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Argonne National Laboratory

RABBLE,

A Program for Computation
of Resonance Absorption
in Multiregion Reactor Cells

by

P. H. Kier and A. A. Robba

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Reactor Physics Division

April 1967

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ABSTRACT

A method of computing resonance absorption in either slab or circularized reactor cells is developed and used to write a FORTRAN program, RABBLE, for the CDC-3600. Since the method uses space- and lethargy-dependent slowing-down sources, the program is well suited for the computation of resonance absorption when the effects of overlapping between resonances is significant. The cell is divided into regions, and the energy range of interest is divided into extremely narrow groups. Regional reaction rates are obtained from the slowing-down sources, first-flight transmission and escape probabilities, and interface currents. These regional reaction rates are accumulated over specified numbers of groups to yield effective cross sections.

RABBLE allows for five compositions, which can be divided into 20 regions. There can be 12 nuclides, all of which can be resonant absorbers. The sum of the resonances is limited to 800. Effective cross sections and average fluxes are edited for up to 1000 intermediate groups and 25 broad groups. The number of fine groups per intermediate group and the number of intermediate groups per broad group are broad-group dependent.

I. THEORY

The reactor cell is divided into regions, and the energy range of interest is divided into many narrow, or fine, groups. Since the resonance cross section and therefore the flux distribution are rapidly varying functions of energy, the fine groups must be extremely narrow if resonance absorption is to be described adequately. We shall specify that the fine group is narrow compared with the maximum lethargy gain per collision with the heaviest of nuclides, and we can assume, therefore, that a neutron has only one collision within a fine group. This collision will cause the neutron to be removed from the group, either because it is absorbed or because it is scattered out of the group. Since a neutron will have only a single collision in a fine group, it is appropriate to use an integral transport theory formulation based on first-flight escape and transmission probabilities.

Since integral transport theory is used, the basic quantity computed is the regional, fine-group collision rate, C_{ij} . With use of cross sections, we obtain reaction rates and fluxes. The reaction rate for process z (fission, absorption, or scattering) for material m for fine group i and region j is

$$z^{Rm}_{ij} = C_{ij} \left(\frac{z^m_{ij}}{\Sigma_{ij}} \right), \quad (1)$$

where z^m_{ij} is the macroscopic cross section for the process and Σ_{ij} is the total macroscopic cross section. The integrated flux is

$$\phi_{ij} = \frac{C_{ij}}{\Sigma_{ij}}. \quad (2)$$

The effective cross section for a broader energy span is the ratio of the accumulated reaction rate to the accumulated integrated flux. The effective cross sections and fluxes edited in RABBLE are described in Section II.

In this formulation, the collision rate is obtained from expressions involving the slowing-down sources, the first-flight escape and transmission probabilities, and the interface currents. First, an expression for the slowing-down source is developed. Then for each geometry option, expressions for the collision rates, interface currents, and escape and transmission probabilities are developed.

A. Slowing-down Source

The calculation of the regional slowing down is based on the assumption that neutrons are scattered elastically and isotropically in the laboratory system. We also assumed that the source is uniform within a region. Since the source is allowed to vary from region to region and a composition can be divided into several regions, the space and lethargy dependence of the slowing-down source can be approximated accurately by this method.

The source for a region for the k th fine group is

$$S_k = \sum_{j=1}^J \sum_{n=1}^{L_j} P_{nj} \Sigma_{s_{k-n,j}} \phi_{k-n} \Delta u_f, \quad (3)$$

where

$P_{nj} \equiv$ probability per unit lethargy that a neutron is scattered down n groups in a scattering collision with material j ,

$L_j \equiv$ maximum number of group through which a neutron can be down-scattered in a scattering collision with material j ,

$\Sigma_{s_{k-n,j}} \phi_{k-n} \equiv$ rate at which neutrons are scattered by material j in group $k - n$,

and

$\Delta u_f \equiv$ lethargy width of a fine group.

Evaluating Eq. 3 numerically would be extremely time-consuming because a neutron can be scattered through so many groups. Fortunately, however, the

form of P_{nj} permits S_k to be expressed in a much more suitable form. $P(u - u')$, the probability per unit lethargy that a neutron is scattered from lethargy u' to u , is given by

$$P(u - u') = \begin{cases} \frac{1}{1 - \alpha} e^{-(u-u')}, & u \geq u' \geq u - \epsilon, \\ 0, & u' < u - \epsilon, \end{cases} \quad (4)$$

where

$$\alpha = \left(\frac{A - 1}{A + 1} \right)^2, \\ \epsilon = 2 \ln \left(\frac{A + 1}{A - 1} \right),$$

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and A is the mass of the scattering material. The probability of a neutron being scattered through n groups of width Δu is then

$$\begin{aligned} P_n \Delta u &= \frac{1}{1 - \alpha} \int_{u_0}^{u_0 + \Delta u} du \int_{u_0 - n\Delta u}^{u_0 - (n-1)\Delta u} du' \exp[-(u - u')] \\ &= \frac{1}{1 - \alpha} (1 - e^{-\Delta u})^2 e^{-(n-1)\Delta u} \approx \frac{\Delta u}{1 - \alpha} (1 - e^{-\Delta u})(1 - \Delta u/2) e^{-(n-1)\Delta u} \\ &\approx \frac{\Delta u}{1 - \alpha} (1 - e^{-\Delta u}) e^{-(n-1)\Delta u}. \end{aligned} \quad (5)$$

Because $P_n = e^{-\Delta u} P_{n-1}$, Eq. 3 can be reduced to

$$\begin{aligned} S_k &= e^{-\Delta u_f} S_{k-1} + \sum_{j=1}^J P_{1j} \Sigma_{s_{k-1,j}} \phi_{k-1} - e^{-\Delta u_f} \sum_{j=1}^J P_{Lj,j} \Sigma_{s_{k-Lj-1,j}} \\ &\quad \times \phi_{k-Lj-1}. \end{aligned} \quad (6)$$

In Eq. 6, we need evaluate only two terms for each material. Although evaluation of Eq. 6 does not require excessive time, it does require excessive memory for the storage of the fine-group fluxes and scattering cross sections. We shall introduce the intermediate group that contains a specified number of fine groups, and we shall specify that the width of an intermediate group is less than the maximum lethargy gain per collision with the heaviest material present. Then the fine-group scattering rates of the last term on the right side of Eq. 6 will be approximated by the intermediate-group scattering rate divided by the number of fine groups per intermediate group. This approximation, which is reasonable since the intermediate group is narrow itself, permits S_k to be computed from the source and scattering rates for the $(k - 1)$ th fine group and the scattering rates for the intermediate group, and greatly reduces storage requirements.

B. Collision Rates

We shall develop expressions for the regional, fine-group collision rates in terms of the slowing-down sources, interface currents, and first-flight escape and transmission probabilities for the four geometry options.

1. Homogeneous Cell

Although RABBLE has been written for the computation of resonance absorption in heterogeneous reactor cells, it does have a space-independent option because of the simplicity of this homogeneous case. Because the fine group is narrow, a neutron will have only one collision within a fine group. Therefore neutron conservation requires that the collision rate must equal the rate at which neutrons are slowed down into the group. That is,

$$C_i = S_i. \quad (7)$$

2. Cylindrical Cell

For a cell described in terms of cylindrical coordinates, the outer boundary of the cell is assumed to be circular. With the assumption of cosine currents at the interfaces between regions, the collision rates are obtained in terms of the following quantities:

J_i^+ $\equiv$ cosine current impinging on the inner surface of the $(i + 1)$ th region,

J_i^- $\equiv$ cosine current impinging on the outer surface of the i th region,

P_i^+ $\equiv$ escape probability through the outer surface of the i th region for flat volume source,

P_i^- $\equiv$ escape probability through the inner surface of the i th region for flat volume source,

T_i^{OI} $\equiv$ transmission probability from the inner to the outer surface of the i th region,

T_i^{IO} $\equiv$ transmission probability from the outer to the inner surface of the i th region,

and

T_i^{OO} $\equiv$ transmission probability from the outer to the outer surface of the i th region.

If the center region is the first region and the outermost region is the I th region, then the collision rates are

$$C_i = \begin{cases} (1 - T_i^{OO}) J_i^- + (1 - P_i^+) S_i, & i = 1; \\ (1 - T_i^{OI}) J_{i-1}^+ + (1 - T_i^{OO} - T_i^{IO}) J_i^- + (1 - P_i^+ - P_i^-) S_i, & i = 2, I. \end{cases} \quad (8)$$

The interface currents are obtained from the following statements of neutron conservation at each interface and the assumption of isotropic return at the outer boundary of the cell:

$$J_i^+ = \begin{cases} T_i^{00} J_i^- + P_i^+ S_i & i = 1 \\ T_i^{0I} J_{i-1}^+ + T_i^{00} J_i^- + P_i^+ S_i & i = 2, I, \end{cases} \quad (9)$$

$$J_i^- = \begin{cases} T_{i+1}^{I0} J_{i+1}^- + P_{i+1}^- S_{i+1} & i = 1, I-1 \\ J_i^+ & i = I. \end{cases} \quad (10)$$

Equations 9 and 10 yield $2I$ equations in $2I$ unknown interface currents. These equations are readily solved by Gauss-Jordan reduction.

The escape and transmission probabilities have the following form:¹

$$P_i^- = \frac{2r_{i-1}}{\Sigma_i A_i} \left[\frac{\pi}{4} - \int_0^{\pi/2} d\phi \cos \phi K_{i3} \{ \Sigma_i f(\phi) \} \right], \quad (11)$$

$$P_i^+ = \frac{2r_i}{\Sigma_i A_i} \left[\frac{\pi}{4} - \int_0^{\pi/2} d\phi \cos \phi \left[K_{i3} \{ \Sigma_i g(\phi) \} - \frac{r_{i-1}}{r_i} [K_{i3} \{ \Sigma_i h(\phi) \} - K_{i3} \{ \Sigma_i f(\phi) \}] \right] \right], \quad (12)$$

$$T_i^{0I} = \frac{4}{\pi} \int_0^{\pi/2} d\phi \cos \phi K_{i3} \{ \Sigma_i f(\phi) \}, \quad (13)$$

$$T_i^{I0} = \frac{4}{\pi} \frac{r_{i-1}}{r_i} \int_0^{\pi/2} d\phi \cos \phi K_{i3} \{ \Sigma_i f(\phi) \}, \quad (14)$$

and

$$T_i^{00} = \frac{4}{\pi} \int_0^{\pi/2} d\phi \cos \phi \left[K_{i3} \{ \Sigma_i g(\phi) \} - \frac{r_{i-1}}{r_i} K_{i3} \{ \Sigma_i h(\phi) \} \right], \quad (15)$$

where

$$K_{i3}(\chi) \equiv \int_0^{\pi/2} e^{-\chi \cos \theta} \sin^2 \theta d\theta,$$

$$f(\phi) = -r_i \cos \phi + \{r_i^2 - r_{i-1}^2 \sin^2 \phi\}^{1/2},$$

$$h(\phi) = 2\{r_i^2 - r_{i-1}^2 \sin^2 \phi\}^{1/2}, \quad g(\phi) = 2r_i \cos \phi,$$

$A_i \equiv$ area of region i ,

$r_i \equiv$ outer radius of region i ,

and

$\Sigma_i \equiv$ macroscopic cross section of region i .

It is seen that P_i^+ , P_i^- , and T_i^{IO} can be expressed in terms of T_i^{OI} and T_i^{OO} as follows:

$$T_i^{IO} = \frac{r_{i-1}}{r_i} T_i^{OI}, \quad (16)$$

$$P_i^- = \frac{\pi r_{i-1}}{2 \Sigma_i A_i} [1 - T_i^{OI}], \quad (17)$$

and

$$P_i^+ = \frac{\pi r_i}{2 \Sigma_i A_i} [1 - T_i^{OO} - T_i^{IO}]. \quad (18)$$

T_i^{OI} and T_i^{OO} are functions of two parameters, which can be chosen as r_{i-1}/r_i and $\Sigma_i(r_i - r_{i-1})$. Since it would be extremely time-consuming to compute these two transmission probabilities for each region and each fine group, in RABBLE they are obtained from interpolation in two-dimensional arrays.

3. Slab Cell--Cosine Interface Currents

Although the assumption of cosine interface currents introduces little error for a circular cell, it might introduce appreciable error for a slab cell because of the properties of plane geometry. Therefore, for the slab cell, RABBLE has two options: one that is based on cosine interface currents, and another that allows for both cosine and (cosine)² interface currents.

For the option based on cosine interface currents, the collision rate is expressed in terms of the following quantities:

$J_1^+ \equiv$ cosine current impinging on the inner surface of the $(i + 1)$ th region,

$J_1^- \equiv$ cosine current impinging on the outer surface of the i th region,

$P_i \equiv$ escape probability from i th region for a flat volume source,

and

$T_i \equiv$ transmission probability through the i th region for a cosine surface current.

The collision rate in terms of these quantities is

$$C_i = \begin{cases} 2(1 - T_i) J_i^- + (1 - P_i) S_i, & i = 1; \\ (1 - T_i)(J_i^- + J_{i-1}^+) + (1 - P_i) S_i, & i = 2, I. \end{cases} \quad (19)$$

As before, the interface currents are obtained from statement of neutron conservation at the interfaces and isotropic return at the boundary of the cell:

$$J_i^+ = \begin{cases} T_i J_i^- + (1/2) P_i S_i & i = 1 \\ T_i J_{i-1}^+ + (1/2) P_i S_i & i = 2, I; \end{cases} \quad (20)$$

$$J_i^- = \begin{cases} T_{i+1} J_{i+1}^- + (1/2) P_{i+1} S_{i+1} & i = 1, I - 1 \\ J_i^+ & i = I. \end{cases} \quad (21)$$

Equations 20 and 21 form a system of $2I$ equations in the $2I$ unknown interface currents that is readily solved by Gauss-Jordan reduction. For this case, only one escape probability, P_i , and one transmission probability, T_i , are needed. P_i is the current emerging from the i th region for a unit, uniform volume source in that region. Similarly, T_i is the current emerging from the i th region for a unit, incident cosine surface current. These quantities are given by²

$$P_i = \frac{1}{\tau} \{1/2 - E_3(\tau)\} \quad (22)$$

and

$$T_i = 2E_3(\tau), \quad (23)$$

where τ is the thickness of the region in mean free paths and $E_n(\tau)$ is the n th-order exponential integral function.

4. Slab Cell--Cosine and (Cosine)² Interface Currents

For this option, the collision rate is expressed in terms of the following quantities:

$J_{0,1}^+ \equiv$ cosine component of the current impinging on the inner surface of the $(i + 1)$ th region,

$J_{1,i}^+ \equiv$ (cosine)² component of the current impinging on the inner surface of the $(i + 1)$ th region,

$J_{0,i}^- \equiv$ cosine component of the current impinging on the outer surface of the i th region,

$J_{1,i}^- \equiv$ (cosine)² component of the current impinging on the outer surface of the i th region,

$P_{0,i} \equiv$ contribution to cosine component of the current leaving the i th region from unit volume source,

$P_{1,i} \equiv$ contribution to $(\cosine)^2$ component of the current leaving the i th region from unit volume source,

$T_i^{00} \equiv$ contribution to cosine component of the current leaving the i th region from unit, incident cosine current,

$T_i^{10} \equiv$ contribution to $(\cosine)^2$ component of the current leaving the i th region from unit, incident cosine current,

$T_i^{01} \equiv$ contribution to cosine component of the current leaving the i th region from unit, incident $(\cosine)^2$ current,

and

$T_i^{11} \equiv$ contribution to $(\cosine)^2$ component of the current leaving the i th region from unit, incident $(\cosine)^2$ current.

In terms of these quantities, the collision rate is given by

$$C_i = \begin{cases} 2(1 - T_i^{00} - T_i^{10}) J_{0,i}^- + 2(1 - T_i^{01} - T_i^{11}) J_{1,i}^- \\ \quad + (1 - P_{0,i} - P_{1,i}) S_i, & i = 1; \\ (1 - T_i^{00} - T_i^{10})(J_{0,i}^- + J_{0,i-1}^+) + (1 - T_i^{01} - T_i^{11})(J_{1,i-1}^+ + J_{1,i}^-) \\ \quad + (1 - P_{0,i} - P_{1,i}) S_i, & i = 2, I. \end{cases} \quad (24)$$

The interface currents are obtained from statement of neutron conservation at each interior interface and no net current at the outer boundary of the cell:

$$J_{0,i}^+ = \begin{cases} T_i^{00} J_{0,i}^- + T_i^{01} J_{1,i}^- + (1/2) P_{0,i} S_i, & i = 1 \\ T_i^{00} J_{0,i-1}^+ + T_i^{01} J_{1,i-1}^+ + (1/2) P_{0,i} S_i, & i = 2, I; \end{cases} \quad (25)$$

$$J_{1,i}^+ = \begin{cases} T_i^{10} J_{0,i}^- + T_i^{11} J_{1,i}^- + (1/2) P_{1,i} S_i, & i = 1 \\ T_i^{10} J_{0,i-1}^+ + T_i^{11} J_{1,i-1}^+ + (1/2) P_{1,i} S_i, & i = 2, I; \end{cases} \quad (26)$$

$$J_{0,i}^- = \begin{cases} T_{i+1}^{00} J_{0,i+1}^- + T_{i+1}^{01} J_{1,i+1}^- + (1/2) P_{0,i+1} S_{i+1}, & i = 1, I - 1 \\ J_{0,i}^+, & i = I; \end{cases} \quad (27)$$

$$J_{1,i}^- = \begin{cases} T_{i+1}^{10} J_{0,i+1}^- + T_{i+1}^{11} J_{1,i+1}^- + (1/2) P_{1,i+1} S_{i+1}, & i = 1, I - 1 \\ J_{1,i}^+, & i = I. \end{cases} \quad (28)$$

Equations 25-28 form a set of 4I equations in the 4I unknown interface currents, which can be solved by Gauss-Jordan reduction.

For this case, several escape and transmission probabilities are needed. $P_{0,i}$ and $P_{1,i}$ can be obtained as follows: Let us assume a unit volume source in the region. Then, by definition, $P_{0,i}$ is the cosine current emerging from the region and $P_{1,i}$ is the $(\cosine)^2$ current emerging from the region. If we let $\psi(\mu)$ be the angular emergent flux, then $\psi(\mu)$ have the form

$$\psi(\mu) = 2P_{0,i} + 3P_{1,i}\mu. \quad (29)$$

From the zeroth and first angular moments of the emergent flux,

$$\Psi = \int_0^1 \psi(\mu) d\mu,$$

and

$$J = \int_0^1 \mu \psi(\mu) d\mu,$$

we obtain two equations from which $P_{0,i}$ and $P_{1,i}$ are obtained:

$$\Psi = 2P_{0,i} + (3/2)P_{1,i} = \frac{1}{\tau} [1 - E_2(\tau)],$$

and

$$J = P_{0,i} + P_{1,i} = \frac{1}{\tau} [1/2 - E_3(\tau)],$$

or

$$P_{0,i} = \frac{1}{\tau} [1/2 - 2E_2(\tau) + 3E_3(\tau)], \quad (30)$$

and

$$P_{1,i} = \frac{2}{\tau} [E_2(\tau) - 2E_3(\tau)]. \quad (31)$$

To obtain T_i^{00} and T_i^{10} , we assume that the angular emergent flux arising from a unit, incident cosine current has the form

$$\psi(\mu) = 2T_i^{00} + 3T_i^{10}\mu.$$

Then from the zeroth and first angular moments of $\psi(\mu)$,

$$\Psi = 2T_i^{00} + (3/2)T_i^{10} = 2E_2(\tau),$$

and

$$J = T_i^{00} + T_i^{10} = 2E_3(\tau),$$

or

$$T_i^{00} = 4E_2(\tau) - 6E_3(\tau), \quad (32)$$

and

$$T_i^{10} = 8E_3(\tau) - 4E_2(\tau). \quad (33)$$

Similarly, to obtain T_i^{01} and T_i^{11} , we assume that the angular emergent flux arising from a unit, incident (cosine)² current has the form

$$\psi(\mu) = 2T_i^{01} + 3T_i^{11}\mu.$$

Then, from the zeroth and first angular moments of $\psi(\mu)$,

$$\Psi = 2T_i^{01} + (3/2)T_i^{11} = 3E_3(\tau)$$

and

$$J = T_i^{01} + T_i^{11} = 3E_4(\tau),$$

or

$$T_i^{01} = 6E_3(\tau) - 9E_4(\tau) \quad (34)$$

and

$$T_i^{11} = 12E_4(\tau) - 6E_3(\tau). \quad (35)$$

II. THE RABBLE PROGRAM

The theory developed in Part I has been used to construct a program for the CDC-3600 to compute effective cross sections and fluxes for a circularized or slab reactor cell for above-thermal energies. This part will describe the program. First, we will give the information necessary for operation of the program, together with the format with which it is punched on cards. Next, we will describe the computed quantities edited as output, and finally the subroutines that comprise the program.

A. Input

<u>Card</u>	<u>Format</u>	<u>Variables</u>	<u>Description</u>
1	9A8		Problem identification.
2	10I6	KREG,	No. of regions; $KREG \leq 20$.
		KMAT,	No. of materials; $KMAT \leq 12$.
		KCOMP,	No. of compositions; $KCOMP \leq 5$.
		KRES,	No. of resonant materials, $KRES > 0$.
		KGP,	No. of intermediate groups, $KGP \leq 1000$.

<u>Card</u>	<u>Format</u>	<u>Variables</u>	<u>Description</u>
		KBG, NOPT,	No. of broad groups, $KBG \leq 25$. If $NOPT = 0$, homogeneous case, then $RMAX = 1.0$ and $NINT(1) =$ $KREG = KCOMP = 1$; $NOPT = 1$, circularized cell with cosine interface currents; $NOPT = 2$, slab cell with cosine inter- face currents; $NOPT = 3$, slab cell with cosine and $(\cosine)^2$ interface currents.
		NTEMP,	If all compositions at the same temperature, $NTEMP = 1$; other- wise, $NTEMP = KCOMP$.
		NPRINT,	If $NPRINT > 0$, edit of effective cross section for intermediate group is omitted.
		MORE	If last problem in batch, $MORE > 0$.
3	12I6	(NIB(I), NFI(I), I=1,KBG)	No. of intermediate groups in Ith broad group; $NIB(I) \leq 100$, $ENIB(I) = KGP$. No. of fine groups per inter- mediate group in Ith broad group.
4	3E12.6	UIGP,	Lethargy width of intermediate group, $UIGP \leq$ maximum lethargy gain per collision with the heaviest material present. $100 \times UIGP \geq$ maximum lethargy gain per collision with the lightest resonant material present. The lethargy width of a fine group, $UIGP/NFI(I)$, should always be less than 10^{-3} .
		ENGP(1),	Maximum energy of the range covered in the calculation (eV).
		TEST	A resonance contributes to the cross sections for fine groups within an intermediate group if (a) the resonance energy lies within the intermediate group or (b) the resonance cross section at either the upper or the lower energy limit of the intermediate group is greater than TEST (barns).
5	5E12.6	(TEMP(I), I=1,KCOMP)	Temperature of the Ith composition (°K), $TEMP(I) > 0$.

<u>Card</u>	<u>Format</u>	<u>Variables</u>	<u>Description</u>
6	5(I2,E10.4)	(NINT(I), RMAX(I),	No. of regions into which Ith composition is divided, $\Sigma NINT(I) = KREG$. Outer boundary of the Ith composition (cm); for slab cells, RMAX(1) is the half thickness of the innermost composition.
7	A6,I6,4E12.6	I=1,KCOMP) NUCLIDE(I) NRES(I), AMU(I), SIGPOT(I), SIGA22(I), SIGF22(I),	Identification of Ith material. No. of resonance for Ith material, $\Sigma NRES(I) < 800$; if $I > KRES$, $NRES(I) = 0$. Atomic weight of Ith material (amu). Potential scattering cross section of Ith material (barns). 2200-m/sec value of $1/v$ absorption cross section for nonresonant materials; constant background absorption cross section for resonant materials (barns). 2200-m/sec value for $1/v$ fission cross section for nonresonant materials; constant background fission cross section for resonant materials (barns).
8	5E12.6	(DEN(I,J) J=1,KCOMP)	Atom density of material I in composition J ($10^{24}/\text{cm}^3$).

Note: Materials must be ordered so that information for resonant materials is read in first. If $NRES(I) > 0$, read in cards 9 for the resonances of material I next; if $NRES(I) = 0$, read in card 7 for material I + 1 next.

9	5E12.6	ER(J), GN(J), GR(J), GF(J), G(J),	Energy of Jth resonance (eV). Neutron width of Jth resonance evaluated at ER(J) (eV). Radiation width of Jth resonance (eV). Fission width of Jth resonance (eV). Statistical spin factor.
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B. Output Edit

The basic quantities computed are ${}_zR_{ij}^m \Delta u_f$, the reaction rate for process z (fission, absorption, or scattering) in material m for fine group i and region j , and $\phi_{ij} \Delta u_f$, the integral flux in fine group i and region j . These fluxes and reaction rates are based on a normalization of a uniform flux per unit lethargy of unity for energies above that at which the calculation begins. Since these quantities are not of primary interest to reactor physicists, the edit will be of effective cross sections and average fluxes, which are of greater interest. The quantities printed in the edit will now be defined.

1. Cell-averaged Neutron Flux for Broad or Intermediate Group I

$$\bar{\phi}_I = \frac{\sum_i \sum_j \phi_{ij} \Delta u_f}{\sum_i \sum_j \Delta u_f \Delta A_j} \quad (36)$$

ΔA_j is the area of region j . The i summation is over all fine groups in the broad or intermediate group; the j summation is over all regions.

2. Cell-averaged Macroscopic Cross Section for Process z and Broad or Intermediate Group I

$${}_z \bar{\Sigma}_I = \frac{\sum_m \sum_i \sum_j {}_z R_{ij}^m \Delta u_f}{\sum_i \sum_j \phi_{ij} \Delta u_f} \quad (37)$$

The m summation is over all materials; the j summation is over all regions, and the i summation is over all fine groups in the broad or intermediate group.

3. Composition-averaged Neutron Fluxes for Broad or Intermediate Group I

$$\bar{\phi}_{Ik} = \frac{\sum_i \sum_j \phi_{ij} \Delta u_f}{\sum_i \sum_j \Delta u_f \Delta A_j} \quad (38)$$

The j summation is over those regions that contain composition k ; the i summation is over all fine groups in the broad or intermediate group.

4. Composition-averaged Microscopic Cross Sections for Process z in Material m for Broad or Intermediate Group I

$${}_z \bar{\sigma}_{Ik}^m = \frac{\sum_i \sum_j {}_z R_{ij}^m \Delta u_f}{N_{mk} \sum_i \sum_j \phi_{ij} \Delta u_f} \quad (39)$$

N_{mk} is the atom density of material m in composition k . The j summation is over those regions that contain composition k ; the i summation is over all fine groups in the broad or intermediate group.

5. Regional Average Neutron Fluxes for Intermediate Group I

$$\bar{\phi}_{Ij} = \frac{\sum_i \phi_{ij} \Delta u_f}{\sum_i \Delta u_f \Delta A_j} \quad (40)$$

The i summation is over all fine groups contained in the intermediate group. These fluxes are printed for each intermediate group in a broad group following the edit of the cross sections for that broad group.

6. Regional Average Neutron Fluxes for Broad Group N

$$\bar{\phi}_{Nj} = \frac{\sum_i \phi_{ij} \Delta u_f}{\sum_i \Delta u_f \Delta A_j} \quad (41)$$

The summation is over all fine groups contained in the broad group.

7. Accumulated Absorption Probability for Broad Group N

$$p_a = \frac{\sum_m \sum_i \sum_j a_{ij}^m \Delta u_f}{\sum_m \sum_j \xi_m N_{mk} \sigma_{p,m} \Delta A_j} \quad (42)$$

ξ_m is the average lethargy increment per collision with material m ; $\sigma_{p,m}$ is the potential scattering cross section of material m . The m summation is over all materials, the j summation is over all regions, and the i summation is for all fine groups in broad groups up to and including broad group N .

A quantity not edited that is frequently of interest is the resonance integral. It is defined as that cross section which, when multiplied by the flux that would be present in the absence of the resonances, ϕ_∞ , gives the true reaction rate. With our normalization, ϕ_∞ is unity. Therefore the resonance integral for process z in material m for composition k and broad group N is

$${}_z(RI)_{Nk}^m = \frac{\sum_i \sum_j {}_z R_{ij}^m \Delta u_f}{N_{mk} \Delta A_k}, \quad (43)$$

where the j summation is over all those regions that contain composition k , and the i summation is over all fine groups in the broad group. The resonance integral can be related to the composition-averaged neutron fluxes and effective cross sections by use of Eqs. 38 and 39 as follows:

$${}_z(RI)_{Nk}^m = \frac{{}_z \bar{\sigma}_{Nk}^m}{\bar{\phi}_{Nk}} \Delta u_b, \quad (44)$$

where Δu_b is the width of the broad group in lethargy.

C. Organization of the Program

RABBLE consists of a main program and nine other subroutines. The appendix contains the complete listing of the source program. The function of each subroutine is described briefly below.

1. Main Program RABBLE: Accumulates reaction rates and integral fluxes over the intermediate groups and broad groups.

2. INPUT: Reads in the input information and then prints this information after calling DATA.

3. DATA: Computes group-independent parameters associated with cross sections, downscattering probabilities, and the geometric configuration.

4. SOURCE: Computes the regional slowing-down sources for a fine group from use of Eq. 6.

5. XSECT: Computes the cross sections for each composition for a fine group. The following expressions are used to obtain the microscopic resonance scattering, absorption, and fission cross sections:

$$\sigma_s = \sum_{k=1}^K \left\{ \frac{\sigma_{ok}\Gamma_{nk}}{\Gamma_k} \psi(\xi, x) + \left(\frac{\sigma_p \sigma_{ok} g_k \Gamma_{nk}}{\Gamma_k} \right)^{1/2} \chi(\xi, x) \right\}, \quad (45)$$

$$\sigma_a = \sum_{k=1}^K \left(\frac{|E_k|}{E} \right)^{1/2} \frac{(\Gamma_{\gamma k} + \Gamma_{fk}) \sigma_{ok} \psi(\xi, x)}{\Gamma_k} \quad (46)$$

and

$$\sigma_f = \sum_{k=1}^K \left(\frac{|E_k|}{E} \right)^{1/2} \frac{\Gamma_{fk} \sigma_{ok} \psi(\xi, x)}{\Gamma_k} \quad (47)$$

where

$E \equiv$ energy corresponding to the average lethargy of the fine group (eV),

$E_k \equiv$ energy of the k th resonance (eV),

Γ_{nk} , $\Gamma_{\gamma k}$, Γ_{fk} , and $\Gamma_k \equiv$ neutron, radiation, fission, and total width of k th resonance (eV),

$x \equiv 2(E - E_k)/\Gamma_k$,

$\xi \equiv (A\Gamma_k^2/4EkT)^{1/2}$,

$A \equiv$ atomic mass (amu),

$kT \equiv$ temperature (eV),

and

$\psi(\xi, x)$ and $\chi(\xi, x) \equiv$ symmetric and antisymmetric, Doppler-broadened, line-shape functions.

6. QUICKW: Uses six-point interpolation³ formulation in two 62×62 tables (TR and TI) of the real and imaginary parts of the complex probability integral, $W(u + iv)$, where $u = \xi x/2$, $v = \xi/2$, $\psi(\xi, x) = (\xi\sqrt{\pi}/2) \times \text{Re}\{W(u + iv)\}$, and $\chi(\xi, x) = \xi\sqrt{\pi} \text{Im}\{W(u + iv)\}$. The tabulated values are given on a mesh of 0.1 for $-0.1 \leq u \leq 6.0$ and $-0.1 \leq v \leq 6.0$. Outside the tabulated range, QUICKW uses the following approximations:

$$W(z) = iz \left(\frac{0.5124242}{z^2 - 0.2752551} + \frac{0.05165436}{z^2 - 2.724745} \right), \quad 6.0 < |z| < 12.0;$$

$$W(z) = \frac{2i}{\sqrt{\pi}} \left(\frac{1}{2z^2 - 1} \right), \quad 12.0 < |z| < 100.0;$$

$$W(z) = \frac{i}{z\sqrt{\pi}}, \quad |z| > 100.0.$$

7. RATES: Computes interface currents and the regional collision rates for a fine group, after calling NTRPLT to obtain escape and transmission probabilities. For the circularized cell, Eqs. 9 and 10 are solved for the interface current, which are then used in Eq. 8 to obtain the regional collision rates. For the slab cell with cosine interface currents, Eqs. 20 and 21 are solved for the interface currents, which are then used in Eq. 19 to obtain the collision rates. For the slab cell with cosine and (cosine)² interface currents, Eqs. 25-28 are solved for the interface currents, which are used in Eq. 24 to obtain collision rates.

8. NTRPLT: Computes regional escape and transmission probabilities by interpolation in tables. For the cylindrical case (NOPT = 1), only T_i^{00} and T_i^{01} need be tabulated. These two transmission probabilities are functions of two parameters: $\tau_i = \Sigma_i(r_i - r_{i-1})$ and (r_{i-1}/r_i) , so four-point bivariate interpolation³ is used. In TABLE1, entries for T_i^{01} are given, and in TABLE2, entries for T_i^{00} are given. The mesh of these tables is as follows:

Range of τ	$\Delta\tau$
0.0-0.4	0.01
0.4-1.0	0.02
1.0-2.6	0.04
2.6-5.0	0.06
5.0-8.0	0.10

For TABLE1, $\Delta(r_{i-1}/r_i) = 0.04$; for TABLE2, $\Delta(r_{i-1}/r_i) = 0.02$. For $\tau > 8.0$, we take $T_i^{01} = 0$ and obtain T_i^{00} from the rational expansion,

$$T_i^{00} = [1 - (r_{i-1}/r_i)^2][0.005725/(\tau - 5.5) - 0.000058\tau + 0.00118].$$

When $r_{i-1}/r_i = 1$, the annular region degenerates into a slab. Therefore, the transmission probability for the slab option with cosine interface currents (NOPT = 2) is obtained from interpolation in the last column of TABLE1.

For the slab cell with cosine and (cosine)² interface currents (NOPT = 3), the second- and fourth-order exponential integral functions are required also. These functions are tabulated in TABLE3 for the same values of τ as the quantities in TABLE1 and TABLE2. Errors in the accuracy of the transmission probabilities obtained from interpolation in these tables do not exceed 2×10^{-4} .

9. RESTEST: Determines, for each intermediate group, which resonances contribute to the cross sections for each fine group in the intermediate group.

10. OUTPUT: Converts the reaction rates and integral fluxes accumulated by the main program to effective cross sections and average fluxes. These quantities are then printed for every intermediate group (if $\text{NPRINT} \leq 0$) and every broad group.

11. Program FLAT: This program is not part of RABBLE. However, it computes the quantities needed in TABLE1, TABLE2, and TABLE3 and writes these tables on tape in the order required by RABBLE. T^{01} and T^{00} are obtained from numerical integration of Eqs. 13 and 15 by use of Weddle's⁴ rule. Subroutine KI3 computes $K_{i3}(X)$ by use of the rational expansions of Gargantini and Pomentale.⁵

RABBLE requires approximately 44K memory spaces. However, the program can be converted for use on a computer with 32K memory spaces without excessive reduction in the size of arrays if the subroutine that computes the complex probability integral is changed. QUICKW requires two 62×62 tables computed by the subroutine W.⁶ If W, a listing of which is given by Kier,¹ is used in RABBLE, these tables are eliminated and the storage requirements are reduced by approximately 7K. Then minor reductions in such quantities as the maximum number of regions or the maximum number of resonances would allow the program to fit in a 32K computer.

III. SAMPLE CALCULATIONS

A set of sample problems has been run to illustrate the dependence of computation time upon the various input options. These problems also give an indication of the dependence of the accuracy of a computation upon the number of regions, the width of a fine group, and, for a slab cell, the angular distribution of the interface currents.

The problems considered a cell with two compositions. The inner composition was pure U^{238} , and the outer composition was a mixture of U^{238} , sodium, and iron. The volumes of the compositions were in the ratio of 3 to 13. The sizes of the inner composition were chosen so that the mean chord for the slab cell and the cylindrical cells were identical, so that in the flat-source approximation the cells were "equivalent." The energy range of the computations was from 1.4 to 1.0 keV, and 25 resonances of U^{238} were included.

Table I gives the results of the computations. The homogeneous option is considerably less time-consuming than the heterogeneous options of which $\text{NOPT} = 2$, slab cell with cosine interface currents, is the fastest, and $\text{NOPT} = 3$, slab cell with cosine and $(\cosine)^2$ interface currents, is the slowest.

Comparison of problems 2 and 6, 9 and 10, and 11 and 12 indicates that the accuracy of a computation is not strongly dependent on the number of regions. Increasing the number of regions from eight to twelve had a negligible effect on the computed quantities. This is not surprising because integral transport methods that do not allow space-dependent sources, such as those based on Chernick's⁷ coupled space-independent integral equations, frequently yield accurate results. Therefore, an excessive number of regions is unnecessary for precise calculations.

TABLE I. Results of the Sample Calculations for the Effect of the Options on the Accuracy and Computation Time of RABBLE

NOPT	NTEMP	Resonances	Regions	TEST, barns	Δu_f	Pa	$\bar{\sigma}_a^{28}$, barns		Time, sec
							Comp. 1	Comp. 2	
1	0	1	25	1	0.0001	0.0001	0.26233	0.8045	49
2	1	1	25	8	0.0001	0.0001	0.31149	0.6527	122
3	1	2	25	8	0.0001	0.0001	0.31149	0.6527	143
4	1	1	25	8	0.0	0.0001	0.31149	0.6527	135
5	1	1	25	8	0.001	0.0001	0.31149	0.6527	120
6	1	1	25	12	0.0001	0.0001	0.31149	0.6532	164
7	1	1	50	8	0.0001	0.0001	0.31776	0.6814	175
8	1	1	25	8	0.0001	0.00005	0.31109	0.6527	244
9	2	1	25	8	0.0001	0.0001	0.31237	0.6611	115
10	2	1	25	12	0.0001	0.0001	0.31260	0.6626	144
11	3	1	25	8	0.0001	0.0001	0.31036	0.6488	136
12	3	1	25	12	0.0001	0.0001	0.31023	0.6483	156

Comparison of problems 9 and 11 or 10 and 12 shows that for the slab option the angular dependence of the interface currents does not have a large effect on the computed quantities. The assumption of cosine interface currents causes the absorption probability to be overestimated by about 1% and causes errors in effective absorption cross sections of between 1 and 2%.

The material composition for the homogeneous problem was obtained by homogenizing the two-composition cell. The homogeneous problem yields a significantly smaller absorption probability than the heterogeneous problems. The explanation for this effect is probably that in homogenizing the cell, relatively light scattering material is introduced in the inner composition, which allows more neutrons to be scattered past the resonances.

Comparison of problems 2, 4, and 5 shows that some saving in computation time is afforded without loss of accuracy by making TEST > 0. Table II gives the input for the second problem, and Table III gives the broad-group cross section and regional-flux-distribution edits for this problem.

704 INPUT DATA

FORM II

TABLE II. Input for a Sample Problem

COST CODE _____

PROGRAM RABBLE

PROBLEM SAMPLE

ORIGINATOR KIER

DATE 12/22/66

PAGE 1 OF 2

										1										2										3										4										5										6										7										8																																																	
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704 INPUT DATA
FORM II

TABLE II (Contd.)

COST CODE _____

[illegible]

TABLE III. Broad-group Edit for a Sample Problem

TEST PROBLEMS 25 RESONANCES, 8 REGIONS, CYLINDRICAL

SUMMARY FOR 1 TH BROAD GROUP 1.40000+003 EV TO 1.00107+003 EV

AVERAGE		SIGMA A	SIGMA F	SIGMA S	FLUX
CELL		1.05061-002	0.00000+000	3.14478-001	8.01542-001
COMPOSITION	MATERIAL				
1					7.90605-001
	U-238	6.52683-001	0.00000+000	1.04541+001	
	FE-56	0.00000+000	0.00000+000	0.00000+000	
	NA-23	0.00000+000	0.00000+000	0.00000+000	
2					8.04075-001
	U-238	8.27525-001	0.00000+000	1.09558+001	
	FE-56	0.00000+000	0.00000+000	1.10000+001	
	NA-23	0.00000+000	0.00000+000	4.00000+000	

CUMULATIVE ABSORPTION PROBABILITY = 0.31149

REGIONAL INTERMEDIATE GROUP FLUXES FOR 1 TH BROAD GROUP

LOWER	1	2	3	4	5	6	7	8
ENERGY (EV)	1	1	1	2	2	2	2	2
1 1.382+003	0.961	0.963	0.965	0.968	0.969	0.970	0.970	0.971
2 1.364+003	0.932	0.934	0.938	0.944	0.946	0.947	0.947	0.947
3 1.347+003	0.882	0.886	0.891	0.902	0.905	0.906	0.907	0.908
4 1.330+003	0.927	0.928	0.931	0.936	0.937	0.938	0.938	0.939
5 1.313+003	0.786	0.791	0.801	0.818	0.823	0.826	0.827	0.828
6 1.296+003	0.855	0.858	0.864	0.872	0.875	0.876	0.877	0.877
7 1.279+003	0.727	0.733	0.743	0.762	0.767	0.770	0.772	0.773
8 1.263+003	0.751	0.757	0.767	0.781	0.785	0.787	0.789	0.789
9 1.247+003	0.828	0.829	0.833	0.833	0.833	0.833	0.833	0.833
10 1.231+003	0.976	0.977	0.979	0.970	0.969	0.968	0.968	0.968
11 1.215+003	0.772	0.778	0.787	0.794	0.797	0.799	0.800	0.800
12 1.199+003	0.708	0.714	0.725	0.737	0.741	0.743	0.744	0.745
13 1.184+003	0.734	0.741	0.754	0.763	0.767	0.769	0.770	0.771
14 1.169+003	0.736	0.743	0.755	0.762	0.765	0.767	0.768	0.769
15 1.154+003	0.709	0.718	0.732	0.741	0.745	0.747	0.749	0.749
16 1.139+003	0.884	0.885	0.891	0.872	0.869	0.867	0.866	0.865
17 1.124+003	0.824	0.832	0.846	0.845	0.846	0.848	0.848	0.849
18 1.110+003	0.726	0.736	0.751	0.754	0.757	0.759	0.760	0.761
19 1.096+003	0.695	0.705	0.722	0.727	0.731	0.733	0.735	0.735
20 1.082+003	0.684	0.695	0.712	0.717	0.721	0.723	0.725	0.725
21 1.068+003	0.711	0.720	0.736	0.738	0.741	0.743	0.744	0.744
22 1.054+003	0.649	0.659	0.676	0.682	0.685	0.687	0.689	0.689
23 1.041+003	0.752	0.760	0.774	0.769	0.770	0.771	0.772	0.772
24 1.027+003	0.628	0.639	0.656	0.662	0.666	0.668	0.669	0.670
25 1.014+003	0.725	0.734	0.747	0.742	0.744	0.744	0.745	0.745
26 1.001+003	0.698	0.707	0.721	0.718	0.720	0.721	0.722	0.722
AVERAGE	0.779	0.785	0.796	0.800	0.803	0.804	0.805	0.806

APPENDIX

Listing of the RABBLE Source Deck

```

PROGRAM RABBLE
COMMON/QW/REZ,AIMZ,REW,AIMW,KI,TR(62,62),TI(62,62)
COMMON/O/EXDU,F1V,KRES,NTEMP,TEST,V(25),SIGP(12,5),XZETA(12,5),
X  SA(12,5),SF(12,5),SS(12,5),DEN(12,5),G(800),GN(800),GF(800),
X  GR(800),ER(800),XRES(800),SIGZ(800),GAMMA(800),SIGIN(800),
X  INCLUDE(800),SIGMIN(800),NEXT(12),LAST(12),NRES(12),SIG(5),
X  SIGA22(12),SIGF22(12),INDEX
COMMON/1/NU,NOPT,UFGP,UIGP,DS1(12,25),DSMAX(12,25),CR(20),RAD(20),
X  RATIO(20),DIFX(20),SOURCE(20),SPP(20),SPN(20),TOI(20),TIO(20),
X  TII(20),TOO(20),CURP(20),CURN(20),CURP1(20),CURN1(20),
X  AREA(20),UMAX(20),FLUX(20,100),FLUXCP(5,100),SCAT(12,5,100),
X  TABLE1(181,26),TABLE2(181,51),TABLE3(181,2)
COMMON/2/KREG,KMAT,KCOMP,KGP,KBG,NPRINT,MORE,IBGP,IFGP,IBG,JBG,
X  ACS,FCS,SCS,PHITOT,PHIT,ACSGP,FCSGP,SCSGP,XAREAT,AREAT,SDD,
X  RAP,NIB(25),SIGABGP(12,5),SIGFBGP(12,5),SIGSBGP(12,5),RMAX(5),
X  ENGP(1001),RIAC(12,5),RIFC(12,5),RISC(12,5),TITLE(9),TEMP(5),
X  NINT(5),MINT(5),XTEMP(20),LREG(20),PHICT(5),PHI(20),PFLUX(20),
X  NX(20),NUCLIDE(12),AMU(12),SIGPOT(12),AREAC(5),XAREAC(5),
X  DR(5),XAREA(20),PHIRT(20),NFI(25)
BANK(0),XSECT,QUICKW,RETEST,/0/,/QW/
BANK(1),RABBLE,SOARCE,INPUT,OUTPUT,DATA,RATES,NTRPLT,/1/,/2/
READ(10)TR
READ(10)TI
READ(11)TABLE1,TABLE2,TABLE3
KI=1
1 CALL INPUT
  IBG=1          $ JBG=1
  ACS=0.  $ FCS=0.  $ SCS=0.  $ PHITOT=0.
  DO 2 I=1,KREG
2  PHIRT(I)=0.
  DO 5 I=1,KCOMP
  PHICT(I)=0.
  DO 5 J=1,KMAT
  RIAC(J,I)=0.  $ RIFC(J,I)=0.
5  RISC(J,I)=0.
  DO 45 IBGP=1,KGP
  CALL RESTEST
  ACSGP=0.  $ FCSGP=0.  $ SCSGP=0.  $ PHIT=0.
  MU=(IBGP-1)/100  $ NU=IBGP-100*MU
  DO 10 J=1,KCOMP
  FLUXCP(J,NU)=0.
  DO 10 K=1,KMAT
  SIGABGP(K,J)=0.  $ SIGFBGP(K,J)=0.
10 SIGSBGP(K,J)=0.
  DO 15 J=1,KREG
15 FLUX(J,NU)=0.
  N=NFI(IBG)
  DO 20 IFGP=1,N
  CALL SOARCE
  DO 20 I=1,KREG
  M=LREG(I)  $ PHI(I)=CR(I)/SIG(M)
  FLUX(I,NU)=FLUX(I,NU)+PHI(I)
  DO 20 J=1,KMAT
  SIGABGP(J,M)=SIGABGP(J,M)+PHI(I)*SA(J,M)
  SIGFBGP(J,M)=SIGFBGP(J,M)+PHI(I)*SF(J,M)
20 SIGSBGP(J,M)=SIGSBGP(J,M)+PHI(I)*SS(J,M)
  DO 25 I=1,KREG

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MAIN 000
COM Q 01
COM 0 01
COM 0 02
COM 0 03
COM 0 04
COM 0 05
COM 1 01
COM 1 02
COM 1 03
COM 1 04
COM 1 05
COM 2 01
COM 2 02
COM 2 03
COM 2 04
COM 2 05
COM 2 06
COM 2 07
BANK 000
BANK 010
MAIN 001
MAIN 002
MAIN 003
MAIN 004
MAIN 010
MAIN 015
MAIN 020
MAIN 021
MAIN 022
MAIN 030
MAIN 040
MAIN 050
MAIN 060
MAIN 070
MAIN 080
MAIN 085
MAIN 090
MAIN 095
MAIN 100
MAIN 110
MAIN 120
MAIN 130
MAIN 140
MAIN 150
MAIN 160
MAIN 165
MAIN 170
MAIN 180
MAIN 190
MAIN 200
MAIN 210
MAIN 220
MAIN 230
MAIN 240
MAIN 250
MAIN 260

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M=LREG(I)      $ PHIRT(I)=PHIRT(I)+FLUX(I,NU)      MAIN 270
FLUXCP(M,NU)=FLUXCP(M,NU)+FLUX(I,NU)              MAIN 280
25 PHICT(M)=PHICT(M)+FLUX(I,NU)                     MAIN 290
DO 40 I=1,KCOMP                                     MAIN 300
  PHIT=PHIT+FLUXCP(I,NU)                             MAIN 310
DO 40 J=1,KMAT                                       MAIN 320
  IF(J-KRES)30,30,35                                MAIN 330
30 SCAT(J,I,NU)=SIGSBGP(J,I)                         MAIN 340
35 RIAC(J,I)=RIAC(J,I)+SIGABGP(J,I)                 MAIN 350
  RIFC(J,I)=RIFC(J,I)+SIGFBGP(J,I)                 MAIN 360
  RISC(J,I)=RISC(J,I)+SIGSBGP(J,I)                 MAIN 370
  ACSGP=ACSGP+SIGABGP(J,I)                         MAIN 380
  FCSGP=FCSGP+SIGFBGP(J,I)                         MAIN 390
40 SCSGP=SCSGP+SIGSBGP(J,I)                         MAIN 400
  PHITOT=PHITOT+PHIT                               MAIN 410
  ACS=ACS+ACSGP      $ FCS=FCS+FCSGP      $ SCS=SCS+SCSGP MAIN 420
  CALL OUTPUT                                         MAIN 430
45 CONTINUE                                          MAIN 440
  IF(MORE)1,1,50                                     MAIN 450
50 STOP                                              MAIN 460
  END                                                MAIN 470
  SUBROUTINE RESTEST                                TEST 000
  COMMON/QW/REZ,AIMZ,REW,AIMW,KI,TR(62,62),TI(62,62) COM Q 01
  COMMON/O/EXDU,FIV,KRES,NTEMP,TEST,V(25),SIGP(12,5),XZETA(12,5), COM 0 01
X   SA(12,5),SF(12,5),SS(12,5),DEN(12,5),G(800),GN(800),GF(800), COM 0 02
X   GR(800),ER(800),XRES(800),SIGZ(800),GAMMA(800),SIGIN(800), COM 0 03
X   INCLUDE(800),SIGMIN(800),NEXT(12),LAST(12),NRES(12),SIG(5), COM 0 04
X   SIGA22(12),SIGF22(12),INDEX                    COM 0 05
  COMMON/1/NU,NOPT,UFGP,UIGP,DS1(12,25),DSMAX(12,25),CR(20),RAD(20), COM 1 01
X   RATIO(20),DIFX(20),SOURCE(20),SPP(20),SPN(20),TOI(20),TIO(20), COM 1 02
X   TII(20),TOD(20),CURP(20),CURN(20),CURP1(20),CURN1(20), COM 1 03
X   AREA(20),UMAX(20),FLUX(20,100),FLUXCP(5,100),SCAT(12,5,100), COM 1 04
X   TABLE1(181,26),TABLE2(181,51),TABLE3(181,2) COM 1 05
  COMMON/2/KREG,KMAT,KCOMP,KGP,KBG,NPRINT,MORE,IBGP,IFGP,IBG,JBG, COM 2 01
X   ACS,FCS,SCS,PHITOT,PHIT,ACSGP,FCSGP,SCSGP,XAREAT,AREAT,SDG, COM 2 02
X   RAP,NIB(25),SIGABGP(12,5),SIGFBGP(12,5),SIGSBGP(12,5),RMAX(5), COM 2 03
X   ENGP(1001),RIAC(12,5),RIFC(12,5),RISC(12,5),TITLE(9),TEMP(5), COM 2 04
X   NINT(5),MINT(5),XTEMP(20),LREG(20),PHICT(5),PHI(20),PFLUX(20), COM 2 05
X   NX(20),NUCLIDE(12),AMU(12),SIGPGT(12),AREAC(5),XAREAC(5), COM 2 06
X   DR(5),XAREA(20),PHIRT(20),NFI(25)              COM 2 07
  BANK(0),XSECT,QUICKW,RESTEST,/0/,/QW/            BANK 000
  BANK(1),RABBLE,SOARCE,INPUT,OUTPUT,DATA,RATES,NTRPLT,/1/,/2/ BANK 010
DO 50 I=1,KRES                                       TEST 010
  N=NEXT(I)      $ L=LAST(I)                         TEST 020
DO 50 J=N,L                                          TEST 030
  IF(1BGP-2)5,15,15                                TEST 040
5  INCLUDE(J)=0                                       TEST 050
  X=2.*(ENGP(1)-ER(J))/GAMMA(J)                     TEST 060
  ZETA=GAMMA(J)*XZETA(I,1)                           TEST 070
  AIMZ=.5*ZETA      $ REZ=X*AIMZ                     TEST 080
  CALL QUICKW                                         TEST 090
  PSI=.88623*ZETA*REW      $ CHI=1.77246*ZETA*AIMW    TEST 100
  SIGM=PSI*SIGZ(J)*(GN(J)+XRES(J)*(GF(J)+GR(J)))+CHI*SIGIN(J) TEST 110
  SIGM=ABSF(SIGM)                                     TEST 115
  IF(SIGM-TEST)25,10,10                              TEST 120
10 INCLUDE(J)=1BGP      $ GO TO 25                   TEST 130
15 IF(SIGMIN(J)-TEST)25,20,20                       TEST 140

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20 INCLUDE(J)=IBGP                                TEST 150
25 K=IBGP+1                                         $ X=2.*(ENGP(K)-ER(J))/GAMMA(J)    TEST 160
    AIMZ=.5*GAMMA(J)*SQRTF(AMU(1)/(3.46668E-04*ENGP(K)*TEMP(1)))    TEST 170
    REZ=X*AIMZ                                       TEST 180
    CALL QUICKW                                     $ Y=3.54492*AIMZ*AIMW    TEST 190
    Z=1.77246*AIMZ*REW*SIGZ(J) $ W=SQRTF(ABSF(ER(J))/ENGP(K))    TEST 200
    SIGMIN(J)=Z*(GN(J)+W*(GF(J)+GR(J)))+Y*SIGIN(J)    TEST 210
    SIGMIN(J)=ABSF(SIGMIN(J))                      TEST 215
    IF(SIGMIN(J)-TEST)35,30,30                      TEST 220
30 INCLUDE(J)=IBGP                                $ GO TO 50    TEST 230
35 IF(ENGP(IBGP)-ER(J))50,40,40                    TEST 240
40 IF(ENGP(K)-ER(J))45,45,50                      TEST 250
45 INCLUDE(J)=IBGP                                TEST 260
50 CONTINUE                                         TEST 270
    RETURN                                          TEST 280
    END                                             TEST 290
    SUBROUTINE OUTPUT                               OUT 000
    COMMON/QW/REZ,AIMZ,REW,AIMW,KI,TR(62,62),TI(62,62)    COM 0 01
    COMMON/O/EXDU,FLV,KRES,NTEMP,TEST,V(25),SIGP(12,5),XZETA(12,5),    COM 0 01
X    SA(12,5),SF(12,5),SS(12,5),DEN(12,5),G(800),GN(800),GF(800),    COM 0 02
X    GR(800),ER(800),XRES(800),SIGZ(800),GAMMA(800),SIGIN(800),    COM 0 03
X    INCLUDE(800),SIGMIN(800),NEXT(12),LAST(12),NRES(12),SIG(5),    COM 0 04
X    SIGA22(12),SIGF22(12),INDEX                  COM 0 05
    COMMON/1/NU,NOPT,UFGP,UIGP,DS1(12,25),DSMAX(12,25),CR(20),RAD(20),    COM 1 01
X    RATIO(20),DIFX(20),SOURCE(20),SPP(20),SPN(20),TOI(20),TIO(20),    COM 1 02
X    TII(20),TGO(20),CURP(20),CURN(20),CURP1(20),CURN1(20),    COM 1 03
X    AREA(20),UMAX(20),FLUX(20,100),FLUXCP(5,100),SCAT(12,5,100),    COM 1 04
X    TABLE1(181,26),TABLE2(181,51),TABLE3(181,2)    COM 1 05
    COMMON/2/KREG,KMAT,KCOMP,KGP,KBG,NPRINT,MORE,IBGP,IFGP,IBG,JBG,    COM 2 01
X    ACS,FCS,SCS,PHITOT,PHIT,ACSGP,FCSGP,SCSGP,XAREAT,AREAT,SDG,    COM 2 02
X    RAP,NIB(25),SIGABGP(12,5),SIGFBGP(12,5),SIGSBGP(12,5),RMAX(5),    COM 2 03
X    ENGP(1001),RIAC(12,5),RIFC(12,5),RISC(12,5),TITLE(9),TEMP(5),    COM 2 04
X    NINT(5),MINT(5),XTEMP(20),LREG(20),PHICT(5),PHI(20),PFLUX(20),    COM 2 05
X    NX(20),NUCLIDE(12),AMU(12),SIGPOT(12),AREAC(5),XAREAC(5),    COM 2 06
X    DR(5),XAREA(20),PHIRT(20),NFI(25)             COM 2 07
    BANK(0),XSECT,QUICKW,RETEST,/O/,/QW/          BANK 000
    BANK(1),RABBLE,SOARCE,INPUT,OUTPUT,DATA,RATES,NTRPLT,/1/,/2/    BANK 010
    IF(IBG-2)1,65,65                                OUT 005
65 IF (JBG-2)70,1,1                                OUT 010
70 W=FLOATF(NFI(IBG-1))/FLOATF(NFI(IBG))           $ XAREAT=W*XAREAT    OUT 011
    DO 75 I=1,KCOMP                                  OUT 012
75 XAREAC(I)=W*XAREAC(I)                            OUT 013
    DO 80 I=1,KREG                                    OUT 014
80 XAREA(I)=W*XAREA(I)                              OUT 015
    1 JBG=IBGP+1                                     $ IF(NPRINT)2,2,10    OUT 020
    2 PRINT 101,IBGP,ENGP(IBGP),ENGP(JBG)          OUT 025
101 FORMAT(1H1,2X,5HGROUP,14,E18.5,6H EV TO,E12.5,3H EV//)    OUT 030
    PRINT 110                                         OUT 040
    ACSGP=ACSGP/PHIT                                OUT 050
    FCSGP=FCSGP/PHIT                                OUT 060
    SCSGP=SCSGP/PHIT                                OUT 070
    PHIT=PHIT*XAREAT                                OUT 080
    PRINT 102,ACSGP,FCSGP,SCSGP,PHIT               OUT 090
102 FORMAT(24X,4HCELL,18X,4E18.5//17X,11HCOMPOSITION,10X,8HMATERIAL)    OUT 100
    DO 5 I=1,KCOMP                                  OUT 110
    ZZ=FLUXCP(I,NU)*XAREAC(I)                       OUT 120
    PRINT 103,I,ZZ                                  OUT 130

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103	FORMAT(26X,I2,72X,E18.5)	OUT	140
	DO 5 J=1,KMAT	OUT	150
	ZY=1./((DEN(J,I)*FLUXCP(I,NU))	OUT	160
	SIGABGP(J,I)=ZY*SIGABGP(J,I)	OUT	170
	SIGFBGP(J,I)=ZY*SIGFBGP(J,I)	OUT	180
	SIGSBGP(J,I)=ZY*SIGSBGP(J,I)	OUT	190
5	PRINT 104, NUCLIDE(J),SIGABGP(J,I),SIGFBGP(J,I),SIGSBGP(J,I)	OUT	200
104	FORMAT (40X,A6,3E18.5)	OUT	210
10	IF(JBG-NIB(IBG))15,20,20	OUT	220
15	JBG=JBG+1 \$ GO TO 60	OUT	230
20	LBGP=JBG-NIB(IBG) \$ XNIB=NIB(IBG)	OUT	240
	PRINT 105,(TITLE(I),I=1,9),IBG,ENGP(LBGP),ENGP(JBGP)	OUT	250
105	FORMAT(1H1,2X,9A8///20X,11HSUMMARY FOR,13,15H TH BROAD GROUP,5X,	OUT	260
	X E12.5,6H EV TO,E12.5,3H EV//)	OUT	270
	PRINT 110	OUT	280
110	FORMAT(21X,7HAVERAGE,29X,7HSIGMA A,11X,7HSIGMA F,11X,7HSIGMA S,	OUT	290
	X14X,4HFLUX/)	OUT	300
	RAP=RAP+ACS*UFGP/SDD \$ ACS=ACS/PHITOT \$ FCS=FCS/PHITOT	OUT	310
	SCS=SCS/PHITOT \$ PHITOT=PHITOT*XAREAT/XNIB	OUT	320
	PRINT 102,ACS,FCS,SCS,PHITOT	OUT	330
	DO 25 I=1,KCOMP	OUT	340
	ZZ=PHICT(I)*XAREAC(I)/XNIB	OUT	350
	PRINT 103,I,ZZ	OUT	360
	DO 25 J=1,KMAT	OUT	370
	ZY=1./((DEN(J,I)*PHICT(I))	OUT	380
	RIAC(J,I)=ZY*RIAC(J,I)	OUT	390
	RIFC(J,I)=ZY*RIFC(J,I)	OUT	400
	RISC(J,I)=ZY*RISC(J,I)	OUT	410
25	PRINT 104,NUCLIDE(J),RIAC(J,I),RIFC(J,I),RISC(J,I)	OUT	420
	PRINT 111,RAP	OUT	430
111	FORMAT(///10X,35HCUMULATIVE ABSORPTION PROBABILITY =,F8.5)	OUT	440
	PRINT 106,IBG,(NX(I),I=1,KREG)	OUT	450
106	FORMAT(1H1,1/20X,38HREGIONAL INTERMEDIATE GROUP FLUXES FOR,14,15H	OUT	460
	XTH BROAD GROUP//9X,5HLOWER,20I6)	OUT	470
	PRINT 107,(LREG(I),I=1,KREG)	OUT	480
107	FORMAT(4X,10HENERGY(EV),20I6)	OUT	490
	DO 35 I=LBGP,IBGP \$ MM=I+1 \$ M=(I-1)/100 \$ N=I-100*M	OUT	510
	DO 30 J=1,KREG	OUT	520
30	PFLUX(J) =XAREA(J)*FLUX(J,N)	OUT	530
35	PRINT 108,I,ENGP(MM),(PFLUX(J) ,J=1,KREG)	OUT	540
108	FORMAT(14,E10.3,20F6.3)	OUT	550
	DO 40 I=1,KREG	OUT	560
40	PHIRT(I)=XAREA(I)*PHIRT(I)/XNIB	OUT	570
	PRINT 109,(PHIRT(I),I=1,KREG)	OUT	580
109	FORMAT(4X,7HAVERAGE,3X,20F6.3)	OUT	600
50	PHITOT=0. \$ ACS=0. \$ FCS=0. \$ SCS=0.	OUT	620
	DO 53 I=1,KREG	OUT	622
53	PHIRT(I)=0.	OUT	624
	DO 55 I=1,KCOMP	OUT	630
	PHICT(I)=0.	OUT	640
	DO 55 J=1,KMAT	OUT	650
	RIAC(J,I)=0.	OUT	660
	RIFC(J,I)=0.	OUT	670
55	RISC(J,I)=0.	OUT	680
	IBG=IBG+1 \$ JBG=1	OUT	690
60	RETURN	OUT	700
	END	OUT	710

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SUBROUTINE SOURCE
COMMON/CW/REZ,AIMZ,REW,AIMW,KI,TR(62,62),TI(62,62)
COMMON/O/EXDU,FIV,KRES,NTEMP,TEST,V(25),SIGP(12,5),XZETA(12,5),
X  SA(12,5),SF(12,5),SS(12,5),DEN(12,5),G(800),GN(800),GF(800),
X  GR(800),ER(800),XRES(800),SIGZ(800),GAMMA(800),SIGIN(800),
X  INCLUDE(800),SIGMIN(800),NEXT(12),LAST(12),NRES(12),SIG(5),
X  SIGA22(12),SIGF22(12),INDEX
COMMON/1/NU,NOPT,UFGP,UIGP,DS1(12,25),DSMAX(12,25),CR(20),RAD(20),COM
X  RATIO(20),DIFX(20),SOURCE(20),SPP(20),SPN(20),TCI(20),TIO(20),COM
X  TII(20),TGO(20),CURP(20),CURN(20),CURP1(20),CURN1(20),
X  AREA(20),UMAX(20),FLUX(20,100),FLUXCP(5,100),SCAT(12,5,100),
X  TABLE1(181,26),TABLE2(181,51),TABLE3(181,2)
COMMON/2/KREG,KMAT,KCOMP,KGP,KBG,NPRINT,MCRE,IBGP,IFGP,IBG,JBG,
X  ACS,FCS,SCS,PHITOT,PHIT,ACSGP,FCSGP,SCSGP,XAREAT,AREAT,SDD,
X  RAP,NIB(25),SIGABGP(12,5),SIGFBGP(12,5),SIGSBGP(12,5),RMAX(5),COM
X  ENGP(1001),RIAC(12,5),RIFC(12,5),RISC(12,5),TITLE(9),TEMP(5),COM
X  NINT(5),MINT(5),XTEMP(20),LREG(20),PHICT(5),PHI(20),PFLUX(20),COM
X  NX(20),NUCLIDE(12),AMU(12),SIGPOT(12),AREAC(5),XAREAC(5),COM
X  DR(5),XAREA(20),PHIRT(20),NFI(25)
BANK(0),XSECT,QUICKW,RETEST,/0/,/QW/
BANK(1),RABBLE,SOURCE,INPUT,OUTPUT,DATA,RATES,NTRPLT,/1/,/2/
XNFI=1./NFI(1BG)      $ UFGP=UIGP*XNFI      $ EXDU=1.-V(1BG)
IF(1BG-1)5,5,35
5 IF(1FGP-1)10,10,35
10 U=UFGP      $ SDD=0.      $ RAP=0.
DO 25 I=1,KMAT
Z=1./(1.-EXP(-UMAX(I)))
DO 25 J=1,KCOMP
IF(I-KRES)20,20,15
15 SA(I,J)=DEN(I,J)*SIGA22(I)
SF(I,J)=DEN(I,J)*SIGF22(I)
20 SIGP(I,J)=DEN(I,J)*SIGPOT(I)
25 SDD=SDD+SIGP(I,J)*AREAC(J)*(1.-(Z-1.)*UMAX(I))
DO 30 I=1,KREG
SOURCE(I)=0.      $ K=LREG(I)
DO 30 J=1,KMAT
30 SOURCE(I)=SOURCE(I)+SIGP(J,K)*AREA(I)
GO TO 100
35 IF(JBG-2)40,36,36
36 INDEX=4      $ GO TO 60
40 IF(1FGP-2)45,41,36
41 INDEX=2      $ GO TO 55
45 IF(1BG-2)46,47,47
46 INDEX=1      $ GO TO 55
47 INDEX=3
50 XS=1.-V(1BG-1)      $ L=1BG-1      $ GO TO 60
55 XS=1.-V(1BG)      $ L=1BG
60 DO 95 I=1,KREG
SOURCE(I)=SOURCE(I)*XS      $ K=LREG(I)
DO 95 J=1,KMAT
SOURCE(I)=SOURCE(I)+DS1(J,L)*PHI(I)*SS(J,K)
Q=U-UMAX(J)      $ N=1
IF(Q)90,90,65
65 LM=1.+Q/UIGP      $ MM=(LM-1)/100      $ M=LM-100*MM
MIB=NIB(1)
66 IF(LM-MIB)70,70,67
67 N=N+1      $ MIB=MIB+NIB(N)      $ GO TO 66

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70 IF(UMAX(J)-99.*UIGP)75,75,90          SOUR 300
75 IF(J-KRES)80,80,85                     SOUR 310
80 SOURCE(I)=SOURCE(I)-DSMAX(J,N)*FLUX(I,M)*SCAT(J,K,M)*XNFI/FLUXCP    SOUR 320
   X      (K,M)                          $ GO TO 95          SOUR 330
85 SOURCE(I)=SOURCE(I)-DSMAX(J,N)*FLUX(I,M)*SIGP(J,K)*XNFI             SOUR 340
   GO TO 95                                                  SOUR 350
90 SOURCE(I)=SOURCE(I)-DSMAX(J,N)*SIGP(J,K)*AREA(I)                  SOUR 360
95 CONTINUE                                                    SOUR 370
100 U=U+UFGP                      $ CALL XSECT                  SOUR 380
    RETURN                                                    SOUR 390
    END                                                       SOUR 400
    SUBROUTINE XSECT                                           XSECT000
      COMMON/QW/REZ,AIMZ,REW,AIMW,KI,TR(62,62),TI(62,62)        COM 0 01
      COMMON/O/EXDU,FIV,KRES,NTEMP,TEST,V(25),SIGP(12,5),XZETA(12,5), COM 0 01
      X  SA(12,5),SF(12,5),SS(12,5),DEN(12,5),G(800),GN(800),GF(800), COM 0 02
      X  GR(800),ER(800),XRES(800),SIGZ(800),GAMMA(800),SIGIN(800), COM 0 03
      X  INCLUDE(800),SIGMIN(800),NEXT(12),LAST(12),NRES(12),SIG(5), COM 0 04
      X  SIGA22(12),SIGF22(12),INDEX                          COM 0 05
      COMMON/1/NU,NOPT,UFGP,UIGP,DSL(12,25),DSMAX(12,25),CR(20),RAD(20), COM 1 01
      X  RATIO(20),DIFX(20),SOURCE(20),SPP(20),SPN(20),TOI(20),TIO(20), COM 1 02
      X  TII(20),TOO(20),CURP(20),CURN(20),CURP1(20),CURN1(20), COM 1 03
      X  AREA(20),UMAX(20),FLUX(20,100),FLUXCP(5,100),SCAT(12,5,100), COM 1 04
      X  TABLE1(181,26),TABLE2(181,51),TABLE3(181,2)        COM 1 05
      COMMON/2/KREG,KMAT,KCOMP,KGP,KBG,NPRINT,MORE,IBGP,IFGP,IBG,JBG, COM 2 01
      X  ACS,FCS,SCS,PHITOT,PHIT,ACSGP,FCSGP,SCSGP,XAREAT,AREAT,SDD, COM 2 02
      X  RAP,NIB(25),SIGABGP(12,5),SIGFBGP(12,5),SIGSBGP(12,5),RMAX(5), COM 2 03
      X  ENGP(1001),RIAC(12,5),RIFC(12,5),RISC(12,5),TITLE(9),TEMP(5), COM 2 04
      X  NINT(5),MINT(5),XTEMP(20),LREG(20),PHICT(5),PHI(20),PFLUX(20), COM 2 05
      X  NX(20),NUCLIDE(12),AMU(12),SIGPOT(12),AREAC(5),XAREAC(5), COM 2 06
      X  DR(5),XAREA(20),PHIRT(20),NFI(25)                    COM 2 07
      BANK(0),XSECT,QUICKW,RESTEST,/O/,/QW/                   BANK 000
      BANK(1),RABBLE,SOARCE,INPUT,OUTPUT,DATA,RATES,NTRPLT,/1/,/2/   BANK 010
      GO TO (3,10,6,20) INDEX                                     XSECT010
3  E=.5*ENGP(1)*(1.+EXDU)                      $ Z=.5*V(IBG)      XSECT030
   DO 4 J=1,KCOMP                                     XSECT040
   DO 4 I=1,KMAT                                       XSECT050
     SA(I,J)=SA(I,J)*FIV                               XSECT060
   SF(I,J)=SF(I,J)*FIV                                $ GO TO 15      XSECT070
6  E=.5*E*(EXDU+1.-V(IBG-1))                      $ GO TO 15      XSECT090
   Z=.5*(V(IBG)+V(IBG-1))                          $ GO TO 15      XSECT100
10 E=E*EXDU                                           $ Z=V(IBG)     XSECT110
15 FDEL=1.+5*Z*(1.+75*Z*(1.+5.*Z/6.))              XSECT115
   GO TO 25                                           XSECT120
20 E=E*EXDU                                           XSECT125
25 DO 40 I=1,KRES                                     XSECT130
   DO 40 J=1,NTEMP                                     XSECT140
     XZETA(I,J)=XZETA(I,J)*FDEL                       XSECT150
     SA(I,J)=SIGA22(I)                                XSECT160
     SF(I,J)=SIGF22(I)                                XSECT170
     SS(I,J)=0.                                         XSECT180
     N=NEXT(I)                                          $ L=LAST(I)    XSECT190
     DO 40 K=N,L                                       XSECT200
     IF(J-1)30,30,35                                  XSECT210
30 XRES(K)=XRES(K)*FDEL                               XSECT220
35 IF(INCLUDE(K)-IBGP)40,36,40                       XSECT230
36 X=2.*(E-ER(K))/GAMMA(K)                           XSECT235
   ZETA=GAMMA(K)*XZETA(I,J)                          XSECT240

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AIMZ=.5*ZETA
REZ=X*AIMZ
CALL QUICKW
PSI=.88623*ZETA*REW
CHI=1.77246*ZETA*AIMW
F=PSI*SIGZ(K)
SA(I,J)=SA(I,J)+F*XRES(K)*(GF(K)+GR(K))
SF(I,J)=SF(I,J)+F*XRES(K)*GF(K)
SS(I,J)=SS(I,J)+F*GN(K)+CHI*SIGIN(K)
40 CONTINUE
DO 65 M=1,KCOMP
J=KCOMP+1-M
SIG(J)=0.
DO 65 I=1,KMAT
IF(I-KRES)45,45,60
45 IF(NTMP-1)50,50,55
50 SA(I,J)=DEN(I,J)*SA(I,1)
SF(I,J)=DEN(I,J)*SF(I,1)
SS(I,J)=DEN(I,J)*SS(I,1)+SIGP(I,J)
GO TO 65
55 SA(I,J)=DEN(I,J)*SA(I,J)
SF(I,J)=DEN(I,J)*SF(I,J)
SS(I,J)=DEN(I,J)*SS(I,J)+SIGP(I,J)
GO TO 65
60 SA(I,J)=SA(I,J)*FDEL
SF(I,J)=SF(I,J)*FDEL
SS(I,J)=SIGP(I,J)
65 SIG(J)=SIG(J)+SA(I,J)+SS(I,J)
CALL RATES
RETURN
END
SUBROUTINE DATA
COMMON/QW/REZ,AIMZ,REW,AIMW,KI,TR(62,62),TI(62,62)
COMMON/O/EXDU,FLV,KRES,NTMP,TEST,V(25),SIGP(12,5),XZETA(12,5),
X SA(12,5),SF(12,5),SS(12,5),DEN(12,5),G(800),GN(800),GF(800),
X GR(800),ER(800),XRES(800),SIGZ(800),GAMMA(800),SIGIN(800),
X INCLUDE(800),SIGMIN(800),NEXT(12),LAST(12),NRES(12),SIG(5),
X SIGA22(12),SIGF22(12),INDEX
COMMON/1/NU,NOPT,UFGP,UIGP,DS1(12,25),DSMAX(12,25),CR(20),RAD(20),
X RATIO(20),DIFX(20),SOURCE(20),SPP(20),SPN(20),TCI(20),TIO(20),
X TII(20),TOO(20),CURP(20),CURN(20),CURP1(20),CURN1(20),
X AREA(20),UMAX(20),FLUX(20,100),FLUXCP(5,100),SCAT(12,5,100),
X TABLE1(181,26),TABLE2(181,51),TABLE3(181,2)
COMMON/2/KREG,KMAT,KCOMP,KGP,KBG,NPRINT,MORE,IBGP,IFGP,IBG,JBG,
X ACS,FCS,SCS,PHITOT,PHIT,ACSGP,FCSGP,SCSGP,XAREAT,AREAT,SDD,
X RAP,NIB(25),SIGABGP(12,5),SIGFBGP(12,5),SIGSBGP(12,5),RMAX(5),
X ENGP(1001),RIAC(12,5),RIFC(12,5),RISC(12,5),TITLE(9),TEMP(5),
X NINT(5),MINT(5),XTEMP(20),LREG(20),PHICT(5),PHI(20),PFLUX(20),
X NX(20),NUCLIDE(12),AMU(12),SIGPOT(12),AREAC(5),XAREAC(5),
X OR(5),XAREA(20),PHIRT(20),NFI(25)
BANK(0),XSECT,QUICKW,RETEST,/0/,/QW/
BANK(1),RABBLE,SOARCE,INPUT,OUTPUT,DATA,RATES,NTRPLT,/1/,/2/
PI=3.14159265 $ FLV=SQRTF(.0253/ENGP(1))
XNFB=1./NFI(1)
DO 35 I=1,KBG
UFGP=UIGP/NFI(I)
V(I)=UFGP*(1.-.5*UFGP*(1.-(UFGP/3.)*(1.-.25*UFGP)))

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XSECT250
XSECT260
XSECT270
XSECT280
XSECT290
XSECT300
XSECT310
XSECT320
XSECT330
XSECT335
XSECT340
XSECT350
XSECT360
XSECT370
XSECT380
XSECT390
XSECT400
XSECT410
XSECT420
XSECT430
XSECT440
XSECT450
XSECT460
XSECT470
XSECT480
XSECT490
XSECT500
XSECT510
XSECT520
XSECT530
XSECT540
DATA 000
COM Q 01
COM 0 01
COM 0 02
COM 0 03
COM 0 04
COM 0 05
COM 1 01
COM 1 02
COM 1 03
COM 1 04
COM 1 05
COM 2 01
COM 2 02
COM 2 03
COM 2 04
COM 2 05
COM 2 06
COM 2 07
BANK 000
BANK 010
DATA 010
DATA 020
DATA 030
DATA 040
DATA 050

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EXDU=1-V(I)          $ VT=(1.-.5*UFGP)*V(I)
DO 35 J=1,KMAT
  IF(I-2)1,30,30
1  IF(AMU(J)-1.1)5,5,10
5  UMAX(J)=20.          $ GO TO 15
10 UMAX(J)=2.*LOGF(1.+2./(AMU(J)-1.))
15 LUMAX=UMAX(J)/UFGP    $ UMAX(J)=UFGP*FLOATF(LUMAX)
  IF(J-KRES)20,20,30
20 DO 25 K=1,NTEMP
25 XZETA(J,K)=SQRTF(AMU(J)/(3.46668E-04*ENGP(1)*TEMP(K)))
  N=NEXT(J)          $ L=LAST(J)
  DO 27 K=N,L          $ AER=ABSF(ER(K))
  XRES(K)=SQRTF(AER/ENGP(1))
  GAMMA(K)=GN(K)+GR(K)+GF(K)
  SIGZ(K)=2.62E+06*G(K)*GN(K)/(AER*GAMMA(K)**2)
27 SIGIN(K)=SQRTF(SIGPOT(J)*G(K)*SIGZ(K)*GN(K))
30 BETA=1./(1.-EXP(-UMAX(J)))    $ DSI(J,I)=BETA*VT
35 DSMAX(J,I)=(BETA-1.)*VT
  Z=EXP(-UIGP)
  DO 40 I=1,KGP
40 ENGP(I+1)=Z*ENGP(I)
  IF(NOPT)100,100,43
100 AREA(1)=1.          $ XAREA(1)=XNFB          $ LREG(1)=1
  AREAC(1)=1.          $ XAREAC(1)=XNFB          $ RAD(1)=1.
  AREAT=1.              $ XAREAT=XNFB          $ GO TO 95
43 MINT(1)=NINT(1)      $ DR(1)=RMAX(1)/FLOATF(NINT(1))
  DO 45 I=2,KCOMP
  DR(I)=(RMAX(I)-RMAX(I-1))/FLOATF(NINT(I))
45 MINT(I)=MINT(I-1)+NINT(I)
  I=1          $ RAD(1)=DR(1)  $LREG(1)=1
  DO 60 J=2,KREG
  IF(J-MINT(I))55,55,50
50 I=I+1
55 LREG(J)=I
60 RAD(J)=RAD(J-1)+DR(I)
  IF(NOPT-2)65,80,80
65 AREAT=PI*RMAX(KCOMP)**2  $ XAREAT=XNFB/AREAT  $ RATIO(1)=0.
  AREAC(1)=PI*RMAX(1)**2    $ XAREAC(1)=XNFB/AREAC(1)
  AREA(1)=PI*RAD(1)**2      $ XAREA(1)=XNFB/AREA(1)
  DO 70 I=2,KREG
  RATIO(I)=RAD(I-1)/RAD(I)
  AREA(I)=PI*(RAD(I)**2-RAD(I-1)**2)
70 XAREA(I)=XNFB/AREA(I)
  DO 75 J=2,KCOMP
  AREAC(J)=PI*(RMAX(J)**2-RMAX(J-1)**2)
75 XAREAC(J)=XNFB/AREAC(J)
  GO TO 95
80 AREAT=RMAX(KCOMP)          $ XAREAT=XNFB/AREAT
  AREAC(1)=RMAX(1)          $ XAREAC(1)=XNFB/AREAC(1)
  AREA(1)=RAD(1)          $ XAREA(1)=XNFB/AREA(1)
  DO 85 I=2,KREG
  AREA(I)=RAD(I)-RAD(I-1)
85 XAREA(I)=XNFB/AREA(I)
  DO 90 J=2,KCOMP
  AREAC(J)=RMAX(J)-RMAX(J-1)
90 XAREAC(J)=XNFB/AREAC(J)
95 RETURN

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DATA 060
DATA 070
DATA 080
DATA 090
DATA 100
DATA 110
DATA 120
DATA 125
DATA 130
DATA 140
DATA 150
DATA 155
DATA 160
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DATA 175
DATA 180
DATA 185
DATA 190
DATA 200
DATA 210
DATA 212
DATA 214
DATA 216
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DATA 220
DATA 230
DATA 240
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DATA 300
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DATA 320
DATA 330
DATA 340
DATA 350
DATA 360
DATA 370
DATA 380
DATA 390
DATA 400
DATA 410
DATA 420
DATA 430
DATA 440
DATA 450
DATA 460
DATA 470
DATA 480
DATA 490
DATA 500
DATA 510
DATA 520
DATA 530

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END
SUBROUTINE INPUT
COMMON/QW/REZ,AIMZ,REW,AIMW,KI,TR(62,62),TI(62,62)
COMMON/O/EXDU,FIV,KRES,NTEMP,TEST,V(25),SIGP(12,5),XZETA(12,5),
X SA(12,5),SF(12,5),SS(12,5),DEN(12,5),G(800),GN(800),GF(800),
X GR(800),ER(800),XRES(800),SIGZ(800),GAMMA(800),SIGIN(800),
X INCLUDE(800),SIGMIN(800),NEXT(12),LAST(12),NRES(12),SIG(5),
X SIGA22(12),SIGF22(12),INDEX
COMMON/1/NU,NOPT,UFGP,UIGP,DS1(12,25),DSMAX(12,25),CR(20),RAD(20),
X RATIO(20),DIFX(20),SOURCE(20),SPP(20),SPN(20),TUI(20),TIG(20),
X TII(20),TOO(20),CURP(20),CURN(20),CURP1(20),CURN1(20),
X AREA(20),UMAX(20),FLUX(20,100),FLUXCP(5,100),SCAT(12,5,100),
X TABLE1(181,26),TABLE2(181,51),TABLE3(181,2)
COMMON/2/KREG,KMAT,KCOMP,KGP,KBG,NPRINT,MORE,IBGP,IFGP,IBG,JBG,
X ACS,FCS,SCS,PHITOT,PHIT,ACSGP,FCSGP,SCSGP,XAREAT,AREAT,SDB,
X RAP,NIB(25),SIGABGP(12,5),SIGFBGP(12,5),SIGSBGP(12,5),RMAX(5),
X ENGP(1001),RIAC(12,5),RIFC(12,5),RISC(12,5),TITLE(9),TEMP(5),
X NINT(5),MINT(5),XTEMP(20),LREG(20),PHICT(5),PHI(20),PFLUX(20),
X NX(20),NUCLIDE(12),AMU(12),SIGPOT(12),AREAC(5),XAREAC(5),
X DR(5),XAREA(20),PHIRT(20),NFI(25)
BANK(0),XSECT,QUICKW,RETEST,/O/,/QW/
BANK(1),RABBLE,SOARCE,INPUT,OUTPUT,DATA,RATES,NTRPLT,/1/,/2/
READ 101,(TITLE(I),I=1,9)
101 FORMAT(9A8)
READ 102,KREG,KMAT,KCOMP,KRES,KGP,KBG,NOPT,NTEMP,NPRINT,MORE
102 FORMAT(12I6)
READ 102,(NIB(I),NFI(I),I=1,KBG)
READ 103,UIGP,ENGP(1),TEST,(TEMP(I),I=1,KCOMP)
103 FORMAT(3E12.6/5E12.6)
READ 104,(NINT(I),RMAX(I),I=1,KCOMP)
104 FORMAT(5(12,E10.4))
DO 10 I=1,KMAT
READ 105,NUCLIDE(I),NRES(I),AMU(I),SIGPOT(I),SIGA22(I),SIGF22(I)
105 FORMAT(A6,I6,4E12.6)
READ 106,(DEN(I,J),J=1,KCOMP)
106 FORMAT(5E12.6)
IF(NRES(I))10,10,5
5 IF(I-1)6,6,7
6 NEXT(I)=1 $ LAST(I)=NRES(I)
GO TO 8
7 NEXT(I)=LAST(I-1)+1
LAST(I)=LAST(I-1)+NRES(I)
8 N=NEXT(I) $ L=LAST(I)
DO 9 J=N,L
9 READ 106,ER(J),GN(J),GR(J),GF(J),G(J)
10 CONTINUE
CALL DATA
PRINT 201,(TITLE(I),I=1,9),KREG,KMAT,KCOMP,KRES,KBG,UIGP,KGP,TEST
201 FORMAT(1H1,2X,9A8//10X,18HNO. CELL REGIONS =,13,29X,15HNO. MATERIAL IN
XALS =,13/10X,18HNO. COMPOSITIONS =,13,29X,24HNO. RESONANT MATERIAL IN
XS =,12/10X,18HNO. BROAD GROUPS =,13,29X,29HLETHARGY WIDTH INTER. GIN
XROUP =,E12.6/10X,25HNO. INTERMEDIATE GROUPS =,14,21X,16HRESONANCE IN
XTEST =,E10.3,8H (BARNs)/)
MOPT=NOPT+1
GO TO (12,15,20,25) MOPT
12 PRINT 215 $ GO TO 30
15 PRINT 202 $ GO TO 30

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20 PRINT 203          $ GO TO 30          IN 280
25 PRINT 204          IN 290
30 PRINT 205          IN 300
215 FORMAT(10X,16HHOMOGENEOUS CASE)      IN 305
202 FORMAT(10X,48HCIRCULARIZED CELL WITH COSINE INTERFACE CURRENTS) IN 310
203 FORMAT(10X,40HSLAB CELL WITH COSINE INTERFACE CURRENTS) IN 320
204 FORMAT(10X,59HSLAB CELL WITH COSINE AND COSINE SQUARED INTERFACE C IN 330
    XURRENTS) IN 340
205 FORMAT(///2X,46HREGION/COMPOSITION/OUTER DIMENSION/TEMPERATURE/) IN 350
    DO 35 I=1,KREG IN 360
    NX(I)=I IN 370
35 XTEMP(I)=TEMP(LREG(I)) IN 380
    PRINT 206,(NX(I),I=1,KREG) IN 390
    PRINT 206,(LREG(I),I=1,KREG) IN 400
    PRINT 207,(RAD(I),I=1,KREG) IN 410
    PRINT 208,(XTEMP(I),I=1,KREG) IN 420
206 FORMAT(20I6) IN 430
207 FORMAT(20F6.3) IN 440
208 FORMAT(20F6.0) IN 450
    PRINT 209,(NX(I),I=1,5) IN 460
209 FORMAT(///2X,14HMATERIAL RES.,8X,40HMASS SIG POT SIG A 1/V IN 470
    X SIG F 1/V,20X,19HCOMPOSITION/DENSITY/23X,5H(AMU),3(5X,7H(BARNS)) IN 480
    X,5(10X,I2)) IN 490
    DO 40 I=1,KMAT IN 500
40 PRINT 210,NUCLIDE(I),NRES(I),AMU(I),SIGPOT(I),SIGA22(I),SIGF22(I), IN 510
    X (DEN(I,J),J=1,KCOMP) IN 520
210 FORMAT(4X,A6,I6,9E12.3) IN 530
    PRINT 211 IN 540
211 FORMAT(///14X,11HBROAD GROUP,8X,17HNO. INTER. GROUPS,5X,20HNO. FIN IN 550
    XE GP/INTER GP,6X,19HMAXIMUM ENERGY (EV),6X,19HMINIMUM ENERGY (EV)) IN 560
    N=1 $ M=N+NIB(1) IN 570
    DO 45 I=1,KEG IN 580
    PRINT 212,I,NIB(I),NFI(I),ENGP(N),ENGP(M) IN 590
    N=M IN 600
45 M=N+NIB(I+1) IN 610
212 FORMAT(3(20X,I5),2(10X,E15.4)) IN 620
    PRINT 213 IN 630
213 FORMAT(1H1/50X,20HRESONANCE PARAMETERS//12X,8HMATERIAL,10X,10HENER IN 640
    XGY(EV),8X,12HGAMMA N (EV),4X,16HGAMMA GAMMA (EV),8X,12HGAMMA F (EV IN 650
    X),19X,1HG) IN 660
    DO 50 I=1,KRES IN 670
    N=NEXT(I) $ L=LAST(I) IN 680
50 PRINT 214,(NUCLIDE(I),ER(J),GN(J),GR(J),GF(J),G(J),J=N,L) IN 690
214 FORMAT(14X,A6,5E20.3) IN 710
    RETURN IN 720
    END IN 730
    SUBROUTINE NTRPLT NPLT 000
    COMMON/QW/REZ,AIMZ,REW,AIMW,KI,TR(62,62),TI(62,62) COM Q 01
    COMMON/O/EXDU,F1V,KRES,NTEMP,TEST,V(25),SIGF(12,5),XZETA(12,5), COM 0 01
X SA(12,5),SF(12,5),SS(12,5),DEN(12,5),G(800),GN(800),GF(800), COM 0 02
X GR(800),ER(800),XRES(800),SIGZ(800),GAMMA(800),SIGIN(800), COM 0 03
X INCLUDE(800),SIGMIN(800),NEXT(12),LAST(12),NRES(12),SIG(5), COM 0 04
X SIGA22(12),SIGF22(12),INDEX COM 0 05
    COMMON/1/NU,NOPT,UFGP,UIGP,DS1(12,25),DSMAX(12,25),CR(20),RAD(20),COM 1 01
X RATIO(20),DIFX(20),SOURCE(20),SPP(20),SPN(20),TOI(20),TIO(20),COM 1 02
X TII(20),TOO(20),CURP(20),CURN(20),CURP1(20),CURN1(20), COM 1 03
X AREA(20),UMAX(20),FLUX(20,100),FLUXCP(5,100),SCAT(12,5,100), COM 1 04

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X      TABLE1(181,26),TABLE2(181,51),TABLE3(181,2)      COM 1 05
COMMON/2/KREG,KMAT,KCOMP,KGP,KBG,NPRINT,MORE,IBGP,IFGP,IBG,JBG, COM 2 01
X      ACS,FCS,SCS,PHITOT,PHIT,ACSGP,FCSGP,SCSGP,XAREAT,AREAT,SDD, COM 2 02
X      RAP,NIB(25),SIGABGP(12,5),SIGFBGP(12,5),SIGSBGP(12,5),RMAX(5), COM 2 03
X      ENGP(1001),RIAC(12,5),RIFC(12,5),RISC(12,5),TITLE(9),TEMP(5), COM 2 04
X      NINT(5),MINT(5),XTEMP(20),LREG(20),PHICT(5),PHI(20),PFLUX(20), COM 2 05
X      NX(20),NUCLIDE(12),AMU(12),SIGPOT(12),AREAC(5),XAREAC(5), COM 2 06
X      DR(5),XAREA(20),PHIRT(20),NFI(25) COM 2 07
BANK(0),XSECT,QUICKW,RETEST,/0/,/QW/ BANK 000
BANK(1),RABBLE,SOARCE,INPUT,OUTPUT,DATA,RATES,NTRPLT,/1/,/2/ BANK 010
DO 300 I=1,KREG NPLT 010
IF(NOPT-1) 10,10,1 NPLT 011
1 IF(I-2) 10,10,2 NPLT 012
2 IF(LREG(I)-LREG(I-1)) 3,3,10 NPLT 013
3 TOI(I)=TOI(I-1) $ SPP(I)=SPP(I-1) NPLT 014
IF(NOPT-2) 300,300,4 NPLT 015
4 TCO(I)=TCO(I-1) $ TII(I)=TII(I-1) NPLT 016
TIO(I)=TIO(I-1) $ SPN(I)=SPN(I-1) $ GO TO 300 NPLT 017
10 NRDEL=25 $ RN2=0. $RN1=1. NPLT 020
15 IF(DIFX(I))140,20,20 NPLT 030
20 IF(DIFX(I)-.4)50,50,25 NPLT 040
25 IF(DIFX(I)-1.)70,70,30 NPLT 050
30 IF(DIFX(I)-2.6)90,90,35 NPLT 060
35 IF(DIFX(I)-5.)110,110,40 NPLT 070
40 IF(DIFX(I)-8.)130,130,160 NPLT 080
50 NFDEL=DIFX(I)/.01+1 NPLT 090
F1=DIFX(I)/.01-NFDEL+1 $ GO TO 150 NPLT 100
70 NFDEL=DIFX(I)/.02+21 NPLT 110
F1=DIFX(I)/.02-NFDEL+21 $ GO TO 150 NPLT 120
90 NFDEL=DIFX(I)/.04+46 NPLT 130
F1=DIFX(I)/.04-NFDEL+46 $ GO TO 150 NPLT 140
110 NFDEL=(DIFX(I)-.2)/.06+71 NPLT 150
F1=(DIFX(I)-.2)/.06-NFDEL+71 $ GO TO 150 NPLT 160
130 NFDEL=DIFX(I)/.1+101 NPLT 170
F1=DIFX(I)/.1-NFDEL+101 $ GO TO 150 NPLT 180
140 PRINT 145 NPLT 190
145 FORMAT(32H A REGION HAS NEGATIVE THICKNESS) NPLT 200
STOP NPLT 210
150 F2=1.-F1 NPLT 220
GO TO (170,200,250),NOPT NPLT 230
160 GO TO (175,220,260),NOPT NPLT 240
170 MRDEL=RATIO(I)/.02+1 $ RM2=MRDEL-RATIO(I)/.02 $ RM1=1.-RM2 NPLT 250
NRDEL=RATIO(I)/.04+1 $ RN2=NRDEL-RATIO(I)/.04 $ RN1=1.-RN2 NPLT 260
TOI(I)=F2*RN2*TABLE1(NFDEL,NRDEL)+F2*RN1*TABLE1(NFDEL,NRDEL+1)+ NPLT 270
X F1*RN1*TABLE1(NFDEL+1,NRDEL+1)+F1*RN2*TABLE1(NFDEL+1,NRDEL) NPLT 280
TCO(I)=F2*RM2*TABLE2(NFDEL,MRDEL)+F2*RM1*TABLE2(NFDEL,MRDEL+1)+ NPLT 290
X F1*RM1*TABLE2(NFDEL+1,MRDEL+1)+F1*RM2*TABLE2(NFDEL+1,MRDEL) NPLT 300
GO TO 180 NPLT 310
175 TOI(I)=0. NPLT 320
TCO(I)=(1.-RATIO(I)**2)*(.005725/(DIFX(I)-5.5)-.000058*DIFX(I)+ NPLT 330
X .00118) NPLT 340
180 TIO(I)=RATIO(I)*TOI(I) NPLT 350
IF(I-1)185,185,190 NPLT 360
185 SPP(I)=.5*SOURCE(I)*(1.-TCO(I)-TIC(I))/(SIG(LREG(I))*RAD(I)) NPLT 370
SPN(I)=0. $ GO TO 300 NPLT 380
190 SPP(I)=.5*SOURCE(I)*(1.-TCO(I)-TIC(I))/(SIG(LREG(I))*(RAD(I)- NPLT 390
X RATIO(I)*RAD(I-1))) NPLT 400

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      SPN(I)=.5*SOURCE(I)*(1.-TOI(I))/(SIG(LREG(I))*(RAD(I)/RATIO(I)-
X      RAD(I-1)))
      GO TO 300
220 TOI(I)=0.          $ GO TO 225
200 TOI(I)=F2*TABLE1(NFDEL,26)+F1*TABLE1(NFDEL+1,26)
225 SPP(I)=.5*(1.-TOI(I))/DIFX(I)          $ GO TO 300
250 E3=.5*(F2*TABLE1(NFDEL,26)+F1*TABLE1(NFDEL+1,26))
      E2=F2*TABLE3(NFDEL,1)+F1*TABLE3(NFDEL+1,1)
      E4=F2*TABLE3(NFDEL,2)+F1*TABLE3(NFDEL+1,2)  $ GO TO 270
260 E2=.0          $ E3=0.          $ E4=0.
270 TOO(I)=4.*E2-6.*E3
      TOI(I)=6.*E3-9.*E4
      TII(I)=12.*E4-6.*E3
      TIO(I)=8.*E3-4.*E2
      SPP(I)=(.5-2.*E2+3.*E3)/DIFX(I)
      SPN(I)=2.*(E2-2.*E3)/DIFX(I)
300 CONTINUE
      RETURN
      END
      SUBROUTINE RATES
      COMMON/QW/REZ,AIMZ,REW,AIMW,KI,TR(62,62),TI(62,62)
      COMMON/O/EXDU,F1V,KRES,NTEMP,TEST,V(25),SIGP(12,5),XZETA(12,5),
X      SA(12,5),SF(12,5),SS(12,5),DEN(12,5),G(800),GN(800),GF(800),
X      GR(800),ER(800),XRES(800),SIGZ(800),GAMMA(800),SIGIN(800),
X      INCLUDE(800),SIGMIN(800),NEXT(12),LAST(12),NRES(12),SIG(5),
X      SIGA22(12),SIGF22(12),INDEX
      COMMON/1/NU,NOPT,UFGP,UGP,DS1(12,25),DSMAX(12,25),CR(20),RAD(20),
X      RATIO(20),DIFX(20),SOURCE(20),SPP(20),SPN(20),TOI(20),TIO(20),
X      TII(20),TOO(20),CURP(20),CURN(20),CURP1(20),CURN1(20),
X      AREA(20),UMAX(20),FLUX(20,100),FLUXCP(5,100),SCAT(12,5,100),
X      TABLE1(181,26),TABLE2(181,51),TABLE3(181,2)
      COMMON/2/KREG,KMAT,KCOMP,KGP,KBG,NPRINT,MCRE,IBGP,IFGP,IBG,JBG,
X      ACS,FCS,SCS,PHITOT,PHIT,ACSGP,FCSGP,SCSGP,XAREAT,AREAT,SDD,
X      RAP,NIB(25),SIGABGP(12,5),SIGFBGP(12,5),SIGSBGP(12,5),RMAX(5),
X      ENGP(1001),RIAC(12,5),RIFC(12,5),RISC(12,5),TITLE(9),TEMP(5),
X      NINT(5),MINT(5),XTEMP(20),LREG(20),PHICT(5),PHI(20),PFLUX(20),
X      NX(20),NUCLIDE(12),AMU(12),SIGPOT(12),AREAC(5),XAREAC(5),
X      DR(5),XAREA(20),PHIRT(20),NFI(25)
      BANK(0),XSECT,QUICKW,RESTEST,/O/,/QW/
      BANK(1),RABBLE,SOARCE,INPUT,OUTPUT,DATA,RATES,NTRPLT,/1/,/2/
      IF(NOPT)1,1,5
      1 CR(1)=SOURCE(1)          $ GO TO 400
      5 DIFX(1)=SIG(1)*RAD(1)
      IF(NOPT-2)20,10,10
      10 DIFX(1)=2.*DIFX(1)
      20 DO 110 I=2,KREG
      110 DIFX(I)=SIG(LREG(I))*(RAD(I)-RAD(I-1))
      KREG1=KREG-1
      GO TO (100,200,300),NOPT
      100 CALL NTRPLT
      X=-TOO(1)
      Z=SPP(1)
      DO 115 K=2,KREG1
      Y=TOI(K)*X
      X=-TOO(K)+Y*TIO(K)
      115 Z=SPP(K)+TOI(K)*Z-Y*SPN(K)
      Y=TOI(KREG)*X

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NPLT 410
 NPLT 420
 NPLT 430
 NPLT 440
 NPLT 450
 NPLT 460
 NPLT 470
 NPLT 480
 NPLT 490
 NPLT 500
 NPLT 510
 NPLT 520
 NPLT 530
 NPLT 540
 NPLT 550
 NPLT 560
 NPLT 570
 NPLT 580
 NPLT 590
 RATE 000
 COM 0 01
 COM 0 01
 COM 0 02
 COM 0 03
 COM 0 04
 COM 0 05
 COM 1 01
 COM 1 02
 COM 1 03
 COM 1 04
 COM 1 05
 COM 2 01
 COM 2 02
 COM 2 03
 COM 2 04
 COM 2 05
 COM 2 06
 COM 2 07
 BANK 000
 BANK 010
 RATE 000
 RATE 000
 RATE 001
 RATE 002
 RATE 003
 RATE 004
 RATE 005
 RATE 010
 RATE 015
 RATE 020
 RATE 025
 RATE 030
 RATE 035
 RATE 040
 RATE 045
 RATE 050
 RATE 055

X= 1.0-TOO(KREG)+Y*TIO(KREG)	RATE 060
Z=SPP(KREG)+TOI(KREG)*Z-Y*SPN(KREG)	RATE 065
CURN(KREG)=Z/X	RATE 070
CURP(KREG)=CURN(KREG)	RATE 075
CURN(KREG1)=SPN(KREG)+TIO(KREG)*CURP(KREG)	RATE 080
DO 120 K=2,KREG1	RATE 085
KA=KREG-K	RATE 090
KB=KA+1	RATE 095
120 CURN(KA)=SPN(KB)+TIO(KB)*CURN(KB)	RATE 100
CURP(1)=SPP(1)+TOO(1)*CURN(1)	RATE 105
DO 125 K=2,KREG1	RATE 110
125 CURP(K)=SPP(K)+TOO(K)*CURN(K)+TOI(K)*CURP(K-1)	RATE 115
CR(1)=(1.0-TOO(1))*CURN(1)+SOURCE(1)-SPP(1)	RATE 120
DO 140 I=2,KREG	RATE 125
140 CR(I)=(1.0-TOI(I))*CURP(I-1)+(1.0-TIO(I)-TOO(I))*CURN(I)+SOURCE(I)	RATE 130
X=SPP(I)-SPN(I)	RATE 135
GO TO 400	RATE 140
200 CALL NTRPLT	RATE 145
DO 205 I=1,KREG	RATE 146
205 SPP(I)=SOURCE(I)*SPP(I)	RATE 147
B=SPP(1)	RATE 150
C=TOI(1)	RATE 155
DO 220 I=2,KREG	RATE 160
B=B+C*SPP(I)/2.0	RATE 165
220 C=C*TOI(I)	RATE 170
DO 230 I=2,KREG	RATE 175
IA=KREG+2-I	RATE 180
B=B+C*SPP(IA)/2.0	RATE 185
230 C=C*TOI(IA)	RATE 190
CURP(1)=-B/(C-1.0)	RATE 195
DO 235 I=2,KREG	RATE 200
235 CURP(I)=SPP(I)/2.0+TOI(I)*CURP(I-1)	RATE 205
CURN(KREG)=CURP(KREG)	RATE 210
DO 240 I=1,KREG1	RATE 215
IA=KREG-I	RATE 220
IB=IA+1	RATE 225
240 CURN(IA)=SPP(IB)/2.0+TOI(IB)*CURN(IB)	RATE 230
CR(1)=(1.-TOI(1))*CURN(1)+SOURCE(1)-SPP(1)	RATE 235
DO 250 I=2,KREG	RATE 240
250 CR(I)=(1.0-TOI(I))*(CURN(I)+CURP(I-1))+SOURCE(I)-SPP(I)	RATE 245
GO TO 400	RATE 250
300 CALL NTRPLT	RATE 255
DO 305 I=1,KREG	RATE 256
SPP(I)=SOURCE(I)*SPP(I)	RATE 257
305 SPN(I)=SOURCE(I)*SPN(I)	RATE 258
U1=-TOO(2)*TOO(1)-TOI(2)*TIO(1)	RATE 260
V1=-TOO(2)*TOI(1)-TOI(2)*TII(1)	RATE 265
W1=-TIO(2)*TOO(1)-TII(2)*TIO(1)	RATE 270
X1=-TIO(2)*TOI(1)-TII(2)*TII(1)	RATE 275
Y1=.5*SPP(2)+TOO(2)*SPP(1)+TOI(2)*SPN(1)	RATE 280
Z1=.5*SPN(2)+TIO(2)*SPP(1)+TII(2)*SPN(1)	RATE 285
DO 310 I=2,KREG1	RATE 290
U2=U1*TOO(I)+V1*TIO(I)	RATE 295
V2=U1*TOI(I)+V1*TII(I)	RATE 300
W2=W1*TOO(I)+X1*TIO(I)	RATE 305
X2=W1*TOI(I)+X1*TII(I)	RATE 310
Y2=Y1-(U1*SPP(I)+V1*SPN(I))/2.0	RATE 315

```

Z2=Z1-(W1*SPP(I)+X1*SPN(I))/2.0
U1=U2*TOO(I+1)+W2*TOI(I+1)
V1=V2*TOO(I+1)+X2*TOI(I+1)
W1=U2*TIO(I+1)+W2*TII(I+1)
X1=V2*TIO(I+1)+X2*TII(I+1)
Y1=SPP(I+1)/2.0+Y2*TOO(I+1)+Z2*TOI(I+1)
310 Z1=SPN(I+1)/2.0+Y2*TIO(I+1)+Z2*TII(I+1)
U2=1.0+U1*TOO(KREG)+V1*TIO(KREG)
V2=U1*TOI(KREG)+V1*TII(KREG)
W2=W1*TOO(KREG)+X1*TIO(KREG)
X2=1.0+W1*TOI(KREG)+X1*TII(KREG)
Y2=Y1-(U1*SPP(KREG)+V1*SPN(KREG))/2.0
Z2=Z1-(W1*SPP(KREG)+X1*SPN(KREG))/2.0
CURP(KREG)=(Y2-Z2*V2/X2)/(U2-W2*V2/X2)
CURP1(KREG)=(Z2-W2*CURP(KREG))/X2
CURN(KREG)=CURP(KREG)
CURN1(KREG)=CURP1(KREG)
DO 320 I=1,KREG1
IA=KREG-I
IB=IA+1
CURN1(IA)=SPN(IB)/2.0+TIO(IB)*CURN(IB)+TII(IB)*CURN1(IB)
320 CURN(IA)=SPP(IB)/2.0+TOO(IB)*CURN(IB)+TOI(IB)*CURN1(IB)
CURP(1)=SPP(1)+TOO(1)*CURN(1)+TOI(1)*CURN1(1)
CURP1(1)=SPN(1)+TIO(1)*CURN(1)+TII(1)*CURN1(1)
DO 330 I=2,KREG1
IA=I-1
CURP(I)=SPP(I)/2.0+TOO(I)*CURP(IA)+TOI(I)*CURP1(IA)
330 CURP1(I)=SPN(I)/2.0+TIO(I)*CURP(IA)+TII(I)*CURP1(IA)
CR(1)=(1.-TOO(1)-TIO(1))*CURN(1)+(1.-TOI(1)-TII(1))*CURN1(1)+
X SOURCE(1)-SPP(1)-SPN(1)
DO 340 I=2,KREG
340 CR(I)=(1.0-TOO(I)-TIO(I))*(CURN(I)+CURP(I-1))+(1.0-TOI(I)-TII(I))*
X(CURN1(I)+CURP1(I-1))+SOURCE(I)-SPP(I)-SPN(I)
400 RETURN
END
SUBROUTINE QUICKW
COMMON/TRTI/TR(62,62),TI(62,62),AIMW,AX,KI,REW,Y
AKI=SIGN(1.,AX)
X=ABS(AX)
TEST=X*X+Y*Y
IF(TEST.LT.36.)GO TO 10
IF(TEST.LT.144.)GO TO 2
IF(TEST.LT.10000.)GO TO 3
A1=1./(1.7724715*TEST)
REW=Y*A1
IF(KI.GT.0)AIMW=X*A1*AKI
RETURN
10 II=X*10.
JJ=Y*10.
I=II+2
J=JJ+2
N=J-1
P=10.*X-II
Q=10.*Y-JJ
15 P2=P*P
Q2=Q*Q
PQ=P*Q

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RATE 320
 RATE 325
 RATE 330
 RATE 335
 RATE 340
 RATE 345
 RATE 350
 RATE 355
 RATE 360
 RATE 365
 RATE 370
 RATE 375
 RATE 380
 RATE 385
 RATE 395
 RATE 400
 RATE 405
 RATE 410
 RATE 415
 RATE 420
 RATE 425
 RATE 430
 RATE 435
 RATE 440
 RATE 445
 RATE 450
 RATE 455
 RATE 460
 RATE 465
 RATE 470
 RATE 475
 RATE 480
 RATE 485
 RATE 490
 RATE 495
 QCK 0000
 QCK 0001
 QCK 0002
 QCK 0003
 QCK 0004
 QCK 0005
 QCK 0006
 QCK 0007
 QCK 0008
 QCK 0009
 QCK 0010
 QCK 0011
 QCK 0012
 QCK 0013
 QCK 0014
 QCK 0015
 QCK 0016
 QCK 0017
 QCK 0018
 QCK 0019
 QCK 0020
 QCK 0021


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HP=.5*P
HQ=.5*Q
HQ2=.5*Q2
HP2=.5*P2
A1=HQ2-HQ
A2=HP2-HP
A3=1.+PQ-P2-Q2
A4=HP2-PQ+HP
A5=HQ2-PQ+HQ
REW=A1*TR(I,N )+A2*TR(I-1,J)+A3*TR(I,J)+A4*TR(I+1,J)+A5*TR(I,J+1)
1+PQ*TR(I+1,J+1)
IF(KI.LE.0) GO TO 8
5 AIMW=A1*TI(I,N )+A2*TI(I-1,J)+A3*TI(I,J)+A4*TI(I+1,J)+A5*TI(I,J+1)
1)+PQ*TI(I+1,J+1)
AIMW=AIMW*AKI
GOTO8
2 A1=X**2-Y**2
A2=2.*X*Y
A3=A2**2
A4=A1-.2752551
A5=A1-2.724745
D1=.5124242/(A4**2+A3)
D2=.05176536/(A5**2+A3)
REW=D1*(A2*X-A4*Y)+D2*(A2*X-A5*Y)
IF(KI.LE.0) GO TO 8
7 AIMW=D1*(A4*X +A2*Y)+D2*(A5*X+A2*Y)
AIMW=AIMW*AKI
GOTO8
3 A1=(X**2-Y**2)*2.
A2=4.*X*Y
A4=A1-1.
D1=1.1283792/(A4**2+A2**2)
REW=D1*(A2*X-A4*Y)
IF(KI.LE.0) GO TO 8
9 AIMW=D1*(A4*X+A2*Y)
AIMW=AIMW*AKI
8 RETURN
END
PROGRAM FLAT
DIMENSION TAB(182,51), TBB(182,51), E2(182), E4(182), X(51), Z(182)
DO 110 I=1,181
IF(I-41) 450,450,400
400 IF(I-71)460,460,410
410 IF(I-111)470,470,420
420 IF(I-151)480,480,430
450 Z(I)=(I-1)*.01
GO TO 500
460 Z(I)=(I-21)*.02
GO TO 500
470 Z(I)=(I-46)*.04
GO TO 500
480 Z(I)=(I-71)*.06+.20
GO TO 500
430 Z(I)=(I-101)*.10
500 DO 100 J=1,50
XJ=J-1
X(J)=.02*XJ

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QCK 0022
QCK 0023
QCK 0024
QCK 0025
QCK 0026
QCK 0027
QCK 0028
QCK 0029
QCK 0030
QCK 0031
QCK 0032
QCK 0033
QCK 0034
QCK 0035
QCK 0036
QCK 0037
QCK 0038
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QCK 0040
QCK 0041
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QCK 0044
QCK 0045
QCK 0046
QCK 0047
QCK 0048
QCK 0049
QCK 0050
QCK 0051
QCK 0052
QCK 0053
QCK 0054
QCK 0055
QCK 0056
QCK 0057
QCK 0058
QCK 0059

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X2=X(J)**2
Q=Z(I)/(1.-X(J))
TAB(I,J)=0.
TBB(I,J)=0.
DO 80 K=1,8
DO 80 L=1,7
W= .9817477E-02
GO TO(30,20,40,10,40,20,40)L
10 W=W+.9817477E-02
20 W=W+.39269908E-01
GO TO 40
30 IF(K-J)40,40,50
40 Y=COSF(.327249234E-01*FLOATF(6*K+L-7))
Y2=Y**2
FY3=2.*Q*Y
FY2=2.*Q*SQRTF(1.-X2*(1.-Y2))
FY1=.5*FY2-Q*Y*X(J)
CALL KI3(Z1,FY1)
CALL KI3(Z2,FY2)
CALL KI3(Z3,FY3)
XTAB=Y*Z1
XTBB=Y*(Z3-X(J)*Z2)
50 TAB(I,J)=TAB(I,J)+W*XTAB
TBB(I,J)=TBB(I,J)+W*XTBB
80 CONTINUE
TAB(I,J)=1.27323954*TAB(I,J)
100 TBB(I,J)=1.27323954*TBB(I,J)
IF(Z(I)-1.0)115,115,120
115 TAB(I,51)=-.57721566+.99999193*Z(I)-.24991055*Z(I)**2+.05519968*
IZ(I)**3-.00976004*Z(I)**4+.00107857*Z(I)**5-LOGF(Z(I))
GO TO 125
120 TAB(I,51)=(EXPF(-Z(I))/Z(I))*(Z(I)**4+8.573328740*Z(I)**3+
118.05901697*Z(I)**2+8.634760892*Z(I)+.2677737343)/(Z(I)**4+
29.573322345*Z(I)**3+25.63295615*Z(I)**2+21.09965308*Z(I)+
33.958496923)
125 E2(I)=EXPF(-Z(I))-Z(I)*TAB(I,51)
TAB(I,51)=EXPF(-Z(I))-Z(I)*E2(I)
E4(I)=(EXPF(-Z(I))-Z(I)*TAB(I,51))/2.0)/3.0
110 TBB(I,51)=0.0
130 WRITE TAPE 11, ((TAB(I,J), I=1,181), J=1,51,2), ((TBB(I,J),
XI=1,181), J=1,51), (E2(I), I=1,181), (E4(I), I=1,181)
PRINT 205
160 IA=1
IC=1
ID=12
300 PRINT 200, IA, IC, (TBB(IA,IB), IB=IC,ID)
IF(ID-39)320,310,330
310 IC=40
PRINT 200, IA, IC, (TBB(IA,IB), IB=IC,51)
IA=IA+1
IC=1
ID=12
GO TO 300
320 IC=ID+1
ID=IC+11
GO TO 300

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330 IC=ID+1
    ID=ID-39
    PRINT 200, IA, IC, (TBB(IA,IB), IB=IC,51), (TBB(IA+1,IB), IB=1,ID)
    IA=IA+1
    IC=ID+1
    ID=IC+11
    IF(IA-181)300,300,340
340 PRINT 210
    IA=1
    IC=1
    ID=23
350 PRINT 200, IA, IC, (TAB(IA,IB), IB=IC,ID,2)
    IF(ID-27)370,360,380
360 IC=29
    PRINT 200, IA, IC, (TAB(IA,IB), IB=IC,51,2)
    IA=IA+1
    IC=1
    ID=23
    GO TO 350
370 IC=ID+2
    ID=IC+22
    GO TO 350
380 IC=ID+2
    ID=ID-28
    PRINT 200, IA, IC, (TAB(IA,IB), IB=IC,51,2), (TAB(IA+1,IB),
X IB=1,ID,2)
    IA=IA+1
    IC=ID+2
    ID=IC+22
    IF(IA-181)350,350,390
390 PRINT 215
    PRINT 220, (E2(I), I=1,181)
    PRINT 225
    PRINT 220, (E4(I), I=1,181)
200 FORMAT (/215, 12F10.6)
205 FORMAT (1H1, 55X, 3HTBB)
210 FORMAT (1H1, 55X, 3HTAB)
215 FORMAT (1H1, 55X, 2HE2)
220 FORMAT (/12F10.6)
225 FORMAT (///55X, 2HE4)
    STOP
    END
    SUBROUTINE K13(Z,X)
    IF(X)10,10,15
10 Z=.785398163
    GO TO 30
15 IF(X-30.) 20,20,25
20 ZD=.16852107+X*(5.05688558+X*(34.1521732+X*(79.7244201+X*(
X 78.79235419+X*(34.81496948+X*(6.561524932+.4172698268*X))))))
    ZN=.13235614+X*(3.86932674+X*(23.8493885+X*(44.6280232+X*(
X 29.46275616+X*(7.112371513+.522969883*X))))))
    Z=EXP(-X)*SQRTF(1.+X)*ZN/ZD
    GO TO 30
25 Z=EXP(-X)*SQRTF(1.570796/X)*(1.-(1.625-5.13281/X)/X)
30 RETURN
    END

```

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