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2D PERT
A TWO-DIMENSIONAL PERTURBATION CODE

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ABSTRACT

Given multigroup fluxes and adjoint fluxes of any cylindrical R-Z configuration, 2D PERT may compute:

1. the prompt-neutron lifetime;
2. the relative worth of various delayed neutrons;
3. the integrals of capture, fission, etc., of given materials over any given region;
4. local perturbations, i.e., danger coefficients;
5. integrated perturbations, i.e., reactivity effect of uniform variation in the cross sections affecting a whole region.

2D PERT is programmed for a 32K IBM-704 using 3 tape units. The code is written in FORTRAN with the exception of two SAP subroutines.

Input fluxes and adjoint fluxes are on tapes which may be obtained either directly from CUREM output or manufactured by a special tape-writing routine.

Homogeneous cross sections and variations of these cross sections are either read in as input information or are computed by the code from a microscopic-cross-section library and atomic densities given as input. A combination of these methods may be used.

I. OUTLINE OF THE PROGRAM

The code is written as a series of the following subroutines monitored by the MAINCODE:

NORMAL computes the normalization factor H and relative worths of various delayed neutrons $W_{k\,k'}$, where

$$H = \int_{\text{reactor}} \left(\sum_{g'} \chi_{g'} \phi^*_{g'} \sum_{g} F_g \phi_g \right) dV$$

and

$$W_{k\,k'} = \frac{1}{H} \int_{\text{reactor}} \left(\sum_{g'} \chi^{k'}_{g'} \phi^*_{g'} \sum_{g'} F^k_g \phi_g \right) dV \quad .$$

Here, g and g' indicate the real and adjoint groups, ϕ and ϕ^* the real and adjoint fluxes, χ the fission spectrum, F is ν times the fission cross section, F^k is ν times the fission cross section of isotope k, and $\chi^{k'}$ is the spectrum of delayed-neutron group k'.

From these quantities, it is possible to obtain the effective delayed-neutron fraction β_{eff} since

$$\beta_{\text{eff}} = \sum_{k,k'} \beta_k \, a_{k'} \, W_{k\,k'} \quad ,$$

where β_k is the delayed-neutron fraction in isotope k and $a_{k'}$ is the relative abundance of delayed neutrons in delayed-neutron group k':

$$\sum_{k'} a_{k'} = 1 \quad .$$

NELIFE computes the prompt-neutron lifetime ℓ^* over regions 1 to N:

$$\ell^* = \frac{1}{H} \int_{\text{reactor}} \sum_{g} \phi^*_g \frac{\phi_g}{v_g} \, dV \quad ,$$

where v_g is the average speed of neutron in group g.

BREED integrates reaction integrals. This is useful when calculating the breeding ratio:

$$B = \int_{\substack{\text{over one} \\ \text{region}}} \sum_{g} RX_g \, \phi_g \, dV \quad .$$

The homogeneous reaction cross sections RX_g are either given as input or computed from the library and atomic densities. They must be loaded in the location normally used for F. If the microscopic library is used, it must be provided with dummy elements having the desired reaction cross sections at the location of the fission cross sections.

LOCPER computes the danger coefficients of given materials at specified points of the reactor and gives the contribution of diffusion, absorption, degradation, and fission effects at each point.

$$\frac{\Delta k}{k} = \frac{1}{H}\left[- \sum_g \delta D_g \overrightarrow{\text{grad}}\, \phi_g^* \overrightarrow{\text{grad}}\, \phi_g - \sum_g \delta A'_g \phi_g^* \phi_g \right.$$

$$\left. + \sum_g \sum_{g'=1}^{g-1} (\phi_g^* - \phi_{g'}^*)\, \delta S^{g' \to g} \phi_{g'} + \sum_{g'} \chi_{g'} \phi_{g'}^* \sum_g \delta F_g \phi_g \right]$$

where δD is the variation of the diffusion coefficient:

$$\delta D = \frac{-\delta \Sigma_{tr}}{3(\Sigma_{tr})^2} = - D^2 \delta (3\Sigma_{tr}) \quad .$$

Here D is the diffusion coefficient of the unperturbed region and $\delta(3\Sigma_{tr})$ is 3 times the transport-cross-section variation caused by the material of which the danger coefficient is computed. Also $\delta A'$ is the variation of the cross section for capture plus fission.

A' does not include removal by scattering cross sections in order to separate the 2 terms representing the pure absorption effect and the degradation effect.

However, the absorption cross section A given as input includes capture, fission, and removal by scattering, from which the code computes A':

$$A'_g = A_g - \sum_{g'} S^{g \to g'} \quad ,$$

where δS is the variation of the scattering matrix $S^{g \to g'}$, which includes both elastic and inelastic scattering, and which allows only down scattering. Further, δF is the variation of the fission term $\nu\sigma_f$.

INTPER computes the reactivity effect of uniform changes of cross section in a given region of the reactor and gives the contribution of diffusion, absorption, degradation, and fission effects.

$$\frac{\Delta k}{k} = \frac{1}{H} \int_{\text{one region}} dV \left[- \sum_g \delta D_g \overrightarrow{\text{grad}}\, \phi_g^* \overrightarrow{\text{grad}}\, \phi_g - \sum_g \delta A'_g \phi_g^* \phi_g \right.$$

$$\left. + \sum_g \sum_{g'=1}^{g-1} (\phi_g^* - \phi_{g'}^*)\, \delta S^{g' \to g} \phi_{g'} + \sum_{g'} \chi_{g'} \phi_{g'}^* \sum_g \delta F_g \phi_g \right] \quad .$$

LIBRY reads the microscopic library from cards or tape when homogeneous cross sections are not given as input.

COMP 1 computes

$$F = \sum_{\substack{\text{all the} \\ \text{elements}}} \nu\sigma_f A_t$$

as used in NORMAL and BREED, from the microscopic library and atomic densities A_t.

COMP 2 computes

$$D = \frac{1}{\sum_{\substack{\text{all the} \\ \text{elements}}} 3\sigma_{tr} A_t}$$

as used in INTPER and LOCPER.

COMP 3 and COMP 4 compute

$$\delta A = \sum_{\substack{\text{all the} \\ \text{elements}}} \sigma_a A_t \quad ,$$

$$\delta S = \sum_{\substack{\text{all the} \\ \text{elements}}} \sigma_{\text{scattering}} A_t \quad ,$$

$$\delta F = \sum_{\substack{\text{all the} \\ \text{elements}}} \nu\sigma_f A_t \quad ,$$

$$\delta(3\Sigma_{tr}) = \sum_{\substack{\text{all the} \\ \text{elements}}} 3\sigma_{tr} A_t$$

and

$$\delta D = -D^2 \, \delta(3\Sigma_{tr})$$

as used in LOCPER and INTPER, respectively.

SUB 1 reads real and adjoint flux from tape as used by NORMAL, NELIFE, and BREED.

SUB 4 reads real and adjoint flux from tape as used by LOCPER and INTPER.

INTEGR integrates $\phi(r,z)$ over a region by considering ϕ constant over an elementary volume ΔV, where

$$\Delta V = \frac{\pi}{2}(h + h')(k + k')\left[R + \frac{1}{4}(h' - h)\right]$$

(see Appendix B).

II. CODE RESTRICTIONS AND LIMITATIONS

Simultaneous computation of the following are not allowed:

1. β_{eff} and reaction integrals;
2. perturbations and β_{eff};
3. perturbations and reaction integrals;
4. local perturbations and integrated perturbations.

The maximum number of groups, regions, and points allowed are:

1. groups, $G \leq 20$;
2. regions, $N \leq 36$;
3. points on the R axis ≤ 50;
4. points on the Z axis ≤ 60.

When computing the normalization factor or β_{eff},

1. There may be as many as 24 regions containing fissionable materials.
2. If there are fewer than 7 regions, each region may contain as many as 1200 points.
3. If there are 7 or more regions, each region may contain as many as 300 points.
4. As many as 6 different relative worths of delayed neutrons, $W_{k\,k'}$ may be computed.

When computing the neutron lifetime:

1. There may be as many as 36 regions.
2. Each region may contain as many as 1200 points.

When computing the breeding ratio:

1. There may be as many as 6 reactions integrated over a maximum of 24 regions.
2. Each region may contain as many as 1200 points.

When computing danger coefficients:

1. As many as 5 materials may be used.
2. The calculation may be performed in as many as 9 regions, each containing a maximum of 300 points, of which as many as 17 in each region may be selected for the calculation of the danger coefficient.

When computing integrated perturbations:

1. As many as 9 perturbations may be used (either 9 perturbations of the same region, or 9 regions perturbed just once, or a combination of both).
2. Each region may contain as many as 300 points.

III. DESCRIPTION OF THE INPUT

A. General Data

Card Set No.	Input	Remarks
1		FORMAT (5A6, 6I6)
	ID	Problem Identification (30 alpha-numeric characters)
	G	Number of groups: $G \leq 20$
	I	Number of points on the R axis: $I \leq 50$
	J	Number of points on the Z axis: $J \leq 60$
	N	Number of regions: $N \leq 36$
	CROS 1	= 0: The homogeneous cross sections used in computing the normalization factor are given as input.
		= 1: The homogeneous cross sections used in computing the normalization factor are computed and the microscopic library is supplied.
	CROS 2	= 0: The homogeneous cross sections used in all computations other than the normalization factor are given as input.
		= 1: The homogeneous cross sections used in all computations other than the normalization factor are computed and the microscopic library is supplied.
2	$i(1),\Delta r(1),\ldots,i(R-1),\Delta(R-1),i(R)$	$\Delta r(r)$ is the radial spacing of points between mesh lines $i(r)$ and $i(r+1)$. $i(1) = 1$, $i(R) = I$. FORMAT (4(I6,E12.8))

Card Set No.	Input	Remarks
3	$j(1), \Delta z(1), j(2), \ldots, j(Z-1), \Delta z(Z-1), j(Z)$	$\Delta z(z)$ is the axial spacing of points between mesh lines $j(z)$ and $j(z+1)$. $J(1) = 1$, $j(Z) = J$. FORMAT (4(I6,E12.8))
4	$i_\ell(1), i_r(1), j_b(1), j_t(1), \ldots,$ $i_\ell(N), i_r(N), j_b(N), j_t(N)$	The points defining the left, right, bottom, and top boundary of each region. Each region must be rectangular, and the boundaries are independent of the mesh spacing. FORMAT (12I6)
5	H	The normalization factor. If the normalization factor is to be computed, H must be set equal to 1. FORMAT (E18.8)
6		FORMAT (5I6)
	INORM	= 0: Ignore the calculation of the normalization factor. Hence the code uses the value given for H.
		= 1: Compute the normalization factor.
	L	= 0: Ignore the calculation of the neutron lifetime.
		= 1: Compute the neutron lifetime.
	IB	= 0: Ignore the calculation of β_{eff}.
		= 1, 2,...,6: Compute β_{eff} for IB relative worths of delayed neutrons.
	IR	= 0: Ignore calculation of reaction integrals.
		= 1, 2,...,6: Compute the reaction integrals for IR reactions.

Card Set No.	Input	Remarks
	IP	= 0: Ignore calculation of perturbations. = 1: Compute local perturbations = 2 Compute integral perturbations

B. Optional Data

1. Normalization Factor (INORM = 1)

$\chi(1),\ldots,\chi(G)$	Fission neutron spectrum. FORMAT (6E12 6)

If CROS 1 = 0

ℓ_1	First region where normalization factor is to be computed FORMAT (I6)
$F(1),\ldots,F(G)$	Fission cross section ($\nu\sigma_f$) for region ℓ_1 from group 1 through group G FORMAT (6E12.6)
ℓ_2	Second region where normalization factor is to be computed.
$F(1),\ldots,F(G)$	Fission cross sections ($\nu\sigma_f$) for region ℓ_2
...	
0	This sentinel indicates that all the information for the last region has been specified.

If CROS 1 = 1

ℓ_1	First region where the normalization factor is to be computed FORMAT (I6)

$EL(1),A_t(1),EL(2),A_t(2),\ldots,999$	Elements and atomic densities of each element constituting the region ℓ_1. Sentinel 999 indicates all such pairs have been specified. FORMAT (4(I6, E12.8))
ℓ_2	Second region where normalization factor is to be computed.
$EL(1),A_t(1),EL(2),A_t(2),\ldots,999$	Elements and atomic densities of each element constituting the region ℓ_2.
...	...
0	This sentinel indicates the information for the last region has been specified.

2. Neutron Lifetime (L = 1)

$V_1^{-1}, V_2^{-1},\ldots, V_G^{-1}$	The inverse of the average speed of neutrons for group 1 through group G. FORMAT (6E12.6)

3. Delayed-neutron Fractions (IB $\neq$ 0)

If CROS 2 = 0

$\chi^1(1),\chi^1(2),\ldots,\chi^1(G)$	First delayed-neutron-group spectrum. FORMAT (6E12.6)
ℓ_1^1	First region where relative worth of first delayed-neutron group is to be computed. FORMAT (I6)
$F(1),F(2),\ldots,F(G)$	Fission cross sections ($\nu\sigma_f$) for group 1 through group G for the isotope emitting the first delayed-neutron group in region ℓ_1^1. FORMAT (6E12.6)
ℓ_2^1	Second region where relative worth of first delayed-neutron group is to be computed.

F(1),F(2),...,F(G)	Fission cross sections ($\nu\sigma_f$) for the isotope emitting the first delayed-neutron group in region ℓ_2^1.
...	...
0	This sentinel indicates the preceding region is the last region where the first delayed-neutron group is to be computed.
...	...
$\chi^{IB}(1),\chi^{IB}(2),...,\chi^{IB}(G)$	Last delayed-neutron group spectrum.
ℓ_1^{IB}	First region where relative worth of last delayed-neutron group is to be computed.
F(1),F(2),...,F(G)	Fission cross sections ($\nu\sigma_f$) for isotope emitting the last delayed-neutron group in region ℓ_1^{IB}.
...	...
0	Sentinel

If CROS 2 = 1

$\chi^1(1),\chi^1(2),...,\chi^1(G)$	First delayed-neutron-group spectrum. FORMAT(6E12.6)
ℓ_1^1	First region where relative worth of first delayed-neutron group is to be computed. FORMAT (I6)
EL,A_t,999	The isotope and its atomic density in region ℓ_1^1, emitting the first delayed-neutron group, followed by the sentinel 999. FORMAT (4(I6, E12.8))
ℓ_2^1	Second region where relative worth of first delayed-neutron group is to be computed.

EL,A_t,999	The isotope and its atomic density in region ℓ_2^1, emitting the first delayed-neutron group.
...	...
0	This sentinel indicates the preceding region is the last region where the first delayed-neutron group is to be computed.
...	...
$\chi^{IB}(1),\chi^{IB}(2),\ldots,\chi^{IB}(G)$	Delayed-neutron spectrum for group IB.
ℓ_1^{IB}	First region where relative worth of last delayed-neutron group is to be computed.
EL,A_t,999	The isotope and its atomic density in region ℓ_1^{IB}, emitting last delayed-neutron group.
...	...
0	Sentinel

4. Reaction Integrals (IR $\neq$ 0)

If CROS 2 = 0

$\chi^1(1),\chi^1(2),\ldots,\chi^1(G)$	Dummy spectrum (is not used in the calculation). FORMAT (6E12.6)
ℓ_1^1	First region where first reaction integral is to be computed. FORMAT (I6)
RX(1),RX(2),...,RX(G)	First reaction cross sections for group 1 through G for region ℓ_1^1. FORMAT (6E12.6)
ℓ_2^1	Second region where first reaction integral is to be computed.
RX(1),RX(2),...,RX(G)	First reaction cross sections for region ℓ_2^1.
...	..

0	This sentinel indicates the preceding region is the last region where the first reaction integral is computed.
$\chi^2(1),\chi^2(2),\ldots,\chi^2(G)$	Dummy spectrum.
ℓ_1^2	First region where second reaction integral is to be computed.
$RX(1),RX(2),\ldots,RX(G)$	Second reaction cross sections for region ℓ_1^2.
...	...
0	Sentinel
...	...
$\chi^{IR}(1),\chi^{IR}(2),\ldots,\chi^{IR}(G)$	Dummy spectrum.
ℓ_1^{IR}	First region where IR^{th} reaction integral is to be computed.
$RX(1),RX(2),\ldots,RX(G)$	IR^{th} reaction cross sections for region ℓ_1^{IR}.
...	...
0	Sentinel

If CROS 2 = 1

$\chi^1(1),\chi^1(2),\ldots,\chi^1(G)$	Dummy spectrum. FORMAT (6E12.6)
ℓ_1^1	First region where first reaction integral is to be computed. FORMAT (I6)
$EL(1),A_t(1),EL(2),A_t(2),\ldots,999$	Elements and atomic densities of each element involved in the first reaction in region ℓ_1^1. Sentinel 999 indicates all such pairs are specified. FORMAT (4(I6, E12.8))
ℓ_2^1	Second region where first reaction integral is to be computed.

$EL(1),A_t(1),EL(2),A_t(2),\ldots,999$	Elements and atomic densities of each element involved in the first reaction in region ℓ_2^1.
...	...
0	This sentinel indicates the preceding region is the last region where the first reaction integral is computed.
$\chi^2(1),\chi^2(2),\ldots,\chi^2(G)$	Dummy spectrum.
ℓ_1^2	First region where second reaction integral is to be computed.
$EL(1),A_t(1),EL(2),A_t(2),\ldots,999$	Elements and atomic densities of each element involved in the second reaction in region ℓ_1^2.
...	...
0	Sentinel
...	...
$\chi^{IR}(1),\chi^{IR}(2),\ldots,\chi^{IR}(G)$	Last dummy spectrum.
ℓ_1^{IR}	First region where last reaction integral is to be computed.
$EL(1),\ A_t(1),El(2),A_t(2),\ldots,999$	Elements and atomic densities of each element involved in the last reaction in region ℓ_1^{IR}.
...	...
0	Sentinel

5. Local Perturbation (IP = 1)

NP	The number of local perturbations or danger coefficients. FORMAT (I6)
ℓ_1	First region where danger coefficients are to be computed. FORMAT (I6)
$i(1),j(1),i(2),J(2),\ldots,888$	Coordinates of the points in region ℓ_1 where danger coefficients are to be computed. Sentinel 888 indicates the end of the point sequence. FORMAT (12I6)

ℓ_2	Second region where danger coefficients are to be computed.
i(1),j(1),i(2),j(2),...,888	Coordinates of points in region ℓ_2 where danger coefficients are to be computed.
...	...
0	This sentinel indicates the end of the region sequence.
$\chi(1),\chi(2),...,\chi(G)$	The fission-neutron spectrum. FORMAT (6E12.6)

If CROS 2 = 0

DID(1)	Identification of the first danger coefficient. FORMAT (A6)
A(1),A(2),...,A(G)	The variation in the absorption cross sections for group 1 through G for the first danger coefficient. These data include the removal by scattering, but the results for the absorption term include only capture plus fission. FORMAT (6E12.6)
F(1),F(2),...,F(G)	The variation of $\nu\Sigma_f$ for group 1 through G for the first danger coefficient. FORMAT (6E12.6)
$S_{1\to2},S_{1\to3},...,S_{1\to G},S_{2\to3},...,S_{G-1\to G}$	The variation of the scattering matrix for the first danger coefficient. There must always be $\frac{1}{2}$ G(G-1) values given. FORMAT (6E12.6)
...	...
DID (NP)	Identification of the last danger coefficient.
A(1),A(2),...,A(G)	The variation in the absorption cross sections for the last danger coefficient.

$F(1),F(2),\ldots,F(G)$	The variation of $\nu\Sigma_f$ for the last danger coefficient.
$S_{1\to2},S_{1\to3},\ldots,S_{1\to G},S_{2\to3},\ldots,S_{G-1\to G}$	The variation of the scattering matrix for the last danger coefficient.
ℓ_1	First region where danger coefficients are to be computed. FORMAT (I6)
$D^1(1),D^1(2),\ldots,D^1(G)$	Variation of the diffusion coefficient for group 1 through G for the first danger coefficient in region ℓ_1. FORMAT (6E12.6)
...	...
$D^{NP}(1),D^{NP}(2),\ldots,D^{NP}(G)$	Variation of the diffusion coefficient for the last danger coefficient in region ℓ_1.
ℓ_2	Second region where danger coefficients are to be computed.
$D^2(1),D^2(2),\ldots,D^2(G)$	Variation of the diffusion coefficient for the first danger coefficient in region ℓ_2.
...	...
$D^{NP}(1),D^{NP}(2),\ldots,D^{NP}(G)$	Variation of the diffusion coefficient for the last danger coefficient in region ℓ_2.
...	...

If CROS 2 = 1

ℓ_1	First region where danger coefficients are to be computed. FORMAT (I6)
$EL(1),A_t(1),EL(2),A_t(2),\ldots,999$	Elements and atomic densities of each element constituting the region ℓ_1. Sentinel 999 indicates all such pairs have been specified. FORMAT (4(I6, E12.8))

ℓ_2	Second region where danger coefficients are to be computed.
EL(1),A_t(1),EL(2),A_t(2),...,999	Elements and atomic densities of each element constituting the region ℓ_2.
. . .	. . .
DID(1)	Identification of the first danger coefficient. FORMAT (A6)
EL(1),A_t(1),EL(2),A_t(2),...,999	Elements and atomic densities of each element constituting the first danger coefficient. The sentinel indicates all such pairs have been specified. FORMAT (4(I6, E12.8))
. . .	. . .
DID (NP)	Identification of the last danger coefficient.
EL(1),A_t(1),EL(2),A_t(2),...,999	Elements and atomic densities of each element constituting the last danger coefficient followed by the atomic density of each element.

6. Integrated Perturbations (IP = 2)

ℓ_1,NP(1),ℓ_2,NP(2),...,0	Regions where integrated perturbations occur, followed by the number of perturbations in each region. Sentinel 0 indicates that information for the last region with integrated perturbations has been specified. FORMAT (12I6)
χ(1),χ(2),...,χ(G)	The fission-neutron spectrum. FORMAT (6E12.6)

If CROS 2 = 0

ℓ_1, DID_1^1	First region where integrated perturbations occur, followed by the identification of the first perturbation of this region. FORMAT (I6, A6)

$D(1), D(2), \ldots, D(G)$	The variation of the diffusion coefficient for group 1 through G for the first perturbation of region ℓ_1. FORMAT (6E12.6)
$A(1), A(2), \ldots, A(G)$	The variation in the absorption cross sections for group 1 through G for the first perturbation of the region ℓ_1. These data include the removal by scattering, but the results for the absorption term include only capture plus fission. FORMAT (6E12.6)
$F(1), F(2), \ldots, F(G)$	The variation of $\nu\Sigma_f$ for group 1 through G for the first perturbation of region ℓ_1. FORMAT (6E12.6)
$S_{1\to 2}, S_{1\to 3}, \ldots, S_{1\to G}, S_{2\to 3}, \ldots, S_{G-1\to G}$	The variation of the scattering matrix, including both inelastic and elastic scattering, for the first perturbation of the region ℓ_1. There must always be $\frac{1}{2}$ G(G-1) values given. FORMAT (6E12.6)
...	...
ℓ_1, DID_1^{NP}	First region where integrated perturbations occur, followed by the identification of the last perturbation of this region.
$D(1), D(2), \ldots, D(G)$	The variation of the diffusion coefficient for the last perturbation of the region ℓ_1.
$A(1), A(2), \ldots, A(G)$	The variation in the absorption cross sections for the last perturbation of the region ℓ_1.
$F(1), F(2), \ldots, F(G)$	The variation of $\nu\Sigma_f$ for the last perturbation of the region ℓ_1.
$S_{1\to 2}, S_{1\to 3}, \ldots, S_{1\to G}, S_{2\to 3}, \ldots, S_{G-1\to G}$	The variation of the scattering matrix for the last perturbation of the region ℓ_1.

ℓ_2, DID_2^1	Second region where integrated perturbations occur, followed by the identification of the first perturbation of this region.
D(1), D(2), ..., D(G)	The variation of the diffusion coefficient for the first perturbation of the region ℓ_2.
A(1), A(2), ..., A(G)	The variation in the absorption cross sections for the first perturbation of the region ℓ_2.
F(1), F(2), ..., F(G)	The variation of $\nu\Sigma_f$ for the first perturbation of the region ℓ_2.
$S_{1\to 2}, S_{1\to 3}, \ldots, S_{1\to G}, S_{2\to 3}, \ldots, S_{G-1\to G}$	The variation of the scattering matrix for the first perturbation of the region ℓ_2.
...	...

If CROS 2 = 1

ℓ_1	First region where integrated perturbations occur. FORMAT (I6)
$EL(1), A_t(1), EL(2), A_t(2), \ldots, 999$	Elements and the atomic densities of each element constituting the region ℓ_1. Sentinel 999 indicates all such pairs have been specified. FORMAT (4(I6, E12.8))
DID_1^1	Identification of the first perturbation for the region ℓ_1. FORMAT (A6)
$EL(1), A_t(1), EL(2), A_t(2), \ldots, 999$	Elements and the atomic densities of each element constituting the first perturbation for the region ℓ_1. FORMAT (4(I6, E12.8))
...	...
DID_1^{NP}	Identification of last perturbation for region ℓ_1.

$EL(1),A_t(1),EL(2),A_t(2),\ldots,999$	Elements and the atomic densities of each element constituting the last perturbation for the region ℓ_1.
ℓ_2	Second region where integrated perturbations occur.
$EL(1),A_t(1),EL(2),A_t(2),\ldots,999$	Elements and the atomic densities of each element constituting the region ℓ_2.
DID_2^1	Identification of the first perturbation for the region ℓ_2,
$EL(1),A_t(1),EL(2),A_t(2),\ldots,999$	Elements and the atomic densities of each element constituting the first perturbation for the region ℓ_2.
...	..

C. Microscopic Library (CROS 1 + CROS 2 > 0)

n_1	Element number ≤ 40. FORMAT (I6)
$\sigma_{a_1},\sigma_{a_2},\ldots,\sigma_{a_G}$	The microscopic absorption cross sections for element n_1 (including capture, fission, and removal by scattering). FORMAT (6E12.6)
$3\sigma_{tr_1},3\sigma_{tr_2},\ldots,3\sigma_{tr_G}$	Three times the microscopic transport cross sections for element n_1. FORMAT (6E12.6)
$\nu\sigma_{f_1},\nu\sigma_{f_2},\ldots,\nu\sigma_{f_G}$	ν times the microscopic fission cross sections for element n_1. FORMAT (6E12.6)
$\sigma_{1\rightarrow 2},\sigma_{1\rightarrow 3},\ldots,\sigma_{1\rightarrow G},\sigma_{2\rightarrow 3},\ldots,\sigma_{G-1\rightarrow G}$	The microscopic degradation matrix for element n_1, including elastic and inelastic downscattering. There must always be $\frac{1}{2}$ G(G-1) values given. FORMAT (6E12.6)
n_2	Element number.
...	...
0	This sentinel indicates all the elements and their cross sections have been specified.

IV. ARRANGEMENT OF INPUT DECK

1. The general data.
2. When CROS 1 + CROS 2 $>$ 0, the microscopic library is to be used. If
   a. sense switch 1 is down, the microscopic library is on tape 2.
   b. sense switch 1 is up, the microscopic library is on cards and must be inserted after the first card of the general data.
3. The optional data.

Computation of the normalization factor, of the neutron lifetime, and one other calculation: β_{eff}, reaction integrals, local, or integrated perturbations, may be performed in that sequence in the same problem. Optional input data must be loaded in this same sequence following the general data.

When computing the normalization factor H, the value found for H is used in the remaining part of the problem.

V. OPERATING INSTRUCTIONS

A standard 72-72 reader board, a SHARE 2 printer board, and the underflow switch are necessary for running this program.

Sense Switches:

1 Up: The microscopic library is on cards.

1 Down: The microscopic library is on tape 2.

No other sense switches are used.

Tapes:

1 Blank for output

2 Microscopic library (when not on cards)

5 "Real" fluxes

6 "Adjoint" fluxes

Running Procedure:

1 Mount and ready tapes.

2 Depress underflow switch and set sense switches.

3 Clear and load cards.

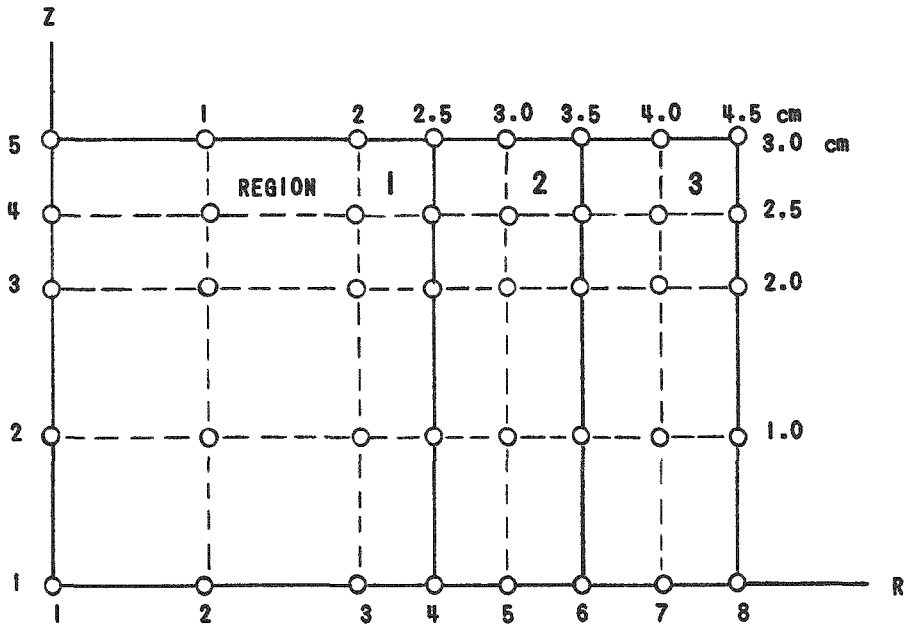
4 At the completion of a series of problems, remove and save tapes 2, 5, and 6.

5 Remove tape 1 and print off-line on program control.

Error Stops:

The reason for each error stop is printed on the on-line printer. An average problem runs 5 to 10 min and problems may be run one after another.

VI SAMPLE PROBLEMS



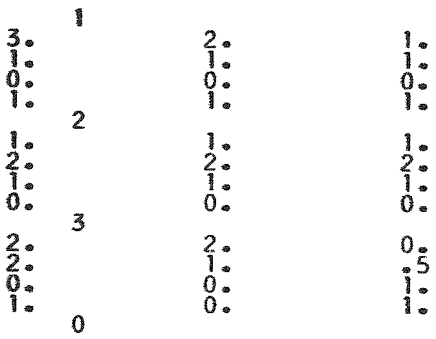
CONFIGURATION FOR THE SAMPLE PROBLEMS

SAMPLE INPUT

```
 FIRST  SAMPLE  PROBLEM                    3     8     5     3     0     1
     1 1.                  3 .5                 8
     1 1.                  3 .5                 5
     1     4     1     5     4     6     1     5     6     8     1     5
1.
     1     0     0     0     1
.25          .5           0.
     1
8.661493-02 0.             0.
     2
0.          4.330746-02    0.
     0
     2
     1
     1     1     4     1     4     5   888
     2
     4     5     6     5   888
     3
     6     5   888
     0
.5           1.           0.
     1
     1 .5                 2 .25          999
     2
     2 .5                 3 1.             1 .5           999
     3
     3 1.           999
1ST DC
     1 1.           999
2ND DC
     3 1.           999

 SECOND  SAMPLE  PROBLEM                    3     8     5     3     0     0
     1 1.                  3 .5                 8
     1 1.                  3 .5                 5
     1     4     1     5     4     6     1     5     6     8     1     5
10.
     0     0     0     0     2
     1     2     2     1     0
0.        1.           0.
    1PERT 1
.25          .25          .25
2.           1.           0.
0.           0.           0.
1.           0.           0.
    1PERT 2
1.           1.           .25
0.           0.           0.
0.           1.           0.
0.           0.           0.
    2PERT 3
.25          .25          .25
2.           1.           0.
0.           0.           0.
1.           0.           0.
```

MICROSCOPIC LIBRARY



FIRST SAMPLE PROBLEM

NORMALIZATION FACTOR 9.999998E 00

CONTRIBUTION OF EACH REGION

1 5.1020E 00 2 4.8980E 00

DANGER COEFFICIENTS

		I	J	DELTAK/K	DIFFUSION	ABSORPTION	DEGRADATION	FISSION
REGION	1							
	1ST DC							
		1	1	-5.900001E 00	4.000001E-01	-8.500002E 00	2.200000E 00	0.
		4	1	-9.000002E-01	4.000001E-01	-2.000000E 00	7.000001E-01	0.
		4	5	-9.000002E-01	4.000001E-01	-2.000000E 00	7.000001E-01	0.
	2ND DC							
		1	1	3.100001E 00	2.000000E-01	-4.000001E-01	1.500000E 00	1.800000E 00
		4	1	1.100000E 00	2.000000E-01	-4.000001E-01	5.000001E-01	8.000002E-01
		4	5	1.100000E 00	2.000000E-01	-4.000001E-01	5.000001E-01	8.000002E-01
REGION	2							
	1ST DC							
		4	5	-1.200000E 00	1.000000E-01	-2.000000E 00	7.000001E-01	0.
		6	5	-6.000001E-01	1.000000E-01	-8.000002E-01	1.000000E-01	0.
	2ND DC							
		4	5	9.500002E-01	5.000001E-02	-4.000001E-01	5.000001E-01	8.000002E-01
		6	5	1.500000E-01	5.000001E-02	-4.000001E-01	1.000000E-01	4.000001E-01
REGION	3							
	1ST DC							
		6	5	9.000002E-01	1.600000E 00	-8.000002E-01	1.000000E-01	0.
	2ND DC							
		6	5	9.000002E-01	8.000002E-01	-4.000001E-01	1.000000E-01	4.000001E-01

SECOND SAMPLE PROBLEM

INTEGRATED PERTURBATIONS

			DELTAK/K	DIFFUSION	ABSORPTION	DEGRADATION	FISSION
REGION	1	PERT 1	-3.534291E 01	-5.890486E 00	-2.356194E 01	-5.890486E 00	0.
REGION	1	PERT 2	5.890486E 00	-5.890486E 00	-0.	0.	1.178097E 01
REGION	2	PERT 3	-3.392920E 01	-5.654866E 00	-2.261947E 01	-5.654866E 00	0.

VII. FORTRAN STATEMENTS AND SAP SUBROUTINES

```
C       TWO DIMENSIONAL PERTURBATION CODE
        DIMENSIONI(20),DR(20),J(20),DZ(20),IINT(36),IEXT(36),
       1DEEPS(20),CHI(20,7),LREG(25,7),Q(25,7),NMAX(7),FIS(20,24,7),
       2JINT(36),JSUP(36),NELE(40),ATOMDN(40),IN(18,10),JN(18,10),
       3KMAX(10),CHIO(20),REC(5),AL(20,5),FL(20,5),SL(190,5),DL(20,10,5),
       4DT(20,10),NUPER(3),RECO(9),DI(20,9),AI(20,9),FI(20,9),
       5SI(190,9),BETA(7),DELWOR(24,7),IREG(10),NUMPER(9)
        EQUIVALENCE(FIS(481),AL),(FIS(581),FL),(FIS(681),SL),
       1(FIS(1631),DL),(FIS(2631),IN),(FIS(2811),JN),(FIS(2991),DT),
       2(FIS(48),DI),(FIS(661),AI),(FIS(841),FI),(FIS(1021),SI)
       3,(FIS(2731),MU),(FIS(2732),NUMPER)
        COMMONFIS,IGRP,IMAX,JMAX,NMAXRE,IBETA,IBREED,NOPER,LOMAX,
       1KRP,INDEX,NOREG,H,SUM1,SUM2,SUM3,SUM4,I,DR,J,DZ,IINT,IEXT,JINT,
       2JSUP,DEEPS,CHI,CHIO,LREG,Q,NMAX,IREG,KMAX,REC,NUPER,RECO,
       3BETA,DELWOR,NELE,ATOMDN
    1  FORMAT(5A6,6I6)
    4  FORMAT(I6,E12.8,I6,E12.8,I6,E12.8,I6,E12.8)
    5  FORMAT(12I6)
   10  FORMAT(E18.8)
   14  FORMAT(6E12.6)
   27  FORMAT(I6,A6)
   80  FORMAT(A6)
  151  FORMAT(1H15A6///)
   48  FORMAT(43H NO SIMULTANEOUS CALCULATION OF BETA AND BR)
   62  FORMAT(45H NO SIMULTANEOUS CALCULATION OF PERT AND BETA)
   65  FORMAT(43H NO SIMULTANEOUS CALCULATION OF PERT AND BR)
   86  FORMAT(40H INCONSISTENCY BETWEEN PERTURBED REGIONS)
  150  READ1,P1,P2,P3,P4,P5,IGRP,IMAX,JMAX,NMAXRE,ICROS1,ICROS2
       IF(ICROS1+ICROS2)13,13,9
    9  CALLLIBRY
   13  WRITEOUTPUTTAPE1,151,P1,P2,P3,P4,P5
       KA=1
    2  KC=KA+3
       READ4,(I(KB),DR(KB),KB=KA,KC)
       DO3KB=KA,KC
       IF(I(KB)-IMAX)3,23,23
    3  CONTINUE
       KA=KA+4
       GOTO2
   23  KA=1
    7  KC=KA+3
       READ4,(J(KB),DZ(KB),KB=KA,KC)
       DO6KB=KA,KC
       IF(J(KB)-JMAX)6,8,8
    6  CONTINUE
       KA=KA+4
       GOTO7
    8  READ5,(IINT(KA),IEXT(KA),JINT(KA),JSUP(KA),KA=1,NMAXRE)
       READ10,H
       READ5,INORM,LIFETI,IBETA,IBREED,IPERT
   12  IF(INORM-1)16,15,16
   15  INDEX=1
       IC=ICROS1
       ASSIGN16TOLA
```

```
 25 READ14,(CHI(KA,INDEX),KA=1,IGRP)
    KD=1
 24 READ27,LREG(KD,INDEX),Q(KD,INDEX)
    IF(LREG(KD,INDEX))21,21,22
 21 NMAX(INDEX)=KD-1
    GOTOLA,(16,44)
 22 IF(IC)32,200,32
200 READ14,(FIS(KA,KD,INDEX),KA=1,IGRP)
    GOTO30
 32 ASSIGN37TOLB
    GOTO156
 37 CALLCOMP1(KD)
 30 KD=KD+1
    GOTO24
 16 IF(LIFETI-1)300,11,300
 11 READ14,(DEEPS(KA),KA=1,IGRP)
300 IF(IBETA*IBREED)46,43,46
 46 WRITEOUTPUTTAPE1,48
    STOP
 43 IF(IBETA)40,40,54
 54 KG=IBETA+1
    GOTO39
 40 IF(IBREED)49,49,55
 55 KG=IBREED+1
 39 IC=ICROS2
    INDEX=1
201 INDEX=INDEX+1
    ASSIGN44TOLA
    GOTO25
 44 IF(INDEX-KG)201,49,49
 49 IF(IPERT*IBETA)60,61,60
 60 WRITEOUTPUTTAPE1,62
    STOP
 61 IF(IPERT*IBREED)63,64,63
 63 WRITEOUTPUTTAPE1,65
    STOP
 64 IF(IPERT-1)87,67,68
 67 READ5,NOPER
    KA=1
 75 READ5,IREG(KA)
    IF(IREG(KA))69,69,70
 69 LOMAX=KA-1
    GOTO71
 70 KB=1
 74 KC=KB+5
    READ5,(IN(KD,KA),JN(KD,KA),KD=KB,KC)
    DO72KD=KB,KC
    IF(IN(KD,KA)-888)72,73,72
 72 CONTINUE
    KB=KB+6
    GOTO74
 73 KMAX(KA)=KD-1
    KA=KA+1
    GOTO75
 71 READ14,(CHIO(KA),KA=1,IGRP)
    IF(ICROS2)76,77,76
```

```
 77 DO79KH=1,NOPER
    READ80,REC(KH)
    READ14,(AL(KA,KH),KA=1,IGRP)
    READ14,(FL(KA,KH),KA=1,IGRP)
    KRP=(IGRP*(IGRP-1))/2
 79 READ14,(SL(KA,KH),KA=1,KRP)
    DO83KI=1,LOMAX
    READ5,IS
    IF(IS-IREG(KI))84,85,84
 84 WRITEOUTPUTTAPE1,86
    STOP
 85 DO83KH=1,NOPER
 83 READ14,(DL(KA,KI,KH),KA=1,IGRP)
    GOTO87
 76 KI=0
202 KI=KI+1
    READ5,IS
    IF(IS-IREG(KI))90,91,90
 90 GOTO84
 91 ASSIGN93TOLB
    GOTO156
 93 CALLCOMP2(KI)
    IF(KI-LOMAX)202,203,203
203 KH=0
204 KH=KH+1
    READ80,REC(KH)
    ASSIGN97TOLB
    GOTO156
 97 CALLCOMP3(KH)
    IF(KH-NOPER)204,205,205
205 GOTO87
 68 KB=1
101 KC=KB+5
    READ5,(IREG(KA),NUMPER(KA),KA=KB,KC)
    DO99KA=KB,KC
    IF(IREG(KA))99,100,99
 99 CONTINUE
    KB=KB+6
    GOTO101
100 LOMAX=KA-1
    READ14,(CHIO(KA),KA=1,IGRP)
    IF(ICROS2)102,103,102
103 KRP=(IGRP*(IGRP-1))/2
    MU=1
    DO105KI=1,LOMAX
    NOPER=NUMPER(KI)
    DO105KH=1,NOPER
    READ27,IS,RECO(MU)
    IF(IS-IREG(KI))106,107,106
106 GOTO84
107 READ14,(DI(KA,MU),KA=1,IGRP)
    READ14,(AI(KA,MU),KA=1,IGRP)
    READ14,(FI(KA,MU),KA=1,IGRP)
    READ14,(SI(KA,MU),KA=1,KRP)
105 MU=MU+1
    GOTO87
```

```
102 MU=1
    KI=0
206 KI=KI+1
    NOPER=NUMPER(KI)
    READ5,IS
    IF(IS-IREG(KI))114,115,114
114 GOTO84
115 ASSIGN117TOLB
    GOTO156
117 CALLCOMP2(KI)
    KH=0
207 KH=KH+1
    READ80,RECO(MU)
    ASSIGN120TOLB
    GOTO156
120 CALLCOMP4(KH)
    MU=MU+1
    IF(KH-NOPER)207,208,208
208 IF(KI-LOMAX)206,87,87
 87 IF(INORM-1)122,125,122
125 INDEX=1
    CALLNORMAL
122 IF(LIFETI-1)124,123,124
123 CALLNELIFE
124 IF(IBETA)128,128,129
129 KG=IBETA+1
    INDEX=1
209 INDEX=INDEX+1
    CALLNORMAL
    IF(INDEX-KG)209,128,128
128 IF(IBREED)132,132,133
133 CALLBREED
132 IF(IPERT-1)134,135,136
135 CALLLOCPER
    GOTO134
136 CALLINTPER
134 GOTO150
156 KA=1
152 KC=KA+3
    READ4,(NELE(KB),ATOMDN(KB),KB=KA,KC)
    DO154KB=KA,KC
    IF(NELE(KB)-999)154,155,154
154 CONTINUE
    KA=KA+4
    GOTO152
155 KRP=KB-1
    GOTOLB,(37,93,97,117,120)
    END(0,1,0,0,0)
```

```
      SUBROUTINENORMAL
      DIMENSIONBETA(7),DELWOR(24,7),NMAX(7),ADJPW(50,60),FLUX(50,60),
     1POWER(300,24),ADJO(50,60),CHI(20,7),LREG(25,7),Q(25,7),A1(300),
     2IEXT(36),IINT(36),JINT(36),JSUP(36),FIS(20,24,7),DEEPS(20),
     3CHIO(20),DUMMY1(80),DUMMY2(37),DUMMY3(900)
      COMMONFIS,IGRP,IMAX,JMAX,NMAXRE,IBETA,IBREED,NOPER,LOMAX,
     1KRP,INDEX,KR,H,SUM1,SUM2,SUM3,SUM4,DUMMY1,IINT,IEXT,JINT,
     2JSUP,DEEPS,CHI,CHIO,LREG,Q,NMAX,DUMMY2,BETA,DELWOR,
     3A1,DUMMY3,FLUX,ADJO,ADJPW,POWER
      BETA(INDEX)=0
      KC=NMAX(INDEX)
      DO3IA=1,IMAX
      DO3JA=1,JMAX
    3 ADJPW(IA,JA)=0
      DO8NU=1,300
      DO8KD=1,24
    8 POWER(NU,KD)=0
      M=0
   10 M=M+1
      IMIX=IMAX+1
      CALLSUB1(IMIX,IGRP,M,FLUX,ADJO,2)
      KB=IGRP+1-M
      DO5IA=1,IMAX
      DO5JA=1,JMAX
    5 ADJPW(IA,JA)=ADJPW(IA,JA)+CHI(KB,INDEX)*ADJO(IA,JA)
      DO6KD=1,KC
      KE=KD*4-23*((KD-1)/6)-3
      KR=LREG(KD,INDEX)
      IB=IINT(KR)
      JB=JINT(KR)
      IC=IEXT(KR)
      JC=JSUP(KR)
      DO6IA=IB,IC
      DO6JA=JB,JC
      NU=(JA-JB)*(IC-IB+1)+(IA-IB+1)
    6 POWER(NU,KE)=POWER(NU,KE)+FIS(M,KD,INDEX)*FLUX(IA,JA)
      IF(M-IGRP)10,11,11
   11 KD=0
   12 KD=KD+1
      KE=KD*4-23*((KD-1)/6)-3
      KR=LREG(KD,INDEX)
      IB=IEXT(KR)-IINT(KR)+1
      JB=JSUP(KR)-JINT(KR)+1
      DO7IP=1,IB
      DO7JP=1,JB
      IC=IINT(KR)+IP-1
      JC=JINT(KR)+JP-1
      NU=(JP-1)*IB+IP
    7 A1(NU)=POWER(NU,KE)*ADJPW(IC,JC)
      CALLINTEGR
      DELWOR(KD,INDEX)=SUM1/H
    4 BETA(INDEX)=BETA(INDEX)+DELWOR(KD,INDEX)
      IF(KD-KC)12,13,13
   13 IF(INDEX-1)100,100,16
  100 H=BETA(1)
```

```
      WRITEOUTPUTTAPE1,17,BETA(1)
   17 FORMAT(21H NORMALIZATION FACTOR25X,1PE16.6///)
      GOTO18
   16 IT=INDEX-1
      WRITEOUTPUTTAPE1,19,IT,BETA(INDEX)
   19 FORMAT(31H WORTH OF DELAYED NEUTRON GROUPI4,11X,1PE16.6///)
   18 KC=NMAX(INDEX)
      WRITEOUTPUTTAPE1,20,(LREG(KD,INDEX),DELWOR(KD,INDEX),KD=1,KC)
   20 FORMAT(28H CONTRIBUTION OF EACH REGION//(I6,1PE12.4,I6,1PE12.4,I6,
     11PE12.4,I6,1PE12.4,I6,1PE12.4,I6,1PE12.4/))
      WRITEOUTPUTTAPE1,15
   15 FORMAT(////////////)
      RETURN
      END(0,1,0,0,0)
```

```
      SUBROUTINENELIFE
      DIMENSIONFLUX(50,60),ADJO(50,60),DX(50,60),DEEPS(20),
     1IEXT(36),IINT(36),JSUP(36),JINT(36),ANO(300),XLIFET(36),
     2I(20),DR(20),J(20),DZ(20),FIS(20,24,7),DU1(729),DU2(900)
      COMMONFIS,IGRP,IMAX,JMAX,NMAXRE,IBETA,IBREED,
     1NOPER,LOMAX,KRP,INDEX,NOREG,H,SUM1,SUM2,SUM3,
     2SUM4,I,DR,J,DZ,IINT,IEXT,JINT,JSUP,DEEPS,
     3DU1,ANO,DU2,FLUX,ADJO,DX
      DO3IA=1,IMAX
      DO3JA=1,JMAX
    3 DX(IA,JA)=0
      M=0
   10 M=M+1
      IMIX=IMAX+1
      CALLSUB1(IMIX,IGRP,M,FLUX,ADJO,1)
      DO4IA=1,IMAX
      DO4JA=1,JMAX
    4 DX(IA,JA)=DX(IA,JA)+DEEPS(M)*FLUX(IA,JA)*ADJO(IA,JA)/H
      IF(M-IGRP)10,11,11
   11 XLI=0
      NOREG=0
   12 NOREG=NOREG+1
      IB=IEXT(NOREG)-IINT(NOREG)+1
      JB=JSUP(NOREG)-JINT(NOREG)+1
      DO6IA=1,IB
      DO6JA=1,JB
      IC=IINT(NOREG)+IA-1
      JC=JINT(NOREG)+JA-1
      NU=(JA-1)*IB+IA
    6 ANO(NU)=DX(IC,JC)
      CALLINTEGR
      XLIFET(NOREG)=SUM1
    5 XLI=XLI+XLIFET(NOREG)
      IF(NOREG-NMAXRE)12,13,13
   13 WRITEOUTPUTTAPE1,7,XLI
    7 FORMAT(17H NEUTRON LIFETIME29X,1PE16.6///)
      WRITEOUTPUTTAPE1,8,(NOREG,XLIFET(NOREG),NOREG=1,NMAXRE)
    8 FORMAT(28H CONTRIBUTION OF EACH REGION//(I6,1PE12.4,I6,1PE12.4,
     1I6,1PE12.4,I6,1PE12.4,I6,1PE12.4,I6,1PE12.4/))
      WRITEOUTPUTTAPE1,15
   15 FORMAT(////////////)
      RETURN
      END(0,1,0,0,0)
```

```
      SUBROUTINEBREED
      DIMENSIONFLUX(50,60),TOTEVE(24,7),NMAX(7),LREG(25,7),
     1Q(25,7),IINT(36),IEXT(36),JINT(36),JSUP(36),EVENT(300),
     2SEC(20,24,7),EVINT(20,24,7),I(20),DR(20),J(20),DZ(20),
     3DEEPS(20),CHI(20,7),CHIO(20),DU1(37),BETA(7),DU2(900),ADJO(50,60)
      COMMONSEC,IGRP,IMAX,JMAX,NMAXRE,IBETA,IBREED,
     1NOPER,LOMAX,KRP,INDEX,KR,H,SUM1,SUM2,SUM3,SUM4,
     2I,DR,J,DZ,IINT,IEXT,JINT,JSUP,DEEPS,CHI,CHIO,
     3LREG,Q,NMAX,DU1,BETA,TOTEVE,EVENT,DU2,FLUX,ADJO,EVINT
      DO8INDEX=1,7
      DO8KD=1,24
    8 TOTEVE(KD,INDEX)=0
      M=0
   11 M=M+1
      CALLSUB1(IMAX+1,IGRP,M,FLUX,ADJO,3)
      KG=IBREED+1
      INDEX=1
   12 INDEX=INDEX+1
      KC=NMAX(INDEX)
      KD=0
   13 KD=KD+1
      KR=LREG(KD,INDEX)
      IB=IINT(KR)
      JB=JINT(KR)
      IC=IEXT(KR)
      JC=JSUP(KR)
      DO5IA=IB,IC
      DO5JA=JB,JC
      IP=IA-IB+1
      JP=JA-JB+1
      NU=(JP-1)*(IC-IB+1)+IP
    5 EVENT(NU)=SEC(M,KD,INDEX)*FLUX(IA,JA)
      CALLINTEGR
      EVINT(M,KD,INDEX)=SUM1
    6 TOTEVE(KD,INDEX)=TOTEVE(KD,INDEX)+EVINT(M,KD,INDEX)
      IF(KD-KC)13,14,14
   14 IF(INDEX-KG)12,15,15
   15 IF(M-IGRP)11,16,16
   16 WRITEOUTPUTTAPE1,10,((LREG(KD,INDEX),Q(KD,INDEX),TOTEVE
     1(KD,INDEX),KD=1,KC),INDEX=2,KG)
   10 FORMAT(14H REGION NUMBERI4,2H, 1A6,8X,1PE12.6//)
      RETURN
      END(0,1,0,0,0)
```

```
      SUBROUTINELOCPER
      DIMENSIONIREG(10),FLUX1(300,20),ADJO1(300,20),PROGRA(300,20),
     1KMAX(10),IEXT(36),IINT(36),JSUP(36),JINT(36),IN(18,10),
     2JN(18,10),DFLUXR(300),DFLUXZ(300),DADJOR(300),DADJOZ(300),
     3I(20),DR(20),J(20),DZ(20),REC(5),CHIO(20),DL(20,10,5),
     4AL(20,5),FL(20,5),SL(190,5),DU1(480),DU2(370),DU3(160),
     5DU4(357),DU5(187)
      COMMONDU1,AL,FL,SL,DL,IN,JN,DU2,IGRP,IMAX,
     1JMAX,NMAXRE,IBETA,IBREED,NOPER,LOMAX,KRP,INDEX,
     2NOREG,H,SUM1,SUM2,SUM3,SUM4,I,DR,J,DZ,IINT,
     3IEXT,JINT,JSUP,DU3,CHIO,DU4,IREG,KMAX,REC,DU5,
     4DFLUXR,DFLUXZ,DADJOR,DADJOZ,FLUX1,ADJO1,PROGRA
      WRITEOUTPUTTAPE1,56
   56 FORMAT(20H DANGER COEFFICIENTS//20X,4HI  J6X,8HDELTAK/K
     18X,9HDIFFUSION7X,10HABSORPTION6X,11HDEGRADATION
     25X,7HFISSION//)
      KI=0
  100 KI=KI+1
      WRITEOUTPUTTAPE1,57,IREG(KI)
   57 FORMAT(7H REGIONI4)
      KA=IREG(KI)
      CALLSUB4(IMAX+1,IGRP,FLUX1,ADJO1,IINT(KA),
     1IEXT(KA),JINT(KA),JSUP(KA))
      KX=KMAX(KI)
      L=IEXT(KA)-IINT(KA)+1
      DO45M=1,IGRP
      DO45KB=1,KX
      IB=IN(KB,KI)-IINT(KA)+1
      JB=JN(KB,KI)-JINT(KA)+1
      NW=(JB+1)*L+IB
      NV=JB*L+IB
      NU=(JB-1)*L+IB
      NT=(JB-2)*L+IB
      NS=(JB-3)*L+IB
      IF(IN(KB,KI)-IINT(KA))1,2,3
    1 WRITEOUTPUTTAPE1,60
   60 FORMAT(28H POINT OUTSIDE OF THE REGION)
      STOP
    2 II=IINT(KA)
      ASSIGN12TONA
      GOTO15
   12 DFLUXR(NU)=(FLUX1(NU+1,M)*(DR0+DR1)**2-FLUX1(NU,M)*(DR1+DR0*2.)
     1*DR1-FLUX1(NU+2,M)*(DR0**2))/D
      DADJOR(NU)=(ADJO1(NU+1,M)*(DR0+DR1)**2-ADJO1(NU,M)*(DR1+DR0*2.)
     1*DR1-ADJO1(NU+2,M)*(DR0**2))/D
      GOTO19
    3 IF(IN(KB,KI)-IEXT(KA))21,16,17
   17 GOTO1
   16 II=IEXT(KA)-2
      ASSIGN13TONA
      GOTO15
   13 DFLUXR(NU)=(FLUX1(NU,M)*(DR0+DR1*2.)*DR0+FLUX1(NU-2,M)*(DR1**2)
     1-FLUX1(NU-1,M)*(DR0+DR1)**2)/D
      DADJOR(NU)=(ADJO1(NU,M)*(DR0+DR1*2.)*DR0+ADJO1(NU-2,M)*(DR1**2)
     1-ADJO1(NU-1,M)*(DR0+DR1)**2)/D
```

```
      GOTO19
   21 II=IN(KB,KI)-1
      ASSIGN14TONA
      GOTO15
   14 DADJOR(NU)=(ADJO1(NU+1,M)*(DR0**2)-ADJO1(NU-1,M)*(DR1**2)
     1+ADJO1(NU,M)*((DR1**2)-(DR0**2)))/D
      DFLUXR(NU)=(FLUX1(NU+1,M)*(DR0**2)-FLUX1(NU-1,M)*(DR1**2)
     1+FLUX1(NU,M)*((DR1**2)-(DR0**2)))/D
      GOTO19
   15 NR=1
    4 IF(II-I(NR))7,6,5
    5 NR=NR+1
      GOTO4
    7 NR=NR-1
    6 DR0=DR(NR)
      II=II+1
   11 IF(II-I(NR))9,8,10
   10 NR=NR+1
      GOTO11
    9 NR=NR-1
    8 DR1=DR(NR)
      D=(DR0+DR1)*DR0*DR1
      GOTONA,(12,13,14)
   19 IF(JN(KB,KI)-JINT(KA))24,25,20
   24 GOTO1
   25 JJ=JINT(KA)
      ASSIGN35TONA
      GOTO26
   35 DFLUXZ(NU)=(FLUX1(NV,M)*(DZ0+DZ1)**2-FLUX1(NU,M)*(DZ1+
     1DZ0*2.)*DZ1-FLUX1(NW,M)*(DZ0**2))/D
      DADJOZ(NU)=(ADJO1(NV,M)*(DZ0+DZ1)**2-ADJO1(NU,M)*(DZ1+
     1DZ0*2.)*DZ1-ADJO1(NW,M)*(DZ0**2))/D
      GOTO45
   20 IF(JN(KB,KI)-JSUP(KA))40,41,42
   42 GOTO1
   41 JJ=JSUP(KA)-2
      ASSIGN36TONA
      GOTO26
   36 DFLUXZ(NU)=(FLUX1(NU,M)*(DZ0+DZ1*2.)*DZ0+FLUX1(NS,M)
     1*(DZ1**2)-FLUX1(NT,M)*(DZ0+DZ1)**2)/D
      DADJOZ(NU)=(ADJO1(NU,M)*(DZ0+DZ1*2.)*DZ0+ADJO1(NS,M)
     1*(DZ1**2)-ADJO1(NT,M)*(DZ0+DZ1)**2)/D
      GOTO45
   40 JJ=JN(KB,KI)-1
      ASSIGN37TONA
      GOTO26
   37 DFLUXZ(NU)=(FLUX1(NV,M)*(DZ0**2)-FLUX1(NT,M)*(DZ1**2)
     1+FLUX1(NU,M)*((DZ1**2)-(DZ0**2)))/D
      DADJOZ(NU)=(ADJO1(NV,M)*(DZ0**2)-ADJO1(NT,M)*(DZ1**2)
     1+ADJO1(NU,M)*((DZ1**2)-(DZ0**2)))/D
      GOTO45
   26 NZ=1
   30 IF(JJ-J(NZ))29,28,27
   27 NZ=NZ+1
      GOTO30
   29 NZ=NZ-1
```

```
 28 DZ0=DZ(NZ)
    JJ=JJ+1
 31 IF(JJ-J(NZ))32,33,34
 34 NZ=NZ+1
    GOTO31
 32 NZ=NZ-1
 33 DZ1=DZ(NZ)
    D=(DZ0+DZ1)*DZ0*DZ1
    GOTONA,(35,36,37)
 45 PROGRA(NU,M)=DFLUXR(NU)*DADJOR(NU)+DFLUXZ(NU)*DADJOZ(NU)
    DO52KH=1,NOPER
    WRITEOUTPUTTAPE1,58,REC(KH)
 58 FORMAT(12H                1A6)
    DO52KB=1,KX
    IB=IN(KB,KI)-IINT(KA)+1
    JB=JN(KB,KI)-JINT(KA)+1
    NU=(JB-1)*L+IB
    UL=0
    VL=0
    YL=0
    ZL=0
    DO53M=1,IGRP
    UL=UL-DL(M,KI,KH)*PROGRA(NU,M)
    VL=VL-AL(M,KH)*FLUX1(NU,M)*ADJO1(NU,M)
    YL=YL+FL(M,KH)*FLUX1(NU,M)
 53 ZL=ZL+CHIO(M)*ADJO1(NU,M)
    XL=YL*ZL/H
    MA=1
    MB=IGRP-1
    YC=0
    YD=0
    DO54MC=1,MB
    MD=MC+1
    YA=0
    YB=0
    DO55MH=MD,IGRP
    YA=YA+SL(MA,KH)*ADJO1(NU,MH)
    YB=YB+SL(MA,KH)
 55 MA=MA+1
    YC=YC+YA*FLUX1(NU,MC)
 54 YD=YD+YB*FLUX1(NU,MC)*ADJO1(NU,MC)
    WL=(YC-YD)/H
    UL=UL/H
    VL=(VL+YD)/H
    X5=UL+VL+WL+XL
 52 WRITEOUTPUTTAPE1,59,IN(KB,KI),JN(KB,KI),X5,UL,VL,WL,XL
    IF(KI-LOMAX)100,101,101
 59 FORMAT(18X,2I3,2X,1P5E16.6)
101 RETURN
    END(0,1,0,0,0)
```

```
      SUBROUTINEINTPER
      DIMENSIONIREG(10),PROGRA(300,20),FLUX1(300,20),ADJO1(300,20),
     1DFLUXR(300),DFLUXZ(300),DADJOR(300),DADJOZ(300),IEXT(36),
     2IINT(36),JSUP(36),JINT(36),I(20),DR(20),J(20),DZ(20),NUPER(3),
     3UI(300),XI(300),VI(300),WI(300),CHIO(20),DI(20,9),AI(20,9),
     4FI(20,9),SI(190,9),DUMMY1(480),DUMMY2(630),RECO(9),NUMPER(9),
     5DY2(160),DY3(357),DY4(15),DY5(175)
      EQUIVALENCE(DFLUXZ,DUMMY1),(DI,DI),(AI,AI),(FI,FI),
     1(SI,SI),(DUMMY2,MU),(DUMMY2(2),NUMPER),(DUMMY2(11),DADJOR),
     2(DUMMY2(311),DADJOZ)
      COMMONDUMMY1,DI,AI,FI,SI,DUMMY2,IGRP,IMAX,JMAX,
     1NMAXRE,IBETA,IBREED,NOPER,LOMAX,KRP,INDEX,NOREG,H,
     2X1,X2,X3,X4,I,DR,J,DZ,IINT,IEXT,JINT,JSUP,DY2,
     3CHIO,DY3,IREG,DY4,NUPER,RECO,DY5,UI,VI,WI,XI,
     4FLUX1,ADJO1,PROGRA,DFLUXR
      WRITEOUTPUTTAPE1,241
241   FORMAT(25H INTEGRATED PERTURBATIONS//30X,8HDELTAK/K
     18X,9HDIFFUSION7X,10HABSORPTION6X,11HDEGRADATION
     25X,7HFISSION//)
      MU=1
      KI=0
301   KI=KI+1
      NOREG=IREG(KI)
      CALLSUB4(IMAX+1,IGRP,FLUX1,ADJO1,IINT(NOREG),
     1IEXT(NOREG),JINT(NOREG),JSUP(NOREG))
      L=IEXT(NOREG)-IINT(NOREG)+1
      K=JSUP(NOREG)-JINT(NOREG)+1
      DO243M=1,IGRP
      NR=1
      NZ=1
      II=IINT(NOREG)
203   IF(II-I(NR))206,205,204
204   NR=NR+1
      GOTO203
206   NR=NR-1
205   DR0=DR(NR)
      II=II+1
210   IF(II-I(NR))209,208,207
207   NR=NR+1
      GOTO210
209   NR=NR-1
208   DR1=DR(NR)
      D=(DR0+DR1)*DR0*DR1
      IB=2
      DO212JB=1,K
      NU=(JB-1)*L+IB
      DFLUXR(NU-1)=(FLUX1(NU,M)*(DR0+DR1)**2-FLUX1(NU-1,M)*(DR1+
     1DR0*2.)*DR1-FLUX1(NU+1,M)*(DR0**2))/D
212   DADJOR(NU-1)=(ADJO1(NU,M)*(DR0+DR1)**2-ADJO1(NU-1,M)*(DR1+
     1DR0*2.)*DR1-ADJO1(NU+1,M)*(DR0**2))/D
      GOTO211
213   IF(II-I(NR))216,215,214
214   NR=NR+1
      GOTO213
216   NR=NR-1
```

```
215 DR1=DR(NR)
    IB=II-IINT(NOREG)+1
    D=(DR0+DR1)*DR0*DR1
211 DO217JB=1,K
    NU=(JB-1)*L+IB
    DFLUXR(NU)=(FLUX1(NU+1,M)*(DR0**2)-FLUX1(NU-1,M)*(DR1**2)
   1+FLUX1(NU,M)*((DR1**2)-(DR0**2)))/D
217 DADJOR(NU)=(ADJO1(NU+1,M)*(DR0**2)-ADJO1(NU-1,M)*(DR1**2)
   1+ADJO1(NU,M)*((DR1**2)-(DR0**2)))/D
    IF(II-IEXT(NOREG)+1)218,219,219
218 II=II+1
    DR0=DR1
    GOTO213
219 DO220JB=1,K
    NU=(JB-1)*L+IB
    DFLUXR(NU+1)=(FLUX1(NU+1,M)*(DR0+DR1*2.)*DR0+FLUX1(NU-1,M)
   1*(DR1**2)-FLUX1(NU,M)*(DR0+DR1)**2)/D
220 DADJOR(NU+1)=(ADJO1(NU+1,M)*(DR0+DR1*2.)*DR0+ADJO1(NU-1,M)
   1*(DR1**2)-ADJO1(NU,M)*(DR0+DR1)**2)/D
    JJ=JINT(NOREG)
223 IF(JJ-J(NZ))226,225,224
224 NZ=NZ+1
    GOTO223
226 NZ=NZ-1
225 DZ0=DZ(NZ)
    JJ=JJ+1
230 IF(JJ-J(NZ))229,228,227
227 NZ=NZ+1
    GOTO230
229 NZ=NZ-1
228 DZ1=DZ(NZ)
    D=(DZ0+DZ1)*DZ0*DZ1
    JB=2
    DO232IB=1,L
    NV=JB*L+IB
    NU=(JB-1)*L+IB
    NT=(JB-2)*L+IB
    DFLUXZ(NT)=(FLUX1(NU,M)*(DZ0+DZ1)**2-FLUX1(NT,M)*(DZ1+DZ0
   1*2.)*DZ1-FLUX1(NV,M)*(DZ0**2))/D
232 DADJOZ(NT)=(ADJO1(NU,M)*(DZ0+DZ1)**2-ADJO1(NT,M)*(DZ1+DZ0
   1*2.)*DZ1-ADJO1(NV,M)*(DZ0**2))/D
    GOTO231
233 IF(JJ-J(NZ))236,235,234
234 NZ=NZ+1
    GOTO233
236 NZ=NZ-1
235 DZ1=DZ(NZ)
    JB=JJ-JINT(NOREG)+1
    D=(DZ0+DZ1)*DZ0*DZ1
231 DO237IB=1,L
    NV=JB*L+IB
    NU=(JB-1)*L+IB
    NT=(JB-2)*L+IB
    DFLUXZ(NU)=(FLUX1(NV,M)*(DZ0**2)-FLUX1(NT,M)*(DZ1**2)
   1+FLUX1(NU,M)*((DZ1**2)-(DZ0**2)))/D
237 DADJOZ(NU)=(ADJO1(NV,M)*(DZ0**2)-ADJO1(NT,M)*(DZ1**2)
```

```
   1+ADJO1(NU,M)*((DZ1**2)-(DZ0**2)))/D
    IF(JJ-JSUP(NOREG)+1)238,239,239
238 JJ=JJ+1
    DZ0=DZ1
    GOTO233
239 DO240IB=1,L
    NV=JB*L+IB
    NU=(JB-1)*L+IB
    NT=(JB-2)*L+IB
    DFLUXZ(NV)=(FLUX1(NV,M)*(DZ0+DZ1*2.)*DZ0+FLUX1(NT,M)*(DZ1
   1**2)-FLUX1(NU,M)*(DZ0+DZ1)**2)/D
240 DADJOZ(NV)=(ADJO1(NV,M)*(DZ0+DZ1*2.)*DZ0+ADJO1(NT,M)*(DZ1
   1**2)-ADJO1(NU,M)*(DZ0+DZ1)**2)/D
    DO243JB=1,K
    DO243IB=1,L
    NU=(JB-1)*L+IB
243 PROGRA(NU,M)=DFLUXR(NU)*DADJOR(NU)+DFLUXZ(NU)*DADJOZ(NU)
    NOPER=NUMPER(KI)
    KH=0
300 KH=KH+1
    DO245IB=1,L
    DO245JB=1,K
    NU=(JB-1)*L+IB
    Y=0
    Z=0
    UI(NU)=0
    VI(NU)=0
    DO246M=1,IGRP
    UI(NU)=UI(NU)-DI(M,MU)*PROGRA(NU,M)
    VI(NU)=VI(NU)-AI(M,MU)*FLUX1(NU,M)*ADJO1(NU,M)
    Y=Y+FI(M,MU)*FLUX1(NU,M)
246 Z=Z+CHIO(M)*ADJO1(NU,M)
    XI(NU)=Y*Z
    MA=1
    MB=IGRP-1
    YC=0
    YD=0
    DO251MC=1,MB
    MD=MC+1
    YA=0
    YB=0
    DO252MH=MD,IGRP
    YA=YA+SI(MA,MU)*ADJO1(NU,MH)
    YB=YB+SI(MA,MU)
252 MA=MA+1
    YC=YC+YA*FLUX1(NU,MC)
251 YD=YD+YB*FLUX1(NU,MC)*ADJO1(NU,MC)
    WI(NU)=YC-YD
245 VI(NU)=VI(NU)+YD
    CALLINTEGR
    X1=X1/H
    X2=X2/H
    X3=X3/H
    X4=X4/H
    X5=X1+X2+X3+X4
    WRITEOUTPUTTAPE1,242,IREG(KI),RECO(MU),X5,X1,X2,X3,X4
```

```
244 MU=MU+1
    IF(KH-NOPER)300,303,303
303 IF(KI-LOMAX)301,302,302
242 FORMAT(7H REGIONI4,4X,A6,5X,1P5E16.6)
302 RETURN
    END(0,1,0,0,1)
```

```
      SUBROUTINELIBRY
      DIMENSIONFIS(20,24,7),DUM1(988),NELE(40),ATOMDN(40),SIGA(20,40),
     1SIGTR3(20,40),SIGFI(20,40),SIGDEG(190,40)
      COMMONFIS,IGRP,DUM1,NELE,ATOMDN,SIGA,SIGTR3,SIGFI,SIGDEG
      KR=(IGRP*(IGRP-1))/2
      IF(SENSESWITCH1)6,5
    5 READ1,N
    1 FORMAT(I6)
      IF(N)2,2,3
    3 READ4,(SIGA(M,N),M=1,IGRP)
    4 FORMAT(6E12.6)
      READ4,(SIGTR3(M,N),M=1,IGRP)
      READ4,(SIGFI(M,N),M=1,IGRP)
      READ4,(SIGDEG(M,N),M=1,KR)
      GOTO5
    6 READINPUTTAPE2,1,N
      IF(N)8,8,7
    7 READINPUTTAPE2,4,(SIGA(M,N),M=1,IGRP)
      READINPUTTAPE2,4,(SIGTR3(M,N),M=1,IGRP)
      READINPUTTAPE2,4,(SIGFI(M,N),M=1,IGRP)
      READINPUTTAPE2,4,(SIGDEG(M,N),M=1,KR)
      GOTO6
    8 REWIND2
    2 RETURN
      END(0,1,0,0,1)
```

```
      SUBROUTINECOMP1(KD)
      DIMENSIONFIS(20,24,7),DUM1(7),DUM2(979),NELE(40),ATOMDN(40),
     1SIGA(20,40),SIGTR3(20,40),SIGFI(20,40),SIGDEG(190,40)
      COMMONFIS,IGRP,DUM1,KRP,INDEX,DUM2,NELE,ATOMDN,SIGA,
     1SIGTR3,SIGFI,SIGDEG
      DO3M=1,IGRP
      X=0
      DO2KB=1,KRP
      N=NELE(KB)
    2 X=X+SIGFI(M,N)*ATOMDN(KB)
    3 FIS(M,KD,INDEX)=X
      RETURN
      END(0,1,0,0,1)
```

```
      SUBROUTINECOMP2(KX)
      DIMENSIONDUM1(2990),DT(20,10),DUM2(170),DUM3(7),DUM4(976),
     1NELE(40),ATOMDN(40),SIGA(20,40),SIGTR3(20,40),SIGFI(20,40),
     2SIGDEG(190,40),DUM5(3)
      COMMONDUM1,DT,DUM2,IGRP,DUM3,KRP,DUM5,KI,DUM4,NELE,
     1ATOMDN,SIGA,SIGTR3,SIGFI,SIGDEG
      KI=KX
      DO2M=1,IGRP
      X=0
      DO3KB=1,KRP
      N=NELE(KB)
    3 X=X+SIGTR3(M,N)*ATOMDN(KB)
    2 DT(M,KI)=1./X
      RETURN
      END(0,1,0,0,0)
```

```
      SUBROUTINECOMP3(KH)
      DIMENSIONDUM1(480),AL(20,5),FL(20,5),SL(190,5),DL(20,10,5),
     1DUM2(360),DT(20,10),DUM4(170),DUM5(6),DUM6(980),NELE(40),
     2ATOMDN(40),SIGA(20,40),SIGTR3(20,40),SIGFI(20,40),SIGDEG(190,40)
      COMMONDUM1,AL,FL,SL,DL,DUM2,DT,DUM4,IGRP,DUM5,
     1LOMAX,KRP,DUM6,NELE,ATOMDN,SIGA,SIGTR3,SIGFI,SIGDEG
      DO4M=1,IGRP
      W=0
      X=0
      Y=0
      DO3KB=1,KRP
      N=NELE(KB)
      W=W+SIGA(M,N)*ATOMDN(KB)
      X=X+SIGFI(M,N)*ATOMDN(KB)
    3 Y=Y+SIGTR3(M,N)*ATOMDN(KB)
      AL(M,KH)=W
      FL(M,KH)=X
      DO4KI=1,LOMAX
    4 DL(M,KI,KH)=-Y*DT(M,KI)**2
      KR=(IGRP*(IGRP-1))/2
      DO5M=1,KR
      Y=0
      DO6KB=1,KRP
      N=NELE(KB)
    6 Y=Y+SIGDEG(M,N)*ATOMDN(KB)
    5 SL(M,KH)=Y
      RETURN
      END(0,1,0,0,1)
```

```
      SUBROUTINECOMP4(KH)
      DIMENSIONDUM1(480),DI(20,9),AI(20,9),FI(20,9),SI(190,9),
     1DUM2(259),DT(20,10),DUM7(170),DUM3(7),DUM5(3),DUM4(976),
     2NELE(40),ATOMDN(40),SIGA(20,40),SIGTR3(20,40),
     3SIGFI(20,40),SIGDEG(190,40)
      COMMONDUM1,DI,AI,FI,SI,MU,DUM2,DT,DUM7,IGRP,DUM3,
     1KRP,DUM5,KI,DUM4,NELE,ATOMDN,SIGA,SIGTR3,
     2SIGFI,SIGDEG
      A=KH
      DO4M=1,IGRP
      W=0
      X=0
      Y=0
      DO3KB=1,KRP
      N=NELE(KB)
      W=W+SIGA(M,N)*ATOMDN(KB)
      X=X+SIGFI(M,N)*ATOMDN(KB)
    3 Y=Y+SIGTR3(M,N)*ATOMDN(KB)
      AI(M,MU)=W
      FI(M,MU)=X
    4 DI(M,MU)=-Y*DT(M,KI)**2
      KR=(IGRP*(IGRP-1))/2
      DO5M=1,KR
      Y=0
      DO6KB=1,KRP
      N=NELE(KB)
    6 Y=Y+SIGDEG(M,N)*ATOMDN(KB)
    5 SI(M,MU)=Y
      RETURN
      END(0,1,0,0,1)
```

```
      SUBROUTINEINTEGR
      DIMENSIONIEXT(36),IINT(36),JSUP(36),JINT(36),I(20),DR(20),
     1J(20),DZ(20),A(300,4),FIS(20,24,7),DU1(10),DU2(749),SUM(4)
      COMMONFIS,DU1,NOREG,H,SUM,I,DR,J,DZ,
     1IINT,IEXT,JINT,JSUP,DU2,A
      L=IEXT(NOREG)-IINT(NOREG)+1
      JJ=JINT(NOREG)
      II=IINT(NOREG)
      NR=1
      NZ=1
      DR0=0.
      DZ0=0.
      DO30K=1,4
   30 SUM(K)=0.
   20 IF(II-IEXT(NOREG))3,18,19
   18 DR1=0.
      GOTO21
    3 IF(II-I(NR))6,5,4
    4 NR=NR+1
      GOTO3
    6 NR=NR-1
    5 DR1=DR(NR)
   21 R=0.
      IF(NR-1)9,9,8
    8 NNR=NR-1
      DO7M=1,NNR
      X=I(M+1)-I(M)
    7 R=R+DR(M)*X
    9 X=II-I(NR)
      R=R+DR(NR)*X
   17 IF(JJ-JSUP(NOREG))13,14,15
   14 DZ1=0.
      GOTO16
   13 IF(JJ-J(NZ))10,11,12
   12 NZ=NZ+1
      GOTO13
   10 NZ=NZ-1
   11 DZ1=DZ(NZ)
   16 IB=II-IINT(NOREG)+1
      JB=JJ-JINT(NOREG)+1
      NU=(JB-1)*L+IB
      DO31K=1,4
   31 SUM(K)=SUM(K)+A(NU,K)*1.5707963
     1*(DR0+DR1)*(DZ0+DZ1)*(R+(DR1-DR0)/4.)
      DZ0=DZ1
      JJ=JJ+1
      GOTO17
   15 DR0=DR1
      JJ=JINT(NOREG)
      II=II+1
      NZ=1
      DZ0=0.
      GOTO20
   19 RETURN
      END(0,1,0,0,1)
```

```
          SUB1
       REL
       ORG
       HTR
       HTR
       HTR
       HTR
       HTR
SUB1   SXD SUB1-1,2
       SXD SUB1-2,1
       CLA 1,4                    ADDRESS OF IMAX+1
       STA *+1
       CLA **
       STO SUB1-3
       CLA 3,4                    ADDRESS OF M
       STA *+1
       CLA **
       STO SUB1-4
       CLA 6,4                    ADDRESS OF CASE NUMBER
       STA *+1
       CLA **
       SUB ONE
       TZE CASE1
       SUB ONE
       TZE CASE2
CASE3  CLA ADC13
       TRA NFST+1
CASE1  CLA SUB1-4
       SUB ONE
       TZE FIRST
       BST 6
       BST 6
NFST   CLA ADC12
       STA TAPE+3
       CLA 4,4                    ADDRESS OF FLUX STORAGE
       STA TAPE
       LXD SUB1-3,1
       RTB 5
JUNK   CPY SUB1-5
       TIX *-1,1,1
       TXI *+1,1,-2
       LXD SUB1-3,2
       TXI *+1,2,-1
       TXI *+1,1,1
TAPE   CPY **,1
       TIX *-2,2,1
       TRA *+2
       TRA **
       CPY SUB1-5
       CLA TAPE
       SUB FIFTY
       STA TAPE
       LXD TAPE-2,1
       LXD SUB1-3,2
       TRA TAPE-2
```

```
C12     CLA ADC13
        STA TAPE+3
        CLA 5,4                         ADDRESS OF ADJOINT FLUX STORAGE
        STA TAPE
        LXD SUB1-3,1
        RTB 6
        TRA JUNK
C13     CLA 2,4                         ADDRESS OF MAX G
        STA *+1
        CLA **
        SUB SUB1-4
        TNZ *+3
        REW 6
        REW 5
        LXD SUB1-1,2
        LXD SUB1-2,1
        TRA 7,4
FIRST   CLA 2,4                         ADDRESS OF MAX G
        STA *+1
        CLA **
        SUB SUB1-4
ADC12   PDX C12,2
        RTB 6
        TIX *-1,2,1
        TRA NFST
CASE2   CLA 4,4
        STA TAPE
        CLA ADC12
        STA TAPE+3
        TRA JUNK-2
ONE     HTR 0,0,1
FIFTY   HTR 50,0,0
ADC13   HTR C13
        END SUB1
```

```
          SUB4
        REL
        ORG
        HTR
        HTR
        HTR
        HTR
        HTR
        HTR
        HTR
        HTR
SUB4    SXD  *-1,4
        SXD  *-3,2
        SXD  *-5,1
        CLA  3,4
        STA  POS4
        CLA  2,4
        STA  POS5
        STZ  SUB4-4
        CLA  POS1
        STA  POS2
        CLA  7,4
        STA  POS7
        STA  *+1
        LXD  **,2
        CLA  8,4
        STA  *+1
        CLA  **
POS7    SUB  **
        ADD  POS1+2
        STO  SUB4-8
        CLA  1,4
        STA  *+1
        CLA  **
        STO  SUB4-5
        PDX  0,1
        CLA  5,4
        STA  POS3
        STA  *+4
        CLA  6,4
        STA  *+1
        CLA  **
        SUB  **
        ADD  POS1+2
        STO  SUB4-7
        LXA  POS1+2,4
POS2    RTB  **
        CPY  SUB4-6
        TIX  *-1,1,1
        LXD  SUB4-5,1
        TIX  *-3,2,1
POS3    LXD  **,1
        LXD  SUB4-5,2
        TXL  POS4-1,1,1
        TXI  *+1,1,-1
```

```
        CPY  SUB4-6
        TXI  *+1,2,-1
        TIX  *-2,1,1
        LXD  SUB4-7,1
POS4    CPY  **,4
        TXI  *+1,2,-1
        TXI  *+1,4,1
        TIX  *-3,1,1
        CPY  SUB4-6
        TIX  *-1,2,1
        CLA  SUB4-8
        SUB  POS1+2
        STO  SUB4-8
        TNZ  POS3
        CLA  POS4
POS9    SUB  CCC
        STA  POS4
        LXA  POS1+2,4
        LXD  SUB4-1,1
        CLA  7,1
        STA  *+1
        LXD  **,2
        STA  *+4
        CLA  8,1
        STA  *+1
        CLA  **
        SUB  **
        ADD  POS1+2
        STO  SUB4-8
        CLA  SUB4-4
        ADD  POS1+2
        STO  SUB4-4
POS5    SUB  **
        LXD  SUB4-5,1
        TNZ  POS2
        CLA  POS2
        SUB  POS1+1
        TZE  POS6
POS8    LXD  SUB4-1,1
        CLA  2,1
        STA  *+1
        CLA  **
        LRS  18
        STA  SUB4-6
        LDQ  SUB4-6
        MPY  CCC
        STQ  SUB4-6
        CLA  SUB4-6
        SUB  CCC
        STA  SUB4-6
        CLA  4,1
        SUB  SUB4-6
        STA  POS4
        CLA  POS5-2
        STD  POS9
        CLA  POS1+1
```

```
        STA  POS2
        LXA  POS1+2,4
        LXD  SUB4-5,1
        STZ  SUB4-4
        TRA  POS2
POS6    LXD  SUB4-3,1
        LXD  SUB4-2,2
        LXD  SUB4-1,4
        CLA  POS8-2
        STD  POS9
        REW  5
        REW  6
        TRA  9,4
POS1    RTB  5
        RTB  6
        HTR  0,0,1
CCC     HTR  300,0,0
        END  SUB4
```

VIII. TAPE-WRITING ROUTINE

This routine may be used to write flux and adjoint flux tapes when CUREM results are not available for input to 2D PERT.

Input Information

All input is punched in standard SAP format, in which G, I + 1, and J are integers. The ϕ and ϕ^* values are floating-point numbers.

Card Set No.	Input	Remarks
1	G	Number of groups. $G \leq 20$.
	I + 1	Number of points plus one on the R axis. $I \leq 60$.
	J	Number of points on the Z axis. $J \leq 60$.
2	ϕ_1	Point-by-point fluxes for real group 1, given a row at a time beginning with point (1,1). A zero must separate rows.
3	ϕ_2	Point-by-point fluxes for real group 2, given a row at a time beginning with point (1,1). A zero must separate rows.
. . .	. . .	. . .
G + 1	ϕ_G	Point-by-point fluxes for the last real group, given a row at a time beginning with point (1,1). A zero must separate rows.
G + 2	$\phi^*_{G'}$	Point-by-point adjoint fluxes for the last adjoint group, given a row at a time beginning with point (1,1). A zero must separate rows.
G + 3	$\phi^*_{G'-1}$	Point-by-point adjoint fluxes for the next to the last adjoint group, given a row at a time beginning with point (1,1). A zero must separate rows.
. . .	. . .	. . .
2G + 1	ϕ^*_1	Point-by-point adjoint fluxes for the first adjoint group, given a row at a time beginning with point (1,1). A zero must separate rows.

Input Deck Arrangement

Card Set 1

Card Set 2

TRA 3,4

Card Set 3

TRA 3,4

. . .

Card Set 2G + 1

TRA 3,4

Note: Sets of fluxes and adjoint fluxes must be followed by a TRA 3,4 card.

Operating Instructions

A standard 72-72 reader board is necessary for running this problem.

Sense Switches:

1 Down

No other sense switches used.

Tapes:

5 Blank for "real" fluxes

6 Blank for "adjoint" fluxes

Running Procedure:

1. Mount and ready tapes.
2. Depress sense switch 1.
3. Clear and load cards.
4. At stop 1300_8 label, remove, and save tapes 5 and 6.

```
                ROUTINE TO MANUFACTURE FLUX TAPE
          ORG   100
I         HED
 INP1     LIB
P         HED
 INP1     SYN   I$INP1
 BEGIN    STZ   TEST
          TSX   INP1,4
                G,0,G+2
          HTR   INP1+23
          CLA   FIVE
          STA   WTP
          LDQ   G+1                          I+1
          MPY   G+2                          J
          STQ   TEMP
          LXA   G,1
 RFLX     TSX   INP1,4
                A,0,0
          HTR   INP1+23
          LXA   NIL,4
          LXA   G+1,2                        I+1
 WTP      WTB   **
          CPY   NIL
          TIX   *-1,2,1
          LXA   TEMP,2
          CPY   A,4
          TXI   *+1,4,-1
          TIX   *-2,2,1
          TIX   RFLX,1,1
          CLA   TEST
          TMI   END
          SSM
          STO   TEST
          CLA   SIX
          STA   WTP
          TRA   RFLX-1
 END      REW   5
          REW   6
          HTR   *
 FIVE     OCT   225
 SIX      OCT   226
 NIL      DEC   0
 TEMP     BSS   1
 TEST     BSS   1
 G        BSS   3
 A        BSS   3000
          END   BEGIN
```

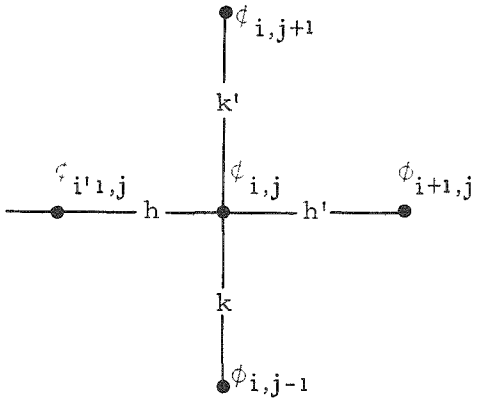
INPUT FOR WRITING REAL AND ADJOINT FLUX TAPES FOR SAMPLE PROBLEMS

```
DEC 3,9,5
DEC 1.,1.,1.,1.,1.,1.,1.,1.,0,1.,1.,1.,1.,1.,1.,1.,1.,0
DEC 1.,1.,1.,1.,1.,1.,1.,1.,0,1.,1.,1.,1.,1.,1.,1.,1.,0
DEC 1.,1.,1.,1.,1.,1.,1.,1.,0
TRA 3,4
DEC 2.,2.,2.,2.,2.,2.,2.,2.,0,2.,2.,2.,2.,2.,2.,2.,2.,0
DEC 2.,2.,2.,2.,2.,2.,2.,2.,0,2.,2.,2.,2.,2.,2.,2.,2.,0
DEC 2.,2.,2.,2.,2.,2.,2.,2.,0
TRA 3,4
DEC 9.,7.,5.,4.,3.,2.,1.,0,0,9.,7.,5.,4.,3.,2.,1.,0,0
DEC 9.,7.,5.,4.,3.,2.,1.,0,0,9.,7.,5.,4.,3.,2.,1.,0,0
DEC 9.,7.,5.,4.,3.,2.,1.,0,0
TRA 3,4
DEC 9.,7.,5.,4.,3.,2.,1.,0,0,9.,7.,5.,4.,3.,2.,1.,0,0
DEC 9.,7.,5.,4.,3.,2.,1.,0,0,9.,7.,5.,4.,3.,2.,1.,0,0
DEC 9.,7.,5.,4.,3.,2.,1.,0,0
TRA 3,4
DEC 1.,1.,1.,1.,1.,1.,1.,1.,0,1.,1.,1.,1.,1.,1.,1.,1.,0
DEC 1.,1.,1.,1.,1.,1.,1.,1.,0,1.,1.,1.,1.,1.,1.,1.,1.,0
DEC 1.,1.,1.,1.,1.,1.,1.,1.,0
TRA 3,4
DEC 2.,2.,2.,2.,2.,2.,2.,2.,0,2.,2.,2.,2.,2.,2.,2.,2.,0
DEC 2.,2.,2.,2.,2.,2.,2.,2.,0,2.,2.,2.,2.,2.,2.,2.,2.,0
DEC 2.,2.,2.,2.,2.,2.,2.,2.,0
TRA 3,4
```

APPENDIX A

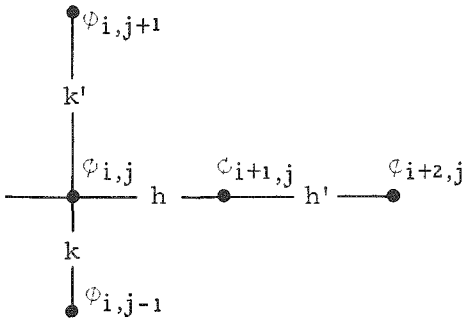
Determination of the Gradient

1. For a point inside a region, the 2 components of the gradient are calculated by a parabolic interpolation with the 4 adjacent points.



$$\vec{\text{grad}}\ \phi \left\{ \begin{array}{l} \dfrac{h^2\,\phi_{i+1,j}-(h')^2\phi_{i-1,j}+[(h')^2-h^2]\phi_{i,j}}{h\,h'\,(h+h')} \\ \\ \dfrac{k^2\,\phi_{i,j+1}-(k')^2\phi_{i,j-1}+[(k')^2-k^2]\phi_{i,j}}{k\,k'\,(k+k')} \end{array} \right.$$

2. For a boundary point, with a noncontinuous gradient, one component of the gradient is determined as in 1, the other is calculated by a parabolic interpolation with 2 adjacent points on the same side of the boundary.

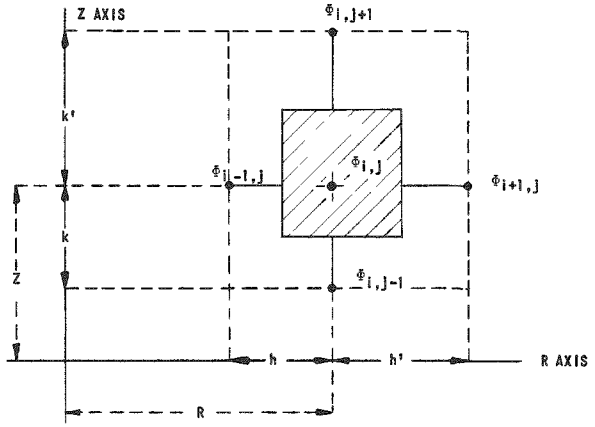


$$\vec{\text{grad}}\ \varphi \left\{ \begin{array}{l} \dfrac{(h+h')^2\varphi_{i+1,j}-h^2\varphi_{i+2,j}-h'(h'+2h)\varphi_{i,j}}{h\,h'\,(h+h')} \\ \\ \dfrac{k^2\,\phi_{i,j+1}-(k')^2\varphi_{i,j-1}+[(k')^2-k^2]\phi_{i,j}}{k\,k'\,(k+k')} \end{array} \right.$$

APPENDIX B

Integration

2D PERT uses the same method as the CUREM code



The integration of $\phi(R,Z)$ is performed by considering ϕ constant over an elementary volume extending from R - (h/2) to R + (h'/2) and from Z - (k/2) to Z + (k'/2):

$$\Delta V = \frac{\pi}{2}(h + h')(k + k')\left[R + \frac{1}{4}(h' - h)\right] \quad .$$

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