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A Code for Calculation of Group Constant of Resonance Energy Region in Heterogeneous Systems

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PEACO
A Code for Calculation of Group Constants of Resonance Energy Region in Heterogeneous Systems

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Summary

A code was developed for calculating effective group constants of resonance energy region in various heterogeneous systems. This code was made by taking characteristic merits of the codes constructed hitherto for the computation of resonance integral. Heterogeneity is treated by a collision probability method in which the first-collision probabilities are computed by a linear interpolation of the values beforehand prepared. An energy interval under consideration is divided into extremely narrow meshes on which the neutron slowing-down equation is solved using a recurrence formula for the slowing down source. Resonance cross sections are read-in from library tapes corresponding to different temperature of the composition including resonant materials.

This code is written in FACOM-230/60 FORTRAN which is a standard type one commonly used. Important information is stored in variable dimensions determined beforehand by input data. Hence, for practical purpose, there is no special limitation on input data, unless total variable dimensions necessary for a calculation do not exceed 34,000.

PEACO：非均質系における共鳴領域群定数計算コード

日本原子力研究所　東海研究所
石黒幸雄・高野秀機

1971年6月28日受理

要　旨

非均質系における共鳴領域の実効群定数を計算するコードを開発した．このコードはこれまで共鳴積分を計算するために作られた種々のコードの利点を取り入れ，さらに計算法に改良を加えたものである．非均質性は衝突確率法で取り扱い，必要な確率の計算には内ソウ法を用いた．計算されるエネルギー範囲は越微細メッシュに分けられ，それらの上で中性子減速方程式は回帰法で順次解かれる．共鳴断面積は一般にはマルチレベル公式で計算されたライブラリー・テープから読み込まれる．このコードは標準的な FACOM-230/60 FORTRAN で書かれており，重要な情報はすべてバリアブル・デメンジョンに蓄えられる．したがって，入力に関する特別な制限はなく，ほとんどの実用問題が取り扱える．

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1. Introduction

There are two main cases in the treatment of resonance absorption of neutron in nuclear reactors. The first is the case where the resonances are considered to be theoretically well-seperated, that is, level-spacings of resonances are much larger than Doppler width; this treatment has been applied to fertile materials at neutron energies below about 10 keV and has been considered to be suitable for most thermal reactors. The second case occurs when the resonances are not well seperated and/or when there are overlapping resonances due to different materials. This case is important for the fast and intermediate reactors.

Various methods are available for the first case and are well discussed, for example, in references (1) and (2). In this case, it is usually assumed that the flux recovers an asymptotic $1/E$ form below each resonance, that is, "the flux recovery between resonances" is assumed in these methods for resonance absorption. Obtaining an exact analytical solution to the equations for neutron slowing-down however is difficult even under the simple assumption of the flux recovery, and this difficulty has led to a number of approximate solutions to the problem. Examples well-known are the first-order solutions such as the narrow-resonance (NR) and wide-resonance (WR) approximations. Improvements were subsequently made by iterating them in the basic equations of neutron balance, including the intermediate resonance (IR) approximation[3),4)].

For heterogeneous systems, if the geometry is represented precisely, the special problem is unnecessarily complicated for the calculation of resonance absorption. The assumption that the neutron flux is spatially constant within each sub-region of the lattice cell simplifies the problem and reduces the transport problem to the determination of the first-flight collision probabilities for the fuel and moderator regions. The simplification was combined with the selected use of the WR or NR approximation. Especially for an analytical treatment, the approximation of representing the collision probability by a rational expression is quite useful and the heterogeneous systems were treated also with the IR approach using the rational approximation[5),6)].

The assumption of the spatially flux is the serious shortcoming on the analytical approach and the most difficult to remove. The coupled effects of the assumptions of the flat ffux and of the flux recovery may introduce serious errors in some situations[7),8)], for example, when the absorber dimension becomes very large, or when a very heavy nuclide is moderator. In practical cases, further complications may arise from the non-uniform distributions of temperature in fuel pin and/or absorber density with fuel burnup. The difficulty of removing these assumptions from analytical methods results in the use of the methods of directly and accurately evaluating resonance capture in heterogeneous systems (such as RICM[9)], RIFF RAFF[10)], RABBLE[11)], SDR[12)] or the Monte Carlo codes[13),14)])

The calculating method of resonance absorption and Doppler coefficient of reactivity in thermal reactors is considered to be fairly satisfactory, because the neutron spectrum does not much deviate from $1/E$ and the resonance absorption almost comes from few resonance levels of fertile materials (^{238}U) at lower energies where accurate resonance parameters are obtained and the assumption of flux recovery is considered to be sufficiently satisfied. Moreover, the ratio of fissile to fertile isotopes is generally quite small, hence the contribution to the Doppler effect from fissile isotopes are very small.

In fast reactors which contain resonance absorbers in higher volume ratio than thermal reactors, the neutron spectrum is entirely different and is much depleted due to resonance absorption. In this case, the resonances at higher energies contribute most to the Doppler effect, where may be the interference between neighboring resonances in the same isotope. Moreover, to make matters worse, the ratio of fissile to fertile isotopes will be generally much larger and the interference effects between various resonance isotopes become quite important. Hence the second case, where the resonances are not well seperated, is important mainly for fast and intermediate reactors.

For fast reactor anlysis, the effective cross sections have often been calculated by using $1/(E\Sigma_t(E))$ spectrum based on the assumption of the constant collision density. Even if we started with this assumption, we however met the difficulty of the calculation of the integrals over the probability distribution[15] of resonance parameters in unresolved resonance regions. Hence, the variuos approximation methods have been proposed for the estimation of the effective cross sections[2,16,17]. These treatments at present however seem to be less complete, and we can not expect that high accuracy for the Doppler coefficient of reactivity in which calculation account must be taken the rapid energy dependence of the α-value of ^{239}Pu and the sodium scattering resonance and/or heterogeneous effects into is obtained from an approximate method started with the $1/(E\Sigma_t(E))$ spectrum[18].

In order to avoid the shortcomings of the semi-analytical methods based on the $1/(E\Sigma_t(E))$, the construction of a resonance sequence over the unresolved region of interest has been considered to be useful meanings for the calculation of the effective cross sections[19,20,21,22]. From the knowledge of the statistical distribution of resonance parameters and level spacing, it is possible to generate a sequence of resonances over some energy interval by a ramdom sampling method. These resonance parameters can then be used in the codes above described, which have been developed for the resolved resonance region.

Though the codes above introduced can be applied only for some limited cases, they have merits, respectively. For example, the RICM-I code[9] can treat only isolated resonances but it can treat fairly general geometries by an interpolation method of collision probability prepared beforehand. The RIFF RAFF[10] and RABBLE[11] codes adopt an excellent calculation method of slowing-down source which serves time and memory of computer to save, however the geometries treated by them are limited to be cylindrical and moderators must have constant scattering cross sections. On the other hand, the SDR code[12] can treat fairly general problems, but the demerit is to consume long computer time. The Monte Carlo procedure can treat quite general problems with complex geometry but it comsumes considerable computer time and yields neither effective cross sections nor flux distributions.

For general uses, we developed a code, PEACO, for the FACOM 230/60 by taking the merits of the above codes in. This code consists of three subcodes: The first code prepares the resonance cross sections at ultra-fine groups, which will be presented in the section 4. The second calculates the collision probability at the discrete interpolation coordinates given beforehand, which will be shown in the section 5. The last one is the routine for the calculation of the flux distribution, the averaged cross sections, the activation, etc.

2. Scheme of PEACO Code

As mentioned in the introduction, PEACO code consists of three main calculating parts. Computing time for resonance cross sections needed for flux-distribution calculation usually takes half of total computing time or more. Mreover, the cross sections for a fixed energy range and temperature may repeatedly have to be calculated for different cases, if both the calculation parts of the resonance cross sections and of the flux are included in a code. Hence, the first part of the PEACO code (PEACO-MCROSS) calculates the resonance cross sections from resonance parameters over the resonance energy ranges needed for usual calculations and the results are written in library tapes. This separation of the cross section part from the flux part was used also in the RICM and SDR codes.

The PEACO-COLLIS code prepares collision probabilities in the geometry of cylindrical rod or of slab at the specified values of the total cross section of resonance absorbing compositions, which are used as representative points for collision-probability interpolation later. As for the interpolation coordinate, we adopted one used in the RICM code. The inclusion of the collision-probability part into the flux-calculation part will restrict the geometry that can be treat by a code, or it may make a code for solving the neutron slowing-down unnecessarily large. The separation of the collision-probability part will serve to save the computing time, when many calculations must be done for a fixed geometry. For more complicated geometries such as clustered fuel elements, collision probabilies should be calculated by other codes, as

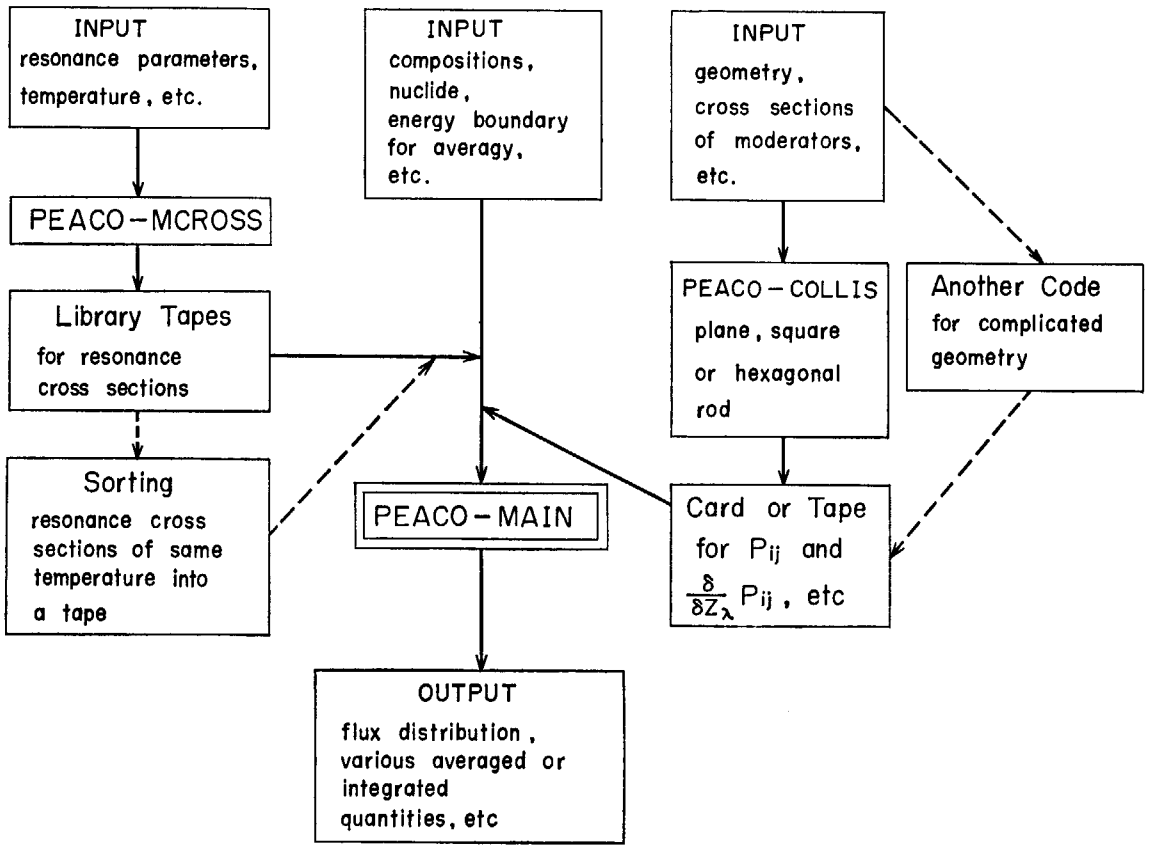

Fig. 1. Scheme of PEACO code

the PEACO code does not have computing device for such a case.

The PEACO-MAIN solves the neutron slowing-down and calculates the various averaged values such as effective resonance cross-sections, using the library tape for resonance cross sections and the input tape or cards prepared by the PEACO-COLLIS or by other codes. The relation between these three codes is schematically shown in **Fig. 1**.

3. Numerical Mothod of Calculating Neutron Flux Distribution

We shall consider a heterogeneous system which may be homogeneous in special case and may generally be infinite lattice of square or hexagonal cell, cylindricalized lattice or clustered type fuel element. This system may consist of several compositions of which the corresponding numbers correspond generally to few different numbers of region, respectively. The resonance-absorbing materials are contained in some compositions, which are called as fuel compositions and are restricted to the following two cases in present treatment.

1) Total cross section of each resonance-absorbing composition slightly differs from others, respectively, for examples, by non-uniform distribution of temperature or of resonance absorber densities with fuel burnup.
2) All the fuel compositions have same temperature and relative ratio of resonance absorber densities in each composition is same as those in others, respectively. For an example of ^{238}U being only a resonance absorber in the system under consideration, any density-distribution of ^{238}U will be permitted.

Special attention should be paid for other kinds of fuel compositions except for the above two cases.

We further assume that neutron balance in such a system can be described by using the first flight collision-probabilities. In order to avoid the flat-flux assumption which should usually be assumed in the collision-probability method, we divide each region of the system into as many sub-regions as necessary or possible. Then, the equation of neutron slowing-down can be expressed as

$$V_i\Sigma_i(u)\phi_i(u)=\underset{j=1}{\overset{J}{Sum}}P_{ij}(u)V_j\left[\underset{k=1}{\overset{K}{Sum}}S_{jk}(u)\right] \tag{3-1}$$

$$S_{ij}(u)=\frac{1}{1-\alpha_k}\int_{u-\varepsilon_k}^{u}e^{-(u-u')}\Sigma_{sjk}(u')\phi_j(u')du' \tag{3-2}$$

with

$$\alpha=((M-1)/(M+1))^2 \quad \text{and} \quad \varepsilon=-\ln\alpha. \tag{3-3}$$

Here, the subscripts (i) ang (j) stand for the sub-region numbers and the (k) corresponds to the nuclear species. P_{ij} is the probability that a neutron born uniformly and isotropically in region j makes its first collision in region i, and other notations have the customary meanings.

By letting $V_i\phi_i(u)e^u$ equal to $\phi_i(u)$, we have

$$\Sigma_i(u)\phi_i(u)=\underset{j,k}{Sum}P_{ij}(u)S_{jk}^0(u) \tag{3-4}$$

with

$$S_{jk}^0(u)=\frac{1}{1-\alpha_k}\int_{u-\varepsilon_k}^{u}\Sigma_{sjk}(u')\phi_j(u')du'. \tag{3-5}$$

Here it should be noted that the equations (3-4) and (3-5) for ϕ_i (u) is simpler than Eqs. (3-1) and (3-2) and the factor e^u multiplied to ϕ_i(u) serves to reduce round errors appeared in the recurrence equations introduced for the numerical calculation of slowing-down source in the next section.

3. 1 Ultra-Fine Group Equation of Neutron Slowing-Down

As the resonance cross sections are the rapidly varying functions of energy, the energy spectrum of neutron flux will be also. To describe this variation accurately, the energy range of interest is divided into extremely narrow groups. For the calculation of the slowing-down source of Eq. (3-5) on this descrete energy meshes, a numerical method based on one developed by KIER[10] will be used. Hence, this ultra-fine groups are assumed to be extremely narrow compared to the maximum lethargy gain per collision with the heaviest nuclides, but they are not limited to be equal width.

In order to obtain the group representation of slowing-down equation, we integrate Eq. (3-4) over the lethary u of the (m+1) th mesh shown in **Fig. 2.** In this case, we assume that the resonance cross sections are given at the mid point of each ultra-fine group and the collision probability $P_{ij}(u)$ is constant in each of the groups. Then,

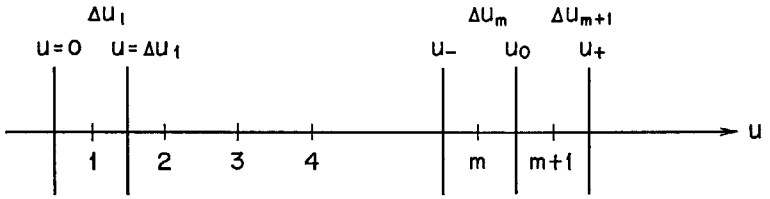

Fig. 2. Lethargy meshes for obtaining ultra-fine group equation

$$\Sigma_i^{m+1}\phi_i^{m+1} \equiv \Sigma_i^{m+1}\int_{u_0}^{u_+}\phi_i(u)du = \underset{j,k}{Sum} P_{ij}^{m+1}S_{jk}^{m+1} \tag{3-6}$$

where

$$S_{jk}^{m+1} = \frac{1}{1-\alpha_k}\int_{u_0}^{u_+}du\int_{u-\varepsilon_k}^{u} f_k(u-u')F_{jk}(u')du' \tag{3-7}$$

with

$$F_{jk}(u) = \Sigma_{sjk}(u)\phi_j(u) \text{ and } f_k(x) = \begin{cases} 1 & 0 \le x \le \varepsilon_k \\ 0 & \text{Otherwise.} \end{cases} \tag{3-8}$$

The slowing-down source of Eq. (3-7) can readily be evaluated by interchanging the order of integrations, i. e.,

$$\begin{aligned}
(1-\alpha_k)S_{jk}^{m+1} &= \int_{-\infty}^{\infty}du'F_{jk}(u')\int_{u_0}^{u_+}f_k(u-u')du \\
&= \int_{u_0}^{u_+}du'F_{jk}(u')\int_{u'}^{u_+}f_k(u-u')du + \int_{u_0-\varepsilon_k}^{u_0}du'F_{jk}(u')\int_{u_0}^{u_+}f_k(u-u')du \\
&\quad - \int_{u_0-\varepsilon_k}^{u_+-\varepsilon_k}du'F_{jk}(u')\int_{u'+\varepsilon_k}^{u_+}f(u-u')du = \int_{u_0}^{u_+}du'F_{jk}(u')(u_+-u') \\
&\quad + \Delta u_{m+1}\int_{u_0-\varepsilon_k}^{u_0}F_{jk}(u)du - \int_{u_0-\varepsilon_k}^{u_+-\varepsilon_k}du'F_{jk}(u')(u_+-u'-\varepsilon_k) \\
&= \frac{\Delta u_{m+1}}{2}\left(F_{jk}^{m+1} - \int_{u_0-\varepsilon_k}^{u_+-\varepsilon_k}F_{jk}(u')du'\right) + \Delta u_{m+1}\left[\int_{u_--\varepsilon_k}^{u_-}F_{jk}(u)du + F_{jk}^{m} - \int_{u_--\varepsilon_k}^{u_0-\varepsilon_k}F_{jk}(u)du\right]
\end{aligned} \tag{3-9}$$

Therefore, equation (3-6) can be expressed by a matrix form as follows.

$$\underset{j}{Sum}A_{ij}^{m+1}\phi_j^{m+1} = Q_i^{m+1} \quad \text{or} \quad A^{m+1}\vec{\phi}^{m+1} = \vec{Q}^{m+1} \tag{3-10}$$

where

$$A_{ij}^{m+1}\equiv\left[\delta_{ij}-\frac{\Delta u_{m+1}}{2\Sigma_i^{m+1}}P_{ij}^{m+1}\underset{k}{Sum}\frac{\Sigma_{sjk}^{m+1}}{1-\alpha_k}\right]\Sigma_i^{m+1}, \tag{3-11}$$

$$Q_i^{m+1}\equiv\Delta u_{m+1}\underset{j,k}{Sum}P_{ij}^{m+1}\left[\bar{S}_{jk}^{m+1}-\frac{1}{2(1-\alpha_k)}F_{jk}^{m-L_k^m}\right] \tag{3-12}$$

and

$$\bar{S}_{jk}^{m+1}\equiv\int_{u_0-\varepsilon_k}^{u_0}F_{jk}(u)du=\bar{S}_{ik}^{m}+\frac{1}{1-\alpha_k}\left[\Sigma_{sjk}^{m}\phi_j^{m}-(\Sigma_{sjk}\phi_j)^{m-L_k^m}\right] \tag{3-13}$$

with

$$(\Sigma_{sjk}\phi_j)^{m-L_k^m}\equiv\int_{u_--\varepsilon_k}^{u_0-\varepsilon_k}F_{jk}(u)du. \tag{3-14}$$

In deriving Eq. (3-12), it was assumed that $F_{jk}^{m-L_k^{m+1}}$ was nearly equal to $F_{jk}^{m-L_k^m}$.

3. 2 Calculation of Slowing-Down Source ($\bar{S}_{jk}^m$)

In order to calculate the slowing-down source given by Eq. (3-13), we must calculate $(\Sigma_{sjk}\phi_j)^{m-L_k^m}$ and hence store all the fluxes and scattering cross sections for exact evaluation of this term if lighter materials are included in the system under consideration. Because this storing is actually impossible, we provide another kind of groups for representation of $\phi_j(u)$ and $\Sigma_{sjk}(u)\,\phi_j(u)$, and these groups are called as fine group and usually have the lethargy width of ten or twenty times of ultra-fine groups. Here, we assume that the lethargy width of this fine group is also narrow compared to the maximum lethargy gain per collision with the heaviest nuclide. This representation of ϕ_j or $\Sigma_{sjk}\phi_j$ by the fine group will be reasonable considering from its sufficient narrowness and rather slow variation of these quantities than the resonance cross sections themself. Mainly important information in the PEACO code is stored in variable dimensions of which sizes are beforehand determined by input data for each problem. Hence, there is no special limitation on group numbers of ϕ_j or $\Sigma_{sjk}\phi_j$ stored, unless total variable dimensions necessary for calculation do not exceed 34, 000. We will later discuss the selecting method of the ultra-fine and fine groups and recommend a group structure there.

Therefore, from above discussion, we can evaluate Eq. (3-14) by

1) Using the averaged value of $(\Sigma_{sjk}\phi_j)$ in the fine group to which the $(m-L_k^m)$ th ultra-fine group belongs, (OPTS-1)
2) an interpolation using three successive averaged-values of $(\Sigma_{sjk}\phi_j)$, where the ultra-fine group belongs to the second value of these three. (OPTS-2)

For the second method, the lethargy width of the fine group is desirable to be narrower than half of the maximum lethargy gain per collision with the heaviest nuclide.

The source term of Eq. (3-13) can successively be evaluated by assuming an initial flux above the starting energy E_1 of calculation. We assume that all the cross sections are energetically constant and the flux distribution is spatially constant at energies $E>E_1$. Then, letting $\phi_j(u)$equal to $V_jw(u)$ and summation over (i) of Eq. (3-4) give

$$w(u)\underset{i}{Sum}V_i\Sigma_i=\underset{k}{Sum}\frac{1}{1-\alpha_k}\int_{u-\varepsilon_k}^{u}w(u')du'\times\underset{j}{Sum}V_j\Sigma_{sjk} \tag{3-15}$$

If we assume $w(u)=e^{\beta u}$, we have

$$\beta=\underset{k}{Sum}\frac{1-(\alpha_k)^\beta}{1-\alpha_k}R_k \tag{3-16}$$

with

$$R_k=\underset{j}{Sum}V_j\Sigma_{sjk}/\underset{j}{Sum}V_j\Sigma_j. \tag{3-17}$$

The equation (3-16) for β can readily be solved by an iteration method starting with $\beta=1$. Hence, we can obtain the expressions for initial flux and source as follows.

$$\phi_j(u)=V_j e^{\beta u} \quad \text{for } u>0, \tag{3-18}$$

$$\bar{S}_{jk}^{0}=\frac{V_j\Sigma_{sjk}}{\beta(1-\alpha_k)}(1-\alpha_k^{\beta}). \tag{3-19}$$

3. 3 Calculation of Flux Distribution

When the slowing-down source of Eq. (3-13) is evaluated by using either option of OPTS 1 or 2, the flux distribution can be obtained from Eqs. (3-10) and (3-11). KIER[10,11] neglected the non-diagonal term in Eq. (3-11), and the accuracy of this neglect will be investigated in the later section. The PEACO code solves Eq. (3-10) for the flux distribution by any of the following three methods.

1) Matrix inversion method (OPTFL-1)

The flux distribution can be given by

$$\phi_j^m=\underset{j}{Sum}(A^m)_{ij}^{-1}Q_j \text{ or } \vec{\phi^m}=(A^m)^{-1}\vec{Q^m}, \tag{3-20}$$

where $(A^m)^{-1}$ is the inverse matrix of A^m and the matrix inversion is accomplished by a subroutine in the PEACO code. This routine is prepared for accuracy check of the following two approximate methods.

2) Matrix perturbation method (OPTFL-2)

Generally the diagonal elements of Eq. (3-11) is considered to be larger than any non-diagonal elements. If the matrix, A, is rewritten as

$$A^m=D^m-B^m \tag{3-21}$$

with

$$(D^m)_{ij}=\Sigma_i^m\delta_{ij} \text{ and } (B^m)_{ij}=\frac{\Delta u^m}{2}P_{ij}^m\underset{k}{Sum}\frac{\Sigma_{sjk}^m}{1-\alpha_k} \tag{3-22}$$

then we have

$$(A^m)^{-1}=(D-B)^{-1}=D^{-1}(1-BD^{-1})^{-1}\cong D^{-1}+D^{-1}BD^{-1} \tag{3-23}$$

Using this approximate expression for the matrix A, we obtain

$$(A^m)_{ij}^{-1}=\frac{1}{\Sigma_j^m}\left[\delta_{ij}+\frac{\Delta u_m P_{ij}^m}{2\Sigma_j^m}\underset{k}{Sum}\frac{\Sigma_{sjk}^m}{1-\alpha_k}\right] \tag{3-24}$$

Hence, the flux distribution is given by

$$\phi_i^m=\frac{1}{\Sigma_i^m}\left[Q_i^m+\underset{j}{Sum}\Delta P_{ij}^m Q_j^m\right] \tag{3-25}$$

where

$$\Delta P_{ij}^m=\frac{\Delta u_m P_{ij}^m}{2\Sigma_j^m}\underset{k}{Sum}\frac{\Sigma_{sjk}^m}{1-\alpha_k} \tag{3-26}$$

3) Approximation of letting $F_{jk}^{m+1}=F_{jk}^{m-L_k^{m+1}}$ in Eq. (3-9) (OPTFL-3)

In this case the flux distribution is given by

$$\phi_j^m=Q_i^m/\Sigma_i^m$$

with

$$Q_i^m=\Delta u_m\underset{j,k}{Sum}P_{ij}^m\bar{S}_{jk}^m.$$

This approxmation was used in RIFF RAFF and RABBLE code, but the accuracy have not been investigated. Discussion will later be made for the accuracy of OPTFL-3.

4. Resonance Cross Sections Used in PEACO-MCROSS Code

The single-level formula of Breit and Wigner for the expression of resonance cross section has been adopted for analysis of resonance absorption in nuclear reactor. As pointed out by many investigators, for fissile elements the single-level formula fails for reproducing shapes of cross sections, because interference effects between levels are significant. ADLER and ADLER[23] derived a formalism for resonance cross sections which can be expressed by resonance parameters independent of energy and the Doppler broadening can be treated by rather simple expressions. For unresolved energy regions where are important for the calculation of Doppler coefficient of fast reactors, however the statistics for the resonance parameters and level spacing is so complicated that its practical application is quite impossible[24]. There is another expression, which was obtained by VOGT[25,26]. This expression seems to be very useful, because the parameters for the R-matrix theory of which the statistics are well known can be used and the Doppler-broadening cross-sections is also given by a simple formula. In the PEACO-MCROSS code, an expression based on the approximation made by VOGT will be used, and details concerning this expression will be seen in Ref. (27).

The predominant contribution to cross sections comes from s-wave neutrons in the resonance energy region of interest, but p-wave neutrons contribute very little. Hence, the interference effects between levels are taken into consideration only for the s-wave neutron cross sections in our expressions. These resonance cross-sections are given by the following equations.

$$\sigma_t(E)\cong 4\pi a^2+\sum_{J\varepsilon S} g_J \sum_{\lambda\varepsilon J}\left[\frac{\pi}{k^2}\frac{\Gamma_{\lambda nJ}\Gamma_\lambda}{(E-E_\lambda)^2+\left(\frac{\Gamma_\lambda}{2}\right)^2}\right.$$

$$+\frac{4\pi a}{k}\frac{\Gamma_{\lambda nJ}(E-E_\lambda)}{(E-E_\lambda)^2+\left(\frac{\Gamma_\lambda}{2}\right)^2}+\frac{\pi}{k^2}\sum_{\lambda'>\lambda}\sqrt{\Gamma_{\lambda nJ}\Gamma_{\lambda' nJ}}\left(\sqrt{\Gamma_{\lambda nJ}\Gamma_{\lambda' nJ}}\right.$$

$$\left.\left.+\sqrt{\Gamma_{\lambda f}\Gamma_{\lambda' f}}\cos\theta_{\lambda\lambda'}\right) g_{\lambda\lambda'}\right]+\frac{\pi}{k^2}\sum_{\lambda\varepsilon p} g_J \sum_{\lambda\varepsilon J}\frac{\Gamma_{\lambda nJ}\Gamma_\lambda}{(E-E_\lambda)^2+\left(\frac{\Gamma_\lambda}{2}\right)^2} \tag{4-1}$$

$$\sigma_\gamma(E)\cong\frac{\pi}{k^2}\left[\sum_{J\varepsilon s} g_J \sum_{\lambda\varepsilon J}\frac{\Gamma_{\lambda nJ}\Gamma_{\lambda\gamma}}{(E-E_\lambda)^2+\left(\frac{\Gamma_\lambda}{2}\right)^2}+\sum_{J\varepsilon p} g_J \sum_{\lambda\varepsilon J}\frac{\Gamma_{\lambda nJ}\Gamma_\gamma}{(E-E_\lambda)^2+\left(\frac{\Gamma_\lambda}{2}\right)^2}\right] \tag{4-2}$$

$$\sigma_f(E)\cong\frac{\pi}{k^2}\left[\sum_{J\varepsilon s} g_J \sum_{\lambda\varepsilon J}\left\{\frac{\Gamma_{\lambda nJ}\Gamma_{\lambda f}}{(E-E_\lambda)^2+\left(\frac{\Gamma_\lambda}{2}\right)^2}\right.\right.$$

$$\left.\left.+2\sum_{\lambda'>\lambda}\sqrt{\Gamma_{\lambda nJ}\Gamma_{\lambda' nJ}}\sqrt{\Gamma_{\lambda f}\Gamma_{\lambda' f}}\cos\theta_{\lambda\lambda'} g_{\lambda\lambda'}\right]+\sum_{J\varepsilon p} g_J \sum_{\lambda\varepsilon J}\frac{\pi}{k^2}\left\{\frac{\Gamma(_{\lambda nJ})^2}{(E-E_\lambda)^2+\left(\frac{\Gamma_\lambda}{2}\right)^2}\right\} \tag{4-3}$$

where

$$g_{\lambda\lambda'}=h_{\lambda\lambda'}\left[\frac{\Delta\Gamma_{\lambda\lambda'}\Gamma_\lambda-4\Delta E_{\lambda\lambda'}(E_\lambda-E)}{(E_\lambda-E)^2+\left(\frac{\Gamma_\lambda}{2}\right)^2}\frac{\Delta\Gamma_{\lambda\lambda'}\Gamma_{\lambda'}-4\Delta E_{\lambda\lambda'}(E_{\lambda'}-E)}{(E_{\lambda'}-E)^2+\left(\frac{\Gamma_{\lambda'}}{2}\right)^2}\right] \tag{4-4}$$

$$h_{\lambda\lambda'}=\frac{1}{\Delta E_{\lambda\lambda}{}^2+\left(\frac{\Delta\Gamma_{\lambda\lambda'}}{2}\right)^2} \tag{4-5}$$

$$\Delta E_{\lambda\lambda'}=E_\lambda-E_{\lambda'} \text{ and } \Delta\Gamma_{\lambda\lambda'}=\Gamma_\lambda-\Gamma_{\lambda'}. \quad (4\text{-}6)$$

Various notations used in Eq. (4-1)~(4-6) are the same as those used in Refs. (26) or (27) and the explanation concerning them will be omitted here.

The Doppler-broadened cross sections for Eqs. (4-1)~(4-3) are also given in Ref. (27). For unresolved resonance-regions, the resonance parameters needed for the calculation of the resonance cross sections can be generated by using a ramdom sampling method[22]. For this purpose, we can use a code, BABEL[28], which generates a sequence of the resonance parameters for Eqs. (4-1)~(4-3) over energy range of interest and writes them in a tape for later use to the PEACO-MCROSS code. The PEACO-MCROSS code was prepared for the present purpose by modifying MCROSS code[27].

5. Calculation of Collision Probability

A great number of methods have been proposed for the calculation of collision probabilities in various geometries. These methods have mainly used to calculate the group constants of thermal energy region in complex geometries. Since the resonance energy ranges of interest are extremely wider than thermal ranges, the geometries that can be treated by a code are restricted, and various kinds of approximations had to be adopted for calculating method of collision probability for a complex geometry. For an example, Wigner's rational approximation and Nordheim-Sauer's model[2,29] for collision probability has frequently used to estimate resonance absorption. Even for a recent high-speed computer, however the inclusion of the calculational routine of collision probabilities for complex geometries in a code will consume considerable computer time.

A simple and convenient method was prepared for calculating collision probabilities in RICM code[9] which estimated the resonance integral of isolated resonances in heterogeneous systems. This is a calculating method using the interpolation of collision probabilities beforehand prepared and is quite useful for many calculations in a fixed geometry or for a calculation of wider energy ranges. We adopted a method based on this interpolation for the estimation of P_{ij}^{m} in Eqs. (3-11) and (3-12), and the PEACO-COLLIS prepares the collision probabilities at the specified values of total cross sections of fuel compositions in cylindrical or plane geometries. The PEACO-COLLIS consists of several sub-codes which was developed by K. TSUCHIHASHI[30]. For a simple calculation of two region problem, the Nordheim-Sauer model is also prepared in the PEACO-MAIN to calculate the collision probability.

5. 1 Nordheim-Sauer's Model for Cylindrical Geometry with Two Regions

The approximate formula proposed for $P_{12}(u)$ by NORDHEIM[2] is given by

$$P_{12}(u)=\frac{P_0 G_\infty}{1-(1-\Sigma_1 l_1 P_0)(1-G_\infty)} \tag{5-1}$$

where P_0 is the escape probability from an isolated system, Σ_1 and $l_1(=4V_1/S)$ are the total cross section and mean chord-length of the system, S is the surface area and G_∞ is the Dancoff coefficent. The combined use of this formula with Sauer's approximation[29] for G_∞ is known to give a sufficient accuracy for two-regions problem in thermal reactor. This approximate formula by Sauer can be written for cylindrical geometries as

$$G_\infty=1-\exp(-\tau\Sigma_2 l_2)/[1+(1-\tau)\Sigma_2 l_2], \tag{5-2}$$

with

$$\tau=\begin{cases}(0.9069\sqrt{1+V_2/V_1}-1)/(V_2/V_1)-0.08 \text{ (square)} & (5\text{-}3)\\ (0.8863\sqrt{1+V_2/V_1}-1)/(V_2/V_1)-0.12 \text{ (hexagonal)} & (5\text{-}4)\end{cases}$$

where Σ_2 and l_2 are the total cross section and mean chord-length $(=4V_2/S)$ of the moderator region, respectively.

Using the reciprocity relation and the conservation of collision probabilities, we obtain

$$P_{11}(u)=1-P_{12}(u), \quad P_{22}=1-P_{21} \tag{5-5}$$

$$P_{21}(u)=V_1\Sigma_1P_{12}(u)/(V_2\Sigma_2). \tag{5-6}$$

The escape probability P_0 in Eq. (5-1) is tabulated in the PEACO-MAIN.

5. 2 Interpolation Method of Collision Probability in PEACO-MAIN code

At first we assume that all the compositions except for fuel compositions have constant cross sections. For such a system, we define a function of total macroscopic cross section, Σ_f, of a fuel composition. This function $Z(\Sigma_f)$ is defined by

$$Z=\begin{cases}\Sigma_f l & (\Sigma_f l\leqq 1)\\ 2-1/(\Sigma_f l) & (\Sigma_f l>1)\end{cases} \tag{5-7}$$

where l is a value having the dimension of [CM] which may conveniently be selected as the mean chord-length of fuel rod. The function $Z(\Sigma_f)$ makes one-to-one correspondence with Σ_f and takes a value between 0 and 2 for a value of Σ_f.

It is known that collision probabilities $P_{ij}(Z)$ for a fixed geometry vary quite smoothly for the variation of Z. The fifteen values of Z was used as the interpolating coordinates of a quadratic interpolation method for collision probabilities in the RICM-I code. The coordinate Z is also used in PEACO code. For such a interpolation method, collision probabilities should beforehand be given at the specified values of Z, and this calculation is done in the PEACO-COLLIS. In the PEACO-MAIN, the collision probabilities in Eqs. (3-11) and (3-12) are evaluated by a linear interpolation method using twenty points of Z as interpolating coordinates.

We shall consider at first a system consisting of several fuel-compositions which satisfy the condition 1 in the section 3. Then, the $P_{ij}(Z_1, Z_2, Z_3,\cdots\cdots)$ for the system can be approximated by

$$P_{ij}(Z_1, Z_2, Z_3\cdots\cdots)\cong P_{ij}(Z^0, Z^0, Z^0\cdots\cdots)+\underset{\lambda}{Sum}(Z_\lambda-Z^0)\frac{\partial}{\partial Z_\lambda}P_{ij}\,|_{\text{all } Z=Z^0} \tag{5-8}$$

where the subscript for Z is the number of fuel composition and Z^0 is the nearest value of the interpolating coordinates to the averaged value of $(Z_1, Z_2\cdots\cdots)$. Here, we assumed that $(Z_1, Z_2,\cdots\cdots)$ did not so much differ from each other, that is, the condition 1 was assumed to be satisfied. It should be noted that the nonuniform distribution of temperature or of resonance-absorbing materials with fuel burnup can readily be treated by this linear interpolation method because of its simplicity. The PEACO-COLLIS prepares also the derivatives $\frac{\partial}{\partial Z_\lambda}P_{ij}$ in Eq. (5-8).

For the case where the condition 2 for fuel compositions in the section 3 is satisfied, it will be sufficient that one of the Z_λ's is selected as the interpolating coordinate, since the coordinate selected can make one-to-one correspondence with the total resonance cross sections for all fuel compositions. Hence, in this case, only one of fuel compositions may be selected as a formal fuel composition if the values of the collision probabilities at the interpolating points is calculated by taking account of the resonance cross sections in other compositions.

On the other hand, the collision probabilities must satisfy two important relations, that is, the conservation law

$$\underset{i}{Sum}P_{ij}=1 \qquad \text{for all } j \tag{5-9}$$

and the reciprocity relation

$$V_i\Sigma_iP_{ij}=V_j\Sigma_jP_{ji} \qquad \text{for all } i, j. \tag{5-10}$$

In the PEACO-MAIN code, the values of P_{ij} and $\frac{\partial}{\partial Z_\lambda} P_{ij}$ are input only for $j \geqq i$ to save the dimensions for them. Hence, at first, the P_{ij} for $j<i$ are calculated from the interpolated P_{ij} for $j \geqq i$ by using Eq. (5-10). Then, the collision probabilities satisfying Eqs. (3-11) and (3-12) are successively obtained by the following equations starting from $j=1$.

$$P_{ij}^* = \frac{1-\eta_1}{\eta_0} P_{ij}, \qquad P_{ji}^* = \frac{1-\eta_1}{\eta_0} P_{ji} \quad (i=j,\ N) \tag{5-11}$$

where

$$\eta_0 = \underset{i=j}{\overset{N}{Sum}} P_{ij} \quad \text{and} \quad \eta_1 = \underset{i=1}{\overset{j-1}{Sum}} P_{ij}^* \tag{5-12}$$

with

$$N = Max(j) = Max(i). \tag{5-13}$$

TABLE 1 Geometries and compositions for accuracy check of collosion probabilities

case	geometry	region	thickness from center(cm)	number of sub-regions	composition ATOMS/(b-cm)	remarks
1	cylinder	1	0.2406	1	1 ^{238}U(1800K) : 0.0294, C : 0.0294	The unit cell of 1000-MW Westinghouse reactor is cylindricalized.
		2	0.3403	1	2 ^{238}U(1200K) : 0.0294, C : 0.0294	
		3	0.3558	1	3 Na : 0.0216	
		4	0.3810	1	4 Fe : 0.0852	
		5	0.5684	1	3	
2	cylinder	1	0.5625	3	1 ^{238}U(290K) : 0.0473,	The example in RABBLE code.
		2	1.297	5	2 ^{238}U(290K) : 0.0071, Fe : 0.0127, Na : 0.01397	
3	plane (center symmetric)	1	0.32	1	1 ^{238}U(290K) : 0.0473	The unit cell of the II-4-S-3H core of FCA.
		2	0.90	1	2 C : 0.0869	
		3	1.06	1	3 N : 0.0396, H : 0.0792	
		4	1.32	1	2	

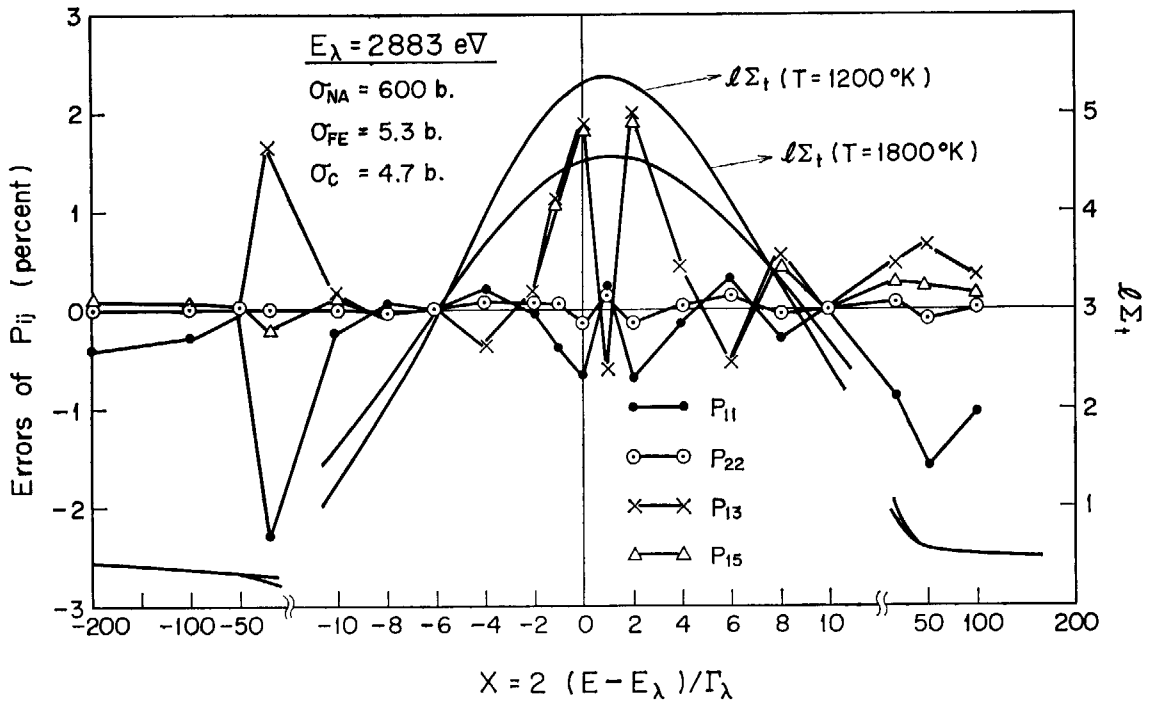

Fig. 3 Errors of collision probabilities for the case no. 1 in TABLE 1.

The collision probabilities given by Eq. (5–11) will readily be known to satisfy Eqs. (5–9) and (5–10).

For the purpose of the accuracy-check of the calculating method of collision probability by Eqs. (5–8)～(5–13), we shall show representative examples calculated in three different geometries for which the various imformation is presented in TABLE 1. Figures 3～7 show the relative error

$$E_p=(P_{ij}{}^*-P_{ij}{}^{exact})\times 100/P_{ij}{}^{exact} \tag{5-14}$$

where $P_{ij}{}^*$ is given by Eqs. (5–8)～(5–13) and $P_{ij}{}^{exact}$ is exactly calculated by the PEACO-

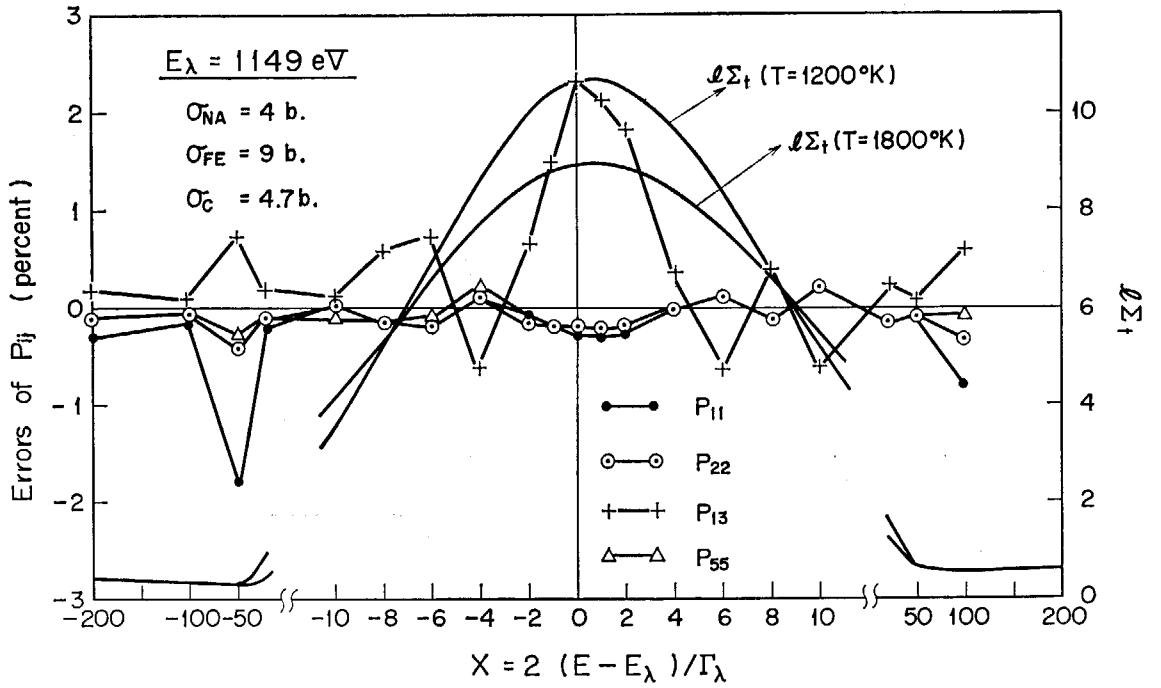

Fig. 4 Errors of collision probabilities for the case no. 1 in TABLE 1.

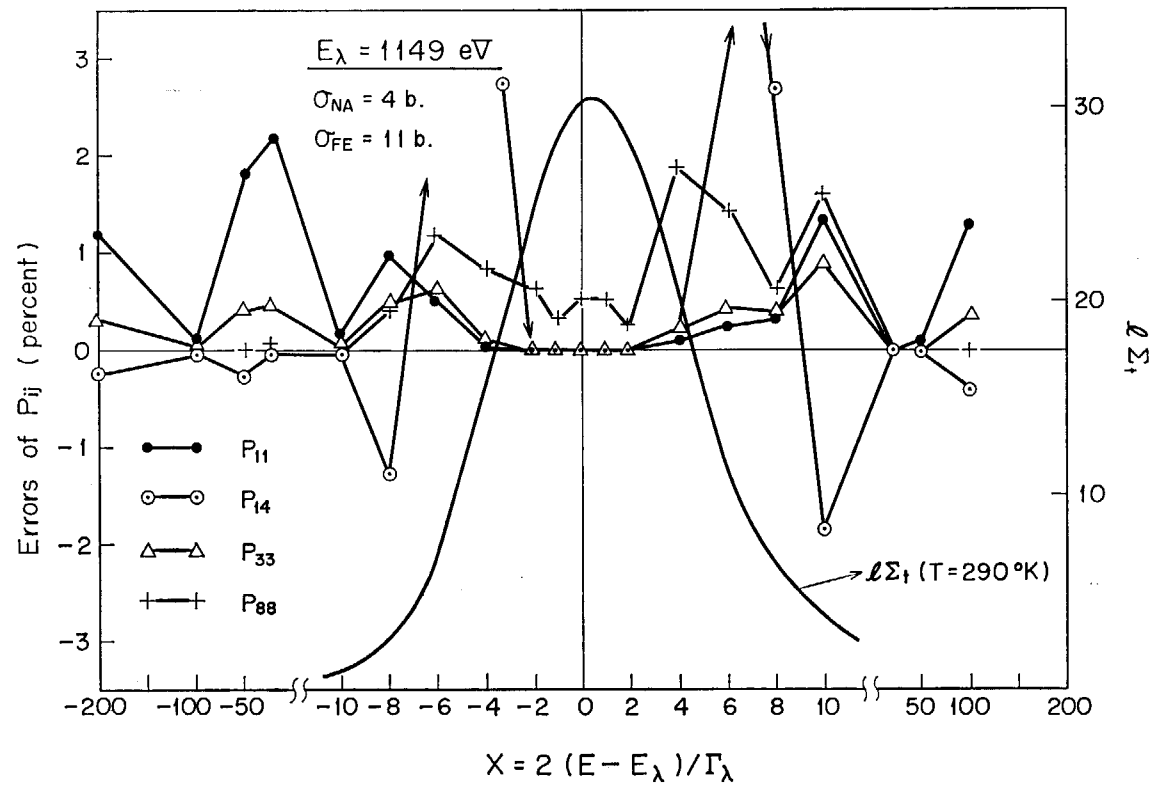

Fig. 5 Errors of collision probabilities for the case no. 2 in TABLE 1.

COLLIS. These calculations were made for the typical resonances of ^{238}U and on twenty points of the variable

$$x=2(E-E_\lambda)/\Gamma_\lambda. \tag{5-15}$$

In these figures, we illustrated only a few values of P_{ij} which are considered to be more important on neutron balance or have larger errors.

It will be seen from these figures that the errors are mostly no more than 2% and, especially for plane geometry, errors are scarcely induced by the present method for calculating collision probability. For some values of x, few P_{ij}'s have fairly large errors, for example, the errors of P_{13} at $x=0$ in **Fig. 3** and of P_{14} at $x=-6$ in **Fig. 5** are about 2.3 and 7%, respec-

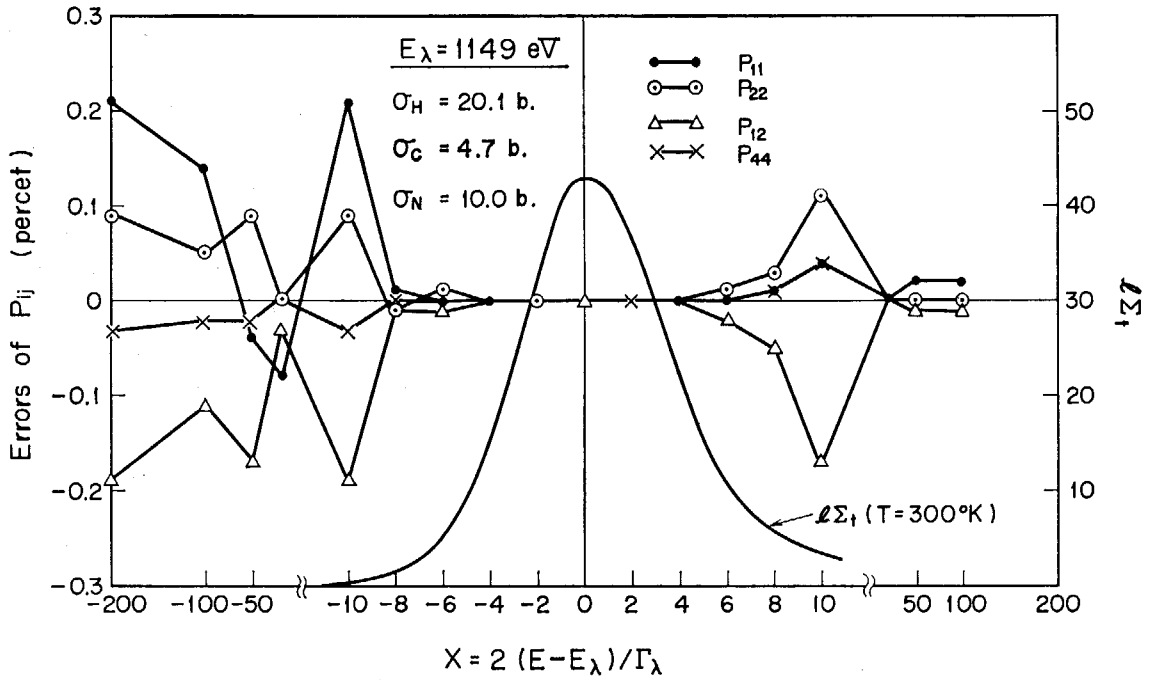

Fig. 6 Errors of collision probabilities for the case no. 3 in **TABLE 1.**

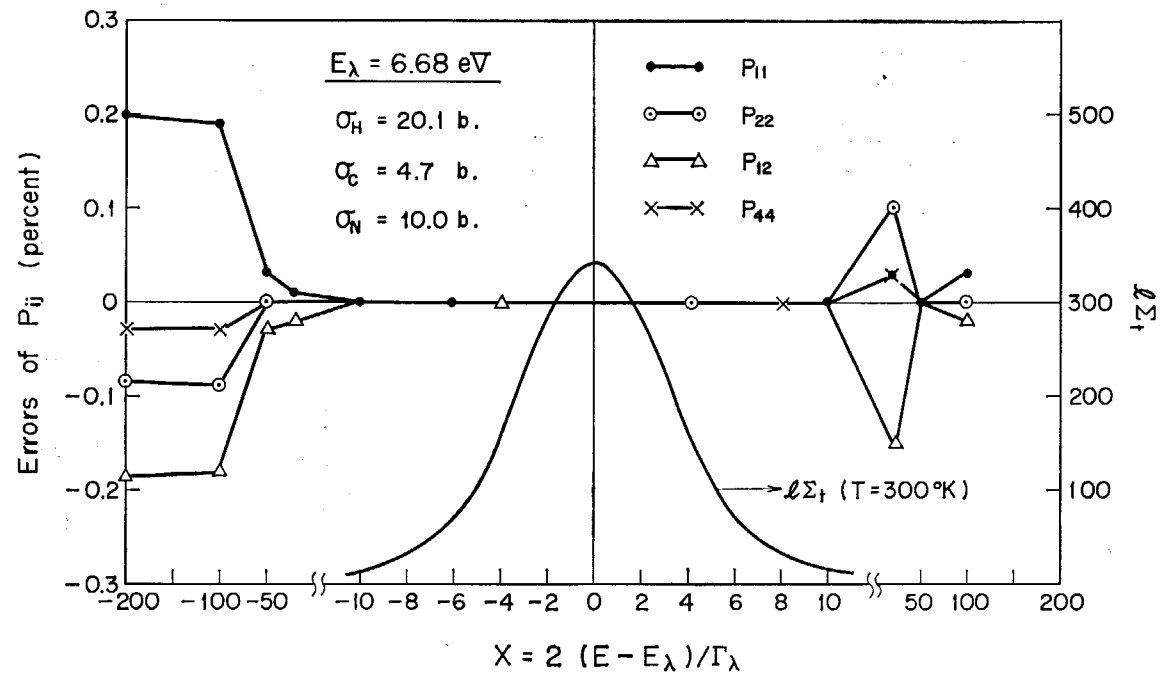

Fig. 7 Errors of collision probabilities for the case no. 3 in **TABLE 1.**

tively. However, it should be noted that the accuracy of such a P_{ij} is not very important for neutron balance due to smallness of the value itself or of the volume where neutrons are born. For an example of P_{14} at $x=-6$ in **Fig. 5**, P_{14} is 0.002933, while P_{11} and P_{44} are 0.6658 and 0.2390, respectively. For one-fuel composition problem, we can raise the accuracy by increasing the points of Z_λ where P_{ij} is given, though the mumber of the points in the present example is twenty. It will also be noted that the accuracy of the flux distribution does not generally so much depend on that of collision probability if Eqs. (5-9) and (5-10) were satisfied.

5. 3 Consideration of Resonance Scatterer and Strong Absorber

When the resonance absorption is studied in a thermal reactor, it will be mostly sufficient that the cross sections of moderator and structural materials are assumed to be energetically constant. In fast reactors, however, the Doppler coefficient of reactivity comes from rather higher energies where all the cross sections must generally be considered to vary with energy. Especially an accurate value for the Doppler coefficient can not be obtained without taking account of the resonance scattering of sodium at $E\approx 2.85$ keV. Moreover, the strong absorption by burnable poisons in thermal power reactors may affect the resonance absorption and the neutron source into thermal energy region. Generally speaking, for an accurate estimation of the effective cross sections in resonance energy region, the variation with energy should be considered for all the cross sections in a system under consideration.

The variation of the cross sections of these materials is usually quite slow compared to that of heavy resonance-absorbers. These slow variation will bring also a slowly energetic variation into the collision probability in the previous section. We assume that this slow variation of the collision probability can be estimated by "a linear interpolation on the fine groups" and it can be neglected in a fine group. Under this assumption, in the PEACO-COLLIS, the collision probabilities are calculated on the necessary number of energy points to express the slow variation of the total cross sections of the compositions except for the fuel. In the PEACO-MAIN, these P_{ij}'s and their derivatives $\frac{\partial}{\partial Z_\lambda}P_{ij}$'s are interpolated on each fine group by a straight line and the resultant values are used to estimate the collision probability on untra-fine groups in the fine group, following Eqs. (5-8)$\sim$(5-13).

In the PEACO-MAIN, the materials are divided into the following five groups.

1) Resonance-absorbing materials (MAOPT=0)

Their cross sections are read from the library tapes prepared by the PEACO-MCROSS.

2) Resonance-scattering material (MAOPT=1)

This material is limited to one element and the cross section is calculated on each fine group by

$$\sigma_t^R(E)=\frac{\sigma_0^R}{x^2+1}+\frac{2\sigma_{0p}^R x}{x^2+1}+\sigma_{p+}+\sigma_{p-} \tag{5-16}$$

$$\sigma_\gamma^R(E)=\sigma_0^R\frac{\Gamma_\gamma}{\Gamma}\frac{1}{x^2+1} \tag{5-17}$$

where

$$x=2(E-E^R)/\Gamma \quad \text{and} \quad \sigma_{0p}^R=(\sigma_p\sigma_0^R\Gamma_n g_J/\Gamma)^{1/2}. \tag{5-18}$$

3) Materials with pointwise cross sections (MAOPT=2)

For these materials, the cross sections are given on a number of energy points that are also used to calculate the collision probability in the PEACO-COLLIS code. The value of

cross section on each fine group are obtained from a linear interpolation.

4) Absorbing material with pointwise cross section (MAOPT=3)

This material is also limited to one and the variation of the cross section are assumed to not affect the collision probability when it exists in moderator region.

5) Materials with constant cross section (MAOPT=4)

For MAOPT=2, 3 and 4, the materials are permitted to have the $1/v$ absorbing cross-section. In this case, attention should be paid for the consistency of the cross sections used in the PEACO-MAIN with those in the PEACO-COLLIS.

6. Group Structure and Accuracy of Calculation

The various approximate methods were introduced for the calculation of the source and flux distributions in the PEACO code. The accuracy of these approximations will largely depend on the group structure of the ultra-fine and fine groups. An intercomparison has been made for the results obtained from these approximations using the simple geometry of the case 2 in TABLE 1 and changing the group structure. The group structures used in the calculation are shown in TABLE 2, and the 25 resonances of ^{238}U same as those in the example of the RABBLE code were used between 999 and 1420 eV. The results obtained are shown in figures from 8 to 10. In these figures is shown the deviation from the standard value which is calculated by using the options OPTS-2 and OPTFL-1 and the finest mesh width of the case 1 in TABLE 2.

In the present example, we could not find any difference between the results obtained from the matrix inversion (OPTFL-1) and the matrix perturbation (OPTFL-2) for the calculation of flux distribution, though the neglect of the non-diagonal terms in Eq. (3-11) introduced a little error to the absorption probability. This results show that a very accurate result can be obtained for the resonance flux from the matrix perturbation method. It should also be noted that the increase of computer time in the matrix perturbation method is no more than 10%, compared to the case of OPTFL-3, while the matrix inversion method takes more than three times of the computer time in the case of OPTFL-3. Moreover, any difference could not be seen between the results obtained from OPTS-1 and OPTS-2, except for the last case in TABLE 2 where the calculation by OPTS-2 were impossible due to wider width of

TABLE 2 Group structures for the test calculation in the energy range from 1420 to 999 eV

case	number of groups		lethargy width ($\times 10^3$)	
	fine	ultra fine[a)]	fine	ultra fine
1	750	10	0.47	0.047
2	375	20	0.94	0.047
3	150	50	2.34	0.047
4	150	25	2.34	0.094
5	25	150	14.07	0.094

a) This shows the number in a fine group.

TABLE 3 A recommened structure of fine and ultra-fine groups for the use of the PEACO code

Upper energy (eV)	Lower energy (eV)	Lethargy[a)]	No. of fine groups	No. of ultra-fine groups[b)]	Mesh width of fine groups	Mesh width of ultra-fine groups
23250	4650	1.1513	2303	10	0.0005	0.00005
4650	465	2.3026	2303	10	0.001	0.0001
465	46.5	〃	767	10	0.003	0.0003
46.5	4.65	〃	460	5	0.005	0.001
4.65	0.465	〃	230	2	0.01	0.005

a) These lethargy widths for the first one are selected to not exceed the maximum lethargy gain per collision with deuteron.

b) This shows the number of ultra-fine groups in a fine one.

the fine group ($2 \cdot \Delta u_m > \varepsilon_{238}$).

It will be seen from Figs. 8~10 that in the energy range from 1 to 1.4 keV we can obtain a sufficient accuracy from the calculation with the group structure of the case 2 in TABLE 2. On the other hand, a group structure such as seen in the example of RABBLE code can not give a very accurate result for various averaged or integrated quantities in this energy range. It will also be seen from these figures that the results from group structures with more ultra-fine groups in a fine group are in general less accurate when the total number of the ultra-fine group is kept constant in this energy range. Here, it should be noted that the infinitely dilute capture cross-section of ^{238}U showed the same value for all the cases considered.

Now, from the above discussion and our experience gained by the use of the PEACO code, we shall recommend a group structure for the ultra fine and fine groups, which is shown in TABLE 3.

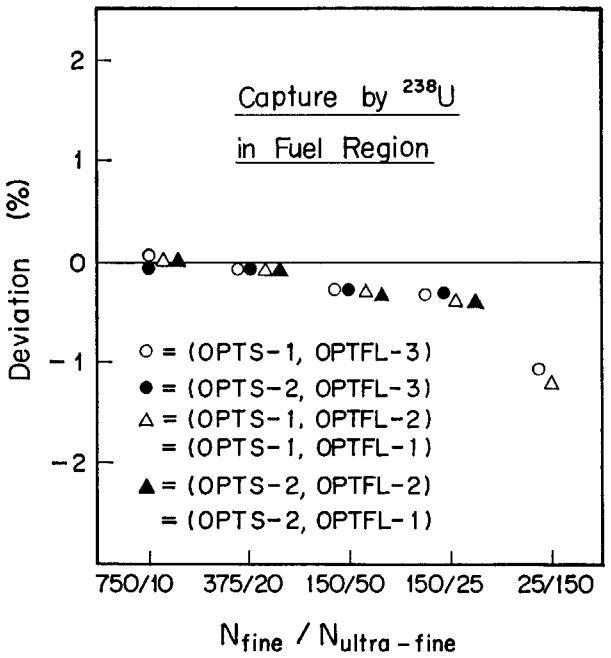

Fig. 8 Deviation of capture cross section of ^{238}U in central fuel region.

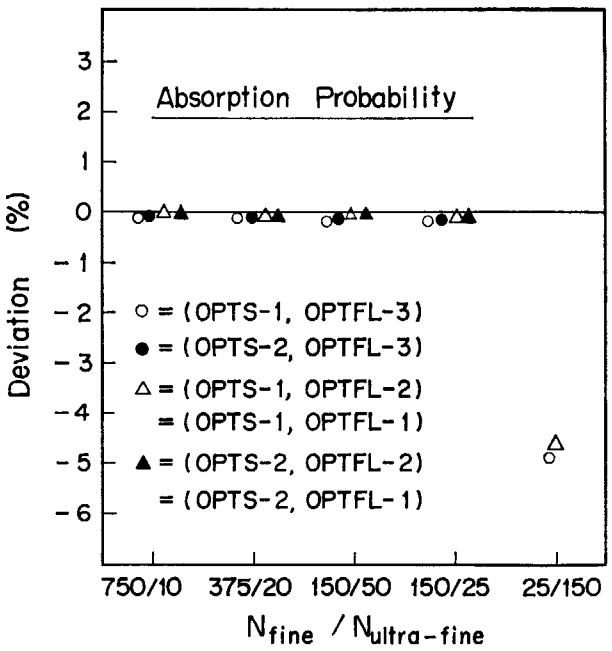

Fig. 9 Deviation of total absorption probability.

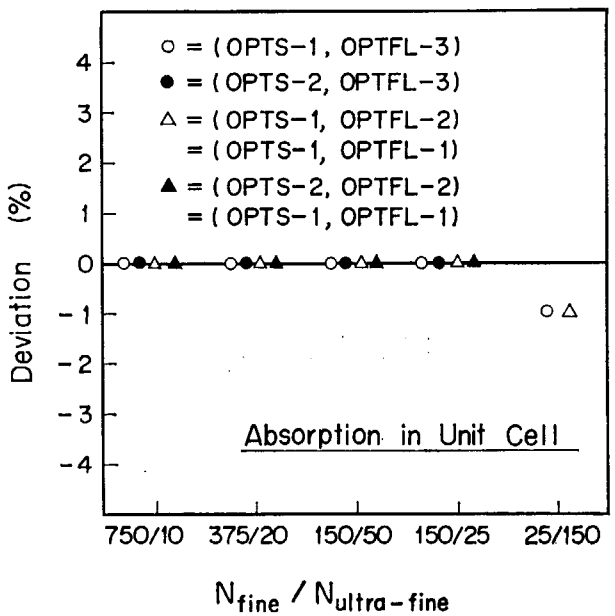

Fig. 10 Deviation of averaged absorption cross section in unit cell.

7. PEACO-MAIN Code

This code is written in FACOM-230/60 FORTRAN which is a standard type one commonly used. In this section, the input imformation necessary for operation of the code will be given, then the quantities printed will briefly be described, and finally the structure of the code will be shown.

7. 1 Input

Card	FORMAT	Variables	Description
1	18A4	TIL(I)	Problem identification
2	12 I 6	KREG	No. of regions ($\leqq$20)
		KMAT	Total no. of materials ($\leqq$10)
		KRES	No. of resonance absorbing nuclides ($\leqq$4)
		KCOMP	No. of compositions ($\leqq$7)
		KCOMPF	No. of fuel compositions ($\leqq$3)
		KTEMP	No. of temperatures considered for resonance cross sections ($\leqq$3)
		NRMAT	A number for special resonance-absorbing nuclide of which the mass is commonly used for other resonance-absorbing nuclides when slowing down sources are calculated.
		NOPT	$=-2$: Hexagonal geometry of two regions is treated by Nordheim model.
			$=-1$: Square geometry treated by Nordheim model.
			$=0$: Homogeneous problem
			$=1$: Plane geometry
			$=2$ or 3 : Cylindrical geometry
			$\geqq 5$: Other geometries except for above ones
		NOPTFL	$=1$: OPTFL-1 in sect. 3.3
			>1 : OPTFL-2
			This option is operated below the energy, EOPT, specified by the next card, if NOPTFL=0, OPTFL-3 is used.
		NOPTS	$=0$: OPTS-1 in sect. 3.2
			>0 : OPTS-2
		NREAD	Logical unit number to read cards or tape for Z_i, V_j, P_{ij} etc. in subroutine INPUT 2
		LISTR	$\neq 0$: Fine group flux in each region is printed
		LISTS	$\neq 0$: Fine group flux in each sub-region is printed.
		NOPTX	$\neq 0$: The case 2 in sect. 3 is treated.
3	E12.5	EOPT	Below this energy (eV), OPTFL-1 or 2 in sect. 3.3 can be operated.
4	12 I 6	KSOUCE	>0 : Thermal neutron source is calculated on KSOUCE points. ($\leqq$40)
		MORE	If MORE=0, more problems than one are treated in a run.
5	12 I 6	(NTEMP(I), I=1, KCOMPF)	Assignation of temperature number to each fuel composition.
6	6E12.5	(TEMP(I), I=1, KTEMP)	Temperature (°K)

Card	FORMAT	Variables	Description
7	2I6, E12.5	(NCOMP(I),	Composition number of the I'th region
		NSUBR(I),	Subregion number on the outer boundary of the I'th region
		RMAX(I),	Distance from center to the outer boundary of the I'th region
		I=1, KREG)	(This information is unnecessary for NOPT≧5.)
8	12I6	KBG	No. of coarse groups for averaging various quantities (≦40)
		KKGP	Total no. of fine groups used to assign the size of variable dimension (≦30000) This may appropriately be selected as a number(≧ true one).
		KSG	No. of energy points where P_{ij} or cross sections of moderator or structural material are given (the case 2 or 3 in sect. 5.3) (≦30)
		KAG	No. of energy points where capture cross section is given. (the case 4 in sect. 5.3) (≦20)
		NBB	Maximum no. of the fine groups a neutron can be slowing-down in a conllision with the lightest atom except for hydrogen.
		NBH	Max. no. of the fine groups a neutron can be slowing-down in a collision with the heavy resonant atom.
		NBR	Max. no. of the fine groups a neutron can be slowing-down in a collision with the resonant scatterer.
9	6E12.5	(EN(I), I=1, KBG+1)	Energy boundaries for coarse groups
	Note : In the following cards relating to the information on materials, the order of materials must follow to the magnitude of MAOPT in sect. 5.3. KMAT sets of the cards are needed.		
10	A4, 8X,	NUCLID(I),	Nuclide identification
	4E12.5, I6,	AMU(I),	Atomic mass
	E10.5	SIGA(I),	Capture cross section for E ≧ starting energy
		SIGF(I),	Fission cross section for E ≧ starting energy
		SIGS(I),	Scattering cross section for E ≧ starting energy
		MAOPT,	Defined in sect. 5.3
		VCAP(I),	2200-m/sec value of $1/v$ absorption cross section
11	6E12.5	(DEN(I, J), J=1, KCOMP)	Atomic number density [atoms/(barns-cm)] of the J'th composition
	Note : The following two cards are unnecessary unless KSG>1 and a nuclide with MAOPT=1 is included.		
12	6E12.5	ERES	E^R in Eq. (5-18)
		PEAK	σ_0^R in Eq. (5-16)
		GJ	g_J in Eq. (5-18)
		GAMT	Γ in Eq. (5-18)
		GAMG	Γ_γ in Eq. (5-17)
13	6E12.5	POTEP	σ_{p+} in Eq. (5-16)
		POTEM	σ_{p-} in Eq. (5-16)
	Note : The following card is unnecessary for KAG≦1.		
14	6E12.5	(EAG(I),	Energy where capture cross section is given to a nuclide with MAOPT=3 (EN(1)>EAG(1)).
		SIGAA(I+1), I=1, KAG−1)	The capture cross section (SIGAA(1)=SIGA(I))
	Note : The following card is unnecessary for KSOUCE≦0		
15	6E12.5	(ESOUCE(I), I=1, KSOUCE)	Energy boundary thermal neutron source is calculated
	Note : All the above cards from 1 to 15 are read from subroutine INPUT 1, while the following information is read from INPUT 2. It should especially be noted that all the information is input from a read unit specified by the logical unit number NREAD. When the PEACO-COLLIS code is used for the calculation of P_{ij}, all the following information is output from it following the needed FORMAT.		
16	7F10.6	(Z(I), I=1, KZ)	Z in Eq. (5-7)

Card	FORMAT	Variables	Description
	Note : At present, in the PEACO-MAIN and COLLIS, the number KZ is fixed to be 20, but any number can be used by a small change of the codes,		
17	7F10.5	RF,	l in Eq. (5-7)
		(V(I), I=1, KSREG)	Subregion volume (KSREG=NSUBR (KREG))
18	7F10.3	(ESG(I),	Energy on which P_{ij} and the cross sections of structural or cladding materials are given.
		I=1, KSG−1)	If KSG≦1, this information is unnecessary.
	Note : The following cards are not needed for the case where KSG≦1 or the materials with MAOT−2 are not included in system. Special attention should be paid for the consistency of the order of materials with that in of the card type 10. Details will be seen from the FORTRAN list of the subroutine INPUT 2.		
	DO I=1, ILAST (until card 20) ILAST=no. of materials with MAOPT=2		
19	7F10.5	(CS2(I, J),	Macroscopic scattering cross section of the (I+ISS)'th material in the (J+JCOMP)'th composition
		J=1, KCOMP-KCOMPF)	Here, the ISS is the number of the last material with MAOPT =0 or 1 just before one with MAOPT=2. JCOMP=0 for NOPT=0, =KCOMPF for NOPT≠0.
20	7F10.5	(CA2(I, J), J=1, KCOMP-KCOMPF)	Macroscopic capture cross section
21	7F10.5	(W(I), I=1, KISREG)	$P_{ij}(i\leqq j)$, KISREG=(KSREG*(KSREG+1))*KZ/2
22	7F10.5	(W1(I), I=1, KMSREG)	$P_{ij}(i\leqq j)$, KMSREG=(KSREG*(KSREG+1))*(KZ−1)*KCOMPF/2
	Note : The information from 19 to 22 must be prepared by KSG sets.		

7. 2 Output

When the neutron flux distribution ϕ_i^m for ultra-fine group is calculated in each subregion, various reaction rates or integrated quantities can be obtained from the use of microsopic cross sections. In this basic quantities computed are

$$A_{xik}^M=\underset{m\varepsilon M}{Sum}\sigma_{xk}^m\phi_i^m \text{ and } \Phi_i^M=\underset{m\varepsilon M}{Sum}\phi_i^m \tag{7-1}$$

with

$$\phi_i^m=\phi_i^m e^{-u_m}/V_i, \tag{7-2}$$

where M shows the fine group number and x stands for capture, fission or scattering.

At first, we can print the flux distributions of the fine group, $\Phi_i^M/\Delta U^M$, by using the option LISTS≠0, where ΔU^M is the fine group width. Also, the flux for each region defined by

$$\tilde{\Phi}_I^M=(\underset{i\varepsilon I}{Sum}\Phi_i^M V_i)/(\Delta U^M \underset{i\varepsilon I}{Sum}V_i) \tag{7-3}$$

can be printed by using the option LISTR≠0, where I shows the region number.

The following quantities are computed and printed for each broad group :

1) Averaged flux in each subregion

$$\hat{\Phi}_i^K=(\underset{M\varepsilon K}{Sum}\Phi_i^M)/U^K \text{ with } U^K=\underset{M\varepsilon K}{Sum}\Delta U^K. \tag{7-4}$$

2) Averaged flux in each region

$$\hat{\Phi}_I^K=(\underset{M\varepsilon K}{Sum}\tilde{\Phi}_I^M\Delta U^M)/U^K. \tag{7-5}$$

3) Effective cross sections in each subregion

$$\hat{\sigma}_{x\mathrm{ik}}^{\mathrm{K}}=(\underset{\mathrm{M}\varepsilon\mathrm{K}}{Sum}A_{x\mathrm{ik}}^{\mathrm{M}})/(\hat{\Phi}_{\mathrm{i}}^{\mathrm{K}}\mathrm{U}^{\mathrm{K}}). \tag{7-6}$$

4) Effective cross sections in each region

$$\hat{\sigma}_{x\mathrm{Ik}}^{\mathrm{K}}=(\underset{\mathrm{M}\varepsilon\mathrm{K}}{Sum}\underset{\mathrm{i}\varepsilon\mathrm{I}}{Sum}A_{x\mathrm{ik}}^{\mathrm{M}}V_{\mathrm{i}}/(\underset{\mathrm{i}\varepsilon\mathrm{I}}{Sum}\hat{\Phi}_{\mathrm{i}}^{\mathrm{K}}\mathrm{U}^{\mathrm{K}}V_{\mathrm{I}}). \tag{7-7}$$

5) Effective removal cross section in each subregion

$$\hat{\sigma}_{\mathrm{rik}}^{\mathrm{K}}=\int_{E_{k+1}}^{E_{k+1}/\alpha_k}\sigma_{\mathrm{sk}}\phi_{\mathrm{i}}\frac{E_{k+1}-\alpha_kE}{(1-\alpha_k)E}dE\Big/\int_{E_{k+1}}^{E_k}\phi_{\mathrm{i}}dE$$

$$=\frac{1}{1-\alpha_k}\frac{E_{k+1}}{E_1}\int_{u_{k+1}-\varepsilon_k}^{u_{k+1}}F_{\mathrm{ik}}(u)\left[1-e^{-(u-u_{k+1}+\varepsilon_k)}\right]du/(\hat{\Phi}_{\mathrm{i}}^{\mathrm{K}}U^{\mathrm{K}}) \tag{7-8}$$

where $(u_{k+1}-\varepsilon_k)\geqq u_k$ is assumed.

6) Effective removal cross section in each region

$$\hat{\sigma}_{\mathrm{rIk}}^{\mathrm{K}}=(\underset{\mathrm{i}\varepsilon\mathrm{I}}{Sum}\sigma_{\mathrm{rik}}^{\mathrm{K}}V_{\mathrm{i}})/V_{\mathrm{I}}. \tag{7-9}$$

For each broad group, the infinite dilution cross sections of the special elements with MAOP $=0\sim3$ are also printed. The above quantities from 1) to 6) are always printed for each subregion, but for each subregion the output of them is omitted when LISTS=0.

The following quantities are obtained from the integration over the whole energy range of calculation and always printed at the last stage of output.

7) Integrated flux in each region

$$\bar{\Phi}_{\mathrm{I}}=\underset{\text{all M}}{Sum}\tilde{\Phi}_{\mathrm{I}}^{\mathrm{M}}\Delta U^{\mathrm{M}}. \tag{7-10}$$

8) Capture and fission activations in each region

$$\bar{A}_{x\mathrm{Ik}}=(\underset{\text{all M}}{Sum}\underset{\mathrm{i}\varepsilon\mathrm{I}}{Sum}A_{x\mathrm{ik}}^{\mathrm{M}}V_{\mathrm{i}})/V_{\mathrm{I}}. \tag{7-11}$$

9) Total capture and fission probabilities

$$P_x=1-\underset{\mathrm{I,k}}{Sum}(\bar{A}_{x\mathrm{Ik}}V_{\mathrm{I}}N_{\mathrm{Ik}})/\overline{\xi\Sigma}_{\mathrm{S}} \tag{7-12}$$

with

$$\overline{\xi\Sigma}_{\mathrm{s}}\cong\left[\underset{}{Sum}\Sigma_{\mathrm{sIk}}V_{\mathrm{I}}\left(1-\frac{\alpha_k\varepsilon_k}{1-\alpha_k}\right)\right](2\beta-1)/\beta \tag{7-13}$$

where β is defined by Eq. (3-16).

The neutron source slowed down into thermal energy range is calculated by the follow equations;

$$S_{\mathrm{i}}(E)=\underset{\mathrm{k}}{Sum}\,S_{\mathrm{ik}}(E)=\underset{\mathrm{k}}{Sum}\frac{1}{E_1}\int_{u-\varepsilon_k}^{u_c}\frac{F_{\mathrm{ik}}(u')}{1-\alpha_k}du' \tag{7-14}$$

where u_c is the lethargy corresponding to the cutoff energy Ec and $u_c\geqq u-\varepsilon_k$ is assumed. Then, the integrated source over a narrow energy interval from E_- to E_+ can be given by

$$\bar{S}_{\mathrm{ik}}\equiv\int_{E_-}^{E_+}S_{\mathrm{ik}}(E)\,dE=\int_{-\infty}^{u_c}du'F_{\mathrm{ik}}(u')\int_{u_-}^{u_+}f(u-u')e^{-u}du\frac{1}{1-\alpha_k} \tag{7-15}$$

where u_+ and u_- correspond to E_- and E_+, respectively. Hence,

$$\bar{S}_{\mathrm{ik}}=0,\quad\text{for }\varepsilon_k<u_--u_c. \tag{7-16}$$

For hydrogen atom,

$$\bar{S}_{\mathrm{ik}}=\int_{-\infty}^{u_c}F_{\mathrm{ik}}(u')du'=\text{constant}. \tag{7-17}$$

On the other hand when $u_+-\varepsilon_k>u_c\geqq u_--\varepsilon_k$,

$$\bar{S}_{ik}=\frac{1}{(1-\alpha_k)E_1}\left[\int_{u_--\varepsilon_k}^{u_c} F(u')\,(E_+-\alpha_k E')du'\right]. \tag{7-18}$$

For $\varepsilon_k > u_+ - u_c$

$$\bar{S}_{ik}=\frac{1}{(1-\alpha_k)E_1}\left[(E_+-E_-)\int_{u_--\varepsilon_k}^{u_c} F_{ik}(u')du'-\int_{u_--\varepsilon_k}^{u_+-\varepsilon_k} F_{ik}(u')\,(E_--\alpha_k E')du'\right]. \tag{7-19}$$

7. 3 Structure of the PEACO-MAIN code

This code consists of a main program and eight sbroutines. The block diagram of the code is shown in Fig. 11, and the complete listing will be given in the Appendix C. The function of each program is given briefly below.

1. Main program MAIN-MAIN : Determines the size of variable dimensions and calls each subroutine.
2. INPUT 1 : Reads in input information.
3. INPUT 2 : Reads in Z_λ, l, V_i and collision probabilities, and reads in also cross sections of the materials with MAOPT=2, and calculates Dancoff factor for the geometry with NOPT <0.
4. DATA : Computes group independent parameters.
5. OUTPUT 1 : Prints input data and group independent parameters.
6. AVERAG : Interpolates collision probabilities on the fine groups, calculates the regional slowing-down source by the use of Eq. (3-13) and accumulates reaction rates and integrated fluxes over the fine groups and broad groups.
7. XSECT : Reads in resonance cross sections from library tapes and calculates collision probabilities and the equations (3-12), (3-20) or (3-25).
8. OUTPUT 2 : Lists the fine group fluxes, calculates effective cross sections and averaged fluxes of each broad group and accumulates various integral quantities over whole energy range.

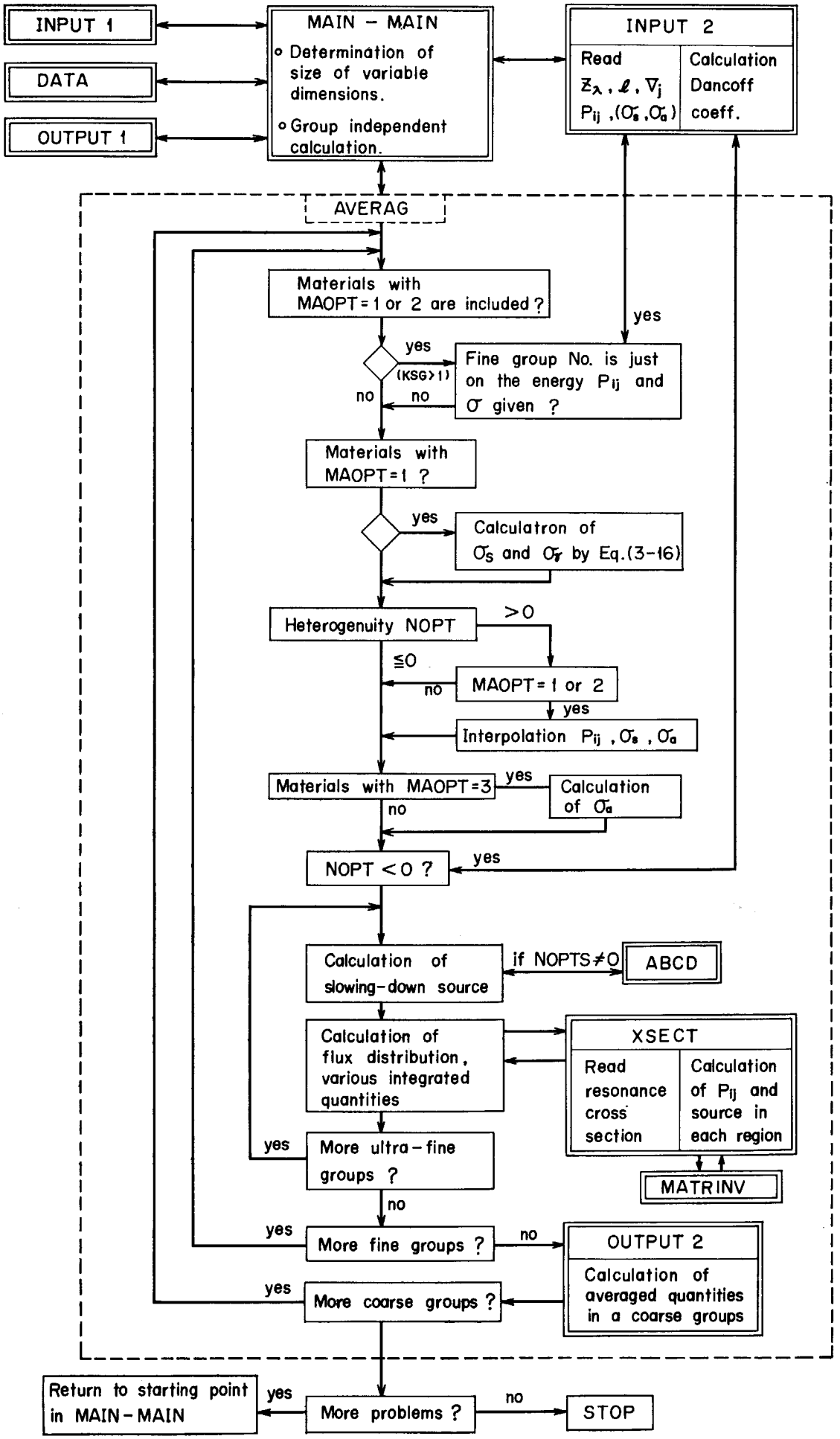

Fig. 11 Block diagram of PEACO- MAIN code.

8. PEACO-MCROSS Code

This code is also written in FACOM-230/60 FORTRAN, and it is prepared for the present purpose by revising the MCROSS code that originates from the GENEX. Here, only the input information and the structure of the library tape of resonance cross sections will be described simply.

8. 1 Input

Card	FORMAT	Variables	Description
1	6I5	IOUT	$\neq 0$, Pointwise resonance cross sections are printed.
		IOTP	$\neq 0$, pointwise resonance cross sections are written in a library tape.
		IREAD	$=0$, resonance parameters of the s and p-wave are read from tapes, and $\neq 0$, they are read by cards.
		IGMO	$=0$, $\Gamma_{\lambda n}^{0}=\Gamma_{\lambda n}/\sqrt{E_\lambda}$ is read in, $=1$, $\Gamma_{\lambda n}$ is read in.
		NONR	>0, smooth part cross sections are added to the resonance part by a step function.
		NSMP	No. of energy boundaries the smooth cross sections are read in.
2	9I5	MF	No. of fission channels, MF=1, a singe-level formula is used for fissionable materials.
		MZ	No. of inelastic channels of the lst. excited levels.
		MQ	No. of inelastic channels of the 2nd. excited levels.
		NORES	No. of blocks the s-wave when resonance parameters are read in.
		NOS	No. of the s-wave resonance levels in a block.
		NOLASS	No. of the s-wave levels in the last block.
		NOREP	No. of blocks when the p-wave resonance parameters are read in.
		NOP	No. of the p-wave resonance levels in a block.
		NOLASP	No. of the p-wave levels in the last block.
3	9I5	NOMESH	No. of energy groups where the fine-group width is different.
		N	No. of the s-wave resonance levels of which the resonance levels are summed up when the resonance cross sections are calculated.
		MP	$=0$, the p-wave resonances are not taken into consideration.
		MSP	$\neq 0$, the interference scattering effect between the s-wave resonances is considered.
		MSS	$=0$, single-evel formula is used for the calculation of resonance cross sections. $\neq 0$, multilevel formula is used.
		NMP	No. of the p-wave resonance levels of which the resonance levels are summed up when the resonance cross sections are calculated.
		IMP	The lowest group number up to which the p-wave resonances considered.
		NT	No. of temperatures
		NEC	$=0$, $\sigma_p=4\pi R^2$ and if NEC$\neq 0$, $\sigma_p=4\pi R^2 f(x)$.
4	6E12.5	EUPPER	The lowest energy boundary

Card	FORMAT	Variables	Description
		AM	Atomic mass
		R	Atomic radius (in Fermi unit)
		EFW 2	The lowest energy boundary above which the contribution of Doppler broadened function F (w_2) can be neglected.
		(TT(I), I=1, NT)	Temperature (°K)
5	6E12.5	(BOUND(I),	Upper energy boundary
		NOIG(I),	No. of fine groups in this energy range
		NFI(I),	No. of ultra-fine group in a fine group
		IMME(I), I=1, NOMESH)	No. of the fine groups which is used to reduce the round error appeared in the lethargy calclulated by summing up the fine group. At every step of this number of the fine groups. the lethargy is renewed to be consistent with energy value. When the energy range where the fine group width is constant is narrower, this number may be selected to be equal to NOIG (I).
	Note : The following, card no. 6, is		not needed for NONR=0.
6	7F10.5	(EBS(I),	Lower energy boundary the smooth cross section is given.
		SCS(I),	Smooth capture cross section for the *s*-wave neutrons
		SFS(I),	Smooth fission 〃
		SES(I),	Smooth elastic 〃
		SCP(I),	Smooth capture cross section for the *p*-wave neutrons
		SFP(I),	Smooth fission 〃
		SEP(I), I=1, NSMP)	Smooth elastic 〃
	Note : The following no. 7 cards is		unnecessary for IREAD=0. Pile up (1+MSS)〔NORES−1)* NOS+NOLASS〕 cards.
7	6E12.5	ES	E_λ for the *s*-wave neutrons
		GS	g_J
		HNS	$\Gamma_{\lambda n}$
		HCS	$\Gamma_{\lambda\gamma}$
		HFS	$\Gamma_{\lambda f}$
		HIS	$\Gamma_{\lambda in}$
		(CF(I), I=1, MF)	$\xi_{\lambda c}=\sqrt{\Gamma_{\lambda c}}/(\Gamma_{\lambda c})^{1/2}$ for c c f.
	Note : The following no. 8 cards is		unnecessary unless IREAD≠0 or MP≠0. Pile up 〔(NOREP−1)*NOP+NOLASP〕 cards.
8	6E12.5	EP	E_λ for the *p*-wave neutrons
		GP	g_J
		HNP	$\Gamma_{\lambda n}$
		HCP	$\Gamma_{\lambda\gamma}$
		HFP	$\Gamma_{\lambda f}$
	Note : The above input, no. 7 and 8, must be read from two separate input-tapes in the binary form when IREAD=0.		

8. 2 Structure of The Library Tape of Resonance Cross Sections

The PEACO-MCROSS code can make only a library tape for each resonant nuclide and each library tape corresponds to the special case of one nuclide on the structure shown below. The contents of the final form of the library tape consist of a few information specifying the fine and ultra-fine groups and of resonance cross sections of several resonant nuclide with a temperature. Hence, a sorting of tapes must be done for the case of few nuclide.

Variable	Description
TEMPT(NN)	Temperature of the NN 'th library tape
KREST	No. of resonant nuclide in this tape ($\leqq 4$)
(NUCLI(I), I=1, KREST)	Identification of nuclide
NOXG	No. of energy ranges with different fine and ultra-fine widths, and these energy ranges are called the cross section groups (NOXG$\leqq$10)
EXG(1)	Starting energy for the calculation of resonance cross sections
(EXG(I+1),	Lower energy boundaries of the I'th cross section group
UIGP(I),	Fine-group width in the I'th cross section group
NOIG(I),	Total no. of fine groups in the I'th cross section group
NFI(I),	No. of ultra-fine groups in a fine group
I=1, NOXG)	
MAXNFI	Maximum no. of NFI(I)
Note : The following NOXG).	resonance cross sections are piled up by the number of (Sum NOIG(I), I=1,
((SAA(J, NN, K)	σ_a for the k'th ultra-fine group in a fine group and for the J'th nuclide
SFF(J, NN, K),	σ_f 〃 〃 〃
SSS(J, NN, K),	σ_s 〃 〃 〃
K=1, NFI(I)),	
J=1, KRES)	

9. PEACO-COLLIS Code

This code calculates the collision probabilities P_{ij} and their derivatives $\frac{\partial}{\partial Z_\lambda} P_{ij}$ for the multi-region lattices on twenty points of Z defined by Eq. (5-7). These values of Z and the corresponding values of $l\Sigma_f$ used are shown in TABLE 4. In this code, l is fixed to be the thickness of fuel plate or the radius of fuel pin. When other codes are used for the calculation of P_{ij} the number of Z and the value of l may be selected adequately. This code consists of several subprograms developed by K. TSUCHIHASHI[30].

TABLE 4 The value of Z and $l\Sigma_f$ used for interpolation of collision probabilities

No.	Z	$l\Sigma_f$	No.	Z	$l\Sigma_f$
1	0.03	0.03	11	1.4	1.6667
2	0.1	0.1	12	1.6	2.5
3	0.2	0.2	13	1.7	3.3333
4	0.4	0.4	14	1.8	5.0
5	0.5	0.5	15	1.875	8.0
6	0.6	0.6	16	1.9333	15.
7	0.7	0.7	17	1.96	20.
8	0.85	0.85	18	1.98	50.
9	1.0	1.0	19	1.99	100.
10	1.2	1.25	20	1.998	500.

9. 1 Input

Card	FORMAT	Variables	Description
1	18A4	TIL	Specification of problem
2	14I5	NREG	No. of regions
		NCOMP	No. of compositions
		NCOMPF	No. of fuel compositions
		MATER	No. of materials except for resonant nuclide
		NSCAT	No. of energy points where the cross sections of structural or coolant materials are given.
3	14I5	IWRITE	Logical unit no. for the output of the information used in the PEACO-MAIN.
		IPRINT	$\neq 0$, the detailed information is given for collision probabilities.
		NOPTI	$\neq 0$, the accuracy of the present method of Eq. (5-8) is checked for the NOPTI resonance levels read below.
		NOPT 2	$\neq 0$, the case 2 in sect. 3 can be treated.
4	14I5	NOPT	<0, plane geometry can be treated.
			$=0$, cylindericalized cell
			$=1$, square lattice
			$=2$, hexagonal lattice
		IBOUND	$=0$, isotropic boundary condition at the outer boundary
			$=1$, perfect reflection boundary condition
			$=2$, fixed reflection boundary condition

Card	FORMAT	Variables	Description
		LIMIT	Maximum path length (cm) beyond which the neutron path is neglected.
		NCELL	No. of unit cells which are considered in the calculation of P_{ij}
		NSYMM	$\neq 0$, the plane geometry treated is center-symmetric.
5	2I5, F10.5	(NOCOM(I),	No. of composition in the I'th region
		NSREG(I),	Subregion number at the outer boundary of the I'th region
		R(I+1), I=1, NREG)	Thickness of the I'th region (cm)
6	7F10.4	(DEN(M),	Atomic number density of resonant nuclide in the M'th fuel composition
		SIGM(M),	Microscopic total cross section of admixed material in the M' th fuel composition per resonant atom
		M=1, NCOMPF)	This card is not needed for NOPT 1=0 or NOPT 2=0.
7		(DEN(M),	Atomic density of resonant nuclide in the M'th composition
		M=NCOMPF+1, NCOMP)	This card is also unnecessary for NOPT 2=0.
8	14I5	(MAOPT(I), I=1, MATER)	MAOPT in Sec. 5.3
9	7F10.4	(ESG(L),	Energy point where the cross sections of structural or coolant material are given.
		L=1, NSCAT−1)	This card is unnecessary for NSCAT≦1.
10	7F10.4	(SSIGS(I, J),	Scattering cross section of the I'th material on the J'th energy point.
		J=1, KGP)	KGP=1 for MAOPT≠2, KGP=NSCAT for MAOPT=2.
11	7F10.4	(SSIGA(I, I), J=1, KGP)	Absorption cross section
12	7F10.4	(DENS(I, N), N=NCOMPF+1, NCOMP)	Atomic number density of the I'th material in the N'th composition
	Note : Pile up the MATER sets of the card no. 10, 11 and 12.		
	Note : The following card is unnecassary for NSCAT≦1 or for the case where the resonance scatterer is absent.		
13	7F10.4	RE	E^R in Eq. (5-18)
		RSIG 0	$\sigma_0{}^R$
		RSIGPP	σ_{p+}
		RSIGPM	σ_{p-}
		RGJ	g_J
		RGT	Γ
		RGN	Γ'_n
	Note : Pile up the NOPTl sets of the card no. 14 and 15.		
14	7F10.5	(TEMP(M), M=1, NCOMPF)	Temperature (in °K)
15	7F10.5	ER	Eo. resonance energy level for the accuracy check
		G	g_J
		GN	Γ'_n
		GT	Γ
		SIGP	σ_p
		AMU	Atomic mass

9. 2 Output from PEACO-COLLIS for PEACO-MAIN

The output for the PEACO-MAIN are made by cards or written on a tape mounted on

the logical unit no. specified by IWRITE. These output have the FORMAT specified below. Description for other output will be omitted because they are printed following to self-evident symbols.

No.	FORMAT	Variable	Description
1	7F10.6	(Z(K), K=1, 20)	Z in Eq. (5-7)
2	7F10.6	RF	l in Eq. (5-7)
		(V(I),	Volume of each subregion
		I=1, IMAX)	IMAX=NSREG (NREG)
3	7F10.2	(ESG(L), L=1, NSCAT−1)	This information is not output when NSCAT≦1.
	Note : All the following information is piled up by NSCAT pairs.		
4	7F10.6	(SSS(L, M, N), N=NTEMP,	Σ_s of the M'th material in the N'th composition
		NCOMP)	NTEMP=NCOMPF+1
5	7F10.6	(AAA(L M, N), N=NTEMP, NCOMP)	Σ_a
	Note : The above information of no. 4 and 5 is piled up by MATER pair.		
6	7F10.6	(W(I, J, K), J=1, I), I=1, IMAX), K=1, 20)	P_{ij}
7	7F10.6	(W 1(M, I, J, K), J=1, I), I=1, IMAX), M=1, NCOMPF), K=1, 20)	$\frac{\partial}{\partial Z_\lambda} P_{ij}$

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Appendix A Sample problem listing of PEACO-MAIN code

To illustrate the use of PEACO-MAIN, a sample problem is presented for the case no. 1 in TABLE 1. In this problem, the five-regions problem is reduced to two-regions one where fuel rod has an averaged temperature, 1500 °K, and the mixed region of sodium bond, cladding and coolant is taken in outer region. For the simplicity, the resonance cross sections of ^{239}Pu are given by effective cross sections and MAOPT for ^{239}Pu is assumed to be 3. The energy range treated extends from 7.73 to 0.1 keV.

```
** INPUT DATA LIST **(THE LIST IS DONE IN THE SAME FORMAT AS INPUT)

 TWO REGION PROBLEM FOR W.H. UNIT CELL
    2    5    1    2    1    1    1
    2    1    0    2    1    0    0
 0.78000E 04
    0    0
    1
 0.15000E 04
    1    2 0.34030E 00
    2    3 0.56840E 00
   10  7000   14   10   850   50   500
 0.77300E 04 0.46500E 04 0.36000E 04 0.27800E 04 0.21500E 04 0.16600E 04
 0.12900E 04 0.10000E 04 0.46500E 03 0.21500E 03 0.10000E 03
U235          238.00000     0.90000     0.0        15.00000    0 0.0
 0.24990E-01 0.0
NA23           23.00000     0.00450     0.0         9.00000    1 0.0
 0.0         0.19667E-01
FE56           56.00000     0.01150     0.0        13.20000    2 0.0
 0.0         0.76290E-02
PU29          239.00000     3.45040     0.0        11.00000    3 0.0
 0.44100E-02 0.0
C-12           12.00000     0.0         0.0         4.80000    4 0.0
 0.29400E-01 0.0
 0.28500E 04 0.60000E 03 0.63100E 00 0.38000E 03 0.10000E 00
 0.46500E 00 0.52570E 00
 0.68550E 04 0.36600E 01 0.33150E 04 0.44586E 01 0.41250E 04 0.45927E 01
 0.31900E 04 0.53646E 01 0.24650E 04 0.67108E 01 0.19050E 04 0.72440E 01
 0.14750E 04 0.83750E 01 0.11450E 04 0.64432E 02 0.88690E 03 0.91560E 01
 0.68550E 03 0.85200E 01 0.53150E 03 0.11123E 02 0.41250E 03 0.78580E 00
 0.31900E 03 0.13510E 02 0.24650E 03 0.27721E 02

** OUTPUT FROM TAPE **

          NUCLID ***      U236
          TAPE NO./TEMPT(NI)/KREST/NOXG/EXG(1)/MAXNFI ****    1   1500.00    1   10  10000.00   20
          EXG/UIGP/NOIG/NFI ***   4650.00   0.00040 1915   10
          EXG/UIGP/NOIG/NFI ***   2150.00   0.00050 1542   10
          EXG/UIGP/NOIG/NFI ***   1000.00   0.00050 1530   15
          EXG/UIGP/NOIG/NFI ***    465.00   0.00079  965   20
          EXG/UIGP/NOIG/NFI ***    215.00   0.00100  771   20
          EXG/UIGP/NOIG/NFI ***    100.00   0.00160  765   10
          EXG/UIGP/NOIG/NFI ***     46.50   0.00200  383   10
          EXG/UIGP/NOIG/NFI ***     10.00   0.00501  307   15
          EXG/UIGP/NOIG/NFI ***      3.00   0.00752  100   10
          EXG/UIGP/NOIG/NFI ***      0.10   0.00975  349    2

                ******** INFORMATION FOR VARIABLE DIMENSION *******
LL1     LL4     LL8     LL12    LL20    LL22    LL23    LL24    LL25    LL26    LL27    LL28
11      51      110     165     2810    9960    21460   11461   41581   11695   11815   11929
 *****      14       1       1
```

TWO REGION PROBLEM FOR W.H. UNIT CELL

******* INPUT DATA LIST FOR PIECKO CODE *******

NO. OF REGIONS	NO. OF MATERIALS	RESONANT MATERIALS	NO. OF COMPOSIT.	NO. OF FUEL COMP.	NO. OF TEMPERATURE
2	5	1	2	1	1

	*** MATERIAL AND CROSS SECTION ***						*** NO. OF COMPOSITION AND DENSITY ***	
NO.	NUCLIDE	MASS	SIGMA-S	SIGMA-A	SIGMA-F	SIGMA-T	* 1	2
1	U238	238.0000	15.0000	0.9000	0.0	15.9000	* 0.0250	0.0
2	NA23	23.0000	9.0000	0.0045	0.0	9.0045	* 0.0	0.0197
3	FE56	56.0000	13.2000	0.0115	0.0	13.2115	* 0.0	0.0076
4	PU29	239.0000	11.0000	3.4504	0.0	14.4504	* 0.0044	0.0
5	C-12	12.0000	4.6800	0.0	0.0	4.6800	* 0.0294	0.0

NO. OF COMPOSITION	TEMPERATURE(K. DEGREES)
1	4500.00

*

*** SLOWING DOWN PROPERTY ***

NO.	NUCLIDE	ALPHA	UMAX(I)	1/(1.-ALF.)
1	U238	0.98333	0.01681	60.0011
2	NA23	0.84028	0.17402	6.2609
3	FE56	0.93106	0.07144	14.5045
4	PU29	0.98340	0.01674	60.2511
5	C-12	0.71598	0.33411	3.5208

OPTION FOR GEOMETRY= 2 ****(I=0,1,2,3,4)(GEOMETRY=HOMO.,PLANE,CYLINDER,SQUARE,HEXAGONAL)****

******* SUBREGION *********			******** REGION *********			
NO.	VOLUME	COMPOSITION	NO.	VOLUME	RMAX	SIGMA-T
1	0.0910	1	1	0.3638	0.3403	0.5987
2	0.2728	1	1	0.3638	0.3403	0.5987
3	0.6512	2	2	0.6912	0.5684	0.2779

SQUARE-WAVE FOR INTERPOLATION OF COLLISION PROBABILITY

NO.	1	2	3	4	5	6	7	8	9	10
Z(I)	0.0100	0.1000	0.2000	0.4000	0.5000	0.6000	0.7000	0.8500	1.0000	1.2000

NO.	11	12	13	14	15	16	17	18	19	20
Z(I)	1.4000	1.6000	1.7000	1.8000	1.8750	1.9333	1.9600	1.9800	1.9900	1.9980

CONSTANT FOR INITIAL FLUX(=V(I)*EXP(C*U)) ******** C= 0.9045

AVERAGE LOGARITHMIC DECREMENT IN HIGHEST ENERGY REGION= 0.02282

***** ENERGY POINTS WHERE COLLISION PROBABILITIES ARE GIVEN (ISS= 2 IVF= 3 IVL= 3) *****

NO. OF SCATTERING GROUP	1	2	3	4	5	6	7	8	9	10
ENERGY(I)	6000.000	5500.000	5000.000	4500.000	4000.000	3500.000	3200.000	2850.000	2700.000	2500.000
NO. OF SCATTERING GROUP	11	12	13							
ENERGY(I)	2000.000	1500.000	400.000							

ABSORPTION CROSS SECTION OF 4TH MATERIAL

NO. OF ABSUPTION GROUP	1	2	3	4	5	6	7	8	9	10
ENERGY(I)	6855.000	5315.000	4125.000	3190.000	2465.000	1905.000	1475.000	1145.000	886.500	685.500
SIGMAA(I)	3.450	3.600	4.459	4.593	5.365	6.717	7.744	8.373	6.443	9.158
NAG(I)	302	938	1512	2026	2541	3056	3568	4074	4496	4820
NO. OF ABSUPTION GROUP	11	12	13	14						
ENERGY(I)	531.200	412.500	319.000	246.500						
SIGMAA(I)	8.520	11.123	0.786	13.51						
NAG(I)	5141	5429	5686	5944						

****** LIST OF INFORMATION TO GROUP STRUCTURE FOR X-SECTION AVERAGE ******

NO.	EN(N)	E(N+1)	DELTA-U	NEG(N)	NIG(N)	NRG(N)))
1	7729.9313	4650.0000	0.5082	2	1271	1
2	4650.0000	3600.0000	0.2559	2	511	7
3	3600.0000	2780.0000	0.2565	2	517	4
4	2780.0000	2150.0000	0.2570	3	514	2
5	2150.0000	1660.0000	0.2557	3	517	1
6	1660.0000	1290.0000	0.2522	3	504	2
7	1290.0000	1000.0000	0.2586	4	509	2
8	1000.0000	465.0000	0.7657	5	965	1
9	465.0000	215.0000	0.7734	6	771	1
10	215.0000	100.0000	0.7655	7	765	1

GROUP STRUCTURE FOR RESONANCE X-SECTION REPRESENTATION

*	X-SECTION GROUP			* INTERMEDIATE GROUP *		* FINE GROUP *	
* NO.	E(N)	E(N+1)	DELTA-U	* NUMBERS	DELTA-U	* NUMBERS	DELTA-U *
1	7729.931	4650.000	0.50823	1271	0.00040	10	0.00004
2	4650.000	2150.000	0.77140	1542	0.00050	10	0.00005
3	2150.000	1000.000	0.76547	1530	0.00050	15	0.00003
4	1000.000	465.000	0.76572	965	0.00079	20	0.00004
5	465.000	215.000	0.77140	771	0.00100	20	0.00005
6	215.000	100.000	0.76547	765	0.00100	10	0.00010
7	100.000	46.500	0.76572	383	0.00200	10	0.00020
8	46.500	10.000	1.53687	307	0.00501	15	0.00033
9	10.000	3.000	1.20397	160	0.00752	10	0.00075
10	3.000	0.100	3.40120	349	0.00975	2	0.00487

******** CALCULATED RESULTS FOR INTERMEDIATE FLUX AND AVERAGED CROSS SECTIONS ********

NO. OF BROAD GROUP= 1.... ENERGY RANGE(7729.931 EV TO 4650.000 EV)....

******** NO. AND FLUX(PER UNIT VOLUME AND LETHARGY) OF EACH REGION ********
(LAST LINE SHOW AVERAGED FLUX OVER CELL)

GROUP NO.	ENERGY /	1	2	
1	7726.39	1.1037	1.0938	1.0973
2	7725.30	1.1002	1.0907	1.0941
3	7722.21	1.1000	1.0905	1.0939
4	7719.12	1.0976	1.0884	1.0917
5	7716.03	1.0934	1.0851	1.0883
6	7712.93	1.0886	1.0804	1.0833
7	7709.87	1.0814	1.0739	1.0766
8	7706.78	1.0772	1.0702	1.0727
9	7703.70	1.0717	1.0653	1.0676
10	7700.62	1.0665	1.0607	1.0629
11	7697.54	1.0649	1.0593	1.0613
12	7694.47	1.0591	1.0541	1.0559
13	7691.39	1.0499	1.0459	1.0464
14	7688.32	1.0436	1.0402	1.0414
15	7685.24	1.0355	1.0330	1.0339
16	7682.17	1.0133	1.0132	1.0132
17	7679.10	0.9956	0.9926	0.9930
18	7676.03	0.8735	0.8862	0.8828
19	7672.96	0.9212	0.9309	0.9274
20	7669.89	1.0285	1.0265	1.0271
21	7666.83	1.0588	1.0538	1.0556
22	7663.76	1.0531	1.0487	1.0503
23	7660.70	1.0460	1.0423	1.0436
24	7657.64	1.0406	1.0378	1.0385
25	7654.57	1.0358	1.0332	1.0341
26	7651.51	1.0314	1.0293	1.0300
27	7648.45	1.0262	1.0247	1.0252
28	7645.40	1.0194	1.0185	1.0188
29	7642.34	1.0134	1.0132	1.0133
30	7639.29	1.0127	1.0126	1.0126
31	7636.23	1.0117	1.0117	1.0117
32	7633.18	1.0076	1.0080	1.0078
33	7630.13	1.0021	1.0031	1.0027
34	7627.08	0.9951	0.9968	0.9962
35	7624.03	0.9820	0.9851	0.9840
36	7620.98	0.9395	0.9471	0.9444
37	7617.93	0.8567	0.8732	0.8673
38	7614.89	0.8430	0.8610	0.8546
39	7611.84	0.9326	0.9408	0.9379
40	7608.80	0.9917	0.9936	0.9929
41	7605.76	0.9883	0.9906	0.9898
42	7602.72	0.9646	0.9729	0.9713
43	7599.68	0.9201	0.9296	0.9262
44	7596.64	0.8052	0.8273	0.8194
45	7593.60	0.7276	0.7587	0.7476
46	7590.57	0.8282	0.8476	0.8406
47	7587.53	0.9826	0.9854	0.9845
48	7584.50	1.0014	1.0020	1.0018
49	7581.47	0.9314	0.9394	0.9365
50	7578.44	0.8852	0.8983	0.8936

```
***** SUMMARY FOR AVERAGED FLUX AND CROSS SECTIONS OF 1 TH BROAD GROUP *****

                    ***** REGIONAL INFORMATION *****

REGION NO.   FLUX   REACTION        U238        NA23        FE56        PU29        C-12

                    ABSORPTION      0.6797      0.0         0.0         3.5979      0.0
                    FISSION         0.0         0.0         0.0         0.0         0.0

     1   0.8152(INTEGRATED VALUE OVER V. AND U =   0.15073 )

                    SCATTERING     14.2552      0.0         0.0        11.0000      4.6600
                    REMOVAL         0.1292      0.0         0.0         0.1341      1.2677

                      -----                                  -----

                    ABSORPTION      0.0         0.0029      0.0108      0.0         0.0
                    FISSION         0.0         0.0         0.0         0.0         0.0

     2   0.8191(INTEGRATED VALUE OVER V. AND U =   0.27109 )

                    SCATTERING      0.0         9.7704     11.2172      0.0         0.0
                    REMOVAL         0.0         1.6944      0.2853      0.0         0.0

                      -----                                  -----


      ***** CELL AVERAGED TOTAL CROSS SECTIONS AND FLUX *****

          ABSORPTION  FISSION  SCATTERING  REMOVAL    FLUX
             0.0136     0.0       0.3723    0.0623   0.4218(INTEGRATED OVER VOLUME AND LETHARGY)


          ***** INFINITE DILUTION XSECTION FOR SPECIAL ELEMENT ****

     TEMPERATURE     REACTION      U238
       1500.00       CAPTURE ....  0.8593
                     FISSION ....  0.0
                     SCATTERING .  16.2657
                     REMOVAL ....  0.1762

   XSECTION OF 2TH MATERIAL .... SCATTERING =   9.96392     REMOVAL =   2.10396

   CAPTURE XSECTION OF 4TH MATERIAL =   5.62054


***** SUMMARY FOR AVERAGED FLUX AND CROSS SECTIONS OF 10 TH BROAD GROUP *****

                    ***** REGIONAL INFORMATION *****

REGION NO.   FLUX   REACTION        U238        NA23        FE56        PU29        C-12

                    ABSORPTION      1.9079      0.0         0.0        13.5455      0.0
                    FISSION         0.0         0.0         0.0         0.0         0.0

     1   0.0147(INTEGRATED VALUE OVER V. AND U =   0.00409 )

                    SCATTERING     14.2065      0.0         0.0        11.0000      4.6600
                    REMOVAL         0.0057      0.0         0.0         0.0675      0.6584

                      -----                                  -----

                    ABSORPTION      0.0         0.0016      0.0070      0.0         0.0
                    FISSION         0.0         0.0         0.0         0.0         0.0

     2   0.0150(INTEGRATED VALUE OVER V. AND U =   0.00746 )

                    SCATTERING      0.0         2.9997     10.5601      0.0         0.0
                    REMOVAL         0.0         0.1318      0.1707      0.0         0.0

                      -----                                  -----


      ***** CELL AVERAGED TOTAL CROSS SECTIONS AND FLUX *****

          ABSORPTION  FISSION  SCATTERING  REMOVAL    FLUX
             0.0381     0.0       0.2814    0.5752   0.0115(INTEGRATED OVER VOLUME AND LETHARGY)

 (ABSORPTION,FISSION AND TOTAL CAPTURE PROBABILITIS) EQUAL ,RESPECTIVELY ....   0.9394    0.0       0.9391


          ***** INFINITE DILUTION XSECTION FOR SPECIAL ELEMENT ****

     TEMPERATURE     REACTION      U238
       1500.00       CAPTURE ....  19.9501
                     FISSION ....  0.0
                     SCATTERING .  67.8730
                     REMOVAL ....  0.0110

   XSECTION OF 2TH MATERIAL .... SCATTERING =   2.99979     REMOVAL =   0.33533

   CAPTURE XSECTION OF 4TH MATERIAL =  13.54564
```

Appendix B

Sample input listing of PEACO-COLLIS and PEACO-MCROSS codes

```
F3600111051OG1406000428G1W0670004008200060O                *** LIST      ***
        SAMPLE INPUT DATA FOR PEACO-COLLIS .. CASE NO. 1 IN TABLE 1

 *** CALCULATION FOR W. H. UNITE CELL  ***
   5    4    2    2    1
   7    0    1    0
   0    0   20   10    0
   1    1 0.2406
   2    2 0.3403
   3    3 0.3558
   4    4 0.3810
   5    5 0.5684
0.0294    4.7       0.0294    4.7
   1    1
600.
0.
0.0216    0.0
5.3
0.0
0.0       0.0862
1800.     1200.
2083.     1.        0.5263    0.5454    10.7      238.

        SAMPLE INPUT DATA FOR PEACO-COLLIS .. CASE NO. 2 IN TABLE 1

 *** TEST CALCULATION OF THE EXAMPLE IN TABLE CO OF ***
   2    2    1    2    1
   7    2    1    1
   0    0   20   10    0
   1    3 0.5625
   2    8 1.297
0.0473    0.
0.00709
   1    1
11.
0.
0.01272
4.
0.
0.01397
270.
1149.     1.        0.274     0.2986    10.       238.

        SAMPLE INPUT DATA FOR PEACO-COLLIS .. CASE NO. 3 IN TABLE 1

  FCA HETEROGENEITY CALCULATION FOR CORD CHECK
   4    3    1    3    1
   7    0    2    0
  -1    1   20   10    1
   1    1 0.32
   2    2 0.90
   3    3 0.96

        2    4 1.28
   0.045     0.
        1    1
   20.1
   0.
   0.          0.0792
   4.7
   0.
   0.0869     0.0
   9.0
   0.0
   0.          0.0336
   300.
   6.67       1.        0.0015    0.0475    10.75     238.      7.8
   300.
   991.73     1.        0.3484    0.3033    10.75     238.

        SAMPLE INPUT DATA FOR PEACO-MCROSS .. CASE NO. 4 IN TABLE 11

      1    1    1    1    0    0
      0    0    0    1   25   25    0    0    0
      1   25    0    4    0    0    0    1    0
    999.0      238.0      8.925      1000.0      490.0
   1420.0     150   25   50
   1380.       1.          .0020       .0246       .0
   1370.       1.          .0020       .0246       .0
   1362.       1.          .0030       .0246       .0
   1350.       1.          .0050       .0246       .0
   1328.       1.          .0130       .0246       .0
   1314.       1.          .0200       .0246       .0
   1306.       1.          .0100       .0246       .0
   1293.       1.          .0080       .0246       .0
   1281.       1.          .0270       .0246       .0
   1276.       1.          .0250       .0246       .0
   1255.       1.          .2360       .0246       .0
   1221.       1.          .0140       .0246       .0
   1204.       1.          .0570       .0246       .0
   1186.       1.          .0340       .0246       .0
   1178.       1.          .0460       .0246       .0
   1149.       1.          .2740       .0246       .0
   1130.       1.          .0190       .0246       .0
   1114.       1.          .0067       .0246       .0
   1100.       1.          .0070       .0246       .0
   1088.       1.          .0060       .0246       .0
   1078.       1.          .0010       .0246       .0
   1061.       1.          .0510       .0246       .0
   1047.       1.          .0067       .0246       .0
   1029.       1.          .0140       .0246       .0
   1014.       1.          .0006       .0246       .0
```

Appendix C Listing of the PEACO-MAIN source deck

```
*GJOB    2262031,TAKANO,HIDEK,431.02                                    GPHIT
*FORTB
C  ....****  MAIN PROGRAMM  ****....
      COMMON KBG,KIGP,KXG,KSG,KAG,K7,KSOUCE,ISS,IAA,NOPT,NOPTFL,NOPTS,
     1NREAD,NRMAT,LISTR,LISTS,MORE,IVF,IVL,NBR,NOPTX,NOPTCP
      COMMON/JJ/ IBG,JBG,IBGP,IFGP,IXG,ISG,IAG,INDEX,INDEX1
      COMMON /AA/ U,UFGP,UBG,EOPT,RF,VMAX,ALPHA,GAM,GUZAI,
     1PHITOT,RCS,ACS,FCS,SCS,PHIT,RCSGP,ACSGP,FCSGP,SCSGP,ENRAT
     2,SODINF,SODR,AAINF,ERFS,GAMT,GJ,POTEN,PEAK,GAMG,POTEN1
      COMMON /BB/ TIL(18),Z(25),PZ(4),NTEMP(3),TEMP(3),SIG(7)
     1,RINF(4,3),AINF(4,3),FINF(4,3),SINF(4,3)
      COMMON /CC/ EN(41),UBGP(40),UIGP(10),UXG(10),EXG(11),VCAP(10),
     1ESG(30),CS1(5,6),CA1(5,6),CS2(5,6),CA2(5,6),EAG(20),SIAA(21
     2),AMU(10),UMAX(10),BETA(10),SIGA(10),SIGF(10),SIGS(10),DEN(10,7),
     3VR(20),RMAX(20),PHIRT(20),FLUXR(20),ESOUCE(40),
     4V(20),S(20),C(20),PHI(20),PHISR(20),PEACO(20),PEACOG
      COMMON /MM/ NIB(40),NBG(40),NFG(40),JBGP(40),NOIG(10),NFI(10),
     1NSG(30),NAG(20),NUCLID(10),NSUBR(20),LSRG(20),NCOMP(20)
      DIMENSION A(34000)
      DOUBLE PRECISION U,UFGP
      DOUBLE PRECISION S,PHI,C
   50 CALL INPUT1
     1(KREG,KSREG,KMAT,KRES,KCOMP,KCOMPF,KTEMP,MAXNFI,KKGP,NBR,NBH)
C * *  INITIALIZATION OF BRO-D GROUP NO.
      IBG=1
      JBG=2
      IXG=1
      IPT=-1
C * * IBG===BROAD GROUP CONTROLER
C * * JBG===INTERMEDIATE GROUP CONTROLER IN A B. GR.
C * * IXG===XSECT GROUP CONTROLER
      ISG=1
      IAG=1
C * * *
      NHK=KMAT*KCOMP
      LL1=1   +NHK
      LL2=LL1+NHK
      LL3=LL2+NHK
      NHK=KRES*KTEMP*MAXNFI
      LL4=LL3+NHK
      LL5=LL4+NHK
      LL6=LL5+NHK
      LL7=LL6+KSREG*KSREG
      NHK=KMAT*KREG
      LL8=LL7+NHK
      LL9=LL8+NHK
      LL10=LL9+NHK
      LL11=LL10+NHK
      NHK=KMAT*KSREG
      LL12=LL11+NHK
      LL13=LL12+NHK
      LL14=LL13+NHK
      LL15=LL14+NHK
      LL16=LL15+NHK
      LL17=LL16+NHK
      LL18=LL17+NHK
      LL19=LL18+NHK
      LL20=LL19+KSREG*NBR
      LL21=LL20+KKGP
      LL22=LL21+KSREG*NBH
      KVR=KSREG
      NVR=NBR
      IF(ISS.EQ.KRES)KVR=1
      IF(ISS.EQ.KRES)NVR=1
      LL23=LL22+KVR*NVR
      KVL=KSREG
      NVL=NBR
      IF(LISTS.LT.1)KVL=1
      IF(LISTS.LT.1)NVL=1
      LL24=LL23+KVL*NVL
      KTMPP=(KSREG*(KSREG+1))/2
      K1SREG=KTMPP*KZ
      KMSREG=KCOMPF*KTMPP*(KZ-1)
      LL25=LL24+K1SREG
      LL26=LL25+KMSREG
      M1SREG=K1SREG
      MMSREG=KMSREG
      IF(KSG.LE.1) M1SREG=1
      IF(KSG.LE.1) MMSREG=1
      LL27=LL26+M1SREG
      LL28=LL27+MMSREG
      NNSG=1
      KKSG=1
      MMSG=1
      IF(ISS.EQ.IVL) GO TO 2
      KKSG=KSG
      MMSG=IVL-ISS
      NNSG=KCOMP-KCOMPF
      IF(NOPT.EQ.0) NNSG=1
    2 LL29=LL28+KKSG*MMSG*NNSG
      PRINT 2100, LL1,LL4,LL8,LL12,LL20,LL22,LL23,LL24,LL25,LL26,LL27
     1,LL28
2100 FORMAT(1H0,///,30X,53H******* INFORMATION FOR VARIABLE DIMENSION
     1 *******  //,3X     12OH        LL1       LL4       LL8       LL12
     2    LL20      LL22      LL23      LL24      LL25      LL26      LL
     327      LL28  /3X,12I10)
      IF(LL29.LT.34000) GO TO 40
      PRINT 2000
2000 FORMAT(1H1,//,10X, 49HINPUT DATA MISS ...(VARIABLE DIMENSION.GT.3
     14000))
      STOP
   40 CALL INPUT 2
     1(KMAT,KCOMP,KCOMPF,KSREG,K1SREG,KMSREG,M1SREG,MMSREG,KKSG,
     2MMSG,NNSG,IPT,A(1),A(LL1),A(LL2),A(LL24),A(LL25),A(LL26),A(LL27),
     3A(LL28))
      CALL DATA
     1(KREG,KSREG,KMAT,KRES,KTEMP,MAXNFI,KKGP,KCOMP,
     2A(LL2),A(LL3),A(LL4),A(LL5),A(LL20))
      CALL OUTPT1
     1(KREG,KSREG,KMAT,KRES,KCOMP,KCOMPF,KTEMP)
      CALL AVERAG
     1(KREG,KSREG,KMAT,KRES,KCOMP,KCOMPF,KTEMP,MAXNFI,KKGP,NBR,NBH,KVR,
     2NVR,KVL,NVL,K1SREG,KMSREG,M1SREG,MMSREG,KKSG,MMSG,NNSG,A(1),
     3A(LL1),A(LL2),A(LL3),A(LL4),A(LL5),A(LL6),A(LL7),A(LL8),A(LL9),
     4A(LL10),A(LL11),A(LL12),A(LL13),A(LL14),A(LL15),A(LL16),A(LL17),
     5A(LL18),A(LL19),A(LL20),A(LL21),A(LL22),A(LL23),A(LL24),
     6A(LL25),A(LL26),A(LL27),A(LL28))
      IF(MORE)1,1,50
    1 STOP
      END
```

```
      SUBROUTINE INPUT1
     1(KREG,KSREG,KMAT,KRES,KCOMP,KCOMPF,KTEMP,MAXNFI,KKGP,NBB,NRH)
      COMMON KBG,KIGP,KXG,KSC,KAG,KZ,KSOUCE,ISS,IAA,NOPT,NOPTFL,NOPTS,
     1NREAD,NRMAT,LISTR,LISTS,MORE,IVF,IVL,NBR,NOPTX,NOPTCP
      COMMON/IJ/ IBG,JBG,IBGP,IFGP,IXG,ISG,IAG,INDEX,INDEX1
      COMMON /AA/ U,UFGP,UBG,EOPT,RF,VMAX,ALPHA,GAM,GUZAI,
     1PHITOT,RCS,ACS,FCS,SCS,PHIT,RCSGP,ACSGP,FCSGP,SCSGP,ENRAT
     2,SODINF,SODR,AAINF,ERES,GAMT,GJ,PUTEP,PEAK,GAMG,POTEM
      COMMON /BB/ TIL(18),Z(25),PZ(4),NTEMP(3),TEMP(3),SIG(7)
     1,RINF(4,3),AINF(4,3),FINF(4,3),SINF(4,3)
      COMMON /CC/ EN(41),UBGP(40),UIGP(10),UXG(10),EXG(11),VCAP(10),
     1ESG(30),CS1(5,6),CA1(5,6),CS2(5,6),CA2(5,6),EAG(20),SIAA(21
     2),AMU(10),UMAX(10),BETA(10),SIGA(10),SIGF(10),SIGS(10),DEN(10,7),
     3VR(20),RMAX(20),PHIRT(20),FLUXR(20),ESOUCE(40),
     4V(20),S(20),C(20),PHI(20),PHISR(20),PEACU(20),PEACOG
      COMMON /MM/ NIB(40),NBG(40),NFG(40),JBGP(40),NOIG(10),NFI(10),
     1NSG(30),NAG(20),NUCLID(10),NSUBR(20),LSRG(20),NCOMP(20)
      DIMENSION TEMPT(10),NUCLI(10)
      DOUBLE PRECISION U,UFGP
      DOUBLE PRECISION S,PHI,C
 3000 FORMAT(1H1,//,20X,67H** INPUT DATA LIST **(THE LIST IS DONE IN THE
     1 SAME FORMAT AS INPUT)  ///20X,18A4)
 3001 FORMAT(1H0,20X,12I6)
 3002 FORMAT(1H0,20X,2I6,E12.5)
 3003 FORMAT(1H0,20X,4I6,E12.5)
 3004 FORMAT(1H0,20X,6E12.5)
 3005 FORMAT(1H0,20X,A4,8X,4F12.5,I6,E12.5)
 3006 FORMAT(1H1,//,10X,22H** OUTPUT FROM TAPE ** /)
 3007 FORMAT(1H0,23X,49HTAPE NO./TEMPT(NT)/KREST/NOXG/EXG(1)/MAXNNFI ***
     1*I5,F10.2,2I5,F10.2,I5)
 3008 FORMAT(1H0,23X,21HEXG/UIGP/NOIG/NFI ** F10.2,F10.5,2I5)
 3009 FORMAT(1H0,23X,10HNUCLID ***  4(6X,A4))
 3010 FORMAT(1H1,////,10X,,92H **** INPUT DATA MISS(KCOMPF.GT.1.AND.NOPT
     1X.GT.0) ..  SUCH A PROBLEM CAN NOT BE TREATED **** )
      KZ=20
      READ 101,(TIL(I),I=1,18)
  101 FORMAT(18A4)
      PRINT 3000,(TIL(I),I=1,18)
      READ 102, KREG,KMAT,KRES,KCOMP,KCOMPF,KTEMP,NRMAT
  102 FORMAT(12I6)
      PRINT3001,KREG,KMAT,KRES,KCOMP,KCOMPF,KTEMP,NRMAT
      READ 102, NOPT,NOPTFL,NOPTS,NREAD,LISTR,LISTS,NOPTX
      PEACOG=0.5
C * * * NOPT.(0,1,2,3) GO TO (HOMO, PLANE,SQUARE,HEX.) (NOPT.LT.0) GO TO
C * *ITHE CORRESPONDING GEOMETRY TREATED BY NORDHEIM APPROXIMATION
C * * IF(NOPT.GT.3) , A COMPLEX GEOMETRY SACH AS CLUSTER IS TREATED)
      PRINT3001,NOPT,NOPTFL,NOPTS,NREAD,LISTR,LISTS,NOPTX
      IF(KCOMPF.NE.1.AND.NOPTX.GT.0) PRINT 3010
      IF(KCOMPF.NE.1.AND.NOPTX.GT.0) STOP
      READ 103, EOPT
      PRINT3004,EOPT
      IF(NOPT.LE.0) NREAD=5
      IF(KRES.EW.1) NRMAT=1
      READ 102, KSOUCE,MORE
      PRINT3001,KSOUCE,MORE
      DO 500 N=1,KTEMP
      NN=N
  500 REWIND NN
      READ(5,102) (NTEMP(I),I=1,KCOMPF)
      PRINT 3001,(NTEMP(N),N=1,KCOMPF)


      READ 103,(TEMP(N),N=1,KTEMP)
      PRINT 3004,(TEMP(I),I=1,KTEMP)
      IF(NOPT)4,1,4
    4 READ 104,(NCOMP(I),NSUBR(I),RMAX(I),I=1,KREG)
  104 FORMAT(2I6,E12.5)
      PRINT 3002,(NCOMP(I),NSUBR(I),RMAX(I),I=1,KREG)
      KSREG=NSUBR(KREG)
      IF(NOPT.GE.0) GO TO 5
      IF(KREG.NE.2.OR.KSREG.NE.2) PRINT 2000
 2000 FORMAT(1H1,//,7X,112HINPUT DATA MISS ....  IF(NOPT.LT.0),THEN KREG=
     1KSREG=2  ...   BEFORE YOU PREPARE INPUT, YOU SHOULD COOL YOUR HEAD
     2 )
      IF(KREG.NE.2.OR.KSREG.NE.2) GO TO 209
      RF=RMAX(1)
      V(1)=3.1416*RF**2
      V(2)=3.1416*RMAX(2)**2-V(1)
      VMAX=V(2)+V(1)
      DO 97 J=1,2
      VR(J)=V(J)
   97 LSRG(J)=NCOMP(J)
      GO TO 5
    1 NCOMP(1)=1
      NSUBR(1)=1
      RMAX(1)=1.
      V(1)=1.
      VMAX=1.
      LSRG(1)=1
      VR(1)=1.
      KSREG=1
    5 CONTINUE
      READ 102, KBG,KKGP,KSC,KAG,NRH,NBB,NBR
      PRINT3001,KBG,KKGP,KSC,KAG,NRH,NBB,NBR
      IF(NREAD.NE.5.AND.KSC.GT.1.AND.NOPT.GT.0) REWIND NREAD
  106 FORMAT(4I6,E12.5)
      KHGG=KBG+1
      READ 103,(EN(I),I=1,KBGG)
      PRINT 3004,(EN(I),I=1,KBGG)
  103 FORMAT(6E12.5)
      IAA=0
      ISS=KRES
      IVF=ISS
      IVL=ISS
      NOPTCP=0                                                          YYY
      DO 3 I=1,KMAT
      READ 105,NUCLID(I),AMU(I),SIGA(I),SIGF(I),SIGS(I),MAOPT,VCAP(I)
      PRINT 3005,NUCLID(I),AMU(I),SIGA(I),SIGF(I),SIGS(I),MAOPT,VCAP(I)
  105 FORMAT(A4,8X,4E12.5,I6,E10.5)
      IF(VCAP(I).GT.0.000001) NOPTCP=NOPTCP+1                           YYY
      VCAP(I)=VCAP(I)*SQRT(0.0253)                                      YYY
      IF(I.LE.KRES) GO TO 50
      IF(MAOPT   -2)51,52,53
   51 ISS=ISS+1
      IVF=ISS+1
      IVL=ISS
      GO TO 50
   52 IVL=IVL+1
      GO TO 50
   53 IF(MAOPT.EQ.3) IAA=1
   50 READ 103,(DEN(I,J),J=1,KCOMP)
      PRINT 3004,(DEN(I,J),J=1,KCOMP)
```

```
    3 CONTINUE
      IF(KSG.LE.1.OR.ISS.LE.KRES) GO TO 6
      READ 103,ERES,PEAK,GJ,GAMT,GAMG
      READ 103,POTEP,POTEM
      PRINT 3004,ERES,PEAK,GJ,GAMT,GAMG
      PRINT 3004,POTEP,POTEM
    6 IF(KAG.LE.1) GO TO 2
      SIAA(1)=SIGA(IAA)
      READ 103,(EAG(I),SIAA(I+1),I=1,KAG-1)
      PRINT3004,(EAG(I),SIAA(I+1),I=1,KAG-1)
    2 IF(KSOUCE.NE.0) READ(5,103)(ESOUCE(I),I=1,KSOUCE)
      IF(KSOUCE.NE.0) PRINT 3004,(ESOUCE(I),I=1,KSOUCE)
      PRINT 3006
      DO 200 NT=1,KTEMP
      NNT=NT
      READ (NNT) TEMP(NT),KREST,(NUCLI(I) ,I=1,KREST),NOXG,EXG(1),
     1(EXG(I+1),UIGP(I),NOIG(I), NFI(I),I=1,NOXG),MAXNFI
      PRINT 3009,(NUCLID(I),I=1,KREST)
      PRINT 3007,NT,TEMPT(NT),KREST,NOXG,EXG(1),MAXNFI
      PRINT 3008,(EXG(I+1),UIGP(I),NOIG(I),NFI(I),I=1,NOXG)
      TMP= ABS(TEMP(NT)-TEMPT(NT))-10.
      IF(TMP) 201,201,202
  202 WRITE(6,1000) NT
 1000 FORMAT(1H1,////,10X, 34HCOOL YOUR HEAD ***  TEMPERATURE IN ,I2,
     146HTH TAPE IS NOT CONSISTENT WITH INPUT DATA  *** )
      GO TO 205
  201 KKK=KRES-KREST
      IF(KKK) 203,204,203
  203 WRITE(6,1001)
 1001 FORMAT(1H1,////,10X, 84HCOOL YOUR HEAD ***  NO. OF RESONANCE MATER
     1IALS IS NOT CONSISTENT WITH INPUT DATA *** )
      GO TO 205
  204 TMP=EXG(1)-EN(1)
      IF(TMP) 206,200,200
  206 WRITE(6,1002)
 1002 FORMAT(1H1,////,10X, 40HCOOL YOUR HEAD ***((E(1) IN TAPE),LT,E1))
      GO TO 205
  200 CONTINUE
      GO TO 210
  205 STOP
  210 KXG=NOXG
      RETURN
      END
      SUBROUTINE INPUT2
     1(KMAT,KCOMP,KCOMPF,KSREG,K1SREG,KMSREG,M1SREG,MMSREG,KKSG,
     2MMSG,NNSG,IPT,SA,SF,SS,W,W1,WW,WW1,CSS)
      COMMON KBG,KIGP,KXG,KSG,KAG,K7,KSOUCE,ISS,IAA,NOPT,NOPTFL,NOPTS,
     1NREAD,NRMAT,LISTR,LISTS,MORE,IVF,IVL,NBR,NOPTX,NOPTCP
      COMMON/JJ/ IBG,JBG,IRGP,IFGP,IXG,ISG,IAG,INDEX,INDEX1
      COMMON /AA/ U,UFGP,UBG,EOPT,RF,VMAX,ALPHA,GAM,GUZAI,
     1PHITOT,RCS,ACS,FCS,SCS,PHIT,RCSGP,ACSGP,FCSGP,SCSGP,ENRAT
     2,SODINF,SODR,AAINF,ERES,GAMT,GJ,POTEN,PEAK,GAMG,POTEN1
      COMMON /BB/ TIL(18),Z(25),PZ(4),NTEMP(3),TEMP(3),SIG(7)
     1,RINF(4,3),AINF(4,3),FINF(4,3),SINF(4,3)
      COMMON /CC/ EN(41),UBGP(40),UIGP(10),UXG(10),EXG(11),VCAP(10),
     1ESG(30),CS1(5,6),CA1(5,6),CS2(5,6),CA2(5,6),EAG(20),SIAA(21
     2),AMU(10),UMAX(10),BETA(10),SIGA(10),SIGF(10),SIGS(10),DEN(10,7),
     3VR(20),RMAX(20),PHIRT(20),FLUXR(20),ESOUCE(40),
     4V(20),S(20),C(20),PHI(20),PHISR(20),PEACO(20),PEACOG
      COMMON /MM/ NIB(40),NBG(40),NEG(40),JBGP(40),NOIG(10),NFI(10),

     1NSG(30),NAG(20),NUCLID(10),NSUBR(20),LSRG(20),NCOMP(20)
      DIMENSION SA(KMAT,KCOMP),SF(KMAT,KCOMP),SS(KMAT,KCOMP),
     1W(K1SREG),W1(KMSREG),WW(M1SREG),WW1(MMSREG),CSS(KKSG,MMSG,NNSG)
      DOUBLE PRECISION U,UFGP
      DOUBLE PRECISION S,PHI,C
      IF(IPT.NE.-1) GO TO 5
      ICS=KCOMPF+1
      IF(NOPT.EQ.0) ICS=1
      DO 12 J=1,KCOMP
      SIG(J)=0.
      DO 13 I=1,KMAT
      SA(I,J)=DEN(I,J)*SIGA(I)
      SF(I,J)=DEN(I,J)*SIGF(I)
      SS(I,J)=DEN(I,J)*SIGS(I)
   13 SIG(J)=SIG(J)+SA(I,J)+SF(I,J)+SS(I,J)
   12 CONTINUE
      IF(IVL.EQ.ISS) GO TO 5
      DO 40 J=ICS,KCOMP
      JJ=J-KCOMPF
      IF(NOPT.EQ.0) JJ=1
      DO 40 I=IVF,IVL
      II=I-ISS
      CS1(II,JJ)=SS(I,J)
      CSS(ISG,II,JJ)=SS(I,J)
   40 CA1(II,JJ)=SA(I,J)
    5 IF(NOPT)70,80,80
C * * * NOPT.(0,1,2,3) GO TO (HOMO, PLANE,SQUARE,HEX,) (NOPT,LT,0) GO TO
C * *1THE CORRESPONDING GEOMETRY TREATED BY NORDHEIM APPROXIMATION
   70 IF(IPT) 60,90,60
   60 NTMP=IABS(NOPT)
      IF(NTMP-2) 71,72,73
   71 PRINT 2000
 2000 FORMAT(1H1,10X,75HCOLLISION PROBABILITY FOR PLANE GEOMETRY IS NOT
     1PREPARED FOR SAUER,S METHOD  )
      STOP
   72 VVR=VR(2)/VR(1)
      TAU=(0.9069*SQRT(1.+VVR)-1.)/VVR=0.08
      GO TO 74
   73 VVR=VR(2)/VR(1)
      TAU=(0.88632*SQRT(1.+VVR)-1.)/VVR=0.12
   74 M=LSRG(2)
      BAR=2.*RF*VVR
      GAM=1.-EXP(-TAU*SIG(M)*BAR)/(1.+(1.+TAU)*SIG(M)*BAR)
      IF(IPT) 80,80,20
   80 IF(ISG.NE.1) GO TO 17
      IF(NOPT.GT.0) READ(NREAD,300) (Z(I),I=1,K7)
      IF(NOPT.GT.0) READ(NREAD,300) RF,(V(I),I=1,KSREG)
  300 FORMAT(7F10.6)
      IF(KSG.GT.1) READ(NREAD,301) (ESG(I),I=1,KSG-1)
  301 FORMAT(7F10.3)
      GO TO 41
   17 IF(IVL.EQ.ISS) GO TO 41
      JL=KCOMP-KCOMPF
      IF(NOPT.EQ.0) JL=1
      DO 42 I=IVF,IVL
      II=I-ISS
      READ(NREAD,300)(CS2(II,J),J=1,JL)
      READ(NREAD,300)(CA2(II,J),J=1,JL)
      PRINT 3000, ISG,(CS2(II,J),J=1,JL)
 3000 FORMAT(1H0,10X,5H.... ,I10,5F10.5,/)
```

```
      DO 42 J=ICS,KCOMP
      JJ=J-KCOMPF
      IF(NOPT.EQ.0) JJ=1
      IF(ISG.NE.KSG) GO TO 42
      SS(I,J)=CS2(II,JJ)
      SA(I,J)=CA2(II,JJ)
   42 CSS(ISG,II,JJ)=CS2(II,JJ)
   41 IF(NOPT.LE.0) GO TO 20
      IF(ISG.GT.1.AND.ISG.NE.KSG) GO TO 30
      READ(NREAD,300   ) (W(I),I=1,K1SREG)
      READ(NREAD,300   )(W1(I),I=1,KMSREG)
      GO TO 20
   30 READ(NREAD,300)(WW(I),I=1,K1SREG)
      READ(NREAD,300)(WW1(I),I=1,KMSREG)
   20 RETURN
      END
      SUBROUTINE DATA
     1(KREG,KSREG,KMAT,KRES,KTEMP,MAXNFI,KKGP,KCOMP,
     2SS,SAA,SFF,SSS,ENGP)
      COMMON KBG,KIGP,KXG,KSG,KMG,KZ,KSOUCE,ISS,IAA,NOPT,NOPTFL,NOPTS,
     1NREAD,NRMAT,LISTR,LISTS,MORE,IVF,IVE,NRR,NOPTX,NOPTCP
      COMMON/JJ/ IBG,JBG,IAGP,IFGP,IXG,ISG,IAG,INDEX,INDEX1
      COMMON /AA/ U,UFGP,UBG,UOPT,RF,VMAX,ALPHA,GAM,GUZAI,
     1PHITOT,RCS,ACS,FCS,SCS,PHIT,RCSGP,ACSGP,FCSGP,SCSGP,ENRAT
     2,SODINF,SODR,AAINF,ERES,GAMT,GJ,POTEN,PEAK,GAMG,POTEN1
      COMMON /BB/ TIL(18),Z(25),PZ(4),NTEMP(3),TEMP(3),SIG(7)
     1,RINF(4,3),AINF(4,3),FINF(4,3),SINF(4,3)
      COMMON /CC/ EN(41),UBGP(40),UIGP(10),UXG(10),EXG(11),VCAP(10),
     1ESG(30),CS1(5,6),CA1(5,6),CS2(5,6),CA2(5,6),EAG(20),SIAA(21
     2),AMU(10),UMAX(10),BETA(10),SIGA(10),SIGF(10),SIGS(10),DEN(10,7),
     3VR(20),PMAX(20),PHIRT(20),FLUXR(20),ESOUCE(40),
     4V(20),S(20),C(20),PHI(20),PHISR(20),PEACO(20),PFACOG
      COMMON /MM/ NIB(40),NBG(40),NFG(40),UBGP(40),NOIG(10),NFI(10),
     1NSG(30),NAG(20),NUCLID(10),NSUBR(20),LSRG(20),NCOMP(20)
      DIMENSION AREAC(20),SUMS(10)
      DIMENSION SS(KMAT,KCOMP),SAA(KRES,KTEMP,MAXNFI),SFF(KRES,KTEMP,MAX
     1NFI),SSS(KRES,KTEMP,MAXNFI),ENGP(KKGP)
      DOUBLE PRECISION U,UFGP
      DOUBLE PRECISION S,PHI,C
      DOUBLE PRECISION B,BTMP,SUM,UI,UX
      PI=3.14159265
      NOXX=KXG+1
      DO 210 NX=2,NOXX
      TMP=ALOG(EN(1)/EXG(NX))
      IF(TMP) 210,210,211
  211 NHK1=NX-1
      UI=UIGP(NHK1)
      TMP1=ALOG(EXG(NHK1)/EN(1))+UI
      NHK2=TMP1/UI
      TMP=UI/NFI(NHK1)
      NHK3=(TMP1-NHK2*UI)/TMP+1.
      NTMP=NFI(NHK1)/2
      IF(NHK3.GT.NTMP)NHK2=NHK2+1
      TMP=(NHK2-1)*UI-TMP/2.
      EN(1)=EXG(NHK1)*EXP(-TMP)
      GO TO 215
  210 CONTINUE
      PRINT 1002
 1002 FORMAT(1H1,///,20X,  64H**** COOL YOUR HEAD.....INPUT DATA MISS(EN
     1(1).LT.EXG(MAX))  **** )


  205 STOP
  215 KXG=NOXX-NHK1
      UOPT=ALOG(EN(1)/UOPT)
      NSTART=NHK3
      DO 216 J=1,KTEMP
      NNT=J
      DO 216 NN=1,NHK1
      KF=NFI(NN)
      IG=NOIG(NN)
      IF(NN.EQ.NHK1) IG=NHK2
      DO 216 II=1,IG
      READ (NNT) ((SAA(I,J,K),SFF(I,J,K),SSS(I,J,K),K=1,KF),I=1,KRES)
  216 CONTINUE
      SUM=-UI/(NFI(NHK1)*2)
      TSUM=SUM
      NSUM=0
      IF=1
      NYY=1
      UX=ALOG(EN(1)/EN(2))+TSUM
      UBGP(1)=UX
      ENGP(1)=EN(1)
      BTMP=ENGP(1)
      EXG(1)=EN(1)
      NF=0
      UXG(1)=0.
      DO 217 NX=1,KXG
      NXX=NHK1+NX-1
      NFI(NX)=NFI(NXX)
      UIGP(NX)=UIGP(NXX)
      B=EXP(-UIGP(NX))
      NOIG(NX)=NOIG(NXX)
      EXG(NX+1)=EXG(NXX+1)
      IF(NX.EQ.1) NOIG(NX)=NOIG(NX)-NHK2+1
      UI=UIGP(NX)
      IL=NOIG(NX)
      DO 218 II=IF,IL
      NSUM=NSUM+1
      BTMP=B*BTMP
      ENGP(NSUM+1)=BTMP
      SUM=SUM+UI
      TMP=UX-SUM
      IF(TMP) 214,219,218
  214 TMP=TMP+UI/2.
      IF(TMP) 204,204,219
  204 NIB(NYY)=NSUM-NF-1
      UBGP(NYY)=SUM-UI
      NF=NSUM-1
      GO TO 213
  219 NIB(NYY)=NSUM-NF
      UBGP(NYY)=SUM
      NF=NSUM
  213 NFG(NYY)=NX
      NBG(NYY)=NFI(NX)
      NYY=NYY+1
      IF(NYY.GT.KBG) GO TO 320
      UX=ALOG(EN(1)/EN(NYY+1))+TSUM
      UBGP(NYY)=UX
  218 CONTINUE
  320 UXG(NX+1)=SUM
      IF(NYY.GT.KBG) GO TO 220
```

```
217 CONTINUE
220 KIGP=NSUM
    IF(KSG.LE.1) NSG(1)=NSUM
    IF(KSG.LE.1) GO TO 221
    ISP=1
    NSG(KSG)=NSUM
    DO 222 I=1,NSUM
    IF(ENGP(I).GT.ESG(ISP)) GO TO 222
    NSG(ISP)=I
    IF(ISP.GE.(KSG-1)) GO TO 221
    ISP=ISP+1
222 CONTINUE
221 IF(KAG.LE.1) NAG(1)=NSUM
    IF(KAG.LE.1) GO TO 225
    NAG(KAG)=NSUM
    IAP=1
    DO 224 I=1,NSUM
    IF(ENGP(I).GT.EAG(IAP)) GO TO 224
    NAG(IAP)=I
    IF(IAP.GE.(KAG-1)) GO TO 225
    IAP=IAP+1
224 CONTINUE
225 IF(NOPT) 232,232,231
231 IF=1
    VMAX=0.
    DO 234 J=1,KREG
    IL=NSUBR(J)
    VR(J)=0.
    DO 235 I=IF,IL
    VMAX=VMAX+V(I)
    VR(J)=VR(J)+V(I)
235 LSRG(I)=NCOMP(J)
    IF=IL+1
234 CONTINUE
    IF(NOPT.GT.4)GO TO 232
    IF(NOPT-2)65,80,80
 80 AREAC(1)=PI*RMAX(1)**2
    DO 75 J=2,KREG
 75 AREAC(J)=PI*(RMAX(J)**2-RMAX(J-1)**2)
    GO TO 95
 65 AREAC(1)=RMAX(1)
    DO 90 J=2,KREG
 90 AREAC(J)=RMAX(J)-RMAX(J-1)
 95 DO 96 I=1,KREG
    TMP= ABS(VR(I)-AREAC(I))/VR(I)-0.01
    IF(TMP.GT.0.)PRINT 1003,I
    IF(TMP.GT.0.) GO TO 205
1003 FORMAT(1H1,////,20X, 4HTHE ,I2,69H REGION VOLUME IS NOT CONSISTENT
   1 WITH ONE USED IN CALCULATION OF C.P. )
 96 CONTINUE
232 SUM=0.
    DO 35 J=1,KMAT
    IF(AMU(J)-1.1)5,5,10
  5 UMAX(J)=20.
    GO TO 35
 10 UMAX(J)=2.*ALOG(1.+2./(AMU(J)-1.))
 35 BETA(J)=1./(1.-EXP(-UMAX(J)))
    DO 240 J=1,KMAT
    SUMS(J)=0.
    DO 240 I=1,KREG

    M=NCOMP(I)
240 SUMS(J)=SUMS(J)+VR(I)*SS(J,M)
    DO 250 I=1,KREG
    M=NCOMP(I)
    SUM=SUM+VR(I)*SIG(M)
250 CONTINUE
    ALPHA=1.
    DO 241 K=1,3
    TMP=0.
    DO 242 J=1,KMAT
    IF(BETA(J).LT.1.01) GO TO 251
    TMP=TMP+(1.-(1.-1./BETA(J))**ALPHA)*BETA(J)*SUMS(J)/SUM
    GO TO 242
251 TMP=TMP+SUMS(J)/SUM
242 CONTINUE
    ALPHA=TMP
1012 FORMAT(1H0,10X,10E10.3)
241 CONTINUE
    GUZAI=0.
    DO 243 I=1,KREG
    M=NCOMP(I)
    DO 243 J=1,KMAT
    TMP=VR(I)*SS(J,M)
    IF(UMAX(J).GT.19.) GO TO 244
    TMPAL=1.-1./BETA(J)
    IF(UMAX(J).LE.0.3) GO TO 245
    GUZAI=GUZAI+TMP*BETA(J)*(1.-TMPAL*(1.+UMAX(J)))
    GO TO 243
245 GUZAI=GUZAI+2.*TMP/(AMU(J)+0.6667)
    GO TO 243
244 GUZAI=GUZAI+TMP
243 CONTINUE
    GUZAI=GUZAI/ALPHA
    TMP=UIGP(1)/VEI(1)
    DO 13 I=1,KSREG
    S(I)=0.
    K=LSRG(I)
    PHI(I)=DBLE(V(I)*TMP)
    DO 13 J=1,KMAT
    IF(BETA(J).LT.1.01) GO TO 252
    S(I)=S(I)+V(I)*SS(J,K)*BETA(J)*(1.-(1.-1/BETA(J))**ALPHA)/ALPHA
    GO TO 13
252 S(I)=S(I)+V(I)*SS(J,K)/ALPHA
 13 CONTINUE
    RETURN
    END
    SUBROUTINE OUTPT1
   1(KREG,KSREG,KMAT,KRES,KCOMP,KCOMPE,KTEMP)
    COMMON KBG,KIGP,KXG,KS,KAG,KZ,KSOUCE,ISS,IAA,NOPT,NOPTFL,NOPTS,
   1NREAD,NRMAT,LISTK,LISTS,MORE,IVE,IVL,NBR,NOPTX,NOPTCP
    COMMON/JJJ/ IBG,JHG,IHG,IEGP,IXG,ISG,IAG,INDEX,INDEX1
    COMMON /AA/ DUEGP,UBG,EOPT,RE,VMAX,ALPHA,GAM,GUZAI,
   1PHITOT,RCS,ACS,FCS,SCS,PHIT,RCSGP,ACSGP,FCSGP,SCSGP,ENRAT
   2,SODINF,SODR,AAINF,ENFS,GAMT,GJ,POTEN,PEAK,GAMG,POTEN1
    COMMON /BB/ TIL(18),Z(25),PZ(4),NTEMP(3),TEMP(3),SIG(7)
   1,RINF(4,3),AINF(4,3),EINF(4,3),SINF(4,3)
    COMMON /CC/ EN(41),UBG(40),UIGP(10),UXG(10),EXG(11),VCMP(10),
   1ESG(30),CS1(5,6),CA1(5,6),CS2(5,6),CA2(5,6),EAG(20),SIAA(21
   2),AMU(10),UMAX(10),BET(10),SIGA(10),SIGF(10),SIGS(10),DEN(10,7),
   3VR(20),RMAX(20),PHIPT(20),FLUXR(20),ESOUCE(40),
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      4V(20),S(20),C(20),PHI(20),PHISR(20),PEACO(20),PEACOG
      COMMON /MM/ NIB(40),NBG(40),NEG(40),JBGP(40),NOIG(10),NFI(10),
     1NSG(30),NAG(20),NUCLID(10),NSUBR(20),LSRG(20),NCOMP(20)
      DOUBLE PRECISION UUBG2
      DOUBLE PRECISION S,PHI,C
      PRINT 200,(TII( I ),I=1,14)
  200 FORMAT(1H1,//,40A,18A4,///)
      PRINT 201,KREG,KMAT,KRCS,KCOMP,KCOMPF,KTEMP
  201 FORMAT(1HO,40X,47H****** INPUT DATA LIST FOR PIECKO CODE ********,
     1//,5X,   11HNO. OF REGIONS      NO. OF MATERIALS    RESONANT MAT
     2ERIALS  NO. OF COMPOSIT.    NO. OF FUEL COMP.   NO. OF TEMPERATURE
     3 ,/5X,I10,5I20,//)
      PRINT 204,(I,I=1,KCOMP)
  204 FORMAT(1HO,//,16X,36H***  MATERIAL AND CROSS SECTION  *** ,20X,39H
     1*** NO. OF COMPOSITION AND DENSITY  *** ,//,3X,65HNO.    NUCLIDE
     2  MASS      SIGMA-S    SIGMA-A    SIGMA-F    SIGMA-T 2H **6(4X,I6)/  )
      DO 112 I=1,KMAT
      TMP=SIGS(I)+SIGA(I)+SIGF(I)
  112 PRINT 205, I,NUCLID(I),AMU(I),SIGS(I),SIGA(I),SIGF(I),TMP,
     1(DEN(I,J),J=1,KCOMP)
  205 FORMAT(1HO,2X,I2,6X,A4,2X,5F10.4,5H  *  ,6F10.4)
      PRINT 270
  270 FORMAT(1HO,///,40X,44HNO. OF COMPOSITION   TEMPERATURE(K. DEGREES)
     1 )
      DO 171 N=1,KCOMPF
      K=NTEMP(N)
  171 PRINT 271,N,TEMP(K)
  271 FORMAT(1HO,40X,I2,16X,F10.2)
      PRINT 250
  250 FORMAT(1HO,///,45X,31H***  SLOWING DOWN PROPERTY  *** ,//,40X, 47H
     1NO.   NUCLIDE    ALPHA      UMAX(I)    1/(1.-ALF.)    )
      DO 150 I=1,KMAT
      TMP=(1.-2./(AMU(I)+1.))**2
  150 PRINT 251,I,NUCLID (I),TMP,UMAX(I),BETA(I)
  251 FORMAT(1HO,39X,I2,5X,A4,1X,2F10.5,F12.4)
      PRINT 202,NOPT
  202 FORMAT(1HL//14X20HOPTION FOR GEOMETRY= ,I2,71H  ****(N=0,1,2,3,4)(
     1GEOMETRY=HOMO.,PLANE,CYLINDER,SQUARE,HEXAGONAL)**** ,///,20X,
     2 70H*****  SUBREGION  **********          ********   REGION   **
     3******** ,//,23X,75HNO.      VOLUME  COMPOSITION            NO.
     4 VOLUME     R-MAX       SIGMA-I )
      NF=1
      DO 110 I=1,KREG
      NL=NSUBR(I)
      DO 111 J=NF,NL
      M=LSRG(J)
  111 PRINT 203, J,V(J),M,I,VR(I),RMAX(I),SIG(M)
  203 FORMAT(1HO,22X,I2,4X,F8.4,6X,I2,16X,I2,4X,F8.4,2X,F8.4,4X,F9.4)
  110 NF=NL+1
      IF(NOPT.LE.0) GO TO 128
  206 FORMAT(1HO,////,40X,53HCOORDINATE FOR INTERPOLATION OF COLLISION P
     1ROBABILITY )
      PRINT 206
      PRINT 207,(I,I=1,10)
      PRINT 208,(Z(I),I=1,10)
      PRINT 207, (I,I=11,K7)
      PRINT 208,(Z(I),I=11,K7)
  207 FORMAT(1HO,13X,3HNO.,10I10)
  208 FORMAT(1H ,12X,4HZ(I),3X,10F10.4,/)
  128 PRINT 260,ALPHA


  260 FORMAT(1HO,///,20X,54HCONSTANT FOR INITIAL FLUX(=V(I)*EXP(C*U)) ***
     1***** C= ,F10.4)
      PRINT 261,GUZAI
  261 FORMAT(1HO,//,20X,   56HAVERAGE LOGALITHMIC LOSS(AT THE HIGHEST EN
     1ERGY REGION)= ,F10.5)
      IF(KSG.LE.1) GO TO 113
      NTMP=(KSG-1)/10
      NL=NTMP+1
      ITMP=1
      KSS=10
      PRINT 209,ISS,IVF,IVL
  209 FORMAT(1HO,///,20X,64H***** ENERGY POINTS WHERE COLLISION PROBABIL
     1ITIS ARE GIVEN (ISS= ,I2,2X,4HIVF= ,I2,2X,4HIVL= ,I2,7H) ***** /)
      DO 10 N=1,NL
      IF(N.GT.1) ITMP=KSS+1
      IF(N.EQ.NL) KSS=KSG-1
      IF(KSS.EQ.0) GO TO 10
      PRINT 210,(I,I=ITMP,KSS)
  210 FORMAT(1HO, 3X,23HNO. OF SCATTERING GROUP ,10I10)
      PRINT 211,(ESG(I),I=ITMP,KSS)
  211 FORMAT(1HO,16X, 9HENERGY(I),3X,10F10.3)
   10 CONTINUE
  113 IF(KAG.LE.1) GO TO 114
      PRINT 220,IAA
  220 FORMAT(1HO,///,30X,27HABSORPTION CROSS SECTION OF,I2,12HTH MATERIA
     1L  )
      NTMP=KSG/10
      NL=NTMP+1
      ITMP=1
      KSS=10
      DO 11 N=1,NL
      IF(N.GT.1) ITMP=KSS+1
      IF(N.GT.1) KSS=KAG-1
      PRINT 221,(I,I=ITMP,KSS)
  221 FORMAT(1HO, 3X,23HNO. OF ABSOPTION GROUP ,10I10)
      PRINT 211,(EAG(I),I=ITMP,KSS)
      PRINT 222,(SIAA(I),I=ITMP,KSS)
  222 FORMAT(1H ,16X, 9HSIGMAA(I),3X,10F10.3)
      PRINT 2222,(NAG(I),I=ITMP,KSS)
   11 CONTINUE
 2222 FORMAT(1H ,16X,9H   NAG(I) ,1X,10I10)
  114 PRINT 230
  230 FORMAT(1H1//17X,
     *          74H***** LIST OF INFORMATION TO GROUP STRUCTURE FOR
     1 X.SECTION AVERAGE ***** ,//,24X,64HNO.   EN(N)    EN(N+1)    DEL
     2TA-U  (NEG(N)    NIB(N)    NBG(N)) )
      DO 130 N=1,KBG
      TMP=UMGP(N)
      IF(N.GT.1) TMP=TMP-UBGP(N-1)
  130 PRINT 231,N,EN(N),EN(N+1),TMP,NEG(N),NIB(N),NBG(N)
  231 FORMAT(1HO,22X,I2,1X,3E10.4,3(I8,2X))
      PRINT 240
  240 FORMAT(1HO,////,29X,54HGROUP STRUCTURE FOR RESONANCE X-SECTION REP
     1RESENTATION ////,21X,10*,10X,  66HX-SECTION  GROUP          * INTE
     2RMEDIATE GROUP *   FINE  GROUP   *,///21X,78H* NO.      E(N)       E
     3(N+1)  DELTA-U * NUMBERS   DELTA-U  * NUMBERS  DELTA-U * )
      DO 140 N=1,KXG
      DELU=UIGP(N)/NFI(N)
      TMP=ALOG(EXG(N)/EXG(N+1))
  140 PRINT 241,N,EXG(N),EXG(N+1),TMP,NOIG(N),UIGP(N),NFI(N),DELU
```

```
241 FORMAT(1H0,22X,I2,2X,2F10.3,F10.5,2(4X,I6,F10.5))
    DO 15 I=1,KRES
 15 UMAX(I)=UMAX(NRMAT)
    RETURN
    END
    SUBROUTINE AVERAG
   1(KREG,KSREG,KMAT,KRES,KCOMP,KCOMPF,KTEMP,MAXNFI,KKGP,NRB,NBH,NVR,
   2NVR,NVL,MVL,K1SREG,KMSREG,M1SREG,MMSREG,KKSG,MMSG,NNSG,
   3SA,SF,SS,SAA,SFF,SSS,    P,          RIRR,RIAR,RIFR,RISR,
   4RIRS,RIAS,RIFS,RISS,                 SIGRBG,SIGABG,SIGFBG,SIGSBG,
   5FLUX,ENGP,SCATH,SCATR,FLUXSR,W,W1,WW,WW1,CSS)
    COMMON KRG,KIGP,KXG,KSG,KAG,K7,KSOUCE,ISS,IAA,NOPT,NOPTFL,NOPTS,
   1NREAD,NRMAT,LISTR,LISTS,MORE,IVF,IVL,NBR,NOPTX,NOPTCP
    COMMON/IJ/ IBG,JBG,IBGP,IFGP,IXG,ISG,IAG,INDEX,INDEX1
    COMMON /AA/ U,UFGP,UBG,FOPT,RF,VMAX,ALPHA,GAM,SUZAI,
   1PHITOT,RCS,ACS,FCS,SCS,PHIT,SCSGP,ACSGP,FCSGP,SCSGP,ENRAT
   2,SODINF,SODR,AAINF,ERES,GAMT,GJ,POTEN,PEAK,GAMG,POTEN1
    COMMON /BB/ TIL(18),Z(25),PZ(4),NTEMP(3),TEMP(3),SIG(7)
   1,RINF(4,3),AINF(4,3),FINF(4,3),SINF(4,3)
    COMMON /CC/ EN(41),UBGP(40),UIGP(10),UXG(10),EXG(11),VCAP(10),
   1ESG(30),CS1(5,6),CA1(5,6),CS2(5,6),CA2(5,6),EAG(20),SIAA(21
   2),AMB(10),UMAX(10),BETA(10),SIGA(10),SIGF(10),SIGS(10),DEN(10*7),
   3VR(20),RMAX(20),PHIRT(20),FLUXR(20),ESOUCE(40),
   4V(20),S(20),C(20),PHI(20),PHISR(20),PEACO(20),PEACOG
    COMMON /MM/ NIB(40),NBG(40),NEG(40),IBGP(40),NOIG(10),NFI(10),
   1NSG(30),NAG(20),NUCLID(10),NSUBR(20),LSRG(20),NCOMP(20)
    DIMENSION SA(KMAT,KCOMP),SF(KMAT,KCOMP),SS(KMAT,KCOMP),
   1SAA(KRES,KTEMP,MAXNFI),SFF(KRFS,KTEMP,MAXNFI),SSS(KRFS,KTEMP,MAXNF
   2I),P(KSREG,KSREG),
   3RIRR(KMAT,KREG),RIAR(KMAT,KREG),RIFR(KMAT,KREG),RISR(KMAT,KREG),
   4RIRS(KMAT,KSREG),RIAS(KMAT,KSREG),RIFS(KMAT,KSREG),RISS(KMAT,KSREG
   5),SIGRBG(KMAT,KSREG),SIGABG(KMAT,KSREG),SIGFBG(KMAT,KSREG),
   6SIGSBG(KMAT,KSREG),      FLUX(KSREG,NBH),ENGP(KKGP),
   7SCATH(KSREG,NBH),SCATR(KVR,NVR),FLUXSR(KVL,NVL),
   8*(K1SREG),W1(KMSREG),WW(M1SREG),WW1(MMSREG),CSS(KKSG,MMSG,NNSG)
    DIMENSION FLUXSS(20)
    DOUBLE PRECISION U,UFGP
    DOUBLE PRECISION S,PHI,C
    DOUBLE PRECISION TMP,TMP1,TMP2,TMP4,TMP5,TMP6,TMP7,TMP10,TMPP
    DOUBLE PRECISION UX,UEXP,PHIEXP,Y1,Y2,Y3,YY
C**CONTROLER FOR NAISOU
    INDEX=1
    INDEX1=1
    IP1=0
    IP2=1
    ICS=KCOMPF+1
    IF(NOPT.EQ.0) ICS=1
    NOXSUM=NOIG(1)+2
    NXSUM=1
    IF(NOPT.EQ.0) P(1,1)=1.
    IF(KAG.GT.1) SIGAA=SIGA(IAA)
    U=0.
    UBG=UBGP(IBG)
    UFGP=DBLE(UIGP(IXG)/NFI(IXG))
    TMP6=DBLE(1./UIGP(IXG))
    TMP4=DEXP(-UFGP)
    ENRAT=EN(IBG+1)/EN(1)
    VSQRT2=0.                                                          YYY
    IF(KSG.GT.1.AND.ISS.NE.KRES) SIGOP=SQRT(PEAK*POTEN*GJ
   1*(GAMT-GAMG)/GAMT)


C * * INITIALIZATION OF X-SECTIONS AND FLUXES OF BROAD GROUP NO. 1
    RCS=0.
    ACS=0.
    FCS=0.
    SCS=0.
    PHITOT=0.
    DO 2 I=1,KREG
    PHIRT(I)=0.
    DO 2 J=1,KMAT
    RIRR(J,I)=0.
    RIAR(J,I)=0.
    RIFR(J,I)=0.
  2 RISR(J,I)=0.
    DO 5 I=1,KSREG
    PHISR(I)=0.
    DO 5 J=1,KMAT
    RIRS(J,I)=0.
    RIAS(J,I)=0.
    RIFS(J,I)=0.
  5 RISS(J,I)=0.
    DO 300 I=1,KSREG
    M=LSRG(I)
    TTT=V(I)*UIGP(1)
    DO 301 J=1,KRES
301 SCATH(I,1)=DEN(J,M)*SIGS(J)*BETA(J)*TTT
    IF(ISS.NE.KRES)
   1SCATH(I,1)=DEN(ISS,M)*SIGS(ISS)*BETA(ISS)*TTT
300 FLUX(I,1)=TTT
C * * * *
C * * INITIALIZATION OF INFINITE XSECTIONS OF SODIUM AND RESONANCE MATERIALS
    SIGSOD=SIGS(ISS)
    SODINF=0.
    AAINF=0.
    SODR=0.
    DO 888 M=1,KRES
    DO 888 N=1,KTEMP
    RINF(M,N)=0.
    AINF(M,N)=0.
    FINF(M,N)=0.
888 SINF(M,N)=0.
C * * * *
    DO 45 IBGP=2,KIGP
    UEXP=DEXP(-U+0.5*UFGP)
    INDEX2=0                                                           YYY
    IF(NUPTCM.GT.0) VSQRT1=1./SQRT(ENGP(IBGP))                         YYY
    IF(IBGP.LT.NOXSUM) GO TO 50
    IXG=IXG+1
    NOXSUM=NOXSUM+NOIG(IXG)
    NXSUM=NXSUM+NOIG(IXG-1)
    UFGP=DBLE(UIGP(IXG)/NFI(IAG))
    TMP4=DEXP(-UFGP)
    UEXP=DEXP(-U+0.5*UFGP)
    TMP6=DBLE(1./UIGP(IXG))
    TMP7=1./UIGP(IXG-1)
C * * CALCULATION OF RESONANCE XSECTION OF SODIUM
 80 IF(KSG.LE.1.AND.KAG.LE.1) GO TO 999
    IF(IBGP.LE.NSG(1).OR.ISG.EQ.NSG) GO TO 81
    INDEX2=1                                                           YYY
    IF(IBGP.LE.NSG(ISG)) GO TO 51
    ISG=ISG+1
```

```
      CALL INPUT2
     1(KMAT,KCOMP,KCOMPF,KSREG,K1SREG,KMSREG,M1SREG,MMSREG,KKSG,
     2MMSG,NNSG,IP1,SA,SF,SS,W,W1,WW,WW1,CSS)
      IF(ISS.EQ.KRES) GO TO 52
      IF(ISG.NE.KSG) GO TO 51
      POTEN=POTEN+POTEN1
      SIGSOD=POTEN
      DO 53 J=ICS,KCOMP
   53 SS(ISS,J)=POTEN*DEN(ISS,J)
      GO TO 81
   51 IF(ISS.EQ.KRES) GO TO 52
      XX=2.*(ENGP(IHGP)-ERES)/GAMT
      RR=(PEAK*2.*XX*SIGOP)/(XX*XX+GAMT/(2.*ERES)+1.)+POTEN+POTEN1
      RA=PEAK*GAMG/((XX*XX+GAMT/(2.*ERES)+1.)*GAMT)
      DO 82 J=ICS,KCOMP
      SA(ISS,J)=RA*DEN(ISS,J)
   82 SS(ISS,J)=RR*DEN(ISS,J)
      SIGSOD=RR
   52 DELE=(ENGP(IHGP)-ESG(ISG))/(ENGP(IHGP-1)-ESG(ISG.
      NNNM=IHGP-NSG(ISG)+5
      IF(NNNM.GT.0) DELE=0.
      F1=1.-DELE
      IF(ISS.EQ.IVL) GO TO 54
      DO 55 J=ICS,KCOMP
      JJ=J-KCOMP
      IF(NOPT.EQ.0) JJ=1
      DO 55 I=IVL,IVL
      II=I-ISS
      CS1(II,JJ)=CS2(II,JJ)*F1+CS1(II,JJ)*DELE
      CA1(II,JJ)=CA2(II,JJ)*F1+CA1(II,JJ)*DELE
      SS(I,J)=CS1(II,JJ)
      SA(I,J)=CA1(II,JJ)
   55 CONTINUE
   54 IF(NOPT.LE.0) GO TO 81
C * * LINEAR INTERPOLATION OF COLLISION PROBABILITY
      DO 57 II=1,K1SREG
   57 W(II)=WW(II)*F1+W1(II)*DELE
      DO 58 II=1,KMSREG
   58 W1(II)=WW1(II)*F1+W1(II)*DELE
   81 IF(KAG.LE.1) GO TO 83                                          YYY
      IF(IHGP.GT.NAG(IAG)) IAG=IAG+1
      IF(IAG.EQ.1.OR.IAG.EQ.KAG) GO TO 83                            YYY
      INDEX2=1
      DELE=(ENGP(IHGP)-EAG(IAG))/(EAG(IAG-1)-EAG(IAG))
      F1=1.-DELE
      SIGAA=SIAA(IAG)*F1+SIA(IAG-1)*DELE
   85 DO 84 J=1,KCOMP
   84 SA(IAA,J)=SIGAA*DEN(IAA,J)
   83 IF(ISG.EQ.KSG.AND.IAG.EQ.KAG) INDEX2=0                         YYY
  999 DO 56 J=ICS,KCOMP
      SIG(J)=0.
      DO 56 I=1,KMAT
      IF(NOPTCP.GT.0) SA(I,J)=SA(I,J)+VCAP(I)*DEN(I,J)*(VSQRT1-VSQRT2)  YYY
   56 SIG(J)=SIG(J)+SS(I,J)+SA(I,J)
      VSQRT2=VSQRT1                                                  YYY
      IF(NOPT.LT.0.AND.INDEX2.GT.0) CALL INPUT2                      YYY
     1(KMAT,KCOMP,KCOMPF,KSREG,K1SREG,KMSREG,M1SREG,MMSREG,KKSG,
     2MMSG,NNSG,IP2,SA,SF,SS,W,W1,WW,WW1,CSS)
      RCSGP=0.                                                       YYY
      ACSGP=0.


      FCSGP=0.
      SCSGP=0.
      PHIT=0.
      NU=(IHGP-1)/NBB
      NU=IHGP-NBB*NU
      NH=(IHGP-1)/NBH
      NH=IHGP-NBH*NH
      NR=(IHGP-1)/NBR
      NR=IHGP-NBR*NR
      DO 10 J=1,KSREG
      FLUX(J,NU)=0.
      FLUXSS(J)=0.
      SCATH(J,NH)=0.
      IF(ISS.NE.KRES) SCATR(J,NR)=0.
      DO 10 K=1,KMAT
      SIGRBG(K,J)=0.
      SIGABG(K,J)=0.
      SIGFBG(K,J)=0.
   10 SIGSBG(K,J)=0.
      DO 15 J=1,KREG
   15 FLUXR(J)=0.
   70 NF=1
      NL=NFI(IXG)
      DO 20 IFGP=NF,NL
      IF(KAG.GT.1) AAINF=AAINF+SIGAA*UFGP
      U=U+UFGP
      TMP5=UFGP*IFGP
      DO 90 I=1,KSREG
      PEACO(I)=0.0
      K=LSR G(I)
      DO 901 J=1,KMAT
      IF(DEN(J,K).LT.0.00001) GO TO 901
      S(I)=S(I)+(SS(J,K)*BETA(J))*PHI(I)
      TMP=U-UMAX(J)
      IF(TMP) 91,91,92
   92 IF(IXG.EQ.1) GO TO 93
      TMP1=U-UXG(IXG)
      NTMP1=TMP1/UIGP(IXG)
      TMP2=UXG(IXG)-TMP
      IF(TMP2) 99,99,94
   94 MX=TMP2*TMP7
      M=NTMP1+MX
      IF(M.GT.NBB) GO TO 901
      TMPP=UFGP*TMP7
      IXXX=IXG-1
      GO TO 95
   93 TMP2=UMAX(J)-TMP5
      M=TMP2*TMP6
      TMPP=UFGP*TMP6
      IXXX=IXG
      MX=M
   95 LM=IBGP-M-1
      IF(NOPTS.LT.1) GO TO 100
      UX=TMP2-(MX+0.5)*UIGP(IXXX)
      TMP10=UIGP(IXXX)
  100 CONTINUE
      IF(IXG.NE.1.AND.IFGP.EQ.1.AND.IBGP.EQ.NXSUM) TMPP=1./NOIG(IXG-1)
      IF(J-ISS) 96,96,97
   96 IF(J-KRES)901,98,99
   98 MM=(LM-1)/NBH
```

```
      M=LM-NBB*MM
      IF(NOPTS.GT.0) GO TO 598
C     S(I)=S(I)-SCATH(I,M)*TMPP
      PEACO(I)=PEACO(I)+SCATH(I,M)*TMPP
      GO TO 901
  598 Y2=SCATH(I,M)
      M33=M+1
      IF(M.EQ.NBH)M33=1
      Y3=SCATH(I,M33)
      IF(M.NE.1) Y1=SCATH(I,M-1)
      IF(LM.NE.1.AND.M.EQ.1) Y1=SCATH(I,NBH)
      CALL ABCD(Y1,Y2,Y3,UX,TMP10,YY)
C     S(I)=S(I)-YY*TMPP
      PEACO(I)=PEACO(I)+YY*TMPP
      GO TO 901
   99 MM=(LM-1)/NBR
      M=LM-NBR*MM
      IF(NOPTS.GT.0) GO TO 599
C     S(I)=S(I)-SCATR(I,M)*TMPP
      PEACO(I)=PEACO(I)+TMPP*SCATR(I,M)
      GO TO 901
  599 Y2=SCATR(I,M)
      M33=M+1
      IF(M.EQ.NBR)M33=1
      Y3=SCATR(I,M33)
      IF(M.NE.1) Y1=SCATR(I,M-1)
      IF(LM.NE.1.AND.M.EQ.1) Y1=SCATR(I,NBR)
      CALL ABCD(Y1,Y2,Y3,UX,TMP10,YY)
C     S(I)=S(I)-YY*TMPP
      PEACO(I)=PEACO(I)+TMPP*YY
      GO TO 901
   97 MM=(LM-1)/NBB
      M=LM-NBB*MM
      IF(J.GT.IVL.OR.ISG.EQ.1) GO TO 580
      IXX=0
      JJ=J-ISS
      KK=K-KCOMPF
      IF(NOPT.EQ.0) KK=1
      IF(NOPT.EQ.0) JJ=1
      DO 581 IY=1,ISG
      IYY=ISG-IY+1
      IF(LM.LT.NSG(IYY)) GO TO 581
      IXX=IYY
      GO TO 582
  581 CONTINUE
      IF(IXX.EQ.0) CTMP=CSS(1,JJ,KK)
      IF(IXX.EQ.0) GO TO 583
  582 IF(IXX.EQ.(KSG-1)) GO TO 580
      DELE=(ENGP(LM)-ESG(IXX+1))/(ESG(IXX)-ESG(IXX+1))
      F1=1.-DELE
      CTMP=CSS(IXX+1,JJ,KK)*F1+CSS(IXX,JJ,KK)*DELE
      GO TO 583
  580 CTMP=SS(J,K)
  583 IF(NOPTS.GT.0) GO TO 597
C     S(I)=S(I)-(CTMP*BETA(J)*FLUX(I,M))*TMPP
      PEACO(I)=PEACO(I)+CTMP*BETA(J)*FLUX(I,M)*TMPP
      GO TO 901
  597 Y2=FLUX(I,M)
      M33=M+1
      IF(M.EQ.NBB)M33=1

      Y3=FLUX(I,M33)
      IF(M.NE.1) Y1=FLUX(I,M-1)
      IF(LM.NE.1.AND.M.EQ.1) Y1=FLUX(I,NBB)
      CALL ABCD(Y1,Y2,Y3,UX,TMP10,YY)
C     S(I)=S(I)-(CTMP*BETA(J)*YY)*TMPP
      PEACO(I)=PEACO(I)+TMPP*YY*BETA(J)*CTMP
      GO TO 901
   91 IF(UMAX(J).GT.19.)GO TO 901
C     S(I)=S(I)-(DEN(J,K)*SIGS(J)*V(I)*BETA(J))*UFGP*DEXP(TMP*ALPHA)
      PEACO(I)=PEACO(I)+DEN(J,K)*SIGS(J)*V(I)*BETA(J)*UFGP
     1*DEXP(TMP*ALPHA)
  901 CONTINUE
      S(I)=S(I)-PEACO(I)
   90 CONTINUE
      CALL XSECTT
     1(KSREG,KMAT,KNES,KCOMP,KCOMPF,KTEMP,MAXNFI,KISREG,KMSREG,
     2SA,SF,SS,SAA,SFF,SSS,P,W,M)
      DO 20 I=1,KSREG
      M=LSRG(I)
      PHI(I)=C(I)/SIG(M)
      FLUX(I,NU)=FLUX(I,NU)+PHI(I)
      UEXP=UEXP*TMP4
      PHIEXP=UEXP*PHI(I)
      FLUXSS(I)=FLUXSS(I)+PHIEXP
      DO 20 J=1,KMAT
      IF(DEN(J,M).LT.0.00001) GO TO 20
      IF(J-ISS) 30,30,35
   30 IF(J-KRES)31,31,32
   31 SCATH(I,NH)=SCATH(I,NH)+BETA(J)*SS(J,M)*PHI(I)
      GO TO 35
   32 SCATR(I,NR)=SCATR(I,NR)+BETA(J)*SS(J,M)*PHI(I)
      TMPU=U*UMAX(J)-UBGP(IBG)
      SODINF=SODINF+SIGSOD*UFGP
      IF(KSG.LE.1.OR.TMPU.LE.0.) GO TO 35
      TMPSOD=SIGSOD*UFGP*(ENRAT/UEXP-(1.-1./BETA(J)))
      SODR=SODR+TMPSOD
   35 TMP2=U*UMAX(J)-UBGP(IBG)
      IF(TMP2)72,72,71
   71 IF(TMP2-0.02)73,73,74
   73 SIGRBG(J,I)=SIGRBG(J,I)+BETA(J)*SS(J,M)*PHI(I)*TMP2
      GO TO 72
   74 SIGRBG(J,I)=SIGRBG(J,I)+BETA(J)*SS(J,M)*PHI(I)
     1*(1.-(1.-1./BETA(J))*UEXP/ENRAT)
   72 SIGABG(J,I)=SIGABG(J,I)+PHIEXP*SA(J,M)
      SIGFBG(J,I)=SIGFBG(J,I)+PHIEXP*SF(J,M)
      SIGSBG(J,I)=SIGSBG(J,I)+PHIEXP*SS(J,M)
   20 CONTINUE
      LF=1
      DO 25 I=1,KREG
      LL=NSUBR(I)
      DO 60 L=LF,LL
      FLUXR(I)=FLUXR(I)+FLUXSS(L)
      PHIRT(I)=PHIRT(I)+FLUXSS(L)
   60 CONTINUE
      LF=LL+1
   25 CONTINUE
      DO 40 I=1,KSREG
      PHIT=PHIT+FLUXSS(I)
      PHISR(I)=PHISR(I)+FLUXSS(I)
      IF(LISTS.GT.0) FLUXSR(I,NU)=FLUXSS(I)
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      DO 40 J=1,KMAT
      RIAS(J,I)=RIAS(J,I)+SIGABG (J,I)
      RIRS(J,I)=RIRS(J,I)+SIGRBG (J,I)
      RIFS(J,I)=RIFS(J,I)+SIGFBG (J,I)
      RISS(J,I)=RISS(J,I)+SIGSBG (J,I)
      RCSGP=RCSGP+SIGRBG (J,I)
      ACSGP=ACSGP+SIGABG (J,I)
      FCSGP=FCSGP+SIGFBG (J,I)
   40 SCSGP=SCSGP+SIGSBG (J,I)
      LF=1
      DO 61 I=1,KREG
      LL=NSUBR(I)
      DO 62 L=LF,LL
      DO 62 J=1,KMAT
      RIAR(J,I)=RIAR(J,I)+SIGABG(J,L)
      RIFR(J,I)=RIFR(J,I)+SIGFBG(J,L)
      RISR(J,I)=RISR(J,I)+SIGSBG(J,L)
   62 RIRR(J,I)=RIRR(J,I)+SIGRBG(J,L)
      LF=LL +1
   61 CONTINUE
      PHITOT=PHITOT+PHIT
      RCS=RCS+RCSGP
      ACS=ACS+ACSGP
      FCS=FCS+FCSGP
      SCS=SCS+SCSGP
      CALL OUTPT2
     1(KREG,KSREG,KMAT,KRES,KCOMP,KCOMPF,KTEMP,MAXNFI,KKGP,NBB,NBH,KVR,
     2NVR,KVL,NVI,K1SREG,KMSREG,M1SREG,MMSKEG,KKSG,MMSG,NNSG,
     3SA,SF,SS,SAA,SFF,SSS,   P,          RIRR,RIAR,RIFR,RISR,
     4RIRS,RIAS,RIFS,RISS,                SIGRBG,SIGABG,SIGFBG,SIGSBG,
     5FLUX,ENGP,SCATH,SCATR,FLUXSR,W,W1,WW,WW1,CSS)
   45 CONTINUE
   20 RETURN
      END
      SUBROUTINE XSECTT
     1(KSREG,KMAT,KRES,KCOMP,KCOMPF,KTEMP,MAXNFI,K1SREG,KMSREG,
     2SA,SF,SS,SAA,SFF,SSS,P,W,W1)
      COMMON KBG,KIGP,KXG,KSG,KAG,KZ,KSOUCE,ISS,IAA,NOPT,NOPTFL,NOPTS,
     1NREAD,NRMAT,LISTK,LISTS,MORE,IVF,IVL,NBR,NOPTX,NOPTCP
      COMMON/IJ/ IBG,JRG,IBGP,IFGP,IXG,ISG,IAG,INDEX,INDEX1
      COMMON /AA/ U,UFGP,UBG,UOPT,KF,VMAX,ALPHA,GAM,GUZAI,
     1PHITOT,RCS,ACS,FCS,SCS,PHIT,KCSGP,ACSGP,FCSGP,SCSGP,FNRAT
     2,SODINF,SODR,AAINF,ERFS,GAMT,GJ,POTEN,PEAK,GAMG,POTEN1
      COMMON /BB/ TIL(18),Z(75),PZ(4),NTEMP(3),TEMP(3),SIG(7)
     1,RINF(4,3),AINF(4,3),FINF(4,3),SINF(4,3)
      COMMON /CC/ EN(41),UBGP(40),UIGP(10),UXG(10),EXG(11),VCAP(10),
     1ESG(30),CS1(5,6),CA1(5,6),CS2(5,6),CA2(5,6),EAG(20),SIAA(21
     2),AMU(10),UMAX(10),BETA(10),SIGA(10),SIGF(10),SIGS(10),DEN(10,7),
     3VR(20),RMAX(20),PHIRT(20),FLUXR(20),ESOUCE(40),
     4V(20),S(20),C(20),PHI(20),PHISR(20),PEACU(20),PEACOG
      COMMON /MM/ NIB(40),NBG(40),NFG(40),UBGP(40),NOIG(10),NFI(10),
     1NSG(30),NAG(20),NUCLID-10),NSUBR(20),LSRG(20),NCOMP(20)
      DIMENSION @(20),Y(20),A(20,20)
      DIMENSION SA(KMAT,KCOMP),SF(KMAT,KCOMP),SS(KMAT,KCOMP),
     1SAA(KRES,KTEMP,MAXNFI),SFF(KRES,KTEMP,MAXNFI),SSS(KRES,KTEMP,MAXNF
     2I),P(KSREG,KSREG), W(K1SREG),W1(KMSREG)
      DOUBLE PRECISION U,UFGP
      DOUBLE PRECISION S,PHI,C
      DOUBLE PRECISION @,Y
      IF(IBGP.EQ.2.OR.IFGP.NE.1) GO TO 5


      DO 10 NT=1,KTEMP
      NNT=NT
      KL=NFI(IXG)
      DO 10 I=1,KRES
   10 READ(NNT) (SAA(I,NT,K),SFF(I,NT,K),SSS(I,NT,K),K=1,KL)
    5 KCOFF=KCOMPF
      IF(NUPTX.GT.0) KCOFF=KCOMP
      DO 20 J=1,KCOFF
      SIG(J)=0.
      M=1
      IF(J.LE.KCOMPF) M=NTEMP(J)
      DO 22 I=1,KRES
      SA(I,J)=SAA(I,M,IFGP)*DEN(I,J)
      SF(I,J)=SFF(I,M,IFGP)*DEN(I,J)
   22 SS(I,J)=SSS(I,M,IFGP)*DEN(I,J)
      DO 23 I=1,KMAT
   23 SIG(J)=SIG(J)+SA(I,J)+SF(I,J)+SS(I,J)
   20 PZ(J)=RF*SIG(J)
      DO 888 I=1,KRES
      DO 888 K=1,KTEMP
      AINF(I,K)=AINF(I,K)+SAA(I,K,IFGP)*UFGP
      FINF(I,K)=FINF(I,K)+SFF(I,K,IFGP)*UFGP
      SINF(I,K)=SINF(I,K)+SSS(I,K,IFGP)*UFGP
      TMPU=U+UMAX(I)-UBGP(IBG)
      IF(TMPU.LE.0.) GO TO 888
      RINF(I,K)=RINF(I,K)+SSS(I,K,IFGP)*BETA(I)*UFGP *TMPU
  888 CONTINUE
      IF(NOPT) 71,11, 74
   71 PZZ=PZ(1)
      PESCP=1.-PC(PZZ)
      P(1,2)=GAM*PESCP/(1.-(1.-2.*PZ(1)*PESCP)*(1.-GAM))
      P(1,1)=1.-P(1,2)
      M=LSRG(2)
      P(2,1)=V(1)*SIG(1)*P(1,2)/(V(2)*SIG(M))
      P(2,2)=1.-P(2,1)
      GO TO 11
   74 DO 75 I=1,KCOMPF
      IF(PZ(I)-1.) 75,75,76
   76 PZ(I)=2.-1./PZ(I)
   75 CONTINUE
      PP=0.
      DO 60 I=1,KCOMPF
   60 PP=PP+PZ(I)
      PP=PP/KCOMPF
      IF(INDEX-1) 1,1,2
    1 N=10
      INDEX=3
      NHK1=(KSREG*(KSREG+1))/2
      KKZ=NHK1*(KZ-1)
    2 IF(PP-Z(1))100,100,101
  101 IF(PP-Z(N))3,3,4
    3 N=N-1
      IF(PP-Z(N)) 3,3,55
    4 N=N+1
      IF(N.LT.KZ.AND.(PP-Z(N)).GT.0.) GO TO 4
      IF(N.EQ.KZ.AND.(PP-Z(N)).GT.0.) GO TO 90
      N=N-1
      GO TO 55
   90 DO 91 I=1,KSREG
      DO 91 J=1,I
```

```
      NHK=(I*(I-1))/2+J+KKZ
   91 P(I,J)=W(NHK)
      GO TO 102
   55 DO 56 M=1,KCOMPF
      PZ(M)=PZ(M)-Z(N)
   56 CONTINUE
      DO 6 I=1,KSREG
      DO 6 J=1,I
C**   P(I,J)=W(I,J,N)
      NHK2=(I*(I-1))/2+J
      NHK3=NHK1*(N-1)+NHK2
      P(I,J)=W(NHK3)
      DO 6 M=1,KCOMPF
      NHK4=NHK1*(KCOMPF*(N-1)+M-1)+NHK2
C**   P(I,J)=P(I,J)+W1(M,I,J,N)*PZ(M)
      P(I,J)=P(I,J)+W1(NHK4)*PZ(M)
    6 CONTINUE
      GO TO 102
  100 DO 103 I=1,KSREG
      DO 103 J=1,I
      NHK2=(I*(I-1))/2+J
  103 P(I,J)=W(NHK2)
  102 DO 7 I=1,KSREG
      MI=LSRG(I)
      JF=I+1
      SUMP=0.
      DO 61 J=1,I
   61 SUMP=SUMP+P(I,J)
      SUMA=SUMP-P(I,I)
      IF(I.EQ.KSREG) P(I,I)=1.-SUMA
      IF(JF.GT.KSREG) GO TO 7
      DO 8 J=JF,KSREG
      MJ=LSRG(J)
      P(I,J)=V(J)*SIG(MJ)*P(J,I)/(V(I)*SIG(MI))
    8 SUMP=SUMP+P(I,J)
      TMPB=(1.-SUMA)/(SUMP-SUMA)
      DO 62 J=1,KSREG
      P(I,J)=P(I,J)*TMPB
      IF(I.EQ.J) GO TO 62
      P(J,I)=P(J,I)*TMPB
   62 CONTINUE
    7 CONTINUE
   11 IF(NOPTFL.EQ.0.OR.U.LT.UOPT) PEACOG=0.0
      IF(NOPT.EQ.0) C(1)=S(1)*UFGP
      IF(NOPT.EQ.0) GO TO 32
      DO 30 I=1,KSREG
      C(I)=0.
      DO 31 J=1,KSREG
C  31 C(I)=C(I)+P(J,I)*S(J)
   31 C(I)=C(I)+P(J,I)*(S(J)-PEACOG*PEACO(J))
   30 C(I)=UFGP*C(I)
C  32 IF(U.LT.UOPT) GO TO 50
   32 IF(NOPTFL.EQ.0.OR.U.LT.UOPT) GO TO 50
      DO 14 I=1,KSREG
      SUM=0.
      M=LSRG(I)
      DO 15 J=1,KMAT
   15 SUM=SUM+SS(J,M)*BETA(J)
   14 O(I)=SUM*UFGP/2.
  202 FORMAT(1H0,10X,10H@(I)*****  ,5F10.5)

      IF(NOPTFL.EQ.1) GO TO 80
      DO 41 I=1,KSREG
      M=LSRG(I)
      TMP=1./SIG(M)
      Y(I)=0.
      DO 40 J=1,KSREG
   40 Y(I)=Y(I)+P(J,I)*@(J)*C(J)*TMP
   41 C(I)=C(I)+Y(I)
      GO TO 50
   80 DO 81 I=1,KSREG
      M=LSRG(I)
      TMP=1./SIG(M)
      A(I,I)=1.-P(I,I)*@(I)*TMP
      DO 81 J=1,KSREG
      IF(J.EQ.I) GO TO 81
      A(I,J)=-P(J,I)*@(J)*TMP
   81 CONTINUE
      CALL MATINV(A,KSREG,C,1,DET,20)
   50 RETURN
      END
      SUBROUTINE ABCD(Y1,Y2,Y3,UX,U,Y)
      DOUBLE PRECISION Y1,Y2,Y3,UX,U,Y
      A=(Y1+Y3-2.*Y2)/(2.*U*U)
      B=0.5*(Y1-Y3)/U
      Y=A*UX*UX+B*UX+Y2
      RETURN
      END
      SUBROUTINE OUTPT2
     1(KREG,KSREG,KMAT,KRES,KCOMP,KCOMPF,KTEMP,MAXNFI,KKGP,NBH,NBH,KVR,
     2NVR,KVL,NVL,K1SREG,KMSREG,M1SREG,MMSREG,KKSG,MMSG,NNSG,
     3SA,SF,SS,SAA,SFF,SSS,   P,          PINR,RIAR,RIFR,RISR,
     4RIRS,RIAS,RIFS,RISS,                SIGRBG,SIGABG,SIGFBG,SIGSBG,
     5FLUX,ENGP,SCATH,SCATR,FLUXSR,W,W1,WW,WW1,CSS)
      COMMON KBG,KIGP,KXG,KSG,KAG,KZ,KSOUCE,ISS,IAA,NOPT,NOPTFL,NOPTS,
     1NREAD,NRMAT,LISTH,LISTS,MORE,IVF,IVL,NBR,NOPTX,NOPTCP
      COMMON/JJ/ IBG,JBG,IBG2,IFGP,IXG,ISG,IAG,INDEX,INDEX1
      COMMON /AA/ U,UFGP,UBG,EOPT,RF,VMAX,ALPHA,GAM,GUZAI,
     1PHITOT,PCS,ACS,FCS,SCS,PHIT,ACSGP,ACSGP,FCSGP,SCSGP,ENRAT
     2,SODINF,SODR,AAINF,ERES,GAMT,GJ,POTEN,PEAK,GAMG,POTEN1
      COMMON /BB/ TIL(18),Z(25),PZ(4),NTEMP(3),TEMP(3),SIG(7)
     1,MINF(4,3),AINF(4,3),FINF(4,3),SINF(4,3)
      COMMON /CC/ EN(41),UBGP(40),UIGP(10),UXG(10),EXG(11),VCAP(10),
     1ESG(30),CS1(5,6),CA1(5,6),CS2(5,6),CA2(5,6),EAG(20),SIAA(21
     2),AMU(10),UMAX(10),BETA(10),SIGA(10),SIGF(10),SIGS(10),DEN(10,7),
     3VR(20),RMAX(20),PHIRT(20),FLUXR(20),ESOUCE(40),
     4V(20),S(20),C(20),PHI(20),PHISR(20),PEACO(20),PEACOG
      COMMON /MM/ NIB(40),NBG(40),NFG(40),JBGP(40),NOIG(10),NFI(10),
     1NSG(30),NAG(20),NUCLID(10),NSUBR(20),LSRG(20),NCOMP(20)
      DIMENSION PHIRR(20),SOURCE(20),SOUSE(20),FAIT(20),ACTA(10,20),ACTF
     1(10,20)
      DIMENSION SA(KMAT,KCOMP),SF(KMAT,KCOMP),SS(KMAT,KCOMP),
     1SAA(KRES,KTEMP,MAXNFI),SFF(KRES,KTEMP,MAXNFI),SSS(KRES,KTEMP,MAXNF
     2I),P(KSREG,KSREG),
     3RIRR(KMAT,KREG),RIAR(KMAT,KREG),RIFR(KMAT,KREG),RISR(KMAT,KREG),
     4RIRS(KMAT,KSREG),RIAS(KMAT,KSREG),RIFS(KMAT,KSREG),RISS(KMAT,KSREG
     5),SIGRBG(KMAT,KSREG),SIGABG(KMAT,KSREG),SIGFBG(KMAT,KSREG),
     6SIGSBG(KMAT,KSREG),FLUX(KSREG,NBB),ENGP(KKGP),
     7SCATH(KSREG,NSH),SCATR(KVR,NVR),FLUXSR(KVL,NVL),
     8W(K1SREG),W1(KMSREG),WW(M1SREG),WW1(MMSREG),CSS(KKSG,MMSG,NNSG)
      DOUBLE PRECISION U,UFGP
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      DOUBLE PRECISION S,PHI,C
C * * STARTING POINT
 3001 FORMAT(1H0,10X,10I10)
      IF(IBGP.GT.2) GO TO 1
      KLIST=-1
      KLISTS=-1
    2 DO 2 I=1,KSREG
      M=LSRG(I)
      SOUSE(I)=0.
      DO 2 J=1,KMAT
      IF(UMAX(J).GT.19.) SOUSE(I)=SOUSE(I)+SIGS(J)*DEN(J,M)
    2 CONTINUE
      FAIT(I)=0.
      DO 3 J=1,KMAT
      ACTA(J,I)=0.
    3 ACTF(J,I)=0.
      UM=UBGP(KBG)
      EPR=ENGP(KIGP)
      KREP=KREG
      ESCAPA=0.
      ESCAPF=0.
      IF(KREG.GT.13) KREP=14
      KSREG1=KSREG
      IF(KSREG.GE.15) KSREG1=14
    1 IF(KSOUCE.LE.0) GO TO 700
      DO 701 I=1,KSREG
      DO 701 J=1,KMAT
      IF(UMAX(J).GT.19.) SOUSE(I)=SOUSE(I)+RIRS(J,I)
  701 CONTINUE
  700 IF(JBG.EQ.2) PRINT 100,IBG,EN(IBG),EN(IBG+1)
      IBGG=IBGP+1
  100 FORMAT(1H1,//20X88H********** CALCULATED RESULTS FOR INTERMEDIATE F
     1LUX AND AVERAGED CROSS SECTIONS  ******** ,//,30X,19HNO. OF GROUP
     2GROUP= ,I2,1H,.... ENERGY RANGE( ,F10.3,6H EV TO,F10.3,8H EV).... )
      IF(JBG.EQ.1.AND.LISTR.NE.0) PRINT 101,(I,I=1,KREP)
  101 FORMAT(1H0,//,25X,75H******** NO. AND FLUX(PER UNIT VOLUME AND LET
     1HARGY) OF EACH REGION ********/
     240X,40H(LAST LINE SHOW AVERAGED FLUX OVER CELL) //3X,20HGROUP NO.
     3  ENERGY /,15(I4,3X) )
      IF(LISTR.EQ.0) GO TO 10
      KLIST=KLIST+1
      IF(KLIST.LE.49) GO TO 705
      KLIST=0
      PRINT 1101,(I,I=1,KREP)
 1101 FORMAT(1H1,//,25X,75H******** NO. AND FLUX(PER UNIT VOLUME AND LET
     1HARGY) OF EACH REGION ********/
     240X,40H(LAST LINE SHOW AVERAGED FLUX OVER CELL) //3X,20HGROUP NO.
     3  ENERGY /,15(I4,3X) )
  705 FE=(ENGP(IBGP)+ENGP(IBGP-1))/2.
      PHIR=PHIT/(VMAX*DIGP(IXG))
      DO 11 I=1,KREG
   11 PHIRR(I)=FLUXR(I)/(VR(I)*DIGP(IXG))
      PRINT 102,IBGG,EE,(PHIRR(I),I=1,KREP),PHIR
  102 FORMAT(1H ,3X,I4,2X,F10.2,2X,15F7.4)
      IF(KREG.GE.15) PRINT 300,(PHIRR(I),I=15,KREG),PHIR
  300 FORMAT(1H ,21X,8F7.4)
   10 IF(JBG-NIB(IBG)) 20,21,21
   20 JBG=JBG+1
      GO TO 30
   21 PRINT 112,IBG,(NUCLID(I),I=1,KMAT)

  112 FORMAT(1H1,//,
     *           20X,53H..... SUMMARY FOR AVERAGED FLUX AND CROSS SECTIO
     1NS OF ,I2,21H TH BROAD GROUP ......///,40X,32H***** REGIONAL INFOR
     2MATION ***** ,//,5X,31HREGION NO.     FLUX     REACTION ,5X,
     37(4X,A4,4X))
      DO 31 I=1,KREG
      M=NCOMP(I)
      TMP=PHIRT(I)
      FAIT(I)=FAIT(I)+PHIPT(I)
      DO 32 J=1,KMAT
      ESCAPA=ESCAPA+RIAR(J,I)
      ESCAPF=ESCAPF+RIFR(J,I)
      ACTA(J,I)=ACTA(J,I)+RIAR(J,I)
      ACTF(J,I)=ACTF(J,I)+RIFR(J,I)
      TMP1=TMP*DEN(J,M)
      RIAR(J,I)=RIAR(J,I)/TMP1
      RIFR(J,I)=RIFR(J,I)/TMP1
      RISR(J,I)=RISR(J,I)/TMP1
   32 RIRR(J,I)=RIRR(J,I)*ENRAT/TMP1
      TMP=TMP/(UBG*VR(I))
      PRINT 113,(RIAR(J,I),J=1,KMAT)
      PRINT 114,(RIFR(J,I),J=1,KMAT)
      PRINT 115,I,TMP,PHIRT(I)
      PRINT 116,(RISR(J,I),J=1,KMAT)
      PRINT 117,(RIRR(J,I),J=1,KMAT)
   31 PRINT 125
  125 FORMAT(1H0,30X,5H-----,30X,5H----- )
  113 FORMAT(1H0,2HX ,10HABSORPTION ,3X,7(1X,F10.4,1X))
  114 FORMAT(1H ,26X,9HFISSION  ,4X,7(1X,F10.4,1X))
  115 FORMAT(1H0,11X,I2,F10.4,33H(INTEGRATED VALUE OVER V. AND U = ,F10.
     15,2H ) )
  116 FORMAT(1H0,26X,10HSCATTERING ,3X,7(1X,F10.4,1X))
  117 FORMAT(1H ,26X,9HREMOVAL  ,4X,7(1X,F10.4,1X))
      IF(LISTR.LT.5) GO TO 1235
      PUNCH 1234,(PHIRT(I),I=1,KREG)
 1234 FORMAT(6E12.5)
 1235 CONTINUE
      ACS=ACS/PHITOT
      FCS=FCS/PHITOT
      SCS=SCS/PHITOT
      RCS=RCS/PHITOT
      PRINT 119,ACS,FCS,SCS,RCS,PHITOT
  119 FORMAT(1H0,///,20X,57H.....  CELL AVERAGED TOTAL CROSS SECTIONS AN
     1D FLUX ,.... ,///25X,4HABSORPTION  FISSION  SCATTERING  REMOVAL
     2  FLUX ,//,25X,5E10.4,37H(INTEGRATED OVER VOLUME AND LETHARGY))
      PRINT 200 ,(NUCLID(J),J=1,KRES)
  200 FORMAT(1H0,///,20X,58H***** INFINITE DILUTION XSECTION FOR SPECIAL
     1 ELEMENT *****  //,15X,28HTEMPERATURE      REACTION     ,4(3X,A4,3X),
     2//)
      DO 70 I=1,KRES
      DO 70 N=1,KTEMP
      AINF(I,N)=AINF(I,N)/UBG
      FINF(I,N)=FINF(I,N)/UBG
      SINF(I,N)=SINF(I,N)/UBG
   70 RINF(I,N)=RINF(I,N)/UBG
      DO 71 N=1,KTEMP
      PRINT 201,TEMP(N),(AINF(I,N),I=1,KRES)
      PRINT 202,(FINF(I,N),I=1,KRES)
      PRINT 203,(SINF(I,N),I=1,KRES)
   71 PRINT 204,(RINF(I,N),I=1,KRES)
```

```
201 FORMAT(1H0,14X,F10.2,6X,12HCAPTURE ....,4F10.4)
202 FORMAT(1H0,30X,12HFISSION ...., 4F10.4)
203 FORMAT(1H0,30X,12HSCATTERING ., 4F10.4)
204 FORMAT(1H0,30X,12HREMOVAL .... ,4F10.4,//)
    IF(ISS.EQ.KRES) GO TO 72
    SOUINF=SOUINF/UBG
    SOUR=SOUR*BETA(ISS)/UBG
    PRINT 205,ISS,SOUINF,SOUR
205 FORMAT(1H0,10X,11HXSECTION OF,I2,29HTH MATERIAL .... SCATTERING =,
   1F10.5,5X,9HREMOVAL = ,F10.5, /)
 72 IF(KAG.EQ.0) GO TO 73
    AAINF=AAINF/UBG
    PRINT 206,AA,AAINF
206 FORMAT(1H0,10X,19HCAPTURE XSECTION OF ,I2,13HTH MATERIAL = ,F10.5)
 73 IF(IBG.NE.KBG) GO TO 34
    PRINT 1236
1236 FORMAT(1H1///,20X,95H..... INTEGRATED FLUX(OVER VR AND U) AND CAP
   1TURE AND FISSION ACTIVATIONS IN EACH REGION ..... )
    PRINT 1237,(NUCLID(J),J=1,KMAT)
1237 FORMAT(1H0,/,35X,38H... ACTIVATIONS FOR EACH MATERIALS ... ,//,2X,
   1   28HREGION NO.  FLUX    REACTION (4X,10(2X,A4,2X),/)
    DO 4 I=1,KREG
    DO 5 J=1,KMAT
    ACTA(J,I)=ACTA(J,I)/VR(I)
  5 ACTF(J,I)=ACTF(J,I)/VR(I)
    PRINT 1238,(ACTA(J,I),J=1,KMAT)
    PRINT 1239,I,FAII(I)
    PRINT 1240,(ACTF(J,I),J=1,KMAT)
  4 CONTINUE
1238 FORMAT(1H ,20X,10HCAPTURE . ,10F10.4)
1239 FORMAT(1H ,5X,I5,F10.3)
1240 FORMAT(1H ,20X,10HFISSION . ,10F10.4,//)
    ESCAPA=ESCAPA/GUZAI
    ESCAPF=ESCAPF/GUZAI
    TMP=ESCAPA*ESCAPF
    PRINT 118,ESCAPA,ESCAPF,TMP
118 FORMAT(1H0,//,10X,77H (ABSORPTION,FISSION AND TOTAL CAPTURE PROBAB
   1ILITIS) EQUAL ,RESPECTIVELY ...,3F10.4)
 34 IF(NOPT.LE.0.OR.LISTS.EQ.0) GO TO 40
    PRINT 110,IBG,(J,J=1,KSREG1)
110 FORMAT(1H1,/,20X,46H..... SUBREGIONAL INTERMEDIATE GROUP FLUX FOR
   1 ,I4,14HTH BROAD GROUP ,//,4X, 9HENERGY(I) ,15(15,3X) )
    LBGP=IBGP-NIB(IBG)+1
    IF(NIB(IBG).GT.NBB) LBGP=IBGP-NBB+1
    IF(LBGP.EQ.1) LBGP=2
    DO 22 I=LBGP,IBGP
    KLISTS=KLISTS+1
    IF(KLISTS.LE.60) GO TO 706
    KLISTS=0
    PRINT 110,IBG,(J,J=1,KSREG1)
706 EE=(ENGP(I)+ENGP(I-1))/2.
    M=(I-1)/NBB
    M=I-NBB*M
    TMP=ALOG(ENGP(I-1)/ENGP(I))
    DO 23 J=1,KSREG1
 23 PHIRR(J)=FLUXSR(J,M)/(VJ(J)*TMP)
    PRINT 111,EE,(PHIRR(J),J=1,KSREG1)
111 FORMAT(1H ,2X,F9.3,15F8.3)
    IF(KSREG.GT.15) PRINT 130,(PHIRR(J),J=16,KSREG)
 22 CONTINUE


130 FORMAT(1H ,11X,15F8.4,/)
    PRINT 120, (NUCLID(I),I=1,KMAT)
120 FORMAT(1H1,40X,36H***** SUB-REGIONAL INFORMATION ***** ,//,2X,
   134HSUBREGION NO.    FLUX    REACTION ,5X,7(4X,A4,4X))
    DO 35 I=1,KSREG
    M=LSRG(I)
    TMP=PHISR(I)
    DO 36 J=1,KMAT
    TMP1=TMP*DEN(J,M)
    RIAS(J,I)=RIAS(J,I)/TMP1
    RIFS(J,I)=RIFS(J,I)/TMP1
    RISS(J,I)=RISS(J,I)/TMP1
 36 RIRS(J,I)=RIRS(J,I)*FNRAT/TMP1
    TMP=TMP/(UBG*V(I))
    PRINT 113,(RIAS(J,I),J=1,KMAT)
    PRINT 114,(RIFS(J,I),J=1,KMAT)
    PRINT 115,I,TMP,PHISR(I)
    PRINT 116,(RISS(J,I),J=1,KMAT)
    PRINT 117,(RIRS(J,I),J=1,KMAT)
 35 PRINT 129
 40 IF(KSOUCE.EQ.0.OR.IBG.NE.KBG)GO TO 45
    WRITE(6,220)(I,I=1,KSREG1)
220 FORMAT(1HL,//,20X,   78H... NEUTRON SOURCE FROM RESONANCE REGION I
   1NTO THERMAL REGION(/UNIT VOLUME) ,4 ,//,8X,
   2 26HENERGY(EV) /SUBREGION NO.= 14I7,/)
    DO 90 K=1,KSOUCE
    EMI=ESOUCE(K)
    DELET=EPR-EMI
    UP=ALOG(EN(1)/EMI)
    DO 91 I=1,KSREG
    SOUCE(I)=SOUSE(I)*DELET
    M=LSRG(I)
    DO 92 J=1,KMAT
    IF(UMAX(J).GT.19.) GO TO 92
    TMP1=UM-UMAX(J)
    TMP2=UP-UMAX(J)
    TMP=0.
    IF(UBGP(KBG).LE.TMP1) GO TO 92
    NTMP1=(UBGP(KBG)-TMP1)/UIGP(IXG)
    IF(NTMP1.GT.NBB)NTMP1=NBB
    IF(UBGP(KBG).LT.TMP2) GO TO 93
    DO 94 L=1,NTMP1
    LMM=IBGP-L
    IF(J-ISS) 95,95,96
 95 IF(J-KRES) 94,80,81
 80 LM=LMM/NBB
    LL=LMM+1-LM*NBB
    TMP=TMP+SCATH(I,LL)
    GO TO 94
 81 LM=LMM/NBB
    LL=LMM+1-LM*NBB
    TMP=TMP+SCATR(I,LL)
    GO TO 94
 96 LM=LMM/NBB
    LL=LMM+1-LM*NBB
    TMP=TMP+SS(J,M)*FLUX(I,LL)*BETA(J)
 94 CONTINUE
    SOUCE(I)=SOUCE(I)+TMP*DELET
 93 YY=EPR
    IF(UBGP(KBG).GE.TMP2) YY=EMI
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```
      NTMP2=1
      TMP=0.
      IF(UBGP(KBG),GE.TMP2) NTMP2=(UBGP(KBG)-TMP2)/UIGP(IXG) +1
      DO 97 L=NTMP2,NTMP1
      NN=IBGP-L+1
      TMP3=YY-(1.-1./BETA(J))*ENGP(NN)
      LMM=IBGP-L
      IF(J-ISS) 98,98,99
   98 IF(J-KRES) 97,82,83
   82 LM=LMM/NBR
      LL=LMM+1-LM*NBR
      TMP=TMP+SCATH(I,LL)*TMP3
      GO TO 97
   83 LM=LMM/NBR
      LL=LMM+1-LM*NBR
      TMP=TMP+SCATR(I,LL)*TMP3
      GO TO 97
   99 LM=LMM/NBR
      LL=LMM+1-LM*NBR
      TMP=TMP+SS(J,M)*FLUX(I,LL)*BETA(JJ)*TMP3
   97 CONTINUE
      SOUCE(I)=SOUCE(I)+TMP
   92 CONTINUE
   91 SOUCE(I)=SOUCE(I)/V(I)
      IF(K.EQ.1) TMPSOU=SOUCE(KSREG)
      DO 89 I=1,KSREG
   89 SOUCE(I)=SOUCE(I)/TMPSOU
      U4=UP
      EM1=EPR
      WRITE(6,221)K,FSOUCE(K),(SOUCE(I),I=1,KSREG1)
  221 FORMAT(1H ,1X,I2,F12.3,20A,14F7.3)
      IF(KSREG.GT.14)PRINT 222,KSREG,(SOUCE(I),I=15,KSREG)
  222 FORMAT(190,6X ,     17HREGION NO. 15 TO,I2,4X,5F7.3)
   90 CONTINUE
      PRINT 223, TMPSOU
  223 FORMAT(1H0,//,10X,43HNORMALIZATION FACTOR OF THERMAL SOURCE ....
     1F10.4 )
C * *  INITIALIZATION OF BROAD GROUP CROSS SECTIONS AND FLUXES
   45 JF=1
      DO 41 I=1,KREG
      JL=NSUBR(I)
      PHIRT(I)=0.
      DO 42 K=1,KMAT
      RIRR(K,I)=0.
      RIAR(K,I)=0.
      RISR(K,I)=0.
      RIFR(K,I)=0.
      DO 42 J=JF,JL
      PHISR(J)=0.
      RIAS(K,J)=0.
      RIFS(K,J)=0.
      RISS(K,J)=0.
   42 RIRS(K,J)=0.
      JF=JL+1
   41 CONTINUE
      KLIST=1
      KLIST5=1
      ACS=0.
      FCS=0.
      SCS=0.


      RCS=0.
      PHITOT=0.
C * * INITIALIZATION OF INFINITE XSECTIONS OF SODIUM AND RESONANCE MATERIALS
      SODINF=0.
      AAINF=0.
      SODR=0.
      DO 888 M=1,KRES
      DO 888 N=1,KTEMP
      RINF(M,N)=0.
      AINF(M,N)=0.
      FINF(M,N)=0.
  888 SINF(M,N)=0.
C * * * *
   20 JBG=2
      IAG=IAG+1
      ENRAT=EN(IAG+1)/EN(1)
      UBG=UBGP(IAG)-UBGP(IBG-1)
   30 RETURN
      END
      SUBROUTINE MATINV(A,N,B,M,DETERM,NN)                              MINV 150
C     MATRIX INVERSION                                                  MINV   1
C     SUBROUTINE MATINV.                                                MINV   2
C                                                                       MINV   3
C          PROGRAMMED BY BURTON S. GARBOW, ARGONNE NATIONAL LABORATORY, MINV   4
C     AND REPORTED IN IBM 7094-709 SHARE LIBRARY AS AN F402.            MINV   5
C          THIS SUBROUTINE COMPUTES THE INVERSE AND DETERMINANT OF       MINV   6
C     MATRIX A, OF ORDER N, BY THE GAUSS-JORDAN METHOD. A=INVERSE       MINV   7
C     REPLACES A, AND THE DETERMINANT OF A IS PLACED IN DETERM. IF      MINV   8
C     M = 1 THE VECTOR B CONTAINS THE CONSTANT VECTOR WHEN MATINV IS    MINV   9
C     CALLED, AND THIS IS REPLACED WITH THE SOLUTION VECTOR.  IF M = 0, MINV  10
C     NO SIMULTANEOUS EQUATION SOLUTIONS ARE CALLED FOR, AND B IS NOT   MINV  11
C     PERTINENT. N IS NOT TO EXCEED NN.                                 MINV 120
C        THIS PROGRAM IS CHANGED INTO VARIABLE DIMENSION FORM           MINV 121
C                                                 BY TSUCHIHASHI JEARI  MINV 122
C     A, N, B, M, AND DETERM IN THE ARGUMENT LIST ARE DUMMY VARIABLES.  MINV  13
C                                                                       MINV  14
      DIMENSION IPIVOT(99),A(NN,NN),B(NN),INDEX(99,2),PIVOT(99)         MINV 160
      EQUIVALENCE(IROW,JROW),(ICOLUM,JCOLUM),(AMAX,T,SWAP)              MINV  17
      DOUBLE PRECISION B
C     INITIALIZATION                                                    MINV  18
      DETERM=1.0                                                        MINV  19
      DO 20 J=1,N                                                       MINV  20
   20 IPIVOT(J)=0                                                       MINV  21
      DO 555 I=1,N                                                      MINV  22
C     SEARCH FOR PIVOT ELEMENT                                          MINV  23
      AMAX=0.0                                                          MINV  24
      DO 105 J=1,N                                                      MINV  25
      IF(IPIVOT(J).EQ.1)GO TO 105                                       MINV  26
      DO 100 K=1,N                                                      MINV  27
      IF(IPIVOT(K)-1)80,100,740                                         MINV  28
   80 IF(ABS(AMAX).GE.ABS(A(J,K)))GO TO 100                             MINV  29
      IROW=J                                                            MINV  30
      ICOLUM=K                                                          MINV  31
      AMAX=A(J,K)                                                       MINV  32
  100 CONTINUE                                                          MINV  33
  105 CONTINUE                                                          MINV  34
      IPIVOT(ICOLUM)=IPIVOT(ICOLUM)+1                                   MINV  35
C     INTERCHANGE ROWS TO PUT PIVOT ELEMENT ON DIAGONAL                 MINV  36
      IF(IROW.EQ.ICOLUM)GO TO 260                                       MINV  37
      DETERM=-DETERM                                                    MINV  38
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      DO 200 L=1,N                                                      MINV 39
      SWAP=A(IROW,L)                                                    MINV 40
      A(IROW,L)=A(ICOLUM,L)                                             MINV 41
  200 A(ICOLUM,L)=SWAP                                                  MINV 42
      IF(M.EQ.0)GO TO 260                                               MINV 43
      SWAP=B(IROW)                                                      MINV 44
      B(IROW)=B(ICOLUM)                                                 MINV 45
      B(ICOLUM)=SWAP                                                    MINV 46
  260 INDEX(I,1)=IROW                                                   MINV 47
      INDEX(I,2)=ICOLUM                                                 MINV 48
      PIVOT(I)=A(ICOLUM,ICOLUM)                                         MINV 49
      DETERM=DETERM*PIVOT(I)                                            MINV 50
C     DIVIDE PIVOT ROW BY PIVOT ELEMENT                                 MINV 51
      A(ICOLUM,ICOLUM)=1.0                                              MINV 52
      DO 350 L=1,N                                                      MINV 53
  350 A(ICOLUM,L)=A(ICOLUM,L)/PIVOT(I)                                  MINV 54
      IF(M.EQ.0)GO TO 380                                               MINV 55
      B(ICOLUM)=B(ICOLUM)/PIVOT(I)                                      MINV 56
C     REDUCE NON-PIVOT ROWS                                             MINV 57
  380 DO 550 L1=1,N                                                     MINV 58
      IF(L1.EQ.ICOLUM)GO TO 550                                         MINV 59
      T=A(L1,ICOLUM)                                                    MINV 60
      A(L1,ICOLUM)=0.0                                                  MINV 61
      DO 450 L=1,N                                                      MINV 62
  450 A(L1,L)=A(L1,L)-A(ICOLUM,L)*T                                     MINV 63
      IF(M.EQ.0)GO TO 550                                               MINV 64
      B(L1)=B(L1)-B(ICOLUM)*T                                           MINV 65
  500 CONTINUE                                                          MINV 66
  550 CONTINUE                                                          MINV 67
C     INTERCHANGE COLUMNS                                               MINV 68
      DO 710 I=1,N                                                      MINV 69
      L=N+1-I                                                           MINV 70
      IF(INDEX(L,1).EQ.INDEX(L,2))GO TO 710                             MINV 71
      JROW=INDEX(L,1)                                                   MINV 72
      JCOLUM=INDEX(L,2)                                                 MINV 73
      DO 700 K=1,N                                                      MINV 74
      SWAP=A(K,JROW)                                                    MINV 75
      A(K,JROW)=A(K,JCOLUM)                                             MINV 76
  700 A(K,JCOLUM)=SWAP                                                  MINV 77
  710 CONTINUE                                                          MINV 78
  740 RETURN                                                            MINV 79
      END                                                               MINV 80
      FUNCTION PC(X)
      DIMENSION PCT(301),PCT1(72),PCT2(72),PCT3(72),PCT4(72),PCT5(13)
      EQUIVALENCE (PCT(1),PCT1(1)),(PCT(73),PCT2(1)),(PCT(145),PCT3(1)),
     1           (PCT(217),PCT4(1)),(PCT(289),PCT5(1))
C      /PC TABLE/ CASE,HOFFMAN  (0.02 CYL 0.--6.0)                      PCT 1000
      DATA PCT1/
     1          .00000,.02561,.04967,.07248,.09421,.11498,.13487,.15396, PCT 1050
     2          .17241,.18996,.20697,.22336,.23918,.25446,.26923,.28351, PCT 1100
     3          .29733,.31070,.32366,.33621,.34838,.36019,.37164,.38276, PCT 1150
     4          .39356,.40405,.41424,.42414,.43377,.44314,.45225,.46112, PCT 1200
     5          .46975,.47816,.48634,.49432,.50209,.50966,.51704,.52424, PCT 1250
     6          .53126,.53811,.54479,.55131,.55767,.56389,.56996,.57588, PCT 1300
     7          .58167,.58733,.59285,.59826,.60354,.60870,.61375,.61869, PCT 1350
     8          .62352,.62825,.63287,.63740,.64183,.64616,.65041,.65457, PCT 1400
     9          .65864,.66263,.66654,.67038,.67413,.67781,.68142,.68495/ PCT 1450
      DATA PCT2/
     1          .68842,.69182,.69516,.69843,.70164,.70479,.70788,.71091, PCT 1500
     2          .71389,.71681,.71966,.72250,.72526,.72798,.73065,.73327, PCT 1550
     3          .73585,.73838,.74087,.74331,.74572,.74808,.75040,.75269, PCT 1600
     4          .75493,.75714,.75931,.76145,.76355,.76562,.76765,.76966, PCT 1650
     5          .77163,.77357,.77548,.77736,.77921,.78103,.78282,.78459, PCT 1700
     6          .78633,.78805,.78974,.79140,.79304,.79465,.79624,.79781, PCT 1750
     7          .79936,.80088,.80239,.80387,.80532,.80677,.80818,.80958, PCT 1800
     8          .81096,.81233,.81367,.81500,.81630,.81759,.81886,.82012, PCT 1850
     9          .82136,.82258,.82379,.82498,.82616,.82732,.82847,.82960/ PCT 1900
      DATA PCT3/
     1          .83071,.83182,.83291,.83399,.83505,.83610,.83714,.83816, PCT 1950
     2          .83917,.84017,.84116,.84214,.84310,.84405,.84500,.84593, PCT 2000
     3          .84685,.84776,.84866,.84955,.85043,.85130,.85216,.85301, PCT 2050
     4          .85385,.85468,.85550,.85632,.85712,.85792,.85870,.85948, PCT 2100
     5          .86025,.86101,.86177,.86251,.86325,.86398,.86471,.86542, PCT 2150
     6          .86613,.86683,.86752,.86821,.86889,.86956,.87023,.87089, PCT 2200
     7          .87154,.87219,.87283,.87346,.87409,.87471,.87533,.87594, PCT 2250
     8          .87654,.87714,.87773,.87832,.87890,.87947,.88004,.88061, PCT 2300
     9          .88117,.88173,.88228,.88282,.88336,.88389,.88443,.88495/ PCT 2350
      DATA PCT4/
     1          .88547,.88598,.88650,.88701,.88751,.88801,.88850,.88899, PCT 2400
     2          .88948,.88996,.89044,.89091,.89138,.89184,.89230,.89276, PCT 2450
     3          .89321,.89365,.89411,.89455,.89499,.89542,.89585,.89628, PCT 2500
     4          .89671,.89713,.89755,.89796,.89837,.89878,.89919,.89959, PCT 2550
     5          .89999,.90038,.90077,.90116,.90155,.90193,.90231,.90268, PCT 2600
     6          .90306,.90343,.90381,.90417,.90453,.90489,.90525,.90560, PCT 2650
     7          .90595,.90631,.90662,.90700,.90734,.90769,.90802,.90835, PCT 2700
     8          .90868,.90902,.90934,.90967,.90999,.91031,.91063,.91095, PCT 2750
     9          .91126,.91157,.91186,.91219,.91250,.91280,.91310,.91340/ PCT 2800
      DATA PCT5/
     1          .91369,.91399,.91429,.91457,.91487,.91515,.91544,.91572, PCT 2850
     2          .91600,.91628,.91656,.91684,.91711/                      PCI 2900
      IF(X.LT.0.)GO TO 660
      IF(X.GT.6.0)GO TO 690
      GO TO 680
  660 PC=1.3333*X-0.5*(ALOG(2./X)+1.25-0.57216)*X*X
      RETURN
  690 PC=1.-0.3/X+0.09375/X**3
      RETURN
  680 N=X/0.02
      DX=X-FLOAT(N)*0.02
      PC=PCT(N+1)+(PCT(N+2)-PCT(N+1))*DX/0.02
      RETURN
      END
```