delta x_i B); \\ J_T &= -D_{i,j,g}(C - B\varphi_{i,j,g}) / (A + \frac{1}{2}\Delta y_j B); \\ J_B &= D_{i,j,g}(B\varphi_{i,j,g} - C) / (A + \frac{1}{2}\Delta y_j B). \end{aligned} \right\} \quad (81)$$

Here  $D_{i,j,g}$  is the diffusion coefficient by point and group, and the areas for each geometry are defined previously.

For RZ or ZR geometry:

The form of the equations is identical to those written for XY geometry (Eqs. 80 and 81).

For R $\theta$  geometry\*:

Internal cell (i,j)

$$\begin{aligned} J_R &= -\frac{D_{i,j,g}D_{i+1,j,g}(\varphi_{i+1,j,g} - \varphi_{i,j,g})}{\frac{1}{2}(\Delta r_i D_{i+1,j,g} + \Delta r_{i+1} D_{i,j,g})}; \\ J_L &= \frac{D_{i,j,g}D_{i-1,j,g}(\varphi_{i,j,g} - \varphi_{i-1,j,g})}{\frac{1}{2}(\Delta r_i D_{i-1,j,g} + \Delta r_{i-1} D_{i,j,g})}; \\ J_T &= -\frac{D_{i,j,g}D_{i,j+1,g} \cos \frac{\Delta\theta_{j+1} - \Delta\theta_j}{4} (\varphi_{i,j+1,g} - \varphi_{i,j,g})}{\frac{1}{2}(\delta_{i,j} D_{i,j+1,g} + \delta_{i,j+1} D_{i,j,g})}; \\ \delta\ell_{i,j} &= \frac{\delta U}{1 + \omega U}; \quad \delta\ell_{i,j+1} = \frac{\omega U \delta_0}{1 + \omega U}; \\ J_B &= \frac{D_{i,j,g}D_{i,j-1,g} \cos \frac{\Delta\theta_j - \Delta\theta_{j-1}}{4} (\varphi_{i,j,g} - \varphi_{i,j-1,g})}{\frac{1}{2}(\delta\ell_{i,j} D_{i,j-1,g} + \delta\ell_{i,j-1} D_{i,j,g})} \end{aligned}$$

External cell (boundary condition,  $A\varphi' + B\varphi = C$ )

$$\begin{aligned} J_R &= -D_{i,j,g}(C - B\varphi_{i,j,g}) / (A + \frac{1}{2}\Delta r_i B); \\ J_L &= D_{i,j,g}(B\varphi_{i,j,g} - C) / (A + \frac{1}{2}\Delta r_i B); \end{aligned}$$

$$J_T = -D_{i,j,g}(C - B\varphi_{i,j,g}) \left/ \left[ A + B(r_{i+1} + r_i) \sin \frac{\Delta\theta_j}{4} \right] \right.;$$

$$J_B = D_{i,j,g}(B\varphi_{i,j,g} - C) \left/ \left[ A + B(r_{U-1} + R_i) \sin \frac{\Delta\theta_j}{4} \right] \right..$$

h. Inhomogeneous case-external source\*

$$ES_{r,g} = W_R \sum_{i,j \in R} E_{i,j,g} V_{i,j},$$

where  $E_{i,j,g}$  is the external source.

### (3) Power Calculations

a. Power density by interval

$$P_{i,j} = \sum_{g=1}^G \sigma_{i,j,g}^F \varphi_{i,j,g}.$$

b. Maximum  $P_{i,j}$  and minimum  $P_{i,j}$  [ $P_{i,j} > 0$ ]

c. Power by region

$$P_R = \sum_{g=1}^G \sigma_{R,G}^F \varphi_{R,G}.$$

d. Average power by region

$$\bar{P}_R = P_R / V_R.$$

e. Total power

$$P = \sum_R P_R.$$

### (4) Balance Calculations

$$B_{R,G} = -L_{R,G} - R_{R,G} + SS_{R,G} + \frac{1}{k_{\text{eff}}} FS_{R,G}.$$

For an inhomogeneous problem\*

$$B_{R,G} = -L_{R,G} - R_{R,G} + SS_{R,G} + FS_{R,G} + ES_{R,G}.$$

Also displayed are balances by region, balances by group and total balance

$$B_R = \sum_G B_{R,G}; \quad B_G = \sum_R B_{R,G};$$

$$B = \sum_{R,G} B_{R,G}.$$

## 6. Implementation of Particular Interface Conditions

The following choice for the current interface trial functions appearing in Eqs. 25 and 26 has been suggested by V. Luco. At the interface  $R_k$  between the  $k$ th and  $(k+1)$ st synthesis region, set

$$A_{gm}^k(z) = D_g^k(R_k^-, z) H_{gm}^{*k}(z), \quad (82)$$

and

$$B_{gn}^k(z) = D_g^k(R_k^-, z) H_{gn}^k(z), \quad (83)$$

where  $D_g^k(R_k^-, z)$  denotes the diffusion constant for the  $g$ th group evaluated at the left side of the interface  $R_k$ . With this choice for the current interface trial functions, the interface matrices defined in Eqs. 35-38 take the following form:

$$A_{gk}^{mn} = \int_0^h D_g^k(R_k^-, z) H_{gm}^{*k}(z) H_{gn}^k(z) dz, \quad (84)$$

$$\bar{A}_{g(k+1)}^{mn} = \int_0^h D_g^k(R_k^-, z) H_{gm}^{*k}(z) H_{gn}^{k+1}(z) dz, \quad (85)$$

$$B_{gk}^{mn} = \int_0^h D_g^k(R_k^-, z) H_{gm}^{*k}(z) H_{gn}^k(z) dz, \quad (86)$$

and

$$\bar{B}_{g(k+1)}^{mn} = \int_0^h D_g^k(R_k^-, z) H_{gm}^{*k+1}(z) H_{gn}^k(z) dz, \quad (87)$$

Note that in this case the matrices  $A_g^k = \{A_{gk}^{mn}\}$  and  $B_g^k = \{B_{gk}^{mn}\}$  are equal and also equal to the matrix  $D_g^k(R_k)$  defined in Eq. 28. These matrices are then used in the interface conditions defined by Eqs. 60-62.

As noted earlier in Section II.B.3, the formalism of this program was used to implement a synthesis procedure based on the method of weighted residuals. As shown, this method differs from the variational approach in that the number of trial functions must be the same in each synthesis region, and the general Buslik interface conditions as defined by Eqs. 60-62 are replaced by interface conditions of the form

$$[\hat{V}_g^k] \bar{\psi}_g^k(R_k) = [\hat{W}_g^{k+1}] \bar{\psi}_g^{k+1}(R_k); \quad (88)$$

$$[\hat{K}_g^k] \frac{d}{dr} \bar{\psi}_g^k(r) \Big|_{r=R_k} = [\hat{L}_g^{k+1}] \frac{d}{dr} \bar{\psi}_g^{k+1}(r) \Big|_{r=R_k}. \quad (89)$$

The condition on the continuity of the flux is of the same form as in Eq. 60. However, the condition on the continuity of the current differs somewhat from the general form as given in Eqs. 61-62. These conditions can be written in the form

$$\frac{d\bar{\psi}_g^k(r)}{dr} \Big|_{r=R_k} + [D_g^k(R_k)]^{-1} [B_g^k] \bar{j}_g^k = 0; \quad (90)$$

$$\frac{d\bar{\psi}_g^{k+1}(r)}{dr} \Big|_{r=R_k} + [D_g^{k+1}(R_k)]^{-1} [\bar{B}_g^{k+1}] \bar{j}_g^k = 0. \quad (91)$$

Since the conditions expressed by Eqs. 90 and 91 are more general than that of Eq. 89, we can choose the matrices  $[B_g^k]$  and  $[\bar{B}_g^{k+1}]$  in order to reduce Eqs. 90 and 91 to Eq. 89. To this end, apply condition 89 in Eqs. 90 and 91; then the following relation or constraint is established:

$$[\hat{K}_g^k] [D_g^k(R_k)]^{-1} [B_g^k] = [\hat{L}_g^{k+1}] [D_g^{k+1}(R_k)]^{-1} [\bar{B}_g^{k+1}]. \quad (92)$$

The following choice was made for simplicity in programming:

$$[B_g^k] = [D_g^k(R_k)] [\hat{K}_g^k]^{-1}; \quad (93)$$

$$[\bar{B}_g^{k+1}] = [D_g^{k+1}(R_k)] [\hat{L}_g^{k+1}]^{-1}. \quad (94)$$

## 7. Integration Procedures and the Formation of Partial Integrals

As seen in Section II.B.3, an essential part of the synthesis approach involves the approximation of the integrals appearing in Eqs. 35-38, with Eqs. 35-38 redefined as in Section 6 above.

The program is given the following:

a. A subdivision

$$0 = h_0 < h_1 < \dots < h_S = h$$

of the interval  $[0, h]$ .

b. A single value associated with  $H_{gm}^{k*}(z)$  in each interval  $[h_{S-1}, h_S]$  and a single value associated with  $H_{gn}^k(z)$  in the same interval.

c. The value associated with each cross section in each interval  $[h_{S-1}, h_S]$ . The cross sections are assumed constant in each interval.

Since, in principle, the trial functions  $H_{gm}^{k*}(z)$  and  $H_{gn}^k(z)$  do not correspond in any way to the particular region of the reactor over which they are being integrated, the most that can be assumed is that the tabular values represent parameters associated with an approximation to a continuous function. It is assumed that the tabular values for the trial functions are generated by means of the two-dimensional diffusion-theory code DARC2D which is a member of the ARC System. In this case, the tabulated values of the trial functions can be associated with the evaluation at the midpoint  $z_S$  of the subinterval  $[h_{S-1}, h_S]$  of a piecewise linear and continuous function on the interval  $[0, h]$ .

However, in the diffusion-theory model, the continuous, piecewise linear functions have joints at the midpoints  $z_S$  and at the subinterval boundaries  $h_S$ . The position of the joint at the interface is constrained through the condition of continuity of current. This constraint cannot be used in this program, since the trial functions are used in regions that are not related to the regions in which these functions were determined. For this reason, the class of piecewise linear functions associated with the tabular values is taken to have joints only at the midpoints  $z_S$  of the subintervals  $[h_{S-1}, h_S]$ .

Since the cross sections are assumed constant in each subinterval, all the integrals appearing in Eqs. 29-34 are sums of integrals of either of the following two types:

$$\int_{h_{S-1}}^{h_S} H^*(z)H(z) dz, \quad (95)$$

and

$$\int_{h_{S-1}}^{h_S} \frac{dH^*(z)}{dz} \frac{dH(z)}{dz} dz. \quad (96)$$

Here we have dropped the indices  $k$ ,  $n$ ,  $m$ , and  $g$ , since they are irrelevant at this point.

By assumption,  $H(z)$  and  $H^*(z)$  are piecewise linear with joints at  $z_S$ ; thus each has the following representation in the subinterval  $[h_{S-1}, h_S]$ :

$$f(z) = \begin{cases} \frac{(z - z_{S-1}) f(z_S) + (z_S - z) f(z_{S-1})}{z_S - z_{S-1}}, & \text{for } h_{S-1} \leq z \leq z_S, \\ \frac{(z - z_S) f(z_{S+1}) + (z_{S+1} - z) f(z_S)}{z_{S+1} - z_S}, & \text{for } z_S \leq z \leq h_S, \end{cases} \quad (97)$$

where  $f(z)$  represents either  $H(z)$  or  $H^*(z)$ .

This representation for  $H(z)$  and  $H^*(z)$  is used in the integral 95, and the resulting quadratic (or cubic if the direction is curvilinear) polynomial is integrated exactly over the subinterval  $[h_{S-1}, h_S]$ . In the same manner, the derivative of the representation 97 is used to approximate the integral 96.

The quadrature formulas resulting from these approximations are moderately accurate in the case of integrals of type 95. These formulas are somewhat less accurate than those used in the inventory modules for diffusion-theory fluxes, since continuity of current has not been accounted for in this case. However, thus far, numerical experience on model problems has indicated that the accuracy of the quadrature formula for 95 is commensurate with the information content of the tabulated values for the trial functions in the following sense. If the trial functions are generated by means of diffusion theory, for the case of model problems, then discrepancies in the flux produced by synthesis versus the flux produced by diffusion theory do not arise from the quadrature formula for 95. Indeed, in the model problems, the discrepancies arose from the quadrature formula for 96. Higher-order quadrature formulas were tried on the model problem in an effort to remove the discrepancies. A quadrature formula for 96 was used which was based on the assumption that  $H(z)$  and  $H^*(z)$  were piecewise quadratics. (In the model problem there were no region boundaries.) The gain in accuracy for this case was only a half place in  $k$ -effective.

Having discussed the quadrature schemes used for approximating Eq. 96, we now describe the procedure by which the cross-section matrices, given by Eqs. 28-38, are generated by this program.

Remembering that the reactor composition structure is a function of  $R$  and  $Z$  but not  $\theta$  allows the reactor to be envisioned as a flat slab. The mesh structure imposed upon the reactor divides it into a

number of mesh cells  $c_{ij}$ ,  $1 \leq i \leq I$  and  $1 \leq j \leq J$ , where  $I$  is the number of intervals in the  $R$  or synthesis direction with  $r_i$ ,  $0 \leq i \leq I$ , as the interval endpoints and  $J$  is the number of intervals in the  $Z$  or transverse direction with  $z_j$ ,  $0 \leq j \leq J$ , as the interval endpoints. Each mesh cell is contained in some reactor region  $R$  which has a unique composition assigned to it. These reactor regions are actually the union of several contiguous rectangles and may cross synthesis boundaries; however, only one composition is assigned to the entire reactor region. The synthesis region boundaries fall on interval boundaries  $z_k$ . Consider a synthesis region  $k$ , and let  $R_{i,j}$  be the region in which the  $ij$  mesh cell lies. Define a cut  $\ell_i$  as the set of mesh cells  $c_{ij}$ ,  $1 \leq j \leq J$ , associated with interval  $i$ . Starting at the first cut  $p$  in synthesis region  $k$ , compare  $R_{p,j}$  and  $R_{p+1,j}$  for all  $j$ . If  $R_{p,j} = R_{p+1,j}$  for all values of  $j$ , then cuts  $p$  and  $p+1$  are said to lie in the same refined region. This comparison is repeated for cuts  $p+1$  and  $p+2$  and continued until cuts  $p+\ell$  and  $p+\ell+1$  are compared with cut  $p+\ell+1$ , the last cut in synthesis region  $k$ . In this manner, the synthesis region  $k$  is divided into  $N$  refined regions. Each refined region  $\bar{r}$  contains a set of contiguous cuts with the property that for any two cuts  $p$  and  $q$  in  $\bar{r}$ ,  $R_{p,j} = R_{q,j}$  for  $1 \leq j \leq J$ ; i.e., all cuts in a refined region are identical. Now for each refined region  $\bar{r}$ , let  $\{\bar{z}_{\bar{r},j}\}$  be the set of mesh-point boundaries dividing the  $j$  and  $(j+1)$ st intervals for which  $R_{p,j} \neq R_{p,j+1}$  with cut  $p$  in refined region  $\bar{r}$ . Then

$$\bigcup_r \{\bar{z}_{r,j}\},$$

where  $r$  is a refined region in synthesis region  $k$ , yields an ordered set of points  $y_\ell$ ,  $1 \leq \ell \leq L_k - 1$ . To this set is added  $y_0 = z_0$  and  $y_{L_k} = z_J$ . These points define the limits of integration for the partial integrals to be defined below. Next define the interval  $[y_{\ell-1}, y_\ell]$  as the  $\ell$ th refined interval in synthesis region  $k$ . Note that the  $(k+1)$ st synthesis region will, in general, have a different region to mesh assignment and hence will not have the same number of refined regions or the same refined interval structure as synthesis region  $k$ .

Defined below are the five types of partial integrals calculated by SYN2D. Each integral is evaluated as the sum of several integrals which are approximated in the manner described previously; i.e.,

$$\int_{y_{\ell-1}}^{y_\ell} H_{gm}^{*k}(z) H_{gn}^k(z) dz = \sum_{s=\underline{s}}^{\bar{s}} \int_{z_{s-1}}^{z_s} H_{gm}^{*k}(z) H_{gn}^k(z) dz$$

with  $z_{\underline{s}-1} = y_{\ell-1}$  and  $z_{\bar{s}} = y_\ell$ . The partial integrals  $I_{g'g}^{mn}$ ,  $J_g^{mn}$ ,  $Q_g^{mn}$ ,  $P_g^{mn}$ , and  $\bar{P}_g^{mn}$  are calculated as follows:

$$I_{g'g}^{mn}(\ell, k) = \int_{y_{\ell-1}}^{y_{\ell}} H_{gm}^{*k}(z) H_{g'n}^k(z) dz, \quad \begin{array}{l} 1 \leq m \leq N_{gk}, \\ 1 \leq n \leq N_{g'k}; \end{array} \quad (98)$$

$$J_g^{mn}(\ell, k) = \int_{y_{\ell-1}}^{y_{\ell}} \frac{dH_{gn}^{*k}(z)}{dz} \frac{dH_{gn}^k(z)}{dz} dz, \quad 1 \leq m, n \leq N_{gk}; \quad (99)$$

$$\hat{P}_g^{mn}(\hat{\ell}, k+1) = \int_{y_{\hat{\ell}-1}}^{y_{\hat{\ell}}} H_{gm}^{*k}(z) H_{gn}^{k+1}(z) dz, \quad \begin{array}{l} 1 \leq m \leq N_{gk}, \\ 1 \leq n \leq N_{g, k+1}; \end{array} \quad (100)$$

$$P_g^{mn}(\ell, k) = \int_{y_{\ell-1}}^{y_{\ell}} H_{gm}^{*k+1}(z) H_{gn}^k(z) dz, \quad \begin{array}{l} 1 \leq m \leq N_{g, k+1}, \\ 1 \leq n \leq N_{gk}; \end{array} \quad (101)$$

$$Q_g^{mn}(\ell, k) = \int_{y_{\ell-1}}^{y_{\ell}} H_{gm}^{*k}(z) H_{gn}^{k+1}(z) dz, \quad \begin{array}{l} 1 \leq m \leq N_{gk}, \\ 1 \leq n \leq N_{g, k+1}; \end{array} \quad (102)$$

with  $\ell$  a refined interval in synthesis region  $k$ , and  $\hat{\ell}$  a refined interval in synthesis region  $k+1$ .

Now the integrals defined in Eqs. 28-34 can be expressed as weighted sums of the above partial integrals expressed in the following form:

$$D_{gk}^{mn}(\bar{r}) = \sum_{\ell} D_g(\bar{r}, z_{\ell}) I_{g'g}^{mn}(\ell, k), \quad (103)$$

$$L_{gk}^{mn}(\bar{r}) = \sum_{\ell} D_g(\bar{r}, z_{\ell}) J_g^{mn}(\ell, k), \quad (104)$$

$$\Sigma_{gk}^{mn}(\bar{r}) = \sum_{\ell} \Sigma_{rg}(\bar{r}, z_{\ell}) I_{gg}^{mn}(\ell, k), \quad (105)$$

$$\Sigma_{g'g, k}^{mn}(\bar{r}) = \sum_{\ell} \Sigma_{g'g}(\bar{r}, z_{\ell}) I_{g'g}^{mn}(\ell, k), \quad (106)$$

$$(\chi_{g'g'}^{\nu_{g'}\Sigma_{fg'}})^{mn}(\bar{r}) = \sum_{\ell} (\chi_{g'g'}^{\nu_{g'}\Sigma_{fg'}})(\bar{r}, z_{\ell}) I_{g'g'}^{mn}(\ell, k), \quad (107)$$

and

$$W_{gk}^{mn} = \sum_{\ell} I_{gg}^{mn}(\ell, k), \quad k = 1 \text{ and } K, \quad (108)$$

where  $z_{\ell} = 0.5 (y_{\ell} - y_{\ell-1})$ ,  $\ell$  a refined interval in synthesis region  $k$ , and  $\bar{r}$  a refined region in synthesis region  $k$ .

The integrals defined for the Luco interface in Section 6 are defined as follows:

$$A_{gk}^{mn} = B_{gk}^{mn} = \sum_{\ell} D_g(R_k^-, z_{\ell}) I_{gg}^{mn}(\ell, k), \quad (109)$$

$$\bar{A}_{g(k+1)}^{mn} = \sum_{\ell} D_g(R_k^-, z_{\ell}) Q_g^{mn}(\ell, k), \quad (110)$$

and

$$\bar{B}_{g(k+1)}^{mn} = \sum_{\ell} D_g(R_k^-, z_{\ell}) P_g^{mn}(\ell, k), \quad (111)$$

with  $\ell$ ,  $z_{\ell}$ , and  $\bar{r}$  as previously defined.

The integrals defined for the Stacey interface in Eqs. 55-58 are defined below, with  $\hat{\ell}$  a refined interval in synthesis region  $k+1$  and  $z_{\hat{\ell}} = 0.5 (y_{\hat{\ell}} - y_{\hat{\ell}-1})$ :

$$\hat{V}_{gk}^{mn} = \sum_{\ell} \left[ I_{gg}^{mn}(\ell, k) + P_g^{mn}(\ell, k) \right], \quad (112)$$

$$\hat{W}_{g(k+1)}^{mn} = \sum_{\hat{\ell}} \left[ I_{gg}^{mn}(\hat{\ell}, k+1) + \hat{P}_g^{mn}(\hat{\ell}, k+1) \right], \quad (113)$$

$$\hat{K}_{gk}^{mn} = \sum_{\ell} D_g(R_k^-, z_{\ell}) \left[ I_{gg}^{mn}(\ell, k) + \hat{P}_g^{mn}(\ell, k) \right], \quad (114)$$

$$\hat{L}_{g(k+1)}^{mn} = \sum_{\hat{\ell}} D_g(R_k^+, z_{\hat{\ell}}) \left[ I_{gg}^{mn}(\hat{\ell}, k+1) + \hat{P}_g^{mn}(\hat{\ell}, k+1) \right]. \quad (115)$$

Defining partial integrals and then using weighted sums to calculate the required integrals has several advantages. First, less computation is required, since many of the integrals differ only in the cross sections used as weighting coefficients, i.e.,  $D_{gk}^{mn}(\bar{r})$  and  $\Sigma_{gk}^{mn}(\bar{r})$  of Eqs. 103 and 105. Second, it is anticipated that the users of SYN2D will be running successive test cases using reactors that are identical in mesh structure, synthesis region definitions, and mesh-point-to-reactor-region assignments, but will differ in the compositions assigned to each reactor region. Generating partial integrals once and saving the results allows successive cases to be run without the necessity of regenerating the same partial integrals for each run and thus effects a savings in time.

Finally, note that the integrals defined by Eqs. 103-107 are defined for every refined region of the reactor. Any integral required by the finite-difference algorithm is computed over some cut  $p$  which lies in some refined region  $\bar{r}$ . Thus the set of integrals defined by Eqs. 103-107 contains the required integrals for all cuts of the reactor.

## 8. Other Geometries and Synthesis-region Configurations

Now with only minor modifications of the discussion in Section 7 above, two additional cases can be considered:

- a. The same cylindrical reactor but with synthesis regions defined as axial slabs, starting at the reactor bottom, or
- b. A flat slab reactor bounded by the planes  $0 \leq x \leq a$ ,  $0 \leq y \leq h$ , which can be of either bounded or unbounded length in the  $z$  direction. The  $k$ th synthesis region is then a slab of the form  $x_{k-1} \leq x \leq x_k$ ,  $0 \leq y \leq b$ , and all  $z$ , where  $x_0$  and  $x_K$  equal 0 and  $a$ , respectively.

The variational functional to be used for Case a is

$$\begin{aligned}
 J \left[ u_g^k(r, z), u_g^{k*}(r, z), \alpha_g^k(z), \beta_g^k(z) \right] &\equiv \sum_{k=1}^K \left\langle 2\pi \int_{V_k} \sum_{g=1}^G \left\{ \nabla u_g^{k*} \cdot D_g \nabla u_g^k \right. \right. \\
 &+ u_g^{k*} \left[ \Sigma_{rg} u_g^k - \sum_{g'=1}^{G-1} \Sigma_{g'g} u_{g'}^k - \lambda \chi_g \sum_{g'=1}^G (v \Sigma_f)_{g'} u_{g'}^k \right] \left. \right\rangle r \, dr \, dz \\
 &- \sum_{k=1}^{K-1} \left\langle 2\pi \int_0^R \sum_{g=1}^G \alpha_g^k \left[ u_g^{(k+1)}(r, z_k) - u_g^k(r, z_k) \right] \right. \\
 &+ \left. \left[ u^{(k+1)*}(r, z_k) - u_g^{k*}(r, z_k) \right] \beta_g^k \right\rangle r \, dr
 \end{aligned} \tag{116}$$

(Contd.)

$$\begin{aligned}
& + \sum_{g=1}^G \left[ \sum_{k=1}^K \left\langle 2\pi R \theta \int_{z_{(k-1)}}^{z_k} \left\{ \gamma C_{gk}^R u_g^{k*}(R, z) u_g^k(R, z) \right. \right. \right. \\
& + (\gamma - 1) \left[ u_g^{k*}(R, z) D_g \frac{\partial u_g^k}{\partial r} \Big|_{r=R} + u_g^k(R, z) D_g \frac{\partial u_g^{k*}}{\partial r} \Big|_{r=R} \right] \Big\} dz \\
& + 2\pi \int_{z_{(k-1)}}^{z_k} \frac{\partial u_g^{k*}}{\partial r} \Big|_{r=0} \cdot \frac{\partial u_g^k}{\partial r} \Big|_{r=0} dz \Big\rangle \\
& + \zeta 2\pi \int_0^R \left\{ \alpha C_{gK}^T u_g^{K*}(r, h) u_g^K(r, h) + (\alpha - 1) \left[ u_g^{K*}(r, h) D_g \frac{\partial u_g^K}{\partial z} \Big|_{z=h} \right. \right. \\
& + \left. \left. u_g^K(r, h) D_g \frac{\partial u_g^{K*}}{\partial z} \Big|_{z=h} \right] \right\} r dr + \eta 2\pi \int_0^R \left\{ \beta C_{gK}^B u_g^{1*}(r, 0) u_g^1(r, 0) \right. \\
& + \left. (1 - \beta) \left[ u_g^{1*}(r, 0) D_g \frac{\partial u_g^1}{\partial z} \Big|_{z=0} + u_g^1(r, 0) D_g \frac{\partial u_g^{1*}}{\partial z} \Big|_{z=0} \right] \right\} r dr, \tag{Contd.} \\
& \tag{116}
\end{aligned}$$

where  $V_k$  is the volume between  $z_{k-1} \leq z \leq z_k$ ,  $0 \leq r \leq R$ .

The  $K$  synthesis regions have as their boundaries  $z_k$ , where  $0 < z_1 < \dots < z_{k-1} < h$ ;  $u_g^{k*}(r, z), u_g^k(r, z)$  are independent-variable functions defined as previously in the  $k$ th synthesis region;  $\alpha_g^k(r), \beta_g^k(r)$  are functions of  $r$  only, defined at the surfaces  $z = z_k$ .

Now proceeding in the same manner as previously, i.e., using Green's theorem and varying  $u_g^{k*}(r, z)$  and  $\alpha_g^k(r)$  arbitrarily, we obtain the following necessary conditions for stationariness, where  $\varphi_g^k$  and  $j_g^k$  are written for the stationary values of  $u_g^k$  and  $\beta_g^k$ :

$$-\nabla \cdot (D_g \nabla \varphi_g^k) + \Sigma_{rg} \varphi_g^k - \sum_{g'=1}^{g-1} \Sigma_{g'g} \varphi_{g'}^k - \lambda \chi_g \sum_{g'=1}^G (\nu \Sigma_{fg})_{g'} \varphi_{g'}^k = 0,$$

$$k = 1, \dots, K; \tag{117}$$

$$\varphi_g^{(k+1)}(r, z_k) = \varphi_g^k(r, z_k), \quad k = 1, \dots, K - 1; \tag{118}$$

$$j_g^k(r) = -D_g \left. \frac{\partial \varphi_g^k}{\partial z} \right|_{z=z_k} = -D_g \left. \frac{\partial \varphi_g^{k+1}}{\partial z} \right|_{z=z_k}, \quad k = 1, \dots, K-1; \quad (119)$$

$$\left. \begin{aligned} \theta C_{gk}^R \varphi_g^k(R, z) &= -\gamma D_g \left. \frac{\partial \varphi_g^k}{\partial r} \right|_{r=R} \\ \frac{\partial \varphi_g^k}{\partial r} \Big|_{r=0} &= 0 \end{aligned} \right\} \quad k = 1, \dots, K; \quad (120)$$

$$\zeta C_{gK}^T \varphi_g^K(r, h) = -\alpha D_g \left. \frac{\partial \varphi_g^K}{\partial z} \right|_{z=h}; \quad (122)$$

and

$$\beta C_{gK}^B \varphi_g^1(r, 0) = +\eta D_g \left. \frac{\partial \varphi_g^1}{\partial z} \right|_{z=0}; \quad (123)$$

with  $g = 1, \dots, G$  in all these equations. These equations correspond to Eqs. 8-14. Hence,  $\varphi_g^k$  and  $j_g^k$  provide the solution to the variational problem. The equations for  $\varphi_g^{k*}$  and  $j_g^{k*}$  could be obtained in a similar manner by varying  $\varphi_g^k(r, z)$  and  $\beta_g^k(r)$ . Now our synthesis assumptions are

$$u_g^k(r, z) = \sum_{n=1}^{N_g^k} H_{gn}^k(r) T_{gn}^k(z) \quad (124)$$

and

$$u_g^{k*}(r, z) = \sum_{n=1}^{N_g^k} H_{gn}^{k*}(r) T_{gn}^k(z) \quad (125)$$

where, as before,  $H_{gn}^k(r)$  and  $H_{gn}^{k*}(r)$  are the known trial functions and  $T_{gn}^k(z)$  and  $T_{gn}^{k*}(z)$  are the unknown functions to be determined.

Finally, the functions  $\beta_g^k(r)$  and  $\alpha_g^k(r)$  are defined as

$$\beta_g^k(r) = \sum_{n=1}^{M_g^k} B_{gn}^k(r) b_{gn}^k, \quad k = 1, \dots, K-1, \quad g = 1, \dots, G, \quad (126)$$

and

$$\alpha_g^k(r) = \sum_{n=1}^{M_g^k} A_{gn}^k(z) a_{gn}^k, \quad k = 1, \dots, K-1, \quad g = 1, \dots, G. \quad (127)$$

Substituting Eqs. 124-127 in Eq. 116 and using the same vector convention as before, we obtain the reduced functional  $J'$ . The reduced functional is

$$\begin{aligned} J' \left[ T_{gn}^k(z), T_{gm}^{k*}(z), b_{gn}^k, a_{gm}^k \right] &\equiv \sum_{g=1}^G \left\langle \sum_{k=1}^K \int_{z_{(k-1)}}^{z_k} 2\pi dz \left( \frac{d\bar{T}_g^{k*}}{dz} \left[ D_g^k \right]_1 \frac{d\bar{T}_g^k}{dz} \right. \right. \\ &+ \bar{T}_g^{k*} \left\{ \left[ L_g^k \right]_1 + \left[ \Sigma_g^k \right]_1 + \left[ C_g^k \right]_1 \right\} \bar{T}_g^k - \sum_{g'=1}^{g-1} \bar{T}_g^{k*} \left[ \Sigma_{g'}^k \right]_1 \bar{T}_{g'}^k, \\ &- \lambda \sum_{g'=1}^G \bar{T}_g^{k*} \left\{ \left[ \chi_{g'}(\nu \Sigma_f)_{g'} \right]_1^k \right\} \bar{T}_{g'}^k \left. \right\rangle + \sum_{g=1}^G \left\langle \sum_{k=1}^{K-1} \left[ 2\pi \bar{a}_g^k \left\{ \left[ A_g^k \right]_1 \bar{T}_g^k(z_k) \right. \right. \right. \\ &- \left. \left. \left[ \bar{A}_g^{(k+1)} \right]_1 \bar{T}_g^{(k+1)}(z_k) \right\} + 2\pi \left\{ \bar{T}_g^{k*}(z_k) \left[ B_g^k \right]_1 - \bar{T}_G^{(k+1)*}(z_k) \left[ \bar{B}_g^{(k+1)} \right]_1 \bar{b}_g^k \right\} \right. \\ &+ 2\pi \left\{ \alpha \zeta C_g^T \bar{T}_g^{K*}(h) \left[ W_g^K \right]_1 \bar{T}_g^K(h) + \zeta(\alpha - 1) \left[ \bar{T}_g^{K*} \left[ D_g^K \right]_1 \frac{d\bar{T}_g^K}{dz} \right]_{z=h} \right. \\ &+ \left. \left. \bar{T}_g^K \left[ D_g^K \right]_1 \frac{d\bar{T}_g^{K*}}{dz} \right]_{z=h} + \eta \beta C_{g1}^B \bar{T}_g^{1*}(0) \left[ W_g^1 \right]_1 \bar{T}_g^1(0) \right. \\ &\left. \left. + \eta(1 - \beta) \left[ \bar{T}_g^{1*} \left[ D_g^1 \right]_1 \frac{d\bar{T}_g^1}{dz} \right]_{z=0} + \bar{T}_g^1 \left[ D_g^1 \right]_1 \frac{d\bar{T}_g^{1*}}{dz} \right]_{z=0} \right. \left. \right\rangle. \quad (128) \end{aligned}$$

Now the matrices  $\left[ D_g^k \right]_1$ ,  $\left[ L_g^k \right]_1$ ,  $\left[ \Sigma_g^k \right]_1$ ,  $\left[ \Sigma_{g'}^k \right]_1$ ,  $\left[ (\chi_{g'}(\nu \Sigma_f)_{g'})^k \right]_1$ ,  $\left[ A_g^k \right]_1$ ,  $\left[ \bar{A}_g^{(k+1)} \right]_1$ ,  $\left[ B_g^k \right]_1$ ,  $\left[ \bar{B}_g^{(k+1)} \right]_1$ ,  $\left[ W_g^K \right]_1$ , and  $\left[ W_g^1 \right]_1$  are defined in a manner similar to the definitions given by Eqs. 28-38. The only difference is that

the integrands are functions of  $r$ , not  $z$ , the limits are 0 to  $R$ , not 0 to  $h$ , and the differential is  $r dr$  instead of  $dz$ .  $[C_g^k]_1$  is given by the expression

$$R \theta \left[ \gamma C_{gk}^R H_{gm}^{k*}(R) H_{gn}^k(R) + (\gamma - 1) D_g(R, z) \left[ H_{gm}^{k*}(R) H_{gn}^{k'} \Big|_{r=R} + H_{gm}^{k*'} \Big|_{r=R} \cdot H_{gn}^k(R) \right] \right. \\ \left. + \left( H_{gm}^{k*'} \Big|_{r=0} \cdot H_{gn}^{k'} \Big|_{r=0} \right) = C_{gk}^{mn}(z). \quad (129)$$

The presence of the  $r$  in each integral does not bother the algorithm used in computing the integrals; it simply has the effect of adding an extra  $z$  to the integrands, which makes the integrands as defined in Section 7 third-degree polynomials.

Now integrating the double gradient term of Eq. 128 by parts, we have

$$J' \equiv \sum_{g=1}^G \left\{ \sum_{k=1}^K \left\langle \int_{z_{(k-1)}}^{z_k} 2\pi dz \bar{T}_g^{k*} \left( -\frac{d}{dz} \left\{ [D_g^k]_1 \frac{d\bar{T}_g^k}{dz} \right\} + \left\{ [L_g^k]_1 + [\Sigma_g^k]_1 + [C_g^k]_1 \right\} \bar{T}_g^k \right. \right. \right. \\ \left. \left. - \sum_{g'=1}^{g-1} [\Sigma_{g'}^k]_1 \bar{T}_{g'}^k + \lambda \sum_{g'=1}^G \left\{ [\chi_g(\nu\Sigma_f)_{g'}]^k \right\}_1 \bar{T}_g^k \right\rangle + 2\pi \sum_{k=1}^{K-1} \left\langle \bar{a}_g^k \left\{ [A_g^k]_1 \bar{T}_g^k(z_k) \right. \right. \right. \\ \left. \left. - [A_g^{(k+1)}]_1 \bar{T}_g^{(k+1)}(z_k) \right\} + \bar{T}_g^{k*}(z_k) \left\{ [D_g^k]_1 \frac{d\bar{T}_g^k}{dz} \Big|_{z=z_k} + [B_g^k]_1 \bar{b}_g^k \right\} \right. \\ \left. - \bar{T}_g^{(k+1)*}(z_k) \left\{ [D_g^{(k+1)}]_1 \frac{d\bar{T}_g^{(k+1)}}{dz} \Big|_{z=z_k} + [B_g^{(k+1)}]_1 \bar{b}_g^{(k+1)} \right\} \right\rangle \\ \left. + 2\pi \left\{ \zeta \alpha C_{gK}^T \bar{T}_g^{K*}(h) [W_g^K]_1 \bar{T}_g^K(h) + [\zeta(\alpha - 1) + 1] \left[ \bar{T}_g^{*}(h) [D_g^K]_1 \frac{d\bar{T}_g^K}{dz} \Big|_{z=h} \right] \right. \right. \\ \left. + \zeta(\alpha - 1) \left[ \bar{T}_g^K(h) [D_g^K]_1 \frac{d\bar{T}_g^{K*}}{dz} \Big|_{z=h} \right] + \eta \beta C_{g1}^B \bar{T}_g^{1*}(0) [W_g^1]_1 \bar{T}_g^1(0) \right. \\ \left. + \left[ \eta(1 - \beta) - 1 \right] \left[ \bar{T}_g^{1*}(0) [D_g^1]_1 \frac{d\bar{T}_g^1}{dz} \Big|_{z=0} \right] + \eta(1 - \beta) + \bar{T}_g^1(0) [D_g^1]_1 \frac{d\bar{T}_g^{1*}}{dz} \Big|_{z=h} \right\}. \quad (130)$$

Now using matrix notation and arbitrarily varying independent-variable functions  $T_{gm}^{k*}(z)$  and  $a_{gm}^k$ , we obtain the following conditions for stationariness, with  $T_{gn}^k(z)$  and  $b_{gn}^k$  replaced by  $\psi_{gn}^k(z)$  and  $j_{gn}^k$ , respectively. The reduced Euler equation is

$$-\frac{d}{dz} \left( [D_g^k]_1 \frac{d\bar{\psi}_g^k}{dz} \right) + [\Sigma_{Rg}^k]_1 \bar{\psi}_g^k - \sum_{g'=1}^{g-1} [\Sigma_{g'g}^k]_1 \psi_{g'}^k - \lambda \sum_{g'=1}^G \left\{ [X_{g'}(\nu \Sigma_{f'}^k)]^k \right\} \bar{\psi}_{g'}^k = 0 \quad (131)$$

in volumes  $V_k$ ,  $k = 1, 2, \dots, K$ , where

$$[\Sigma_{Rg}^k]_1 = [L_g^k]_1 + [\Sigma_g^k]_1 + [C_g^k]_1.$$

At the synthesis-region interfaces  $z_k$ ,

$$[A_g^k]_1 \bar{\psi}_g^k(z_k) = [\bar{A}_g^{(k+1)}]_1 \bar{\psi}_g^{(k+1)}(z_k), \quad (132)$$

$$[D_g^k]_1 \frac{d\bar{\psi}_g^k}{dz} \Big|_{z=z_k} + [B_g^k]_1 \bar{j}_g^k = 0, \quad (133)$$

and

$$[D_g^{(k+1)}]_1 \frac{d\bar{\psi}_g^{(k+1)}}{dz} \Big|_{z=z_k} + [\bar{B}_g^{(k+1)}]_1 \bar{j}_g^k = 0. \quad (134)$$

At the reactor top,

$$\alpha [D_g^K]_1 \frac{d\bar{\psi}_g^K}{dz} \Big|_{z=h} + \zeta C_{gK}^T [W_g^K] \bar{\psi}_g^K(h) = 0, \quad (135)$$

and at the reactor bottom,

$$\beta [D_g^1]_1 \frac{d\bar{\psi}_g^1}{dz} \Big|_{z=0} - \eta C_{gK}^B [W_g^1] \bar{\psi}_g^1(0) = 0. \quad (136)$$

The adjoint equations could be obtained in a similar fashion.

The finite-difference approximation that will be used to solve the system of equations (Eqs. 131-136) is essentially the same as that previously used. The reactor domain in this case is the interval  $[0, h]$  with the mesh  $0 = \rho_0 < \dots < \rho_I = h$ . Now in any interval  $[\rho_{i-1}, \rho_i]$ , we have a differential system consisting of the interface conditions of Eq. 65 along with the equation

$$-\frac{d}{dz} \left( D_i \frac{d\psi}{dz} \right) + (\Sigma_R)_i \psi = f_i(z).$$

Generating  $\Omega_i$  and integrating the above equation with respect to  $z$  yields, in the same fashion as before, the matrices

$$\left. \begin{aligned} G_i &= B_i \Omega_i^{-1} \hat{A}_i, \quad N_i \times N_{i+1}, \quad i = 1, 2, \dots, I-1; \\ H_i &= \hat{B}_{i-1} \Omega_i^{-1} A_{i-1}, \quad N_i \times N_{i-1}, \quad i = 2, 3, \dots, I; \\ E_i &= B_i \Omega_i^{-1} A_i + \hat{B}_{i-1} \Omega_i^{-1} \hat{A}_{i-1} + V_i \Sigma_R i, \quad i = 2, 3, \dots, I-1; \\ E_1 &= B_1 \Omega_1^{-1} A_1 + D_1 \left[ \eta D_1 + \frac{\beta}{2} C_{g1}^B \delta_1 W_1 \right]^{-1} \beta C_{g1}^B W_1 + V_1 \Sigma_R I; \end{aligned} \right\} (137)$$

and

$$E_I = D_I \left[ \alpha D_I + \frac{\zeta}{2} C_{gK}^T \delta_I W_I \right]^{-1} \zeta C_{gK}^T W_I + \hat{B}_{I-1} \Omega_I^{-1} \hat{A}_{I-1} + V_I \Sigma_R I;$$

where

$$\delta_i = \rho_i - \rho_{i-1}, \quad W_I = \begin{bmatrix} W_g^K \end{bmatrix}, \quad W_1 = \begin{bmatrix} W_g^1 \end{bmatrix}, \quad \text{and } V_i = \delta_i.$$

From this point the discussion reverts to that for Eqs. 69-76, and we have solved for the unknown functions  $T_{gn}^k(z)$ .

For Case b, the variational functional to be used is

$$\begin{aligned} J \left[ u_g^k(x, y), u_g^{k*}(x, y), \alpha_g^k(y), \beta_g^k(y) \right] &= \sum_{k=1}^K \left\langle \int_{V_k} \sum_{g=1}^G \left\{ \nabla u_g^{k*} \cdot D_g \nabla u_g^k \right. \right. \\ &+ u_g^{k*} \left[ \Sigma_{rg} u_g^k - \sum_{g'=1}^{G-1} \Sigma_{g'g} u_{g'}^k - \lambda \chi_g \sum_{g'=1}^G (\nu \Sigma_f)_{g'} u_{g'}^k \right] \left. \right\rangle dx dy \\ &- \sum_{k=1}^{K-1} \left\langle \int_0^h \sum_{g=1}^G \alpha_g^k \left[ u_g^{(k+1)}(x_k, y) - u_g^k(x_k, y) \right] + \left[ u_g^{(k+1)*}(x_k, y) \right. \right. \\ &\left. \left. - u_g^{k*}(x_k, y) \right] \beta_g^k \right\rangle dy + \sum_{g=1}^G \left[ \sum_{k=1}^K \left\langle \int_{x_{(k-1)}}^{x_k} \left\{ \alpha C_{gk}^T u_g^{k*}(x, h) u_g^k(x, h) \right. \right. \right. \end{aligned} \quad (138)$$

(Contd.)

$$\begin{aligned}
& + (\alpha - 1) \left[ u_g^{k*}(x, h) D_g \frac{\partial u_g^k}{\partial y} \Big|_{y=h} + u_g^k(x, h) D_g \frac{\partial u_g^{k*}}{\partial y} \Big|_{y=h} \right] dx \\
& + \eta \int_{x(x_{k-1})}^{x_k} \left\{ \beta C_{gk}^B u_g^{k*}(x, 0) u_g^k(x, 0) + (1 - \beta) \left[ u_g^{k*}(x, 0) D_g \frac{\partial u_g^k}{\partial y} \Big|_{y=0} \right. \right. \\
& \left. \left. + u_g^k(x, 0) D_g \frac{\partial u_g^{k*}}{\partial y} \Big|_{y=0} \right] \right\} dx + \theta \int_0^h \left\{ \gamma C_{gK}^R u_g^{K*}(a, y) u_g^K(a, y) \right. \\
& \left. + (\gamma - 1) \left[ u_g^{K*}(a, y) D_g \frac{\partial u_g^K}{\partial x} \Big|_{x=a} + u_g^K(a, y) D_g \frac{\partial u_g^{K*}}{\partial x} \Big|_{x=a} \right] \right\} dy \\
& + \epsilon \int_0^h \left\{ \delta C_{g1}^L u_g^{1*}(0, y) u_g^1(0, y) + (1 - \delta) \left[ u_g^{1*}(0, y) D_g \frac{\partial u_g^1}{\partial x} \Big|_{x=0} \right. \right. \\
& \left. \left. + u_g^1(0, y) D_g \frac{\partial u_g^{1*}}{\partial x} \Big|_{x=0} \right] \right\} dy.
\end{aligned}
\tag{138}$$

(Contd.)  
(138)

Upon varying  $u_g^{k*}$  and  $u_g^k$ , the functional yields Eqs. 8-13 as the conditions of stationariness, where  $x_k$  replaces  $R_k$ ,  $y$  replaces  $z$ ,  $x$  replaces  $r$ , and  $a$  replaces  $R$ , while in place of Eq. 14 we have

$$\delta C_{g1}^L \varphi_g^k(0, y) = +\epsilon D_g \frac{\partial \varphi_g^1}{\partial x} \Big|_{x=0}.
\tag{139}$$

The synthesis assumptions used are Eqs. 23-26 with  $x$  and  $y$  instead of  $r$  and  $z$ . Substituting these synthesis assumptions in Eq. 138 yields the reduced functional Eq. 128 with  $2\pi$ ,  $\alpha$ ,  $\zeta$ ,  $C_{gK}^T$ ,  $\eta$ ,  $\beta$ ,  $C_{g1}^B$ , and  $z$  replaced by  $1$ ,  $\theta$ ,  $\gamma$ ,  $C_{gK}^R$ ,  $\epsilon$ ,  $\delta$ ,  $C_{g1}^L$ , and  $x$ , respectively. The matrices are defined by Eqs. 28-38 with  $z$  replaced by  $y$ . The technique for solving this reduced functional is the same as for Eq. 128, since Eq. 130 and all that follows is applicable.

## C. General Program Description

### 1. Capabilities

a. Geometry Types. The module SYN2D is capable of handling three geometry types, X-Y, R-Z, and Z-R. The first type, X-Y, indicates a rectangular reactor being synthesized in the X direction with the trial functions as functions of Y. In the second case, R-Z, the reactor is a right circular cylinder being synthesized in the radial direction with the trial functions as functions of Z. The Z-R geometry is again a right circular cylinder; however, in this case the direction of synthesis is the Z-axis, while the trial functions are functions of R. In both the R-Z and Z-R geometries, there is no dependence upon  $\theta$ .

b. Boundary-condition Types. The following boundary conditions can be applied at the external faces of the reactor. The ability of the code to satisfy these conditions will ultimately depend upon the trial functions supplied and how well they can be combined. The acceptable boundary conditions for each face are

$$(1) \quad \varphi = 0;$$

$$(2) \quad \frac{\partial \varphi}{\partial n} = 0;$$

and

$$(3) \quad \frac{\partial \varphi}{\partial n} + \frac{B}{D} \varphi = 0,$$

where D is the diffusion coefficient at the edge, and B is a user-supplied constant which can vary with group and refined region.

In X-Y geometry there are four faces at which boundary conditions are applied, and any of the above may be used. However, in R-Z for the fourth face on the left ( $R = 0$ ), and in Z-R for the first face on the bottom ( $R = 0$ ), only condition type 1 may be applied. In the direction of synthesis, the same boundary condition must be applied over the entire face for a given group, but may vary from group to group. In a nonsynthesis direction, the boundary condition used may vary with each group and refined region. For a discussion of refined regions, see Section 1.g below.

c. Calculation Type. The only calculation of which SYN2D is capable is a real homogeneous k-effective calculation.

d. Energy-group Structure. Only downscattering is allowed; however, there is no limit to the number of groups that are downscattered into from each energy group.

e. Fission-spectrum Type. Only  $\chi$  vectors can be presently handled. Thus  $\chi$  is only a function of composition and group.

f. Buckling. Buckling in the Z direction can be accepted when the geometry type is X-Y. Otherwise, no buckling is allowed.

g. Synthesis-region Structure. Synthesis-region boundaries may be placed anywhere; however, they must lie on mesh-cell boundaries.

At least two synthesis regions must be defined. There is no upper limit to the number of regions defined.

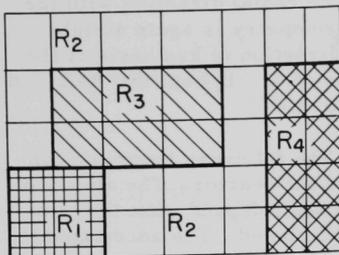


Fig. 2. Typical Synthesis Region

Consider a particular synthesis region. It will be bounded on the left and right by synthesis boundaries and will contain intervals in the synthesis direction. Now consider the one-dimensional cuts obtained from each interval by moving in the direction perpendicular to the synthesis direction. (Figure 2 illustrates a typical synthesis region containing four reactor regions,  $R_1$ ,  $R_2$ ,  $R_3$ , and  $R_4$ , plus the imposed mesh structure.) When two adjacent cuts differ, a change has taken place. A group of contiguous intervals which produce the same cut is called a refined region. Figure 2 contains 7 intervals and five refined regions. The intervals defining the five refined regions are 1, 2, 3-4, 5, 6-7. The union of the refined regions for all synthesis regions yields the set of refined regions for the problem.

h. Trial-function Structure. The real and adjoint trial functions on the input-data sets are paired together, depending upon their position on each library. Thus, the  $n$ th real trial function is paired with the  $n$ th adjoint trial function. The number of trial functions used can be varied by group within a synthesis region and can also vary between different synthesis regions, subject to Section 1.i below. This scheme provides the user with a great deal of flexibility.

i. Synthesis Interface Conditions. Since each synthesis region is independent of all other regions, some relationship between regions must be imposed in order to solve the finite-difference equations. The two interface conditions listed below provide the relations necessary to calculate the mixing functions. The asymmetric interface condition considers each synthesis boundary by using the trial functions in the region to the left only as the connecting link. The symmetric interface condition considers the trial functions on both sides of the synthesis boundary. This second condition provides a symmetry that would not be present in the first case. It does, however, require that there be a constant number of trial functions used for each group and all synthesis regions. No such restriction is imposed when the asymmetric interface is used.

A more complete discussion of these interface conditions appears in Section 6.

j. Region and Composition Assignments. The definition of the mesh structure, placement of the reactor regions, and assignment of the various compositions to these regions are handled by the ARC System module GNIP (NUI002) using the A.NIP data set.

k. Restart Capabilities. When running problems of a similar nature, one can achieve large savings in time if certain data sets are saved. The boundary conditions, geometry-mesh structure, regions, compositions, and composition-to-region assignments, the code-generated trial-function libraries, the code-computed partial integrals, and the code-calculated mixing functions all can be saved for later runs. Subsequent runs then need change only selected data sets. See Section 2.g (below) for more information on this feature.

l. Problem Size and Storage Requirements. The synthesis module is capable of running quite large problems which require considerable core storage. All storage is allocated dynamically. This allows great flexibility in the sizes of various arrays. The main core storage available is approximately 60,000-70,000 double words. This varies, depending upon the data sets open and their buffer sizes. The bulk core available is approximately 125,000 double words, but it can also vary.

Listed below are formulas for the core requirements of the largest arrays in each section of the computation.

<u>Formula</u>	<u>Section</u>
$N\{J[\max(G,K)] + GK\}$	Problem-dependent trial-function library generation
$J(8N+2) + N^2R$	Partial integral generation
$N^2\{3I + 2RR + 4K + \overline{RR}(2G - 1) + R\}$	Finite-difference matrix generation
$N[I(1 + 2N + 2G) + NG]$	Power iteration
$J(I+N) + GIN$	Flux reconstitution
$J(2I+1) + R(9G+8) + 7G + I$	Standard output calculation

Here,

G is the number of energy groups,

I is the number of points in the synthesis direction,

J is the number of points in the trial-function direction,

K is the number of synthesis regions,

N is the  $\max_k(N_k)$ , where  $N_k$  is the largest number of real trial

functions per synthesis region k taken over all energy groups,

R is the number of reactor regions,  
 RR is the number of refined regions,

and

$\overline{RR}$  is the  $\max_k(RR_k)$ , where  $RR_k$  is the number of refined regions  
 in synthesis region k.

Now given a particular problem, the values of these parameters are either known or can be easily calculated. Substitution into the above formulas yields six numbers. The largest of these numbers, L, represents the core requirements of the largest arrays. Addition of 5-10% more core for smaller arrays should yield the number of double words required by the POINTR container array. Thus for a problem in which  $G = 20$ ,  $I = J = 50$ ,  $K = 10$ ,  $N = 5$ ,  $R = 20$ ,  $RR = 25$ , and  $\overline{RR} = 4$ , a main core POINTR allocation of 14,500 double words with a bulk core allocation of zero double words would be sufficient.

The algorithms used above indicate minimal core requirements. Increasing the size of the container array above this figure will increase the efficiency of POINTR and may allow the trial functions to be held in core for the library generation step.

## 2. User Options

a. Interface Conditions. Either the asymmetric or symmetric interface conditions may be used. See Section 1.i above.

b. Adjoint Option. The user can specify that the real trial functions be used for both the real and adjoint trial functions, or he can specify both real and adjoint trial functions.

c. Print Options. The user can specify the amount of printout he wishes to receive. There are three levels. The first provides minimal output only; the last provides a total output capability. The second provides a fairly extensive but not total capability. The user should experiment to see which type he really requires. (See Section G.2 for a more detailed explanation of the options.) The less printout required, the faster the module will run.

d. Error-print Options. Should an error be suspected, the user can print out the POINTR arrays which hold the various matrices and check their values, using the POINTR debugging flag.

e. Preprocessing Option. This option provides the capability of generating the partial integrals and trial-function libraries and then terminating the calculation. These data sets would then be used in a later run. (See Section 2.g below.)

f. Boundary-matrix Option. In a given synthesis region the boundary conditions applied at the reactor top face, bottom face, or both faces could be  $\phi = 0$ . In this case, some of the trial functions (both real and adjoint of each pair) may be known to satisfy the condition on the face or faces where it applies. The user can indicate these functions, and the code when it calculates the associated boundary matrices will use this fact. This can eliminate some of the computational error and produce a slightly better k-effective.

g. Restart Options. Section 1.k above indicates the capabilities the user has to save data sets. The saving of ARC System data sets BC and GEOM will save a call to the GNIP module by the path STP008. Saving the data set XS.C.MIN saves calls to the modules INHOMG and HOMOG. If SYN2D is being used independently of the path STP008, then the user's path will dictate whether these data sets can be saved.

Since XS.C.MIN involves only the composition cross-section data, it may be changed independently of other data sets. BC contains the boundary condition information, while GEOM contains the mesh-structure and region-structure information. Changes in either of these types of data will require a call to GNIP. FR.TG contains the calculated mixing functions. Saving this data set will be of aid if the job runs out of time, in which case the code need not start the iterations from the beginning but can pick up from where it left off. Data sets LIB.REAL, LIB.MIX, and LIB.ADJT are the code-generated trial-function libraries. These data sets need be regenerated only when changes in the user-supplied trial functions for the problem are made. Finally, data set LIB.PART contains the partial integrals which are generated from the three previous data sets. A set of partial integrals is generated for each synthesis region. The sub-intervals over which the partial integrals are generated are defined as the union of the top and bottom coordinates of the reactor regions in each refined region, which lie in each synthesis region. Referring to Fig. 2, there are three partial integrals required for each integration. The integration is performed over the following sets of intervals: 1-2, 3-4, and 5. See Section D below for additional information on restarting problems.

### 3. Data Sets Used

<u>Upper-interface Data Sets</u>	<u>Records Read</u>
A.SYN2D, Module-dependent BCD Input	All
BC, Boundary Condition Specifications	All
FR.TG, Mixing Functions	All
FR.TRIAL, User-input Real Synthesis Trial-function Library	All required
FA.TRIAL, User-input Adjoint Synthesis Trial-function Library	All required

<u>Upper-interface Data Sets</u>	<u>Records Read</u>
GEOM, Geometry Data	All
LIB.ADJT, Code-refined Adjoint Trial-function Library	All
LIB.MIX, Code-refined Real Trial-function Library	All
LIB.PART, Partial Integrals	All
LIB.REAL, Code-refined Real Trial-function Library	All
XS.C.MIN, Macroscopic Composition Cross Sections	All

The data sets BC and GEOM are usually generated from data in data set A.NIP. XS.C.MIN is generated from data in A.NIP and in the macroscopic group cross-section data set XS.ISO.

<u>Lower-interface Data Sets</u>	<u>Records Written</u>
FR.D2, Two-dimensional Real Group Fluxes	All
FR.PN, Power-normalized Real Regional Group Fluxes	All
FR.TG, Mixing Functions	All
LIB.ADJT, Code-refined Adjoint Trial-function Library	All
LIB.MIX, Code-refined Real Trial-function Library	All
LIB.PART, Partial Integrals	All
LIB.REAL, Code-refined Real Trial-function Library	All

#### D. Description of Program Execution

The SYN2D program is invoked, along with the other ARC System computational modules listed in Section A.2 above, by standard path STP008. This standard path is executed using the catalogued procedure ARCSP008, which contains the job control language and data-set definitions needed for execution. This section defines the input to the catalogued procedure ARCSP008, describes the procedure, and tells the user options available through the procedure.

It then briefly describes the path STP008 and its options.

##### 1. Catalogued Procedure Description

a. Definition and Listing of the JCL Deck Necessary for the Execution of the Catalogued Procedure. Following is a listing of the JCL deck required to execute the catalogued procedure ARCSP008, which calls the ARC System standard path STP008.

```
//JOB CARD
  ACCOUNTING CARD
/*SETUP DDNAME=DUMMY,DEVICE=2314,ID=DISKLL
/*SETUP DDNAME=DUMMY,DEVICE=2314,ID=DISKMM
// EXEC ARCSP008,
//
//          FATRIAL='ADJOINT.DS.NAME',FATVOL=DISKLL,
//          FRTRIAL='REAL.DS.NAME',FRTVOL=DISKLL,
//          MICRXS1='MXSN.FILE1',MICRXS2='MXSN.FILE2',MICRVOL=DISKNN
// OTHER SYMBOLIC PARAMETERS WHICH MAY BE REQUIRED
//SYSUDUMP DD UNIT=(CTC,DEFER)
```

```

OTHER DD CARDS FOR DSRN 42=65 AS REQUIRED BY NUMBER OF ENERGY GROUPS
//STP008,SYNIN DD *
BLOCK=OLD
DATASET=XS.ISO
DATASET=FR.TRIAL
DATASET=FA.TRIAL
  OTHER DATA SETS WHICH ARE OLD
BLOCK=STP008
DATASET=A,SYN2D
  BCD FOR DATA SET A,SYN2D
DATASET=A,NIP
  BCD FOR DATA SET A,NIP
/*

```

The JOB CARD should have a minimum main core region size of 550K, but need have no bulk core allocation unless quite large problems are being run. If the type 02 card of data set A.SYN2D requests a bulk allocation of  $n$ , then a bulk core allocation of  $8n$  should be put on the JOB CARD.

Setup cards will be required for the disks containing the microscopic cross sections, for the input trial-function libraries, and possibly for those data sets being saved.

The symbolic parameters listed give the data sets that must be old, along with their disk locations. ADJOINT.DS.NAME and REAL.DS.NAME must be replaced by the adjoint and real trial-function data-set names. MXSN.FILE1 and MXSN.FILE2 should be replaced by the names of the microscopic cross-section data-set files. Other symbolic parameters can be added as desired to save new data sets or to use old ones. Refer to Section D.1.b below and C.1.k above.

Information on how to add the extra scratch data sets and when to add them is contained in Section D.1.b below.

Only data sets that are referenced in the symbolic parameter list can appear under the BLOCK=OLD heading. These data sets, which have previously been created, should be referenced in this section by their standard ARC names. Note that although the disposition of a data set is old, the information the data set contains is not necessarily pertinent to this problem. Hence, the data set will be referenced in the symbolic parameter list; it will not be referenced in the BLOCK=OLD list. Finally, only the following additional data sets should ever appear in this list (BLOCK=OLD): BC, GEOM, LIB.ADJT, LIB.MIX, LIB.PART, LIB.REAL, and FR.TG.

b. Description of Catalogued-procedure Deck. Following is a listing of the catalogued procedure ARCS008.

```

//ARCSPO08 PRQC ADJTLIB='&LIBADJTL',ADJTDSP='(,DELETE)',ADJTVOL=SCRTW0, X
// BC='&BCND01',BCDSP='(,DELETE)',BCVOL=SYSSCR, X
// COMPS1='&XSECT1',COMPDSP='(,DELETE)',COMPVOL=SCRONE, X
// COMPS2='&XSECT2',DISKNO=28, X
// FATRIAL='&FATRIAL',FATVOL=SCRONE, X
// FLXTW0D='&FRLD01',FLXDSP='(,DELETE)',FLXVOL=SYSSCR, X
// FRTRIAL='&FRTRIAL',FRTVOL=SCRONE, X
// GEOM='&GEOMDS1',GEOMDSP='(,DELETE)',GEOMVOL=SCRTW0, X
// MICRXS1='&MICRXS1',MICRXS2='&MICRXS2',MICRVOL=SCRONE, X
// MIXLIB='&LIBGMIX',MIXDSP='(,DELETE)',MIXVOL=SCRTW0, X
// PARTLIB='&LIBPART',PARTDSP='(,DELETE)',PARTVOL=SCRONE, X
// REALLIB='&LIBREAL',REALDSP='(,DELETE)',REALVOL=SYSSCR, X
// TGFR='&FRLTG1',TG DSP='(,DELETE)',TG VOL=SYSSCR
//
//STPO08 EXEC PGM=STPO08
//STEPLIB DD DSN=00DISKNO,,MODLIB,UNIT=DISK,DISP=(SHR,PASS), X
// VOL=SER=DISK0DISKNO
//FT05F001 DD DDNAME=SYSIN THIS CARD DEFINES INPUT DATA SET X
// FT06F001 DD UNIT=(CTC,DEFER), X
// DCB=(RECFM=VBSA,LRECL=137,BLKSIZE=1511) X
// THIS CARD DEFINES THE OUTPUT DATA SET
//FT09F001 DD UNIT=2314,SPACE=(CYL,(1,1)), X
// DCB=(RECFM=VBS,LRECL=84,BLKSIZE=3364) X
// ARC SYSTEM OS360 CORRESPONDENCE
//FT11F001 DD DSN=&ANIP,UNIT=DISK,SPACE=(CYL,(1,1)), X
// DCB=(RECFM=VBS,LRECL=84,BLKSIZE=1684) X
// GENERAL NEUTRONICS INPUT DATA
//FT12F001 DD DSN=&ASYN200,UNIT=DISK,SPACE=(TRK,(1,1)), X
// DCB=(RECFM=VBS,LRECL=84,BLKSIZE=760) X
// 2-D SYNTHESIS MODULE DEPENDENT DATA SET
//FT13F001 DD DSN=&BHUM0G,UNIT=DISK,SPACE=(CYL,(1,1)), X
// DCB=(RECFM=VBS,LRECL=X,BLKSIZE=3460) X
// MATERIAL AND COMPOSITION SPECIFICATIONS
//FT14F001 DD DSN=&BC,UNIT=DISK,SPACE=(TRK,(1,1)), X
// DCB=(RECFM=VBS,LRECL=X,BLKSIZE=304), X
// VOL=SER=&BCVOL,DISP=&BCDSP X
// BOUNDARY CONDITION SPECIFICATIONS
//FT15F001 DD DSN=&FATRIAL,UNIT=DISK,DISP=(OLD,KEEP), X
// VOL=SER=&FATVOL X
// USER SUPPLIED ADJOINT TRIAL FUNCTIONS
//FT16F001 DD DSN=&FLXTW0D,UNIT=DISK,SPACE=(CYL,(3,1),RLSE), X
// DCB=(RECFM=VBS,LRECL=X,BLKSIZE=7294), X
// VOL=SER=&FLXVOL,DISP=&FLXDSP X
// REAL TWO DIMENSIONAL FLUX DATA SET
//FT17F001 DD DSN=&FRPN,UNIT=DISK,SPACE=(CYL,(1,1)), X
// DCB=(RECFM=VBS,LRECL=X,BLKSIZE=1604) X
// POWER NORMALIZED REGION FLUXES
//FT18F001 DD DSN=&GTGFR,UNIT=DISK,SPACE=(CYL,(1,1)), X
// DCB=(RECFM=VBS,LRECL=X,BLKSIZE=7004), X
// VOL=SER=&GTGVOL,DISP=&GTGDSP X
// MIXING FUNCTIONS DATA SET
//FT19F001 DD DSN=&FRTRIAL,UNIT=DISK,DISP=(OLD,KEEP), X
// VOL=SER=&FRTVOL X
// USER SUPPLIED REAL TRIAL FUNCTIONS
//FT20F001 DD DSN=&GEOM,UNIT=DISK,SPACE=(CYL,(1,1)), X
// DCB=(RECFM=VBS,LRECL=X,BLKSIZE=804), X
// VOL=SER=&GEOMVOL,DISP=&GEOMDSP X
// GEOMETRY SPECIFICATIONS DATA SET
//FT21F001 DD DSN=&ADJTLIB,UNIT=DISK,SPACE=(CYL,(3,1),RLSE), X
// DCB=(RECFM=VBS,LRECL=X,BLKSIZE=7204), X
// VOL=SER=&ADJTVOL,DISP=&ADJTDSP X
// CODE GENERATED ADJOINT TRIAL FUNCTION LIBRARY
//FT22F001 DD DSN=&MIXLIB,UNIT=DISK,SPACE=(CYL,(3,1),RLSE), X

```

```

//          DCB=(RECFM=VBS,LRECL=X,BLKSIZE=7204),          X
//          VOL=SER=&MIXVOL,DISP=&MIXNSP                    X
//          CODE GENERATED REAL TRIAL FUNCTIONS (MATRIX GENERATION) X
//FT23F001 DD DSN=&PARTLIB,UNIT=DISK,SPACE=(CYL,(3,1),RLSE), X
//          DCB=(RECFM=VBS,LRECL=X,BLKSIZE=7172),          X
//          VOL=SER=&PARTVOL,DISP=&PARTDSP                  X
//          CODE GENERATED PARTIAL INTEGRALS
//FT24F001 DD DSN=&REALLIB,UNIT=DISK,SPACE=(CYL,(3,1),RLSE), X
//          DCB=(RECFM=VBS,LRECL=X,BLKSIZE=2164),          X
//          VOL=SER=&REALVOL,DISP=&REALDSP                  X
//          CODE GENERATED REAL TRIAL FUNCTION LIBRARY
//FT25F001 DD DSN=&SCROO1,UNIT=DISK,SPACE=(CYL,(1,3),RLSE), X
//          DCB=(RECFM=VBS,LRECL=X,BLKSIZE=7060),          X
//          VOL=SER=SCRONE                                  X
//          SCRATCH DATA SET CONTAINS H MATRICES
//FT26F001 DD DSN=&SCROO2,UNIT=DISK,SPACE=(CYL,(2,5),RLSE), X
//          DCB=(RECFM=VBS,LRECL=X,BLKSIZE=4324),          X
//          VOL=SER=SCRTWO                                  X
//          SCRATCH DATA SET CONTAINS FISSION MATRICES
//FT27F001 DD DSN=&SCROO3,UNIT=DISK,SPACE=(CYL,(1,3),RLSE), X
//          DCB=(RECFM=VBS,LRECL=X,BLKSIZE=7060),          X
//          VOL=SER=SCRTWO                                  X
//          SCRATCH DATA SET CONTAINS V & U INVERSE MATRICES
//FT28F001 DD DSN=&SCROO4,UNIT=DISK,SPACE=(CYL,(2,3),RLSE), X
//          DCB=(RECFM=VBS,LRECL=X,BLKSIZE=4324),          X
//          VOL=SER=SYSSCR                                  X
//          SCRATCH DATA SET CONTAINS SCATTERING MATRICES
//FT29F001 DD DSN=&SPICNO,UNIT=DISK,SPACE=(76,1),          X
//          DCB=(RECFM=VBS,LRECL=X,BLKSIZE=76)            X
//          CODE INDEPENDENT CONSTANTS SPECIFICATIONS
//FT32F001 DD DSN=&COMPXS1,UNIT=DISK,SPACE=(CYL,(1,1)),    X
//          DCB=(RECFM=VBS,LRECL=X,BLKSIZE=1028),          X
//          VOL=SER=&COMPVOL,DISP=&COMPDSP                  X
//          FILE 1 OF DATA SET XS.C.MIN
//FT32F002 DD DSN=&COMPXS2,UNIT=DISK,SPACE=(CYL,(1,1)),    X
//          DCB=(RECFM=VBS,LRECL=X,BLKSIZE=7172),          X
//          VOL=SER=&COMPVOL,DISP=&COMPDSP                  X
//          FILE 2 OF COMPOSITION CROSS SECTION DATA SET XS.C.MIN
//FT34F001 DD DSN=&MICRXS1,UNIT=DISK,DISP=SHR,VOL=SER=&MICRVOL X
//          THIS IS FILE 1 OF THE DATA SET XS.ISO DEFINING X
//          ISOTOPE CROSS SECTIONS
//FT34F002 DD DSN=&MICRXS2,UNIT=DISK,DISP=SHR,VOL=SER=&MICRVOL X
//          THIS IS FILE 2 OF THE DATA SET XS.ISO DEFINING X
//          ISOTOPE CROSS SECTIONS
//FT35F001 DD DSN=&XSISO2A,UNIT=DISK,SPACE=(CYL,(1,1)),    X
//          DCB=(RECFM=VBS,LRECL=X,BLKSIZE=644)            X
//          FILE 1 OF DATA SET XS.ISO2 CONTAINS A SHORTENED FORM OF X
//          THE DATA SET XS.ISO
//FT35F002 DD DSN=&XSISO2B,UNIT=DISK,SPACE=(CYL,(1,1)),    X
//          DCB=(RECFM=VBS,LRECL=X,BLKSIZE=7172)          X
//          FILE 2 OF DATA SET XS.ISO2
//FT37F001 DD DSN=&XSMMIN,UNIT=DISK,SPACE=(CYL,(1,1)),    X
//          DCB=(RECFM=VBS,LRECL=X,BLKSIZE=7172)          X
//          DATA SET XS.M.MIN CONTAINS MATERIALS CROSS SECTIONS
//FT40F001 DD UNIT=DISK,SPACE=(CYL,(2,1),RLSE),DISP=(,DELETE), X
//          DCB=(RECFM=VBS,LRECL=X,BLKSIZE=7204)          X
//FT41F001 DD UNIT=DISK,SPACE=(CYL,(2,1),RLSE),DISP=(,DELETE), X
//          DCB=(RECFM=VBS,LRECL=X,BLKSIZE=7204)          X
//FT42F001 DD UNIT=DISK,SPACE=(CYL,(2,1),RLSE),DISP=(,DELETE), X
//          DCB=(RECFM=VBS,LRECL=X,BLKSIZE=7204)          X
//FT43F001 DD UNIT=DISK,SPACE=(CYL,(2,1),RLSE),DISP=(,DELETE), X
//          DCB=(RECFM=VBS,LRECL=X,BLKSIZE=7204)          X

```

```

//FT44F001 DD UNIT=DISK,SPACE=(CYL,(2,1),RLSE),DISP=(,DELETE),           X
//          DCB=(RECFM=VBS,LRECL=X,BLKSIZE=7204)                          X
//FT45F001 DD UNIT=DISK,SPACE=(CYL,(2,1),RLSE),DISP=(,DELETE),           X
//          DCB=(RECFM=VBS,LRECL=X,BLKSIZE=7204)                          X
//          DATA SETS NUMBERED 40-45 & 25-28 ARE REQUIRED TO GENER= X
//          ATE THE CODE GENERATED TRIAL FUNCTION DATA SETS.           X
//          ONE DATA SET FOR EACH ENERGY GROUP.  HENCE FOR MOPE       X
//          THAN TEN GROUPS ADD OTHER DATA SETS SIMILAR TO # 40,       X
//          OTHERWISE DO NOTHING.                                         X
//          EX.  //STP008,FTNNF001 DD ETC,      WHERE NN=46,47,....      X

```

Section 1.a above outlined the general procedure for executing this catalogued procedure. All that now remains is to add any required scratch data sets and to make the appropriate substitutions of data-set names, volumes, and dispositions in the symbolic parameter list. Listed below are the catalogued procedure symbolic data-set names, followed by their ARC System names and the data-set reference numbers to which they apply.

<u>Symbolic Name</u>	<u>ARC Name</u>	<u>DSRN</u>
ADJTLIB	LIB.ADJT	21
BC	BC	14
COMPXS1	XS.C.MIN file 1	32 file 1
COMPXS2	XS.C.MIN file 2	32 file 2
FATRIAL	FA.TRIAL	15
FLXTWOD	FR.D2	16
FRTRIAL	FR.TRIAL	19
GEOM	GEOM	20
MICRXS1	XS.ISO file 1	34 file 1
MICRXS2	XS.ISO file 2	34 file 2
MIXLIB	LIB.MIX	22
PARTLIB	LIB.PART	23
REALLIB	LIB.REAL	24
TGFR	FR.TG	18

The two files of XS.C.MIN and XS.ISO must always be paired.

In addition to the data sets referenced in Section 1.a, these are the only data sets that may be permanently saved. Now, for example, suppose that the ARC System data set FR.TG is to be saved under the name of REAL.MIXING on a disk named DISK18. Then the following card would be inserted in the symbolic parameter list (see Section 1.a above):

```
//TGFR='REAL.MIXING',TGDSP='(NEW,KEEP)',TGVOL=DISK18,X
```

If this data set had been previously defined on this disk, this same card would be used, but the word "NEW" would be replaced by "OLD." The symbolic parameters TGDSP and TGVOL can be found in the symbolic parameter list at the beginning of the catalogued procedure. They are used to give the

data-set disposition and disk identifier, respectively. This same technique is used for any other data set. The catalogue procedure already contains the default options that ordinarily make these data sets temporary.

c. Scratch Data Sets. This catalogued procedure is presently designed to run problems having six energy groups. If problems containing more than six energy groups are to be run, then extra scratch data sets must be added when generating the ARC System data sets LIB.ADJT, LIB.MIX, and LIB.REAL. One scratch data set is required for each energy group in excess of six groups. The data-set reference numbers should be in sequence and begin at number 42. Refer to the procedure listing for the proper form of the required DD cards.

## 2. Path Description

a. Listing and Notes. Presently only one path exists that calls the synthesis module. This path (STP008) is listed below.

```

MEMBER NAME SYN2DPH
C PATH STP008                                00000100
  REAL*8 PATH,XSC,DSNAME(240),BC,GEOM        00000200
  REAL*4 TIME2,TIME1,DTIME                   00000300
  DATA XSC/*XS.C.MIN*/,GEOM/*GEOM          /*,BC/*BC          /*          00000400
  DATA DSNAME/                               00000500
  1'A.NIP      *,'A.SYN2D  *,'B.HCMOG *,'BC      *,'FA.TRIAL','FR.D2  *,00000600
  2'FR.PN      *,'FR.TG    *,'FR.TRIAL','GEOM    *,'LIB.ADJT','LIB.MIX *,00000700
  3'LIB.PART   *,'LIB.REAL *,'SCROO1  *,'SCROO2  *,'SCROO3  *,'SCROO4  *,00000800
  4'SP.CIGN    *,'SP.CRIT  *,'XS.C.AUX', 'XS.C.MIN', 'XS.DELAY', 'XS.ISO  *,00000900
  5'XS.ISO2   *,'XS.M.AUX', 'XS.M.MIN',
A'S */                                         00001000
  TIME2=TLEFT(DTIME)                          00001100
  PRINT 20                                     00001200
  CALL SYSTEM(DSNAME)                          00001300
  CALL BCDDS(*STP008  ',N1)                    00001400
  CALL SNIFF( BC      ',N1,0)                  00001500
  IF(-N1.GE.0) GO TO 5                          00001600
  CALL SNIFF( GEOM    ',N3,0)                  00001700
  IF(-N3.GE.0) GO TO 5                          00001800
  PRINT 25,BC,N1,GEOM,N3                       00001900
  GO TO 7                                       00002000
5 CALL LINK('NUI002  ')                        00002100
7 CALL SNIFF(XSC,N2,0)                          00002200
  IF(N2.GT.0) GO TO 10                         00002300
  CALL LINK('NUI001  ')                        00002400
  CALL LINK('NUC001  ',4,0,0,0,1)              00002500
  GO TO 9                                       00002600
10 CONTINUE                                    00002700
  PRINT 30, N2                                  00002800
9 CALL LINK('AJC005  ')                        00002900
  TIME1=TLEFT(DTIME)                          00003000
  DTIME=(TIME2-TIME1)/6000.                   00003100
  IF(DTIME.LE.0.0) DTIME=DTIME+1440.0         00003200
  PRINT 50,DTIME                               00003300
  PRINT 60                                     00003400
20 FORMAT(' MODULE STP008 HAS BEEN ENTERED. ') 00003500
25 FORMAT(' DATA SET ',A8,' IS ASSUMED TO EXIST ON DSRN ',I3,/) 00003600
30 FORMAT ('1',20X,'DATA SET XS.C.MIN EXISTS'/ 00003700
  1      '0',20X,'MACROSCOPIC COMPOSITION X-SECTIONS ARE ASSUMED'/ 00003800
  2      21X,'TO BE ON DATA SET REFERENCE NUMBER',I3) 00003900
50 FORMAT(' TIME FOR THE EXECUTION OF STP008 IS ',F10.4,' MINUTES. ') 00004000
60 FORMAT(' MODULE STP008 HAS JUST BEEN EXITED FROM. ') 00004100
  RETURN                                       00004200
  END                                         00004300

```

The data sets referred to in the data statement containing the DSNAME array are not all required by SYN2D. They exist because they are required by other modules called by the path, or for future expansion and modification purposes. The extra data sets, listed in order, are SP.CICN, SP.CRIT, XS.C.AUX, XS.DELAY, XS.ISO, XS.M.AUX, and XS.M.MIN.

b. ARC System Modules Called by This Path. The following ARC System modules are referenced by this path. Their system names and arguments are listed, followed by their common names in brackets.

NUC001 (4,0,0,0,1)	[HOMOG]
NUI001	[INHOMG]
NUI002	[GNIP]
AJC005	[SYN2D]

c. Path Options. The only options presently available enable the user to skip the modules HOMOG and INHOMG or GNIP if the data sets XS.C.MIN or GEOM and BC are old. If both GEOM and BC are old data sets, then the module GNIP will not be called. Should both be new or if only one is old, GNIP will be called to regenerate these data sets. The combination of INHOMG and HOMOG is called if XS.C.MIN is new; otherwise no call is made. In most cases it will be advantageous for the user to employ the catalogued procedure when running test cases using the path. (Refer to Section D.1 above.)

#### E. Module-dependent Input to SYN2D

The module-dependent input to module SYN2D consists of the BCD data set A.SYN2D, which provides for the user options described in Section C. This section displays the specifications for this data set.

##### A.SYN2D Data-set Specifications

- |           |            |  |
|-----------|------------|--|
| <u>01</u> | (12X,10A6) | Problem Title  |
|           | Col 13-72  | Problem title  |
|           |            | This will appear on each page of output. A different title should be used with each problem run. |
| <u>02</u> | (12X,8I6)  | Problem Options  |
|           | Col 13-18  | Maximum number of iterations   |
|           | 19-24      | Problem type option on interface condition   |
|           |            | 1 Asymmetric interface   |
|           |            | 2 Symmetric interface  |

- 25-30 Output option  
 0 Limited output  
 1 Normal output (normally used value)  
 2 All program output
- 31-36 Debugging print option (POINTR)  
 0 No POINTR printout (normally used value)  
 1 Standard full printout  
 2 Debugging dumps printout  
 3 Full debugging printout
- 38-42 Size of main core POINTR array (if 0 or negative the default is 60000)
- 43-48 Size of bulk core POINTR array (if negative none is requested; if 0 the default is 120,000)
- 49-54 Adjoint option  
 0 Real and adjoint trial functions are different  
 1 The program should use the real trial functions also as adjoints
- 03 (12X,5E12.5) Outer-iteration Convergence Criteria
- Col 13-24 Flux-difference convergence criterion, on sum of the absolute value of the flux difference divided by the normed sum of the absolute values of the flux ( $10^{-6}$  is recommended)
- 25-36 Flux-bounds convergence criterion, on  $(\bar{\lambda} - \underline{\lambda})$  ( $10^{-5}$  is recommended)
- 37-48 k-effective difference convergence criterion ( $10^{-7}$  is recommended)
- 49-60 Power-normalization factor for burnup
- 04 (12X,10I6) Synthesis-region Options
- Col 13-18 Number of synthesis regions
- 19-24 The maximum number of real trial functions in any synthesis region for any group
- 25-30 Preprocess option (generates partial integrals and program-used function libraries)  
 0 Generates the above and runs a complete case  
 1 Generates the above and terminates run
- 05 (12X,5E12.5) Synthesis-region Boundaries
- Col 13-24 First synthesis boundary (which must be greater than zero)
- 25-36 Second boundary

- 37-48 Third boundary  
 49-60 Fourth boundary  
 61-72 Fifth boundary

Additional boundaries start on the next card and continue as above with five per card. Only the internal boundaries are required.

\*\*\*\*NOTICE: If a synthesis boundary that is not on a mesh line is input, the code will move this boundary toward the left to the first mesh line that it encounters, and this mesh line will be the synthesis boundary. If more than one boundary is placed between two adjacent mesh lines, the first is handled as above and the remaining points are moved to the right to correspond one-to-one with mesh lines. This feature is quite useful, for suppose we wish to have two mesh lines in the interval (0,1) and we wish to have synthesis boundaries at  $1/3$  and  $2/3$ . These numbers cannot be input to machine accuracy, but if we input 0.4 and 0.7 the code will assume that we meant  $1/3$  and  $2/3$ .

06A (12X,1016) Synthesis-region Trial-function Assignments

Col 13-18  $G_{final}$

19-24 Number of real functions for this region for the range of  $G_{initial}$  to  $G_{final}$  (note  $G_{initial}$  is either 1 or the previous  $G_{final}$  plus 1 if previous  $G_{final}$  was not equal to GMAX)

25-30 Zeroing options

This option is used if one of the boundary conditions applied in this synthesis region is  $\varphi = 0$  and certain trial functions used in this region satisfy this condition. This ensures that no contribution to the boundary matrices is made unless applicable.

0 This option is not used

1 Use this option in the BC matrix generation

06B (12X,1016) Real and Adjoint Trial-function Choices

Col 13-18 First function number on library

19-24 Second function number on library

25-30 Third function number on library

31-36 Fourth function number on library

37-42 Fifth function number on library

43-48 Sixth function number on library

- 49-54 Seventh function number on library  
 55-60 Eighth function number on library  
 61-66 Ninth function number on library  
 67-72 Tenth function number on library

If there are more functions, the above procedure is repeated on succeeding cards. When the last function number has been given, the rest of card is left blank.

06C (12X,10I6) Trial-function Boundary-condition Options

This card is used only if columns 25-30 on the 06A card are not zero. It has the same format as the 06B cards. A zero is placed in the corresponding column if the function satisfies the boundary condition  $\phi = 0$ ; otherwise, a 1 appears.

Cards 06A, 06B, and 06C must be used for every synthesis region (06C only where applicable). The set for region two follows the set for region one, etc. If in any region  $G_{\text{final}}$  is not equal to GMAX, then we use another 06A card, where the new  $G_{\text{final}}$  is greater than the previous  $G_{\text{final}}$ , followed by the 06B and if necessary the 06C card, and we repeat this as many times as necessary until  $G_{\text{final}} = \text{GMAX}$  on the 06A card. Then we proceed to the next synthesis region.

07 (12X,8I6) Scratch Data-set Reference Numbers

These scratch data sets are used by the code in generating the trial function library, exclusive of SCR001, SCR002, SCR003, and SCR004. Since one scratch data set is needed for each energy group (NGROUP - 4), scratch data set reference numbers must be given.

Col 13-18 First DSRN (if using the catalogued procedure, use 41)

19-24 Second DSRN (if using the catalogued procedure, use 42)

Continue in this fashion until all the data-set reference numbers needed are given. When the catalogued procedure is used, succeeding data-set reference numbers should be 43, 44, etc. Eight numbers appear on each card.

The card type number, as given above, can appear in the first two or three columns of each card. It is not read by the SYN2D program, which expects the cards to be in the order described.

## F. Error Messages

This section describes the error messages that can be generated by this program. The messages are listed under the names of the subroutines generating them, which appear in alphabetical order. Error messages generated by subroutine entry points are listed under the name of the corresponding subroutine.

For each error, the complete error message is listed, followed by descriptions of the significance of the message to the user and of the action taken by the program when the error is encountered.

### BCONDS

- Message: THE BOUNDARY CONDITION APPLIED AT THE REACTOR  
aaaaaaaa FOR REFINED REGION rrrr IS NOT  
HOMOGENEOUS  
  
ERROR NUMBER 1 IN SUBROUTINE BCONDS
- Significance: The letters aaaaaaaaa will be replaced by 'TOP' or 'BOTTOM'  
to indicate which reactor face is not correct; rrrr will be  
the number of the refined region in which the improper  
boundary condition was encountered. The allowable bound-  
ary conditions are  $\phi = 0$ ,  $\phi' = 0$ , and  $\phi' + (B/D)\phi = 0$ ,  
where B is a user-supplied constant and D is the diffusion  
coefficient at the reactor face. The boundary condition  
applied had a nonzero number on the right of the equal sign.
- Action Taken: Execution is terminated.
- Message: THE BOUNDARY CONDITION APPLIED AT THE REACTOR  
aaaaaaaa FOR REFINED REGION rrrr IS NOT A PROPER  
TYPE  
  
ERROR NUMBER 1 IN SUBROUTINE BCONDS
- Significance: The boundary condition applied was homogenous, but of an  
incorrect type. Refer to the previous message.
- Action Taken: Execution is terminated.
- Message: THE BOUNDARY CONDITION APPLIED AT THE REACTOR  
aaaaaaaa FOR REFINED REGION rrrr IS NOT CONSISTENT  
FOR THE ENTIRE REGION  
  
THE BOUNDARY CONDITION APPLIED AT THE REACTOR  
aaaaaaaa FOR REFINED REGION rrrr IS NOT  
HOMOGENEOUS  
  
ERROR NUMBER 1 IN SUBROUTINE BCONDS

Significance: A change in boundary condition has taken place in this refined region. Refer to the first message.

Action Taken: Execution is terminated.

Message: THE BOUNDARY CONDITION APPLIED AT THE REACTOR  
aaaaaaaa FOR REFINED REGION rrrr IS NOT CONSISTENT  
FOR THE ENTIRE REGION

THE BOUNDARY CONDITION APPLIED AT THE REACTOR  
aaaaaaaa FOR REFINED REGION rrrr IS NOT A PROPER  
TYPE

ERROR NUMBER 1 IN SUBROUTINE BCONDS

Significance: A change in the boundary condition has taken place in this refined region. Refer to the second message.

Action Taken: Execution is terminated.

### CALC1

Message: \*\*\*\*\*DRRMN FOR REFINED REGION rrr IS SINGULAR. NO  
INVERSE.

ERROR NUMBER 1 IN SUBROUTINE CALC1

Significance: Determinant  $[D_{gk}(r)] = 0$  where  $r$  is in refined region rrr. Therefore we cannot find its inverse or compute  $\Omega_I$ . The trial functions used in the synthesis region containing refined region  $r$  are not linearly independent.

Action Taken: Execution is terminated.

Message: \*\*\*\*\*OMEGA IS SINGULAR FOR INTERVAL iii, HENCE NO  
INVERSE.

ERROR NUMBER 2 IN SUBROUTINE CALC1

Significance: Determinant  $\Omega_{iii} = 0$ ; hence  $\Omega^{-1}$  does not exist.

Action Taken: Execution is terminated.

### COFGEN

Message: DATA SET LIB.PART IS NOT CONSISTENT WITH THIS  
PROBLEM

ERROR NUMBER 1 IN SUBROUTINE COFGEN

Significance: One of the following errors was detected on data set  
LIB.PART:

- a. The number of synthesis regions does not agree with this problem.
- b. The number of energy groups does not agree with this problem.

- c. The time key on this data set does not agree with the key on the code-generated data sets LIB.ADJT, LIB.MIX, and LIB.REAL. The time key is used to ensure that data sets LIB.ADJT, LIB.MIX, and LIB.REAL were all generated in the same run.

Either use the correct version of LIB.PART, or regenerate it.

Action Taken: Execution is terminated.

Message: DATA SET LIB.PART IS NOT CONSISTENT WITH THIS PROBLEM

ERROR NUMBER 2 IN SUBROUTINE COFGEN

Significance: Either the number of partial integrals per synthesis region necessary to generate the complete integral is not correct, or there are not enough partial integrals to generate all the required integrals for all synthesis regions and energy groups.

Either use the correct version of LIB.PART, or regenerate it.

Action Taken: Execution is terminated.

Message: THE BOUNDARY CONDITIONS APPLIED ON THE aaaaaaaa FOR GROUP gggg ARE NOT CONSISTENT

ERROR NUMBER 3 IN SUBROUTINE COFGEN

Significance: The name aaaaaaaa can only be 'LEFT' or 'RIGHT,' while gggg indicates the energy group in which the error was encountered. The boundary condition along the indicated face can change only with energy group and not with position on the face.

Action Taken: Execution is terminated.

Message: CAN NOT INVERT THE MATRIX L IN THE SYMMETRIC OPTION HENCE DMN CAN NOT BE GENERATED FOR SYNTHESIS REGION kkkk GROUP gggg

ERROR NUMBER 4 IN SUBROUTINE COFGEN

Significance: The matrix  $\hat{L}$  calculated for the synthesis boundary between synthesis region kkkk and synthesis region kkkk + 1 for energy group gggg when using the symmetric option is singular. Refer to Section II.B. above for more information on this option. The trial functions used in both regions may be dependent. A better choice of trial functions in these two regions should help.

Action Taken: Execution is terminated.

D2DOUT

Message: ERROR NUMBER 1 IN SUBROUTINE D2DOUT

Significance: Trace-back error from other routines in the output segment.

Action Taken: Execution is terminated.

DSRNCK

Message: TROUBLE ON DSRN nnnn INFORMATION IS NOT CONSISTENT WITH THIS PROBLEM

DS CLAIMS GMAX=gggg JMAX=jjjj KMAX=kkkk and  
 NGKMX=llll BUT GMAX=gggg' JMAX=jjjj' KMAX=kkkk'  
 AND NGKMX=llll'

ERROR NUMBER 1 IN SUBROUTINE DSRNCK

Significance: The data set LIB.ADJT on DSRN nnnn does not agree with this problem. The information obtained from A.NIP and A.SYN2D gives the number of energy groups (gggg'), the number of trial-function values (jjjj'), the number of synthesis regions (kkkk'), and the maximum number of trial functions used in any synthesis region (llll'). These numbers do not agree with the values found on LIB.ADJT. If kkkk is negative, then the inverse of  $\hat{K}$  could not be computed and hence the matrix 3MN could not be calculated.

Either use correct data sets, or regenerate the correct data sets.

Action Taken: Execution is terminated.

Message: NUMBER OF TRIAL FUNCTIONS PER SYNTHESIS REGION AND GROUP ON DSRN nnnn DOES NOT AGREE WITH THIS PROBLEM

ERROR NUMBER 2 IN SUBROUTINE DSRNCK

Significance: The data set LIB.ADJT on DSRN nnnn does not contain the proper arrangement of trial functions for this problem.

Either use correct data sets, or regenerate the correct data sets.

Action Taken: Execution is terminated.

Message: DSRN nnnn AND DSRN mmmm ARE NOT CONSISTENT  
 ERROR NUMBER 3 IN SUBROUTINE DSRNCK

Significance: The time keys for the two data sets are not the same, indicating that they were not created in the same run. Refer to normal output information previously printed to identify these data sets.

.....: use the correct data sets, or regenerate them.

Action Taken: Execution is terminated.

FXVOL Refer to error message for IFXVOL.

GPCAL Refer to error message for IGPCAL.

IFXNRM

Message: ERROR NUMBER 1 SUBROUTINE IFXNRM

Significance: Geometry type is not XY, RZ, ZR, or Rθ.

Action Taken: The power normalization factor for burnup is not computed.

IFXVOL

Message: Group ggg

ERROR NUMBER 1 IN SUBROUTINE FXVOL

Significance: ggg is the record number at which an I/O error was detected when reading the external source data set. This error should never appear for this module.

Action Taken: None.

IGPCAL

Message: ERROR NUMBER 1 IN SUBROUTINE GPCAL

Significance: Error trace-back from REGBAL.

Action Taken: Execution is terminated.

ILKCEL

Message: ERROR NUMBER i IN SUBROUTINE LKCELL

Significance: Boundary condition type other than 0, 1, or 2 has been specified on the right, left, top, or bottom boundary. The value of i indicates which boundary.

Action Taken: Execution is terminated.

IVOL

Message: ERROR NUMBER 1 IN SUBROUTINE IVOL

Significance: Geometry type is not XY, RZ, ZR, OR Rθ.

Action Taken: IVOL, the function value, is set to 1, and normal return is made.

Message: ERROR NUMBER 1 IN SUBROUTINE VOL

Significance: Geometry type is not XY, RZ, ZR, or Rθ.

Action Taken: VOL, the function value, is set to 0, and normal return is made.

LIB

Message: \*\*\*\*\*SNIFF UNABLE TO LOCATE FR.TRIAL  
 ERROR NUMBER 1 IN SUBROUTINE LIB

Significance: This data set could not be located by ARC System sub-  
 routine SNIFF. This implies that the data set has not  
 been written.

Action Taken: Execution is terminated.

Message: \*\*\*\*\*SNIFF UNABLE TO LOCATE FA.TRIAL  
 ERROR NUMBER 2 IN SUBROUTINE LIB

Significance: This data set could not be located by ARC System sub-  
 routine SNIFF. This implies that the data set has not  
 been written.

Action Taken: Execution is terminated.

Message: \*\*\*\*\*THE TRIAL FUNCTION LIBRARIES ARE NOT CONSISTENT  
 ERROR NUMBER 3 IN SUBROUTINE LIB

TROUBLE ON DSRN iiiii

IT HAS nnnnn FUNCTIONS AND CLAIMS

GMAX=ggggg AND JMAX=jjjjj

BUT GMAX=ggggg' AND JMAX=jjjjj'

TROUBLE ON DSRN kkkkk

IT HAS mmmmm FUNCTIONS AND CLAIMS

GMAX=lllll AND JMAX=ppppp

BUT GMAX=ggggg' AND JMAX=jjjjj'

ERROR NUMBER 7 IN SUBROUTINE LIB

Significance: The number of real trial functions nnnnn on DSRN iiiii is  
 not the same as the number of adjoint trial functions  
 mmmmm on DSRN kkkk.

Action Taken: Execution is terminated.

Message: ERROR NUMBER 4 IN SUBROUTINE LIB

\*\*\*\*\*UNABLE TO LOCATE LIB.REAL OR LIB.ADJT OR  
 LIB.MIX IN PATH DSNNAME ARRAY

Significance: One of these data sets could not be located by ARC System  
 subroutine SNIFF. This implies that the data set has not  
 been written.

Action Taken: Execution is terminated.

Message: \*\*\*\*\*UNABLE TO FIND ALL FLUX FUNCTIONS FOR GROUP ppp  
 REGION kkk CHECK 06B INPUT  
 ERROR NUMBER 5 IN SUBROUTINE LIB  
 TROUBLE ON DSRN kkkkk  
 IT HAS nnnnn FUNCTIONS AND CLAIMS  
 GMAX=ggggg' AND JMAX=jjjjj'  
 BUT GMAX=ggggg and JMAX=jjjjj  
 ERROR NUMBER 7 IN SUBROUTINE LIB

Significance: The module is unable to find all the required flux trial  
 functions for energy group ggggg, synthesis region kkkkk.  
 Trouble could be on 06B input cards, or the user-supplied  
 library could be in error.

Action Taken: Execution is terminated.

Message: TROUBLE ON DSRN kkkkk  
 IT HAS nnnnn FUNCTIONS AND CLAIMS  
 GMAX=ggggg' AND JMAX=jjjjj'  
 BUT GMAX=ggggg AND JMAX=jjjjj  
 ERROR NUMBER 7 IN SUBROUTINE LIB

Significance: The nnnnn trial functions on data-set reference kkkkk are  
 not consistent with this problem. The data set has ggggg'  
 energy groups and jjjjj' points per function, while this  
 problem has ggggg energy groups and jjjjj points in the  
 nonsynthesis direction. Make the data set and problem  
 consistent, and resubmit.

Action Taken: Execution is terminated.

### MTGEN1

Message: \*\*\*\*\*D FOR REFINED REGION 1 IS SINGULAR FOR GROUP ggg  
 HENCE INVERSE DOESN'T EXIST

Significance: Determinant of  $D_{g_1}(1) = 0$ . Therefore its inverse  $(D_{g_1})^{-1}$ ,  
 does not exist. The trial functions used are probably not  
 linearly independent.

Action Taken: Execution is terminated.

Message: \*\*\*\*\*B.C. MATRIX NOT INVERTIBLE VALUE=vv (1 IS LEFT,  
 LESS THAN 1 RIGHT)  
 ERROR NUMBER 2 IN SUBROUTINE MTGEN1

Significance: The determinant of  $[C_1 D_{gk}(r) + 0.5 C_2 \delta W_{gk}] = 0$ ; hence the inverse does not exist. If  $vv$  is 1 then  $k = 1$ ,  $\delta = \delta_1$ ,  $r = 1$ , and this matrix is needed to compute  $E_1$ . If  $vv$  is less than 1, then  $k = K$ ,  $\delta = \delta_{\text{IMAX}}$ , and  $r$  is the last refined region. The computation is for  $E_{\text{IMAX}}$ . Note that  $C_1$  and  $C_2$  vary with group and reactor face.

Action Taken: Execution is terminated.

Message: ERROR NUMBER 3 IN SUBROUTINE MTGEN1

Significance: The vertical boundary condition given is  $DC.C_1\phi' + C_2\phi = C_3$ .  $C_3$  should be zero and is not.  $C_3$  is ignored, i.e., assumed to be zero.

Action Taken: None (execution continues).

Message: ERROR NUMBER 4 IN SUBROUTINE MTGEN1

Significance: The vertical boundary condition required is  $DC.C_1\phi' + C_2\phi = 0$ , where  $DC$  is the diffusion coefficient. (This is a type 2 boundary condition unless  $C_1$  or  $C_2$  is zero.) User has input wrong boundary condition type for the values of  $C_1$  and  $C_2$  that the code receives. Program assumes that the type 2 boundary condition was implied.

Action Taken: None (execution continues).

LKCELL Refer to error messages for subroutine ILKCEL.

MTGEN2

Message: \*\*\*\*\*E(1) IS SINGULAR

ERROR NUMBER 1 IN SUBROUTINE MTGEN2

Significance:  $\text{DET}(E_1) = 0$ , hence  $U_1^{-1} = E_1^{-1}$  does not exist. The energy group in which this occurs can be deduced from the previous printout.

Action Taken: Execution is terminated.

Message: \*\*\*\*\*U(ii) IS SINGULAR

ERROR NUMBER 2 IN SUBROUTINE MTGEN2

Significance:  $\text{DET}(U_{ii}) = 0$ , hence  $U_{ii}^{-1}$  does not exist. The energy group in which this occurs can be deduced from the previous printout.

Action Taken: Execution is terminated.

PCOMP

Message: \*\*\*\*\*SEARCH CALCULATED A NEGATIVE aaaaaaaa VALUE

COMPOSITION SEARCH TERMINATED

ERROR NUMBER 1 IN SUBROUTINE PCOMP

where aaaaaaaa represents a cross-section type:

DIF COEF, REMOVAL, FISSION, NU FISS, CHI MTRX,  
or SCATTER.

Significance: In adding the modifier composition to the original composition on a search pass, the search calculated a negative value or values of some cross-section type or types (only the most recently calculated type being indicated). Presently, module SYN2D has no search capability; hence, this message should never appear.

Action Taken: The concentration search is terminated, without output of data sets.

PROCES

Message: DATA SET LIB.PART IS NOT IN THE PATH DSNAME  
ARRAY

ERROR NUMBER 1 IN SUBROUTINE PROCES

Significance: This data set could not be found by ARC System subroutine SNIFF. This implies that the data set has not been written.

Action Taken: Execution is terminated.

PRTBC

Message: \*\*\*\*\*CALCULATION TYPE IS K CALC BOUNDARY CONDITIONS  
INDICATE CALCULATION SHOULD BE INHOMOGENEOUS

Significance: One or more inhomogenous boundary or interface conditions have been defined, and the calculation is not a source type. Either the boundary conditions or the calculation type is in error. No inhomogeneous capability presently exists for SYN2D.

Action Taken: Execution is terminated.

RBND

Message: \*\*\*\*\*DATA SET BC NOT FOUND

ERROR NUMBER 1 IN SUBROUTINE RBND

Significance: This data set could not be found by ARC System subroutine SNIFF. This implies that the data set has not been written.

Action Taken: Execution is terminated.

Message: ERROR NUMBER 2 IN SUBROUTINE RBNDC  
 Significance: The number of boundary conditions defined is less than 2.  
 Action Taken: Execution is terminated.

Message: ERROR NUMBER 3 IN SUBROUTINE RBNDC  
 Significance: If the number of horizontal boundary conditions is zero and geometry is not  $R\theta$  full periodic, then an error exists. (Module SYN2D has no  $R\theta$  capability.)  
 Action Taken: Execution is terminated.

Message: ERROR NUMBER 4 IN SUBROUTINE RBNDC  
 Significance: Error return from PRTBC  
 Action Taken: Execution is terminated.

### RCDEP

Message: \*\*\*\*\*A.SYN2D NOT FOUND BY SNIFF  
 ERROR NUMBER 1 IN SUBROUTINE RCDEP  
 Significance: This data set could not be found by ARC System subroutine SNIFF. This implies that the data set has not been written.  
 Action Taken: Execution is terminated.

Message: POINTR STORAGE COULD NOT BE ALLOCATED  
 ERROR NUMBER 2 IN SUBROUTINE RCDEP  
 Significance: The container array size requested on the A.SYN2D type 02 card exceeds the space available. Increase the region sizes on the job card, and/or decrease the array sizes on the type 02 card.  
 Action Taken: Execution is terminated.

Message: \*\*\*\*\*ALL REQUIRED SCRATCH DATA SETS ARE NOT IN THE PATH  
 ERROR NUMBER 3 IN SUBROUTINE RCDEP  
 Significance: All four scratch data sets SCR001, SCR002, SCR003, and SCR004 were not found in the path DSNAME array.  
 Action Taken: Execution is terminated.

### RCOMP

Message: \*\*\*\*\*DATA SET XS.C.MIN NOT FOUND  
 ERROR NUMBER 1 IN SUBROUTINE RCOMP

Significance: This data set could not be found by ARC System subroutine SNIFF. This implies that the data set has not been written.

Action Taken: Execution is terminated.

Message: ERROR NUMBER 2 IN SUBROUTINE RCOMP

Significance: This end of the first file of XS.C.MIN was not found, and the second file thus could not be read.

Action Taken: Execution is terminated.

Message: ERROR NUMBER 3 IN SUBROUTINE RCOMP

Significance: Data set XS.DELAY could not be found by ARC System subroutine SNIFF. This implies that the data set has not been written.

Action Taken: Execution is terminated.

Message: ERROR NUMBER 4 IN SUBROUTINE RCOMP

Significance: The number of families, NFAM, defined in XS.C.MIN was zero, and the kinetics option indicates that delayed data are desired for an  $\alpha$ -calculation. (Note that module SYN2D contains no kinetics capability.)

Action Taken: Execution is terminated.

Message: ERROR NUMBER 5 IN SUBROUTINE RCOMP

Significance: Trace-back for previously encountered error.

Action Taken: Execution is terminated.

Message: ERROR NUMBER 6 IN SUBROUTINE RCOMP

Significance: Error in reading record type 1 of data set XS.C.MIN.

Action Taken: Execution is terminated.

Message: ERROR NUMBER 8 IN SUBROUTINE RCOMP

Significance: Data set A.KIN2D is not present for kinetics option 3. (Note that kinetics options are not implemented for SYN2D.)

Action Taken: Execution is terminated.

#### RGEOM

Message: ERROR NUMBER 1 IN SUBROUTINE RGEOM

Significance: This data set could not be found by ARC System subroutine SNIFF. This implies that the data set has not been written.

Action Taken: Execution is terminated.

Message: ERROR NUMBER 2 IN SUBROUTINE RGEOM

Significance: The geometry type number is not 4, 5, 6, or 8. It may be a one-dimensional type (1, 2, or 3), may be XY geometry with 45° symmetry (7), which is not available, or may be meaningless. The geometry type selected in data set A.NIP (card type 3, cols. 13-18) should be checked.

Action Taken: Execution is terminated.

#### RGROUP

Message: \*\*\*\*\*TRANSPORT CROSS-SECTION = 0. DIFFUSION  
COEFFICIENT = 1.0E + 15

FOR COMPOSITION aaaaaaaaa, GROUP iii

Significance: A transport cross section of zero for this composition and group was read from data set XS.C.MIN, and hence the diffusion coefficient  $D_{c,g}=1/(3\sigma_{TR})$  could not be calculated. The diffusion coefficient is set to 1.

Action Taken: Processing continues.

Message: \*\*\*\*\*ERROR IN READING RECORD 03 OF XS.C.MIN ON DSRN iii  
ERROR NUMBER 1 IN SUBROUTINE RGROUP

Significance: An error was encountered in attempting to read a record of type 3 for some composition.

Action Taken: Execution is terminated.

#### RMESH

Message: \*\*\*\*\*ERROR IN RECORD iii OF DATA SET ON DSRN nnnn  
ERROR NUMBER 1 IN SUBROUTINE RMESH

Significance: A readerror was encountered when trying to read the data set GEOM.

Action Taken: Execution is terminated.

#### RSDEF

Message: \*\*\*\*\*INVALID GEOMETRY TYPE  
ERROR NUMBER 1 IN SUBROUTINE RSDEF

Significance: Geometry type is not 2-D geometry type XY, RZ, or ZR.

Action Taken: Execution is terminated.

Message: ERROR NUMBER 2 IN SUBROUTINE RSDEF

Significance: An error has been committed in POINTR. Probably more space was requested than was available. Increase the size of the container array, or decrease the problem size, and resubmit.

Action Taken: Execution is terminated.

Message: THE THREE DATA SETS LIB.REAL LIB.ADJT LIB.MIX  
MUST BE EITHER ALL NEW OR ALL OLD BUT NOT  
MIXED

ERROR NUMBER 3 IN SUBROUTINE LIB

Significance: The disposition of these three data sets was not consistent.  
SNIFF detected some as new and some as old. Refer to the  
BCD input deck, and verify the disposition of these data sets  
in the BLOCK = OLD list.

Action Taken: Execution is terminated.

Message: ERROR NUMBER 4 IN SUBROUTINE RSDEF

Significance: Same as Error 2 above.

Action Taken: Execution is terminated.

Message: \*\*\*\*\*AN INPUT ERROR MAY HAVE BEEN COMMITTED.\*\*\*\*\*  
\*\*\*\*\*CHECK STATUS OF ALL PREPROCESS DATA SETS.\*\*\*\*\*  
\*\*\*\*\*PROCEED WITH CAUTION.\*\*\*\*\*

Significance: The disposition, as detected by SNIFF, of the data sets  
LIB.ADJT, LIB.REAL, and LIB.MIX does not agree with  
the disposition of LIB.PART. If the first three are old,  
no error will occur in generating LIB.PART. However, if  
only the last data set is old, the first three when generated  
will not agree with it. Check the BCD input to verify the  
disposition of these four data sets in the BLOCK = OLD list.

Action Taken: None

#### RVEL

Message: \*\*\*\*\*NUMBER OF GROUPS DOES NOT AGREE IN XS.ISO

DSRN=iii, GMAX=jjjj, NGROUP=ggg

ERROR NUMBER 1 IN SUBROUTINE RVEL

Significance: As stated, the number of groups defined in XS.C.MIN does  
not agree with the number from XS.ISO. DSRN is the data-  
set number associated with XS.ISO, GMAX is the number of  
groups defined in GEOM, and NGROUP is the number  
defined in XS.ISO.

Action Taken: Execution is terminated.

Message: ERROR IN READING XS.ISO, RECORD iii

ERROR NUMBER 2 IN SUBROUTINE RVEL

Significance: System error in reading this data set. Resubmit job to see if error vanishes. Note iii is the record on which an error was encountered.

Action Taken: Execution is terminated.

### RXSCO1

Message: \*\*\*\*\*ERROR IN READING RECORD 01 OF XS.C.MIN ON  
DSRN iii

ERROR NUMBER 1 IN SUBROUTINE RXSCO1

Significance: An error occurred in attempting to read this record.

Action Taken: Execution is terminated.

### SINCAL

Message: \*\*\*\*\*KEFF=0, THEREFORE 1/KEFF IS UNDEFINED.

ERROR NUMBER 1 IN SUBROUTINE SINCAL

Significance: k-effective equals zero during iterations.

Action Taken: Execution is terminated.

Message: \*\*\*\*\*INNER PRODUCT OF OLD AND NEW FLUXES IS ZERO.  
NEW KEFF IS NOT DEFINED.

ERROR NUMBER 2 IN SUBROUTINE SINCAL

Significance:  $(\psi^{(n)}, \psi^{(n-1)}) = 0$ ; we cannot improve our previous k-effective approximation.

Action Taken: Execution is terminated.

Message: ERROR NO UPSCATTERING IS ALLOWED. EXECUTION  
TERMINATED.

ERROR NUMBER 3 IN SUBROUTINE SINCAL

Significance: The iteration section is not capable of handling upscattering. Scattering cross sections must be modified to remove up-scattering before the problem will run.

Action Taken: Execution is terminated.

### SYNCAL

Message: \*\*\*\*\*ERROR IN POINTR

ERROR NUMBER 1 IN SUBROUTINE SYNCAL

Significance: Error in POINTR. Probably PUTPNT requested more space than was available. Increase the size of the container array, or decrease the problem size, and resubmit.

Action Taken: Execution is terminated.

SYNDEF

Message: \*\*\*\*\*INCORRECT NUMBER OF SYNTHESIS REGIONS  
 ERROR NUMBER 1 IN SUBROUTINE SYNDEF

Significance: There is an error in the synthesis-region boundary input in data set A.SYN2D or the X-direction interval input in data set A.NIP or both, resulting in an incorrect number of synthesis regions.

Action Taken: Execution is terminated.

Message: \*\*\*\*\*ERROR IN INPUT. CHECK 04 and 06A CARDS.  
 ERROR NUMBER 2 IN SUBROUTINE SYNDEF

Significance: The number of trial functions for same synthesis region and energy group is larger than the second number on the type 04 card of A.SYN2D. Check to see if the trial function assignments are correct on the 06A cards. If they are not, fix them; otherwise, correct the 04 card and resubmit.

Action Taken: Execution is terminated.

Message: \*\*\*\*\*GFIN NOT PROPERLY DEFINED ON ALL OF THE 06A CARDS  
 ERROR NUMBER 3 IN SUBROUTINE SYNDEF

Significance: The last energy-group definitions are not properly defined on the 06A cards of data set A.SYN2D for the number of energy groups defined for the problem, or the ranges from the first energy group to the last energy group in each synthesis region are not correct.

Action Taken: Execution is terminated.

Message: THE SYMMETRIC INTERFACE IMPLIES A CONSTANT NUMBER OF TRIAL FUNCTIONS  
 ERROR NUMBER 4 IN SUBROUTINE SYNDEF

Significance: To use the symmetric interface option, the same number of trial functions must be used for every synthesis region in a given energy group. The number of trial functions may, however, vary with energy groups.

Action Taken: Execution is terminated.

SYNGEN

Message: \*\*\*\*\*POINTR ERROR. PROBABLY NOT ENOUGH STORAGE.  
 IMAX=iii, JMAX=jjj, KMAX=kkk  
 GMAX=ggg, NGKMX=nnn, NGKPMX=mmm,

RRMAX=rrr

ERROR NUMBER {3} IN SUBROUTINE SYNGEN

Significance: POINTR error. Probably occurred when requesting more storage than was available in array BLK. Increase the size of the container array, or decrease the problem size, and resubmit.

Action Taken: Execution is terminated.

Message: \*\*\*\*SNIFF UNABLE TO LOCATE 'XS.C.MIN' IN PATH DSNAME  
ARRAY

ERROR NUMBER 2 IN SUBROUTINE SYNGEN

Significance: This data set could not be located by ARC System subroutine SNIFF. This indicates that the data set has not been written.

Action Taken: Execution is terminated.

VOL Refer to the error messages for IVOL.

## G. Sample Input and Output

### 1. Input

Listed below is the sample input to SYN2D (AJC005) using the path STP008 and the catalogued procedure ARCSP008. The format of data set A.SYN2D is described in Section II.E. The data set A.NIP is described in the ARC System documentation, ANL-7711.<sup>1</sup> Data sets listed under 'BLOCK=OLD' are data sets that already exist and will be used as input to the path. The formats of FA.TRIAL and FR.TRIAL are described in Section III.E; XS.ISO is described in ANL-7711. For a detailed description of how to prepare sample input, refer to Sections II.4 and II.5. The input shown here corresponds to the sample output that follows.

Sample Input

BCD INPUT

BLOCK=OLD

DATASET=XS.ISO

DATASET=FR.TRIAL

DATASET=FA.TRIAL

BLOCK=STP008

DATASET=A.SYNZD

	SAMPLE	ADJOINT	WEIGHTING	DISCONTINUOUS TRIAL FUNCTIONS			
01							
02	100	2	1	0	30000	-1	0
03	1.0	E-04	1.0	E-04	1.0	E-061.1495	E+09
04		2	2	0			
05	38.1						
06A		6	2	1			
06B		1	3				
06C		0	0				
06A		6	2	1			
06B		3	5				
06C		0	0				
07	41	42					

DATASET=A.NIP

	SAMPLE	ADJOINT	WEIGHTING	DISCONTINUOUS TRIAL FUNCTIONS			
01							
02							
03		51	0	0			
04		3	2	3	2		
06	CZA1	0.0		38.1		0.0	7.5962
06	ABA11	38.1		50.8		0.0	7.5962
06	ABA21	50.8		63.5		0.0	7.5962
06	ABA31	63.5		76.2		0.0	7.5962
06	CZA2	0.0		38.1		7.5962	20.0977
06	ABA12	38.1		50.8		7.5962	20.0977
06	ABA22	50.8		63.5		7.5962	20.0977
06	ABA32	63.5		76.2		7.5962	20.0977
06	CZA3	0.0		38.1		20.0977	33.1111
06	ABA13	38.1		50.8		20.0977	33.1111
06	ABA23	50.8		63.5		20.0977	33.1111
06	ABA33	63.5		76.2		20.0977	33.1111
06	CZA4	0.0		38.1		33.1111	46.20598

06	ABA14	38.1	50.8	33.1111	46.20598		
06	ABA24	50.8	63.5	33.1111	46.20598		
06	ABA34	63.5	76.2	33.1111	46.20598		
06	CZA5	0.0	38.1	46.20598	59.3283		
06	ABA15	38.1	50.8	46.20598	59.3283		
06	ABA25	50.8	63.5	46.20598	59.3283		
06	ABA35	63.5	76.2	46.20598	59.3283		
06	CZA6	0.0	38.1	59.3283	72.4633		
06	ABA16	38.1	50.8	59.3283	72.4633		
06	ABA26	50.8	63.5	59.3283	72.4633		
06	ABA36	63.5	76.2	59.3283	72.4633		
06	CZA7	0.0	38.1	72.4633	87.376		
06	ABA17	38.1	50.8	72.4633	87.376		
06	ABA27	50.8	63.5	72.4633	87.376		
06	ABA37	63.5	76.2	72.4633	87.376		
06	CZB1	0.0	38.1	87.376	96.9819		
06	ABB11	38.1	50.8	87.376	96.9819		
06	ABB21	50.8	63.5	87.376	96.9819		
06	ABB31	63.5	76.2	87.376	96.9819		
06	CZB2	0.0	38.1	96.9819	107.072		
06	ABB12	38.1	50.8	96.9819	107.072		
06	ABB22	50.8	63.5	96.9819	107.072		
06	ABB32	63.5	76.2	96.9819	107.072		
06	CZC1	0.0	38.1	107.072	123.698		
06	ABC11	38.1	50.8	107.072	123.698		
06	ABC21	50.8	63.5	107.072	123.698		
06	ABC31	63.5	76.2	107.072	123.698		
06	RB11	0.0	38.1	123.698	136.9427		
06	RB12	38.1	50.8	123.698	136.9427		
06	RB13	50.8	63.5	123.698	136.9427		
06	RB14	63.5	76.2	123.698	136.9427		
06	RB21	0.0	38.1	136.9427	150.2054		
06	RB22	38.1	50.8	136.9427	150.2054		
06	RB23	50.8	63.5	136.9427	150.2054		
06	RB24	63.5	76.2	136.9427	150.2054		
06	REFRD	0.0	76.2	150.2054	163.4		
06	REFAX	76.2	129.54	0.0	163.4		
09	X	5	38.1	2	50.8	2	63.5
09	X	2	76.2	2	129.54		
09	Y	3	7.5962	3	20.0977	3	33.1111
09	Y	3	46.20598	3	59.3283	3	72.4633
09	Y	3	87.376	4	96.9819	4	107.072
09	Y	6	123.698	4	136.9427	3	150.2054

09	Y	3 163.4			
13	M1	U238	1.0		
13	M2	PU239	1.0		
13	M3	PU240	1.0		
13	M4	PU241	1.0		
13	M5	PU242	1.0		
13	M6	U235	1.0		
13	M7	O 16	1.0		
13	M8	LUPF	1.0		
13	M9	TA181	1.0		
13	M10	SS	1.0		
13	M11	NA 23	1.0		
13	M12	O 16	1.0		
14	CZA1	M1	0.72268D-02M2	0.87732D-03M3	0.38228D-03
14	CZA1	M4	0.11058D-03M5	0.54023D-04M6	0.13058D-04
14	CZA1	M7	0.23803D-05M8	0.58751D-03M9	0.0 D+00
14	CZA1	M10	0.12709D-01M11	0.83235D-02M12	0.18588D-01
14	CZA2	M1	0.72307D-02M2	0.87714D-03M3	0.38210D-03
14	CZA2	M4	0.11082D-03M5	0.53978D-04M6	0.13105D-04
14	CZA2	M7	0.23696D-05M8	0.58383D-03M9	0.0 D+00
14	CZA2	M10	0.12709D-01M11	0.83235D-02M12	0.18588D-01
14	CZA3	M1	0.72407D-02M2	0.87664D-03M3	0.38164D-03
14	CZA3	M4	0.11145D-03M5	0.53860D-04M6	0.13232D-04
14	CZA3	M7	0.23412D-05M8	0.57417D-03M9	0.0 D+00
14	CZA3	M10	0.12709D-01M11	0.83235D-02M12	0.18588D-01
14	CZA4	M1	0.72573D-02M2	0.87577D-03M3	0.38084D-03
14	CZA4	M4	0.11250D-03M5	0.53660D-04M6	0.13444D-04
14	CZA4	M7	0.22934D-05M8	0.55815D-03M9	0.0 D+00
14	CZA4	M10	0.12709D-01M11	0.83235D-02M12	0.18588D-01
14	CZA5	M1	0.72807D-02M2	0.87443D-03M3	0.37964D-03
14	CZA5	M4	0.11401D-03M5	0.53365D-04M6	0.13749D-04
14	CZA5	M7	0.22241D-05M8	0.53585D-03M9	0.0 D+00
14	CZA5	M10	0.12709D-01M11	0.83235D-02M12	0.18588D-01
14	CZA6	M1	0.73117D-02M2	0.87228D-03M3	0.37774D-03
14	CZA6	M4	0.11603D-03M5	0.52932D-04M6	0.14164D-04
14	CZA6	M7	0.21270D-05M8	0.50700D-03M9	0.0 D+00
14	CZA6	M10	0.12709D-01M11	0.83235D-02M12	0.18588D-01
14	CZA7	M1	0.73574D-02M2	0.86766D-03M3	0.37362D-03
14	CZA7	M4	0.11910D-03M5	0.52110D-04M6	0.14823D-04
14	CZA7	M7	0.19627D-05M8	0.46734D-03M9	0.0 D+00
14	CZA7	M10	0.12709D-01M11	0.83235D-02M12	0.18588D-01
14	CZB1	M1	0.68689D-02M2	0.10580D-02M3	0.50307D-03
14	CZB1	M4	0.17133D-03M5	0.70584D-04M6	0.14604D-04

14	CZB1	M7	0.15873D-05M8	0.52088D-03M9	0.0	D+00
14	CZB1	M10	0.12709D-01M11	0.83235D-02M12	0.18588D-01	
14	CZB2	M1	0.69338D-02M2	0.10684D-02M3	0.49822D-03	
14	CZB2	M4	0.17915D-03M5	0.68975D-04M6	0.15629D-04	
14	CZB2	M7	0.13432D-05M8	0.44344D-03M9	1.4964	D-03
14	CZB2	M10	0.12709D-01M11	0.83235D-02M12	0.18588D-01	
14	CZC1	M1	0.68873D-02M2	0.10627D-02M3	0.50472D-03	
14	CZC1	M4	0.17414D-03M5	0.70455D-04M6	0.14898D-04	
14	CZC1	M7	0.15396D-05M8	0.49332D-03M9	0.0	D+00
14	CZC1	M10	0.12709D-01M11	0.83235D-02M12	0.18588D-01	
14	RB11	M1	0.11620D-01M2	0.29455D-03M3	0.97752D-05	
14	RB11	M4	0.18926D-06M5	0.33145D-08M6	0.28462D-04	
14	RB11	M7	0.18154D-05M8	0.65575D-04M9	0.0	D+00
14	RB11	M10	0.23619D-01M11	0.38902D-02M12	0.21713D-01	
14	RB21	M1	0.11756D-01M2	0.20124D-03M3	0.50488D-05	
14	RB21	M4	0.70958D-07M5	0.87727D-09M6	0.30837D-04	
14	RB21	M7	0.13315D-05M8	0.25584D-04M9	0.0	D+00
14	RB21	M10	0.23619D-01M11	0.38902D-02M12	0.21713D-01	
14	ABA11	M1	0.98658D-02M2	0.35007D-03M3	0.17292D-04	
14	ABA11	M4	0.45742D-06M5	0.11319D-07M6	0.21840D-04	
14	ABA11	M7	0.22527D-05M8	0.92241D-04M9	0.0	D+00
14	ABA11	M10	0.12709D-01M11	0.83235D-02M12	0.18588D-01	
14	ABA12	M1	0.98688D-02M2	0.34816D-03M3	0.17096D-04	
14	ABA12	M4	0.44988D-06M5	0.11065D-07M6	0.21891D-04	
14	ABA12	M7	0.22406D-05M8	0.91336D-04M9	0.0	D+00
14	ABA12	M10	0.12709D-01M11	0.83235D-02M12	0.18588D-01	
14	ABA13	M1	0.98767D-02M2	0.34310D-03M3	0.16581D-04	
14	ABA13	M4	0.43028D-06M5	0.10410D-07M6	0.22023D-04	
14	ABA13	M7	0.22087D-05M8	0.88964D-04M9	0.0	D+00
14	ABA13	M10	0.12709D-01M11	0.83235D-02M12	0.18588D-01	
14	ABA14	M1	0.98898D-02M2	0.33458D-03M3	0.15729D-04	
14	ABA14	M4	0.39845D-04M5	0.93716D-08M6	0.22247D-04	
14	ABA14	M7	0.21545D-05M8	0.85058D-04M9	0.0	D+00
14	ABA14	M10	0.12709D-01M11	0.83235D-02M12	0.18588D-01	
14	ABA15	M1	0.99085D-02M2	0.32231D-03M3	0.14537D-04	
14	ABA15	M4	0.35516D-06M5	0.80082D-08M6	0.22577D-04	
14	ABA15	M7	0.20758D-05M8	0.79656D-04M9	0.0	D+00
14	ABA15	M10	0.12709D-01M11	0.83235D-02M12	0.18588D-01	
14	ABA16	M1	0.99336D-02M2	0.30543D-03M3	0.12948D-04	
14	ABA16	M4	0.29987D-06M5	0.63557D-08M6	0.23017D-04	
14	ABA16	M7	0.19652D-05M8	0.72717D-04M9	0.0	D+00
14	ABA16	M10	0.12709D-01M11	0.83235D-02M12	0.18588D-01	
14	ABA17	M1	0.99713D-02M2	0.27914D-03M3	0.10585D-04	

14	ABA17 M4	0.22309D-06M5	0.42454D-08M6	0.23719D-04
14	ABA17 M7	0.17857D-05M8	0.63278D-04M9	0.0 D+00
14	ABA17 M10	0.12709D-01M11	0.83235D-02M12	0.18588D-01
14	ABB11 M1	0.10019D-01M2	0.24452D-03M3	0.77451D-05
14	ABB11 M4	0.14077D-06M5	0.22684D-08M6	0.24667D-04
14	ABB11 M7	0.15381D-05M8	0.52410D-04M9	0.0 D+00
14	ABB11 M10	0.12709D-01M11	0.83235D-02M12	0.18588D-01
14	ABB12 M1	0.10071D-01M2	0.20615D-03M3	0.51542D-05
14	ABB12 M4	0.76969D-07M5	0.99924D-09M6	0.25729D-04
14	ABB12 M7	0.12658D-05M8	0.40646D-04M9	0.92000D-03
14	ABB12 M10	0.12709D-01M11	0.83235D-02M12	0.18588D-01
14	ABC11 M1	0.10034D-01M2	0.23319D-03M3	0.73912D-05
14	ABC11 M4	0.13454D-06M5	0.21927D-08M6	0.24976D-04
14	ABC11 M7	0.14701D-05M8	0.48876D-04M9	0.0 D+00
14	ABC11 M10	0.12709D-01M11	0.83235D-02M12	0.18588D-01
14	RB12 M1	0.11795D-01M2	0.16765D-03M3	0.33187D-05
14	RB12 M4	0.37660D-07M5	0.36859D-09M6	0.31705D-04
14	RB12 M7	0.10950D-05M8	0.21135D-04M9	0.0 D+00
14	RB12 M10	0.23619D-01M11	0.38902D-02M12	0.21713D-01
14	RB22 M1	0.11863D-01M2	0.11264D-03M3	0.16303D-05
14	RB22 M4	0.13184D-07M5	0.90540D-10M6	0.33092D-04
14	RB22 M7	0.77763D-06M8	0.93033D-05M9	0.0 D+00
14	RB22 M10	0.23619D-01M11	0.38902D-02M12	0.21713D-01
14	ABA21 M1	0.10048D-01M2	0.23141D-03M3	0.80046D-05
14	ABA21 M4	0.14616D-04M5	0.23648D-08M6	0.24866D-04
14	ABA21 M7	0.15945D-05M8	0.36197D-04M9	0.0 D+00
14	ABA21 M10	0.12709D-01M11	0.83235D-02M12	0.18588D-01
14	ABA22 M1	0.10050D-01M2	0.22997D-03M3	0.79054D-05
14	ABA22 M4	0.14352D-06M5	0.23073D-08M6	0.24904D-04
14	ABA22 M7	0.15849D-05M8	0.35810D-04M9	0.0 D+00
14	ABA22 M10	0.12709D-01M11	0.83235D-02M12	0.18588D-01
14	ABA23 M1	0.10055D-01M2	0.22616D-03M3	0.76446D-05
14	ABA23 M4	0.13666D-06M5	0.21596D-08M6	0.25000D-04
14	ABA23 M7	0.15595D-07M8	0.34794D-04M9	0.0 D+00
14	ABA23 M10	0.12709D-01M11	0.83235D-02M12	0.18588D-01
14	ABA24 M1	0.10063D-01M2	0.21972D-03M3	0.72126D-05
14	ABA24 M4	0.12552D-06M5	0.19253D-08M6	0.25175D-04
14	ABA24 M7	0.15162D-05M8	0.33114D-04M9	0.0 D+00
14	ABA24 M10	0.12709D-01M11	0.83235D-02M12	0.18588D-01
14	ABA25 M1	0.10075D-01M2	0.21042D-03M3	0.66065D-05
14	ABA25 M4	0.11038D-06M5	0.16184D-08M6	0.25423D-04
14	ABA25 M7	0.14530D-05M8	0.30722D-04M9	0.0 D+00
14	ABA25 M10	0.12709D-01M11	0.83235D-02M12	0.18588D-01

14	ABA26 M1	0.10092D-01M2	0.19761D-03M3	0.58022D-05
14	ABA26 M4	0.91199D-07M5	0.12505D-08M6	0.25767D-04
14	ABA26 M7	0.13642D-05M8	0.27718D-04M9	0.0 D+00
14	ABA26 M10	0.12709D-01M11	0.88325D-02M12	0.18588D-01
14	ABA27 M1	0.10110D-01M2	0.17799D-03M3	0.46377D-05
14	ABA27 M4	0.65447D-07M5	0.79833D-09M6	0.26305D-04
14	ABA27 M7	0.12227D-05M8	0.23437D-04M9	0.0 D+00
14	ABA27 M10	0.12709D-01M11	0.83235D-02M12	0.18588D-01
14	ABB21 M1	0.10147D-01M2	0.15308D-03M3	0.32857D-07
14	ABB21 M4	0.39066D-07M5	0.39687D-09M6	0.27016D-04
14	ABB21 M7	0.10318D-05M8	0.18522D-04M9	0.0 D+00
14	ABB21 M10	0.12709D-01M11	0.83235D-02M12	0.18588D-01
14	ABB22 M1	0.10179D-01M2	0.12611D-03M3	0.20809D-05
14	ABB22 M4	0.19634D-07M5	0.15645D-09M6	0.27788D-04
14	ABB22 M7	0.82348D-06M8	0.13866D-04M9	0.92000D-03
14	ABB22 M10	0.12709D-01M11	0.83235D-02M12	0.18588D-01
14	ABC21 M1	0.10157D-01M2	0.14457D-03M3	0.30532D-05
14	ABC21 M4	0.35902D-07M5	0.36427D-09M6	0.27247D-04
14	ABC21 M7	0.97448D-06M8	0.17088D-04M9	0.0 D+00
14	ABC21 M10	0.12709D-01M11	0.83235D-02M12	0.18588D-01
14	RB13 M1	0.11876D-01M2	0.10039D-03M3	0.12789D-05
14	RB13 M4	0.91239D-08M5	0.54764D-10M6	0.33406D-04
14	RB13 M7	0.69470D-06M8	0.80771D-05M9	0.0 D+00
14	RB13 M10	0.23619D-01M11	0.38902D-02M12	0.21713D-01
14	RB23 M1	0.11913D-01M2	0.67538D-04M3	0.61953D-06
14	RB23 M4	0.31349D-08M5	0.13221D-10M6	0.34244D-04
14	RB23 M7	0.48793D-06M8	0.40146D-05M9	0.0 D+00
14	RB23 M10	0.23619D-01M11	0.38902D-02M12	0.21713D-01
14	ABA31 M1	0.10162D-01M2	0.14195D-03M3	0.33283D-05
14	ABA31 M4	0.40587D-07M5	0.42055D-09M6	0.27091D-04
14	ABA31 M7	0.10675D-05M8	0.14357D-04M9	0.0 D+00
14	ABA31 M10	0.12709D-01M11	0.83235D-02M12	0.18588D-01
14	ABA32 M1	0.10163D-01M2	0.14097D-03M3	0.32831D-05
14	ABA32 M4	0.39780D-07M5	0.40939D-09M6	0.27118D-04
14	ABA32 M7	0.10603D-05M8	0.14195D-04M9	0.0 D+00
14	ABA32 M10	0.12709D-01M11	0.83235D-02M12	0.18588D-01
14	ABA33 M1	0.10166D-01M2	0.13835D-03M3	0.31641D-05
14	ABA33 M4	0.37683D-07M5	0.38070D-09M6	0.27190D-04
14	ABA33 M7	0.10413D-05M8	0.13770D-04M9	0.0 D+00
14	ABA33 M10	0.12709D-01M11	0.83235D-02M12	0.18588D-01
14	ABA34 M1	0.10172D-01M2	0.13392D-03M3	0.29665D-05
14	ABA34 M4	0.34279D-07M5	0.33530D-09M6	0.27312D-04
14	ABA34 M7	0.10087D-05M8	0.13062D-04M9	0.0 D+00

14		ABA34 M10	0.12709D-01M11	0.83235D-02M12	0.18588D-01
14		ABA35 M1	0.10179D-01M2	0.12750D-03M3	0.26896D-05
14		ABA35 M4	0.29673D-07M5	0.27627D-09M6	0.27491D-04
14		ABA35 M7	0.96108D-06M8	0.12069D-04M9	0.0 D+00
14		ABA35 M10	0.12709D-01M11	0.83235D-02M12	0.18588D-01
14		ABA36 M1	0.10190D-01M2	0.11866D-03M3	0.23253D-05
14		ABA36 M4	0.23929D-07M5	0.20695D-09M6	0.27739D-04
14		ABA36 M7	0.89431D-06M8	0.10762D-04M9	0.0 D+00
14		ABA36 M10	0.12709D-01M11	0.83235D-02M12	0.18588D-01
14		ABA37 M1	0.10205D-01M2	0.10533D-03M3	0.18125D-05
14		ABA37 M4	0.16506D-07M5	0.12555D-09M6	0.28122D-04
14		ABA37 M7	0.78990D-06M8	0.89278D-05M9	0.0 D+00
14		ABA37 M10	0.12709D-01M11	0.83235D-02M12	0.18588D-01
14		ABB31 M1	0.10224D-01M2	0.88773D-04M3	0.12373D-05
14		ABB31 M4	0.92728D-08M5	0.57654D-10M6	0.28620D-04
14		ABB31 M7	0.65134D-06M8	0.68708D-05M9	0.0 D+00
14		ABB31 M10	0.12709D-01M11	0.83235D-02M12	0.18588D-01
14		ABB32 M1	0.10243D-01M2	0.71458D-04M3	0.74392D-06
14		ABB32 M4	0.42755D-08M5	0.20271D-10M6	0.29148D-04
14		ABB32 M7	0.50279D-06M8	0.50228D-05M9	0.92000D-03
14		ABB32 M10	0.12709D-01M11	0.83235D-02M12	0.18588D-01
14		ABC31 M1	0.10230D-01M2	0.83146D-04M3	0.11259D-05
14		ABC31 M4	0.82503D-08M5	0.50677D-10M6	0.28778D-04
14		ABC31 M7	0.60958D-06M8	0.62629D-05M9	0.0 D+00
14		ABC31 M10	0.12709D-01M11	0.83235D-02M12	0.18588D-01
14		RB14 M1	0.11925D-01M2	0.56321D-04M3	0.45356D-06
14		RB14 M4	0.19871D-08M5	0.71746D-11M6	0.34502D-04
14		RB14 M7	0.42414D-06M8	0.31618D-05M9	0.0 D+00
14		RB14 M10	0.23619D-01M11	0.38902D-02M12	0.21713D-01
14		RB24 M1	0.11945D-01M2	0.38150D-04M3	0.22058D-06
14		RB24 M4	0.68812D-09M5	0.17597D-11M6	0.34984D-04
14		RB24 M7	0.29814D-06M8	0.17322D-05M9	0.0 D+00
14		RB24 M10	0.23619D-01M11	0.38902D-02M12	0.21713D-01
14		REFAX M10	4.26485E-02M11	1.0952 E-02M12	
14		REFRD M10	7.8857 E-02M11	1.65375E-03M12	
15	CZA1	CZA1			
15	CZA2	CZA2			
15	CZA3	CZA3			
15	CZA4	CZA4			
15	CZA5	CZA5			
15	CZA6	CZA6			
15	CZA7	CZA7			
15	CZB1	CZB1			

15	CZB2	CZB2
15	CZC1	CZC1
15	RB11	RB11
15	RB21	RB21
15	ABA11	ABA11
15	ABA12	ABA12
15	ABA13	ABA13
15	ABA14	ABA14
15	ABA15	ABA15
15	ABA16	ABA16
15	ABA17	ABA17
15	ABB11	ABB11
15	ABB12	ABB12
15	ABC11	ABC11
15	RB12	RB12
15	RB22	RB22
15	ABA21	ABA21
15	ABA22	ABA22
15	ABA23	ABA23
15	ABA24	ABA24
15	ABA25	ABA25
15	ABA26	ABA26
15	ABA27	ABA27
15	ABB21	ABB21
15	ABB22	ABB22
15	ABC21	ABC21
15	RB13	RB13
15	RB23	RB23
15	ABA31	ABA31
15	ABA32	ABA32
15	ABA33	ABA33
15	ABA34	ABA34
15	ABA35	ABA35
15	ABA36	ABA36
15	ABA37	ABA37
15	ABB31	ABB31
15	ABB32	ABB32
15	ABC31	ABC31
15	RB14	RB14
15	RB24	RB24
15	REFAX	REFAX
15	REFRD	REFRD

## 2. Output

No sample output is listed for other modules called by the path STP008.

Listed below is an example of the output produced by the module SYN2D. Not every page is shown, but at least one page of each type is given as an example of what to expect. Refer to Section II.B.5 for a detailed description of the computations involved in calculating monitoring information and the various volumes and inventories described.

Before proceeding further, we should introduce a note of caution. The results yielded by SYN2D will only be as good as the trial functions used. A poor choice of trial functions can result in a bad approximation, for example, partially negative, two-dimensional flux. When negative fluxes are encountered, the resultant inventories that are calculated are no longer correct and in some cases can be totally meaningless. Hence, before looking at inventories, the user should check for negative fluxes.

The first page of output, which has no output page number, indicates that the link to the module was successfully completed. This is followed by a list of all data sets that were open when this module was called. If the data sets are ARC System data sets, both their names and their reference numbers are listed; otherwise, only their numbers are given. These open data sets are then closed.

Output page 1 contains user-supplied information from data set A.SYN2D. The maximum number of iterations is the limit after which the iterations monitored on page 105 will be terminated. The k-effective difference, the normed flux difference, and the k-effective limits differences are the convergence criteria applied to columns 4, 10, and 7 of the iteration monitored data, respectively. The power-normalization factor for burnup is given in watts. The POINTR allocation is the size of the container array in double words (R\*8) for both main and bulk core. The current interface condition can be either 'asymmetric', indicating that at each synthesis interface the trial functions on the left are weighted by the diffusion coefficient on the left in crossing the interface, or 'symmetric', indicating that trial functions from both synthesis regions are used in crossing the interface. The final message tells whether the user-supplied real trial functions are to be used as adjoints also.

Page 2 contains information on the reactor's physical characteristics and the user-imposed mesh. It first prints the geometry type (XY, RZ, or ZR). This is followed by the mesh interval boundaries in the J-direction for the first mesh interval, followed by the mesh interval boundaries for all intervals in the I-direction. For each mesh cell thus defined, the mesh-interval lengths, two-dimensional mesh-cell volumes,

Sample Output

\*\*\*\*\*MODULE AJC009 HAS BEEN ENTERED.\*\*\*\*\*

THE FOLLOWING DATA SETS WERE OPEN BUT HAVE BEEN REWOUND  
DATA SET NAME DSRN

XS.M.MIN	37
XS.ISO2	35
SCR002	26
FR.D2	16
	6

SAMPLE,ADJOINT WEIGHTING, DISCONTINUOUS TRIAL FUNCTIONS

PAGE 1

MAXIMUM NUMBER OF OUTER ITERATIONS= 100

OUTER ITERATION CONVERGENCE CRITERIA  
KEFF DIFFERENCE 0.1000000D-05  
SUM OF ABSOLUTE VALUE OF FLUX DIFFERENCE 0.1000000D-03  
DIVIDED BY THE NORMED SUM OF THE ABSOLUTE VALUES OF THE FLUX.  
KEFF LIMITS DIFFERENCE 0.1000000D-03  
POWER NORMALIZATION FOR BURNUP CALCULATION 0.1149500D 10  
\*\*\*\*POINTER SPACE HAS BEEN ALLOCATED.  
MAIN CORE IS. 30000 AND BULK CORE IS 0

THE SYMMETRIC CURRENT INTERFACE CONDITION WILL BE ASSUMED.  
THE REAL & ADJOINT TRIAL FUNCTIONS WILL NOT BE IDENTICAL.

SAMPLE, ADJOINT WEIGHTING, DISCONTINUOUS TRIAL FUNCTIONS

PAGE 2

## GEOMETRY DATA

## ZR GEOMETRY

J= 1 FROM MESH LINE 0.0 TO MESH LINE 2.532  
 MESH INTERVAL= 2.532

MESH LINES	MESH INTERVAL NUMBER	MESH INTERVAL LENGTH	MESH INTERVAL VOLUME	REGION NUMBER	COMP NUMBER
0.0	1	7.620	153.481	1	1
7.620	2	7.620	153.481	1	1
15.240	3	7.620	153.481	1	1
22.860	4	7.620	153.481	1	1
30.480	5	7.620	153.481	1	1
38.100	6	6.350	127.901	2	13
44.450	7	6.350	127.901	2	13
50.800	8	6.350	127.901	3	25
57.150	9	6.350	127.901	3	25
63.500	10	6.350	127.901	4	37
69.850	11	6.350	127.901	4	37
76.200	12	26.670	537.184	50	49
102.870	13	26.670	537.184	50	49
129.540					

J= 2 FROM MESH LINE 2.532 TO MESH LINE 5.064

SAMPLE,ADJOINT WEIGHTING, DISCONTINUOUS TRIAL FUNCTIONS

PAGE 3

DATA FOR COMPOSITION CZA1

GROUP	DIF COEF	REMOVAL	NU*FISSION	CHI	FISSION
1	3.00535D 00	4.32421D-02	1.89903D-02	5.88153D-01	6.31015D-03
2	1.75449D 00	1.42947D-02	5.31772D-03	3.79164D-01	1.80765D-03
3	1.27725D 00	1.04123D-02	4.81215D-03	3.09440D-02	1.66460D-03
4	9.53959D-01	1.31736D-02	7.61058D-03	1.72015D-03	2.64081D-03
5	1.02302D 00	2.98655D-02	2.14460D-02	1.74621D-05	7.44039D-03
6	9.70739D-01	5.78219D-02	5.72980D-02	2.00987D-06	1.98775D-02

SAMPLE,ADJOINT WEIGHTING, DISCONTINUOUS TRIAL FUNCTIONS

PAGE 4

TRANSFER CROSS SECTION FOR COMPOSITION CZA1

GROUP	FROM GROUP							
1	1	0.0						
2	1	3.35727D-02	2	0.0				
3	1	2.65260D-03	2	1.10645D-02	3	0.0		
4	1	7.41881D-05	2	2.23511D-05	3	5.91735D-03	4	0.0
5	1	1.72381D-08	2	6.33154D-08	3	3.83849D-07	4	2.29634D-03
							5	0.0
6	2	1.23186D-09	3	4.06005D-09	4	7.56576D-08	5	2.06397D-03
							6	0.0



SAMPLE,ADJOINT WEIGHTING, DISCONTINUOUS TRIAL FUNCTIONS  
THE LARGEST CONDITION NUMBER FOR MATRIX D FOR GROUP...  
THE LARGEST CONDITION NUMBER FOR MATRIX D FOR GROUP...  
THE LARGEST CONDITION NUMBER FOR MATRIX D FOR GROUP...  
THE LARGEST CONDITION NUMBER FOR MATRIX D FOR GROUP...  
THE LARGEST CONDITION NUMBER FOR MATRIX D FOR GROUP...  
THE LARGEST CONDITION NUMBER FOR MATRIX D FOR GROUP...  
THE LARGEST CONDITION NUMBER FOR MATRIX D FOR GROUP...  
THE FOLLOWING DATA SETS WERE OPEN BUT HAVE BEEN REMOVED

			PAGE	104
1 IS	0.610D 04	IN REGION NUMBER	2	
2 IS	0.354D 04	IN REGION NUMBER	2	
3 IS	0.199D 04	IN REGION NUMBER	2	
4 IS	0.151D 04	IN REGION NUMBER	2	
5 IS	0.467D 03	IN REGION NUMBER	2	
6 IS	0.115D 04	IN REGION NUMBER	2	

DATA SET NAME DSRN

SCR004	28
SCR001	25
SCR003	27
SCR002	26
LIB.PART	23
	6

TIME FOR EXECUTION OF SYNGEN IS 0.0772 MINUTES.

SAMPLE, ADJOINT WEIGHTING, DISCONTINUOUS TRIAL FUNCTIONS

PAGE 105

## PROBLEM ITERATION HISTORY

OUTER NO.	NO. IN.	LATEST KEFF	KEFF DIFF	LAMDA UP	LAMDA DOWN	LAMDA DIFF	SUM OF FLX DIFF	SUM OF OLD FLX	QUOTIENT OF LAST TWO NORMED						
1	0	1.0000000	00	1.1067400	00	7.5174560	00	1.9615560-03	7.5154940	00	1.1615820	02	1.5600000	02	4.7731000-03
2	0	2.1067400	00	-9.0953130	-01	2.0791250	00	5.0962150-03	2.0740290	00	6.5377120	01	1.2365920	02	3.3890240-03
3	0	1.1972090	00	-3.0423300	-03	1.3651510	00	6.5843650-02	1.2993080	00	9.2255260	00	6.1772840	01	9.5734600-04
4	0	1.1941670	00	-4.3686120	-02	1.1099590	00	1.5618310-01	9.5373190	-01	5.4552960	00	5.9397950	01	5.8873830-04
5	0	1.1504810	00	-3.4524470	-02	1.0506830	00	3.3213180-01	7.1855110	-01	3.4427520	00	5.6372140	01	3.9148640-04
6	0	1.1159560	00	-2.5253500	-02	1.0270970	00	4.6941050-01	5.5768640	-01	2.3091920	00	5.4088280	00	2.7367320-04
7	0	1.0907030	00	-1.8680300	-02	1.0157700	00	2.6498530-01	7.5078490	-01	1.6360640	00	5.2402670	01	2.0013470-04
8	0	1.0720220	00	-1.4074450	-02	1.0097910	00	1.1631470-01	8.9347630	-01	1.1998570	00	5.1158510	01	1.5034430-04
9	0	1.0579480	00	-1.0773230	-02	1.0064290	00	3.2718310-01	6.7924550	-01	9.0237850	-01	5.0222530	01	1.1517690-04
10	0	1.0471750	00	-8.3540080	-03	1.0044330	00	5.7214650-01	4.3228630	-01	6.9179990	-01	4.9514940	01	8.9561160-05
11	0	1.0388210	00	-6.5487950	-03	1.0031870	00	4.2274580-01	5.8044110	-01	5.3843210	-01	4.8971930	01	7.0478900-05
12	0	1.0322720	00	-5.1814600	-03	1.0023800	00	3.0256830-01	6.9981200	-01	4.2416120	-01	4.8556420	01	5.5996340-05
13	0	1.0270910	00	-4.1323630	-03	1.0018220	00	8.3128690-02	9.1869300	-01	3.3740250	-01	4.8227720	01	4.4846330-05
14	0	1.0229580	00	-3.3182320	-03	1.0014200	00	1.3711630-01	8.6430400	-01	2.7052340	-01	4.7982760	01	3.6140580-05
15	0	1.0196400	00	-2.6800290	-03	1.0011230	00	3.2777800-02	9.6834510	-01	2.1831200	-01	4.7845190	01	2.9249250-05
16	0	1.0169600	00	-2.1752550	-03	1.0008970	00	2.6980840-01	7.3108880	-01	1.7711750	-01	4.7769120	01	2.3767830-05
17	0	1.0147850	00	-1.7728840	-03	1.0007230	00	1.5823520-01	8.4248750	-01	1.4432610	-01	4.7735650	01	1.9381060-05
18	0	1.0130120	00	-1.4499670	-03	1.0005860	00	4.5556450-01	5.4502130	-01	1.1802990	-01	4.7711520	01	1.5857840-05
19	0	1.0115620	00	-1.1893070	-03	1.0004770	00	9.5442970-01	4.6047490	-02	9.6811550	-02	4.7695450	01	1.3011450-05
20	0	1.0103720	00	-9.7786290	-04	1.0003900	00	9.6076520-01	3.9624990	-02	7.9602160	-02	4.7682760	01	1.0701360-05
21	0	1.0093950	00	-8.0562440	-04	1.0003200	00	9.6637090-01	3.3949150	-02	6.5586260	-02	4.7674000	01	8.8184750-06
22	0	1.0085890	00	-6.6482950	-04	1.0002630	00	9.7129240-01	2.8970770	-02	5.4125150	-02	4.7666770	01	7.2787820-06
23	0	1.0079240	00	-5.4939920	-04	1.0002170	00	9.7558240-01	2.4634450	-02	4.4729890	-02	4.7660780	01	6.0160590-06
24	0	1.0073750	00	-4.5453120	-04	1.0001790	00	9.7929780-01	2.0881190	-02	3.7007740	-02	4.7655800	01	4.9779680-06
25	0	1.0069200	00	-3.7640240	-04	1.0001480	00	9.8249710-01	1.7650860	-02	3.0647710	-02	4.7651670	01	4.1228290-06
26	0	1.0065440	00	-3.1194910	-04	1.0001220	00	9.8523800-01	1.4884420	-02	2.5400610	-02	4.7648240	01	3.4172180-06
27	0	1.0062320	00	-2.5870200	-04	1.0001010	00	9.8757580-01	1.2525540	-02	2.1065540	-02	4.7645390	01	2.8341780-06
28	0	1.0059730	00	-2.1466040	-04	1.0000840	00	9.8956230-01	1.0521720	-02	1.7479750	-02	4.7643020	01	2.3518600-06
29	0	1.0057590	00	-1.7819690	-04	1.0000700	00	9.9124470-01	8.8250330	-03	1.4510840	-02	4.7641050	01	1.9524800-06
30	0	1.0055800	00	-1.4798280	-04	1.0000580	00	9.9266550-01	7.3923770	-03	1.2050670	-02	4.7639410	01	1.6215120-06
31	0	1.0054320	00	-1.2293000	-04	1.0000480	00	9.9386250-01	6.1855150	-03	1.0010690	-02	4.7638050	01	1.3470550-06
32	0	1.0053090	00	-1.0214490	-04	1.0000400	00	9.9486900-01	5.1708920	-03	8.3181740	-03	4.7636920	01	1.1193340-06
33	0	1.0052070	00	-8.4892450	-05	1.0000330	00	9.9571380-01	4.3193290	-03	6.9132890	-03	4.7635980	01	9.3030430-07
34	0	1.0051220	00	-7.0566590	-05	1.0000280	00	9.9642190-01	3.6056390	-03	5.7466990	-03	4.7635200	01	7.7331900-07
35	0	1.0050520	00	-5.8666990	-05	1.0000230	00	9.9701470-01	3.0082160	-03	4.7796700	-03	4.7634550	01	6.4293860-07
36	0	1.0049930	00	-4.8780040	-05	1.0000190	00	9.9751040-01	2.5086230	-03	3.9725290	-03	4.7634000	01	5.3459560-07
37	0	1.0049440	00	-4.0563470	-05	1.0000160	00	9.9792460-01	2.0911920	-03	3.3034080	-03	4.7633550	01	4.4455410-07
38	0	1.0049040	00	-3.3733800	-05	1.0000130	00	9.9827050-01	1.7426580	-03	2.7472240	-03	4.7633180	01	3.6970890-07
39	0	1.0048700	00	-2.8056040	-05	1.0000110	00	9.9855910-01	1.4518220	-03	2.2848440	-03	4.7632870	01	3.0748590-07
40	0	1.0048420	00	-2.3335280	-05	1.0000090	00	9.9879980-01	1.2092510	-03	1.9003980	-03	4.7632610	01	2.5574990-07

PROBLEM ITERATION HISTORY									
OUTER NO.	NO. IN.	LATEST KEFF	KEFF DIFF	LAMDA UP	LAMDA DOWN	LAMDA DIFF	SUM OF FLX DIFF	SUM OF OLD FLX	QUOTIENT OF LAST TWO NORMED
41	0	1.004819D 00	-1.940980D-05	1.000008D 00	9.990005D-01	1.007020D-03	1.580715D-03	4.763239D 01	2.127289D-07
42	0	1.004799D 00	-1.614533D-05	1.000006D 00	9.991678D-01	8.384773D-04	1.314862D-03	4.763221D 01	1.769518D-07
43	0	1.004783D 00	-1.343036D-05	1.000005D 00	9.993072D-01	6.980522D-04	1.093759D-03	4.763206D 01	1.471965D-07
44	0	1.004770D 00	-1.11725D-05	1.000004D 00	9.994233D-01	5.810816D-04	9.098612D-04	4.763194D 01	1.224482D-07
45	0	1.004759D 00	-9.294022D-06	1.000004D 00	9.995200D-01	4.836675D-04	7.569005D-04	4.763184D 01	1.018631D-07
46	0	1.004749D 00	-7.7317C7D-06	1.000003D 00	9.996005D-01	4.025538D-04	6.296669D-04	4.763175D 01	8.474025D-08
47	0	1.004741D 00	-6.432120D-06	1.000003D 00	9.996675D-01	3.350222D-04	5.238295D-04	4.763168D 01	7.049681D-08
48	0	1.004735D 00	-5.351047D-06	1.000002D 00	9.997233D-01	2.788049D-04	4.357876D-04	4.763162D 01	5.864823D-08
49	0	1.004730D 00	-4.451725D-06	1.000002D 00	9.997697D-01	2.320108D-04	3.625473D-04	4.763157D 01	4.879161D-08
50	0	1.004725D 00	-3.703582D-06	1.000001D 00	9.998084D-01	1.930636D-04	3.016188D-04	4.763153D 01	4.059190D-08
51	0	1.004722D 00	-3.081193D-06	1.000001D 00	9.998406D-01	1.606495D-04	2.509318D-04	4.763149D 01	3.377045D-08
52	0	1.004718D 00	-2.563414D-06	1.000001D 00	9.998673D-01	1.336741D-04	2.087640D-04	4.763147D 01	2.809552D-08
53	0	1.004716D 00	-2.132657D-06	1.000001D 00	9.998896D-01	1.112260D-04	1.736832D-04	4.763144D 01	2.337435D-08
54	0	1.004714D 00	-1.774292D-06	1.000001D 00	9.999081D-01	9.254598D-05	1.444981D-04	4.763142D 01	1.944661D-08
55	0	1.004712D 00	-1.476151D-06	1.000001D 00	9.999236D-01	7.700210D-05	1.202176D-04	4.763141D 01	1.617894D-08
56	0	1.004711D 00	-1.228112D-06	1.000000D 00	9.999364D-01	6.406818D-05	1.000173D-04	4.763139D 01	1.346038D-08
57	0	1.004709D 00	-1.021754D-06	1.000000D 00	9.999471D-01	5.330621D-05	8.321151D-05	4.763138D 01	1.119865D-08
58	0	1.004708D 00	-8.500713D-07	1.000000D 00	9.999560D-01	4.435163D-05	6.922973D-05	4.763137D 01	9.316975D-09

CONVERGED KEFF = 1.004707429D 00

DATASET FR.TG HAS BEEN WRITTEN OUT ON DSRN 18  
 TIME FOR EXECUTION OF SYNCAL IS 1.3798 MINUTES.

CALCULATED MIXING FUNCTIONS FOR GROUP 1									
R-AXIS	Z-AXIS	Z-AXIS	Z-AXIS						
	1	2	3	4	5	6	7		
1	1.234343D 00	1.180684D 00	1.073175D 00	9.086603D-01	6.729918D-01	-1.730639D 00	-9.201929D-01		
2	-2.559379D-02	-2.439591D-02	-2.181466D-02	-1.720381D-02	-8.670236D-03	2.965897D 00	1.590138D 00		
R-AXIS	Z-AXIS								
	8	9	10	11	12	13			
1	-4.915409D-01	-2.715758D-01	-1.507991D-01	-8.988520D-02	-1.367915D-02	-1.239848D-03			
2	8.558058D-01	4.766942D-01	2.666018D-01	1.599450D-01	2.426600D-02	2.192445D-03			

R-AXIS	INPUT TRIAL FUNCTIONS FOR GROUP 1 REGION 1	
	FNT NO. 1	FNT NO. 2
1	9.1485320-04	5.0112070-03
2	9.1442480-04	4.9894740-03
3	9.1356770-04	4.9456010-03
4	9.1186620-04	4.8571870-03
5	9.0859470-04	4.7476250-03
6	9.0416470-04	4.6223240-03
7	8.9845560-04	4.4718540-03
8	8.9139230-04	4.3020500-03
9	8.8308210-04	4.1119550-03
10	8.7348370-04	3.8980830-03
11	8.6262600-04	3.6755220-03
12	8.5053590-04	3.4407260-03
13	8.3719420-04	3.1899310-03
14	8.2269240-04	2.9417190-03
15	8.0708830-04	2.6908020-03
16	7.9044980-04	2.4311790-03
17	7.7310570-04	2.1851490-03
18	7.5539610-04	1.9465770-03
19	7.3671560-04	1.6945720-03
20	7.1913000-04	1.4547550-03
21	7.0680790-04	1.2314610-03
22	7.0569340-04	1.0717140-03
23	6.9719520-04	9.7541580-04
24	6.8227410-04	8.8544860-04
25	6.6195320-04	8.0062480-04
26	6.3567500-04	7.1664360-04
27	6.0728740-04	6.4258200-04
28	5.7845000-04	5.7986570-04
29	5.4925540-04	5.2692900-04
30	5.1899930-04	4.8100410-04
31	4.8348920-04	4.3614010-04
32	4.4323360-04	3.9326980-04
33	3.9791360-04	3.5190230-04
34	3.4690270-04	3.1154160-04
35	2.8914020-04	2.7163920-04
36	2.0343210-04	2.2165510-04
37	1.3696480-04	1.7578450-04
38	9.4031280-05	1.3959540-04
39	6.5404680-05	1.1006320-04
40	4.2020400-05	8.0731310-05
41	2.6231260-05	5.6320520-05
42	1.6152440-05	3.7106040-05
43	7.8393170-06	1.8006340-05
44	3.3593690-06	7.7162240-06
45	9.2225550-07	2.1183530-06

SAMPLE,ADJOINT WEIGHTING, DISCONTINUOUS TRIAL FUNCTIONS

UN-NORMALIZED FLUX WILL BE READ FROM DSRN 25

RECORD 1 OF REAL WRITTEN OUT ON DATA SET REFERENCE NUMBER 16

REGION	VOLUME	POWER	AVERAGE POWER
CZA1	6.906653D 03	4.155585D-03	6.016786D-07
ABA11	2.302218D 03	2.456991D-04	1.067228D-07
ABA21	2.302218D 03	1.177187D-04	5.113273D-08
ABA31	2.302218D 03	4.570678D-05	1.985337D-08
CZA2	4.144013D 04	2.486600D-02	6.000464D-07
ABA12	1.381338D 04	1.693852D-03	1.226241D-07
ABA22	1.381338D 04	7.157275D-04	5.181409D-08
ABA32	1.381338D 04	2.898805D-04	2.098549D-08
CZA3	8.287988D 04	4.926972D-02	5.944714D-07
ABA13	2.762663D 04	3.625902D-03	1.312467D-07
ABA23	2.762663D 04	1.474135D-03	5.335922D-08
ABA33	2.762663D 04	5.829272D-04	2.110020D-08
CZA4	1.243206D 05	7.256719D-02	5.837101D-07
ABA14	4.144020D 04	5.973358D-03	1.441440D-07
ABA24	4.144020D 04	2.123638D-03	5.124585D-08
ABA34	4.144020D 04	8.253523D-04	1.991671D-08
CZA5	1.657597D 05	9.388806D-02	5.664105D-07
ABA15	5.525324D 04	6.559963D-03	1.187254D-07
ABA25	5.525324D 04	2.551247D-03	4.617371D-08
ABA35	5.525324D 04	9.778786D-04	1.769812D-08
CZA6	2.072014D 05	1.120538D-01	5.407968D-07
ABA16	6.906713D 04	7.175960D-03	1.038983D-07
ABA26	6.906713D 04	2.731723D-03	3.955170D-08
ABA36	6.906713D 04	1.031939D-03	1.494110D-08
CZA7	2.853085D 05	1.429226D-01	5.009407D-07
ABA17	9.510283D 04	7.947695D-03	8.356948D-08
ABA27	9.510283D 04	2.963441D-03	3.116039D-08
ABA37	9.510283D 04	1.105270D-03	1.162184D-08
CZB1	2.119701D 05	1.150956D-01	5.429801D-07
ABB11	7.065671D 04	4.642337D-03	6.570271D-08
ABB21	7.065671D 04	1.692007D-03	2.394687D-08
ABB31	7.065671D 04	6.249610D-04	8.845035D-09
CZB2	2.464423D 05	1.149361D-01	4.663815D-07
ABB12	8.214743D 04	4.285715D-03	5.217102D-08
ABB22	8.214743D 04	1.531745D-03	1.864630D-08
ABB32	8.214743D 04	5.615313D-04	6.835653D-09
CZC1	4.592424D 05	1.570228D-01	3.419170D-07
ABC11	1.530808D 05	5.820799D-03	3.802436D-08
ABC21	1.530808D 05	2.094003D-03	1.367907D-08
ABC31	1.530808D 05	7.645989D-04	4.994741D-09
RB11	4.131989D 05	2.409883D-02	5.832259D-08
RB12	1.377330D 05	3.685123D-03	2.675556D-08
RB13	1.377330D 05	1.264362D-03	9.179804D-09
RB14	1.377330D 05	4.600334D-04	3.340038D-09
RB21	4.558403D 05	7.835217D-03	1.718851D-08
RB22	1.519468D 05	2.117716D-03	1.393722D-08
RB23	1.519468D 05	7.199727D-04	4.738322D-09
RB24	1.519468D 05	2.645571D-04	1.741117D-09
REFRD	9.905687D 05	0.0	0.0
REFAX	4.474113D 06	0.0	0.0

TOTAL POWER = 1.000000D 00

FR.PN WRITTEN OUT ON DATA SET REFERENCE NUMBER 17

NORMALIZATION FACTOR FOR BURNUP= 3.748571D 01

RECORD 2 OF REAL WRITTEN OUT ON DATA SET REFERENCE NUMBER 16

SAMPLE,ADJOINT WEIGHTING, DISCONTINUOUS TRIAL FUNCTIONS

PROBLEM TYPE K CALC.				REAL FLUX FOR GROUP			1	
R-AXIS	Z-AXIS 3.810	Z-AXIS 11.430	Z-AXIS 19.050	Z-AXIS 26.670	Z-AXIS 34.290	Z-AXIS 41.275	Z-AXIS 47.625	
1.266	2.670317D-05	2.555373D-05	2.327500D-05	1.987635D-05	1.526556D-05	2.707412D-06	2.477325D-06	
3.798	2.670390D-05	2.555438D-05	2.327538D-05	1.987594D-05	1.526290D-05	3.202165D-06	2.738133D-06	
6.330	2.670563D-05	2.555594D-05	2.327638D-05	1.987530D-05	1.525766D-05	4.209034D-06	3.268976D-06	
9.680	2.670996D-05	2.555988D-05	2.327912D-05	1.987463D-05	1.524756D-05	6.264800D-06	4.353058D-06	
13.847	2.667705D-05	2.552814D-05	2.324922D-05	1.984561D-05	1.521417D-05	7.560166D-06	5.025130D-06	
18.014	2.661672D-05	2.547016D-05	2.319531D-05	1.979573D-05	1.516361D-05	8.304011D-06	5.398270D-06	
22.267	2.653147D-05	2.538827D-05	2.311943D-05	1.972640D-05	1.509592D-05	8.807731D-06	5.337551D-06	
26.604	2.641482D-05	2.527630D-05	2.301603D-05	1.963311D-05	1.500838D-05	9.045403D-06	5.730219D-06	
30.942	2.627097D-05	2.513827D-05	2.288874D-05	1.951891D-05	1.490316D-05	9.154540D-06	5.749820D-06	
35.294	2.610093D-05	2.497514D-05	2.273841D-05	1.938440D-05	1.478030D-05	9.258258D-06	5.761649D-06	
39.659	2.589536D-05	2.477800D-05	2.255709D-05	1.922335D-05	1.463685D-05	9.167508D-06	5.667437D-06	
44.023	2.565757D-05	2.455001D-05	2.234760D-05	1.903805D-05	1.447410D-05	9.016267D-06	5.538289D-06	
48.393	2.538948D-05	2.429301D-05	2.21159D-05	1.882974D-05	1.429258D-05	8.925739D-06	5.438416D-06	
52.767	2.508143D-05	2.399778D-05	2.184087D-05	1.859213D-05	1.408963D-05	8.663194D-06	5.246848D-06	
57.141	2.473892D-05	2.366560D-05	2.154016D-05	1.832504D-05	1.386752D-05	8.378510D-06	5.042877D-06	
61.517	2.436831D-05	2.331450D-05	2.121490D-05	1.804487D-05	1.362886D-05	8.266133D-06	4.929462D-06	
65.896	2.396517D-05	2.292830D-05	2.086154D-05	1.773736D-05	1.337438D-05	7.950581D-06	4.709920D-06	
70.274	2.354491D-05	2.252580D-05	2.049337D-05	1.741757D-05	1.311161D-05	7.571457D-06	4.457822D-06	
74.949	2.310186D-05	2.210143D-05	2.010522D-05	1.708041D-05	1.283452D-05	7.210568D-06	4.212750D-06	
79.920	2.26853D-05	2.170361D-05	1.974132D-05	1.676419D-05	1.257427D-05	6.626282D-06	3.850410D-06	
84.891	2.243324D-05	2.146082D-05	1.951850D-05	1.656798D-05	1.240470D-05	6.101134D-06	3.523141D-06	
88.577	2.250561D-05	2.152968D-05	1.957956D-05	1.661428D-05	1.242164D-05	5.891711D-06	3.378161D-06	
90.978	2.229153D-05	2.132469D-05	1.939230D-05	1.645248D-05	1.229134D-05	5.720877D-06	3.268858D-06	
93.380	2.186162D-05	2.091327D-05	1.901748D-05	1.613208D-05	1.204427D-05	5.548113D-06	3.158170D-06	
95.781	2.125040D-05	2.032843D-05	1.848508D-05	1.567842D-05	1.169906D-05	5.401952D-06	3.060091D-06	
98.243	2.044244D-05	1.955540D-05	1.778164D-05	1.507998D-05	1.124670D-05	5.365883D-06	3.023562D-06	
100.766	1.955825D-05	1.870948D-05	1.701203D-05	1.442585D-05	1.075418D-05	5.209366D-06	2.924487D-06	
103.288	1.865151D-05	1.784201D-05	1.622295D-05	1.375561D-05	1.025096D-05	4.928664D-06	2.761153D-06	
105.811	1.776232D-05	1.695692D-05	1.541794D-05	1.307222D-05	9.739067D-06	4.557267D-06	2.551197D-06	
108.458	1.676113D-05	1.603383D-05	1.457847D-05	1.235988D-05	9.206492D-06	4.059059D-06	2.274686D-06	
111.229	1.62273D-05	1.494457D-05	1.358796D-05	1.151970D-05	8.579345D-06	3.616570D-06	2.028266D-06	
114.000	1.432645D-05	1.370455D-05	1.246043D-05	1.056357D-05	7.866541D-06	3.267796D-06	1.832499D-06	
116.771	1.286238D-05	1.230403D-05	1.118705D-05	9.48395D-06	7.062466D-06	3.004173D-06	1.682692D-06	
119.542	1.121023D-05	1.072361D-05	9.750147D-06	8.266004D-06	6.155987D-06	2.824549D-06	1.578127D-06	
122.313	9.33554E-06	8.930239D-06	8.119691D-06	6.884144D-06	5.128190D-06	2.735813D-06	1.522384D-06	
125.354	6.547348D-06	6.263227D-06	5.695048D-06	4.829503D-06	3.601007D-06	3.032483D-06	1.671209D-06	
128.665	4.390008D-06	4.199566D-06	3.818856D-06	3.239376D-06	2.418311D-06	3.132000D-06	1.715175D-06	
131.976	3.007896D-06	2.870845D-06	2.610776D-06	2.215269D-06	1.655883D-06	2.972578D-06	1.622294D-06	
135.287	2.078522D-06	1.988415D-06	1.808414D-06	1.534908D-06	1.148772D-06	2.687014D-06	1.463147D-06	
139.153	1.328543D-06	1.270972D-06	1.156017D-06	9.815310D-07	7.357317D-07	2.304717D-06	1.252178D-06	
143.574	8.252990D-07	7.895498D-07	7.181968D-07	6.100025D-07	4.579107D-07	1.783075D-06	9.675078D-07	
147.995	5.065388D-07	4.846030D-07	4.408330D-07	3.745084D-07	2.814069D-07	1.263066D-06	6.847765D-07	
152.405	2.458419D-07	2.319567D-07	2.139524D-07	1.817626D-07	1.365768D-07	8.903833D-07	4.810565D-07	
156.803	1.053502D-07	1.007880D-07	9.168465D-08	7.789039D-08	5.852700D-08	5.301293D-07	2.858034D-07	
161.201	2.892204D-08	2.766956D-08	2.517041D-08	2.138344D-08	1.606756D-08	1.722285D-07	9.277235D-08	

R-AXIS	PROBLEM TYPE K CALC.				REAL FLUX FOR GROUP 1		
	Z-AXIS 53.975	Z-AXIS 60.325	Z-AXIS 66.675	Z-AXIS 73.025	Z-AXIS 89.535	Z-AXIS 116.205	
1.266	1.828325D-06	1.314973D-06	8.805667D-07	6.065145D-07	8.636833D-08	7.278049D-09	
3.798	1.965440D-06	1.390677D-06	9.222716D-07	6.311984D-07	9.013773D-08	7.620895D-09	
6.330	2.247908D-06	1.544803D-06	1.007204D-06	6.814651D-07	9.781338D-08	8.318994D-09	
9.680	2.622622D-06	1.859693D-06	1.180753D-06	7.842037D-07	1.135000D-07	9.745556D-09	
13.847	3.173505D-06	2.048655D-06	1.384261D-06	8.439920D-07	1.226942D-07	1.058775D-08	
18.014	3.361958D-06	2.146211D-06	1.334192D-06	8.725914D-07	1.271744D-07	1.100567D-08	
22.267	3.475865D-06	2.200753D-06	1.360370D-06	8.859284D-07	1.293675D-07	1.121959D-08	
26.604	3.508964D-06	2.209140D-06	1.360110D-06	8.831414D-07	1.291360D-07	1.121648D-08	
30.942	3.500735D-06	2.193360D-06	1.345749D-06	8.715580D-07	1.275930D-07	1.109699D-08	
35.294	3.485973D-06	2.172426D-06	1.327877D-06	8.574973D-07	1.257008D-07	1.094846D-08	
39.659	3.413283D-06	2.118765D-06	1.291420D-06	8.321510D-07	1.221063D-07	1.064703D-08	
44.023	3.320581D-06	2.053233D-06	1.247970D-06	8.024180D-07	1.178600D-07	1.028799D-08	
48.393	3.242055D-06	1.994651D-06	1.207942D-06	7.744891D-07	1.139055D-07	9.956990D-09	
52.767	3.114433D-06	1.908874D-06	1.152781D-06	7.375208D-07	1.085767D-07	9.501550D-09	
57.141	2.979870D-06	1.819071D-06	1.095289D-06	6.991123D-07	1.030324D-07	9.026927D-09	
61.517	2.893183D-06	1.755421D-06	1.052172D-06	6.691917D-07	9.878565D-08	8.670450D-09	
65.896	2.750723D-06	1.661508D-06	9.925232D-07	6.295654D-07	9.305110D-08	8.178124D-09	
70.274	2.591476D-06	1.558686D-06	9.281084D-07	5.871961D-07	8.689199D-08	7.646657D-09	
74.949	2.434685D-06	1.456438D-06	8.636247D-07	5.445759D-07	8.070994D-08	7.114526D-09	
79.920	2.215980D-06	1.320423D-06	7.806100D-07	4.910284D-07	7.285634D-08	6.430091D-09	
84.891	2.017791D-06	1.196815D-06	7.050118D-07	4.421883D-07	6.569829D-08	5.806768D-09	
88.577	1.923983D-06	1.135108D-06	6.658744D-07	4.162145D-07	6.193775D-08	5.483749D-09	
90.978	1.854567D-06	1.090744D-06	6.382735D-07	3.981524D-07	5.930601D-08	5.256066D-09	
93.380	1.785918D-06	1.047181D-06	6.113041D-07	3.805679D-07	5.673961D-08	5.033622D-09	
95.781	1.726019D-06	1.008796D-06	5.873801D-07	3.648908D-07	5.445678D-08	4.836260D-09	
98.243	1.698063D-06	9.882542D-07	5.734592D-07	3.552281D-07	5.308547D-08	4.721167D-09	
100.766	1.637425D-06	9.500949D-07	5.499727D-07	3.399815D-07	5.085582D-08	4.527481D-09	
103.288	1.543324D-06	8.939679D-07	5.167660D-07	3.190805D-07	4.775522D-08	4.253963D-09	
105.811	1.425097D-06	8.249810D-07	4.766503D-07	2.941871D-07	4.403851D-08	3.923659D-09	
108.458	1.271743D-06	7.368432D-07	4.260272D-07	2.630994D-07	3.937381D-08	3.507016D-09	
111.229	1.134689D-06	6.578474D-07	3.805476D-07	2.351140D-07	3.517860D-08	3.132680D-09	
114.000	1.025093D-06	5.942637D-07	3.437454D-07	2.123657D-07	3.177567D-08	2.829718D-09	
116.771	9.403812D-07	5.446300D-07	3.147886D-07	1.943475D-07	2.908868D-08	2.591284D-09	
119.542	8.801175D-07	5.086738D-07	2.935103D-07	1.809518D-07	2.710885D-08	2.416004D-09	
122.313	8.461749D-07	4.874059D-07	2.804600D-07	1.724995D-07	2.586450D-08	2.308392D-09	
125.354	8.123344D-07	5.263125D-07	3.007717D-07	1.839051D-07	2.765123D-08	2.475064D-09	
128.665	9.404651D-07	5.342538D-07	3.038845D-07	1.850565D-07	2.787762D-08	2.500328D-09	
131.976	8.869022D-07	5.022769D-07	2.849526D-07	1.731335D-07	2.610953D-08	2.344374D-09	
135.287	7.983323D-07	4.511945D-07	2.555283D-07	1.550197D-07	2.339469D-08	2.102183D-09	
139.153	6.818922D-07	3.846001D-07	2.174344D-07	1.317078D-07	1.989099D-08	1.788697D-09	
143.574	5.262723D-07	2.964732D-07	1.674405D-07	1.013334D-07	1.531027D-08	1.377386D-09	
147.995	3.722094D-07	2.095212D-07	1.182541D-07	7.152457D-08	1.080949D-08	9.727531D-10	
152.405	2.606814D-07	1.462684D-07	8.232535D-08	4.967133D-08	7.515570D-09	6.771478D-10	
156.803	1.545804D-07	8.655984D-08	4.863400D-08	2.929792D-08	4.436225D-09	4.000620D-10	
161.201	5.013895D-08	2.805337D-08	1.575083D-08	9.482615D-09	1.436263D-09	1.295450D-10	

POWER NORMALIZATION  
FLUX NORMALIZATION FACTOR = 3.748571D 01

SAMPLE, ADJOINT WEIGHTING, DISCONTINUOUS TRIAL FUNCTIONS

PAGE 139

POWER PER INTERVAL								
R-AXIS	Z-AXIS 3.810	Z-AXIS 11.430	Z-AXIS 19.050	Z-AXIS 26.670	Z-AXIS 34.290	Z-AXIS 41.275	Z-AXIS 47.625	
1.266	7.1419260-07	6.8439680-07	6.2634960-07	5.4332750-07	4.4099350-07	1.1249960-07	9.2045810-08	
3.798	7.1409250-07	6.8430110-07	6.2626220-07	5.4325020-07	4.4092200-07	1.1539310-07	9.3566430-08	
6.330	7.1389120-07	6.8410870-07	6.2608630-07	5.4309440-07	4.4077750-07	1.2126620-07	9.6651030-08	
9.680	7.1363500-07	6.8386400-07	6.2586260-07	5.4289370-07	4.4057790-07	1.3271540-07	1.0252460-07	
13.847	7.1251620-07	6.8279650-07	6.2489530-07	5.4206530-07	4.3989270-07	1.3967860-07	1.0601250-07	
18.014	7.1083660-07	6.8119440-07	6.2344500-07	5.4082950-07	4.3889260-07	1.4289220-07	1.0739320-07	
22.267	7.0893250-07	6.7937940-07	6.2180550-07	5.3943900-07	4.3777630-07	1.4797480-07	1.0992990-07	
26.604	7.0591700-07	6.7650160-07	6.1919830-07	5.3721770-07	4.3599480-07	1.5141280-07	1.1169980-07	
30.942	7.0221310-07	6.7296570-07	6.1599240-07	5.3448260-07	4.3380070-07	1.5299170-07	1.1227130-07	
35.294	6.9838360-07	6.6931080-07	6.1268080-07	5.3166070-07	4.3153900-07	1.6821090-07	1.2377230-07	
39.659	6.9308210-07	6.6424620-07	6.0808110-07	5.2772530-07	4.2837790-07	1.6681230-07	1.2234900-07	
44.023	6.8691720-07	6.5835460-07	6.0272560-07	5.2313590-07	4.2468700-07	1.6434460-07	1.2019460-07	
48.393	6.8063200-07	6.5234870-07	5.9726660-07	5.1845780-07	4.2092360-07	1.4233200-07	1.0254130-07	
52.767	6.7248590-07	6.4455820-07	5.9017270-07	5.1235910-07	4.1600550-07	1.3856370-07	9.9575640-08	
57.141	6.6326260-07	6.3573460-07	5.8213070-07	5.0543340-07	4.1040940-07	1.3428170-07	9.6247080-08	
61.517	6.5372690-07	6.2661060-07	5.7381100-07	4.9826090-07	4.0460240-07	1.2671240-07	9.0134510-08	
65.896	6.4210150-07	6.1548160-07	5.6365050-07	4.8947970-07	3.9746790-07	1.2196920-07	8.6515690-08	
70.274	6.2914100-07	6.0307000-07	5.5230800-07	4.7965570-07	3.8945300-07	1.1666070-07	8.2568100-08	
74.949	6.1412950-07	5.8868940-07	5.3915340-07	4.6823560-07	3.8008690-07	1.0550000-07	7.4087610-08	
79.920	5.9556550-07	5.7089320-07	5.2284400-07	4.5401780-07	3.6833080-07	9.8417620-08	6.9063600-08	
84.891	5.7464930-07	5.5082750-07	5.0441720-07	4.3787450-07	3.5482720-07	9.1621420-08	6.4204570-08	
88.577	6.7298020-07	6.4509980-07	5.9081120-07	5.1307290-07	4.1634340-07	8.1570720-08	5.6533450-08	
90.978	6.5591550-07	6.2872460-07	5.7576440-07	4.9988140-07	4.0532380-07	7.9008350-08	5.4649840-08	
93.380	6.3608040-07	6.0969690-07	5.5829850-07	4.8461640-07	3.9269240-07	7.6462740-08	5.2792450-08	
95.781	6.1341150-07	5.8795390-07	5.3834970-07	4.6720800-07	3.7836130-07	7.4109610-08	5.1057410-08	
98.243	5.9446870-07	5.6978340-07	5.2167790-07	4.5266490-07	3.6641520-07	6.6619170-08	4.5257150-08	
100.766	5.6695910-07	5.4340910-07	4.9751130-07	4.3164960-07	3.4928730-07	6.4292950-08	4.3571430-08	
103.288	5.4050200-07	5.1805410-07	4.7430510-07	4.1152610-07	3.3300600-07	6.1052740-08	4.1359710-08	
105.811	5.1498000-07	4.9360490-07	4.5195190-07	3.9219380-07	3.1747340-07	5.7125300-08	3.8750520-08	
108.458	4.8617490-07	4.6601650-07	4.2674320-07	3.7042090-07	3.0003770-07	5.5519480-08	3.8085070-08	
111.229	4.5762600-07	4.3867370-07	4.0176140-07	3.4885590-07	2.8280950-07	5.0615630-08	3.4833800-08	
114.000	4.2646600-07	4.0882730-07	3.7448630-07	3.2530350-07	2.6398890-07	4.6363040-08	3.1963230-08	
116.771	3.9322040-07	3.7698360-07	3.4538820-07	3.0018540-07	2.4394670-07	4.2702580-08	2.9437720-08	
119.542	3.5837980-07	3.4361510-07	3.1490570-07	2.7389650-07	2.2303390-07	3.9614720-08	2.7243170-08	
122.313	3.2244310-07	3.0920290-07	2.8348690-07	2.4684210-07	2.0161640-07	3.7130440-08	2.5393470-08	
125.354	2.7922090-08	9.3862240-08	8.5848880-08	7.42118460-08	5.9167530-08	3.5193600-08	2.2909230-08	
128.665	7.5748220-08	7.2615460-08	6.6495990-08	5.7650850-08	4.6359760-08	3.4492730-08	2.2145060-08	
131.976	5.9131460-08	5.6702080-08	5.1968790-08	4.5166120-08	3.6584270-08	3.2091840-08	2.0474480-08	
135.287	4.6363140-08	4.4469790-08	4.0789160-08	3.5525420-08	2.8952940-08	2.8849050-08	1.8355570-08	
139.153	2.7506790-08	2.6385430-08	2.4205570-08	2.1087180-08	1.7187920-08	2.2061930-08	1.3688460-08	
143.574	1.9669660-08	1.8873660-08	1.7330170-08	1.5134150-08	1.2419180-08	1.7289200-08	1.0748050-08	
147.995	1.4056160-08	1.3491870-08	1.2400370-08	1.0855620-08	8.9668530-09	1.2505820-08	7.8052740-09	
152.405	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
156.803	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
161.201	0.0	0.0	0.0	0.0	0.0	0.0	0.0	

6

R-AXIS	POWER PER INTERVAL					
	Z-AXIS 53.975	Z-AXIS 60.325	Z-AXIS 66.675	Z-AXIS 73.025	Z-AXIS 89.535	Z-AXIS 116.205
1.266	5.667849D-08	4.316782D-08	2.199764D-08	1.699850D-08	0.0	0.0
3.798	5.745788D-08	4.358834D-08	2.222104D-08	1.712739D-08	0.0	0.0
6.330	5.903944D-08	4.444139D-08	2.267472D-08	1.738913D-08	0.0	0.0
9.680	5.818772D-08	4.301891D-08	2.350647D-08	1.784922D-08	0.0	0.0
13.847	5.994229D-08	4.390686D-08	2.397303D-08	1.809663D-08	0.0	0.0
18.014	6.060268D-08	4.415685D-08	2.409650D-08	1.812927D-08	0.0	0.0
22.267	6.155581D-08	4.452421D-08	2.418820D-08	1.810425D-08	0.0	0.0
26.604	6.220992D-08	4.479386D-08	2.423908D-08	1.808586D-08	0.0	0.0
30.942	6.225945D-08	4.467305D-08	2.409302D-08	1.793404D-08	0.0	0.0
35.294	6.092145D-08	4.352301D-08	2.341749D-08	1.737467D-08	0.0	0.0
39.659	6.003374D-08	4.278923D-08	2.295940D-08	1.700895D-08	0.0	0.0
44.023	5.880316D-08	4.182460D-08	2.238319D-08	1.656004D-08	0.0	0.0
48.393	5.602947D-08	3.968884D-08	2.120289D-08	1.563793D-08	0.0	0.0
52.767	5.426307D-08	3.836951D-08	2.044650D-08	1.506396D-08	0.0	0.0
57.141	5.230909D-08	3.692020D-08	1.962473D-08	1.444263D-08	0.0	0.0
61.517	4.874937D-08	3.422097D-08	1.816401D-08	1.331142D-08	0.0	0.0
65.896	4.666263D-08	3.269129D-08	1.730638D-08	1.266826D-08	0.0	0.0
70.274	4.441556D-08	3.106786D-08	1.640333D-08	1.199748D-08	0.0	0.0
74.949	3.963913D-08	2.756564D-08	1.455493D-08	1.059721D-08	0.0	0.0
79.920	3.685014D-08	2.561015D-08	1.348115D-08	9.816298D-09	0.0	0.0
84.891	3.416098D-08	2.371647D-08	1.244632D-08	9.061776D-09	0.0	0.0
88.577	2.994737D-08	2.062511D-08	1.087485D-08	7.869260D-09	0.0	0.0
90.978	2.890566D-08	1.988159D-08	1.046791D-08	7.571126D-09	0.0	0.0
93.380	2.788296D-08	1.915487D-08	1.007144D-08	7.282004D-09	0.0	0.0
95.781	2.692900D-08	1.847326D-08	9.700655D-09	7.011378D-09	0.0	0.0
98.243	2.388955D-08	1.622160D-08	8.583597D-09	6.158221D-09	0.0	0.0
100.766	2.296883D-08	1.557069D-08	8.229391D-09	5.900056D-09	0.0	0.0
103.288	2.178061D-08	1.476063D-08	7.792464D-09	5.586988D-09	0.0	0.0
105.811	2.039120D-08	1.383038D-08	7.293508D-09	5.232448D-09	0.0	0.0
108.458	1.998174D-08	1.365872D-08	7.136807D-09	5.150223D-09	0.0	0.0
111.229	1.826935D-08	1.251440D-08	6.532620D-09	4.720569D-09	0.0	0.0
114.000	1.675785D-08	1.149216D-08	5.994614D-09	4.334909D-09	0.0	0.0
116.771	1.542790D-08	1.057989D-08	5.516080D-09	3.988515D-09	0.0	0.0
119.542	1.427192D-08	9.772220D-09	5.094126D-09	3.679106D-09	0.0	0.0
122.313	1.329690D-08	9.072188D-09	4.730415D-09	3.407267D-09	0.0	0.0
125.354	1.219841D-08	8.041357D-09	4.375872D-09	3.070905D-09	0.0	0.0
128.665	1.176564D-08	7.677407D-09	4.173404D-09	2.905138D-09	0.0	0.0
131.976	1.086018D-08	7.052465D-09	3.829205D-09	2.655224D-09	0.0	0.0
135.287	9.722959D-09	6.300165D-09	3.416617D-09	2.364953D-09	0.0	0.0
139.153	7.415412D-09	4.723685D-09	2.646508D-09	1.810861D-09	0.0	0.0
143.574	5.817085D-09	3.710927D-09	2.076986D-09	1.422785D-09	0.0	0.0
147.995	4.221780D-09	2.701642D-09	1.511005D-09	1.037340D-09	0.0	0.0
152.405	0.0	0.0	0.0	0.0	0.0	0.0
156.803	0.0	0.0	0.0	0.0	0.0	0.0
161.201	0.0	0.0	0.0	0.0	0.0	0.0

MAXIMUM POWER= 0.71419D-06 OCCURS AT POINT 3.810 1.266

MINIMUM POWER= 0.10373D-08 OCCURS AT POINT 73.025 147.995

POWER NORMALIZATION  
FLUX NORMALIZATION FACTOR = 3.748571D 01

REGION	FLUX VOLUME					
	GROUP 1	GROUP 2	GROUP 3	GROUP 4	GROUP 5	GROUP 6
CZA1	1.528743D-01	6.197454D-01	6.640517D-01	2.946828D-01	2.284962D-02	8.577667D-04
ABA11	7.724667D-03	6.830172D-02	1.309372D-01	6.725748D-02	7.377736D-03	4.955717D-04
ABA21	4.115664D-03	3.677603D-02	7.244808D-02	4.449730D-02	5.956786D-03	5.370837D-04
ABA31	1.866184D-03	1.812486D-02	3.945704D-02	2.837660D-02	4.476111D-03	5.797908D-04
CZA2	9.152676D-01	3.705283D 00	3.974898D 00	1.761976D 00	1.365624D-01	5.120326D-03
ABA12	8.710185D-02	4.025453D-01	7.863375D-01	4.005919D-01	4.345125D-02	2.893705D-03
ABA22	3.605563D-02	2.156271D-01	4.363369D-01	2.674216D-01	3.505299D-02	3.147254D-03
ABA32	1.466927D-02	1.059409D-01	2.373081D-01	1.685441D-01	2.632688D-02	3.401295D-03
CZA3	1.810893D 00	7.325884D 00	7.889546D 00	3.490362D 00	2.704982D-01	1.011891D-02
ABA13	2.035167D-01	1.004675D 00	1.572672D 00	7.880312D-01	8.395613D-02	5.522500D-03
ABA23	7.869722D-02	5.043026D-01	8.784159D-01	5.236698D-01	6.735892D-02	5.971660D-03
ABA33	3.085941D-02	2.377276D-01	4.761857D-01	3.290116D-01	5.042753D-02	6.441950D-03
CZA4	2.659854D 00	1.075559D 01	1.165145D 01	5.139650D 00	3.983438D-01	1.485445D-02
ABA14	3.063687D-01	1.662057D 00	2.292591D 00	1.136098D 00	1.184742D-01	7.675931D-03
ABA24	1.141880D-01	8.009389D-01	1.290594D 00	7.502568D-01	9.425287D-02	8.207264D-03
ABA34	4.381939D-02	3.670079D-01	6.969403D-01	4.693251D-01	7.020703D-02	8.822023D-03
CZA5	3.430494D 00	1.387081D 01	1.512269D 01	6.639981D 01	5.143882D-01	1.911164D-02
ABA15	3.832501D-01	2.167418D 00	2.846814D 00	1.407281D 00	1.435247D-01	9.157140D-03
ABA25	1.383418D-01	1.017800D 00	1.615170D 00	9.229826D-01	1.130742D-01	9.657735D-03
ABA35	5.204439D-02	4.575842D-01	8.688863D-01	5.745960D-01	8.373200D-02	1.033534D-02
CZA6	4.092923D 00	1.654203D 01	1.810049D 01	7.874198D 00	6.077167D-01	2.245984D-02
ABA16	4.352136D-01	2.502348D 00	3.184144D 00	1.577030D 00	1.574119D-01	9.910143D-03
ABA26	1.516930D-01	1.148207D 00	1.820932D 00	1.026868D 00	1.226579D-01	1.026856D-02
ABA36	5.577246D-02	5.071204D-01	9.758021D-01	6.359978D-01	9.021678D-02	1.092514D-02
CZA7	5.342916D 00	2.128658D 01	2.304062D 01	9.758894D 01	7.330897D-01	2.634390D-02
ABA17	4.979010D-01	2.967617D 00	3.714069D 00	1.881954D 00	1.865361D-01	1.166081D-02
ABA27	1.680159D-01	1.332379D 00	2.141465D 00	1.214496D 00	1.427339D-01	1.157745D-02
ABA37	6.040306D-02	5.783106D-01	1.143015D 00	7.473361D-01	1.037892D-01	1.213862D-02
CZB1	3.832276D 00	1.450551D 01	1.518865D 01	6.038260D 00	4.016281D-01	1.227719D-02
ABB11	3.125527D-01	1.855868D 00	2.294528D 00	1.202332D 00	1.235045D-01	7.983111D-03
ABB21	1.020829D-01	8.203229D-01	1.331777D 00	7.697141D-01	9.229660D-02	7.274063D-03
ABB31	3.583182D-02	3.508509D-01	7.085683D-01	4.708870D-01	6.608910D-02	7.385343D-03
CZB2	3.865941D 00	1.460765D 01	1.517041D 01	5.672831D 00	3.151126D-01	7.318094D-03
ABB12	3.210792D-01	1.823108D 00	2.229761D 00	1.219015D 00	1.343271D-01	9.097684D-03
ABB22	1.021007D-01	7.941380D-01	1.300478D 00	7.751285D-01	9.789966D-02	7.491229D-03
ABB32	3.510573D-02	3.360596D-01	6.903005D-01	4.718257D-01	6.892024D-01	7.283877D-03
CZC1	5.005126D 00	1.930399D 01	2.097694D 01	8.432463D 00	5.886037D-01	2.045766D-02
ABC11	3.859204D-01	2.395738D 00	2.989315D 00	1.634570D 00	1.671198D-01	1.071358D-02
ABC21	1.220970D-01	1.035075D 00	1.750202D 00	1.036401D 00	1.224388D-01	9.311784D-03
ABC31	4.181182D-02	4.349180D-01	9.272985D-01	6.295187D-01	8.650678D-02	9.272674D-03
RB11	1.345832D 00	7.971928D 00	1.092089D 01	5.046525D 00	5.240933D-01	3.830446D-02
RB12	3.145752D-01	1.400834D 00	1.717689D 00	9.661841D-01	9.329402D-02	5.394266D-03
RB13	9.559417D-02	5.979711D-01	1.010115D 00	6.095020D-01	6.812097D-02	4.932160D-03
RB14	3.166197D-02	2.485868D-01	5.340549D-01	3.688024D-01	4.801798D-02	5.014471D-03
RB21	3.299499D-01	3.047156D 00	5.420232D 00	2.921117D 00	3.805770D-01	4.075538D-02
RB22	2.078068D-01	9.275284D-01	1.093429D 00	6.118685D-01	5.720153D-02	2.947911D-03
RB23	6.219794D-02	3.913061D-01	6.455712D-01	3.847276D-01	4.163260D-02	2.852694D-03
RB24	2.033016D-02	1.609508D-01	3.406691D-01	2.322177D-01	2.928107D-02	2.963525D-03
REFRD	1.436493D-01	1.304619D 00	2.403817D 00	1.433387D 00	2.169809D-01	3.759138D-02
REFAX	1.127612D-01	2.809712D 00	7.521610D 00	7.465152D 00	1.824870D 00	6.433787D-01

REGION	REGION AVERAGED REAL FLUXES. NORMALIZED FOR BURNUP					
	GROUP	GROUP	GROUP	GROUP	GROUP	GROUP
	1	2	3	4	5	6
CZA1	7.8874650	3.1975430	3.4261390	1.5204000	1.1789130	4.4256010
ABA11	1.1956500	1.0571970	2.0266900	1.0410340	1.1619510	7.6706260
ABA21	6.3703630	5.6923180	1.1213760	6.9610770	9.2201140	8.3131620
ABA31	2.8885420	2.8054270	6.1072940	4.3922260	6.9282740	8.9741960
CZA2	7.8704150	3.1861840	3.4180270	1.5151290	1.1743050	4.4029840
ABA12	2.2469750	1.0384500	2.0286190	1.0334110	1.1209160	7.4649170
ABA22	9.3013060	5.5625530	1.1256220	6.8987010	9.0426540	8.1190010
ABA32	3.7842460	2.7329660	6.1218600	4.3479480	6.7915710	8.7743530
CZA3	7.7859970	3.1497900	3.3921390	1.5006940	1.1630170	4.3506610
ABA13	2.6250820	1.2958900	2.0285280	1.0164500	1.0829170	7.1232550
ABA23	1.0150850	6.5048020	1.1330340	6.7546100	8.6883620	7.7026100
ABA33	3.9804340	3.0663550	6.1421320	4.2437910	6.5044490	8.3092190
CZA4	7.6240420	3.0829170	3.3397010	1.4731980	1.1417880	4.2577880
ABA14	2.6344700	1.4292050	1.9714030	9.7693300	1.0187620	6.6005460
ABA24	9.8190500	6.8872870	1.1097840	6.4514710	8.1048200	7.0574400
ABA34	3.7680370	3.1559070	5.9930010	4.0357340	6.0371140	7.5860730
CZA5	7.3747680	2.9819020	3.2510270	1.4274420	1.1058150	4.1085590
ABA15	2.4716970	1.3978340	1.8359970	9.0759860	9.2563430	5.9057180
ABA25	8.9220870	6.5641000	1.0416720	5.9525950	7.2925010	6.2285670
ABA35	3.3565010	2.9511000	5.6037120	3.7057450	5.4001320	6.6655760
CZA6	7.0390100	2.8448980	3.1129220	1.3542050	1.0451510	3.8626440
ABA16	2.2454410	1.2910620	1.6428270	8.1365270	8.1215080	5.1130400
ABA26	7.8264520	5.9240600	9.3949200	5.2980210	6.3284140	5.2979600
ABA36	2.8775250	2.6164370	5.0345540	3.2813420	4.6546450	5.6367190
CZA7	6.6732030	2.6586540	2.8777300	1.2188680	9.1561540	3.2903040
ABA17	1.8656070	1.1119500	1.3916410	7.0515770	6.9894040	4.3692400
ABA27	6.2954600	4.9923510	8.0239510	4.5506480	5.3481570	4.3380070
ABA37	2.2632690	2.1668970	4.2828120	2.8003230	3.8889230	4.5482710
CZB1	6.4424750	4.2383540	2.5533780	1.0150980	6.7518070	2.0639310
ABB11	1.5763060	9.3799250	1.1572060	6.0637530	6.2287370	4.0261450
ABB21	5.1483750	4.1371580	6.7165880	3.8819210	4.6548200	3.6685490
ABB31	1.8071160	1.7694570	3.5735430	2.3748380	3.3330900	3.7246710
CZB2	5.5899860	2.1122040	2.1935760	8.2026700	4.5563930	1.0581650
ABB12	1.3928000	7.9084070	9.6724150	5.2879320	5.8269390	3.9464580
ABB22	4.4289990	3.4448690	5.6413070	3.3624080	4.2467740	3.2495990
ABB32	1.5228410	1.4577830	2.9944350	2.0467190	2.9896720	3.1596440
CZC1	3.8836820	1.4978750	1.6276860	6.5430930	4.5672170	1.5873930
ABC11	8.9835440	5.5768540	6.9585960	3.8049890	3.8902530	2.4939310
ABC21	2.8422020	2.4094700	4.0741600	2.4125570	2.8501590	2.1676180
ABC31	9.7330510	1.0124120	2.1585870	1.4654080	2.0137250	2.1585140
RB11	1.1606530	6.8750340	9.4182340	4.3521500	4.5198090	3.3033980
RB12	8.1387400	3.6242610	4.4440330	2.4997270	2.4137180	3.1595610
RB13	2.4732280	1.5470800	2.6133850	1.5769130	1.7624370	1.2760560
RB14	8.1916350	6.4314780	1.3817150	9.5417140	1.2423290	1.2973520
RB21	2.5793240	2.3820600	4.2371690	2.2835790	2.9750930	3.1859780
RB22	4.8734780	2.1752360	2.5643060	1.4349520	1.3414880	6.9134300
RB23	1.4586640	9.1768940	1.5139930	9.0226160	9.7636620	6.6901280
RB24	4.7678220	3.7746110	7.9893580	5.4459610	6.8669850	6.9500470
REFRD	5.1676070	4.6932060	8.6474390	5.1564350	7.8056220	1.3523040
REFAX	8.9809720	2.2378210	5.9906580	5.9456900	1.4534350	5.1242510

## SAMPLE,ADJOINT WEIGHTING, DISCONTINUOUS TRIAL FUNCTIONS

PAGE 143

REGION	LEAKAGE					
	GROUP 1	GROUP 2	GROUP 3	GROUP 4	GROUP 5	GROUP 6
CZA1	8.748208D-04	1.450054D-03	1.521609D-04	7.124769D-05	-9.288167D-06	-1.869484D-06
ABA11	-1.603778D-03	-1.140608D-03	3.058790D-04	9.135169D-05	2.491457D-05	2.088576D-06
ABA21	-2.580880D-04	-1.629242D-04	-1.930815D-04	-2.488214D-05	3.607221D-06	3.986522D-07
ABA31	-9.322208D-05	-1.025701D-04	-1.304235D-04	-4.809006D-05	-5.996158D-06	-2.147540D-06
CZA2	3.719848D-03	8.956743D-03	1.006457D-03	4.359381D-04	-5.191873D-05	-1.067565D-05
ABA12	-2.159686D-03	-9.394758D-03	1.800535D-03	4.873845D-04	1.260890D-04	1.009977D-05
ABA22	-3.899690D-04	-2.013598D-03	-1.152988D-03	-1.765625D-04	1.157520D-05	1.661567D-06
ABA32	-1.854936D-04	-1.032052D-03	-7.924517D-04	-3.031768D-04	-4.150491D-05	-1.289548D-05
CZA3	5.975638D-03	1.276007D-02	2.319461D-03	9.670262D-04	-7.762764D-05	-1.948879D-05
ABA13	-2.990111D-03	-4.432276D-03	3.960236D-03	1.001453D-03	2.351940D-04	1.908955D-05
ABA23	-1.202391D-03	-1.631987D-03	-1.954927D-03	-3.108791D-04	2.378239D-05	3.101852D-06
ABA33	-4.876474D-04	-1.122967D-03	-1.457757D-03	-5.757612D-04	-7.983574D-05	-2.482685D-05
CZA4	8.356802D-03	1.414672D-02	4.912571D-03	1.797864D-03	-5.123137D-05	-2.505745D-05
ABA14	-3.885268D-03	-1.519051D-03	4.902403D-03	1.282983D-03	2.975934D-04	2.564053D-05
ABA24	-1.925338D-03	-3.690762D-03	-2.560501D-03	-4.233594D-04	3.132214D-05	3.789793D-06
ABA34	-7.432846D-04	-2.166099D-03	-2.074633D-03	-8.180947D-04	-1.154914D-04	-3.526137D-05
CZA5	1.116978D-02	1.723475D-02	1.000941D-02	3.280649D-03	6.454268D-05	-2.570497D-05
ABA15	-5.635722D-03	-1.189003D-03	2.816022D-03	9.670312D-04	2.834803D-04	2.849220D-05
ABA25	-2.585387D-03	-5.525151D-03	-3.109532D-03	-5.344228D-04	3.118594D-05	3.606820D-06
ABA35	-9.555750D-04	-3.034933D-03	-2.656185D-03	-1.018713D-03	-1.457079D-04	-4.330380D-05
CZA6	1.343768D-02	2.175049D-02	1.812275D-02	5.679131D-03	3.085196D-04	-1.888370D-05
ABA16	-6.951075D-03	-2.413890D-03	-2.239163D-03	-2.966020D-04	1.507015D-04	2.574207D-05
ABA26	-2.864823D-03	-6.564487D-03	-3.353417D-03	-7.905012D-04	-4.625462D-06	1.608611D-06
ABA36	-1.025828D-03	-3.500125D-03	-3.033783D-03	-1.249634D-03	-1.864095D-04	-4.919078D-05
CZA7	1.356894D-02	3.374033D-02	3.550589D-02	1.149168D-02	1.115786D-03	1.985977D-05
ABA17	-1.331381D-02	-9.993537D-03	-1.104765D-02	-1.069133D-03	1.684179D-04	3.424362D-05
ABA27	-3.669105D-03	-8.593175D-03	-3.899193D-03	-9.303595D-04	-3.270987D-05	2.364052D-06
ABA37	-1.266844D-03	-4.422983D-03	-3.725385D-03	-1.501856D-03	-2.430567D-04	-6.249391D-05
CZB1	3.427576D-02	4.212726D-02	2.747749D-02	6.389439D-03	3.993444D-04	2.478355D-05
ABB11	-1.221568D-02	-1.108102D-02	-1.132007D-02	-5.378845D-04	2.532502D-04	3.639426D-05
ABB21	-2.538171D-03	-5.676807D-03	-2.541819D-03	-9.094971D-04	-1.363104D-04	-1.051003D-05
ABB31	-8.494539D-04	-2.854017D-03	-2.454643D-03	-1.144087D-03	-2.365623D-04	-5.052653D-05
CZB2	1.827850D-02	3.847630D-02	2.670257D-02	-6.617636D-03	-3.180113D-03	-2.235014D-04
ABB12	-7.558791D-03	-9.862600D-03	-1.160944D-02	2.398690D-03	1.264016D-03	1.268525D-04
ABB22	-1.502566D-03	-4.842510D-03	-1.890862D-03	7.481396D-05	2.581440D-04	1.364788D-05
ABB32	-5.003199D-04	-2.446255D-03	-2.076938D-03	-5.434822D-04	1.020468D-05	-4.451055D-05
CZC1	5.454329D-02	5.720179D-02	3.464708D-02	7.849146D-03	-2.021886D-04	-1.945216D-05
ABC11	-2.131101D-02	-1.922053D-02	-2.164782D-02	-1.835520D-03	2.142798D-04	4.600476D-05
ABC21	-4.486262D-03	-8.800837D-03	-4.101862D-03	-1.663830D-03	-2.216737D-04	-1.632697D-05
ABC31	-1.445273D-03	-4.203705D-03	-3.758224D-03	-1.810837D-03	-3.482606D-04	-7.164289D-05
RB11	-4.762331D-02	-3.600235D-02	3.039342D-03	3.329620D-03	1.958693D-03	2.523366D-04
RB12	9.181227D-03	4.189649D-03	-6.391353D-03	-3.783262D-04	-2.803331D-04	-4.443936D-05
RB13	-9.327190D-04	-3.995171D-03	-1.816340D-03	-4.816530D-04	-4.291892D-05	-5.196988D-06
RB14	-2.492724D-04	-1.787254D-03	-1.508089D-03	-6.129475D-04	-1.151169D-04	-3.269712D-05
RB21	-1.323430D-02	-3.056854D-02	-1.376846D-02	-3.416508D-03	-8.371991D-05	-6.654965D-05
RB22	6.494870D-03	1.215922D-02	4.995343D-04	7.518759D-05	-3.264561D-04	-6.623848D-05
RB23	-1.421960D-03	-2.193051D-03	-9.724682D-04	-4.896232D-04	-4.109185D-05	-2.054311D-06
RB24	-4.149385D-04	-9.940150D-04	-8.843678D-04	-4.985892D-04	-8.179628D-05	-1.803782D-05
REFRD	-2.926225D-03	-4.141515D-03	-3.309296D-03	-1.013685D-03	3.998880D-05	2.729457D-04
REFAX	-3.658773D-03	-1.542715D-02	-1.521071D-02	-2.463790D-03	1.016762D-03	8.119922D-04

REGION	REMOVAL+ALPHA/V+D*B**2					
	GROUP 1	GROUP 2	GROUP 3	GROUP 4	GROUP 5	GROUP 6
CZA1	6.610611D-03	8.859101D-03	6.914297D-03	3.882021D-03	6.824155D-04	4.959770D-05
ABA11	3.723193D-04	9.428864D-04	1.266384D-03	7.733347D-04	1.499276D-04	1.453083D-05
ABA21	1.992986D-04	5.036940D-04	6.909147D-04	5.036524D-04	1.132505D-04	1.364559D-05
ABA31	9.041749D-05	2.455079D-04	3.694314D-04	3.077477D-04	7.907302D-05	1.251635D-05
CZA2	3.958864D-02	5.297092D-02	4.138935D-02	2.320989D-02	4.076801D-03	2.958882D-04
ABA12	4.198457D-03	5.556070D-03	7.603342D-03	4.603612D-03	8.819008D-04	8.463459D-05
ABA22	1.744372D-03	2.944986D-03	4.142237D-03	2.972547D-03	6.568821D-04	7.781757D-05
ABA32	7.107339D-04	1.434866D-03	2.221531D-03	1.827362D-03	4.647691D-04	7.330982D-05
CZA3	7.838083D-02	1.047555D-01	8.215863D-02	4.596821D-02	8.066180D-03	5.838032D-04
ABA13	9.811414D-03	1.386059D-02	1.519407D-02	9.043334D-03	1.698378D-03	1.604468D-04
ABA23	3.807602D-03	6.884956D-03	8.333772D-03	5.814675D-03	1.259111D-03	1.468330D-04
ABA33	1.495190D-03	3.218974D-03	4.455901D-03	3.564531D-03	8.886699D-04	1.382612D-04
CZA4	1.152554D-01	1.538562D-01	1.213507D-01	6.766633D-02	1.185628D-02	8.547110D-04
ABA14	1.481204D-02	2.307856D-02	2.237892D-02	1.325155D-02	2.465589D-03	2.336786D-04
ABA24	5.525285D-03	1.092842D-02	1.223211D-02	8.315610D-03	1.754338D-03	1.999015D-04
ABA34	2.123334D-03	4.967527D-03	6.517249D-03	5.078689D-03	1.233628D-03	1.880012D-04
CZA5	1.488815D-01	1.985223D-01	1.575342D-01	8.737704D-02	1.526994D-02	1.095490D-03
ABA15	1.848768D-02	2.984602D-02	2.741580D-02	1.605657D-02	2.864206D-03	2.587768D-04
ABA25	6.695080D-03	1.387525D-02	1.528613D-02	1.020357D-02	2.091748D-03	2.320098D-04
ABA35	2.521982D-03	6.189592D-03	8.116795D-03	6.206520D-03	1.464900D-03	2.179525D-04
CZA6	1.779904D-01	2.369038D-01	1.885927D-01	1.035460D-01	1.797620D-02	1.280767D-03
ABA16	2.100404D-02	3.440531D-02	3.058433D-02	1.790898D-02	3.106831D-03	2.737387D-04
ABA26	7.370664D-03	1.577088D-02	1.736316D-02	1.134468D-02	2.252316D-03	2.420510D-04
ABA36	2.703014D-03	6.854008D-03	9.103117D-03	6.853123D-03	1.569063D-03	2.270763D-04
CZA7	2.329973D-01	3.050707D-01	2.400912D-01	1.281682D-01	2.156539D-02	1.490175D-03
ABA17	2.404479D-02	4.070415D-02	3.552938D-02	2.121660D-02	3.619125D-03	3.107097D-04
ABA27	8.132143D-03	1.810488D-02	2.016017D-02	1.330059D-02	2.583372D-03	2.647264D-04
ABA37	2.927762D-03	7.806118D-03	1.064053D-02	8.023128D-03	1.788918D-03	2.467469D-04
CZB1	1.658829D-01	2.136037D-01	1.646900D-01	8.457978D-02	1.325449D-02	8.178202D-04
ABB11	1.510504D-02	2.542853D-02	2.183216D-02	1.342537D-02	2.342605D-03	2.026096D-04
ABB21	4.943612D-03	1.112054D-02	1.248964D-02	8.372091D-03	1.642539D-03	1.598459D-04
ABB31	1.737074D-03	4.728354D-03	6.579074D-03	5.031924D-03	1.126448D-03	1.459635D-04
CZB2	1.803329D-01	2.283514D-01	1.773760D-01	9.770074D-02	1.580935D-02	8.240192D-04
ABB12	1.614655D-02	2.579656D-02	2.220424D-02	1.585011D-02	3.906642D-03	4.763018D-04
ABB22	5.143291D-03	1.115788D-02	1.279663D-02	9.886077D-03	2.749227D-03	3.703272D-04
ABB32	1.769553D-03	4.698191D-03	6.737031D-03	5.940032D-03	1.891040D-03	3.463281D-04
CZC1	2.170693D-01	2.846737D-01	2.277623D-01	1.182597D-01	1.942455D-02	1.362795D-03
ABC11	1.865524D-02	3.272138D-02	2.839320D-02	1.819481D-02	3.146475D-03	2.675240D-04
ABC21	5.914690D-03	1.402347D-02	1.639453D-02	1.125014D-02	2.168155D-03	2.021370D-04
ABC31	2.027042D-03	5.858104D-03	8.602279D-03	6.716431D-03	1.468828D-03	1.814967D-04
RB11	8.083611D-02	1.227074D-01	1.153970D-01	6.756460D-02	1.240960D-02	1.175315D-03
RB12	1.893970D-02	2.134098D-02	1.782766D-02	1.255348D-02	2.059746D-03	1.403577D-04
RB13	5.759725D-03	9.058398D-03	1.038376D-02	7.794852D-03	1.449327D-03	1.167496D-04
RB14	1.908277D-03	3.751545D-03	5.455366D-03	4.667991D-03	9.971376D-04	1.111934D-04
RB21	1.986018D-02	4.655555D-02	5.652467D-02	3.825031D-02	8.552487D-03	1.107565D-03
RB22	1.252015D-02	1.406575D-02	1.126013D-02	7.847761D-03	1.225134D-03	7.100656D-05
RB23	3.748481D-03	5.911129D-03	6.605191D-03	4.882428D-03	8.698864D-04	6.433284D-05
RB24	1.225456D-03	2.425223D-03	3.470921D-03	2.926800D-03	6.020010D-04	6.391227D-05
REFRD	7.738334D-03	9.910820D-03	1.135743D-02	9.553095D-03	3.327468D-03	2.829366D-04
REFAX	3.690971D-03	1.813757D-02	3.258354D-02	3.157188D-02	1.581334D-02	2.664341D-03

		SCATTERING					
REGION	GROUP	GROUP	GROUP	GROUP	GROUP	GROUP	
	1	2	3	4	5	6	
CZA1	0.0	5.132404D-03	7.262681D-03	3.954619D-03	6.769896D-04	4.718659D-05	
ABA11	0.0	2.967063D-04	8.178981D-04	7.899857D-04	1.563223D-04	1.545548D-05	
ABA21	0.0	1.593427D-04	4.422170D-04	4.374817D-04	1.045801D-04	1.248815D-05	
ABA31	0.0	7.253159D-05	2.176831D-04	2.382062D-04	6.598990D-05	9.385925D-06	
CZA2	0.0	3.073596D-02	4.343040D-02	2.367255D-02	4.047988D-03	2.820237D-04	
ABA12	0.0	3.346037D-03	4.956878D-03	4.748088D-03	9.310812D-04	9.102631D-05	
ABA22	0.0	1.395413D-03	2.630231D-03	2.635140D-03	6.218023D-04	7.347996D-05	
ABA32	0.0	5.701585D-04	1.284958D-03	1.432915D-03	3.919520D-04	5.520474D-05	
CZA3	0.0	6.085258D-02	8.589958D-02	4.699018D-02	8.019375D-03	5.586707D-04	
ABA13	0.0	7.820666D-03	1.232798D-02	9.502784D-03	1.831654D-03	1.758857D-04	
ABA23	0.0	3.046264D-03	6.133199D-03	5.306809D-03	1.217601D-03	1.411974D-04	
ABA33	0.0	1.199558D-03	2.876685D-03	2.875979D-03	7.651326D-04	1.057421D-04	
CZA4	0.0	8.947875D-02	1.261857D-01	6.940572D-02	1.181012D-02	8.228308D-04	
ABA14	0.0	1.179395D-02	2.034887D-02	1.386889D-02	2.641541D-03	2.482840D-04	
ABA24	0.0	4.421422D-03	9.706827D-03	7.798548D-03	1.744560D-03	1.975854D-04	
ABA34	0.0	1.703737D-03	4.428824D-03	4.209650D-03	1.091463D-03	1.472212D-04	
CZA5	0.0	1.155811D-01	1.628579D-01	9.010173D-02	1.526014D-02	1.062744D-03	
ABA15	0.0	1.474643D-02	2.642976D-02	1.721234D-02	3.271296D-03	3.007149D-04	
ABA25	0.0	5.359106D-03	1.231540D-02	9.760058D-03	2.146256D-03	2.370495D-04	
ABA35	0.0	2.024024D-03	5.513877D-03	5.248001D-03	1.336297D-03	1.755849D-04	
CZA6	0.0	1.381774D-01	1.944190D-01	1.078757D-01	1.810050D-02	1.255882D-03	
ABA16	0.0	1.676273D-02	3.050552D-02	1.925589D-02	3.666098D-03	3.298397D-04	
ABA26	0.0	5.907286D-03	1.401965D-02	1.116662D-02	2.417619D-03	2.590809D-04	
ABA36	0.0	2.169910D-03	6.105682D-03	5.893546D-03	1.479118D-03	1.891897D-04	
CZA7	0.0	1.808952D-01	2.507434D-01	1.373949D-01	2.243953D-02	1.515504D-03	
ABA17	0.0	1.920581D-02	3.614463D-02	2.246364D-02	4.375264D-03	3.909122D-04	
ABA27	0.0	6.516367D-03	1.608824D-02	1.293922D-02	2.824195D-03	2.992427D-04	
ABA37	0.0	2.351326D-03	6.953989D-03	6.902871D-03	1.738153D-03	2.176589D-04	
CZB1	0.0	1.271464D-01	1.702583D-01	9.049895D-02	1.387604D-02	8.300289D-04	
ABB11	0.0	1.207867D-02	2.267561D-02	1.388107D-02	2.795467D-03	2.588555D-04	
ABB21	0.0	3.964767D-03	9.907475D-03	8.047473D-03	1.790000D-03	1.935182D-04	
ABB31	0.0	1.395794D-03	4.217607D-03	4.279033D-03	1.095171D-03	1.386031D-04	
CZB2	0.0	1.390800D-01	1.812625D-01	9.230781D-02	1.329711D-02	6.675541D-04	
ABB12	0.0	1.295423D-02	2.297663D-02	1.365673D-02	2.867962D-03	2.855988D-04	
ABB22	0.0	4.136198D-03	9.893949D-03	7.953255D-03	1.823982D-03	2.082093D-04	
ABB32	0.0	1.425386D-03	4.162534D-03	4.218379D-03	1.110316D-03	1.465921D-04	
CZC1	0.0	1.663171D-01	2.265195D-01	1.249851D-01	1.938173D-02	1.216703D-03	
ABC11	0.0	1.492279D-02	2.916259D-02	1.808264D-02	3.800489D-03	3.502867D-04	
ABC21	0.0	4.744355D-03	1.248189D-02	1.057433D-02	2.410274D-03	2.567372D-04	
ABC31	0.0	1.629080D-03	5.220006D-03	5.599012D-03	1.464106D-03	1.814256D-04	
RB11	0.0	6.515179D-02	1.088434D-01	7.027938D-02	1.375415D-02	1.366977D-03	
RB12	0.0	1.531292D-02	1.950998D-02	1.107579D-02	2.633961D-03	2.434492D-04	
RB13	0.0	4.664565D-03	8.179419D-03	6.498480D-03	1.661714D-03	1.777894D-04	
RB14	0.0	1.547127D-03	3.369470D-03	3.432190D-03	1.005483D-03	1.253330D-04	
RB21	0.0	1.604337D-02	4.094534D-02	3.483565D-02	7.963273D-03	9.930231D-04	
RB22	0.0	1.013641D-02	1.293204D-02	7.053614D-03	1.668222D-03	1.492896D-04	
RB23	0.0	3.038214D-03	5.354412D-03	4.153902D-03	1.048950D-03	1.086649D-04	
RB24	0.0	9.939784D-04	2.181626D-03	2.189522D-03	6.331215D-04	7.643020D-05	
REFRD	0.0	7.181371D-03	9.647472D-03	9.374887D-03	4.543447D-03	6.772862D-04	
REFAX	0.0	3.447249D-03	1.755175D-02	2.914567D-02	1.706435D-02	3.647033D-03	

FISSION							
REGION	GROUP 1	GROUP 2	GROUP 3	GROUP 4	GROUP 5	GROUP 6	GROUP 6
CZA1	7.1614450-03	4.6167620-03	3.7677950-04	2.0944830-05	2.1262170-07	2.4472460-08	
ABA11	4.1316770-04	2.6635640-04	2.1737660-05	1.2083770-06	1.2266860-08	1.4118980-09	
ABA21	1.9710210-04	1.2706560-04	1.0369980-05	5.7645780-07	5.8519190-09	6.7354770-10	
ABA31	7.5397560-05	4.8606480-05	3.9668320-06	2.2051270-07	2.2385370-09	2.5765250-10	
CZA2	4.2852390-02	2.7625610-02	2.2545590-03	1.2532890-04	1.2722780-06	1.4643740-07	
ABA12	2.8521950-03	1.8387220-03	1.5006030-04	8.3417160-06	8.4681040-08	9.7466690-09	
ABA22	1.1953810-03	7.7062520-04	6.2891630-05	3.4960890-06	3.5490600-08	4.0849180-09	
ABA32	4.7873920-04	3.0862840-04	2.5187530-05	1.4001520-06	1.4213660-08	1.6359730-09	
CZA3	8.4905990-02	5.4736270-02	4.4670920-03	2.4832160-04	2.5208400-06	2.9014520-07	
ABA13	6.1091850-03	3.9384030-03	3.2141770-04	1.7867320-05	1.8138040-07	2.0876630-08	
ABA23	2.4627910-03	1.5876850-03	1.2957290-04	7.2028410-06	7.3119730-08	8.4159790-09	
ABA33	9.6283420-04	6.2070950-04	5.0656840-05	2.8159680-06	2.8586340-08	3.2902470-09	
CZA4	1.2504880-01	8.0615100-02	6.5790940-03	3.6572590-04	3.7126720-06	4.2732330-07	
ABA14	1.0112940-02	6.5195020-03	5.3206430-04	2.9576970-05	3.0025110-07	3.4558480-08	
ABA24	3.5468220-03	2.2865260-03	1.8660610-04	1.0373270-05	1.0530440-07	1.2120380-08	
ABA34	1.3624470-03	8.7832770-04	7.1681370-05	3.9847030-06	4.0450760-08	4.6558260-09	
CZA5	1.6178130-01	1.0429540-01	8.5116690-03	4.7315610-04	4.8032500-06	5.5284740-07	
ABA15	1.1047530-02	7.1220030-03	5.8123510-04	3.2310340-05	3.2799880-07	3.7752210-08	
ABA25	4.2578710-03	2.7449180-03	2.2401600-04	1.2452850-05	1.2641530-07	1.4550220-08	
ABA35	1.6124180-03	1.0394760-03	8.4832900-05	4.7157850-06	4.7872350-08	5.1004100-09	
CZA6	1.9308000-01	1.2447270-01	1.0158370-02	5.6469440-04	5.7325030-06	6.5980310-07	
ABA16	1.2076300-02	7.7852210-03	6.3536110-04	3.5319150-05	3.5854290-07	4.1267780-08	
ABA26	4.5540120-03	2.9358310-03	2.3959660-04	1.3318960-05	1.3520760-07	1.5562210-08	
ABA36	1.6987630-03	1.0951400-03	8.9375680-05	4.9683140-06	5.0435910-08	5.8051020-09	
CZA7	2.4632610-01	1.5879890-01	1.2959760-02	7.2042160-04	7.3133690-06	8.4175860-07	
ABA17	1.3355320-02	8.6097610-03	7.0265280-04	3.9059840-05	3.9651650-07	4.5638490-08	
ABA27	4.9298990-03	3.1781470-03	2.5937230-04	1.4418280-05	1.4636730-07	1.6846670-08	
ABA37	1.8139790-03	1.1694160-03	9.5437450-05	5.3052820-06	5.3856640-08	6.1988240-09	
CZB1	1.9906400-01	1.2833040-01	1.0473200-02	5.8219560-04	5.9101660-06	6.8025190-07	
ABB11	7.7841860-03	5.0182240-03	4.0954320-04	2.2766140-05	2.3111080-07	2.6600530-08	
ABB21	2.8060700-03	1.8089870-03	1.4763360-04	8.2068170-06	8.3311620-08	9.5890510-09	
ABB31	1.0213900-03	6.5845870-04	5.3737600-05	2.9872250-06	3.0324850-08	3.4903480-09	
CZB2	1.9886820-01	1.2820420-01	1.0462900-02	5.8162310-04	5.9043540-06	6.7958290-07	
ABB12	7.1666840-03	4.6201400-03	3.7705510-04	2.0960150-05	2.1277730-07	2.4490370-08	
ABB22	2.5311120-03	1.6317300-03	1.3316740-04	7.4026570-06	7.5148170-08	8.6494490-09	
ABB32	9.1315000-04	5.8867960-04	4.8042840-05	2.6706580-06	2.7111220-08	3.1204640-09	
CZC1	2.7144320-01	1.7499110-01	1.4281230-02	7.9388070-04	8.0590910-06	9.2759010-07	
ABC11	9.7499430-03	6.2854870-03	5.1296600-04	2.8515320-05	2.8947370-07	3.3318010-08	
ABC21	3.4673720-03	2.2353070-03	1.8242610-04	1.0140900-05	1.0294550-07	1.1848880-08	
ABC31	1.2464860-03	8.0357090-04	6.5580380-05	3.6455540-06	3.7007890-08	4.2595570-09	
RB11	4.0427390-02	2.6062290-02	2.1269740-03	1.1823660-04	1.2002800-06	1.3815060-07	
RB12	6.1368750-03	3.9562540-03	3.2287460-04	1.7948310-05	1.8220250-07	2.0971250-08	
RB13	2.0791070-03	1.3403360-03	1.0938640-04	6.0806930-06	6.1782840-08	7.1048340-09	
RB14	7.4412210-04	4.7971250-04	3.9149910-05	2.1763080-06	2.2092820-08	2.5428530-09	
RB21	1.3012980-02	8.3890680-03	6.8464180-04	3.8058620-05	3.8635260-07	4.4468650-08	
RB22	3.5097880-03	2.2626520-03	1.8465770-04	1.0264960-05	1.0420490-07	1.1993830-08	
RB23	1.1774770-03	7.5908320-04	6.1949680-05	3.4437270-06	3.4959040-08	4.0233700-09	
RB24	4.2543370-04	2.7426400-04	2.2383010-05	1.2442510-06	1.2631030-08	1.4538140-09	
REFRD	0.0	0.0	0.0	0.0	0.0	0.0	
REFAX	0.0	0.0	0.0	0.0	0.0	0.0	

## SAMPLE, ADJOINT WEIGHTING, DISCONTINUOUS TRIAL FUNCTIONS

PAGE 147

REGION	TOTAL BALANCE					
	GROUP	GROUP	GROUP	GROUP	GROUP	GROUP
	1	2	3	4	5	6
CZA1	-3.575406D-04	-5.816199D-04	5.712369D-04	2.219731D-05	4.073953D-06	-5.172663D-07
ABA11	1.642690D-03	7.595401D-04	-7.327296D-04	-7.349800D-05	-1.850763D-05	-1.162521D-06
ABA21	2.549681D-04	-5.495689D-05	-4.529482D-05	-4.071480D-05	-1.227177D-05	-1.555426D-06
ABA31	7.784889D-05	-2.202747D-05	-1.737653D-05	-2.123194D-05	-7.084645D-06	-9.826313D-07
CZA2	-6.568741D-04	-3.695528D-03	3.278589D-03	1.514604D-04	2.437209D-05	-3.043090D-06
ABA12	8.000595D-04	9.014832D-03	-4.297642D-03	-3.346053D-04	-7.682430D-05	-3.698346D-06
ABA22	-1.646230D-04	1.231039D-02	-2.964215D-04	-1.573651D-04	-4.661966D-05	-5.995113D-06
ABA32	-4.874417D-05	4.745274D-04	-1.190521D-04	-8.987722D-05	-3.129804D-05	-5.207966D-06
ABA13	1.516967D-04	-2.183163D-03	5.867642D-03	3.021022D-04	3.333223D-05	-5.354923D-06
ABA23	-7.407413D-04	-2.312301D-03	-6.506418D-03	-5.242188D-04	-1.017376D-04	-3.629879D-06
ABA33	-1.539588D-04	-6.264591D-04	-1.166797D-04	-1.898177D-04	-6.522022D-05	-8.729089D-06
ABA33	-4.921970D-05	-2.786472D-04	-7.104014D-05	-1.099879D-04	-4.367306D-05	-7.688926D-06
CZA4	8.106517D-04	1.713200D-03	6.470744D-03	3.055401D-04	8.764627D-06	-6.397472D-06
ABA14	-8.612102D-04	-3.276607D-03	-6.402873D-03	-6.362055D-04	-1.213418D-04	-1.100076D-05
ABA24	-6.974362D-05	-5.404184D-04	2.209478D-04	-8.337800D-05	-4.099599D-05	-6.093900D-06
ABA34	-2.398603D-05	-2.234787D-04	5.755292D-05	-4.702240D-05	-2.663360D-05	-5.513955D-06
CZA5	9.719993D-04	3.630755D-03	3.786123D-03	-8.502441D-05	-6.955905D-05	-6.490308D-06
ABA15	-1.856189D-03	-6.821954D-03	-3.223554D-03	2.208963D-04	1.239356D-04	1.348344D-05
ABA25	1.282282D-04	-2.589310D-04	3.617689D-04	1.033027D-04	2.344744D-05	1.447509D-06
ABA35	3.845647D-05	-9.602883D-05	1.377018D-04	6.488783D-05	1.715287D-05	9.410671D-07
CZA6	7.473154D-04	3.412596D-03	-2.185721D-03	-7.873728D-04	-1.785166D-04	-5.344215D-06
ABA16	-2.033246D-03	-7.479947D-03	2.792738D-03	1.678663D-03	4.089220D-04	3.039988D-05
ABA26	2.683417D-05	-3.770332D-04	2.483769D-04	6.257011D-04	1.700626D-04	1.543686D-05
ABA36	1.361741D-05	-9.396365D-05	1.253051D-04	2.950011D-04	9.651549D-05	1.130987D-05
CZA7	-1.394227D-03	1.389847D-04	-1.195458D-02	-1.547881D-02	-2.343622D-04	6.307353D-06
ABA17	2.561765D-03	-2.935378D-03	1.236225D-02	2.355044D-03	5.881151D-04	4.600433D-05
ABA27	4.437522D-04	1.679158D-04	8.541794D-05	5.833447D-04	2.736784D-04	3.689911D-05
ABA37	1.445614D-04	1.321274D-04	1.338379D-04	3.868791D-04	1.923452D-04	3.341198D-05
CZB1	-2.027354D-03	-8.554259D-04	-1.148503D-02	1.092054D-04	2.280843D-04	3.766928D-05
ABB11	4.858349D-03	2.725869D-03	1.257115D-02	1.016240D-03	1.998418D-04	1.987810D-05
ABB21	3.874824D-04	3.215495D-04	1.065918D-04	5.930477D-04	2.383548D-04	4.419179D-05
ABB31	1.289841D-04	1.768302D-04	1.466609D-04	3.941698D-04	2.053154D-04	4.316956D-05
CZB2	-6.749317D-04	-1.441051D-04	-1.240220D-02	1.803600D-03	6.737483D-04	6.771264D-05
ABB22	-1.454657D-03	1.618768D-03	1.275712D-02	-4.571206D-03	-2.302484D-03	-3.175311D-04
ABB21	-1.121471D-03	-5.550871D-04	-8.792781D-04	-2.000268D-03	-1.183314D-03	-1.757572D-04
ABB32	-3.603621D-04	-2.406289D-04	-4.497410D-04	-1.175513D-03	-7.909015D-04	-1.552224D-04
CZC1	-1.441111D-03	-1.387274D-03	-2.167563D-02	-3.335852D-04	1.673924D-04	4.935318D-05
ABC11	1.236003D-02	7.677985D-03	2.927777D-02	1.751728D-03	4.400221D-04	3.679108D-05
ABC21	2.022697D-03	1.746560D-03	3.707951D-04	9.981080D-04	4.638948D-04	7.093894D-05
ABC31	6.588764D-04	7.744868D-04	4.412238D-04	6.970469D-04	3.435755D-04	7.157604D-05
RB11	7.025169D-03	4.386956D-03	-7.475925D-03	-4.971549D-04	-6.129553D-04	-6.053626D-05
RB12	-2.201280D-02	-6.279988D-03	8.395034D-03	-1.081499D-03	8.547297D-04	1.475517D-04
RB13	-2.757640D-03	9.353942D-04	-2.791290D-04	-8.086668D-04	2.553675D-04	6.624389D-05
RB14	-9.183688D-04	6.030067D-05	-5.388411D-04	-6.206875D-04	1.234838D-04	4.683921D-05
RB21	6.326134D-03	8.406118D-03	-1.129442D-03	3.972116D-05	-5.051090D-04	-7.794798D-05
RB22	-1.552168D-02	-1.383651D-02	1.356164D-03	-8.591182D-04	7.696479D-04	1.445335D-04
RB23	-1.154560D-03	7.566383D-05	-2.166515D-04	-2.354755D-04	2.201899D-04	4.639043D-05
RB24	-3.870775D-04	-1.642504D-04	-3.826496D-04	-2.374499D-04	1.129294D-04	3.055720D-05
REFRD	-4.812109D-03	1.412066D-03	1.599335D-03	8.354775D-04	8.160993D-04	1.214039D-04
REFAX	-3.219806D-05	7.368334D-04	1.789203D-04	3.757372D-05	2.342430D-04	1.706992D-04

## REGION AVERAGED FISSION SOURCE

REGION	GROUP					
	1	2	3	4	5	6
CZA1	1.036891D-06	6.684515D-07	5.455312D-08	3.032559D-09	3.078506D-11	3.543318D-12
ABA11	1.794651D-07	1.156956D-07	9.442055D-09	5.248753D-10	5.328279D-12	5.132775D-13
ABA21	8.561402D-08	5.519272D-08	4.504343D-09	2.503924D-10	2.541862D-12	2.925647D-13
ABA31	3.274997D-08	2.111290D-08	1.723048D-09	9.578271D-11	9.723395D-13	1.119149D-13
CZA2	1.034080D-06	6.666392D-07	5.440521D-08	3.024337D-09	3.070160D-11	3.533711D-12
ABA12	2.064806D-07	1.331117D-07	1.086340D-08	6.038868D-10	6.130365D-12	7.055964D-13
ABA22	8.653793D-08	5.578833D-08	4.552952D-09	2.530945D-10	2.569292D-12	2.957219D-13
ABA32	3.465765D-08	2.234272D-08	1.823416D-09	1.013620D-10	1.028978D-12	1.184339D-13
CZA3	1.024446D-06	6.604289D-07	5.389839D-08	2.996163D-09	3.041559D-11	3.500792D-12
ABA13	2.211340D-07	1.425582D-07	1.163435D-08	6.467429D-10	6.565419D-12	7.556706D-13
ABA23	8.914557D-08	5.746940D-08	4.690146D-09	2.607210D-10	2.646713D-12	3.046329D-13
ABA33	3.485168D-08	2.246780D-08	1.833624D-09	1.019295D-10	1.034739D-12	1.190970D-13
CZA4	1.005857D-06	6.484452D-07	5.292038D-08	2.941797D-09	2.986369D-11	3.437269D-12
ABA14	2.440370D-07	1.573231D-07	1.283933D-08	7.137266D-10	7.245406D-12	8.339361D-13
ABA24	8.588891D-08	5.517653D-08	4.503022D-09	2.503189D-10	2.541116D-12	2.924789D-13
ABA34	3.287743D-08	2.119506D-08	1.729754D-09	9.615549D-11	9.761238D-13	1.123505D-13
CZA5	9.759985D-07	6.291961D-07	5.134944D-08	2.854469D-09	2.897718D-11	3.335233D-12
ABA15	1.999436D-07	1.288975D-07	1.051948D-08	5.847682D-10	5.936282D-12	6.832578D-13
ABA25	7.706102D-08	4.967886D-08	4.054350D-09	2.253777D-10	2.287925D-12	2.633369D-13
ABA35	2.918233D-08	1.881295D-08	1.535347D-09	8.534856D-11	8.664171D-13	9.972339D-14
CZA6	9.318471D-07	6.007330D-07	4.902653D-08	2.725341D-09	2.766634D-11	3.184357D-12
ABA16	1.748488D-07	1.127196D-07	9.199182D-09	5.113743D-10	5.191223D-12	5.975025D-13
ABA26	6.593603D-08	4.250692D-08	3.469040D-09	1.928408D-10	1.957626D-12	2.253200D-13
ABA36	2.459583D-08	1.585617D-08	1.294041D-09	7.193457D-11	7.302447D-13	8.405015D-14
CZA7	8.633677D-07	5.565865D-07	4.542368D-08	2.525062D-09	2.563320D-11	2.950345D-12
ABA17	1.404303D-07	9.053107D-08	7.388348D-09	4.107116D-10	4.169345D-12	4.798858D-13
ABA27	5.183745D-08	3.341800D-08	2.727283D-09	1.516072D-10	1.539034D-12	1.771417D-13
ABA37	1.907387D-08	1.229633D-08	1.003518D-09	5.578469D-11	5.662990D-13	6.518023D-14
CZB1	9.391134D-07	6.054174D-07	4.940883D-08	2.746593D-09	2.788207D-11	3.209187D-12
ABB11	1.101691D-07	7.102261D-08	5.796240D-09	3.222078D-10	3.270896D-12	3.764756D-13
ABB21	3.971414D-08	2.560248D-08	2.089449D-09	1.161506D-10	1.179104D-12	1.357132D-13
ABB31	1.445567D-08	9.319125D-09	7.605448D-10	4.227801D-11	4.291857D-13	4.939868D-14
CZB2	8.069566D-07	5.202200D-07	4.245577D-08	2.360078D-09	2.395837D-11	2.757574D-12
ABB12	8.724173D-08	5.624205D-08	4.589980D-09	2.551529D-10	2.590188D-12	2.981270D-13
ABB22	3.081183D-08	1.986343D-08	1.621078D-09	9.011428D-11	9.147964D-13	1.052918D-13
ABB32	1.111599D-08	7.166136D-09	5.848368D-10	3.251055D-11	3.300313D-13	3.798614D-14
CZC1	5.910675D-07	3.810429D-07	3.109737D-08	1.728675D-09	1.756866D-11	2.019827D-12
ABC11	6.369148D-08	4.105993D-08	3.350950D-09	1.862763D-10	1.890986D-12	2.176499D-13
ABC21	2.265060D-08	1.4660214D-08	1.191698D-09	6.624542D-11	6.724913D-13	7.740281D-14
ABC31	8.142666D-09	5.249326D-09	4.284037D-10	2.381458D-11	2.417540D-13	2.782555D-14
RB11	9.784001D-08	6.307444D-08	5.147579D-09	2.861493D-10	2.904849D-12	3.343440D-13
RB12	4.455632D-08	2.872409D-08	2.344207D-09	1.303123D-10	1.322868D-12	1.522602D-13
RB13	1.509520D-08	9.731411D-09	7.941920D-10	4.414842D-11	4.481733D-13	5.158412D-14
RB14	5.402643D-09	3.482917D-09	2.842450D-10	1.580092D-11	1.604033D-13	1.846219D-14
RB21	2.854724D-08	1.840352D-08	1.501933D-09	8.349113D-11	8.475613D-13	9.755312D-14
RB22	2.309880D-08	1.489108D-08	1.215279D-09	6.755627D-11	6.857984D-13	7.893443D-14
RB23	7.749274D-09	4.995718D-09	4.077065D-10	2.266404D-11	2.300743D-13	2.648123D-14
RB24	2.799887D-09	1.805000D-09	1.473082D-10	8.188732D-12	8.312802D-14	5.657919D-15
REFRD	0.0	0.0	0.0	0.0	0.0	0.0
REFAX	0.0	0.0	0.0	0.0	0.0	0.0

## SAMPLE,ADJOINT WEIGHTING, DISCONTINUOUS TRIAL FUNCTIONS

PAGE 149

REGION	TERMS	SUMMED OVER	GROUPS	SCATTERING	FISSION	ABSORPTION	EXT SOURCE	BALANCE
REGION	LEAKAGE	REMOVAL						
CZA1	2.5371260-03	2.6998040-02	1.7073880-02	1.2176170-02	9.9241630-03	0.0	-3.4216960-04	
ABA11	-2.3201520-03	3.5193810-03	2.0763700-03	7.0248380-04	1.4430120-03	0.0	1.5763330-03	
ABA21	-6.3497000-04	2.0244560-03	1.1561100-03	3.3512070-04	8.6834620-04	0.0	1.0017440-04	
ABA31	-3.8244940-04	1.1046940-03	6.0379680-04	1.2819390-04	5.0089700-04	0.0	9.1456680-05	
CZA2	1.4056390-02	1.6153150-01	1.0216890-01	7.2859310-02	5.9362570-02	0.0	-9.0102320-04	
ABA12	-9.1303350-03	2.2928020-02	1.4073110-02	4.8494130-03	8.8549050-03	0.0	5.1021220-03	
ABA22	-3.7198810-03	1.2538840-02	7.3560660-03	2.0324330-03	5.1827760-03	0.0	5.6001490-04	
ABA32	-2.3675750-03	6.7325720-03	3.7351880-03	8.1397110-04	2.9973840-03	0.0	1.8034780-04	
CZA3	2.1925080-02	3.1991310-02	2.0232040-01	1.4436050-01	1.1759280-01	0.0	4.1662560-03	
ABA13	-2.2064150-03	4.9768240-02	3.1658970-02	1.0387080-02	1.8109270-02	0.0	-5.5644440-03	
ABA23	-5.0732990-03	2.6246950-02	1.5845070-02	4.1873340-03	1.0401880-02	0.0	-1.1608650-03	
ABA33	-3.7487950-03	1.3761530-02	7.8230970-03	1.6370480-03	5.9384300-03	0.0	-5.6025690-04	
CZA4	2.9177660-02	4.7083960-01	2.9770310-01	2.1261290-01	1.7313650-01	0.0	9.3025020-03	
ABA14	1.1043010-03	7.6220330-02	4.8901540-02	1.7194420-02	2.7318790-02	0.0	-1.1309240-02	
ABA24	-8.5648480-03	3.8955660-02	2.3868940-02	6.0304450-03	1.5086720-02	0.0	-5.1968210-04	
ABA34	-5.9528640-03	2.0108430-02	1.1580850-02	2.3164860-03	8.5275780-03	0.0	-2.6908180-04	
CZA5	4.1733420-02	6.0868040-01	3.8486360-01	2.7506680-01	2.2381680-01	0.0	8.2278030-03	
ABA15	-2.7296990-03	9.4929070-02	6.1960540-02	1.8783450-02	3.2968520-02	0.0	-1.1543380-02	
ABA25	-1.1719700-02	4.8383790-02	2.981870-02	7.2393990-03	1.8565920-02	0.0	3.5926390-04	
ABA35	-7.8544170-03	2.4717740-02	1.4297780-02	2.7414970-03	1.0419960-02	0.0	1.6311120-04	
CZA6	5.9279680-02	7.2628980-01	4.5982840-01	3.2828220-01	2.6646140-01	0.0	1.0029570-03	
ABA16	-1.1724290-02	1.0728320-01	7.0520080-02	2.0532610-02	3.6763160-02	0.0	-4.6024710-03	
ABA26	-1.3576250-02	5.4343750-02	3.3770260-02	7.7429090-03	2.0573500-02	0.0	7.0937840-04	
ABA36	-9.0449700-03	2.7309400-02	1.5837450-02	2.8883030-03	1.1471960-02	0.0	4.4778530-04	
CZA7	9.5442480-02	9.2938290-01	5.9298860-01	4.1881330-01	3.3639430-01	0.0	-1.4985760-02	
ABA17	-3.5221460-02	1.2542480-01	8.2580250-02	2.2707230-02	4.2844500-02	0.0	1.4977800-02	
ABA27	-1.7126910-02	6.2545880-02	3.8667270-02	8.3819890-03	2.3878620-02	0.0	1.5910080-03	
ABA37	-1.1222620-02	3.1433200-02	1.8164000-02	3.0841980-03	1.3269200-02	0.0	1.0231630-03	
CZB1	1.1064450-01	6.4482870-01	4.0260980-01	3.3845640-01	2.4021890-01	0.0	-1.3992850-02	
ABA11	-3.4865000-02	7.8336310-02	5.1689670-02	1.3234980-02	2.6646640-02	0.0	2.1391330-02	
ABA21	-1.1813120-02	3.8728270-02	2.3903230-02	4.7709910-03	1.4825030-02	0.0	1.7367180-03	
ABA31	-7.5892900-03	1.9348840-02	1.1126210-02	1.7366610-03	8.2226310-03	0.0	1.0951300-03	
CZB2	7.3436110-02	7.0039440-01	4.2661500-01	3.3812350-01	2.7377940-01	0.0	-1.0676170-02	
ABA12	-2.5241270-02	8.4380410-02	5.2741150-02	1.2185080-02	3.1639250-02	0.0	5.7300060-03	
ABA22	-7.8893330-03	4.2103430-02	2.4015590-02	4.3034960-03	1.8087840-02	0.0	-5.9151760-03	
ABA32	-5.6013020-03	2.1382180-02	1.1063210-02	1.5525730-03	1.0318970-02	0.0	-3.1723680-03	
CZC1	1.5384460-01	8.6855240-01	5.3842010-01	4.6151840-01	3.3013230-01	0.0	-2.4620860-02	
ABC11	-6.3754600-02	1.0137860-01	6.6318790-02	1.6577230-02	3.5059840-02	0.0	4.5194320-02	
ABC21	-1.9290790-02	4.9953120-02	3.0467580-02	5.8953610-03	1.9485540-02	0.0	5.6729940-03	
ABC31	-1.1637940-02	2.4854180-02	1.4093630-02	2.1193240-03	1.0760550-02	0.0	2.9867850-03	
RB11	-7.5045670-02	4.0009000-01	2.5939570-01	6.8736230-02	1.4069430-01	0.0	2.7655540-03	
RB12	6.2764240-03	7.2861910-02	4.8776100-02	1.0434160-02	2.4085810-02	0.0	-1.9976970-02	
RB13	-7.2739990-03	3.4652810-02	2.1181970-02	3.5349790-03	1.3380850-02	0.0	-2.5884300-03	
RB14	-4.3053770-03	1.6891510-02	9.4796020-03	1.2651860-03	7.4119740-03	0.0	-1.8472040-03	
RB21	-5.1108070-02	1.7085080-01	1.0078070-01	2.2125180-02	7.0070110-02	0.0	1.3059470-02	
RB22	1.8836120-02	4.6989940-02	3.1939580-02	5.9674790-03	1.5050360-02	0.0	-2.7946960-02	
RB23	-5.1202490-03	2.2081450-02	1.3704140-02	2.0019930-03	8.3773050-03	0.0	-1.2644430-03	
RB24	-2.8917450-03	1.0714310-02	6.0746780-03	7.2333910-04	4.6396350-03	0.0	-1.0279410-03	
REFRD	-1.0717890-02	4.2170090-02	3.1424460-02	0.0	1.0745620-02	0.0	-2.7736270-05	
REFAX	-3.4931680-02	1.0446160-01	7.0856040-02	0.0	3.3605600-02	0.0	1.3260720-03	

## TOTAL TERMS SUMMED OVER REGIONS

GROUP	LEAKAGE	REMOVAL	SCATTERING	FISSION	ABSORPTION	EXT SOURCE	BALANCE
1	2.855684D-03	1.729437D 00	0.0	1.719846D 00	1.729437D 00	0.0	-2.050446D-02
2	2.644910D-02	2.425088D 00	1.349034D 00	1.108732D 00	1.076054D 00	0.0	1.033784D-03
3	2.953596D-02	2.074359D 00	2.018301D 00	9.048491D-02	5.605790D-02	0.0	4.467091D-03
4	1.318071D-02	1.209809D 00	1.216205D 00	5.029975D-03	-6.396415D-03	0.0	-1.777887D-03
5	2.309350D-03	2.287157D-01	2.328619D-01	5.106186D-05	-4.146245D-03	0.0	1.887718D-03
6	5.638948D-04	2.042268D-02	2.151646D-02	5.877148D-06	-1.093786D-03	0.0	5.357405D-04

TOTAL LEAKAGE = 0.748947D-01  
 TOTAL REMOVAL = 0.768783D 01  
 TOTAL SCATTER = 0.483792D 01  
 TOTAL FISSION = 0.292415D 01  
 TOTAL ABSRPTN = 0.284991D 01  
 TOTAL BALANCE = -0.143580D-01

TIME FOR EXECUTION OF SYNOUT IS 0.2318 MINUTES.  
 THE FOLLOWING DATA SETS WERE OPEN BUT HAVE BEEN REMOUND  
 DATA SET NAME DSRN

SCR001 25  
 6

THE TOTAL RUNNING TIME FOR THE EXECUTION OF SYN2D WAS 2.0305 MINUTES.  
 MODULE AJC009 HAS JUST BEEN LEFT BEHIND.

\*\*\*\*\*

\*\*\*\*\*

\*\*\*\*\*

TIME FOR THE EXECUTION OF STP008 IS 3.0027 MINUTES.  
 MODULE STP008 HAS JUST BEEN EXITED FROM.

and the reactor region and composition numbers assigned to each are printed. The page shown contains this data for one J-direction mesh interval; the rest are in the same format.

For XY geometry there will be a page giving buckling information. Each reactor region is listed by number, followed by the number of the composition assigned to that region. Then the buckling and transverse half-height for each reactor region is given. If the buckling is zero the half-height is set to 0.5 and should be ignored. The reactor region and composition numbers used here are consistent with those used on page 2.

Pages 3 and 4 contain all of the macroscopic composition cross sections for every energy group for one composition. Page 3 contains the diffusion coefficient  $[1/(3\sigma_{TR})]$ , removal  $(\sigma_R)$ , nu times fission  $(\nu \cdot \sigma_f)$ , fission spectrum  $(\chi)$ , and fission  $(\sigma_f)$ . If a composition is nonfissionable, only the first two columns appear. Page 4 contains the scattering  $(\sigma_{g'g})$  for each  $g$  and every  $g'$ . The scattering for any  $g'$  not appearing in this table is zero. These data will be printed for every composition.

Page 103 again gives the geometry type and a set of coordinate axes. The variable defining the domain of the trial functions is always the vertical variable; the synthesis variable is always the horizontal one. This is followed by the values of the synthesis interface boundaries and the number of refined regions calculated by SYN2D. Next are printed the data-set reference numbers used by SYN2D for the two user-supplied trial-function libraries and the three module-generated trial-function libraries. If all the trial functions are held in core during the generation of these library data sets, a message to this effect is printed. Finally, the data-set reference number used to store the partial integrals and the actual time used by the module so far are printed.

Page 104 contains the maximum condition number over  $g$  for  $D_g^k(x)$ , which is computed for all values of mesh interval  $x$  and synthesis region  $k$ . The maximum is printed out for each energy group  $g$ . This is an attempt to check the linear independence of the trial functions. The exponent of the condition number is an indication of the ill-conditioning of the matrices. If the exponent is less than seven, the matrices are fairly well conditioned. The range seven to 13 indicates some degree of breakdown. Above 14, the matrices are definitely ill-conditioned. After the condition numbers are printed, all open data sets are rewound and the time required to calculate the finite-difference matrices is printed.

Pages 105-106 contain the iteration-monitoring information and indicate the data-set reference number on which the mixing functions are written out. The time spent in performing the iterations is also printed.

Page 107 contains the calculated mixing functions for the highest-energy group. The integers appearing under the heading 'X-AXIS' are the mesh intervals in which the mixing functions take on the indicated values. The mixing functions are defined at the center of each mesh interval. In each synthesis region, the integers appearing under the heading 'Y-AXIS' indicate which trial function each mixing function is associated with. When a different number of trial functions is used in each synthesis region, the mixing functions would be handled as follows, where for simplicity only two synthesis regions are assumed: Suppose that two trial functions are used in the first synthesis region, and three in the second. Then three mixing functions would be printed for each synthesis region, but the third mixing function in the first synthesis region would be identically zero. One page like this is printed for each energy group.

Page 108 contains the real trial functions for the highest-energy group for synthesis region one. The integers appearing under 'FNT NO.' give the function number; each function corresponds to the mixing function in the same synthesis region with the same number, as shown on page 107. One page like this is printed for each synthesis region and group.

Page 125 gives the data-set reference number on which the unnormalized, reconstituted two-dimensional flux was previously stored. This is followed by the message that the first record of ARC System data set FR.D2 was written on the given data-set reference number.

Page 126 gives the total power in the reactor, the volume of each reactor region, the power in each region, and the average power of each region. The data-set reference number on which the ARC System data set FR.PN is written is followed by the burnup normalization factor and the message that the two-dimensional flux for the first energy group has been written.

Pages 127-128 are two of a number of pages giving the normalized two-dimensional flux for the highest-energy group. The last page of this flux printout indicates that the flux for the second-highest energy group has been written on ARC System data set FR.D2. One of these pages is printed for each energy group.

Pages 139-140 give the power per interval for the reactor. The maximum and minimum nonzero power and the coordinates at which these values occur is also printed.

Page 141 contains the flux volume by reactor region and energy group.

Page 142 contains the region-averaged real fluxes, normalized for burnup by reactor region and energy group.

Pages 143-147 contain the leakage, removal, scattering, fission source, and balance, respectively, by reactor region and energy group.

Page 148 contains the region-averaged fission source summed by reactor region and energy group.

Page 149 contains the leakage, removal, scattering, fission source, absorption, external source, and balance by region summed over all energy groups, then by group summed over all regions, and finally summed over the reactor. This is followed by the time required to calculate the reconstructed two-dimensional flux and perform the output edits. Then all open data sets are closed, the total time spent in executing SYN2D is printed, and execution is terminated.

The output described above is printed when the print flag is set to 1. When the print flag is set to 2, the magnitude and sign of the neutron currents across reactor region boundaries will be printed immediately preceding the normalized two-dimensional fluxes. Finally, when the print flag is set to 0, only the first unnumbered page, along with the data corresponding to that on pages 104-108, and parts of pages 125, 126, and 149 will be printed. Hence, setting the print flag to 0 yields a very brief amount of output.

## H. J2DTOLIB, A Generator Program for Synthesis Trial-function Libraries

### 1. Introduction

The purpose of this program is to generate trial-function libraries FR.TRIAL and FA.TRIAL, which are input data sets to the synthesis module SYN2D (AJC005). Since the record structure of both data sets is identical, only the construction of the real library (FR.TRIAL) will be considered here, with all comments applicable to FA.TRIAL. To generate the real trial-function library, J2DTOLIB accepts as input the two-dimensional flux FR.D2 and/or the one-dimensional flux FR.D1. Great flexibility presently exists in the way that the input data sets may be combined to form the output data set. The option also exists of creating several output data sets during one run. Finally, notice that different types of input data sets may be combined.

### 2. Input Data Sets

Any number of the following in any order is acceptable as input; any data set with the same record structure will also work.

- a. FR.D2 (FA.D2)
- b. FR.D1 (FA.D1)
- c. J2D, a card deck specified below.

### 3. Output Data Sets

Any number of output data sets can be produced, each having the format of FR.TRIAL (FA.TRIAL).

### 4. Scratch Data Sets Used

J2DTOLIB requires GMAX scratch data sets, where GMAX is the number of energy groups.

### 5. Method of Operation

Figure 3 represents a typical two-dimensional XY reactor configuration with 20 intervals in each direction, with compositions  $c_1$ ,  $c_2$ ,  $c_3$ , and  $c_4$  assigned to the four reactor regions. (It is assumed that this problem has actually been run and that the resulting two-dimensional multigroup flux  $F_g(x,y)$  has been put out on FR.D2.) To make a trial function from this flux, an x-direction interval number  $I_x$  is input, yielding the trial function  $f_g(y) = F_g(x_{I_x}, y)$ .

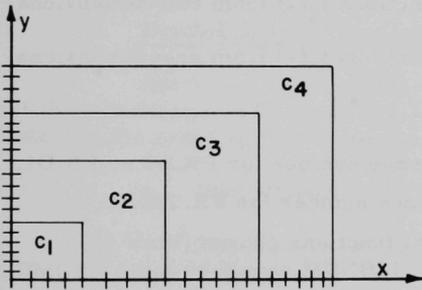


Fig. 3. Typical Two-dimensional XY Reactor Configuration

As many x-direction intervals as desired may be input, in any order and with duplications. J2DTOLIB will put the trial functions out on FR.TRIAL in the order in which they are specified. Note that for each x-direction interval indicated, there exists one  $f_g(y)$  for each energy group. These are all picked and used to generate FR.TRIAL (i.e., if J2DTOLIB is given an input  $I_x$ , FR.TRIAL gets the set  $\{f_g(y)\}_{g=1}^{GMAX}$ ). This is necessary because the trial functions used by SYN2D are group-dependent.

Trial functions may also be generated by indicating a y-direction interval number,  $J_y$ . The function then generated is  $f_g(x) = F_g(x, y_{J_y})$ . The one-dimensional data set FR.D1 is handled in the same fashion, except that in this case J2DTOLIB assumes that the two-dimensional map contains only one x-direction interval.

Previously, it has been noted that J2DTOLIB requires GMAX scratch data sets. This arises because of the incompatibility of FR.D2 and FR.TRIAL. Thus, each record of FR.TRIAL contains the set  $\{f_g(y)\}_{g=1}^{GMAX}$ , while each record of FR.D2 contains only one  $f_g(y)$ . These GMAX scratch data sets must be numbered consecutively, and must start with data-set reference number eight.

## 6. Input-card Specifications (J2D deck)

There are only four types of input cards to this program. All cards are set up with a structure of (16I5). Several input data sets can be used to create one output data set; however, only one output data set at a time can be created. The card types are listed below, and the structure of the deck is indicated in Section II.7.

### Card Type One

Cols. 1-5 NUMCRD--Number of type-2 cards used. (Only one type-1 card is used per run.)

### Card Type Two

Cols. 1-5 NOCARD--Number of type-3 cards used before next type-2 card.

Cols. 6-10 ICK--Creation option used.

0--Creates trial functions  $f_g(y)$  from two-dimensional output

1--Creates trial functions  $f_g(x)$  from two-dimensional output

2--Creates trial functions  $f_g(y)$  from one-dimensional output

### Card Type Three

Cols. 1-5 LIBRED--Data-set reference number for FR.D2 or FR.D1.

Cols. 6-10 LIBRIT--Data-set reference number for FR.TRIAL.

Cols. 11-15 LIBNUM--Number of trial functions chosen (limit 35).  
When ICK = 2, LIBNUM should be 1.

### Card Type Four

(NUM(L),L=1,LIBNUM)--Functions desired (indicated by interval numbers).  
When ICK = 2, NUM should be 1.

## 7. Sample Input

Following is a sample input which could be used to generate trial-function libraries. The input data-set types and data-set reference numbers are, respectively, FR.D2-1,3,4,13 and FR.D1-16,17,18. The output data sets (FR.TRIAL) are on data-set reference numbers 2 and 14. The two output data sets created could also be used as real and adjoint trial-function libraries. The card images and card types are listed below.

<u>Card Images</u>	<u>Card Types</u>
3	1
2 0	2
1 2 3	3
3 4 7	4
3 2 3	3
1 5 8	4
2 1	2
4 2 2	3
6 12	4
13 14 5	3
1 3 5 7 9	4
3 2	2
16 14 1	3
1	4
17 14 1	3
1	4
18 14 1	3
1	4

#### 8. Printed Output: Messages and Significance

Below are listed all 12 messages J2DTOLIB can generate. Not all these messages will appear on a given run, so they are not necessarily listed by the order in which they will appear.

- a. THE NUMBER OF OPTIONS USED IS nnnn

This should be the first printed message, where nnnn is NUMCRD from card type 1.

- b. dddd DATA SETS WILL BE READ AND/OR WRITTEN WITH OPTION NUMBER pppp

This indicates that a block of type-3 and -4 cards follow; pppp is the option used for this block (ICK), and dddd indicates the number of type-3 cards (NOCARD). This message will appear for each type-2 card.

- c. ATTEMPTING TO READ TOO MANY FUNCTIONS AT ONE TIME(nnnn)

After this message has been printed, execution is terminated; nnnn is the number of functions (LIBNUM) that the program is trying to read following one type-3 card. Break the indicated type-3 and -4 cards into several sets until no more than 35 functions are referenced by each set. Change the preceding type-2 card to reflect this change.

d. DSRN READ IS rrrr DSRN WRITTEN IS wwww

NUMBER OF FUNCTIONS READ AND WRITTEN IS nnnn

This message will appear for each type-3 card, where rrrr is LIBRED, wwww is LIBRIT, and nnnn is LIBNUM.

e. FUNCTION NUMBERS  $r_1 r_2 r_3 \dots r_{16}$

This lists the function numbers on each type-4 card.

f. CONVERGED EIGENVALUE IS kkkk

JMAX = jjjj

IMAX = iiiii

GMAX = gggg

This gives some of the information read from the input data set; kkkk is the eigenvalue, and gggg is the number of energy groups; iiiii and jjjj can take on various values, depending upon ICK. If ICK equals two, IMAX is one and JMAX is the number of mesh points for the one-dimensional problem. If ICK equals zero, IMAX is the number of x-direction mesh points and JMAX is the number of y-direction mesh points. If ICK equals 1, they are the reverse.

g. SPACE REQUIRED IS ssss SPACE AVAILABLE IS aaaa  
ERROR

The problem requires more space than is available; execution is terminated. Presently aaaa is 20000. To run this problem, increase the size of array ARRAY and change the value of NUMBER in the data statement to correspond to the increase. (See program listing in Section II.9 below.)

h. MISSION ACCOMPLISHED.\*\*\*

This signifies the successful completion of the job.

i. FLUX FOR GROUP gggg IS nnnn (1) FOR IN (2) FOR OUT

This message appears twice per group when ICK equals zero or one and signifies that we are dealing with the two-dimensional flux for group gggg. When nnnn equals one, we have successfully read in this flux. When nnnn equals two, the desired trial functions have been temporarily written out on the scratch data set. If ICK equals two, this message will appear once per group only, when nnnn equals two.

- j. THERE WILL BE nnnn FUNCTIONS ON DSRN dddd

DATA SETS HAVE BEEN REWOUND AND ARE BEING READ.

This message appears just before the generation of FR.TRIAL on data-set reference number dddd; nnnn is the total number of trial functions to be put on this data set.

- k. FUNCTION NUMBER mmmm HAS BEEN WRITTEN OUT

This message appears after each function mmmm has been printed out and written on data-set reference number dddd (message j).

- l. INTERVAL iiiii DOES NOT EXIST. THEREFORE NO TRIAL FUNCTION CAN BE GENERATED.

This message appears when iiiii exceeds the value of IMAX. No interval corresponds to this value; hence, no valid trial function can be generated. J2DTOLIB will, however, attempt to write a function and, if successful, will continue execution.

## 9. JCL and Program Listings

Following is a sample job-control language deck for executing this program. Here, FR.D2 is on data-set reference number 1, FR.TRIAL is on data-set reference number 16, and the GMAX scratch data sets begin at data-set reference number 8. Below the job deck is a listing of the program.

```
//JOB CARD
  ACCOUNTING CARD
/*SETUP DDNAME=DUMMY,DEVICE=2314,ID=DISKLL
//LIBGEN EXEC PROC=PTHCLG
//PTH.SYSIN DD *
  CARD DECK TO BE COMPILED (J2DTOLIB DECK)
/*
//GO,FT01F001 DD DSNAME=GE,CDRT,R,DISP=(OLD,KEEP),UNIT=DISK,
//GO,FT01F001 DD UNIT=2314,VOL=SER=DISKLL,DISP=(OLD,KEEP),DSN=FR.D2
//FT08F001 DD UNIT=DISK,SPACE=(CYL,(1,1)),VOLUME=SER=SCRONE,
//
  DCB=(RECFM=VB,LRECL=256,BLKSIZE=7172)
  OTHER SCRATCH DATA SETS WHICH ARE REQUIRED
//GO,FT16F001 DD DSN=FR.TRIAL,DISP=(NEW,KEEP),VOL=SER=DISKLL,UNIT=2314,
//
  SPACE=(CYL,(1,1)),DCB=(RECFM=VB,LRECL=256,BLKSIZE=7172)
//GO,SYSIN DD *
J2DTOLIB BCD CARD DECK
```

```

C
C   PROGRAM J2DTOLIB
C
C   IMPLICIT REAL*8(A-H,O-Z)
C   DIMENSION ARRAY(20000)
C   DATA NUMBER/20000/
C   COMMON/INFO/NINTI,NINTJ,NGROUP,LIBRED,LIBRIT,NOFUNT,NUM(50),ICK,
1   LIBNUM,NSPACE,IDSRN(30)
C
C   NUMCRD=NUMBER OF CARDS CONTAINING NOCARD&ICK.
C   NOCARD=NUMBER OF CARDS CONTAINING LIBRED WHICH FOLLOW.
C   ICK   -CREATION OPTION.
C           0-READS 2-DFLUXES FROM DSRN LIBRED AND TAKES FLUXES FOR INTERVAL
C           POINTS J AND ALL GROUPS G & PUTS THEM OUT AS 1 RECORD ON
C           DSRN LIBRIT, DIFFERENT LIBRED'S CAN BE PUT OUT ON ONE LIBRIT,
C           1-SAME AS OPTION 0 EXCEPT IT FLIPS THE RECORDS OF FR,DZ
C           TO GENERATE TRIAL FUNCTIONS FROM HORIZONTAL PROFILES IN
C           STEAD OF VERTICAL ONES.
C           2-READS THE OUTPUT FROM A 1-DIMENSIONAL JOB AND PUTS IT
C           IN PROPER FORM SO THAT IT CAN MIX WITH OTHER FUNCTIONS
C           AND OTHER OPTIONS.
C   LIBRED=DSRN WHERE FLUXES ARE TAKEN FROM.
C   LIBRIT=DSRN WHERE TRIAL FUNCTIONS ARE STORED.
C   LIBNUM=NUMBER OF FUNCTIONS TAKEN FROM LIBRED TO PUT ON LIBRIT,
C   NUM   -FUNCTIONS FROM INTERVALS NUMBERED BY NUM.
C$$$$$ LIMITS**NUM(50),6 GROUPS OR LESS.
C$$$$$ LIMITS**IDSRN(30)
C   EXAMPLE CARDO INDICATES 1 NOCARD FOLLOWS.
C   1
C   EXAMPLE CARD1, INDICATES 2 DATA SET CARDS WITH 0 OPTION.
C   2   0
C   CARD2, READING FROM FT03 & WRITING ON FT04 TWO FUNCTIONS.
C   3   4   2
C   CARD3 GIVES INTERVAL NUMBERS.
C   1   5
C   CARD4, READING FROM FT05 & WRITING ON FT04 TWO FUNCTIONS.
C   5   4   2
C   CARD5 GIVES INTERVAL NUMBERS.
C   2   3
C   DO 9 I=1,30
C   9   IDSRN(I)=I+7
C       NOFUNT=0
C       READ(5,2) NUMCRD
C       PRINT 25 ,NUMCRD
C       DO 13 II=1,NUMCRD
C       READ(5,2) NOCARD,ICK
C       PRINT 26,NOCARD,ICK
C       DO 10 I=1,NOCARD
C       READ(5,2) LIBRED,LIBRIT,LIBNUM
C       IF(LIBNUM,LT.51) GO TO 36
C       PRINT 27,LIBNUM
C       STOP
C   36 READ(5,2)(NUM(J),J=1,LIBNUM)
C       REWIND LIBRED
C       IF(ICK.EQ.2)READ(LIBRED) NINTJ,NGROUP,EVALUE
C       IF((ICK.EQ.0).OR.(ICK.EQ.1))READ(LIBRED) NINTI,NINTJ,NGROUP,EVALUE
C       IF(ICK.EQ.2) NINTI=1
C       IF((ICK.EQ.0).OR.(ICK.EQ.2) ) GO TO 20
C       NOT=NINTI
C       NINTI=NINTJ

```

```

NINTJ=NOT
20 IF(NOFUNT,NE,0) GO TO 24
LIB=LIBRIT
24 IF(LIBRIT,EQ,LIB) GO TO 23
LIB=LIBRIT
CALL RITFLX
NOFUNT=0
DO 18 J=1,NGROUP
NOT=IDSRN(J)
REWIND NOT
18 CONTINUE
23 NOFUNT=NOFUNT+LIBNUM
17 PRINT 7,LIBRED,LIBRIT,LIBNUM
PRINT 8,(NUM(J),J=1,LIBNUM)
PRINT 1,EVALUE,NINTJ,NINTI,NGROUP
NSPACE=NINTJ*MAXO(NINTI,NGROUP)
IF(NSPACE,GT,NUMBER) GO TO 70
CALL REDFLX(ARRAY)
10 CONTINUE
13 CONTINUE
CALL RITFLX
DO 5 I=1,NGROUP
NOT=IDSRN(I)
REWIND NOT
5 CONTINUE
100 PRINT 111
STOP
70 PRINT 3,NSPACE,NUMBER
1 FORMAT(' CONVERGED EIGENVALUE IS ',D20,10,/, ' JMAX= ',I4,/,
1 ' IMAX= ',I4,/, ' GMAX= ',I4)
2 FORMAT(16I5)
3 FORMAT(' SPACE REQUIRED IS',I6, ' SPACE AVAILABLE IS',I6, ' ERROR')
7 FORMAT(/,/,/)
1 ' DSRN READ IS ',I5, ' DSRN WRITTEN IS ',I5, ' NUMBER OF FUNC
1 TIONS READ AND WRITTEN IS ',I5)
8 FORMAT(' FUNCTION NUMBERS',16I5)
25 FORMAT(' THE NUMBER OF OPTIONS USED IS ',I5)
26 FORMAT(' ',/,/,/,/)
1 ' 15, ' DATA SETS WILL BE READ AND/OR WRITTEN WITH OPTION
1 NUMBER ',I5)
27 FORMAT(/,/,/,/ ' ATTEMPTING TO READ TOO MANY FUNCTIONS AT ONE TIME('
1 ',I4,').')
111 FORMAT(' MISSION ACCOMPLISHED.***')
STOP
END
SUBROUTINE REDFLX(FLUX)
IMPLICIT REAL*8(A-H,O-Z)
COMMON/INFO/NINTI,NINTJ,NGROUP,LIBRED,LIBRIT,NOFUNT,NUM(50),ICK,
1 LIBNUM,NSPACE,IDSRN(30)
DIMENSION FLUX(NINTJ,NINTI)
DATA IONE/1/,ITWO/2/
MLIB=LIBRIT
NLIB=LIBRED
IF(ICK,EQ,2) GO TO 17
DO 7 LG=1,NGROUP
IF(ICK,EQ,0) READ(NLIB) ((FLUX(J,I),I=1,NINTI),J=1,NINTJ)
IF(ICK,EQ,1) READ(NLIB) ((FLUX(I,J),I=1,NINTJ),J=1,NINTI)
PRINT 20 ,LG,IONE
NOT=IDSRN(LG)
DO 10 I=1,LIBNUM

```

```

      IF(NUM(I),GT,NINTI) PRINT 24,NUM(I)
      WRITE(NDT)(FLUX(J,NUM(I)),J=1,NINTJ)
10  CONTINUE
      PRINT 20 ,LG,ITWO
      7  CONTINUE
      REWIND NLIB
      RETURN
17  CONTINUE
      READ(NLIB)((FLUX(J,I),J=1,NINTJ),I=1,NGROUP)
      DO 19 LG=1,NGROUP
      NUT=IDSRN(LG)
      WRITE(NDT)(FLUX(J,LG),J=1,NINTJ)
      PRINT 20 ,LG,ITWO
19  CONTINUE
      REWIND NLIB
      RETURN
      ENTRY RITFLX
51  DO 16 NG=1,NGROUP
      NUT=IDSRN(NG)
      REWIND NDT
16  CONTINUE
      PRINT 18,NOFUNT,MLIB
      PRINT 21
50  CONTINUE
      WRITE(MLIB ) NOFUNT,NINTJ,NGROUP
      3  DO 5 I=1,NOFUNT
      DO 13 LG=1,NGROUP
      NUT=IDSRN(LG)
      READ(NDT)(FLUX(J,LG),J=1,NINTJ)
11  PRINT 6, (FLUX(J,LG),J=1,NINTJ)
13  CONTINUE
      WRITE(MLIB )((FLUX(J,L),J=1,NINTJ),L=1,NGROUP)
      PRINT 23,I
      5  CONTINUE
      REWIND MLIB
      6  FORMAT(' ',6D20.10,/)
18  FORMAT(' THERE WILL BE ',I5,' FUNCTIONS ON DSRN ',I5)
20  FORMAT(' FLUX FOR GROUP ',I3,' IS ',I3,' (1) FOR IN (2) FOR OUT.')
```

21 FORMAT(' DATA SETS HAVE BEEN REWOUND AND ARE BEING READ. ',//,I1')

23 FORMAT('FUNCTION NUMBER ',I3,' HAS BEEN WRITTEN OUT. ',//,I1')

24 FORMAT(' INTERVAL ',I3,' DOES NOT EXIT, THEREFORE NO TRIAL FUNCTIO

IN CAN BE GENERATED.')

```

      RETURN
      END
```

### III. PROGRAMMER'S DESCRIPTION OF SYN2D

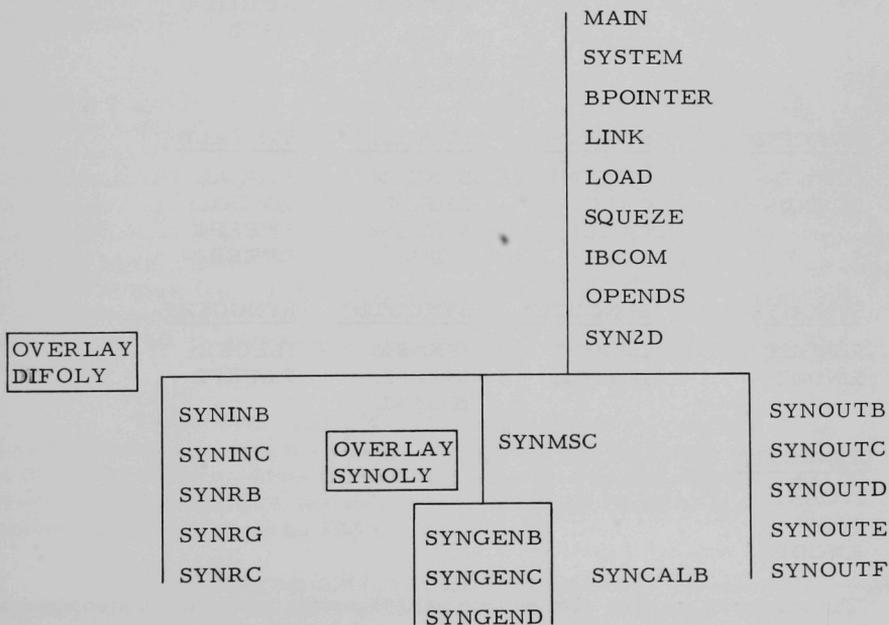
#### A. Description of Program Flow

This section defines the overlay structure of SYN2D and the flow of logic through the subroutines which form the program.

Section 1 consists of an overlay structure diagram showing the ARC System segments and SYN2D module segments from library SEGLIB required by this module and their positions in the overlay hierarchy defined in library OVERLAY. This is followed by a list of the subroutines located in each SYN2D module segment. The segments are listed in the order the linkage editor uses to eliminate cross-references.

Section 2 describes the flow of logic through the subroutines making up the module and illustrates this flow.

#### 1. Overlay Structure



## Subroutines contained in each SYN2D segment

<u>SYN2D</u>	<u>SYNDIF2D*</u>	<u>SYNINB</u>	<u>SYNINC</u>
Module SYN2D	ERRMSG	SYNIN	LIB
CLOSE	PAGHED	RCDEP	FPRIME
	IVOL	RSDEF	PROCES
	IAREA	SYNDEF	RIEMAN
	PGEOM	RRCALC	VALUES
	GETBND		DSRNCK
	PCOMP		
<u>SYNRB*</u>	<u>SYNRG*</u>	<u>SYNRC*</u>	<u>SYNMSC</u>
RBNCD	RGEOM	RCOMP	D2DCAL
STORBC	RMESH	RXSC01	MINV (IBM SSP routine)
PRTBC		RGROUP	GMPRD (IBM SSP routine)
		GETCHI	MOVE
		DIMSCT	MADD
		PCKSCT	NUMMLT
		RVEL	MSUB
		RDELAY	
		RKIN	
<u>SYNGENB</u>	<u>SYNGENC</u>	<u>SYNGEND</u>	<u>SYNCALB</u>
COFGEN	MTGEN1	SYNGEN	SYNCAL
BCONDS	CALC1	CHECK	SINCAL
	CALC2	MTGEN2	SWEEP1
		NORM	SWEEP2
<u>SYNOUTB</u>	<u>SYNOUTC*</u>	<u>SYNOUTD*</u>	<u>SYNOUTE*</u>
SYNOUT	D2DOUT	IFXNRM	ILKCEL
SINOUT	IFXVOL	IGPCAL	FLUXPR
		IRGBAL	
<u>SYNOUTF*</u>			
ITOBAL			
FLOP			
TWODPR			

The segments marked with an asterisk (\*) contain subroutines also used by the two-dimensional diffusion module.

## 2. Description of Program Structure and Flow

Module SYN2D is entered by execution of a LINK command in a path. Its first call is to TLEFT (IBM routine) to obtain the amount of computer time remaining before execution of the module is terminated

Then CLOSE is called to rewind any open data sets. Next, SYN2D calls subroutine SYNIN, which controls the reading of all data sets needed for execution and creates the preprocess data sets.

SYNIN first calls TLEFT, and then calls RCDEP to read module-dependent data from data set A.SYN2D. The first five records are read, the first two being ignored since they are set up by BCDDS<sup>†</sup> to describe the data-set structure. Variables used by the two-dimensional diffusion capability, which shares some of these subroutines, are set to the appropriate values for a real, homogenous k-effective calculation. POINTR<sup>†</sup> is initialized, and if bulk core has been requested, a call to entry BULK of POINTR is made. Calls to SNIFF<sup>†</sup> are made to get the data-set reference numbers for A.SYN2D and the four scratch data sets used by the module.

SYNIN next calls RGEOM, which controls input of all geometry data from data set GEOM. SNIFF is called to obtain the data-set reference number for GEOM. The first record is read, and storage is allocated; then RMESH is called, and the remaining records of GEOM are read. RGEOM then initializes functions IVOL and IAREA, and if a print of geometry data is requested, PGEOM is called.

SYNIN then calls RCOMP to read in the composition data. SNIFF is called to get the data-set reference number for XS.C.MIN. Storage is then allocated and RXSC01 is called to read in the composition names from the first record of SX.C.MIN. RCOMP then calls GETCHI to read the next record if there is a set-wide fission spectrum. RDELAY is not called, since this module has no kinetics option. RGROUP is then called once for each composition, to read the group-dependent XS.C.MIN data. RCOMP next calls DIMSCT to set up the position of the scattering terms in the scattering array, PCKSCT to pack the scattering array by compositions, and, if requested, PCOMP to print the composition-related data. RCOMP's final call is to RVEL to set up dummy neutron speeds by group, which are not used by synthesis.

SYNIN next calls RBND, which controls the reading of the boundary-condition data from data set BC. Storage is allocated, and a call to SNIFF is made to obtain the data-set reference number for BC. BC is read in RBND; the data are stored in an array by STORBC and, if requested, are printed out by PRTBC.

SYNIN then calls RSDEF, which checks the geometry type, reads the next record (type 04 card) of data set A.SYN2D, allocates storage, and then calls SYNDEF to read the types 05,06A, 06B, and 06C cards from data set A.SYN2D. These cards define the synthesis-region boundaries and the trial functions that will be used by this problem. RSDEF then calls RRCALC

---

<sup>†</sup>ARC System utility subroutine.

to determine the X-direction refined region boundaries for the entire reactor and the Y-direction refined interval boundaries for each synthesis region. RSDEF next makes several calls to SNIFF to obtain the data-set reference numbers for the data sets LIB.REAL, LIB.ADJT, and LIB.MIX. If these data sets have not been previously written, a call to LIB is made. LIB calls SNIFF to obtain the data-set reference numbers for LIB.REAL, LIB.ADJT, LIB.MIX, FR.TRIAL, and FA.TRIAL. The three problem-dependent trial-function libraries are then created by LIB. If all the real trial functions required cannot be held in core at one time, the last record of A.SYN2D is read to indicate which scratch data sets should be used in the trial-function library generation. When the three data sets are old, LIB is not called.

RSDEF then calls SNIFF for the data-set reference number of LIB.PART. If this data set has not been written, RSDEF calls PROCES to generate the partial integrals. PROCES first calls SNIFF to obtain the data-set reference number for LIB.PART and then calls DSRNCK, which checks to see if the data sets LIB.REAL, LIB.ADJT, and LIB.MIX are consistent with each other and with the specifications for this problem. PROCES then calculates the partial integrals, using RIEMAN to perform the actual integration, FPRIME to differentiate the trial functions, and VALUES to calculate the values for each trial function at the reactor boundaries. These three subroutines are called repetitively, with RIEMAN and VALUES writing the records of LIB.PART just before each return to PROCESS. Finally PROCES calls CLOSE to rewind the data sets.

If LIB.PART is old, no call to PROCES is made. If neither LIB nor PROCES was called by RSDEF, a call to DSRNCK is made. Finally, RSDEF calls CLOSE.

Following the call to RSDEF, SYNIN calls TLEFT and prints the time required for the execution of the subroutine SYNIN. Control is then returned to SYN2D. For a preprocessing run, execution is terminated here.

SYN2D next calls D2DCAL, which is not a two-dimensional diffusion subroutine. D2DCAL calls SYNGEN, which is the driver for the generation of the coefficient matrices.

SYNGEN first calls TLEFT and then calls SNIFF to obtain the data-set reference number for data set XS.C.MIN. Array storage is then allocated and CHECK is called to generate the interval-to-synthesis-region correspondence. Next SYNGEN initializes COFGEN, MTGEN1, and MTGEN2 and then calls entry COFF1 of COFGEN once for each group. COFGEN calculates all the coefficient matrices  $[D_{gk}(r)]$ ,  $[L_{gk}(r)]$ ,  $[\Sigma_{gk}(r)]$ ,  $[\Sigma_{g',k}(r)]$ ,  $[(\chi_{g\nu} \nu_{g'} \Sigma_{fg'})_{k}(r)]$ ,  $[W_{gk}]$ ,  $[A_g^k]$ ,  $[\bar{A}_g^{(k+1)}]$ ,  $[B_g^k]$ , and  $[\bar{B}_g^{(k+1)}]$ , calling BCOND5 to

calculate  $[C_{gk}(r)]$ . These matrices are calculated from the partial integrals generated previously. Calls to GETBND entries VERBND and HORBND by COFGEN and BCONDS are made to obtain the boundary conditions applied at the reactor left and right boundaries and top and bottom boundaries, respectively. COFGEN writes the fission matrices  $\{[(\chi_{g\nu_g}, \Sigma_{fg})_k(r)]\}$  and the scattering matrices  $\{[\Sigma'_{g'g,k}(r)]\}$  on scratch data sets SCR002 and SCR004, respectively. After the call to COFGEN, SYNGEN calls entry MTGN1 of MTGEN1, which is the driver for the generation of the matrices  $\{H_i\}$ ,  $\{G_i\}$ , and  $\{E_i\}$ . First MTGEN1 calls CALC1 to generate  $\Omega_i^{-1}$ ; then CALC2 is called to calculate  $E_i$ ,  $G_i$ , and  $H_i$ . (Note that  $E_{\text{IMAX}}$  and part of  $E_i$  are computed in MTGEN1.) The norm of  $[D_{gk}(r)]$  is also approximated by MTGEN1, and the largest norm is printed out.

Next SYNGEN calls MTGEN2 (entry MTGN2), which computes the matrices  $\{U_i^{-1}\}$ ,  $\{V_i\}$ , and  $\{H_i\}$  from  $\{E_i\}$ ,  $\{G_i\}$ , and  $\{H_i\}$  and writes  $\{U_i^{-1}\}$  and  $\{V_i\}$  on scratch data set SCR003 and  $\{H_i\}$  on scratch data set SCR001. Finally, after COFGEN, MTGEN1, and MTGEN2 have been called once for each group, SYNGEN calls CLOSE and TLEFT and prints out the time required for the execution of SYNGEN.

D2DCAL next calls SYNCAL, which calls TLEFT, allocates array storage, and then calls SINCAL. SINCAL first initializes SWEEP1 and SWEEP2 and then performs the required power iterations necessary for the problem's solution. After each outer iteration, monitoring information is printed out. SWEEP1 performs the forward sweep of the Choleski method, while SWEEP2 performs the backward sweep. SINCAL returns control to SYNCAL when the power iterations have converged, the maximum number of iterations has been exceeded, less than 30 sec of computer time remains, or a program-detectable error has been encountered. SNIFF is called by SINCAL to obtain the data-set reference number for FR.TG, which is written before control is returned to SYNCAL. Finally, SYNCAL calls TLEFT and prints the time required for the execution of SYNCAL.

After the call to SYNCAL, D2DCAL returns control to module SYN2D. SYN2D then calls SYNOUT, which in turn calls TLEFT, allocates storage, and then calls SINOUT to calculate the final reconstructed two-dimensional fluxes from the mixing functions calculated in SINCAL and the user-supplied real trial functions.

SINOUT calls TWODPR to print out the mixing functions and, if requested, the real trial functions. SINOUT writes the unnormalized two-dimensional fluxes on SCR001 for later use by D2DOUT. After calculation of the two-dimensional fluxes for all energy groups, SINOUT returns control to SYNOUT, which then calls D2DOUT, which is the two-dimensional diffusion-output edit driver. SINOUT allocates storage and then initializes IFXVOL, IFXNRM, IGPCAL, IRGBAL, GETBND, ILKCEL, and ITOBAL. Then entry

FXVOL of IFXVOL is called by D2DOUT to calculate the regional flux integrals for all groups. IFXVOL then calls entry VOL of IVOL to help calculate the region volumes.

D2DOUT then calls entry FLXNRM of IFXNRM, which calculates the power-normalization factor for burnup and then normalizes regional flux integrals and region-averaged fluxes for data set FR.PN. FLXNRM also calculates total power, power, and average power by region. The data-set reference number for FR.PN is obtained by a call to SNIFF.

D2DOUT next calls entry of IGPCAL, which normalizes the two-dimensional fluxes for all groups to one fission in the reactor and accumulates the power density by mesh point. SNIFF is called to obtain the data-set reference number for FR.D2, which is then written out. If desired, entry REGBAL of IRGBAL is then called by GPCAL.

REGBAL calls entry LKCELL of ILKCEL, which calculates the total leakage out of a cell and the neutron currents across each interface of the cell. Using this information, REGBAL calculates the contribution to the total balance by region and group, including leakage, removal, scattering, and fission. It also calculates and prints neutron currents across region boundaries if desired.

D2DOUT then, if requested, calls FLUXPR to print out the two-dimensional fluxes and power. Next, if desired, entry TOTBAL of ITOBAL is called by D2DOUT.

ITOBAL calculates the following arrays by region and group: flux integrals, averaged flux integrals, leakage, removal contribution to balance, scattering source contribution, fission-source integrals, output balance sums, average fission-source integrals, and source volume integrals. These arrays are then printed out. The arrays are next summed over all groups for each region and printed out. Then they are summed over all regions for each group and printed out. Finally, each array is summed over both region and group and printed out.

TWODPR is called in each case to print out the arrays.

After the call to TOTBAL, D2DOUT returns control to SYNOUT. (FLOP is never called, since the problem type is never adjoint.) SYNOUT then calls TLEFT and prints the time required for the execution of SYNOUT, after which control is returned to SYN2D.

SYN2D then calls FREE to release the storage held by the container array. A TLEFT call is made, and the total time required to execute the SYN2D module is printed out. Then control is returned to the calling path.

Figure 4 is a diagrammatic subroutine calling map. This map contains no logic and is only intended to show the subroutine calling hierarchy. Entry-point references have been indicated only when the main calling sequence is not called in the same subroutine as the entry point.

## B. Common-block Descriptions

This section provides detailed information about the common blocks used by the SYN2D subroutines. The common blocks appear in alphabetical order by name.

For each common block, all variables are listed in order of appearance in the block by name and type, and each is defined. If a variable is dimensioned, the dimension follows the variable name in parentheses. In addition, there appears for each variable a list of the subroutines in which the value of the variable is set (S) or modified (M).

A special case is the BLKSTR common block, which contains the container array BLK used by the dynamic storage allocation module POINTR (see ANL-7711<sup>1</sup>). Section C contains a list of all names of all arrays that may be defined in the container array at any point in the execution of the module.

For the SINGLE common block, which contains the single variables used by the program, the local name of each variable is given, followed by its location in the FLT or INT array, the subroutines where its value is set or modified, and its definition.

### 1. BCBLK

<u>Name</u>	<u>Type</u>	Subroutines Where Values Are Set or Modified	<u>Definition</u>
MSHTYP	R*4	M-RBNDC	Alphanumeric data, printed to indicate whether mesh line at which boundary condition applies is horizontal or vertical ('HOR' or 'VER,' respectively).
MESH	I*4	M-RBNDC	Mesh-line number and side indicator to which this record refers.  For a vertical interface, - sign is left side of line, + sign is right side of line. For a horizontal interface, + sign is top side of line, - sign is bottom side of line.



<u>Name</u>	<u>Type</u>	Subroutines Where Values Are Set		<u>Definition</u>
			<u>or Modified</u>	
MESH1	I*4	M-RBND	C	The mesh-line number defining the beginning of the boundary-condition interval along this interface.
MESH2	I*4	M-RBND	C	The mesh-line number defining the end of the boundary-condition interval along this interface.
GINT	I*4	M-RBND	C	The initial high-energy group number to which this set of constants applies.
GFIN	I*4	M-RBND	C	The final lower-energy group number to which this set of constants applies.
ITYPE	I*4	M-RBND	C	The type of boundary condition: ITYPE = 1, $C_1\phi' + C_2\phi = C_3$ , ITYPE = 2, $C_1D\phi' + C_2\phi = C_3D$ , where D is the diffusion coefficient.
C(4)	R*4	M-RBND	C	The boundary-condition constants $C_1$ , $C_2$ , and $C_3$ , referred to by ITYPE. ( $C_4$ is not used at present.)

2. BLKSTR

<u>Name</u>	<u>Type</u>	Subroutines Where Values Are Set		<u>Definition</u>
			<u>or Modified</u>	
BLK(1)	R*8	S-RCDEP	C	This array, whose size is defined at execution time, is used as the container array for the dynamic storage array allocation program, POINTR.

3. HEADER

<u>Name</u>	<u>Type</u>	Subroutines Where Values are Set		<u>Definition</u>
			<u>or Modified</u>	
TITLE(10)	R*8	S-RCDEP	C	Page heading (10A6), from data set A.SYN2D.

<u>Name</u>	<u>Type</u>	<u>Subroutines Where Values Are Set or Modified</u>	<u>Definition</u>
NPAGE	I*4	S-RCDEP M-PAGHED	Page number, initialized at zero and incremented with each printing.

4. NAMBLK

<u>Name</u>	<u>Type</u>	<u>Subroutines Where Values Are Set or Modified</u>	<u>Definition</u>
NAME	R*8	S-ERRMSG	Name of subroutine calling ERRMSG (A8).

5. SINGLE

<u>Name</u>	<u>Type</u>	<u>Definition</u>
FLT(100)	R*8	100 floating-point single variables, described below.
INT(200)	I*4	200 integer single variables, described below.

<u>Name</u>	<u>Position in FLT Array</u>	<u>Subroutines Where Values Are Set or Modified</u>	<u>Definition</u>
PROB	1	S-RCDEP	Problem type, set to 'REAL' for use by the two-dimensional diffusion subroutines.
{ KEFF LAMDA }	2	S-SINCAL	Computed k-effective for problem.
ALPHA	3	S-RCDEP	Inverse reactor time period $\alpha$ (set to 0 for use by the two-dimensional diffusion subroutines).
PROBT	5	S-RCDEP	Calculation type, set to 'KCALC' for use by the two-dimensional diffusion subroutines.
MU	6	Not set	$\mu = 1/k_{\text{fixed}}$ (used only in two-dimensional diffusion-source calculations).

<u>Name</u>	<u>Position in FLT Array</u>	<u>Subroutines Where Values Are Set or Modified</u>	<u>Definition</u>
EPOFLX	11	S-RCDEP	Flux-difference convergence criterion for outer iterations, $\epsilon_\varphi$ : $\epsilon_\varphi \geq \sum_{\text{gin}}  1 - \varphi_{\text{gin}}^{(\ell-1)} / \varphi_{\text{gin}}^{(\ell)} .$
EPSLAM	12	S-RCDEP	Flux-bounds-difference convergence criterion for outer iterations, $\epsilon_\lambda$ : $\epsilon_\lambda \geq (\lambda_{\text{UP}}^\ell - \lambda_{\text{DN}}^\ell),$ where $\lambda_{\text{UP}}^\ell = \max_{\text{gin}} (W_{\text{gin}}),$ $\lambda_{\text{DN}}^\ell = \min_{\text{gin}} (W_{\text{gin}}),$ and $W_{\text{gin}} =  \varphi_{\text{gin}}^{(\ell)} / \varphi_{\text{gin}}^{(\ell-1)} .$
EPSKEF	13	S-RCDEP	k-effective convergence criterion, $\epsilon_k$ : $\epsilon_k \geq  v^{(\ell)} - v^{(\ell-1)} ,$ where $v^\ell$ is the $\ell$ th eigenvalue approximation.
GEOM	31	S-RGEOM	Geometry type: XY, RX, XR, or RT.
XL	32	S-RMESH	Left reactor boundary.
XR	33	S-RMESH	Right reactor boundary.
YB	34	S-RMESH	Bottom reactor boundary.
YT	35	S-RMESH	Top reactor boundary.
POWIN	71	S-RCDEP	Burnup calculation power normalization factor. If user input is 0.0 or blank, POWIN is set to 1.0.

<u>Name</u>	<u>Position in INT Array</u>	<u>Subroutines Where Values Are Set or Modified</u>	<u>Definition</u>
MKRTHY	1	S-RCDEP	Problem type, set to 0 for use by two-dimensional diffusion subroutines.

<u>Name</u>	<u>Position in INT Array</u>	<u>Subroutines Where Values Are Set or Modified</u>	<u>Definition</u>
KINOPT	2	S-RCDEP	Kinetics option, set to 0 since SYN2D has no kinetics capability.
MAXSIZ	4	S-RCDEP	Maximum size of the variable-dimensional main storage array BLK which is used by POINTR (default 60000).
IPRINT	5	S-RCDEP	POINTR debugging print flag. 0: No print. 1: POINTR trace prints. 2: POINTR dumps. 3: Both dumps and trace prints.
KORDER	6	S-RCDEP	
KOUT	7	S-RCDEP	Printed output flag. 0: Problem specifications and iteration history only. 1: Above, plus balance calculations. 2: Above, plus power calculations.
NMAX	11	S-RCDEP	Maximum number of outer iterations.
MXBULK	19	S-RCDEP	Size of the variable dimensional bulk core array BLK which is used by POINTR (default 120000).
IRTPER	30	S-IVOL	RO geometry periodic flag, set to 0 for use by two-dimensional diffusion subroutines.
RMAX	31	S-RGEOM	Number of reactor regions.
IMAX	32	S-RGEOM	Number of X-direction mesh intervals.
JMAX	33	S-RGEOM	Number of Y-direction mesh intervals.
NBCDEF	34	S-RBNDC	Number of boundaries with boundary conditions (should always be 4).
CMAX	35	S-RCOMP	Number of compositions.
FSCMAX	36	S-RCOMP	Number of fissionable compositions.
GMAX	37	S-RCOMP	Number of energy groups.
GMAXUP	38	S-RCOMP M-RGROUP	Number of upscatter groups.

<u>Name</u>	<u>Position in INT Array</u>	<u>Subroutines Where Values Are Set or Modified</u>	<u>Definition</u>
MTRCHI	39	S-RCOMP	$\chi$ matrix flag (always set to 1, since only $\chi$ vectors are allowed).
CHIDIM	40	S-RCOMP	First dimension of $\chi$ array CHI(CHIDIM,GMAX), where CHIDIM = FSCMAX*GMAX**MTRCHI.
SCTDIM	41	S-RCOMP	First dimension of packed scattering array (SCTXS(SCTDIM,GMAX)), where $\text{SCTDIM} = \sum_{C=1}^{\text{CMAX}} [\text{SCTLIM}(1,C) + \text{SCTLIM}(2,C) + 1].$
NFAM	44	S-RCOMP	Number of delayed families (should be 0).
MAXUP	46	S-RGROUP M-COFGEN	Maximum upscattering over all compositions, $\max_C [\text{SCTLIM}(2,C)]$ (should be 0).
MAXDN	47	S-RGROUP	Maximum downscattering over all compositions, $\max_C [\text{SCTLIM}(1,C)]$ .
NBLACK	50	S-RCDEP	Number of black compositions (set to 0).
$\left\{ \begin{array}{l} \text{NLIB} \\ \text{NTH} \end{array} \right\}$	51	S-RCDEP	Scratch data-set reference number for SCR001 (see Section III.E).
$\left\{ \begin{array}{l} \text{ILIB} \\ \text{IFISS} \end{array} \right\}$	52	S-RCDEP	Scratch data-set reference number for SCR002 (see Section III.E).
JLIB	53	S-RCDEP	Scratch data-set reference number for SCR003 (see Section III.E).
KLIB	54	S-RCDEP	Scratch data-set reference number (presently 94, but not now in use).
LLIB	55	S-RCDEP	Scratch data-set reference number (presently 95, but not now in use).
$\left\{ \begin{array}{l} \text{MLIB} \\ \text{ISCAT} \end{array} \right\}$	56	S-RCDEP	Scratch data-set reference number for SCR004 (see Section III.E).

<u>Name</u>	<u>Position in INT Array</u>	<u>Subroutines Where Values Are Set or Modified</u>	<u>Definition</u>
ITERNO	57	S-SINCAL	Number of outer iterations used.
IPROB	93	S-RCDEF	Calculation type, set to 0 for use by two-dimensional diffusion modules.
KFLAG	94	S-RCDEF	Search flag for type of variable prescribed, set to 0 for use by two-dimensional diffusion modules. (SYN2D has no search capability.)
{ N NINPUT }	101	S-RCDEF	Data-set reference number for data set A.SYN2D.
KMAX	102	S-RSDEF	Number of synthesis regions.
NGKMX	103	S-SYNDEF	Maximum number of real trial functions per synthesis region over all regions and all groups.
NGKPMX	104	S-RSDEF	Identical to NGKMX above. NGKPMX remains from an earlier version of the code.
NALPHA	105	S-RSDEF	Indicates, along with NBETA, the weight function to use when generating the coefficient matrices. 1: for RZ geometry. 0: for XY and ZR geometry.
RRMAX	106	S-RRCALC	Number of refined regions.
NBETA	107	S-RSDEF	See NALPHA. 1: for XY geometry. 0: for RZ and ZR geometry.
IADJT	108	S-RCDEF	Adjoint trial-function flag. 1: Real trial functions should be used as adjoints also. 0: User will supply adjoint trial functions.
N1	110	S-RSDEF	Data-set reference number for data set LIB.REAL.
N2	111	S-RSDEF	Data-set reference number for data set LIB.ADJT.
N3	112	S-RSDEF	Data-set reference number for data set LIB.MIX.

<u>Name</u>	<u>Position in INT Array</u>	<u>Subroutines Where Values Are Set or Modified</u>	<u>Definition</u>
LPART	113	S-RSDEF S-PROCES	Data-set reference number for data set LIB.PART.
TIMEKY	115	S-DSRNCK S-LIB	Time key which is put on LIB.ADJT, LIB.MIX, LIB.PART, and LIB.REAL to give a key for identification. Indicates if the data sets are consistent, i.e., were created on the same problem run.
IOPT	117	S-RCDEP	Interface option flag. 1: Use asymmetric interface condition. 2: Use symmetric interface condition.
KOPT	118	S-RSDEF	Preprocess option. 1: Preprocess only. 0: Run entire problem.

### C. Dynamic Storage Array Allocation

This section describes all arrays which may be defined by this module in common block /BLKSTR/BLK, using the facilities of the dynamic storage allocation module POINTR (see ANL-7711<sup>1</sup>). The arrays are listed in alphabetical order of the name given them in the POINTR name table.

The following information is given for each array:

1. Type.
2. Dimension, in terms of module variables.
3. Names of subroutines where action is taken that affects the status of the array in the container, followed in parentheses by the action taken in the subroutine. (Here, significant POINTR calls are generally PUTPNT, which allocates space in the container for the array; REDEF, which sets aside space if the array is not present or redefines its space allocation if it is; and WIPOUT, which removes the array from the name table, thus making it inaccessible. The meaning of any other POINTR calls listed can be found in the POINTR documentation.)
4. Names of subroutines in which the value of elements of the array are set (S) or modified (M).

tion of the array contents.

If the meaning of a variable used as the dimension of an array is not known, it can be found in the subroutine in which a call to PUTPNT or REDEF is made for that array.

Name	Type	Dimension	Subroutines Issuing Significant POINTR Calls	Subroutines Where Values Are Set or Modified	Definition
AMN	R*8	(NGKMX,NGKMX, KMAX-1)	SYNGEN(PUTPNT) SYNGEN(WIPOUT)	M-COFGEN	Agk for all groups g and all required synthesis regions k.
AREA	R*8	(NGKMX,NGKMX)	SYNGEN(PUTPNT)  SYNCAL(WIPOUT)	M-CALC1 M-CALC2 M-COFGEN M-SWEEP1 M-SWEEP2	Temporary matrix storage array.
BLKCMP	R*8	(NBLACK)	RCDEP(PUTPNT)	Not set or modified	Names of compositions defined as black compositions, used only by two-dimensional diffusion subroutines. (NBLACK is set to 0 in RCDEP.)
BLKGRP	I*4	(NBLACK,2)	RCDEP(PUTPNT)	Not set or modified	Numbers of initial and final energy groups between which a composition named in BLKCMP is defined as being black. For a composition BLKCMP(N), BLKGRP(N,1) is the initial energy group, and BLKCMP(N,2) is the final energy group. If BLKGRP(N,1) = 0, the condition is applied over all energy groups in the composition. If BLKGRP(N,2) = 0 and BLKGRP(N,1) ≠ 0, the condition applies only to the energy group indicated by BLKGRP(N,1). Used only by two-dimensional diffusion subroutines. (NBLACK is set to 0 in RCDEP.)
BMN	R*8	(NGKMX,NGPMX, KMAX-1)	SYNGEN(PUTPNT) SYNGEN(WIPOUT)	M-COFGEN	Egk for all groups g and all required synthesis regions k.
BNDC JBNDC	R*4 I*4	(11,NBCDEF)	RBNDC(PUTPNT)	S-STORBC	For each boundary condition NBC(NBC=1,NBCDEF), 11 terms, defined as follows: JBNDC(1,NBC)--alphanumeric name indicating whether this boundary condition applies to a vertical (VER) or horizontal (HOR) line. JBNDC(2,NBC)--vertical or horizontal mesh-line number, positive if the condition applies on the top or the right side of the line, negative if it applies on the left or bottom.

Name	Type	Dimension	Subroutines Issuing Significant POINTR Calls	Subroutines Where Values Are Set or Modified	Definition
BNDC (Contd.)					<p>upper and lower mesh-line numbers defining the interval over which this boundary condition applies.</p> <p>JBNDC(3,NBC) JBNDC(4,NBC)</p> <p>JBNDC(5,NBC)--number of initial (higher) energy group to which condition applies. JBNDC(6,NBC)--number of final (lower) energy-group to which condition applies. JBNDC(7,NBC)--boundary-condition type number:  <math>1 - C_1\varphi' + C_2\varphi = C_3,</math>  <math>2 - C_1D\varphi' + C_2\varphi = C_3D,</math>            where D is the diffusion coefficient.            BNDC(8,NBC)--C1            BNDC(9,NBC)--C2            BNDC(10,NBC)--C3            BNDC(11,NBC)--C4 (not currently used)</p>
BSQ	R*8	(RMAX)	RGEOM(PUTPNT)	S-RMESH	Buckling values from data set GEOM when applicable. If $B^2$ is not defined for a given region, BSQ(R) = 0.
CHI	R*8	(CHIDIM,GMAX)	RCOMP(PUTPNT)	S-RGROUP	Fission-spectrum fractions stored as vectors ( $\chi_C^g$ ) or matrices ( $\chi_C^{g's}$ ) for each fissionable composition. (Note that the synthesis module cannot handle matrices.)
CMN	R*8	(NGKMX,NGKMX, KMAX-1)	SYNGEN(PUTPNT) SYNGEN(WIPOUT)	M-COFGEN	$\bar{A}_g^{(k+1)}$ for all groups g and all required synthesis regions k.
CMPMSH	I*2	(JMAX,IMAX)	RGEOM(PUTPNT)	S-MESH	Mesh-to-composition correspondence, defined in data set GEOM. For any mesh interval (I,J), CMPMSH(J,I) is the number of the composition defined in interval (I,J).
CMPNAM	R*8	(CMAX)	RCOMP(PUTPNT)	S-RXSCO1	Composition names, defined in data set XS.C.MIN. CMPNAM(C) is the name of the composition whose number is C.
CMPREG	I*2	(RMAX)	RGEOM(PUTPNT)	S-MESH	Region-to-composition correspondence.
CNUM	R*8	(IMAX)	D2DOUT(PUTPNT)	S-FLUXPR	X-direction mesh interval centers for output prints.
CRDUM	I*4	(RMAX)	RGEOM(PUTPNT)	S-MESH	Temporary storage for region-to-composition correspondence array as read from data set GEOM (stored in I*2 array CMPREG).

Name	Type	Dimension	Subroutines Issuing Significant POINTR Calls	Subroutines Where Values Are Set or Modified	Definition
DC	R*8	(CMAX,GMAX)	RCOMP(PUTPNT)	S-RGROUP	Diffusion coefficients by composition and group. Diffusion coefficients are formed from the transport coefficients which are read into this array from data set XS.C.MIN [DC = 1/(3ETR)].
DCCHI	R*8	(NFAM,GMAX) for kinetics option 1 or 2 (0) for kinetics option 0	RCOMP(PUTPNT) RCOMP(WIPOUT)	S-RGROUP	Delayed neutron-emitter-yield spectrum $\chi^g_i$ by family and group, from data set XS.DELAY. (Kinetics option is set to 0 in RCDEP.)
DECCON	R*8	(NFAM) for kinetics option 1 or 2 (0) for kinetics option 0	RCOMP(PUTPNT) RCOMP(WIPOUT)	S-RDELAY	Decay constants by family for delayed neutrons from data set XS.DELAY. (Kinetics option is set to 0 in RCDEP.)
DICHI	R*8	(NFAM,GMAX) for kinetics option 2 (0) for kinetics option 0 or 1	RCOMP(PUTPNT) RCOMP(WIPOUT)	S-RDELAY	Delayed-neutron spectrum $\chi^g$ by family and group, from data set XS.DELAY. (Kinetics option is set to 0 in RCDEP.)
DMN	R*8	(NGKMX,NGKMX, KMAX-1)	SYNGEN(PUTPNT) SYNGEN(WIPOUT)	M-COFGEN	$\bar{B}_g^{(k+1)}$ for all groups g and all required synthesis regions k.
DNSCT	I*4	(GMAX)	RCOMP(PUTPNT)	S-RGROUP	Number of groups of down-scattering given for each group in a given composition block in data set XS.C.MIN.
DRRMN	R*8	(NGKMX,NGKMX, RRMAX)	SYNGEN(PUTPNT) SYNGEN(WIPOUT)	M-COFGEN	$D_{gk}(r)$ for all groups g and all refined regions r.
DX	R*8	(IMAX)	RGEOM(PUTPNT)	S-RMESH	Lengths of X-direction mesh intervals.
EXTHHT	R*8	(RMAX)	RGEOM(PUTPNT)	S-RMESH	Extrapolated region half-height read from data set GEOM. If BSQ(R) = 0.0, EXTHHT(R) = 0.0.
F	R*8	(RMAX,GMAX)	D2DOUT(PUTPNT)	S-IRGBAL	Fission-source integral F(R,G) by region and group for output edit.
FG	R*8	(GMAX)	D2DOUT(PUTPNT)	S-ITOBAL	Fission-source integral by groups. $FG(G) = \sum_{R=1}^{RMAX} F(R,G).$
FISXS	R*8	(FSCMAX,GMAX)	RCOMP(PUTPNT)	S-RGROUP	Fission cross section by composition and group, from data set XS.C.MIN. Data are stored only for fissionable compositions.
FIXSRC	R*8	(IMAX,JMAX) for source calculation (0) for k-effective calculation	D2DOUT(PUTPNT)	S-IFXVOL	External fixed source by interval and group. 1) From data set ES.D2D, weighted using fission-spectrum weighting over groups, if desired, and/or 2) From external delayed-neutron source, used when KINOPT = 1. (Module SYN2D cannot handle an external source.)

Name	Type	Dimension	Subroutines Issuing Significant POINTR Calls	Subroutines Where Values Are Set or Modified	Definition
FLUX	R*8	(IMAX,JMAX)	D2DOUT(PUTPNT)	M-IFXVOL M-IGPCAL	Temporary storage for two-dimensional fluxes for energy group G.
FLX	R*8	(NGKMX,IMAX)	SYNCAL(PUTPNT) SYNCAL(WIPOUT)	M-SINCAL	Temporary storage for the mixing function iterates for the Gth group. It is compared with $\varphi_G$ for convergence and then stored in $\varphi_G$ .
		(IMAX,JMAX)	SYNOUT(PUTPNT) SYNOUT(WIPOUT)	M-SINOUT	The reconstituted flux, which is calculated in SINOUT.
FR	R*8	(RMAX)	D2DOUT(PUTPNT)	S-ITOBAL	Fission-source integral by regions, $FR(R) = \sum_{G=1}^{GMAX} F(R,G).$
FSCMP	I*2	(CMAX)	RCOMP(PUTPNT)	S-GROUP	Indices corresponding to fissionable compositions. For any composition C, if FSCMP(C) = 0, C is not a fissionable composition; if FSCMP(C) is some nonzero integer, it is the position of that composition in arrays dimensioned with FSCMAX.
FV	R*8	(RMAX,GMAX)	D2DOUT(PUTPNT)	S-IFXVOL M-IFXNRM	Regional flux integrals by group for output edit, normalized for k-effective calculations, not normalized for source calculations.
GINT	R*8	(NGKMX,NGKMX, IMAX-1)	SYNGEN(PUTPNT) SYNGEN(WIPOUT)	S-CALC2 M-MTGEN2	Temporary storage for the matrices $G_i$ , $i = 1, 2, \dots, IMAX - 1$ for a given energy group. These matrices are generated in CALC2. Later, in MTGEN2, we store $U_i^{-1} * G_i$ for $i = 1, 2, \dots, IMAX - 1$ in GINT.
GRPT	R*8	(GMAX)	D2DOUT(PUTPNT)		Not used.
HADJG	R*8	(JMAX,NGKMX,2)	RSDEF(REDEF)	M-PROCES	Temporary storage for two sets of adjoint trial functions which correspond to the real trial functions held by array HG.
		(NGKMX,2)	RSDEF(REDEF) SYNGEN(WIPOUT)	M-BCONDS	Temporary storage for the calculated values on the reactor top and bottom of the adjoint trial functions. These values correspond to the real trial-function values held by array HG and are used in calculating the boundary matrices.
HADJP	R*8	(JMAX,NGKMX,2)	RSDEF(REDEF)	M-PROCESS	Temporary storage for two sets of adjoint trial function derivatives for the synthesis regions and energy groups, corresponding to the adjoint trial functions held by array HADJG.

Name	Type	Dimension	Subroutines Issuing Significant POINTR Calls	Subroutines Where Values Are Set or Modified	Definition
HADJP (Contd.)		(NGKMX,2)	RSDEF(REDEF) SYNGEN(WIPOUT)	M-BCONDS	Temporary storage for the derivatives of the adjoint trial functions calculated for the reactor top and bottom. These derivatives correspond to the function values held by array HADJP and are used in calculating the boundary matrices.
HG	R*8	(JMAX,NGKMX, GMAX*(KMAX+1)) or (JMAX,NGKMX, MAX(GMAX,KMAX))	RSDEF(PUTPNT)	M-LIB	Temporary storage used in generating the code-required library in subroutine LIB. The dimensions of the array depend upon whether the trial functions can be held in core for the library creation (first dimension) or not.
	R*8	(JMAX,NGKMX,2)	RSDEF(REDEF)	M-PROCES	Temporary storage for two sets of real trial functions for various synthesis regions and energy groups when calculating the partial integrals in subroutine process. Refer to PROCES for more details.
	R*8	(NGKMX,2)	RSDEF(REDEF)	M-BCONDS	Temporary storage for the calculated values on the reactor top and bottom of each real trial function for a particular synthesis region and energy group. These numbers are used in calculating the boundary matrices.
HINT	R*8	(JMAX,NGKMX)	SYNOUT(PUTPNT) SYNOUT(WIPOUT)	M-SINOUT	Temporary storage for the real trial functions when reconstituting the two-dimensional flux.
	R*8	(NGKMX,NGKMX, IMAX-1)	SYNGEN(PUTPNT) SYNCAL(WIPOUT)	M-CALC2 M-SINCAL	Contains $H_{I+1}$ , $I = 1, 2, \dots, \text{IMAX} - 1$ for all energy groups $G$ . $H_{I+1}$ is stored in HINT(1,1,1). $H_{I+1}$ is calculated in CALC2 and later written out in subroutine MTGEN2. The matrices $H_{I+1}$ and $G_I$ are later stored here in subroutine SINCAL.
HP	R*8	(JMAX,NGKMX,2)	RSDEF(REDEF)	M-PROCES	Temporary storage for two sets of real trial-function derivatives for the synthesis regions and energy groups corresponding to the function presently held in array HG. These derivatives are used in calculating the partial integrals computed in PROCES.
		(NGKMX,2)	RSDEF(REDEF) SYNGEN(WIPOUT)	M-BCONDS	Temporary storage for the derivatives of the real trial functions calculated for the reactor top and bottom. These derivatives correspond to the function values held by array HG and are used in calculating the boundary matrices.

Name	Type	Dimension	Subroutines Issuing Significant POINTR Calls	Subroutines Where Values Are Set or Modified	Definition
IDSNO	I*2	(MAX(GMAX,4))	RSDEF(PUTPNT) RSDEF(WIPOUT)	S-LIB	GMAX scratch data-set reference numbers, if the trial functions cannot be core-contained when generating the code-used trial function library. These reference numbers refer to scratch data sets, which will be used to generate the library data sets.
IFLAGS	I*4	(IMAX)	SYNGEN(PUTPNT) SYNGEN(WIPOUT)	S-CHECK	Synthesis-region indicator. IFLAGS(I) = 0 implies that the right endpoint of interval I, i.e., X(I+1), is not a synthesis boundary, while IFLAGS(I) = 1 implies that it is.
IPNT	I*2	(GMAX)	RSDEF(PUTPNT) RSDEF(WIPOUT)	M-LIB	Required if the trial functions are not core-held during the library generation. In this case, GMAX scratch data sets are used, one for each group. The number IPNT(G) indexes the arrays LWHRNO and LWHRSR. These arrays locate all the required trial functions for energy group G, which have been stored on the data set whose reference number is IDSNO(G).
JUNK	R*8	(NGKMX,NGKMX)	SYNGEN(PUTPNT)	M-MTGEN1 M-CALC1	Temporary storage for $D_g(r)$ , where r is first l and then RMAX, that is, the diffusion matrix for the first and last refined region.
L	R*8	(RMAX,GMAX)	D2DOUT(PUTPNT)	S-IRGBAL	Leakage by region and group for output edits.
L1	I*4	(NGKMX)	SYNGEN(PUTPNT) SYNGEN(WIPOUT)	M-MINV	Temporary storage.
LG	R*8	(GMAX)	D2DOUT(PUTPNT)	S-ITOBAL	Leakage by groups, $LG(G) = \sum_{R=1}^{RMAX} L(R,G).$
LIBFLX	I*2	(GMAX,KMAX,MAXNUM)	RSDEF(PUTPNT) RSDEF(WIPOUT)	S-SYNDEF	LIBFLX(G,K,N) tells which function on the input trial function libraries is the Nth trial function for the Kth synthesis region and the Gth energy group.
LWHRNO	I*2	(GMAX,KMAX*NGKMX)	RSDEF(PUTPNT)	S-LIB	Used when the trial functions required to generate the trial-function libraries cannot be core-contained. Each scratch data set (data-set reference number IDSNO(G)) contains all the trial functions for group G. The number N = LWHRNO(G,I) indicates which trial function is contained in the Ith record. Refer to LWHRSR.

Name	Type	Dimension	Subroutines Issuing Significant POINTR Calls	Subroutines Where Values Are Set or Modified	Definition
LWHRSR	I*2	(GMAX,KMAX*NGKMX)	RSDEF(PUTPNT) RSDEF(WIPOUT)	S-LIB	Refer to LWHRNO. The number $K = LWHRSR(G,1)$ indicates which synthesis region the trial function in the $l$ th record belongs in. Hence the arrays LWHRNO and LWHRSR indicate, for each scratch data set, the energy group, synthesis region and function number of every function stored on that scratch data set.
M1	I*4	(NGKMX)	SYNGEN(PUTPNT) SYNGEN(PUTPNT)	M-MINV	Temporary storage.
MSHCMP	I*4	(IMAX,JMAX)	RGEOM(PUTPNT) RGEOM(WIPOUT)	S-RMESH	Temporary storage for mesh-to-composition correspondence as read from data set GEOM (stored in I*2 array CMPMSH).
MSHREG	I*4	(IMAX,JMAX)	RGEOM(PUTPNT) RGEOM(WIPOUT)	S-RMESH	Temporary storage for mesh-to-region correspondence as read from data set GEOM (stored in I*2 array REGMSH).
NBP	I*4	(GMAX,KMAX)	RSDEF(REDEF) SYNCAL(REDEF) SYNOUT(WIPOUT)	M-PROCES M-DSRNCK M-SYNCAL	Used to check the data sets after a restart for consistency with the current problem.
NDUMRJ	I*4	(GMAX*KMAX)	SYNGEN(PUTPNT) SYNGEN(WIPOUT)	S-COFGEN	The array NUMRRJ from the old data set LIB.PART. This array is compared with the current NUMRRJ array.
NN	I*2	(GMAX,KMAX)	RSDEF(PUTPNT) SYNOUT(WIPOUT)	S-SYNDEF	The number of trial functions in energy group $G$ , synthesis region $K$ .
NNP	I*2	(0)	RSDEF(PUTPNT) SYNOUT(WIPOUT)		A dummy array allocated immediately before array NN. Hence both arrays are equivalenced, and any reference to $NNP(G,K)$ actually obtains $NN(G,K)$ . This array is a remnant from an earlier version of the code.
NTRIAL	I*2	(GMAX*KMAX*MAXNUM)	RSDEF(PUTPNT)	S-SYNDEF	Refer to array NZERO. The numbers stored in NTRIAL should be only 0 or 1, indicating that the functions do or do not satisfy the imposed boundary condition $\varphi = 0$ .
		(NTRL)	RSDEF(REDEF) SYNGEN(WIPOUT)		The size of NTRIAL is redefined after returning from SYNDEF. The number NTRL is the actual storage required.
NUFIS	R*8	(FSCMAX,GMAX)	RCOMP(PUTPNT)	S-RGROUP	$\nu_{\sigma f}$ cross section by composition and group, where $\nu$ is the number of neutrons released per fission for that group, from data set XS.C.MIN.

Name	Type	Dimension	Subroutines Issuing Significant POINTR Calls	Subroutines Where Values Are Set or Modified	Definition
NUMRRJ	I*2	(KMAX)	RSDEF(REDEF) SYNGEN(WIPOUT)	S-RRCALC	The number of Y-direction refined intervals per synthesis region.
NUSIGF	R*8	(NGKMX,NGKMX,GMAX, MANY)  (NGKMX,NGKMX,GMAX)	RSDEF(REDEF)  SYNCAL(REDEF) SYNCAL(WIPOUT)	M-COFGEN  M-SINCAL	Temporary storage for the fission matrices, which are calculated a synthesis region at a time for all groups in COFGEN and then read in for one refined region and group at a time in SINCAL.
NZERO	I*2	(GMAX,KMAX)	RSDEF(PUTPNT) SYNGEN(WIPOUT)	S-SYNDEF	Used to index the array NTRIAL. Normally, NZERO(G,K) is set to zero and NTRIAL is not referenced. If, however, the user specifies that for a given group G and synthesis region K the trial functions may or may not satisfy the imposed boundary condition $\varphi = 0$ , this information is then stored in array NTRIAL and starts at NTRIAL(NZERO(G,K)).
PHI	R*8	(NGKMX,IMAX,GMAX)	SYNCAL(PUTPNT) SYNOU(T(WIPOUT)	M-SINCAL	The calculated mixing functions.
PHI2	R*8	(NGKMX,IMAX,GMAX)	SYNCAL(PUTPNT) SYNOU(T(WIPOUT)	M-SINCAL	The calculated mixing functions for each group, collected until the iteration has been completed. The mixing functions are then passed to array PHI.
PHYREG	I*2	(IMAX)	RSDEF(PUTPNT) RSDEF(WIPOUT)	S-RRCALC	PHYREG(I) tells in which physical region the Ith interval lies.
POWERPI	R*8	(JMAX,IMAX)	D2DOUT(PUTPNT)	S-FLUXPR	Total power density by mesh interval.
PR	R*8	(RMAX)	D2DOUT(PUTPNT)	S-IFXNRM	Power by region.
RAF	R*8	(RMAX,GMAX)	D2DOUT(PUTPNT)	S-IFXNRM	Region-averaged flux integrals by group, for output edit and for data set FR.PN.
RAFS	R*8	(RMAX,GMAX)	D2DOUT(PUTPNT)	S-ITOBAL	Region-averaged fission-source integral by group, for output edit.
REGHHT	R*8	(RMAX)	RGEOM(PUTPNT)	S-RMESH	Actual region half-height read from data set GEOM. If BSQ(R) = 0.0, REGHHT(R) = 0.5.
REGMSH	I*2	(JMAX,IMAX)	RGEOM(PUTPNT)	S-RMESH	Mesh-to-region correspondence defined in data set GEOM. For any mesh interval (I,J), REGMSH(J,I) is the number of the reactor region to which (I,J) belongs.
REGNAM	R*8	(RMAX)	RGEOM(PUTPNT)	S-RMESH	Region names defined in data set GEOM. REGNAM(R) is the name of the region whose number is R.

Name	Type	Dimension	Subroutines Issuing Significant POINTR Calls	Subroutines Where Values Are Set or Modified	Definition
REM	R*8	(CMAX,GMAX)	RCOMP(PUTPNT)	S-RGROUP	Removal cross section $\sigma_R$ by composition and group, from data set XS.C.MIN.
RESULT	R*8	MAX[(NGKMX,NGKMX, NUMMAX),(NGKMX,4)]	RSDEF(REDEF) SYNGEN(WIPOUT)	M-PROCES M-VALUES	Temporary storage for the partial integrals computed in PROCES. RESULT is also used to temporarily hold the extrapolated values of the trial functions computed in VALUES at the reactor top and bottom. NUMMAX is the maximum number of Y-direction refined intervals per synthesis region.
RG	R*8	(GMAX)	D2DOUT(PUTPNT)	S-ITOBAL	Removal by groups, $RG(G) = \sum_{R=1}^{RMAX} RMVL(R,G).$
RMVL	R*8	(RMAX,GMAX)	D2DOUT(PUTPNT)	S-IRGBAL	Removal contribution to balance by region and group for output edit, including $\alpha/v$ and $DB^2$ terms.
RNUM	R*8	(JMAX)	D2DOUT(PUTPNT)	S-FLUXPR	Y-direction mesh interval centers for output prints.
ROOM	R*8	(NGKMX,NGKMX)	SYNGEN(PUTPNT) SYNGEN(WIPOUT)	M-MTGEN1 M-CALC1 M-CALC2	Temporary matrix storage.
RR	I*2	(IMAX)	RSDEF(PUTPNT) SYNOUT(WIPOUT)	S-RRCALC	RR(I) tells in which refined region the Ith interval lies. (Used in subroutines as array REFREG.)
		(RMAX)	D2DOUT(PUTPNT)	S-ITOBAL	Removal contribution to balance by region for output edit, including $\alpha/v$ and $DB^2$ terms.
RRFJ	I*2	(IMAX*JMAX)	RSDEF(PUTPNT)	S-RRCALC	The set of first intervals of each Y-direction refined interval for all synthesis regions.
		(LLEN)	RSDEF(REDEF) SYNGEN(WIPOUT)		The size of RRFJ is redefined after returning from RRCALC to use only the required storage (LLEN).
RRFRST	I*2	(IMAX)	RSDEF(PUTPNT)	S-RRCALC	RRFRST(R) is the first interval of refined region R.
		(RRMAX)	RSDEF(REDEF) SYNGEN(WIPOUT)		The size of RRFRST is redefined after the call to RRCALC to use only the required storage (RRMAX).
RRJLOC	I*2	(KMAX+1)	RSDEF(REDEF) SYNGEN(WIPOUT)	S-RRCALC	Index for the array RRFJ. RRJLOC(K) indicates where the first interval of the first Y-direction refined interval of synthesis region K is stored.
RV	R*8	(RMAX)	D2DOUT(PUTPNT)	S-IFXVOL M-IFXNRM	Physical region volume. When the third dimension is infinite, RV is the region volume per unit height.

Name	Type	Dimension	Subroutines Issuing Significant POINTR Calls	Subroutines Where Values Are Set or Modified	Definition
S	R*8	(RMAX,GMAX)	D2DOUT(PUTPNT)	S-IRGBAL	Scattering contribution to balance by region and group for output edits.
SCTCOF	R*8	(NGKMX,NGKMX, GMAX-1,MANY)	RSDEF(REDEF) SYNGEN(WIPOUT)	M-COFGEN	Temporary storage for the scattering matrices, which are calculated a synthesis region at a time for all groups in COFGEN and then written out.
SCTDUM	R*8	(SCTDIM,GMAX)	RCOMP(PUTPNT) RCOMP(WIPOUT)	S-RGROUP	Array used to read in full scattering cross sections before packing into SCTXS.
SCTLIM	I*2	(2,CMAX)	RCOMP(PUTPNT)	S-RGROUP	Scattering-array bandwidths for each composition C. SCTLIM(1,C) is the maximum width of the upscattering band for composition C, and SCTLIM(2,C) is the maximum width of the downscattering band SCTLIM(1,C) + SCTLIM(2,C) + 1 is the maximum bandwidth.
SCTLOC	I*2	(CMAX,GMAX)	RCOMP(PUTPNT)	S-DIMSCT M-PCKSCT	Location of specified scattering band in SCTXS. For a given composition C and group G, SCTLOC(C,G) gives the location of the band of elements $\sigma_C^{g \rightarrow B}$ .
SCTXS	R*8	(SCTDIM,GMAX)	RCOMP(PUTPNT)	S-RGROUP	Scattering cross section $\sigma_C^{g \rightarrow B}$ by composition, bandwidth, and group, packed from SCTDUM.
SETCHI	R*8	(ISCHI,GMAX)	RCOMP(PUTPNT) RCOMP(WIPOUT)	S-GETCHI	Set-wide fission spectrum $\chi_B^{g \rightarrow B}$ , if one is defined in data set XS.C.MIN. Values are transferred into the CHI array for compositions using the set-wide $\chi_B^{g \rightarrow B}$ .
SG	R*8	(GMAX)	D2DOUT(PUTPNT)	S-ITOBAL	Scattering by groups, $SG(G) = \sum_{R=1}^{RMAX} S(R,G).$
SIGMAR	R*8	(NGKMX,NGKMX, RRMAX)	SYNGEN(PUTPNT) SYNGEN(WIPOUT)	M-COFGEN M-BCONDS	The sum of the two matrices $(\Sigma_R)_{gk}(r)$ and $L_{gk}(r)$ for energy group G and all re-fined regions, calculated and stored in COFGEN. $C_{gk}(r)$ is added in subroutine BCONDS.
SOG	R*8	(GMAX)	D2DOUT(PUTPNT)	S-ITOBAL	External source by groups for output edit, $SOG(G) = \sum_{R=1}^{RMAX} SV(R,G).$
SOR	R*8	(RMAX)	D2DOUT(PUTPNT)	S-ITOBAL	External source by regions for output edit, $SOR(R) = \sum_{G=1}^{GMAX} SV(R,G).$

Name	Type	Dimension	Subroutines Issuing Significant POINTR Calls	Subroutines Where Values Are Set or Modified	Definition
SPACE	R*8	(NGKMX,NGKMX)	SYNGEN(PUTPNT) SYNGEN(WIPOUT)	M-MTGEN1 M-CALC1 M-CALC2	Temporary matrix storage.
SR	R*8	(RMAX)	D2DOUT(PUTPNT)	S-ITOBAL	Scattering contribution to balance by region and group for output edit.
SV	R*8	(RMAX,GMAX)	D2DOUT(PUTPNT)	S-IFXVOL	External source by region and group for output edit, including external source due to inhomogeneous interface conditions and to delayed data, if present.
SYNMSH	I*2	(IMAX)	RSDEF(PUTPNT) SYNOUT(WIPOUT)	S-SYNDEF	SYNMSH(I) tells in which synthesis region the Ith interval lies.
T	R*8	(RMAX,GMAX)	D2DOUT(PUTPNT)	S-IRGBAL	Output balance by regions and groups, $T(R,G) = -L(R,G) - RMVL(R,G) + S(R,G) + F(R,G)/KEFF$ for a k-effective calculation.
TG	R*8	(GMAX)	D2DOUT(PUTPNT)	S-ITOBAL	Output balance by groups, $TG(G) = \sum_{R=1}^{RMAX} T(R,G).$
TR	R*8	(RMAX)	D2DOUT(PUTPNT)	S-ITOBAL	Output balance by regions, $TR(R) = \sum_{G=1}^{GMAX} T(R,G).$
UINT	R*8	(NGKMX,NGKMX,IMAX)	SYNGEN(PUTPNT) SYNCAL(WIPOUT)	M-CALC2 M-MTGEN2 M-SINCAL	$E_I$ for $I = 1, 2, \dots, IMAX$ , generated in CALC2; $U_I^{-1}$ , $I = 1, 2, \dots, IMAX$ , calculated in MTGEN2 and then written out; $U_I^{-1}$ , $I = 1, 2, \dots, IMAX$ for group G during iterations, calculated in SINCAL.
UPSCT	I*4	(GMAX)	RCOMP(PUTPNT) RCOMP(WIPOUT)	S-RGROUP	Number of groups of up-scattering given for each group in a given composition block in XS.C.MIN.
VEL	R*8	(GMAX)	RCOMP(PUTPNT)	RVEL	Neutron speeds, set to 1, for all groups.
WINT	R*8	(IMAX)	SYNCAL(PUTPNT) SYNCAL(WIPOUT)	S-SINCAL	$WINT(I) = DX(I)$ in XY or ZR geometry; $WINT(I) = DX(I) \cdot [X(I) + DX(I)/2]$ in RZ geometry.
WMN	R*8	(NGKMX,NGKMX)	SYNGEN(PUTPNT) SYNGEN(WIPOUT)	M-COFGEN	$W_{g,K}$ for energy group g and the last synthesis region K.
WORK	R*8	(NGKMX,NGKMX)	SYNGEN(PUTPNT)	M-MTGEN1 M-CALC1 M-CALC2	Temporary matrix storage.
X	R*8	(IMAX+1)	SYNGEN(WIPOUT) RGEOM(PUTPNT)	S-RMESH	X-direction mesh-line locations.
XSYNPT	R*8	(KMAX+1)	RSDEF(PUTPNT) RSDEF(WIPOUT)	S-SYNDEF	Synthesis boundaries excluding the origin. (Only the first KMAX words are used.)

Name	Type	Dimension	Subroutines Issuing Significant POINTR Calls	Subroutines Where Values Are Set or Modified	Definition
Y	R*8	(JMAX+1)	RGEOM(PUTPNT)	S-RMESH	Y-direction mesh-line locations.
ZMN	R*8	(NGKMX,NGKMX)	SYNGEN(PUTPNT) SYNGEN(WIPOUT)	M-COFGEN	W <sub>g</sub> , for energy group g and the first synthesis region.

#### D. Subroutine Descriptions

This section describes all subroutines that are part of the SYN2D module. The descriptions appear in alphabetical order by subroutine name.

Each subroutine description begins with a listing of the calling sequence of the subroutine and of its entry points, if any. Subsection a is a list of the arguments of the subroutine and its entry points. For arguments defined in any common block, the name of the common block is noted. Other arguments are listed in their order of appearance, with the type of each argument, its dimensions in the subroutine if it is an array, and its definition or use. The four types of variables used are I\*2, denoting an integer halfword (16 bits); I\*4, denoting an integer fullword (32 bits); R\*4, denoting a floating-point fullword (32 bits); and R\*8, denoting a floating-point doubleword (64 bits).

Arrays or variables from a common block which are used in a subroutine are defined in the documentation for their respective common blocks.

Subsection b contains a listing of important variables which are local to the subroutine, in a format like that of Subsection a.

Subsection c describes the functions performed by the subroutine in terms of the overall purpose of the module, where applicable. Refer to Section II.B. when a more detailed description or explanation is required.

Subsection d lists all subroutines called by this subroutine. Subroutine entry points called by this subroutine are not listed if the main subroutine entry is also called. Thus, if this subroutine invokes subroutine A and also entry point AA subroutine A, only A will appear in the list of Subsection d. If, however, this subroutine invokes only entry point AA, then AA will appear in the list. POINTR, BULK, and FREE are the only entry points of the dynamic storage subroutine listed. POINTR entry points PUTPNT, BETPNT, IGET, WIPOUT, etc., are not listed in Subsection d.

Subsection e lists all subroutines that call this subroutine.

1. Subroutine BCONDS(HG,HP,HADJG,HADJP,RRFRST,SIGMAR,CMPMSH,DC,NZERO,NN,NTRIAL,CMAX,JMAX,GMAX,IMAX,RRMAX,NGKMX,LPART,\*)

Entry points

Entry: BNDCND(G,R1,LASTR1,K,\*)

a. Arguments. The first 11 arguments of the main calling sequence appear in the common block BLKSTR. The remaining seven arguments of the main calling sequence are members of the common block SINGLE. The optional return and the entry-point arguments are defined below.

<u>Name</u>	<u>Type</u>	<u>Definition</u>
*	-	Error return to calling subroutine.
G	I*4	Present energy group.
R1	I*4	First refined region of synthesis region K.
LASTR1	I*4	Last refined region of synthesis region K.
K	I*4	Present synthesis region.

b. Important Local Variables

<u>Name</u>	<u>Type</u>	<u>Definition</u>
MPLACE	I*4	Has significance only if the boundary condition is $\varphi = 0$ , when it represents $m$ in Subsection c(3) below.
NPLACE	I*4	Has significance only if the boundary condition is $\varphi = 0$ , when it represents $n$ in Subsection c(3) below.
NUMBER	I*4	Location in the array NTRIAL where the boundary condition information on the trial functions is stored.

c. Functions and Tasks Performed by This Subroutine. This subroutine calculates the boundary-condition matrices for the top and bottom of the reactor in synthesis region K and energy group G for each refined region. Each boundary matrix, after it is computed, is added to the contents of the array SIGMAR, which already contains the sum of the matrices  $L$  and  $\Sigma_r$  for that refined region. The boundary condition applied at the reactor top (or bottom) must be invariant in each refined region for group G, but may be group-dependent. The changing of the boundary condition at the top face is completely independent of the boundary-condition changes at the bottom face.

The three boundary conditions allowed at each face for each refined region and the matrices generated in each case are as follows:

(1) If  $\varphi' = 0$ , no matrix is generated.

(2) If  $\varphi' + \frac{\beta}{D}\varphi = 0$ , the matrix C is generated, where  $C^{mn}(a) = \beta H_g^{*m}(a)H_g^n(a)$ , and a can be 0 or h for the reactor bottom or top, respectively.  $\beta$  is the user-supplied constant and D is the diffusion coefficient at that particular face.

(3) If  $\varphi = 0$  the matrix C is generated, where

$$C^{mn}(a) = \omega D \left[ H_g^{*m}(a) \left. \frac{dH_g^n}{dy} \right|_{y=a} + H_g^n(a) \left. \frac{dH_g^{*m}}{dy} \right|_{y=a} \right],$$

$\omega = 1$  or  $-1$  depending upon if  $a = 0$  or  $h$ , respectively. D and a are defined as above.

If the user has indicated that certain of the trial functions in a particular synthesis region satisfy the boundary condition  $\varphi = 0$ , then the entire matrix as defined above need not be calculated. Now, if a trial function  $\bar{m}$  is zero at the boundary, its adjoint is also zero. The elements  $C^{mn}$  for  $m$  and  $n \neq \bar{m}$  are calculated as defined above. However, if  $m = \bar{m}$ , only the second part of the computation need be performed. Conversely, if  $n = \bar{m}$ , only the first half of the computation is performed. Finally, if  $\varphi = 0$  at both the reactor top and bottom, it is assumed that if a trial function satisfies the top condition is also satisfies the bottom condition. This is the only case in which this assumption is made. Note that the values stored in HG, HADJG, HP, and HADJP are the actual computed function values and derivatives at the reactor faces.

d. Subroutines Called by This Subroutine. HORBND (entry in GETBND), ERRMSG.

e. Subroutine Calling This Subroutine. COFGEN.

2. Subroutine CALC1(NGKMX,NGKPMX,SYNMSH,REFREG,NN,NNP,DRRMN,AMN,BMN,CMN,DMN,IFLAGS,AREA,ROOM,SPACE,WORK,DX,L1,M1,IM1,KBAR,GMAX,RRMAX,KMAX,IMAX,JUNK)

Entry points

Entry: CLC1(\*,G,I,ZNORM)

a. Arguments. The constants NGKMX, NGKPMX, GMAX, RRMAX, KMAX, and IMAX appear in common block SINGLE. The constants IM1 and KBAR are IMAX - 1 and KMAX - 1, respectively. The remaining arguments in the calling sequence are located in common block BLKSTR with REFREG listed as RR. The entry-point arguments are listed below.

<u>Name</u>	<u>Type</u>	<u>Definition</u>
G	I*4	Present energy group.
I	I*4	Present interval for which we want $\Omega_I$ .
ZNORM	R*8	Condition number of $D_{gk}(r)$ .

b. Important Local Variables

<u>Name</u>	<u>Type</u>	<u>Definition</u>
K	I*4	Used in dimensioning matrices.
IRR	I*4	Refined region in which interval I lies.
NNN	I*4	Rank of $\Omega^{-1}$
DET	R*8	Determinant of $D_{gk}(r)$ .
XNORM	R*8	Column norm of $D_{gk}(r)$ .
YNORM	R*8	Column norm of $[D_{gk}(r)]^{-1}$
NGKP	I*4	One dimension of some of the coefficient matrices used.

c. Functions and Tasks Performed by This Subroutine. This routine calculates the condition number ZNORM of  $D_{gk}(r)$ , the diffusion matrix, and  $\Omega_I^{-1}$ , which is stored in array AREA. The number ZNORM is calculated as XNORM\*YNORM and is just a crude attempt to calculate a norm for the matrix  $D_{gk}(r)$ . The larger this norm, the less linearly independent are the associated trial functions. The matrix  $\Omega_I$  is defined by

$$\Omega_I = \frac{1}{2}[\delta_i A D_{gk}^{-1}(r_i) B + \delta_{i+1} C D_{gk}^{-1}(r_{i+1}) D],$$

where  $\delta_i$  is the length of mesh interval  $i$ , and  $r_i$  is the refined region in which the  $i$ th interval lies.

The matrices A, B, C, and D will be the identity matrix if intervals  $i$  and  $i + 1$  lie in the same synthesis region; otherwise  $A = A_k$ ,  $B = B_k$ ,  $C = \bar{A}_k$ , and  $D = \bar{B}_k$ . These matrices are stored in arrays AMN, BMN, CMN, and DMN, respectively. Refer to Section II.B. for more information on how  $\Omega_I$  is calculated. Notice that if the intervals lie in different synthesis regions,  $D_{gk}^{-1}(r_{i+1})$  is calculated and stored in the same array space as  $D_{gk}(r_{i+1})$  was originally stored.

d. Subroutines Called by This Subroutine. NORM, MINV, NUMMLT, MADD, GMPRD, ERRMSG.

e. Subroutine Calling This Subroutine. MTGEN1.

3. Subroutine CALC2(NGKMX,NGKPMX,SYNMSH,REFREG,NN,NNP,AMN,BMN,CMN,DMN,IFLAGS,DX,L1,M1,IM1,KBAR,GMAX,GINT,HINT,UINT,RRMAX,KMAX,IPOINT,JPOINT,KPOINT,LPOINT,X,IMAX,SIGMAR,NALPHA)

Entry points

Entry: CLC2(\*,G,I,WINT)

a. Arguments. Arguments 3-14, 18-20, 27, and 29 of the calling sequence are listed in the common block BLKSTR with array REFRREG listed as RR. Arguments 1, 2, 17, 21, 22, 28, and 30 are listed in common block SINGLE. The remaining calling sequence arguments and entry point arguments are listed below.

<u>Name</u>	<u>Type</u>	<u>Definition</u>
IM1	I*4	IMAX-1.
KBAR	I*4	KMAX-1.
IPOINT	I*4	Pointer for the array AREA in the common block BLKSTR.
JPOINT	I*4	Pointer for the array ROOM in the common block BLKSTR.
KPOINT	I*4	Pointer for the array SPACE in the common block BLKSTR.
LPOINT	I*4	Pointer for the array WORK in the common block BLKSTR.
*	-	Error return to calling subroutine.
G	I*4	Present energy group number.
I	I*4	Present x-direction interval number.
WINT	R*8	If NALPHA = 0, DX(I), i.e., $\delta_i$ . If NALPHA = 1, DX(I)*(X(I) + 0.5DX(I)), i.e., $\delta_i r_i$ .

b. Important Local Variables

Name	Type	Definition
K	I*4	Synthesis region in which interval I lies.
NNN	I*4	Dimension of $\Omega^{-1}$ from CALC1.
RDX	R*8	$R_I^\alpha$ , i.e., $X(I+1)**NALPHA$ .
KM1	I*4	Synthesis region in which interval (I - 1) lies.
IRR	I*4	Refined region in which interval I lies.
KP1	I*4	Synthesis region in which interval (I + 1) lies.

c. Functions and Tasks Performed by This Subroutine. This routine generates the matrices  $G_I$ ,  $H_{I+1}$ , and  $E_I$  for a given I. These matrices are stored in the arrays GINT, HINT and UINT for later use. The formulas used for generating these three matrices for each I are

$$G_I = x_{I+1}^\alpha B \Omega_I^{-1} C, \quad 1 \leq I < \text{IMAX}; \quad (82)$$

$$H_{I+1} = x_{I+1}^\alpha D \Omega_I^{-1} A, \quad 1 \leq I < \text{IMAX}; \quad (83)$$

$$E_I = x_I^\alpha B \Omega^{-1} A + x_{I-1}^\alpha \bar{D} \Omega_{I-1}^{-1} \bar{C} + \omega [L(r_I) + \Sigma_R(r_I) + \tilde{C}(r_I)], \quad (84)$$

$$2 < I < \text{IMAX};$$

$$E_I = x_I^\alpha B \Omega^{-1} A + C_2(1 - \alpha) D_{g1}(r_1) \left[ C_1 D_{g1}(r_1) + C_2 W_{g1} \frac{\delta_1}{2} \right]^{-1} W_{g1} + \omega [L(r_1) + \Sigma_R(r_1) + \tilde{C}(r_1)]; \quad (85)$$

$$E_q = x_q^\alpha \hat{C}_2 D_{gk}(r_q) \left[ \hat{C}_1 D_{gk}(r_q) + \hat{C}_2 W_{gk} \frac{\delta_q}{2} \right]^{-1} W_{gk} + x_{q-1}^\alpha \bar{D} \Omega_{q-1}^{-1} \bar{C} + \omega [L(r_q) + \Sigma_R(r_q) + \tilde{C}(r_q)], \quad (86)$$

where  $a = \text{NALPHA}$ ,  $\omega = \text{WINT}$ ,  $\delta_i = \text{DX}(I)$ ,  $q = \text{IMAX}$ , and  $r_i$  is the refined region in which interval  $i$  lies. The numbers  $C_i$  and  $\hat{C}_i$  arise from the boundary conditions that are applied (i.e.,  $C_1 \varphi' + C_2 \varphi = 0$ ) at the reactor ends. The matrices  $\{D_{gk}\}$ ,  $\{L\}$ ,  $\{\Sigma_R\}$ , and  $\{\tilde{C}\}$  are the diffusion matrices, the double gradient matrices, the removal matrices, and the boundary-condition matrices from the nonsynthesis direction, respectively, while the matrices  $W_{gk}$  are the synthesis-direction boundary-condition matrices. The matrices  $A$ ,  $B$ ,  $C$ ,  $D$ ,  $\bar{C}$ , and  $\bar{D}$  vary, depending upon where the synthesis boundaries lie. There are four cases to consider.

I. If both  $x_I$  and  $x_{I+1}$  are synthesis boundaries, then  $A = A_k$ ,  $B = B_k$ ,  $C = \bar{A}_{k+1}$ ,  $D = \bar{B}_{k+1}$ ,  $\bar{C} = \bar{A}_k$ , and  $\bar{D} = \bar{B}_k$ .

II. If only  $x_I$  is a synthesis boundary, then  $A = B = C = D = I$ , the identity matrix, and  $\bar{C}$  and  $\bar{D}$  are given in Case I above.

III. If only  $x_{I+1}$  is a synthesis boundary, then  $\bar{C} = \bar{D} = I$  and  $A$ ,  $B$ ,  $C$ , and  $D$  are given in Case I above.

IV. If neither  $x_I$  nor  $x_{I+1}$  is a synthesis boundary, then  $A = B = C = D = \bar{C} = \bar{D} = I$ , the identity matrix.

The actual calculation of the matrices is straightforward; however, the following points should be noted.

(1) Array BLK(IPOINT) contains  $\Omega_I^{-1}$  until no longer needed.

(2) The matrix  $x_{I+1}^\alpha D \Omega_I^{-1}$  is calculated for the matrix  $H_{I+1}$  and temporarily stored in array BLK(LPOINT); however, before leaving the routine, it is stored in array BLK(KPOINT) for calculating the matrix  $E_{I+1}$  on the next pass.

(3)  $x_{I+1}^\alpha B \Omega_I^{-1}$  is calculated for  $G_I$  and stored in BLK(IPOINT) since  $\Omega_I^{-1}$  is no longer needed. Later this matrix is used in computing  $E_I$ .

(4) The first term of Eq. 85 is calculated in subroutine MTGEN1 and added to  $E_I$  just before leaving the subroutine MTGEN1.

(5) The matrix specified by Eq. 86 is calculated in subroutine MTGEN1 using 2 above.

For a more complete description of the generation of these matrices, see Section II.B.

d. Subroutines Called by This Subroutine. NUMMLT, MOVE, MADD, GMPRD.

e. Subroutine Calling This Subroutine. MTGEN1.

4. Subroutine CHECK(IMAX,IFLAGS,SYNMSH)

a. Arguments. The number IMAX is listed in common block SINGLE. The arrays IFLAG and SYNMSH are defined in common block BLKSTR.

b. Important Local Variables. None.

c. Functions and Tasks Performed by This Subroutine. This subroutine compares the x-direction intervals  $i$  and  $i - 1$  to see if both lie in the same synthesis region. If both intervals do not lie in the same synthesis region, then IFLAGS(I-1) is set to one; otherwise, it is set to zero.

d. Subroutines Called by This Subroutine. None.

e. Subroutine Calling This Subroutine. SYNGEN.

5. Subroutine CLOSE

a. Arguments. None.

b. Important Local Variables

<u>Name</u>	<u>Type</u>	<u>Definition</u>
IDSN	I*4	Flag used by subroutines OPENDS and CLOSE.
IDSRN(10)	I*4	The data set reference numbers of all open data sets.

c. Functions and Tasks Performed by This Subroutine. The purpose of this subroutine is to close all data sets that are open when this subroutine is called and to list each data set that has been rewind. The subroutine OPENDS returns the number IDSN and a partially filled array IDSRN. The absolute value of IDSN is the number of data sets that are open. IDSN is set to 10 before calling OPENDS to give the length of the array IDSRN. The first IDSN numbers of array IDSRN contain the data-set reference numbers to be rewind. Finally, after these data sets are rewind, another call to OPENDS will be made if IDSN was returned as a negative number by OPENDS, indicating that more than 10 data sets were open.

d. Subroutines Called by This Subroutine. OPENDS (ARC System subroutine), SNIFF (ARC System subroutine).

e. Subroutines Calling This Subroutine. SYN2D, RSDEF, SYNGEN.

6. Subroutine COFGEN(RESULT, HG, HP, HADJG, HADJP, NN, SIGMAR, AMN, BMN, CMN, DMN, DRRMN, RRFRST, NUSIGF, SCTCOF, NBP, NDUMRJ, NUMRRJ, CMPMSH, RR FJ, SYNMSH, SCTXS, REGMSH, REM, DC, BSQ, WMN, ZMN, FSCMP, CHI, LL, MM, SPACE, AREA, SCTLOC, SCTLIM, NUFIS, RRJLOC, TIMEKY, CMAX, JMAX, NGKMX, GMAX, KMAX, IOPT, RRMAT, FSCMAX, CHDIM, IMAX, NALPHA, NBETA, GM1, SCTDIM, MAXDN, MAXUP, IFISS, ISCAT, LPART, \*)

Entry points

Entry: COEFF(G,\*)

a. Arguments. The first 38 arrays are listed in the common block BLKSTR. The arrays LL and MM are listed as L1 and M1, respectively. The remaining arguments, except GM1, are listed in common block SINGLE, with IFISS and ISCAT listed as ILIB and MLIB, respectively. Other arguments are listed below.

<u>Name</u>	<u>Type</u>	<u>Definition</u>
GM1	I*4	GMAX-1.
*	-	Error return to calling subroutine.
G	I*4	Present energy group.

b. Important Local Variables

<u>Name</u>	<u>Type</u>	<u>Definition</u>
R1	I*4	The first refined region in synthesis region K.
LASTR1	I*4	The last refined region in synthesis region K.
IPNT	I*4	Index used to store the fission and scattering matrices.
IP	I*4	Index used to properly pack the scattering matrices.
I	I*4	Either the first or last interval in a refined region, used to isolate proper cross sections.
J	I*4	First interval in each Y-direction refined interval.
ICMP	I*4	Composition number used for indexing fission-related cross-section arrays, which indicates, if greater than zero, the fission cross-section index. (If it is zero, the composition is not fissionable.)
NFSCMP	I*4	

<u>Name</u>	<u>Type</u>	<u>Definition</u>
GPL0	I*4	The lowest group into which downscattering occurs.
GPHI	I*4	The highest group into which upscattering occurs.
NEXT1	I*4	First interval of next refined region.
NEXTR1	I*4	First refined region of next synthesis region
NUMBER	I*4	The number of Y-direction refined intervals in each synthesis region.
IPOINT	I*4	Points to the location (less one) in array RRFJ where the first Y-direction Interval number of the first Y-direction refined interval for synthesis region K is stored. The number in location (IPOINT + 1) is always 1, and the numbers stored in successive locations following it contain the first Y-direction interval numbers for the successive refined intervals in that synthesis region.

c. Functions and Tasks Performed by This Subroutine. This subroutine generates all of the matrices required by this problem except the boundary matrices calculated in the subroutine BCONDS. These matrices are defined in Section II.B. by Eqs. 28-30 and 32-38 for the asymmetric interface condition and by Eqs. 28-30, 32-34, and 55-58 for the symmetric interface condition. Each time this routine is called all of the matrices for group G are generated. The matrices are generated a synthesis region at a time, using the partial integrals generated in subroutine PROCES and stored on the data set whose reference number is LPART. The fission and scattering matrices are core-held until they have been generated for all the refined regions in a synthesis region. Then these matrices are written out on the data sets whose reference numbers are IFISS and ISCAT, respectively. The other matrices are kept in core by refined or synthesis region, depending upon their type. The removal matrices ( $\Sigma_R$ ), boundary condition matrices (C) generated by BCONDS, and the double-gradient inner-product matrices (L) are added together for each refined region and stored in array SIGMAR. Subroutine PROCES generates five types of partial integrals for each Y-direction refined interval  $r \in R(k)$  defined below.

$$(1) I_{g'g}^{mn}(k,r) = \int_{\underline{y}}^{\bar{y}} H_{gk}^{*m} H_{g'k}^n dy, \quad r \in R(k);$$

$$(2) J_g^{mn}(k,r) = \int_{\underline{y}}^{\bar{y}} H_{gk}^{*m} H_{gk}^n dy, \quad r \in R(k);$$

$$(3) \hat{P}_g^{mn}(k+1,r) = \int_{\underline{y}}^{\bar{y}} H_{g,k+1}^{*m} H_{gk}^n dy, \quad r \in R(k);$$

$$(4) \hat{P}_g^{mn}(k+1,r) = \int_{\underline{y}}^{\bar{y}} H_{gk}^{*m} H_{g,k+1}^n dy, \quad r \in R(k);$$

$$(5) Q_g^{mn}(k+1,r) = \int_{\underline{y}}^{\bar{y}} H_{gk}^{*m} H_{g,k+1}^n dy, \quad r \in R(k+1),$$

where  $R(k)$  is the set of  $Y$ -direction refined intervals for synthesis region  $k$ . For a more detailed description of how these partial integrals are combined to generate the final matrices, refer to Section II.B.

Notice that when the routine is initialized, it checks the data sets LIB.ADJT, LIB.MIX, LIB.PART, and LIB.REAL for consistency with the problem and each other. Also, if the left or right boundary condition is  $\varphi' = 0$ , the corresponding matrix  $W_{gk}$  need not be calculated.

d. Subroutines Called by This Subroutine. BCONDS, VERBND (entry in GETBND), ERRMSG, MINV, GMPRD.

e. Subroutine Calling This Subroutine. SYNGEN.

7. Subroutine DIMSCT(SCTLIM,SCTLOC,SCTDIM,CMAX,\*)

a. Arguments. The first two arguments are defined in common block BLKSTR. The remaining two are defined in common block SINGLE. The asterisk indicates an error return to a specified location in the calling subroutine.

b. Important Local Variables. None.

c. Functions and Tasks Performed by This Subroutine. This subroutine uses the scattering bandwidths for each composition (set up in array SCTLIM in subroutine RGROUP) to set up in the first CMAX locations of the array SCTLOC the position in an array SCTXS of the final element of the scattering array  $\sigma_{c-1}^{g' \rightarrow g}$  corresponding to the composition preceding a given composition  $c$  (CMPNO).

The position corresponding to the last scattering element for the composition preceding  $CMPNO = 1$  is 0; for each succeeding CMPNO, the position is  $SCTLOC(CMPNO)=SCTLOC(CMPNO-1)+SCTLIM(1,CMPNO-1)+SCTLIM(2,CMPNO-1)+1$ , where  $SCTLIM(1,CMPNO-1)+SCTLIM(2,CMPNO-1)+1$  is the bandwidth corresponding to composition  $CMPNO-1$ .

This subroutine also computes the first dimension SCTDIM of the scattering array SCTXS; this dimension is computed as the position of the final element of composition CMAX-1, SCTLOC(CMAX), plus the bandwidth of the last composition, SCTLIM(1,CMAX)+SCTLIM(2,CMAX)+1. In other words, the first dimension of SCTXS is the sum over all compositions of the bandwidths associated with each composition; the second dimension is GMAX. Hence, in the scattering array, each composition and group is allocated only the maximum bandwidth associated with the composition.

- d. Subroutines Called by This Subroutine. None.
  - e. Subroutine Calling This Subroutine. RCOMP.
8. Subroutine DSRNCK(TIMEKY,GMAX,JMAX,KMAX,NGKMX,LMIX,LADJT,LREAL,NN,NBP,\*)
- a. Arguments. The first five arguments are defined in common block SINGLE. The next three arguments are also defined in common block SINGLE, under the names N3, N2, and N1, respectively. The remaining two arguments are defined in common block BLKSTR. The asterisk indicates an error return to a specified location in the calling subroutine.
  - b. Important Local Variables. None.
  - c. Functions and Tasks Performed by This Subroutine. This subroutine checks the three data sets LIB.REAL, LIB.ADJT, and LIB.MIX for consistency. The first word on each data set is a coded key which must be identical for all three data sets; otherwise, execution is terminated immediately. After checking to see that the key is correct, the data set LIB.ADJT is read further to see that the three data sets are consistent with this problem. Thus the adjoint trial functions of LIB.ADJT must agree in the number of energy groups, the number of points, the number of synthesis regions, and the number of functions per synthesis region and group defined for the problem; otherwise, execution is terminated.
  - d. Subroutine Called by This Subroutine. ERRMSG.
  - e. Subroutines Calling This Subroutine. RSDEF, PROCES.
9. Subroutine D2DCAL(\*)
- a. Arguments. The asterisk indicates an error return to a specified location in the calling subroutine.
  - b. Important Local Variables. None.
  - c. Functions and Tasks Performed by This Subroutine. This subroutine exists to call SYNGEN and SYNCAL. Note that this is not a two-dimensional diffusion-theory subroutine.

- d. Subroutines Called by This Subroutine. SYNGEN, SYNCAL.
- e. Subroutine Calling This Subroutine. SYN2D.

10. Subroutine D2DOUT(\*)

a. Arguments. The asterisk indicates an error return to a specified location in the calling subroutine.

b. Important Local Variables

<u>Name</u>	<u>Type</u>	<u>Definition</u>
POWBRN	R*8	Normalization factor.
POWTOT	R*8	Not used.
NERR	I*4	Error flag from LKCELL (boundary condition type incorrect).

c. Functions and Tasks Performed by This Subroutine. This subroutine is the driver for all output edits. It allocates storage for arrays in the POINTR container array, initializes subroutine arguments, and calls subroutines for output edit. It also causes the reordering of data set FA.D2 in the proper manner by group for an adjoint calculation by calling FLOP. (This reordering is not used by the synthesis module.)

d. Subroutines Called by This Subroutine. IFXVOL, IRGBAL, GETBND, IGPCAL, ITOBAL, FLUXPR, ILKCEL, PAGHED, IFXNRM, ERRMSG, FLOP.

- e. Subroutine Calling This Subroutine. SYNCAL.

11. Subroutine ERRMSG(NAM1,NUM)

a. Arguments

<u>Name</u>	<u>Type</u>	<u>Definition</u>
NAM1(2)	R*4	Name of subroutine calling this subroutine (A8).
NUM	I*4	Number assigned to error in subroutine calling this subroutine.

- b. Important Local Variables. None.

c. Functions and Tasks Performed by This Subroutine. This subroutine prints the name of the subroutine calling it and the error number assigned to the error which occurred, in the format

## ERROR NUMBER iiii IN SUBROUTINE aaaaaaaa

and returns control to calling subroutine. The name is input as an R\*4 array of dimension 2 in NAM1 and is set equal to the R\*4 array NAM2, which is equivalenced to the R\*8 member NAME of common block /NAMBLK/ to allow the name to be kept in a common block.

d. Subroutines Called by This Subroutine. None.

e. Subroutines Calling This Subroutine. BCONDS, CALC1, COFGEN, DSRNCK, D2DOUT, GETCHL, IFXVOL, IFXNRM, IGPCAL, ILKCEL, IVOL, LIB, MTGEN1, MTGEN2, PCOMP, PROCES, RBND, RCDEP, RCOMP, RGEOM, RGROUP, RMESH, RSDEF, RVEL, RXSC01, SINCAL, SYNCAL, SYNDEF, SYNGEN.

12. Subroutine FLOP(FLUX,POWTOT,POWBRN,JMAX,GMAX)

a. Arguments. The first argument is defined in common block BLKSTR; the last two are defined in common block SINGLE. The remaining arguments are defined below.

<u>Name</u>	<u>Type</u>	<u>Definition</u>
POWTOT	R*8	$\int v \sigma_f \varphi \, dv.$
POWBRN	R*8	$\int \sigma_f \varphi \, dv.$

b. Important Local Variables

<u>Name</u>	<u>Type</u>	<u>Definition</u>
GA	I*4	Indicates which record to skip to when re-ordering the data set containing the adjoint fluxes for normalization and output as data set FA.D2.
NFAD2	I*4	Data-set reference number for FA.D2.

c. Functions and Tasks Performed by This Subroutine. This subroutine is only called when an adjoint calculation is specified, and it writes FA.D2. It takes the latest fluxes from the data set whose reference number is NTH, reorders them in the proper manner by group, normalizes them by POWBRN, and then writes them on FA.D2. The references in the subroutine to POWTOT are no longer required. This subroutine is not used by the synthesis module.

d. Subroutine Called by This Subroutine. SNIFF (ARC System subroutine).

e. Subroutine Calling This Subroutine. D2DOUT.

13. Subroutine FLUXPR(X,Y,CNUM,RNUM,FLUX,P,IMAX,JMAX,G)

a. Arguments. The first six arguments are listed in common block BLKSTR. The seventh and eighth are listed in common block SINGLE. The remaining argument indicates which energy group is presently being considered.

b. Important Local Variables

<u>Name</u>	<u>Type</u>	<u>Definition</u>
IPONE	I*4	TWODPR flag for printing rows.
JPONE	I*4	TWODPR flag for printing columns.
INV	I*4	TWODPR flag for printing out array exactly as stored.
PMAX	R*8	Maximum power density.
PMIN	R*8	Minimum power density (greater than 0).

c. Functions and Tasks Performed by This Subroutine. This subroutine sets up row and column titles depending upon the geometry type, the heading for the output, and the actual coordinates for each mesh point. It calls subroutine TWODPR to print out the flux array for each energy group and after the last energy group calls subroutine TWODPR to print out the power density by interval. It also picks up and prints out the maximum and minimum nonzero power density and the mesh-cell locations where these occur.

d. Subroutine Called by This Subroutine. TWODPR.

e. Subroutine Calling This Subroutine. D2DOUT.

14. Subroutine FPRIME(KMAX,GMAX,JMAX,NGKMX,NN,DY,HG,HP)

Entry points

Entry: FPRM(HG,HP,G,KNOW)

a. Arguments. The first four arguments are defined in common block SINGLE. The arrays NN and DY are defined in common block BLKSTR. The arrays HG and HP are defined in common block BLKSTR either as HG and JP or as HADJG and HADJP, depending on whether real or adjoint trial functions are being used. All other arguments are listed below.

<u>Name</u>	<u>Type</u>	<u>Definition</u>
G	I*4	Present energy group number. Present synthesis region number.

b. Important Local Variables. None.

c. Functions and Tasks Performed by This Subroutine. This subroutine takes the tabular function values HG and computes the derivatives HP for each. Note that the array HG can contain either real or adjoint trial functions. The derivatives  $H'_j$  are computed as follows:

$$H'_j = 2(H_{j+1} - H_j)/(\delta_j + \delta_{j+1}), \quad 1 \leq j < J,$$

and

$$H'_J = H_{J-1},$$

where  $\delta_j$  is the length of the  $j$ th interval. This subroutine differentiates all the real functions in a synthesis region in one pass. Another call with appropriate substitutions in the calling sequence of FPRM will differentiate the adjoint functions.

d. Subroutines Called by This Subroutine. None.

e. Subroutine Calling This Subroutine. PROCES.

#### 15. Subroutine GETBND(BNDC,JBND)

Entry points

Entry: VERBND(IMESH,JMESH,NGRP,DIFCOE,C1,C2,C3,C4, ITYPE)

Entry: HORBND(IMESH,JMESH,NGRP,DIFCOE,C1,C2,C3,C4, ITYPE)

a. Arguments. The two arguments in the main calling sequence are both references to the array defined in common block BLKSTR as BNDC. The arguments of the entry points are defined below.

<u>Name</u>	<u>Type</u>	<u>Definition</u>
IMESH	I*4	X-direction mesh-line number (negative for left side of line and positive for right side when VERBND is called).
JMESH	I*4	Y-direction mesh-line number (negative for bottom side of mesh line and positive for top side when HORBND is called).
NGRP	I*4	Present energy-group number.
DIFCOE	R*8	Diffusion coefficient corresponding to IMESH, JMESH, and NGRP (from DC array).

<u>Name</u>	<u>Type</u>	<u>Definition</u>
C1	R*8	First boundary-condition coefficient.
C2	R*8	Second boundary-condition coefficient.
C3	R*8	Third boundary-condition coefficient.
C4	R*8	Fourth boundary-condition coefficient.
ITYPE	I*4	Boundary-condition type (0, 1, 2, or 3).

b. Important Local Variables. None.

c. Functions and Tasks Performed by This Subroutine.

GETBND is the initialization entry; VERBND and HORBND perform the specified functions. VERBND checks through the vertical mesh lines for which boundary conditions have been defined, comparing JBNDC(2,NBC), where NBC = 1, ..., NBCDEF, to IMESH. If a match is found, the mesh-line numbers in the Y-direction between which the condition applies, JBNDC(3,NBC) and JBNDC(4,NBC), and group numbers between which the condition applies, JBNDC(5,NBC) and JBNDC(6,NBC), are checked. If  $JBNDC(3,NBC) \leq JMESH \leq JBNDC(4,NBC)$ , and if  $JBNDC(5,NBC) \leq NGRP \leq JBNDC(6,NBC)$ , the arguments returned are defined as follows:

```
ITYPE = JBNDC(7,NBC)
      C1 = BNDC(8,NBC)
      C2 = BNDC(9,NBC)
      C3 = BNDC(10,NBC)
      C4 = BNDC(11,NBC)
```

Further, if ITYPE = 2

```
C1 = C1*D1FCOE
C3 = C3*D1FCOE
```

If no match is found, ITYPE and all constants (C1, C2, C3, and C4) are set to zero. The same calculations are performed by HORBND except that JBNDC(2,NBC) is compared to JMESH and JBNDC(3,NBC) and JBNDC(4,NBC) are compared to IMESH for horizontal boundaries.

d. Subroutines Called by This Subroutine. None.

e. Subroutines Calling This Subroutine. GETBND is called by MTGEN1, D2DOUT. VERBND is called by COFGEN, ILKCEL, MTGEN1.

HORBND is called by BCONDS, ILKCEL.

16. Subroutine GETCHI(SETCHI,MTRCHI,GMAX,NTAPE)

a. Arguments. The first argument is defined in common block BLKSTR; the next two are found in common block SINGLE. The remaining argument is the data-set reference number for XS.C.MIN.

b. Important Local Variables. None.

c. Functions and Tasks Performed by This Subroutine. This subroutine reads the set-wide fission spectrum  $\chi^g/g$ , if one exists, from record type 2 of data set XS.C.MIN.

d. Subroutine Called by This Subroutine. ERRMSG.

e. Subroutine Calling This Subroutine. RCOMP.

17. Subroutine IAREA(REGMSH,BSQ,REGHHT,X,Y,DX,DY,RMAX,IMAX,JMAX,\*)

Entry points

Entry: AREA(AREAL,AREAR,AREAT,AREAB,I,J)

a. Arguments. The first seven arguments are defined in common block BLKSTR; the remaining three appear in common block SINGLE. The asterisk indicates an error return to the calling subroutine. The entry-point arguments are defined below.

<u>Name</u>	<u>Type</u>	<u>Definition</u>
AREAL	R*8	Area on left of cell.
AREAR	R*8	Area on right of cell.
AREAT	R*8	Area on top of cell.
AREAB	R*8	Area on bottom of cell.
I	I*4	X-direction mesh-interval number.
J	I*4	Y-direction mesh-interval number.

b. Important Local Variables. None.

c. Functions and Tasks Performed by This Subroutine. This subroutine calculates the area per unit height associated with a specified mesh cell (I,J), where  $A_L$  is the area on the left,  $A_R$  is the area on the right,  $A_T$  is the area on the top, and  $A_B$  is the area on the bottom.

For XY geometry,

$$A_R = A_L = \Delta Y_j; A_T = A_B = \Delta X_i.$$

For RZ geometry,

$$A_R = 2\pi R_{i+1} \Delta Z_j; A = 2\pi R_i \Delta Z_j;$$

$$A_T = A_B = \pi \Delta R_i (2R_i + \Delta R_i).$$

For ZR geometry,

$$A_R = A_L = \pi \Delta R_j (2R_j + \Delta R_j);$$

$$A_T = 2\pi \Delta Z_i R_{j+1}; A_B = 2\pi \Delta Z_i R_j.$$

For RO geometry, which is not used by the synthesis module,

$$A_R = R_{i+1} \Delta O_j; A_L = R_i \Delta O_j;$$

$$A_T = A_B = \Delta R_i$$

d. Subroutines Called by This Subroutine. None.

e. Subroutines Calling This Subroutine. ILKCEL, RGEOM.

18. Subroutine IFXNRM(CMPREG, PSCMP, FISXS, NUFIS, FV, RAF, RV, REGNAM, PR, RMAX, FSCMAX)

Entry points

Entry: FLXNRM(POWTOT, POWBRN)

a. Arguments. The first nine arguments are defined in common block BLKSTR; the remaining two arguments are defined in common block SINGLE. The two entry-point arguments are listed below.

<u>Name</u>	<u>Type</u>	<u>Definition</u>
POWTOT	R*8	$\int v \sigma_f \phi \, dv.$
POWBRN	R*8	$\int \sigma_f \phi \, dv.$

b. Important Local Variables. None.

c. Functions and Tasks Performed by This Subroutine. Entry point IFXNRM is used to initialize the arguments, check geometry type and set up FACT, the normalization factor for data set FR.PN.

Entry point FLXNRM calculates the normalization factor  $\text{POWBRN} \left( \sum_R \sum_G \sigma_f \phi \Delta V \right)$ . It normalizes regional flux integrals and region-averaged fluxes for FR.PN when applicable. It calculates total power, power and average power by region. Finally, it writes out data set FR.PN if required. The power calculations are not performed when the problem is adjoint.

d. Subroutines Called by This Subroutine. PAGHED, ERRMSG, SNIFF (ARC System subroutine).

e. Subroutine Calling This Subroutine. D2DOUT.

19. Subroutine IFXVOL(FV,RV,SV,FIXSRC,REGMSH,FLUX,RMAX,JMAX,IMAX)

Entry points

Entry: FXVOL

a. Arguments. The first six arguments are defined in common block BLKSTR; the remaining three appear in common block SINGLE.

b. Important Local Variables. None.

c. Functions and Tasks Performed by This Subroutine.

IFXVOL is an initialization entry which zeroes out arrays for future summations. Entry FXVOL reads in pointwise fluxes and (if needed) the total fixed source one group at a time. The flux-regional integrals and source-volume integrals are approximated by summation. The region volumes are calculated. The source volume is reordered by group if the problem is adjoint. The reordering makes this data consistent with the structure of D2DOUT.

d. Subroutines Called by This Subroutine. ERRMSG, VOL (entry in IVOL).

e. Subroutine Calling This Subroutine. D2DOUT.

20. Subroutine IGPCAL(FLUX,P,FISXS,CMPMSH,FSCMP,FSCMAX,JMAX)

Entry points

Entry: GPCAL(G,POWTOT,POWBRN,NERR)

a. Arguments. The first five arguments are defined in common block BLKSTR; the remaining two are defined in common block SINGLE. The entry-point arguments are listed below.

<u>Name</u>	<u>Type</u>	<u>Definition</u>
G	I*4	Present energy-group number.
POWTOT	R*8	$\int v \sigma_f \varphi \, dv$ .
POWBRN	R*8	$\int \sigma_f \varphi \, dv$ .
NERR	I*4	Error flag from REGBAL.

b. Important Local Variables. None.

c. Functions and Tasks Performed by This Subroutine. Entry point IGPCAL initializes the arguments of the subroutine. It writes the first record of FR.D2 or FA.D2. Finally, it zeroes out array P for future accumulations.

Entry point GPCAL reads in fluxes one group at a time, normalizes them with POWBRN (when applicable), and accumulates power density by mesh point. It writes the rest of the records of FR.D2 or FA.D2 and closes the data set. If the KOUT print flag is on, subroutine REGBAL is called.

d. Subroutines Called by This Subroutine. ERRMSG, SNIFF (ARC System subroutine), REGBAL.

e. Subroutine Calling This Subroutine. D2DOUT.

21. Subroutine ILKCEL(CMPMSH,DC,X,DX,Y,DY,FLUX,CMAX,JMAX)

Entry points

Entry: LKCELL(LIJ,JIJL,JIJR,JIJB,JIJT,X1,Y1,DX1,DY1,I,J,G,NERR)

a. Arguments. The first seven arrays are defined in common block BLKSTR; the remaining two are found in common block SINGLE. The entry-point arguments are listed below.

<u>Name</u>	<u>Type</u>	<u>Definition</u>
LIJ	R*8	Total leakage out of cell (I,J,G).
JIJL	R*8	Current across left cell interface.
JIJR	R*8	Current across right cell interface.
JIJB	R*8	Current across bottom cell interface.
JIJT	R*8	Current across top cell interface.

<u>Name</u>	<u>Type</u>	<u>Definition</u>
X1	R*8	X-direction coordinate of point (I,J).
Y1	R*8	Y-direction coordinate of point (I,J).
DX1	R*8	Mesh interval size in X-direction.
DY1	R*8	Mesh interval size in Y-direction.
I	I*4	X-direction mesh cell number.
J	I*4	Y-direction mesh cell number.
G	I*4	Energy group number.
NERR	I*4	Error flag for incorrect boundary-condition type.

b. Important Local Variables

<u>Name</u>	<u>Type</u>	<u>Definition</u>
AREAL	R*8	Area on left of cell (I,J).
AREAR	R*8	Area on right of cell (I,J).
AREAT	R*8	Area on top of cell (I,J).
AREAB	R*8	Area on bottom of cell (I,J).
DIJL	R*8	Gradient $\phi$ times diffusion coefficient on left.
DIJR	R*8	Gradient $\phi$ times diffusion coefficient on right.
DIJT	R*8	Gradient $\phi$ times diffusion coefficient on top.
DIJB	R*8	Gradient $\phi$ times diffusion coefficient on bottom.
DELU	R*8	$(R_{i+1} + R_j) \sin \frac{\Delta\theta_j + \Delta\theta_{j+1}}{4}$ for R $\theta$ geometry.
WU	R*8	$W_U = \sin(0.5\Delta\theta_{j+1}) / \sin(0.5\Delta\theta_j)$ for R $\theta$ geometry.

c. Functions and Tasks Performed by This Subroutine. Entry point ILKCEL initializes the arguments passed to this subroutine. For a given geometry point and group (I,J,G), the entry point LKCELL calculates the total leakage (LIJ) out of the cell and the neutron currents across each interface of the cell, i.e., top JIJT, bottom JIJB, left JIJL, and right JIJR. It also returns the position of the mesh cell (X1,Y1) and the mesh interval size (DX1,DY1). NERR is set equal to 1 if a boundary condition type  $\geq 2$  is specified. Note that the synthesis module cannot synthesize for R $\theta$  geometry.

d. Subroutines Called by This Subroutine. AREA, ERRMSG, VERBND (entry in GETBND), HORBND (entry in GETBND).

e. Subroutine Calling This Subroutine. D2DOUT.

22. Subroutine IRGBAL(REGMSH,CMPREG,L,RMVL,S,F,T,REM,SCTXS,NUFIS,CHI,CMPMSH,DC,DX,FLUX,BSQ,SCTLIM,SCTLOC,FV,FSCMP,SV,REGNAM,VEL,JMAX,RMAX,SCTDIM,HIDIM,IMAX,CMAX,FSCMAX)

Entry points

Entry: REGBAL(G,FLUX,NERR)

a. Arguments. The first 23 arguments are defined in common block BLKSTR; the remaining seven are defined in common block SINGLE. The entry-point arguments are listed below.

<u>Name</u>	<u>Type</u>	<u>Definition</u>
G	I*4	Present energy group number.
NERR	I*4	Error trace back flag.

b. Important Local Variables

<u>Name</u>	<u>Type</u>	<u>Definition</u>
CL	R*8	Neutron current on left region boundary.
CR	R*8	Neutron current on right region boundary.
CB	R*8	Neutron current on bottom region boundary.
CT	R*8	Neutron current on top region boundary.

c. Functions and Tasks Performed by This Subroutine. Entry point IRGBAL is used to initialize the arguments and to zero out arrays L, RMVL, S, and F for future accumulations.

Entry point REGBAL calculates the contributions to total balance by region and group for leakage (using a call to entry point LKCELL), removal, scattering, and fission. It will also calculate and print neutron currents across region boundaries when the KOUT print flag is 2.

d. Subroutines Called by This Subroutine. LKCELL (entry in ILKCEL), PAGHED.

e. Subroutines Calling This Subroutine. D2DOUT, IGPCAL.

23. Subroutine ITOBAL(LR,RR,SR,FR,TR,SOR,LG,RG,SG,FG,G,  
SOG,L,RMVL,S,F,T,RNUM,CNUM,FV,SV,RAF,RV,A,RMAX)

Entry points

Entry: TOTBAL

a. Arguments. The last argument is listed in common block SINGLE; all the previous arguments are defined in common block BLKSTR.

b. Important Local Variables

<u>Name</u>	<u>Type</u>	<u>Definition</u>
X	R*8	First used as absorption by region, later as absorption by group.
LTOT	R*8	Leakage summed over regions and groups.
RTOT	R*8	Removal summed over regions and groups.
STOT	R*8	Scattering summed over regions and groups.
FTOT	R*8	Fission summed over regions and groups.
TTOT	R*8	Balance summed over regions and groups.
ATOT	R*8	Absorption summed over regions and groups.

c. Functions and Tasks Performed by This Subroutine. Entry ITOBAL initializes arguments to the subroutine, zeroes out arrays for future summations, and initializes INV,IPONE, and JPONE.

Entry TOTBAL calls the subroutine TWODPR to print out the arrays FV,RAF,L,RMVL,S,F,T,A, and SV.

It accumulates each of the above arrays by region and then by group and then sums over both regions and groups. It prints out these summations for all regions and groups.

d. Subroutines Called by This Subroutine. TWODPR, PAGHED.

e. Subroutine Calling This Subroutine. D2DOUT.

24. Function IVOL(REGMSH,BSQ,REGHHT,X,Y,DX,DY,RMAX,IMAX,  
JMAX)

Entry points

Entry: VOL(I,J)

a. Arguments. The first seven arguments are defined in the common block BLKSTR; the remaining three are located in common block SINGLE. The entry-point arguments are listed below.

<u>Name</u>	<u>Type</u>	<u>Definition</u>
I	I*4	X-direction mesh interval number.
J	I*4	Y-direction mesh interval number.

b. Important Local Variables. None.

c. Functions and Tasks Performed by This Function. This function calculates the volume per unit height  $V_{ij}$  of a specified mesh cell (I,J) according to the reactor geometry type. The initialization call is made to IVOL and calls for the volume value are made to VOL. The volume is computed as follows:

$$\Delta V_{ij} = \Delta X_i \cdot \Delta Y_j \text{ for XY geometry,}$$

$$\Delta V_{ij} = \pi \Delta R_i (2R_i + \Delta R_i) \Delta Z_j \text{ for RZ geometry,}$$

$$\Delta V_{ij} = \pi \Delta R_j (2R_j + \Delta R_j) \Delta Z_i \text{ for ZR geometry,}$$

and

$$\Delta V_i = \frac{1}{2} \Delta R_i \Delta \theta_j (2R_i + \Delta R_i) \text{ for R}\theta \text{ geometry.}$$

Note that R $\theta$  geometry is not handled by the synthesis module SYN2D.

d. Subroutine Called by This Function. ERRMSG.

e. Subroutines Calling This Function. RGEOM, IFXVOL, PGEOM.

25. Subroutine LIB(\* ,GMAX,JMAX,NGKMX,KMAX,ICORE,NN,HG,LIBFLX,LWHRNO,LWHRSR,IDSNO,IPNT)

a. Arguments. The asterisk indicates an error return to a specified location in the calling subroutine. The next four arguments are defined in common block SINGLE. ICORE is a flag passed from RSDEF to indicate if the trial functions used to generate the trial function libraries can be core contained. The remaining arrays are listed in common block BLKSTR.

b. Important Local Variables

<u>Name</u>	<u>Type</u>	<u>Definition</u>
IFLAG	I*4	Trial-function library flag. 0--Working with the trial functions from FR.TRIAL. 1--Working with the trial functions from FA.TRIAL.
LTEST	I*4	Temporarily contains a trial-function number from the user input data sets which are required for this problem.
LIBDS1	I*4	Data-set reference number for FR.TRIAL.
LIBDS2	I*4	Data-set reference number for FA.TRIAL.

c. Functions and Tasks Performed by This Subroutine. This subroutine generates the problem-dependent trial-function libraries from the user-supplied trial-function libraries. Several different options can be handled; however, the creation of the real and adjoint data sets are similar. First, the real trial functions are read a function at a time for all groups. (Refer to the structure of FR.TRIAL in Section III.E.) If the trial functions are core-contained, the needed function for each group is stored in array HG once for each synthesis region in which it is used. When they are not core-held, the needed function for each group G is written on the scratch data set IDSNO(G) once for each synthesis region which uses it.

After all the input trial functions required have been read in the data set LIB.REAL is written. When the trial functions are core-held, this is straightforward. When the trial functions are not all core-held, each scratch data set is read, the trial functions for all synthesis regions and one group are core held, and the data set LIB.REAL is written. If the adjoints are set equal to the reals the data set LIB.ADJT is also written. Finally the data set LIB.MIX is written.

When the trial functions are not core-held, each scratch data set is written again with the trial functions that were previously on this data set. The trial functions are then properly ordered on each scratch data set by synthesis region. After all the scratch data sets have been written the second time, they are read again. This time, however, only one record at a time is read from each data set and written on data set LIB.MIX. Thus a record is read from the first scratch data set, a record from the second, and so on, until one record from each has been read. Then the process is repeated until all the records have been read. Data set LIB.MIX is then complete. Next the adjoint trial function data set is read, and the trial functions are handled in the same fashion, except now the only data set to be written is LIB.ADJT. This corresponds to data set LIB.REAL in structure and content.

These three data sets are keyed for this problem and must be used together on a problem with the same geometry, the same number of synthesis regions, the same number of trial functions per synthesis region, and the same number of energy groups; otherwise, a terminal error will be encountered by this module.

d. Subroutines Called by This Subroutine. SNIFF (ARC System subroutine), ERRMSG, TLEFT (IBM subroutine).

e. Subroutine Calling This Subroutine. RSDEF.

26. Subroutine MADD(A,B,M,N,C)

a. Arguments

<u>Name</u>	<u>Type</u>	<u>Definition</u>
A(M,N)	R*8	See c below.
B(M,N)	R*8	See c below.
M	I*4	First dimension of A, B, and C.
N	I*4	Second dimension of A, B, and C.
C(M,N)	R*8	See c below.

b. Important Local Variables. None.

c. Functions and Tasks Performed by This Subroutine.

Array A is added to array B and the result is stored in array C. Neither A nor B is changed unless the array C is input as the same array as A or B.

d. Subroutines Called by This Subroutine. None.

e. Subroutines Calling This Subroutine. MTGEN1, CALC1, CALC2, SWEEP1, SWEEP2, SINCAL.

27. Subroutine MOVE(A,M,N,B)

a. Arguments

<u>Name</u>	<u>Type</u>	<u>Definition</u>
A(M,N)	R*8	See c below.
M	I*4	First dimension of A and B.
N	I*4	Second dimension of A and B.
B(M,N)	R*8	See c below.

b. Important Local Variables. None.

c. Functions and Tasks Performed by This Subroutine. This subroutine copies the contents of array A into the array B. Array A remains unchanged.

d. Subroutines Called by This Subroutine. None.

e. Subroutines Calling This Subroutine. MTGEN1, CALC1, CALC2, MTGEN2.

28. Subroutine MSUB(A,B,M,N,C)

a. Arguments

<u>Name</u>	<u>Type</u>	<u>Definition</u>
A(M,N)	R*8	See c below.
B(M,N)	R*8	See c below.
M	I*4	First dimension of A, B, and C.
N	I*4	Second dimension of A, B, and C.
C(M,N)	R*8	See c below.

b. Important Local Variables. None.

c. Functions and Tasks Performed by This Subroutine. This subroutine subtracts array B from array A and stores the results in array C. Arrays A and B remain unchanged by this process unless array C is the same array input as A or B.

d. Subroutines Called by This Subroutine. None.

e. Subroutine Calling This Subroutine. MTGEN2.

29. Subroutine MTGEN1(DRRMN,NGKMX,NGKPMX,RRMAX,GMAX,KMAX,IMAX,NN,NNP,SYNSH,REFREG,NOWMAX,IFLAGS,DX,AMN,BMN,CMN,DMN,KBAR,X,L1,M1,SIGMAR,UINT,IM1,JUNK)

Entry points

Entry: MTGN1(\*,G)

a. Arguments. Arguments 2-7 are located in common block SINGLE. Arguments 1, 8-11, 13-18, 20-24, and 26 are defined in common block BLKSTR, with array REFREG listed as RR. The remaining calling-sequence arguments and entry-point arguments are listed below.

<u>Name</u>	<u>Type</u>	<u>Definition</u>
NOWMAX	I*4	NOWMAX = NGKMX = NGKPMX.
KBAR	I*4	KMAX - 1.
IM1	I*4	IMAX - 1.
*	-	Error return to calling subroutine.
G	I*4	Present energy group number.

b. Important Local Variables

<u>Name</u>	<u>Type</u>	<u>Definition</u>
JFLAG	I*4	Storage check flags. 0--Nothing stored in ZMN. 1--Something stored in ZMN.
KKEEP	I*4	Synthesis region containing the largest value of ZNORM.
IMSH1	I*4	Boundary condition side input to VERBND.
IMSH	I*4	X-direction interval corresponding to IMSH1, either the first or last interval.
YNORM	R*8	Column norm of $D_{gk}(r)$ , computed for each $r$ .
XNORM	R*8	Column norm of $D_{gk}^{-1}(r)$ , computed for each $r$ .
ZNORM	R*8	A condition number for matrix $D_{gk}(r)$ , computed for all $r$ (only the largest is kept as WNORM).
WNORM	R*8	The largest computed condition number.
WINT	R*8	$\delta_1 r^\alpha$ , which is computed as $DX(I)(X(I)+0.5DX(I))^{**}NALPHA$ .

c. Functions and Tasks Performed by This Subroutine. This subroutine is a driver responsible for generating the matrices  $E_i$ ,  $G_i$ , and  $H_i$  for each energy group  $G$ . The subroutine also returns an estimate of the condition numbers of the matrices  $D_{gk}(r)$ . Refer to the documentation of the subroutines CALC1 and CALC2 as well as to Section II.B. for more detail on how these matrices are generated. Subroutine GETBND (entry VERBND) is called to obtain the boundary conditions on the reactor left and right. If the geometry type is RZ, the boundary condition on the left is assumed to be  $\varphi' = 0$ . The matrices  $E_{IMAX}$  and  $\overline{M}$  are computed here.  $E_{IMAX}$  is defined in CALC2;  $\overline{M}$  is defined as

$$\overline{M}_1 = C_2 D_{g1}(1) [C_1 D_{gk}(1) + 0.5 C_2 \delta_1 W_{g1}]^{-1} W_{g1}.$$

If  $C_2 = 0$ ,  $\bar{M} = 0$  and the calculation is omitted. If  $C_1 = 0$ , then  $\bar{M} = 2D_{g_1}(1)/\delta_1$ , where the numbers  $C_i$  are from the boundary condition equation  $C_1\phi' + C_2\phi = C_3$ .  $C_3$  should be identically zero in all cases. The matrix  $\bar{M}$ , if computed, is stored in array BLK(IZMN). Finally, after all other matrices have been generated,  $E_{IMAX}$  is calculated. For this calculation,  $R^\alpha \bar{M}_{IMAX}$  is required where  $R^\alpha = X(IMAX+1)**NALPHA$  and  $D_{g_1}(1)$ ,  $W_{g_1}$ , and  $\delta$  are replaced by  $D_{gk}(\bar{r})$ ,  $W_{gk}$ , and  $\delta_{IMAX}$ , respectively. Note K is the last synthesis region, and  $\bar{r}$  is the last refined region in synthesis region K. Finally, a check is made to see if anything was stored in ZMN by this subroutine. Anything stored is then added to  $E_1$ .

d. Subroutines Called by This Subroutine. CALC1,CALC2, NORM,MINV,MOVE,GMPRD,GETBND,NUMMLT,MADD,ERRMSG.

e. Subroutine Calling This Subroutine. SYNGEN.

30. Subroutine MTGEN2(HINT,GINT,UINT,WORK,AREA,L1,M1,NN,IMAX,GMAX,KMAX,SYNMSH,NGKMX,IM1,SPACE)

Entry points

Entry: MTGN2(G,\*)

a. Arguments. Arguments 1-8, 12, and 15 are located in common block BLKSTR; arguments 9-11 and 13 appear in common block SINGLE. The remaining arguments are defined below.

<u>Name</u>	<u>Type</u>	<u>Definition</u>
IM1	I*4	IMAX-1.
G	I*4	Present energy group number.
*	-	Error return to calling subroutine.

b. Important Local Variables

<u>Name</u>	<u>Type</u>	<u>Definition</u>
K	I*4	Synthesis region in which interval I lies.
NGK	I*4	Number of trial functions per synthesis region K.
DET	R*8	Determinant ( $U^{-1}$ ) (checks to see if $U^{-1}$ exists).
KP1	I*4	Synthesis region in which the (I+1)th interval lies.
KM1	I*4	Synthesis region in which the (I-1)th interval lies.

<u>Name</u>	<u>Type</u>	<u>Definition</u>
NGK1	I*4	Number of trial functions for synthesis region KP1.
NGKM1	I*4	Number of trial functions for synthesis region KM1.

c. Functions and Tasks Performed by This Subroutine: This subroutine factors the tridiagonal matrix  $P_g$  (whose elements are matrices).

(1)  $P_g = LU$ , where  $L$  is the lower triangular,  $U$  is the upper triangular.

$$(2) \quad P_g = \begin{bmatrix} E_1 & -G_1 & 0 & \dots & 0 \\ -H_2 & E_2 & -G_2 & \dots & 0 \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ \vdots & \vdots & \vdots & \vdots & E_{I-1} & -G_{I-1} \\ 0 & 0 & 0 & \dots & -H_I & E_I \end{bmatrix}$$

$$(3) \quad L = \begin{bmatrix} U_1 & 0 & \dots & 0 \\ -H_2 & U_2 & \dots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ \vdots & \vdots & \vdots & U_I \\ 0 & 0 & \dots & -H_I & U_I \end{bmatrix}, \quad U = \begin{bmatrix} ID & -V_1 & \dots & 0 \\ & ID & \ddots & \\ & & \ddots & -V_{I-1} \\ 0 & \dots & & ID \end{bmatrix},$$

where ID is the identity matrix and

$$(4a) \quad U_1^{-1} = E_1^{-1}, \quad V_1 = U_1^{-1}G_1;$$

$$(4b) \quad U_i^{-1} = (E_i - H_i * V_{i-1})^{-1}, \quad V_i = U_i^{-1} * G_i,$$

$$2 \leq i \leq IMAX \text{ with } G_{IMAX} \equiv 0.$$

The dimensions of the matrices are

$$(5) \quad U_i \text{ and } E_i, \quad N_i \times N_i;$$

$$H_i, \quad N_i \times N_{i-1};$$

$$G_i \text{ and } V_i, \quad N_i \times N_{i+1},$$

where  $N_i$  is the number of trial functions used in the synthesis region in which interval  $i$  lies.

Since only IM1  $H_i$  matrices exist, they are packed upward in array HINT. The subroutine calculates the matrices  $U_i^{-1}$  and  $V_i$  and writes them out on the data set whose reference number is JLIB. The matrices  $H_i$  are written out on the data set whose reference number is NLIB.

Notice that upon entering the subroutine, the matrices  $E_i$ ,  $H_i$ , and  $G_i$  are stored in arrays UINT, HINT, and GINT, respectively, while upon termination of the subroutine,  $U_i^{-1}$  and  $V_i$  replace  $E_i$  and  $G_i$ , respectively, in storage. This subroutine is called once for each group.

d. Subroutines Called by This Subroutine. MINV, ERRMSG, MOVE, GMPRD, MSUB.

e. Subroutine Calling This Subroutine. SYNGEN.

31. Subroutine NORM(ARRAY,N,ANORM)

a. Arguments

<u>Name</u>	<u>Type</u>	<u>Definition</u>
ARRAY(N,N)	R*8	The square matrix whose column norm we wish to know.
N	I*4	Number of columns and rows in ARRAY.
ANORM	R*8	Column norm returned by the routine.

b. Important Local Variables

<u>Name</u>	<u>Type</u>	<u>Definition</u>
ZNORM	R*8	Intermediate sum of the absolute values of a column.

c. Functions and Tasks Performed by This Subroutine. This subroutine finds a norm of a square matrix array by obtaining  $ANORM = \max(ZNORM_i)$  for  $i = 1, \dots, N$ , where  $ZNORM_i$  is sum of the absolute values of the elements of the  $i$ th column.

d. Subroutines Called by This Subroutine. None.

e. Subroutines Calling This Subroutine. MTGEN1, CALC1.

32. Subroutine NUMMLT(X,M,N,A,B)a. Arguments

<u>Name</u>	<u>Type</u>	<u>Definition</u>
X	R*8	See c below.
M	I*4	First dimension of A and B.
N	I*4	Second dimension of A and B.
A(M,N)	R*8	See c below.
B(M,N)	R*8	See c below.

b. Important Local Variables. None.

c. Functions and Tasks Performed by This Subroutine. This subroutine multiplies array A by X and stores the result in array B. Both X and array A remain unchanged, unless the same array is input as both A and B.

d. Subroutines Called by This Subroutine. None.

e. Subroutines Calling This Subroutine. CALC2, CALC1, MTGEN1, SINCAL.

33. Subroutine PAGHEDa. Arguments. None.b. Important Local Variables. None.

c. Functions and Tasks Performed by This Subroutine. This subroutine updates the page number and prints a page heading and the number from the common block HEADER at the top of a page. The page heading must have been initialized and the page number set to zero before the first call to this subroutine.

d. Subroutines Called by This Subroutine. None.

e. Subroutines Calling This Subroutine. TWODPR, D2DOUT, IFXNRM, IRGBAL, ITOBAL, PCOMP, PGEOM, PRTBC, RCDEP, RSDEF, RVEL, SINCAL.

34. Subroutine PCKSCT(SCTLIM,SCTLOC,SCTDUM,SCTXS,CMAX,DUMDIM,SCTDIM,GMAX,\*)

a. Arguments. The first four arrays are located in common NUMSTR. DUMDIM, defined as CMAX\*GMAX, is the first dimension

of array SCTDUM. The remaining arguments are listed in common block SINGLE. The asterisk indicates an error return to the calling subroutine.

b. Important Local Variables

<u>Name</u>	<u>Type</u>	<u>Definition</u>
ML	I*4	Lowest-numbered group from which down-scattering into group G can occur for a given composition C, according to number of down-scattering groups in G.
MU	I*4	Highest-numbered group from which upscattering into given group G can occur for a given composition C, according to number of upscattering groups in G.
HLIM1	I*4	Lower limit of group number from which down-scattering into group G can occur for a given composition C ( $\max(1, ML)$ ).
HLIM2	I*4	Upper limit of group number from which up-scattering into group G can occur for a given composition C ( $\min(GMAX, MU)$ ).
GSUB1	I*4	Position of desired scattering element $\sigma_C^{g \rightarrow g}$ in array SCTXS.
GSUB2	I*4	Position of desired scattering element $\sigma_C^{g \rightarrow g}$ in array SCTDUM.

c. Functions and Tasks Performed by This Subroutine. This subroutine packs the scattering data from the SCTDUM array, dimensioned (CMAX\*GMAX\*GMAX), into which the data was read from data set XS.C.MIN,

into the SCTXS array, dimensioned ( $GMAX * \sum_{C=1}^{CMAX} SCTLIM(1, C) + SCTLIM(2, C) + 1$ )), where  $SCTLIM(1, C) + SCTLIM(2, C) + 1$  is the maximum bandwidth associated with a given composition C.

At the beginning of this subroutine, the first CMAX locations of the array SCTLOC contain the locations of the last position assigned in SCTXS to the preceding composition; in other words,  $SCTLOC(CMPNO, 1) + 1$  is the location of the first position in SCTXS assigned to composition CMPNO.

By the end of the subroutine, SCTLOC will contain a reference to the first element of the band of groups H from which scattering occurs into a given group G for a given composition CMPNO. Hence, the array SCTXS is "packed" from  $G = GMAX$  to  $G = 1$  in descending order by groups, so that the first CMAX locations of SCTLOC, used in the packing procedure, will not be destroyed until the final pass.

The packing is accomplished as follows: For a given composition CMPNO and group G, the number ML of the lowest-numbered group from which downscattering could occur is found by subtracting the maximum number of downscattering groups associated with the composition (SCTLIM(1,CMPNO)) from the group number G. Since this number could be negative, the lower limit HLIM1 of the actual possible scattering band for this group G is then computed as  $\max(1, ML)$ . Similarly, the number MU of the highest-numbered group from which upscattering into group G could occur is found by adding SCTLIM(2,CMPNO) to G. Since this number could be greater than GMAX, the upper limit HLIM2 of the possible scattering band for this group G is then computed as  $\min(GMAX, MU)$ .

The scattering location SCTLOC(CMPNO,G) associated with the band for that composition and group is then computed as the sum of the first location in SCTXS assigned to the composition, CMPNO, and the difference between the number of possible downscattering groups in the composition and the group number G:  $SCTLOC(CMPNO,G) = (SCTLOC(CMPNO,1) + SCTLIM(1,CMPNO) - G)$ . This number may be negative; it corresponds to  $-ML$  plus the location of scattering elements associated with the composition.

Finally, using the limits set up from  $H = HLIM1, \dots, HLIM2$ , the elements of the scattering band associated with CMPNO and G are packed. The scattering element  $\sigma_{CMPNO H \rightarrow G}$  is fetched from SCTDUM(GSUB2,G), where GSUB2 is simply  $(CMPNO-1)*GMAX+H$ , and stored in SCTXS(GSUB1,G), where GSUB1 is  $SCTLOC(CMPNO,G)+H$ .

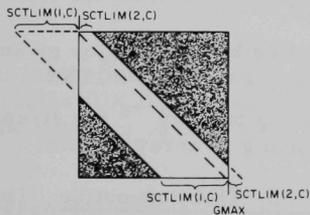


Fig. 5. Bandwidth Structure

Although a full bandwidth  $SCTLIM(1,CMPNO) + SCTLIM(2,CMPNO) + 1$  is allocated for use by each group G in the composition, then, only the elements actually present for that group G are actually stored or fetched. The other locations are not used. This can be seen in Fig. 5; for a given composition CMPNO, the array SCTDUM looks like  $GMAX * GMAX$  square in the diagram, where the white area represents the maximum bandwidth associated with the composition.

All the elements in the parallelogram are stored as a rectangle which is GMAX long and the bandwidth wide in the array SCTXS, but only the elements of the parallelogram that fall within the larger square actually exist and are referenced for a given group G.

- d. Subroutines Called by This Subroutine. None.
- e. Subroutine Calling This Subroutine. RCOMP.

35. Subroutine PCOMP(DC,REM,FSCMP,FISXS,NUFIS,CHI,SCTLIM,SCTLOC,SCTXS,CMPNAM,CMAX,FSCMAX,CHIDIM,SCTDIM,GMAX,IERR,\*)

a. Arguments. The first 10 arguments are listed in common block BLKSTR; the next five are listed in common block SINGLE. The flag IERR and the asterisk are defined below.

<u>Name</u>	<u>Type</u>	<u>Definition</u>
IERR	I*4	Error flag (input from search module). = 0--No error. ≠ 0--A given cross section has been made negative during concentration search (not possible in SYN2D).
*	-	Error return to calling subroutine if IERR > 0.

b. Important Local Variables

<u>Name</u>	<u>Type</u>	<u>Definition</u>
AB(6)	R*8	Cross-section data names corresponding to IERR flag values.
CLIM1	I*4	Lower limit of fission-spectrum values $\chi_c^{g \rightarrow g}$ for given fissionable composition c and group g for $\chi$ -matrix in array CHI.
SLIM1	I*4	Lower limit of scattering band $\sigma_c^{g \rightarrow g}$ for given composition c and group g in array SCTXS.
SLIM2	I*4	Upper limit of scattering band $\sigma_c^{g \rightarrow g}$ for given composition c and group g in array SCTXS.

c. Functions and Tasks Performed by This Subroutine. This subroutine prints cross-section data by composition, as read from data set XS.C.MIN and modified for use by the two-dimensional synthesis and diffusion modules.

Data printed for a nonfissionable composition are simply the composition name and the group number and diffusion coefficient and removal cross section for each group, followed by a table containing the scattering cross section.

For a fissionable composition, the composition name is followed by the group number, diffusion coefficient, removal cross section, nu times fission cross section, fission-spectrum cross section, if present as a vector, and fission cross section. If the fission spectrum is a matrix, it is printed in a separate table, and in either case the scattering cross section is printed in the last table for that composition.

The IERR flag must be set to zero before calling this subroutine from any subroutine other than the two-dimensional diffusion search driver, or return may be made to the calling subroutine through the first return provided in the calling sequence.

d. Subroutines Called by This Subroutine. PAGHED, ERRMSG.

e. Subroutine Calling This Subroutine. RCOMP.

36. Subroutine PGEOM(X,DX,Y,DY,BSQ,REGHHT,REGMSH, CMPMSH,CMPREG,IMAX,JMAX,RMAX)

a. Arguments. The first nine arguments are defined in common block BLKSTR; the remaining three are listed in common block SINGLE.

b. Important Local Variables

<u>Name</u>	<u>Type</u>	<u>Definition</u>
VLM	R*8	Volume of a mesh cell (from function VOL).

c. Functions and Tasks Performed by This Subroutine. This subroutine prints geometry data, as read from data set GEOM and modified for use by the two-dimensional diffusion and synthesis modules. It first prints the name of the geometry type.

Second, it prints a table of mesh-dependent data, consisting of mesh-line locations (X,Y), mesh-interval numbers, mesh-interval lengths (DX,DY), mesh-interval volumes per unit height (function VOL), and the numbers of the region and the composition corresponding to the interval.

Finally, if the geometry is not RZ or ZR, a table of region-dependent data is printed, consisting of the region number, the corresponding composition number, the buckling  $B^2$  (BSQ) in the region, and the actual half-height  $(H_L)_R$  (REGHHT) of the region.

d. Subroutines Called by This Subroutine. PAGHED, VOL (entry in IVOL).

e. Subroutine Calling This Subroutine. RGEOM.

37. Subroutine PROCES(LMIX,LREAL,LADJT,LPART,JMAX, NGKMX,GMAX,KMAX,NAB,RESULT,HG,HADJG,NN,NBP,HP, HADJP,DY,NUMRRJ,RRJLOC,RRFJ,Y,TIMEKY,\*)

a. Arguments. The first eight arguments and the last argument are defined in common block SINGLE with LMIX, LREAL, and LADJT

listed as N3, N1, and N2, respectively. The variable NAB is defined as the sum of NALPHA and NBETA, which are defined in common block SINGLE. The remaining arguments are defined in common block BLKSTR. The asterisk indicates an error return to the calling subroutine.

b. Important Local Variables

<u>Name</u>	<u>Type</u>	<u>Definition</u>
LPNT	I*4	Location in arrays HADJG and HADJP where the adjoint trial functions and derivatives for synthesis region K and energy group LG are stored.
NPNT	I*4	Location in arrays HADJG and HADJP where the adjoint trial functions and derivatives for synthesis region K - 1 and energy group LG are stored.
IPNT	I*4	Location in arrays HG and HP where the real trial functions and derivatives for synthesis region K and energy group G are stored.
JPNT	I*4	Location in arrays HG and HP where the real trial functions and derivatives for synthesis region K - 1 and energy group LG are stored.

c. Functions and Tasks Performed by This Subroutine. This subroutine is the driver for the partial integral generation and the calculation of the trial functions at the boundaries of the reactor. Five different types of partial integrals are calculated. Refer to Section II.B. for a more detailed description of the partial integrals. Due to storage requirements, all required trial functions cannot be held in core at the same time. The method of generating these partial integrals is also dependent upon the order in which the resultant matrices are used in the iteration section of the code. With these restrictions in mind, the partial integrals are generated and the I/O handled in the following manner. The adjoints for energy group g and synthesis region k are read in, and their derivatives calculated. The real trial functions for synthesis region k, energy group g' = 1 are then read in, and their derivatives calculated. The partial integrals of their products are then calculated. If g' = g, the partial integrals of the products of the derivatives are also calculated. Both integrations are performed in synthesis region k. Finally, if k > 1, with g' still equal to g, the last three partial-integral sets are created. Note that the trial functions for the (k - 1)st synthesis region were stored previously. Next, the values of IPNT and JPNT are interchanged and g' is increased by 1. When g' = GMAX, the real trial functions for the next synthesis region k + 1 and energy group g' = 1 are read, while the adjoints for the new synthesis region are also read. When k = KMAX, g is advanced by 1 and the process starts again. Note that the values of LPNT and NPNT are interchanged whenever the adjoint trial functions are read, but the values of IPNT and JPNT are only

changed when  $g' = g$ . Finally, the calculated partial integrals are written in subroutine RIEMAN, and the values of the trial functions at the boundaries are written in subroutine VALUES.

d. Subroutines Called by This Subroutine. SNIFF (ARC System subroutine), ERRMSG, DSRNCK, RIEMAN, FPRIME, VALUES and CLOSE.

e. Subroutine Calling This Subroutine. RSDEF.

### 38. Subroutine PRTEBC(X,Y,BNDC,JBND,NV,NH,\*)

a. Arguments. The first four arguments are defined in common block BLKSTR, and BNDC and JBND both refer to the array named BNDC. The remaining arguments are listed below.

<u>Name</u>	<u>Type</u>	<u>Definition</u>
NV	I*4	Number of vertical boundary conditions given.
NH	I*4	Number of horizontal boundary conditions given.
*	-	Error return to calling subroutine.

### b. Important Local Variables

<u>Name</u>	<u>Type</u>	<u>Definition</u>
IP	I*4	Flag indicating inhomogeneous boundary conditions are defined.

c. Functions and Tasks Performed by This Subroutine. This subroutine checks to see if any boundary conditions defined are inhomogeneous. If any are found to be, it makes the IP flag nonzero.

The subroutine prints the boundary condition data and then checks the calculation type and the IP flag. If any inhomogeneous boundary conditions appear and the calculation is not a source calculation, an error is flagged. The (\*) in the calling sequence is an error return.

d. Subroutine Called by This Subroutine. PAGHED.

e. Subroutine Calling This Subroutine. RBND.

### 39. Subroutine RBND(\*)

a. Arguments. The asterisk indicates an error return to the calling subroutine.

b. Important Local Variables

<u>Name</u>	<u>Type</u>	<u>Definition</u>
NTAPE	I*4	Data set reference number of BC.
ITYPEL	I*4	Boundary condition type on left reactor boundary.
ITYPER	I*4	Boundary condition type on right reactor boundary.
IBNDC	I*4	Location of BNDC array in BLK.
IX	I*4	Location of X array in BLK.
IY	I*4	Location of Y array in BLK.
NVBND	I*4	Number of vertical boundary conditions defined.
NHBND	I*4	Number of horizontal boundary conditions defined.
ITYPEB	I*4	Boundary condition type at bottom of reactor.
ITYPET	I*4	Boundary condition type at top of reactor.
NVBND1	I*4	NVBND + 1.
CDUM(4)	R*8	Boundary condition coefficients as read from BC (stored in R*4 array C).

c. Functions and Tasks Performed by This Subroutine. This subroutine controls the reading of the boundary and interface condition data from data set BC.

The first record of BC gives the boundary condition types at the left, right, bottom and top boundaries, which are ignored, and the numbers NVBND and NHBND, i.e., the number of boundary and interface conditions defined in the succeeding records of the data set.

The subroutine reads the contents of each succeeding record and stores each in the common block BCBLK. For each, it then calls STORBC to store the data in the BNDC array before reading the next record.

This subroutine then calls PRTBC to print the boundary condition data from the BNDC array, if desired, and to check for consistency of boundary condition types with the calculation type.

d. Subroutines Called by This Subroutine. SNIFF (ARC System subroutine), ERRMSG, STORBC, PRTBC.

e. Subroutine Calling This Subroutine. SYNIN.

40. Subroutine RCDEP(\*)

- a. Arguments. The asterisk represents an error return to the calling subroutine.
- b. Important Local Variables. None.
- c. Functions and Tasks Performed by This Subroutine. This subroutine reads in the first three card types of the module-dependent data from data set A.SYN2D. The data are stored in the common blocks SINGLE and HEADER for later reference. Default options are supplied when necessary for some of the input parameters. The remaining user-supplied data on data set A.SYN2D are read later in subroutines SYNDEF and LIB. Finally, the container array BLK, used by the dynamic storage routine POINTR, is allocated and the scratch-data-set reference numbers are determined.
- d. Subroutines Called by This Subroutine. SNIFF (ARC System subroutine), ERRMSG, PAGHED, POINTR (ARC System subroutine), BULK (entry in POINTR).
- e. Subroutine Calling This Subroutine. SYNIN.

41. Subroutine RCOMP(\*)

- a. Arguments. The asterisk represents an error return to the calling subroutine.
- b. Important Local Variables

<u>Name</u>	<u>Type</u>	<u>Definition</u>
NTAPE	I*4	Data-set reference number for XS.C.MIN.
ISCHI	I*4	Set-wide fission spectrum. 0--No set-wide $\chi$ . 1--Set $\chi$ -vector. GMAX--Set $\chi$ -matrix.
NTAPE1	I*4	Data-set reference number XS.DELAY.
IERR	I*4	Error flag set to zero before calling PCOMP.

- c. Functions and Tasks Performed by This Subroutine. This subroutine controls the reading of composition- and group-dependent data from XS.C.MIN, XS.DELAY, and XS.ISO.

The first thing read is the first record of XS.C.MIN and the end-of-file following that record. If a set-wide fission spectrum  $\chi^g$

is present, the MTRCHI flag is set for a  $\chi$ -vector or  $\chi$ -matrix, accordingly, and GETCHI is called to read the set-wide  $\chi^g$ 's from the second record of XS.C.MIN. If no set-wide  $\chi$  is present, MTRCHI is set up for a matrix temporarily. (SYN2D handles only  $\chi$ -vectors.)

Space for storage of arrays is then allocated, and RDELAY is called to read delayed data from XS.DELAY if the kinetics option is 2. (SYN2D has no kinetics option.) Following this, the CMAX composition blocks of XS.C.MIN are read by calling RGROUP once for each composition.

The subroutine then sets up scattering-band positions in the scattering array and packs the scattering array by calling DIMSCT and PCKSCT. If a print of composition data is desired ( $KOUT \neq 0$ ), PCOMP is then called, and finally RVEL is called to read the neutron speeds, if required from data set XS.ISO. (Neutron speeds are not used by SYN2D.)

d. Subroutines Called by This Subroutine. SNIFF (ARC System subroutine), ERRMSG, GETCHI, RDELAY, RGROUP, DIMSCT, PCKSCT, PCOMP, RVEL, RXSC01.

e. Subroutine Calling This Subroutine. SYNIN.

42. Subroutine RDELAY(DEC CON, DICHI, NFAM, GMAX, NTAPE, \*)

a. Arguments. The first two arguments are defined in common block BLKSTR; the next two are found in common block SINGLE. NTAPE is the data-set reference number for XS.DELAY. The asterisk represents an error return to the calling subroutine.

b. Important Local Variables. None.

c. Functions and Tasks Performed by This Subroutine. This subroutine reads delayed data for kinetics options 1 or 2 from data set XS.DELAY. It skips the first three records and reads the decay constants (DEC CON) from the fourth record and the delayed-neutron spectrum (DICHI) from the fifth. (Delayed data are not required by the SYN2D module.)

d. Subroutines Called by This Subroutine. None.

e. Subroutine Calling This Subroutine. RCOMP.

43. Subroutine RGEOM(\*)

a. Arguments. The asterisk represents an error return to a specified statement number in the calling subroutine.

b. Important Local Variables

<u>Name</u>	<u>Type</u>	<u>Definition</u>
NTAPE	I*4	Data set reference number for GEOM.
LAREA	I*4	Length of area record (record 06 of GEOM).
LZONE	I*4	Length of zone record (record 07 of GEOM).
NFIN	I*4	Number of finite geometry type.
NIL	I*4	Number of finite directions.

c. Functions and Tasks Performed by This Subroutine. This subroutine reads geometry data from data set GEOM and modifies it for use by the two-dimensional diffusion and synthesis modules. Only record 1 is actually read within RGEOM; record types 2-9 are read in RMESH.

RGEOM modifies the geometry type NGEOM read from data set SP.CICN, which should be the same as that read from GEOM, so that its possible values are 1, 2, 3, or 4. (The geometry type is read from SP.CICN, so that any change made to a type 03 card in A.NIP during a MODIFY will be found in SP.CICN; hence, if GEOM is not being modified by any other card type, it can remain an old data set.)

The space needed for geometry-related arrays is then allocated, and RMESH is called to read record types 2-9 and modify the contents appropriately. IVOL and IAREA are initialized, and the geometry-related data are printed by PGEOM if the output option flag KOUT is greater than zero.

d. Subroutines Called by This Subroutine. SNIFF (ARC System subroutine), RMESH, PGEOM, ERRMSG.

e. Subroutine Calling This Subroutine. SYNIN.

44. Subroutine RGROUP(DC,REM,FSCMP,NUFIS,CHI,DNSCT,UPST,SCTLIM,SCTXS,SETCHI,DECCON,DICHI,DCCHI,FISXS,CMPNAM,BLKCOMP,BLKGRP,CMAX,FSCMAX,CHIDIM,NFAM,ISCHI,SCTDIM,NFSCMP,CMPNO,NBLACK,NTAPE,\*)

a. Arguments. The first 17 arguments are defined in common block BLKSTR; arguments 18-21, 23, and 26 can be found in common block SINGLE. The remaining arguments are described below.

<u>Name</u>	<u>Type</u>	<u>Definition</u>
ISCHI	I*4	Set-chi flag. 0--No set-wide $\chi$ . 1--Set-wide $\chi$ -vector. GMAX--Set-wide $\chi$ -matrix.

<u>Name</u>	<u>Type</u>	<u>Definition</u>
NFSCMP	I*4	Index of this composition in arrays of fissionable data.
CMPNO	I*4	Number of this composition.
NTAPE	I*4	Data-set reference number for XS.C.MIN.
*	-	Error return to calling subroutine.

b. Important Local Variables

<u>Name</u>	<u>Type</u>	<u>Definition</u>
ICHI	I*4	Fission-spectrum flag for this composition. - 1-- Uses set $\chi$ . 0-- Nonfissionable. 1-- Uses own $\chi$ -vector. GMAX-- Uses own $\chi$ -matrix.
CLIM1	I*4	Position of first element of fission spectrum for this composition in array CHI.
CLIM2	I*4	Position of last element of fission spectrum for this composition in array CHI.
NB	I*4	Black composition flag. 0-- This composition not defined as black. 1-- This composition defined as black for some group or groups.
SCTDN	I*4	Number of groups of downscattering for given group in this composition.
SCTUP	I*4	Number of groups of upscattering for given group in this composition.
SLIM1	I*4	Position of first element of scattering cross section for given group in dummy array.
SLIM2	I*4	Position of last element of scattering cross section for given group in dummy array.
IH	I*4	Position of Hth element in scattering array for given group G.
IK	I*4	Position of Kth element in scattering array for given group G.
DUMSCT	R*8	Dummy variable used in flipping positions of scattering-array elements for given group.
G	I*4	Position of Gth (self-scattering) element in scattering array for given group G.

<u>Name</u>	<u>Type</u>	<u>Definition</u>
SUM	R*8	Sum of delayed data over families, to be added to fission spectrum.
GSUB	I*4	Scattering-array index.

c. Functions and Tasks Performed by This Subroutine. This subroutine reads a composition block from XS.C.MIN for all groups G of a given composition CMPNO and modifies the data for use by all diffusion modules.

RGROUP first reads the initial record of the composition block, containing the fission-spectrum flag ICHI and the number of up-scattering and downscattering groups defined for each group, UPSCT and DNSCT. Using the fission-spectrum flag, the locations for the fission-spectrum elements for this composition are set aside in the array CHI, if any are needed. Elements for this composition are then all set to zero.

Next, the subroutine checks to see if this composition is black for any groups, by comparing this composition name with those defined as black (BLKCOMP). If any match is found, a flag NB is set, and the group limits, for that composition are set up in BLKGRP, if either or both is zero. If the first group limit is zero, the limits are set to 1 and GMAX; if the first is nonzero and the second is zero, the second is set to the first, so that the condition applies to only one group. The composition name is compared to all compositions defined as black, even after a match is found, so that group limits will be made uniform for all occurrences of definition of this composition as a black composition. (A composition name might appear more than once if it were defined as black for two or more noncontiguous sets of groups, e.g., for G = 1 to 7 and for G = 16.) Black composition data are not defined for SYN2D.

The subroutine then begins to perform a series of tasks for each group in this composition. It sets up the locations in the scattering array assigned to the band associated with this composition and group (SLIM1, SLIM2), and also the maximum scattering bandwidth which will be associated with the scattering for this composition after the data have been packed, defined by  $SCTLIM(1,CMPNO) + SCTLIM(2,CMPNO) + 1$ . Here  $SCTLIM(1,CMPNO)$  is the maximum number of groups of downscattering, and  $SCTLIM(2,CMPNO)$  is the maximum number of groups of upscattering.

The cross-section data for this composition and group are then read according to the proper format, depending on whether the composition is fissionable or nonfissionable, on whether the fission spectrum is present as a matrix or vector or the set-wide  $\chi$  is used, and on whether delayed data for an alpha calculation are to be read. If the set-wide fission spectrum is to be used for this composition, the fission spectrum for this composition and group in the array CHI is set equal to the set-wide  $\chi$ .

The diffusion coefficient for this composition and group is then set up using the transport coefficient:  $D_{c,g} = 1/(3\sigma_{TR})$ , unless  $\sigma_{TR} = 0$ , in which case  $D_{c,g}$  is set to  $1.0E + 15$ . Then, if this composition was defined as black over any group or groups, the subroutine checks to see if this group is between the group limits. If it is, the diffusion coefficient  $D_{c,g}$  is set to zero.

The subroutine then reverses the order of the elements in the scattering array for this composition and group, since they are read in order from the scattering from highest-number group into  $g$  through scattering from the lowest-number group into  $g$  and are stored in the opposite order, and then sets the self-scattering term to zero. This completes the list of tasks performed for each group for this composition.

Finally, if delayed data for an alpha calculation is present, the delayed fission-spectrum terms are added into the fission-spectrum array CHI.

- d. Subroutine Called by This Subroutine. ERRMSG.
  - e. Subroutine Calling This Subroutine. RCOMP.
45. Subroutine RIEMAN(DY,RESULT,Y,NUMRRJ,RRFJ,HP,HADJP,HG,HADJG,RRJLOC,NAB,JMAX,NGKMX,LPART)

Entry points

Entry: RIEHAT(NREAL,K,HP,HADJP)

Entry: RIEINT(NREAL,NADJT,K,HG,HP,HADJG,HADJP)

a. Arguments. The first nine arguments of the main calling sequence are defined in common block BLKSTR; the last three arguments are defined in common block SINGLE. The remaining arguments are defined below.

<u>Name</u>	<u>Type</u>	<u>Definition</u>
NAB	I*4	NALPHA + NBETA (refer to common block SINGLE).
NREAL	I*4	The number of real trial functions in array HG.
K	I*4	Present synthesis region number.
NADJT	I*4	The number of adjoint trial functions in array HADJG.

b. Important Local Variables

<u>Name</u>	<u>Type</u>	<u>Definition</u>
NUMBER	I*4	The number of Y-direction refined intervals in synthesis region K.
IPOINT	I*4	Location in array RRFJ where the first Y-direction refined interval number is stored.
J1	I*4	First interval of the Y-direction refined region L.
J2	I*4	Last interval of the Y-direction refined region L.
A1	R*8	The leading coefficient of $H_n = A_{1Y} + A_2$ .
A2	R*8	The second coefficient of $H_n = A_{1Y} + A_2$ .
B1	R*8	The leading coefficient of $H_m^* = B_{1Y} + B_2$ .
B2	R*8	The second coefficient of $H_m^* = B_{1Y} + B_2$ .
A	R*8	The leading coefficient of the combined product polynomial.
B	R*8	The second coefficient of the combined product polynomial.
C	R*8	The last coefficient of the combined product polynomial.
XMY	R*8	$\hat{y}_{j+1} - \hat{y}_j$ , where $\hat{y}_{j+1}$ and $\hat{y}_j$ are the upper and lower limits of integration.
XPY	R*8	$\hat{y}_{j+1} + \hat{y}_j$ , with the above comment applying.
XY	R*8	$\hat{y}_j \hat{y}_{j+1}$ , with the above comment applying.

c. Functions and Tasks Performed by This Subroutine. This subroutine performs all the integrations the problem requires. The two different types of integrals generated are

$$a) J_{(r_i)}^{mn} = \int_{y_{i-1}}^{y_i} H_m^*(y) H_n^*(y) y^{1-NAB} dy \quad 1 \leq m, n \leq NREAL,$$

and

$$b) I_{(r_i)}^{mn} = \int_{y_{i-1}}^{y_i} H_m^*(y) H_n(y) y^{1-NAB} dy \quad \begin{matrix} 1 \leq m \leq NADJT, \\ 1 \leq n \leq NREAL, \end{matrix}$$

where NAB is either 0 or 1, depending upon geometry,  $r_i$  is the  $i$ th Y-direction refined interval in synthesis region K, and  $y_q$  are the mesh cell boundaries. The partial integrals J and I are calculated by entry points RIEHAT and RIEINT, respectively. Refer to Section II.B and II.C as well as to the documentation of subroutine RRCALC for the definition of partial integrals and Y-direction refined intervals.

The partial integral  $J_{(r_i)}^{mn}$  when NAB is zero is approximated by

$$\hat{J}_{(r_i)}^{mn} = \sum_{j=\ell}^{\bar{\ell}} \frac{1}{2} \delta_j \left[ H_m^{*'}(y_j) H_n'(y_j) + H_m^{*'}(y_{j-1}) H_n'(y_{j-1}) \right],$$

where  $\delta_j$  is the length of the Y-direction interval  $j$  and the intervals  $j$  are all the Y-direction intervals in the Y-direction refined interval  $r_i$  whose first and last intervals are  $\ell$  and  $\bar{\ell}$ , respectively. If NAB is one, then  $J_{(r_i)}^{mn}$  is approximated by

$$\begin{aligned} \hat{J}_{(r_i)}^{mn} = & \sum_{j=\ell}^{\bar{\ell}} \frac{1}{4} \delta_j (y_j + y_{j+1}) \left[ H_m^{*'}(y_j) H_n'(y_j) + H_m^{*'}(y_{j-1}) H_n'(y_{j-1}) \right] \\ & + \frac{1}{8} \delta_j^2 \left[ H_m^{*'}(y_j) H_n'(y_j) - H_m^{*'}(y_{j-1}) H_n'(y_{j-1}) \right]. \end{aligned}$$

The partial integrals are temporarily stored in array RESULT and are written out on the data set whose reference number is LPART when all of the partial integrals of this type for the Kth synthesis region with all of its Y-direction refined intervals have been calculated. The arrays HP and HADJP contain the derivatives of the functions H and  $H^*$ , respectively, and hence the functions  $H'$  and  $H^{*'}$  are piecewise constant.

For the calculation of the integrals I, the assumption is made that both H and  $H^*$  are linear between mesh-cell centers. Hence the partial integral  $I_{(r_i)}^{mn}$  is approximated by  $\hat{I}_{(r_i)}^{mn}$ , which is defined below with  $\rho$  equal to  $1 - \text{NAB}$ :

$$\begin{aligned} \hat{I}_{(r_i)}^{mn} = & \sum_{j=\ell}^{\bar{\ell}} \int_{y_{j-1}}^{y_j} \left[ H_m^{*'}(y) \left( y - y_j - \frac{\delta_j}{2} \right) + H_m^*(y_j) \right] \left[ H_n'(y) \left( y - y_j - \frac{\delta_j}{2} \right) \right. \\ & \left. + H_n(y_j) \right] y^\rho dy. \end{aligned}$$

Here  $H_m^{*'}$  and  $H_n'$  can each assume only two values in each interval, the numbers  $y_q$  are mesh-cell boundaries, and the  $j$  intervals all lie in the  $r_i$ th Y-direction refined region. Since by assumption the trial functions are linear between mesh-cell centers, the above approximation for  $I_{(r_i)}^{mn}$  is replaced by

$$\begin{aligned}
\hat{I}_{(r_i)}^{mn} = & \int_{y_{\ell-1}}^{\bar{y}_{\ell}} \left[ H_m^{*'}(y_{\ell}) \left( y - y_{\ell} - \frac{\delta_{\ell}}{2} \right) + H_m^*(y_{\ell}) \right] \left[ H_n'(y_{\ell}) \left( y - y_{\ell} - \frac{\delta_{\ell}}{2} \right) \right. \\
& + H_n(y_{\ell}) \left. \right] y^{\rho} dy + \int_{\bar{y}_{\bar{\ell}}}^{y_{\bar{\ell}}} \left[ H_m^{*'}(y_{\bar{\ell}}) \left( y - y_{\bar{\ell}} - \frac{\delta_{\bar{\ell}}}{2} \right) \right. \\
& + H_m^*(y_{\bar{\ell}}) \left. \right] \left[ H_n'(y_{\bar{\ell}}) \left( y - y_{\bar{\ell}} - \frac{\delta_{\bar{\ell}}}{2} \right) + H_n(y_{\bar{\ell}}) \right] y^{\rho} dy \\
& + \sum_{j=\bar{\ell}}^{\bar{\ell}-1} \int_{\bar{y}_j}^{\bar{y}_{j+1}} \left[ H_m^{*'}(y_j) \left( y - y_j - \frac{\delta_j}{2} \right) + H_m^*(y_j) \right] \left[ H_n'(y_j) \left( y - y_j - \frac{\delta_j}{2} \right) \right. \\
& \left. + H_n(y_j) \right] y^{\rho} dy.
\end{aligned}$$

Note that  $\bar{y}_q$  are mesh-cell centers, while  $y_{\rho}$  are mesh-cell boundaries.

Each term of every integrand is first expressed in the form  $f = ay + b$ . These polynomials are then multiplied and integrated, with the internal function FRIEMN used to calculate the value of each integral. FRIEMN calculates  $F(Y) - F(X) = XMY \{ XPY^2 - 2^{\rho}XY \} A + XPY * B + C - \rho * B * XY$ . After all the partial integrals for all Y-direction refined intervals in synthesis region K have been calculated, they are written out on the data set whose reference number is LPART.

d. Subroutines Called by This Subroutine. None.

e. Subroutine Calling This Subroutine. PROCES.

46. Subroutine RKIN(DECCON,DICHI,DCCHI,NFAM,GMAX,M,K,\*)

a. Arguments. The first three arguments are located in common block BLKSTR; the next three are defined in common block SINGLE, with M listed under MTRCHI. K is the data-set reference number for A.KIN2D. The asterisk indicated an error return to the calling subroutine.

b. Important Local Variables. None.

c. Functions and Tasks Performed by This Subroutine. This subroutine reads the ARC System data set A.KIN2D. RKIN is not called when using the synthesis module, since it has no kinetics option.

d. Subroutine Called by This Subroutine. PAGHED.

Subroutine Calling This Subroutine. RCOMP.

47. Subroutine RMESH(REGMSH,CMPMSH,MSHREG,MSHCMP,CMPREG,CRDUM,X,Y,DX,DY,BSQ,REGHHT,EXTHHT,REGNAM,LAREA,LZONE,NFIN,NIL,RMAX,IMAX,JMAX,NTAPE,\*)

a. Arguments. The first 14 arrays are located in common block BLKSTR; arguments 19-21 are defined in common block SINGLE. The remaining arguments are defined below.

<u>Name</u>	<u>Type</u>	<u>Definition</u>
LAREA	I*4	Length of area record (record 06 of GEOM).
LZONE	I*4	Length of zone record (record 07 of GEOM).
NFIN	I*4	Number of finite geometry type.
NIL	I*4	Number of directions of finite geometry.
NTAPE	I*4	Data-set reference number for GEOM.
*	-	Error return to calling subroutine.

b. Important Local Variables

<u>Name</u>	<u>Type</u>	<u>Definition</u>
NR	I*4	Indicates the record number where a read error occurred.

c. Functions and Tasks Performed by This Subroutine. This subroutine reads record types 2-9 of data set GEOM and modifies the data for use by the synthesis module.

It first reads mesh-line locations from record type 2 into arrays X and Y and then sets up XL, XR, YT, and YB and the mesh-interval lengths DX and DY. It then reads region-to-mesh correspondence (record type 3), composition-to-mesh correspondence (record type 4), and composition-to-region correspondence (record type 5) into the temporary I\*4 arrays MSHREG, MSHCMP, and CRDUM and transfers them to the I\*2 arrays REGMSH, CMPMSH, and CMPREG for permanent storage. Record types 6 and 7 (area and zone definitions) are skipped if present.

Finite geometry data, including buckling, actual half-height and extrapolated half-height, are then read into the arrays BSQ, REGHHT, and EXTHHT from record type 8 if it is present. If buckling data for a given region R are not present, BSQ(R) is set to zero, and for any region and direction in which BSQ(R) is zero, both the actual and the extrapolated half-heights are set to 0.5.

Finally, the region names are read from record type 9 into array REGNAM.

- d. Subroutine Called by This Subroutine. ERRMSG.
- e. Subroutine Calling This Subroutine. RGEOM.
48. Subroutine RRCALC(SYNMSH,REGMSH,REFREG,IMAX,JMAX,RRMAX,LEN,KMAX,PHYREG,RRF,RRFJ,RRJLOC,NUMRRJ,NUMMAX,MANY)

a. Arguments. Arrays 1-3 and 9-12 are defined in common block BLKSTR, with array REFREG listed as RR and array RRF listed as RRRFRST. The constants numbered 4-6 and 8 are listed in common block SINGLE. The remaining arguments are defined below.

<u>Name</u>	<u>Type</u>	<u>Definition</u>
LEN	I*4	The number of contiguous I*2 words used in array RRFJ starting with RRFJ(1) (used to redefine the storage for RRFJ).
NUMMAX	I*4	The maximum number of Y-direction refined intervals per synthesis region taken over all synthesis regions (used to define storage for array RESULT).
MANY	I*4	The maximum number of refined regions per synthesis region taken over all synthesis regions (used to define storage for arrays NUSIGF and SCTCOF).

b. Important Local Variables

<u>Name</u>	<u>Type</u>	<u>Definition</u>
IRRF	I*4	Pointer for array RRF to indicate where the first interval number of the next refined region can be stored.
IRR	I*4	First interval of a synthesis region.
JRR	I*4	Last interval of a synthesis region.
IRREND	I*4	Last refined region of a synthesis region K.
IPLACE	I*4	The position in RRFJ where the first interval of the next Y-direction interval is stored.

c. Functions and Tasks Performed by This Subroutine. This subroutine calculates the X-direction interval-to-refined region correspondence and the Y-direction refined intervals per synthesis region. The refined regions are calculated from left to right, with the first interval in refined region 1. Interval  $i + 1$  lies in a different refined region from

interval  $i$  if their respective synthesis regions or their respective Y-direction cuts differ. A Y-direction cut for interval  $i$  is the set of points  $j$ ,  $1 \leq j \leq J$ , and the reactor region assignment  $\{R_j^i\}_{j=1}^J$  for these cuts. Cuts are identical when  $R_j^i = R_j^p$ ,  $1 \leq j \leq J$  and  $i \neq p$ . Each synthesis region will contain a number of refined regions, each of which by definition contains identical cuts. Let  $\{R_j^\ell\}_{j=1}^J$ ,  $\ell = 1, \dots, N$ , be the reactor-region assignments for the  $N$  refined regions in synthesis region  $k$ . Now if  $\{\bar{R}_\ell\}$  is the set of points  $j$  with the property that  $R_{j-1}^\ell \neq R_j^\ell$  for each  $\ell$ , then  $\bigcup_\ell \{\bar{R}_\ell\}$  plus the point  $j = 1$  is the set of first Y-direction intervals for each Y-direction refined interval in synthesis region  $k$ .

The integrations performed in subroutine PROCES are performed over these refined intervals for each synthesis region.

d. Subroutines Called by This Subroutine. None.

e. Subroutine Calling This Subroutine. RSDEF.

49. Subroutine RSDEF(\*)

a. Arguments. The asterisk represents an error return to the calling subroutine.

b. Important Local Variables

<u>Name</u>	<u>Type</u>	<u>Definition</u>
MAXNUM	I*4	Input value used by POINTR routines to allocate storage, MAXNUM $\geq$ NGKMX.
LLEN	I*4	Value returned by RRCALC as the amount of storage required for array RRFJ, LLEN $\leq$ IMAX*JMAX.
NUMMAX	I*4	The largest number of refined intervals in any synthesis region.
MANY	I*4	The largest number of refined regions in any synthesis region.
NTRL	I*4	Value returned by RRCALC as the amount of storage required for array NTRIAL, NTRL $\leq$ GMAX*KMAX*MAXNUM.
ICORE	I*4	Flag passed to LIB to indicate whether, when generating the trial-function libraries, all the trial functions can be core-contained. ICORE = 1-- Functions can be core-contained. ICORE = 0-- Functions cannot be core-contained.

<u>Name</u>	<u>Type</u>	<u>Definition</u>
JFLAG	I*4	Error checking flag, set initially to zero. IFLAG = 0,2--No problem. IFLAG = 1--The consistency keys on the trial-function libraries do not match.

c. Functions and Tasks Performed by This Subroutine. This subroutine is a driver routine. RSDEF allocates storage, reads more of the module-dependent data, and calls other routines. The called routines define the synthesis regions and trial functions per region from the A.SYN2D data set, calculate the refined regions and refined intervals, generate the module-required trial-function libraries, and finally calculate the partial integrals over each refined interval. The original storage allocation for several of the arrays is redefined after the actual space required has been determined. Finally, arrays NN and NNP are equivalenced, since the present version of the code uses routines where the array NNP was defined.

d. Subroutines Called by This Subroutine. PAGHED, ERRMSG, SYNDEF, SNIFF (ARC System subroutine), LIB, PROCES, DSRNCK, CLOSE.

e. Subroutine Calling This Subroutine. SYNIN.

#### 50. Subroutine RVEL(VEL,GMAX,\*)

a. Arguments. Array VEL is listed in common block BLKSTR, GMAX is defined in common block SINGLE, and the asterisk is an error return to the calling subroutine.

#### b. Important Local Variables

<u>Name</u>	<u>Type</u>	<u>Definition</u>
NTAPE	I*4	Data-set reference number for XS.ISO.
NGROUP	I*4	Number of energy groups defined on XS.ISO.
NISO	I*4	Number of isotopes defined on XS.ISO.
ISO	R*8	Dummy variable used to read isotope names from XS.ISO.
LOC	I*4	Dummy variable used to read number of records in second file to be skipped in order to read isotope data for given isotope I.
NGP1	I*4	NGROUP + 1, for use in reading record type 3 of XS.ISO.
IC	I*4	Fission-spectrum flag for isotope set.

<u>Name</u>	<u>Type</u>	<u>Definition</u>
E	R*8	Dummy variable used to read energy boundaries of groups.
U	R*8	Dummy variable used to read lethargy boundaries of groups.

c. Functions and Tasks Performed by This Subroutine. This subroutine reads neutron speeds for groups from record type 3 of data set XS.ISO if the problem involves an  $\alpha$ -search, a search for a prescribed  $\alpha$ , or a nonzero  $\alpha$ . If none of these conditions is met, the speeds are set to 1 in all groups. If the speeds are read from XS.ISO and if the output flag KOUT is greater than zero, the speeds and the data-set reference number are printed.

d. Subroutines Called by This Subroutine. SNIFF (ARC System subroutine), PAGHED, ERRMSG.

e. Subroutine Calling This Subroutine. RCOMP.

51. Subroutine RXSC01 (CMPNAM,N,\*)

a. Arguments. Array CMPNAM is listed in common block BLKSTR, N is the data-set reference number for XS.C.MIN, and the asterisk represents an error return to the calling subroutine.

b. Important Local Variables. None.

c. Functions and Tasks Performed by This Subroutine. This subroutine reads record type 1 of XS.C.MIN to get the composition names.

d. Subroutine Called by This Subroutine. ERRMSG.

e. Subroutine Calling This Subroutine. RCOMP.

52. Subroutine SINCAL(\*,SYNMSH,NN,PHI,FLX,NUSIGF,REFREG, WINT,JUNK,IMAX,KMAX,GMAX,NGKMX,NNP,PHI2).

a. Arguments. The first eight arguments following the asterisk and the last two arguments are defined in common block BLKSTR, with REFREG and NNP listed as RR and NBP, respectively. The remaining arguments are defined in common block SINGLE. The asterisk indicates an error return to the calling subroutine.

b. Important Local Variables

<u>Name</u>	<u>Type</u>	<u>Definition</u>
-------------	-------------	-------------------

II	I*4	Pointer for array UINT
----	-----	------------------------

<u>Name</u>	<u>Type</u>	<u>Definition</u>
12	I*4	Pointer for array HINT in common block BLKSTR.
13	I*4	Pointer for array AREA in common block BLKSTR.
LAMDA	R*8	k-effective iterate.
RDX	R*8	$1/k^{(n-1)}$ -effective.
ZLAMUP	R*8	$\bar{\lambda} = \max_{g,i,n} \left[ \frac{\psi_{g,i,n}^{(\ell)}}{\psi_{g,i,n}^{(\ell-1)}} \right]$ . If $\psi_{g,i,n}^{(\ell)} \frac{\text{SUM}(2)}{\text{GIN}} \leq \text{EPSLAM}$ , the ratio is not computed.
ZLAMDN	R*8	$\min_{g,i,n} \left[ \frac{\psi_{g,i,n}^{(\ell)}}{\psi_{g,i,n}^{(\ell-1)}} \right]$ . See comment above.
GLOW	I*4	Lowest energy-group scattering into group G.
GUP	I*4	Highest energy-group scattering into group G. (Since there is no upscattering, GUP = G.)
SUM(1)	R*8	$\sum_{g,i,n} \left  \psi_{g,i,n}^{(\ell)} - \psi_{g,i,n}^{(\ell-1)} \right $ .
SUM(2)	R*8	$\sum_{g,i,n} \left  \psi_{g,i,n}^{(\ell)} \right $ .
SUM(3)	R*8	$\langle \psi^{(\ell)}, \psi^{(\ell)} \rangle$ i.e., inner product of $\psi^{(\ell)}$ with itself.
SUM(4)	R*8	$\langle \psi^{(\ell)}, \psi^{(\ell-1)} \rangle$ .
RESULT(1)	R*8	k-effective for last iteration, $k^{n-1}$ .
RESULT(2)	R*8	$k^n - k^{n-1}$ .
RESULT(3)	R*8	$\bar{\lambda}$ .
RESULT(4)	R*8	$\underline{\lambda}$ .
RESULT(5)	R*8	$\bar{\lambda} - \underline{\lambda}$ .
RESULT(6)	R*8	SUM(1).
RESULT(7)	R*8	SUM(2).
RESULT(8)	R*8	SUM(1)/[SUM(2)*GIN].

Note the array RESULT holds this data for printing out. However, RESULT(7) is modified for computing  $\bar{\lambda}$  and  $\underline{\lambda}$ .

c. Functions and Tasks Performed by This Subroutine. This subroutine performs the power iterations required to obtain the dominant eigenvalue and eigenvector for this problem. Refer to Eqs. 61-71 in Section II.B.4 for a detailed description of the mathematics involved.

After a call to SNIFF to check on the disposition of the mixing-functions data set, FR.TG is read if old and used as the initial approximation for this problem. If FR.TG is not old, the first eigenvalue and each component of the eigenvector are set to one. Each iteration consists of solving the equation

$$P_g \psi_g = f_g, \quad g = 1, \dots, G,$$

for  $\psi_g$ . For each  $g$ , the generation of  $f_g$  proceeds in the following manner: The fission matrices  $F_{r(i)}^{g'g}$  are read for all  $g'$ , where  $1 \leq g' \leq G$  and  $r(i)$  is a refined region. Then the vectors  $q_i^g$  are defined as

$$q_i^g = \sum_{g'=1}^G \frac{w_i}{\lambda^{(n-1)}} F_{r(i)}^{g'g} \psi_{g'i}^{(n-1)}, \quad 1 \leq i \leq I,$$

where  $\psi_{g'i}$  is a vector of length  $N_i$  and  $w_i = (\rho_i^\alpha - \rho_{i-1}^\alpha)/2$  with  $\rho_i$  as the right mesh-cell boundary and  $\alpha$  is NALPHA from common block SINGLE. Note that the refined regions change as  $i$  increases, necessitating the reading of more fission matrices. Next the scattering matrices  $S_{r(i)}^{g'g}$  are read for  $g_L \leq g' < g$  and the vectors

$$p_i^g = \sum_{g'=g_L}^{g-1} w_i S_{r(i)}^{g'g} \psi_{g'i}^{(n-1)}$$

are calculated. Finally, the vector  $f_g = (f_g^1, \dots, f_g^I)$ , with

$$f_g^i = p_i^g + q_i^g$$

is formed. The actual calculation of the vector  $p_g^{-1} f_g$  is performed by the routines SWEEP1 and SWEEP2. Both the fission and scattering matrices are stored in array NUSIGF, while vector  $f_g$  is stored in array FLX and  $\psi$  is stored in array PHI. The LAMDA of the code is actually the desired  $k$ -effective. The matrices  $U_i^{-1}$  and  $V_i$  are read from the data set whose reference number is JLIB and stored in the same location in array BLK; the matrices  $H_i$  are read from the data set whose reference number is NLIB. The iterations are terminated when one of the following conditions is encountered:

- (1) An error the code checks for has been encountered.
- (2) Less than 30 sec of computer time remains for the completion of this problem.
- (3) The required number of iterations has been completed.
- (4) The following convergence criteria have been satisfied:

$$|k^n - k^{n-1}| \leq \text{EPSKEF},$$

$$|\lambda_{\text{up}} - \lambda_{\text{dn}}| \leq \text{EPSLAM},$$

and

$$\frac{\sum_{g,i,n} |\psi_{g,i,n}^{(\ell)} - \psi_{g,i,n}^{(\ell-1)}|}{\text{GIN} \sum_{g,i,n} |\psi_{g,i,n}^{(\ell)}|} \leq \text{EPOFLX},$$

where G is the number of energy groups, I is the number of mesh points in the X direction, and N is the maximum number of trial functions used in any synthesis region for any group. The numbers EPSKEF, EPSLAM, and EPOFLX are user-supplied.

After the iterations have ceased, the data set FR.TG is written.

d. Subroutines Called by This Subroutine. MADD, SWEEP1, SWEEP2, PAGHED, GMPRD, TLEFT (IBM function), ERRMSG, NUMMLT, SNIFF (ARC System subroutine).

e. Subroutine Calling This Subroutine. SYNCAL.

53. Subroutine SINOUT(TG,FLX,HG,SYNMSH,NN,IMAX,JMAX,GMAX,KMAX,NGKMX,NALPHA,NBETA,NLIB)

a. Arguments. The first five arrays are defined in common block BLKSTR; the remaining arguments are defined in common block SINGLE.

b. Important Local Variables

<u>Name</u>	<u>Type</u>	<u>Definition</u>
AA(13)	R*8	Alphanumeric data.
BB(9)	R*8	Alphanumeric data.
CC(30)	R*8	Alphanumeric data.
ROWT	R*8	Row title used by TWODPR.
COLT	R*8	Column title used by TWODPR.
K	I*4	Synthesis region indicator.
G	I*4	Present energy group number.
NGK	I*4	Number of trial functions for energy group G and synthesis region K.

d. Functions and Tasks Performed by This Subroutine. This subroutine sets up information for the printout routine TWODPR, calculates the reconstituted flux

$$\Phi_{gk}(x,y) = \sum_{n=1}^{N_{gk}} H_{gk}^n(y) T_g^n(x)$$

for all energy groups  $g$  and synthesis regions  $k$ , and writes it out on the data set whose reference number is NLIB. It also prints out the mixing functions  $T_g$  and, if the print flag KOUT is greater than zero, it prints out the real trial functions  $H_{gk}$ .

d. Subroutine Called by This Subroutine. TWODPR.

e. Subroutine Calling This Subroutine. SYNOUT.

#### 54. Subroutine STORBC(SAVE,BNDC,NBC)

a. Arguments

<u>Name</u>	<u>Type</u>	<u>Definition</u>
SAVE(11)	R*4	Address of MSHTYP from subroutine RBNDC (location of common block BCBLK).
BNDC (11,NBCDEF)	R*4	Boundary-condition data from data set BC. (Refer to common block BLKSTR).
NBC	I*4	Number of boundary-condition record just read in RBNDC.

b. Important Local Variables. None.

c. Functions and Tasks Performed by This Subroutine. For each boundary condition NBC, NBC = 1, ..., NBCDEF, defined in data set BC, this subroutine stores the 11 boundary-condition definition terms in the locations (1,NBC), ..., (11,NBC) of the array BNDC. The boundary-condition terms are obtained from the common block BCBLK through referencing its first element, MSHTYP. The first one and last four elements of each 11 in BNDC are R\*4. The rest are I\*4.

d. Subroutines Called by This Subroutine. None.

e. Subroutine Calling This Subroutine. RBNDC.

55. Subroutine SWEEP1(UINT,AREA,NN,SYNMSH,HINT,NGKMX,IMAX,GMAX,KMAX,FLX)

Entry points

Entry: SWEP1(G)

a. Arguments. The first five arguments and the last argument are defined in common block BLKSTR; the remaining arguments are defined in common block SINGLE. The argument G in entry point SWEP1 is the present energy-group number.

b. Important Local Variables. None.

c. Functions and Tasks Performed by This Subroutine. We have  $P_g \hat{\Phi}_g = F$ , where  $P_g = L_g \hat{U}_g$ ,  $L_g$  being lower triangular and  $\hat{U}_g$  being upper triangular. (Note that  $P$  is a tridiagonal matrix whose elements are matrices.) This routine begins to invert  $P$ , i.e., it calculates  $W = L^{-1}F$ . (Note that  $FLX = F$ , with  $F = (f_1 \dots f_{IMAX})$  and  $W = (w_1 \dots w_{IMAX})$ .) The actual inversion of  $L$  is performed in subroutine MTGEN2. The calculation of  $w_i$  is performed as follows for each group:

$$w_i = U_i^{-1}f_i \quad \text{for } i = 1,$$

$$w_i = U_i^{-1}(f_i + H_i w_{i-1}) \quad \text{for } i = 2, 3, \dots, IMAX.$$

For a more detailed description, refer to Section II.B.

The array FLX that the subroutine returns is the new  $W$ , which is then operated upon in SWEEP2. Thus, the array FLX contains first  $F$  and then  $W$ . The calling sequence just initializes the subroutine.

d. Subroutines Called by This Subroutine. GMPRD, MOVE, MADD.

e. Subroutine Calling This Subroutine. SINCAL.

56. Subroutine SWEEP2(AREA,NN,SYNMSH,VINT,NGKMX,IMAX,GMAX,KMAX,FLX)

Entry points

Entry: SWEP2(G)

a. Arguments. The first four arguments and the last are defined in common block BLKSTR, with VINT listed as GINT. The remaining arguments are defined in common block SINGLE. The entry-point argument G is the present energy-group number.

b. Important Local Variables. None.

c. Functions and Tasks Performed by This Subroutine. We have  $L_g U_g \Phi_g = F_g$ ,  $L_g$  being lower triangular and  $U_g$  being upper triangular. (Note that  $L_g U_g$  is a tridiagonal matrix whose elements are matrices.) In SWEEP1 we inverted  $L_g$  and obtained  $U_g \Phi_g = L_g^{-1} F_g = W_g$ ; now we will obtain  $\Phi_g = U_g^{-1} W_g$ . The actual inversion of  $U_g$  is done in subroutine MTGEN2. The calculation of  $\Phi_g$  proceeds as follows for each group, with  $W_g = (w_1, \dots, w_{\text{IMAX}})$ :

$$\Phi_{g,\text{IMAX}} = w_{g,\text{IMAX}} \quad \text{for } i = \text{IMAX};$$

$$\Phi_{g,i} = w_{g,i} + w_{g,i} w_{g,i+1} \quad \text{for } i = \text{IMAX} - 1, \dots, 2, 1.$$

Refer to Section II.B for a more detailed description. The array FLX that the subroutine returns is actually  $\Phi_g$ , although initially FLX held  $W_g$ . When we have finished,  $\Phi_g$  represents one iteration toward an approximation of the mixing functions. The calling sequence just initializes the subroutine.

d. Subroutines Called by This Subroutine. GMPRD, MADD.

e. Subroutine Calling This Subroutine. SINCAL.

57. Program SYN2D (Main program)

a. Arguments. None.

b. Important Local Variables. None.

c. Functions and Tasks Performed by This Program. This program is the main driver for the module. It calls all the subroutines either directly or indirectly. It also prints out a message telling how long execution of the module took.

d. Subroutines Called by This Program. CLOSE, SYNIN, D2DCAL, SYNOUT, FREE.

e. Program Calling This Program. STP012, the two-dimensional synthesis path.

58. Subroutine SYNCAL(\*)

a. Arguments. The asterisk indicates an error return to the calling subroutine.

b. Important Local Variables. None.

c. Functions and Tasks Performed by This Subroutine. This subroutine is a driver for the power iterations. It sets up storage for the arrays that will be required by the iteration subroutine, calculates

$$\omega_i = \begin{cases} \delta_i r_i & \text{if NALPHA} = 1, \text{ RZ geometry} \\ \delta_i & \text{if NALPHA} = 0, \text{ XY or ZR geometry} \end{cases}$$

and prints out a message telling how long it took to execute the subroutine.

d. Subroutines Called by This Subroutine. ERRMSG, SINCAL, TLEFT (IBM function).

e. Subroutine Calling This Subroutine. D2DCAL.

59. Subroutine SYNDEF(GMAX,KMAX,IMAX,SYNMSH,LIBFLX,NN,X,NZERO,NTRIAL,XSYNPT,MAXNUM,NTRL,\*)

a. Arguments. The first three arguments are defined in common block SINGLE; the next seven arrays are defined in common block BLKSTR. The integer MAXNUM is defined in the data-set specifications for A.SYN2D card type 04 columns 19-24. NTRL is returned as the number of I\*2 locations used in array NTRIAL. The asterisk represents an error return to the calling subroutine.

b. Important Local Variables

<u>Name</u>	<u>Type</u>	<u>Definition</u>
GINT	I*4	First group for which the trial-function input information applies.
GFIN	I*4	Last group for which the trial-function input information applies. (It applies to all G for which $GINT \leq G \leq GFIN$ .)
NSTATS	I*4	Flag to indicate whether card type 06C is present and should be read (Card read if NSTATS $\neq$ 0); also used to indicate position in NTRIAL for energy group G and synthesis region K where data from the type 06C card are stored.
NGK	I*4	Temporarily holds number of real trial functions in synthesis region K for group G.

c. Functions and Tasks Performed by This Subroutine. This subroutine reads in the synthesis boundary points (XSYNPT) and determines the interval-to-synthesis region correspondence (SYNMSH). It also reads in the function numbers, from data set A.SYN2D, for the trial functions to be used for each group in a given synthesis region. This routine also reads in the function flags which indicate whether the trial functions in a given

synthesis region and energy group satisfy the boundary condition  $\phi = 0$  at the reactor top and/or bottom. These data, if present, are stored in array NTRIAL and indexed through array NZERO. This subroutine also prints out the synthesis boundaries that it will use in its calculations.

d. Subroutine Called by This Subroutine. ERRMSG.

e. Subroutine Calling This Subroutine. RSDEF.

60. Subroutine SYNGEN(\*)

a. Arguments. The asterisk indicates an error return to the calling subroutine.

b. Important Local Variables

<u>Name</u>	<u>Type</u>	<u>Definition</u>
KBAR	I*4	KMAX - 1, used for dimensioning.
NOWMAX	I*4	Equals NGKMX (see INT 103 in commonblock SINGLE).
IM1	I*4	IMAX - 1, used for allocating storage.
IGM	I*4	GMAX - 1, used by subroutine COFGEN.

c. Functions and Tasks Performed by This Subroutine. This subroutine allocates the storage space in array BLK which will be needed later to store the finite-difference matrices. All synthesis-related matrix calculations are controlled by this subroutine and those called by it. The subroutine prints out the time required for execution of this section, and if a detectable error is encountered, it prints out an error message. It initializes several subroutines which are later called at their entry points.

d. Subroutines Called by This Subroutine. TLEFT (IBM function), COFGEN, CLOSE, ERRMSG, CHECK, MTGEN1, MTGEN2, SNIFF (ARC System subroutine).

e. Subroutine Calling This Subroutine. D2DCAL.

61. Subroutine SYNIN(\*)

a. Arguments. The asterisk indicates an error return to the calling subroutine.

b. Important Local Variables. None.

c. Functions and Tasks Performed by This Subroutine. SYNIN is a driver subroutine. It calls subroutines that read in module-dependent data, calculate required information from the user's input, including partial integrals, refined regions, Y-direction refined intervals, etc., and store these data until needed by other sections of the code. It also prints out a message giving the time spent in execution of the subroutine.

d. Subroutines Called by This Subroutine. RCDEP, RGEOM, RCOMP, RBND, RSDEF, TLEFT (IBM function).

e. Subroutine Calling This Subroutine. SYN2D.

## 62. Subroutine SYNOUT(\*)

a. Arguments. The asterisk indicates an error return to the calling subroutine.

b. Important Local Variables. None.

c. Functions and Tasks Performed by This Subroutine. This subroutine is a driver for the printout subroutine. It wipes out arrays from BLK and creates storage for the reconstituted flux and trial functions. Then the output subroutines are called. Finally, it prints a message telling the time it took to execute SYNOUT. Note that subroutine D2DOUT is a two-dimensional diffusion subroutine, as are the subroutines called by D2DOUT.

d. Subroutines Called by This Subroutine. TLEFT (IBM function), SINOUT, D2DOUT.

e. Subroutine Calling This Subroutine. SYN2D.

## 63. Subroutine TWODPR(ARRAY,ICT,JCT,TITLE,ROWT,COLT, INVRT,IPONE,JPONE,RNUM,CNUM)

a. Arguments

<u>Name</u>	<u>Type</u>	<u>Definition</u>
ARRAY (ICT,JCT)	R*8	Two-dimensional array to be printed.
ICT	I*4	Number of rows in array.
JCT	I*4	Number of columns in array.
TITLE(9)	R*8	Title of array (9A8).
ROWT	R*8	Row title (A8).
COLT	R*8	Column title (A8).

<u>Name</u>	<u>Type</u>	<u>Definition</u>
INVRT	I*4	Array transposition flag. 0--Print array as given. 1--Transpose rows and columns in printing.
IPONE	I*4	Row numbering flag. 0--Number rows with integers 1, 2, ..., ICT for INVRT = 0, or 1, 2, ..., JCT for INVRT = 1. 1--Number rows with members of floating-point array RNUM. 2--Label rows with members of alphanumeric array RNUM.
JPONE	I*4	Column numbering flag. 0--Number columns with integers 1, 2, ..., JCT for INVRT = 0, or 1, 2, ..., ICT for INVRT = 1. 1--Number columns with members of floating-point array CNUM. 2--Number columns with integers JCT, JCT - 1, ..., 1 for INVRT = 0, or ICT, ICT - 1, ..., 1 for INVRT = 1.
RNUM (ICT or JCT)	R*8	Numbers or labels for rows if IPONE = 1 or JPONE = 2.
CNUM (JCT or ICT)	R*8	Numbers for columns if JPONE = 1.

b. Important Local Variables

<u>Name</u>	<u>Type</u>	<u>Definition</u>
II	I*4	Number of first row to be printed on page for INVRT = 0.
IJ	I*4	Number of first row to be printed on page for INVRT = 1.
IMAX	I*4	Number of last row to be printed on page for INVRT = 0.
JMAX	I*4	Number of last row to be printed on page for INVRT = 1.
MIN	I*4	Number of first column to be printed on page.
MAX	I*4	Number of last column to be printed on page.

<u>Name</u>	<u>Type</u>	<u>Definition</u>
IFLAG	I*4	New page flag. 0--Start new page. 1--Stay on same page (NROW + IDIF < 57).
IEND	I*4	Number of last column (JCT for INVRT = 0, ICT for INVRT = 1).
NROW	I*4	Approximate number of rows printed on page (sum of IDIF's).
JCI	I*4	Increasing index on columns, JCI = 1, ..., MAX - MIN + 1.
JFLIP(7)	I*4	Flipped column integer indices for JPONE = 2: IEND - MIN + 1, IEND - (MIN + 1) + 1, ..., IEND - MAX + 1.
IDIF	I*4	Approximate number of rows printed in pass: IDIF = (IMAX - II) + 5 for INVRT = 0, IDIF = (JMAX - IJ) + 5 for INVRT = 1.
ID	I*4	Integer row number I for IPONE = 0.
FID	R*8	Floating-point row number RNUM(I) for IPONE = 1, or alphanumeric label RNUM(I) for IPONE = 2.

c. Functions and Tasks Performed by This Subroutine. This subroutine prints a given two-dimensional array ARAY(ICT,JCT) in a format selected using the various options offered by the subroutine. The array is printed with a maximum of seven columns and 52 rows to a page. All rows are printed for a given group of seven or less columns before the next set of columns is begun.

The major option offered is that of transposing the array, by setting INVRT to 1, so that rows are printed as columns and columns as rows. This does not affect the array contents, but merely the order in which they are printed. It also does not affect column and row headings and labels; these are used as input and are not affected by the INVRT flag.

Other options concern the manner in which columns and rows are indexed. A general column title is printed above each column, and a general row title before every row; these general titles can be followed by various types of individual labels.

For rows, the options are as follows:

IPONE = 0: The rows are numbered with the integers 1, 2, ..., ICT, for INVRT = 0; for INVRT = 1, the range is 1, 2, ..., JCT.

IPONE = 1: The rows are numbered with the members of the floating-point array RNUM(ICT) for INVRT = 0, or RNUM(JCT) for INVRT = 1, in F10.3 format.

IPONE = 2: The rows are labeled with the members of the alphanumeric array RNUM(ICT) for INVRT = 0, or RNUM(JCT) for INVRT = 1, in A8 format.

For columns, the options are as follows:

JPONE = 0: The columns are numbered with the integers 1, 2, ..., JCT for INVRT = 0, or 1, 2, ..., ICT for INVRT = 1.

JPONE = 1: The columns are numbered with the members of the floating-point array CNUM(JCT) for INVRT = 0, or CNUM(ICT) for INVRT = 1, in F10.3 format.

JPONE = 2: The columns are numbered with the integers JCT, JCT - 1, ..., 1 for INVRT = 0, or ICT, ICT - 1, ..., 1 for INVRT = 1.

If IPONE is zero, any array or dummy variable can be used in the calling sequence in place of RNUM, since RNUM will not be used; the same holds true for CNUM when JPONE is either zero or two.

As many complete sets of seven columns, each for all rows, as can be fit on one page will be printed to a page. Breaking up of sets of seven columns on successive pages will be done only if there are more than 52 rows. On each page, the general page heading and page number, set up in common block HEADER for subroutine PAGHED, are printed, followed by the input array title. Column and row headings are printed for each column and row. Array members are printed in 1PE15.6 format.

d. Subroutine Called by This Subroutine. PAGHED.

e. Subroutines Calling This Subroutine. SINOUT, ITOBAL,  
FLUXPR.

64. Subroutine VALUES(HG,HP,HADJG,HADJP,JMAX,LPART,  
RESULT,DY,NGKMX)

Entry points

Entry: VALUE(HG,HP,HADJG,HADJP,NGK)

a. Arguments. The first four arguments as well as the seventh and eighth are listed in common block BLKSTR; the three remaining constants are defined in common block SINGLE. The constant NGK is the number of trial functions being passed in the arrays HG and HADJG.

b. Important Local Variables. None.

c. Functions and Tasks Performed by This Subroutine. This subroutine computes the values of the trial functions at the reactor top and bottom for all the trial functions in a given synthesis region and group. The computed values of the real and adjoint trial functions and their associated derivatives are then written out on the data set whose reference number is LPART. These numbers will be used later to calculate the boundary matrices. For the reactor top, the value  $H_T$  is computed as follows for each trial function:

$$H_T = 0.5\delta_J H_J' + H_J,$$

where  $\delta_J$  is the length of the last interval J. For the reactor bottom, the value  $H_B$  is computed for each trial function as follows:

$$H_B = -0.5\delta_1 H_1' + H_1.$$

Repeated calls to this subroutine are made for each synthesis region and energy group. Note that the arrays passed in the entry calling sequence are subarrays, consisting of half of the original arrays.

d. Subroutines Called by This Subroutine. None.

e. Subroutine Calling This Subroutine. PROCES.

#### E. Data-set Usage

This section contains descriptions of all data sets used by this module. For each data set used, the following information is given:

1. The name of the data set, if it is an ARC System data set, or a description of its contents and function, if it is a scratch data set used only within the module.
2. The record structure of the data set, if it is a scratch data set.
3. Names of subroutines in which the data set is read and/or written, along with a list of the record types that are read and/or written and the name of the variable containing the data-set reference number.

A complete description of the record structure and contents of each ARC System data set appears in ANL-7711.

##### 1. Data Set A.SYN2D

- a. Name. A.SYN2D, Module-dependent BCD Input.

b. Record Structure. Refer to A.SYN2D Data-set Specifications, Section II.E.

<u>Read in Subroutines</u>	<u>Card Types</u>	<u>Reference Variables</u>
RCDEP	Types 01-03	N
RSDEF	Type 04	NINPUT
SYNDEF	Types 05,06A, 06B,06C	NINPUT
LIB	Type 07	NYSN2D

c. Written in Subroutines. None.

## 2. Data Set BC

a. Name. BC, Boundary Condition Specifications.

b. Record Structure. ARC System data set.

<u>Read in Subroutines</u>	<u>Record Types</u>	<u>Reference Variables</u>
RBND C	All	NTAPE

c. Written in Subroutines. None.

## 3. Data Set FA.TRIAL

a. Name. FA.TRIAL, User-input Adjoint Synthesis Trial-function Library.

b. Description. The adjoint trial-function library for all groups, which is user-supplied. Each record after the first contains one adjoint trial function for each energy group.

c. Structure and Content

### (1) Logical Record 1

<u>Word Number</u>	<u>Variable Name</u>	<u>Type</u>	<u>Description</u>
1	LCMAX	I*4	Number of records that follow.
2	JMAX	I*4	Number of function values for each function.
3	GMAX	I*4	Number of energy groups.

(2) Logical Record I  $2 \leq I \leq \text{LCMAX} + 1$ 

<u>Record Format</u>	<u>Type</u>	<u>Description</u>
((HG(J,G),J=1,JMAX),G=1,GMAX))	R*8	Adjoint library trial-function number I-1 for all groups.
<u>Read in Subroutines</u>	<u>Record Types</u>	<u>Reference Variables</u>
LIB	All required	LIBNO
d. <u>Written in Subroutines</u> . None. (Refer to Section II.H.)		
4. <u>Data Set FR.D2</u>		
a. <u>Name</u> . FR.D2, Two-dimensional Real Group Fluxes.		
b. <u>Record Structure</u> . ARC System data set.		

<u>Read in Subroutine</u>	<u>Record Types</u>	<u>Reference Variable</u>
RFLUX	All	NTAPE

<u>Written in Subroutine</u>	<u>Record Type</u>	<u>Reference Variable</u>
IGPCAL	All	NX

5. Data Set FR.PN

a. Name. FR.PN, Power-normalized Real Regional Group Fluxes.

b. Record Structure. ARC System data set.

Read in subroutines. None.

<u>Written in Subroutine</u>	<u>Record Types</u>	<u>Reference Variable</u>
IFXNRM	All	NFRPN

6. Data Set FR.TG

a. Name. FR.TG, Mixing Functions.

b. Description. One-dimensional multigroup mixing functions and their associated k-effective.

c. Structure and Content(1) Logical Record 1

<u>Word Number</u>	<u>Variable Name</u>	<u>Type</u>	<u>Description</u>
1	KEFF	R*8	k-effective.
2	GMAX	I*4	Number of energy groups.
3	KMAX	I*4	Number of synthesis regions.
4	IMAX	I*4	Number of synthesis direction space points.

(2) Logical Record 2

<u>Record Format</u>	<u>Type</u>	<u>Description</u>
((NNP(G,K),G=1,GMAX), K=1,KMAX)	I*4	The number of real trial functions used in synthesis region K, energy group G.

(3) Logical Record 3

<u>Record Format</u>	<u>Type</u>	<u>Description</u>
((TG(N,I,G),N=1,NGKMX), I=1,IMAX),G=1,GMAX)	R*8	The mixing function value for trial function N at space point I for energy group G. Note that $NGKMX = \max_{G,K} (NNP(G,K))$ .

<u>Read in Subroutine</u>	<u>Record Types</u>	<u>Reference Variable</u>
SINCAL	All	LIB1

<u>Written in Subroutine</u>	<u>Record Types</u>	<u>Reference Variable</u>
SINCAL	All	LIB1

7. Data Set FR.TRIAL

a. Name. FR.TRIAL, User-input Real Synthesis Trial-function Library.

b. Description. The real trial-function library for all groups, which is user-supplied. Each record after the first contains one real trial function for each energy group.

c. Structure and Content(1) Logical Record 1

<u>Word Number</u>	<u>Variable Name</u>	<u>Type</u>	<u>Description</u>
1	LCMAX	I*4	The number of records that follow.
2	JMAX	I*4	Number of function values for each function.
3	GMAX	I*4	Number of energy groups.

(2) Logical Record I  $2 \leq I \leq \text{LCMAX} + 1$ 

<u>Record Format</u>	<u>Type</u>	<u>Description</u>
((HG(J,G),J=1,JMAX),G=1,GMAX)	R*8	Real library trial function number I - 1 for all groups.

<u>Read in Subroutine</u>	<u>Record Types</u>	<u>Reference Variable</u>
LIB	All required	LIBNO

d. Written in Subroutines. None. (Refer to Section II.H.)

8. Data Set GEOM

- a. Name. GEOM, Geometry Data.
- b. Record Structure. ARC System data set.

<u>Read in Subroutine</u>	<u>Record Types</u>	<u>Reference Variables</u>
RGEOM	1	NTAPE
RMESH	All of 2-9 present	NTAPE

c. Written in Subroutines. None.

9. Data Set LIB.ADJT

a. Name. LIB.ADJT, Code-refined Adjoint Trial-function Library.

b. Description. This data set contains all the adjoint trial functions required by this problem and only those required by this problem. LIB.ADJT is generated by module SYN2D from a more general data set containing many trial functions (FA.TRIAL). This data set is used to

generate the partial integrals. TIME2, defined below, keys the four data sets LIB.ADJT, LIB.MIX, LIB.PART, and LIB.REAL to ensure that they are consistent with each other and with the problem. TIME2 must be the same on each of these data sets.

c. Structure and Content

(1) Logical Record 1

<u>Word Number</u>	<u>Variable Name</u>	<u>Type</u>	<u>Description</u>
1	TIME2	R*4	Data-set consistency key.
2	GMAX	I*4	Number of energy groups.
3	JMAX	I*4	Number of points at which trial functions are defined.
4	KMAX	I*4	Number of synthesis regions.
5	NGKMX	I*4	Maximum number of trial functions in any synthesis region for any group.

(2) Logical Record 2

<u>Record Format</u>	<u>Type</u>	<u>Description</u>
((NN(G,K),G=1,GMAX), K=1,KMAX)	I*2	The number of adjoint trial functions used in synthesis region K, energy group G.

(3) Logical Record I  $3 \leq I \leq GMAX * KMAX + 2$

<u>Record Format</u>	<u>Type</u>	<u>Description</u>
((HG(J,N),J=1,JMAX), N=1,NGK)	R*8	The set of adjoint trial functions used in synthesis region K, energy group G, where $I = (G - 1) * KMAX + K + 2$ . NGK is the number of adjoint trial functions in synthesis region K, energy group G.

<u>Read in Subroutines</u>	<u>Record Types</u>	<u>Reference Variables</u>
DSRNCK	1 and 2	LADJT
PROCES	All	LADJT
<u>Written in Subroutine</u>	<u>Record Types</u>	<u>Reference Variables</u>
LIB	All	N2 LIB LIBRIT

10. Data Set LIB.MIX

a. Name. LIB.MIX, Code-refined Real Trial-function Library.

b. Description. This data set contains all the real trial functions required by the problem and only those required by the problem. The data set LIB.MIX is generated by module SYN2D from a more general data set containing many trial functions (FR.TRIAL). This data set is used to generate the partial integrals. Refer to data set LIB.ADJT (Section 9 above).

c. Structure and Content

(1) Logical Record 1

<u>Word Number</u>	<u>Variable Name</u>	<u>Type</u>	<u>Description</u>
1	TIME2	R*4	Data set consistency key.

(2) Logical Record 2  $2 \leq I \leq \text{GMAX} * \text{KMAX} + 1$ 

<u>Record Format</u>	<u>Type</u>	<u>Description</u>
((HG(J,N),J=1,JMAX), N=1,NGK)	R*8	The set of real trial functions used in synthesis region K, energy group G, where $I = (K - 1) * \text{GMAX} + G + 1$ . JMAX is the number of points at which the trial functions are defined, NGK is the number of real trial functions in synthesis region K, energy group G, KMAX is the number of synthesis regions, and GMAX is the number of energy groups.

<u>Read in Subroutines</u>	<u>Record Types</u>	<u>Reference Variables</u>
DSRNCK	1	LMIX
PROCES	All	LMIX

<u>Written in Subroutine</u>	<u>Record Types</u>	<u>Reference Variables</u>
LIB	All	N3

11. Data Set LIB.PART

a. Name. LIB.PART, Partial Integrals.

b. Description. This data set contains all the partial integrals required by the problem, plus the calculated values of the real and adjoint trial functions at the reactor top and bottom and their derivatives

i.e.,  $H_{gk}^n(0)$ ,  $H_{gk}^n(h)$ ,  $H_{gk}^{*n}(0)$ ,  $H_{gk}^{*n}(h)$ ,  $H_{gk}^{in}(0)$ ,  $H_{gk}^{in}(h)$ ,  $H_{gk}^{*in}(0)$  and  $H_{gk}^{*in}(h)$ .

The data set LIB.PART is calculated using the trial functions from data sets LIB.ADJT and LIB.MIX. Refer to data set LIB.ADJT (Section 9 above).

c. Structure and Content

(1) Logical Record 1

<u>Word Number</u>	<u>Variable Name</u>	<u>Type</u>	<u>Definition</u>
1	TIME2	R*4	Data-set consistency key.
2	GMAX	I*4	Number of energy groups.
3	KMAX	I*4	Number of synthesis regions.

(2) Logical Record 2

<u>Record Format</u>	<u>Type</u>	<u>Definition</u>
(NUMRRJ(K),K=1,KMAX)	I*2	The number of Y-direction refined intervals per synthesis region.
((NN(G,K),G=1,GMAX), K=1,KMAX)	I*2	The number of trial functions per synthesis region and energy group.

(3) Logical Record I  $3 \leq I \leq GMAX(KMAX(GMAX+5)-3) + 2$

There are six types of logical records which record I can be.

<u>Record Type</u>	<u>Record Format</u>	<u>Type</u>	<u>Definition</u>
3	((R(M,N,L), L=1,NM),M=1,NA), N=1,NR)	R*8	Partial integrals of $\int H_{gk}^{*n} H_{g'k}^n dy$ , where NM is the number of Y-direction refined intervals for synthesis region k, NA is the number of adjoint trial functions in synthesis region k for energy group g, and NR is the number of real trial functions in synthesis region k for energy group g'.

<u>Record Type</u>	<u>Record Format</u>	<u>Type</u>	<u>Definition</u>
4	(HG(M),M=1,NGK), (HP(M),M=1,NGK), (HADJG(M),M=1,NGK), (HADJP(M),M=1,NGK), (RG(M),M=1,NGK), (RP(M),M=1,NGK), (RADJG(M),M=1,NGK), (RADJP(M),M=1,NGK)	R*8	Calculated values of the real and adjoint trial functions and their derivatives at the reactor top and bottom for each group. The first four arrays are the real trial functions and derivatives followed by the adjoint trial functions and derivatives for the reactor top. The last four arrays have the same structure for the reactor bottom.
5	((R(M,N,L),L=1,NM), M=1,NR),N=1,NR)	R*8	Partial integrals of $\int_{H_{gk}^{*n} H_{gk}^n} dy$ , where NM is the number of Y-direction refined intervals for synthesis region k and NR is the number of real trial functions for energy group g synthesis region k.
6	((R(M,N,L),L=1,NM), M=1,NA),N=1,NR)	R*8	Partial integrals of $\int_{H_{g,k-1}^{*m} H_{gk}^n} dy$ , where NM is the number of Y-direction refined intervals in synthesis region k - 1, NA is the number of adjoint trial functions in synthesis region k - 1, energy group g, and NR is the number of real trial functions in synthesis region k, energy group g.
7	((R(M,N,L),L=1,NM), M=1,NA),N=1,NR)	R*8	Partial integrals of $\int_{H_{g,k-1}^{*m} H_{gk}^n} dy$ , where NM is the number of Y-direction refined intervals in synthesis region k, NA is the number of adjoint trial functions in synthesis region k - 1, energy group g, and NR is the number of real trial functions in synthesis region k, energy group g.

<u>Record Type</u>	<u>Record Format</u>	<u>Type</u>	<u>Definition</u>
8	((R(M,N,L),L=1,NM), M=1,NA),N=1,NR)	R*8	Partial integrals of $\int_{H_{gk}^{*m} H_{g,k-1}^n} dy$ , where NM is the number of Y-direction re-fined intervals in synthesis re-gion k - 1, energy group g, NA is the number of adjoint trial functions in synthesis region k, and NR is the number of real trial functions in synthesis region k - 1.

These records are written out with the following structure and logic:

```

DO 10 LG=1,GMAX
DO 10 K=1,KMAX
DO 10 G=1,GMAX
WRITE RECORD TYPE 3
If LG≠G GO TO 10
WRITE RECORD TYPES 4 and 5
If K > 1 WRITE RECORD TYPES 6, 7, and 8
10 CONTINUE

```

<u>Read in Subroutines</u>	<u>Record Types</u>	<u>Reference Variables</u>
----------------------------	---------------------	----------------------------

COFGEN	1, 2, and I, where I is all rec- ord types 3-8 except type 4.	LPART
BCONDS	All type 4 records.	LPART

<u>Written in Subroutines</u>	<u>Record Types</u>	<u>Reference Variables</u>
-------------------------------	---------------------	----------------------------

PROCES	1 and 2.	LPART
RIEMAN	All record types 3-8, except type 4.	LPART
VALUES	Record type 4.	LPART

## 12. Data Set LIB.REAL

a. Name. LIB.REAL, Code-refined Real Trial-function Library.

b. Description. This data set contains all the real trial functions required by the problem and only those required by the problem. LIB.REAL is generated by module SYN2D from a more general data set containing many trial functions (FR.TRIAL). The sole function of the data set is to supply the real trial functions in proper form to reconstitute the final two-dimensional flux. Refer to data set LIB.ADJT.

c. Structure and Content

(1) Logical Record 1

<u>Word Number</u>	<u>Variable Name</u>	<u>Type</u>	<u>Description</u>
1	TIME2	R*4	Data-set consistency key.

(2) Logical Record I  $2 \leq I \leq KMAX*GMAX + 1$

<u>Record Format</u>	<u>Type</u>	<u>Description</u>
((HG(J,N),J=1,JMAX),N=1,NGK)	R*8	The set of real trial functions used in synthesis region K, energy group G, where $I = (G-1)*KMAX+K+1$ . JMAX is the number of points at which the trial functions are defined, NGK is the number of real trial functions in synthesis region K, energy group G, KMAX is the number of synthesis regions, and GMAX is the number of energy groups.

<u>Read in Subroutines</u>	<u>Record Types</u>	<u>Reference Variables</u>
DSRNCK	1	LREAL
SINOUT	All	LIB

<u>Written in Subroutine</u>	<u>Record Types</u>	<u>Reference Variables</u>
LIB	All	LIB LIBRIT

13. Data Set SCR001

a. Name. SCR001, Scratch Data Set 1.

b. This scratch data set is used by the module SYN2D to temporarily hold trial functions while creating data sets LIB.ADJT, LIB.MIX, and LIB.REAL. SCR001 is used only if the real trial function cannot be

core-held. Next, SCR001 is used to hold the matrices  $\{H_i\}_{i=1}^{IM1}$  for all energy groups. Finally, SCR001 temporarily stores the unnormalized two-dimensional fluxes before output editing.

c. Structure and Content

(1) Logical Record I. This contains the real trial functions for all synthesis regions for energy group one. This data set aids in creating LIB.REAL. The functions appear on this data set in the same order as obtained from the data set FR.TRIAL. If the same real trial function is used in two or more synthesis regions, it will appear that number of times on this data set; i.e., the same trial function will be written that many times consecutively. All records have the same format. There are  $\bar{N}$  records,  $\bar{N} = \sum_{k=1}^K N_{1,k}$ , where  $N_{g,k}$  is the number of trial functions required for energy group  $g$ , synthesis region  $k$ .

<u>Record Format</u>	<u>Type</u>	<u>Definition</u>
(HG(J),J=1,JMAX)	R*8	Real trial function defined at JMAX Y-direction space points.

<u>Read in Subroutine</u>	<u>Records</u>	<u>Reference Variable</u>
LIB	All	IDSN
<u>Written in Subroutine</u>	<u>Records</u>	<u>Reference Variable</u>
LIB	All	IDSN

(2) Logical Record II. This contains the same trial functions as I above. This data set aids in creating LIB.MIX. In this case, the trial functions have been reordered by synthesis regions, i.e., the trial functions for the first region are first, followed by those for the second, etc.

<u>Record Format</u>	<u>Type</u>	<u>Definition</u>
(HG(J),J=1,JMAX)	R*8	The real trial functions defined at JMAX space points.

<u>Read in Subroutine</u>	<u>Records</u>	<u>Reference Variable</u>
LIB	All	IDSN
<u>Written in Subroutine</u>	<u>Records</u>	<u>Reference Variable</u>
LIB	All	IDSN

(3) Logical Record III. This contains the adjoint trial functions for all synthesis regions for energy group one. This data set aids in creating LIB. The functions appear on this data set in the same order as obtained from the data set FA.TRIAL. If the same adjoint trial function is used in two or more synthesis regions, it will appear that number of times on this data set; i.e., the same adjoint function will be written that many times consecutively. All records have the same format.

<u>Record Format</u>	<u>Type</u>	<u>Definition</u>
(HG(J),J=1,JMAX)	R*8	Real trial function defined at JMAX space points.
<u>Read in Subroutine</u>	<u>Records</u>	<u>Reference Variables</u>
LIB	All	IDSN
<u>Written in Subroutine</u>	<u>Records</u>	<u>Reference Variables</u>
	All	IDSN

(4) Logical Record IV. There is one record for each energy group. Each record L contains the matrices  $\{H_i\}_{i=1}^{IM1}$  for energy group L. Each matrix  $H_{i,g}$  is packed and uses only the storage required, with all unused locations appearing at the end of each subarray. Thus, if  $H_q$  is a 4 x 4 matrix stored in a 5 x 5 array, the first 16 storage locations are used and the remaining nine are unused. All records have the same format.

<u>Record Format</u>	<u>Type</u>	<u>Definition</u>
((H(N,I),N=1,NGKSQ), I=1,IM1)	R*8	Array H contains the matrices $\{H_i\}$ , where NGKSQ is the square of the maximum number of real trial functions for any synthesis region and energy group. IM1 is one less than the number of space points in the direction of synthesis.
<u>Read in Subroutine</u>	<u>Records</u>	<u>Reference Variable</u>
SINCAL	All	NLIB
<u>Written in Subroutine</u>	<u>Records</u>	<u>Reference Variable</u>
MTGEN2	All	NLIB

(5) Logical Record V. There is one record for each energy group. Each record L contains the two-dimensional fluxes for energy

<u>Record Format</u>	<u>Type</u>	<u>Definition</u>
((FLX(J,I),J=1,JMAX), I=1,IMAX)	R*8	The two-dimensional fluxes, with IMAX space points in the synthesis direction and JMAX space points in the trial-function direction.

<u>Read in Subroutine</u>	<u>Records</u>	<u>Reference Variable</u>
FXVOL(entry in IFXVOL)	All	NTH

<u>Written in Subroutine</u>	<u>Records</u>	<u>Reference Variable</u>
SINOUT	All	NLIB

#### 14. Data Set SCR002

a. Name. SCR002, Scratch Data Set 2.

b. Description. This scratch data set is used by the module SYN2D to temporarily hold trial functions while creating data sets LIB.ADJT, LIB.MIX, and LIB.REAL. SCR002 is used only if the real trial functions cannot be core-held. Next, SCR002 is used to hold the fission matrices  $\{(\chi_g \nu_{g'} \Sigma_{fg'})_k(r)\}$  for all refined regions and energy group combinations.

c. Structure and Content

(1) Logical Records I, II, and III. These are identical to items I, II, and III of SCR001, except that SCR002 holds the trial functions for energy group two. There are  $\bar{N}$  records, where  $\bar{N}$  is defined as for SCR001,  $g = 2$ .

(2) Logical Record IV. This contains the fission matrices  $\{(\chi_g \nu_{g'} \Sigma_{fg'})_k(r)\}$ . These matrices are packed. Refer to item IV of SCR001 for packing information. The total number of records is  $RG$ , where  $R$  is the number of refined regions in the reactor and  $G$  is the number of energy groups. All records have the same format. Record  $I = (\bar{G} - 1)G + \bar{R}$  contains the fission matrices for refined region  $\bar{R}$  energy group  $\bar{G}$ , for all  $G'$  energy groups.

<u>Record Format</u>	<u>Type</u>	<u>Description</u>
((F(N,G),N=1,NGKSQ), G=1,GMAX)	R*8	Array F contains the fission matrices, where NGKSQ is the square of the maximum number of real trial functions for any synthesis region and energy group and GMAX is the number of energy groups.

<u>Read in Subroutine</u>	<u>Records</u>	<u>Reference Variable</u>
SINCAL	All	ILIB
<u>Written in Subroutine</u>	<u>Records</u>	<u>Reference Variable</u>
COFGEN	All	IFISS

### 15. Data Set SCR003

a. Name. SCR003, Scratch Data Set 3.

b. Description. This scratch data set is used by the module SYN2D to temporarily hold trial functions while creating data sets LIB.ADJT, LIB.MIX, and LIB.REAL. SCR003 is used only if the trial functions cannot be core-held. Next, SCR003 is used to hold the matrices  $\{U_i^{-1}\}_{i=1}^I$  and  $\{V_i\}_{i=1}^{IM1}$  for all energy groups.

c. Structure and Content

(1) Logical Records I, II, and III. These are identical to items I, II, and III of SCR001, except that SCR003 holds the trial functions for energy group three. There are  $\bar{N}$  records, where  $\bar{N}$  is defined as for SCR001,  $g = 3$ .

(2) Logical Record IV. This contains the matrices  $\{U_i^{-1}\}_{i=1}^I$  and  $\{V_i\}_{i=1}^{IM1}$  for all energy groups. These matrices are packed. Refer to item IV of SCR001 for packing information. There are two records for each energy group. Each two-record set has the same format.

<u>Record Format</u>	<u>Type</u>	<u>Definition</u>
((U(N,I),N=1,NGKSQ), I=1,IMAX)	R*8	Array U contains the matrices $\{U_i^{-1}\}$ where NGKSQ is the square of the maximum number of real trial functions for any synthesis region and energy group and IMAX is the number of space points in the direction of synthesis.
((V(N,I),N=1,NGKSQ), I=1,IM1)	R*8	Array V contains the matrices $\{V_i\}$ , where IM1 is IMAX-1.

<u>Read in Subroutine</u>	<u>Records</u>	<u>Reference Variable</u>
SINCAL	All	JLIB
<u>Written in Subroutine</u>	<u>Records</u>	<u>Reference Variable</u>
	All	JLIB

16. Data Set SCR004

a. Name. SCR004, Scratch Data Set 4.

b. Description. This scratch data set is used by module SYN2D to temporarily hold trial functions while creating data sets LIB.ADJT, LIB.MIX, and LIB.REAL. SCR004 is used only if the real trial functions cannot be core-held. Next, SCR004 is used to hold the scattering matrices  $\{\Sigma_{g',g,k}(r)\}$  for all refined regions and energy group combinations in which both  $g'$  and  $g$  are within the scattering band.

c. Structure and Content

(1) Logical Records I, II, and III. These are identical to items I, II, and III of SCR001, except that SCR004 holds the trial functions for energy group four. There are  $\bar{N}$  records, where  $\bar{N}$  is defined as for SCR001,  $g = 4$ .

(2) Logical Record Number IV. This contains the scattering matrices  $\{\Sigma_{g',g,k}(r)\}$ . These matrices are packed. Refer to item IV of SCR001 for packing information. The number of matrices varies from record to record, but for each group  $g$  a record contains the nonzero matrices for all  $g'$ . The records are structured so that the records for all refined regions  $r$  appear for each energy group  $g$ .

<u>Record Format</u>	<u>Type</u>	<u>Definition</u>
((S(N,G),N=1,NGKSQ), G=GLOW,IUP)	R*8	Array S contains the scattering matrices. One record is used for each refined region, with NGKSQ the square of the maximum number of real trial functions for any synthesis region and energy group, GLOW = MAX(1,( $\bar{G}$ -MAXDN)) and IUP = MIN(GMAX,( $\bar{G}$ +MAXUP)). (If GLOW $\geq$ IUP this record does not exist.) MAXDN is the maximum downscattering, MAXUP is the maximum upscattering. (Both MAXUP and MAXDN are read from ARC System data set XS.C.MIN, record 1.) GMAX is the number of energy groups, and $\bar{G}$ is the present energy group number.

<u>Read in Subroutine</u>	<u>Records</u>	<u>Reference Variable</u>
SINCAL	All	MLIB
<u>Written in Subroutine</u>	<u>Records</u>	<u>Reference Variable</u>
COFGEN	All	ISCAT

17. Data Set XS.C.MIN

- a. Name. XS.C.MIN, Macroscopic Composition Cross Sections.
- b. Record Structure. ARC System data set.

<u>Read in Subroutines</u>	<u>Record Types</u>	<u>Reference Variables</u>
RCOMP	Type 1 of file 1.	N
RXSCO1	Type 1 of file 1.	N
GETCHI	Type 2 of file 2.	NTAPE
RGROUP	Types 3 and 4 of file 2.	NTAPE
SYNGEN	Type 1 of file 1.	INEED

- c. Written in Subroutines. None.

18. Data Set XS.ISO2 or XS.ISO

- a. Name. XS.ISO2, Problem-Dependent Microscopic Group Cross Sections or XS.ISO, Microscopic Group Cross Sections.
- b. Record Structure. ARC System data set.

<u>Read in Subroutine</u>	<u>Record Types</u>	<u>Reference Variables</u>
RVEL	Type 3 of file 1	NTAPE

- c. Written in Subroutines. None.

19. Unnamed Scratch Data Sets

a. Description. Four scratch data sets, SCR001, SCR002, SCR003, and SCR004, are already supplied with the module SYN2D. However, in creating data sets LIB.ADJT, LIB.MIX, and LIB.REAL, one scratch data set must be provided for every energy group if the real trial functions cannot be core-held. Hence, for a six-group problem, for example, two additional scratch data sets must be supplied.

b. Structure and Content. Items I, II, and III are identical to items I, II, and III of SCR001, except that the Ith user-supplied scratch data set holds the trial functions for the  $(I+4)$ th energy group. There are  $\bar{N}$  records, where  $\bar{N}$  is defined as for SCR001,  $g = (I+4)$ . Refer to Section II.D.1.c for restrictions on reference numbers for scratch data sets when using the catalogued procedure ARCSPO12.

## ACKNOWLEDGMENTS

Part of the input section of this program and most of the output section were taken from the ARC System Two-dimensional Diffusion Theory Capability, DARC2D. The original development of these sections was done by T. A. Daly and A. S. Kennedy.

## REFERENCES

1. L. C. Just, H. Henryson II, A. S. Kennedy, S. D. Sparck, B. J. Toppel, and P. M. Walker, *The System Aspects and Interface Data Sets of the Argonne Reactor Computation (ARC) System*, ANL-7711 (Apr 1971).
2. E. A. Kovalsky and D. E. Neal, *The ARC System Neutronics Input Processor*, ANL-7713 (Jan 1971).
3. E. A. Kovalsky, J. Zapatka, H. Henryson II, J. Hoover, and P. M. Walker, *The ARC System Cross-section Homogenization and Modification Capabilities*, ANL-7714 (June 1971).
4. A. L. Buslik, *A Variational Principle for the Neutron Diffusion Equation Using Discontinuous Trial Functions*, WAPD-TM-610 (1966).
5. S. H. Crandall, *Engineering Analysis*, McGraw-Hill, New York, N.Y. (1956).



