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RABID: An Integral Transport-theory Code for Neutron Slowing Down in Slab Cells

by

Arne P. Olson

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Applied Physics Division

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ABSTRACT

This report consists of the theory behind the methods used in the RABID code to solve the integral transport equation in slab geometry for cells with repeating boundary conditions, together with a user's guide, sample problems, and code listings. Space- and lethargy-dependent slowing-down sources are used with cross sections obtained by the single-level Breit-Wigner formalism for s- and p-wave resonances, to calculate resonance absorption, broad-group average fluxes and cross sections, and foil reaction rates.

RABID is coded in FORTRAN-IV for the IBM/360-75. A core requirement of 420 k bytes permits up to 300 resonances, 20 materials having resonances, 10 materials without resonances, 30 regions in the cell, and 25 broad groups.

I. INTRODUCTION

A tractable approach to the computation of resonance absorption, average neutron fluxes, and group cross sections for multiplate fast-reactor cells of the ZPR type has been developed by Kier and Robba.[1] Their technique, described here as the "RABBLE Method," assumes that the neutron currents at plate interfaces can be resolved into two components: one with a cosine angular distribution, the other with a cosine-squared angular distribution. This assumption enables the definition of transmission probabilities for these current components and, together with escape probabilities for spatially flat isotropic sources, leads to a simple solution of the spatial part of the integral transport equation.

A more accurate treatment of the spatial dependence of neutron flux is possible if one makes no assumptions about the angular distribution of the interface currents. Instead, the integral transport equation is solved "exactly" by the RABID code under the assumption that the slowing-down source is spatially linear, rather than flat as in RABBLE.

Initially, RABID consisted of the RABBLE code with a completely changed collision-rate calculation. Major evolutionary changes and

improvements have since affected virtually every section of code taken from RABBLE. For example, input/output subroutines have been changed to deal with foil calculations and transverse bucklings. Changes in the cross-section subroutines now permit p-wave resonances in addition to s-waves. The slowing-down-source calculation now accounts for ingroup scattering and uses much more effective storage of scattering rates to reduce or eliminate errors in the source contribution from fine groups one scattering interval distant. These and other topics will be developed at greater length.

II. THEORY

A. Integral Transport Equation

The integral form of the Boltzmann transport equation in a source-free infinite medium is

$$\phi(\vec{r}, u) = \iiint \overrightarrow{dr'} \int_0^u \frac{du' F_s(u', \vec{r}') P(u' \to u) \exp\left[-\Sigma_t(u, \vec{r}')|\vec{r} - \vec{r}'|\right]}{4\pi|\vec{r} - \vec{r}'|^2}, \tag{1}$$

where the scattering rate at lethargy u' and space point $\vec{r}'$ is

$$F_s(u', \vec{r}') = \Sigma_s(u')\phi(\vec{r}', u'). \tag{2}$$

The probability per unit lethargy that a neutron is scattered from u' to u is

$$P(u' \to u) = \begin{cases} \dfrac{1}{1 - \alpha} e^{-(u-u')}, & u \geq u' \geq u - \epsilon, \\ 0, & u' < u - \epsilon, \end{cases} \tag{3}$$

where

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

and A is the ratio of target nuclide mass to neutron mass.

Equation 1 can be reduced to one-dimensional form for infinite slab geometry by integrating over the other two spatial coordinates as follows:

$$\iiint \frac{d\vec{r}' F_s(u', \vec{r}') \exp[-\Sigma_t(u, \vec{r}')|\vec{r} - \vec{r}'|]}{4\pi|\vec{r} - r'|^2}$$

$$= \int dx' F_s(u', x') \int_0^\infty \frac{2\pi r \, dr \exp[-\Sigma_t(u, \vec{r}')(r^2 + |x - x'|^2)^{1/2}]}{4\pi(r^2 + |x - x'|^2)}$$

$$= \int dx' F_s(u', x) \int_1^\infty \exp[-\Sigma_t(u)|x - x'|t] \, dt/t$$

$$= \tfrac{1}{2} \int dx' F_s(u', x') E_1[\Sigma_t(u)|x - x'|], \tag{4}$$

where the scattering source now depends only on x' and u', and the exponential integral functions are[2]

$$E_n(Z) \equiv \int_1^\infty \exp(-Zt) \, dt/t^n. \tag{5}$$

Equation 1 now becomes

$$\phi(x, u) = \tfrac{1}{2} \int dx' \int_0^u du' F_s(u', x') P(u' \to u) \, E_1[\Sigma_t(u)|x - x'|]. \tag{6}$$

The following similar equation for the neutron current can be obtained:

$$\vec{J}(x, u) = \tfrac{1}{2} \int dx' \int_0^u du' F_s(u', x') P(u' \to u) \, E_2[\Sigma_t(u)|x - x'|]. \tag{7}$$

The lethargy dependence must now be converted from a continuous function to a multigroup formalism in which the group lethargy width is very narrow ($\Delta u \lesssim 10^{-3}$). Now define

$$\phi_\ell(x) \Delta u = \int_{u_{\ell min}}^{u_{\ell max}} \phi(x, u') \, du', \tag{8}$$

$$f_{s\ell}(x') \Delta u = \int_{u_{\ell min}}^{u_{\ell max}} du' F_s(u', x'), \tag{9}$$

(where $u_{\ell min}$ and $u_{\ell max}$ are lower and upper lethargy bounds, respectively, corresponding to group ℓ),

$$P_\ell \Delta u = \frac{1}{1-\alpha} \int_{u_0}^{u_0+\Delta u} du \int_{u_0-\ell\Delta u}^{u_0-(\ell-1)\Delta u} du' \, e^{-(u-u')}$$

$$= \frac{(1-e^{-\Delta u})^2}{1-\alpha} e^{-(\ell-1)\Delta u}, \qquad \ell = 1, 2, \ldots, L, \tag{10}$$

and

$$P_s \Delta u = \frac{1}{1-\alpha} \int_{u_0}^{u_0+\Delta u} du \int_{u_0}^{u} du' \, e^{-(u-u')} = \frac{1}{1-\alpha} (\Delta u - 1 + e^{-\Delta u}). \tag{11}$$

Let $L = \epsilon/\Delta u$ be an integral number of groups (by a minor adjustment to the mass ratio A, if necessary). Then the slowing-down source in group k from all other groups is

$$S_{0k}(x') = \sum_{\ell=1}^{L} f_{sk-\ell}(x') P_\ell \Delta u - \alpha \Sigma_{sk-\ell} \phi_{k-L} P_s \Delta u, \tag{12}$$

and the ingroup (self-scatter) source is

$$S_{sk}(x') = \Sigma_{sk} \phi_k P_s \Delta u,$$

where $P_s \Delta u$ is the probability for self-scatter. Some of the neutrons scattered in group k - L cannot reach group k, leading to the term

$$\alpha \Sigma_{sk-L} \phi_{k-L} P_s \Delta u.$$

Now Eqs. 6 and 7 become

$$\phi_k(x) = \tfrac{1}{2} \int dx' \left[\sum_{\ell=1}^{L} f_{sk-\ell}(x') P_\ell \Delta u + \Sigma_{sk} \phi_k P_s \Delta u \right] E_1(\Sigma_{tk} |x - x'|) \tag{13}$$

and

$$\vec{J}_k(x) = \tfrac{1}{2} \int dx' \left[\sum_{\ell=1}^{L} f_{sk-\ell}(x') P_\ell \Delta u + \Sigma_{sk} \phi_k P_s \Delta u \right] E_2(\Sigma_{tk} |x - x'|). \tag{14}$$

B. Collision Rates

The collision rate within a plate is the difference between the uncollided current in and the uncollided current out. For example, the current at τ mean free paths beyond a plate of optical thickness τ_1 is

$$\vec{J}(\tau,\tau_1) = \tfrac{1}{2}\int_0^{t_1} dx'[S_0(x') + S_s(x')]\, E_2(\tau + \Sigma_{t1}x'). \tag{15}$$

Since the self-scatter term is never more than 1 or 2% of the total source, it is a good approximation to assume that both source components have the same x'-dependence; that is,

$$S(x') = S_0(x') + S_s(x') = \overline{S} + (x' - t_1/2)\,\Delta S/t_1. \tag{16}$$

Then,

$$\vec{J}(\tau,\tau_1) = \tfrac{1}{2}\int_0^{t_1} dx'\, S(x')E_2(\tau + \Sigma_{t1}x') = \frac{\overline{S}}{2\tau_1}[E_3(\tau) - E_3(\tau+\tau_1)]$$

$$+ \frac{\Delta S}{2\tau_1}\left\{[E_3(\tau) + E_3(\tau_1+\tau)]/2 - \frac{1}{\tau_1}[E_4(\tau) - E_4(\tau_1+\tau)]\right\}. \tag{17}$$

To obtain the collision rate in plate 2 due to the source in plate 1, in which τ mean free paths separate the plates, one evaluates Eq. 17 at both sides of plate 2:

$$C\vec{R}(1\rightarrow 2) = \vec{J}(\tau,\tau_1) - \vec{J}(\tau+\tau_2,\tau_1). \tag{18}$$

Assuming an array of unit cells which repeat to infinity in both directions (periodic boundary conditions), the contribution by all plates of type 1 (in a given direction--the superscript arrow denotes this direction) is

$$C\vec{R}_\infty(1\rightarrow 2) = \sum_{m=0}^{\infty}[\vec{J}(\tau+mh,\tau_1) - \vec{J}(\tau+\tau_2)+mh,\tau_1)], \tag{19}$$

where h is the optical thickness of the unit cell. The average collided flux is

$$\phi = CR/\Sigma_t. \tag{20}$$

Equation 19 evaluated in forward and backward directions yields collision probabilities in an N-region unit cell of the form

$$\underline{P} = \begin{pmatrix} P_{11} & P_{21} & \dots & P_{N1} \\ P_{12} & P_{22} & \dots & P_{N2} \\ & & \vdots & \\ P_{1N} & P_{2N} & \dots & P_{NN} \end{pmatrix},$$

where $P_{ij} = [C\vec{R}_\infty(i\rightarrow j) + C\overleftarrow{R}_\infty(j\leftarrow i)]/S_i$.

With sources and collision rates written as vectors, the transport equation becomes

$$\overrightarrow{CR} = \underline{P}[\vec{S}_0 + \underline{R}\overrightarrow{CR}], \tag{21}$$

where $\underline{R}$ is a diagonal matrix

$$\underline{R} = \begin{pmatrix} \left(\frac{\Sigma_s P_s}{\Sigma_t}\right)_1 & & O \\ & \ddots & \\ O & & \left(\frac{\Sigma_s P_s}{\Sigma_t}\right)_N \end{pmatrix}.$$

Solving Eq. 21, we obtain

$$\overrightarrow{CR} = [\underline{P}^{-1} - \underline{R}]^{-1}\,\vec{S}_0. \tag{22}$$

RABID uses MATINV[3]--a standard ANL System/360 Library Subroutine--to perform the matrix inversions shown in Eq. 22. This routine is very fast, relative to the time involved in calculating the $\underline{P}$ matrix. Computation time increases only a few percent, relative to an approximate method of solving Eq. 21 which bypasses the matrix inversions. For completeness, the approximate method formerly used will now be described.

A simple but reasonable approximation is to solve Eq. 21 using an estimate of $\overrightarrow{CR}$ on the right-hand side. In general, the variation of collision rates from fine group k - 1 to fine group k is a few percent or less. Also, the ingroup-scattered source contribution is very small. Equation 21 is approximated as follows:

$$\overrightarrow{CR}_k \approx \overrightarrow{CR}_{k-1}, \text{ in right-hand side;} \tag{23}$$

$$\overrightarrow{CR}'_k = \underline{P}[\vec{S}_{0k} + \underline{R}\overrightarrow{CR}_{k-1}] = \underline{P}\vec{S}'. \tag{24}$$

Now correct the source using the best estimate available for $\overrightarrow{CR}_k$,

$$\vec{S} - \vec{S}' \approx \underline{R}(\overrightarrow{CR}' - \overrightarrow{CR}_{k-1}). \tag{25}$$

This accounts for single ingroup scattering collisions. Multiple ingroup scattering collisions lead to

$$\vec{S} - \vec{S}' \approx \underline{R}(\underline{I} - \underline{R})^{-1}\,(\overrightarrow{CR}' - \overrightarrow{CR}_{k-1}). \tag{26}$$

The increment to the collision-rate vector is also $\vec{S} - \vec{S}'$, if one ignores the spatial transfer of this very small correction. The collision-rate vector becomes

$$\overrightarrow{CR}_k \approx \overrightarrow{CR}'_k + \vec{S} - \vec{S}'. \tag{27}$$

In the limiting case of one-region (homogeneous) problems, the exact solution of Eq. 22 is

$$CR_k = S_{0k}/(1 - R), \tag{28}$$

which is also obtained by the approximate method.

We have seen that this approximation method is exact for homogeneous problems. Its basic fault for heterogeneous problems is the errors in the spatial transfer of ingroup-scattered neutrons. In the rather extreme example of a binary cell consisting of a heavy-atom absorber plate and a light-atom moderator plate, the flux in the absorber plate was overestimated by about 1% when it was optically thin. Physically, most of the ingroup-scattered neutrons were produced by collisions in the absorber plate and should have suffered their next collision in the optically thick moderator plate. However, in the approximation method, the ingroup-scattered neutrons tended to remain in the absorber plate, giving too high a flux there.

To represent neutron losses by leakage from a finite-sized system with buckling B^2, one need only scale the collision-probability matrix $\underline{P}$ by a nonleakage probability, PNL. A reasonable definition of PNL is obtained as follows:

$$PNL_k = \frac{\langle \Sigma_t \rangle_k}{\langle \Sigma_t \rangle_k + \langle D \rangle_k B^2}, \tag{29}$$

where k is the fine-group index, A_i is the thickness of region i,

$$\langle \Sigma_t \rangle_k = \sum_{i=1}^{KREG} (\Sigma_{tk}\phi_k A)_i \Big/ \sum_{i=1}^{KREG} (\phi_k A)_i, \tag{30}$$

the flux-volume-weighted total macroscopic cross section for the unit cell,

$$\langle \Sigma_t \rangle_k \approx \sum_{i=1}^{KREG} (\Sigma_{tk}\phi_{k-1} A)_i \Big/ \sum_{i=1}^{KREG} (\phi_{k-1} A)_i, \tag{31}$$

and

$$\langle D\rangle_k = \left[\frac{3 \sum_{m=1}^{KCOMP} A_m \sum_{j=1}^{KMAT} N_{jm}\sigma_{tj}\left(\frac{\sigma_{aj}}{\sigma_{sj}} + 1 - \bar{\mu}_{oj}\right)}{\sum_{m=1}^{KCOMP} A_m} \right]^{-1} . \tag{32}$$

This prescription for the diffusion coefficient comes from Weinberg and Wigner.[4] Hopefully, a better recipe for $\langle D\rangle$ can be found, for example, by using a transport-theory code, which will account for leakage parallel and perpendicular to the plates in slab geometry. Meanwhile, note that PNL is rather insensitive to errors in $\langle D\rangle$, for large systems. Also, group-averaged cross sections will in general be quite insensitive to $\langle D\rangle$. Provision has been made to use broad-group-dependent bucklings in finite systems.

C. Slowing-down Source

The slowing-down source would be very time-consuming to calculate directly because hundreds or even thousands of fine-group scattering rates contribute. Using the property that $P_\ell = e^{-\Delta u}P_{\ell-1}$, we can obtain the following recursion relation:

$$S_k = e^{-\Delta u}S_{k-1} + (P_1 - e^{-\Delta u}P_s)[(\Sigma_s\phi)_{k-1} - \alpha(\Sigma_s\phi)_{k-L-1}]$$
$$+ P_s[(\Sigma_s\phi)_k - \alpha(\Sigma_s\phi)_{k-L}]. \tag{33}$$

Equation 33 is written for a single material in a given region. Generalization to many materials and regions requires that Eq. 33 be evaluated in a given region for all isotopes, as P_1, P_s, and α are material-dependent, while $\Sigma_s\phi$ depends both on material and region. However, all we need to solve Eq. 21 are the $\vec{S}_0$ vector elements,

$$S_{0k} = S_k - P_s(\Sigma_s\phi)_k. \tag{34}$$

All components of S_{0k} are known, as $(\Sigma_s\phi)_{k-1}$ is the previous fine-group scattering rate, $(\Sigma_s\phi)_{k-L}$ is obtained by parabolic interpolation from a table of scattering rates for each material/region pair, and $(\Sigma_s\phi)_{k-L-1}$ is the previous interpolated value of $(\Sigma_s\phi)_{(k-1)-L}$. After Eq. 21 has been solved by performing the matrix manipulations of Eq. 22, the fluxes can be found by using Eq. 20. Then the term $P_s(\Sigma_s\phi)_k$ is calculated and S_k follows from Eq. 34.

D. Deletion of Ingroup Scattering

The matrix inversions of Eq. 22 can be eliminated (saving a few percent of computer time) by introducing the assumption that ingroup scattering does not occur. That is, $P_s = 0$. To conserve neutrons, P_ℓ as defined in Eq. 10 must be slightly altered. The sum of the downscatter probabilities must remain unity. Noting that

$$\sum_{\ell=1}^{L} P_\ell = 1 - e^{-\Delta u} \neq 1, \tag{35}$$

we see that dividing P_ℓ by $1 - e^{-\Delta u}$ will conserve neutrons when ingroup scattering has zero probability. In that case,

$$P'_\ell \Delta u \equiv P_\ell \Delta u/(1 - e^{-\Delta u}) = \frac{1 - e^{-\Delta u}}{1 - \alpha} e^{-(\ell-1)\Delta u}, \quad \ell = 1, 2, \ldots, L. \tag{36}$$

The user can decide whether to include ingroup scattering by his choice of the value for the input variable KS. An exhaustive study has not been made to establish how important this choice is. Certainly in many typical problems, where $L \gtrsim 100$, one can safely ignore ingroup scattering. Problems for which $L < 100$ should be examined using both options before arbitrarily ignoring ingroup scattering.

III. STORAGE OF SCATTERING RATES

In the past, RABBLE[1] and RABID have been known to generate absorption probabilities in excess of unity, and slowing-down sources less than zero. These events were the result of overapproximations in calculating the slowing-down sources. Originally, scattering rates were stored for each material (isotope or element) of each composition (which might be spatially averaged over several regions), lethargy-averaged over each intermediate group. Removing the spatial averaging eased the problem somewhat. Then a better system of lethargy-averaging was devised for RABID which gave further improvements by better utilizing the memory space available. The intermediate group size no longer was involved; instead, a lethargy width was optimally chosen for each material.

At this point, 200 scattering rates were retained--enough to eliminate lethargy averaging for heavy materials. The latest development is to retain a variable number of scattering rates. This number is problem-dependent and is automatically chosen to be as large as possible. The method eliminates waste storage formerly reserved for zero-density materials and space for extra materials not in use.

To give an example, suppose one had a two-composition problem with 10 regions (five of each composition), where one composition had four materials, and the other had two. A total of 30 plate/material combinations* are involved in the slowing-down-source calculation. Each one will have $[40{,}000/30]_{integer} = 1333$ words, versus 200 in the previous method. Hence, lethargy averaging need not be performed at all in many problems and is over a narrower lethargy range if required. Also, it is now possible to solve a problem with 30 compositions, 20 isotopes, and 300 resonances using only 420 k bytes. For a homogeneous problem using KMAT materials, the space per material is $(40{,}000/KMAT)_{integer}$.

The scattering rate $(\Sigma_s\phi)_{k-L}$ is required by Eq. 33 for each region/material pair. Tables of scattering rates are stored for each pair at equal lethargy intervals within a given broad group. (They vary with broad groups because the fine-group width Δu is broad-group dependent.) The lethargy interval is selected automatically to maximize the number of tabular entries between group k and group k-L, consistent with memory available. This is equivalent to choosing an interval width that is the smallest possible integral multiple of the fine-group width, and storing the average scattering rate over the interval.

It is not necessary to use the same Δu throughout a problem to maintain a prescribed level of numerical accuracy. The Doppler width,

$$w = \left(\frac{4EkT}{A}\right)^{1/2},$$

determines Δu by the empirical rule, $\Delta u \leq w/4E$. At lower energies, Δu can be increased. Then an interpolation scheme is necessary to extract $(\Sigma_s\phi)_{k-L}$ from the table, since the group boundaries extrapolated back from group k will not in general match up with the group boundaries previously used when the scattering rates were stored.

The "bookkeeping" involved in storing scattering rates is rather complicated. The following discussion (not at all needed by, nor recommended for, the casual user) is for a fixed table size of 200 entries. The code now uses a generalized table size of NOX entries for NISO plate/material pairs (NOX = 40,000/NISO - 1).

At this point, let us define the parameters involved in FORTRAN-coding the method:

J = isotope number,

IBG = broad group number of fine group k,

*Each plate/material combination is defined as a nonzero-density material in a given plate.

N = broad group number of fine group k - L,

I = region number,

K = composition number,

USTR(IBG) = lower lethargy bound of broad group IBG,

DUSTR(IBG) = lethargy width of broad group IBG,

MULT(J,N) = multiplicity, or number of fine groups per averaging interval,

INUI(J,N) = number of first averaging interval in broad group N for isotope J,

INUF(J,N) = number of last averaging interval in broad group N for isotope J,

LM = number of averaging interval containing group k - L,

M = LM (Modulo 200),

Q = lethargy at center of fine group k - L,

U = lethargy at upper end of fine group k,

UMAX(J,IBG) = ϵ for isotope J in broad group IBG rounded to closest integral multiple of the fine-group lethargy width,

JNU(J) = number of interval currently being incremented for isotope J,

JMULT(J) = number of fine-group scattering rates currently included in averaging interval JNU(J),

UIGP = intermediate-group lethargy width,

UFGP = fine-group lethargy width,

and

PL = fraction of averaging interval from center of interval LM to point Q.

Using these definitions, we obtain

$$\text{MULT(J,IBG)} = [1 + \text{UMAX(J,IBG)}/(\text{UFGP}*173)]_{\text{integer}}. \tag{37}$$

Although 200 values of scattering rates will be retained, one must account for the one currently being incremented which is unavailable for use, and also allow for an extra interval for the three-point interpolation scheme beyond fine group k - L. Also, extra intervals are required for 25 broad-group boundaries. Then,

$$\mathrm{SCAT(J,I,JNU(J))} = \sum_{\ell=1}^{\mathrm{MULT(J,N)}} (\Sigma_s\phi)_{\ell,I}/\mathrm{MULT(J,N)}. \tag{38}$$

Figure 1 illustrates the method for MULT(J,N) = 2 and MULT(J,IBG) = 3.

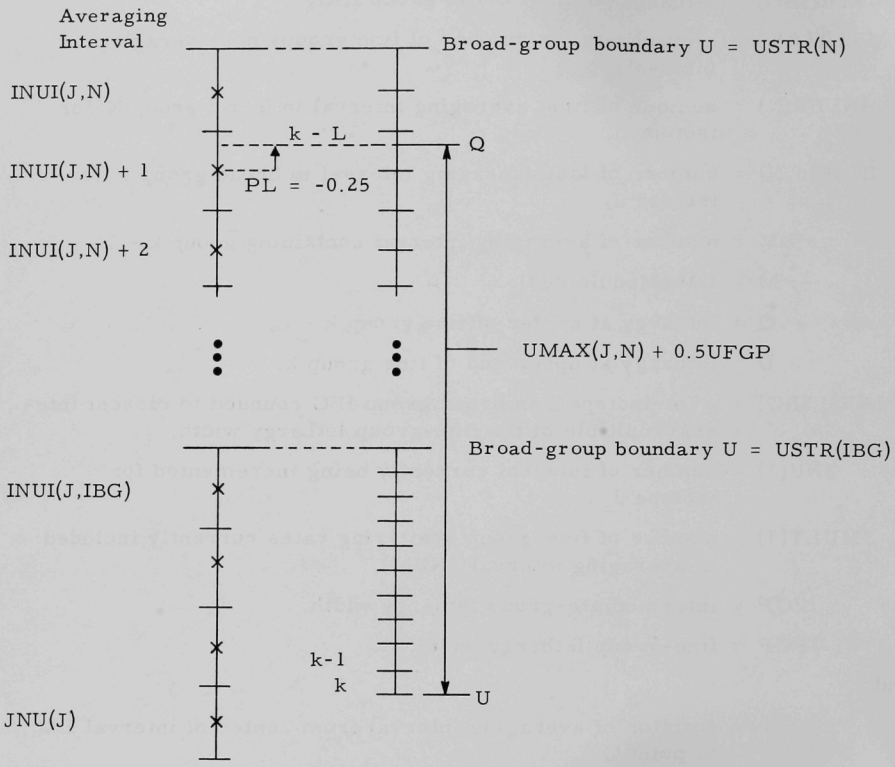

Fig. 1. Details of Scattering-rate Storage and Retrieval

$$\left.\begin{aligned} \mathrm{PL} &= \mathrm{INUI(J,N)} + (\mathrm{Q} - \mathrm{USTR(N)})/(\mathrm{UFGP_N} * \mathrm{MULT(J,N)}) - 0.5 \\ \mathrm{LM} &= [\mathrm{PL} + 0.5]_{\mathrm{integer}} \\ \mathrm{PL} &= \mathrm{PL} - \mathrm{LM}. \end{aligned}\right\} \tag{39}$$

The scattering rate at point Q is obtained from the Lagrange three-point formula

$$f(x_0 + ph) \approx \frac{p(p-1)}{2} f_{-1} + (1 - p^2) f_0 + \frac{p(p+1)}{2} f_1, \tag{40}$$

where $f(x) = \Sigma_s\phi(u)$, PL = p, and f_0 is $\langle\Sigma_s\phi\rangle$ at the center of averaging interval LM.

In many problems, a fine-group width of 10^{-4} lethargy units is adequately small. The following table indicates the worth of retaining scattering rates by this method for a fine-group width of 10^{-4}, for a fixed table length of 200.

Atomic Weight	ϵ	No. of Fine Groups per Averaging Interval
>202	<0.0198	1
$101 < A < 202$	$0.0198 < \epsilon < 0.0396$	2
$67 < A < 101$	$0.0396 < \epsilon < 0.0584$	3
$51 < A < 67$	$0.0584 < \epsilon < 0.0792$	4
$40 < A < 51$	$0.0792 < \epsilon < 0.0990$	5
$33 < A < 40$	$0.0990 < \epsilon < 0.1188$	6
$29 < A < 33$		7
$25 < A < 29$		8
$23 < A < 25$		9
$20 < A < 23$		10

Although light isotopes require several fine groups per averaging interval, the effect of errors due to averaging in scattering rates is reduced because the relative size of the source correction varies roughly as the atomic weight. Equivalently, the number of fine groups in the range ϵ roughly varies inversely with atomic weight. Another helpful condition arises from the fact that resonances tend to be broader for lighter isotopes, which permits a wider averaging interval for the same accuracy.

IV. FOILS BETWEEN REGIONS

A standard experiment on ZPR-type fast-reactor mockups is that of determining relative reaction rates within a unit cell by means of "small" (in both thickness and diameter) foils placed between the plates. It is reasonable to assume that the foils have essentially no effect on the neutron-flux distribution in a typical unit cell. Using this assumption, one can obtain the following collision rate in the foil by evaluating Eq. 18 at both sides of the foil (τ_f mean free paths thick):

$$\overrightarrow{CR}(1 \rightarrow \text{foil}) = \vec{J}(\tau, \tau_1) - \vec{J}(\tau + \tau_f, \tau_1). \tag{41}$$

Again, assuming an array of unit cells which repeat to infinity in both directions, the contribution by all plates of type 1 in a given direction is

$$\overrightarrow{CR}_{\infty}(1 \rightarrow \text{foil}) = \sum_{m=0}^{\infty} [\vec{J}(\tau + mh, \tau_1) - \vec{J}(\tau + \tau_f + mh, \tau_1)]. \tag{42}$$

The assumption that the foil has no effect on the cell means that the optical thickness of the unit cell h does not include τ_f and that there is no slowing-down source in the foil. Also, the optical thickness τ between plate 1 and the foil does not include contributions by foils at interfaces.

V. RESONANCE CROSS SECTIONS

The RABBLE[1] cross-section generation routine XSECT has been modified to account for the dependence of s-wave cross sections on scatterer mass number. The factor in the Breit-Wigner formula of $\pi\lambda\!\!\!^{-2}$ was assumed to be 2.62×10^6 b/eV in RABBLE, good enough for most resonant materials (heavy atomic weights). It is now more correctly calculated as $2.60385 \times 10^6 \left(1 + \frac{1}{A}\right)^2$ b/eV, where A is the scatterer mass number. The s-wave resonance cross sections are

$$\sigma_s^s = \sigma_0^s \frac{\Gamma_n^s}{\Gamma^s} \Psi(\xi, x) + \left(\frac{\sigma_p \sigma_0 g_J^s \Gamma_n}{\Gamma^s}\right)^{1/2} \chi(\xi, x) \tag{43}$$

and

$$\sigma_a^s = \sigma_0^s \sqrt{\frac{|E_0|}{E}} \frac{\Gamma_f^s + \Gamma_\gamma^s}{\Gamma^s} \Psi(\xi, x), \tag{44}$$

where

σ_0^s = peak height of s-wave resonance

$$= \frac{2.60385 \times 10^6}{|E_0|} \left(1 + \frac{1}{A}\right)^2 g_J^s \frac{\Gamma_n^s}{\Gamma^s},$$

$$x = \frac{2}{\Gamma^s}(E - E_0),$$

$$\Gamma^s = \Gamma_\gamma^s + \Gamma_f^s + \Gamma_n^s,$$

$$\xi = \Gamma^s/\Delta; \ \Delta = 2\left(\frac{kTE}{A}\right)^{1/2}; \ g_J^s = \frac{2J + 1}{2(2I + 1)},$$

J = total spin of compound nucleus,

I = spin of target nucleus,

E = neutron energy (in laboratory), eV,

E_0 = resonance energy (in laboratory), eV,

and

σ_p = potential scattering cross section.

Further modifications now permit treatment of p-wave resonances as follows:[5]

$$\sigma_s^p = \sigma_0^p \frac{\Gamma_n^p}{\Gamma^p}\sqrt{\frac{|E_0|}{E}}\left\{\Psi(\xi, x)+\frac{\Gamma^p}{2E_0}\chi(\xi, x)+\left(\frac{\Gamma^p}{2E_0}\right)^2 [1 - \Psi(\xi, x)]\right\}, \quad (45)$$

$$\sigma_f^p = \sigma_0^p \frac{\Gamma_f^p}{\Gamma^p}\sqrt{\frac{|E_0|}{E}}\left[\Psi(\xi, x) + \frac{\Gamma^p}{4E_0}\chi(\xi, x)\right], \quad (46)$$

$$\sigma_\gamma^p = \sigma_0^p \frac{\Gamma_\gamma^p}{\Gamma^p}\sqrt{\frac{|E_0|}{E}}\left[\Psi(\xi, x) + \frac{\Gamma^p}{4E_0}\chi(\xi, x)\right], \quad (47)$$

and

$$\sigma_a^p = \sigma_f^p + \sigma_\gamma^p, \quad (48)$$

where

σ_0^p = peak height of p-wave resonance

$$= \frac{2.60385 \times 10^6}{|E_0|}\left(1+\frac{1}{A}\right)^2 g_J^p \frac{\Gamma_n^p}{\Gamma^p},$$

$$x = \frac{2}{\Gamma^p}(E - E_0),$$

$$\Gamma^p = \Gamma_\gamma^p + \Gamma_f^p + \Gamma_n^p,$$

$$\xi = \Gamma^p/\Delta;\ \Delta = 2\left(\frac{kTE}{A}\right)^{1/2};\ g_J^p = \frac{(2J+1)}{2(2I+1)},$$

J = total spin of compound nucleus,

I = spin of target nucleus,

E = neutron energy (in laboratory), eV,

E_0 = resonance energy (in laboratory), eV,

$$\Gamma_n^p = \Gamma_n^0 \sqrt{E_0} v_1(E_0),$$

$$v_1(E_0) = \frac{\sigma_p E_0}{2.60385 \times 10^6\left(1+\frac{1}{A}\right)^2 + \sigma_p E_0} = \text{p-wave penetration factor},$$

Γ_n^0 = reduced neutron width,

and

σ_p = potential scattering cross section.

Doppler-broadened line-shape functions Ψ and χ are obtained from the complex probability integral W as follows:

$$\Psi(\xi, x) = \frac{\xi\sqrt{\pi}}{2} \text{Re } W\left(\frac{\xi x}{2}, \frac{\xi}{2}\right), \tag{49}$$

and

$$\chi(\xi, x) = \xi\sqrt{\pi} \text{ Im } W\left(\frac{\xi x}{2}, \frac{\xi}{2}\right). \tag{50}$$

Values of Re W and Im W are obtained from subroutine QUICKW.[6]

VI. OUTPUT EDIT

As explained in the Introduction, much of the RABBLE code was initially used in RABID and modified as necessary. The output edit is composed of all the normal RABBLE output plus resonance integrals, special output for foils at interfaces in the unit cell, the execution time, and a table showing the number of fine groups used to lethargy-average scattering rates for each material in each broad group. The edited quantities will now be defined, after the nomenclature is established.

Variable	Definition
k	Fine-group index
I	Intermediate- or broad-group index
i	Region index
j	Material index
ℓ	Interface index (ℓ = 1 at right of first region)
m	Composition index
n	Foil-composition index
ϕ_{ik}	Spatially integrated flux per unit lethargy in fine group k and region i
${}_zR_{ik}^j$	= $\phi_{ik}\Sigma_z^{jk}\Delta u$ = reaction rate for process z (f = fission, a = absorption, s = scattering) in fine group k integrated over region i

Variable	Definition
Δu	Fine-group lethargy width
A_i	Thickness of region i (cm)
ΔU_I	Lethargy width of intermediate or broad group I
u_I	Lower lethargy bound of group I
x_m	Left boundary of composition m ($x_1 = 0$)
N_{jm}	Atom number density of material j in composition m

A. Regional Average Flux

$$\overline{\phi}_{iI} = \frac{\int_{u_I}^{u_{I+1}} \phi_i(u)\, du}{A_i \int_{u_I}^{u_{I+1}} du} \approx \frac{\sum_k \phi_{ik} \Delta u}{A_i \Delta U_I}. \tag{51}$$

B. Composition-averaged Flux

$$\overline{\phi}_{mI} = \frac{\int_{x_m}^{x_{m+1}} dx \int_{u_I}^{u_{I+1}} \phi(u, x)\, du}{\int_{x_m}^{x_{m+1}} dx \int_{u_I}^{u_{I+1}} du} \approx \frac{\sum_i \overline{\phi}_{iI}}{\sum_i i}. \tag{52}$$

C. Cell-averaged Flux

$$\overline{\phi}_I = \frac{\int_0^{\infty} dx \int_{u_I}^{u_{I+1}} \phi(u, x)\, du}{\int_0^{\infty} dx \int_{u_I}^{u_{I+1}} du} \approx \frac{\sum_m \overline{\phi}_{mI} A_m}{\sum_m A_m}. \tag{53}$$

D. Composition-averaged Microscopic Cross Section for Process z

$$z\overline{\sigma}^j_{mI} = \frac{\int_{x_m}^{x_{m+1}} dx \int_{u_I}^{u_{I+1}} \Sigma^j_z(u) \phi(u, x)\, du}{N_{jm} \int_{x_m}^{x_{m+1}} dx \int_{u_I}^{u_{I+1}} \phi(u, x)\, du} \approx \frac{\sum_i \sum_k {}_zR^j_{ik}}{N_{jm} \sum_i \sum_k \phi_{ik}}. \tag{54}$$

E. Cell-averaged Macroscopic Cross Section for Process z

$$ {}_z\overline{\Sigma}_I = \frac{\int_0^\infty dx \int_{u_I}^{u_{I+1}} \phi(u,x)\,{}_z\Sigma(u,x)\,du}{\int_0^\infty dx \int_{u_I}^{u_{I+1}} \phi(u,x)\,du} \approx \frac{\sum_j \sum_i \sum_k {}_zR^j_{ik}}{\sum_i \sum_k \phi_{ik}}. \tag{55} $$

In the above five definitions, $\sum_k$ is over all fine groups within Group I, $\sum_i$ is over all regions in the composition m, and $\sum_j$ is over all materials.

F. Resonance Integral for Process z

The resonance integral is defined as that cross section which, when multiplied by the flux that would be present in the absence of resonances, ϕ_∞, gives the true reaction rate. The normalization used assumes $\phi_\infty = 1$.

$$ {}_z(RI)^j_{mI}\phi_\infty = \frac{\int_{x_m}^{x_{m+1}} dx \int_{u_I}^{u_{I+1}} {}_z\Sigma^j(u)\phi(u,x)\,du}{N_{jm}A_m} \approx {}_z\bar{\sigma}^j_{mI}\bar{\phi}_{mI}\Delta U_I. \tag{56} $$

The symbols printed out are RA and RF for absorption and fission resonance integrals. Scattering resonance integrals are not printed but can be calculated as shown.

G. Accumulated Absorption Probability for a Broad Group

$$ RAP = \frac{\int_0^\infty dx \int_{u_I}^{u_{I+1}} \phi(u,x)\,{}_a\Sigma(u,x)\,du}{SDD} \approx \frac{\sum_j \sum_i \sum_k {}_aR^j_{ik}}{SDD}, \tag{57} $$

where the slowing-down density at the lethargy corresponding to the start of the problem is

$$ SDD = \phi_\infty \sum_m A_m \sum_j N_{jm}\xi_j\sigma^j_p \tag{58} $$

and

$$ \xi = 1 - \frac{\alpha}{1-\alpha}\epsilon. \tag{59} $$

H. Foil Resonance Integral for Process z

Microscopic average foil cross sections are not calculated; hence, microscopic resonance integrals for foils can only be obtained if the foil consists of just one material. In that case,

$$ {}_z(RI)_{nI}^{\ell j}\phi_\infty = \frac{\int_{u_I}^{u_{I+1}} {}_z\Sigma^n(u)\phi_\ell^n(u)\,du}{N_{jn}A_n} \approx {}_z\bar{\Sigma}_{\ell I}^n\bar{\phi}_{\ell I}^n\Delta U_I/N_{jn}. \tag{60} $$

The quantity edited is ${}_z\bar{\Sigma}_{\ell I}^n\bar{\phi}_{\ell I}^n\Delta U_I$. The flux incident upon all foils is the same. Although it is not edited directly, one can obtain it by defining an optically thin foil (say $\tau < 10^{-4}$ mean free paths) for which $\sigma_a = \sigma_f = 0$ and σ_s is independent of energy. Then the broad-group-average flux ϕ_{inc} incident upon foils can be extracted from

$$ RS(F) = \Sigma_s\phi_{inc}\Delta U_I. \tag{61} $$

VII. INPUT PREPARATION

A. Choice of Group Sizes

The intermediate-group size no longer has any effect on the slowing-down source (it did in RABBLE[1]), but is still involved in calculating resonance cross sections. If the energy at the peak of a resonance lies within a given intermediate group, it automatically is included, regardless of the magnitude of the cross section. If not within the given intermediate group, it is included only if $\sigma_t >$ TEST (an input variable) at either end of the intermediate group. Thus, to save running time, the user should use a small intermediate-group size if he specifies TEST > 0. For example, 0.01 lethargy unit is reasonable.

The choice of fine-group size Δu_I = UIGP/NFI(I) can be placed on a consistent basis by comparison with the Doppler width

$$ w = \sqrt{\frac{4E_0kT}{A}}, \tag{62} $$

where E_0 is the resonance energy, k is Boltzmann's constant (8.6164×10^{-5} eV/°K), T is the temperature, and A is the mass number of the resonant material. A satisfactory rule of thumb is to choose Δu_I so that $\Delta u_I \leq w/4E$.

B. Input Description for RABID

The following overall restrictions must be observed:

Parameter	Range
Regions	$1 \leq KREG \leq 30$
Materials	$1 \leq KMAT \leq 20$
Resonant materials	$1 \leq KRES \leq 20$
Compositions	$1 \leq KCOMP \leq 30$
Resonances	$1 \leq \sum_{J=1}^{KRES} NRES(J) \leq 300$
Intermediate groups	$1 \leq KGP \leq 1000$
Broad groups	$1 \leq KBG \leq 25$

Card	Format	Variable	Description
1	18A4	(TITLE(I),I=1,18)	Problem identification
2	10I6	KREG	No. of regions; $1 \leq KREG \leq 30$.
		KMAT	No. of materials; $1 \leq KMAT \leq 20$.
		KCOMP	No. of compositions; $1 \leq KCOMP \leq 30$.
		KRES	No. of resonant materials; $1 \leq KRES \leq 20$.
		KGP	No. of intermediate groups; $1 \leq KGP \leq 1000$.
		KBG	No. of broad groups; $1 \leq KBG \leq 25$.
		NOPT	NOPT = 0, homogeneous; $1 \leq NOPT \leq 3$, normal, heterogeneous; NOPT = 4, special case with resonance interference term $\chi(\xi, x)$ set to zero. If KREG = 1, the result is homogeneous anyway.
		NTEMP	If all compositions at the same temperature, NTEMP = 1; otherwise, NTEMP = III. III = KCOMP + KFOIL $\leq$ 35.
		NPRINT	If NPRINT > 0, edit of intermediate group output is omitted.
			If NPRINT < 0, fine-group fluxes and intermediate-group output are printed. MORE = 0 for the first problem in a batch.
		MORE	If the last problem in a batch, MORE > 0 gives elegant stop. Otherwise, an "end of data set" error will terminate the run. MORE < 0 denotes the next problem to be a modification problem.*

*A modification problem is one in which some input variables from the preceding problem need modification, while the other input variables remain fixed. Any or all input variables may be changed using the NAMELIST feature of FORTRAN-IV.[7] The NAMELIST name is MOD. This convenient input feature results in considerable savings in cards and labor needed to run a sequence of closely related problems. A new title card (type-1) is assumed to precede the NAMELIST input for a modification problem.

Card	Format	Variable	Description
3	12I6	(NIB(I),	No. of intermediate groups in Ith broad group; $1 \leq NIB(I) \leq 100$, and $\Sigma NIB(I) = KGP$.
		NFI(I),I=1, KBG)	No. of fine groups per intermediate group in Ith broad group, chosen such that $UIGP/NFI(I) \leq 10^{-3}$.
4	3E12.6,4I6	UIGP	Lethargy width of intermediate group.
		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 lower energy limit of the intermediate group exceeds TEST (barns).
		KFOIL	No. of foils to edit interface fluxes and average cross sections; $0 \leq KFOIL \leq 5$. Computation time is minimized by handling a problem with several foils in a single run as opposed to several runs, each with a single foil.
		KBSQ	If $KBSQ > 0$, read type-5 cards for the broad-group transverse bucklings. If $KBSQ \leq 0$, omit type-5 cards.
		KS	$KS > 0$ deletes ingroup scattering by adjusting group-transfer probabilities.
		KB	$KB \neq 0$ implies broad-group-dependent values of flat-background absorption and fission cross sections are to be read as type-11 cards.
5	5E12.6	(BSQ(I),I=1,KBG)	Broad-group transverse bucklings.
6	5E12.6	(TEMP (I),I=1, III)	Temperature of Ith composition (°K), if $I \leq KCOMP$. Temperature of foil I - KCOMP otherwise. $III = KCOMP + KFOIL \leq 35$.
7	5(I2,E10.4)	(NINT(I),	No. of regions into which Ith composition is divided, if $I \leq KCOMP$. Not used if $I > KCOMP$.
		RMAX(I),	Outer boundary of Ith composition, if $I \leq KCOMP$.
		I=1, III)	Thickness of foil I-KCOMP, if $I > KCOMP$ (cm).
8	A6,I6,4E12.6	(NUCLID(I),	Identification of Ith material.
		NRES(I),	No. of resonances for Ith material; $\Sigma NRES(I) \leq 300$. If $I > KRES$, $NRES(I) = 0$.
		AMU(I),	Atomic weight of Ith material (AMU).
		SIGPOT(I),	Potential scattering cross section of Ith material (b).

Card	Format	Variable	Description
		SIGA22(I),	2200-m/sec (0.0253 eV) value of 1/v absorption cross section for resonant materials. Constant-background absorption cross section for resonant materials (b).
		SIGF22(I), I=1,KMAT)	2200-m/sec (0.0253-eV) value of 1/v fission cross section for nonresonant materials. Constant-background fission cross section for resonant materials (b).
9	5E12.6	(DEN(I,J), J=1,III)	Atom density of material I in composition J, if I ≤ KCOMP. If I > KCOMP, atom density of material I in foil I - KCOMP ($10^{24}/cm^3$).

NOTE: Materials must be ordered so that information for resonant materials is read first. If NRES(I) > 0, read in cards 10 for the resonances of material I next; if NRES(I) = 0, read in card 8 for material I + 1 next.

10	5E12.6	(ER(J),	Energy of Jth resonance (eV).
		GN(J),	Neutron width of Jth resonance at ER(J) (eV).
		GR(J),	Radiation width of Jth resonance (eV).
		GF(J),	Fission width of Jth resonance (eV).
		G(J),	Statistical spin factor.
		J=1,NRES(I))	$g = \frac{2J' + 1}{2(2I' + 1)}$, where J' is the spin of the compound nucleus and I' is the spin of the target nucleus. For s-waves, G(J) ≥ 0. To denote a p-wave, tag a minus sign on G(J).
11	6E12.5		If KB ≠ 0, KBG sets of type-11 cards are required.
		(SIGA22(I),	Constant-background absorption cross section for resonant materials, for a given broad group.
		SIGF22(I), I=1,KRES)	Constant-background fission cross section for resonant materials, for a given broad group.

C. Error Messages

Only a few consistency checks on input parameters are performed. A few calculated quantities are checked to see if they are physically reasonable. If they are not, the problem may be aborted, or some corrective action taken. Listed below are the checks and decisions made by the code.

1. RATES

a. KREG < 0 sets IERR = 1, prints ***KREG**, and returns to MAIN, where the problem is aborted. Input for the next problem is then processed.

b. Optical thicknesses TAU are checked. TAU $<$ 0 sets IERR = 1, prints K, TAU(K), IBGP, and IFGP, followed by *****PROBLEM ABORTED. Control returns to MAIN, which aborts the problem. Input for the next problem is then processed.

c. Collision rates are inspected. If CR $<$ 0, the $\overrightarrow{CR}$ vector and the $\underline{P}$ matrix are printed followed by the message NEG. COLL. RATE ZEROED OUT. Then SOURCE(I), TQ(I), DS(I), TAU(I), and ITRY(I) are printed out for $1 \leq I \leq$ KREG. The $\overrightarrow{CR}$ are renormalized so that the smallest value is zero and neutron conservation is maintained. A gross error in calculating $\underline{P}$ is required for this error.

2. <u>SOARCE</u>

a. SOURCE $<$ 0 prints I, SOURCE(I), and energy E. The problem continues using

$$\text{SOURCE(I)} = \sum_{j=1}^{\text{KMAT}} \text{DS1(J)*PHI(I)*SL(J,LREG(I))}$$

= downscatter contribution from previous group.

3. <u>INPUT</u>

a. KREG $\neq \sum_{K=1}^{\text{KCOMP}}$ NINT(K) prints KREG NOT CONSISTENT WITH NINT, and problem is aborted. Input for the next problem is read.

b. LAST(KRES) $>$ 300 prints $>$ 300 RESONANCES, and problem is aborted. Input for the next problem is read.

c. $\sum_{I=1}^{\text{KBG}} \neq$ KGP prints their values. KGP is reset to the smaller value and printed. Problem is aborted if KGP $>$ 1000 or KGP $\leq$ 0; then input for next problem is read.

4. <u>MATINV</u>

DETERM = 0 implies MATINV is trying to invert a singular matrix. It immediately returns to RATES, which does <u>not</u> check for failure.

D. <u>Timing Considerations</u>

The most important factors influencing the computer time (CPU time) required are the number of regions, the number of foils, the unit-cell

optical thickness, and the number of fine groups. The basic quantity the user wants to know is calculational speed, in fine groups per minute (since total time varies directly with the number of fine groups). Table I gives an estimate which should be within ± 20% for typical problems having a unit-cell optical thickness >0.2 mean free path. The time per fine group needed to obtain region collision rates and fluxes is

$$t_\phi \approx 0.01\{2.368 + N[-0.582 + N(0.24 - 0.00094N)]\} \text{ (sec)}, \qquad N \geq 2. \tag{63}$$

The time per fine group needed to obtain interface collision rates for a foil is

$$t_f \approx 0.01\{1.463 + N[-1.092 + N(0.407 - 0.0071N)]\} \text{ (sec)}, \qquad N \geq 2. \tag{64}$$

In Eqs. 63 and 64, N is the number of regions. Then the total time per fine group is

$$t_{total} = t_\phi + t_f * \text{KFOIL}. \tag{65}$$

TABLE I. Calculational Speed (all compositions at same temperature)

No. of Regions	No. of Fine Groups per Minute			No. of Regions	No. of Fine Groups per Minute		
	No Foils	One Foil	Two Foils		No Foils	One Foil	Two Foils
1	43,000	37,700	33,800	11	250	133	73
2	2,780	2,000	1,560	12	215	95	62
3	2,180	1,360	990	13	180	82	53
4	1,570	860	595	14	155	71	46
5	1,120	565	380	15	135	62	40
6	820	390	260	16	119	55	36
7	620	285	185	18	94	44	29
8	480	215	140	20	76	37	24
9	375	170	110	25	49	25	17
10	305	137	89	30	34	19	13

Homogeneous problems are a special case. For these, a single-material problem gave

$$t_{total} = 0.0014 + 0.00036M \text{(sec)}, \tag{66}$$

Equations 63-66 are for all compositions at the same temperature. Times will increase if more than one temperature is involved, or for greater complexity in terms of numbers of resonances and materials. Conversely, some problems with large N may be quicker because fine groups for which the unit cell optical thickness is large (on a resonance peak) have essentially uncoupled regions. RABID assumes that regions more than nine mean free paths apart are totally uncoupled.

APPENDIX A

Numerical Methods Used to Obtain Collision Rates

1. Introduction

Integral transport theory was used in Section II to derive plate-to-plate collision probabilities in infinite slab geometry as used in the RABID code. The "exact" analytic expressions derived involve many infinite sums of the exponential integral functions[2]

$$E_n(z) = \int_1^\infty e^{-zt}\, dt/t^n, \qquad n \geq 0. \tag{A.1}$$

A needed related function is

$$\alpha_n(z) = \int_1^\infty t^n e^{-zt}\, dt, \qquad n \geq 0. \tag{A.2}$$

The sum we wish to evaluate numerically for a unit cell of optical thickness h is

$$S_n(z, h) = \int_1^\infty \frac{e^{-zt}\, dt}{(1 - e^{-ht})\, t^n} = \sum_{k=0}^{\infty} E_n(z + kh), \qquad n > 0. \tag{A.3}$$

A very fast, accurate method for calculating $S_n(z, h)$ has been derived on the basis of special Gaussian quadrature formulas. That is, let

$$\int_1^\infty \exp(-x) f(x)\, dx/x^n = \sum_{i=1}^{M} w_{i,n} f(t_{i,n}) + R_M(z) \tag{A.4}$$

and

$$\int_1^\infty g(x)\, dx/x^n = \sum_{i=1}^{M} [w_{i,n} \exp(t_{i,n})] g(t_{i,n}) + R_M(z), \tag{A.5}$$

where $R_M(z)$ is the remainder (or error in the Mth order quadrature), $f(x)$ is an arbitrary function, $g(x) = e^{-x} f(x)$, and $w_{i,n}$ and $t_{i,n}$ are quadrature weights and nodes, respectively. The quadratures are exact if $f(x)$ is a polynomial of degree less than or equal to $2M - 1$. One obtains

$$S_n(z, h) \approx \sum_{i=1}^{M} \left[\frac{w_{i,n} \exp(t_{i,n})}{1 - \exp(-ht_{i,n})} \right] \exp(-zt_{i,n}). \tag{A.6}$$

In this application, h remains constant for a given fine group. A useful method of evaluating exponential integrals also results from Eq. A.5:

$$E_n(x) \approx \sum_{i=1}^{M} [w_{i,n} \exp(t_{i,n})] \exp(-xt_{i,n}).$$

The methods used to evaluate the nodes $t_{i,n}$, weights $w_{i,n}$, and $w_{i,n} \exp(t_{i,n})$ of Eqs. A.4 and A.5 are discussed in Sections 2 and 3 below. Tables of results to 16 significant figures for $n = 0(1)10$ and $M = 2(1)10$ have been published.[8]

2. The Equations To Be Solved

The construction of the quadrature formulas of order M follows the method used by Chandrasekhar.[9] Given a weighting function $t^{-n} \exp(-t)$, define its ℓth moment over $[1, \infty]$ to be

$$\alpha_{n,\ell} = \int_1^\infty t^{\ell-n} \exp(-t)\, dt, \qquad \ell = 0, 1, \ldots, 2M - 1. \tag{A.7}$$

We require that

$$\alpha_{n,\ell} = \sum_{i=1}^{M} w_i t_i^\ell, \qquad \ell = 0, 1, \ldots, 2M - 1. \tag{A.8}$$

Equations A.8 are a nonlinear system of 2M equations in the 2M unknowns w_i and t_i. To solve Eqs. A.8, form the sums

$$\alpha_{n,i+M} + \sum_{\ell=0}^{M} c_\ell \alpha_{n,i+\ell}, \qquad i = 0, 1, \ldots, M - 1, \tag{A.9}$$

where the c_ℓ's are undetermined constants. Use of Eqs. A.8 in Eq. A.9 gives

$$\sum_{j=1}^{M} w_j t_j^i \left(t_j^M + \sum_{\ell=0}^{M-1} c_\ell t_j^\ell \right), \qquad i = 0, 1, \ldots, M - 1. \tag{A.10}$$

The c_ℓ's can now be defined as the unique solution to

$$\alpha_{n,i+M} + \sum_{\ell=0}^{M-1} c_\ell \alpha_{n,i+\ell} = 0, \qquad i = 0, 1, \ldots, M - 1. \tag{A.11}$$

Then, from Eq. A.10,

$$t_j^M + \sum_{\ell=0}^{M-1} c_\ell t_j^\ell = 0, \qquad j = 1, \ldots, M.$$

The nodes t_i are the roots of

$$F(t) = t^M + \sum_{\ell=0}^{M-1} c_\ell t^\ell = 0. \tag{A.12}$$

The weights w_i are obtained from any M of Eqs. A.8 upon insertion of the t_i.

3. Computational Methods and Results

All computations were carried out on a CDC-1604 computer with 25-digit accuracy. The fundamental quantities required accurately are the moments

$$\begin{aligned} \alpha_{n,\ell} &= \int_1^\infty \exp(-t)\, dt/t^{n-\ell} \\ &= E_{n-\ell}(1), \qquad \text{if } n - \ell > 0, \\ &= \exp(-1), \qquad \text{if } n - \ell = 0, \\ &= \exp(-1) + (\ell - n)\,\alpha_{n,\ell-1}, \qquad \text{if } n - \ell < 0. \end{aligned} \tag{A.13}$$

First $E_1(1)$ was evaluated to 25S from the series

$$E_1(x) = -(\gamma + \ln x) + x - \frac{x^2}{2 \cdot 2!} + \frac{x^3}{3 \cdot 3!} - \ldots,$$

including terms up to the 30th power. Then the recursion relation $E_n(x) = [\exp(-x) - xE_{n-1}(x)]/(n-1)$ was used to generate other $E_n(1)$. Less than one significant figure is lost in $E_{10}(1)$, and this loss is not important, because the α_ℓ differ by 7 to 17 orders of magnitude at low and high ℓ, depending on M (as shown in Table II). The magnitude range is less for smaller M.

Equations A.11 have a symmetric matrix of coefficients. The square-root method[10] was used to solve Eqs. A.11. The roots of Eq. A.12 were obtained by Newton's method of linear interpolation. Ten refinements in each root were performed to ensure accuracy to the limitations of the computer. The first M of Eqs. A.8 were then solved by the Gauss elimination method.

TABLE II. The Moments $\alpha_{n,\ell} = \int_1^\infty \exp(-t)\, dt/t^{n-\ell}$

$n - \ell$	$\alpha_{n,\ell}$	$n - \ell$	$\alpha_{n,\ell}$
10	3.6393994031416401634164 5E-02	-5	1.199286978218901968401 41E 02
9	4.0333494888694706888043 0E-02	-6	7.199400663725126233624 40E 02
8	4.5211482061884666491180 1E-02	-7	5.039948344048759805858 68E 03
7	5.1399066738249656157263 2E-02	-8	4.031995463183124988919 10E 04
6	5.9485040741944384651944 3E-02	-9	3.628799595659224204450 41E 05
5	7.0454237461720398335802 4E-02	-10	3.628799963538665375892 73E 06
4	8.6062491324560728252314 2E-02	-11	3.991679996680476030626 23E 07
3	1.0969196719776013683858 2E-01	-12	4.790015999695365648465 90E 08
2	1.4849550677592204791836 0E-01	-13	6.227020799971854784177 12E 09
1	2.1938393439552027367716 4E-01	-14	8.717829119997384641965 11E 10
0	3.6787944117144232159552 4E-01	-15	1.307674367999975575735 94E 12
-1	7.3575888234288464319104 7E-01	-16	2.092278988799997709121 62E 13
-2	1.8393972058572116079776 2E 00	-17	3.556874280959999784301 16E 14
-3	5.8860710587430771455283 8E 00	-18	6.402373705727999979621 53E 15
-4	2.3912163676143750903709 0E 01	-19	1.216451004088319999806 88E 17

The accuracy of the results for M = 4 and 8 for n = 0 was confirmed by comparison with the work of Rabinowitz and Weiss.[11] The nodes are identical to all 18S of their tables. The weights also agree to all 18S upon scaling their results by a factor of e = 2.718 ... (corresponding to the change of variables: t = x - 1). A similar check with Abramowitz and Stegun[12] for M = 2 and 10 for n = 0 indicated a difference of at most a half-digit in the 12th and last place of their tables. The number of accurate significant figures obtained is approximately 20 - 0.4n. For uniformity, the tabled values have been rounded to 16 figures.

4. Optically Thin Unit Cells

The Gaussian quadratures derived here are least accurate for either z or h small (say, <0.1). Also, the error increases as z or h approaches zero and as M decreases. A complementary numerical technique has been derived which rapidly becomes more accurate as h decreases. The Euler-MacLaurin summation formula[13] leads to

$$S_n(z,h) = E_{n+1}(z)/h + E_n(z)/2 + hE_{n-1}(z)/12$$
$$- h^3E_{n-3}(z)/720 + h^5E_{n-5}(z)/30{,}240$$
$$- h^7E_{n-7}(z)/1{,}209{,}600 + h^9E_{n-9}(z)/47{,}900{,}160 - \ldots, \quad \text{(A.14)}$$

where $E_{n-\ell}(z)$ is replaced by $\alpha_{\ell-n}(z)$ if $n - \ell < 0$. The truncation error of the series in Eq. A.14 is less than the absolute value of the first neglected term for h sufficiently small.

Much simpler expressions can be obtained using the recursion relation

$$E_n(z) = [e^{-z} - zE_{n-1}(z)]/(n-1) \tag{A.15}$$

and the definition

$$E_0(z) = e^{-z}/z. \tag{A.16}$$

For example,

$$S_2(z,h) \approx \tfrac{1}{2}\{\exp(-z)[1/h + h/6z - h^3(1+z)/360z^2] + E_2(z)(1 - z/h - h/6z)\}$$
$$+ h^5/5040z^4 \tag{A.17}$$
$$|\text{error}| < h^7\alpha_5(z)/1{,}209{,}600 < h^7/10{,}080z^6.$$

$$S_3(z,h) \approx \tfrac{1}{12}\{\exp(-z)[(4-2z)/h + 3 - (h^3/60z)(1 - [h^2/(21z^2)] \cdot [1 + z + z^2/2])]$$
$$+ E_2(z)(h - 3z + 2z^2/h)\} \tag{A.18}$$
$$|\text{error}| < h^7\alpha_4(z)/1{,}209{,}600 < h^7/50{,}400z^5.$$

$$S_4(z,h) \approx \tfrac{1}{12}\left\{\exp(-z)\left[\frac{3-z}{h} + 2 + h^3(1-z)/60z^2\right]\right.$$
$$\left. + E_3(z)(z^2/h + h - 2z - h^3/30z^2)\right\} \tag{A.19}$$
$$|\text{error}| < h^5\alpha_1(z)/30{,}240 < h^5/30{,}240z^2.$$

Equations A.17-19 require $z \geq h$ for accuracy. Equation A.17 in particular benefits by the restriction $z \geq 2h$. For small arguments, $E_2(z)$ and $E_3(z)$ are quickly obtained from series expansions.

Another numerical difficulty arises for optically thin plates, such as thin foils. The collision rate in the foil involves taking the difference $S_{n+1}(z,h) - S_{n+1}(z+\Delta,h)$, where Δ is very small. In this case, all numerical accuracy is eventually lost for Δ sufficiently small. A Taylor series expansion about $z + \Delta/2$ yields

$$E_{n+1}(z - \Delta/2) - E_{n+1}(z + \Delta/2) = \Delta[E_n(z) + \Delta^2 E_{n-2}(z)/24 + \Delta^4 E_{n-4}(z)/1920 + \ldots], \tag{A.20}$$

where again $\alpha_{\ell-n}(z)$ is substituted for $E_{n-\ell}(z)$ if $n - \ell < 0$. Equation A.20 is a rapidly convergent expansion for $\Delta < 0.01$, which improves in accuracy as $\Delta \to 0$. It also leads to easy numerical evaluation via the Gaussian quadrature of Eq. A.6:

$$S_{n+1}(z, h) - S_{n+1}(z + \Delta, h) \approx \Delta \sum_{i=1}^{M} \left[\frac{w_{i,n} \exp(t_{i,n})}{1 - \exp(-ht_{i,n})} \right] \exp[-(z + \Delta/2)\, t_{i,n}]$$

$$\cdot\, (1 + \Delta^2 t_{i,n}^2/24 + \Delta^4 t_{i,n}^4/1920), \qquad \Delta < 0.01. \quad \text{(A.21)}$$

The given numerical techniques are all in use in several codes such as RABID, and in versions of the perturbation-theory heterogeneity-effect codes CALHET[14] and CALHET-2.[15]

APPENDIX B

Coding Description

RABID consists of the main program and 22 subprograms, about half of which are small functions or subroutines that return a single calculated number. This diversity of special subprograms is required in order to optimize computation speed and numerical accuracy over several ranges of arguments. The logical connections between the various parts of RABID are shown in Fig. 2. Calls to subprograms are represented by traveling down the connecting links; returns go in the opposite direction. Most of the program uses common blocks of storage to save running time by eliminating or minimizing lists of formal parameters. As a result, duplication of variable names is also minimized. It is coded entirely in the FORTRAN IV language.[7,16] The purpose of each subprogram is described briefly below.

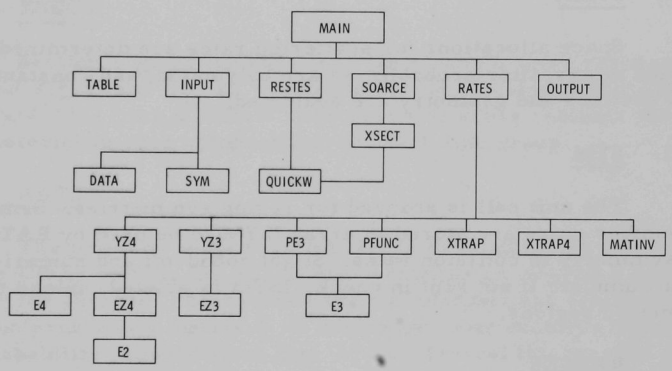

Fig. 2. Subroutine Hierarchy in RABID

1. MAIN

The main program (MAIN) controls the logical sequence of much of the code. At the start of the first problem in a batch, subroutine TABLE is called. Also, the tables of real and imaginary parts of the complex probability integral W are transferred from a data set on the disc to the TR and TI arrays in core storage. Succeeding problems in a batch assume all tables are available. Numerous variables are initialized after subroutines INPUT, DATA, SYM, and RESTES have been called and executed. The main loop is DO 45 IBGP = 1, KGP (card 78), which runs over all intermediate groups. Within this is another loop over fine groups: DO 22 IFGP = 1, N (card 103). Subroutines SOARCE, XSECT, and RATES are cycled through in the inner loop. Also within this loop, reaction rates, integral fluxes, and scattering rates are accumulated and stored. Subroutine OUTPUT is called from inside the outer loop.

2. TABLE

The exponential integrals $E_3(Z)$ and $E_4(Z)$ are obtained from two polynomial and rational approximations (Ref. 12, 5.1.53 and 5.1.56, p. 231). Values are tabulated for Z as follows: 0(0.01)2(0.02)4(0.08)6.4. For $1 \leq I \leq 331$, TAB(I) is E_3 while TAB(I+331) is E_4. Functions E3 and E4 use these tables.

3. INPUT

All required card input is read, DATA is called, and problem specifications are printed. SYM is called, followed by a consistency check on KGP and NIB(I).

4. DATA

Space allocations for scattering rates are determined, ingroup-scatter and downscatter probabilities are calculated, and constants related to cross sections and geometry are evaluated.

5. SYM

The unit cell is scanned for region symmetries. Symmetric-region number pairs are stored in array ISYM to be used by RATES to ensure symmetry in collision rates. Slight round-off and numerical errors tend to accumulate if not kept in check. ISYM is printed, unless there are no symmetric regions.

6. RESTES

The name is a six-character truncation of RESTEST from RABBLE. This subprogram determines which resonances are to be included when calculating cross sections for the fine groups in any intermediate group. The resonance contributes if

a. The resonance energy lies within the intermediate group, or

b. The resonance cross sections at either the upper or lower energy limit of the intermediate group exceeds the input parameter TEST.

7. QUICKW

$\mathrm{Re}W(\xi x/2, \xi/2)$ and $\mathrm{Im}W(\xi x/2, \xi/2)$ are obtained by six-point interpolation within two 62 x 62 tables (TR and TI) or from rational approximations if the arguments of W are outside the tables.[6]

8. SOARCE

The source for the first fine group in a problem is obtained under the assumption that $\phi(u) = \phi_\infty$ for u less than the lethargy at the start of the problem. The source in Region I is

$$SI(I) = A_i \sum_j N_{ji} \sigma_p^j. \tag{B.1}$$

The source is calculated from Eq. 30, which is equivalent to Eq. 12 for all other fine groups. Numerical round-off is controlled by keeping all increments to the source in a separate array called DS. Hence the total source in Region I is SI(I) + DS(I).

9. XSECT

Section V gives the equations for s- and p-wave resonance cross sections and $\Psi(\xi, x)$ and $\chi(\xi, x)$, which are evaluated using $\mathrm{Re}W(\xi x/2, \xi/2)$ and $\mathrm{Im}W(\xi x/2, \xi/2)$ from QUICKW. Macroscopic cross sections are obtained for each material in each composition, for each fine group.

10. RATES

The primary purpose of RATES is to produce the collision-rate vector $\overrightarrow{CR}$ by solving Eq. 22. It also produces an interface collision-rate vector for each foil. Many auxiliary calculations are required before the collision probability matrix $\underline{P}$ is evaluated. For example, the non-leakage probability is found from Eqs. 29-32. Optical thicknesses τ_i are obtained for regions and the unit cell, h. Fourth-order quadrature weights are found from Eq. A.6, for $S_3(z, h)$ and $S_4(z, h)$.

The spatially flat slowing-down source is linearized in compositions having more than one region. If the linear component exceeds 1% of the flat source strength, it is retained. Otherwise, it is dropped. A further test requires the linear component of the current leaving a source region to exceed 1% of the flat-component current in order to be retained. These measures save computer time on negligible effects.

Uncollided neutron currents from flat source components are followed from left to right across the unit cell. Given a flat source strength of PNL in region i, the collision rate in region j is found from Eqs. 17-20. Reciprocity is used to find the collision rate in region i from a flat source in region j. Collision rates due to linear source components are calculated by following currents in both directions across the unit cell. The collision rate in the "last" region (i+KREG - 1) is found from neutron conservation. Hence KREG(KREG - 1) collision probabilities need be obtained to account

for flat source components, with twice this number to account for linear source components, because reciprocity does not apply.

After $\overrightarrow{CR}$ and $\vec{\phi}$ are obtained, the ingroup scattering contribution to the source, $\overrightarrow{\Sigma_s P_s \phi}$, is obtained. Numerical round-off is controlled by dropping the total increment to the source from group k - 1 to k if its magnitude is less than 0.5×10^{-6} times $\vec{S}_0$.

11. OUTPUT

Intermediate- and broad-group average fluxes and cross sections defined in Section VI are printed if requested.

12. E2

The following series expansion is evaluated:

$$E2(x) \approx 1 - x(1 - \gamma - \ln x) - \frac{x^2}{1 \cdot 2!} + \frac{x^3}{2 \cdot 3!} - \frac{x^4}{3 \cdot 4!}, \qquad 0 \leq x \leq 0.6. \qquad \text{(B.2)}$$

13. E3

Linear interpolation within tables of $E_3(z)$ stored by TABLE is used to obtain $E_3(x)$, for $0 \leq x \leq 6.4$, with error $<0.01\%$. For $x > 6.4$, the following asymptotic approximation is used:

$$E_3(x) = e^{-x}\left\{1 + \frac{3}{D}[1 + (3 - 2x)/D]\right\}/(x+3), \qquad \text{(B.3)}$$

where

$$D = (x+3)^2.$$

The error is 1/30% or less.

14. E4

Linear interpolation within tables of $E_4(z)$ stored by TABLE is used to obtain $E_4(x)$, for $0 \leq x \leq 6.4$, with error $<0.01\%$. For $x > 6.4$, the following asymptotic approximation is used:

$$E_4(x) = e^{-x}\left\{1 + \frac{4}{D}[1 + (4 - 2x)/D]\right\}/(x+4), \qquad \text{(B.4)}$$

where

$$D = (x+4)^2.$$

The error is 1/30% or less.

15. PE3

For $x < 0.6$, $E_3(x)$ is evaluated from the expansion

$$E_3(x) \approx \tfrac{1}{2} - x + \frac{x^2}{2}(1.5 - \gamma - \ln x) + \frac{x^3}{3!} - \frac{x^4}{2 \cdot 4!} + \frac{x^5}{3 \cdot 5!} - \frac{x^6}{4 \cdot 6!}. \tag{B.5}$$

The error is $\leq 1.1 \times 10^{-6}$. For $x \geq 0.6$, E3 is called.

16. PFUNC

The probability of escape without a collision from a slab of optical thickness x is (for a flat or linear source)

$$P = [0.5 - E_3(x)]/x. \tag{B.6}$$

If $x \geq 0.6$, $E_3(x)$ is obtained from E3; otherwise, the following double-precision series expansion is used:

$$0.5 - E_3(x) \approx +x - \frac{x^2}{2}(1.5 - \gamma - \ln x) - \frac{x^3}{3!} + \frac{x^4}{2 \cdot 4!} - \frac{x^5}{3 \cdot 5!} + \frac{x^6}{4 \cdot 6!} - \frac{x^7}{4 \cdot 7!}. \tag{B.7}$$

The error is $\leq 7 \times 10^{-8}$. High accuracy is needed to give good results for very thin slabs.

17. XTRAP

$$S_3(z, h) \approx \sum_{i=1}^{M} w_{i,3} e^{-zt_{i,3}} + C(z, h). \tag{B.8}$$

$$C(z, h) = (0.004126 + 0.00628 e^{-19.8h})\, e^{-18.2z}, \qquad z < 0.3,$$

$$= 0, \quad z \geq 0.3. \tag{B.9}$$

The M index lies between 1 and 4, depending on z.

18. XTRAP4

$$S_4(z, h) \approx \sum_{i=1}^{M} w_{i,4} e^{-zt_{i,4}} \tag{B.10}$$

The M index lies between 1 and 4, depending on z.

19. YZ3

Numerous options are exercised to maximize both speed and accuracy in evaluating a difference of the infinite sums of exponential integrals.

a. $\Delta > 0.01$ $(\Delta = z - y)$

(1) $h \leq 0.2$

$$S_3(y, h) - S_3(z, h) \approx EZ3(y, h) - EZ3(z, h). \tag{B.11}$$

(2) $h > 0.2$

$$S_3(y, h) - S_3(z, h) \approx \sum_{i=1}^{M} w_{i,3}\left(e^{-yt_{i,3}} - e^{-zt_{i,3}}\right) + C(y, h) - C(z, h). \tag{B.12}$$

See XTRAP for C and M.

b. $\Delta \leq 0.01$

(1) $\Delta < 0.0001$

From Eq. A.20,

$$S_3(y, h) - S_3(z, h) \approx \Delta S_2(y + \Delta/2, h). \tag{B.13}$$

The first few terms of $S_2(y + \Delta/2, h)$ are found "exactly" using $E2(z)$ for $z < 0.6$.

For $z \geq 0.6$, from Eq. A.21,

$$S_3(y, h) - S_3(z, h) \approx \Delta \sum_{i=1}^{4} w_{i,2}[1 + u(1 + 0.0125u)]\, e^{-qt_{i,2}}, \tag{B.14}$$

where $u = \Delta^2 t_{i,2}^2/24$, and $q = y + \Delta/2$.

(2) $0.0001 \leq \Delta \leq 0.01$

Function PFUNC is used to get accurate differences in $E_3(y) - E_3(y + \Delta)$ as follows:

$$PFUNC(x) = (0.5 - E_3(x))/x. \tag{B.15}$$

$$\therefore E_3(x) - E_3(x+\Delta) = (x+\Delta)\,\mathrm{PFUNC}(x+\Delta) - x\,\mathrm{PFUNC}(x)$$

$$= x(\mathrm{PFUNC}(x+\Delta) - \mathrm{PFUNC}(x)) + \Delta\,\mathrm{PFUNC}(x). \qquad \text{(B.16)}$$

In this way, ℓ exact terms are found for

$$0 \le \ell < \left(\frac{0.6 - y - \Delta}{h}\right)_{\substack{\text{truncated}\\ \text{integer}}}.$$

Then the remainder of $S_3(y, h) - S_3(z, h)$ is found from Eq. B.14.

20. <u>YZ4</u>

This routine is much like YZ3, but is inherently more accurate because $S_4(z, h)$ is easier to sum than $S_3(z, h)$. Less numerical effort is justified since YZ4 is only involved in relatively small effects from linear source components. The options are:

a. <u>$\Delta > 0.01$ ($\Delta = z - y$)</u>

(1) <u>$h \le 0.3$</u>

$$S_4(y, h) - S_4(z, h) \approx EZ4(y, h) - EZ4(z, h). \qquad \text{(B.17)}$$

(2) <u>$h > 0.3$</u>

$$S_4(y, h) - S_4(z, h) \approx \sum_{i=1}^{M} w_{i,4}\left[e^{-yt_{i,4}} - e^{-zt_{i,4}}\right]. \qquad \text{(B.18)}$$

$1 \le M \le 4$, depending on y.

b. <u>$\Delta < 0.01$</u>

$$S_4(y, h) - S_4(z, h) \approx \Delta\left\{\sum_{i=1}^{4} w_{i,3}[1 + u(1 + 0.0125u)]\, e^{-qt_{i,3}} + C(q, h)\right\}, \qquad \text{(B.19)}$$

where $u = \Delta^2 t_{i,3}^2/24$ and $q = y + \Delta/2$. See XTRAP for $C(q, h)$.

21. <u>EZ3</u>

Equation A.18 gives

$$S_3(z, h) \approx E_3(z) + E_3(z+h) + S_3(z+2h, h).$$

In other words, two exact terms are calculated before summing the series to infinity.

22. EZ4

Equation A.19 gives

$$S_4(z, h) \approx E_4(z) + S_4(z+h, h).$$

In other words, a single exact term is calculated before summing the series to infinity.

23. MATINV

This is a standard ANL System/360 Library Subroutine,[3] which performs matrix inversions. Numerical accuracy is maximized by pivoting on the largest element during reduction to a triangular system.

APPENDIX C

Listing of RABID

```
//APORAEBR JOB (R,P26010,45,X00011),APO,CLASS=A,PRTY=8
// EXEC FTNHCLX,XREG=420K,CARDS=BCD,OPT=2,TIME=4
//C.SYSIN DD *
C      PROGRAM RABID                                                    RAB    1
       COMMON/E/NUCLID(20),UFGP,V(25),EXDU,UMAX(20,25),P1(20,25),       RAB    2
      X      PS(20,25),SOURCE(30),SDD,ACS,FCS,SCS,PHITOT,PHIT,ACSGP,FCSGP,RAB    3
      X SCSGP,RAP,SIGABG(20,30),SIGFBG(20,30),SIGSBG(20,30),DS1(20),    RAB    4
      X DSMAX(20),ALP(20,25),SCL(20,30),DSL(20),DPS(20),BSQ(25)         RAB    5
       COMMON/QW/REZ,AIMZ,REW,AIMW,    TR(62,62),TI(62,62)              RAB    6
       COMMON/A/      F1V,SL(20,30), TEST,       SIGP(20,30),XZETA(20,30), RAB    7
      XSA(20,30),SF(20,30),SS(20,30),DEN(20,30),G(300),GN(300),GF(300), RAB    8
      X     GR(300),ER(300),XRES(300),SIGZ(300),GAMMA(300),SIGIN(300),  RAB    9
      X                  SIGMIN(300),     SIG(30),                      RAB   10
      X     SIGA22(20),SIGF22(20),       XN,XC,ETOT,TOT3,WORK(60),P(30) RAB   11
       COMMON/B/                UIGP,                        CR(30),RAD(35),RAB   12
      X     RATIO(30),DIFX(30),            SPP(30),SPN(30),              RAB   13
      X     AREA(35),          FLUX(30,100),FLUXCP(30,100),SCAT(40000),  RAB   14
      XTAB(662),TOT,TT(60,5),                        AF(30,5),FF(30,5),  RAB   15
      X V11,V12,V13,SSF(30,5),USTR(25),DUSTR(25)                        RAB   16
       COMMON/C/                                                        RAB   17
      X     XAREAT,AREAT,RMAX(30),                                      RAB   18
      X     ENGP(1001),RIAC(20,30),RIFC(20,30),RISC(20,30),TEMP(30),    RAB   19
      X                      XTEMP(30),         PHICT(30),PHI(30),PFLUX(30),RAB   20
      XSIGTR(30),BARMU(30),    AMU(20),SIGPOT(20),AREAC(30),XAREAC(30),  RAB   21
      XGX2(10),GW2(10),WW2(10),                                         RAB   22
      X    DR(30),XAREA(30),PHIRT(30),          GX3(10),GX4(10),GW3(10), RAB   23
      X     GW4(10),WW3(10),WW4(10),V1,V2,V3,V4,V5,V6,V7,V8,V9,V10      RAB   24
       COMMON/D/KI,KRES,NTEMP,INCLUD(300),                              RAB   25
      X     NEXT(20),LAST(20),NRES(20),INDEX, KS,                       RAB   26
      X  NU,NOPT,ISYM(30),III,KFOIL,KREG,KMAT,KCOMP,KGP,KBG,NPRINT,MORE, RAB   27
      X  IBGP,IFGP,IBG,JBG,NIB(25),NINT(30),MINT(30),LREG(35),NX(30),   RAB   28
      X     NFI(25),TITLE(18),KB     ,MULT(20,25),JNU(20),JMULT(20),    RAB   29
      X  INUI(20,25),INUF(20,25),NOX,NISO,KBSQ                          RAB   30
       REAL*8 NUCLID                                                    RAB   31
       DIMENSION DS(30),SOR(30),SI(30)                                  RAB   32
       DIMENSION LOC(20,30)                                             RAB   33
       REAL*8 TIME,DS,SOR,SI                                            RAB   34
       REAL*8 UFGP,V,EXDU,UMAX,DS1,DSMAX,SOURCE,SDD,ACS,FCS,SCS,PHITOT, RAB   35
      X  PHIT,ACSGP,FCSGP,SCSGP,RAP,SIGABG,SIGFBG,SIGSBG,P1,PS,ALP,DSL RAB   36
       REAL*8 DPS                                                       RAB   37
       CALL TABLE                                                       RAB   38
       READ(8) ((TR(I,J),I=1,62), J=1,62)                               RAB   39
       READ(8) ((TI(I,J),I=1,62), J=1,62)                               RAB   40
       MORE=0                                                           RAB   41
     1 CALL TIMSET                                                      RAB   42
       IERR=0                                                           RAB   43
       CALL INPUT                                                       RAB   44
       IBG=1                                                            RAB   45
       JBG=1                                                            RAB   46
       NXN=NISO*NOX                                                     RAB   47
       DO 11 I=1,NISO                                                   RAB   48
    11 SCAT(I)=0.                                                       RAB   49
       JI=0                                                             RAB   50
       DO 12 I=1,KREG                                                   RAB   51
C      FLAT FLUX FOR FIRST NON-LEAKAGE CALCULATION                      RAB   52
       PHI(I)=1.                                                        RAB   53
```

```
      M=LREG(I)                                                         RAB   54
      DO 12 J=1,KMAT                                                    RAB   55
      IF(DEN(J,M))13,12,13                                              RAB   56
   13 JI=JI+1                                                           RAB   57
      LOC(J,I)=JI                                                       RAB   58
   12 CONTINUE                                                          RAB   59
      ACS=0.0D0                                                         RAB   60
      FCS=0.0D0                                                         RAB   61
      SCS=0.0D0                                                         RAB   62
      PHITOT=0.0D0                                                      RAB   63
      DO 2 I=1,KREG                                                     RAB   64
    2 PHIRT(I)=0.                                                       RAB   65
      DO 5 I=1,KCOMP                                                    RAB   66
      PHICT(I)=0.                                                       RAB   67
      DO 5 J=1,KMAT                                                     RAB   68
      RIAC(J,I)=0.0                                                     RAB   69
      RIFC(J,I)=0.0                                                     RAB   70
    5 RISC(J,I)=0.                                                      RAB   71
      DO 6 I=1,KREG                                                     RAB   72
      DO 6 K=1,KFOIL                                                    RAB   73
      AF(I,K)=0.                                                        RAB   74
      SSF(I,K)=0.                                                       RAB   75
    6 FF(I,K)=0.                                                        RAB   76
      DO 45 IBGP=1,KGP                                                  RAB   77
      IF(JBG-1)8,8,9                                                    RAB   78
    8 DO 7 J=1,KMAT                                                     RAB   79
      DS1(J)=P1(J,IBG)+PS(J,IBG)*(V(IBG)-1.0D0)                         RAB   80
      DSMAX(J)=ALP(J,IBG)*DS1(J)                                        RAB   81
      DPS(J)=PS(J,IBG)                                                  RAB   82
      DSL(J)=ALP(J,IBG)*DPS(J)                                          RAB   83
    7 CONTINUE                                                          RAB   84
      IF(KB.EQ.0     ) GO TO 9                                          RAB   85
      IF(IBG.EQ. 1) GO TO 9                                             RAB   86
      READ(5,110) (SIGA22(I),SIGF22(I),I=1,KRES)                        RAB   87
  110 FORMAT(6E12.5)                                                    RAB   88
      WRITE(6,111) (I,SIGA22(I),SIGF22(I),I=1,KRES)                     RAB   89
  111 FORMAT(///' REVISION OF BACKGROUND CROSS SECTIONS FOR NEXT BROAD GRAB   90
     XROUP'/' MATERIAL',3X,'SIGA22(I)',6X,'SIGF22(I)'/(I6,4X,2E12.5))   RAB   91
    9 CALL RESTES                                                       RAB   92
      ACSGP=0.0D0                                                       RAB   93
      FCSGP=0.0D0                                                       RAB   94
      SCSGP=0.0D0                                                       RAB   95
      PHIT=0.0D0                                                        RAB   96
      MU=(IBGP-1)/100                                                   RAB   97
      NU=IBGP-100*MU                                                    RAB   98
      DO 10 J=1,KCOMP                                                   RAB   99
      FLUXCP(J,NU)=0.                                                   RAB  100
      DO 10 K=1,KMAT                                                    RAB  101
      SIGABG (K,J)=0.D0                                                 RAB  102
      SIGFBG(K,J)=0.0D0                                                 RAB  103
   10 SIGSBG (K,J)=0.D0                                                 RAB  104
      DO 15 J=1,KREG                                                    RAB  105
   15 FLUX(J,NU)=0.                                                     RAB  106
      N=NFI(IBG)                                                        RAB  107
      DO 22 IFGP=1,N                                                    RAB  108
      CALL SOARCE(IERR,DS,SOR,SI)                                       RAB  109
```

```
      IF(IERR)16,16,1                                                   RAB  110
C        IERR GRTR 0 ABORTS PROBLEM                                     RAB  111
   16 CALL RATES(IERR,DS,SOR,SI)                                        RAB  112
      JI=0                                                              RAB  113
      IF(IERR)17,17,1                                                   RAB  114
   17 DO 20 I=1,KREG                                                    RAB  115
  201 M=LREG(I)                                                         RAB  116
      PHI(I)=CR(I)/SIG(M)                                               RAB  117
      FLUX(I,NU)=FLUX(I,NU)+PHI(I)                                      RAB  118
      DO 24 J=1,KMAT                                                    RAB  119
      IF(DEN(J,M))29,24,29                                              RAB  120
   29 JI=JI+1                                                           RAB  121
      SCAT(JI+JNU(J))=SCAT(JI+JNU(J))+PHI(I)*SS(J,M)                    RAB  122
      SL(J,M)=SS(J,M)                                                   RAB  123
      SIGABG (J,M)=SIGABG (J,M)+PHI(I)*SA(J,M)                          RAB  124
      SIGFBG (J,M)=SIGFBG (J,M)+PHI(I)*SF(J,M)                          RAB  125
      SIGSBG (J,M)=SIGSBG (J,M)+PHI(I)*SS(J,M)                          RAB  126
   24 CONTINUE                                                          RAB  127
      IF(KFOIL)20,20,27                                                 RAB  128
   27 DO 26 K=1,KFOIL                                                   RAB  129
      DO 26 J=1,KMAT                                                    RAB  130
      AF(I,K)=AF(I,K)+TT(I,K)*SA(J,KCOMP+K)                             RAB  131
      SSF(I,K)=SSF(I,K)+TT(I,K)*SS(J,KCOMP+K)                           RAB  132
   26 FF(I,K)=FF(I,K)+TT(I,K)*SF(J,KCOMP+K)                             RAB  133
   20 CONTINUE                                                          RAB  134
      DO 30 J=1,KMAT                                                    RAB  135
      JMULT(J)=JMULT(J)+1                                               RAB  136
      IF(JMULT(J)-MULT(J,IBG))30,31,31                                  RAB  137
   31 JMULT(J)=0                                                        RAB  138
      DK=1.0/MULT(J,IBG)                                                RAB  139
      JJJ=JNU(J)                                                        RAB  140
      JNU(J)=JNU(J)+NISO                                                RAB  141
      IF(JNU(J)-NXN)34,34,33                                            RAB  142
   33 JNU(J)=0                                                          RAB  143
   34 DO 32 I=1,KREG                                                    RAB  144
      IF( DEN(J,LREG(I) ) )35,32,35                                     RAB  145
   35 SCAT(LOC(J,I)+JJJ)=SCAT(LOC(J,I)+JJJ)*DK                          RAB  146
      SCAT(LOC(J,I)+JNU(J))=0.                                          RAB  147
   32 CONTINUE                                                          RAB  148
   30 CONTINUE                                                          RAB  149
      IF(NPRINT)21,22,22                                                RAB  150
   21 WRITE(6,101)(PHI(I),I=1,KREG)                                     RAB  151
C       NPRINT LESS ZERO GIVES FINE GROUP FLUX OUTPUT                   RAB  152
  101 FORMAT(1H ,7HPHI(I)=,(8E14.7))                                    RAB  153
   22 CONTINUE                                                          RAB  154
      DO 25 I=1,KREG                                                    RAB  155
      M=LREG(I)                                                         RAB  156
      PHIRT(I)=PHIRT(I)+FLUX(I,NU)                                      RAB  157
      FLUXCP(M,NU)=FLUXCP(M,NU)+FLUX(I,NU)                              RAB  158
   25 PHICT(M)=PHICT(M)+FLUX(I,NU)                                      RAB  159
      DO 40 I=1,KCOMP                                                   RAB  160
      PHIT=PHIT+FLUXCP(I,NU)                                            RAB  161
      DO 40 J=1,KMAT                                                    RAB  162
      RIAC(J,I)=RIAC(J,I)+SIGABG (J,I)                                  RAB  163
      RIFC(J,I)=RIFC(J,I)+SIGFBG (J,I)                                  RAB  164
      RISC(J,I)=RISC(J,I)+SIGSBG (J,I)                                  RAB  165
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      ACSGP=ACSGP+SIGABG (J,I)                                          RAB  166
      FCSGP=FCSGP+SIGFBG (J,I)                                          RAB  167
   40 SCSGP=SCSGP+SIGSBG (J,I)                                          RAB  168
      PHITOT=PHITOT+PHIT                                                RAB  169
      ACS=ACS+ACSGP                                                     RAB  170
      FCS=FCS+FCSGP                                                     RAB  171
      SCS=SCS+SCSGP                                                     RAB  172
      IF(JBG-NIB(IBG))44,60,60                                          RAB  173
   60 DO 62 J=1,KMAT                                                    RAB  174
      IF(JMULT(J))62,62,69                                              RAB  175
   69 JJJ=JNU(J)+NISO                                                   RAB  176
      IF(JJJ-NXN)70,70,71                                               RAB  177
   71 JJJ=0                                                             RAB  178
   70 DO 63 I=1,KREG                                                    RAB  179
      IF(DEN(J,LREG(I) ) )72,63,72                                      RAB  180
   72 NXX=LOC(J,I)+JNU(J)                                               RAB  181
      SCAT(NXX)=SCAT(NXX)/JMULT(J)                                      RAB  182
      SCAT(LOC(J,I)+JJJ)=0.                                             RAB  183
   63 CONTINUE                                                          RAB  184
      JNU(J)=JJJ                                                        RAB  185
   62 CONTINUE                                                          RAB  186
   44 CALL OUTPUT                                                       RAB  187
   45 CONTINUE                                                          RAB  188
      CALL TIMEL(TIME)                                                  RAB  189
      WRITE(6,100) TIME                                                 RAB  190
  100 FORMAT(1H0,6H TIME=,F10.3,5H SEC.)                                RAB  191
      GO TO 1                                                           RAB  192
      END                                                               RAB  193
      SUBROUTINE INPUT                                                  INP    1
      COMMON/E/NUCLID(20),UFGP,V(25),EXDU,UMAX(20,25),P1(20,25),        INP    2
     X     PS(20,25),SOURCE(30),SDD,ACS,FCS,SCS,PHITOT,PHIT,ACSGP,FCSGP,INP    3
     X SCSGP,RAP,SIGABG(20,30),SIGFBG(20,30),SIGSBG(20,30),DS1(20),     INP    4
     X DSMAX(20),ALP(20,25),SCL(20,30),DSL(20),DPS(20),BSQ(25)          INP    5
      COMMON/QW/REZ,AIMZ,REW,AIMW,   TR(62,62),TI(62,62)                INP    6
      COMMON/A/     F1V,SL(20,30), TEST,      SIGP(20,30),XZETA(20,30), INP    7
     XSA(20,30),SF(20,30),SS(20,30),DEN(20,30),G(300),GN(300),GF(300),  INP    8
     X    GR(300),ER(300),XRES(300),SIGZ(300),GAMMA(300),SIGIN(300),    INP    9
     X                 SIGMIN(300),     SIG(30),                        INP   10
     X    SIGA22(20),SIGF22(20),      XN,XC,ETOT,TOT3,WORK(60),P(30)    INP   11
      COMMON/B/              UIGP,                        CR(30),RAD(35),INP   12
     X    RATIO(30),DIFX(30),          SPP(30),SPN(30),                 INP   13
     X    AREA(35),          FLUX(30,100),FLUXCP(30,100),SCAT(40000),  INP   14
     XTAB(662),TOT,TT(60,5),                        AF(30,5),FF(30,5),  INP   15
     X V11,V12,V13,SSF(30,5),USTR(25),DUSTR(25)                         INP   16
      COMMON/C/                                                         INP   17
     X    XAREAT,AREAT,RMAX(30),                                        INP   18
     X    ENGP(1001),RIAC(20,30),RIFC(20,30),RISC(20,30),TEMP(30),      INP   19
     X                      XTEMP(30),        PHICT(30),PHI(30),PFLUX(30),INP   20
     XSIGTR(30),BARMU(30),   AMU(20),SIGPOT(20),AREAC(30),XAREAC(30),   INP   21
     XGX2(10),GW2(10),WW2(10),                                          INP   22
     X   DR(30),XAREA(30),PHIRT(30),        GX3(10),GX4(10),GW3(10),    INP   23
     X    GW4(10),WW3(10),WW4(10),V1,V2,V3,V4,V5,V6,V7,V8,V9,V10        INP   24
      COMMON/D/KI,KRES,NTEMP,INCLUD(300),                               INP   25
     X    NEXT(20),LAST(20),NRES(20),INDEX, KS,                         INP   26
     X  NU,NOPT,ISYM(30),III,KFOIL,KREG,KMAT,KCOMP,KGP,KBG,NPRINT,MORE, INP   27
     X  IBGP,IFGP,IBG,JBG,NIB(25),NINT(30),MINT(30),LREG(35),NX(30),    INP   28
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   X    NFI(25),TITLE(18),KB     ,MULT(20,25),JNU(20),JMULT(20),        INP   29
   X  INUI(20,25),INUF(20,25),NOX,NISO,KBSQ                              INP   30
    REAL*8 UFGP,V,EXDU,UMAX,DS1,DSMAX,SOURCE,SDD,ACS,FCS,SCS,PHITOT,     INP   31
   X  PHIT,ACSGP,FCSGP,SCSGP,RAP,SIGABG,SIGFBG,SIGSBG,P1,PS,ALP,DSL     INP   32
    REAL*8 DPS                                                          INP   33
    REAL*8 NUCLID                                                       INP   34
    NAMELIST/MOD/TITLE,KREG,KMAT,KCOMP,KRES,KGP,KBG,NOPT,NTEMP,NPRINT,INP   35
   X  MORE,NIB,NFI,UIGP,ENGP,TEST,KFOIL,KBSQ,KS,BSQ,TEMP,NINT,RMAX,    INP   36
   X  NUCLID,NRES,AMU,SIGPOT,SIGA22,SIGF22,DEN,ER,GN,GR,GF,G,KB         INP   37
    IF(MORE)80,1,90                                                     INP   38
  1 READ (5,101) (TITLE(I),I=1,18)                                      INP   39
101 FORMAT (18A4)                                                       INP   40
    READ (5,102) KREG,KMAT,KCOMP,KRES,KGP,KBG,NOPT,NTEMP,NPRINT,MORE    INP   41
102 FORMAT(12I6)                                                        INP   42
    READ (5,102) (NIB(I),NFI (I),I=1,KBG)                               INP   43
    READ (5,107) UIGP,ENGP(1),TEST,KFOIL,KBSQ,KS,KB                     INP   44
107 FORMAT(3E12.6,4I6)                                                  INP   45
    III=KFOIL+KCOMP                                                     INP   46
    IF(KBSQ)71,71,70                                                    INP   47
 70 READ(5,106) (BSQ(I),I=1,KBG)                                        INP   48
    GO TO 72                                                            INP   49
 71 DO 73 I=1,KBG                                                       INP   50
 73 BSQ(I)=0.                                                           INP   51
 72 READ (5,103) (TEMP(I),I=1,III)                                      INP   52
103 FORMAT(5E12.6)                                                      INP   53
    READ (5,104) (NINT(I),RMAX(I),I=1,III)                              INP   54
104 FORMAT(5(I2,E10.4))                                                 INP   55
    DO 10 I=1,KMAT                                                      INP   56
    READ (5,105)NUCLID(I),NRES(I),AMU(I),SIGPOT(I),SIGA22(I),SIGF22(I)INP   57
105 FORMAT(A6,I6,4E12.6)                                                INP   58
    READ (5,106) (DEN(I,J),J=1,III)                                     INP   59
106 FORMAT(5E12.6)                                                      INP   60
    IF(NRES(I))10,10,5                                                  INP   61
  5 IF(I-1)6,6,7                                                        INP   62
  6 NEXT(1)=1                                                           INP   63
    LAST(1)=NRES(1)                                                     INP   64
    GO TO 8                                                             INP   65
  7 NEXT(I)=LAST(I-1)+1                                                 INP   66
    LAST(I)=LAST(I-1)+NRES(I)                                           INP   67
  8 N=NEXT(I)                                                           INP   68
    L=LAST(I)                                                           INP   69
    DO 9 J=N,L                                                          INP   70
  9 READ (5,106) ER(J),GN(J),GR(J),GF(J),G(J)                           INP   71
 10 CONTINUE                                                            INP   72
1000 CALL DATA                                                          INP   73
    WRITE (6,201) (TITLE(I),I=1,18),KREG,KMAT,KCOMP,KRES,KBG,UIGP,      INP   74
   X KGP,TEST,NOPT,KFOIL                                                INP   75
201 FORMAT(1H1,6H RABID,/,                                              INP   76
   1          2X,18A4///10X,18HNO. CELL REGIONS =,I3,29X,15HNO. MATERIINP   77
   XALS =,I3/10X,18HNO. COMPOSITIONS =,I3,29X,24HNO. RESONANT MATERIALINP   78
   XS =,I2/10X,18HNO. BROAD GROUPS =,I3,29X,29HLETHARGY WIDTH INTER. GINP   79
   XROUP =,E12.6/10X,25HNO. INTERMEDIATE GROUPS =,I4,21X,16HRESONANCE INP   80
   XTEST =,E10.3,8H (BARNS),6H NOPT=,I2,7H KFOIL=,I2,/)                 INP   81
    IF(KS)12,12,11                                                      INP   82
 11 WRITE(6,220)                                                        INP   83
220 FORMAT(//,' SCATTERING TRANSFER PROBABILITIES ADJUSTED TO REMOVE IINP   84
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   XN-GROUP SCATTERING')                                                INP   85
 12 IF(V11)13,30,13                                                     INP   86
 13 WRITE(6,225)                                                        INP   87
225 FORMAT(/,' RESONANT MATERIALS HAVE BROAD-GROUP-DEPENDENT ABSORPTIOINP   88
   XN AND FISSION CROSS SECTIONS')                                      INP   89
 30 WRITE (6,205)                                                       INP   90
205 FORMAT(///2X,46HREGION/COMPOSITION/OUTER DIMENSION/TEMPERATURE/)   INP   91
    DO 35 I=1,KREG                                                      INP   92
    NX(I)=I                                                             INP   93
 35 XTEMP(I)=TEMP(LREG(I))                                              INP   94
    WRITE (6,206) (NX(I),I=1,KREG)                                      INP   95
    WRITE (6,206) (LREG(I),I=1,KREG)                                    INP   96
    WRITE (6,207) (RAD(I),I=1,KREG)                                     INP   97
    WRITE (6,208) (XTEMP(I),I=1,KREG)                                   INP   98
206 FORMAT(15I8)                                                        INP   99
207 FORMAT(15F8.5)                                                      INP  100
208 FORMAT(15F8.2)                                                      INP  101
    IF(KFOIL)39,39,36                                                   INP  102
 36 WRITE(6,230) (I,LREG(KREG+I),RMAX(KCOMP+I),                         INP  103
   1                                          TEMP(KCOMP+I),I=1,KFOIL)INP  104
230 FORMAT(///5H FOIL,2X,11HCOMPOSITION,7X,9HTHICKNESS,4X,11HTEMPERATUINP  105
   XRE/(I5,7X,I6,6X,E12.5,F10.3))                                       INP  106
 39 WRITE (6,209)                                                       INP  107
209 FORMAT(///2X,14HMATERIAL  RES.,8X,40HMASS    SIG POT   SIG A 1/V   INP  108
   X  SIG F 1/V)                                                        INP  109
    DO 40 I=1,KMAT                                                      INP  110
 40 WRITE (6,210) NUCLID(I),NRES(I),AMU(I),SIGPOT(I),SIGA22(I),         INP  111
   X  SIGF22(I)                                                         INP  112
210 FORMAT(1H ,A6,I7,6X,4E12.5)                                         INP  113
    DO 400 I=1,KMAT                                                     INP  114
400 WRITE (6,401) I     ,(DEN(I,J),J=1,III)                             INP  115
401 FORMAT(1H0,7HISOTOPE,      I5,/,(10E12.5))                          INP  116
    WRITE (6,211)                                                       INP  117
211 FORMAT(///1H ,11HBROAD GROUP,4X,17HNO. INTER. GROUPS,4X,20HNO. FININP  118
   XE GP/INTER GP,4X,19HMAXIMUM ENERGY (EV),4X,19HMINIMUM ENERGY (EV),INP  119
   X 4X,8HBUCKLING)                                                     INP  120
    N=1                                                                 INP  121
    M=N+NIB(1)                                                          INP  122
    DO 45 I=1,KBG                                                       INP  123
    WRITE (6,212) I,NIB(I),NFI (I),ENGP(N),ENGP(M),BSQ(I)               INP  124
    N=M                                                                 INP  125
 45 M=N+NIB(I+1)                                                        INP  126
212 FORMAT(6X,I5,2(17X,I5),3( 7X,E15.4))                                INP  127
    WRITE(6,240) (I,I=1,KBG)                                            INP  128
240 FORMAT(1H1,82H NUMBER OF FINE GROUPS USED TO LETHARGY-AVERAGE SCATINP  129
   XTERING RATES FOR EACH MATERIAL///17H BROAD GROUP NO.=,25I4)         INP  130
    DO 46 J=1,KMAT                                                      INP  131
    WRITE(6,241) NUCLID(J),(MULT(J,I),I=1,KBG)                          INP  132
241 FORMAT(1H0,5X,A6,5X,25I4)                                           INP  133
 46 CONTINUE                                                            INP  134
    PRINT 213                                                           INP  135
213 FORMAT(1H1/50X,20HRESONANCE PARAMETERS//12X,8HMATERIAL,10X,10HENERINP  136
   XGY(EV),8X,12HGAMMA N (EV),4X,16HGAMMA GAMMA (EV),8X,12HGAMMA F (EVINP  137
   X),16X,1HG)                                                          INP  138
    DO 50 I=1,KRES                                                      INP  139
    N=NEXT(I)                                                           INP  140
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      L=LAST(I)                                                         INP   141
   50 WRITE (6,214) (NUCLID(I),ER(J),GN(J),GR(J),GF(J),G(J),J=N,L)      INP   142
  214 FORMAT(14X,A6,5E20.5)                                             INP   143
      CALL SYM(ISYM,DEN,AREA,KMAT,KREG,LREG)                            INP   144
      ISUM=0                                                            INP   145
      DO 55 I=1,KBG                                                     INP   146
   55 ISUM=ISUM+NIB(I)                                                  INP   147
      IF(ISUM-KGP)56,57,56                                              INP   148
   56 WRITE(6,215) KGP,ISUM                                             INP   149
      ISUM=MINO(KGP,ISUM)                                               INP   150
  215 FORMAT(//9H ****KGP=,I4,9H RESET TO,I4)                           INP   151
      KGP=ISUM                                                          INP   152
   57 IF(KGP-1000)59,59,58                                              INP   153
   58 WRITE(6,216)                                                      INP   154
  216 FORMAT(//21H ****KGP EXCEEDS 1000)                                INP   155
      GO TO 1                                                           INP   156
   59 IF(KGP)1,1,60                                                     INP   157
   60 RETURN                                                            INP   158
C           MODIFICATION PROBLEM USING NAMELIST FEATURE OF FORTRAN IV   INP   159
   80 READ(5,101) (TITLE(I),I=1,18)                                     INP   160
      READ(5,MOD)                                                       INP   161
      GO TO 1000                                                        INP   162
   90 STOP                                                              INP   163
      END                                                               INP   164
      SUBROUTINE RATES(IERR,DDS,SOR,SI)                                 RTS     1
      COMMON/E/NUCLID(20),UFGP,V(25),EXDU,UMAX(20,25),P1(20,25),        RTS     2
     X     PS(20,25),SOURCE(30),SDD,ACS,FCS,SCS,PHITOT,PHIT,ACSGP,FCSGP,RTS     3
     X SCSGP,RAP,SIGABG(20,30),SIGFBG(20,30),SIGSBG(20,30),DS1(20),     RTS     4
     X DSMAX(20),ALP(20,25),SCL(20,30),DSL(20),DPS(20),BSQ(25)          RTS     5
      COMMON/QW/REZ,AIMZ,REW,AIMW,   TR(62,62),TI(62,62)                RTS     6
      COMMON/A/     F1V,SL(20,30), TEST,      SIGP(20,30),XZETA(20,30), RTS     7
     XSA(20,30),SF(20,30),SS(20,30),DEN(20,30),G(300),GN(300),GF(300),  RTS     8
     X    GR(300),ER(300),XRES(300),SIGZ(300),GAMMA(300),SIGIN(300),    RTS     9
     X                  SIGMIN(300),     SIG(30),                       RTS    10
     X    SIGA22(20),SIGF22(20),      XN,XC,ETOT,TOT3,WORK(60),P(30)    RTS    11
      COMMON/B/              UIGP,                        CR(30),RAD(35),RTS    12
     X    RATIO(30),DIFX(30),          SPP(30),SPN(30),                 RTS    13
     X    AREA(35),          FLUX(30,100),FLUXCP(30,100),SCAT(40000),  RTS    14
     XTAB(662),TOT,TT(60,5),                        AF(30,5),FF(30,5),   RTS    15
     X V11,V12,V13,SSF(30,5),USTR(25),DUSTR(25)                         RTS    16
      COMMON/C/                                                         RTS    17
     X    XAREAT,AREAT,RMAX(30),                                        RTS    18
     X    ENGP(1001),RIAC(20,30),RIFC(20,30),RISC(20,30),TEMP(30),      RTS    19
     X                  XTEMP(30),        PHICT(30),PHI(30),PFLUX(30),RTS    20
     XSIGTR(30),BARMU(30),   AMU(20),SIGPOT(20),AREAC(30),XAREAC(30),   RTS    21
     XGX2(10),GW2(10),WW2(10),                                          RTS    22
     X   DR(30),XAREA(30),PHIRT(30),        GX3(10),GX4(10),GW3(10),    RTS    23
     X    GW4(10),WW3(10),WW4(10),V1,V2,V3,V4,V5,V6,V7,V8,V9,V10        RTS    24
      COMMON/D/KI,KRES,NTEMP,INCLUD(300),                               RTS    25
     X    NEXT(20),LAST(20),NRES(20),INDEX, KS,                         RTS    26
     X  NU,NOPT,ISYM(30),III,KFOIL,KREG,KMAT,KCOMP,KGP,KBG,NPRINT,MORE, RTS    27
     X  IBGP,IFGP,IBG,JBG,NIB(25),NINT(30),MINT(30),LREG(35),NX(30),    RTS    28
     X    NFI(25),TITLE(18),KB     ,MULT(20,25),JNU(20),JMULT(20),      RTS    29
     X  INUI(20,25),INUF(20,25),NOX,NISO,KBSQ                           RTS    30
      REAL*8 NUCLID                                                     RTS    31
      REAL*8 UFGP,V,EXDU,UMAX,DS1,DSMAX,SOURCE,SDD,ACS,FCS,SCS,PHITOT,  RTS    32
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     X  PHIT,ACSGP,FCSGP,SCSGP,RAP,SIGABG,SIGFBG,SIGSBG,P1,PS,ALP,DSL   RTS   33
      REAL*8 DPS,DDS,SOR,SI                                            RTS   34
      REAL*8 DEL,QQ,PFUNC                                              RTS   35
      DIMENSION Q(30),          TAU(35),        TTAU(30),TQ(60),T(30)  RTS   36
      DIMENSION RR(30)                                                 RTS   37
      DIMENSION SI(30),DS(30),ITRY(30),PIJ(30,30),R(30),DDS(30),SOR(30) RTS   38
      EQUIVALENCE (KREG,II)                                            RTS   39
      PNL=1.                                                           RTS   40
      IF(KBSQ)15,15,5                                                  RTS   41
C        FIND NON-LEAKAGE PROBABILITY PNL                              RTS   42
C        ASSUME D IS 1/(3SIGMA TOT)  WHERE SIGMA TOT IS FLUX-WTD       RTS   43
    5 V1=0.                                                            RTS   44
      V2=0.                                                            RTS   45
      DO 10  I=1,KREG                                                  RTS   46
      V2=V2+PHI(I)                                                     RTS   47
   10 V1=V1+PHI(I)*SIG(LREG(I))                                        RTS   48
      V1=V1/V2                                                         RTS   49
      D=0.                                                             RTS   50
      DO 11 K=1,KCOMP                                                  RTS   51
      D=D+SIGTR(K)*AREAC(K)                                            RTS   52
   11 CONTINUE                                                         RTS   53
      D=RMAX(KCOMP)/(3.*D)                                             RTS   54
      PNL=V1/(V1+D*BSQ(IBG))                                           RTS   55
   15 IF(II-1)20,30,80                                                 RTS   56
   20 WRITE (6,25)                                                     RTS   57
   25 FORMAT(10H ***KREG**)                                            RTS   58
      IERR=1                                                           RTS   59
      RETURN                                                           RTS   60
   30 CONTINUE                                                         RTS   61
      R(1) = 0.0                                                       RTS   62
      CR(1) = SOURCE(1)                                                RTS   63
      IF (IBGP.EQ.1.AND.IFGP.EQ.1) GO TO 60                            RTS   64
      CR(1)=CR(1)*PNL                                                  RTS   65
      IF(KS.GT.0) GO TO 41                                             RTS   66
      DO 40  J=1,KMAT                                                  RTS   67
      IF (DEN(J,1)) 35,40,35                                           RTS   68
   35 R(1) = R(1) + DPS(J) * SS(J,1)                                   RTS   69
   40 CONTINUE                                                         RTS   70
      R(1) = R(1)/SIG(1)                                               RTS   71
   41 CR(1)=PNL*SOURCE(1)/(1.-R(1))                                    RTS   72
      QQ=     SOR(1)+R(1)*CR(1)                                        RTS   73
C      CHECK IF SOURCE CORRECTION LESS THAN ROUNDOFF                   RTS   74
      IF(SOURCE(1))45,55,45                                            RTS   75
   45 IF( DABS(QQ/SOURCE(1))-0.5D-06 )50,50,55                         RTS   76
   50 QQ=0.0D0                                                         RTS   77
   55 DDS(1)=DDS(1)+QQ                                                 RTS   78
      SOURCE(1)=(SI(1)+DDS(1))*PNL                                     RTS   79
   60 IF(KFOIL)75,75,65                                                RTS   80
   65 DO 70  L=1,KFOIL                                                 RTS   81
      DEL=SIG (L+1)*AREA(L+1)                                          RTS   82
      ZZ=DEL*PFUNC(DEL)                                                RTS   83
      TT(1,L) = ZZ * SOURCE(1)/(DEL * SIG(1) * (1.0 - R(1)))           RTS   84
   70 CONTINUE                                                         RTS   85
   75 RETURN                                                           RTS   86
   80 I2=II-2                                                          RTS   87
      TOT=0.                                                           RTS   88
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      JJJ=KREG+KFOIL                                                    RTS   89
      DO 115 K=1,JJJ                                                    RTS   90
      TAU(K)=SIG (LREG(K))*AREA(K)                                      RTS   91
      IF(TAU(K))85,95,95                                                RTS   92
   85 WRITE(6,90 ) K,TAU(K),IBGP,IFGP                                   RTS   93
   90 FORMAT(5H TAU(,I2,2H)=,E12.5,17H INTERMEDIATE GR.,I3,2X,9H FINE GRRTS   94
     1.,I3,/,21H *****PROBLEM ABORTED)                                  RTS   95
      IERR=1                                                            RTS   96
      RETURN                                                            RTS   97
   95 IF(K-II)100,100,115                                               RTS   98
  100 TTAU(K)=0.0                                                       RTS   99
      IF(TAU(K))110,110,105                                             RTS  100
  105 TTAU(K)=1./TAU(K)                                                 RTS  101
  110 Q(K)=0.5*SOURCE(K)*PNL                                            RTS  102
      TQ(K)=TTAU(K)*Q(K)                                                RTS  103
      TQ(K+II)=TQ(K)                                                    RTS  104
      TOT=TOT+TAU(K)                                                    RTS  105
  115 CONTINUE                                                          RTS  106
      L=0                                                               RTS  107
      DO 145 I=1,KCOMP                                                  RTS  108
      IF(NINT(I)-1)120,120,125                                          RTS  109
  120 DS(L+1)=0.                                                        RTS  110
      ITRY(L+1)=0                                                       RTS  111
      L=L+1                                                             RTS  112
      GO TO 145                                                         RTS  113
  125 M=NINT(I)-1                                                       RTS  114
      IF(M-2)140,130,130                                                RTS  115
  130 DO 135 J=2,M                                                      RTS  116
  135 DS(L+J)=0.5*(TQ(L+J+1)-TQ(L+J-1))                                 RTS  117
  140 DS(L+M+1)=(TQ(L+M+1)-TQ(L+M))                                     RTS  118
      DS(L+1)=     (TQ(L+2)-TQ(L+1))                                    RTS  119
      L=L+NINT(I)                                                       RTS  120
  145 CONTINUE                                                          RTS  121
      DO 150 I=1,II                                                     RTS  122
      Q(I) = 0.5                                                        RTS  123
      TQ(I) = TQ(I)/SOURCE(I)                                           RTS  124
      DS(I) = DS(I)/SOURCE(I)                                           RTS  125
  150 CONTINUE                                                          RTS  126
      DO 175 I=1,II                                                     RTS  127
C     DO SELF-ABSORPTION ONLY                                           RTS  128
      M=II+I                                                            RTS  129
      QQ=TAU(I)                                                         RTS  130
      P(I)=PFUNC(QQ)                                                    RTS  131
      WORK(I)=TAU(I)                                                    RTS  132
      WORK(M)=TAU(I)                                                    RTS  133
      ITRY(I)=0                                                         RTS  134
      IF(TQ(I))160,155,160                                              RTS  135
  155 IF( ABS(DS(I))-.000001)170,170,165                                RTS  136
  160 IF( ABS(DS(I)/TQ(I) )-.01)170,170,165                             RTS  137
  165 ITRY(I)=1                                                         RTS  138
      GO TO 175                                                         RTS  139
  170 DS(I)=0.                                                          RTS  140
  175 CONTINUE                                                          RTS  141
      DO  180 I=1,4                                                     RTS  142
      WW2(I)=GW2(I)/(1.- EXP(TOT*GX2(I)))                               RTS  143
      WW3(I)=GW3(I)/(1.- EXP( TOT*GX3(I)))                              RTS  144
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      WW4(I)=GW4(I)/(1.- EXP( TOT*GX4(I)))                              RTS  145
  180 CONTINUE                                                          RTS  146
      XC=.004126+.00628* EXP(-19.8*TOT)                                 RTS  147
      ASSIGN 295 TO JSWCH                                               RTS  148
      ASSIGN 360 TO JRSWCH                                              RTS  149
      IF(TOT-4.5)190,190,185                                            RTS  150
  185 ASSIGN 285 TO JSWCH                                               RTS  151
      ASSIGN 350 TO JRSWCH                                              RTS  152
C     DO NEIGHBOUR AND SAME CELL CONTRIBUTIONS                          RTS  153
C        BY CALCULATING CURRENT IN - CURRENT OUT                        RTS  154
  190 V1=TOT                                                            RTS  155
      V2=TOT                                                            RTS  156
      CALL XTRAP                                                        RTS  157
      A1=V7                                                             RTS  158
      CALL XTRAP4                                                       RTS  159
      A3=V8                                                             RTS  160
      AA1=A1+0.5                                                        RTS  161
C                                                                       RTS  162
      DO 195 IR=1,II                                                    RTS  163
      RR(IR) = 0.0                                                      RTS  164
      DO 195 JR=1,II                                                    RTS  165
  195 PIJ (IR,JR) = 0.0                                                 RTS  166
C                                                                       RTS  167
      DO 420 I=1,II                                                     RTS  168
      NN=II+I-1                                                         RTS  169
      IR=II+1-I                                                         RTS  170
      MM=II+IR                                                          RTS  171
      X6=0.                                                             RTS  172
      F7=0.                                                             RTS  173
      X8=0.                                                             RTS  174
      FS=TQ(I)                                                          RTS  175
      V4=TAU(I)                                                         RTS  176
      X1=TOT + TAU(I)                                                   RTS  177
      IF(TAU(I)-.01)200,200,205                                         RTS  178
  200 V3=TOT                                                            RTS  179
      CALL YZ3                                                          RTS  180
      A2=V9                                                             RTS  181
      GO TO 210                                                         RTS  182
  205 V3=2.*TOT                                                         RTS  183
      CALL YZ3                                                          RTS  184
      PT=PE3(TOT)                                                       RTS  185
      A2=V9+PT-PE3(X1)                                                  RTS  186
  210 X2=TOT+TAU(IR)                                                    RTS  187
      X3=TOT-TAU(I)                                                     RTS  188
      FIN=Q(I)*( P(I) +       A2*TTAU(I) )                              RTS  189
      F9=0.                                                             RTS  190
      V3=0.0                                                            RTS  191
      ASSIGN 330 TO ISWCH                                               RTS  192
      IF(ITRY(I))235,235,215                                            RTS  193
  215 ASSIGN 325 TO ISWCH                                               RTS  194
      DFS=DS(I)                                                         RTS  195
      V1=TAU(I)                                                         RTS  196
      V4=TAU(I)                                                         RTS  197
      CALL XTRAP                                                        RTS  198
      CALL YZ4                                                          RTS  199
      F9=DFS*(0.5*(AA1+V7)-TTAU(I)*V10)                                 RTS  200
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```
      IF(FIN)220,230,220                                                RTS  201
  220 IF( ABS(F9/FIN)-.01)225,225,230                                   RTS  202
  225 ASSIGN 330 TO ISWCH                                               RTS  203
      F9=0.                                                             RTS  204
      GO TO 235                                                         RTS  205
  230 V1=X3                                                             RTS  206
      V2=X3+TOT                                                         RTS  207
      CALL XTRAP                                                        RTS  208
      CALL XTRAP4                                                       RTS  209
      V8=V8+E4(X3)                                                      RTS  210
      F7=DFS*(0.5*(V7+A1)-TTAU(I)*(V8-A3))                              RTS  211
  235 X6=0.                                                             RTS  212
       X4=TOT-TAU(IR)                                                   RTS  213
      V1=X2                                                             RTS  214
      V1=X2                                                             RTS  215
      CALL XTRAP                                                        RTS  216
      BIN=0.                                                            RTS  217
      BOUTL=0.                                                          RTS  218
      ASSIGN 380 TO IRSWCH                                              RTS  219
      IF(ITRY(IR))260,260,240                                           RTS  220
  240 ASSIGN 365 TO IRSWCH                                              RTS  221
      V1=TOT+TAU(IR)                                                    RTS  222
      CALL XTRAP                                                        RTS  223
      BIN=Q(IR)*(P(IR)+(A1-V7)*TTAU(IR))                                RTS  224
      DSR=DS(IR)                                                        RTS  225
      V1=TAU(IR)                                                        RTS  226
      V4=TAU(IR)                                                        RTS  227
      CALL XTRAP                                                        RTS  228
      CALL YZ4                                                          RTS  229
      X6=DSR*(0.5*(AA1+V7)-TTAU(IR)*V10)                                RTS  230
      IF(BIN)245,255,245                                                RTS  231
  245 IF( ABS(X6/BIN)-.01)250,250,255                                   RTS  232
  250 ASSIGN 380 TO IRSWCH                                              RTS  233
      GO TO 260                                                         RTS  234
  255 BIN=-X6                                                           RTS  235
      V1=X4                                                             RTS  236
      V2=X4+TOT                                                         RTS  237
      CALL XTRAP                                                        RTS  238
      CALL XTRAP4                                                       RTS  239
      V8=V8+E4(X4)                                                      RTS  240
      BOUTL=-                                                           RTS  241
     1   DSR*(0.5*(V7+A1)-TTAU(IR)*(V8-A3))                             RTS  242
  260 V4=TAU(I)                                                         RTS  243
      IF(TAU(I)-.01)265,265,270                                         RTS  244
  265 V3=X3                                                             RTS  245
      CALL YZ3                                                          RTS  246
      FOUTL=FS*V9                                                       RTS  247
      GO TO 275                                                         RTS  248
  270 V3=X3+TOT                                                         RTS  249
      CALL YZ3                                                          RTS  250
      FOUTL=FS*(V9+PE3(X3)-PT)                                          RTS  251
  275 CONTINUE                                                          RTS  252
      PIJ(I,I)=2.*(Q(I)*(1.-P(I))+FOUTL-FS*A2      ) + PIJ(I,I)          RTS  253
C       THIS IS RR(I) FROM I-TH PLATE IN ALL UNIT CELLS AND IS NOT      RTS  254
C         CONTRIBUTED TO BY LINEAR SOURCE TERM, BY SYMMETRY             RTS  255
      X1=WORK(I)                                                        RTS  256
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      X2=WORK(IR)                                                       RTS  257
      X5=WORK(NN)                                                       RTS  258
      V3=0.                                                             RTS  259
      IF(I2)335,335,280                                                 RTS  260
  280 CONTINUE                                                          RTS  261
C                                                                       RTS  262
C                                                                       RTS  263
      DO 335 K=1,I2                                                     RTS  264
      J=I+K                                                             RTS  265
      IF (J.GT.II) J = J - II                                           RTS  266
      GO TO JSWCH,(295,285)                                             RTS  267
  285 IF(V3-9.)295,290,290                                              RTS  268
  290 PIJ(I,J) = PIJ(I,J) + FIN                                         RTS  269
      PIJ(J,I) = PIJ(J,I) + FIN * TQ(J)/TQ(I)                           RTS  270
      FIN=FOUTL                                                         RTS  271
      GO TO 340                                                         RTS  272
  295 V4=WORK(J)                                                        RTS  273
      THICK=X1                                                          RTS  274
      IF(X1-V4)300,300,305                                              RTS  275
  300 V4=X1                                                             RTS  276
      THICK=WORK(J)                                                     RTS  277
  305 IF(V4-.1)310,310,315                                              RTS  278
  310 CALL YZ3                                                          RTS  279
      C1=V9                                                             RTS  280
      V3=V3+THICK                                                       RTS  281
      CALL YZ3                                                          RTS  282
      C1=FS*(C1-V9)                                                     RTS  283
      FOUT=FIN-C1                                                       RTS  284
      PIJ(I,J) = PIJ(I,J) + C1                                          RTS  285
      PIJ(J,I) = PIJ(J,I) + C1 * TQ(J)/TQ(I)                            RTS  286
      V3=V3+WORK(J)-THICK                                               RTS  287
      GO TO ISWCH,(330,325)                                             RTS  288
  315 V3=V3+WORK(J)                                                     RTS  289
      V4=X1                                                             RTS  290
      CALL YZ3                                                          RTS  291
      FOUT=FS*V9                                                        RTS  292
  320 PIJ(I,J) = PIJ(I,J) + FIN - FOUT                                  RTS  293
      PIJ(J,I) = PIJ(J,I) + (FIN-FOUT) * TQ(J)/TQ(I)                    RTS  294
      GO TO ISWCH,(330,325)                                             RTS  295
  325 V1=V3                                                             RTS  296
      CALL XTRAP                                                        RTS  297
      X9=V7                                                             RTS  298
      V1=V3+V4                                                          RTS  299
      CALL XTRAP                                                        RTS  300
      X9=0.5*(X9+V7)                                                    RTS  301
      CALL YZ4                                                          RTS  302
      ABC=DFS*(X9-TTAU(I)*V10)                                          RTS  303
      PIJ(I,J) = PIJ(I,J) + F9 - ABC                                    RTS  304
      F9=ABC                                                            RTS  305
  330 FIN=FOUT                                                          RTS  306
  335 CONTINUE                                                          RTS  307
C                                                                       RTS  308
  340 V3=0.                                                             RTS  309
      IF (I2)370,370,345                                                RTS  310
  345 CONTINUE                                                          RTS  311
C                                                                       RTS  312
```

```
C
      DO 370 K=1,I2
      M=MM-K
      IF (M.GT.II) M = M - II
      V3=V3+WORK(M)
      GO TO JRSWCH,(360,350)
  350 IF(V3-9.)360,355,355
  355 PIJ(IR,M)=PIJ(IR,M) + BIN
      GO TO 380
  360 V4=   X2
      GO TO IRSWCH,(380,365)
  365 V1=V3
      CALL XTRAP
      X10=V7
      V1=V3+V4
      CALL XTRAP
      X10=0.5*(X10+V7)
      CALL YZ4
      BOUT=    -DSR*(X10-TTAU(IR)*V10)
      PIJ(IR,M)=PIJ(IR,M) + BIN - BOUT
      BIN=BOUT
  370 CONTINUE
C
  375 CONTINUE
      PIJ(IR,I  ) = PIJ(IR,I  ) + BIN - BOUTL
  380 V3=TOT-X1-X5
      V4=X1
      THICK=X5
      IF(X5-X1)385,390,390
  385 V4=X5
      THICK=X1
  390 IF(V4-.01)395,395,400
  395 CALL YZ3
      C1=V9
      V3=V3+THICK
      CALL YZ3
      C1=FS*(C1-V9)
      GO TO 405
  400 C1=FIN-FOUTL
  405 CONTINUE
      IF (NN.GT.II) NN = NN - II
      PIJ(I,NN) = PIJ(I,NN) + C1 + F9 - F7
      PIJ(NN,I) = PIJ(NN,I) + C1 * TQ(NN)/TQ(I)
C
      NDX=0
      R(I) = 0.0
      IF(KS.GT.0) GO TO 420
      M = LREG(I)
      DO 415 J=1,KMAT
      IF (DEN(J,M)) 410,415,410
  410 R(I) = R(I) + DPS(J) * SS(J,M)
  415 CONTINUE
      R(I) = R(I)/SIG(M)
  420 CONTINUE
C
C
```

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C                                                                       RTS  369
      IF(KS.GT.0) GO TO 430                                             RTS  370
      IF(IBGP.EQ.1.AND.IFGP.EQ.1) GO TO 430                             RTS  371
      CALL MATINV (PIJ,II,RR ,0,DETERM,30)                              RTS  372
C                                                                       RTS  373
      DO 425 L=1,II                                                     RTS  374
      PIJ(L,L) = PIJ(L,L) - R(L)                                        RTS  375
  425 CONTINUE                                                          RTS  376
C                                                                       RTS  377
      CALL MATINV (PIJ,II,RR ,0,DETERM,30)                              RTS  378
C                                                                       RTS  379
  430 DO 435 K=1,II                                                     RTS  380
      CR(K) = 0.0                                                       RTS  381
      DO 435 KK=1,II                                                    RTS  382
      CR(K) = CR(K) + PIJ(KK,K) * SOURCE(KK)                            RTS  383
  435 CONTINUE                                                          RTS  384
      DO  437 I=1,KREG,2                                                RTS  385
      IF(ISYM(I))438,438,436                                            RTS  386
  436 AVG=0.5*(CR(ISYM(I))+CR(ISYM(I+1)))                               RTS  387
      CR(ISYM(I))=AVG                                                   RTS  388
      CR(ISYM(I+1))=AVG                                                 RTS  389
  437 CONTINUE                                                          RTS  390
  438 CONTINUE                                                          RTS  391
C                                                                       RTS  392
      DO 460 I=1,II                                                     RTS  393
      IF(IBGP.EQ.1.AND.IFGP.EQ.1) GO TO 455                             RTS  394
      QQ=R(I)*CR(I)+SOR(I)                                              RTS  395
C      CHECK IF SOURCE CORRECTION LESS THAN ROUNDOFF                    RTS  396
      IF(SOURCE(I))440,450,440                                          RTS  397
  440 IF(DABS(QQ/SOURCE(I))-.50D-06)445,445,450                         RTS  398
  445 QQ=0.0D0                                                          RTS  399
  450 DDS(I)=DDS(I)+QQ                                                  RTS  400
      SOURCE(I)=(SI(I)+DDS(I))*PNL                                      RTS  401
  455 TQ(I)=0.5*SOURCE(I)*TTAU(I)                                       RTS  402
      DS(I)=DS(I)*SOURCE(I)                                             RTS  403
  460 CONTINUE                                                          RTS  404
C                                                                       RTS  405
C                                                                       RTS  406
      DO 475 K=1,II                                                     RTS  407
      M=II+K                                                            RTS  408
      DO  465 L=1,KFOIL                                                 RTS  409
      IT(K,L)=0.                                                        RTS  410
      IT(M,L)=0.                                                        RTS  411
  465 CONTINUE                                                          RTS  412
      IF(CR(K))470,475,475                                              RTS  413
  470 NDX=1                                                             RTS  414
  475 CONTINUE                                                          RTS  415
      IF(NDX)530,530,480                                                RTS  416
  480 WRITE (6,485) (CR(I),I=1,II)                                      RTS  417
  485 FORMAT(1H0,(5E17.8))                                              RTS  418
      DO 490 J=1,II                                                     RTS  419
  490 WRITE (6,485) (PIJ(I,J),I=1,II)                                   RTS  420
      WRITE (6,495) (SOURCE(I),TQ(I),DS(I),TAU(I),ITRY(I),I=1,II)       RTS  421
  495 FORMAT(1H0,26HNEG. COLL. RATE ZEROED OUT,/,(4E20.8,I5))           RTS  422
      V3=1.0E+30                                                        RTS  423
      V1=0.                                                             RTS  424
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      V2=0.                                                             RTS  425
      DO 505 I=1,KREG                                                   RTS  426
      V1=V1+SOURCE(I)                                                   RTS  427
      V2=V2+CR(I)                                                       RTS  428
      IF(CR(I)-V3)500,505,505                                           RTS  429
  500 V3=CR(I)                                                          RTS  430
  505 CONTINUE                                                          RTS  431
      V2=V2-KREG*V3                                                     RTS  432
      V1=V1/V2                                                          RTS  433
      DO 510 I=1,KREG                                                   RTS  434
      CR(I)=V1*(CR(I)-V3)                                               RTS  435
  510 CONTINUE                                                          RTS  436
C     THIS NORMALISES TO SUM(CR(I)-SOURCE(I))=0.                        RTS  437
C     AND SETS MINIMUM COLLISION RATE TO ZERO                           RTS  438
  530 IF(KFOIL)610,610,535                                              RTS  439
C       BEGIN FOIL CALCULATIONS                                         RTS  440
  535 DO 600 I=1,KREG                                                   RTS  441
      X1=WORK(I)                                                        RTS  442
      FS=TQ(I)                                                          RTS  443
      DFS=DS(I)                                                         RTS  444
      V3=0.                                                             RTS  445
      IR=II+1-I                                                         RTS  446
      SR=TQ(IR)                                                         RTS  447
      DSR=DS(IR)                                                        RTS  448
      MM=II+IR                                                          RTS  449
      DO 565 K=1,KREG                                                   RTS  450
      J=I+K                                                             RTS  451
      DO  560 L=1,KFOIL                                                 RTS  452
      V4=   TAU(II+L)                                                   RTS  453
      CALL YZ3                                                          RTS  454
      X2=V9                                                             RTS  455
      X10=0.                                                            RTS  456
      IF(DFS)540,545,540                                                RTS  457
  540 CALL YZ4                                                          RTS  458
      X10=V10                                                           RTS  459
  545 V3=V3+X1                                                          RTS  460
      CALL YZ3                                                          RTS  461
      X3=V9                                                             RTS  462
      V10=0.                                                            RTS  463
      IF(DFS)550,555,550                                                RTS  464
  550 CALL YZ4                                                          RTS  465
  555 V3=V3-X1                                                          RTS  466
      TT(J-1,L)=TT(J-1,L)+FS*(X2-X3)+DFS*((X2+X3)*.5-TTAU(I)*(X10-V10)) RTS  467
  560 CONTINUE                                                          RTS  468
      V3=V3+WORK(J)                                                     RTS  469
  565  CONTINUE                                                         RTS  470
      X1=WORK(IR)                                                       RTS  471
      V3=0.                                                             RTS  472
      DO 595 K=1,KREG                                                   RTS  473
      M=MM-K                                                            RTS  474
      DO  590 L=1,KFOIL                                                 RTS  475
      V4=   TAU(II+L)                                                   RTS  476
      CALL YZ3                                                          RTS  477
      X2=V9                                                             RTS  478
      X10=0.                                                            RTS  479
      IF(DSR)570,575,570                                                RTS  480
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570 CALL YZ4                                                            RTS  481
    X10=V10                                                             RTS  482
575 V3=V3+X1                                                            RTS  483
     CALL YZ3                                                           RTS  484
    X3=V9                                                               RTS  485
    V10=0.                                                              RTS  486
    IF(DSR)580,585,580                                                  RTS  487
580 CALL YZ4                                                            RTS  488
585 V3=V3-X1                                                            RTS  489
    TT(M,L)=TT(M,L)+SR*(X2-X3)-DSR*((X2+X3)*.5-TTAU(IR)*(X10-V10))      RTS  490
590 CONTINUE                                                            RTS  491
    V3=V3+WORK(M)                                                       RTS  492
595 CONTINUE                                                            RTS  493
600  CONTINUE                                                           RTS  494
    DO  605 L=1,KFOIL                                                   RTS  495
    DO 605 I=1,KREG                                                     RTS  496
    TT(I,L)=(TT(I,L)+TT(I+KREG,L))/TAU (II+L)                           RTS  497
605 CONTINUE                                                            RTS  498
610  RETURN                                                             RTS  499
    END                                                                 RTS  500
    SUBROUTINE DATA                                                     DAT    1
    COMMON/E/NUCLID(20),UFGP,V(25),EXDU,UMAX(20,25),P1(20,25),          DAT    2
   X     PS(20,25),SOURCE(30),SDD,ACS,FCS,SCS,PHITOT,PHIT,ACSGP,FCSGP,DAT    3
   X SCSGP,RAP,SIGABG(20,30),SIGFBG(20,30),SIGSBG(20,30),DS1(20),       DAT    4
   X DSMAX(20),ALP(20,25),SCL(20,30),DSL(20),DPS(20),BSQ(25)            DAT    5
    COMMON/QW/REZ,AIMZ,REW,AIMW,   TR(62,62),TI(62,62)                  DAT    6
    COMMON/A/     F1V,SL(20,30), TEST,      SIGP(20,30),XZETA(20,30),  DAT    7
   XSA(20,30),SF(20,30),SS(20,30),DEN(20,30),G(300),GN(300),GF(300),    DAT    8
   X    GR(300),ER(300),XRES(300),SIGZ(300),GAMMA(300),SIGIN(300),      DAT    9
   X                 SIGMIN(300),     SIG(30),                          DAT   10
   X    SIGA22(20),SIGF22(20),      XN,XC,ETOT,TOT3,WORK(60),P(30)      DAT   11
    COMMON/B/              UIGP,                      CR(30),RAD(35),DAT   12
   X    RATIO(30),DIFX(30),            SPP(30),SPN(30),                 DAT   13
   X    AREA(35),          FLUX(30,100),FLUXCP(30,100),SCAT(40000),     DAT   14
   XTAB(662),TOT,TT(60,5),                        AF(30,5),FF(30,5),    DAT   15
   X V11,V12,V13,SSF(30,5),USTR(25),DUSTR(25)                           DAT   16
    COMMON/C/                                                           DAT   17
   X    XAREAT,AREAT,RMAX(30),                                          DAT   18
   X    ENGP(1001),RIAC(20,30),RIFC(20,30),RISC(20,30),TEMP(30),        DAT   19
   X                     XTEMP(30),         PHICT(30),PHI(30),PFLUX(30),DAT   20
   XSIGTR(30),BARMU(30),    AMU(20),SIGPOT(20),AREAC(30),XAREAC(30),    DAT   21
   XGX2(10),GW2(10),WW2(10),                                            DAT   22
   X   DR(30),XAREA(30),PHIRT(30),         GX3(10),GX4(10),GW3(10),    DAT   23
   X    GW4(10),WW3(10),WW4(10),V1,V2,V3,V4,V5,V6,V7,V8,V9,V10          DAT   24
    COMMON/D/KI,KRES,NTEMP,INCLUD(300),                                 DAT   25
   X    NEXT(20),LAST(20),NRES(20),INDEX, KS,                           DAT   26
   X  NU,NOPT,ISYM(30),III,KFOIL,KREG,KMAT,KCOMP,KGP,KBG,NPRINT,MORE,  DAT   27
   X  IBGP,IFGP,IBG,JBG,NIB(25),NINT(30),MINT(30),LREG(35),NX(30),      DAT   28
   X    NFI(25),TITLE(18),KB     ,MULT(20,25),JNU(20),JMULT(20),        DAT   29
   X  INUI(20,25),INUF(20,25),NOX,NISO,KBSQ                             DAT   30
    REAL*8 UFGP,V,EXDU,UMAX,DS1,DSMAX,SOURCE,SDD,ACS,FCS,SCS,PHITOT,    DAT   31
   X  PHIT,ACSGP,FCSGP,SCSGP,RAP,SIGABG,SIGFBG,SIGSBG,P1,PS,ALP         DAT   32
    REAL*8          DSL,DPS                                             DAT   33
    REAL*8 NUCLID                                                       DAT   34
    REAL*8 VT,BETA,UARG                                                 DAT   35
    GX2(1)=-1.177891426                                                 DAT   36
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      GX2(2)=-2.077191119                                               DAT   37
      GX2(3)=-4.163318952                                               DAT   38
      GX2(4)=-8.243369530                                               DAT   39
      GW2(1)=.341652502                                                 DAT   40
      GW2(2)=.324695119                                                 DAT   41
      GW2(3)=.166569908                                                 DAT   42
      GW2(4)=.0832491983                                                DAT   43
      GX3(1)=-1.13889383                                                DAT   44
      GX3(2)=-1.85532327                                                DAT   45
      GX3(3)=-3.61600813                                                DAT   46
      GX3(4)=-7.28316919                                                DAT   47
      GW3(1)=.251036872                                                 DAT   48
      GW3(2)=.178254373                                                 DAT   49
      GW3(3)=.0531086307                                                DAT   50
      GW3(4)=.0134690502                                                DAT   51
      GX4(1)=-1.11147228                                                DAT   52
      GX4(2)=-1.68851498                                                DAT   53
      GX4(3)=-3.15938155                                                DAT   54
      GX4(4)=-6.41012357                                                DAT   55
      GW4(1)=.194827289                                                 DAT   56
      GW4(2)=.113795599                                                 DAT   57
      GW4(3)=.0215903023                                                DAT   58
      GW4(4)=.00280124126                                               DAT   59
      PI=3.14159265                                                     DAT   60
      FIV=SQRT(0.0253/ENGP(1))                                          DAT   61
      XNFB=1./NFI(1)                                                    DAT   62
      DO 200 J=1,KMAT                                                   DAT   63
  200 BARMU(J)=.6666667/AMU(J)                                          DAT   64
      NISO=0                                                            DAT   65
      DO 2 K=1,KCOMP                                                    DAT   66
      DO 2 J=1,KMAT                                                     DAT   67
      IF(DEN(J,K))3,2,3                                                 DAT   68
    3 NISO=NISO+NINT(K)                                                 DAT   69
    2 CONTINUE                                                          DAT   70
      NOX=40000/NISO-1                                                  DAT   71
      DO 35 I=1,KBG                                                     DAT   72
      UFGP=UIGP/NFI(I)                                                  DAT   73
      EXDU=DEXP(-UFGP)                                                  DAT   74
      V(I)=1.0D0-EXDU                                                   DAT   75
C          DELETION OF INGROUP SCATTERING PROBABILITY AND               DAT   76
C        REDEFINITION OF DOWNSCATTER PROBABILITIES TO CONSERVE NEUTRONS DAT   77
      VT=V(I)*V(I)/UFGP                                                 DAT   78
      IF(KS.GT.0) VT=V(I)                                               DAT   79
      DO 35 J=1,KMAT                                                    DAT   80
      IF(AMU(J)-1.1)5,5,10                                              DAT   81
    5 UMAX(J,I)=20.0D0                                                  DAT   82
      GO TO 15                                                          DAT   83
   10 UARG=1.0D0+2.0D0/(AMU(J)-1.)                                      DAT   84
      UMAX(J,I)=2.0D0*DLOG(UARG)                                        DAT   85
C     ROUND TO NEAREST INTEGER MULTIPLE                                 DAT   86
   15 LUMAX=UMAX(J,I)/UFGP + .5                                         DAT   87
C     MULT IS THE  NUMBER OF FINE GROUPS AVERAGED OVER FOR SCAT         DAT   88
      MULT(J,I)=1+LUMAX/(NOX-26)                                        DAT   89
C     NEED AN EXTRA INTERVAL FOR 3RD INTERPOLATION POINT AND ONE FOR    DAT   90
C     CHANGING CURRENT INTERVAL AND 25 FOR BROAD GROUP BOUNDS           DAT   91
      UMAX(J,I)=UFGP*DFLOAT(LUMAX)                                      DAT   92
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      ALP(J,I)=DEXP(-UMAX(J,I))                                         DAT   93
      IF(I-2)1,30,30                                                    DAT   94
    1 IF(J-KRES)20,20,30                                                DAT   95
   20 DO 25 K=1,NTEMP                                                   DAT   96
   25 XZETA(J,K)=SQRT (AMU(J)/(3.46668E-04*ENGP(1)*TEMP(K)))            DAT   97
      N=NEXT(J)                                                         DAT   98
      L=LAST(J)                                                         DAT   99
      A2 = 1.0 + 1.0/AMU(J)                                             DAT  100
      A4 = A2 * A2                                                      DAT  101
      DO 27 K=N,L                                                       DAT  102
      AER=ABS (ER(K))                                                   DAT  103
      XRES(K)=SQRT (AER/ENGP(1))                                        DAT  104
      GAMMA(K)=GN(K)+GR(K)+GF(K)                                        DAT  105
      SIGZ(K)=2.60385E+06 * A4 * G(K) * GN(K)/(AER * GAMMA(K)**2)       DAT  106
      IF (G(K).GE.0.0) GO TO 26                                         DAT  107
      SIGZ(K) = 2.60385E+06 * A4 * (-G(K)) * GN(K)/(AER * GAMMA(K))     DAT  108
   26 ABSS=ABS (SIGPOT(J)*G(K)*SIGZ(K)*GN(K))                           DAT  109
   27 SIGIN(K)=SQRT (ABSS)                                              DAT  110
   30 BETA=1.0D0/(1.0D0-ALP(J,I))                                       DAT  111
      P1(J,I)=BETA*VT                                                   DAT  112
      PS(J,I)=BETA*(UFGP-V(I))/UFGP                                     DAT  113
      IF(KS.GT.0) PS(J,I)=0.0D0                                         DAT  114
   35 CONTINUE                                                          DAT  115
      USTR(1)=0.                                                        DAT  116
      DUSTR(1)=UIGP*NIB(1)                                              DAT  117
      DO 36 J=1,KMAT                                                    DAT  118
      JNU(J)=0                                                          DAT  119
      JMULT(J)=0                                                        DAT  120
      INUI(J,1)=1                                                       DAT  121
      INUF(J,1)=INUI(J,1)+( NIB(1)*NFI(1)-1)/MULT(J,1)                  DAT  122
   36 CONTINUE                                                          DAT  123
      IF(KBG-1)38,38,37                                                 DAT  124
   37 DO 39 I=2,KBG                                                     DAT  125
      DUSTR(I)= NIB(I)*UIGP                                             DAT  126
      USTR(I)=USTR(I-1)+DUSTR(I-1)                                      DAT  127
      DO 39 J=1,KMAT                                                    DAT  128
      INUI(J,I)=INUF(J,I-1)+1                                           DAT  129
      INUF(J,I)=INUI(J,I)+( NIB(I)*NFI(I)-1)/MULT(J,I)                  DAT  130
   39 CONTINUE                                                          DAT  131
   38 Z=UIGP                                                            DAT  132
      DO 40 I=1,KGP                                                     DAT  133
      ENGP(I+1)=ENGP(1)*EXP(-Z)                                         DAT  134
   40 Z=Z+UIGP                                                          DAT  135
      IF(KREG-1)100,100,41                                              DAT  136
   41 IF(NOPT)100,100,43                                                DAT  137
  100 AREA(1)=1.0                                                       DAT  138
      XAREA(1)=XNFB                                                     DAT  139
      LREG(1)=1                                                         DAT  140
      AREAC(1)=1.0                                                      DAT  141
      XAREAC(1)=XNFB                                                    DAT  142
      RAD(1)=1.0                                                        DAT  143
      AREAT=1.0                                                         DAT  144
      XAREAT=XNFB                                                       DAT  145
      GO TO 95                                                          DAT  146
   43 MINT(1)=NINT(1)                                                   DAT  147
      DR(1)=RMAX(1)/FLOAT (NINT(1))                                     DAT  148
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      DO 45 I=2,KCOMP                                                   DAT  149
      DR(I)=(RMAX(I)-RMAX(I-1))/FLOAT (NINT(I))                         DAT  150
   45 MINT(I)=MINT(I-1)+NINT(I)                                         DAT  151
      I=1                                                               DAT  152
      RAD(1)=DR(1)                                                      DAT  153
      AREA(1)=RAD(1)                                                    DAT  154
      LREG(1)=1                                                         DAT  155
      DO 60 J=2,KREG                                                    DAT  156
      IF(J-MINT(I))55,55,50                                             DAT  157
   50 I=I+1                                                             DAT  158
   55 LREG(J)=I                                                         DAT  159
      AREA(J)=DR(I)                                                     DAT  160
   60 RAD(J)=RAD(J-1)+DR(I)                                             DAT  161
   80 AREAT=RMAX(KCOMP)                                                 DAT  162
      XAREAT=XNFB/AREAT                                                 DAT  163
      AREAC(1)=RMAX(1)                                                  DAT  164
      XAREAC(1)=XNFB/AREAC(1)                                           DAT  165
      XAREA(1)=XNFB/AREA(1)                                             DAT  166
      DO 85 I=2,KREG                                                    DAT  167
   85 XAREA(I)=XNFB/AREA(I)                                             DAT  168
      DO 90 J=2,KCOMP                                                   DAT  169
      AREAC(J)=RMAX(J)-RMAX(J-1)                                        DAT  170
   90 XAREAC(J)=XNFB/AREAC(J)                                           DAT  171
   95 IF(KFOIL)96,96,119                                                DAT  172
  119 DO 120 I=1,KFOIL                                                  DAT  173
      LREG(KREG+I)=KCOMP+I                                              DAT  174
      AREA(KREG+I)=RMAX(KCOMP+I)                                        DAT  175
  120 CONTINUE                                                          DAT  176
   96 RETURN                                                            DAT  177
      END                                                               DAT  178
      SUBROUTINE SOARCE(IERR,DS,SOR,SI)                                 SOA    1
      COMMON/E/NUCLID(20),UFGP,V(25),EXDU,UMAX(20,25),P1(20,25),        SOA    2
     X      PS(20,25),SOURCE(30),SDD,ACS,FCS,SCS,PHITOT,PHIT,ACSGP,FCSGP,SOA    3
     X SCSGP,RAP,SIGABG(20,30),SIGFBG(20,30),SIGSBG(20,30),DS1(20),     SOA    4
     X DSMAX(20),ALP(20,25),SCL(20,30),DSL(20),DPS(20),BSQ(25)          SOA    5
      COMMON/QW/REZ,AIMZ,REW,AIMW,    TR(62,62),TI(62,62)               SOA    6
      COMMON/A/      F1V,SL(20,30), TEST,       SIGP(20,30),XZETA(20,30), SOA    7
     XSA(20,30),SF(20,30),SS(20,30),DEN(20,30),G(300),GN(300),GF(300),  SOA    8
     X     GR(300),EK(300),XRES(300),SIGZ(300),GAMMA(300),SIGIN(300),   SOA    9
     X                   SIGMIN(300),      SIG(30),                     SOA   10
     X     SIGA22(20),SIGF22(20),       XN,XC,ETOT,TOT3,WORK(60),P(30)  SOA   11
      COMMON/B/                UIGP,                        CR(30),RAD(35),SOA   12
     X     RATIO(30),DIFX(30),            SPP(30),SPN(30),               SOA   13
     X     AREA(35),          FLUX(30,100),FLUXCP(30,100),SCAT(40000),  SOA   14
     XTAB(662),TOT,TT(60,5),                        AF(30,5),FF(30,5),   SOA   15
     X V11,V12,V13,SSF(30,5),USTR(25),DUSTR(25)                         SOA   16
      COMMON/C/                                                         SOA   17
     X     XAREAT,AREAT,RMAX(30),                                       SOA   18
     X     ENGP(1001),RIAC(20,30),RIFC(20,30),RISC(20,30),TEMP(30),     SOA   19
     X                       XTEMP(30),        PHICT(30),PHI(30),PFLUX(30),SOA   20
     XSIGTR(30),BARMU(30),    AMU(20),SIGPOT(20),AREAC(30),XAREAC(30),  SOA   21
     XGX2(10),GW2(10),WW2(10),                                          SOA   22
     X    DR(30),XAREA(30),PHIRT(30),        GX3(10),GX4(10),GW3(10),   SOA   23
     X     GW4(10),WW3(10),WW4(10),V1,V2,V3,V4,V5,V6,V7,V8,V9,V10       SOA   24
      COMMON/D/KI,KRES,NTEMP,INCLUD(300),                               SOA   25
     X     NEXT(20),LAST(20),NRES(20),INDEX, KS,                        SOA   26
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     X  NU,NOPT,ISYM(30),III,KFOIL,KREG,KMAT,KCOMP,KGP,KBG,NPRINT,MORE,  SOA   27
     X  IBGP,IFGP,IBG,JBG,NIB(25),NINT(30),MINT(30),LREG(35),NX(30),     SOA   28
     X     NFI(25),TITLE(18),KB     ,MULT(20,25),JNU(20),JMULT(20),      SOA   29
     X  INUI(20,25),INUF(20,25),NOX,NISO,KBSQ                            SOA   30
      DIMENSION DS(30),SI(30),SOR(30)                                    SOA   31
      REAL*8 NUCLID                                                      SOA   32
      REAL*8 DS,SI,SOUR,PL,Q,Z,XS,U,XNFI,SOR                             SOA   33
      REAL*8 UFGP,V,EXDU,UMAX,DS1,DSMAX,SOURCE,SDD,ACS,FCS,SCS,PHITOT,   SOA   34
     X  PHIT,ACSGP,FCSGP,SCSGP,RAP,SIGABG,SIGFBG,SIGSBG,P1,PS,ALP,DSL   SOA   35
      REAL*8 DPS                                                         SOA   36
      XNFI=1.0D0/NFI(IBG)                                                SOA   37
      UFGP=UIGP*XNFI                                                     SOA   38
      EXDU=1.0D0-V(IBG)                                                  SOA   39
      IF(IBGP-1)5,5,35                                                   SOA   40
    5 IF(IFGP-1)10,10,35                                                 SOA   41
   10 U=UFGP                                                             SOA   42
      NOX1=NOX+1                                                         SOA   43
      NXN=NOX*NISO                                                       SOA   44
      SDD=0.0D0                                                          SOA   45
      RAP=0.0D0                                                          SOA   46
      DO 25 I=1,KMAT                                                     SOA   47
      Z=1.0D0/(1.0D0-DEXP(-UMAX(I,IBG)))                                 SOA   48
      DO 25 J=1,III                                                      SOA   49
      IF(I-KRES)20,20,15                                                 SOA   50
   15 SA(I,J)=DEN(I,J)*SIGA22(I)                                         SOA   51
      SF(I,J)=DEN(I,J)*SIGF22(I)                                         SOA   52
   20 SIGP(I,J)=DEN(I,J)*SIGPOT(I)                                       SOA   53
      IF(J-KCOMP)24,24,25                                                SOA   54
   24 SDD=SDD+SIGP(I,J)*AREAC(J)*(1.0D0-(Z-1.0D0)*UMAX(I,IBG))           SOA   55
   25 CONTINUE                                                           SOA   56
      DO 31 I=1,KREG                                                     SOA   57
      SI(I)=0.0D+00                                                      SOA   58
      DS(I)=0.0D+00                                                      SOA   59
      SOR(I)=0.0D0                                                       SOA   60
      K=LREG(I)                                                          SOA   61
      DO 30 J=1,KMAT                                                     SOA   62
      SCL(J,I)=SIGP(J,K)*AREA(I)                                         SOA   63
   30 SI(I)=SI(I)+SIGP(J,K)*AREA(I)                                      SOA   64
   31 SOURCE(I)=SI(I)                                                    SOA   65
      INDEX=1                                                            SOA   66
      CALL XSECT(IERR)                                                   SOA   67
      GO TO 100                                                          SOA   68
   35 IF(JBG-2)40,36,36                                                  SOA   69
   36 INDEX=4                                                            SOA   70
      GO TO 60                                                           SOA   71
   40 IF(IFGP-2)45,41,36                                                 SOA   72
   41 INDEX=2                                                            SOA   73
      GO TO 55                                                           SOA   74
   45 IF(IBG-2)46,47,47                                                  SOA   75
   46 INDEX=1                                                            SOA   76
      GO TO 55                                                           SOA   77
   47 INDEX=3                                                            SOA   78
   55 XS=-V(IBG)                                                         SOA   79
      L=IBG                                                              SOA   80
   60 CALL XSECT(IERR)                                                   SOA   81
      JI=0                                                               SOA   82
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      DO 95 I=1,KREG                                                    SOA   83
      K=LKEG(I)                                                         SOA   84
      SOUR=(SI(I)+DS(I))*XS                                             SOA   85
      DO 98 J=1,KMAT                                                    SOA   86
      IF(DEN(J,K))61,98,61                                              SOA   87
   61 SOUR=SOUR+PHI(I)*(SL(J,K)*DS1(J))                                 SOA   88
     X   -SCL(J,I)*DSMAX(J)                                             SOA   89
      JI=JI+1                                                           SOA   90
      Q=U-UMAX(J,IBG)-0.5D0*UFGP                                        SOA   91
      N=1                                                               SOA   92
      UU=DUSTR(1)                                                       SOA   93
      IF(Q-1.0D-8)90,90,64                                              SOA   94
   64 Q=Q-1.0D-8                                                        SOA   95
   66 IF(Q-UU)70,70,67                                                  SOA   96
   67 N=N+1                                                             SOA   97
      UU=UU+DUSTR(N)                                                    SOA   98
      GO TO 66                                                          SOA   99
   70 PL=-.5+INUI(J,N)+(Q-USTR(N))*NFI(N)/(UIGP*MULT(J,N))              SOA  100
      LM=PL+.5                                                          SOA  101
      MM=(LM-1)/NOX1                                                    SOA  102
      M=NISO*(LM-NOX1*MM-1)                                             SOA  103
      PL=PL-LM                                                          SOA  104
      ML=M-NISO                                                         SOA  105
      IF(ML)200,201,201                                                 SOA  106
  200 ML=NXN                                                            SOA  107
  201 MH=M+NISO                                                         SOA  108
      IF(MH-NXN)203,203,202                                             SOA  109
  202 MH=0                                                              SOA  110
  203 XL=SCAT(JI+ML)                                                    SOA  111
      XO=SCAT(JI+M )                                                    SOA  112
      XH=SCAT(JI+MH)                                                    SOA  113
      IF(LM-INUI(J,N)-1)261,230,230                                     SOA  114
C      THIS IS SPECIAL CASE AT START OF A BROAD GROUP                   SOA  115
  261 IF(INUF(J,N)-LM)221,210,221                                       SOA  116
C      THIS IS NOT INTERPOLATION AT ALL                                 SOA  117
  210 VVV=XO                                                            SOA  118
      GO TO 75                                                          SOA  119
C        2-POINT INTERPOLATION ON 2 HIGH POINTS                         SOA  120
  221 VVV=(1.-PL)*XO + PL*XH                                            SOA  121
      GO TO 75                                                          SOA  122
  230 IF(INUF(J,N)-LM)241,232,241                                       SOA  123
C      USE 2 LOW POINTS                                                 SOA  124
  232 PL=PL+1.                                                          SOA  125
      VVV=(1.-PL)*XL+PL*XO                                              SOA  126
      GO TO 75                                                          SOA  127
C      NORMAL 3-POINT INTERPOLATION                                     SOA  128
  241 VVV=0.5*PL*(PL-1.)*XL + (1.-PL*PL)*XO +0.5*PL*(1.+PL)*XH          SOA  129
   75 SOUR=SOUR-VVV*DSL(J)                                              SOA  130
      SCL(J,I)=VVV                                                      SOA  131
      GO TO 98                                                          SOA  132
   90 SOUR=SOUR-DSL(J)*SCL(J,I)                                         SOA  133
   98 CONTINUE                                                          SOA  134
      SOURCE(I)=SI(I)+DS(I)+SOUR                                        SOA  135
      SOR(I)=SOUR                                                       SOA  136
   95 CONTINUE                                                          SOA  137
      DO 96 I=1,KREG                                                    SOA  138
```

```
      IF(SOURCE(I))97,96,96                                             SOA  139
   97 E=ENGP(1)*DEXP(-U)                                                SOA  140
      PRINT 102,I,SOURCE(I),E                                           SOA  141
  102 FORMAT(8H SOURCE(,I2,2H)=,E15.8,2X,22HRESET TO 1 DOWNSCATTER,2X,  SOA  142
     X  2HE=,E13.5)                                                     SOA  143
      SOURCE(I)=0.                                                      SOA  144
      K=LREG(I)                                                         SOA  145
      DO 961 J=1,KMAT                                                   SOA  146
      IF(DEN(J,K))962,961,962                                           SOA  147
  962 SOURCE(I)=DS1(J)*PHI(I)*SL(J,K)        +SOURCE(I)                 SOA  148
  961 CONTINUE                                                          SOA  149
      DS(I)=SOURCE(I)-SI(I)                                             SOA  150
   96 CONTINUE                                                          SOA  151
  100  U=U+UFGP                                                         SOA  152
      RETURN                                                            SOA  153
      END                                                               SOA  154
      SUBROUTINE YZ3                                                    YZ3    1
      COMMON/E/NUCLID(20),UFGP,V(25),EXDU,UMAX(20,25),P1(20,25),        YZ3    2
     X      PS(20,25),SOURCE(30),SDD,ACS,FCS,SCS,PHITOT,PHIT,ACSGP,FCSGP,YZ3    3
     X SCSGP,RAP,SIGABG(20,30),SIGFBG(20,30),SIGSBG(20,30),DS1(20),     YZ3    4
     X DSMAX(20),ALP(20,25),SCL(20,30),DSL(20),DPS(20),BSQ(25)          YZ3    5
      COMMON/QW/REZ,AIMZ,REW,AIMW,    TR(62,62),TI(62,62)               YZ3    6
      COMMON/A/      F1V,SL(20,30), TEST,       SIGP(20,30),XZETA(20,30), YZ3    7
     XSA(20,30),SF(20,30),SS(20,30),DEN(20,30),G(300),GN(300),GF(300),  YZ3    8
     X    GR(300),ER(300),XRES(300),SIGZ(300),GAMMA(300),SIGIN(300),    YZ3    9
     X                  SIGMIN(300),      SIG(30),                      YZ3   10
     X    SIGA22(20),SIGF22(20),       XN,XC,ETOT,TOT3,WORK(60),P(30)   YZ3   11
      COMMON/B/              UIGP,                        CR(30),RAD(35),YZ3   12
     X    RATIO(30),DIFX(30),            SPP(30),SPN(30),                YZ3   13
     X    AREA(35),          FLUX(30,100),FLUXCP(30,100),SCAT(40000),    YZ3   14
     XTAB(662),TOT,TT(60,5),                        AF(30,5),FF(30,5),   YZ3   15
     X V11,V12,V13,SSF(30,5),USTR(25),DUSTR(25)                         YZ3   16
      COMMON/C/                                                         YZ3   17
     X    XAREAT,AREAT,RMAX(30),                                        YZ3   18
     X    ENGP(1001),RIAC(20,30),RIFC(20,30),RISC(20,30),TEMP(30),      YZ3   19
     X                     XTEMP(30),         PHICT(30),PHI(30),PFLUX(30),YZ3   20
     XSIGTR(30),BARMU(30),   AMU(20),SIGPOT(20),AREAC(30),XAREAC(30),   YZ3   21
     XGX2(10),GW2(10),WW2(10),                                          YZ3   22
     X   DR(30),XAREA(30),PHIRT(30),        GX3(10),GX4(10),GW3(10),    YZ3   23
     X    GW4(10),WW3(10),WW4(10),V1,V2,V3,V4,V5,V6,V7,V8,V9,V10        YZ3   24
      COMMON/D/KI,KRES,NTEMP,INCLUD(300),                               YZ3   25
     X    NEXT(20),LAST(20),NRES(20),INDEX, KS,                         YZ3   26
     X  NU,NOPT,ISYM(30),III,KFOIL,KREG,KMAT,KCOMP,KGP,KBG,NPRINT,MORE, YZ3   27
     X  IBGP,IFGP,IBG,JBG,NIB(25),NINT(30),MINT(30),LREG(35),NX(30),    YZ3   28
     X    NFI(25),TITLE(18),KB     ,MULT(20,25),JNU(20),JMULT(20),      YZ3   29
     X  INUI(20,25),INUF(20,25),NOX,NISO,KBSQ                           YZ3   30
      REAL*8 NUCLID                                                     YZ3   31
      REAL*8 UFGP,V,EXDU,UMAX,DS1,DSMAX,SOURCE,SDD,ACS,FCS,SCS,PHITOT,  YZ3   32
     X  PHIT,ACSGP,FCSGP,SCSGP,RAP,SIGABG,SIGFBG,SIGSBG,P1,PS,ALP,DSL   YZ3   33
      REAL*8 DPS                                                        YZ3   34
      REAL*8 B,PFZ,PFUNC,C                                              YZ3   35
      EQUIVALENCE (V3,   Y),(V4, DEL)                                   YZ3   36
      V9=0.                                                             YZ3   37
      A=Y                                                               YZ3   38
      IF(DEL-.01)18,18,15                                               YZ3   39
   18 IF(DEL-.0001)40,50,50                                             YZ3   40
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```
40 DEL2=0.                                                              YZ3   41
   DIF=0.                                                               YZ3   42
41 IF(A-.6)42,11,11                                                     YZ3   43
42 DIF=DIF+E2(A)*DEL                                                    YZ3   44
   A=A+TOT                                                              YZ3   45
   GO TO 41                                                             YZ3   46
50 DEL2=.0416666667*DEL*DEL                                             YZ3   47
   DIF=0.                                                               YZ3   48
   B=A+DEL                                                              YZ3   49
19 IF(B-.6)10,11,11                                                     YZ3   50
10 PFZ=PFUNC(B)                                                         YZ3   51
   C=A                                                                  YZ3   52
   DIF=DIF+C*(PFZ-PFUNC(C))+DEL*PFZ                                     YZ3   53
   A=A+TOT                                                              YZ3   54
   B=A+DEL                                                              YZ3   55
   GO TO 19                                                             YZ3   56
11 Q= A+0.5*DEL                                                         YZ3   57
   DO 12 I=1,4                                                          YZ3   58
   U=GX2(I)*GX2(I)*DEL2                                                 YZ3   59
   V9=V9+WW2(I)*(1.+U*(1.+.0125*U))* EXP(Q*GX2(I))                      YZ3   60
12 CONTINUE                                                             YZ3   61
   V9=V9*DEL +DIF                                                       YZ3   62
   RETURN                                                               YZ3   63
15 Z=Y+DEL                                                              YZ3   64
   IF(TOT-.2)30,30,31                                                   YZ3   65
30 V9=EZ3(Y,TOT)-EZ3(Z,TOT)                                             YZ3   66
   RETURN                                                               YZ3   67
31 IF(Y-.3)7,8,8                                                        YZ3   68
 8 IF(Y-3.16)20,20,21                                                   YZ3   69
20 M=0.633*(7.89-Y)                                                     YZ3   70
   GO TO 22                                                             YZ3   71
21 M=1.+6.2/Y                                                           YZ3   72
   GO TO 22                                                             YZ3   73
 7 V9 =XC* EXP(-18.2*Y)                                                 YZ3   74
   M=4                                                                  YZ3   75
   IF(Z-.3)9,22,22                                                      YZ3   76
 9 V9 =V9 -XC* EXP(-18.2*Z)                                             YZ3   77
22 DO 1 I=1,M                                                           YZ3   78
   V9 =V9 +WW3(I)*( EXP( Y*GX3(I)) -  EXP( Z*GX3(I)))                   YZ3   79
 1 CONTINUE                                                             YZ3   80
 2 RETURN                                                               YZ3   81
   END                                                                  YZ3   82
   SUBROUTINE YZ4                                                       YZ4    1
   COMMON/E/NUCLID(20),UFGP,V(25),EXDU,UMAX(20,25),P1(20,25),           YZ4    2
  X      PS(20,25),SOURCE(30),SDD,ACS,FCS,SCS,PHITOT,PHIT,ACSGP,FCSGP,YZ4    3
  X SCSGP,RAP,SIGABG(20,30),SIGFBG(20,30),SIGSBG(20,30),DS1(20),        YZ4    4
  X DSMAX(20),ALP(20,25),SCL(20,30),DSL(20),DPS(20),BSQ(25)             YZ4    5
   COMMON/QW/REZ,AIMZ,REW,AIMW,    TR(62,62),TI(62,62)                  YZ4    6
   COMMON/A/      F1V,SL(20,30), TEST,       SIGP(20,30),XZETA(20,30), YZ4    7
  XSA(20,30),SF(20,30),SS(20,30),DEN(20,30),G(300),GN(300),GF(300),     YZ4    8
  X     GR(300),ER(300),XRES(300),SIGZ(300),GAMMA(300),SIGIN(300),      YZ4    9
  X                  SIGMIN(300),      SIG(30),                         YZ4   10
  X     SIGA22(20),SIGF22(20),       XN,XC,ETCT,TOT3,WORK(60),P(30)     YZ4   11
   COMMON/B/                UIGP,                        CR(30),RAD(35),YZ4   12
  X     RATIO(30),DIFX(30),              SPP(30),SPN(30),                YZ4   13
  X     AREA(35),          FLUX(30,100),FLUXCP(30,100),SCAT(40000),     YZ4   14
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      XTAB(662),TOT,TT(60,5),                          AF(30,5),FF(30,5),     YZ4    15
      X V11,V12,V13,SSF(30,5),USTR(25),DUSTR(25)                              YZ4    16
       COMMON/C/                                                              YZ4    17
      X     XAREAT,AREAT,RMAX(30),                                            YZ4    18
      X     ENGP(1001),RIAC(20,30),RIFC(20,30),RISC(20,30),TEMP(30),          YZ4    19
      X                     XTEMP(30),         PHICT(30),PHI(30),PFLUX(30),YZ4    20
      XSIGTR(30),BARMU(30),    AMU(20),SIGPUT(20),AREAC(30),XAREAC(30),       YZ4    21
      XGX2(10),GW2(10),WW2(10),                                               YZ4    22
      X   DR(30),XAREA(30),PHIRT(30),          GX3(10),GX4(10),GW3(10),       YZ4    23
      X     GW4(10),WW3(10),WW4(10),V1,V2,V3,V4,V5,V6,V7,V8,V9,V10            YZ4    24
       COMMON/D/KI,KRES,NTEMP,INCLUD(300),                                    YZ4    25
      X     NEXT(20),LAST(20),NRES(20),INDEX, KS,                             YZ4    26
      X  NU,NOPT,ISYM(30),III,KFOIL,KREG,KMAT,KCOMP,KGP,KBG,NPRINT,MORE,      YZ4    27
      X  IBGP,IFGP,IBG,JBG,NIB(25),NINT(30),MINT(30),LREG(35),NX(30),         YZ4    28
      X     NFI(25),TITLE(18),KB     ,MULT(20,25),JNU(20),JMULT(20),          YZ4    29
      X  INUI(20,25),INUF(20,25),NOX,NISO,KBSQ                                YZ4    30
       REAL*8 NUCLID                                                          YZ4    31
       REAL*8 UFGP,V,EXDU,UMAX,DS1,DSMAX,SOURCE,SDD,ACS,FCS,SCS,PHITOT,       YZ4    32
      X  PHIT,ACSGP,FCSGP,SCSGP,RAP,SIGABG,SIGFBG,SIGSBG,P1,PS,ALP,DSL       YZ4    33
       REAL*8 DPS                                                             YZ4    34
       EQUIVALENCE (V3,   Y),(V4, DEL)                                        YZ4    35
       V10=0.                                                                 YZ4    36
       IF(DEL-.01)11,11,15                                                    YZ4    37
   11  Q=Y+0.5*DEL                                                            YZ4    38
       DEL2=.0416666667*DEL*DEL                                               YZ4    39
       DO 12 I=1,4                                                            YZ4    40
       W=GX3(I)*GX3(I)*DEL2                                                   YZ4    41
       V10=V10+WW3(I)*(1.+W*(1.+.0125*W))* EXP(Q*GX3(I))                      YZ4    42
   12  CONTINUE                                                               YZ4    43
       IF(Q-.3)13,14,14                                                       YZ4    44
   13  V10=V10+XC* EXP(-18.2*Q)                                               YZ4    45
   14  V10=V10*DEL                                                            YZ4    46
       RETURN                                                                 YZ4    47
   15  Z=Y+DEL                                                                YZ4    48
       IF(TOT-.3)3,3,4                                                        YZ4    49
    3   V10=EZ4(Y,TOT)-EZ4(Z,TOT)                                             YZ4    50
       RETURN                                                                 YZ4    51
    4  IF(Y-3.64)20,20,21                                                     YZ4    52
   20  M=0.549*(9.10-Y)                                                       YZ4    53
       GO TO 22                                                               YZ4    54
   21  M=1.+6.81/Y                                                            YZ4    55
   22  DO 1 I=1,M                                                             YZ4    56
       V10=V10+WW4(I)*( EXP( Y*GX4(I)) -  EXP( Z*GX4(I)))                     YZ4    57
    1  CONTINUE                                                               YZ4    58
    2  RETURN                                                                 YZ4    59
       END                                                                    YZ4    60
       SUBROUTINE XSECT(IERR)                                                 XSE     1
       COMMON/E/NUCLID(20),UFGP,V(25),EXDU,UMAX(20,25),P1(20,25),             XSE     2
      X     PS(20,25),SOURCE(30),SDD,ACS,FCS,SCS,PHITOT,PHIT,ACSGP,FCSGP,XSE     3
      X SCSGP,RAP,SIGABG(20,30),SIGFBG(20,30),SIGSBG(20,30),DS1(20),          XSE     4
      X DSMAX(20),ALP(20,25),SCL(20,30),DSL(20),DPS(20),BSQ(25)               XSE     5
       COMMON/QW/REZ,AIMZ,REW,AIMW,    TR(62,62),TI(62,62)                    XSE     6
       COMMON/A/     F1V,SL(20,30), TEST,       SIGP(20,30),XZETA(20,30),    XSE     7
      XSA(20,30),SF(20,30),SS(20,30),DEN(20,30),G(300),GN(300),GF(300),       XSE     8
      X     GR(300),ER(300),XRES(300),SIGZ(300),GAMMA(300),SIGIN(300),        XSE     9
      X                    SIGMIN(300),     SIG(30),                          XSE    10
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     X     SIGA22(20),SIGF22(20),        XN,XC,ETOT,TOT3,WORK(60),P(30)
      COMMON/B/                UIGP,                          CR(30),RAD(35),
     X     RATIO(30),DIFX(30),              SPP(30),SPN(30),
     X     AREA(35),          FLUX(30,100),FLUXCP(30,100),SCAT(40000),
     XTAB(662),TOT,TT(60,5),                          AF(30,5),FF(30,5),
     X V11,V12,V13,SSF(30,5),USTR(25),DUSTR(25)
      COMMON/C/
     X     XAREAT,AREAT,RMAX(30),
     X     ENGP(1001),RIAC(20,30),RIFC(20,30),RISC(20,30),TEMP(30),
     X                      XTEMP(30),          PHICT(30),PHI(30),PFLUX(30),
     XSIGTR(30),BARMU(30),    AMU(20),SIGPOT(20),AREAC(30),XAREAC(30),
     XGX2(10),GW2(10),WW2(10),
     X    DR(30),XAREA(30),PHIRT(30),          GX3(10),GX4(10),GW3(10),
     X     GW4(10),WW3(10),WW4(10),V1,V2,V3,V4,V5,V6,V7,V8,V9,V10
      COMMON/D/KI,KRES,NTEMP,INCLUD(300),
     X     NEXT(20),LAST(20),NRES(20),INDEX, KS,
     X  NU,NOPT,ISYM(30),III,KFOIL,KREG,KMAT,KCOMP,KGP,KBG,NPRINT,MORE,
     X  IBGP,IFGP,IBG,JBG,NIB(25),NINT(30),MINT(30),LREG(35),NX(30),
     X     NFI(25),TITLE(18),KB     ,MULT(20,25),JNU(20),JMULT(20),
     X  INUI(20,25),INUF(20,25),NOX,NISO,KBSQ
      REAL*8 UFGP,V,EXDU,UMAX,DS1,DSMAX,SOURCE,SDD,ACS,FCS,SCS,PHITOT,
     X  PHIT,ACSGP,FCSGP,SCSGP,RAP,SIGABG,SIGFBG,SIGSBG,P1,PS,ALP
      REAL*8          DSL,DPS,E
      REAL*8 NUCLID
      GO TO (3,10,6,20),INDEX
    3 E=0.5*ENGP(1)*(1.0+EXDU)
      Z=0.5*V(IBG)
      DO 4 J=1,III
      DO 4 I=1,KMAT
      SA(I,J)=SA(I,J)*F1V
    4 SF(I,J)=SF(I,J)*F1V
      GO TO 15
    6 E=.5*E*(EXDU+1.-V(IBG-1))
      Z=0.5*(V(IBG)+V(IBG-1))
      GO TO 15
   10 E=E*EXDU
      Z=V(IBG)
   15 FDEL=1.+.5*Z*(1.+.75*Z*(1.+5.*Z/6.))
      GO TO 25
   20 E=E*EXDU
   25 XYZ=1.77246
      IF(NOPT-4)70,71,71
   71 XYZ=0.
   70 DO 40 I=1,KRES
C      NOPT GREATER 3 IMPLIES NO INTERFERENCE TERM  CHI
      DO 40 J=1,NTEMP
      XZETA(I,J)=XZETA(I,J)*FDEL
      SA(I,J)=SIGA22(I)
      SF(I,J)=SIGF22(I)
      SS(I,J)=0.
      N=NEXT(I)
      L=LAST(I)
      DO 40 K=N,L
      IF(J-1)30,30,35
   30 XRES(K)=XRES(K)*FDEL
   35 IF(INCLUD (K)-IBGP)40,36,40
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```
   36 X=2.*(E-ER(K))/GAMMA(K)                                           XSE   67
      ZETA=GAMMA(K)*XZETA(I,J)                                          XSE   68
      AIMZ=.5*ZETA                                                      XSE   69
      REZ=X*AIMZ                                                        XSE   70
      CALL QUICKW                                                       XSE   71
      PSI=.88623*ZETA*REW                                               XSE   72
      CHI=XYZ*ZETA*AIMW                                                 XSE   73
C                                                                       XSE   74
      IF (G(K).LT.0.0) GO TO 39                                         XSE   75
C                                                                       XSE   76
      F=PSI*SIGZ(K)                                                     XSE   77
      SA(I,J)=SA(I,J)+F*XRES(K)*(GF(K)+GR(K))                           XSE   78
      SF(I,J)=SF(I,J)+F*XRES(K)*GF(K)                                   XSE   79
      SS(I,J)=SS(I,J)+F*GN(K)+CHI*SIGIN(K)                              XSE   80
      GO TO 40                                                          XSE   81
C                                                                       XSE   82
   39 CONTINUE                                                          XSE   83
      F1 = PSI + (GAMMA(K) * CHI/ (4.0 * ER(K)))                        XSE   84
      GO2 = GAMMA(K)/ (2.0 * ER(K))                                     XSE   85
      F2 = PSI + GO2 * (CHI + GO2 * (1.0-PSI))                          XSE   86
      SA(I,J)= SA(I,J) + F1 * XRES(K) * SIGZ(K) * (GR(K)+GF(K))/GAMMA(K)XSE   87
      SF(I,J) = SF(I,J) + F1 * XRES(K) * SIGZ(K) * GF(K)/GAMMA(K)       XSE   88
      SS(I,J) = SS(I,J) + F2 * SIGZ(K) * GN(K)/GAMMA(K)                 XSE   89
C                                                                       XSE   90
   40 CONTINUE                                                          XSE   91
      DO 66 M=1,III                                                     XSE   92
      J=III+1-M                                                         XSE   93
      SIG(J)=0.                                                         XSE   94
      SIGTR(J)=0.                                                       XSE   95
      DO 66 I=1,KMAT                                                    XSE   96
      IF(I-KRES)45,45,60                                                XSE   97
   45 IF(NTEMP-1)50,50,55                                               XSE   98
   50 SA(I,J)=DEN(I,J)*SA(I,1)                                          XSE   99
      SF(I,J)=DEN(I,J)*SF(I,1)                                          XSE  100
      SS(I,J)=DEN(I,J)*SS(I,1)+SIGP(I,J)                                XSE  101
      GO TO 90                                                          XSE  102
   55 SA(I,J)=DEN(I,J)*SA(I,J)                                          XSE  103
      SF(I,J)=DEN(I,J)*SF(I,J)                                          XSE  104
      SS(I,J)=DEN(I,J)*SS(I,J)+SIGP(I,J)                                XSE  105
   90 IF(SS(I,J)-.05D0*SIGP(I,J))92,65,65                               XSE  106
C  92 WRITE (6,100) I,J,SS(I,J),E                                       XSE  107
   92 CONTINUE                                                          XSE  108
  100 FORMAT(34H SCATTERING CROSS SECTION <.05SIGP,  4H SS(,I2,1H,I2,2H)XSE  109
     1=,E12.5,7HENERGY=,E12.5)                                          XSE  110
      SS(I,J)=0.05D0*SIGP(I,J)                                          XSE  111
      GO TO 65                                                          XSE  112
   60 SA(I,J)=SA(I,J)*FDEL                                              XSE  113
      SF(I,J)=SF(I,J)*FDEL                                              XSE  114
      SS(I,J)=SIGP(I,J)                                                 XSE  115
   65 SIG(J)=SIG(J)+SA(I,J)+SS(I,J)                                     XSE  116
      X=0.                                                              XSE  117
      IF(SS(I,J).NE.0.) X=SA(I,J)/SS(I,J)                               XSE  118
      SIGTR(J)=SIGTR(J)+ (SA(I,J)+SS(I,J))*(X+1.-BARMU(I))              XSE  119
   66 CONTINUE                                                          XSE  120
      RETURN                                                            XSE  121
      END                                                               XSE  122
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      SUBROUTINE RESTES                                                 RES    1
      COMMON/E/NUCLID(20),UFGP,V(25),EXDU,UMAX(20,25),P1(20,25),        RES    2
     X     PS(20,25),SOURCE(30),SDD,ACS,FCS,SCS,PHITOT,PHIT,ACSGP,FCSGP,RES    3
     X SCSGP,RAP,SIGABG(20,30),SIGFBG(20,30),SIGSBG(20,30),DS1(20),     RES    4
     X DSMAX(20),ALP(20,25),SCL(20,30),DSL(20),DPS(20),BSQ(25)          RES    5
      COMMON/QW/REZ,AIMZ,REW,AIMW,   TR(62,62),TI(62,62)                RES    6
      COMMON/A/      FLV,SL(20,30), TEST,       SIGP(20,30),XZETA(20,30), RES    7
     XSA(20,30),SF(20,30),SS(20,30),DEN(20,30),G(300),GN(300),GF(300),  RES    8
     X    GR(300),ER(300),XRES(300),SIGZ(300),GAMMA(300),SIGIN(300),    RES    9
     X                 SIGMIN(300),      SIG(30),                       RES   10
     X    SIGA22(20),SIGF22(20),       XN,XC,ETOT,TOT3,WORK(60),P(30)   RES   11
      COMMON/B/              UIGP,                        CR(30),RAD(35),RES   12
     X    RATIO(30),DIFX(30),            SPP(30),SPN(30),                RES   13
     X    AREA(35),          FLUX(30,100),FLUXCP(30,100),SCAT(40000),   RES   14
     XTAB(662),TOT,TT(60,5),                          AF(30,5),FF(30,5), RES   15
     X V11,V12,V13,SSF(30,5),USTR(25),DUSTR(25)                         RES   16
      COMMON/C/                                                         RES   17
     X    XAREAT,AREAT,RMAX(30),                                        RES   18
     X    ENGP(1001),RIAC(20,30),KIFC(20,30),RISC(20,30),TEMP(30),      RES   19
     X                      XTEMP(30),        PHICT(30),PHI(30),PFLUX(30),RES   20
     XSIGTR(30),BARMU(30),   AMU(20),SIGPOT(20),AREAC(30),XAREAC(30),   RES   21
     XGX2(10),GW2(10),WW2(10),                                          RES   22
     X   DR(30),XAREA(30),PHIRT(30),        GX3(10),GX4(10),GW3(10),    RES   23
     X    GW4(10),WW3(10),WW4(10),V1,V2,V3,V4,V5,V6,V7,V8,V9,V10        RES   24
      COMMON/D/KI,KRES,NTEMP,INCLUD(300),                               RES   25
     X    NEXT(20),LAST(20),NRES(20),INDEX, KS,                         RES   26
     X  NU,NOPT,ISYM(30),III,KFOIL,KREG,KMAT,KCOMP,KGP,KBG,NPRINT,MORE, RES   27
     X  IBGP,IFGP,IBG,JBG,NIB(25),NINT(30),MINT(30),LREG(35),NX(30),    RES   28
     X    NFI(25),TITLE(18),KB    ,MULT(20,25),JNU(20),JMULT(20),       RES   29
     X  INUI(20,25),INUF(20,25),NOX,NISO,KBSQ                           RES   30
      REAL*8 UFGP,V,EXDU,UMAX,DS1,DSMAX,SOURCE,SDD,ACS,FCS,SCS,PHITOT,  RES   31
     X  PHIT,ACSGP,FCSGP,SCSGP,RAP,SIGABG,SIGFBG,SIGSBG,P1,PS,ALP,DSL   RES   32
      REAL*8 DPS                                                        RES   33
      REAL*8 NUCLID                                                     RES   34
      DO 50 I=1,KRES                                                    RES   35
      N=NEXT(I)                                                         RES   36
      L=LAST(I)                                                         RES   37
      DO 50 J=N,L                                                       RES   38
      IF(IBGP-2)5,15,15                                                 RES   39
    5 INCLUD (J)=0.                                                     RES   40
      X=2.*(ENGP(1)-ER(J))/GAMMA(J)                                     RES   41
      ZETA=GAMMA(J)*XZETA(I,1)                                          RES   42
      AIMZ=0.5*ZETA                                                     RES   43
      REZ=X*AIMZ                                                        RES   44
      CALL QUICKW                                                       RES   45
      PSI=0.88623*ZETA*REW                                              RES   46
      CHI=1.77246*ZETA*AIMW                                             RES   47
      IF(G(J).LT.0.0) GO TO 6                                           RES   48
C          S-WAVE                                                       RES   49
      SIGM=PSI*SIGZ(J)*(GN(J)+XRES(J)*(GF(J)+GR(J))) +CHI*SIGIN(J)      RES   50
      GO TO 7                                                           RES   51
C          P-WAVE                                                       RES   52
    6 F1=PSI+(GAMMA(J)*CHI/(4.0*ER(J)))                                 RES   53
      GO2=GAMMA(J)/(2.0*ER(J))                                          RES   54
      F2=PSI+GO2*(CHI+GO2*(1.0-PSI))                                    RES   55
      SIGM=SIGZ(J)*(F1*XRES(J)*(GR(J)+GF(J))+F2*GN(J))/GAMMA(J)         RES   56
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    7 SIGM= ABS(SIGM)                                                   RES   57
      IF(SIGM-TEST)25,10,10                                             RES   58
   10 INCLUD (J)=IBGP                                                   RES   59
      GO TO 25                                                          RES   60
   15 IF(SIGMIN(J)-TEST)25,20,20                                        RES   61
   20 INCLUD (J)=IBGP                                                   RES   62
   25 K=IBGP+1                                                          RES   63
      X=2.0*(ENGP(K)-ER(J))/GAMMA(J)                                    RES   64
      AIMZ=.5*GAMMA(J)* SQRT(AMU(I)/(3.46668E-04*ENGP(K)*TEMP(1)))      RES   65
      REZ=X*AIMZ                                                        RES   66
      CALL QUICKW                                                       RES   67
      Z=1.77246*AIMZ*REW                                                RES   68
      Y=3.54492*AIMZ*AIMW                                               RES   69
C        Z=PSI,  Y=CHI                                                  RES   70
      W= SQRT( ABS(ER(J))/ENGP(K))                                      RES   71
      IF(G(J).LT.0.0) GO TO 26                                          RES   72
C          S-WAVE                                                       RES   73
      SIGMIN(J)=SIGZ(J)*Z*(GN(J)+W*(GF(J)+GR(J))) + Y*SIGIN(J)          RES   74
      GO TO 27                                                          RES   75
C         P-WAVE                                                        RES   76
   26 F1=Z+ GAMMA(J)*Y/(4.0*ER(J))                                      RES   77
      GO2=GAMMA(J)/(2.0*ER(J))                                          RES   78
      F2=Z+GO2*(Y+GO2*(1.0-Z))                                          RES   79
      SIGMIN(J)=SIGZ(J)*(F1*W*(GR(J)+GF(J)) + F2*GN(J))/GAMMA(J)        RES   80
   27 SIGMIN(J)= ABS(SIGMIN(J))                                         RES   81
      IF(SIGMIN(J)-TEST)35,30,30                                        RES   82
   30 INCLUD(J)=IBGP                                                    RES   83
      GO TO 50                                                          RES   84
   35 IF(ENGP(IBGP)-ER(J))50,40,40                                      RES   85
   40 IF(ENGP(K)-ER(J))45,45,50                                         RES   86
   45 INCLUD (J)=IBGP                                                   RES   87
   50 CONTINUE                                                          RES   88
      RETURN                                                            RES   89
      END                                                               RES   90
      SUBROUTINE OUTPUT                                                 OUT    1
      COMMON/E/NUCLID(20),UFGP,V(25),EXDU,UMAX(20,25),P1(20,25),        OUT    2
     X     PS(20,25),SOURCE(30),SDD,ACS,FCS,SCS,PHITOT,PHIT,ACSGP,FCSGP,OUT    3
     X SCSGP,KAP,SIGABG(20,30),SIGFBG(20,30),SIGSBG(20,30),DS1(20),     OUT    4
     X DSMAX(20),ALP(20,25),SCL(20,30),DSL(20),DPS(20),BSQ(25)          OUT    5
      COMMON/QW/REZ,AIMZ,REW,AIMW,   TR(62,62),TI(62,62)                OUT    6
      COMMON/A/     F1V,SL(20,30), TEST,       SIGP(20,30),XZETA(20,30), OUT    7
     XSA(20,30),SF(20,30),SS(20,30),DEN(20,30),G(300),GN(300),GF(300),  OUT    8
     X    GR(300),ER(300),XRES(300),SIGZ(300),GAMMA(300),SIGIN(300),    OUT    9
     X                  SIGMIN(300),      SIG(30),                      OUT   10
     X    SIGA22(20),SIGF22(20),       XN,XC,ETOT,TOT3,WORK(60),P(30)   OUT   11
      COMMON/B/              UIGP,                        CR(30),RAD(35),OUT   12
     X    RATIO(30),DIFX(30),            SPP(30),SPN(30),                OUT   13
     X    AREA(35),          FLUX(30,100),FLUXCP(30,100),SCAT(40000),    OUT   14
     XTAB(662),TOT,TT(60,5),                        AF(30,5),FF(30,5),   OUT   15
     X V11,V12,V13,SSF(30,5),USTR(25),DUSTR(25)                         OUT   16
      COMMON/C/                                                         OUT   17
     X    XAREAT,AREAT,RMAX(30),                                        OUT   18
     X    ENGP(1001),RIAC(20,30),RIFC(20,30),RISC(20,30),TEMP(30),      OUT   19
     X                     XTEMP(30),         PHICT(30),PHI(30),PFLUX(30),OUT   20
     XSIGTR(30),BARMU(30),    AMU(20),SIGPOT(20),AREAC(30),XAREAC(30),  OUT   21
     XGX2(10),GW2(10),WW2(10),                                          OUT   22
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     X   DR(30),XAREA(30),PHIRT(30),          GX3(10),GX4(10),GW3(10),     OUT    23
     X     GW4(10),WW3(10),WW4(10),V1,V2,V3,V4,V5,V6,V7,V8,V9,V10          OUT    24
      COMMON/D/KI,KRES,NTEMP,INCLUD(300),                                  OUT    25
     X     NEXT(20),LAST(20),NRES(20),INDEX, KS,                           OUT    26
     X   NU,NOPT,ISYM(30),III,KFOIL,KREG,KMAT,KCOMP,KGP,KBG,NPRINT,MORE,   OUT    27
     X   IBGP,IFGP,IBG,JBG,NIB(25),NINT(30),MINT(30),LREG(35),NX(30),      OUT    28
     X     NFI(25),TITLE(18),KB     ,MULT(20,25),JNU(20),JMULT(20),        OUT    29
     X   INUI(20,25),INUF(20,25),NOX,NISO,KBSQ                             OUT    30
      REAL*8 NUCLID                                                        OUT    31
      REAL*8 UFGP,V,EXDU,UMAX,DS1,DSMAX,SOURCE,SDD,ACS,FCS,SCS,PHITOT,     OUT    32
     X   PHIT,ACSGP,FCSGP,SCSGP,RAP,SIGABG,SIGFBG,SIGSBG,P1,PS,ALP,DSL    OUT    33
      REAL*8 DPS                                                           OUT    34
      DIMENSION LLLL(20)                                                   OUT    35
      RAP=RAP+ACSGP*UFGP/SDD                                               OUT    36
      ZZ=1./NFI(IBG)                                                       OUT    37
      IF(IBG-2)1,65,65                                                     OUT    38
   65 IF(JBG-2)70,1,1                                                      OUT    39
   70 W=FLOAT (NFI(IBG-1))/FLOAT (NFI(IBG))                                OUT    40
      XAREAT=W*XAREAT                                                      OUT    41
      DO 75 I=1,KCOMP                                                      OUT    42
   75 XAREAC(I)=W*XAREAC(I)                                                OUT    43
      DO 80 I=1,KREG                                                       OUT    44
   80 XAREA(I)=W*XAREA(I)                                                  OUT    45
    1 JBGP=IBGP+1                                                          OUT    46
      IF (NPRINT) 2,2,10                                                   OUT    47
    2 WRITE (6,101) IBGP,ENGP(IBGP),ENGP(JBGP)                             OUT    48
  101 FORMAT(1H0,2X,5HGROUP,I4,E18.5,6H EV TO,E12.5,3H EV/)                OUT    49
      WRITE (6,110)                                                        OUT    50
      ACSGP=ACSGP/PHIT                                                     OUT    51
      FCSGP=FCSGP/PHIT                                                     OUT    52
      SCSGP=SCSGP/PHIT                                                     OUT    53
      PHIT=PHIT*XAREAT                                                     OUT    54
      WRITE (6,102) ACSGP,FCSGP,SCSGP,PHIT                                 OUT    55
  102 FORMAT(24X,4HCELL,18X,4D18.5//17X,11HCOMPOSITION,10X,8HMATERIAL)     OUT    56
      DO 5 I=1,KCOMP                                                       OUT    57
      ZZ=FLUXCP(I,NU)*XAREAC(I)                                            OUT    58
      WRITE (6,103) I,ZZ                                                   OUT    59
  103 FORMAT(26X,I2,72X,E18.5)                                             OUT    60
      DO 5 J=1,KMAT                                                        OUT    61
      ZY=0.                                                                OUT    62
      IF(DEN(J,I))16,5,16                                                  OUT    63
   16 ZY=1./(DEN(J,I)*FLUXCP(I,NU))                                        OUT    64
   17 SIGABG (J,I)=ZY*SIGABG (J,I)                                         OUT    65
      SIGFBG (J,I)=ZY*SIGFBG (J,I)                                         OUT    66
      SIGSBG (J,I)=ZY*SIGSBG (J,I)                                         OUT    67
      WRITE (6,1104) NUCLID(J),SIGABG(J,I),SIGFBG(J,I),SIGSBG(J,I)         OUT    68
    5 CONTINUE                                                             OUT    69
 1104 FORMAT(40X,A6,3D18.5)                                                OUT    70
  104 FORMAT(4H RA=,E12.5,5X,3HRF=,E12.5,4X,A6,3E18.5)                     OUT    71
   10 IF(JBG-NIB(IBG))15,20,20                                             OUT    72
   15 JBG=JBG+1                                                            OUT    73
      GO TO 60                                                             OUT    74
   20 LBGP=JBGP-NIB(IBG)                                                   OUT    75
      XNIB=NIB(IBG)                                                        OUT    76
      WRITE(6,105)(TITLE(I),I=1,18),IBG,ENGP(LBGP),ENGP(JBGP)              OUT    77
  105 FORMAT(1H1,2X,18A4///20X,23HSUMMARY FOR BROAD GROUP,I3,        5X,   OUT    78
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   X     E12.5,6H EV TO,E12.5,3H EV//)                                    OUT   79
    WRITE (6,110)                                                         OUT   80
110 FORMAT(21X,7HAVERAGE,29X,7HSIGMA A,11X,7HSIGMA F,11X,7HSIGMA S,       OUT   81
   X14X,4HFLUX/)                                                          OUT   82
    ACS=ACS/PHITOT                                                        OUT   83
    FCS=FCS/PHITOT                                                        OUT   84
    SCS=SCS/PHITOT                                                        OUT   85
    PHITOT=PHITOT*XAREAT/XNIB                                             OUT   86
    WRITE (6,102) ACS,FCS,SCS,PHITOT                                      OUT   87
    DO 25 I=1,KCOMP                                                       OUT   88
    ZZ=PHICT(I)*XAREAC(I)/XNIB                                            OUT   89
    WRITE (6,103) I,ZZ                                                    OUT   90
    DO 25 J=1,KMAT                                                        OUT   91
    ZY=0.                                                                 OUT   92
    IF(DEN(J,I))27,25,27                                                  OUT   93
 27 ZY=1./(DEN(J,I)*PHICT(I))                                             OUT   94
 28 RIAC(J,I)=ZY*RIAC(J,I)                                                OUT   95
    RIFC(J,I)=ZY*RIFC(J,I)                                                OUT   96
    RISC(J,I)=ZY*RISC(J,I)                                                OUT   97
    RA=RIAC(J,I)*ZZ*UIGP*NIB(IBG)                                         OUT   98
    RF=RIFC(J,I)*ZZ*UIGP*NIB(IBG)                                         OUT   99
    WRITE (6,104) RA,RF,NUCLID(J),RIAC(J,I),RIFC(J,I),RISC(J,I)           OUT  100
 25 CONTINUE                                                              OUT  101
    WRITE (6,111) RAP                                                     OUT  102
111 FORMAT(////10X,35HCUMULATIVE ABSORPTION PROBABILITY =,D13.6)          OUT  103
    MIN=1                                                                 OUT  104
    MNO=KREG                                                              OUT  105
 26 MAX=MINO (MNO,16) + MIN-1                                             OUT  106
    WRITE (6,106) IBG,(NX(I),I=MIN,MAX)                                   OUT  107
106 FORMAT(1H1,//20X,50HREGIONAL INTERMEDIATE GROUP FLUXES FOR BROAD GOUT  108
   XROUP,I4,       //9X,5HLOWER,/,16X,16I6)                              OUT  109
    WRITE (6,107) (LREG(I),I=MIN,MAX)                                     OUT  110
107 FORMAT(3X,10HENERGY(EV),/,16X,16I6)                                   OUT  111
    DO 35 I=LBGP,IBGP                                                     OUT  112
    MM=I+1                                                                OUT  113
    M=(I-1)/100                                                           OUT  114
    N=I-100*M                                                             OUT  115
    DO 30 J=MIN,MAX                                                       OUT  116
 30 LLLL(J)=XAREA(J)*FLUX(J,N)*10000.+ 0.5                                OUT  117
 35 WRITE (6,108) I,ENGP(MM),(LLLL(J),J=MIN,MAX)                          OUT  118
108 FORMAT(1H ,I4,E12.5,16I6)                                             OUT  119
    DO 40 I=MIN,MAX                                                       OUT  120
 40 LLLL(I)=10000.*XAREA(I)*PHIRT(I)/XNIB+0.5                             OUT  121
    WRITE (6,109) (LLLL(I),I=MIN,MAX)                                     OUT  122
109 FORMAT(1H ,2X,7HAVERAGE,7X,16I6)                                      OUT  123
    IF(KFOIL)50,50,210                                                    OUT  124
210 ZZ=1.0/(NIB(IBG)*NFI(IBG))                                            OUT  125
    DO 42 K=1,KFOIL                                                       OUT  126
    DO 41 I=1,KREG                                                        OUT  127
    AF(I,K)=AF(I,K)*ZZ                                                    OUT  128
    SSF(I,K)=SSF(I,K)*ZZ                                                  OUT  129
 41 FF(I,K)=FF(I,K)*ZZ                                                    OUT  130
    WRITE(6,120) K,(I,AF(I,K),FF(I,K),SSF(I,K),I=1,KREG)                  OUT  131
120 FORMAT(///,5H FOIL,I3,/,                                              OUT  132
   110H INTERFACE,          11H   RA(F)   ,3X,7HRF(F)   ,4X,7HRS(F)   ,  OUT  133
   2            /(4X,I2,4X,3E12.5))                                      OUT  134
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42  CONTINUE                                                          OUT  135
50 PHITOT=0.0D0                                                       OUT  136
   ACS=0.0D0                                                          OUT  137
   FCS=0.0D0                                                          OUT  138
   SCS=0.0D0                                                          OUT  139
   DO 53 I=1,KREG                                                     OUT  140
53 PHIRT(I)=0.                                                        OUT  141
   DO 55 I=1,KCOMP                                                    OUT  142
   PHICT(I)=0.                                                        OUT  143
   DO 55 J=1,KMAT                                                     OUT  144
   RIAC(J,I)=0.                                                       OUT  145
   RIFC(J,I)=0.                                                       OUT  146
55 RISC(J,I)=0.                                                       OUT  147
   IBG=IBG+1                                                          OUT  148
   JBG=1                                                              OUT  149
   DO 56 I=1,KREG                                                     OUT  150
   DO 56 K=1,KFOIL                                                    OUT  151
   AF(I,K)=0.                                                         OUT  152
   FF(I,K)=0.                                                         OUT  153
56 CONTINUE                                                           OUT  154
60 RETURN                                                             OUT  155
   END                                                                OUT  156
   SUBROUTINE XTRAP                                                   XT     1
   COMMON/E/NUCLID(20),UFGP,V(25),EXDU,UMAX(20,25),P1(20,25),         XT     2
  X     PS(20,25),SOURCE(30),SDD,ACS,FCS,SCS,PHITOT,PHIT,ACSGP,FCSGP,XT     3
  X SCSGP,RAP,SIGABG(20,30),SIGFBG(20,30),SIGSBG(20,30),DS1(20),      XT     4
  X DSMAX(20),ALP(20,25),SCL(20,30),DSL(20),DPS(20),BSQ(25)           XT     5
   COMMON/QW/REZ,AIMZ,REW,AIMW,   TR(62,62),TI(62,62)                 XT     6
   COMMON/A/      FIV,SL(20,30), TEST,       SIGP(20,30),XZETA(20,30), XT     7
  XSA(20,30),SF(20,30),SS(20,30),DEN(20,30),G(300),GN(300),GF(300),   XT     8
  X     GR(300),ER(300),XRES(300),SIGZ(300),GAMMA(300),SIGIN(300),    XT     9
  X                  SIGMIN(300),      SIG(30),                       XT    10
  X     SIGA22(20),SIGF22(20),       XN,XC,ETOT,TOT3,WORK(60),P(30)   XT    11
   COMMON/B/                UIGP,                          CR(30),RAD(35),XT    12
  X     RATIO(30),DIFX(30),            SPP(30),SPN(30),               XT    13
  X     AREA(35),          FLUX(30,100),FLUXCP(30,100),SCAT(40000),   XT    14
  XTAB(662),TOT,TT(60,5),                          AF(30,5),FF(30,5),  XT    15
  X V11,V12,V13,SSF(30,5),USTR(25),DUSTR(25)                          XT    16
   COMMON/C/                                                          XT    17
  X     XAREAT,AREAT,RMAX(30),                                        XT    18
  X     ENGP(1001),RIAC(20,30),RIFC(20,30),RISC(20,30),TEMP(30),      XT    19
  X                      XTEMP(30),         PHICT(30),PHI(30),PFLUX(30),XT    20
  XSIGTR(30),BARMU(30),   AMU(20),SIGPOT(20),AREAC(30),XAREAC(30),    XT    21
  XGX2(10),GW2(10),WW2(10),                                           XT    22
  X   DR(30),XAREA(30),PHIRT(30),         GX3(10),GX4(10),GW3(10),    XT    23
  X     GW4(10),WW3(10),WW4(10),V1,V2,V3,V4,V5,V6,V7,V8,V9,V10        XT    24
   COMMON/D/KI,KRES,NTEMP,INCLUD(300),                                XT    25
  X     NEXT(20),LAST(20),NRES(20),INDEX, KS,                         XT    26
  X  NU,NOPT,ISYM(30),III,KFOIL,KREG,KMAT,KCOMP,KGP,KBG,NPRINT,MORE,  XT    27
  X  IBGP,IFGP,IBG,JBG,NIB(25),NINT(30),MINT(30),LREG(35),NX(30),     XT    28
  X     NFI(25),TITLE(18),KB     ,MULT(20,25),JNU(20),JMULT(20),      XT    29
  X  INUI(20,25),INUF(20,25),NOX,NISO,KBSQ                            XT    30
   REAL*8 UFGP,V,EXDU,UMAX,DS1,DSMAX,SOURCE,SDD,ACS,FCS,SCS,PHITOT,   XT    31
  X  PHIT,ACSGP,FCSGP,SCSGP,RAP,SIGABG,SIGFBG,SIGSBG,P1,PS,ALP,DSL    XT    32
   REAL*8 DPS                                                         XT    33
   REAL*8 NUCLID                                                      XT    34
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      EQUIVALENCE (X,V1)                                                XT    35
      V7=0.                                                             XT    36
      IF(X-.3)5,6,6                                                     XT    37
    5 V7   =   XC* EXP(-18.2*X)                                         XT    38
      M=4                                                               XT    39
      GO TO 22                                                          XT    40
    6 IF(X-3.16)20,20,21                                                XT    41
   20 M=0.633*(7.89-X)                                                  XT    42
      GO TO 22                                                          XT    43
   21 M=1.+6.2/X                                                        XT    44
   22 DO 1 I=1,M                                                        XT    45
      V7   =V7   +WW3(I)* EXP( X*GX3(I))                                XT    46
    1 CONTINUE                                                          XT    47
    2  RETURN                                                           XT    48
      END                                                               XT    49
      SUBROUTINE XTRAP4                                                 XT4    1
      COMMON/E/NUCLID(20),UFGP,V(25),EXDU,UMAX(20,25),P1(20,25),        XT4    2
     X     PS(20,25),SOURCE(30),SDD,ACS,FCS,SCS,PHITOT,PHIT,ACSGP,FCSGP,XT4    3
     X SCSGP,RAP,SIGABG(20,30),SIGFBG(20,30),SIGSBG(20,30),DS1(20),     XT4    4
     X DSMAX(20),ALP(20,25),SCL(20,30),DSL(20),DPS(20),BSQ(25)          XT4    5
      COMMON/QW/REZ,AIMZ,REW,AIMW,   TR(62,62),TI(62,62)                XT4    6
      COMMON/A/     F1V,SL(20,30), TEST,       SIGP(20,30),XZETA(20,30), XT4    7
     XSA(20,30),SF(20,30),SS(20,30),DEN(20,30),G(300),GN(300),GF(300),  XT4    8
     X    GR(300),ER(300),XRES(300),SIGZ(300),GAMMA(300),SIGIN(300),    XT4    9
     X                 SIGMIN(300),     SIG(30),                        XT4   10
     X    SIGA22(20),SIGF22(20),       XN,XC,ETOT,TOT3,WORK(60),P(30)   XT4   11
      COMMON/B/                UIGP,                      CR(30),RAD(35),XT4   12
     X    RATIO(30),DIFX(30),            SPP(30),SPN(30),                XT4   13
     X    AREA(35),          FLUX(30,100),FLUXCP(30,100),SCAT(40000),   XT4   14
     XTAB(662),TOT,TT(60,5),                          AF(30,5),FF(30,5), XT4   15
     X V11,V12,V13,SSF(30,5),USTR(25),DUSTR(25)                         XT4   16
      COMMON/C/                                                         XT4   17
     X    XAREAT,AREAT,RMAX(30),                                        XT4   18
     X    ENGP(1001),RIAC(20,30),RIFC(20,30),RISC(20,30),TEMP(30),      XT4   19
     X                      XTEMP(30),         PHICT(30),PHI(30),PFLUX(30),XT4   20
     XSIGTR(30),BARMU(30),   AMU(20),SIGPOT(20),AREAC(30),XAREAC(30),   XT4   21
     XGX2(10),GW2(10),WW2(10),                                          XT4   22
     X   DR(30),XAREA(30),PHIRT(30),          GX3(10),GX4(10),GW3(10),  XT4   23
     X    GW4(10),WW3(10),WW4(10),V1,V2,V3,V4,V5,V6,V7,V8,V9,V10        XT4   24
      COMMON/D/KI,KRES,NTEMP,INCLUD(300),                               XT4   25
     X    NEXT(20),LAST(20),NRES(20),INDEX, KS,                         XT4   26
     X  NU,NOPT,ISYM(30),III,KFOIL,KREG,KMAT,KCOMP,KGP,KBG,NPRINT,MORE, XT4   27
     X  IBGP,IFGP,IBG,JBG,NIB(25),NINT(30),MINT(30),LREG(35),NX(30),    XT4   28
     X    NFI(25),TITLE(18),K8     ,MULT(20,25),JNU(20),JMULT(20),      XT4   29
     X  INUI(20,25),INUF(20,25),NOX,NISO,KBSQ                           XT4   30
      REAL*8 UFGP,V,EXDU,UMAX,DS1,DSMAX,SOURCE,SDD,ACS,FCS,SCS,PHITOT,  XT4   31
     X  PHIT,ACSGP,FCSGP,SCSGP,RAP,SIGABG,SIGFBG,SIGSBG,P1,PS,ALP,DSL   XT4   32
      REAL*8 DPS                                                        XT4   33
      REAL*8 NUCLID                                                     XT4   34
      EQUIVALENCE (X,V2)                                                XT4   35
      V8=0.                                                             XT4   36
      IF(X-3.64)20,20,21                                                XT4   37
   20 M=0.549*(9.10-X)                                                  XT4   38
      GO TO 22                                                          XT4   39
   21 M=1.+6.81/X                                                       XT4   40
   22 DO 1 I=1,M                                                        XT4   41
```

```
    1 V8     =V8     +WW4(I)* EXP( X*GX4(I))                                XT4    42
    2  RETURN                                                               XT4    43
      END                                                                   XT4    44
      FUNCTION E3(X)                                                        E3      1
      COMMON/E/NUCLID(20),UFGP,V(25),EXDU,UMAX(20,25),P1(20,25),            E3      2
     X      PS(20,25),SOURCE(30),SDD,ACS,FCS,SCS,PHITOT,PHIT,ACSGP,FCSGP,E3      3
     X SCSGP,RAP,SIGABG(20,30),SIGFBG(20,30),SIGSBG(20,30),DS1(20),         E3      4
     X DSMAX(20),ALP(20,25),SCL(20,30),DSL(20),DPS(20),BSQ(25)              E3      5
      COMMON/QW/REZ,AIMZ,REW,AIMW,    TR(62,62),TI(62,62)                   E3      6
      COMMON/A/      F1V,SL(20,30), TEST,       SIGP(20,30),XZETA(20,30),  E3      7
     XSA(20,30),SF(20,30),SS(20,30),DEN(20,30),G(300),GN(300),GF(300),      E3      8
     X     GR(300),ER(300),XRES(300),SIGZ(300),GAMMA(300),SIGIN(300),       E3      9
     X                   SIGMIN(300),      SIG(30),                         E3     10
     X     SIGA22(20),SIGF22(20),       XN,XC,ETOT,TOT3,WORK(60),P(30)      E3     11
      COMMON/B/                UIGP,                          CR(30),RAD(35),E3     12
     X     RATIO(30),DIFX(30),              SPP(30),SPN(30),                 E3     13
     X     AREA(35),           FLUX(30,100),FLUXCP(30,100),SCAT(40000),     E3     14
     XTAB(662),IOT,TT(60,5),                          AF(30,5),FF(30,5),     E3     15
     X V11,V12,V13,SSF(30,5),USTR(25),DUSTR(25)                             E3     16
      COMMON/C/                                                             E3     17
     X     XAREAT,AREAT,RMAX(30),                                           E3     18
     X     ENGP(1001),RIAC(20,30),RIFC(20,30),RISC(20,30),TEMP(30),         E3     19
     X                     XTEMP(30),          PHICT(30),PHI(30),PFLUX(30),E3     20
     XSIGTR(30),BARMU(30),    AMU(20),SIGPOT(20),AREAC(30),XAREAC(30),      E3     21
     XGX2(10),GW2(10),WW2(10),                                              E3     22
     X    DR(30),XAREA(30),PHIRT(30),          GX3(10),GX4(10),GW3(10),    E3     23
     X     GW4(10),WW3(10),WW4(10),V1,V2,V3,V4,V5,V6,V7,V8,V9,V10           E3     24
      COMMON/D/KI,KRES,NTEMP,INCLUD(300),                                   E3     25
     X     NEXT(20),LAST(20),NRES(20),INDEX, KS,                            E3     26
     X   NU,NOPT,ISYM(30),III,KFOIL,KREG,KMAT,KCOMP,KGP,KBG,NPRINT,MORE,   E3     27
     X   IBGP,IFGP,IBG,JBG,NIB(25),NINT(30),MINT(30),LREG(35),NX(30),      E3     28
     X     NFI(25),TITLE(18),KB     ,MULT(20,25),JNU(20),JMULT(20),         E3     29
     X   INUI(20,25),INUF(20,25),NOX,NISO,KBSQ                              E3     30
      REAL*8 NUCLID                                                         E3     31
      REAL*8 UFGP,V,EXDU,UMAX,DS1,DSMAX,SOURCE,SDD,ACS,FCS,SCS,PHITOT,      E3     32
     X  PHIT,ACSGP,FCSGP,SCSGP,RAP,SIGABG,SIGFBG,SIGSBG,P1,PS,ALP,DSL       E3     33
      REAL*8 DPS                                                            E3     34
      IF(X-2.)70,70,30                                                      E3     35
   30 IF(X-4.)71,71,31                                                      E3     36
   31 IF(X-6.4)111,111,160                                                  E3     37
  160 D=(X+3.)**2.                                                          E3     38
      E3= EXP(-X)*(1.+(3./D)*(1.+(3.-2.*X)/D))/(X+3.)                       E3     39
C          ERROR IS 1/30 PERCENT OR LESS                                    E3     40
      RETURN                                                                E3     41
   70 XX=100.*X+1                                                           E3     42
      NFDEL=XX                                                              E3     43
      F1=XX-NFDEL                                                           E3     44
      E3=TAB(NFDEL)+(TAB(NFDEL+1)-TAB(NFDEL))*F1                            E3     45
      RETURN                                                                E3     46
   71 XX=50.*X+101                                                          E3     47
      NFDEL=XX                                                              E3     48
      F1=XX-NFDEL                                                           E3     49
  112 E3=TAB(NFDEL)+(TAB(NFDEL+1)-TAB(NFDEL))*F1                            E3     50
      RETURN                                                                E3     51
  111 XX=X*12.5+251                                                         E3     52
      NFDEL=XX                                                              E3     53
```

```
      F1=XX-NFDEL                                                       E3     54
      GO TO 112                                                         E3     55
      END                                                               E3     56
      FUNCTION E4(X)                                                    E4      1
      COMMON/E/NUCLID(20),UFGP,V(25),EXDU,UMAX(20,25),P1(20,25),        E4      2
     X      PS(20,25),SOURCE(30),SDD,ACS,FCS,SCS,PHITOT,PHIT,ACSGP,FCSGP,E4      3
     X SCSGP,RAP,SIGABG(20,30),SIGFBG(20,30),SIGSBG(20,30),DS1(20),     E4      4
     X DSMAX(20),ALP(20,25),SCL(20,30),DSL(20),DPS(20),BSQ(25)          E4      5
      COMMON/QW/REZ,AIMZ,REW,AIMW,   TR(62,62),TI(62,62)                E4      6
      COMMON/A/      F1V,SL(20,30), TEST,       SIGP(20,30),XZETA(20,30), E4      7
     XSA(20,30),SF(20,30),SS(20,30),DEN(20,30),G(300),GN(300),GF(300),  E4      8
     X    GR(300),ER(300),XRES(300),SIGZ(300),GAMMA(300),SIGIN(300),    E4      9
     X                 SIGMIN(300),      SIG(30),                       E4     10
     X    SIGA22(20),SIGF22(20),       XN,XC,ETOT,TOT3,WORK(60),P(30)   E4     11
      COMMON/B/              UIGP,                        CR(30),RAD(35),E4     12
     X    RATIO(30),DIFX(30),            SPP(30),SPN(30),                E4     13
     X    AREA(35),          FLUX(30,100),FLUXCP(30,100),SCAT(40000),   E4     14
     XTAB(662),TOT,TT(60,5),                          AF(30,5),FF(30,5), E4     15
     X V11,V12,V13,SSF(30,5),USTR(25),DUSTR(25)                         E4     16
      COMMON/C/                                                         E4     17
     X    XAREAT,AREAT,RMAX(30),                                        E4     18
     X    ENGP(1001),RIAC(20,30),RIFC(20,30),RISC(20,30),TEMP(30),      E4     19
     X                      XTEMP(30),         PHICT(30),PHI(30),PFLUX(30),E4     20
     XSIGTR(30),BARMU(30),   AMU(20),SIGPOT(20),AREAC(30),XAREAC(30),   E4     21
     XGX2(10),GW2(10),WW2(10),                                          E4     22
     X   DR(30),XAREA(30),PHIRT(30),        GX3(10),GX4(10),GW3(10),    E4     23
     X    GW4(10),WW3(10),WW4(10),V1,V2,V3,V4,V5,V6,V7,V8,V9,V10        E4     24
      COMMON/D/KI,KRES,NTEMP,INCLUD(300),                               E4     25
     X    NEXT(20),LAST(20),NRES(20),INDEX, KS,                         E4     26
     X  NU,NOPT,ISYM(30),III,KFOIL,KREG,KMAT,KCOMP,KGP,KBG,NPRINT,MORE, E4     27
     X  IBGP,IFGP,IBG,JBG,NIB(25),NINT(30),MINT(30),LREG(35),NX(30),    E4     28
     X    NFI(25),TITLE(18),KB    ,MULT(20,25),JNU(20),JMULT(20),       E4     29
     X  INUI(20,25),INUF(20,25),NUX,NISO,KBSQ                           E4     30
      REAL*8 UFGP,V,EXDU,UMAX,DS1,DSMAX,SOURCE,SDD,ACS,FCS,SCS,PHITOT,  E4     31
     X  PHIT,ACSGP,FCSGP,SCSGP,RAP,SIGABG,SIGFBG,SIGSBG,P1,PS,ALP,DSL   E4     32
      REAL*8 DPS                                                        E4     33
      REAL*8 NUCLID                                                     E4     34
      IF(X-2.)70,70,30                                                  E4     35
   30 IF(X-4.)71,71,31                                                  E4     36
   31 IF(X-6.4)111,111,160                                              E4     37
  160 D=(X+4.)**2.                                                      E4     38
      E4= EXP(-X)*(1.+(4./D)*(1.+(4.-2.*X)/D))/(X+4.)                   E4     39
      RETURN                                                            E4     40
C          ERROR IS 1/30 PERCENT OR LESS                                E4     41
   70 XX=100.*X+332                                                     E4     42
      NFDEL=XX                                                          E4     43
      F1=XX-NFDEL                                                       E4     44
      E4=TAB(NFDEL)+(TAB(NFDEL+1)-TAB(NFDEL))*F1                        E4     45
      RETURN                                                            E4     46
   71 XX=50.*X+432                                                      E4     47
      NFDEL=XX                                                          E4     48
      F1=XX-NFDEL                                                       E4     49
  112 E4=TAB(NFDEL)+(TAB(NFDEL+1)-TAB(NFDEL))*F1                        E4     50
      RETURN                                                            E4     51
  111 XX=X*12.5+582                                                     E4     52
      NFDEL=XX                                                          E4     53
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      F1=XX-NFDEL                                                       E4    54
      GO TO 112                                                         E4    55
      END                                                               E4    56
      SUBROUTINE TABLE                                                  TAB    1
      COMMON/E/NUCLID(20),UFGP,V(25),EXDU,UMAX(20,25),P1(20,25),        TAB    2
     X     PS(20,25),SOURCE(30),SDD,ACS,FCS,SCS,PHITOT,PHIT,ACSGP,FCSGP,TAB    3
     X SCSGP,RAP,SIGABG(20,30),SIGFBG(20,30),SIGSBG(20,30),DS1(20),     TAB    4
     X DSMAX(20),ALP(20,25),SCL(20,30),DSL(20),DPS(20),BSQ(25)          TAB    5
      COMMON/QW/REZ,AIMZ,REW,AIMW,   TR(62,62),TI(62,62)                TAB    6
      COMMON/A/     F1V,SL(20,30), TEST,      SIGP(20,30),XZETA(20,30), TAB    7
     XSA(20,30),SF(20,30),SS(20,30),DEN(20,30),G(300),GN(300),GF(300),  TAB    8
     X    GR(300),ER(300),XRES(300),SIGZ(300),GAMMA(300),SIGIN(300),    TAB    9
     X                  SIGMIN(300),      SIG(30),                      TAB   10
     X    SIGA22(20),SIGF22(20),       XN,XC,ETOT,TOT3,WORK(60),P(30)   TAB   11
      COMMON/B/              UIGP,                        CR(30),RAD(35),TAB   12
     X    RATIO(30),DIFX(30),            SPP(30),SPN(30),                TAB   13
     X    AREA(35),          FLUX(30,100),FLUXCP(30,100),SCAT(40000),    TAB   14
     XTAB(662),TOT,TT(60,5),                          AF(30,5),FF(30,5),  TAB   15
     X V11,V12,V13,SSF(30,5),USTR(25),DUSTR(25)                         TAB   16
      COMMON/C/                                                         TAB   17
     X    XAREAT,AREAT,RMAX(30),                                        TAB   18
     X    ENGP(1001),RIAC(20,30),RIFC(20,30),RISC(20,30),TEMP(30),      TAB   19
     X                      XTEMP(30),         PHICT(30),PHI(30),PFLUX(30),TAB   20
     XSIGTR(30),BARMU(30),   AMU(20),SIGPOT(20),AREAC(30),XAREAC(30),   TAB   21
     XGX2(10),GW2(10),WW2(10),                                          TAB   22
     X   DR(30),XAREA(30),PHIRT(30),         GX3(10),GX4(10),GW3(10),   TAB   23
     X    GW4(10),WW3(10),WW4(10),V1,V2,V3,V4,V5,V6,V7,V8,V9,V10        TAB   24
      COMMON/D/KI,KRES,NTEMP,INCLUD(300),                               TAB   25
     X    NEXT(20),LAST(20),NRES(20),INDEX, KS,                         TAB   26
     X  NU,NOPT,ISYM(30),III,KFOIL,KREG,KMAT,KCOMP,KGP,KBG,NPRINT,MORE, TAB   27
     X  IBGP,IFGP,IBG,JBG,NIB(25),NINT(30),MINT(30),LREG(35),NX(30),    TAB   28
     X    NFI(25),TITLE(18),KB     ,MULT(20,25),JNU(20),JMULT(20),      TAB   29
     X  INUI(20,25),INUF(20,25),NOX,NISO,KBSQ                           TAB   30
      REAL*8 UFGP,V,EXDU,UMAX,DS1,DSMAX,SOURCE,SDD,ACS,FCS,SCS,PHITOT,  TAB   31
     X  PHIT,ACSGP,FCSGP,SCSGP,RAP,SIGABG,SIGFBG,SIGSBG,P1,PS,ALP,DSL   TAB   32
      REAL*8 DPS                                                        TAB   33
      REAL*8 NUCLID                                                     TAB   34
C     FORM TABLES                                                       TAB   35
    1 DO 110 I=1,331                                                    TAB   36
      IF(I-201)450,450,400                                              TAB   37
  450 ZZZZ=(I-1)*.01+.000000001                                         TAB   38
      GO TO 500                                                         TAB   39
  400 IF(I-301)650,650,600                                              TAB   40
  650 ZZZZ=(I-101)*.02                                                  TAB   41
      GO TO 500                                                         TAB   42
  600 ZZZZ=(I-251)*.08                                                  TAB   43
  500 IF(ZZZZ-1.)115,115,120                                            TAB   44
  115 TAB(I)    =-.57721566+.99999193*ZZZZ-.24991055*ZZZZ**2+.05519968* TAB   45
     1ZZZZ**3-.00976004*ZZZZ**4+.00107857*ZZZZ**5-ALOG(ZZZZ)            TAB   46
      GO TO 116                                                         TAB   47
  120 TAB(I)   =( EXP(-ZZZZ)/ZZZZ)*(ZZZZ**4+8.573328740*ZZZZ**3+        TAB   48
     1 18.05901697*ZZZZ**2+8.634760892*ZZZZ+.2677737343)/(ZZZZ**4+      TAB   49
     2 9.573322345*ZZZZ**3 +25.63295615*ZZZZ**2+21.09965308*ZZZZ+       TAB   50
     3 3.958496923)                                                     TAB   51
  116 E2= EXP(-ZZZZ)-ZZZZ*TAB(I)                                        TAB   52
      TAB(I)=0.5*( EXP(-ZZZZ)-ZZZZ*E2)                                  TAB   53
```

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      TAB(I+331)=0.33333333*( EXP(-ZZZZ)-ZZZZ*TAB(I))                    TAB    54
C       TAB(I) IS E3 WHILE TAB(I+331) IS E4                              TAB    55
  110  CONTINUE                                                          TAB    56
      RETURN                                                             TAB    57
      END                                                                TAB    58
      FUNCTION EZ3(P,H)                                                  EZ3     1
      A=P+H                                                              EZ3     2
      Z=A+H                                                              EZ3     3
      Z2=Z*Z                                                             EZ3     4
      H2=H*H                                                             EZ3     5
      FF2=(H2*H/(1260.*Z))*(21.-H2*(1.+Z*(1.+0.5*Z))/Z2)                 EZ3     6
      EZ3=PE3(P)  +PE3(A)+                                               EZ3     7
     X  .08333333333*( EXP(-Z)*(((4.-2.*Z)/H)+3.-FF2)                    EZ3     8
     X  + E2(Z)*(H-3.*Z+(2.*Z2/H)))                                      EZ3     9
      RETURN                                                             EZ3    10
      END                                                                EZ3    11
      FUNCTION EZ4(P,H)                                                  EZ4     1
      Z=P+H                                                              EZ4     2
      HZ=H*(H/Z)**2                                                      EZ4     3
      EZ4=.08333333333*( EXP(-Z)*( (3.-Z)/H + 2.          +HZ*(1.-Z)/60.)EZ4     4
     1  +PE3(Z)*(Z*Z/H+H-2.*Z-HZ/30.))+E4(P)                             EZ4     5
      RETURN                                                             EZ4     6
      END                                                                EZ4     7
      FUNCTION E2(Q)                                                     E2      1
C     USED BY EZ3 FOR SMALL Q                                            E2      2
      DIMENSION A(5)                                                     E2      3
      DATA                                                               E2      4
     X   A/1.,0.,-.5, .08333333333,-.01388888889/                        E2      5
      X=Q+1.0E-20                                                        E2      6
      A(2)=-.4227843351+ALOG(X)                                          E2      7
      E2=A(5)*X                                                          E2      8
      DO 11 K=1,3                                                        E2      9
      L=5-K                                                              E2     10
      E2=(E2+A(L))*X                                                     E2     11
   11 CONTINUE                                                           E2     12
      E2=E2+A(1)                                                         E2     13
      RETURN                                                             E2     14
      END                                                                E2     15
      FUNCTION PE3(S)                                                    PE3     1
C     USED BY EZ3 FOR SMALL S                                            PE3     2
      DIMENSION B(7)                                                     PE3     3
      DATA                                                               PE3     4
     X   B/.5,-1.,0.,0.1666666667,-.02083333333, .002777777778,          PE3     5
     X  -.000347222222/                                                  PE3     6
      IF(S-.6)2,1,1                                                      PE3     7
    1 PE3=E3(S)                                                          PE3     8
      RETURN                                                             PE3     9
C        E3 TABLES FOR LESS THAN .6 NOT REQUIRED NOW                     PE3    10
    2 X=S+1.0E-20                                                        PE3    11
      B(3)=-(-.9227843351+ALOG(X))/2.                                    PE3    12
      PE3=B(7)*X                                                         PE3    13
      DO 11 K=1,5                                                        PE3    14
      L=7-K                                                              PE3    15
      PE3=(PE3+B(L))*X                                                   PE3    16
   11 CONTINUE                                                           PE3    17
      PE3=PE3+B(1)                                                       PE3    18
```

```
      RETURN                                                            PE3    19
      END                                                               PE3    20
      FUNCTION PFUNC(S)                                                 PFU     1
      IMPLICIT REAL*8(A-H,O-Z)                                          PFU     2
      REAL*4 E3,T                                                       PFU     3
      DIMENSION B(8)                                                    PFU     4
      DATA                                                              PFU     5
     X   B/.5D0,-1.D0,0.D0,.1666666666667D0,-.02083333333333D0,          PFU     6
     X.0027777777777778D0,-.0003472222222222,.0000396825396 8D0/        PFU     7
      IF(S-.6)2,1,1                                                     PFU     8
    1 T=S                                                               PFU     9
      PFUNC=(.5-E3(T))/T                                                PFU    10
      RETURN                                                            PFU    11
    2 IF(S)3,4,4                                                        PFU    12
    3 S=0.0D0                                                           PFU    13
    4 X=S+1.0D-20                                                       PFU    14
      B(3)=-(-.9227843350985D0+DLOG(X))*.5D0                            PFU    15
      PE3=B(8)*X                                                        PFU    16
      DO 11 K=1,6                                                       PFU    17
      L=8-K                                                             PFU    18
      PE3=(PE3+B(L))*X                                                  PFU    19
   11 CONTINUE                                                          PFU    20
      PFUNC=-PE3/X                                                      PFU    21
      RETURN                                                            PFU    22
      END                                                               PFU    23
      SUBROUTINE SYM(ISYM,DEN,AREA,KMAT,KREG,LREG)                      SYM     1
      DIMENSION ISYM(30),LREG(35),DEN(20,30),AREA(35)                   SYM     2
      DO 1 I=1,KREG                                                     SYM     3
    1 ISYM(I)=0                                                         SYM     4
      K=1                                                               SYM     5
      M=KREG-1                                                          SYM     6
      IF(M)62,62,2                                                      SYM     7
    2 DO 60 I=1,M                                                       SYM     8
      IJ=I+1                                                            SYM     9
      DO 60 J=IJ,KREG                                                   SYM    10
      II=I                                                              SYM    11
      JJ=J                                                              SYM    12
   10 DO 15 L=1,KMAT                                                    SYM    13
      TI=AREA(II)*DEN(L,LREG(II))                                       SYM    14
      TJ=AREA(JJ)*DEN(L,LREG(JJ))                                       SYM    15
      IF(TI-TJ)11,15,11                                                 SYM    16
   11 TT=AMAX1(TI,TJ)                                                   SYM    17
      IF(( ABS(TI-TJ))/TT-1.0E-6      )15,15,60                         SYM    18
   15 CONTINUE                                                          SYM    19
      IF(II-KREG)30,20,20                                               SYM    20
   20 II=0                                                              SYM    21
   30 IF(JJ-1)40,40,50                                                  SYM    22
   40 JJ=KREG+1                                                         SYM    23
   50 II=II+1                                                           SYM    24
      JJ=JJ-1                                                           SYM    25
      IF(I-II)10,70,10                                                  SYM    26
   70 ISYM(K)=I                                                         SYM    27
      ISYM(K+1)=J                                                       SYM    28
      K=K+2                                                             SYM    29
   60 CONTINUE                                                          SYM    30
      K=K-1                                                             SYM    31
```

```
      IF(K)62,62,61
   61 WRITE(6,100) (ISYM(KK),KK=1,K)
  100 FORMAT(/,42H THE FOLLOWING PAIRS ARE SYMMETRIC REGIONS,/,(20I6))
      GO TO 63
   62 WRITE (6,101)
  101 FORMAT(/,21H NO SYMMETRIC REGIONS)
   63 RETURN
      END
      SUBROUTINE MATINV (A,N,B,M,DETERM,NMAX)
C
C      MATRIX INVERSION WITH ACCOMPANYING SOLUTION OF LINEAR EQUATIONS
C
C**** REMOVE NEXT STATEMENT IN SINGLE PRECISION VERSION
C      IMPLICIT REAL*8 (A-H,O-Z)
      REAL*4 PIVOT
      DIMENSION A(NMAX,N),B(NMAX,M)
      COMMON /F402/PIVOT(100),INDEX(100)
C
C     INITIALIZE DETERMINANT AND PIVOT ELEMENT ARRAY
C
      DETERM = 1.0
      DO 20 I=1,N
      PIVOT (I) = 0.0
   20 CONTINUE
C
C     PERFORM SUCCESSIVE PIVOT OPERATIONS (GRAND LOOP)
C
      DO 550 I=1,N
C
C     SEARCH FOR PIVOT ELEMENT AND EXTEND DETERMINANT PARTIAL PRODUCT
C
      AMAX = 0.0
      DO 105 J=1,N
      IF (PIVOT(J).NE.0.0) GO TO 105
      DO 100 K=1,N
      IF (PIVOT(K).NE.0.0) GO TO 100
      TEMP = ABS(A(J,K))
      IF (TEMP.LT.AMAX) GO TO 100
      IROW = J
      ICOLUM = K
      AMAX = TEMP
  100 CONTINUE
  105 CONTINUE
      INDEX(I) = 4096*IROW+ICOLUM
      J = IROW
      AMAX = A(J,ICOLUM)
      DETERM = AMAX * DETERM
C
C     RETURN IF MATRIX IS SINGULAR (ZERO PIVOT) AFTER COLUMN INTERCHANGE
C
      IF (DETERM.EQ.0.0) GO TO 600
C
      PIVOT(ICOLUM) = AMAX
C
C     INTERCHANGE ROWS TO PUT PIVOT ELEMENT ON DIAGONAL
C
```

actual order 30 → 0 max size (30)

working arrays

```
      IF (IROW.EQ.ICOLUM) GO TO 260                                     MAT   49
      DETERM = -DETERM                                                  MAT   50
      DO 200 K=1,N                                                      MAT   51
      SWAP = A(J,K)                                                     MAT   52
      A(J,K) = A(ICOLUM,K)                                              MAT   53
      A(ICOLUM,K) = SWAP                                                MAT   54
  200 CONTINUE                                                          MAT   55
      IF (M.LE.0) GO TO 260                                             MAT   56
      DO 250 K=1,M                                                      MAT   57
      SWAP = B(J,K)                                                     MAT   58
      B(J,K) = B(ICOLUM,K)                                              MAT   59
      B(ICOLUM,K) = SWAP                                                MAT   60
  250 CONTINUE                                                          MAT   61
C                                                                       MAT   62
C     DIVIDE PIVOT ROW BY PIVOT ELEMENT                                 MAT   63
C                                                                       MAT   64
  260 K = ICOLUM                                                        MAT   65
      A(ICOLUM,K) = 1.0                                                 MAT   66
      DO 350 K=1,N                                                      MAT   67
      A(ICOLUM,K) = A(ICOLUM,K)/AMAX                                    MAT   68
  350 CONTINUE                                                          MAT   69
      IF (M.LE.0) GO TO 380                                             MAT   70
      DO 370 K=1,M                                                      MAT   71
      B(ICOLUM,K) = B(ICOLUM,K)/AMAX                                    MAT   72
  370 CONTINUE                                                          MAT   73
C                                                                       MAT   74
C      REDUCE NON-PIVOT ROWS                                            MAT   75
  380 DO 550 J=1,N                                                      MAT   76
      IF (J.EQ.ICOLUM) GO TO 550                                        MAT   77
      T = A(J,ICOLUM)                                                   MAT   78
      A(J,ICOLUM) = 0.0                                                 MAT   79
      DO 450 K=1,N                                                      MAT   80
      A(J,K) = A(J,K)-A(ICOLUM,K)*T                                     MAT   81
  450 CONTINUE                                                          MAT   82
      IF (M.LE.0) GO TO 550                                             MAT   83
      DO 500 K=1,M                                                      MAT   84
      B(J,K) = B(J,K)-B(ICOLUM,K)*T                                     MAT   85
  500 CONTINUE                                                          MAT   86
  550 CONTINUE                                                          MAT   87
C                                                                       MAT   88
C     INTERCHANGE COLUMNS AFTER ALL PIVOT OPERATIONS HAVE BEEN PERFORMEDMAT   89
C                                                                       MAT   90
  600 DO 710 I=1,N                                                      MAT   91
      I1 = N+1-I                                                        MAT   92
      K = INDEX(I1)/4096                                                MAT   93
      ICOLUM = INDEX(I1)-4096*K                                         MAT   94
      IF (K.EQ.ICOLUM) GO TO 710                                        MAT   95
      DO 705 J=1,N                                                      MAT   96
      SWAP = A(J,K)                                                     MAT   97
      A(J,K) = A(J,ICOLUM)                                              MAT   98
      A(J,ICOLUM) = SWAP                                                MAT   99
  705 CONTINUE                                                          MAT  100
  710 CONTINUE                                                          MAT  101
C                                                                       MAT  102
      RETURN                                                            MAT  103
      END                                                               MAT  104
```

```
      SUBROUTINE QUICKW                                                 QKW    1
      COMMON/QW/AX,Y,REW,AIMW,TR(62,62),TI(62,62)                       QKW    2
      X=AX                                                              QKW    3
      TEST=X*X+Y*Y                                                      QKW    4
      IF (TEST.LT.36.   ) GO TO 10                                      QKW    5
      IF (TEST.LT.144.   ) GO TO 2                                      QKW    6
      IF (TEST.LT.10000.   ) GO TO 3                                    QKW    7
      A1=0.5641896/TEST                                                 QKW    8
      REW=Y*A1                                                          QKW    9
      AIMW=X*A1                                                         QKW   10
      RETURN                                                            QKW   11
   10 AKI=SIGN(1.0,AX)                                                  QKW   12
      X=ABS(AX)                                                         QKW   13
      II=X*10.                                                          QKW   14
      JJ=Y*10.                                                          QKW   15
      I=II+2                                                            QKW   16
      J=JJ+2                                                            QKW   17
      N=J-1                                                             QKW   18
      P=10.*X-II                                                        QKW   19
      Q=10.*Y-JJ                                                        QKW   20
   15 P2=P*P                                                            QKW   21
      Q2=Q*Q                                                            QKW   22
      PQ=P*Q                                                            QKW   23
      HP=.5*P                                                           QKW   24
      HQ=.5*Q                                                           QKW   25
      HQ2=.5*Q2                                                         QKW   26
      HP2=.5*P2                                                         QKW   27
      A1=HQ2-HQ                                                         QKW   28
      A2=HP2-HP                                                         QKW   29
      A3=1.+PQ-P2-Q2                                                    QKW   30
      A4=HP2-PQ+HP                                                      QKW   31
      A5=HQ2-PQ+HQ                                                      QKW   32
      REW=A1*TR(I,N   )+A2*TR(I-1,J)+A3*TR(I,J)+A4*TR(I+1,J)+A5*TR(I,J+1)QKW   33
     1+PQ*TR(I+1,J+1)                                                   QKW   34
    5 AIMW=AKI*(                                                        QKW   35
     1      A1*TI(I,N   )+A2*TI(I-1,J)+A3*TI(I,J)+A4*TI(I+1,J)+A5*TI(I,J+1QKW   36
     2)+PQ*TI(I+1,J+1) )                                                QKW   37
      RETURN                                                            QKW   38
    2 A1=(X+Y)*(X-Y)                                                    QKW   39
      A2=2.*X*Y                                                         QKW   40
      A3=A2*A2                                                          QKW   41
      A4=A1-.2752551                                                    QKW   42
      A5=A1-2.724745                                                    QKW   43
      D1=.5124242/(A4*A4+A3)                                            QKW   44
      D2=.05176536/( A5*A5+A3)                                          QKW   45
      D12A2=(D1+D2)*A2                                                  QKW   46
      DADA=D1*A4+D2*A5                                                  QKW   47
      REW=D12A2*X-Y*DADA                                                QKW   48
    7 AIMW=D12A2*Y+X*DADA                                               QKW   49
      RETURN                                                            QKW   50
    3 A1=2.*(X+Y)*(X-Y)                                                 QKW   51
      A2=4.*X*Y                                                         QKW   52
      A22=A2*A2                                                         QKW   53
      A4=A1-1.                                                          QKW   54
      A42=A4*A4                                                         QKW   55
      D1=1.1283792/(A42+A22)                                            QKW   56
```

```
      REW=D1*(A2*X-A4*Y)                                                QKW    57
      AIMW=1.1283792/(A4*X+A2*Y)                                        QKW    58
C     SECOND TERM OF THE CONTINUED FRACTION                             QKW    59
      A5=A42-  4.*A4-A22-2.                                             QKW    60
      A52=A5*A5                                                         QKW    61
      A6=A2*(A4+A4-4.   )                                               QKW    62
      A62=A6*A6                                                         QKW    63
      D1=  1./(A52+A62)                                                 QKW    64
      A1=1.  +(A5+A5)*D1                                                QKW    65
      A2=D1*(A6+A6)                                                     QKW    66
      REW=REW*A1+AIMW*A2                                                QKW    67
      AIMW=AIMW*A1-REW*A2                                               QKW    68
      RETURN                                                            QKW    69
      END                                                               QKW    70
//L.SYSLMOD DD DSN=TEMP.APORABID(RABIDA1),DISP=(NEW,CATLG),UNIT=DKTEMP
//X.FT05F001 DD DDNAME=SYSIN
//X.FT06F001 DD SYSOUT=A,DCB=(RECFM=FBA,LRECL=132,BLKSIZE=1584),        X
//           SPACE=(1584,(60,60))
//X.FT08F001 DD DSN=TEMP.GLGATRTI,DISP=SHR,UNIT=DKTEMP,                 X
//     DCB=(RECFM=VB,LRECL=500,BLKSIZE=5004),SPACE=(TRK,(5,1))
//X.SYSIN DD *
```

APPENDIX D

Sample Problems

1. Description of Problems

The first problem is the simplest possible case: homogeneous, one material, one resonance, and no absorption (obtained by setting G = 0 for the resonance, and zero background-absorption cross section). Physically, the flux must remain constant at unity. The output intermediate-group fluxes are scaled by 10,000 and rounded to the closest integral value.

The unit cell for the second problem consists of two compositions, each subdivided into four regions. Composition 1 is ^{238}U, and composition 2 is ^{12}C. An infinitely thin ^{238}U foil will sample interface conditions.

The third problem is a representation of the core of ZPR-3 Assemblies 53 and 54. The compositions are:

a. Drawer + matrix + matrix + drawer

b. Four carbon plates

c. Cladding

d. ZPR fuel plate

e. Cladding

f. Six carbon plates

g. Cladding

h. SEFOR fuel plate

i. Cladding

j. Three carbon plates

This case is one of a series of problems designed to calculate ^{238}U capture rates across the cell at positions corresponding to those used in an activation-foil scan. The activation-foil scan experiment and the procedure used to calculate the scan will now be described briefly with a comparison of results.

In the experiments, depleted-uranium foils were irradiated in the cell locations as shown in Fig. 3. The foils were counted by a Ge(Li) gamma-ray spectrometer. The activations were obtained from three gamma rays (209.8, 228.2, and 277.6 keV) which follow the beta decay of ^{239}Np. The experimental errors of ±1.5% include a ±0.4% contribution from statistics.

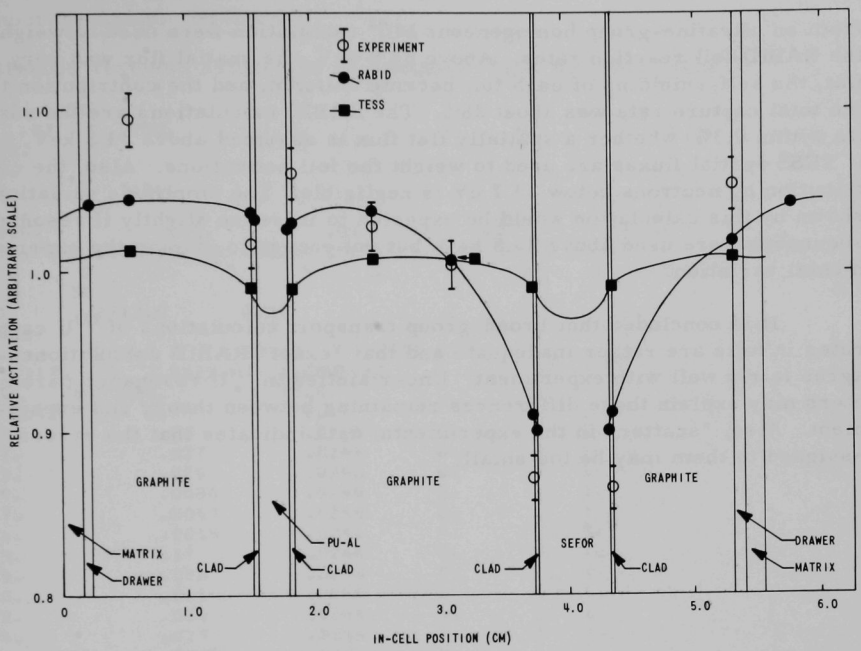

Fig. 3. ^{238}U In-cell Capture Rates in ZPR-3 Assemblies 53 and 54. ANL Neg. No. Id-103-A11290.

Heterogeneously self-shielded, 23-epithermal-group neutron cross sections generated by MC^2 were used by the TESS transport code in a one-dimensional, double S_{12} cell calculation. The amplitude variation exhibited by this calculation was clearly too small, because the self-shielding of each foil was inadequately accounted for.

Essentially "exact" calculations of the reaction rates in each foil were obtained from the integral transport code RABID. Uranium-238 capture cross sections in the energy range from 24.8 to 3.35 keV (a span of 8 MC^2 fine groups, each 0.25 lethargy unit wide) were obtained from statistically generated resolved resonance sequences for (ℓ, J) states of $(\frac{1}{2}, 0)$, $(\frac{1}{2}, 1)$, and $(\frac{3}{2}, 1)$. The Schmidt tabulation was used for both the unresolved and the resolved resonance parameters. The resonance sequences were centered on each MC^2 fine group. Resolved ^{238}U resonances were used from 3.35 keV down to 13.7 eV. Resolved resonances for aluminum, iron, chromium, and nickel were used over 24.8 keV to 13.7 eV. Smooth cross sections for ^{239}Pu were used down to 275 eV, below which resolved resonance parameters were used. Similarly, ^{240}Pu was accounted for by smooth cross sections above 130 eV, and resolved resonances below. Fine-group fluxes

from an ultrafine-group homogeneous MC^2 calculation were used to weight the RABID foil reaction rates. Above 24.8 keV, the spatial flux was very flat, the self-shielding of each foil became uniform, and the contribution to the total capture rate was about 28%. The RABID calculations are the same (to within 0.3%) whether a spatially flat flux is assumed above 24.8 keV, or if TESS spatial fluxes are used to weight the foil activations. Also, the contribution by neutrons below 13.7 eV is negligible. The amplitude variation shown by this calculation would be expected to increase slightly if resonance sequences were used above 24.8 keV, but not enough to display the experimental variation.

It is concluded that broad-group transport calculations of ^{238}U capture rates in foils are rather inadequate and that "exact" RABID calculations agree fairly well with experiment. Uncertainties in ^{238}U resonance parameters may explain those differences remaining between theory and experiment. Also, "scatter" in the experimental data indicates that the errors assigned to them may be too small.

2. Input for Sample Problems

```
HOMOGENEOUS TEST--NO ABSORPTION OR LEAKAGE.  FLUX MUST STAY FLAT.
     1     1     1     1    30     1     3     1     1
    30    50
      .02      1000.          0.           0     0
   300.
 1  1.
A-200       1   200.          1.          0.
     1.
  10000.          .01          .01          .00          0.
 PLATE,FOIL EQUIVALENCE THEORY CHECK  1/8 IN U-238 1 IN C      8 REGION
     8     2     2     1     5     1     4     1     1     0
     5    50
 0.01        2613.0       0.01             1     1
   .001
 293.0       293.0        293.0        293.0
 4   .3175    4  2.8575      1.000E-10
U 238      66  238.          10.6
     .042        0.           1.
 1245.          .23          .0246       0.          1.
 1267.          .027         .0246       0.          1.
 1273.          .029         .0246       0.          1.
 1299.          .0036        .0246       0.          1.
 1317.          .0047        .0246       0.          1.
 1336.          .0015        .0246       0.          1.
 1393.          .17          .0246       0.          1.
 1405.          .082         .0246       0.          1.
 1420.          .011         .0246       0.          1.
 1428.          .034         .0246       0.          1.
 1444.          .023         .0246       0.          1.
 1474.          .0805        .0246       0.          1.
 1523.          .21          .0246       0.          1.
 1546.          .002         .0246       0.          1.
 1550.          .002         .0246       0.          1.
 1565.          .0024        .0246       0.          1.
 1623.          .09          .0246       0.          1.
 1638.          .0404        .0246       0.          1.
 1662.          .16          .0246       0.          1.
 1688.          .07          .0246       0.          1.
 1709.          .05          .0246       0.          1.
 1723.          .014         .0246       0.          1.
 1756.          .07          .0246       0.          1.
 1782.          .5           .0246       0.          1.
 1798.          .0021        .0246       0.          1.
 1808.          .017         .0246       0.          1.
 1846.          .0133        .0246       0.          1.
 1902.          .0209        .0246       0.          1.
 1917.          .0219        .0246       0.          1.
 1969.          .577         .0246       0.          1.
 1975.          .467         .0246       0.          1.
 2024.          .202         .0246       0.          1.
 2031.          .0496        .0246       0.          1.
 2089.          .0137        .0246       0.          1.
 2097.          .0101        .0246       0.          1.
 2124.          .0046        .0246       0.          1.
 2146.          .0347        .0246       0.          1.
 2153.          .1760        .0246       0.          1.
```

```
2172.          .0023        .0246       0.          1.
2186.          .365         .0246       0.          1.
2194.          .0023        .0246       0.          1.
2201.          .113         .0246       0.          1.
2230.          .0047        .0246       0.          1.
2236.          .0047        .0246       0.          1.
2242.          .0014        .0246       0.          1.
2259.          .0656        .0246       0.          1.
2266.          .145         .0246       0.          1.
2281.          .11          .0246       0.          1.
2289.          .0024        .0246       0.          1.
2302.          .00096       .0246       0.          1.
2316.          .0144        .0246       0.          1.
2337.          .00483       .0246       0.          1.
2352.          .063         .0246       0.          1.
2356.          .0631        .0246       0.          1.
2393.          .0112        .0246       0.          1.
2410.          .00441       .0246       0.          1.
2427.          .0813        .0246       0.          1.
2446.          .111         .0246       0.          1.
2454.          .00247       .0246       0.          1.
2490.          .0549        .0246       0.          1.
2521.          .01          .0246       0.          1.
2549.          .343         .0246       0.          1.
2559.          .217         .0246       0.          1.
2581.          .244         .0246       0.          1.
2599.          .561         .0246       0.          1.
2604.          .0025        .0246       0.          1.
C  12      0   12.          4.7
   0.          .075         0.
     U-238 FUILS IN ZPR-3 ASSY 53      C-17       RESONANCE SET-02
   12     9    10     5    10     1     3     1     1     1
   10    12
  .0008457   21967.5        0.001        1
       300.        300.        300.        300.        300.
       300.        300.        300.        300.        300.
       300.
 1  .4661    1  1.7361    1  1.76658   1  2.02312   1  2.0536
 3  3.9586   1  3.98908   1  4.56312   1  4.5936    1  5.5461
   0.0127
 U-238    20        238.        10.6         0.0         0.0
        0.0         0.0         0.0         0.0         0.0
        0.0         0.0   0.0308768         0.0         0.0
     0.0476
 2.17871E 04 8.70641E-04 2.46000E-02 0.0        -2.00000E 00   1   1   2
 2.17964E 04 2.60020E-02 2.46000E-02 0.0        -2.00000E 00   1   1   2
 2.18056E 04 1.60871E-04 2.46000E-02 0.0        -2.00000E 00   1   1   2
 2.18149E 04 4.23203E-03 2.46000E-02 0.0        -2.00000E 00   1   1   2
 2.18241E 04 9.03192E-03 2.46000E-02 0.0        -2.00000E 00   1   1   2
 2.18334E 04 5.57224E-03 2.46000E-02 0.0        -2.00000E 00   1   1   2
 2.18426E 04 2.20094E-03 2.46000E-02 0.0        -2.00000E 00   1   1   2
 2.18519E 04 2.11191E-02 2.46000E-02 0.0        -2.00000E 00   1   1   2
 2.18611E 04 7.17102E-03 2.46000E-02 0.0        -2.00000E 00   1   1   2
 2.18704E 04 3.26603E-02 2.46000E-02 0.0        -2.00000E 00   1   1   2
 2.18796E 04 1.90628E-05 2.46000E-02 0.0        -2.00000E 00   1   1   2
 2.18889E 04 5.65034E-02 2.46000E-02 0.0        -2.00000E 00   1   1   2
```

```
2.18981E 04 3.13407E-03 2.46000E-02 0.0          -2.00000E 00   1   1   2
2.19074E 04 1.72296E-02 2.46000E-02 0.0          -2.00000E 00   1   1   2
2.19166E 04 1.13291E-02 2.46000E-02 0.0          -2.00000E 00   1   1   2
2.19259E 04 4.19695E-02 2.46000E-02 0.0          -2.00000E 00   1   1   2
2.19351E 04 1.40241E-02 2.46000E-02 0.0          -2.00000E 00   1   1   2
2.19444E 04 4.47596E-04 2.46000E-02 0.0          -2.00000E 00   1   1   2
2.19536E 04 9.06997E-02 2.46000E-02 0.0          -2.00000E 00   1   1   2
2.19629E 04 1.46722E-03 2.46000E-02 0.0          -2.00000E 00   1   1   2
   AL      2          27.          1.4       0.0018          0.0
                                                .002936
        0.0          0.0          0.0          0.0          0.0

5.90600E 03 2.00000E 01          0.0          0.0 4.16700E-01
3.50400E 04 1.50000E 03          0.0          0.0 5.83300E-01
   FE      6      55.8500         5.22          0.0          0.0
   0.035370          0.0     0.061970          0.0     0.061970
 0.          .06197       0.          .06197

1.15000E 03 5.60000E-02 6.73000E-01          0.0 9.16800E-01
3.90000E 03 2.20000E 02          1.0          0.0 2.17000E-02
6.00000E 03 4.20000E 02          1.7          0.0 2.17000E-02
8.00000E 03 1.00000E 03          3.0          0.0 5.84000E-02
2.70000E 04          0.0          6.0          0.0 2.17000E-02
2.83000E 04 1.67000E 03          1.5          0.0 9.16800E-01
   CR      5        52.01         3.71          0.0          0.0
    0.00880          0.0     0.015410          0.0      0.01541
 0.          .01541       0.          .01541

4.25000E 03 1.00000E 02          0.0          0.0 5.96000E-02
6.60000E 03 1.70000E 03          3.0          0.0 4.31000E-02
2.35000E 04 4.90000E 02          0.0          0.0 2.38000E-02
2.65000E 04 5.00000E 02          0.0          0.0 2.38000E-02
2.87000E 04 5.10000E 02          0.0          0.0 4.31000E-02
   NI      4        58.7         6.57          0.0          0.0
    0.00385          0.0      0.00675          0.0 .00675
 0.          .00675       0.          .00675

4.60000E 03 1.30000E 03          0.0          0.0 3.66000E-02
1.25000E 04 2.60000E 03          0.0          0.0 2.61600E-01
1.55000E 04 1.54000E 03          0.0          0.0 6.77600E-01
2.87000E 04 1.11000E 03          0.0          0.0 2.61600E-01
PU-240      0       240.00       13.180       199.00          0.0
         0.0          0.0          0.0   0.00135160          0.0
         0.0          0.0  6.62280E-04          0.0          0.0

PU-239      0       239.00       10.320       662.00          0.0
         0.0          0.0          0.0    0.0284290          0.0
         0.0          0.0  7.07625E-03          0.0          0.0

   MU      0       96.000       7.0000       69.400          0.0
   0.
   0.          0.          .002463
   0.
    C      0      12.        4.7
 0.          .08183       0.          0.          0.
 .08183      0.          0.          0.          .08183
 0.
/*
```

3. Output from Sample Problems

```
RABID
HOMOGENEOUS TEST--NO ABSORPTION OR LEAKAGE.  FLUX MUST STAY FLAT.

        NO. CELL REGIONS =  1                          NO. MATERIALS =  1
        NO. COMPOSITIONS =  1                          NO. RESONANT MATERIALS = 1
        NO. BROAD GROUPS =  1                          LETHARGY WIDTH INTER. GROUP =0.200000E-01
        NO. INTERMEDIATE GROUPS =  30                  RESONANCE TEST = 0.0       (BARNS) NOPT= 3 KFOIL= 0

RESONANT MATERIALS HAVE BROAD-GROUP-DEPENDENT ABSORPTION AND FISSION CROSS SECTIONS


 REGION/COMPOSITION/OUTER DIMENSION/TEMPERATURE

      1
      1
1.00000
 300.00


 MATERIAL  RES.        MASS    SIG POT   SIG A 1/V    SIG F 1/V
A-200       1       0.20000E 03 0.10000E 01 0.0         0.0

ISOTOPE    1
0.10000E 01


BROAD GROUP    NO. INTER. GROUPS    NO. FINE GP/INTER GP    MAXIMUM ENERGY (EV)    MINIMUM ENERGY (EV)    BUCKLING
        1                   30                    50            0.1000E 04            0.5488E 03            0.0


 NUMBER OF FINE GROUPS USED TO LETHARGY-AVERAGE SCATTERING RATES FOR EACH MATERIAL

BROAD GROUP NO.=    1

     A-200          1
```

RESONANCE PARAMETERS

MATERIAL	ENERGY(EV)	GAMMA N (EV)	GAMMA GAMMA (EV)	GAMMA F (EV)	G
A-200	0.10000E 05	0.10000E-01	0.10000E-01	0.0	0.0

NO SYMMETRIC REGIONS

HOMOGENEOUS TEST--NO ABSORPTION OR LEAKAGE. FLUX MUST STAY FLAT.

SUMMARY FOR BROAD GROUP 1 0.10000E 04 EV TO 0.54881E 03 EV

	AVERAGE		SIGMA A	SIGMA F	SIGMA S	FLUX
	CELL		0.0	0.0	0.10000D 01	0.99999D 00
	COMPOSITION	MATERIAL				
	1					0.99999E 00
RA= 0.0	RF= 0.0	A-200	0.0	0.0	0.10000E 01	

CUMULATIVE ABSORPTION PROBABILITY = 0.0

REGIONAL INTERMEDIATE GROUP FLUXES FOR BROAD GROUP 1

LOWER ENERGY(EV)	1	1
1	0.98020E 03	10000
2	0.96079E 03	10000
3	0.94176E 03	10000
4	0.92312E 03	10000
5	0.90484E 03	10000
6	0.88692E 03	10000
7	0.86936E 03	10000
8	0.85214E 03	10000
9	0.83527E 03	10000
10	0.81873E 03	10000
11	0.80252E 03	10000
12	0.78663E 03	10000
13	0.77105E 03	10000
14	0.75578E 03	10000
15	0.74082E 03	10000
16	0.72615E 03	10000
17	0.71177E 03	10000
18	0.69768E 03	10000
19	0.68386E 03	10000
20	0.67032E 03	10000
21	0.65705E 03	10000
22	0.64404E 03	10000
23	0.63128E 03	10000
24	0.61878E 03	10000
25	0.60653E 03	10000
26	0.59452E 03	10000
27	0.58275E 03	10000
28	0.57121E 03	10000
29	0.55990E 03	10000
30	0.54881E 03	10000
AVERAGE		10000

TIME= 2.213 SEC.

```
RABID
 PLATE,FOIL EQUIVALENCE THEORY CHECK  1/8 IN U-238 1 IN C      8 REGION

        NO. CELL REGIONS =  8                          NO. MATERIALS =  2
        NO. COMPOSITIONS =  2                          NO. RESONANT MATERIALS = 1
        NO. BROAD GROUPS =  1                          LETHARGY WIDTH INTER. GROUP =0.100000E-01
        NO. INTERMEDIATE GROUPS =   5                  RESONANCE TEST = 0.100E-01 (BARNS) NOPT= 4 KFOIL= 1

RESONANT MATERIALS HAVE BROAD-GROUP-DEPENDENT ABSORPTION AND FISSION CROSS SECTIONS


 REGION/COMPOSITION/OUTER DIMENSION/TEMPERATURE

      1       2       3       4       5       6       7       8
      1       1       1       1       2       2       2       2
0.07937 0.15875 0.23812 0.31750 0.95250 1.58750 2.22250 2.85750
 293.00  293.00  293.00  293.00  293.00  293.00  293.00  293.00


FOIL  COMPOSITION       THICKNESS    TEMPERATURE
   1            3       0.10000E-09   293.000


 MATERIAL  RES.        MASS    SIG POT   SIG A 1/V    SIG F 1/V
U 238      66       0.23800E 03 0.10600E 02 0.0         0.0
C  12       0       0.12000E 02 0.47000E 01 0.0         0.0

ISOTOPE    1
0.42000E-01 0.0          0.10000E 01

ISOTOPE    2
0.0          0.75000E-01 0.0


BROAD GROUP    NO. INTER. GROUPS    NO. FINE GP/INTER GP    MAXIMUM ENERGY (EV)    MINIMUM ENERGY (EV)    BUCKLING
        1                    5                    50            0.2613E 04            0.2486E 04            0.1000E-02


 NUMBER OF FINE GROUPS USED TO LETHARGY-AVERAGE SCATTERING RATES FOR EACH MATERIAL


BROAD GROUP NO.=   1

     U 238         1

     C  12         1
```

RESONANCE PARAMETERS

MATERIAL	ENERGY(EV)	GAMMA N (EV)	GAMMA GAMMA (EV)	GAMMA F (EV)	G
U 238	0.12450E 04	0.23000E 00	0.24600E-01	0.0	0.10000E 01
U 238	0.12670E 04	0.27000E-01	0.24600E-01	0.0	0.10000E 01
U 238	0.12730E 04	0.29000E-01	0.24600E-01	0.0	0.10000E 01
U 238	0.12990E 04	0.36000E-02	0.24600E-01	0.0	0.10000E 01
U 238	0.13170E 04	0.47000E-02	0.24600E-01	0.0	0.10000E 01
U 238	0.13360E 04	0.15000E-02	0.24600E-01	0.0	0.10000E 01
U 238	0.13930E 04	0.17000E 00	0.24600E-01	0.0	0.10000E 01
U 238	0.14050E 04	0.82000E-01	0.24600E-01	0.0	0.10000E 01
U 238	0.14200E 04	0.11000E-01	0.24600E-01	0.0	0.10000E 01
U 238	0.14280E 04	0.34000E-01	0.24600E-01	0.0	0.10000E 01
U 238	0.14440E 04	0.23000E-01	0.24600E-01	0.0	0.10000E 01
U 238	0.14740E 04	0.80500E-01	0.24600E-01	0.0	0.10000E 01
U 238	0.15230E 04	0.21000E 00	0.24600E-01	0.0	0.10000E 01
U 238	0.15460E 04	0.20000E-02	0.24600E-01	0.0	0.10000E 01
U 238	0.15500E 04	0.20000E-02	0.24600E-01	0.0	0.10000E 01
U 238	0.15650E 04	0.24000E-02	0.24600E-01	0.0	0.10000E 01
U 238	0.16230E 04	0.90000E-01	0.24600E-01	0.0	0.10000E 01
U 238	0.16380E 04	0.40400E-01	0.24600E-01	0.0	0.10000E 01
U 238	0.16620E 04	0.16000E 00	0.24600E-01	0.0	0.10000E 01
U 238	0.16880E 04	0.70000E-01	0.24600E-01	0.0	0.10000E 01
U 238	0.17090E 04	0.50000E-01	0.24600E-01	0.0	0.10000E 01
U 238	0.17230E 04	0.14000E-01	0.24600E-01	0.0	0.10000E 01
U 238	0.17560E 04	0.70000E-01	0.24600E-01	0.0	0.10000E 01
U 238	0.17820E 04	0.50000E 00	0.24600E-01	0.0	0.10000E 01
U 238	0.17980E 04	0.21000E-02	0.24600E-01	0.0	0.10000E 01
U 238	0.18080E 04	0.17000E-01	0.24600E-01	0.0	0.10000E 01
U 238	0.18460E 04	0.13300E-01	0.24600E-01	0.0	0.10000E 01
U 238	0.19020E 04	0.20900E-01	0.24600E-01	0.0	0.10000E 01
U 238	0.19170E 04	0.21900E-01	0.24600E-01	0.0	0.10000E 01
U 238	0.19690E 04	0.57700E 00	0.24600E-01	0.0	0.10000E 01
U 238	0.19750E 04	0.46700E 00	0.24600E-01	0.0	0.10000E 01
U 238	0.20240E 04	0.20200E 00	0.24600E-01	0.0	0.10000E 01
U 238	0.20310E 04	0.49600E-01	0.24600E-01	0.0	0.10000E 01
U 238	0.20890E 04	0.13700E-01	0.24600E-01	0.0	0.10000E 01
U 238	0.20970E 04	0.10100E-01	0.24600E-01	0.0	0.10000E 01
U 238	0.21240E 04	0.46000E-02	0.24600E-01	0.0	0.10000E 01
U 238	0.21460E 04	0.34700E-01	0.24600E-01	0.0	0.10000E 01
U 238	0.21530E 04	0.17600E 00	0.24600E-01	0.0	0.10000E 01
U 238	0.21720E 04	0.23000E-02	0.24600E-01	0.0	0.10000E 01
U 238	0.21860E 04	0.36500E 00	0.24600E-01	0.0	0.10000E 01
U 238	0.21940E 04	0.23000E-02	0.24600E-01	0.0	0.10000E 01
U 238	0.22010E 04	0.11300E 00	0.24600E-01	0.0	0.10000E 01
U 238	0.22300E 04	0.47000E-02	0.24600E-01	0.0	0.10000E 01
U 238	0.22360E 04	0.47000E-02	0.24600E-01	0.0	0.10000E 01
U 238	0.22420E 04	0.14000E-02	0.24600E-01	0.0	0.10000E 01
U 238	0.22590E 04	0.65600E-01	0.24600E-01	0.0	0.10000E 01
U 238	0.22660E 04	0.14500E 00	0.24600E-01	0.0	0.10000E 01
U 238	0.22810E 04	0.11000E 00	0.24600E-01	0.0	0.10000E 01
U 238	0.22890E 04	0.24000E-02	0.24600E-01	0.0	0.10000E 01
U 238	0.23020E 04	0.96000E-03	0.24600E-01	0.0	0.10000E 01
U 238	0.23160E 04	0.14400E-01	0.24600E-01	0.0	0.10000E 01
U 238	0.23370E 04	0.48300E-02	0.24600E-01	0.0	0.10000E 01
U 238	0.23520E 04	0.63000E-01	0.24600E-01	0.0	0.10000E 01

U 238	0.23560E 04	0.63100E-01	0.24600E-01	0.0	0.10000E 01
U 238	0.23930E 04	0.11200E-01	0.24600E-01	0.0	0.10000E 01
U 238	0.24100E 04	0.44100E-02	0.24600E-01	0.0	0.10000E 01
U 238	0.24270E 04	0.81300E-01	0.24600E-01	0.0	0.10000E 01
U 238	0.24460E 04	0.11100E 00	0.24600E-01	0.0	0.10000E 01
U 238	0.24540E 04	0.24700E-02	0.24600E-01	0.0	0.10000E 01
U 238	0.24900E 04	0.54900E-01	0.24600E-01	0.0	0.10000E 01
U 238	0.25210E 04	0.10000E-01	0.24600E-01	0.0	0.10000E 01
U 238	0.25490E 04	0.34300E 00	0.24600E-01	0.0	0.10000E 01
U 238	0.25590E 04	0.21700E 00	0.24600E-01	0.0	0.10000E 01
U 238	0.25810E 04	0.24400E 00	0.24600E-01	0.0	0.10000E 01
U 238	0.25990E 04	0.56100E 00	0.24600E-01	0.0	0.10000E 01
U 238	0.26040E 04	0.25000E-02	0.24600E-01	0.0	0.10000E 01

THE FOLLOWING PAIRS ARE SYMMETRIC REGIONS
1 4 2 3 5 8 6 7

PLATE,FOIL EQUIVALENCE THEORY CHECK 1/8 IN U-238 1 IN C 8 REGION

SUMMARY FOR BROAD GROUP 1 0.26130E 04 EV TO 0.24856E 04 EV

			AVERAGE	SIGMA A	SIGMA F	SIGMA S	FLUX
			CELL	0.29647D-02	0.0	0.38710D 00	0.98211D 00
	COMPOSITION	MATERIAL					
	1						0.96669E 00
RA= 0.31196E-01	RF= 0.0	U 238		0.64542E 00	0.0	0.15926E 02	
	2						0.98403E 00
RA= 0.0	RF= 0.0	C 12		0.0	0.0	0.47000E 01	

CUMULATIVE ABSORPTION PROBABILITY = 0.291976D-02

REGIONAL INTERMEDIATE GROUP FLUXES FOR BROAD GROUP 1

LOWER ENERGY(EV)	1	2	3	4	5	6	7	8
	1	1	1	1	2	2	2	2
1 0.25870E 04	8549	8325	8325	8549	9157	9337	9337	9157
2 0.25613E 04	9987	9822	9822	9987	9999	9941	9941	9999
3 0.25358E 04	9068	8799	8799	9068	9445	9510	9510	9445
4 0.25105E 04	11144	11168	11168	11144	10685	10464	10464	10685
5 0.24856E 04	9913	9897	9897	9913	9934	9932	9932	9934
AVERAGE	9732	9602	9602	9732	9844	9837	9837	9844

FOIL 1

INTERFACE	RA(F)	RF(F)	RS(F)
1	0.59221E 00	0.0	0.14942E 02
2	0.54922E 00	0.0	0.14359E 02
3	0.59221E 00	0.0	0.14942E 02
4	0.88561E 00	0.0	0.19195E 02
5	0.10821E 01	0.0	0.21627E 02
6	0.11212E 01	0.0	0.22132E 02
7	0.10821E 01	0.0	0.21627E 02
8	0.88561E 00	0.0	0.19195E 02

TIME= 73.332 SEC.

```
RABID
      U-238 FOILS IN ZPR-3 ASSY 53     C-17      RESONANCE SET-02

         NO. CELL REGIONS = 12                          NO. MATERIALS =  9
         NO. COMPOSITIONS = 10                          NO. RESONANT MATERIALS = 5
         NO. BROAD GROUPS =  1                          LETHARGY WIDTH INTER. GROUP =0.845700E-03
         NO. INTERMEDIATE GROUPS =  10                  RESONANCE TEST = 0.100E-02 (BARNS) NOPT= 3 KFOIL= 1

RESONANT MATERIALS HAVE BROAD-GROUP-DEPENDENT ABSORPTION AND FISSION CROSS SECTIONS


 REGION/COMPOSITION/OUTER DIMENSION/TEMPERATURE

      1       2       3       4       5       6       7       8       9      10      11      12
      1       2       3       4       5       6       6       6       7       8       9      10
0.46610 1.73610 1.76658 2.02312 2.05360 2.68860 3.32360 3.95860 3.98908 4.56312 4.59360 5.54610
 300.00  300.00  300.00  300.00  300.00  300.00  300.00  300.00  300.00  300.00  300.00  300.00


FOIL  COMPOSITION        THICKNESS     TEMPERATURE
  1          11         0.12700E-01    300.000


 MATERIAL  RES.        MASS     SIG POT   SIG A 1/V    SIG F 1/V
 U-238     20        0.23800E 03 0.10600E 02 0.0          0.0
    AL      2        0.27000E 02 0.14000E 01 0.18000E-02 0.0
    FE      6        0.55850E 02 0.52200E 01 0.0          0.0
    CR      5        0.52010E 02 0.37100E 01 0.0          0.0
    NI      4        0.58700E 02 0.65700E 01 0.0          0.0
PU-240      0        0.24000E 03 0.13180E 02 0.19900E 03 0.0
PU-239      0        0.23900E 03 0.10320E 02 0.66200E 03 0.0
    MO      0        0.96000E 02 0.70000E 01 0.69400E 02 0.0
     C      0        0.12000E 02 0.47000E 01 0.0          0.0

ISOTOPE    1
0.0          0.0          0.0          0.0          0.0          0.0          0.0          0.30877E-01 0.0          0.0
0.47600E-01

ISOTOPE    2
0.0          0.0          0.0          0.29360E-02 0.0          0.0          0.0          0.0          0.0          0.0
0.0

ISOTOPE    3
0.35370E-01 0.0          0.61970E-01 0.0          0.61970E-01 0.0          0.61970E-01 0.0          0.61970E-01 0.0
0.0

ISOTOPE    4
0.88000E-02 0.0          0.15410E-01 0.0          0.15410E-01 0.0          0.15410E-01 0.0          0.15410E-01 0.0
0.0
```

```
ISOTOPE    5
0.38500E-02 0.0         0.67500E-02 0.0         0.67500E-02 0.0         0.67500E-02 0.0         0.67500E-02 0.0
0.0

ISOTOPE    6
0.0         0.0         0.0         0.13516E-02 0.0         0.0         0.0         0.66228E-03 0.0         0.0
0.0

ISOTOPE    7
0.0         0.0         0.0         0.28429E-01 0.0         0.0         0.0         0.70762E-02 0.0         0.0
0.0

ISOTOPE    8
0.0         0.0         0.0         0.0         0.0         0.0         0.0         0.24630E-02 0.0         0.0
0.0

ISOTOPE    9
0.0         0.81830E-01 0.0         0.0         0.0         0.81830E-01 0.0         0.0         0.0         0.81830E-01
0.0


BROAD GROUP    NO. INTER. GROUPS    NO. FINE GP/INTER GP    MAXIMUM ENERGY (EV)    MINIMUM ENERGY (EV)    BUCKLING
        1                   10                      12            0.2197E 05             0.2178E 05            0.0


 NUMBER OF FINE GROUPS USED TO LETHARGY-AVERAGE SCATTERING RATES FOR EACH MATERIAL

BROAD GROUP NO.=    1

      U-238         1

         AL         2

         FE         1

         CR         1

         NI         1

     PU-240         1

     PU-239         1

         MO         1

          C         4
```

RESONANCE PARAMETERS

MATERIAL	ENERGY(EV)	GAMMA N (EV)	GAMMA GAMMA (EV)	GAMMA F (EV)	G
U-238	0.21787E 05	0.87064E-03	0.24600E-01	0.0	-0.20000E 01
U-238	0.21796E 05	0.26002E-01	0.24600E-01	0.0	-0.20000E 01
U-238	0.21806E 05	0.16087E-03	0.24600E-01	0.0	-0.20000E 01
U-238	0.21815E 05	0.42320E-02	0.24600E-01	0.0	-0.20000E 01
U-238	0.21824E 05	0.90319E-02	0.24600E-01	0.0	-0.20000E 01
U-238	0.21833E 05	0.55722E-02	0.24600E-01	0.0	-0.20000E 01
U-238	0.21843E 05	0.22009E-02	0.24600E-01	0.0	-0.20000E 01
U-238	0.21852E 05	0.21119E-01	0.24600E-01	0.0	-0.20000E 01
U-238	0.21861E 05	0.71710E-02	0.24600E-01	0.0	-0.20000E 01
U-238	0.21870E 05	0.32660E-01	0.24600E-01	0.0	-0.20000E 01
U-238	0.21880E 05	0.19063E-04	0.24600E-01	0.0	-0.20000E 01
U-238	0.21889E 05	0.56503E-01	0.24600E-01	0.0	-0.20000E 01
U-238	0.21898E 05	0.31341E-02	0.24600E-01	0.0	-0.20000E 01
U-238	0.21907E 05	0.17230E-01	0.24600E-01	0.0	-0.20000E 01
U-238	0.21917E 05	0.11329E-01	0.24600E-01	0.0	-0.20000E 01
U-238	0.21926E 05	0.41969E-01	0.24600E-01	0.0	-0.20000E 01
U-238	0.21935E 05	0.14024E-01	0.24600E-01	0.0	-0.20000E 01
U-238	0.21944E 05	0.44760E-03	0.24600E-01	0.0	-0.20000E 01
U-238	0.21954E 05	0.90700E-01	0.24600E-01	0.0	-0.20000E 01
U-238	0.21963E 05	0.14672E-02	0.24600E-01	0.0	-0.20000E 01
AL	0.59060E 04	0.20000E 02	0.0	0.0	0.41670E 00
AL	0.35040E 05	0.15000E 04	0.0	0.0	0.58330E 00
FE	0.11500E 04	0.56000E-01	0.67300E 00	0.0	0.91680E 00
FE	0.39000E 04	0.22000E 03	0.10000E 01	0.0	0.21700E-01
FE	0.60000E 04	0.42000E 03	0.17000E 01	0.0	0.21700E-01
FE	0.80000E 04	0.10000E 04	0.30000E 01	0.0	0.58400E-01
FE	0.27000E 05	0.0	0.60000E 01	0.0	0.21700E-01
FE	0.28300E 05	0.16700E 04	0.15000E 01	0.0	0.91680E 00
CR	0.42500E 04	0.10000E 03	0.0	0.0	0.59600E-01
CR	0.66000E 04	0.17000E 04	0.30000E 01	0.0	0.43100E-01
CR	0.23500E 05	0.49000E 03	0.0	0.0	0.23800E-01
CR	0.26500E 05	0.50000E 03	0.0	0.0	0.23800E-01
CR	0.28700E 05	0.51000E 03	0.0	0.0	0.43100E-01
NI	0.46000E 04	0.13000E 04	0.0	0.0	0.36600E-01
NI	0.12500E 05	0.26000E 04	0.0	0.0	0.26160E 00
NI	0.15500E 05	0.15400E 04	0.0	0.0	0.67760E 00
NI	0.28700E 05	0.11100E 04	0.0	0.0	0.26160E 00

NO SYMMETRIC REGIONS

U-238 FOILS IN ZPR-3 ASSY 53 C-17 RESONANCE SET-02

SUMMARY FOR BROAD GROUP 1 0.21968E 05 EV TO 0.21783E 05 EV

AVERAGE			SIGMA A	SIGMA F	SIGMA S	FLUX
CELL			0.24082D-02	0.0	0.36450D 00	0.10212D 01
	COMPOSITION	MATERIAL				
	1					0.10688E 01
RA= 0.13867E-04	RF= 0.0	FE	0.15342E-02	0.0	0.16921E 01	
RA= 0.47774E-06	RF= 0.0	CR	0.52855E-04	0.0	0.37863E 01	
RA= 0.0	RF= 0.0	NI	0.0	0.0	0.16769E 02	
	2					0.10252E 01
RA= 0.0	RF= 0.0	C	0.0	0.0	0.47000E 01	
	3					0.10217E 01
RA= 0.13256E-04	RF= 0.0	FE	0.15341E-02	0.0	0.16922E 01	
RA= 0.45671E-06	RF= 0.0	CR	0.52856E-04	0.0	0.37863E 01	
RA= 0.0	RF= 0.0	NI	0.0	0.0	0.16770E 02	
	4					0.10162E 01
RA= 0.15469E-04	RF= 0.0	AL	0.18000E-02	0.0	0.86361E 00	
RA= 0.18390E-02	RF= 0.0	PU-240	0.21400E 00	0.0	0.13180E 02	
RA= 0.61179E-02	RF= 0.0	PU-239	0.71190E 00	0.0	0.10320E 02	
	5					0.10202E 01
RA= 0.13236E-04	RF= 0.0	FE	0.15341E-02	0.0	0.16922E 01	
RA= 0.45602E-06	RF= 0.0	CR	0.52856E-04	0.0	0.37863E 01	
RA= 0.0	RF= 0.0	NI	0.0	0.0	0.16770E 02	
	6					0.10099E 01
RA= 0.0	RF= 0.0	C	0.0	0.0	0.47000E 01	
	7					0.10140E 01
RA= 0.13155E-04	RF= 0.0	FE	0.15340E-02	0.0	0.16923E 01	
RA= 0.45327E-06	RF= 0.0	CR	0.52858E-04	0.0	0.37863E 01	
RA= 0.0	RF= 0.0	NI	0.0	0.0	0.16770E 02	
	8					0.10061E 01
RA= 0.24576E-02	RF= 0.0	U-238	0.28885E 00	0.0	0.10992E 02	
RA= 0.18208E-02	RF= 0.0	PU-240	0.21400E 00	0.0	0.13180E 02	
RA= 0.60570E-02	RF= 0.0	PU-239	0.71190E 00	0.0	0.10320E 02	
RA= 0.63499E-03	RF= 0.0	MO	0.74632E-01	0.0	0.70000E 01	
	9					0.10189E 01
RA= 0.13219E-04	RF= 0.0	FE	0.15340E-02	0.0	0.16922E 01	
RA= 0.45548E-06	RF= 0.0	CR	0.52858E-04	0.0	0.37863E 01	
RA= 0.0	RF= 0.0	NI	0.0	0.0	0.16770E 02	
	10					0.10262E 01
RA= 0.0	RF= 0.0	C	0.0	0.0	0.47000E 01	

CUMULATIVE ABSORPTION PROBABILITY = 0.444990D-03

REGIONAL INTERMEDIATE GROUP FLUXES FOR BROAD GROUP 1

LOWER ENERGY(EV)	1	2	3	4	5	6	7	8	9	10	11	12
	1	2	3	4	5	6	6	6	7	8	9	10
1 0.21949E 05	10671	10217	10186	10125	10169	10077	10024	9973	9967	9827	10022	10175
2 0.21930E 05	10744	10278	10242	10183	10226	10142	10113	10125	10199	10129	10250	10304
3 0.21912E 05	10692	10243	10209	10151	10193	10107	10067	10047	10077	9976	10129	10234
4 0.21893E 05	10718	10268	10232	10175	10217	10135	10106	10115	10182	10112	10232	10290
5 0.21875E 05	10668	10234	10201	10145	10185	10103	10064	10043	10072	9972	10122	10225
6 0.21856E 05	10677	10245	10211	10156	10196	10116	10083	10076	10122	10039	10171	10251
7 0.21838E 05	10685	10257	10222	10168	10207	10130	10103	10112	10177	10112	10225	10279
8 0.21819E 05	10685	10261	10226	10173	10211	10137	10113	10130	10205	10149	10252	10292
9 0.21801E 05	10686	10267	10231	10180	10217	10144	10125	10151	10237	10193	10283	10308
10 0.21783E 05	10651	10244	10210	10160	10196	10123	10096	10103	10162	10098	10208	10263
AVERAGE	10688	10252	10217	10162	10202	10121	10090	10087	10140	10061	10189	10262

FOIL 1

INTERFACE	RA(F)	RF(F)	RS(F)
1	0.14441E-01	0.0	0.54269E 00
2	0.13937E-01	0.0	0.52334E 00
3	0.13929E-01	0.0	0.52304E 00
4	0.13908E-01	0.0	0.52232E 00
5	0.13912E-01	0.0	0.52247E 00
6	0.13789E-01	0.0	0.51829E 00
7	0.13737E-01	0.0	0.51745E 00
8	0.13682E-01	0.0	0.51894E 00
9	0.13663E-01	0.0	0.51863E 00
10	0.13733E-01	0.0	0.52111E 00
11	0.13756E-01	0.0	0.52159E 00
12	0.14430E-01	0.0	0.54254E 00

TIME= 69.339 SEC.

APPENDIX E

Glossary of Symbols

1. Mathematical Symbols

Symbol	Section	Equation	Definition
Γ^x	V	-	Total width of resonance (x = s for s-waves, x = p for p-waves).
Γ_z	V	-	Neutron width for process z (z = γ, f, and n for capture, fission, and scattering, respectively).
Γ_n^p	V	-	$\Gamma_n^0 \sqrt{E_0}\, v_1(E_0)$, where Γ_n^0 is the reduced neutron width and $v_1(E_0) = \dfrac{\sigma_p E_0}{2.60385 \times 10^6 \left(1 + \frac{1}{A}\right)^2 + \sigma_p E_0}$ = p-wave penetration factor.
Δ	A.4	A.20	Foil optical thickness.
Δ	V	-	$2\left(\frac{kTE}{A}\right)^{1/2}$ = Doppler width of a resonance at energy E; k is Boltzmann's constant.
ΔU_I	VI	-	Lethargy width of intermediate or broad group I.
ΔS	II.B	16	Spatially linear slowing-down source component.
Δu	II.A	8	Lethargy width of a fine group.
Σ_z	II.A	-	Macroscopic neutron cross section for process z.

Process	z
Absorption	a
Capture	c
Fission	f
Scattering	s
Total	t
Potential scattering	p

${}_z\overline{\Sigma}_I$	VI.E	55	Cell-averaged macroscopic cross section for process z.

Symbol	Section	Equation	Definition
${}_z\overline{\Sigma}^n_{\ell I}$	VI.H	60	Average macroscopic cross section for process z in group I, for foil n at interface ℓ.
α	II.A	3	$\left(\frac{A-1}{A+1}\right)^2$, where A is the ratio of target nuclide mass to neutron mass.
$\alpha_n(z)$	A.1	A.2	$\int_1^\infty t^n e^{-zt}\,dt, \quad n \geq 0.$
$\alpha_{n,\ell}$	A.1	A.7	$\int_1^\infty t^{\ell-n} e^{-t}\,dt$ = ℓth moment of e^{-t}/t^n weighting function.
γ	B.12	B.2	Euler's constant = 0.5772156649... .
ϵ	II.A	-	$2\,\ell n\,\frac{A+1}{A-1}$ = maximum lethargy increment upon elastic scattering.
ξ	V	43	$\Gamma/\Delta;\ \Delta = 2\left(\frac{kTE}{A}\right)^{1/2}$ = Doppler width.
ξ	VI.G	59	Average lethargy increment for an elastic scattering collision.
$\overline{\mu}_{0j}$	II.B	32	$2/(3A)$ for material j.
σ_0^x	V	-	Peak value of resonance cross section, barns (x = s or p for s- or p-waves).
σ_z	V	-	Microscopic neutron cross section for process z (barns).

Process	z
Absorption	a
Capture	c
Fission	f
Scattering	s
Total	t
Potential scattering	p

${}_z\overline{\sigma}^j_{mI}$	VI.F	56	Composition-averaged microscopic cross section for process z.

Symbol	Section	Equation	Definition
$\phi(\vec{r}, u)$	II.A	1	Neutron flux per unit lethargy at space point $\vec{r}$ and lethargy u.
$\phi(x, u)$	II.A	6	Neutron flux per unit lethargy at space point x and lethargy u (one-dimensional slab geometry).
$\phi_\ell(x)$	II.A	8	Average neutron flux per unit lethargy at space point x in lethargy group ℓ.
ϕ_{ik}	VI	-	Spatially integrated flux per unit lethargy in fine group k and region i.
$\overline{\phi}^n_{\ell I}$	VI.H	60	Average neutron flux per unit lethargy integrated over foil n in broad group I at interface ℓ.
ϕ_∞	VI	-	Neutron flux per unit lethargy that would be present in the absence of resonances, far from neutron sources. The code assumes $\phi_\infty = 1$.
ϕ_{inc}	VI.H	61	Neutron flux per unit lethargy incident upon a foil.
$\overline{\phi}_I$	VI.C	53	Cell-averaged flux in intermediate or broad group I.
$\overline{\phi}_{iI}$	VI.A	51	Regional average flux in intermediate or broad group I.
$\overline{\phi}_{mI}$	VI.B	52	Composition-averaged flux in intermediate or broad group I.
$\chi(\xi, x)$	V	50	Antisymmetric Doppler-broadened line-shape function.
$\Psi(\xi, x)$	V	49	Symmetrical Doppler-broadened line-shape function.
A	II.A	-	Ratio of target nuclide mass to neutron mass (elastic scattering).
A_i	II.B	30	Thickness of region i (cm).
B^2	II.B	29	Buckling of finite medium for nonleakage probability.

Symbol	Section	Equation	Definition
$C(z, h)$	B.17	B.9	Approximate error correction for $S_2(z, h)$ for $z < 0.3$.
$\overrightarrow{CR}(1 \rightarrow 2)$	II.B	18	Collision rate in region 2 due to a neutron source in region i, for neutrons proceeding to the right.
$\overrightarrow{CR}_\infty(1 \rightarrow 2)$	II.B	19	Collision rate in region 2 due to neutron sources in all type 1 regions, for an infinitely repeating array of unit cells, for neutrons proceeding to the right.
$\langle D \rangle_k$	II.B	32	Cell-averaged diffusion coefficient for neutron leakage from finite systems.
E	V	44	Neutron energy (in laboratory), eV.
E_0	V	44	Resonance energy (in laboratory), eV.
E_n	II.A	5	Exponential integral function of order $n \geq 0$.
$F_s(u', \vec{r}')$	II.A	2	Scattering rate at lethargy u' and space point $\vec{r}'$.
$\vec{J}(x, u)$	II.A	7	Neutron current/unit lethargy at space point x and lethargy u.
$\vec{J}(\tau, \tau_1)$	II.B	17	Neutron current at τ mean free paths beyond a source region of optical thickness τ_1.
L	II.A	12	$= \epsilon/\Delta u$ = number of fine groups that contribute to slowing-down source from elastic scattering (not including ingroup scattering).
N_{jm}	VI.D	54	Atom number density of material j in composition m.
$P(u' \rightarrow u)$	II.A	3	Probability of elastic scattering from lethargy u' to u.
$\underline{P}$	II.B	21	P_{ij} is probability of a neutron born in region i suffering its next collision in region j.
P_ℓ	II.A	10	Probability of elastic scattering from group $k - \ell$ to k; $1 < \ell < \epsilon/\Delta u$.

Symbol	Section	Equation	Definition
P_s	II.A	11	Probability of ingroup elastic scattering.
$\underline{R}$	II.B	22	$R_{ij} = (\Sigma_s P_s/\Sigma_t)_i, \quad i = j,$ $= 0, \quad i \neq j.$
$R_M(z)$	A.1	A.4	Remainder of Mth-order Gauss quadrature.
${}_zR^j_{ik}$	VI.D	54	$(\phi_{ik})_z \Sigma^{jk} \Delta u$ = reaction rate for process z in fine group k and material j integrated over region i.
RAP	VI.G	57	Accumulated absorption probability.
${}_zRI^j_{mI}$	VI.F	56	Resonance integral for process z in material j, in composition m and group I.
${}_zRI^{\ell j}_{nI}$	VI.H	60	Resonance integral for process z in material j, in group I, in foil n, at interface ℓ.
$\overline{S}$	II.B	16	Spatially flat slowing-down source component.
$S(x')$	II.B	16	Total elastic scattering source at space point x'.
$S_n(z, h)$	A.1	A.3	$\sum_{k=0}^{\infty} E_n(z + kh), \quad n \geq 0.$
$S_{sk}(x')$	II.A	-	Ingroup elastic scattering source in group k at space point x'.
$S_{0k}(x')$	II.A	12	Slowing-down source in group k at space point x' from all groups $k - \ell$, $1 \leq \ell \leq L$.
SDD	VI.G	58	Slowing-down density at the lethargy corresponding to the start of the problem.
$W(z)$	V	49	Complex probability integral, where $z = u + iv$.
$f_{s\ell}(x')$	II.A	9	Average scattering rate per unit lethargy in group ℓ at space point x'.
g_J	V	43	$\frac{2J + 1}{2(2I + 1)}$, where J = total spin of compound nucleus and I is spin of target nucleus.

Symbol	Section	Equation	Definition
h	II.B	19	Optical thickness of unit cell.
t_l	II.B	15	Thickness of source region l (cm).
$t_{i,n}$	A.1	A.4	Gaussian quadrature abscissas of order M, $1 \leq i \leq M$, for exponential integral function of order n.
u_I	VI.A	51	Lower lethargy bound of group I.
x	V	43	$2(E - E_0)/\Gamma$.
x_m	VI.B	52	Left boundary of composition m ($x_1 = 0$).
w	III	-	$= \left(\frac{4EkT}{A}\right)^{1/2}$ = Doppler width of a resonance at energy E; k is Boltzmann's constant.
$w_{i,n}$	A.1	A.4	Gaussian quadrature weights of order M, $1 \leq i \leq M$, for exponential integral function of order n.

2. Code Symbols

QUANTITIES DENOTED BY * ARE INPUT VARIABLES

ABC		LINEAR SOURCE COMPONENT CURRENT LEAVING A REGION FROM RIGHT
ACS		BROAD GROUP AVERAGE ABSORPTION CROSS SECTION FOR CELL
ACSGP		INTERMEDIATE GROUP AVERAGE ABSORPTION CROSS SECTION FOR CELL
AF		BROAD GROUP AVERAGE FOIL MACROSCOPIC ABSORPTION CROSS SECTION
AIMW		IMAGINARY PART OF COMPLEX PROBABILITY INTEGRAL W(Z)
AIMZ		IMAGINARY PART OF ARGUMENT FOR COMPLEX PROBABILITY INTEGRAL W(Z)
ALP		ALPHA=((A-1)/(A+1))**2
AMU	*	MATERIAL MASS (UNITS OF NEUTRON MASS)
AREA		REGION THICKNESS
AREAC		THICKNESS OF COMPOSITION
AREAT		TOTAL THICKNESS OF UNIT CELL
AX		REZ (QUICKW)
BARMU		AVERAGE COSINE OF SCATTERING ANGLE, 2/(3A)
BIN		BACK DIRECTION LINEAR SOURCE CURRENT ENTERING ON RIGHT
BOUT		BACK DIRECTION LINEAR SOURCE CURRENT LEAVING ON LEFT
BOUTL		LAST VALUE OF BOUT NEEDED
BSQ	*	BUCKLING FOR NEUTRON LEAKAGE FROM FINITE SYSTEMS
CR		COLLISION RATE VECTOR
D		DIFFUSION COEFFICIENT FOR CELL
DDS		DS IN RATES
DEN	*	MATERIAL ATOM DENSITY MATRIX (10**24 ATOMS/BARN-CM)
DETERM		DETERMINANT OF MATRIX INVERTED BY MATINV
DFS		FORWARD LINEAR SOURCE COMPONENT (LEFT TO RIGHT) (RATES)
DIFX		NOT USED
DPS		PS
DR		REGION THICKNESS
DS		SUM OF ALL CORRECTIONS TO SOURCE IN GROUP K COMPARED TO ASYMPTOTIC VALUE ENTERING PROBLEM FROM ABOVE
DS		LINEAR SOURCE COMPONENT (RATES)
DSL		ALP*PS
DSMAX		RECURSION COEFFICIENT FOR ELASTIC SCATTERING FROM GROUP K-1-L TO K
DSR		REVERSE DIRECTION LINEAR SOURCE COMPONENT (RIGHT TO LEFT) (RATES)
DS1		RECURSION COEFFICIENT FOR ELASTIC SCATTERING FROM GROUP K-1 TO K
DUSTR		BROAD GROUP LETHARGY WIDTH
ENGP		UPPER ENERGY BOUND (EV) OF INTERMEDIATE GROUPS (* ENGP(1))
ER	*	RESONANCE ENERGY (EV)
ETOT		NOT USED
EXDU		DEXP(-UFGP)
FCS		BROAD GROUP AVERAGE FISSION CROSS SECTION FOR CELL
FCSGP		INTERMEDIATE GROUP AVERAGE FISSION CROSS SECTION FOR CELL
FF		BROAD GROUP AVERAGE FOIL MACROSCOPIC FISSION CROSS SECTION
FFF		BROAD GROUP AVERAGE FOIL FLUX
FFLUX		INTERMEDIATE GROUP AVERAGE FOIL FLUX
FIN		FLAT SOURCE COMPONENT CURRENT ENTERING A REGION FROM LEFT
FLUX		INTERMEDIATE GROUP AVERAGE FLUX IN A REGION
FLUXCP		INTERMEDIATE GROUP AVERAGE FLUX IN A COMPOSITION
FOUT		FLAT SOURCE COMPONENT CURRENT LEAVING A REGION FROM RIGHT
FOUTL		LAST VALUE OF FOUT NEEDED
FS		FORWARD FLAT COMPONENT SOURCE (CURRENT TO RIGHT) (RATES)
FIV		SQRT(.0253/ENGP(1))

```
F9          LINEAR SOURCE COMPONENT CURRENT ENTERING A REGION FROM LEFT
G       *   STATISTICAL SPIN FACTOR FOR A RESONANCE
GAMMA       TOTAL WIDTH (EV) OF A RESONANCE
GF      *   FISSION WIDTH (EV) FOR A RESONANCE
GN      *   NEUTRON WIDTH (EV) FOR A RESONANCE
GR      *   RADIATION WIDTH (EV) FOR A RESONANCE
GW2         GAUSS QUADRATURE WEIGHTS FOR E2
GW3         GAUSS QUADRATURE WEIGHTS FOR E3
GW4         GAUSS QUADRATURE WEIGHTS FOR E4
GX2         GAUSS QUADRATURE ABSCISSAS*(-1) FOR E2
GX3         GAUSS QUADRATURE ABSCISSAS*(-1) FOR E3
GX4         GAUSS QUADRATURE ABSCISSAS*(-1) FOR E4
IBG         BROAD GROUP NUMBER
IBGP        INTERMEDIATE GROUP NUMBER
IERR        ERROR INDICATOR IF POSITIVE (FOR SOARCE,RATES,AND XSECT)
IFGP        FINE GROUP NUMBER (WITHIN AN INTERMEDIATE GROUP)
II          KREG
III         KFOIL+KCOMP
INCLUD      SET TO IBGP AT START OF INT. GR. IBGP IF THIS RESONANCE TO BE INCLUDED
            IN RESONANT CROSS SECTION CALCULATIONS FOR THIS INT. GROUP.
            ZERO IF THIS RESONANCE IS NOT IMPORTANT.
INDEX       1=FIRST FINE GROUP IN FIRST INTERMEDIATE GROUP
            2=2ND FINE GROUP IN ANY BROAD GROUP
            3=FIRST FINE GROUP IN ANY BUT FIRST BROAD GROUP
            4=NOT FIRST INTERMEDIATE GROUP IN ANY BROAD GROUP
INUF        NUMBER OF LAST  SCATTERING RATE AVERAGING INTERVAL IN A BROAD GROUP
INUI        NUMBER OF FIRST SCATTERING RATE AVERAGING INTERVAL IN A BROAD GROUP
ISYM        NON-ZERO PAIRS ARE SYMMETRIC REGION NUMBERS
ITRY        POSITIVE IF LINEAR SOURCE TERMS PRESENT AND TO BE INCLUDED (RATES)
JBG         INTERMEDIATE GROUP NUMBER WITHIN A BROAD GROUP
JMULT       FINE GROUP COUNTER FOR AVERAGING SCATTERING RATES
JNU         POSITION COUNTER IN SCATTERING RATE TABLE SCAT (UNITS OF NISO)
KB      *   >0 IMPLIES THAT BROAD GROUP DEPENDENT SMOOTH BACKGROUND CROSS
            SECTIONS ARE TO BE READ FOR FIRST KRES MATERIALS
KBG     *   NUMBER OF BROAD GROUPS
KBSQ    *   SWITCH TO INPUT BUCKLINGS IF >0 ELSE SET BUCKLINGS TO ZERO
KCOMP   *   NUMBER OF COMPOSITIONS
KFOIL   *   NUMBER OF FOILS  (MINUS SIGN TAG SAYS LAST IS INFINITELY THIN)
KGP     *   NUMBER OF INTERMEDIATE GROUPS
KMAT    *   NUMBER OF MATERIALS (MATERIAL=ISOTOPE OR COLLECTION OF ISOTOPES)
KREG    *   NUMBER OF REGIONS
KRES    *   NUMBER OF RESONANT MATERIALS
KS      *   >0 IMPLIES THAT THE ELASTIC SCATTERING PROBABILITIES ARE TO BE
            MODIFIED TO REMOVE INGROUP SCATTERING.  INGROUP SCATTERING IS
            INCLUDED OTHERWISE
LAST        LAST  RESONANCE OF A MATERIAL IS AT THIS LOCATION IN RESONANCE LIST
LLLL        SCALED INTERMEDIATE GROUP FLUXES ROUNDED TO NEAREST INTEGER(OUTPUT)
LOC         SEQUENCE NUMBER OF NON-ZERO ATOM DENSITY MATERIAL/REGION PAIRS
            OBTAINED IN MAIN BY OUTER LOOP OVER REGIONS AND INNER LOOP OVER MATS.
LREG        COMPOSITION NUMBER FOR A REGION
MH          INDEX OF SCATTERING RATE 1 ABOVE MO (SOARCE)
MINT        NUMBER OF LAST REGION IN A COMPOSITION
ML          INDEX OF SCATTERING RATE 1 BELOW MO (SOARCE)
MO          INDEX OF SCATTERING RATE CLOSEST TO FINE GROUP K-L  (SOARCE)
MORE    *   >0 IMPLIES THIS IS LAST PROBLEM, OTHERWISE ADDITIONAL INPUT IS READ
MULT        MULTIPLICITY, OR NUMBER OF FINE GROUPS USED TO AVERAGE SCATTERING RATE
```

NDX		IF COLLISION RATE FOUND TO BE NEGATIVE,NDX IS SET TO 1 TO INITIATE SPECIAL OUTPUT AND RENORMALIZATION OF COLL. RATES TO CONSERVE NEUTRONS AND BE NON-NEGATIVE (MINIMUM SET TO ZERO)
NEXT		FIRST RESONANCE OF A MATERIAL IS AT THIS LOCATION IN RESONANCE LIST
NFI	*	NUMBER OF FINE GROUPS PER INTERMEDIATE GR. IN A BROAD GROUP
NIB	*	NUMBER OF INTERMEDIATE GROUPS PER BROAD GROUP
NINT	*	NUMBER OF REGIONS PER COMPOSITION (EQUAL THICKNESS)
NISO		NUMBER OF REGION/MATERIAL PAIRS WITH NON-ZERO ATOM DENSITY
NOPT	*	NOT POSITIVE IMPLIES A HOMOGENEOUS 1 REGION PROBLEM POSITIVE IMPLIES A HETEROGENEOUS MULTI-REGION PROBLEM >3 IMPLIES NO INTERFERENCE TERM CHI IN RESONANT CROSS SECTIONS
NOX		40000/NISO-1
NOX1		NOX+1
NPRINT	*	<0 GIVES FINE GROUP FLUX OUTPUT AND INTERMEDIATE GROUP OUTPUT =0 GIVES INTERMEDIATE GROUP OUTPUT >0 SUPPRESSES ALL OUTPUT FOR FINE AND INTERMEDIATE GROUPS
NRES	*	NUMBER OF RESONANCES FOR A MATERIAL
NTEMP	*	NUMBER OF DIFFERENT TEMPERATURES
NU		INTERMEDIATE GROUP NUMBER (MODULO 100)
NUCLID	*	ALPHAMERIC NAME FOR MATERIAL(ISOTOPE OR COLLECTION OF ISOTOPES)
NX		REGION NUMBER
NXN		NOX*NISO
P		PROBABILITY OF ESCAPE WITHOUT A COLLISION FROM A REGION
PFLUX		NOT USED
PHI		SPATIALLY INTEGRATED FINE GROUP FLUX IN GROUP K
PHICT		BROAD GROUP AVERAGE FLUX IN COMPOSITION
PHIRT		BROAD GROUP AVERAGE REGION FLUXES
PHIT		INTERMEDIATE GROUP AVERAGE FLUX FOR CELL
PHITOT		BROAD GROUP AVERAGE FLUX FOR CELL
PIJ		MATRIX TO BE INVERTED BY MATINV. IF IT IS THE COLLISION PROBABILITY MATRIX, THEN PIJ(I,J) IS TRANSFER PROBABILITY FROM I TO J
PL		INTERPOLATION INTERVAL FRACTION FOR SCATTERING RATE AT K-L
PNL		NON-LEAKAGE PROBABILITY (RATES)
PS		INGROUP ELASTIC SCATTERING TRANSFER PROBABILITY
P1		MAJOR COMPONENT OF ELASTIC TRANSFER PROBABILITY FROM GROUP K-1 TO K
Q		.5*SOURCE*PNL (RATES)
Q		LETHARGY AT MIDPOINT OF FINE GROUP K-L (SOARCE)
R		DPS*SS (RATES)
RA		BROAD GROUP RESONANCE INTEGRAL FOR ABSORPTION
RA(F)		BROAD GROUP RESONANCE INTEGRAL FOR FOIL ABSORPTION
RAD		DISTANCE FROM LEFT BOUNDARY OF CELL TO RIGHT BOUNDARY OF REGION
RAP		CUMULATIVE ABSORPTION PROBABILITY
RATIO		NOT USED
REW		REAL PART OF COMPLEX PROBABILITY INTEGRAL W(Z)
REZ		REAL PART OF ARGUMENT FOR COMPLEX PROBABILITY INTEGRAL W(Z)
RF		BROAD GROUP RESONANCE INTEGRAL FOR FISSION
RF(F)		BROAD GROUP RESONANCE INTEGRAL FOR FOIL FISSION
RIAC		BROAD GROUP AVERAGE MICROSCOPIC CROSS SECTION FOR ABSORPTION
RIFC		BROAD GROUP AVERAGE MICROSCOPIC CROSS SECTION FOR FISSION
RISC		BROAD GROUP AVERAGE MICROSCOPIC CROSS SECTION FOR SCATTERING
RMAX	*	DISTANCE FROM LEFT BOUNDARY OF CELL TO RIGHT BOUNDARY OF COMPOSITION
SA		MACROSCOPIC ABSORPTION CROSS SECTION IN FINE GROUP K
SCAT		TABLE OF SCATTERING RATES FOR EACH MATERIAL/REGION PAIR
SCL		ELASTIC SCATTERING RATE FROM GROUP K-1-L TO K
SCS		BROAD GROUP AVERAGE SCATTERING CROSS SECTION FOR CELL
SCSGP		INTERMEDIATE GROUP AVERAGE SCATTERING CROSS SECTION FOR CELL

```
SDD        SLOWING DOWN DENSITY ENTERING PROBLEM FROM ABOVE IN ENERGY
SF         MACROSCOPIC FISSION    CROSS SECTION IN FINE GROUP K
SI         ASYMPTOTIC SLOWING DOWN SOURCE ABOVE PROBLEM
SIG        TOTAL MICROSCOPIC CROSS SECTION IN GROUP K
SIGABG     INTERMEDIATE GROUP AVERAGE ABSORPTION CROSS SECTION
SIGA22 *   FLAT BACKGROUND ABSORPTION CROSS SECTION FOR RESONANT MATERIALS.
           .0253 EV 1/V ABSORPTION CROSS SECTION FOR NON-RESONANT MATERIALS
SIGFBG     INTERMEDIATE GROUP AVERAGE FISSION    CROSS SECTION
SIGF22 *   FLAT BACKGROUND FISSION    CROSS SECTION FOR RESONANT MATERIALS.
           .0253 EV 1/V FISSION    CROSS SECTION FOR NON-RESONANT MATERIALS
SIGIN      S-WAVE INTERFERENCE CONTRIBUTION TO SCATTERING CROSS SECTION=SIGIN*CHI
SIGMIN     RESONANCE CROSS SECTION TO BE COMPARED TO TEST
SIGP       MACROSCOPIC POTENTIAL SCATTERING CROSS SECTION
SIGPOT *   MATERIAL POTENTIAL SCATTERING CROSS SECTION
SIGSBG     INTERMEDIATE GROUP AVERAGE SCATTERING CROSS SECTION
SIGTR      MACROSCOPIC TRANSPORT CROSS SECTION FOR A COMPOSITION
SL         SCATTERING CROSS SECTION IN GROUP K-1
SUR        SUM OF ALL DIFFERENCES BETWEEN SOURCE IN GROUP K-1 AND THAT IN GROUP K
           MINUS INGROUP SCATTERING CONTRIBUTION IN GROUP K
SOURCE     SLOWING DOWN SOURCE IN GROUP K
SPN        NOT USED
SPP        NOT USED
SS         MACROSCOPIC SCATTERING CROSS SECTION IN FINE GROUP K
SSF        BROAD GROUP AVERAGE FOIL MACROSCOPIC SCATTERING CROSS SECTION
TAB        E3 AND E4 TABLES
TAU        REGION OPTICAL THICKNESS (RATES)
TEMP   *   TEMPERATURE OF COMPOSITION (DEGREES KELVIN)
TEST   *   VALUE OF RESONANT CROSS SECTION TO BE EXCEEDED IF RESONANCE IS TO BE
           INCLUDED IN FINE GROUP FLUX CALCULATIONS WITHIN AN INTERMEDIATE GROUP
           (THE RESONANCE IS AUTOMATICALLY INCLUDED IF IT LIES WITHIN THE INTER-
           MEDIATE GROUP)
TI         TABLE OF IMAGINARY PART OF W(Z)
TITLE  *   ALPHAMERIC TITLE OF PROBLEM
TOT        OPTICAL THICKNESS OF UNIT CELL(H)
TOT3       NOT USED
TQ         Q/REGION OPTICAL THICKNESS
TR         TABLE OF REAL PART OF W(Z)
TT         FOIL COLLISION RATE IN FINE GROUP K
TTAU       1/REGION OPTICAL THICKNESS
U          UPPER LETHARGY BOUND OF FINE GROUP K (SCARCE)
UFGP       FINE GROUP LETHARGY WIDTH
UIGP   *   INTERMEDIATE GROUP LETHARGY WIDTH
UMAX       UPPER LETHARGY BOUND OF BROAD GROUP
USTR       LOWER LETHARGY BOUND OF A BROAD GROUP (U=0 AT E=ENGP(1))
V          1.-EXDU
V1         ARGUMENT OF S3(V1,H) IN XTRAP
V2         ARGUMENT OF S4(V2,H) IN XTRAP4
V3         Y, IN YZ3 AND YZ4, FOR SUMMING E3 AND E4 FUNCTIONS
V4         DELTA, WHERE Z=Y+V4, IN YZ3 AND YZ4
V5         NOT USED
V6         NOT USED
V7         S3(V1,H) IN XTRAP
V8         S4(V2,H)
V9         S3(Y,H)-S3(Z,H)
V10        S4(Y,H)-S4(Z,H)
V11        NOT USED
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V12	NOT USED
V13	NOT USED
WORK	DOUBLE LENGTH OPTICAL THICKNESS VECTOR
WW2	GAUSS QUADRATURE WEIGHTS FOR S2(Z,H)
WW3	GAUSS QUADRATURE WEIGHTS FOR S3(Z,H)
WW4	GAUSS QUADRATURE WEIGHTS FOR S4(Z,H)
XAREAC	XNFB/AREAC
XAREAT	XNFB/AREAT
XC	.004126+.00628*EXP(-19.8*TOT)
XN	NOT USED
XNFB	1/NFI(IBG)
XRES	SQRT(ER/ENERGY OF GROUP K)
XTEMP	TEMPERATURE OF REGION (DEGREES KELVIN)
Y	AIMZ (QUICKW)
Y	ARGUMENT IN S3(Y,H) OR S4(Y,H) IN YZ3 AND YZ4
Z	ARGUMENT IN S3(Z,H) OR S4(Z,H) IN YZ3 AND YZ4

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