MASTER

WAPD-TM-135

AEC RESEARCH AND
DEVELOPMENT REPORT

P1MG — A ONE-DIMENSIONAL MULTIGROUP P_1 CODE FOR THE IBM-704

JULY 1959

CONTRACT AT-11-1-GEN-14

BETTIS PLANT—PITTSBURGH, PA. OPERATED FOR THE
U.S. ATOMIC ENERGY COMMISSION BY BETTIS ATOMIC
POWER DIVISION, WESTINGHOUSE ELECTRIC CORPORATION

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of 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. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

P1MG — A ONE-DIMENSIONAL MULTIGROUP P_1 CODE FOR THE IBM-704

H. Bohl, Jr. • E.M. Gelbard • G.R. Culpepper • P.F. Buerger

Contract AT-11-1-GEN-14

July 1959

Price \$2.00

**Available from the Office of Technical Services,
Department of Commerce,
Washington 25, D. C.**

NOTE

This document is an interim memorandum prepared primarily for internal reference and does not represent a final expression of the opinion of Westinghouse. When this memorandum is distributed externally, it is with the express understanding that Westinghouse makes no representation as to completeness, accuracy, or usability of information contained therein.

**BETTIS PLANT • PITTSBURGH, PA.
OPERATED FOR THE U.S. ATOMIC ENERGY COMMISSION BY
BETTIS ATOMIC POWER DIVISION, WESTINGHOUSE ELECTRIC CORPORATION**

STANDARD EXTERNAL DISTRIBUTION

UC-34: Physics and Mathematics, TID-4500, 14th Edition

Copies

616

SPECIAL EXTERNAL DISTRIBUTION

Manager, Pittsburgh Naval Reactors Operations Office, AEC
 Argonne National Laboratory, W. F. Miller
 Brookhaven National Laboratory, J. Chernick
 Brookhaven National Laboratory, M. Rose
 David Taylor Model Basin, H. Polachek
 Knolls Atomic Power Laboratory, R. Ehrlich
 Los Alamos Scientific Laboratory, B. Carlson
 New York University, R. Richtmyer
 Oak Ridge National Laboratory, A. Householder
 University of California Radiation Laboratory, Livermore, S. Fernbach

3

2

1

1

2

10

2

2

2

2

Total

643

LEGAL NOTICE

This report was prepared as an account of Government sponsored work. Neither the United States, nor the Commission, nor any person acting on behalf of the Commission:

A. Makes any warranty or representation, expressed or implied, with respect to the accuracy, completeness, or usefulness of the information contained in this report, or that the use of any information, apparatus, method, or process disclosed in this report may not infringe privately owned rights; or

B. Assumes any liabilities with respect to the use of, or for damages resulting from the use of any information, apparatus, method, or process disclosed in this report.

As used in the above, "person acting on behalf of the Commission" includes any employee or contractor of the Commission, or employee of such contractor, to the extent that such employee or contractor of the Commission, or employee of such contractor prepares, disseminates, or provides access to, any information pursuant to his employment or contract with the Commission, or his employment with such contractor.

CONTENTS

	Page No.
PART ONE: PHYSICS AND NUMERICAL ANALYSIS OF CODE	1
I. INTRODUCTION	1
II. P_1 EQUATIONS	1
III. MULTIGROUP EQUATIONS	2
IV. TRANSVERSE BUCKLING	3
V. SPATIAL DIFFERENCE EQUATIONS	5
VI. BOUNDARY CONDITIONS	6
Cartesian Geometry	6
Other Geometries	6
Right-Hand Boundary Conditions	7
VII. METHOD OF SOLUTION	7
VIII. THERMAL GROUP	8
IX. DISCUSSION	8
X. EDIT OF FEW-GROUP AVERAGES	9
PART TWO: PROGRAMMING AND OPERATION OF CODE	11
I. INTRODUCTION	11
II. GLOSSARY	11
Indices—Superscripts and Subscripts	11
Quantities	12
III. EQUATIONS USED IN P1MG2	14
Coefficient Routine	14
Iteration Routine	16
Edit Routine	19
IV. PREPARATION OF INPUT	21
Form I	21
Form II	22
Form III	23
V. OUTPUT	24
On-Line Output	24
Off-Line Output	24
VI. CARD PUNCHING	26
Form I	26
Form II	26
Form III	26
VII. OPERATOR'S NOTES	27
704 Requirements	27
Material Needed to Run One Problem	27
Running Instructions	27
Progress of Program	27
Restart	29
Force Edit	29
Printing Off-Line	30
One Iteration Option	30
Error Stops	30

VIII. LIBRARY TAPE ROUTINES	34
LTP4	34
LTP5	35
LTP6	36
IX. GENERAL INFORMATION	37
PART THREE: APPENDICES	38
APPENDIX A: INPUT FORMS FOR SAMPLE PROBLEM, FORMS I, II, AND III	38
APPENDIX B: CHOMP CARDS	41
APPENDIX C: FLOATING POINT NUMBERS	41
Input Form	41
Output Form	42
APPENDIX D: BLANK CARDS IN INPUT DECK	42
APPENDIX E: CODE NUMBERS FOR ISOTOPES	43
List by Code Number	43
List by Isotope	44
APPENDIX F: SAMPLE PROBLEM	44
REFERENCES	68

The P_1 multigroup code described in this report was written for the IBM-704 in order to determine the accuracy of the few-group diffusion scheme with various imposed conditions and also to provide an alternate computational method when this scheme fails to be sufficiently accurate. The code solves for the spatially dependent multigroup flux, taking into account such nuclear phenomena as slowing down of neutrons resulting from elastic and inelastic scattering, the removal of neutrons resulting from epithermal capture and fission resonances, and the regeneration of fast neutrons resulting from fissioning which may occur in any of as many as 80 fast multigroups or in the one thermal group. The code will accept as input a physical description of the reactor (that is: slab, cylindrical, or spherical geometry, number of points and regions, composition description, group dependent boundary conditions, transverse buckling, and mesh sizes) and a prepared library of nuclear properties of all the isotopes in each composition. The code will produce as output multigroup fluxes, currents, and isotopic slowing-down densities, in addition to pointwise and regionwise few-group macroscopic cross sections.

P1MG—A ONE-DIMENSIONAL MULTIGROUP P_1 CODE FOR THE IBM-704

H. Bohl, Jr., E. M. Gelbard, G. R. Culpepper, and P. F. Buerger

PART ONE: PHYSICS AND NUMERICAL ANALYSIS OF CODE

I. INTRODUCTION

Few-group diffusion theory provides the reactor designer with a very convenient computing tool. Two-, three-, and four-group diffusion codes, programmed for various machines, have been in widespread use for some time. It is important, therefore, to understand the range of validity of the few-group model.

In preparing input parameters for a few-group calculation, it is necessary to approximate the flux spectrum in the different regions of the reactor. This cannot always be done satisfactorily since the spectrum may change rapidly with position in the neighborhood of an interface. Insofar as the flux spectrum is in doubt, the accuracy of the few-group approximation is open to question.

To assess the accuracy of the few-group scheme under different conditions, and to provide an alternative computational device when this scheme fails, a P_1 multigroup code, the P1MG code, has been written for the IBM-704. It should be stressed that P1MG was not designed to treat transport effects, and that errors, resulting from the limitations of a P_1 approximation, occur in the P1MG equations as they do in some forms of the few-group diffusion equations.

II. P_1 EQUATIONS

The P_1 equations, in a Greuling-Goertzel approximation (Ref 1), may be written in the form

$$\nabla \cdot \bar{j} + (\Sigma_a + \Sigma_{in}) \varphi + \sum_i \frac{\partial q_i}{\partial u} = S \quad (1.1)$$

$$\gamma_i \frac{\partial q_i}{\partial u} + q_i = (\xi \Sigma_s)_i \varphi \quad (1.2)$$

$$\frac{1}{3} \nabla \varphi + \Sigma_{tr} \bar{j} + \sum_i \frac{\partial \bar{p}_i}{\partial u} = 0 \quad (1.3)$$

and

$$\zeta_i \left(\frac{\partial \bar{p}_i}{\partial u} \right) + \bar{p}_i = (\eta \Sigma_s)_i \bar{j} , \quad (1.4)$$

where*

$\bar{j}$ and φ are the current and the scalar flux, respectively

i is an index denoting various isotopes

q_i is the isotropic slowing-down density resulting from the i^{th} isotope

$\bar{p}_i$ is the anisotropic slowing-down density resulting from the i^{th} isotope

S is the fission source S_f plus the inelastic scattering into lethargy m

γ_i , ξ_i , ζ_i , and η_i are parameters whose values may be deduced from the slowing-down properties of each isotope

Σ_a , Σ_s , and Σ_{in} are the macroscopic absorption, scattering, and inelastic scattering cross sections, respectively.

III. MULTIGROUP EQUATIONS

After a group structure has been established, Eqs (1.1) and (1.3) may be integrated over each non-thermal group (Ref 2), yielding

$$\Delta^m \{ \nabla \cdot \bar{j}^m + [(\Sigma_a^s + \Sigma_{in}) \varphi]^m \} + \sum_i [q_i^m - q_i^{m-1}] = (S\Delta)^m - [1 - (p_a)^m] \sum_i q_i^{m-1} \quad ** (1.5)$$

$$\Delta^m \left[\frac{1}{3} \nabla \varphi^m + (\Sigma_{tr} \bar{j})^m \right] + \sum_i \left[\bar{p}_i^m - \bar{p}_i^{m-1} \right] = 0 \quad (1.6)$$

for the m^{th} group. In Eqs (1.5) and (1.6), the absorption cross section has been split into a smooth absorption term Σ_a^s and a contribution resulting from resonances. The resonance escape probability $(p_a)^m$ is treated as in MUFT-4 (Ref 2), and will not be discussed in detail in this report.

In a central difference approximation, Eqs (1.2) and (1.4) become

$$\gamma_i^m \frac{q_i^m - q_i^{m-1}}{\Delta^m} + \frac{1}{2} [q_i^m + q_i^{m-1}] = (\xi \Sigma_s)_i^m \varphi^m \quad \dagger (1.7)$$

and

$$\zeta_i^m \frac{\bar{p}_i^m - \bar{p}_i^{m-1}}{\Delta^m} + \frac{1}{2} [\bar{p}_i^m + \bar{p}_i^{m-1}] = (\eta \Sigma_s)_i^m \bar{j}^m . \quad (1.8)$$

Equations (1.7) and (1.8) may be solved for q_i^m and $\bar{p}_i^m$ as follows:

$$q_i^m = \frac{[(\xi \Sigma_s)_i \varphi]^m}{\frac{1}{2} + \frac{\gamma_i^m}{\Delta^m}} - q_i^{m-1} \left(\frac{\frac{1}{2} - \frac{\gamma_i^m}{\Delta^m}}{\frac{1}{2} + \frac{\gamma_i^m}{\Delta^m}} \right) \quad (1.9)$$

* A detailed discussion of Eqs (1.1) through (1.4) will be found in Ref 1.

** The contribution of inelastic scattering processes, which simply transfer neutrons from one part of the m^{th} group to another, should be subtracted from $(\Sigma_{in})^m$. However, inelastic scattering from the m^{th} group to the m^{th} group should be a small effect if m is small, and this effect has been neglected.

† In the PLMG code, Eq (1.7) is replaced by the more general expression:

$$\gamma_i^m \left(\frac{q_i^m - q_i^{m-1}}{\Delta^m} \right) + [f_A q_i^m + f_B q_i^{m-1}] = (\xi \Sigma_s)_i^m \varphi^m ,$$

but only the values $f_A = f_B = \frac{1}{2}$ are commonly used.

$$\bar{p}_i^m = \frac{[(\eta \Sigma_s)_i \bar{j}]^m}{\frac{1}{2} + \frac{\zeta_i^m}{\Delta^m}} - \bar{p}_i^{m-1} \left(\frac{\frac{1}{2} - \frac{\zeta_i^m}{\Delta^m}}{\frac{1}{2} + \frac{\zeta_i^m}{\Delta^m}} \right) \quad (1.10)$$

Eliminating q_i^m and $\bar{p}_i^m$ from Eqs (1.5) and (1.6) results in:

$$\nabla \cdot \bar{j}^m + \left[(\Sigma_{in} + \Sigma_a^s)^m + \sum_i \frac{(\xi \Sigma_s)_i^m}{\frac{\Delta^m}{2} + \gamma_i^m} \right] \varphi^m = S^m + \sum_i q_i^{m-1} \left[\frac{1}{\frac{\Delta^m}{2} + \gamma_i^m} - \frac{1 - (p_a)^m}{\Delta^m} \right], \quad (1.11)$$

and

$$\frac{1}{3} \nabla \varphi^m + \left[\Sigma_{tr}^m + \sum_i \frac{(\eta \Sigma_s)_i^m}{\frac{\Delta^m}{2} + \zeta_i^m} \right] \bar{j}^m = \sum_i \frac{\bar{p}_i^{m-1}}{\frac{\Delta^m}{2} + \zeta_i^m}. \quad (1.12)$$

IV. TRANSVERSE BUCKLING

It will be assumed that the flux is separable in the x, y, and z directions for slabs, and in the r and z directions for cylinders. More precisely, let

$$\varphi(x, y, z) = \Phi(z) (\cos B_x x) \cos B_y y \quad (1.13)$$

in the slab case; and

$$\varphi(r, z) = \Phi(z) (\cos B_z z) \quad (1.14)$$

or

$$\varphi(r, z) = \Phi(z) J_0(B_r r) \quad (1.15)$$

in cylinder problems. Conventional physical approximations are implied by the assumption of separability.

For convenience, the argument of Φ will be denoted by ρ in all cases, and the slab will be treated first. Again, assuming separability:

$$\bar{j}_z(x, y, z) = [J_z(z) (\cos B_x x) \cos B_y y] \hat{z}, \quad (1.16)$$

$$\bar{j}_x(x, y, z) = [J_x(z) (\sin B_x x) \cos B_y y] \hat{x}, \quad (1.17)$$

and

$$\bar{j}_y(x, y, z) = [J_y(z) (\cos B_x x) \sin B_y y] \hat{y}, \quad (1.18)$$

where $\hat{x}$, $\hat{y}$, and $\hat{z}$ are unit vectors. Separated expressions for q and $\bar{p}$ resemble those for φ and $\bar{j}$, respectively. To abbreviate notation in the work which follows, let

$$\sigma^m(\rho) (\cos B_x x) \cos B_y y = S^m + \sum_i q_i^{m-1} \left[\frac{1}{\frac{\Delta^m}{2} + \gamma_i^m} - \frac{1 - (p_a)^m}{\Delta^m} \right], \quad (1.19)$$

$$\beta^m = 3 \left[\Sigma_{tr}^m + \sum_i \frac{(\eta \Sigma_s)_i^m}{\frac{\Delta^m}{2} + \zeta_i^m} \right], \quad (1.20)$$

and

$$\sigma^m = (\Sigma_{in} + \Sigma_a^s)^m + \sum_i \frac{(\xi \Sigma_s)_i^m}{\frac{\Delta^m}{2} + \gamma_i^m}. \quad (1.21)$$

Then, from Eq (1.11),

$$\frac{\partial(J_\rho)^m}{\partial\rho} + B_x(J_x)^m + B_y(J_y)^m + (\alpha\Phi)^m = \sigma^m. \quad (1.22)$$

Equation (1.12) yields three scalar equations. Upon introducing the definition

$$t^m = \frac{3 \sum_i (P_\rho)_i^{m-1}}{\frac{\Delta^m}{2} + \zeta_i^m}, \quad (1.23)$$

these scalar equations may be written in the form:

$$\frac{\partial\Phi^m}{\partial\rho} + (\beta J_\rho)^m = t^m, \quad (1.24)$$

$$-B_x\Phi^m + (\beta J_x)^m = \frac{3 \sum_i (P_x)_i^{m-1}}{\frac{\Delta^m}{2} + \zeta_i^m}, \quad (1.25)$$

and

$$-B_y\Phi^m + (\beta J_y)^m = \frac{3 \sum_i (P_y)_i^{m-1}}{\frac{\Delta^m}{2} + \zeta_i^m}. \quad (1.26)$$

Eliminating $(J_x)^m$ and $(J_y)^m$ from Eq (1.22) results in

$$\frac{\partial(J_\rho)^m}{\partial\rho} + [\alpha^m + D^m B^2]\Phi^m = \sigma^m - \frac{3D^m B_x \sum_i (P_x)_i^{m-1}}{\frac{\Delta^m}{2} + \zeta_i^m} - \frac{3D^m B_y \sum_i (P_y)_i^{m-1}}{\frac{\Delta^m}{2} + \zeta_i^m}. \quad (1.27)$$

Here,

$$D^m = \frac{1}{\beta^m}$$

is, in effect, a corrected diffusion constant. With further abbreviation of the notation, Eq (1.27) may be rewritten in the form:

$$\frac{\partial(J_\rho)^m}{\partial\rho} + (\alpha\Phi)^m = s^m. \quad (1.28)$$

In summary, the quantities Φ^m and $(J_\rho)^m$ satisfy the relationships

$$\frac{\partial(J_\rho)^m}{\partial\rho} + (\alpha\Phi)^m = s^m \quad (1.29)$$

and

$$\frac{\partial\Phi^m}{\partial\rho} + (\beta J_\rho)^m = t^m, \quad (1.30)$$

under the auxiliary conditions

$$-B_{x,y}\Phi^m + (\beta J_{x,y})^m = \frac{3 \sum_i (P_{x,y})_i^{m-1}}{\frac{\Delta^m}{2} + \zeta_i^m}, \quad (1.31)$$

$$Q_i^m = \frac{[(\xi\Sigma_s)_i\Phi]^m}{\frac{1}{2} + \frac{\gamma_i^m}{\Delta^m}} - Q_i^{m-1} \left(\frac{\frac{1}{2} - \frac{\gamma_i^m}{\Delta^m}}{\frac{1}{2} + \frac{\gamma_i^m}{\Delta^m}} \right), \quad (1.32)$$

and

$$(P_{\rho, x, y})_i^m = \frac{[(\eta \Sigma_s)_i J_{\rho, x, y}]^m}{\frac{1}{2} + \frac{\zeta_i^m}{m}} - (P_{\rho, x, y})_i^{m-1} \left(\frac{\frac{1}{2} - \zeta_i^m}{\frac{1}{2} + \frac{\gamma_i^m}{\Delta^m}} \right). \quad (1.33)$$

In other geometries, the following modifications are required in the basic equations:
The expression

$$\frac{\partial(J_\rho)^m}{\partial \rho}$$

in Eq (1.29) is replaced by the expression

$$\frac{\partial(J_\rho)^m}{\partial \rho} + \frac{G}{\rho} (J_\rho)^m,$$

where $G = 1$ if Eq (1.14) is valid, $G = 0$ if Eq (1.15) is valid, and $G = 2$ in spherical geometry. There can be only one transverse buckling. The various special cases will be subsumed in the following work if Eq (1.29) is replaced by

$$\frac{\partial(J_\rho)^m}{\partial \rho} + \frac{G}{\rho} (J_\rho)^m + (a\Phi)^m = s^m. \quad (1.34)$$

V. SPATIAL DIFFERENCE EQUATIONS

Let the subscript n denote the n^{th} mesh point. Multiply Eq (1.34) by ρ^G and integrate the resulting equation from the midpoint of the mesh interval, preceding this point to the midpoint of the interval following it. To leading order in the mesh width h ,

$$\begin{aligned} (\rho_{n+1/2})^G (J_\rho)_{n+1/2}^m - (\rho_{n-1/2})^G (J_\rho)_{n-1/2}^m + \frac{1}{2} (\rho_n)^G [(a^m h)_{n+} + (a^m h)_{n-}] \Phi_n^m \\ = \frac{1}{2} (\rho_n)^G [(s^m h)_{n+} + (s^m h)_{n-}]. \end{aligned} \quad (1.35)$$

The $n+$ and $n-$ subscripts indicate parametric values to the right and left of point n , respectively. Equation (1.24) can also be written in difference form:

$$\frac{(\Phi_{n+1} - \Phi_n)^m}{h_{n+}} + [\beta_{n+} (J_\rho)_{n+1/2}]^m = t_{n+1/2}^m \quad (1.36)$$

and

$$\frac{(\Phi_n - \Phi_{n-1})^m}{h_{n-}} + [\beta_{n-} (J_\rho)_{n-1/2}]^m = t_{n-1/2}^m. \quad (1.37)$$

The $(J_\rho)^m$ terms may now be eliminated from Eq (1.35), with the aid of Eq (1.36) and Eq (1.37); thus

$$\begin{aligned} - \left[D_{n+}^m \frac{(\rho_{n+1/2})^G}{h_{n+}} (\Phi_{n+1} - \Phi_n)^m - D_{n-}^m \frac{(\rho_{n-1/2})^G}{h_{n-}} (\Phi_n - \Phi_{n-1})^m \right] \\ + \frac{1}{2} (\rho_n)^G [(a^m h)_{n+} + (a^m h)_{n-}] \Phi_n^m = \frac{1}{2} (\rho_n)^G [(s^m h)_{n+} + (s^m h)_{n-}] \\ - [(\rho_{n-1/2})^G (D_{n+} t_{n+1/2})^m - (\rho_{n-1/2})^G (D_{n-} t_{n-1/2})^m]. \end{aligned} \quad (1.38)$$

Equation (1.38) is the basic three-point difference equation which will be solved in each group m .

VI. BOUNDARY CONDITIONS

The left- and right-hand boundary conditions available in P1MG have the form

$$J_L^m = -(C\Phi)_L^m \text{ and } J_R^m = -(C\Phi)_R^m . \quad (1.39)$$

For cylinders and spheres, C_L^m must be zero. The left-hand boundary condition will be discussed separately for Cartesian and non-Cartesian geometries.

Cartesian Geometry

Integrating Eq (1.34) from the origin to the midpoint of the first mesh interval (to leading order in h):

$$(J_\rho)_0^m = (J_\rho)_{1/2}^m + \frac{1}{2}(a^m h)_{0+} \bar{\Phi}_0^m - \frac{1}{2}(s^m h)_{0+} = -(C_L \bar{\Phi}_0)^m . \quad (1.40)$$

From Eq (1.35),

$$(J_\rho)_{1/2}^m = \left[t_{1/2}^m - \frac{(\bar{\Phi}_1 - \bar{\Phi}_0)^m}{h_{0+}} \right] D_{0+}^m . \quad (1.41)$$

When Eq (1.41) is used to eliminate $(J_\rho)_{1/2}^m$ from Eq (1.40), a linear relation between $\bar{\Phi}_1^m$ and $\bar{\Phi}_0^m$ results. This relation supplements the three-point difference equation which is valid at interior mesh points.

It should be noted that a vanishing flux condition is not explicitly provided. However, the flux may be made to vanish, approximately, by inserting, for C_L^m , a very large positive number. The number 4×10^{20} is used for this purpose in P1MG when a vanishing flux is requested at the left-hand boundary. This device has proved very effective.

Other Geometries

At the origin, Eq (1.34) becomes

$$[1 + G] \frac{\partial (J_\rho)^m}{\partial \rho} \bigg|_{\rho=0} + (a\Phi)_0^m = s_0^m , \quad (1.42)$$

by L'Hospital's Rule. Now, if $(J_\rho)_0^m$ vanishes in all groups, t_0^m must also vanish, and it is clear from Eq (1.30) that

$$\frac{\partial \bar{\Phi}^m}{\partial \rho} \bigg|_{\rho=0} = 0 .$$

Differentiating Eq (1.30) at the origin results in

$$\frac{\partial (J_\rho)^m}{\partial \rho} \bigg|_{\rho=0} = D_0^m \left[\frac{\partial t_{1/2}^m}{\partial \rho} - \frac{\partial^2 \bar{\Phi}^m}{\partial \rho^2} \right] \bigg|_{\rho=0} \quad (1.43)$$

if β^m is constant in the first region. This restriction could be removed, without difficulty, from the difference equations. However, to simplify the programming, it has been assumed in the P1MG code that the composition of all materials is uniform over regions (Part Two, Section IV).

It has been shown that $\bar{\Phi}^m$ is symmetric at the origin. Similarly, it can be shown that t^m is antisymmetric. Therefore, in a central difference approximation,

$$\frac{\partial t^m}{\partial \rho} \sim \frac{2t_{1/2}^m}{h_{0+}} , \quad \frac{\partial^2 \bar{\Phi}^m}{\partial \rho^2} \sim \frac{2}{h_{0+}^2} (\bar{\Phi}_1 - \bar{\Phi}_0)^m , \quad (1.44)$$

and Eq (1.43) becomes

$$\left. \frac{\partial (J_\rho)^m}{\partial \rho} \right|_{\rho=0} = D_0^m \left[\frac{2t_{1/2}^m}{h_{0+}} - \frac{2}{h_{0+}^2} (\bar{\Phi}_1 - \bar{\Phi}_0)^m \right]. \quad (1.45)$$

Inserting this expression into Eq (1.42), a linear relation between $\bar{\Phi}_1^m$ and $\bar{\Phi}_0^m$ is again obtained.

Right-Hand Boundary Conditions

At the outer boundary, in all permitted geometries,

$$(\rho_R)^G (J_\rho)_R^m = \frac{1}{2} (\rho_R)^G (s^m h)_{R-} + [\rho^G (J_\rho)^m]_{R-1/2} - \frac{1}{2} (a^m h)_{R-} (\rho^G \bar{\Phi}^m)_R \quad (1.46)$$

and

$$\frac{(\bar{\Phi}_R - \bar{\Phi}_{R-1})^m}{h_{R-}} + [\beta_{R-} (J_\rho)_{R-1/2}]^m = t_{R-1/2}^m. \quad (1.47)$$

With the aid of Eq (1.39) and Eq (1.46), $(J_\rho)_{R-1/2}^m$ may be eliminated from Eq (1.47), which then becomes a linear difference equation in $\bar{\Phi}_R^m$ and $\bar{\Phi}_{R-1}^m$.

VII. METHOD OF SOLUTION

In order to facilitate discussion of the procedure used to solve the PLMG equations, it will be helpful to write out explicitly the term s^m appearing in Eq (1.38):

$$s^m = (S_f)^m + (S_{in})^m + \sum_i Q_i^{m-1} \left[\frac{1}{\frac{\Delta^m}{2} + \gamma_i^m} - \frac{1 - (p_a)^m}{\Delta^m} \right] \quad (1.48)$$

where

$$(S_f)^m = \frac{\chi^m \sum_\ell \left\{ [(\nu \Sigma_f^S) \bar{\Phi} \Delta]^\ell + \sum_\ell v_i^\ell [1 - (p_f)_i^\ell] Q_i^{\ell-1} \right\}}{\lambda}, \quad (1.49)$$

or

$$(S_f)^m = \chi^m g_f,$$

and

$$(S_{in})^m = \sum_{\ell < m} K_\ell^m (\Sigma_{in} \bar{\Phi} \Delta)^\ell. \quad (1.50)$$

In Eqs (1.49) and (1.50)

$(\chi \Delta)^m$ is that fraction of the fission spectrum feeding into the m^{th} group,

$(p_f)^\ell$ is the fission resonance escape probability in the ℓ^{th} group (as in MUFT 4, Ref 2),

$(\Sigma_{in})^\ell$ is the macroscopic inelastic scattering cross section in the ℓ^{th} group,

$K_\ell^m \Delta^\ell$ is the probability that a neutron, inelastically scattered in the ℓ^{th} group, will be scattered into the m^{th} group.

The PLMG equations are solved by an iterative process, which starts from a guessed source function $(g_f)^{(0)}$. Now, $Q_i^0 = 0$ and $\bar{P}_i^0 = 0$ if no fission neutrons are produced with lethargies smaller than u_0 . Therefore, it is possible to construct the function s^1 in Eq (1.38), while $t^1 = 0$. With the inhomogeneous term in the first group given, the difference equations in the first group are solved (Ref 3) for $\bar{\Phi}^1$. Equation (1.36) or Eq (1.37) then determines $(J_\rho)^1$ at midpoints of mesh intervals, and Eq (1.31) may be used to evaluate the transverse current (or currents) at mesh points. Equations (1.32) and (1.33) fix the values of Q and $\bar{P}$ in the first group. Having computed all the relevant first group quantities, s^2 can be constructed at mesh points and t^2 at mesh interval midpoints. The second

group equation is then solved for $\bar{\Phi}^2$, etc. After all the group equations have been solved, an improved fission source function $(g_f)^{(1)}$ is constructed from the $\bar{\Phi}$ and Q values. As in the WANDA code (Ref 3), the volume integral of g_f is normalized to 1, i. e., the eigenvalue estimate λ is given by the expression

$$\lambda = \sum_l \int \left\{ [(\nu \Sigma_f^S) \bar{\Phi} \Delta]^l + \sum_i \nu_i^l [1 - (p_f)_i^l] Q_i^{l-1} \right\} dV \quad (1.51)$$

Extrapolation on g_f is available, as in the WANDA code. Experience indicates that an extrapolation factor which works effectively in a given WANDA problem will also be effective in the corresponding PLMG problem.

VIII. THERMAL GROUP

It should be noted that the thermal group is treated somewhat differently from the fast and epithermal groups because of the slightly artificial character of the thermal group, and because there is no slowing down from the thermal group. The thermal group equations are:

$$\nabla \cdot \bar{j}^M + (\Sigma_a \bar{\Phi})^M = \sum_i q_i^{M-1} \quad (1.52)$$

and

$$\frac{1}{3} \nabla \bar{\Phi}^M + (\Sigma_{tr} \bar{j})^M = \sum_i \bar{p}_i^{M-1} \quad (1.53)$$

or, in separated notation,

$$\frac{\partial (J_\rho)^M}{\partial \rho} + G_\rho (J_\rho)^M + (\Sigma_a \bar{\Phi})^M = \sum_i Q_i^{M-1} \quad (1.54)$$

$$\frac{1}{3} \frac{\partial \bar{\Phi}^M}{\partial \rho} + (\Sigma_{tr} J_\rho)^M = \sum_i (P_\rho)_i^{M-1} \quad (1.55)$$

and

$$-\frac{1}{3} B_{x,y} \bar{\Phi}^M + (\Sigma_{tr} J_{x,y})^M = \sum_i (P_{x,y})_i^{M-1} \quad (1.56)$$

The spatial difference equation in the thermal group is formally identical with Eq (1.38), with parameters redefined as follows:

$$a^M = (\Sigma_a)^M + D^M \beta^2 \quad (1.57)$$

where

$$D^M = \frac{1}{\beta^M} = \frac{1}{3(\Sigma_{tr})^M} \quad (1.58)$$

$$s^M = \sum_i Q_i^{M-1} - 3D^M B_x \sum_i (P_x)_i^{M-1} - 3D^M B_y \sum_i (P_y)_i^{M-1} \quad (1.58)$$

and

$$t^M = 3 \sum_i (P_\rho)_i^{M-1} \quad (1.59)$$

Because of the difficulties inherent in a one-velocity model of the thermal group, there is no clear-cut procedure for determining $(\Sigma_a)^M$ and $(\Sigma_{tr})^M$. Therefore, macroscopic constants for the thermal group are precomputed by any procedure considered appropriate and inserted into the code as input.

IX. DISCUSSION

In order to facilitate checkout of the code, and to permit a meaningful comparison between

few-group and multigroup results, the P1MG equations have been forced to conform closely to the equations in MUFT 4. It will be noted that the buckling appears in the MUFT 4 expression for the resonance escape probability (Ref 2). Exactly the same expression, Eq (2. 20), is used to compute resonance escape probabilities in P1MG. The effect of the buckling term on p-resonance is, generally, very small, but a value for this "resonance buckling" is required as input to the P1MG code. It will be seen that the P1MG treatment of resonances implies that slowing-down predominates over leakage. If the flux in a region is determined primarily by the leakage, rather than by the slowing-down density, the P1MG resonance model will be inadequate.

In all, four input bucklings must be supplied to P1MG, namely, the "resonance buckling" already discussed, B_x , B_y , and B^2 .

If there is only one transverse buckling, this can be entered as B_x , with $B_y = 0$, or vice versa. Of course B_x , B_y , and B^2 should satisfy the relation $B^2 = B_x^2 + B_y^2$, but B_x , B_y , and B^2 are taken to be independent quantities here. It is possible, for example, to specify $B_x = B_y = 0$ and $B^2 \neq 0$. In this case the transverse buckling term in the group equations is simply $D^m B^2$.

Anisotropic slowing down into the thermal group is explicitly taken into account in the P1MG code, while it is neglected in few-group codes.* It may be that such a refinement is superfluous at present, because of the crudity of the one-group thermal model. At any rate, the effect appears to be quite small.

X. EDIT OF FEW-GROUP AVERAGES

In a few-group approximation, the non-thermal neutrons are assigned to a small number of groups which will be referred to, for convenience, as "macro-groups." These are to be distinguished from the P1MG "micro-groups." In order to facilitate comparisons between few-group and multi-group results, a few-group edit has been provided as a P1MG output option. This routine computes and prints macro-group parameters, as follows:

$$\Phi_n^k = \sum_{m=K_l}^{K_u} (\Phi_n \Delta)^m, \quad (1.60)$$

$$(\Sigma_r)_n^k = \frac{\sum_i Q_{i,n}^{K_u}}{\Phi_n^k}, \quad (1.61)$$

$$(\Sigma_a)_n^k = \frac{\sum_{m=K_l}^{K_u} \left\{ (\Sigma_a^3 \Phi_n \Delta)^m + [1 - (p_a)^m] \sum_i Q_{i,n}^{m-1} \right\}}{\Phi_n^k}, \quad (1.62)$$

$$(\nu \Sigma_f)_n^k = \frac{\sum_{m=K_l}^{K_u} \left\{ [(\nu \Sigma_f^s) \Phi_n \Delta]^m + \sum_i \nu_i^m [1 - (p_f)_i^m] \sum_i Q_{i,n}^{m-1} \right\}}{\Phi_n^k} \quad (1.63)$$

and

$$D_{n+1/2}^k = \frac{h \sum_{m=K_l}^{K_u} [(J_\rho)_{n+1/2} \Delta]^m}{(\Phi_n - \Phi_{n+1})^k}. \quad (1.64)$$

* For example, this effect is neglected in the MUFT-WANDA system.

Here K_l and K_u are the lowest and highest lethargy micro-groups, respectively, in macro-group k . Cut-points for the macro-groups may be specified as desired, provided that the whole non-thermal energy range is divided into three such groups, at most.

If the few-group edit is requested, region checks for each macro-group will be printed out, as in the WANDA code. It should be noted, however, that the transverse buckling is not treated rigorously in the region-check calculation. For this reason, apparent imbalances in the region check may occur when the transverse buckling is very high. However, no such difficulty has as yet been observed.

PART TWO: PROGRAMMING AND OPERATION OF CODE

I. INTRODUCTION

The equations used in programming P1MG are listed in Part Two, Section III in approximately the order in which they are used. In this part of the report, the authors have taken the liberty of passing on information in the form of warning signs, by underlining descriptive phrases, which indicate the places where errors are most apt to occur in preparing input. Wherever possible, the program stop which might result from a particular piece of incorrect data is indicated after the description of that data.

The P1MG1 version required that microscopic data for the thermal group also be supplied in the library. The second version, P1MG2, requires that the problem requester supply the necessary thermal macroscopic cross sections for each problem. However, the library used by P1MG2 still contains a set of dummy thermal microscopic cross sections which should not be overlooked when data are prepared for the library as described in Section VIII of this part of the report.

Part Two is a description of P1MG2, since this is the more practical of the two versions and the only version available for distribution.

II. GLOSSARY

Indices—Superscripts and Subscripts

a	absorption [Eqs (2.14), (2.20), (2.25), and (2.71)]
A	denotes the first of a set of two numbers [Eq (2.31)]
B	denotes the second of a set of two numbers [Eq (2.31)]
Bpt ₁	Breakpoint No. 1 [Footnote (*) p 19; Eq (2.68)]
Bpt ₂	Breakpoint No. 2 [Footnote (*) p 19; Eq (2.68)]
c	capture [Eq (2.13)] or card number (Part Two, Section IV)
f	fission [Eqs (2.11) and (2.30a)]
G	geometry [Eq (2.37)]
i	isotope [Eqs (2.1) and (2.2)]
in	inelastic scattering [Eq (2.16)]
j	region [Eq (2.1)]
J	region farthest from origin [Eq (2.48)]
k	resonance within a group [Eq (2.20)] or few-group scheme [Eq (2.64)]
K _l	lowest value of m in few-group l of scheme k [Eq (2.64)]
K _u	highest value of m in few-group l of scheme k [Eq (2.64)]
l	lowest value [Eq (2.64), see K _l]
L	lower bound of the resonances (Part Two, Section VIII) or left [see (C _L) ^m , Eq (2.44)]
m	group [Eq (2.1)]

M	group number of the highest lethargy group or thermal group [Eq (2. 57)]
n	point [Eq (1. 35)]
n_j	interface point at right end of region j [Eq (2. 76)]
N	point farthest from the origin ($n = 0$) [Eq (2. 48)]
r	group from which scattering is occurring [Eq (2. 29)] or control parameter (Part Two, Section IV, Form II)
R	removal [Eq (2. 65)] or right [see $(C_R)^m$, Eq (2. 48)]
s	smooth [Eqs (2. 11), (2. 13), and (2. 14)]
t	iteration [Eq (2. 36)]
T	total [Eq (2. 80)] or converged iteration number [Eq (2. 38b)]
u	upper [Eq (2. 64), see K_u]
U	upper bound of the inelastic scattering matrix [Eq (2. 68); Part Two, Section VIII]
v	few-group [Eq (2. 64)]
x	one of the three Cartesian coordinates [Eqs (2. 41) and (2. 52), see y and ρ]
y	one of the three Cartesian coordinates [Eqs (2. 41) and (2. 54), see x and ρ]
ρ	the coordinate corresponding to the direction in which the flux shape is being computed
+ or -	"interval to the right" or "interval to the left"

Quantities

$a_i^{r, m}$	an element in the inelastic scattering matrix—probability of scattering from multigroup r to multigroup m for isotope i [Eq (2. 29)]
$\Lambda_{j, i}^m$	as defined by Eq (2. 19)
$A^{r, m}$	as defined by Eq (2. 29)
$b_n^{m, (t)}$	as defined by Eqs (2. 45) and (2. 47)
$(B^2)_j$	total buckling (Part Two, Section IV)
$(B_R^2)_j$	resonance buckling [Part Two, Section IV; Eq (2. 19)]
$(B_x)_j$	component of buckling in the transverse x-direction [Eqs (2. 41) and (2. 52)]
$(B_y)_j$	component of buckling in the transverse y-direction [Eqs (2. 41) and (2. 54)]
$c_n^{m, (t)}$	as defined by Eq (2. 43)
$c(G)$	a parameter dependent upon the geometry [Eqs (2. 83) and (2. 84)]
C_j^m	macroscopic symmetric scattering cross section of hydrogen as defined by Eq (2. 1)
$(C_L)^m$	parameter which controls the left-hand boundary condition as defined by Eq (1. 39)
$(C_R)^m$	parameter which controls the right-hand boundary condition as defined by Eq (1. 39)
d_j^m	as defined by Eq (2. 9)
$d_{n_j}^{v, k}$	as defined by Eqs (2. 78) and (2. 79)
D_j^m	diffusion coefficient as defined by Eq (2. 30)

$D_{n+1/2}^{v,k}$	average diffusion coefficient for few-group v of scheme k at midpoint $n+1/2$ [Eq (2. 73)]
f_A	factor A [Eq (2. 31)]
f_B	factor B [Eq (2. 41)]
$(g_f)_n^{(t)}$	as defined by Eq (2. 38)
h_j	mesh size [Eq (2. 32)]
H_{n_j}	as defined by Eqs (2. 76) and (2. 77)
$j_{n+}^{m,(t)}$	current [Eqs (2. 50), (2. 52), (2. 54), (2. 59), and (2. 60)]
$J_{n_j}^{v,k}$	total current [Eqs (2. 83) and (2. 84)]
ℓ_n^m	as defined by Eq (2. 33)
$L_{j,i}^{m,k}$	self-shielding factor [Eq (2. 20)]
$(m_a)_i^{m,k}$	absorption resonance parameter [Eq (2. 20)]
$N_{j,i}$	number density [Eq (2. 1)]
$(p_a)_j^m$	absorption resonance escape probability [Eq (2. 25)]
$(p_f)_{j,i}^m$	fission resonance escape probability [Eq (2. 23)]
$P_{n+,i}^{m,(t)}$	anisotropic slowing-down density [Eqs (2. 51), (2. 53), and (2. 55)]
$Q_{n,i}^{m,(t)}$	isotropic slowing-down density [Eq (2. 56)]
$(r_a)_i^{m,k}$	absorption resonance parameter [Eq (2. 20)]
$(RI_a)_{j,i}^{m,k}$	absorption resonance integral [Eq (2. 20)]
$(RI_f)_{j,i}^m$	fission resonance integral [Eq (2. 22)]
$s_n^{(t)}$	as defined by Eq (2. 36)
$s_{n+}^{m,(t)}$	as defined by Eq (2. 41)
$(S_f)_n^{m,(t)}$	as defined by Eq (2. 39)
$t_{n+}^{m,(t)}$	as defined by Eq (2. 42)
U_j^m	as defined by Eq (2. 8)
V_j^m	as defined by Eq (2. 2)
Y_j^m	as defined by Eq (2. 6)
α_i^m	fission to absorption ratio [Eq (2. 22)]
α_j^m	as defined by Eq (2. 31)
β_j^m	as defined by Eq (2. 30)
γ_i^m	age number [Eq (2. 27)]
δ_{n+1}^m	as defined by Eqs (2. 44) and (2. 46)
δ	convergence parameter (Part Two, Section IV)
Δ^m	lethargy increment [Eq (2. 28)]
ϵ	error criterion [Eqs (2. 61) and (2. 63)]
ζ_i^m	anisotropic slowing-down coefficient [Eq (2. 28)]
η_i^m	isotropic slowing-down coefficient [Eq (2. 4)]

θ	extrapolation factor [Eq (2. 38b)]
κ_n^m	as defined by Eq (2. 35)
$(\kappa_1)_i^m$	as defined by Eq (2. 28)
$(\kappa_2)_{j,i}^m$	as defined by Eq (2. 4)
$(\kappa_3)_i^m$	as defined by Eq (2. 27)
$(\kappa_4)_{j,i}^m$	as defined by Eq (2. 5)
$(\kappa_5)_{j,i}^m$	as defined by Eq (2. 26)
$\lambda^{(t)}$	eigenvalue [Eq (2. 37)]
$\lambda_{\max}$	maximum pointwise eigenvalue [Eq (2. 62a)]
$\lambda_{\min}$	minimum pointwise eigenvalue [Eq (2. 62b)]
μ	as defined by Eq (2. 34)
μ_1^m	average cosine of the scattering angle [Eq (2. 6)]
ν_i^m	average number of neutrons produced per fission [Eqs (2. 12) and (2. 26)]
ξ_i^m	average logarithmic energy decrement per collision [Eq (2. 5)]
ξ_j^m	as defined by Eq (2. 10)
π	3. 141592654 [Eq (2. 20)]
ρ_n	radius from origin [Eq (2. 32)]
$(\sigma_f)_i^m$	microscopic smooth fission cross section [Eq (2. 11)]
$(\sigma_{in})_i^m$	microscopic inelastic scattering cross section [Eq (2. 16)]
$(\sigma_c)_i^m$	microscopic smooth capture cross section [Eq (2. 13)]
(σ_s)	microscopic symmetric scattering cross section [Eq (2. 1)]
Σ_j^m	macroscopic total cross section as defined by Eq (2. 17)
$(\Sigma_T)_{nj}^{v,k}$	macroscopic total cross section as defined by Eq (2. 80)
$(\Sigma_a)_j^m$	macroscopic smooth absorption cross section [Eq (2. 14)]
$(\Sigma_f)_j^m$	macroscopic smooth fission cross section [Eq (2. 11)]
$(\Sigma_{in})_j^m$	macroscopic inelastic scattering cross section [Eq (2. 16)]
$(\Sigma_{tr})_j^m$	macroscopic transport cross section [Eq (2. 15)]
τ	one iteration parameter (Part Two, Section IV)
$\phi_n^{m,(t)}$	multigroup flux [Eqs (2. 36), (2. 40), (2. 48), and (2. 49)]
$\Phi_n^{v,k}$	few group flux [Eq (2. 64)]
χ^m	normalized source distribution spectrum component [Eq (2. 39)]
$\omega_n^{m,(t)}$	number of neutrons inelastically scattered into lethargy group m per unit lethargy

III. EQUATIONS USED IN P1MG2

Coefficient Routine*

$$(1. 2) \quad (\Sigma_s)_{j,i}^m = N_{j,i} (\sigma_s)_i^m \quad (2. 1)$$

* The number at the left of each equation refers to the equation in Part One where the quantity is first introduced or derived.

or, for $i = 01$ in Eq (2.1),

$$C_j^m = N_{j, 01} (\sigma_s)_{01}^m \cdot$$

$$V_j^m = \sum_i (\Sigma_s)_{j, i}^m \quad (2.2)$$

where the summation [in Eq (2.2)] includes only the nonhydrogenous moderators.

$$(\Sigma_s)_j^m = \sum_i (\Sigma_s)_{j, i}^m \quad (2.3)$$

$$(1.4) \quad (\eta \Sigma_s)_{j, i}^m = (\kappa_2)_{j, i}^m = \eta_i^m (\Sigma_s)_{j, i}^m \quad (2.4)$$

$$(1.2) \quad (\xi \Sigma_s)_{j, i}^m = (\kappa_4)_{j, i}^m = N_{j, i} (\xi \sigma_s)_i^m \quad (2.5)$$

$$Y_j^m = \sum_{i \neq 01} N_{j, i} (\bar{\mu} \sigma_s)_i^m \quad (2.6)$$

$$[(1 - \bar{\mu}) \Sigma_s]_j^m = \sum_i (\Sigma_s)_{j, i}^m - N_{j, i} (\bar{\mu} \sigma_s)_i^m \quad (2.7)$$

$$U_j^m = \sum_i (\kappa_4)_{j, i}^m \quad (2.8)$$

where the summation [in Eq (2.8)] includes only the nonhydrogenous moderators.

$$d_j^{m-1} = C_j^{m-1} + V_j^{m-1} \quad (2.9)$$

$$\bar{\xi}_j^m = \frac{C_j^m + U_j^m}{d_j^m} \quad (2.10)$$

$$(1.49) \quad (\Sigma_f^s)_j^m = \sum_i N_{j, i} (\sigma_f^s)_i^m \quad (2.11)$$

$$(1.49) \quad (\nu \Sigma_f^s)_{j, i}^m = \sum_i \nu_i^m (\Sigma_f^s)_{j, i}^m \quad (2.12)$$

$$(\Sigma_c^s)_j^m = \sum_i N_{j, i} (\sigma_c^s)_i^m \quad (2.13)$$

$$(1.5) \quad (\Sigma_a^s)_j^m = (\Sigma_c^s + \Sigma_f^s)_j^m \quad (2.14)$$

$$(1.3) \quad (\Sigma_{tr})_j^m = [\Sigma_a^s + \Sigma_{in} + (1 - \bar{\mu}) \Sigma_s]_j^m \quad (2.15)$$

$$(1.1) \quad (\Sigma_{in})_j^m = \sum_i N_{j, i} (\sigma_{in})_i^m \quad (2.16)$$

$$\Sigma_j^m = [\Sigma_a^s + \Sigma_{in} + \Sigma_s]_j^m \quad (2.17)$$

$$G_j^{m-1} = \Sigma_j^{m-1} - Y_j^{m-1} \quad (2.18)$$

$$A_{j, i}^m = \frac{1}{N_{j, i}} \left[d_j^{m-1} + \frac{(B_R^2)_j}{3G_j^{m-1}} \right] \quad (2.19)$$

$$(RI_a)_{j,i}^{m,k} = \frac{[(m_a)L_j]_i^{m,k}}{\xi_j^m} \left(\frac{\pi/2}{\sqrt{A_{j,i}^m [A_{j,i}^m + (r_a)_i^{m,k}]}} \right) \quad (2.20)$$

where $k = 1, 2, 3, \dots, K \leq 8$.

$$(RI_a)_{j,i}^m = \sum_k (RI_a)_{j,i}^{m,k} \quad (2.21)$$

$$(RI_f)_{j,i}^m = \alpha_i^m (RI_a)_{j,i}^m \quad (2.22)$$

$$(1.49) \quad (p_f)_{j,i}^m = e^{-(RI_f)_{j,i}^m} \quad (2.23)$$

$$(RI_a)_j^m = \sum_i (RI_a)_{j,i}^m \quad (2.24)$$

$$(1.5) \quad (p_a)_j^m = e^{-(RI_a)_j^m} \quad (2.25)$$

$$(1.49) \quad (\kappa_5)_{j,i}^m = v_i^m [1 - (p_f)_{j,i}^m] \quad (2.26)$$

$$(1.2) \quad (\kappa_3)_i^m = \gamma_i^m \quad (2.27)$$

$$(1.10) \quad (\kappa_1)_i^m = \zeta_i^m + \frac{\Delta^m}{2} \quad (2.28)$$

$$(1.50) \quad A_j^{r,m,\Delta^m} = \sum_i N_{j,i} (A)_i^{r,m,\Delta^r} \quad (2.29)$$

$$(1.20), (1.27) \quad \beta_j^m = 3 \left[(\Sigma_{tr})_j^m + \sum_i \frac{(\kappa_2)_{j,i}^m}{(\kappa_1)_i^m} \right] = \frac{1}{D_j^m} \quad (2.30)$$

$$(1.21) \quad \alpha_j^m = (\Sigma_a^s)_j^m + (\Sigma_{in})_j^m + \sum_i \frac{(\kappa_4)_{j,i}^m}{(\kappa_3)_i^m + f_{A\Delta^m}} + \left(\frac{B^2}{\beta^m} \right)_j \quad (2.31)$$

where $B^2 \equiv$ Total Buckling; (see Part One, Section IX and Part Two, Section IV).

$$(1.35) \quad \rho_n = \rho_{n-1} + h_-, \quad \rho_0 = 0 \quad (2.32)$$

$$(1.38) \quad \ell_n^m = \frac{\beta_+^m h_-}{\beta_-^m h_+} \left(\frac{2\rho_n + h_-}{2\rho_n + h_+} \right)^G \quad (2.33)$$

$$(1.38) \quad \mu_n^m = \frac{\beta_+^m h_+}{2} \left(\frac{\rho_n}{\rho_n + \frac{h_+}{2}} \right)^G \quad (2.34)$$

$$(1.38) \quad \kappa_n^m = \ell_n^m + \mu_n^m (\alpha_+^m h_+ + \alpha_-^m h_-) - 1 \quad (2.35)$$

Iteration Routine

$$(1.49) \quad s_n^{(t)} = \sum_m \left[(v\Sigma_f)_{n,\Delta}^{(t)} + \sum_i (\kappa_3)_{+,i} Q_{n,i}^{(t)} \right]^m \quad (2.36)$$

(1.51)

$$\lambda^{(t)} = \int s^{(t)} dV_G$$

*(2.37)

where

$$dV_0 = d\rho,$$

$$dV_1 = 2\pi\rho d\rho,$$

and

$$dV_2 = 4\pi\rho^2 d\rho.$$

$$(g_f)_n^{(2)} = \frac{s_n^{(1)}}{\lambda^{(1)}}$$

(2.38a)

$$(g_f)_n^{(t+1)} = (\theta + 1) \frac{s_n^{(t)}}{\lambda^{(t)}} - \theta (g_f)_n^{(t)}, \quad 1 < t \leq T$$

(2.38b)

For $(g_f)_n^{(1)}$ and $\lambda^{(0)}$, see Part Two, Section IV.

(1.49)

$$(S_f)_n^{m, (t)} = \chi_n^m (g_f)_n^{(t)}$$

(2.39)

(1.50)

$$\omega_{n+}^{m, (t)} = \frac{\sum_{r < m} A_+^{r, m} \varphi^{r, (t)} \Delta^r}{\Delta^m}, \quad \omega_n^{1, (t)} \equiv 0$$

(2.40)

(1.27)

$$s_{n+}^{m, (t)} = (S_f)_n^{m, (t)} + \sum_i Q_{n+, i}^{m-1, (t)} \left[\frac{f_A + f_B}{(\kappa_3)_i^m + f_A \Delta^m} - \frac{1 - (p_a)_j^m}{\Delta^m} \right]$$

$$+ \omega_{n+}^{m, (t)} - \frac{3}{\beta_+^m} \left[(B_x)_+ \sum_i \frac{(P_x)_{n+, i}^{m-1, (t)}}{(\kappa_1)_i^m} + (B_y)_+ \sum_i \frac{(P_y)_{n+, i}^{m-1, (t)}}{(\kappa_1)_i^m} \right]$$

(2.41)

(1.23)

$$t_{n+}^{m, (t)} = 3 \sum_i \frac{(P_\rho)_{n+, i}^{m-1, (t)}}{(\kappa_1)_i^m}, \quad t_{n+}^{1, (t)} \equiv 0$$

(2.42)

(1.38)

$$c_n^{m, (t)} = - (t^{m, (t)})_{n+} + \ell_n^m (t^{m, (t)})_{n-} + \mu_n^m [(s^{m, (t)})_{n+} + (s^{m, (t)})_{n-}]$$

(2.43)

$$\delta_1^m = \frac{[(\alpha\beta)h^2]_1}{2(1+G)} + (C_L)^m (\beta^m h)_1$$

(2.44)

$$b_0^{m, (t)} = - (h_1 t_{1/2}^{m, (t)}) + \frac{s_0^{m, (t)} (h^2 \beta^m)_1}{2(1+G)}$$

(2.45)

$$\delta_{n+1}^m = \kappa_n^m + \frac{\delta_n^m + (1 - \ell_n^m)}{1 + \delta_n^m}$$

(2.46)

$$b_n^{m, (t)} = c_n^{m, (t)} + \left(\frac{\ell_n^m}{1 + \delta_n^m} \right) b_{n-1}^{m, (t)}$$

(2.47)

* All integrals are computed using Simpson's Rule.

$$\varphi_N^{m,(t)} = \frac{\left(\frac{\rho_N - \frac{h_J}{2}}{\rho_N}\right)^G \left[\left(\frac{t_{N-}^{(t)}}{\beta_J}\right)^m + \frac{b_{n-1}^{m,(t)}}{(1 + \delta_n^m)(\beta^m h)_J} + \frac{s_{N-}^{m,(t)} h_J}{2} \right]}{\left(\frac{\rho_N - \frac{h_J}{2}}{\rho_N}\right)^G \frac{\delta_n^m}{(1 + \delta_n^m)(\beta^m h)_J} + \frac{(\alpha^m h)_J}{2} - (C_R)^m} \quad (2.48)$$

$$\varphi_n^{m,(t)} = \frac{\varphi_{n+1}^{m,(t)} + b_n^{m,(t)}}{1 + \delta_{n+1}^m} \quad (2.49)$$

$$(1.36) \quad (j_{\rho})_{n+}^{m,(t)} = \frac{1}{\beta_+^m} \left(t_{n+}^{m,(t)} - \frac{\varphi_{n+1}^{m,(t)} - \varphi_n^{m,(t)}}{h_+} \right) \quad (2.50)$$

$$(1.10), (1.33) \quad (P_{\rho})_{n+,i}^{m,(t)} = \frac{1}{(\kappa_1)_i^m} \left\{ [(\kappa_1)_i - \Delta]^m (P_{\rho})_{n+,i}^{m-1,(t)} + [(\kappa_2)_{+,i} (j_{\rho})_{n+\Delta}^{(t)}]^m \right\} \quad (2.51)$$

where $(P_{\rho})_{n+,i}^{0,(t)} \equiv 0$.

$$(1.25) \quad (j_x)_{n+}^{m,(t)} = \frac{1}{\beta_+^m} \left[(B_x)_+ \varphi_n^{m,(t)} + 3 \sum_i \frac{(P_x)_{n+,i}^{m-1,(t)}}{(\kappa_1)_i^m} \right] \quad (2.52)$$

$$(1.33) \quad (P_x)_{n+,i}^{m,(t)} = \frac{1}{(\kappa_1)_i^m} \left\{ [(\kappa_1)_i - \Delta]^m (P_x)_{n+,i}^{m-1,(t)} + [(\kappa_2)_{+,i} (j_x)_{n+\Delta}^{(t)}]^m \right\} \quad (2.53)$$

where, $(P_x)_{n+,i}^{0,(t)} \equiv 0$.

$$(1.26) \quad (j_y)_{n+}^{m,(t)} = \frac{1}{\beta_+^m} \left[(B_y)_+ \varphi_n^{m,(t)} + 3 \sum_i \frac{(P_y)_{n+,i}^{m-1,(t)}}{(\kappa_1)_i^m} \right] \quad (2.54)$$

$$(1.33) \quad (P_y)_{n+,i}^{m,(t)} = \frac{1}{(\kappa_1)_i^m} \left\{ [(\kappa_1)_i - \Delta]^m (P_y)_{n+,i}^{m-1,(t)} + [(\kappa_2)_{+,i} (j_y)_{n+\Delta}^{(t)}]^m \right\} \quad (2.55)$$

where, $(P_y)_{n+,i}^{0,(t)} \equiv 0$.

$$(1.32) \quad Q_{n,i}^{m,(t)} = \frac{1}{(\kappa_3)_i^m + f_A \Delta^m} \left\{ [(\kappa_3)_i^m - f_B \Delta^m] Q_{n,i}^{m-1,(t)} + [(\kappa_4)_{+,i} \varphi_n^{(t)} \Delta]^m \right\} \quad (2.56)$$

where, $Q_{n,i}^{0,(t)} \equiv 0$.

$$(1.59) \quad t_{n+}^{M,(t)} = 3 \sum_i (P_{\rho})_{n+}^{M-1,(t)} \quad (2.57)$$

$$(1.58) \quad s_{n+}^{M,(t)} = \sum_i Q_{n,i}^{M-1,(t)} - \frac{3}{\beta_+^M} \left[(B_x)_+ \sum_i (P_x)_{n+,i}^{M-1,(t)} + (B_y)_+ \sum_i (P_y)_{n+,i}^{M-1,(t)} \right] \quad (2.58)$$

$$(1.56) \quad (j_x)_{n+}^{M,(t)} = \frac{1}{\beta_+^M} \left[3 \sum_i (P_x)_{n+,i}^{M-1,(t)} + (B_x)_+ \varphi_n^M \right] \quad (2.59)$$

$$(1.56) \quad (j_y)_{n+}^{M,(t)} = \frac{1}{\beta_+^M} \left[3 \sum_i (P_y)_{n+,i}^{M-1,(t)} + (B_y)_+ \varphi_n^M \right] \quad (2.60)$$

$$\left| \frac{\lambda^{(t)} - \lambda^{(t-1)}}{\lambda^{(t)}} \right| < \epsilon \quad (2.61)$$

$$\lambda_{\max}^{(t)} = \max_n \left\{ \frac{S_n^{(t)}}{(g_f)_n^{(t)}} \right\} \quad (2.62a)$$

$$\lambda_{\min}^{(t)} = \min_n \left\{ \frac{S_n^{(t)}}{(g_f)_n^{(t)}} \right\} \quad (2.62b)$$

$$\frac{\lambda_{\max}^{(t)} - \lambda_{\min}^{(t)}}{\lambda_{\max}^{(t)}} < \epsilon \quad (2.63)$$

Edit Routine

$$(1.60) \quad \Phi_n^{v,k} = \sum_{m=K_l}^{K_u} (\varphi_n \Delta)^m, \quad (2.64)$$

where $k = 1, 2$, or 3 . $v = 1; 1, 2$; or $1, 2, 3$.*

$$(1.61) \quad (\Sigma_R)_n^{1,1} = \frac{\sum_i Q_{n,i}^{M-1}}{\Phi_n^{1,1}} \quad (2.65)$$

$$(\Sigma_R)_n^{1,2} = \frac{\sum_i Q_{n,i}^{Bpt_2}}{\Phi_n^{1,2}} \quad (2.66)$$

$$(\Sigma_R)_n^{2,2} = \frac{\sum_i Q_{n,i}^{M-1}}{\Phi_n^{2,2}} \quad (2.67)$$

$$(\Sigma_R)_n^{1,3} = \frac{\sum_i Q_{n,i}^{Bpt_1} + \sum_{m=Bpt_1+1}^{Bpt_2 \text{ or } U} (\omega \Delta)^m}{\Phi_n^{1,3}} \quad ** (2.68)$$

*	K_l	K_u	v	k
	1	M-1	1	1
	1	Bpt ₂	1	2
	Bpt ₂ +1	M-1	2	2
	1	Bpt ₁	1	3
	Bpt ₁ +1	Bpt ₂	2	3
	Bpt ₂ +1	M-1	3	3

NOTE: K_l and K_u are the lowest and highest lethargy microgroups, respectively, which are included in macrogroup v of scheme k . Also, see Part One, Section X.

** U is used if U is less than Bpt₂.

$$(\Sigma_R)_n^{2,3} = \frac{\sum_i Q_{n,i}^{Bpt_2}}{\Phi_n^{2,3}} \quad (2.69)$$

$$(\Sigma_R)_n^{3,3} = \frac{\sum_i Q_{n,i}^{M-1}}{\Phi_n^{3,3}} \quad (2.70)$$

$$(1.62) \quad (\Sigma_a)_n^{v,k} = \frac{\sum_{m=K_l}^{K_u} \left\{ [(\Sigma_a^s)_n \varphi_n \Delta]^m + [(1 - (p_a)^m) \sum_i Q_{n,i}^{m-1}] \right\}}{\Phi_n^{v,k}} \quad (2.71)$$

$$(1.63) \quad (v\Sigma_f)_n^{v,k} = \frac{\sum_{m=K_l}^{K_u} \left\{ [(v\Sigma_f^s)_n \varphi_n \Delta]^m + \sum_i \binom{m}{j,i} \sum_i Q_{n,i}^{m-1} \right\}}{\Phi_n^{v,k}} \quad (2.72)$$

$$(1.64) \quad D_{n+1/2}^{v,k} = \frac{h_j \sum_{m=K_l}^{K_u} (j_{n+1/2} \Delta)^m}{\Phi_n^{v,k} - \Phi_{n+1}^{v,k}} \quad (2.73)$$

For each region and for each macrogroup,

$$\int (\Sigma_a \Phi)_n^v dV_G. \quad (2.74)$$

For each region,

$$\int (\Sigma_a \Phi)_n^M dV_G. \quad (2.75)$$

$$H_{n_j} = \frac{\left(\rho_{n_j}\right)^{G+1} - \left(\rho_{n_j} - \frac{h_j}{2}\right)^{G+1}}{G+1} \quad (2.76)$$

$$H_{n_{j-1}} = \frac{\left(\rho_{n_{j-1}} + \frac{h_j}{2}\right)^{G+1} - \left(\rho_{n_{j-1}}\right)^{G+1}}{G+1} \quad (2.77)$$

$$d_{n_j}^{v,k} = \frac{\sum_{m=K_l}^{K_u} \frac{(\varphi_{n_j} \Delta)^m}{\beta_j^m}}{\Phi_{n_j}^{v,k}} \quad (2.78)$$

$$d_{n_{j-1}}^{v,k} = \frac{\sum_{m=K_l}^{K_u} \frac{(\varphi_{n_{j-1}} \Delta)^m}{\beta_{j-1}^m}}{\Phi_{n_{j-1}}^{v,k}} \quad (2.79)$$

$$(\Sigma_T)_{n_j}^{v,k} = (\Sigma_R + \Sigma_a)_{n_j}^{v,k} + d_{n_j}^{v,k} (B^2)_j \quad (2.80)$$

$$(\Sigma_T)_{n_{j-1}}^{v,k} = (\Sigma_R + \Sigma_a)_{n_{j-1}}^{v,k} + d_{n_{j-1}}^{v,k} (B^2)_j \quad (2.81)$$

$$\chi^{v,k} = \sum_{m=K_l}^{K_u} (\chi_\Delta)^m \quad (2.82)$$

$$J_{n_j}^{v,k} = c(G) \left\{ - \left(\rho_{n_{j-1}/2} \right)^G D_{n_{j-1}/2}^{v,k} \frac{(\Phi_{n_j} - \Phi_{n_{j-1}})^{v,k}}{h_{j-}} + H_{n_j} \left[\chi^{v,k} (g_f)_{n_{j-}} + (\Sigma_R \Phi)_{n_{j-}}^{v-1,k} - (\Sigma_T \Phi)_{n_{j-}}^{v,k} \right] \right\}, \quad (2.83)$$

where $c(0) = 1$, $c(1) = 2\pi$, $c(2) = 4\pi$.

$$J_{n_{j-1}}^{v,k} = c(G) \left\{ - \left(\rho_{n_{j-1}+1/2} \right)^G D_{n_{j-1}+1/2}^{v,k} \frac{(\Phi_{n_{j-1}+1} - \Phi_{n_{j-1}})^{v,k}}{h_j} + H_{n_{j-1}} \left[\chi^{v,k} (g_f)_{n_{j-1}+} + (\Sigma_R \Phi)_{n_{j-1}+}^{v-1,k} - (\Sigma_T \Phi)_{n_{j-1}+}^{v,k} \right] \right\} \quad (2.84)$$

$$(J_{n_j} - J_{n_{j-1}})^{v,k} = \chi^{v,k} \int (g_f) dV_G + \int (\Sigma_R \Phi)^{v-1,k} dV_G - \int (\Sigma_T \Phi)^{v,k} dV_G \quad (2.85)$$

$$(g_f)_j^{(T)} = \frac{\int g_f dV}{\int dV} \quad (2.86)$$

IV. PREPARATION OF INPUT

Form I*

Problem Identification: Any 8 digit, fixed-point, decimal integer.

Total Groups: Number of lethargy groups including the thermal group. The corresponding library of data must be used in running the problem (fixed point integer, $M \leq 80$).

Total Points: Total number of mesh points in entire problem, excluding the origin which is designated as point 0 (zero) (fixed point even integer, $N \leq 200$).

Total Regions: A region is defined by the information specified on Form II. Therefore, in proceeding along the reactor from the origin, whenever it is necessary to specify a change in Form II, a new region of the reactor is defined (fixed point integer, $J \leq 15$).

Geometry: Specify one type of geometry as indicated under the space provided for this parameter (fixed point integer, $G = 0, 1$, or 2).

Source Distribution Spectrum: Source spectra for different types of sources can be stored in the library (Part Two, Section VIII). The number assigned to the source spectrum to be used is specified here (fixed point integer).

Breakpoints: For edits 3, 4, 5, and 6, it is necessary to indicate the number of the last multigroup included in few-group 1 and the last multigroup included in group 2 of a three-fast group scheme. The numbers of these two multigroups are Breakpoint No. 1 and Breakpoint No. 2, respectively.

* See Appendix A.

5: A programming constant which selects the type of convergence desired (fixed point integer, 0 or 1).

Normal Convergence (0):

$$\left| \frac{\lambda^{(t)} - \lambda^{(t-1)}}{\lambda^{(t)}} \right| < \epsilon$$

Pointwise Convergence (1): Normal convergence

$$\frac{\lambda_{\max} - \lambda_{\min}}{\lambda_{\max}} < \epsilon$$

Edit: Call number of the type of edit desired. See description of output (fixed point integer 1, 2, 3, 4, 5, or 6).

Convergence Criterion: (Floating point; max 8 places; $0 < \epsilon < 1$.)

Extrapolation Factor: (Floating point*; max 4 places) [See Eq (2.38b)]

f_A and f_B: Both of these factors should be the floating point number one-half, i. e., 505. (See Part One, Section III.)

Use Tape: (Fixed point integer) (See Part Two, Section IX.)

Boundary Conditions: $j^m + C_{L,R}^m \phi^m = 0$ (See Part One, Section VI.)

m: Group number corresponding to the first set of parameters in that row (fixed point integer). If m of the first row is equal to zero, the first set of parameters in that row will be used in all groups and this will constitute a complete specification of the Boundary Conditions. If m of the first row is not equal to zero, a pair of parameters must be specified for all the groups, 4 groups to a row.

C_L: Left-hand boundary condition (floating point; max 4 places).

C_R: Right-hand boundary condition (floating point; max 4 places).

At either boundary C_L or C_R for a zero flux derivative condition, C = 000; and for a zero flux condition, C = 704. C_L must be 000 for problems in cylindrical and spherical geometries but can take on any value in slab geometry. C_R can take on any value in any geometry independent of C_L.

Form II

Mesh Point Number at Right-Hand End of Region: (Fixed point even integer, $n_j \leq N$)

Total Elements: Total number of isotopes in the region. (Fixed point integer, $1 < I_j \leq 10$)

Mesh Size h_j: Distance between mesh points in this region. (Floating point; $h_j \geq 0$)

Total Buckling B²: (Floating point; max 8 places; $B^2 \geq 0$)

Resonance Buckling B_R²: (Floating point; max 8 places; $B_R^2 \geq 0$) (See Part One, Section IX.)

Transverse Buckling:

x-direction B_x: (Floating point; max 8 places; $B_x \geq 0$)

y-direction B_y: (Floating point; max 8 places; $B_y \geq 0$)

If either B_x or B_y is not zero, then B² must equal B_x² plus B_y². (See Part One, Section IX.)

* See Appendix C.

Macroscopic Thermal Cross Sections: *

D: Thermal diffusion constant (floating point; max 8 places).

Σ_a : Macroscopic thermal absorption cross section (floating point; max 8 places).

$\nu\Sigma_f$: Macroscopic thermal nu-fission cross section (floating point; max 8 places).

j: Number of this region counting sequentially from the origin which is the left-hand point of region number one (fixed point integer).

i+r: i is the code number for the isotope (see Appendix E); r = 100, if the isotope is to be treated as a nonhydrogenous moderator in this region, otherwise r = 0. If hydrogen is not present in a region, at least one nonhydrogenous moderator must be specified (fixed point integer).

N_i : Number density of isotope i in this region (floating point; max 5 places; $N_i > 0$).

k: Total number of absorption resonances in a group (fixed point integer, $0 \leq k \leq 8$).

If k = 9 in the first row for any isotope, all the resonances will have the same self-shielding factor, equal to the first entry in that row; and this then constitutes a complete specification of the self-shielding factors of isotope i.

If k $\neq$ 9 in the first row for an isotope, self-shielding factors must be specified for every group from the lower bound of the resonance groups** up to and including group M. In this case, each row will be sufficient for one group. The k for a particular row must correspond to the number of resonances in that group for that isotope as found in the P1MG2 library.

L: Resonance self-shielding factor (floating point; max 4 places).

For every isotope in this region which has resonance data in the P1MG2 library, an L-factor, or L-factors, must be specified.

To insure proper card punching, the Forms II should follow Form I in ascending order according to region numbers.

Form III

If a set of floating binary source cards which are punched from a special WANDA program† are not available as input to P1MG, then a pointwise source guess and an estimate of the initial eigenvalue must be specified on this form.

Initial Eigenvalue Estimate: (Floating point; max 8 places)

c: Card number, c = 1, 2, 3, (fixed point integer).

τ : A control parameter punched only on the first decimal source card. If $\tau = 000$, iterate to convergence. If $\tau = 001$, one iteration; i. e., the multigroup fluxes are completed only once, with no renormalization of the source or computation of an eigenvalue.

S: Source (floating point; max 8 places). If c = 0 in the first row, the source distribution will be assumed constant over all regions and equal in magnitude to the first source in that row. The first space in the first row is not to be used, as indicated. If c $\neq$ 0 in the first row, a pointwise source distribution must be specified starting with the origin. At points which lie on interfaces between regions, an extra value of the source must be specified and is entered in the next space in the row (or the first space in the next row).

* See Part One, Section VIII.

** See Ref 2, Library Tape Preparation, p 17.

† See Appendix B.

Groups to Be Edited: If it is desired to edit the flux, current, and slowing down densities in certain groups only, enter in ascending order the group numbers of the multigroups to be edited. If none are indicated, all will be edited. If $M + 1$ is entered, none of the multigroups will be edited (fixed point integer).

It is not necessary to include a Form III in a problem, if there is no decimal source to be specified, and if all the fluxes are to be edited.

V. OUTPUT

On-Line Output

As the problem is being run, the following information will be printed on the on-line printer during the coefficient tape preparation routine:

- 1) **PROLOG:** This is a form printed at the beginning of any normal run or of any restart. It should be filled out completely by the 704 operator in the event of trouble which may arise during the running of a problem. Tape reel numbers and the tape unit letters are filled in for those tapes which have been saved to make it possible to duplicate the particular machine situation existing at the time the trouble occurred or to provide the necessary information for a future restart.
- 2) **Edit of all the input:** An edit of the entire input is impossible when restarting a problem; therefore, this is the only record of the input data used in the problem.

As the problem is being run during the iteration routine:

- 1) **Initial eigenvalue:** This will either be the converged eigenvalue from a WANDA problem, the estimated eigenvalue from Form III, or the latest eigenvalue in the case of a restart using cards from a Restart-Dump.
- 2) **Initial sources:** These will be either the converged sources from a WANDA problem, the source distribution as specified on Form III, or the latest source in the case of a restart using cards from a Restart-Dump.
- 3) **Eigenvalues:** At the end of each iteration the normal eigenvalue or the minimum, normal, and maximum eigenvalues will be printed for supervisory inspection. On the same line with the eigenvalues will appear the "nearness to convergence" quantity (NTC) which is useful to the operator in determining how much longer the problem might run. If pointwise convergence is requested, then NTC will be the left half of Inequality (2.61). After Inequality (2.61) is satisfied, then NTC will be the left half of Inequality (2.63).

Off-Line Output

All the information which was printed on-line during the iteration routine will appear on the off-line printout. The following information will be written on tape during the final edit routine:

- 1) **Final Edit No. 1:** (This edit will also be performed as part of each of the other final edits.)
 - a) **Converged eigenvalue:*** For one iteration problem, this is identical with the initial eigenvalue.
 - b) **Normalized source:** This is the source which would have been used in the next iteration had there been a next iteration. In the case of one iteration problem this is identical with the initial source.

* If any edit other than Final Edit No. 1 is requested, the problem will have converged according to the prescribed criterion; however, one more iteration beyond this converged iteration is required in order to accumulate the necessary information required to produce these edits. This converged eigenvalue is then that eigenvalue computed after the extra iteration.

- c) **Regional source averages:** These are the source averages averaged over the volume of each of the regions defined by Form II [Eq (2.86)].
- d) **Flux:** This is the flux which corresponds to the converged eigenvalue and which was used in computing the new normalized source. Depending on how the selection of groups was specified at the bottom of Form III, the flux for each group at each point is edited.
- 2) **Final Edit No. 2:** If Edit No. 2 has been requested, the following information will be printed:
- a) **Slowing down densities:** For every isotope i of each region of the same groups m as were printed in Final Edit No. 1, there will be printed a

$$\sum_i Q_{n,i}^m$$

at each mesh point n , including the double value at interfaces.

- b) **Current:** For the same groups as mentioned in (a), $(j_z)_{n+1/2}^m$ will be printed ($n = 0, 1, 2, \dots, N-1$).
- 3) **Final Edit No. 3:** If Edit No. 3 has been requested, the following set of pointwise average, fast few-group quantities will be printed:

- a) **Diffusion:** This is the diffusion coefficient at each midpoint averaged over groups m , where $m = 1, 2, \dots, M-1$ [Eq (2.73)].
- b) **Removal:** At each point, including the double value at interfaces, there will be printed a removal cross section averaged over multigroups m ($m = 1, 2, \dots, M-1$) [Eqs (2.65) through (2.70)].

Absorption: An absorption cross section will be printed as for removal [Eq (2.71)].

Nu-fission: A nu-fission cross section will be printed as for removal [Eq (2.72)].

Flux: Average fast few-group flux will be printed as for removal [Eq (2.64)].

- c) **Fast regionwise absorption:**

$$\sum_{n_j < n \leq n_{j+1}} (\Sigma_a)_n^{1,1} \Phi_n^1 (dV_G)_n$$

where ($j = 1, 2, \dots, j$), Φ_n is defined in Eq (2.64), and the summation is defined in Eq (2.74).

- d) **Thermal regionwise absorption:** Same as in fast regionwise absorption for Φ^M only.
- 4) **Final Edit No. 4:** If Edit No. 4 has been requested, there will be two sets of average pointwise cross sections, as in (a) and (b) of Final Edit No. 3. Here, the first set will be averages over multigroups 1 through Breakpoint No. 2, and the second set will be averages over the multigroups from Breakpoint No. 2 through $M-1$.
- 5) **Final Edit No. 5:** If edit number 5 has been requested, there will be three sets of average pointwise cross sections, as in (a) and (b) of Final Edit No. 3. Here, the first set will be averages over multigroups 1 through Breakpoint No. 1; the second set will be averages over multigroups from Breakpoint No. 1 through Breakpoint No. 2; and the third set will be averages over the multigroups from Breakpoint No. 2 through $M-1$.
- 6) **Final Edit No. 6:** If Edit No. 6 has been requested, Final Edits No. 5 and No. 3 will be performed.

Region checks will be edited after each few-group, except for Final Edit No. 3 when performed as a part of Final Edit No. 6.

All input which is in a floating point form (see Appendix C) will be edited in a floating point form, except for the convergence criteria, extrapolation factor, L-factors, and the initial eigenvalue. Quantities computed by the code are edited in a floating point form with the exception of the eigenvalues printed after each iteration.

All printing both on-line and off-line is done so that the paper can be cut to 8-1/2 in. x 11 in. size.

VI. CARD PUNCHING

All numbers on the cards are positive and are punched with their sign in the preceding column. There must be one and only one punch in every column of each card; columns 1-72 are the only columns under consideration. If the information specified for a particular card does not fill all the columns to 72, then a word of +000...0 should be punched to fill out that card. Every card should have the positive eight-place Problem Identification found at the top of Form I punched in columns 1-9. All floating point fields must be at least 3 columns.

The last card, which is punched from the information found at the bottom of Form III, or which is blank if Form III is not included in the problem, is an exception to everything stated in the preceding paragraph.

Before a problem is punched, a check of the forms should be made such that: (1) the Problem Identification is the same on Forms II and III as that found on Form I, (2) the Forms II are arranged so that the mesh point numbers are in ascending order and are all even numbers, and (3) the Form III is present, or that a set of binary cards has been included with the Forms I and II. (See Appendix A.)

Form I

Card No. 1: The data should be punched as found in normal reading order. The four numbers (ϵ , θ , f_A , f_B) should be in x-s 50 floating point form. The units position of the tape number is punched in column 72.

Cards No. 2: Each row becomes one card. Punch only as many cards as there are rows with information filled in. C_L and C_R should be x-s 50 floating point form.

Form II

Card No. 3: The data should be punched as found in normal reading order. All four bucklings should be in x-s 50 floating point form.

Card No. 4: Last three numbers are in x-s 50 floating point form, i. e., D , Σ_a , and $\nu\Sigma_f$.

Cards No. 5: Each row becomes one card. Punch only as many cards as there are rows with information filled in. N_i should be in x-s 50 floating point form.

Cards No. 6: Each row becomes one card. Punch only as many cards as there are rows with information filled in. Each card must have 8 L-numbers. L should be in x-s 50 floating point form.

If a set of binary cards has been submitted with the problem, place this deck immediately after the last Card No. 6 of the last Form II. These binary cards will take the place of Cards No. 7 so that the only other card needed is the "last card." The binary cards should have their Problem Identification punched in columns 73-80. The top card must be blank in columns 1-72.

Form III*

Cards No. 7: Each row becomes one card. The first floating point number of the first card, i. e., the box which is "x-ed out," should be the initial eigenvalue estimate. The field preceding the

* See Appendix D.

eigenvalue estimate may or may not be zero. Punch only as many cards as there are rows with information filled in. The initial eigenvalue estimate and S should be in x-s 50 floating point form.

Last Card: This is punched according to the information found at the bottom of the form under "Groups to be edited." If there are no entries, the card is blank. A 9 is punched in the column, or columns, indicated by the entries. If Form III is not included in this problem, the Last Card is a blank.

Two additional blank cards should be placed after the Last Card.

VII. OPERATOR'S NOTES

704 Requirements

Magnetic core storage	16K or 32K
Magnetic tapes	10
Physical magnetic drums	2
High speed card reader	1
Punch	1
Printer	1
Sense lights	4
Sense switches	6
Peripheral equipment	
Tape-to-printer	1
Card-to-tape	1 (optional)
Floating point arithmetic unit	
Additional instructions	
STZ	
CAD	

Material Needed to Run One Problem

P1MG2 Library-Program tape. (See column 72 of 1st input card for L-P tape number.)

Nine blank tapes, eight at least 100 feet long, and one which is a full reel.

One problem deck.

Restart-Dump deck.

Restart-Positioning card (for all restarts).

Running Instructions

- 1) Mount P1MG2 Library-Program tape as logical tape 1.
- 2) Mount nine blank tapes as logical tapes 2-0. Logical tape 5 must be a full tape.
- 3) Insert GL OUT-2 printer board.
- 4) Insert standard SHARE punch board.
- 5) Place problem deck in card reader.
- 6) Push CLEAR.
- 7) Push LOAD TAPE.

Progress of Program

Coefficient Tape Writing Program

The following steps should be observed by the operator during the coefficient tape writing program:

- 1) The PROLOG is printed. This form is to be filled out in the event that a problem must be removed before it is completed or in the event that it has been requested that certain tapes be saved.
- 2) A complete statement of the problem to be solved is next printed. From this, an estimate of the running time of the problem can be made.
- 3) Next, a region by region printout of the input will follow. For each region:
 - a) The entire library on tape 1 is read.
 - b) Tapes 3, 4, and 5 are written with one record for each point.
 - c) Tapes 2, 6-0 are written with one record each.
 - d) Drums 1-4 are written with one record each.
- 4) After the last region has been processed all tapes are rewound:
 - a) Tapes 3-0 are individually sorted and rewound.
 - b) Drums 1-4 are individually sorted.
 - c) Tape 2 is read into the core and rewound.
- 5) Tapes 3-0, the data in core from tape 2, and drums 1-4 are merged onto tape 2, one record at a time.
- 6) Tapes 2-0 are rewound.

In the event of a computer error before step 6, restarting is impossible. All time is waste time. Step 6 is the first plateau. At this point, tapes 8 and 9 are no longer needed and may be replaced by any other tapes.

Iteration Program

The following steps should be observed by the operator during the iteration program:

- 1) More input will be read from the cards.
- 2) This input will be printed on-line and off-line on tape 5 (initial eigenvalue and initial source).
- 3) During each iteration, tape 2 will be read completely and tape 3 will be written with a full set of fluxes. Both tapes will be rewound.
- 4) The eigenvalue will be printed for each iteration. The nearness to convergence (NTC) of the problem will also be printed. The problem is converged when NTC is less than the error criterion which is found in the right side of the inequality printed on the first page of the input printout.
- 5) Upon convergence, the paper will be restored on-line.
- 6) If any other edit than Edit No. 1 is requested, another iteration will be made after convergence (there will be a line printed indicating convergence) during which tapes 3-7 are written, after which tapes 2-7 are rewound, another eigenvalue printed, and the paper restored. However, if the criterion for convergence is not met on this extra iteration, another iteration is performed. If the criterion is still not met, then the program will print CONVERGENCE CRITERION WAS NOT SATISFIED ON THE EXTRA ITERATION. Save tapes 0, 1, 2, 3, 4, 5, 6, 7.

Edit Program

The following steps should be observed by the operator during the edit program:

- 1) The BCD tape to be printed off-line is written on tape 5.
- 2) The type of edit, as determined by the Edit Number indicated on the first page of the on-line printout in Part One, is performed.

Upon completion of the edit routine, the computer indicates to the operator that it is finished.

The following tapes must be taken off:

Tape 1: save.

Tape 5: print off-line with carriage control set to PROGRAM.

Tapes 2 and 0, the coefficient tapes, may be saved if the requester so indicates.

WARNING

Successive PLMG problems cannot
be run without changing tape 5.

NOTE

If sense switch 1 is thrown while the
edit routine is running, then an auto-
matic Restart Dump is performed
after the edit is completed.

Restart

In the event of machine failure after reaching the iteration part, a definite procedure should be followed:

- 1) A Restart-Dump should be performed.
 - a) Place Restart-Dump deck in hopper.
 - b) Push CLEAR.
 - c) At punch unit: (1) The operator may precede blank cards with a binary card in whose label field (columns 73-80) the problem identification has been punched and is blank in columns 1-72, and then (2) push START.
 - d) Push LOAD CARDS. Stop at 00172.
 - e) Run out punch unit. The binary source cards which have been punched are sequentially numbered in binary in the 9LD. The last card, the one without a sequence number, becomes the top card and must be blank in columns 1-72.
- 2) Place the Restart-Positioning card in front of the binary source cards and place the last three cards of the original input deck after the binary source cards; then place this combined deck in the card reader hopper.
- 3) Rewind tapes 1, 2, 3, 4, 6, 7, and 0.
- 4) Place sense switch 2 down.
- 5) Push CLEAR.
- 6) Push LOAD CARDS

A new PROLOG will be printed and control will be transferred to the iteration part.

Force Edit

If a running-time limit has been specified for a problem, the problem can be stopped by throwing sense switch 1. Upon completion of the iteration which is being processed at the time the switch is thrown, the program will print FORCED EDIT on-line and then proceed with the editing as specified

by the input. At the end of the edit, a set of floating binary cards which have the latest source distribution and eigenvalue punched on them will be punched. It would be desirable, for identification purposes, to have a card in the punch hopper with the problem identification punched in columns 73-80. These CHOMP cards from P1MG should be returned to the requester along with all the on-line and off-line printing.

Printing Off-Line

Tape 5 will contain one file of output for the problem. Set printer carriage control to PROGRAM.

There will be a clear indication of the end of the output for a problem.

One Iteration Option

The program will proceed as before except that, during the iteration part, only what would amount to the extra iteration after convergence will be performed. The coefficient and edit parts will remain the same. There will be no eigenvalues printed on-line. See the explanation of τ in Part Two, Section IV.

Error Stops

In the Coefficient Program:

An asterisk (*) indicates some sort of error in the input. Do not run the problem any further.

Mark the stop number and the card being read.

00250	Machine error occurred in GL OUT2.
00737	Machine error occurred in WH 001.
00772	Machine error occurred in WH 001.
01055	Double punch, blank column, or both. *
01270	Range error in input number. Check card order. *
02627	Blank card. *
02630	Machine error.
02674	Wrong Library-Program Tape. *
03743	Blank card. *
03750	Problem identification error. *
03753	Type 2 cards out of order, too high. *
03755	Type 2 cards out of order, too low. *
04032	Blank card. *
04033	Machine error.
04037	Problem identification error. *
04055	Duplicate interface number. *
04057	Interface numbers out of order. *
04064	Bad tape 1.
04102	Total number of elements equals zero. *
04104	Total number of elements greater than 10. *
04113	Zero mesh size. *
04142	Blank card. *
04143	Machine error.
04250	Blank card. *
04251	Machine error.
04255	Problem identification error. *
04261	Wrong region number on thermal cross-section card. *
04405	Blank card. *
04406	Machine error.

04412 Problem identification error. *
 04416 Wrong region on number density card. *
 04424 Illegitimate element number. *
 04432 Elements out of order. *
 04441 Zero number density. *
 04456 Unwanted end of file indication from tape 1.
 04457 Bad tape 1.
 04467 Wrong group structure on tape 1 library. *
 04472 Source spectrum not on library. *
 04665 Element not in library. *
 04670 Element not in library. *
 04703 Unwanted end of file indication from tape 1.
 04704 Bad tape 1.
 04727 Unwanted end of file indication from tape 1.
 04730 Bad tape 1.
 05151 (Divide-Check indicator should be on.) Hydrogen not present in region, therefore,
 nonhydrogenous moderator must be specified. *
 05201 Blank card. *
 05207 Problem identification error. *
 05213 Wrong element number on L-factor cards. *
 05252 Blank cards. *
 05253 Machine error.
 05310 Unwanted end of file indication from tape 1.
 05311 Bad tape 1.
 05325 Unwanted end of file indication from tape 1.
 05326 Bad tape 1.
 05364 k from tape disagrees with k from resonance L-factor card. *
 05375 Exponential of the isotopic resonance integral is out of range. *
 05411 k from tape disagrees with k from resonance L-factor card. *
 05433 Square root radicand was negative. *
 05475 Exponential of the total resonance integral is out of range. *
 05621 Unwanted end of file indication from tape 1.
 05622 Bad tape 1.
 05652 Unwanted end of file indication from tape 1.
 05653 Bad tape 1.
 05765 Unwanted end of file indication from tape 2.
 05766 Bad tape 2.
 06221 Unwanted end of file indication from tape 3.
 06222 Bad tape 3.
 06227 Unwanted end of file indication from tape 4.
 06230 Bad tape 4.
 06235 Unwanted end of file indication from tape 5.
 06236 Bad tape 5.
 06251 Bad drum 1.
 06255 Bad drum 2.
 06261 Bad drum 3.
 06273 Bad drum 4.
 06301 Unwanted end of file indication from tape 6.
 06302 Bad tape 6.

06307 Unwanted end of file indication from tape 7.
 06310 Bad tape 7.
 06315 Unwanted end of file indication from tape 8.
 06316 Bad tape 8.
 06323 Unwanted end of file indication from tape 9.
 06324 Bad tape 9.
 06331 Unwanted end of file indication from tape 10.
 06332 Bad tape 10.
 06341 False end of record skip from tape 1.
 06364 Unwanted end of file indication while reading tape. Display storage location 06360 to determine tape number. If 223, possible code error. If 224 or 225, machine error. Start over from beginning.
 06365 Bad tape. See 06364 error stop.
 06411 Unwanted end of file indication. Display storage location 06405 to determine tape number.
 06412 Bad tape. See 06411 error stop.
 06473 Unwanted end of file indication. Display storage location 06467 to determine tape number.
 06474 Bad tape. See 06473 error stop.
 06533 Unwanted end of file indication. Display storage location 06527 to determine tape number.
 06534 Bad tape. See 06533 error stop.
 06574 Unwanted end of file indication from tape 10.
 06575 Bad tape 10.
 06632 Unwanted end of file indication from tape 10.
 06633 Bad tape 10.
 06667 Bad drum. Display storage location 10136 to determine drum number.
 06720 Bad drum. See 06667 error stop.
 06742 Bad drum 4.
 07002 Unwanted end of file indication from tape 2.
 07003 Bad tape 2.
 07075 Unwanted end of file indication from tape 2.
 07076 Bad tape 2.
 07177 Bad drum 2.
 07203 Bad drum 3.
 07211 Unwanted end of file indication from tape 3.
 07212 Bad tape 3.
 07217 Unwanted end of file indication from tape 4.
 07220 Bad tape 4.
 07225 Unwanted end of file indication from tape 5.
 07226 Bad tape 5.
 07234 Unwanted end of file indication from tape 6.
 07235 Bad tape 6.
 07242 Unwanted end of file indication from tape 7.
 07243 Bad tape 7.
 07250 Unwanted end of file indication from tape 8.
 07251 Bad tape 8.
 07256 Unwanted end of file indication from tape 9.
 07257 Bad tape 9.

07266	Unwanted end of file indication from tape 10.
07267	Bad tape 10.
07272	Bad drum 4.
07361	Unwanted end of file indication from tape 2.
07362	Bad tape 2.
07377	Bad drum 1.
07411	Unwanted end of file indication from tape 10.
07412	Bad tape 10.

In the Iteration Program:

00261	Machine or code error. GL OUT2.
00340	Machine or code error. GL OUT2.
02274	Machine error. End-of-file return. Writing tape 3.
03042	Machine error. End-of-file return. Writing tape 4.
03050	Machine error. End-of-file return. Writing tape 6.
03053	Could not write tape 6.
03054	Could not write tape 4.
03076	Machine error. End-of-file return. Writing tape 7.
03077	Could not write tape 7.
03126	Failed three times to write sources on drum.
03127	Machine error. End-of-file return. Reading tape 2.
03130	Could not read tape 2. Bad coefficient tape.
03132	Could not write tape 3. Error from RTT or calling sequence.
03133	Could not write tape 3. Error from check sum.
15341	Count end-of-file. Machine error.
16007	Machine error. End-of-file return. Reading tape 2 for first time.
16010	Bad tape 2. Error return when reading.
16011	Check sums on binary source cards do not check. †
16012	Source cards numbered wrong. †
16013	Identification words from tape and cards do not check. †
16315	Machine error. WII 001.
16350	Machine error. WH 001.
16433	Double punch, blank column. †
16646	Range error. Floating decimal number out-of-range. †

In the Edit Program:

For all indicated stops except 02124, restart dump and restart.

00574	Machine error.
00653	Machine error.
01456	Machine error.
01457	Will not read tape 2.
02124	Reads sources from drum incorrectly. Dump drum 1 and save tapes 2 and 0.
13376	Machine error.
03377	Will not read tape 2.
03431	Machine error.
03432	Will not read tape 3.
04065	Machine error.
04066	Will not read tape 0.

† Save program tape and tapes 2 and 0.

04267	Machine error.
04270	Will not read tape 4.
04545	Machine error.
04546	Will not read tape 7.
04630	Machine error.
04631	Will not read tape 6.

Restart Dump:

00172 Normal stop. If any other stop, dump drum 1 and save tapes 2 and 0.

VIII. LIBRARY TAPE ROUTINES

There are three library tape routines: LTP4, LTP5, and LTP6. These are essentially the same as the library tape routines LTP1, LTP2, and LTP3, respectively, for MUFT-4 (Ref 2, pp 16-22); the operating instructions are identical, with the exception of the error stops.

LTP4

A library program tape consists of the same data files as a MUFT-4 library tape, with the following changes:

File 1: Coefficient program replaces the MUFT-4 program.

File 2: $\Delta^M = 1$.

File 3: The additional microscopic quantities, η and ζ , are parameters which determine the anisotropic slowing-down density for each element (Part One, Section II). At present, it is assumed (as in MUFT) that all anisotropic slowing down is the result of hydrogen. Correspondingly, η and ζ are set equal to zero for all other elements. Values for hydrogen are selected so as to make the slowing-down model consistent with MUFT-3 and -4. These two values are put on a second card in the same format as the other eight microscopic quantities, filling in the rest of the card with zeros. This card is placed after the other data card for that group.

File 4 and 5: L, the lower bound of resonances, must be greater than U, the upper bound of inelastic matrix.

File 7: Iteration program.

File 8: Edit program.

There are two options available in writing the library program tape: (1) taking the library data from tape or (2) reading the data from cards.

In the first option, all the blank cards are removed from the assembled library decks and the data are then written onto tape via a 714 card-to-tape converter. This tape is then used as logical tape 8 by the input routine WH 001 B in writing the library program tape.

In the second option, the assembly of the library decks is the same as in MUFT-4, and the decks are inserted in LTP4 between cards LTP40283 and LTP40284. Cards LTP40261 through LTP40282 (WH 001 B) must be removed.

The end-of-program stop is 00533.

Error Stops

00204	Machine error. WH 001 B. BCD conversion.
00334	Range error. WH 001 B.
01021	Tape-read failure. Tape 8.
01045	Double punch, blank column, or both.
02145	Blank card return. Reading data for table of contents.

02146	Card count end-of-file return. Machine error or number of elements wrong.
02260	Wrong format or order of element numbers on second card(s).
02273	Machine error. End of file return when writing tape 1.
02274	Machine error. RWT2 error return when writing tape 1.
02304	Blank card return. Read data for lethargy increments.
02305	Machine error or number of groups wrong.
02326	Same as 02273.
02327	Same as 02274.
02354	Blank card return. Reading data for file 4, 5, or 6.
02355	Count end of file return. Machine error.
02421	Same as 02273. Writing record in file 3.
02422	Same as 02274.
02571	Same as 02273. Writing record in file 4.
02572	Same as 02274.
02720	Same as 02273. Writing record in file 5.
02721	Same as 02274.
02744	File number wrong on card in a source spectrum deck.
02751	Same as 02273. Writing record in file 6.
02752	Same as 02274.
06123	Input error. File number wrong in deck 1, file 2.
06124	Input error. File number wrong, should be 3.
06125	Input error. Element number wrong or deck misplaced, file 3.
06127	Input error. Group number wrong in deck for file 3.
06130	Input error. Element number wrong or deck misplaced, file 4.
06131	Input error. File number wrong on resonance R cards, file 4.
06132	Input error. Too many resonances specified on deck 1 card.
06133	Input error. File number wrong on resonance M cards, file 4.
06134	Input error. Element number wrong on resonance M cards, file 4.
06135	Input error. Number of resonances wrong on resonance M card.
06136	Input error. Element number wrong on second deck, file 4.
06137	Input error. File number wrong on second deck, file 4.
06140	Input error. Too many parameters (fission ratios) are specified.
06141	Input error. Element number wrong in set 1, file 5.
06142	Input error. File number wrong in set 1, file 5.
06143	Input error. File number wrong in set 2, file 5.
06144	Input error. Element number wrong in set 2, file 5.
06146	Input error. Group number wrong in set 2, file 5.
06147	Input error. Group number wrong in set 1, file 5.
06150	Input error. Source spectrum number wrong.
06152	Input error. File number wrong in deck 2, file 2.

LTP5

End of run programmed stop is 14011.

Error Stops

00213	Machine error, WH 001.
00246	Machine error, WH 001.
00331	Double punch, blank column, or both.
00544	Range error. Floating decimal number out-of-range.
02156	Error in reading program from tape 2.

02201 Error in writing program on tape 1.
 02226 Same as 02156.
 02257 Same as 02201.
 02265 Error in reading tape 2.
 02326 Blank card return from WH 001.
 02327 Count end of file return. Machine error.
 03103 Machine error. End of file return from RWT2.
 03104 Machine error. RWT2 error return.
 03130 Error in reading tape 2.
 03150 Same as 03103.
 03151 Same as 03104.
 03164 Same as 03103.
 03165 Same as 03104.
 03173 Same as 03103.
 03174 Same as 03104.
 03241 Input error. File No. wrong in deck 1, file 4 (R card).
 03242 Input error. Too many resonances (absorption) on one card.
 03243 Input error. File No. wrong in deck 1, file 5 (M card).
 03244 Input error. Machine or code error.
 03245 Input error. File No. wrong.
 03246 Input error. Element No. wrong in new deck.
 03247 Input error. Group No. wrong.
 03250 Input error. File No. wrong.
 03251 Input error. Group No. wrong in set 1, file 5.
 03252 Input error. File No. wrong in set 1, file 5.
 03253 Input error. File No. wrong in set 2, file 5.
 03254 Input error. Group No. wrong in set 2, file 5.
 03255 Input error. Element not on tape.
 03256 Input error. Group No. wrong on card with two cross section values.
 03257 Input error. Too many resonances (fission) on one card.
 03260 Input error. Element No. wrong in set 2, file 5.
 03261 Input error. Element No. wrong in set 1, file 5.
 03262 Input error. Source spectrum No. wrong.

LTP6

End of run programmed stop is 03361.

Error Stops

00251 Machine or code error. GL OUT2.
 00330 Machine or code error. GL OUT2.
 02225 Machine error. Reading tape 1. End of file return from RWT2.
 02226 Error in reading tape 1.
 02344 Same as 02225.
 02345 Same as 02226.
 02457 Same as 02225.
 02460 Error on tape 1. Table of contents does not check.
 02642 Same as 02225.
 02643 Same as 02460.
 03016 Same as 02225.
 03017 Same as 02460.

03126	Same as 02225.
03127	Same as 02460.
03243	Same as 02225.
03244	Same as 02460.
06507	Machine or code error.

IX. GENERAL INFORMATION

Libraries may be numbered if desired. This number is punched into 8LA of binary card LTP40196 before writing the L-P tape. The check-sum on this binary card must be corrected. The program will interrogate the last field of the first input card of each P1MG2 problem in order to determine if the proper library is being used. This field should contain the number specified on Form I. (See Part Two, Section IV.)

APPENDIX A: INPUT FORMS FOR SAMPLE PROBLEM, FORMS I, II, AND III

Cards # 2[illegible]

C_L = Left hand boundary condition C_R = Right hand boundary condition.
 $C = 000$, for $\phi'' = 0$. $C = 704$, for $\phi = 0$

m = Group number of first set of conditions in that row.

m = (All groups have same conditions as first set in the row.

Card #4 Card #3

Problem Identification 35020041
(8 digits)

Mesh point number at right hand end of region 10 (n_j) Total elements 6 (I_j)
 Mesh size 50762 Total buckling 484032 Resonance Buckling 485
 Transverse bucklings: x-direction 49635 y-direction 000

Macroscopic Thermal Cross Sections for Region 1

D 502897

Σ 4977505

$v \Sigma_f$ 50134594

r = 100, nonhydrogenous moderator

N_i , number density, for element i of region j .

[illegible]

k = 9, one factor for all resonances

[illegible]

Form III

PLMG2

Problem Identification 35020041
(8 digits)

Initial eigenvalue estimate 5110144253

Source distribution
c, card number

c=0, for flat source guess

T = 000 converge
001 one iteration

Cards # 7

c	T	S	S	S	S	S
001	000	4900660220	4982834320	4982693940	4982276600	4981594190
002	000	4900660220	4979532790	4978239360	4976864270	4975520430
003	000	4974374980	4973676350	4929602520	4928232130	4926270080
004	000	4924062590	4921807070	4919614560	4917544840	4915626850
005	000	4913870980	4912276530	4910836530	4895407700	4883779900
006	000	4873375300	4864111200	4855951200	4848942800	4843280700
007	000	4839417900	4838260900	4841508900	0000000000	0000000000
008	000	0000000000	0000000000	0000000000	}	}
}	000	}	}	}	}	}
}	000	}	}	}	}	}
	000					
	000					
	000					
	000					
	000					
	000					
	000					
	000					
	000					

Groups to be edited 10 25 54 55

Card # 8

To completely eliminate flux editing enter group number M+1.

APPENDIX B: CHOMP CARDS

Since the running time of a P1MG problem using a flat source guess is prohibitively long, an option has been included in WANDA-3 (Ref 3) such that the converged eigenvalue and source are punched out in floating binary in a form which is acceptable as input to P1MG. Sense switch 6 must be down during the running of the WANDA problem. The CHOMP cards are then used as input to the P1MG problem in place of the decimal source guess which would have been specified on Form III.

A CHOMP deck which is to be inserted in a P1MG problem consists of the following cards:

- 1) A card which is blank in columns 1-72. All of the CHOMP cards which are punched by WANDA will have the problem number automatically punched into columns 73-80. This "blank" is used by the program to signal that binary cards and not decimal cards are to follow.
- 2) A set of cards with a sequence number punched in 9LD and a card check sum in 9R. The first card will have the converged (or latest) eigenvalue in 8L followed by S_0 in 8R, S_1 in 7L, etc., in the same order as the information is placed on the decimal input source cards for P1MG.

The "last card" (which is read in by the edit routine) and two blank cards should follow the last card of a CHOMP deck within a P1MG input deck.

CHOMP cards are punched out by the P1MG code in two different instances:

- 1) Throughout the entire iteration and edit routines of P1MG the latest values of the eigenvalue and source are stored on drum 1 such that if there is a power failure or any program stop which requires a restart, this latest eigenvalue and source can be punched out in the CHOMP format via the Restart-Dump deck of P1MG which should be available at the console. Then, to restart the P1MG problem, the last section of the P1MG input deck—the source guess, the "last card," and two blanks—should be removed, the source guess replaced by the CHOMP deck just punched, and the Restart-Positioning card placed on top of the CHOMP cards. The rest of the instructions are found in Part Two, Section VII.
- 2) If a problem must be manually stopped by forcing it to proceed to the editing routine (sense switch 1 down), at the end of the edit a CHOMP deck is automatically punched so that the problem can be continued at a later time. (See Part Two, Section VII for tape saving.)

In summary, any CHOMP deck for a given P1MG problem is in the form whereby it can be read into the problem from the beginning or via restart.

In order that a CHOMP deck, which has been punched out by WANDA, be accepted as input to a P1MG problem, the total number of points and regions must be the same in the problems run on both codes.

APPENDIX C: FLOATING POINT NUMBERS

Input Form

In order to convert a fixed point number of the form

xx. xxxx

to a floating point number of the form

EEfff...f ,

(which in this code is called the excess-50 floating point form), write the fixed point number as a fraction

$$0.1 \leq .fff \dots f < 1.0$$

times the corresponding power of ten. Fifty plus this power of ten becomes the x-s 50 exponent part, $23 < EE < 88$, and the fraction is the x-s 50 fraction part, $fff \dots f$. Some examples of converting are

<u>fixed</u>	<u>x-s 50</u>
3.141592654	5131415927*
0.00036348	4736348

An x-s 50 floating point zero is entered as 000.

Output Form

All floating point numbers are of the form

$$\pm PP \pm fff \dots f ,$$

which is easily interpreted as

$$\pm(0. fff \dots f) \cdot 10^{\pm PP}$$

APPENDIX D: BLANK CARDS IN INPUT DECK

An input deck to P1MG2 consists of the following:

- 1) A set of cards which is punched in the manner described in Part Two, Section VI from information supplied on Form I and one or more Forms II. There must be no blanks in this portion.
- 2) A set of cards which will be either:
 - a) Decimal Cards punched from information supplied on Form(s) III, or
 - b) Binary Cards (CHOMP cards)** which are obtained from one of two places:

WANDA—In which case columns 73–80 will contain the WANDA Problem Number in decimal.

P1MG2—Restart -Dump, in which case columns 73–80 will most likely be blank.

In order for the P1MG2 code to know whether decimal cards or binary cards are to be expected for source cards, a blank card should be placed ahead of the binary source cards only, never ahead of the decimal source cards. The program input routine reads only columns 1–72 of any card and, thereby, determines if a card is a blank or not; thus, there may be punches in columns 73–80 and still the card would be considered as a blank. There should be no blank cards within the binary or decimal source decks themselves. Some of the binary cards may look like blanks except for a few 9-punches in columns 1–72; however, this is the card number (in binary) of that source card, and these cards must be included as part of the binary source deck.

* The upper limit on the number of significant places in any x-s 50 fraction part is eight. However, the maximum number of places permitted in the fraction part of each piece of data, as indicated after the explanation of each piece of data in Part Two, Section IV, should be adhered to in order to insure that all the data will fit on their respective punchcard.

** See Appendix B.

3) An edit card (referred to previously as the "last card") which is punched from information supplied on Form III. There is only one card of this type for any P1MG2 problem. If no form is supplied, this card is a blank. If Form III is supplied and the lines labeled "Groups to be edited" are blank, this card is blank. If there are any entries in these lines, a 9 is punched in the columns indicated by the numbers entered.

4) Two blank cards which function solely to get the last card into the 704 card reader.

APPENDIX E: CODE NUMBERS FOR ISOTOPES

List by Code Number

<u>Code Number</u>	<u>Element</u>	<u>Code Number</u>	<u>Element</u>
001	H-1	039	Be-7
002	O-16	040	Be-9
003	Zr	041	F
004	C	042	Cl
005	Mo	043	Eu-151
006	Fe	045	P
007	Ni	046	Na
008	Nb	047	S
009	Al	048	Pb
010	Sn	049	Y
011	Cr	050	U-233
012	Co	051	U-234
013	Cd	053	Ag
014	Hf	054	Hf-177
015	Mn-55	055	Si
017	Li	056	Au
018	U-235	057	Th-227
019	U-236	058	Th-228
020	U-238	059	Th-229
021	Pu-239	060	Th-230
022	Pu-240	061	Th-231
023	Pu-241	062	Th-232
024	Pm-149	063	Th-233
025	I-135	064	Th-234
026	Sm-149	065	Pa-233
027	Xe-135	094	Hf-174
028	Fission Products	095	Hf-178
029	B-10	096	Hf-179
038	Deuterium	097	Hf-180

List by Isotope

<u>Element</u>	<u>Code Number</u>	<u>Element</u>	<u>Code Number</u>
Ag	053	Ni	007
Al	009	O-16	002
Au	056	P	045
B-10	029	Pa-233	065
Be-7	039	Pb	048
Be-9	040	Pm-149	024
C	004	Pu-239	021
Cd	013	Pu-240	022
Cl	042	Pu-241	023
Co	012	S	047
Cr	011	Si	055
Deuterium	038	Sm-149	026
Eu-151	043	Sn	010
F	041	Tl-227	057
Fe	006	Th-228	058
Fission Products	028	Th-229	059
H-1	001	Th-230	060
Hf	014	Th-231	061
Hf-174	094	Th-232	062
Hf-177	054	Th-233	063
Hf-178	095	Th-234	064
Hf-179	096	U-233	050
Hf-180	097	U-234	051
I-135	025	U-235	018
In	017	U-236	019
Li	016	U-238	020
Mn-55	015	Xe-135	027
Mo	005	Y	049
Na	046	Zr	003
Nb	008		

APPENDIX F: SAMPLE PROBLEM

The sample problem is constructed from the data as specified on the input forms of Appendix A. The Forms II for the second and third region are not included in Appendix A, but the information which is entered on them can be determined from this appendix.

The first two pages of the printouts in this appendix are IBM-704 listings of the input cards. The first page is the listing of the input deck with the decimal source cards (cards numbered 15 through 24) as specified by Form III. The second page is a card-image listing of the CHOMP-type source cards which are punched out by WANDA-3. (See Appendix B.)

The rest of the printouts in this appendix are those which will be created on the on-line printer and the off-line printer when the sample problem is run.

C1
02
C3
04
05
06
07
C8
09
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27

25
26
27

[illegible][illegible]

PIMG2

PROBLEM IDENTIFICATION 35020041

ON OFF

YES

OPERATOR -----

RESTART

ON OFF

NO

LOGICAL
TAPE
NUMBER

PHYSICAL
TAPE UNIT
LETTER

REEL
NUMBER

1	.	.	.	---	.	.	.	---
2	.	.	.	---	.	.	.	---
3	.	.	.	---	.	.	.	---
4	.	.	.	---	.	.	.	---
5	.	.	.	---	.	.	.	---
6	.	.	.	---	.	.	.	---
7	.	.	.	---	.	.	.	---
8	.	.	.	---	.	.	.	---
9	.	.	.	---	.	.	.	---
0	.	.	.	---	.	.	.	---

P1M32

35020041

55 GROUPS 44 POINTS 3 REGIONS

SLAB GEOMETRY SOURCE SPECTRUM NUMBER 1

CONVERGENCE CRITERION

$$\text{ABSOLUTE VALUE OF } \frac{\frac{\text{LAMBDA}_T - \text{LAMBDA}_{T-1}}{\text{LAMBDA}_T}}{\text{LAMBDA}_T} \neq .00050000$$

AND

$$\frac{\text{LAMBDA}_T - \text{LAMBDA}_{T-1}}{\text{LAMBDA}_T} \neq .00050000$$

EXTRAPOLATION FACTOR OF .00000

$$\begin{matrix} F & = & .500 & F & = & .500 \\ A & & & B & & \end{matrix}$$

EDIT 5 HAS BEEN REQUESTED

FEW GROUP BREAKPOINT 1 IS AT GROUP 10
 FEW GROUP BREAKPOINT 2 IS AT GROUP 25

GROUPWISE BOUNDARY CONDITION $J + C0 = 0$

GROUP	AT LEFT BOUNDARY C =	AT RIGHT BOUNDARY C =
ALL	00000000	20 40000000

REGION 1

35020041

ENDS AT POINT 10 MESH SIZE 76200000

TOTAL NUMBER OF ELEMENTS 6

TOTAL BUCKLING -2 40320000 RESONANCE BUCKLING -2 50000000

TRANSVERSE BUCKLING
X-DIRECTION -1 53499999
Y-DIRECTION 00000000

MACROSCOPIC THERMAL CROSS SECTIONS

DIFFUSION	ABSORPTION	NU-FISSION
28970000	-1 77504999	13459400

ELEMENT	NUMBER DENSITY
---------	----------------

1	-1 38564000
2	-1 16983000
3	-1 18547000
4	-2 22996000
18	-3 16590000
20	-4 12080000

RESONANCE SELF SHIELDING FACTORS

ELEMENT	K	L
---------	---	---

20	9	1.0000 .0000 .0000 .0000 .0000 .0000 .0000 .0000
----	---	--

TOTAL NUMBER OF ELEMENTS 5

TOTAL BUCKLING -2 40320000 RESONANCE BUCKLING -2 50000000

```

TRANSVERSE BUCKLING
X-DIRECTION -1 63495999
Y-DIRECTION  00000000

```

MACROSCOPIC THERMAL CROSS SECTIONS

DIFFUSION	ABSORPTION	NU-FISSION
30574100	-1 46159999	-1 48048000

ELEMENT	NUMBER	DENSITY
1	1	1.000
2	2	4.000
3	3	9.000
4	4	16.000
5	5	25.000
6	6	36.000
7	7	49.000
8	8	64.000
9	9	81.000
10	10	100.000
11	11	121.000
12	12	144.000
13	13	169.000
14	14	196.000
15	15	225.000
16	16	256.000
17	17	289.000
18	18	324.000
19	19	361.000
20	20	400.000
21	21	441.000
22	22	484.000
23	23	529.000
24	24	576.000
25	25	625.000
26	26	676.000
27	27	729.000
28	28	784.000
29	29	841.000
30	30	900.000
31	31	961.000
32	32	1024.000
33	33	1089.000
34	34	1156.000
35	35	1225.000
36	36	1296.000
37	37	1369.000
38	38	1444.000
39	39	1521.000
40	40	1600.000
41	41	1681.000
42	42	1764.000
43	43	1849.000
44	44	1936.000
45	45	2025.000
46	46	2116.000
47	47	2209.000
48	48	2304.000
49	49	2401.000
50	50	2500.000
51	51	2601.000
52	52	2704.000
53	53	2809.000
54	54	2916.000
55	55	3025.000
56	56	3136.000
57	57	3249.000
58	58	3364.000
59	59	3481.000
60	60	3600.000
61	61	3721.000
62	62	3844.000
63	63	3969.000
64	64	4096.000
65	65	4225.000
66	66	4356.000
67	67	4489.000
68	68	4624.000
69	69	4761.000
70	70	4900.000
71	71	5041.000
72	72	5184.000
73	73	5329.000
74	74	5476.000
75	75	5625.000
76	76	5776.000
77	77	5929.000
78	78	6084.000
79	79	6241.000
80	80	6400.000
81	81	6561.000
82	82	6724.000
83	83	6889.000
84	84	7056.000
85	85	7225.000
86	86	7396.000
87	87	7569.000
88	88	7744.000
89	89	7921.000
90	90	8100.000
91	91	8281.000
92	92	8464.000
93	93	8649.000
94	94	8836.000
95	95	9025.000
96	96	9216.000
97	97	9409.000
98	98	9604.000
99	99	9801.000
100	100	10000.000

```

1      -1 30460000
2      -1 28960000
3      -2 86412999
18     -4 48960000
20     -2 67600000

```

RESONANCE SELF SHIELDING FACTORS

ELEMENT	K	L							
20	9	.7416	.0000	.7000	.0000	.0000	.0000	.0000	.0000

REGION 3

35020041

ENDS AT POINT 44 MESH SIZE 1 15000000

TOTAL NUMBER OF ELEMENTS 2

TOTAL BUCKLING -2 40320000 RESONANCE BUCKLING -2 50000000

TRANSVERSE BUCKLING
X-DIRECTION -1 63499999
Y-DIRECTION 00000000

MACROSCOPIC THERMAL CROSS SECTIONS

DIFFUSION	ABSORPTION	NU-FISSION
15190000	-1 19100000	00000000

ELEMENT	NUMBER DENSITY
---------	----------------

1	-1 6*139999
2	-1 33570000

PIMG2

35020041

INITIAL EIGENVALUE 1.01442529

INITIAL SOURCES

REGION 1

POINT

0	-1 82834319	-1 82693939	-1 82276599	-1 81594190
4	-1 80668219	-1 75532789	-1 78239360	-1 76864270
8	-1 75520430	-1 74374979	-1 73676350	

REGION 2

POINT

10	-1 29602520	-1 28232130	-1 26270080	-1 24062590
14	-1 21807070	-1 19613560	-1 17544840	-1 15626850
18	-1 13870980	-1 12275530	-1 10836530	-2 95407698
22	-2 83779399	-2 73375300	-2 64111199	-2 55951200
26	-2 48942799	-2 43280700	-2 39417900	-2 38260900
30	-2 41508399			

REGION 3

POINT

30	00000000	00000000	00000000	00000000
34	00000000	00000000	00000000	00000000
38	00000000	00000000	00000000	00000000
42	00000000	00000000	00000000	

EIGENVALUES

ITERATION	MIN	NORMAL	MAX	NTC
1	.99452356	1.00424217	1.04742564	.01014

2	1.00152108	1.00323835	1.01914945	.00100
3	1.00174649	1.00271292	1.01105395	.00052

4	1.00192670	1.00243683	1.00684005	.00488
5	1.00202711	1.00229236	1.00459945	.00256

6	1.00207649	1.00221689	1.00342239	.00134
---	------------	------------	------------	--------

7	1.00210530	1.00217748	1.00280689	.00070
---	------------	------------	------------	--------

CONVERGED EIGENVALUE

8	1.00211921	1.00215690	1.00248548	.00037
---	------------	------------	------------	--------

9 1.00212649 1.00214617 1.00231770 .00019

P1M52 EDIT IS COMPLETED

PING2

55 GROUPS 44 POINTS 3 REGIONS

SLAB GEOMETRY

CONVERGENCE CRITERION

 $\lambda - \lambda_{T-1}$

ABSOLUTE VALUE OF $\frac{\lambda - \lambda_{T-1}}{\lambda_T} \neq .00050000$

AND

$\frac{\lambda - \lambda_{T-1}}{\lambda_T} \neq .00050000$

EXTRAPOLATION FACTOR OF .00000

$F = .500 \quad F = .500$
A B

EDIT 5 HAS BEEN REQUESTED

GROUPWISE BOUNDARY CONDITON $J + C\Phi = 0$

GROUP	AT LEFT BOUNDARY C =	AT RIGHT BOUNDARY C =
1	00000000	20 40000000
2	00000000	20 40000000
3	00000000	20 40000000
4	00000000	20 40000000
5	00000000	20 40000000
6	00000000	20 40000000
7	00000000	20 40000000
8	00000000	20 40000000
9	00000000	20 40000000
10	00000000	20 40000000
11	00000000	20 40000000
12	00000000	20 40000000
13	00000000	20 40000000
14	00000000	20 40000000
15	00000000	20 40000000
16	00000000	20 40000000
17	00000000	20 40000000
18	00000000	20 40000000
19	00000000	20 40000000
20	00000000	20 40000000
21	00000000	20 40000000
22	00000000	20 40000000
23	00000000	20 40000000
24	00000000	20 40000000
25	00000000	20 40000000
26	00000000	20 40000000
27	00000000	20 40000000
28	00000000	20 40000000

29	00000000	20 40000000
30	00000000	20 40000000
31	00000000	20 40000000
32	00000000	20 40000000
33	00000000	20 40000000
34	00000000	20 40000000
35	00000000	20 40000000
36	00000000	20 40000000
37	00000000	20 40000000
38	00000000	20 40000000
39	00000000	20 40000000
40	00000000	20 40000000
41	00000000	20 40000000
42	00000000	20 40000000
43	00000000	20 40000000
44	00000000	20 40000000
45	00000000	20 40000000
46	00000000	20 40000000
47	00000000	20 40000000
48	00000000	20 40000000
49	00000000	20 40000000
50	00000000	20 40000000
51	00000000	20 40000000
52	00000000	20 40000000
53	00000000	20 40000000
54	00000000	20 40000000
55	00000000	20 40000000

P1MG2

35020041

INITIAL EIGENVALUE 1.01442529

INITIAL SOURCES

REGION 1

POINT

0	-1 82834319	-1 82693939	-1 82276599	-1 81594190
4	-1 80658219	-1 79532789	-1 78239360	-1 76864270
8	-1 75520430	-1 74374979	-1 73676350	

REGION 2

POINT

10	-1 29602520	-1 28232130	-1 26270080	-1 24062590
14	-1 21807070	-1 19614560	-1 17544840	-1 15626850
18	-1 13870980	-1 12276530	-1 10836530	-2 95407698
22	-2 83775899	-2 73375300	-2 64111199	-2 55951200
26	-2 48942799	-2 43280700	-2 39417900	-2 38260900
30	-2 41506899			

REGION 3

POINT

30	00000000	00000000	00000000	00000000
34	00000000	00000000	00000000	00000000
38	00000000	00000000	00000000	00000000
42	00000000	00000000	00000000	

EIGENVALUES

ITERATION	MIN	NORMAL	MAX	NTC
1	.99452361	1.00424223	1.04742564	.01014
2	1.00152116	1.00323941	1.01914950	.00100
3	1.00174659	1.00271298	1.01105392	.00052
4	1.00192873	1.00243589	1.00684012	.00488
5	1.00202717	1.00229241	1.00459948	.00256
6	1.00207858	1.00221695	1.00342244	.00134
7	1.00210534	1.00217754	1.00280696	.00070
		CONVERGED EIGENVALUE		
8	1.00211924	1.00215696	1.00248554	.00037
9	1.00212656	1.00214621	1.00231773	.00019

FINAL EDIT NO. 5

CONVERGED EIGENVALUE 1.00214621

NORMALIZED SOURCE

REGION 1

POINT				
0	-1 82615274	-1 82462908	-1 82009006	-1 81263950
4	-1 80247829	-1 78955335	-1 77563994	-1 76047034
8	-1 74592115	-1 73426559	-1 72886934	

REGION 2

POINT				
10	-1 29345521	-1 28099134	-1 26193990	-1 24039335
14	-1 21843590	-1 19710238	-1 17690668	-1 15809808
18	-1 14077946	-1 12496421	-1 11060859	-2 97634513
22	-2 85948702	-2 75461351	-2 66108486	-2 57878125
26	-2 50853410	-2 45275470	-2 41646979	-2 40907296
30	-2 44747707			

REGION 3

POINT				
30	00000000	00000000	00000000	00000000
34	00000000	00000000	00000000	00000000
38	00000000	00000000	00000000	00000000
42	00000000	00000000	00000000	

REGIONAL SOURCE AVERAGE

REGION			
1	-1 78437038	-1 13199140	00000000

FLUX

GROUP 10

POINT				
0	34345210	34251306	34009645	33590385
4	33003777	32250147	31329808	30242884
8	28988926	27556207	25970544	22695914
12	19828327	17354003	15224918	13387102
16	11791698	10398114	-1 91738327	-1 80930611

35020041 PAGE 2

20	-1 71352160	-1 62836034	-1 55243795	-1 48457383
24	-1 42372043	-1 36888639	-1 31903081	-1 27289684
28	-1 22874049	-1 18389545	-1 13410199	-2 88595433
32	-2 59581260	-2 40696984	-2 28163459	-2 19696420
36	-2 13885276	-3 98387459	-3 69806203	-3 49299333
40	-3 34290161	-3 22991020	-3 14120422	-4 67154256
44	00000000			

GROUP 25

POINT				
0	-1 67568279	-1 67429347	-1 67015074	-1 66332926
4	-1 65394909	-1 64216589	-1 62814974	-1 61204307
8	-1 59387668	-1 57338667	-1 54953699	-1 50305836
12	-1 45738105	-1 41231427	-1 36907250	-1 32869429
16	-1 29174274	-1 25836816	-1 22845360	-1 20174128
20	-1 17791633	-1 15665311	-1 13763593	-1 12056371
24	-1 10514588	-2 91094265	-2 78117621	-2 65930595
28	-2 54300398	-2 43170823	-2 32913795	-2 23473157
32	-2 16144072	-2 10993539	-3 75101775	-3 51720006
36	-3 35925066	-3 25125087	-3 17630366	-3 12338545
40	-4 85201222	-4 56810714	-4 34755203	-4 16490378
44	00000000			

GROUP 54

POINT				
0	-1 53591030	-1 53480171	-1 53146073	-1 52583957
4	-1 51785364	-1 50738295	-1 49429529	-1 47851376
8	-1 46012499	-1 43939166	-1 41667155	-1 37726608
12	-1 34001533	-1 30597497	-1 27494578	-1 24644821
16	-1 22021111	-1 19613380	-1 17416669	-1 15424053
20	-1 13624430	-1 12002919	-1 10542212	-2 92241042
24	-2 80310285	-2 69477552	-2 59634311	-2 50737234
28	-2 42814446	-2 35921396	-2 30107100	-2 23613641
32	-2 17535082	-2 12517592	-3 87412937	-3 60489102
36	-3 41811337	-3 28974200	-3 20124583	-3 13950365
40	-4 95553540	-4 63307757	-4 38552834	-4 18241935
44	00000000			

GROUP 55

POINT				
0	56623213	56519681	56211456	55706259
4	55019119	54176134	53220777	52223674
8	51296791	50612552	50426435	49201695
12	46373436	42857532	39127121	35422680
16	31868131	28527746	25432666	22593763
20	20008883	17667856	15556674	13661526
24	11973362	10493862	-1 92441275	-1 82781604
28	-1 77047305	-1 77245648	-1 86974550	-1 10252424
32	-1 97445469	-1 83428808	-1 67174575	-1 52000665
36	-1 39197909	-1 28986131	-1 21100566	-1 15111290
40	-1 10576437	-2 71028073	-2 43596525	-2 20711018
44	00000000			

FAST FEW GROUP 1

DIFFUSION

POINT				
0.5	1	25910285	1 25903641	1 25890252
4.5	1	25841883	1 25805682	1 25760188
8.5	1	25634749	1 25550253	1 22768426
12.5	1	22964651	1 23055056	1 23129173
16.5	1	23226440	1 23254455	1 23273073
20.5	1	23293284	1 23298916	1 23303133
24.5	1	23305430	1 23295100	1 23259296
28.5	2	22964041	1 22605909	1 21073317
32.5	1	22275579	1 22805865	1 23302855
36.5	1	24237567	1 24693046	1 25149670
40.5	1	26064832	1 25490557	1 26836526
				1 25869821
				1 25703894
				1 22864441
				1 23185717
				1 23285239
				1 23305967
				1 23165978
				1 21701294
				1 23776928
				1 25609427
				1 27035507

REMOVAL

ABSORPTION

NU-FISSION

FAST FLUX

REGION 1

POINT				
0	-1	65902275	-3 65655777	-3 61115445
1	-1	65899753	-3 65667683	-3 61116296
2	-1	65892134	-3 65704143	-3 61118902
3	-1	65879257	-3 65767484	-3 61123413
4	-1	65860905	-3 65861869	-3 61130105
5	-1	65836879	-3 65993801	-3 61139395
6	-1	65807145	-3 66172999	-3 61151914
7	-1	65772044	-3 65413864	-3 61168581
8	-1	65732708	-3 65738026	-3 61190765
9	-1	65691708	-3 67178881	-3 61220571
10	-1	65654241	-3 67769968	-3 61261350
				62593347
				62440696
				61982516
				61218071
				60145911
				58763485
				57066472
				55047661
				52695144
				49989421
				46898932

REGION 2

POINT				
10	-1	69542864	-2 44046289	-2 79652474
11	-1	69945772	-2 44156356	-2 79739062
12	-1	70140689	-2 44257425	-2 79847055
13	-1	70225217	-2 44341704	-2 79948964
14	-1	70255494	-2 44408037	-2 80033927
15	-1	70261809	-2 44458527	-2 80100080
16	-1	70259265	-2 44456460	-2 80149741
17	-1	70254575	-2 44525172	-2 80186640
18	-1	70250156	-2 44547515	-2 80214481
19	-1	70246428	-2 44565712	-2 80236370
20	-1	70243018	-2 44581378	-2 80254631
21	-1	70239298	-2 44555638	-2 80270901
22	-1	70234441	-2 44609265	-2 80286288
23	-1	70227145	-2 44622892	-2 80301692
24	-1	70214611	-2 44637397	-2 80318441
25	-1	70190312	-2 44654836	-2 80339868
				46898932
				40302033
				34915727
				30438201
				26657771
				23423639
				20626798
				18187179
				16044838
				14153853
				12478127
				10988519
				-1 96608944
				-1 84747450
				-1 74121066
				-1 64564819

35020041 PAGE 4

26	-1 70138925	-2 44680815	-2 80375236	-1 55914232
27	-1 70025396	-2 44730423	-2 80449491	-1 47982787
28	-1 69770438	-2 44843496	-2 80627897	-1 40523267
29	-1 69159116	-2 45127565	-2 81084452	-1 33160365
30	-1 67786396	-2 45911664	-2 82343623	-1 25273355

REGION 3

POINT				
30	10735014	-2 13917605	00000000	-1 25273355
31	10358026	-2 14901638	00000000	-1 17803253
32	10035147	-2 15848838	00000000	-1 12659735
33	-1 97570052	-2 16762315	00000000	-2 90734184
34	-1 95147489	-2 17644254	00000000	-2 65454316
35	-1 93011799	-2 18494336	00000000	-2 47460595
36	-1 91110824	-2 19309430	00000000	-2 34535869
37	-1 89411711	-2 20082773	00000000	-2 25165970
38	-1 87898910	-2 20804295	00000000	-2 18302062
39	-1 86571597	-2 21460430	00000000	-2 13207456
40	-1 85440712	-2 22034650	00000000	-3 93566863
41	-1 84525390	-2 22508561	00000000	-3 63675340
42	-1 83848585	-2 22863745	00000000	-3 39540986
43	-1 83432039	-2 23084212	00000000	-3 18933268
44				

REGIONWISE FEW GROUP CONSTANTS

REGION	REMOVAL	ABSORPTION	NU-FISSION	DIFFUSION
1	-1 65815360	-3 86216219	-3 61154438	1 25787064
2	-1 70059389	-2 44586603	-2 80280688	1 23140184
3	-1 91209272	-2 19599735	00000000	1 24360926

FAST REGIONWISE ABSORPTION

REGION 1	-2 37713799	-1 21809700	-3 18319197
----------	-------------	-------------	-------------

REGION CHECKS

REGION 1	11148368	11890848
2	-1-98352242	-10357036
3	-1-12345189	-1-11985483

FAST FEW GROUP 2

DIFFUSION

POINT				
.5	1 11045995	1 11061653	1 11093665	1 11144093
4.5	1 11215636	1 11312043	1 11437817	1 11597316
8.5	1 11792648	1 12017040	1 11737841	1 11183424
12.5	1 10839456	1 10625225	1 10492449	1 10411469
16.5	1 10363321	1 10335605	1 10320172	1 10311665
20.5	1 10306481	1 10301951	1 10295680	1 10285064
24.5	1 10267275	1 10240547	1 10208540	1 10190016
28.5	1 10234311	1 10438908	1 10324796	1 10108617
32.5	1 10112339	1 10207901	1 10336121	1 10470423
36.5	1 10599929	1 10721242	1 10834397	1 10940564
40.5	1 11040126	1 11130334	1 11202959	1 11244836

REMOVAL	ABSORPTION	NU-FISSION	FAST FLUX
---------	------------	------------	-----------

REGION 1

POINT				
0	-1 84931300	-3 41224256	-3 78152011	62955409
1	-1 84942182	-3 41225003	-3 78154736	62815944
2	-1 84976000	-3 41231456	-3 78163235	62399274
3	-1 85035160	-3 41241255	-3 78178488	61710670
4	-1 85127875	-3 41256419	-3 78202059	60759266
5	-1 85257098	-3 41278262	-3 78235937	59558494
6	-1 85428081	-3 41308124	-3 78282095	58126555
7	-1 85633205	-3 41346763	-3 78341516	56486688
8	-1 85867451	-3 41393132	-3 78412199	54666794
9	-1 86055553	-3 41441869	-3 78485143	52697687
10	-1 86058041	-3 41478222	-3 78536245	50608451

REGION 2

POINT				
10	-1 68621906	-2 22465993	-3 23635004	50608451
11	-1 69027929	-2 22569734	-3 23685849	46105591
12	-1 69661802	-2 22683119	-3 23746427	41508668
13	-1 70207335	-2 22773360	-3 23795610	37081114
14	-1 70597863	-2 22835702	-3 23829731	32968823
15	-1 70848282	-2 22874826	-3 23851089	29231375
16	-1 70995009	-2 22897404	-3 23863318	25875960
17	-1 71073245	-2 22909297	-3 23869667	22882404
18	-1 71109912	-2 22914805	-3 23872527	20213753
19	-1 71122986	-2 22916736	-3 23873453	17849862
20	-1 71122917	-2 22916695	-3 23873332	15741567
21	-1 71114104	-2 22915347	-3 23872527	13862326
22	-1 71095593	-2 22912538	-3 23870947	12183521
23	-1 71060585	-2 22907203	-3 23868003	10679030
24	-1 70994818	-2 22887111	-3 23862460	-1 93243584
25	-1 70874902	-2 22878529	-3 23852269	-1 80954010

35020041 PAGE 6

26	-1 70670656	-2 22846442	-3 23834701	-1 69668236
27	-1 70364761	-2 22797229	-3 23807880	-1 59101711
28	-1 70031626	-2 22740068	-3 23777264	-1 48921659
29	-1 70120765	-2 22739084	-3 23779492	-1 38745864
30	-1 72576848	-2 23083338	-3 23978391	-1 28188525

REGION 3

POINT

30	15775773	-4 13073875	00000000	-1 28188525
31	16422239	-4 13351959	00000000	-1 19105929
32	16666725	-4 13443638	00000000	-1 12889389
33	16697411	-4 13450596	00000000	-2 87484701
34	16647905	-4 13425673	00000000	-2 59964859
35	16575305	-4 13392249	00000000	-2 41520299
36	16502538	-4 13359455	00000000	-2 29002047
37	16427507	-4 13330350	00000000	-2 20386344
38	16382207	-4 13305651	00000000	-2 14367440
39	16326569	-4 13285273	00000000	-2 10091294
40	16299997	-4 13268939	00000000	-3 69885559
41	16271931	-4 13256398	00000000	-3 46702544
42	16252016	-4 13247497	00000000	-3 28616656
43	16240092	-4 13242164	00000000	-3 13590725
44				

REGIONWISE FEW GROUP CONSTANTS

REGION	REMOVAL	ABSORPTION	NU-FISSION	DIFFUSION
1	-1 85383630	-3 41307244	-3 78279689	1 11371790
2	-1 70616975	-2 22832707	-3 23828301	1 10469469
3	16416258	-4 13325037	00000000	1 10662470

FAST REGIONWISE ABSORPTION

REGION 1	-2 18448441	-1 13603949	-5 14628833
----------	-------------	-------------	-------------

REGION CHECKS

REGION 1	-1 34850400	-1 42102013
2	-1-24963238	-2-58642626
3	-2-74917304	-2-72330232

FAST FEW GROUP 3

DIFFUSION

POINT				
0.5	64990708	64939146	64832340	64661937
4.5	64418028	64098448	63716669	63318997
8.5	62997242	62905936	72195275	72816527
12.5	73303673	73501887	73504627	73415288
16.5	73311816	73213523	73135114	73076673
20.5	73033775	73001006	72974847	72957213
24.5	72960620	73015224	73174928	73516421
28.5	74117714	74973689	60838009	58914025
32.5	57720485	57054264	56733648	56631830
36.5	56657208	56746794	56861923	56981919
40.5	57096425	57198428	57278685	57324223

REMOVAL ABSORPTION NU-FISSION FAST FLUX

REGION 1

POINT				
0	-1 82258564	-2 69257177	-1 10273476	55546813
1	-1 82254900	-2 69257464	-1 10273508	55436207
2	-1 82251282	-2 69257758	-1 10273519	55104847
3	-1 82219605	-2 69256276	-1 10273251	54553802
4	-1 82155707	-2 69249844	-1 10272244	53783821
5	-1 82039134	-2 69233628	-1 10269812	52793708
6	-1 81844642	-2 69200759	-1 10265002	51578105
7	-1 81548640	-2 69141809	-1 10256541	50124831
8	-1 81146291	-2 69043313	-1 10242595	48412582
9	-1 80696658	-2 68882898	-1 10219783	46410529
10	-1 80533852	-2 68615049	-1 10179842	44083616

REGION 2

POINT				
10	-1 63975798	-1 15490874	-2 30042498	44083616
11	-1 63598188	-1 15542612	-2 29922739	39974967
12	-1 63166791	-1 15568170	-2 29881224	36217207
13	-1 62983474	-1 15582819	-2 29881094	32696388
14	-1 63003264	-1 15590996	-2 29903214	29380864
15	-1 63130029	-1 15595361	-2 29933623	26281368
16	-1 63288894	-1 15597458	-2 29963376	23417114
17	-1 63436609	-1 15598223	-2 29987983	20799692
18	-1 63553768	-1 15598260	-2 30006045	18428884
19	-1 63636169	-1 15597965	-2 30017862	16294374
20	-1 63685297	-1 15597574	-2 30024362	14375095
21	-1 63705556	-1 15597180	-2 30026438	12662297
22	-1 63701222	-1 15596758	-2 30024679	11121715
23	-1 63677509	-1 15596156	-2 30019484	-1 97348814
24	-1 63645512	-1 15595072	-2 30011765	-1 84795132
25	-1 63633474	-1 15593036	-2 30004628	-1 73362478

35020041 PAGE 8

26	-1 63707907	-1 15589415	-2 30006725	-1 62859197
27	-1 64007064	-1 15583435	-2 30038125	-1 53160392
28	-1 64775217	-1 15574155	-2 30139032	-1 44229909
29	-1 66319645	-1 15563311	-2 30380909	-1 36179922
30	-1 68540127	-1 15534303	-2 30893777	-1 29310871

REGION 3

POINT				
30	14907427	-3 94005092	00000000	-1 29310871
31	15534741	-3 97175305	00000000	-1 21960902
32	16042369	-3 99491012	00000000	-1 15686265
33	16364503	-2 10092459	00000000	-1 10918874
34	16531510	-2 10164858	00000000	-2 75238216
35	16585684	-2 10186379	00000000	-2 51819011
36	16570152	-2 10177094	00000000	-2 35842406
37	16520240	-2 10153073	00000000	-2 24923328
38	16459414	-2 10124730	00000000	-2 17387500
39	16400646	-2 10097692	00000000	-2 12105699
40	16349997	-2 10074525	00000000	-3 83234732
41	16309857	-2 10056214	00000000	-3 55314003
42	16281010	-2 10043069	00000000	-3 33758847
43	16263666	-2 10035168	00000000	-3 15994721
44				

REGIONWISE FEW GROUP CONSTANTS

	REMOVAL	ABSORPTION	NU-FISSION	DIFFUSION
REGION				
1	-1 81755797	-2 69148794	-1 10257720	64087942
2	-1 63834713	-1 15583820	-2 30028475	73260188
3	16275174	-2 10044204	00000000	57431274

FAST REGIONWISE ABSORPTION

REGION			
1	-1 27309688	-1 93108524	-3 12783406

REGION CHECKS

REGION		
1	-1 21136695	-1 25358908
2	-1-17241223	-1-10891326
3	-2-29049689	-2-28271724

THERMAL REGIONWISE ABSORPTION

REGION

1

31803150

33254366

35020041 PAGE 9
-1 16536625

P1MG2 EDIT IS COMPLETED 35020041 PAGE 10

REFERENCES

1. E. Greuling, F. Clark, and G. Goertzel, "A Multigroup Approximation to the Boltzmann Equation for Critical Reactors," NDA 10-96.
2. H. Bohl, E. M. Gelbard, and G. H. Ryan, "MUFT-4, Fast Neutron Spectrum Code for the IBM-704," Bettis Atomic Power Division Report WAPD-TM-72 (July 1957).
3. O. J. Marlowe, C. P. Saalbach, L. M. Culpepper, and D. S. McCarty, "WANDA-A One-Dimensional Few-Group Diffusion Equation Code for the IBM-704," Bettis Atomic Power Division Report WAPD-TM-28 (November 1956).

PLMG - A ONE-DIMENSIONAL
MULTIGROUP P₁ CODE FOR THE IBM-704

H. Bohl, Jr.

CONTRACT AT-11-1-GEN-14

March 1960

Available from the Office of Technical Services,
Department of Commerce
Washington 25, D. C.

NOTE

This document is an interim memorandum prepared primarily for internal reference and does not represent a final expression of the opinion of Westinghouse. When this memorandum is distributed externally, it is with the express understanding that Westinghouse makes no representation as to completeness, accuracy, or usability of information contained therein.

BETTIS ATOMIC POWER LABORATORY
PITTSBURGH, PENNSYLVANIA
OPERATED FOR THE U.S. ATOMIC ENERGY COMMISSION BY
WESTINGHOUSE ELECTRIC CORPORATION

STANDARD EXTERNAL DISTRIBUTION

	<u>No. Copies</u>
UC-34: Physics and Mathematics, TID-4500, 15th Edition	615

SPECIAL EXTERNAL DISTRIBUTION

Manager, Pittsburgh Naval Reactors Operations Office, AEC	3
Argonne National Laboratory, W. F. Miller	2
Brookhaven National Laboratory, J. Chernick	1
Brookhaven National Laboratory, M. Rose	1
David Taylor Model Basin, H. Polachek	2
Knolls Atomic Power Laboratory, R. Ehrlich	10
Los Alamos Scientific Laboratory, B. Carlson	2
New York University, R. Richtmyer	2
Oak Ridge National Laboratory, A. Householder	2
University of California Radiation Laboratory, Livermore, S. Fernbach	2
Total	643

 LEGAL NOTICE

This report was prepared as an account of Government sponsored work. Neither the United States, nor the Commission, nor any person acting on behalf of the Commission:

A. Makes any warranty or representation, expressed or implied, with respect to the accuracy, completeness, or usefulness of the information contained in this report, or that the use of any information, apparatus, method, or process disclosed in this report may not infringe privately owned rights; or

B. Assumes any liabilities with respect to the use of, or for damages resulting from the use of any information, apparatus, method, or process disclosed in this report.

As used in the above, "person acting on behalf of the Commission" includes any employee or contractor of the Commission, or employee of such contractor, to the extent that such employee or contractor of the Commission, or employee of such contractor prepares, disseminates, or provides access to, any information pursuant to his employment or contract with the Commission, or his employment with such contractor.

P1MG - A ONE-DIMENSIONAL MULTIGROUP
P₁ CODE FOR THE IBM-704

The following two sentences should be added to the report WAPD-TM-135 in the sections indicated.

Part TWO, Section IV, Form II, to the paragraph describing "i + r" (p. 23) add:

"Isotopes must be entered in ascending order according to i."

Part TWO, Section VIII, LTP4, to the paragraph concerning File 3 (p. 34) add:

"Since isotropic slowing down due to hydrogen is not treated separately in this program as it is in MUFT-4, γ and $\xi \sigma_s$ must be entered in the P1MG2 library as equal to 1 and σ_s , respectively, in order to be consistent with MUFT-4."