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MASTER

Argonne National Laboratory

DEL,
A PERTURBATION PROGRAM
WRITTEN IN FORTRAN

by

Louis C. Kvitek

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ARGONNE NATIONAL LABORATORY
9700 South Cass Avenue
Argonne, Illinois 60440

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Reactor Physics Division

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ABSTRACT

DEL[†] is a perturbation-theory code which determines the fractional change in k_{eff} due to a perturbation in macroscopic cross sections and/or in the buckling. It is written in FORTRAN for the IBM-704 computer with 32K core storage and at least six tape drives, including one for the FORTRAN Subroutine Library. The analysis assumes the input of the radial distributions of sources and fluxes to result from a one-dimensional diffusion-theory calculation (see Section II-A, NFLT). Preparation of the cross-section tape is described in Appendix B.

The printed results include the radial distributions of $\Delta k/k$ and the volumetrically-weighted quantity $(\Delta k/k)/\Delta V$, together with their individual terms and the respective pass totals and grand totals thereof. The grand totals may, at the option of the user, include results from previous passes. The reference system need not be critical. The basic restrictions are as follows:

1. Energy groups ≤ 30 .
2. Mesh points ≤ 125 .
3. Regions ≤ 50 .
4. Isotopes ≤ 20 .
5. $\nabla\phi = 0$ at the origin.

I. MATHEMATICAL ANALYSIS

A. The Perturbation Equation

With the assumption that the real and adjoint sources, S and S^* , respectively, are normalized by a factor of $1/k_{eff}$, it can be shown from the presentation on perturbation analysis by D. Meneghetti^{††} that a

[†]The ANL AMD Job No. for this code is RP342X. A modified version of DEL is being prepared for the CDC-3600 under Job No. RP319X.

^{††}Introductory Fast Reactor Analysis, ANL-6809 (Dec 1963).

first-order approximation to the fractional change in k_{eff} of a system (critical or off-critical), due to a slight perturbation of the macroscopic cross sections of isotope MP, may be written

$$\frac{\Delta k}{k} = \sum_{\ell=1}^5 P_{\ell} / Q, \quad (1)$$

where, with ΔV being the volume corresponding to the perturbation, and V the volume of the reactor,

$$k_{\text{eff}} P_1 = \int_{\Delta V} S^* \sum_j \Phi_j \delta(\nu \Sigma_f)_{j,MP} dV; \quad (2)$$

$$k_{\text{eff}} P_2 = - \int_{\Delta V} \sum_j \Phi_j \Phi_j^* \delta \Sigma_{c+f,j,MP} dV; \quad (3)$$

$$k_{\text{eff}} P_3 = - \int_{\Delta V} \sum_j \nabla \Phi_j \cdot \nabla \Phi_j^* \delta D_j dV; \quad (4)$$

$$k_{\text{eff}} P_4 = - \int_{\Delta V} \sum_{j=1}^{NG-1} \Phi_j (\Phi_j^* - \Phi_{j+1}^*) \delta \Sigma_{er,j,MP} dV; \quad (5)$$

$$k_{\text{eff}} P_5 = - \int_{\Delta V} \sum_{j=1}^{NLGS} \Phi_j \sum_{k=1}^{NGRS} (\Phi_j^* - \Phi_{j+k}^*) \delta \Sigma_{in,j \rightarrow j+k,MP} dV; \quad (6)$$

$$Q = \int_V SS^* dV; \quad (7)$$

$$k_{\text{eff}} S = \sum_m \sum_j (\nu \Sigma_f)_{j,m} \Phi_j; \quad (8)$$

and

$$k_{\text{eff}} S^* = \sum_j \chi_j \Phi_j. \quad (9)$$

In view of the cross sections involved in the definitions[†] of the P terms, we may describe the terms of $\Delta k/k$ in Eq. (1) according to the following list:

[†] See Appendix D for definitions of the mathematical symbols, and Section II-A for the summation limits.

<u>Quantity</u>	<u>Definition</u>
P_1/Q	Source Term
P_2/Q	Capture + Fission Term
P_3/Q	Leakage Term
P_4/Q	Elastic Removal Term
P_5/Q	Inelastic Scattering Term

The terms of the volumetrically-weighted quantity $(\Delta k/k)\Delta V$ may be similarly defined. The radial distributions and the totals of all these quantities appear in the list of printed results. (See Section IV for a detailed list of all output.) In addition to these terms, if the user specifies a change in buckling, δB^2 (see Section II-A, DB2), the quantity

$$P_3' = - \frac{\delta B^2}{k_{\text{eff}}} \int_{\Delta V} \sum_j D_j \phi_j \phi_j^* dV/Q \quad (1a)$$

is added to the leakage term in Eq. (1). When the geometry is that of a slab or cylinder, the vector-dot product in Eq. (4) gives rise to a transverse-leakage component involving the product of one-dimensional real and adjoint fluxes and a radial-leakage component involving the product of the derivatives of these fluxes (see Sections I-B and I-C below). All three components of the leakage term are listed separately in the output.

Although the elastic-removal component as defined above is limited to removal from group j to group $j + 1$, a broader treatment may be achieved by either incorporating an elastic-removal matrix into the inelastic matrix of the isotope being perturbed, or by making a second pass on the same region and perturbing another isotope whose cross-section data consist of only the desired elastic-removal matrix entered as inelasticities. The results of successive passes may be accumulated at the option of the user (see Section II-A, KLRT).

In the analysis below, the following definitions of the functions $f_n(\xi_i)$ will be employed (the subscript i denotes evaluation at the radial point ξ_i):

$$f_1 = S_1^* \sum_{j=1}^{NG} \phi_{i,j} \delta(\nu \Sigma_f)_{j,MP}; \quad (10a)$$

$$f_2 = \sum_{j=1}^{NG} \phi_{i,j} \phi_{i,j}^* \delta \Sigma_{c+f,j,MP}; \quad (10b)$$

$$f_3 = \sum_{j=1}^{NG} \frac{d\phi_{i,j}}{d\xi} \frac{d\phi_{i,j}^*}{d\xi} \delta D_j; \quad (10c)$$

$$f_4 = \sum_{j=1}^{NG-1} \phi_{i,j} (\phi_{i,j}^* - \phi_{i,j+1}^*) \delta \Sigma_{er,j,MP}; \quad (10d)$$

$$f_5 = \sum_{j=1}^{NLGS} \phi_{i,j} \sum_{j=1}^{NGRS} (\phi_{i,j}^* - \phi_{i,j+k}^*) \delta \Sigma_{in,j \rightarrow j+k,MP}; \quad (10e)$$

$$f_6 = \sum_{j=1}^{NG} \phi_{i,j} \phi_{i,j}^* \delta D_j; \quad (10f)$$

and

$$f_7 = S_{f,i} S_{f,i}^*. \quad (10g)$$

Also define the functions

$$I_1(\alpha, \beta_n) = 2 \int_0^\alpha \cos^2(\beta_n \xi) d\xi = \alpha + \frac{1}{2\beta_n} \sin(2\alpha\beta_n); \quad (11a)$$

$$I_2(\alpha, \beta_n) = 2 \int_0^\alpha \sin^2(\beta_n \xi) d\xi = 2\alpha - I_1(\alpha, \beta_n); \quad (11b)$$

$$I_3(\alpha) = \int_0^\alpha \xi J_0^2(\gamma_n \xi) d\xi = \frac{\alpha^2}{2} [J_0^2(\gamma_n \alpha) + J_1^2(\gamma_n \alpha)]; \quad (12a)$$

and

$$I_4(\alpha) = \int_0^\alpha \xi J_1^2(\gamma_n \xi) d\xi = \frac{\alpha^2}{2} [J_1^2(\gamma_n \alpha) + J_2^2(\gamma_n \alpha)] \\ - \frac{\alpha}{\gamma_n} J_1(\gamma_n \alpha) J_2(\gamma_n \alpha). \quad (12b)$$

B. Slab Geometry

Since the neutron flux ϕ input to DEL is assumed to result from a one-dimensional solution, it is related to the multidimensional neutron flux Φ

for a given energy group j and radial point i , in the case of a rectangular parallelepiped ($X_n \leq 10^{10}$, $10^{-10} < Y_n < 10^{10}$), by the expression

$$\Phi_{i,j} = \phi_j(z_i) \cos(\gamma_n x) \cos(\lambda_n y). \quad (13)$$

Hence, the vector-dot product in the leakage term becomes

$$\begin{aligned} \nabla \Phi_{i,j} \cdot \nabla \Phi_{i,j} = & \phi_{i,j} \phi_{i,j}^* [\gamma_n^2 \sin^2(\gamma_n x) \cos^2(\lambda_n y) + \lambda_n^2 \cos^2(\gamma_n x) \sin^2(\lambda_n y)] \\ & + \frac{d\phi_{i,j}}{dz} \frac{d\phi_{i,j}^*}{dz} \cos^2(\gamma_n x) \cos^2(\lambda_n y), \end{aligned} \quad (14)$$

where the eigenvalues are defined by

$$\gamma_n = \pi / (X_n + 2\Delta X_n)$$

and

$$\lambda_n = \pi / (Y_n + 2\Delta Y_n). \quad (15)$$

Here X_n and Y_n are the dimensions in the x - y plane of the subregion being perturbed. These dimensions differ from the overall dimensions of the reactor region n by the amounts $2\Delta X_n$ and $2\Delta Y_n$, respectively. (See Fig. 1.) The user may run successive problems changing these dimensions and/or successive passes changing the radial limits of perturbation and combine results to obtain configurations such as rings, discs, and shells, depending on the geometry.

Fig. 1. Parallelepiped Slab

With the definitions of Eqs. (10) and (11), the perturbation equation, Eq. (1), for the rectangular parallelepiped may be written

$$\frac{\Delta k}{k} = \frac{\int_{\Delta V} \left\{ F \left[f_1(z) - \sum_{\ell=2}^5 f_{\ell}(z) \right] - T f_6(z) \right\} dz}{G \int_V f_7(z) dz},$$

where

$$\begin{aligned} F &= I_1\left(\frac{X_n}{2}, \gamma_n\right) I_1\left(\frac{Y_n}{2}, \lambda_n\right), \\ T &= \gamma_n^2 I_1\left(\frac{Y_n}{2}, \lambda_n\right) I_2\left(\frac{X_n}{2}, \gamma_n\right) + \lambda_n^2 I_1\left(\frac{X_n}{2}, \gamma_n\right) I_2\left(\frac{Y_n}{2}, \lambda_n\right), \end{aligned} \quad (17b)$$

and

$$G = I_1\left(\frac{X_n}{2} + \Delta X_n, \gamma_n\right) I_1\left(\frac{Y_n}{2} + \Delta Y_n, \lambda_n\right). \quad (17c)$$

In the output section entitled "Summary," the values of F , T , and G include the factor $\Delta z_n/2$, which comes from the trapezoidal integration[†] employed over a given interval

$$\int_{z_i}^{z_{i+1}} f_{\ell}(z) dz = \frac{\Delta z_n}{2} \left[f_{\ell}(z_{i+1}) + f_{\ell}(z_i) \right] \quad (18)$$

for all ℓ .

When $X_n > 10^{10}$, the set of values assumed is

$$F = G = 1; \quad (19a)$$

and

$$T = \lambda_n = \gamma_n = 0. \quad (19b)$$

This might be called the infinite parallelepiped slab. In this case, the input value of Y_n is ignored.

It may be desirable to consider the case of a semi-infinite parallelepiped slab, i.e., a parallelepiped slab that is infinite in only one direction. This is possible under the option $X_n \leq 10^{10}$, $Y_n \geq 10^{10}$. In this case, the development follows that above for the finite parallelepiped slab, with the additional definitions

[†] Trapezoidal integration is also employed in the diffusion theory code REX (see Reactor Physics Constants, ANL-5800, Second Edition, July 1963).

$$I_1[g(Y_n), \lambda_n] = 1,$$

and

$$\lambda_n = I_2[g(Y_n), \lambda_n] = 0,$$

where $g(Y_n)$ is any function of Y_n .

For a finite cylindrical slab ($X_n \leq 10^{10}$, $Y_n \leq 10^{-10}$), the fluxes are related by the equation

$$\Phi_{i,j} = \phi_j(z_i) J_0(\gamma_n r), \quad (20)$$

from which

$$\nabla \Phi_{i,j} \cdot \nabla \Phi_{i,j}^* = \gamma_n^2 J_1^2(\gamma_n r) \phi_{i,j} \phi_{i,j}^* + J_0^2(\gamma_n r) \frac{d\phi_{i,j}}{dz} \frac{d\phi_{i,j}^*}{dz}, \quad (21)$$

where the eigenvalue is defined by

$$\gamma_n = 2.4048 / \left(\frac{H_n}{2} + \Delta X_n \right). \quad (22)$$

The input value of $H_n = 2R_n$ is the diameter of the subregion being perturbed, which differs from the overall diameter of the reactor region by the amount $2\Delta R_n$. The input value $\Delta X_n = \Delta R_n$. (See Fig. 2.)

Fig. 2. Cylindrical Slab

Equation (16) again represents the perturbation equation, but with the different definitions from Eqs. (10) and (12) of

$$F = 2\pi I_3(H_n/2), \quad (23a)$$

$$T = 2\pi \gamma_n^2 I_4(H_n/2), \quad (23b)$$

and

$$G = 2\pi I_3 \left(\frac{H_n}{2} + \Delta X_n \right). \quad (23c)$$

The printed values of F , T , and G include the factor $\Delta z_n/2$, which stems from the method of trapezoidal integration described by Eq. (18).

For an infinite cylindrical slab ($X_n \leq 10^{10}$, $Y_n \geq 10^{10}$),

$$F = G = 2\pi, \quad (24a)$$

and

$$T = \gamma_n = 0. \quad (24b)$$

C. Cylindrical Geometry

In this geometry, the multidimensional flux Φ is related to the one-dimensional flux ϕ by the expression

$$\Phi_{i,j} = \phi_j(r_i) \cos(\gamma_n z), \quad (25)$$

so that

$$\nabla \Phi_{i,j} \cdot \nabla \Phi_{i,j}^* = \gamma_n^2 \phi_{i,j} \phi_{i,j}^* \sin^2(\gamma_n z) + \frac{d\phi_{i,j}}{dr} \frac{d\phi_{i,j}^*}{dr} \cos^2(\gamma_n z), \quad (26)$$

where the eigenvalue is defined as

$$\gamma_n = \pi / (H_n + 2\Delta X_n). \quad (27)$$

The input value H_n is the height of the subregion being perturbed, which differs from the overall height of the reactor region by the amount $2\Delta X_n$. (See Fig. 3.)

Fig. 3. Cylinder

The values of F , T , and G of the perturbation Eq. (16) are

$$F = 2\pi I_1 \left(\frac{H_n}{2}, \gamma_n \right), \quad (28a)$$

$$T = 2\pi \gamma_n^2 I_2 \left(\frac{H_n}{2}, \gamma_n \right), \quad (28b)$$

and

$$G = 2\pi I_1 \left(\frac{H_n}{2} + \Delta X_n, \gamma_n \right). \quad (28c)$$

The printout values of F , T , and G include the factor $\Delta r_n/2$, which is employed in the pointwise integration

$$\int_{r_i}^{r_{i+1}} r f_\ell(r) dr = \frac{\Delta r_n}{2} [r_i f(r_i) + r_{i+1} f(r_{i+1})] \quad (29)$$

for all ℓ .

For the infinite cylinder ($H_n \geq 10^{10}$),

$$F = G = 2\pi, \quad (30a)$$

and

$$T = \gamma_n = 0. \quad (30b)$$

D. Spherical Geometry

In the case of a sphere, the two fluxes $\phi_{i,j}$ and $\Phi_{i,j}$ are identical, so that

$$\nabla \phi_{i,j} : \nabla \phi_{i,j}^* = \frac{d\phi_{i,j}}{dr} \frac{d\phi_{i,j}^*}{dr}, \quad (31)$$

and, in Eq. (16),

$$F = G = 4\pi, \quad (32a)$$

and

$$T = \gamma_n \equiv 0. \quad (32b)$$

Here again the printed values of F, T, and G include the factor $\Delta r_n/2$, which comes from

$$\int_{r_i}^{r_{i+1}} r^2 f_\ell(r) dr = \frac{\Delta r_n}{2} \left\{ r_i^2 f_\ell(r_i) + r_{i+1}^2 f_\ell(r_{i+1}) + \frac{\Delta r_n}{3} [r_i f_\ell(r_i) - r_{i+1} f_\ell(r_{i+1})] \right\} \quad (33)$$

for all ℓ . Equation (33) arises from the Newton-Cotes method of quadratures, assuming linearity of the function $r f_\ell(r)$ in the given interval. This assumption is also employed in REX. (See footnote on page 10.)

E. Evaluation of Flux Derivatives

The normal derivative of the flux ϕ for a given energy group j and point i not at a boundary is evaluated by the expression

$$\frac{d\phi}{d\xi} = \frac{1}{2\Delta\xi} \left\{ \left(1 + \frac{\Delta\xi}{2\xi}\right)^k \phi(\xi + \Delta\xi) + \left[\left(1 - \frac{\Delta\xi}{2\xi}\right)^k - \left(1 + \frac{\Delta\xi}{2\xi}\right)^k \right] \phi(\xi) - \left(1 - \frac{\Delta\xi}{2\xi}\right)^k \phi(\xi - \Delta\xi) \right\}, \quad (34)$$

where $k = 0, 1$, or 2 , according to whether the geometry is slab, cylindrical, or spherical, respectively. The derivative is initialized to zero at the center of the reactor. At the outer edge of a region, the flux derivative will be evaluated according to

$$\frac{d\phi}{d\xi} = \frac{1}{2\Delta\xi} [3\phi(\xi) - 4\phi(\xi - \Delta\xi) + \phi(\xi - 2\Delta\xi)]. \quad (35a)$$

At the inner edge of a region (not the center), there is an option, $DERV \leq 0$, of using the expression

$$\frac{d\phi}{d\xi} = \frac{1}{2\Delta\xi} [4\phi(\xi + \Delta\xi) - 3\phi(\xi) - \phi(\xi + 2\Delta\xi)], \quad (35b)$$

or, if $DERV > 0$, the expression

$$\frac{d\phi}{d\xi} = \frac{d\phi}{d\xi_0} \frac{D_0}{D}, \quad (35c)$$

where $d\phi/d\xi_0$ has been evaluated from Eq. (35a) at the point interior to the boundary, together with the corresponding value of the diffusion coefficient D_0 , and D is the diffusion coefficient of the region under consideration. In the calculation of either D or D_0 , the change in the homogenized, transport cross section will be ignored if the input option $NTR2 \leq 0$.

The option $DERV > 0$ should be used only when the region interior to the one under consideration has been perturbed on the previous pass, since otherwise the values for D_0 will not be available. This restriction may be circumvented, however, by running a pseudoperturbation for the previous region. To save machine time in the pseudoperturbation, perturb only two intervals and set DVF to zero.

F. Calculation of δD

The perturbation in the diffusion coefficient is calculated under the option $NTR2 \leq 0$ from the differential expression

$$\delta D_j = -\delta \Sigma_{tr,j,MP} / (3\Sigma_{tr,j,H}^2), \quad (36)$$

where MP is the number of the material being perturbed, and H implies the homogenized, macroscopic, transport cross section. There is the additional option $NTR2 > 0$ of noting the change in the homogenized, transport cross section. Under the latter option, δD_j will be larger in magnitude if the material is being removed. That is, if H_1 refers to full density and H_2 to perturbed density, then under the option $NTR2 > 0$,

$$\delta D_j = -\delta \Sigma_{tr,j,MP} / (3\Sigma_{tr,j,H_1} \Sigma_{tr,j,H_2}). \quad (37)$$

II. INPUT

A. List of Symbols

<u>Symbol</u>	<u>Definition</u>	<u>Restrictions</u>
PN	Problem number.	
NC	Number of cards used for PD.	$>0, \leq 3$
USER	User's name and address.	
PD	Problem description. Use NC cards.	
NGRP	Number of energy groups.	≤ 30
NGRS	Maximum number of groups receiving neutrons scattered down from any one particular group.	≤ 29

<u>Symbol</u>	<u>Definition</u>	<u>Restrictions</u>
NREG	Number of regions in reactor.	
NLRP	Number of outermost reactor region to be perturbed.	≤ 50
NSRP	Number of subregions to be perturbed.	
NGE ϕ	1: Slab. 2: Cylinder. 3: Sphere.	
NFLT	Number of flux tapes used in this problem. 1: Real solution precedes adjoint solution on drive No. 2. 2: Real solution is on drive No. 3. Adjoint solution is on drive No. 4.	$\dagger$
NPR1	1: Print all fluxes and derivatives. 0: Omit this printout.	
NPR2	1: Print pointwise sources, products of sources, products of fluxes summed over energy, and corresponding integrals together with regional sums. 0: Omit this printout.	
DERV	See Section I-E.	
NPRS	Number of problems to be skipped on tape. Count only real solutions. The corresponding adjoints will be skipped automatically.	
N	Number of reactor region. (Note: The next six values pertain to region N.)	
NINT	Number of intervals.	$\dagger\dagger$
RB	Outer radius for a cylinder or sphere. Height for a slab.	

$\dagger$ For a given solution, the radial distribution of the source is on record No. 2 and the fluxes are on records 4 through NGRP + 3. The problem number and values for k_{eff} and the enrichment are taken from the first record. This structure is compatible with that of tape 6 provided by the multigroup diffusion-theory code REX (ANL AMD Job No. RP269 or RP122). The user should specify which reel is to be placed on which drive, according to Section III-B-1.

$$\dagger\dagger \quad 3 \leq \sum_{N=1}^{\text{NREG}} [\text{NINT}(N) + 1] \leq 125.$$

<u>Symbol</u>	<u>Definition</u>	<u>Restrictions</u>
H	See Figs. 1-3.	
Y		
DX		
DY		
NRBP	Number of the reactor region being perturbed.	
INTS	Interval in which perturbation begins.	
INTF	Interval in which perturbation ends. (Note: Intervals within a given region are numbered beginning with unity.)	
NMAT	>1: Volume fractions will be input. 1: Perturbed cross sections will be input. ≤ 0 : There will be no more input after this card for this "pass." The perturbations from the previous "pass" will be employed.	See note, p. 18 $NMAT \leq 20$
NLGS	Number of last group scattering downward in MATP.	
MATP	Identification number of the material being perturbed.	
NTR2	See Section I-F.	
KLRT	>0. Clear "Grand Totals" before proceeding. ≤ 0 : Accumulate "Grand Totals."	
DB2	Perturbation in the buckling.	
MN	Identification number of material on tape.	10^3
CVF	Original volume fraction or atom density.	
DVF	Change in volume fraction or atom density of material with ID number MATP. This number multiplies the cross sections on tape to obtain the perturbations therein.	
DNSF	Perturbation in $\nu\sigma_f$.	
DCPF	Perturbation in σ_{c+f} .	
DDIN	Perturbation in diffusion coefficient.	
DERS	Perturbation in σ_{er} .	
DINS	Perturbation in σ_{inel} .	

B. Card Input Data

<u>Card ID No.</u>	<u>Format</u>	<u>Data</u>
1000	F9.5,8XI1,6X6A6	PN,NC,USER
2000	12A6	PD
3000	12I6	NGRP,NGRS,NREG,NLRP,NSRP,NGEO, NFLT,NPR1,NPR2,DERV,NPRS
4000	2I6,5E12.5	N,NINT(N),RB(N),H(N),Y(N),DX(N),DY(N)
5000	8I6,E12.5	NRBP,INTS,INTF,NMAT,NLGS,MATP, NTR2,KLRT,DB2
6000	12I6	MN(1),MN(2),...,MN(NMAT)
7000	6E12.5	CVF(1),CVF(2),...,CVF(NMAT),DVF
8100	6E12.5	DNSF(1),DNSF(2),...,DNSF(NGRP)
8200	6E12.5	DCPF(1),DCPF(2),...,DCPF(NGRP)
8300	6E12.5	DDIF(1),DDIF(2),...,DDIF(NGRP)
8400	6E12.5	DERS(1),DERS(2),...,DERS(NGRP-1)
8501	6E12.5	DINS(1,2), DINS(1,3),...,DINS(1,1+NGRS)
8502	6E12.5	DINS(2,3),DINS(2,4),...,DINS(2,2+NGRS)
:	:	:
85NL	6E12.5	DINS(NLGS,NLGS+1),...,DINS(NLGS, NLGS+NGRS)

(Note: Use NC of the 2000 series cards.

Use NREG of the 4000 series cards.

Use NSRP sets of 5000 and higher-numbered series cards.

Omit 6000 and 7000 series cards when $NMAT \leq 1$.

Omit 8000 series cards when $NMAT \neq 1$.)

III. DESCRIPTION OF PROGRAM

A. Basic Flow Chart

B. Operating Instructions[†]

1. Ready tapes:

<u>Drive</u>	<u>Tape Information</u>
1	FORTTRAN Subroutine Library.
2	Real Then Adjoint Flux Solutions.
3	Real Flux Solution.
4	Adjoint Flux Solution.
5	Cross Sections.
6	Output.

(Note: Use either drives 2 or 3 and 4 for a given problem, according to user option NFLT. Also see option NMAT with reference to drive 5.)

2. Clear and load cards.
3. Normal stop: HPR 0,1 (no cards in the card reader).
4. Running time: ~20 sec/pass after initial pass (40 sec).
5. End of file is provided on tape 6 after each pass.

IV. OUTPUT

A. General Description

On the first pass, a complete edit of all card input is automatically provided, together with the perturbations as calculated from cross-section tape input and 6000-7000 series card input data, or read in directly from 8000 series cards. Additional data may be provided according to options NPR1 and NPR2 of Section II-B. On each succeeding pass, only the card input data necessary for that pass will be printed, together with the perturbations used in that pass. At the conclusion of each pass are printed the results, which are included in the list in Section IV-B below in the order encountered. At the beginning of each phase of the results is included a brief explanation of what follows, where otherwise there might be ambiguity because of the repetition of column heads. The final phase of printout is entitled "Summary" and includes two columns labeled "Total." These refer, in each case, to the column immediately to the left. Where this is $\Delta k/k$,

[†]These instructions pertain to a nonmonitor system.

the total is simply the accumulated sum. Where it is $(\Delta k/k)/\Delta V$, the total volume perturbed, as well as the total change in reactivity to and including that interval, is considered in the result. The "Grand Totals" are self-explanatory and will include the results of previous passes according to the option KLRT.

B. Correlation between Symbols

<u>Output</u>	<u>Mathematical Definition</u>	<u>Reference Eq.</u>
R(I)	ξ_i	
PHI(I,J)	$\phi_j(\xi_i)$	
PHI*(I,J)	$\phi_j^*(\xi_i)$	
DPHI(I,J)	$\left. \frac{d\phi_j}{d\xi} \right _{\xi_i}$	(36),(37)
DPHI*(I,J)	$\left. \frac{d\phi_j^*}{d\xi} \right _{\xi_i}$	(36),(37)
S	Real source	(8)
S*	Adjoint source	(9)
SS*	$S(\xi_i)S^*(\xi_i)$	
PP*	$\sum_j \phi_j(\xi_i)\phi_j^*(\xi_i)$	
ISS*	$\int S(\xi)S^*(\xi) dV_i$	(7)
IPP*	$\int \sum_j \phi_j(\xi)\phi_j^*(\xi) dV_i$	

REGIONAL TOTALS:

N	Region number	
ISS*	$\int S(\xi)S^*(\xi) dV_N$	(7)

<u>Output</u>	<u>Mathematical Definition</u>	<u>Reference Eq.</u>
IPP*	$\int \sum_j \phi_j(\xi) \phi_j^*(\xi) dV_N$	
C	Enrichment value from REX solution	
K	Multiplication constant from same. The value from the real solution is used for k_{eff} in the perturbation calculation.	

THE FOLLOWING INTEGRANDS ARE GIVEN FOR EACH POINT IN THE SUBREGION BEING PERTURBED:

NSF	$f_1(\xi_i)$	(10a)
ABS	$f_2(\xi_i)$	(10b)
R LEAK	$f_3(\xi_i)$	(10c)
T LEAK	$f_6(\xi_i)$	(10f)
B LEAK	$\delta B^2 \sum_j \phi_{i,j} \phi_{i,j}^* D_j$	
ELR	$f_4(\xi_i)$	(10d)
INEL	$f_5(\xi_i)$	(10e)

RADIAL DISTRIBUTION OF $\Delta k/k$, TOGETHER WITH THE CORRESPONDING COMPONENTS:

NSF	P_1/Q = Source term	(2)
ABS	P_2/Q = Capture + fission term	(3)
R LEAK	Radial component of the leakage term	
T LEAK	Transverse component of the leakage term	
B LEAK	P_3 = Buckling component of the leakage term	(1a)
ELR	P_4/Q = Elastic removal term	(5)
INEL	P_5/Q = Inelastic scattering term	(6)
DK/K	$\Delta k/k$ evaluated over (i,i+1)	(1)

<u>Output</u>	<u>Mathematical Definition</u>	<u>Reference Eq.</u>
RADIAL DISTRIBUTION OF $(\Delta k/k)/\Delta V$ TOGETHER WITH THE CORRESPONDING COMPONENTS:		
(Note: The values printed in this section are simply those from the section immediately above, divided by the corresponding increment in volume.)		
SUMMARY OF RESULTS FOR PASS NO._____, REGION NO._____.		
F	Integrating constant for $f_l (l \neq 6, 7)$	
T	Integrating constant for f_6	
G	Integrating constant for f_7	
TS	Q	(7)
EI	Eigenvalue for region being perturbed	(15),(22),(27)
	For a parallelepiped, $EI = \sqrt{\gamma_n^2 + \lambda_n^2}$	
	For all infinite geometries and spheres, $EI = 0$.	

(Note: See Section IV-A for description of remaining output.)

APPENDIX A
FORTRAN Statements and
Storage Locations for DEL

001 6/2/65 KVITEK, L. C. RP 342X
 HUMMEL H 01646RP 342X41491-53116704060251049000
 \$ COMPILE, ROW BINARY MODE

2949 ** 6981
 001

```

C   DEL, A PERTURBATION CODE WRITTEN IN FORTRAN BY L. C. KVITEK.
      DIMENSION RD(12,3),E3(50),MNUM(20),CVF(20),ATN(20),XTR(20,30),
      1D1(30),D2(30),DINS(30,29),DNFS(30),DCFP(30),DDIN(30),DERS(30),
      2PHI(125,30),APH(125,30),DPHI(125,30),DAPH(125,30),S(125),PPD(125),
      3AS(125),R(125),V(125),DKDV(7,125),PAP(125),SAS(125),DR(50),DX(50),
      4NINT(50),H(50),VR(50),RB(50),SR(50),PR(50),D(7,125),DK(7,125),
      5PP(125),SS(125),DT(125),DDT(125),Y(50),EIG(50),P(21),NAME(6),
      6E1(50),E2(50),TOT(7),GR2(8),GX(50),GY(50),DY(50),DOLD(30),DIF(30)
      7,GR1(8)
      INT1F(Z,G)=Z+.5/G*SINF(2.*G*Z)
      INT2F(Z,G)=2.*Z-INT1F(Z,G)
      INT3F(A,B,C)=A**2/2.*(B**2+C**2)
      INT4F(A,B,C,D)=INT3F(A,B,C)-A/D*B*C

C   INPUT 1000 THRU 5000 SERIES CARDS.
C
C   1 READ 2, PN,NC,(NAME(N),N=1,6)
C   2 FORMAT (F9.5,8X11,6X6A6)
C   READ 3, ((RD(L,N),L=1,12),N=1,NC)
C   3 FORMAT (12A6)
C   READ 4, NG,NGRS,NR,NLRP,NSRP,NGEO,NFT,NPR1,NPR2,NS2,NPS
C   4 FORMAT (12I6)
C   READ 5, (K,NINT(N),RB(N),H(N),Y(N),DX(N),DY(N),N=1,NR)
C   5 FORMAT (2I6,5E12.5)
C
C   FIND R(I), DR(N), AND NPT.
C
C   NPT=0
C   I=1
C   R(1)=0.
C   DO 11 N=1,NR
C   NPT=NPT+NINT(N)+1
C   SS(NPT)=0.
C   PP(NPT)=0.
C   FN=NINT(N)
C   IF (N-1) 6,6,7
C   6 DR(1)=RB(1)/FN
C   GO TO 8
C   7 DR(N)=(RB(N)-RB(N-1))/FN
C   8 I=I+1
C   R(I)=R(I-1)+DR(N)
C   IF (I-NPT) 8,9,9
C   9 IF (N-NR) 10,11,11
C   10 I=I+1
C   R(I)=R(I-1)
C   11 CONTINUE

```

C

```

C      FIND V(I).
C
      PI=3.1415927
      I=0
      DO 270 N=1,NLRP
      NI=NINT(N)
      I=I+1
      DO 17 L=1,NI
      IF (NGEQ-2) 12,161,164
12     IF (H(N)-1.E+10) 13,16,16
13     IF (Y(N)-1.E-10) 14,14,250
14     V(I)=PI*(R(I+1)-R(I))*(H(N)/2.)*2
333    V(I)=V(I)*2.
      GO TO 17
250    IF (Y(N)-1.E+10) 15,16,16
15     V(I)=H(N)*Y(N)*(R(I+1)-R(I))
      GO TO 333
16     V(I)=R(I+1)-R(I)
      GO TO 333
161    IF (H(N)-1.E+10) 162,163,163
162    V(I)=PI*H(N)*(R(I+1)**2-R(I)**2)
      GO TO 17
163    V(I)=PI*(R(I+1)**2-R(I)**2)
      GO TO 17
164    V(I)=4./3.*PI*(R(I+1)**3-R(I)**3)
17     I=I+1
270    V(I)=0.

C      READ FLUXES FROM REX TAPE 6 MOUNTED ON DRIVE 2 OR 3 AND 4.
C
      N=2
      L=1
18     IF (NFT-1) 20,20,19
19     N=N+1
20     IF (L-1) 21,21,22
21     IF (NPS) 221,221,220
220    IF (NFT-1) 860,860,861
860    NRS=(NG+3)*NPS*2
      GO TO 862
861    NRS=(NG+3)*NPS
862    I=N-1
      DO 222 K=1,NFT
      I=I+1
      DO 222 J=1,NRS
222    READ TAPE I
221    READ TAPE N, X,X,X,PNT1,X,C1,X,FK1
      READ TAPE N, X,X,X,(S(I),I=1,NPT)
      GO TO 23
22    READ TAPE N, X,X,X,PNT2,X,C2,X,FK2
      READ TAPE N, X,X,X,(AS(I),I=1,NPT)
23    READ TAPE N
      DO 26 J=1,NG

```

```

      IF (L-1) 24,24,25
24  READ TAPE N, X,X,X,(PHI(I,J),I=1,NPT)
      GO TO 26
25  READ TAPE N, X,X,X,(APH(I,J),I=1,NPT)
26  CONTINUE
      L=L+1
      IF (L-2) 18,18,170

```

C
C
C

FIND FLUX DERIVATIVES.

```

170 K=NGEO-1
      I=0
      DO 189 N=1,NLRP
        EIG(N)=0.
        NP=NINT(N)+1
        C=DR(N)/2.
        DO 189 L=1, NP
          I=I+1
          IF (I-1) 171,171,173
171  DO 172 J=1,NG
          DPHI(I,J)=0.
172  DAPH(I,J)=0.
          GO TO 189
173  IF (I-NPT) 174,179,179
174  A=(1.+C/R(I))*K
          B=(1.-C/R(I))*K
175  IF (L-1) 176,176,178
176  DO 177 J=1,NG
          DPHI(I,J)=(4.*PHI(I+1,J)-3.*PHI(I,J)-PHI(I+2,J))/2./DR(N)
177  DAPH(I,J)=(4.*APH(I+1,J)-3.*APH(I,J)-APH(I+2,J))/2./DR(N)
          GO TO 189
178  IF (L-NP) 185,179,179
179  DO 180 J=1,NG
          DPHI(I,J)=(3.*PHI(I,J)-4.*PHI(I-1,J)+PHI(I-2,J))/2./DR(N)
180  DAPH(I,J)=(3.*APH(I,J)-4.*APH(I-1,J)+APH(I-2,J))/2./DR(N)
          GO TO 189
185  I4=I+1
186  I5=I-1
187  DO 188 J=1,NG
          DPHI(I,J)=A*PHI(I4,J)+(B-A)*PHI(I,J)-B*PHI(I5,J)
          DAPH(I,J)=A*APH(I4,J)+(B-A)*APH(I,J)-B*APH(I5,J)
          DPHI(I,J)=DPHI(I,J)/(R(I4)-R(I5))
188  DAPH(I,J)=DAPH(I,J)/(R(I4)-R(I5))
189  CONTINUE
          NPT2=I
          NPASS=1
          NRPL=0

```

C
C
C

INPUT PARAMETERS FOR SUBREGION BEING PERTURBED.

```

160 READ74, NRP,INTS,INTF,MT,NLGS,MP,NTR2,KLRT,DB2
74  FORMAT(8I6,E12.5)

```

```

      DO 27 J=1,NG
27  DOLD(J)=D2(J)
      IF (NPASS-1) 165,165,157
157  IF (KLRT) 166,166,165
165  PV=0.
      DO 1166 K=1,8
1166 GR1(K)=0.
166  IF (MT-1) 59,28,31
28  NMAT=1
      DB2=0.

```

C
C
C

INPUT PERTURBED CROSS SECTIONS.

```

      READ 29, (DNFS(J),J=1,NG)
29  FORMAT (6E12.5)
      READ 29, (DCFP(J),J=1,NG)
      READ 29, (DDIN(J),J=1,NG)
      READ 29, (DERS(J),J=1,NG)
      DO 30 J=1,NLGS
30  READ 29, (DINS(J,K),K=1,NGRS)
      GO TO 59

```

C
C
C
C

INPUT MATERIAL NUMBERS AND VOLUME FRACTIONS, READ CROSS SECTIONS FROM DRIVE 5, AND FIND PERTURBATIONS.

```

31  READ 4, (MNUM(M),M=1,MT)
      READ 29, (CVF(M),M=1,MT),DVF
      IFLAG=0
      REWIND 5
      NMAT=MT
      DO 49 M=1,NMAT
32  READ TAPE 5, MNT,N,N,N,N,ATN(M)
      IF (MNT-MNUM(M)) 43,34,48
43  DO 44 L=1,5
44  READ TAPE 5
      GO TO 32
34  IF (MNUM(M)-MP) 47,45,47
45  READ TAPE 5, (DNFS(J),J=1,NG)
      READ TAPE 5, (DCFP(J),J=1,NG)
      READ TAPE 5, (XTR(M,J),J=1,NG)
      READ TAPE 5, (DERS(J),J=1,NG)
      READ TAPE 5, ((DINS(J,K),K=1,NGRS),J=1,NG)
      M1=M
      DO 46 J=1,NG
      DNFS(J)=DNFS(J)*DVF
      DCFP(J)=DCFP(J)*DVF
      DERS(J)=DERS(J)*DVF
      DO 46 K=1,NGRS
46  DINS(J,K)=DINS(J,K)*DVF
      GO TO 49
47  READ TAPE 5
      READ TAPE 5

```



```

      READ TAPE 5, (XTR(M,J),J=1,NG)
      READ TAPE 5
      READ TAPE 5
      GO TO 49
48  REWIND 5
      MSTOP=M
      IFLAG=IFLAG+1
      IF (IFLAG-1) 32,32,684
49  CONTINUE
      DO 56 J=1,NG
      D1(J)=0.
      D2(J)=0.
      DO 55 M=1,NMAT
      D1(J)=D1(J)+CVF(M)*XTR(M,J)
      IF (NTR2) 50,50,51
50  D2(J)=D1(J)
      GO TO 55
51  IF (MNUM(M)-MP) 52,53,52
52  VF=CVF(M)
      GO TO 54
53  VF=CVF(M)+DVF
54  D2(J)=D2(J)+VF*XTR(M,J)
55  CONTINUE
      DIF(J)=1./3./D2(J)
56  DDIN(J)=-DVF*XTR(M1,J)*DIF(J)/D1(J)
59  IF (NPASS-1) 61,61,60
60  IF (NRP-NRPL) 61,61,66
      FIND SAS(I) AND PAP(I).
      C
      C
      C
61  DO 65 I=1,NPT
      DO 62 K=1,5
      DK(K,I)=0.
      DKDV(K,I)=0.
62  D(K,I)=0.
      IF (NPASS-1) 63,63,65
63  SAS(I)=S(I)*AS(I)
      PAP(I)=0.
      DO 64 J=1,NG
64  PAP(I)=PAP(I)+PHI(I,J)*APH(I,J)
65  CONTINUE
66  CONTINUE
      C
      C
      C
      FIND PERTURBATION BOUNDARIES AND INTEGRANDS OF NUMERATOR.
      N=1
      I2=0
67  IF (N-NRP) 68,69,69
68  I2=I2+NINT(N)+1
      N=N+1
      GO TO 67
69  IF (NS2) 184,184,57

```

```

57 IF (NRP-NRPL-1) 184,181,184
181 DO 182 J=1,NG
284 DNEW=D2(J)
285 DPHI(I2+1,J)=DPHI(I2,J)*(DNEW/DOLD(J))
182 DAPH(I2+1,J)=DAPH(I2,J)*(DNEW/DOLD(J))
184 I1=I2+INIS
      I2=I2+INTF+1
      DO 773 I=I1,I2
      DO 669 K=1,7
669 D(K,I)=0.
      DO 73 J=1,NG
      D(1,I)=D(1,I)+PHI(I,J)*AS(I)*DNFS(J)
      D(2,I)=D(2,I)+(PHI(I,J)*APH(I,J))*DCFP(J)
      D(3,I)=D(3,I)+DPHI(I,J)*DAPH(I,J)*DDIN(J)
      D(4,I)=D(4,I)+(PHI(I,J)*APH(I,J))*DDIN(J)
      D(5,I)=D(5,I)+(PHI(I,J)*APH(I,J))*DIF(J)
      IF (J-NG) 70,73,73
70 D(6,I)=D(6,I)+PHI(I,J)*(APH(I,J)-APH(I,J+1))*DERS(J)
      IF (J-NLGS) 71,71,73
71 SCAT=0.
      DO 72 K=1,NGRS
      JPK=J+K
72 SCAT=SCAT+(APH(I,J)-APH(I,JPK))*DINS(J,K)
      D(7,I)=D(7,I)+PHI(I,J)*SCAT
73 CONTINUE
773 D(5,I)=D(5,I)*DB2
      I2=I2-1
C
C      FIND EIGENVALUES AND INTEGRATION CONSTANTS.
C
      M=NGEO-1
      IF (NPASS-1) 798,798,822
798 DO 813 N=1,NR
799 IF (NGEO-2) 800,807,811
800 IF (H(N)-1.E+10) 801,801,806
801 IF (Y(N)-1.E-10) 802,802,803
802 EIG(N)=2.4048/(H(N)/2.+DX(N))
      A1=EIG(N)*H(N)/2.
      BN=BESJF(A1,0.,2,18,XLOCF(P))
      F=PI*DR(N)*INT3F(H(N)/2.,P(1),P(2))
      T=PI*DR(N)*EIG(N)*2*INT4F(H(N)/2.,P(2),P(3),EIG(N))
      A2=2.4048
      BN=BESJF(A2,0.,2,18,XLOCF(P))
      G=PI*DR(N)*INT3F(H(N)/2.+DX(N),P(1),P(2))
      GO TO 812
803 IF (Y(N)-1.E+10) 804,909,909
804 GX(N)=PI/(H(N)+2.*DX(N))
      GY(N)=PI/(Y(N)+2.*DY(N))
      F=DR(N)/2.*INT1F(H(N)/2.,GX(N))*INT1F(Y(N)/2.,GY(N))
      T=DR(N)/2.*(GX*GX*INT1F(Y(N)/2.,GY(N))*INT2F(H(N)/2.,GX(N))+
1GY*GY*INT1F(H(N)/2.,GX(N))*INT2F(Y(N)/2.,DY(N)))
      G=DR(N)/2.*INT1F(H(N)/2.+DX(N),GX(N))*INT1F(Y(N)/2.+DY(N),GY(N))

```

```

      EIG(N)=SQRTF(GX(N)**2+GY(N)**2)
      GO TO 812
909  EIG(N)=PI/(H(N)+2.*DX(N))
      F=(DR(N)/2.)*INT1F(H(N)/2.,EIG(N))
      T=(DR(N)/2.)*EIG(N)*EIG(N)*INT2F(H(N)/2.,EIG(N))
      G=(DR(N)/2.)*INT1F(H(N)/2.+DX(N),EIG(N))
      GO TO 812
809  F=PI*DR(N)
      T=0.
      G=F
      GO TO 812
806  EIG(N)=0.
      F=DR(N)/2.
      T=0.
      G=F
      GO TO 812
807  IF (H(N)-1.E+10) 808,809,809
808  EIG(N)=PI/(H(N)+2.*DX(N))
      Z=EIG(N)
      F=PI*DR(N)*INT1F(H(N)/2.,Z)
      T=PI*DR(N)*Z**2*INT2F(H(N)/2.,Z)
      G=PI*DR(N)*INT1F(H(N)/2.+DX(N),Z)
      GO TO 812
811  EIG(N)=0.
      F=PI*DR(N)*2.
      T=0.
      G=F
812  E1(N)=F
      E2(N)=G
813  E3(N)=T
CCC  FIND DK/K AND (DK/K)/DV.
80  I=0
      TS=0.
      DO 810 N=1,NR
      G=E2(N)
      ERR=G*DR(N)/3.
      SR(N)=0.
      PR(N)=0.
      NI=NINT(N)
      DO 81 L=1,NI
      I=I+1
      IF (NGEO-2) 841,842,842
841  SS(I)=G*(SAS(I)+SAS(I+1))
      PP(I)=G*(PAP(I)+PAP(I+1))
      GO TO 821
842  SS(I)=G*(SAS(I)*R(I)**M+SAS(I+1)*R(I+1)**M)
      PP(I)=G*(PAP(I)*R(I)**M+PAP(I+1)*R(I+1)**M)
      IF (NGEO-3) 821,817,821
817  SS(I)=SS(I)+ERR*(R(I)*SAS(I)-R(I+1)*SAS(I+1))
      PP(I)=PP(I)+ERR*(R(I)*PAP(I)-R(I+1)*PAP(I+1))

```

```

821 CONTINUE
   SR(N)=SR(N)+SS(I)
   81 PR(N)=PR(N)+PP(I)
      I=I+1
810 TS=TS+SR(N)
822 F=E1(NRP)
      G=E2(NRP)
      T=E3(NRP)
      VP=0.
      DO 823 I=I1,I2
         VP=VP+V(I)
         DT(I)=0.
823 DDT(I)=0.
         PV=PV+VP
         ER=DR(N)/3./TS/FK1
         TDK=0.
         DO 883 K=1,7
            TOT(K)=0.
            IF (K-4) 824,825,824
824 FAC=F/TS/FK1
            ERR=F*ER
            GO TO 826
825 FAC=T/TS/FK1
            ERR=T*ER
826 DO 83 I=I1,I2
            IF (NGEO-2) 827,828,828
827 DK(K,I)=FAC*(D(K,I)+D(K,I+1))
            GO TO 838
828 DK(K,I)=FAC*(D(K,I)*R(I)**M+D(K,I+1)*R(I+1)**M)
            IF (NGEO-3) 838,829,838
829 DK(K,I)=DK(K,I)+ERR*(D(K,I)*R(I)-D(K,I+1)*R(I+1))
838 IF (K-1) 840,840,839
839 DK(K,I)=-DK(K,I)
840 DKDV(K,I)=DK(K,I)/V(I)
            DT(I)=DT(I)+DK(K,I)
            TOT(K)=TOT(K)+DK(K,I)
            TDK=TDK+DK(K,I)
            83 DDT(I)=DDT(I)+DKDV(K,I)
            GR1(K)=GR1(K)+TOT(K)
883 GR2(K)=GR1(K)/PV
            GR1(8)=GR1(8)+TDK
            GR2(8)=GR1(8)/PV
            I3=I2+1

C
C
C      PRINT RESULTS.
684 IF (NPASS-1) 84,84,85
   84 NP=0
      NS=0
   85 NS=NS+1
      NP=NP+1
      WRITE OUTPUT TAPE 6, 86, PN,(NAME(I),I=1,6),NP,((RD(L,M),L=1,12),M

```

```

1=1,NC)
86 FORMAT (20H1DEL PROBLEM NUMBER F9.5,15H, SUBMITTED BY 6A6,
125X4HPAGEI3//((1X12A6))
GO TO (87,102,112,114,120,122,128,130,132,138,141,148,150,91), NS
87 WRITE OUTPUT TAPE 6, 88, NG,NGRS,NR,NLRP,NSRP,NGEO,NFT,NPR1,
1NPR2,NS2,NPS
88 FORMAT (/68H NGRP      NGRS      NREG      NLRP      NSRP      NGEO
1 NFLT      NPR1      5X4HNPR25X4HDERV5X4HNPRS//15,11I9)
WRITE OUTPUT TAPE 6, 90, (N,NINT(N),RB(N),H(N),Y(N),DX(N),DY(N),
1N=1,NR)
90 FORMAT (/14H      N      NINT8X7HR OUTER 9X6H H(N) 10X4HY(N)11X5HDX(N
1)10X5HDY(N)//((15,19,2X1P5E15.5))
91 WRITE OUTPUT TAPE 6, 92, NRP,INTS,INTF,MT,NLGS,MP,NTR2,KLRT,DB2
92 FORMAT (/59H NRBP      INTS      INTF      NMAT      NLGS      MATP
1 NTR25X4HKLRT13X3HDB2//15,7I9,1PE21.5)
93 WRITE OUTPUT TAPE 6, 94, (MNUM(I),CVF(I),I=1,NMAT)
94 FORMAT (/89H MATN      CRITICAL VF      MATN      CRITICAL VF      MATN
1 CRITICAL VF      MATN      CRITICAL VF4X19HMATN      CRITICAL VF//((15,1
2PE15.5,18,E15.5,18,E15.5,18,E15.5,18,E15.5,18,E15.5))
WRITE OUTPUT TAPE 6, 95, DVF
95 FORMAT (/5H DVF=1PE15.5)
WRITE OUTPUT TAPE 6, 89
89 FORMAT (/15H PERTURBATIONS.)
WRITE OUTPUT TAPE 6, 96, (J,DNFS(J),DCFP(J),DDIN(J),DERS(J),(DINS(
1J,K),K=1,4),J=1,NG)
96 FORMAT (/5H      J6X4HDNSF10X4HDC+F10X4HDDIF10X4HDELR8X8HJ TO J+16X8
1HJ TO J+26X8HJ TO J+36X8HJ TO J+47//((15,1P8E14.5))
IF (NGRS-4) 99,99,97
97 WRITE OUTPUT TAPE 6, 98, (J,(DINS(J,K),K=5,12),J=1,NLGS)
98 FORMAT (/17H      J      J TO J+56X8HJ TO J+66X8HJ TO J+76X8HJ TO J+86
1X8HJ TO J+96X8HJ TO J+105X8HJ TO J+115X8HJ TO J+127//((15,1P8E14.5))
99 IF (NPASS-1) 100,100,121
100 IF (NPR1) 113,113,85
102 L=0
WRITE OUTPUT TAPE 6, 103
103 FORMAT (/15H      J4X1HI7X4HR(I)9X8HPHI(I,J)7X9HPHI*(I,J)6X9HDPHI(I,
1J)5X10HDPHI*(I,J)//)
DO 111 J=1,NG
DO 111 I=1,NPT2
104 L=L+1
IF (L-50) 105,105,110
105 IF (I-1) 106,106,108
106 WRITE OUTPUT TAPE 6, 107, J,I,R(I),PHI(I,J),APH(I,J),DPHI(I,J),DAP
1H(I,J)
107 FORMAT (2I5,1P5E15.5)
GO TO 111
108 WRITE OUTPUT TAPE 6, 109, I,R(I),PHI(I,J),APH(I,J),DPHI(I,J),DAPH(
1I,J)
109 FORMAT (1I0,1P5E15.5)
GO TO 111
110 NS=2
GO TO 85

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111 CONTINUE
    GO TO 113
112 WRITE OUTPUT TAPE 6, 103
    L=1
    GO TO 106
113 IF (NPR2) 121,121,850
850 NS=3
    GO TO 85
114 WRITE OUTPUT TAPE 6, 115
115 FORMAT (/5H      19X1HR14X1HS13X2HS*13X3HSS*12X3HPP*11X4HISS*11X4HI
    1PP*//)
    L=0
    DO 119 I=1,NPT
    L=L+1
    IF (L-50) 116,116,118
116 WRITE OUTPUT TAPE 6, 117, I,R(I),S(I),AS(I),SAS(I),PAP(I),SS(I),PP
    1(I)
117 FORMAT (15,1P7E15.5)
    GO TO 119
118 NS=4
    GO TO 85
119 CONTINUE
    WRITE OUTPUT TAPE 6, 190, (N,SR(N),PR(N),N=1,NR)
    GO TO 121
120 WRITE OUTPUT TAPE 6, 115
    L=1
    GO TO 116
121 NS=5
    GO TO 85
122 WRITE OUTPUT TAPE 6, 123, PNT1,C1,FK1,PNT2,C2,FK2
123 FORMAT (/47H THE REAL FLUXES ARE TAKEN FROM PROBLEM NUMBER F9.5,10
    1H WHERE C= F7.5,8H AND K= F8.6,1H./47H THE ADJ. FLUXES ARE TAKEN F
    2ROM PROBLEM NUMBER F9.5,10H WHERE C= F7.5,8H AND K= F8.6,1H./84H T
    3HE FOLLOWING INTEGRANDS ARE GIVEN FOR EACH POINT IN THE SUBREGION
    4BEING PERTURBED.)
    WRITE OUTPUT TAPE 6, 124
124 FORMAT(/3H      17X1HR 11X3HNSF 10X3HABS8X6HR LEAK7X6HT LEAK7X6HB LEAK
    1 9X3HELR 9X4HINEL //)
    L=0
    DO 127 I=11,13
    L=L+1
    IF (L-50) 125,125,126
125 WRITE OUTPUT TAPE 6,1117, I,R(I),(D(K,I),K=1,7)
1117 FORMAT(13,1P9E13.5)
    GO TO 127
126 NS=6
    GO TO 85
127 CONTINUE
    GO TO 129
128 IF (IFLAG-1) 630,630,628
628 WRITE OUTPUT TAPE 6, 629, MNUM(MSTOP)
629 FORMAT(/32H CROSS SECTIONS FOR MATERIAL NO. 13,19H ARE NOT ON TAPE

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1 5.)
GO TO 168
630 WRITE OUTPUT TAPE 6, 124
L=1
GO TO 125
129 NS=7
GO TO 85
130 WRITE OUTPUT TAPE 6, 131
131 FORMAT (/72H RADIAL DISTRIBUTION OF DK/K TOGETHER WITH THE CORRESP
ONDING COMPONENTS.)
MS=1
132 WRITE OUTPUT TAPE 6, 137
L=0
GO TO (133,139), MS
133 DO 136 I=11,12
139 L=L+1
IF (L-50) 134,134,135
134 WRITE OUTPUT TAPE 6,1117, I,R(I),(DK(K,I),K=1,7),DT(I)
GO TO 136
135 MS=2
NS=8
GO TO 85
136 CONTINUE
137 FORMAT(/3H 17X1HR 11X3HNSF 10X3HABS8X6HR LEAK7X6HT LEAK7X6HB LEAK
1 9X3HELR 9X4HINEL 9X4HDK/K //)
NS=9
WRITE OUTPUT TAPE 6, 301, (TOT(K),K=1,7),TDK
301 FORMAT(/1H 4X11HPASS TOTALS 1P8E13.5)
WRITE OUTPUT TAPE 6, 1301, (GR1(K),K=1,8)
1301 FORMAT(/1H 2X13H GRAND TOTALS 1P8E13.5)
GO TO 85
138 WRITE OUTPUT TAPE 6, 140
140 FORMAT (/77H RADIAL DISTRIBUTION OF (DK/K)/DV TOGETHER WITH THE CO
RRRESPONDING COMPONENTS.)
MS=1
141 WRITE OUTPUT TAPE 6, 142
142 FORMAT(/3H 16X2HDV11X3HNSF 10X3HABS8X6HR LEAK7X6HT LEAK7X6HB LEAK
1 9X3HELR 9X4HINEL 7X9H(DK/K)/DV //)
L=0
GO TO (143,144), MS
143 DO 147 I=11,12
144 L=L+1
IF (L-50) 145,145,146
145 WRITE OUTPUT TAPE 6,1117, I,V(I),(DKDV(K,I),K=1,7),DDT(I)
GO TO 147
146 MS=2
NS=10
GO TO 85
147 CONTINUE
DO 302 K=1,7
302 TOT(K)=TOT(K)/VP
TDK=TDK/VP

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WRITE OUTPUT TAPE 6, 301, (TOT(K),K=1,7),TOK
WRITE OUTPUT TAPE 6, 1301, (GR2(K),K=1,8)
NS=11
MS=1
GO TO 85
148 WRITE OUTPUT TAPE 6, 149, NPASS,NRP, F,T,G,TS,EIG(NRP)
149 FORMAT(/32H SUMMARY OF RESULTS FOR PASS NO. 13,12H, REGION NO. 13,
11H.//4H F=1PE12.5/4H T=E12.5/4H G=E12.5/4H TS=E12.5/4H EI=E12.5
2)
150 WRITE OUTPUT TAPE 6, 151
151 FORMAT (/5H 19X1HR13X2HDV12X4HDK/K11X5HTOTAL8X9H(DK/K)/DV8X5HTO
11AL//)
L=0
GO TO (152,153), MS
152 D3=0.
D4=0.
VT=0.
DO 156 I=11,12
153 L=L+1
D3=D3+DT(I)
VT=VT+V(I)
D4=D3/VT
IF (L-50) 154,154,155
154 WRITE OUTPUT TAPE 6, 117, I,R(I),V(I),DT(I),D3,DDT(I),D4
GO TO 156
155 MS=2
NS=12
GO TO 85
156 CONTINUE
WRITE OUTPUT TAPE 6, 1159
1159 FORMAT( /13H PASS TOTALS.)
WRITE OUTPUT TAPE 6, 159, VT,D3,D4
159 FORMAT ( /18H VOLUME PERTURBED=1PE12.5/12X6H DK/
1K=E12.5/7X11H (DK/K)/DV=E12.5)
WRITE OUTPUT TAPE 6, 1168
1168 FORMAT( /14H GRAND TOTALS.)
WRITE OUTPUT TAPE 6, 159, PV,GR1(8),GR2(8)
168 END FILE 6
NPASS=NPASS+1
NS=13
NRPL=NRP
IF (NPASS-NSRP) 160,160,1
190 FORMAT (/17H REGIONAL TOTALS.//5H N7X4HISS*11X4HIPP*//15,1P2E1
15.5))
END ( 1 , 1 , 0 , 1 , 0 )

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ANL-30

NAMES OF ARITHMETIC STATEMENT FUNCTIONS WITH CORRESPONDING INTERNAL FORMULA NUMBERS AND OCTAL LOCATIONS

INT1	IFN	LOC	INT2	IFN	LOC	INT3	IFN	LOC	INT4	IFN	LOC	IFN	LOC	
	2	07605		3	07623		4	07641		5	07655			
EXTERNAL FORMULA NUMBERS WITH CORRESPONDING INTERNAL FORMULA NUMBERS AND OCTAL LOCATIONS														
EFN	IFN	LOC	EFN	IFN	LOC	EFN	IFN	LOC	EFN	IFN	LOC	EFN	IFN	LOC
1	6	00015	1	12	00037	2	13	00000	3	22	00000	4	26	00000
5	33	00000	6	43	00214	7	45	00222	8	46	00231	9	49	00245
10	50	00252	11	52	00261	12	60	00315	13	61	00323	14	62	00327
333	63	00345	250	65	00351	15	66	00355	16	68	00367	161	70	00374
162	71	00401	163	73	00417	164	75	00433	17	76	00453	270	77	00461
18	80	00476	19	81	00503	20	82	00512	21	83	00516	220	84	00523
860	85	00527	861	87	00544	862	88	00553	222	92	00574	222	94	00000
221	95	00616	221	98	00641	22	108	00673	22	111	00716	23	120	00746
23	122	00000	24	125	01017	24	132	01041	25	134	01044	25	141	01066
26	142	01070	170	145	01107	171	154	01151	172	156	01157	173	158	01166
174	159	01172	175	161	01222	176	162	01226	177	164	01253	178	166	01273
179	167	01300	180	169	01325	185	171	01345	186	172	01352	187	173	01357
188	177	01435	189	178	01457	160	182	01476	160	184	01522	74	185	00000
27	187	01527	157	189	01540	165	190	01544	1166	192	01547	166	193	01553
28	194	01560	29	202	00000	30	222	01707	30	227	01725	31	229	01732
31	234	01752	32	245	02041	32	247	02063	43	249	02073	44	250	02074
44	251	00000	34	253	02110	45	254	02117	45	259	02134	46	292	02274
47	294	02306	47	295	00000	48	309	02372	48	309	02372	49	313	02410
50	320	02451	51	322	02454	52	323	02457	53	325	02463	54	326	02466
55	327	02472	56	329	02505	59	330	02522	60	331	02527	61	332	02533
62	336	02556	63	338	02567	64	341	02574	65	342	02603	66	343	02611
67	346	02617	68	347	02623	69	350	02635	57	351	02641	181	352	02647
284	353	02653	285	354	02655	182	355	02661	184	356	02670	669	360	02761
70	368	03056	71	370	03074	72	373	03112	73	375	03141	773	376	03152
798	380	03207	799	381	03212	800	382	03216	801	383	03222	802	384	03226
803	393	03413	804	394	03417	909	401	03633	809	406	03730	806	410	03741
807	415	03753	808	416	03757	811	422	04063	812	426	04077	813	428	04103
80	429	04107	841	440	04150	842	443	04166	817	446	04257	821	448	04305
81	450	04310	810	452	04322	822	453	04331	823	460	04351	824	467	04427
825	470	04441	826	472	04452	827	474	04461	828	476	04470	829	478	04527
838	479	04542	839	480	04547	840	481	04551	83	485	04565	883	487	04577
684	491	04620	84	492	04624	85	494	04652	86	509	00000	87	511	04747
87	513	04773	88	514	00000	90	521	00000	91	522	05032	91	524	05054
92	525	00000	93	526	05056	93	531	05077	94	532	00000	95	536	00000
89	539	00000	96	548	00000	97	550	05174	97	557	05227	98	558	00000
99	559	05231	100	560	05235	102	561	05242	103	564	00000	104	567	05273
105	569	05302	106	570	05312	106	572	05332	107	573	00000	108	575	05337
108	577	05356	109	578	00000	110	580	05363	111	582	05370	112	584	05405
112	585	05414	113	588	05422	850	589	05426	114	591	05434	114	592	05443
115	593	00000	116	598	05467	116	600	05510	117	601	00000	118	603	05514
119	605	05521	120	613	05554	120	614	05563	121	617	05570	122	619	05574
122	621	05613	123	622	00000	124	625	00000	125	630	05671	125	636	05713

1117	637	00000
628	646	05761
130	655	06005
133	663	06042
136	677	06142
138	696	06226
143	704	06253
147	718	06353
150	741	06472
154	755	06546
159	769	00000

126	639	05720
629	647	00000
130	656	06014
139	664	06074
137	678	00000
140	697	00000
144	705	06305
302	720	06362
150	742	06501
154	757	06566
1168	772	00000

127	641	05725
630	649	05764
131	657	00000
134	666	06103
301	686	00000
141	699	06236
145	707	06314
148	737	06444
151	743	00000
155	759	06572
168	776	06663

128	643	05741
630	650	05773
132	659	06024
134	672	06127
1301	693	00000
141	700	06245
145	713	06340
148	739	06465
152	746	06510
156	762	06601
168	776	06663

628	644	05746
129	653	06000
132	660	06033
135	674	06133
138	695	06217
142	701	00000
146	715	06344
149	740	00000
153	750	06526
1159	765	00000
190	781	00000

STORAGE NOT USED BY PROGRAM

DEC	OCT
25818	62332

DEC	OCT
32562	77462

LOCATIONS OF NAMES IN TRANSFER VECTOR

EXP(2	DEC	OCT
(CSH)	8	00010
(RTN)	7	00007

BESJ	DEC	OCT
(FIL)	4	00004
(STH)	0	00000
	1	00001

SIN	DEC	OCT
(IOH)I	11	00013
	9	00011

SQRT	DEC	OCT
(IOH)O	3	00003
	2	00002

XLOC	DEC	OCT
(LEV)	5	00005
	10	00012

STORAGE LOCATIONS FOR VARIABLES APPEARING IN DIMENSION AND EQUIVALENCE SENTENCES

H	DEC	OCT
EIG	24502	57666
DX	23702	56226
DOLD	24602	60032
DIF	23360	55500
DAFH	23330	55442
AS	10536	24450
PAP	25277	61275
P	24902	60506
SR	23652	56144
V	24352	57440
	25027	60703

GY	DEC	OCT
E3	23460	55644
DT	25817	62331
DNFS	24002	56702
DEFS	25647	62057
D2	25557	61725
APH	25677	62115
PHI	18036	43164
RB	21786	52432
S	24402	57522
XTR	25527	61667
	23256	55330

GX	DEC	OCT
E2	23510	55726
D	23575	56027
DK	5911	13427
DDT	5036	11654
D1	23877	56505
MNUM	25707	62153
PPD	25767	62247
RD	25402	61472
SS	23292	55374
Y	24127	57077
	23752	56310

GR2	DEC	OCT
E1	23518	55736
DR	23625	56111
DKDV	24652	60114
DDIN	6786	15202
CVF	25587	61763
NAME	25747	62223
PP	23631	56117
R	24252	57274
TOT	25152	61100
	23525	55745

GR1	DEC	OCT
DY	23300	55404
DPHI	23410	55562
DINS	14286	33716
DCFP	22656	54200
ATN	25617	62021
NINT	25727	62177
PR	24552	57750
SAS	24302	57356
VR	24777	60311
	24452	57604

STORAGE LOCATIONS FOR VARIABLES NOT APPEARING IN DIMENSION, EQUIVALENCE OR COMMON SENTENCES

I	DEC	OCT
I4	4161	10101
F	4156	10074
ER	4151	10067
D4	4146	10062
B	4141	10055
JPK	4136	10050
M1	4131	10043
MSTOP	4126	10036
NGRS	4121	10031
	4116	10024

INTS	DEC	OCT
I3	4160	10100
FN	4155	10073
ERR	4150	10066
D3	4145	10061
BN	4140	10054
J	4135	10047
MNT	4130	10042
MT	4125	10035
NG	4120	10030
	4115	10023

INTF	DEC	OCT
I2	4159	10077
FK2	4154	10072
DVF	4149	10065
C	4144	10060
A	4139	10053
KLRT	4134	10046
MP	4129	10041
NC	4124	10034
NI	4119	10027
	4114	10022

IFLAG	DEC	OCT
I1	4158	10076
FK1	4153	10071
DNEW	4148	10064
C2	4143	10057
A2	4138	10052
K	4133	10045
M	4128	10040
NFT	4123	10033
NLGS	4118	10026
	4113	10021

I5	DEC	OCT
G	4157	10075
FAC	4152	10070
DB2	4147	10063
C1	4142	10056
A1	4137	10051
L	4132	10044
MS	4127	10037
NGEO	4122	10032
NLRP	4117	10025
	4112	10020

NMAT	4111	10017	NPASS	4110	10016	NPR1	4109	10015	NPR2	4108	10014	NP	4107	10013
NPS	4106	10012	NPT2	4105	10011	NPT	4104	10010	NRPL	4103	10007	NRP	4102	10006
NR	4101	10005	NRS	4100	10004	N	4099	10003	NS2	4098	10002	NSRP	4097	10001
NS	4096	10000	NTR2	4095	07777	PI	4094	07776	PN	4093	07775	PNT1	4092	07774
PNT2	4091	07773	PV	4090	07772	SCAT	4089	07771	TDK	4088	07770	T	4087	07767
TS	4086	07766	VF	4085	07765	VP	4084	07764	VT	4083	07763	X	4082	07762
Z	4081	07761												

STORAGE LOCATIONS FOR SYMBOLS NOT APPEARING IN SOURCE PROGRAM

E)86Q	DEC	OCT	E)A6Q	DEC	OCT	E)96Q	DEC	OCT	E)66Q	DEC	OCT	E)36Q	DEC	OCT
E)194	2459	04633	E)174	2468	04644	E)16Q	2464	04640	E)10C	2462	04636	E)90	2472	04650
E)9K	3228	06234	E)9J	2585	05031	E)9A	2472	04650	E)96	151	00227	E)93	3449	06571
E)8S	3384	06470	E)8N	3363	06443	E)8M	3299	06343	E)8L	3266	06302	E)8H	3214	06216
E)8G	3162	06132	E)8E	3105	06041	E)82	3090	06022	E)7V	3076	06004	E)7S	3039	05737
E)70	3035	05733	E)7N	3022	05716	E)7I	2891	05513	E)71	2843	05433	E)63	2820	05404
E)5Q	2801	05361	E)5P	2781	05335	E)5M	2721	05241	E)5E	2534	04746	E)5A	2165	04165
E)4D	2016	03740	E)45	2007	03727	E)3H	1802	03412	E)3D	1632	03140	E)2I	1581	03055
E)23	1330	02462	E)1G	1272	02370	E)17	1101	02115	E)15	1081	02071	E)13	829	01475
E)11	629	01165	E)1T	442	00672	E)1R	355	00543	E)1Q	338	00522	E)1K	328	00510
E)1G	316	00474	E)1E	282	00432	E)1B	256	00400	E)1	251	00373	E)788	209	00321
D)77M	180	00264	D)72A	169	00251	D)726	144	00220	D)6Y6	12	00014	D)680	2998	05666
D)548	2759	05307	D)49M	710	01306	D)496	668	01234	D)480	3267	06303	D)481	3130	06072
D)480	1305	02431	D)468	3413	06525	D)448	3268	06304	D)42F	3131	06073	D)411	2870	05466
D)388	2861	05455	D)37M	2264	04330	D)32A	1306	02432	D)32C	814	01456	D)28H	317	00475
D)27T	2999	05667	D)25E	2760	05310	D)18M	711	01307	D)188	669	01235	D)17M	3040	05740
D)19K	2833	05421	D)194	1630	03136	D)146	1604	03104	C)20B	1056	02040	C)209	3506	06662
D)159	3385	06471	D)14I	3229	06235	C)20E	3091	06023	C)204	3000	05670	C)202	2761	05311
D)126	1539	03003	D)110	1361	02521	C)109	1287	02407	C)107	1140	02164	C)106	712	01310
C)208	670	01236	C)206	397	00615	C)103	4080	07760	C)102	4079	07757	C)101	4078	07756
C)105	4077	07755	C)10A	4076	07754	C)10A	4075	07753	C)101	4074	07752	C)100	4073	07751
C)105	4072	07750	C)104	4071	07747	C)10A	4070	07746	C)100	4069	07745	C)100	4068	07744
C)105	4067	07743	C)104	4066	07742	C)103	4065	07741	C)100	4064	07740	C)100	4063	07737
C)105	4062	07736	C)104	4061	07735	C)103	4060	07734	C)100	4059	07733	C)100	4058	07732
C)105	4057	07731	C)104	4056	07730	C)103	4055	07727	C)100	4054	07726	C)100	4053	07725
C)105	4052	07724	C)104	4051	07723	C)103	3960	07570	C)100	3659	07113	C)100	3571	06763
C)105	3590	07006	C)104	3708	07174	C)103	3705	07171	C)100	3665	07121	C)100	3567	06757
C)105	3586	07002	C)104	3601	07021	C)103	3623	07047	C)100	3639	07067	C)100	3653	07105
C)105	3680	07140	C)104	3694	07156	C)103	3722	07212	C)100	3768	07270	C)100	3771	07273
C)105	3782	07306	C)104	3785	07311	C)103	3788	07314	C)100	3802	07332	C)100	3823	07357
C)105	3842	07402	C)104	3849	07411	C)103	3878	07446	C)100	3895	07467	C)100	3911	07507
C)105	3846	07406	C)104	3931	07533	C)103	3945	07551	C)100	3949	07555	C)100	3947	07553
C)105	3952	07560	C)104	3954	07562	C)103	3956	07564	C)100	3959	07567	C)100	4043	07713
C)105	4041	07711	C)104	4040	07710	C)103	3521	06701	C)100	3542	06726	C)100	32767	77777
C)105	4037	07705	C)104	4033	07701	C)103	3552	06740	C)100	4032	07700	C)100	4031	07677

SIN	(LEV)	(IOH)I	SUBROUTINES NOT PUNCHED FROM LIBRARY	XLOC	BESJ	SQRT	(IOH)O
(STH)	(FIL)	(CSH)	(RTN)	EXP(2)			

APPENDIX B

RITAP5, A FORTRAN Program for
Preparing Cross-section Input to DEL
(Job No. RP360X)

I. LIST OF SYMBOLS

<u>Symbol</u>	<u>Definition</u>	<u>Restrictions</u>
MATN	Material identification number.	$<10^3$
NX	Number of different reactions other than inelastic scattering to be input. For use with DEL, $NX = 4$.	
NGRP	Number of energy groups.	≤ 30
NGRS	Largest number of energy groups receiving neutrons scattered down from any one particular group.	
NLGS	Number of last energy group scattering down.	≤ 29
NOPT	>1 : Input ν_j and $\sigma_{f,j}$ separately. ≤ 1 : Input $\nu_j \sigma_{f,j}$.	
ATNO	Atom density.	

II. DESCRIPTION OF PROGRAM

The above list contains the control-card symbols to be input with FORMAT (6I6, E12.5). The control card will be followed by the appropriate cross sections in FORMAT (6E12.5), with each different reaction beginning on a new card. For the correct order of input and the energy group limits on individual reactions, see the Sample Input Form on page 44. There will be one block of cards consisting of a control card and cross sections for each material. As many blocks as desired may be input successively, but the material numbers should be in chronological order. Blocks may be added to an existing cross section tape by making the first MATN one greater than the last MATN already on tape. All control cards for a given tape must have the same value for NGRP.

Before writing the cross sections (which for use with DEL are $\nu\sigma_f$, σ_{c+f} , σ_{tr} , σ_{er} , and σ_{inel}) on output tape 5, the code multiplies each by the value ATNO. Later, in DEL, they are again multiplied by the value CVF. Therefore ATNO may be input as unity if the user desires to input atom fractions for the values CVF in DEL.

III. OPERATING INSTRUCTIONS

A. Ready Tapes.

1. FORTRAN Subroutine Library.

5. Output (binary).

B. Sense Switch Setting.

1. UP for use with DEL.

DOWN implies no inelastic cross-section input.

C. Clear and Load Cards.

D. Normal Stop: HPR 0,1.

704 INPUT DATA
FORM II

IV. SAMPLE INPUT FORM

COST CODE _____

DATA I.D. 36

PROBLEM RITAP (RP360X)

ORIGINATOR L. C. Kvitek

DATE 7-8-64

PAGE 1 OF 1

1									2									3									4									5									6									7									8																										
1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9																											
M, A, T, N									N, X									N, G, R, P									N, G, R, S									N, L, G, S									N, O, P, T									A, T, N, O																																			
1									2																											N, G, R, P																																																					
f, 1									f, 2																											f, N, G, R, P									Omit if NOPT ≤ 1 .																																												
1 f, 1									2 f, 2																											(1, 2, 3)									f, N, G, R, P									Omit if NOPT > 1 .																																			
c + f, 1									c + f, 2																											c + f, N, G, R, P																																																					
tr, 1									tr, 2																											tr, N, G, R, P																																																					
er, 1									er, 2																											er, N, G, R, P																																																					
inel, 1 $\rightarrow$ 2									inel, 1 $\rightarrow$ 3																											inel, 1 $\rightarrow$ NGRS+1																																																					
inel, 2 $\rightarrow$ 3									inel, 2 $\rightarrow$ 4																											inel, 2 $\rightarrow$ NGRS+2																																																					
inel, N $\rightarrow$ N+1									inel, N $\rightarrow$ N+2																											inel, N $\rightarrow$ NGRS+N									(N = N, L, G, S)																																												

APPENDIX C
FORTRAN Statements and
Storage Locations for RITAP5

* 015 12/11/64 KVITEK, L. C. RP 3 X
 KVITEK L 06981RP 360X44111-53116704121141816000
 \$ COMPILE, ROW 8 BINARY MODE

2949 ** 6981
 015

C
 C
 C
 C
 C

RITAPS
 THIS CODE PREPARES BINARY CROSS SECTIONS ON TAPE DRIVE 5. UP TO 5
 TYPES OF REACTION MAY BE WRITTEN FOR EACH MATERIAL. FOR USE WITH
 DEL (RP 342 X), NX=4. THERE IS A 30 GROUP LIMIT WITH UP TO 29
 SCATTERING DOWN.

```

    DIMENSION DX(4,30),DS(30,29),UN(30),SF(30)
    L=1
1   READ 13, MN,NX,NG,NK,NJ,NFOPT,ATN
    IF (MN-1) 5,5,2
2   IF (L-1) 3,3,5
3   NS=(MN-1)*(NX+2)
    DO 4 N=1,NS
4   READ TAPE 5
5   WRITE TAPE 5, MN,NK,NJ,NX,NG,ATN
    IF (NFOPT-1) 8,8,6
6   READ 14, (UN(J),J=1,NG)
    READ 14, (SF(J),J=1,NG)
    DO 7 J=1,NG
7   DX(1,J)=UN(J)*SF(J)*ATN
    K1=2
    GO TO 9
8   K1=1
9   DO 10 K=K1,NX
    READ 14, (DX(K,J),J=1,NG)
    DO 10 J=1,NG
10  DX(K,J)=DX(K,J)*ATN
    IF (SENSE SWITCH 1) 21,20
20  DO 11 J=1,NJ
    READ 14, (DS(J,K),K=1,NK)
    DO 11 K=1,NK
11  DS(J,K)=DS(J,K)*ATN
21  DO 12 K=1,NX
12  WRITE TAPE 5, (DX(K,J),J=1,NG)
    IF (SENSE SWITCH 1) 23,22
22  WRITE TAPE 5, ((DS(J,K),K=1,NK),J=1,NJ)
23  L=L+1
13  FORMAT(6I6,E12.5)
14  FORMAT(6E12.5)
    GO TO 1
END ( 1, 1, 0, 1, 0 )

```

ANL-30

EXTERNAL FORMULA NUMBERS WITH CORRESPONDING INTERNAL FORMULA NUMBERS AND OCTAL LOCATIONS

EFN	IFN	LOC	EFN	IFN	LOC	EFN	IFN	LOC	EFN	IFN	LOC	EFN	IFN	LOC
1	3	00006	1	5	00026	2	7	00035	3	8	00041	4	10	00056
4	11	00000	5	12	00071	5	14	00103	6	16	00112	6	21	00132
7	29	00162	8	32	00176	9	33	00200	10	33	00200	20	43	00260
11	51	00324	21	52	00335	12	3	00350	12	58	00360	22	60	00367
22	67	00414	23	68	00416	13	09	00000	14	70	00000			

STORAGE NOT USED BY PROGRAM

DEC OCT
1353 02511

DEC OCT
32562 77462

LOCATIONS OF NAMES IN TRANSFER VECTOR

(CSH) DEC OCT
1 00001

(IOH)I DEC OCT
2 00002

(LEV) DEC OCT
3 00003

(RTN) DEC OCT
0 00000

DEC OCT

STORAGE LOCATIONS FOR VARIABLES APPEARING IN DIMENSION AND EQUIVALENCE SENTENCES

DX DEC OCT
1292 02414

DS DEC OCT
1172 02224

SF DEC OCT
1322 02452

UN DEC OCT
1352 02510

DEC OCT

STORAGE LOCATIONS FOR VARIABLES NOT APPEARING IN DIMENSION, EQUIVALENCE OR COMMON SENTENCES

ATN DEC OCT
302 00456
NG 297 00451

K1 DEC OCT
301 00455
NJ 296 00450

L DEC OCT
300 00454
NK 295 00447

MN DEC OCT
299 00453
NS 294 00446

NFORT DEC OCT
298 00452
NX 293 00445

STORAGE LOCATIONS FOR SYMBOLS NOT APPEARING IN SOURCE PROGRAM

8)E DEC OCT
286 00436
7) 289 00441

8)D DEC OCT
288 00440

1) DEC OCT
290 00442

2) DEC OCT
274 00422

6) DEC OCT
280 00430

SUBROUTINES NOT PUNCHED FROM LIBRARY

(LEV) (IOH)I

(CSH)

(RTN)

APPENDIX D

Glossary of Mathematical Symbols Not Defined in Text

<u>Symbol</u>	<u>Definition</u>
i	Spatial point index
j	Energy group index
m	Material number index (MP indicates the material perturbed)
n	Region number index
ξ	Radial distance from midplane
Φ	Multidimensional neutron flux
ϕ	One-dimensional neutron flux
$*$	Indicates adjoint quantity
ν	Number of neutrons emitted per fission
σ_f	Microscopic fission cross section
σ_{tr}	Microscopic transport cross section
$\sigma_{er,j}$	Microscopic elastic-removal cross section from j to $j + 1$
$\sigma_{in,j \rightarrow j+k}$	Microscopic inelastic-scattering cross section from j to $j + k$
Σ_x	Macroscopic cross section of type x
χ	Fraction of the prompt-fission spectrum
S	Real source
S^*	Adjoint source
k_{eff}	Effective multiplication factor
D	Diffusion coefficient
$\delta \Sigma_x$	Perturbation in Σ_x
δD	Perturbation in D