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CANDID-1D, A One-dimensional,
Multigroup Diffusion-theory Program
for the CDC-3600

by

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I. PREFACE

As part of the reactor reprogramming effort associated with the acquisition of the CDC-3600, a cooperative programming project was undertaken with the Control Data Corporation. Specifications for the development of multigroup one- and two-dimensional diffusion-theory programs were prepared by Argonne National Laboratory, and the responsibility of the program development was assumed by CDC and a subcontractor, Computer Applications, Incorporated. At the end of the project, preliminary versions of the one- and two-dimensional programs CANDID-1D and CANDID-2D were released together with the document, CANDID2D, A Two-dimensional Neutron Diffusion Program,¹ and some preliminary CANDID-1D documentation.

The program described here is an extension and modification of this initial effort made workable on the Laboratory's CDC-3600 configuration. Programming details are, in general, as described in Ref. 1, and for this reason many have been omitted.

The original version of the CANDID-1D program was prepared by Donald Brown, Peter Kaestner, Ward Sangren, and Thomas Zielinski of CAI; and Sanford Elkin of CDC.

II. INTRODUCTION

CANDID was based upon the United Kingdom Atomic Energy Authority's CRAM program developed by Hassitt² to solve the multigroup diffusion equations.

CANDID-1D is written for the solution of one-dimensional problems in plane, cylindrical, and spherical geometries. The real or adjoint solution may be calculated, and homogeneous (eigenvalue) or inhomogeneous (external source) problems may be solved.

Three criticality search options are provided in addition to the flux-convergence, or k_{eff} , calculation. These are:

1. Critical dimension, in which the size of a designated region or regions may be varied to achieve criticality.
2. Concentration, in which the amount of certain designated materials in one or more specified compositions is varied to achieve criticality.
3. Buckling, in which the transverse buckling of a designated region or regions is varied to achieve criticality.

A fixed k_{eff} may be specified for these searches rather than the criticality value, $k_{\text{eff}} = 1$.

Fission-spectrum matrices are allowed as material-dependent and incident neutron energy-dependent functions, and scattering is permitted from any energy group to any other.

All the boundary conditions as provided for diffusion-theory applications in the general input specifications³ are not currently usable. Those available are the flux or current equal zero and the logarithmic derivative condition.

A group-collapsing facility was included in the design criteria, but has not been implemented.

Cross-section data are obtained either from tapes generated by the ANL cross-section library program, XLIBIT,⁴ or from the general input type 700000 cards.

The program is written in FORTRAN 63 for the CDC-3600, requiring a minimum of eight tape units.

III. DESCRIPTION OF INPUT REQUIREMENTS

The input requirements for this program are as reported in the general specifications for ANL reactor programs.³ That document (ANL-7194) describes these specifications in detail. This section describes the program-dependent CANDID-1D input and minor program exceptions.

A. Program-dependent Input Types

The program-dependent input deck (see Fig. 1) for CANDID-1D problems will always contain a type 121000 and 122000 card. The 110000, 131000, 132000, 133000, 14XXXX, 150000, and 170000 cards are included only as necessary.

Fig. 1
Arrangement of Input Deck

All card types with the exception of 14XXXX require at most a single card.

The input information to be specified on each card type is described in the following paragraphs.

1. Type 110000

Execution will be suppressed if column 7 is nonzero nonblank. This option is included to provide the user a check of his input data before execution, if desired.

The final fluxes will be punched in 6XXXXX format if column 8 contains a nonzero punch.

Columns 9-80 should be blank. They are ignored by the program.

2. Type 121000

The type 121000 card contains the type identification and nine six-column fields for right-justified integer data. A single type 121000 card is required with fields 2 and 3 nonblank. Field 1 may be left blank or, if punched, must be identical to field 2. Fields 4-9 are optional and may be specified or left blank. Program values assigned when these fields are blank are indicated with the appropriate field definition below:

Field	Symbol	Columns	Definition	Program-assigned Value
1	MAXE	7-12	Number of groups in cross-section set.	
2	GMAX	13-18	Number of groups used in problem.	
3	MAXR	19-24	Number of regions.	
4	NØITMAX	25-30	Maximum number of outer iterations.	50
5	NIITMAX	31-36	Maximum number of inner iterations.	1 or 8*
6	NFSITMAX	37-42	Number of outer iterations with fixed fission source.	1

*1, unless upscatter is present; then 8.

<u>Field</u>	<u>Symbol</u>	<u>Columns</u>	<u>Definition</u>	<u>Program-assigned Value</u>
7	NXTMAX	43-48	Maximum number of extrapolations for k_{eff} .	10
8	NINTMAX	49-54	Maximum number of interpolations for k_{eff} .	20
9		55-60	Frequency of criticality search parameter output (=N criticality search parameter is printed every Nth control cycle). This is in addition to the automatic initial and converged cycle edit of the criticality search parameter.	10 ⁶

3. Type 122000

Exactly one type 120000 card is required. It contains two integer fields. The first field contains the number of compositions to be defined. This quantity is right-justified in columns 7-12. The second field, columns 67-72, will, in general, be left blank. A nonzero integer provides detailed editing for debugging purposes.

4. Type 131000

The type 131000 card contains the type identification and five 12-column fields of floating-point data. All five quantities are optional, and the entire card may be omitted if all program-assigned values are desired. The field definitions and assigned values for these criticality search parameters are:

<u>Field</u>	<u>Symbol</u>	<u>Columns</u>	<u>Definition</u>	<u>Program-assigned Value</u>
1	EFFKZ	7-18	Desired value of k_{eff_0} , k_0 .	1.0
2	XLUB,AK1	19-30	Upper bound on criticality search parameter.	0.

<u>Field</u>	<u>Symbol</u>	<u>Columns</u>	<u>Definition</u>	<u>Program-assigned Value</u>
3	XB,AK2	31-42	Second guess for criticality search parameter.	0.
4	XGLB,AK2	43-54	Lower bound on criticality search parameter.	0.
5	KDOT	55-66	Guess for dk_{eff}/dX , where X is the criticality search parameter.	0.

The quantity specified in field 5 will take precedence over that specified in field 3 for determining the second value of the search parameter when both are present.

5. Type 132000

FIELD									
1		ϵ_K		2	$\epsilon_{\Delta K}$		3	ϵ_{ϕ}	
1	3	2	0	0	0				
1		6	7		18	19	30	31	42 43
								54	55
									66 67

The type 132000 card has the same format as type 131000 and may be omitted if program-assigned values of convergence criteria and minimum flux are acceptable.

<u>Field</u>	<u>Symbol</u>	<u>Columns</u>	<u>Definition</u>	<u>Program-assigned Value</u>
1	EPSI1	7-18	Convergence criterion for outer bounds of K.	0.001
2	EPSI2	19-30	Convergence criterion for sources.	0.001
3	EPSI5	31-42	Smallest flux value considered.	1.0×10^{-6}
4	EPSI6	43-54	Neutron-balance criterion.	1.0×10^{-10}
5		55-66	Initial guess at k_{eff} .	1.0

6. Type 133000

FIELD									
1		2		3					
1	3	3	0	0	0				
1		6	7		18	19	30	31	42

The type 133000 card contains three floating-point fields. Any of these quantities, or the entire card, may be omitted if the program-assigned values are to be used.

<u>Field</u>	<u>Column</u>	<u>Definition</u>	<u>Program-assigned Value</u>
1	7-18	Extrapolation parameter.	1.0
2	19-30	Convergence criterion for flux per inner iteration.	0.001
3	31-42	Convergence criterion for sum of flux differences.	10.0

7. Type 14XXXX

The type 14XXXX cards contain the buckling input data given by composition and/or energy. If no buckling input is necessary, the 14XXXX card(s) will not appear.

COMPOSITION			BUCKLING(j)			BUCKLING(j+1)			BUCKLING(j+2)			BUCKLING(j+3)			BUCKLING(j+4)			j	CARD NO.		
1	4																				
1	2	3	6	7	18	19	30	31	42	43	54	55	66	67	69	70	72	73			

Columns 3-6 contain the composition number written as a right-justified integer. These columns are left blank if the buckling data given are independent of composition.

Five 12-column floating-point fields are provided on each card for the buckling information. If data are energy-independent, only the first buckling field, columns 7-18, is used on each card. When energy-dependent data are specified, data for up to five groups are given per card. In this case, the group field (columns 67-69) designates the group, j , corresponding to the initial value $B^2(j)$ appearing in columns 7-18. $B^2(j+1)$ appears in columns 19-30, etc. The group field must contain a right-justified integer when energy-dependent buckling values are given. It is left blank for energy-independent data.

An additional field, columns 70-72, contains the card number for each 14XXXX card. Card numbering is sequential, i.e., 1, 2, ..., and required when more than a single 14XXXX card is used.

8. Type 150000

The type 150000 card is included to permit normalization to a given power level. The user specifies the power level in number of fissions and auxiliary quantities as required for the geometry.

NORMDS			BUCKCORE			COREPOWR			CORE HH		
1	5	0	0	0	0						
1	6	7	12	13	24	25	36	37	48	49	

Columns 7-12 nonzero, nonblank indicate the normalization option is to be exercised. Columns 13-24 contain in floating-point format B^2 , the transverse core buckling for cylindrical geometry; columns 25-36 represent

the desired power level (number of fissions), a floating-point quantity; and columns 37-48 contain the half height of the active core for cylindrical geometry.

9. Type 160000

The type 160000 card was designated for use by general interface condition specification, but the necessary programming was not implemented.

10. Type 170000

Whenever an external source (inhomogeneous) problem is to be solved, a type 170000 card may be used.

EXT. INDEX						FISSION N.F.																							
1	7	0	0	0	0																								
1						6	7					12	13																

Columns 7-12 contain a right-justified integer designating the number of iterations per source extrapolation.

Columns 13-24 give a fission normalization factor in floating-point format. This number reduces the system multiplication factor and accelerates flux convergence.

If either or both of these quantities are not given, program-assigned values of 1 and 1.0 are used.

B. Exceptions to the General Input Specifications

The remaining cards required to specify a CANDID-1D problem are described in the general input specifications,³ with the following exceptions:

1. End Card

The end card indicating the completion of input data for each problem for CANDID-1D must contain the statement END OF PROBLEM beginning in column 7.

2. Type 700000

If cross-section modification cards are included (7 series), a card containing END OF PROBLEM beginning in column 3 must be appended to the modification deck.

3. Type 2XXXXX

The overlay region assignment feature is not implemented in CANDID-1D. Standard region assignment is required.

IV. CANDID-1D OVERLAY LOGIC

CANDID-1D is composed of a main section and eight overlays, as shown in Fig. 2.

Fig. 2. CANDID-1D Overlay Logic

V. CANDID-1D DICTIONARY

FORTRAN		Definition	Input from Card Type
Variable	Dimension		
A(C,G)	CMAX·GMAX	Removal cross section for each composition and group $= \sigma_{c,j} + \sigma_{f,j} + \sum_{k=1}^J \sigma(j \rightarrow k).$	*
AK1		Upper bound for criticality search parameter, X.	131000
AK2		Lower bound for criticality search parameter, X.	131000
AMBDA ARRAY	IULTIMAT	k_{eff} Master array symbol for real variables (= JARRAY, LARRAY, NARRAY).	
AX1		Initial guess for criticality search parameter, X.	500000
AX2		Second guess for criticality search parameter, X.	500000
BSQ(C,G) C	CMAX·GMAX	Buckling terms, $B_{c,j}^2$. Composition index.	14XXXX
CHI(C,G)	CMAXFS·GMAX	χ_j fission-spectrum fractions for group j, given for each fissionable composition.	*
CHI(C,G,H)	CMAXFS·GMAX ²	$\chi(k,j)$ fission-spectrum fractions for group j from incident neutrons of group k given for each fissionable composition.	*
CMAX		Number of compositions used.	122000
CMAXFS		Number of fissionable compositions used.	
D(C,G)	CMAX·GMAX	Diffusion coefficient, D_j , given for each composition.	*
DK1		$K_1 - k_0$, difference between initial value of K and value sought.	
DK2		$K_2 - k_0$, difference between second value of K and value sought.	
DXP(I)	IMAX	Region dimension modifier for mesh interval, i.	5XXXXX
EFFK		K^n = value of K calculated.	
EFFKM1		K^{n-1} = value of K calculated in previous iteration.	

*ANL cross-section nomenclature defined in Ref. 4.

FORTRAN		Definition	Input from Card Type
Variable	Dimension		
EFFKZ		k_0 , value of k_{eff} being sought.	131000
EMAX		$\bar{K}^n = \text{MAXIMUM}_{(\text{groups, intervals})} \phi^n / \phi^{n-1}$, where n is the iteration index.	
EMIN		$\underline{K}^n = \text{MINIMUM}_{(\text{groups, intervals})} \phi^n / \phi^{n-1}$.	
EPSI1		$\epsilon_K =$ convergence criterion for $\bar{K}^n - \underline{K}^n$.	132000
EPSI2		$\epsilon_{\Delta K} =$ convergence criterion for sources $ K^n - K^{n-1} $.	132000
EPSI3		$\epsilon =$ convergence criterion for criticality $ K^n - k_0 $.	500000
EPSI4		$\delta =$ flux convergence criterion. $\bar{K}^n - \underline{K}^n$, used for inhomogeneous problems.	500000
EPSI5		$\epsilon_\phi =$ minimum flux value to be considered in computing $\bar{K}$ and $\underline{K}$.	132000
EPSI6		Neutron balance criterion.	132000
ERRORCTR		Error counter; if > 100 , program exits.	
F(M,G)	MMAXFS.GMAX	Fission cross section for each fissionable material and group $= \sigma_{f,j}$.	*
FGNU(C,G) FSIG(C,G)	CMAFVS.GMAX	Number of neutrons emitted per fission multiplied by the fission cross section, given for each fissionable composition and group, $= \nu \sigma_{f,j}$.	*
FIS(C,G)	CMAFVS.GMAX	Fission cross section for each fissionable composition and group $= \sigma_{f,j}$.	*
FLUX(I,G)	IMAX.GMAX	$\phi_{i,j}$, neutron flux for each interval and group.	
FLXVLM(R,G)	MAXR.GMAX	Flux-volume integral array given by region and group.	
G		Energy group index, $= j$.	
GMAX		Maximum number of energy groups, $= J$.	121000
GNU(M,G)	MMAXFS.GMAX	$\nu_j =$ number of neutrons emitted per fission, given for each fissionable material and group.	*

FORTRAN		Definition	Input from Card Type
Variable	Dimension		
IADJ	9	Adjoint problem indicator = 0, real problem; = 1, adjoint problem.	
IAJCH		Fission fraction indicator = 1, real problem, x_j ; = 2, real problem, $x(k,j)$; = 3, adjoint problem, x_j ; = 4, adjoint problem, $x(k,j)$.	
ICARD		Array used as card read buffer.	
ICHIV		x -indicator = 1, x_j = 2, $x(k,j)$.	
ICONV	9	Convergence indicator = 1, another outer iteration; = 2, change search parameter, X ; = 3, converged.	
ICSET		Cross-section set identification.	400000000000
ID		First digit of card type field.	All
IDSET		Cross-section set identification.	400000000000
IGEOM	9	Geometry indicator = 1, slab; = 2, cylinder; = 3, sphere.	200000
IGP		Total length of scattering vector $= \sum_{c=1}^{C_{MAX}} \left[\max_{m \in c} F_j(m) + \max_{m \in c} G_j(m) + 1 \right]$	*
IMATNAME		Material or isotope designation.	400000
IMAX		Total number of mesh intervals.	
INT	MAXR	Region/interval indicator for initial flux guess.	600000
IREGNO		Region numbers.	2XXXXX
ITCTR		Iteration counter.	
ITITLE		Array name used for page title.	100000
ITMAX	MAXR	Maximum number of iterations.	121000
ITYPE		Problem type indicator = 1, k_{eff} or flux-convergence calculation; = 2, external-source calculation; = 3, composition search; = 4, dimension search; = 5, buckling search.	500000

FORTRAN		Definition	Input from Card Type
Variable	Dimension		
ITYPEL	IULTIMAT	Boundary condition, left boundary, X_L .	300000
ITYPER		Boundary condition, right boundary, X_R .	300000
IULTIMAT		Maximum length of ARRAY, machine memory-size dependent.	
JARRAY		Master array symbol for integer variables.	
JXL		Boundary condition indicator for left boundary = 1, ϕ = constant; = 2, ϕ = 0; = 3, ϕ' = 0; = 4, log der. = constant.	
JXR		Boundary condition indicator for right boundary = 1, ϕ = constant; = 2, ϕ = 0; = 3, ϕ' = 0; = 4, log der. = constant.	
KDOT		Derivative of K with respect to search parameter.	131000
LAM		Convergence indicator, 1 $\rightarrow$ convergence.	
LAMBDA	2	Two most recent values of K.	
LARRAY	IULTIMAT	Master array symbol for logical variables.	
LCOMPD	MAXR	Region-composition correspondence array.	420000
LMAT	LMAT	Number of materials used in problem.	
LMOD		Length of modification specification array.	
LREGD		Composition-region correspondence array.	
MAT		Material numbers used in first level of mixing.	400000
MAXR		Number of regions used in problem.	
MOD		Specified modifications for criticality search.	
NARRAY		Master array symbol for integer variables.	
NIIT		Inner-iteration counter.	

FORTRAN		Definition	Input from Card Type
Variable	Dimension		
NIINTMAX	9	Maximum number of inner iterations.	121000
NINTMAX		Maximum number of interpolations for k_{eff} .	121000
NOBSQ		Buckling option indicator = 0, no buckling input; = 1, buckling input.	14XXXX
NOFBSQ		Buckling option indicator = 4 → buckling values given by group and composition.	14XXXX
NTAPE		Tape assignment array.	
NTAPE(1)		Input tape = NTAPEIN.	
NTAPE(2)		Output tape = NTAPEOUT.	
NTAPE(3)		Cross-section library tape = NTAPELIB.	
NTAPE(4)		Coefficients tape = NTAPECOE.	
NTAPE(5)		Composition cross-section tape = NTAPECCS.	
NTAPE(6)	6	Problem tape = NTAPEPRB.	
NTAPE(7)		Material cross-section tape = NTAPEMCS.	
NTAPE(8)		Overlay tape = NTAPEOVR.	
NXTMAX		Maximum number of extrapolations for k_{eff} .	121000
PROBNM		Problem name.	100000
PROBNO		Problem number.	100000
RMAX		Number of regions.	
X		Criticality search parameter.	
XA		Initial guess for criticality search parameter.	500000
XB		Second guess for criticality search parameter.	131000
XGLB		Lower bound for criticality search parameter.	131000
XLUB		Upper bound for criticality search parameter.	131000

VI. FINITE-DIFFERENCE EQUATIONS, CONVERGENCE, AND CRITICALITY-SEARCH ALGORITHMS

A. Finite-difference Equations

The basic equation to be solved at each point, x , of a homogeneous region for the one-dimensional geometries is

$$D_j \nabla^2 \phi_j(x) - A_j \phi_j(x) + Q_j(x) = 0, \quad (1)$$

where j represents the energy group index, x is the space variable in any of the three one-dimensional geometries, D is the regional diffusion coefficient, A is the regional neutron-removal cross section, and Q is the neutron source, which may be due to fission, scattering, and an external component.

The Laplacian ∇^2 is

$$\frac{d^2}{dx^2} \text{ for plane geometry;}$$

$$\frac{d^2}{dx^2} + \frac{2}{x} \frac{d}{dx} \text{ for spherical geometry;}$$

$$\frac{d^2}{dx^2} + \frac{1}{x} \frac{d}{dx} \text{ for cylindrical geometry.}$$

The removal cross-section term is

$$A_j = \sigma_{c,j} + \sigma_{f,j} + \sum_k \sigma(j \rightarrow k) + D_j B_j^2,$$

and the source term is

$$Q_j = \frac{1}{k_{\text{eff}}} \sum_k \chi(k, j) v_k \sigma_{f,k} \phi_k(x) + \sum_k \sigma(k \rightarrow j) \phi_k(x) + S_j(x).$$

To construct the finite-difference equation, a mesh structure is imposed. With i as the mesh point index, the mesh interval is formed as $\Delta x_i = x_i - x_{i-1}$. The difference equation will have the form

$$a_i \phi_{i+1} - b_i \phi_i + c_i \phi_{i-1} + f_i = 0 \quad (2)$$

for all three one-dimensional geometries. In Eq. 2, the group index j is implied, ϕ_i refers to the average flux in Δx_i , and the other coefficients are functions of the materials and geometry used.

In slab geometry, Eq. 1 is integrated between x_{i-1} and x_i . We approximate

$$\int_{x_{i-1}}^{x_i} (A\phi - Q) dx \approx (A_i \phi_i - Q_i) \Delta x_i, \quad (3)$$

and

$$\int_{x_{i-1}}^{x_i} D_i \frac{d^2 \phi}{dx^2} dx = D_i \left. \frac{d\phi}{dx} \right|_{x=x_i^-} - D_i \left. \frac{d\phi}{dx} \right|_{x=x_{i-1}^+}. \quad (4)$$

Using the continuity of flux and current at the interfaces x_i and x_{i-1} , we obtain (using the first two terms of a Taylor expansion)

$$\left. \begin{aligned} \phi(x_i) &= \phi_i + \frac{\Delta x_i}{2} \left. \frac{d\phi}{dx} \right|_{x=x_i^-} = \phi_{i+1} - \frac{\Delta x_{i+1}}{2} \left. \frac{d\phi}{dx} \right|_{x=x_i^+} \\ \phi(x_{i-1}) &= \phi_i - \frac{\Delta x_i}{2} \left. \frac{d\phi}{dx} \right|_{x=x_{i-1}^+} = \phi_{i-1} + \frac{\Delta x_{i-1}}{2} \left. \frac{d\phi}{dx} \right|_{x=x_{i-1}^-}, \\ \text{and} \\ D_i \left. \frac{d\phi}{dx} \right|_{x=x_i^-} &= D_{i+1} \left. \frac{d\phi}{dx} \right|_{x=x_i^+} \\ D_{i-1} \left. \frac{d\phi}{dx} \right|_{x=x_{i-1}^-} &= D_i \left. \frac{d\phi}{dx} \right|_{x=x_{i-1}^+} \end{aligned} \right\} \quad (5)$$

Substituting from Eqs. 5 into the right-hand side of Eq. 4 and then equating this to the right-hand side of Eq. 3, we obtain

$$\begin{aligned} & \frac{2D_i D_{i+1}}{D_{i+1} \Delta x_i + D_i \Delta x_{i+1}} \phi_{i+1} - \left[\frac{2D_i D_{i+1}}{D_{i+1} \Delta x_i + D_i \Delta x_{i+1}} + \frac{2D_i D_{i-1}}{D_i \Delta x_{i-1} + D_{i-1} \Delta x_i} + A_i \Delta x_i \right] \phi_i \\ & + \frac{2D_i D_{i-1}}{D_i \Delta x_{i-1} + D_{i-1} \Delta x_i} \phi_{i-1} + Q_i \Delta x_i = 0, \end{aligned} \quad (6)$$

which is in the form of Eq. 2 with

$$\left. \begin{aligned} a_i &= \frac{2D_i D_{i+1}}{D_{i+1} \Delta x_i + D_i \Delta x_{i+1}}, \\ c_i &= a_{i-1}, \\ b_i &= a_i + c_i + A_i \Delta x_i, \\ \text{and} \\ f_i &= Q_i \Delta x_i. \end{aligned} \right\} \quad (7)$$

Proceeding in a similar manner for cylindrical and spherical geometry, we obtain:

<u>Cylinder</u>	<u>Sphere</u>
$a_i = \frac{2x_i D_i D_{i+1}}{D_{i+1} \Delta x_i + D_i \Delta x_{i+1}}$	$a_i = \frac{2x_i^2 D_i D_{i+1}}{D_{i+1} \Delta x_i + D_i \Delta x_{i+1}}$
$c_i = a_{i-1}$	$c_i = a_{i-1}$
$b_i = a_i + c_i + \frac{1}{2} A_i (x_i^2 - x_{i-1}^2)$	$b_i = a_i + c_i + \frac{1}{3} A_i (x_i^3 - x_{i-1}^3)$
$f_i = \frac{1}{2} Q_i (x_i^2 - x_{i-1}^2)$	$f_i = \frac{1}{3} Q_i (x_i^3 - x_{i-1}^3)$

Equation 2 is solved in a stepwise manner using the following algorithm:

We solve for Γ_i and Ω_i

$$\Gamma_i = \frac{a_i}{b_i - c_i \Gamma_{i-1}}, \quad i = 2, 3, \dots, I_{\max} - 1,$$

with

$$\Gamma_1 = \frac{a_1}{b_1};$$

$$\Omega_i = \frac{c_i \Omega_{i-1} + f_i}{b_i - c_i \Gamma_{i-1}}, \quad i = 2, 3, \dots, I_{\max},$$

with

$$\Omega_1 = \frac{f_1}{b_1}.$$

Then, with

$$\phi_{I_{\max}} = \Omega_{I_{\max}},$$

$$\phi_{i-1} = \Gamma_{i-1} \phi_i + \Omega_{i-1}, \quad i = I_{\max}, I_{\max} - 1, \dots, 2.$$

The boundary conditions supply the necessary starting values.

B. Convergence Testing

Depending on the type of problem being solved, various convergence criteria are applied. In flux-convergence problems, two tests are made:

$$1. \quad \bar{K}^n - \underline{K}^n < \epsilon_K,$$

where

$$\left. \begin{aligned} \bar{K}^n &= \max_{i,j} \frac{\phi_{i,j}^n}{\phi_{i,j}^{n-1}} \\ \underline{K}^n &= \min_{i,j} \frac{\phi_{i,j}^n}{\phi_{i,j}^{n-1}} \end{aligned} \right\} \text{ for } \phi_{i,j} > \varepsilon_\phi,$$

and ε_K and ε_ϕ are specified as input parameters in the program-dependent input.

$$2. \quad |K^n - K^{n-1}| < \varepsilon_{\Delta K},$$

where

$$K^n = \left[\sum_{i,j} \phi_{i,j}^n \cdot \phi_{i,j}^n \right]^{1/2}$$

and $\varepsilon_{\Delta K}$ appears in the program-dependent input.

In external source calculations (inhomogeneous problems), a single test is made:

$$\bar{K}^n - \underline{K}^n < \varepsilon_4, \text{ where } \varepsilon_4 \text{ is an input parameter.}$$

When the criticality search option is invoked, the convergence testing employed is best illustrated by the flow chart for the CONVERGE subroutine shown in Fig. 3.

Fig. 3. Flow Chart for CONVERGE Subroutine

Fig. 3 (Contd.)

C. Criticality Search Procedure

The criticality search procedure is based upon the adjustment of a search parameter X to attain either the critical value of k_{eff} ($k_{\text{eff}} = 1.0$), or a specified value ($k_{\text{eff}} = k_0$). The relationship of this control parameter to the problem specification is

$$W = W^0(1 + X \cdot \Delta W).$$

W may be the amount of material included (volume fractions), as in the composition or buckling searches, or the mesh interval, as in the dimension search. W^0 and ΔW are specified initially as problem parameters, and may be material- or region-dependent.

The search procedure is initiated in either of two ways: by specifying two guesses for the control parameter, X^0 and X^1 ; or by specifying a single control parameter guess, X^0 , together with an estimate of dK/dX . Problem input includes, in addition, upper, $\bar{X}$, and lower, $\underline{X}$, bounds for the control parameter. Simple linear extrapolation and interpolation formulas are used to calculate the critical value of X such that

$$|K^n(X) - k_0| < \epsilon.$$

This criticality search procedure is programmed as subroutine CONTROL. A descriptive flow chart is shown in Fig. 4.

VII. DESCRIPTION OF OUTPUT

The output consists of (a) a monitor line for each flux iteration listing the value of K and the maximum and minimum flux values, together with their respective mesh-point and energy-group indices; (b) a listing of the value of the control search parameter, extrapolation, and interpolation counts at each control adjustment, together with the current values of those quantities being varied by the criticality search procedure; and (c) final values as follows:

1. Fluxes for each mesh interval and each group normalized either to one fission per unit volume or to a specified power level.
2. Flux volume integrals for each region and group.
3. Total power per region.
4. Flux and leakage values at each exterior boundary and region interface for each energy group.
5. Net leakage and other balance quantities for each region and group and summed over the reactor and over energy.

Fig. 4. Descriptive Flow Chart for Subroutine CONTROL

APPENDIX
Sample Problem

1. Input

```

100000167.045    CANDID 1-D TEST 30AUG65
121000          3      3      2                      1
122000          2
131000          1.0      1.0E4      -3.0E3      -1.0E4
132000          .001      .001      .000001
144001 .00197593
144002 .00197593
200000 X 0.0      100.00000
2 10.0      4554.96000
2 254.96000      30100.00000
300000 X      X
400000000000 167
400000      1U235 0.07120      U238 0.7405      FE .09280
400000      2U238 0.6      FE 0.2      NA 0.2
410000      1      11.00
410000      2      21.00
420000      1      1
420000      2      2
500000 X.0005      X .0005      .00197593 .00002
600000X
60000118.0
60000125.0
600001.1
600002.01
60000210.0
600002.1
      END OF PROBLEM

```

```

100000167.045    CANDID 1-D TEST 30AUG65
121000          3      3      2                      1
122000          2
131000          1.0      1.0E4      -3.0E3      -1.0E4
132000          .001      .001      .000001
144001 .00197593
144002 .00197593
200000 X 0.0      100.00000
2 10.0      4554.96000
2 254.96000      30100.00000
300000 X      X
400000000000 167
400000      1U235 0.07120      U238 0.7405      FE .09280
400000      2U238 0.6      FE 0.2      NA 0.2
410000      1      11.00
410000      2      21.00
420000      1      1
420000      2      2
500000 X.0005      X .0005      .00197593 .00002
600000X
60000118.0
60000125.0
600001.1
600002.01
60000210.0
600002.1
      END OF PROBLEM

```

2. Output

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BUCKLING DATA.

THE DATA IS CONSTANT OVER ALL ENERGY GROUPS BUT VARIES WITH COMPOSITION.

THE VALUE FOR COMPOSITION NUMBER 1 IS 1.9759-003
THE VALUE FOR COMPOSITION NUMBER 2 IS 1.9759-003

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CODE DEPENDENT DATA OR INPUT IF DIFFERENT THAN ZERO.

VOLUME SOURCE DATA HAVE NOT BEEN INPUT.

ENERGY GROUPS IN CROSS SECTION DATA.....	3
ENERGY GROUPS TO USE IN PROBLEM.....	3
NUMBER OF REGIONS.....	2
MAXIMUM NUMBER OF ITERATIONS.....	50
MAXIMUM NUMBER OF EXTRAPOLATIONS ON K-EFFECTIVE.....	10
MAXIMUM NUMBER OF INTERPOLATIONS ON K-EFFECTIVE.....	20
PRINT PERIOD FOR FISSION SOURCE K.....	1
NUMBER OF COMPOSITIONS.....	2

DESIRED K-EFFECTIVE.....	1.0000+000
UPPER BOUND ON SEARCH PARAMETER.....	1.0000+004
SECOND GUESS ON SEARCH PARAMETER.....	-3.0000+003
LOWER BOUND ON SEARCH PARAMETER.....	-1.0000+004
CONVERGENCE CRITERION ON OUTER BOUNDS OF K.....	1.0000-003
CONVERGENCE CRITERION FOR SOURCES.....	1.0000-003
SMALLEST FLUX VALUE USED IN COMPUTING K-BOUNDS.....	1.0000-006
AGREEMENT REQUIRED IN NEUTRON BALANCE.....	1.0000-010
FIRST GUESS AT K-EFFECTIVE.....	1.0000+000
CONVERGENCE CRITERION ON FLUX PER INNER ITERATION...	1.0000-003
CONVERGENCE CRITERION FOR SUM OF FLUX DIFFERENCES...	1.0000+001

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REACTOR GEOMETRY

GEOMETRY TYPE	LEFT BOUND	RIGHT BOUND
1D-SLAB	0.0000+000	1.0000+002

REGION BOUNDARIES

REGION NO.	LEFT BDRY.	NO. X-MESH	RIGHT BDRY.
1	0.0000+000	45	5.4960+001
2	5.4960+001	30	1.0000+002

MESH DEFINITION

CONSTANT INTERVAL PER REGION METHOD - X(R) DIRECTON

IMAX = 75

X(R) PLUS DELTA X(R) FROM LEFT TO RIGHT OF REACTOR

MESH NO.	1	2	3	4	5	6	7	8	9	10
ABSCISSA	1.2213+000	2.4427+000	3.6640+000	4.8853+000	6.1067+000	7.3280+000	8.5493+000	9.7707+000	1.0992+001	1.2213+001
MESH NO.	11	12	13	14	15	16	17	18	19	20
ABSCISSA	1.3435+001	1.4656+001	1.5877+001	1.7099+001	1.8320+001	1.9541+001	2.0763+001	2.1984+001	2.3205+001	2.4427+001
MESH NO.	21	22	23	24	25	26	27	28	29	30
ABSCISSA	2.5648+001	2.6869+001	2.8091+001	2.9312+001	3.0533+001	3.1755+001	3.2976+001	3.4197+001	3.5419+001	3.6640+001
MESH NO.	31	32	33	34	35	36	37	38	39	40
ABSCISSA	3.7861+001	3.9083+001	4.0304+001	4.1525+001	4.2747+001	4.3968+001	4.5189+001	4.6411+001	4.7632+001	4.8853+001
MESH NO.	41	42	43	44	45	46	47	48	49	50
ABSCISSA	5.0075+001	5.1296+001	5.2517+001	5.3739+001	5.4960+001	5.6181+001	5.7403+001	5.8624+001	5.9846+001	6.1067+001
MESH NO.	51	52	53	54	55	56	57	58	59	60
ABSCISSA	6.3968+001	6.5189+001	6.6411+001	6.7632+001	6.8853+001	7.0075+001	7.1296+001	7.2517+001	7.3739+001	7.4960+001
MESH NO.	61	62	63	64	65	66	67	68	69	70
ABSCISSA	7.8981+001	8.0202+001	8.1424+001	8.2645+001	8.3867+001	8.5088+001	8.6310+001	8.7531+001	8.8753+001	9.0000+001
MESH NO.	71	72	73	74	75					
ABSCISSA	9.3995+001	9.5216+001	9.6438+001	9.7659+001	9.8881+001	1.0000+002				

PROB. NO. 1.A7045+002 10CANDID CANDID 1-D TEST 30AUG65										PAGE NO. 5																
Z MESH POINTS	REGION MAP (REGION NUMBER BY MESH POINT) R MESH POINTS																									Z MESH POINTS
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	

	1*	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1*	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	
	R MESH POINTS																									

PROB. NO. 1.67045+002 1DCANDID CANDID 1-D TEST 30AUG65															PAGE NO. 6																
Z MESH POINTS	REGION MAP (REGION NUMBER BY MESH POINT) R MESH POINTS																														Z MESH POINTS
	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50						

	1*	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1*	2	2	2	2	2*	1					

	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50						
	R MESH POINTS																														

PROB. NO. 1,67045+002 1DCANDID CANDID 1-D TEST 30AUG65										PAGE NO. 7																					
Z MESH POINTS		REGION MAP (REGION NUMBER BY MESH POINT) R MESH POINTS																												Z MESH POINTS	
		51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75					

		1*	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2*	1			

		51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75					
		R MESH POINTS																													

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BOUNDARY CONDITION DATA

LEFT FACE OR AXIS	RIGHT OR OUTER FACE
-------------------	---------------------

DER. FLUX = 0.0	FLUX = 0.0
-----------------	------------

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MATERIAL ASSIGNMENT DATA

THE CROSS SECTION SET IS IDENTIFIED AS 167

MATERIAL MAKEUP

MATERIAL NUMBER	ISOTOPE ID	NUMBER DENSITY	ISOTOPE ID	NUMBER DENSITY	ISOTOPE ID	NUMBER DENSITY	ISOTOPE ID	NUMBER DENSITY
1	U235	7.120000+002	U238	7.405000+001	FE	9.280000+002		
2	U238	6.000000+001	FE	2.000000+001	NA	2.000000+001		

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COMPOSITION MAKEUP

COMPOSITION NUMBER	MATERIAL NUMBER/ID	VOLUME FRACTION	MATERIAL NUMBER/ID	VOLUME FRACTION	MATERIAL NUMBER/ID	VOLUME FRACTION	MATERIAL NUMBER/ID	VOLUME FRACTION
1	1	1.000000+000						
2	2	1.000000+000						

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COMPOSITION ASSIGNMENT BY REGION NUMBER

REGION NO.	1	2
COMPOSITION NO.	1	2

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PROBLEM TYPE

CRITICALITY SEARCH VARYING BUCKLING UNIFORMLY

FRACTIONAL MODIFIER..... 2.0000-005
 CONVERGENCE CRITERION (EPSILON)..... 5.0000-004
 INITIAL GUESS AT SEARCH PARAMETER.... 0.0000+000

FLUX CONVERGENCE CRITERION (DELTA)... 5.0000-004

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THE FLUX VALUES WHICH WERE INPUT ARE GIVEN BELOW

REGION NO.	FLUX VALUE	FLUX VALUE	FLUX VALUE	FLUX VALUE	FLUX VALUE	ENERGY GROUP	CARD NO.
1	18.0					1	
1	25.0					2	
1	.1					3	
2	.01					1	
2	10.0					2	
2	.1					3	

CONTROL VALUE (X) = 0.000000+000 NXT = 0 NINT = 0

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THE LAST BUCKLING TERMS USED IN THIS PROBLEM ARE GIVEN BELOW.

ENERGY GROUP	BUCKLING TERMS FOR EACH COMPOSITION.	
	1	2
1	1.9759-003	1.9759-003
2	1.9759-003	1.9759-003
3	1.9759-003	1.9759-003

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COMPOSITION NUMBER... 1

ENERGY GROUP	DIFFUSION COEFFICIENT	REMOVAL CROSS SECTION	FISSION CROSS SECTION	FISSION REACTION RATE
1	1.5904+000	1.1034+001	2.3274+002	6.4501+002
2	1.1411+000	1.2272+002	4.7846+003	1.1962+002
3	3.9931+001	5.9311+002	2.0506+002	5.1264+002

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COMPOSITION NUMBER... 1

ENERGY GROUP	FISSION SPECTRUM
1	5.7600+001
2	4.2400+001
3	0.0000+000

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COMPOSITION NUMBER... 1

ENERGY GROUP	GROUPS FROM WHICH NEUTRONS ARE SCATTERED. (SUM DOWN TO OBTAIN TOTAL SCATTERING CROSS-SECTION PER ENERGY GROUP.)		
	1	2	3
1	0.0000+000	0.0000+000	0.0000+000
2	8.5246+002	0.0000+000	0.0000+000
3	0.0000+000	1.9674+005	0.0000+000

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COMPOSITION NUMBER... 2

ENERGY GROUP	DIFFUSION COEFFICIENT	REMOVAL CROSS SECTION	FISSION CROSS SECTION	FISSION REACTION RATE
1	1.7705+000	9.1260+002	1.5257+002	4.2721+002
2	1.2526+000	5.7668+003	0.0000+000	0.0000+000
3	4.4619+001	2.3301+002	0.0000+000	0.0000+000

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COMPOSITION NUMBER... 2

ENERGY GROUP	FISSION SPECTRUM
1	0.0000+000
2	0.0000+000
3	0.0000+000

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COMPOSITION NUMBER... 2

ENERGY GROUP	GROUPS FROM WHICH NEUTRONS ARE SCATTERED. (SUM DOWN TO OBTAIN TOTAL SCATTERING CROSS-SECTION PER ENERGY GROUP.)		
	1	2	3
1	0.0000+000	0.0000+000	0.0000+000
2	7.4780+002	0.0000+000	0.0000+000
3	0.0000+000	4.8240+004	0.0000+000

1	KEFF=	2.5785+000	MAX K,PT.,GP.	3.1411+002	46	1	MIN K,PT.,GP.	1.6871+002	75	2
2	KEFF=	9.8303+001	MAX K,PT.,GP.	1.0321+000	1	1	MIN K,PT.,GP.	7.3614+001	47	1
3	KEFF=	9.8997+001	MAX K,PT.,GP.	1.0290+000	1	1	MIN K,PT.,GP.	8.4178+001	66	1
4	KEFF=	9.9315+001	MAX K,PT.,GP.	1.0251+000	1	1	MIN K,PT.,GP.	8.9362+001	51	1
5	KEFF=	9.9487+001	MAX K,PT.,GP.	1.0209+000	1	1	MIN K,PT.,GP.	9.2359+001	60	1
6	KEFF=	9.9589+001	MAX K,PT.,GP.	1.0168+000	1	1	MIN K,PT.,GP.	9.4288+001	62	1
7	KEFF=	9.9651+001	MAX K,PT.,GP.	1.0133+000	1	1	MIN K,PT.,GP.	9.5621+001	45	1
8	KEFF=	9.9690+001	MAX K,PT.,GP.	1.0102+000	1	1	MIN K,PT.,GP.	9.6584+001	60	1
9	KEFF=	9.9715+001	MAX K,PT.,GP.	1.0076+000	1	1	MIN K,PT.,GP.	9.7301+001	66	1
10	KEFF=	9.9731+001	MAX K,PT.,GP.	1.0055+000	1	1	MIN K,PT.,GP.	9.7847+001	49	1
11	KEFF=	9.9742+001	MAX K,PT.,GP.	1.0039+000	1	1	MIN K,PT.,GP.	9.8267+001	45	1
12	KEFF=	9.9749+001	MAX K,PT.,GP.	1.0025+000	1	1	MIN K,PT.,GP.	9.8593+001	66	1
13	KEFF=	9.9754+001	MAX K,PT.,GP.	1.0015+000	1	1	MIN K,PT.,GP.	9.8847+001	50	1
14	KEFF=	9.9758+001	MAX K,PT.,GP.	1.0007+000	1	1	MIN K,PT.,GP.	9.9046+001	48	1
15	KEFF=	9.9760+001	MAX K,PT.,GP.	1.0000+000	1	1	MIN K,PT.,GP.	9.9202+001	62	1
16	KEFF=	9.9762+001	MAX K,PT.,GP.	9.9951+001	1	1	MIN K,PT.,GP.	9.9324+001	45	1
17	KEFF=	9.9764+001	MAX K,PT.,GP.	9.9911+001	1	1	MIN K,PT.,GP.	9.9420+001	68	1
18	KEFF=	9.9765+001	MAX K,PT.,GP.	9.9880+001	1	1	MIN K,PT.,GP.	9.9496+001	45	1
19	KEFF=	9.9765+001	MAX K,PT.,GP.	9.9855+001	1	1	MIN K,PT.,GP.	9.9555+001	65	1
20	KEFF=	9.9766+001	MAX K,PT.,GP.	9.9836+001	1	1	MIN K,PT.,GP.	9.9601+001	46	1
21	KEFF=	9.9766+001	MAX K,PT.,GP.	9.9821+001	1	1	MIN K,PT.,GP.	9.9637+001	68	1
22	KEFF=	9.9767+001	MAX K,PT.,GP.	9.9810+001	1	1	MIN K,PT.,GP.	9.9665+001	57	1
23	KEFF=	9.9767+001	MAX K,PT.,GP.	9.9801+001	1	1	MIN K,PT.,GP.	9.9688+001	48	1
24	KEFF=	9.9767+001	MAX K,PT.,GP.	9.9793+001	1	1	MIN K,PT.,GP.	9.9705+001	61	1
25	KEFF=	9.9767+001	MAX K,PT.,GP.	9.9788+001	1	1	MIN K,PT.,GP.	9.9719+001	68	1
26	KEFF=	9.9767+001	MAX K,PT.,GP.	9.9784+001	1	1	MIN K,PT.,GP.	9.9729+001	54	1
CONTROL ADJUSTMENT.										
27	KEFF=	9.9768+001	MAX K,PT.,GP.	9.9780+001	1	1	MIN K,PT.,GP.	9.9738+001	48	1

CONTROL VALUE (X) = -3.000000+003 NXT = 0 NINT = 0

THE LAST BUCKLING TERMS USED IN THIS PROBLEM ARE GIVEN BELOW.

ENERGY GROUP		BUCKLING TERMS FOR EACH COMPOSITION.	
		1	2
1	1.8574+003	1.8574+003	
2	1.8574+003	1.8574+003	
3	1.8574+003	1.8574+003	

PROB. NO. 1.67045+002 1DCANDID CANDID 1-D TEST 30AUG65										PAGE NO. 23	
28	KEFF=	1.0076+000	MAX K,PT.,GP.	1.0352+000	75	3	MIN K,PT.,GP.	9.9908-001	41	1	
29	KEFF=	1.0049+000	MAX K,PT.,GP.	1.0066+000	68	1	MIN K,PT.,GP.	1.0048+000	23	1	
30	KEFF=	1.0049+000	MAX K,PT.,GP.	1.0056+000	58	1	MIN K,PT.,GP.	1.0049+000	18	1	

CONTROL ADJUSTMENT.

31	KEFF=	1.0049+000	MAX K,PT.,GP.	1.0053+000	45	1	MIN K,PT.,GP.	1.0049+000	13	1	
----	-------	------------	---------------	------------	----	---	---------------	------------	----	---	--

CONTROL VALUE (X) = -9.611921+002 NXT = 0 NINT = 0

PROB. NO. 1.67045+002 1DCANDID CANDID 1-D TEST 30AUG65										PAGE NO. 24	
--	--	--	--	--	--	--	--	--	--	-------------	--

THE LAST BUCKLING TERMS USED IN THIS PROBLEM ARE GIVEN BELOW.

ENERGY GROUP		BUCKLING TERMS FOR EACH COMPOSITION.	
		1	2
1	1.9379-003	1.9379-003	
2	1.9379-003	1.9379-003	
3	1.9379-003	1.9379-003	

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32	KEFF=	9.9915-001	MAX K,PT.,GP.	1.0040+000	42	1	MIN K,PT.,GP.	9.8004-001	75	3	
33	KEFF=	9.9998-001	MAX K,PT.,GP.	1.0000+000	18	1	MIN K,PT.,GP.	9.9889-001	50	1	
CONVERGED											
34	KEFF=	9.9998-001	MAX K,PT.,GP.	1.0000+000	1	1	MIN K,PT.,GP.	9.9952-001	68	1	

FLUXES NORMALIZED TO ONE FISSION

MESH	GROUP 1	GROUP 2	GROUP 3	MESH
1	3.21874+001	3.60099+000	1.17454+003	1
2	3.21596+001	3.59789+000	1.17354+003	2
3	3.21042+001	3.59169+000	1.17152+003	3
4	3.20211+001	3.58239+000	1.16849+003	4
5	3.19104+001	3.57001+000	1.16445+003	5
6	3.17722+001	3.55455+000	1.15941+003	6
7	3.16067+001	3.53603+000	1.15337+003	7
8	3.14139+001	3.51446+000	1.14633+003	8
9	3.11940+001	3.48986+000	1.13831+003	9
10	3.09473+001	3.46226+000	1.12930+003	10
11	3.06739+001	3.43167+000	1.11933+003	11
12	3.03741+001	3.39813+000	1.10839+003	12
13	3.00480+001	3.36166+000	1.09649+003	13
14	2.96961+001	3.32229+000	1.08365+003	14
15	2.93186+001	3.28006+000	1.06988+003	15
16	2.89158+001	3.23500+000	1.05518+003	16
17	2.84880+001	3.18716+000	1.03958+003	17
18	2.80356+001	3.13657+000	1.02309+003	18
19	2.75590+001	3.08328+000	1.00571+003	19
20	2.70586+001	3.02733+000	9.87479+004	20
21	2.65347+001	2.96877+000	9.68403+004	21
22	2.59877+001	2.90766+000	9.48505+004	22
23	2.54182+001	2.84405+000	9.27812+004	23
24	2.48264+001	2.77799+000	9.06354+004	24
25	2.42128+001	2.70954+000	8.84170+004	25
26	2.35778+001	2.63877+000	8.61310+004	26
27	2.29218+001	2.56573+000	8.37846+004	27
28	2.22450+001	2.49050+000	8.13877+004	28
29	2.15476+001	2.41315+000	7.89553+004	29
30	2.08300+001	2.33375+000	7.65099+004	30
31	2.00920+001	2.25238+000	7.40861+004	31
32	1.93336+001	2.16912+000	7.17380+004	32
33	1.85543+001	2.08408+000	6.95504+004	33
34	1.77533+001	1.99735+000	6.76571+004	34
35	1.69294+001	1.90904+000	6.62708+004	35
36	1.60809+001	1.81928+000	6.57292+004	36
37	1.52049+001	1.72821+000	6.65704+004	37
38	1.42977+001	1.63601+000	6.96525+004	38
39	1.33538+001	1.54287+000	7.63450+004	39
40	1.23657+001	1.44903+000	8.88345+004	40
41	1.13230+001	1.35479+000	1.10614+003	41
42	1.02113+001	1.26051+000	1.47264+003	42
43	9.01116+002	1.16667+000	2.07705+003	43
44	7.69559+002	1.07386+000	3.06192+003	44
45	6.22779+002	9.82850+001	4.65512+003	45
46	4.47014+002	8.89337+001	7.34938+003	46
47	3.16432+002	7.97634+001	8.90198+003	47
48	2.23996+002	7.13434+001	9.59753+003	48
49	1.58562+002	6.36739+001	9.72610+003	49
50	1.12243+002	5.67300+001	9.49031+003	50

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FLUXES NORMALIZED TO ONE FISSION

MESH	GROUP 1	GROUP 2	GROUP 3	MESH
51	7.04542-003	5.04716-001	9.03058-003	51
52	5.62440-003	4.48505-001	8.44330-003	52
53	3.98139-003	3.98150-001	7.79376-003	53
54	2.81834-003	3.53131-001	7.12539-003	54
55	1.99505-003	3.12939-001	6.46629-003	55
56	1.41225-003	2.77093-001	5.83396-003	56
57	9.99701-004	2.45143-001	5.23856-003	57
58	7.07666-004	2.16674-001	4.68525-003	58
59	5.00939-004	1.91304-001	4.17588-003	59
60	3.54600-004	1.68688-001	3.71009-003	60
61	2.51009-004	1.48511-001	3.28612-003	61
62	1.77676-004	1.30490-001	2.90140-003	62
63	1.25762-004	1.14370-001	2.55288-003	63
64	8.90085-005	9.99190-002	2.23728-003	64
65	6.29851-005	8.69295-002	1.95131-003	65
66	4.45544-005	7.52134-002	1.69170-003	66
67	3.14948-005	6.46003-002	1.45532-003	67
68	2.22319-005	5.49356-002	1.23917-003	68
69	1.56490-005	4.60779-002	1.04041-003	69
70	1.09526-005	3.78975-002	8.56381-004	70
71	7.57653-006	3.02745-002	6.84537-004	71
72	5.11382-006	2.30969-002	5.22481-004	72
73	3.26757-006	1.62592-002	3.67922-004	73
74	1.81522-006	9.66673-003	2.18654-004	74
75	5.81699-007	3.20452-003	7.25361-005	75

MULTIPLY THE ABOVE FLUXES BY 5.33201-002 TO GET THE FLUXES USED IN THE CALCULATION

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FLUX VOLUME INTEGRALS

REG NO.	GROUP 1	GROUP 2	GROUP 3	TOTAL	REG NO.
1	1.28731+001	1.45387+002	6.15652-002	1.58321+002	1
2	2.29725-001	1.15036+001	1.93141-001	1.19264+001	2
	1.31028+001	1.56890+002	2.54706-001	1.70248+002	

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POWER DISTRIBUTION

REGION	POWER
1	9.96495-001
2	3.50501-003

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BOUNDARY FLUX AND LEAKAGE GROUP 1					
REGION	LEFT FLUX	RIGHT FLUX	LEFT LEAKAGE	RIGHT LEAKAGE	REGION
1	3.21874-001	5.39249-002	0.00000+000	2.17543-002	1
2	5.39249-002	0.00000+000	-2.17543-002	1.37198-006	2

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BOUNDARY FLUX AND LEAKAGE GROUP 2					
REGION	LEFT FLUX	RIGHT FLUX	LEFT LEAKAGE	RIGHT LEAKAGE	REGION
1	3.60099+000	9.38738-001	0.00000+000	8.24308-002	1
2	9.38738-001	0.00000+000	-8.24308-002	5.34708-003	2

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BOUNDARY FLUX AND LEAKAGE GROUP 3					
REGION	LEFT FLUX	RIGHT FLUX	LEFT LEAKAGE	RIGHT LEAKAGE	REGION
1	1.17456-003	5.93804-003	0.00000+000	-8.38888-004	1
2	5.93804-003	0.00000+000	8.38888-004	4.31148-005	2

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LEAKAGE BALANCE QUANTITIES					
REG NO.	GROUP 1	GROUP 2	GROUP 3	TOTAL	REG NO.
1	2.17543-002	8.24308-002	-8.38888-004	1.03346-001	1
2	-2.17529-002	-7.70837-002	8.82003-004	-9.79546-002	2
	1.37198-006	5.34708-003	4.31148-005	5.39157-003	

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REMOVAL BALANCE QUANTITIES

REG NO.	GROUP 1	GROUP 2	GROUP 3	TOTAL	REG NO.
1	1.42040+000	1.78422+000	3.65152+003	3.20827+000	1
2	2.09647+002	6.63387+002	4.50031+003	9.18037+002	2
	1.44136+000	1.85056+000	8.15183+003	3.30007+000	

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BUCKLING BALANCE QUANTITIES

REG NO.	GROUP 1	GROUP 2	GROUP 3	TOTAL	REG NO.
1	3.96762+002	3.21518+001	4.76417+005	3.61242+001	1
2	7.88220+004	2.79238+002	1.67008+004	2.88791+002	2
	4.04644+002	3.49442+001	2.14649+004	3.90121+001	

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FISSION SOURCE BALANCE QUANTITIES

REG NO.	GROUP 1	GROUP 2	GROUP 3	TOTAL	REG NO.
1	1.48181+000	1.09077+000	0.00000+000	2.57258+000	1
2	0.00000+000	0.00000+000	0.00000+000	0.00000+000	2
	1.48181+000	1.09077+000	0.00000+000	2.57258+000	

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SCATTERING SOURCE BALANCE QUANTITIES

REG NO.	GROUP 1	GROUP 2	GROUP 3	TOTAL	REG NO.
1	0.00000+000	1.09738+000	2.86028-003	1.10024+000	1
2	0.00000+000	1.71788-002	5.54932-003	2.27282-002	2
	0.00000+000	1.11455+000	8.40959-003	1.12296+000	

NO VOLUME SOURCE

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BALANCE QUANTITY TOTALS BY REGION OVER GROUP

REGION	LEAKAGE(R)	REMOVAL(R)	BUCKLING(R)	FISSION SOURCE(R)	SCATTERING SOURCE(R)	EXTERNAL SOURCE(R)	BALANCE TOTAL(R)	REGION
1	1.03346-001	3.20827+000	3.61242-001	2.57258+000	1.10024+000	0.00000+000	-4.01232-005	1
2	-9.79546-002	9.18037-002	2.88791-002	0.00000+000	2.27282-002	0.00000+000	-1.95541-010	2
	5.39157-003	3.30007+000	3.90121-001	2.57258+000	1.12296+000	0.00000+000	-4.01234-005	

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BALANCE QUANTITY TOTALS BY GROUP OVER REGION

GROUP	LEAKAGE(G)	REMOVAL(G)	BUCKLING(G)	FISSION SOURCE(G)	SCATTERING SOURCE(G)	EXTERNAL SOURCE(G)	BALANCE TOTAL(G)	GROUP
1	1.37198-006	1.44136+000	4.04644-002	1.48181+000	0.00000+000	0.00000+000	-2.31104-005	1
2	5.34708-003	1.85056+000	3.49442-001	1.09077+000	1.11455+000	0.00000+000	-1.70130-005	2
3	4.31148-005	8.15183-003	2.14649-004	0.00000+000	8.40959-003	0.00000+000	0.00000+000	3
	5.39157-003	3.30007+000	3.90121-001	2.57258+000	1.12296+000	0.00000+000	-4.01234-005	

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