

TIMS-1 : A Processing Code for Production  
of Group Constants of Heavy Resonant Nuclei

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Page	Line	Printed	To be corrected
1	↓ 2	<u>of</u> diffusion	<u>or</u> diffusion
1	↑ 1	<u>fact</u>	<u>fast</u>
3	Eq. (4)	( $\sigma_0$ , $T$ , <u>P</u> )	( $\sigma_0$ , $T$ , <u>R</u> )
31	↓ 5	we <u>were</u>	we —
III	↑ 6	<u>Colculated</u>	<u>Calculated</u>
III	↑ 7	<u>With</u>	<u>with</u>

# TIMS-1: A Processing Code for Production of Group Constants of Heavy Resonant Nuclei

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The TIMS-1 code calculates the infinitely dilute group cross sections and the temperature dependent self-shielding factors for arbitrary values of  $\sigma_0$  and  $R$ , where  $\sigma_0$  is the effective background cross section of potential scattering and  $R$  the ratio of the atomic number densities for two resonant nuclei if any. This code is specifically programmed to use the evaluated nuclear data file of ENDF/B or JENDL as input data.

In the unresolved resonance region, the resonance parameters and the level spacings are generated by using Monte Carlo method from the Porter-Thomas and Wigner distributions respectively. The Doppler broadened cross sections are calculated on the ultra-fine lethargy meshes of about  $10^{-3} \sim 10^{-5}$  using the generated and resolved resonance parameters.

The effective group constants are calculated by solving the neutron slowing down equation with the use of the recurrence formula for the neutron slowing down source. The output of the calculated results is given in a format being consistent with the JAERI-Fast set (JFS) or the Standard Reactor Analysis Code (SRAC) library.

Both FACOM 230/75 and M200 versions of TIMS-1 are available.

Keywords ; Processing Code, Group Constant Production, Heavy Resonant Nuclei, ENDF/B, JENDL, JAERI-Fast Set, SRAC Library, Recurrence Formula, Monte Carlo Method, Resonance Region

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## TIMS-1: 重い共鳴核種の群定数作成の処理コード

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1980年3月28日 受理

TIMS-1 コードは、無限希釈断面積と、温度依存の自己遮蔽因子を実効ポテンシャル散乱断面積と 2 共鳴核種の原子数比の関数として計算する。特に、このコードは ENDF/B 又は JENDL の評価済み核データ・ファイルを入力データとして使用するように設計してある。

非分離共鳴領域においては、モンテカルロ法を用いてポーター・トーマスとウィグナー分布に従って、共鳴パラメータとレベル間隔を発生させる。これらの共鳴パラメータと分離パラメータを用いて、約  $10^{-3} \sim 10^{-5}$  の極詳細レサージ・メッシュでドップラー断面積を計算する。又、中性子の減速源に対する漸化式を用いて減速方程式を解き、実効断面積を計算する。計算結果は JFS 又は SRAC ライブライア形式で出力される。

TIMS-1 は FACOM 230/75 と M200 両方で使用可能である。

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## 1. Introduction

The multigroup transport of diffusion calculations are often based on the concept of multigroup constants set such as the ABBN<sup>1)</sup> or JAERI-Fast set<sup>2)~4)</sup>. The principal advantage of the multigroup constant method is that reactor calculation can be made by using the same group constant set for the various reactors with different compositions and sizes. Consequently, some processing codes such as ETOX<sup>5)</sup>, MINX<sup>6)</sup> and PROF-GROUCH-G<sup>7)</sup> were developed to calculate economically and conveniently, the group constants using an updated data file. However, the calculational method of group constants used in these codes are different. Especially, the effective cross sections in resonance energy region are calculated by using various methods.

Though the ETOX and MINX codes can take into account for both the composition and temperature dependence of group cross sections, the effective group cross sections are calculated by assuming the constancy of collision density. Moreover, the isolated narrow-resonance approximation is used for unresolved resonance region. Therefore, the mutual interference between resonances of different nuclei and the self-overlapping effects are ignored. Furthermore, the self-shielding of elastic removal cross section is assumed to be neglected.

The presently developed TIMS-1 code, which is the modified version of TIMS<sup>8)</sup>, calculates the effective cross sections by solving numerically the neutron slowing down equation using the recurrence formula<sup>9)</sup> for slowing down source, in order to avoid the errors<sup>9), 10)</sup> caused from the approximations used in the ETOX and MINX codes. For this purpose, TIMS-1 generates required resonance levels and parameters in the unresolved resonance region by using Monte Carlo method<sup>11)~13)</sup>. TIMS-1 is a code system which is composed of some codes, ARCFIT-2<sup>14)</sup>, ARCFIT-3<sup>14)</sup>, MCROSS-2<sup>15)</sup> and PEACO-II<sup>16)</sup> developed for the production of the JAERI Fast set (JFS)<sup>3), 4)</sup>.

In the development of TIMS-1, some modifications for these codes were made as follows: The ARCFIT-2 code was modified to calculate the average cross sections using the same formulas as those used in the ENDF/B-IV processing<sup>17)</sup>. The ARCFIT-3 was designed to search automatically a ladder of resonance parameters which satisfies the assumed convergence conditions for average cross sections and average resonance parameters. In the MCROSS-2 code, the interpolation routine for smooth cross sections was added in the calculation of ultrafine group cross sections. The PEACO-II code was simplified by excluding the heterogeneous cell calculation routine and an output routine was added to provide the multigroup constants being suitable for the interface code XTABPDS for the JFS library. This code is called PEACO-7.

An important merit produced by the development of TIMS-1 is that the group constants of the JFS type can easily and automatically, be produced from the ENDF/B-IV or JENDL nuclear data file with preparing only several input data cards. The libraries of group constants for ENDF/B-IV, JENDL-1 and 2 were produced with the use of TIMS-1, and they are used for the analysis of fast reactor.

In Chapter 2, the general features of TIMS-1 are described. The calculational methods of group constants are described in Chapter 3. The description and specification of input and output are described in Chapter 4. The comparisons between the group constants calculated with TIMS-1 and ETOX are described in Chapter 6. The effects of the differences between the generated group constants on some integral quantities are studied by performing fast reactor calculations.

## 2. General Features of TIMS-1

The JAERI Fast set Version II (JFS-2)<sup>14</sup> was produced by using both the processing codes, TIMS-1 and PROF-GROUCH-G-II<sup>15</sup>. TIMS-1 calculates the group constants of heavy nuclei in resonance energy region, and on the other hand, PROF-GROUCH-G-II produces the group constants of light and intermediate nuclei and those of heavy nuclei in smooth region above resonance energy. The flow diagram of the TIMS-1 code is shown in Fig. 1, and the general features are as follows:

- (1) READFL: The resonance parameters and floor correction cross sections<sup>17)</sup> are read from the data file in the ENDF/B format, and suitably arranged for the ARCFIT-2, ARCFIT-3 and MCROSS-2 codes.
- (2) ARCFIT-2: In the unresolved resonance region the average cross sections are calculated by using the average resonance parameters. The formulas of the average cross sections are the same as those used in the ENDF/B-IV<sup>17)</sup> processing.
- (3) ARCFIT-3: In the unresolved region, the resonance parameters and the level spacings are generated by using Monte Carlo method from the Porter-Thomas and Wigner distributions, respectively. The ladders of resonance parameters are repeatedly generated until a ladder satisfies the following conditions:

$$\left| \frac{\langle \sigma_x \rangle - \bar{\sigma}_x}{\langle \sigma_x \rangle} \right|_{\Delta E_n} \leq \varepsilon_\sigma, \quad (1)$$

$$\left| \frac{\langle \Gamma_x \rangle - \bar{\Gamma}_x}{\langle \Gamma_x \rangle} \right|_{\Delta E_n} \leq \varepsilon_\Gamma, \quad (2)$$

$$\Delta E_n = \frac{1}{2}(E_{n-1} + E_n) - \frac{1}{2}(E_n + E_{n+1}) \quad (3)$$

where  $x$  stands for the fission, capture, elastic and/or inelastic scattering reaction,  $\langle \sigma_x \rangle$  is the evaluated average

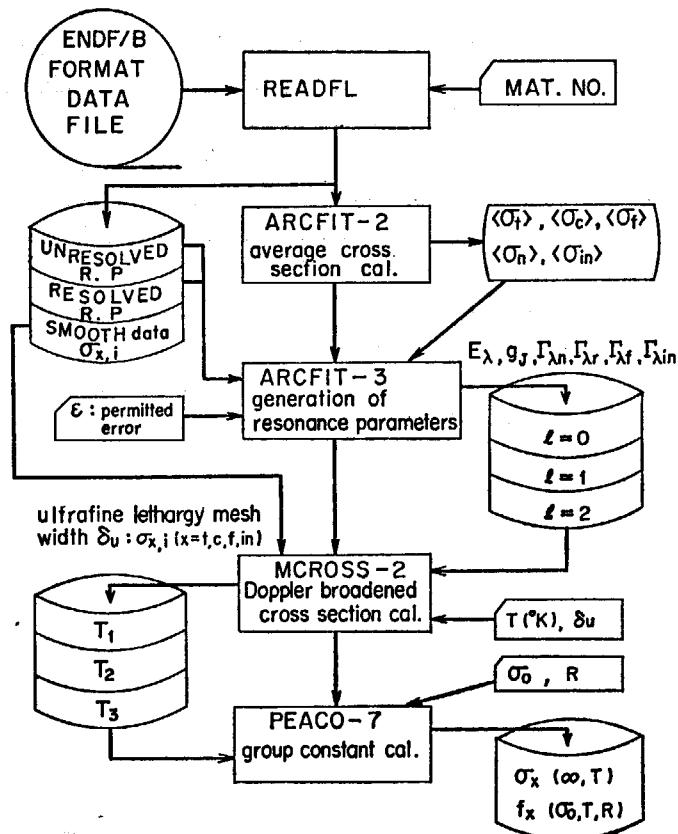


Fig. 1 Flow diagram of TIMS-1 code

TABLE I Ultrafine and fine group structures used in the MCROSS-2 code

Group no.	Energy boundary (eV)	No. of fine group	No. of ultrafine group	Lethargy width
1	100000-46500	766	7660	0.0001
2	46500-21500	772	7720	0.0001
3	21500-10000	766	7660	0.0001
4	10000- 4650	766	7660	0.0001
5	4650- 1000	768	7680	0.0002
6	1000- 465	383	3830	0.0002
7	465- 100	615	6150	0.00025
8	100- 46.5	307	3070	0.00025
9	46.5- 10	308	3080	0.0005
10	10- 4.65	153	1530	0.0005
11	4.65- 0.2	630	6300	0.0005

cross section calculated with the evaluated average partial width  $\langle \Gamma_x \rangle$  by the ARCFIT-2 code,  $\bar{\sigma}_x$  and  $\Gamma_x$  mean the values of the cross section and partial width averaged over a generated ladder of resonance parameters, respectively, and  $\varepsilon_\sigma$  and  $\varepsilon_\Gamma$  are the assumed errors for the average cross sections and partial width in the energy range  $\Delta E_n$ , respectively.

The generated ladder of resonance parameters are connected finally with the resolved resonance parameters and a set of resonance parameters is supplied in the energy range from the unresolved to the resolved regions.

(4) MCROSS-2: The Doppler broadened cross sections are calculated on the ultrafine lethargy meshes of about  $10^{-3} \sim 10^{-5}$  as shown in TABLE I. The calculations are performed by use of either the Breit-Wigner single-level formula or the multilevel formula<sup>19)</sup>. The symmetric and asymmetric Doppler line shape functions are calculated by using the Buckler method<sup>20)</sup>.

(5) PEACO-7: The neutron spectra on the ultrafine lethargy meshes are calculated by solving numerically the neutron slowing down equation with the use of the recurrence formula developed by Kier<sup>8)</sup> in which the lethargy meshes are assumed to be extremely narrow compared to the maximum lethargy gain per collision with the heaviest nuclei in the considered system.

The effective group cross section for reaction  $x$  is calculated by using the neutron spectra as follows:

$$\bar{\sigma}_x(\sigma_0, T, R) = \sum_{m \in \Delta E} \sigma_x^m(T) \phi^m(\sigma_0, T, R) / \sum_{m \in \Delta E} \phi^m(\sigma_0, T, P), \quad (4)$$

where  $\phi^m$  is the neutron spectrum at the ultrafine lethargy group ( $m$ ),  $\sigma_x^m$  the energy-dependent cross section at temperature  $T$  (°K),  $\sigma_0$  the admixture background potential scattering cross section of the Bondarenko type and  $R$  the atomic density ratio of the resonant element (2) to the resonant element (1) of interest. Furthermore, a special "total" cross section is calculated as

$$\bar{\sigma}_t(\sigma_0, T, R) = \frac{\sum_{m \in \Delta E} \phi^m(\sigma_0, T, R)}{\sum_{m \in \Delta E} \phi^m(\sigma_0, T, R)} - \frac{\sum_{m \in \Delta E} \phi^m(\sigma_0, T, R)}{\sum_{m \in \Delta E} (R\sigma_{t,1}(T) + R\sigma_{t,2}(T) + \sigma_0)}, \quad (5)$$

where  $\sigma_{t,1}$  is the total cross section of the resonant element (1) of interest and  $\sigma_{t,2}$  that of the other resonant element (2). This special total cross section thus defined is used to calculate the effective diffusion coefficient. The special total cross section of Eq. (5) is shown to approach to the commonly defined total cross section of Eq. (4), when  $\sigma_0$  value becomes infinite.

The elastic removal cross section is given by

$$\bar{\sigma}_{er}(\sigma_0, T, R) = \frac{\sum_{m \in \Delta E} \sigma_n^m(T) \phi^m(\sigma_0, T, R) \frac{E_L - \alpha E_m}{(1-\alpha)E_m}}{\sum_{m \in \Delta E} \phi^m(\sigma_0, T, R)}, \quad (6)$$

$$\Delta E' = E_L/\alpha - E_L, \quad (7)$$

$$\alpha = (A_1 - 1)^2 / (A_1 + 1)^2, \quad (8)$$

where  $E_L$  is the lower energy boundary of integration interval  $\Delta E$ ,  $\sigma_n^m(T)$  the elastic scattering cross section and  $A_1$  the atomic mass for the resonant element (1) of interest.

The resonance self-shielding factors, i.e., the  $f$ -factors are defined by

$$f_x(\sigma_0, T, R) = \frac{\sigma_x(\sigma_0, T, R)}{\sigma_x(\infty, 300, 0)}. \quad (9)$$

The output of the infinitely dilute cross sections  $\sigma_x(\infty, 300, 0)$  and the  $f$ -factors  $f_x(\sigma_0, T, R)$  is given by the PEACO-7 code in a format being consistent with the JAERI-Fast set library.

### 3. Calculational Method

#### 3.1 Doppler-broadened Cross Sections

The reaction cross section is generally expressed in terms of the collision matrix

$$\sigma_{cc'}^J(E) = \frac{\pi}{k^2} g_J |\delta_{cc'} - U_{cc'}^J|^2, \quad (10)$$

where  $J$  is the spin quantum number of the compound nucleus,  $g_J$  the spin statistical factor,  $\delta_{cc'}$  the Kronecker's delta,  $k (=2mE/\hbar)$  the neutron wave number,  $m$  the neutron mass and the subscripts  $c$  and  $c'$  are the incident and exit channels, respectively. In  $R$ -matrix theory, the collision matrix is given by<sup>21)</sup>

$$U_{cc'} = \exp[-i(\phi_c + \phi_{c'})] [\delta_{cc'} + i \sum_{\lambda, \lambda'} \sqrt{\Gamma_{\lambda c} \Gamma_{\lambda' c'}} A_{\lambda \lambda'}], \quad (11)$$

where  $\phi_c$  is the hard sphere potential scattering phase shift,  $\lambda$  the resonance level in the  $J$ -state, and  $\Gamma_{\lambda c}$  denotes the partial width for decay of the state  $(\lambda, J)$  through channel  $c$ . The inverse of the level matrix  $A$  is known to be expressed as follows<sup>21), 22)</sup>:

$$A_{\lambda \lambda'}^{-1} = (E_\lambda - E) \delta_{\lambda \lambda'} - \frac{i}{2} \sum_c (\Gamma_{\lambda c}^{1/2} \Gamma_{\lambda' c'}^{1/2}), \quad (12)$$

where  $E_\lambda$  is the resonance energy. Practically, the calculation of the cross sections in terms of the level matrix is very difficult when several interacting levels are present.

Using the nature of the unitarity and symmetry of the collision matrix in Eq. (10) and the approximate level matrix  $A'$ <sup>19)</sup>:

$$A'_{\lambda \lambda'} = \frac{\delta_{\lambda \lambda'}}{E_\lambda - E - \frac{i}{2} \Gamma_\lambda} + \frac{i}{2} (1 - \delta_{\lambda \lambda'}) \frac{\sum_c (\Gamma_{\lambda c}^{1/2} \Gamma_{\lambda' c'}^{1/2})}{(E_\lambda - E - \frac{i}{2} \Gamma_\lambda)(E_{\lambda'} - E - \frac{i}{2} \Gamma_{\lambda'})},$$

the total cross section is given by

$$\begin{aligned} \sigma_t^J(E) &= \frac{2\pi}{k^2} g_J R_e (1 - U_{nn}^J) \\ &= \frac{2\pi}{k^2} g_J \left[ 2 \sin^2 \phi_n + \sum_\lambda \left( \frac{(E_\lambda - E) \Gamma_{\lambda n} \sin 2\phi_n + \frac{1}{2} \Gamma_\lambda \Gamma_{\lambda n} \cos 2\phi_n}{|Z_\lambda|^2} \right) \right. \\ &\quad \left. + \frac{1}{2} \sum_\lambda \sum_{\lambda' \neq \lambda} \sqrt{\Gamma_{\lambda n} \Gamma_{\lambda' n}} G_{\lambda \lambda'} (H_{\lambda \lambda'}^r \sin 2\phi_n + H_{\lambda \lambda'}^i \cos 2\phi_n) \right] \end{aligned} \quad (13)$$

where

$$Z_\lambda = (E_\lambda - E) - \frac{i}{2} \Gamma_\lambda, \quad (14)$$

$$\Gamma_\lambda = \sum_c \Gamma_{\lambda c} = \Gamma_{\lambda n} + \Gamma_{\lambda \gamma} + \Gamma_{\lambda f}, \quad (15)$$

$$G_{\lambda \lambda'} = \sum_c (\Gamma_{\lambda c}^{1/2} \Gamma_{\lambda' c'}^{1/2}), \quad (16)$$

$\Gamma_{\lambda n}$ =the neutron width,

$\Gamma_{\lambda \gamma}$ =the capture width,

$\Gamma_{\lambda f}$ =the fission width,

$$H_{\lambda \lambda'}^r = \frac{1}{2|Z_\lambda - Z_{\lambda'}|^2} \left[ \frac{\Gamma_\lambda (E_\lambda - E_{\lambda'}) + (E_\lambda - E) (\Gamma_\lambda - \Gamma_{\lambda'})}{|Z_\lambda|^2} - \frac{\Gamma_{\lambda'} (E_\lambda - E_{\lambda'}) + (E_{\lambda'} - E) (\Gamma_\lambda - \Gamma_{\lambda'})}{|Z_{\lambda'}|^2} \right], \quad (17)$$

$$H_{\lambda \lambda'}^i = \frac{1}{2|Z_\lambda - Z_{\lambda'}|^2} \left[ \frac{\Gamma_\lambda (\Gamma_\lambda - \Gamma_{\lambda'}) - 2(E_\lambda - E) (E_\lambda - E_{\lambda'})}{|Z_\lambda|^2} - \frac{\Gamma_{\lambda'} (\Gamma_\lambda - \Gamma_{\lambda'}) - 2(E_{\lambda'} - E) (E_\lambda - E_{\lambda'})}{|Z_{\lambda'}|^2} \right]. \quad (18)$$

In the right hand side of Eq. (13), the first term is the potential scattering, the second the single-level part and

the third the interference term between the resonance levels. The interference term can be written by

$$\sigma_{t,M^J}(E) = \pi \frac{E}{k^2} g_J \sum_{\lambda} \left[ \frac{\frac{1}{2} u_{\lambda}^t \Gamma_{\lambda} + v_{\lambda}^t (E_{\lambda} - E)}{|Z_{\lambda} - Z_{\lambda'}|^2} \right], \quad (19)$$

where

$$u_{\lambda}^t = \sum_{\lambda' \neq \lambda} \frac{\sqrt{\Gamma_{\lambda n^0} \Gamma_{\lambda' n^0}} G_{\lambda \lambda'} [2(E_{\lambda} - E_{\lambda'}) \sin 2\phi_n + (\Gamma_{\lambda} - \Gamma_{\lambda'}) \cos 2\phi_n]}{|Z_{\lambda} - Z_{\lambda'}|^2}, \quad (20)$$

$$v_{\lambda}^t = \sum_{\lambda' \neq \lambda} \frac{\sqrt{\Gamma_{\lambda n^0} \Gamma_{\lambda' n^0}} G_{\lambda \lambda'} [-(\Gamma_{\lambda} - \Gamma_{\lambda'}) \sin 2\phi_n + (E_{\lambda} - E_{\lambda'}) \cos 2\phi_n]}{|Z_{\lambda} - Z_{\lambda'}|^2}, \quad (21)$$

and  $\Gamma_{\lambda n^0}$  is the reduced neutron width.

From Eq. (10), on the other hand, the expression for the capture and fission cross sections is given by

$$\begin{aligned} \sigma_y^J(E) &= \sum_{c' \in y} \sigma_{cc'} = \frac{\pi}{k^2} g_J \sum_{c' \in y} \left| \sum_{\lambda, \lambda'} \sqrt{\Gamma_{\lambda c} \Gamma_{\lambda' c'}} A_{\lambda \lambda'} \right|^2, \\ &= \frac{\pi}{k^2} g_J \sum_{\lambda} \left[ \frac{\Gamma_{\lambda n} \Gamma_{\lambda y}}{|Z_{\lambda}|^2} + \sum_{\lambda' \neq \lambda} \sqrt{\Gamma_{\lambda n} \Gamma_{\lambda' n}} G_{\lambda \lambda'} H_{\lambda \lambda'} \right]. \end{aligned} \quad (22)$$

In Eq. (22), the second term in the parenthesis shows the interference effect between resonance levels. Arranging the term in the same manner as for Eq. (19), it is written by

$$\sigma_{y,M^J}(E) = \pi \frac{E}{k^2} g_J \left[ \frac{\frac{1}{2} u_{\lambda}^y \Gamma_{\lambda} + v_{\lambda}^y (E_{\lambda} - E)}{|Z_{\lambda}|^2} \right], \quad (23)$$

where

$$u_{\lambda}^y = \sum_{\lambda' \neq \lambda} \frac{\sqrt{\Gamma_{\lambda n^0} \Gamma_{\lambda' n^0}} G_{\lambda \lambda'} (\Gamma_{\lambda} - \Gamma_{\lambda'})}{|Z_{\lambda} - Z_{\lambda'}|^2}, \quad (24)$$

and

$$v_{\lambda}^y = \sum_{\lambda' \neq \lambda} \frac{-2 \sqrt{\Gamma_{\lambda n^0} \Gamma_{\lambda' n^0}} C_{\lambda \lambda'} (E_{\lambda} - E_{\lambda'})}{|Z_{\lambda} - Z_{\lambda'}|^2}. \quad (25)$$

The results described above are based on the center of mass system. Therefore, in the laboratory coordinate system, the energy magnitude must be changed by multiplying by a factor  $(A_m + 1)/A_m$ , where  $A_m$  is the atomic mass. Actually, as the target nuclei in the thermal motion, the chemical binding effect and the thermal motion must be considered. In the present paper, the chemical binding effect is neglected and a Maxwellian distribution is assumed for the velocity of target nuclei. Then, on the basis of the method developed by Buckler and Pull<sup>20</sup>, the Doppler broadened cross sections corresponding to Eqs. (13) and (22) are given, respectively by,

$$\begin{aligned} \sigma_t^J(E) &= \sigma_p(E) + \frac{4\pi}{k^2} \sqrt{\frac{\alpha}{2m\pi}} g_J \sum_{\lambda} \left[ \left( \Gamma_{\lambda n^0} + \frac{1}{2} u_{\lambda}^t \right) \Phi_{\lambda}^r \right] \\ &\quad + \frac{8\pi R}{k} \sqrt{\frac{\alpha}{2m\pi}} g_J \sum_{\lambda} \left[ \left( \Gamma_{\lambda n^0} + \frac{1}{4kR} v_{\lambda}^t \right) \Phi_{\lambda}^i \right], \end{aligned} \quad (26)$$

and

$$\sigma_y^J(E) = \frac{4\pi}{k^2} \sqrt{\frac{\alpha}{2m\pi}} g_J \sum_{\lambda} \left[ \left( \frac{\Gamma_{\lambda n} \Gamma_{\lambda y}}{\Gamma_{\lambda}} + \frac{1}{2} u_{\lambda}^y \right) \Phi_{\lambda}^r + \frac{1}{2} v_{\lambda}^y \Phi_{\lambda}^i \right], \quad (27)$$

where

$$\Phi_{\lambda}^r = R_e(F(w_1) - F(w_2)),$$

$$\Phi_{\lambda}^i = I_m(F(w_1) - F(w_2)),$$

$$F(w) = \int_0^\infty \exp(-x^2) \frac{w}{x^2 + w^2} dx,$$

$$w_1 = \sqrt{\alpha} (b + i(a - v)),$$

$$w_2 = \sqrt{\alpha} (b + i(a + v)),$$

$$a - ib = (2E_{\lambda} - i\Gamma_{\lambda})^{1/2},$$

$$\alpha = A_m/2KT,$$

$$R = (1.23 \times A_m^{1/3} + 0.8) \times 10^{-1} \text{ (in units of } 10^{-12} \text{ cm)}$$

$$K = \text{Boltzmann constant},$$

$$T = \text{the temperature } (^{\circ}\text{K}),$$

$v$ =the neutron velocity,

and  $\sigma_p$ =the potential scattering cross section.

The resonance scattering cross section is given by

$$\begin{aligned}\sigma_n^J(E) &= \sigma_t^J(E) - \sigma_p(E) - \sum_y \sigma_y^J(E) \\ &= \frac{4\pi}{k^2} \sqrt{\frac{\alpha}{2m\pi}} g_J \sum_{\lambda} \left[ \left( \frac{\Gamma_{\lambda n}^0 \Gamma_{\lambda n}}{\Gamma_{\lambda}} + \frac{1}{2} u_{\lambda}^n \right) \Phi_{\lambda}^r \right] + \frac{8\pi R}{k} \sqrt{\frac{\alpha}{2m\pi}} g_J \sum_{\lambda} \left[ \left( \Gamma_{\lambda n}^0 + \frac{1}{4kR} v_{\lambda}^n \right) \Phi_{\lambda}^i \right],\end{aligned}\quad (28)$$

where

$$u_{\lambda}^n = u_{\lambda}^t - \sum_y u_{\lambda}^y, \quad (29)$$

and

$$v_{\lambda}^n = v_{\lambda}^t - \sum_y v_{\lambda}^y. \quad (30)$$

When  $\sqrt{E_{\lambda}/E}$  is assumed to be nearly equal to unity and  $(1/2)\Gamma_{\lambda}/E_{\lambda} \ll 1$ , the functions  $\Phi_{\lambda}^r$  and  $\Phi_{\lambda}^i$  can be related to the usual Doppler line shape functions  $\psi_{\lambda}(\theta, x)$  and  $\chi_{\lambda}(\theta, x)$ , respectively. The assumption will be sufficiently satisfied near resonance energy in relatively higher energy region. Using the well-known symbols, Eqs. (26), (27) and (28) can be written, respectively, by

$$\sigma_t^J(E) = \sigma_p(E) + \sum_{\lambda} \left[ \sigma_{0\lambda} \left( 1 + u_{\lambda t} \right) \psi_{\lambda}(\theta, x) + \sigma_{0p\lambda} \left( 1 + \frac{\sigma_{0\lambda}}{\sigma_{0p\lambda}} v_{\lambda t} \right) \chi_{\lambda}(\theta, x) \right], \quad (31)$$

$$\sigma_y^J(E) = \sum_{\lambda} \sigma_{0\lambda} \left[ \left( \frac{\Gamma_{\lambda y}}{\Gamma_{\lambda}} + u_{\lambda y} \right) \psi_{\lambda}(\theta, x) + v_{\lambda y} \chi_{\lambda}(\theta, x) \right] \quad (32)$$

and

$$\sigma_n^J(E) = \sum_{\lambda} \left[ \sigma_{0\lambda} \left( \frac{\Gamma_{\lambda n}}{\Gamma_{\lambda}} + u_{\lambda n} \right) \psi_{\lambda}(\theta, x) + \sigma_{0p\lambda} \left( 1 + \frac{\sigma_{0\lambda}}{\sigma_{0p\lambda}} v_{\lambda n} \right) \chi_{\lambda}(\theta, x) \right], \quad (33)$$

where

$$\sigma_{0\lambda} = \frac{4\pi}{k^2} g_J \frac{\Gamma_{\lambda n}}{\Gamma_{\lambda}}, \quad (34)$$

$$\sigma_{0p\lambda} = 2\sqrt{\sigma_{0\lambda} \sigma_p g_J \Gamma_{\lambda n} / \Gamma_{\lambda}}, \quad (35)$$

$$u_{\lambda t} = u_{\lambda}^t / 2\Gamma_{\lambda n}^0, \quad v_{\lambda t} = v_{\lambda}^t / 2\Gamma_{\lambda n}^0, \quad (36)$$

$$u_{\lambda y} = u_{\lambda}^y / 2\Gamma_{\lambda n}^0, \quad v_{\lambda y} = v_{\lambda}^y / 2\Gamma_{\lambda n}^0, \quad (37)$$

$$u_{\lambda n} = u_{\lambda}^n / 2\Gamma_{\lambda n}^0 \text{ and } v_{\lambda n} = v_{\lambda}^n / 2\Gamma_{\lambda n}^0. \quad (38)$$

In Eqs. (26), (27) and (28) or (31), (32) and (33), each reaction cross section is represented by the summation of a symmetric and an asymmetric functions. These expressions are the same as the single-level ones except for containing the coefficients  $u_{\lambda}$  and  $v_{\lambda}$ , which show the interference effect between levels. From Eqs. (20), (21), (24) and (25), it will be seen that the  $u_{\lambda}$  and  $v_{\lambda}$  becomes smaller when the level distance become farther. Therefore, if the cross sections will be well fitted by the single-level expression, the coefficients  $u_{\lambda}$  and  $v_{\lambda}$  will be nearly equal to zero. Hence they may be considered as a kind of correction parameters for the single-level fits obtained on the base of the  $R$ -matrix theory. They will be easily obtained from the least squares method<sup>19)</sup> coupled with the single-level fit.

On the other hand, if the  $R$ -matrix parameters are given, the  $u_{\lambda}$  and  $v_{\lambda}$  can be obtained from Eqs. (20), (21), (24) and (25). In the unresolved resonance rigion, the interference parameters ( $u_{\lambda}, v_{\lambda}$ ) can be calculated by using the generated resonance parameters and energies, where the off-diagonal elements of the level matrix are defined according to the Vogt's definition<sup>21)</sup> as follows:

$$G_{\lambda\lambda'} = \Gamma_{\lambda n} \Gamma_{\lambda' n} + (\Gamma_{\lambda t})^{1/2} (\Gamma_{\lambda' t})^{1/2} \cos \theta_{\lambda\lambda'}, \quad \lambda \neq \lambda', \quad (39)$$

in which the capture channel is neglected because of the sign fluctuation for  $(\Gamma_{\lambda t})^{1/2}$ . For the neutron channels, only the entrance channel is taken into consideration. The off-diagonal terms for the fission channel is defined by the scalar product of two vectors whose components are equal to  $(\Gamma_{\lambda t})^{1/2}$ . The Vogt's multilevel parameters in Eq. (39) can be generated by using an assumed distribution for  $(\Gamma_{\lambda t})^{1/2}$  as will be described in the Section 3.3.

The reaction cross sections for  $p$ - and  $d$ - wave neutrons are assumed to be respectively expressed by the single-level formula, due to their smaller contribution, as follows:

$$\sigma_t(E) = \frac{4\pi}{k^2} \sqrt{\frac{\alpha}{2m\pi}} \frac{(\mu_i)}{E} g_J \sum_{\lambda} \Gamma_{\lambda n} \left( E_{\lambda} \Phi_{\lambda}^r(w) + \frac{1}{2} \Gamma_{\lambda} \Phi_{\lambda}^i(w) \right), \quad (40)$$

$$\sigma_y(E) = \frac{4\pi}{k^2} \sqrt{\frac{\alpha}{2m\pi}} \frac{(\mu_l)}{E} g_J \sum_{\lambda} \frac{\Gamma_{\lambda n} i^0 \Gamma_{\lambda y}}{\Gamma_{\lambda}} \left( E_{\lambda} \Phi_{\lambda}^r(w) + \frac{1}{2} \Gamma_{\lambda} \Phi_{\lambda}^i(w) \right), \quad (41)$$

where

$$\mu_l = \begin{cases} (k\bar{R})^2 / (1 + (k\bar{R})^2) & \text{for } l=1 \\ (k\bar{R})^4 / (9 + 3(k\bar{R})^2 + (k\bar{R})^4) & \text{for } l=2, \end{cases} \quad (42)$$

$$\Gamma_{\lambda n} i^0 = \Gamma_{\lambda n} / \mu_l \sqrt{E}. \quad (44)$$

### 3.2 Average Cross Sections in the Unresolved Resonance Region

The average cross sections are defined by

$$\langle \sigma_x \rangle = \frac{1}{\Delta E} \int_{\Delta E} \sigma_x(E) dE \quad (45)$$

where  $x$  stands for the capture, fission, elastic and inelastic scattering reactions. The energy interval  $\Delta E$  is calculated from the energy points designated in the nuclear data file. For the average resonance parameters provided in the file, Eq. (45) is expressed by using a single-level Breit-Wigner formula as follows<sup>17)</sup>:

$$\langle \sigma_c \rangle_{\Delta E} = \frac{2\pi}{k^2} \sum_l \sum_J g_J \left\langle \frac{\Gamma_n \Gamma_\gamma}{\Gamma} \right\rangle_{l,J} / \bar{D}_{l,J}, \quad (46)$$

$$\langle \sigma_f \rangle_{\Delta E} = \frac{2\pi}{k^2} \sum_l \sum_J g_J \left\langle \frac{\Gamma_n \Gamma_f}{\Gamma} \right\rangle_{l,J} / \bar{D}_{l,J}, \quad (47)$$

$$\langle \sigma_{in} \rangle_{\Delta E} = \frac{2\pi}{k^2} \sum_l \sum_J g_J \left\langle \frac{\Gamma_n \Gamma_{in}}{\Gamma} \right\rangle_{l,J} / \bar{D}_{l,J}, \quad (48)$$

$$\langle \sigma_n \rangle_{\Delta E} = \frac{4\pi}{k^2} \sum_l \sum_J g_J (2l+1) \sin^2 \phi_l + \frac{2\pi^2}{k^2} \sum_l \sum_J \frac{g_J}{\bar{D}_{l,J}} \left[ \left\langle \frac{\Gamma_n \Gamma_n}{\Gamma} \right\rangle_{l,J} - 2 \bar{F}_{n,l,J} \sin^2 \phi_l \right], \quad (49)$$

$$\langle \sigma_t \rangle_{\Delta E} = \langle \sigma_c \rangle_{\Delta E} + \langle \sigma_f \rangle_{\Delta E} + \langle \sigma_n \rangle_{\Delta E} + \langle \sigma_{in} \rangle_{\Delta E}, \quad (50)$$

where the brackets mean the statistical average over the  $\chi$ -square distribution with a designated degree of freedom. The integrations for the statistical average are written by using average resonance parameters as follows:

$$\left\langle \frac{\Gamma_n \Gamma_\gamma}{\Gamma} \right\rangle = \bar{F}_\gamma \left\langle \frac{u}{1+u+v+w} \right\rangle = \bar{F}_\gamma \int_0^\infty \int_0^\infty \int_0^\infty \frac{u P_\nu(u) P_\eta(v) P_\zeta(w)}{1+au+bv+cw} du dv dw, \quad (51)$$

$$\left\langle \frac{\Gamma_n \Gamma_f}{\Gamma} \right\rangle = \bar{F}_\gamma \left\langle \frac{uv}{1+u+v+w} \right\rangle = \bar{F}_\eta b \int_0^\infty \int_0^\infty \int_0^\infty \frac{u P_\nu(u) v R_\eta(v) P_\zeta(w)}{1+au+bv+cw} du dv dw, \quad (52)$$

$$\left\langle \frac{\Gamma_n \Gamma_n}{\Gamma} \right\rangle = \bar{F}_\gamma \left\langle \frac{u^2}{1+u+v+w} \right\rangle = \bar{F}_\eta a \int_0^\infty \int_0^\infty \int_0^\infty \frac{u^2 P_\nu(u) P_\eta(v) P_\zeta(w)}{1+au+bv+cw} du dv dw, \quad (53)$$

$$\left\langle \frac{\Gamma_n \Gamma_{in}}{\Gamma} \right\rangle = \bar{F}_\gamma \left\langle \frac{uw}{1+u+v+w} \right\rangle = \bar{F}_\eta c \int_0^\infty \int_0^\infty \int_0^\infty \frac{u P_\nu(u) P_\eta(v) w P_\zeta(w)}{1+au+bv+cw} du dv dw, \quad (54)$$

where  $u = \Gamma_n / \bar{F}_\gamma$ ,  $v = \Gamma_f / \bar{F}_\gamma$ ,  $w = \Gamma_{in} / \bar{F}_\gamma$ ,  $a = \Gamma_n / \bar{F}_\eta$ ,  $b = \Gamma_f / \bar{F}_\eta$ ,  $c = \Gamma_{in} / \bar{F}_\eta$  and  $\nu$ ,  $\eta$  and  $\zeta$  are the numbers of degree of freedom for neutron, fission and inelastic scattering widths, respectively. The function  $P(u)$  is the  $\chi$ -square distribution function given by

$$P_n(x) dx = \frac{n}{2\Gamma(n/2)} \left( \frac{nx}{2\bar{x}} \right)^{\frac{n}{2}-1} \exp \left( -\frac{nx}{2\bar{x}} \right) \frac{dx}{\bar{x}}, \quad (55)$$

where  $\bar{x}$  is the mean value of  $x$ ,  $n$  the degree of freedom and  $\Gamma(n/2)$  the  $\Gamma$ -function. Each integration is numerically performed by using the Gauss-Laguerre formula with fifteen points.

The average neutron widths for  $l$ th-wave neutrons and spin  $J$ -states are defined as

$$\Gamma_{n,l,J} = \Gamma_{n,l,J}^0 \sqrt{E} \mu_l \nu_{n,l,J}. \quad (56)$$

In Eq. (49),  $\phi_l$  is the phase shift given by

$$\phi_{l=0} = k\bar{R}, \quad (57)$$

$$\phi_{l=1} = k\bar{R} - \tan^{-1} k\bar{R}, \quad (58)$$

$$\phi_{l=2} = k\bar{R} - \tan^{-1} \left( \frac{3k\bar{R}}{3-(k\bar{R})^2} \right), \quad (59)$$

where  $\bar{R}$  is the effective scattering radius (in units of  $10^{-12}$  cm).

### 3.3 Generation of Resonance Parameters by Monte Carlo Method

Resonance widths and level spacing are distributed around their mean values according to the  $\chi^2$ - and Wigner distributions, respectively. The  $\chi^2$ -distribution of Eq. (55) is known as the distribution that a statistical variable

$$x = X_1^2 + X_2^2 + \dots + X_n^2 \quad (60)$$

follows, where the  $n$  samples  $X_1, X_2, \dots, X_n$  distribute normally

$$P(x)dx = \frac{1}{\sqrt{2\pi}} \exp(-x^2/2)dx. \quad (61)$$

Hence, the statistical variables distributed according to the  $\chi^2$ -distribution are produced by generating the samples which distribute normally.

Now, let  $\xi_1$  and  $\xi_2$  are independent samples distributed uniformly in the range from 0 to 1, then, the variables  $x_1$  and  $x_2$  defined by

$$x_1 = (-2\ln\xi_1)^{1/2} \sin 2\pi\xi_2 \quad (62)$$

$$x_2 = (-2\ln\xi_1)^{1/2} \cos 2\pi\xi_2 \quad (63)$$

are distributed normally. That is, the Jacobian is

$$\frac{\partial(\xi_1, \xi_2)}{\partial(x_1, x_2)} = \frac{1}{2\pi} \exp\left(-\frac{x_1^2 + x_2^2}{2}\right) \quad (64)$$

or

$$d\xi_1 d\xi_2 = P(x_1)dx_1 \cdot P(x_2)dx_2. \quad (65)$$

The Wigner distribution needed for level spacing is obtained from the  $\chi^2$ -distribution with 2 degrees of freedom,

$$P_2(x)dx = e^{-x}dx \quad (66)$$

by the variable inversion

$$y = 2\sqrt{x/\pi}, \quad (67)$$

that is,

$$P_2(x)dx = \frac{\pi}{2}y \exp(-\pi y^2/4)dy. \quad (68)$$

The Vogt's parameters in Eq. (39) are defined by

$$\cos\theta_{\lambda\lambda'} = \sum_c \xi_{\lambda c} \xi_{\lambda' c} = \sum_c \sqrt{\Gamma_{\lambda c} \Gamma_{\lambda' c}} / (\Gamma_{\lambda i})^{1/2} (\Gamma_{\lambda' i})^{1/2} \quad (69)$$

where  $c$  is the open fission channel.

### 3.4 Calculation of Neutron Spectrum

Neutron balance equation in an infinite homogeneous system can be expressed as

$$\Sigma_t(u)\phi(u) = \sum_i \frac{1}{1-\alpha_i} \int_{u-\varepsilon_i}^u e^{u'-u} \Sigma_{si}(u')\phi(u')du' \quad (70)$$

$$\varepsilon_i = -\ln\alpha_i \quad (71)$$

where  $\Sigma_{si}$  is the scattering cross section of the  $i$ -th scatterer and  $\phi(u)$  the neutron spectrum at the lethargy  $u$ .

Letting  $\psi(u) = \phi(u)e^u$ , Eq. (70) is written as

$$\Sigma_t(u)\psi(u) = \sum_i \frac{1}{1-\alpha_i} \int_{u-\varepsilon_i}^u \Sigma_{si}(u')\psi(u')du'. \quad (72)$$

This equation is more simple than Eq. (70). In the PEACO<sup>23)</sup> code, Eq. (72) is used in place of Eq. (70), because the factor  $\exp(u)$  multiplied to  $\phi(u)$  may serve to reduce round errors appeared in the recurrence formula introduced later for the numerical calculation of neutron slowing-down source.

The energy range of interest is divided into so extremely narrow lethargy width (ultrafine groups) that the resonance cross sections can be described enough accurately, and the ultrafine group is assumed to be less than the maximum lethargy gain per collision with the heaviest nuclide. On the ultrafine group representation,

the flux and collision density are defined by

$$\phi^m = \int_{u_0}^{u_+} \phi(u) du = \int_{u_0}^{u_+} \phi(u) e^u du \quad (73)$$

$$F_i^m = \int_{u_0}^{u_+} \Sigma_{si}(u) \phi(u) du = \Sigma_{si}^m \phi^m \quad (74)$$

where  $u_+$  and  $u_0$  are the upper and lower lethargy boundaries of the ultrafine group  $m$ , respectively. Then, the slowing down source is shown to be written as

$$\begin{aligned} S_i^m &= \int_{u_0}^{u_+} S_i(u) du = \frac{1}{1-\alpha_i} \int_{u_0}^{u_+} du \int_{u-\varepsilon_i}^u \Sigma_{si}(u') \phi(u') du' \\ &\approx \frac{\Delta u_m}{1-\alpha_i} \int_{u_0-\varepsilon_i}^{u_+} F_i(u) du \\ &= S_i^{m-1} + \frac{\Delta u_m}{1-\alpha_i} [F_i^{m-1} - F_i^{m-L_i^m-1}] \end{aligned} \quad (75)$$

where  $\Delta u_m$  is the lethargy width of ultrafine group  $m$  and  $L_i^m$  is the maximum number of groups which corresponds to the maximum lethargy gain by elastic collision. In the derivation of Eq. (75), the self-scatter term was neglected because the effect of self-scatter was shown to be quite insignificant<sup>23)</sup>. In the PEACO-7 code, the scattering rate  $F_i^{m-L_i^m-1}$  is approximately calculated by using the intermediate-group method of Kier<sup>8)</sup>. The accuracy of this approximation was also studied and shown to be quite satisfactory<sup>23)</sup>. Assuming the asymptotic flux distribution below the lethargy range under consideration, the neutron spectra can be calculated recurrently by using Eq. (75) for the slowing down source. Using the calculated neutron spectra, the group constants are calculated by Eqs. (4)~(9) as described in Section 2.

In Eq. (72), two resonant materials and a fictitious moderator with the admixture potential scattering cross section  $\sigma_0$ , are considered for calculating the group constants of the JFS type. It was found<sup>3)</sup> that the mass of fictitious moderators should be determined as follows: The logarithmic energy loss  $\xi$  of the fictitious mass is equal to the average  $\bar{\xi}$  of the moderators of interest in the present calculation. The fictitious mass  $A=30$ <sup>3)</sup> was recommended for producing the group constants for fast reactor calculation. In the TIMS-1 code,  $A=30$  is beforehand ready as the default value of the moderator mass.

#### 4. Description and Specification of I/O

The input cards of TIMS-1 are mainly prepared by the "namelist" format. Hence, the input variables are beforehand ready in the TIMS-1 code. Therefore, the users need to prepare only the several input data which they want to change from the default values when the group constants for the JFS or SRAC type are calculated. The group structures of the JFS and SRAC types are shown in TABLES 2 and 3.

The TIMS-1 code consists of seventeen overlay segments as shown in Fig. 2. The segments 1, 2, 3, 4, 5 and 6 correspond to the subprograms READFL, ARCFIT-2, ARCFIT-3, MCROSS-2, PEACO-7 and XSPLT respectively. These programs are written by a standard FORTRAN IV for FACOM-230/75 and M200 computer. The used core storages are 97 K words. The computational costs for using FACOM-230/75 computer are shown for typical resonant materials in TABLE 4, where the used nuclear data file was ENDF/B-IV. The computing time for FACOM-M200 is about one third of that for FACOM-230/75.

The main function of each subroutine shown in Fig. 2 is explained bellow:

- FTMAIN —controls the flow of the calculations.
- BLOCKD —sets the default values of input data.
- PAGE —changes newly the listing page at starting main subprogram.
- READFL —reads the data file of ENDF/B-IV or JENDL.
- PREFL —searches the data file of the material corresponding to the material number.
- FINDPT —arranges the nuclear data for the ARCF3 subroutine, when the energy dependence of average fission width is not considered in ENDF/B-IV.
- RONLY —sets up only the data in the resolved resonance region.
- ARCF2 —reads the data for unresolved region from the file produced by READFL or FINDPT.
- MOLDER —calculates the average cross sections.
- CLPSD —collapses the calculated average cross sections over the modified energy interval.
- ARCF3 —generates a ladder of resonance parameters.
- FPORT —generates the statistical variables with the  $\chi^2$ -distribution using the random number.
- FUGO —determines the random sign for the Vogt's multilevel parameters.
- IMAX —searches the maximum value for resonance energies.
- PORTER —generates the variables according to the Porter-Thomas distribution.
- BBLINP —lists the input data from the nuclear data file.
- BBLOUT —lists the results for a ladder satisfying two conditions of Eqs. (1) and (2).

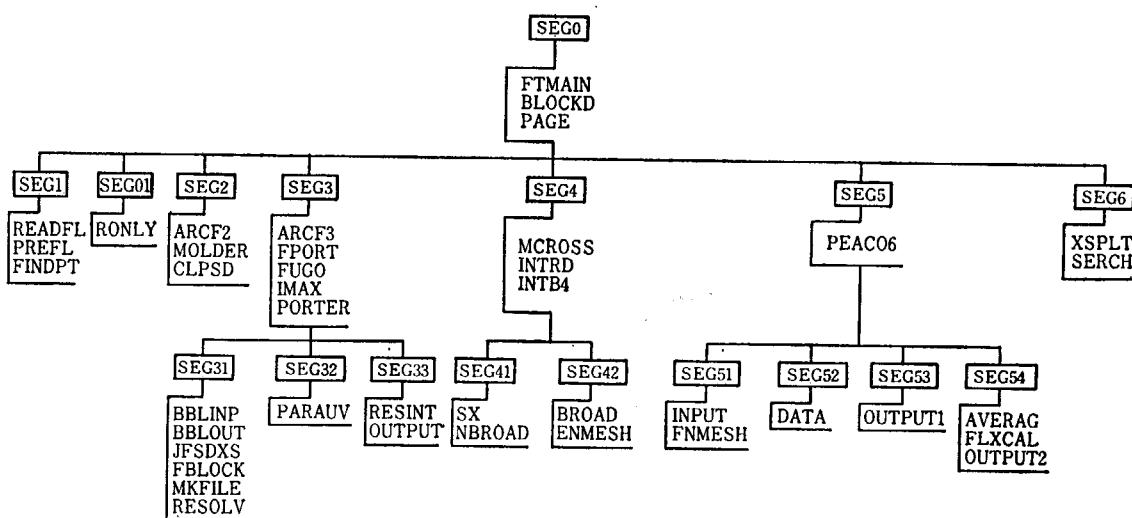


Fig. 2 Overlay structure of TIMS-1

**JFSDXS** —calculates the differences between the average cross sections calculated with MOLDER and RESINT for the JFS energy group structure.  
**FBLOCK** —is the blocking routine for producing the file of the generated resonance parameters as described in Section 4.2.  
**MKFILE** —makes a ladder by connecting the generated and resolved resonance parameters.  
**RESOLV** —makes a blocking files when the group constants are calculated for the resolved region.  
**PARAUV** —calculates the (u, v) multilevel parameters.  
**RESINT** —calculates the average cross sections for the generated resonance parameters.  
**OUTPUT** —lists the results calculated with RESINT.  
**MCROSS** —controls the data files of resonance parameters to calculate ultrafine group cross sections and output the results.  
**INTRD** —reads the data files of floor correction cross sections arranged in READFL.  
**INTB4** —interpolates the floor correction cross sections at ultrafine group energy.  
**SX** —calculates the ultrafine group cross sections depending on temperature.  
**NBROAD** —calculates the Doppler shape functions by using asymptotic formula and interpolation method.

TABLE 2 Seventy group structure of JFS library

Group	Upper energy	Lower energy	Lethargy width	Group	Upper energy	Lower energy	Lethargy width
1	10.5 (MeV)	8.3 (MeV)	0.2351	36	1.66 (KeV)	1.29 (KeV)	0.2522
2	8.3 (MeV)	6.5 (MeV)	0.2445	37	1.29 (KeV)	1.00 (KeV)	0.2546
3	6.5 (MeV)	5.1 (MeV)	0.2426	38	1000.0 (eV)	773.0 (eV)	0.2575
4	5.1 (MeV)	4.0 (MeV)	0.2429	39	773.0 (eV)	598.0 (eV)	0.2567
5	4.0 (MeV)	3.1 (MeV)	0.2549	40	598.0 (eV)	465.0 (eV)	0.2516
6	3.1 (MeV)	2.5 (MeV)	0.2151	41	465.0 (eV)	360.0 (eV)	0.2559
7	2.5 (MeV)	1.9 (MeV)	0.2744	42	360.0 (eV)	278.0 (eV)	0.2585
8	1.9 (MeV)	1.4 (MeV)	0.3054	43	278.0 (eV)	215.0 (eV)	0.2570
9	1.4 (MeV)	1.1 (MeV)	0.2412	44	215.0 (eV)	166.0 (eV)	0.2587
10	1.1 (MeV)	0.8 (MeV)	0.3185	45	166.0 (eV)	129.0 (eV)	0.2522
11	0.8 (MeV)	0.63 (MeV)	0.2389	46	129.0 (eV)	100.0 (eV)	0.2546
12	0.63 (MeV)	0.50 (MeV)	0.2311	47	100.0 (eV)	77.3 (eV)	0.2575
13	0.50 (MeV)	0.40 (MeV)	0.2231	48	77.3 (eV)	59.8 (eV)	0.2567
14	0.40 (MeV)	0.31 (MeV)	0.2549	49	59.8 (eV)	46.5 (eV)	0.2516
15	0.31 (MeV)	0.25 (MeV)	0.2151	50	46.5 (eV)	36.0 (eV)	0.2559
16	0.25 (MeV)	0.20 (MeV)	0.2231	51	36.0 (eV)	27.8 (eV)	0.2585
17	0.20 (MeV)	0.15 (MeV)	0.2877	52	27.8 (eV)	21.5 (eV)	0.2570
18	0.15 (MeV)	0.12 (MeV)	0.2231	53	21.5 (eV)	16.6 (eV)	0.2587
19	0.12 (MeV)	0.1 (MeV)	0.1823	54	16.6 (eV)	12.9 (eV)	0.2522
20	100.0 (KeV)	77.3 (KeV)	0.2575	55	12.9 (eV)	10.0 (eV)	0.2546
21	77.3 (KeV)	59.8 (KeV)	0.2567	56	10.0 (eV)	7.73 (eV)	0.2575
22	59.8 (KeV)	46.5 (KeV)	0.2516	57	7.73 (eV)	5.98 (eV)	0.2567
23	46.5 (KeV)	36.0 (KeV)	0.2559	58	5.98 (eV)	4.65 (eV)	0.2516
24	36.0 (KeV)	27.8 (KeV)	0.2585	59	4.65 (eV)	3.60 (eV)	0.2559
25	27.8 (KeV)	21.5 (KeV)	0.2570	60	3.60 (eV)	2.78 (eV)	0.2585
26	21.5 (KeV)	16.6 (KeV)	0.2587	61	2.78 (eV)	2.15 (eV)	0.2570
27	16.6 (KeV)	12.9 (KeV)	0.2522	62	2.15 (eV)	1.66 (eV)	0.2587
28	12.9 (KeV)	10.0 (KeV)	0.2546	63	1.66 (eV)	1.29 (eV)	0.2522
29	10.0 (KeV)	7.73 (KeV)	0.2575	64	1.29 (eV)	1.00 (eV)	0.2546
30	7.73 (KeV)	5.98 (KeV)	0.2567	65	1.00 (eV)	0.773 (eV)	0.2575
31	5.98 (KeV)	4.65 (KeV)	0.2516	66	0.773 (eV)	0.598 (eV)	0.2567
32	4.65 (KeV)	3.60 (KeV)	0.2559	67	0.598 (eV)	0.465 (eV)	0.2516
33	3.60 (KeV)	2.78 (KeV)	0.2585	68	0.465 (eV)	0.360 (eV)	0.2559
34	2.78 (KeV)	2.15 (KeV)	0.2570	69	0.360 (eV)	0.278 (eV)	0.2585
35	2.15 (KeV)	1.66 (KeV)	0.2587	70	0.278 (eV)	0.215 (eV)	0.2570

- BROAD —calculates the tables of Doppler functions.
- ENMESH —sets the energy boundaries and lethargy widths shown in TABLE 1.
- PEACO6 —controls the calculating routine of neutron spectra and group cross sections.
- INPUT —reads the data for group constant calculation.
- FNMESH —sets the energy group boundaries for JFS and SRAC libraries.
- DATA —sets the initial data for calculating the neutron spectra.
- OUTPUT1 —lists the input data information.
- AVERAG —reads the data files of the ultrafine group cross sections produced in MCROSS.
- FLXCAL —calculates the neutron spectra by solving numerically neutron slowing down equation using the recurrence formula.
- OUTPUT2 —lists the infinite dilute cross sections, effective cross sections, fluxes and self-shielding factors.
- XSPLOT —plots the temperature dependent cross sections from the data files produced in MCROSS by using Calcomp plotter.
- SERCH —searches the data of cross sections over the energy interval assigned by the users.

TABLE 3 Seventy-four group structure of SRAC library

Group	Upper energy	Lower energy	Lethargy width	Group	Upper energy	Lower energy	Lethargy width
1	10.0 (MeV)	7.7880 (MeV)	0.250	38	961.12 (eV)	748.52 (eV)	0.25
2	7.7880 (MeV)	6.0653 (MeV)	0.250	39	748.52 (eV)	582.95 (eV)	0.25
3	6.0653 (MeV)	4.7237 (MeV)	0.250	40	582.95 (eV)	454.00 (eV)	0.25
4	4.7237 (MeV)	3.6788 (MeV)	0.250	41	454.00 (eV)	353.58 (eV)	0.25
5	3.6788 (MeV)	2.8650 (MeV)	0.250	42	353.58 (eV)	275.36 (eV)	0.25
6	2.8650 (MeV)	2.2313 (MeV)	0.250	43	275.36 (eV)	214.45 (eV)	0.25
7	2.2313 (MeV)	1.7377 (MeV)	0.250	44	214.45 (eV)	167.02 (eV)	0.25
8	1.7377 (MeV)	1.3534 (MeV)	0.250	45	167.02 (eV)	130.07 (eV)	0.25
9	1.3534 (MeV)	1.0540 (MeV)	0.250	46	130.07 (eV)	101.30 (eV)	0.25
10	1.0540 (MeV)	0.82085 (MeV)	0.250	47	101.30 (eV)	78.893 (eV)	0.25
11	0.82085 (MeV)	0.63928 (MeV)	0.250	48	78.893 (eV)	61.442 (eV)	0.25
12	0.63928 (MeV)	0.49787 (MeV)	0.250	49	61.442 (eV)	47.851 (eV)	0.25
13	0.49787 (MeV)	0.38774 (MeV)	0.250	50	47.851 (eV)	37.267 (eV)	0.25
14	0.38774 (MeV)	0.30199 (MeV)	0.250	51	37.267 (eV)	29.023 (eV)	0.25
15	0.30197 (MeV)	0.23518 (MeV)	0.250	52	29.023 (eV)	22.603 (eV)	0.25
16	0.23518 (MeV)	0.18316 (MeV)	0.250	53	22.603 (eV)	17.603 (eV)	0.25
17	0.18316 (MeV)	0.14264 (MeV)	0.250	54	17.603 (eV)	13.710 (eV)	0.25
18	0.14264 (MeV)	0.11109 (MeV)	0.250	55	13.710 (eV)	10.677 (eV)	0.25
19	0.11109 (MeV)	0.086517 (MeV)	0.250	56	10.677 (eV)	8.3153 (eV)	0.25
20	86.517 (KeV)	67.379 (KeV)	0.250	57	8.3153 (eV)	6.4760 (eV)	0.25
21	67.379 (KeV)	52.475 (KeV)	0.250	58	6.4760 (eV)	5.0435 (eV)	0.25
22	52.475 (KeV)	40.868 (KeV)	0.250	59	5.0435 (eV)	3.9279 (eV)	0.25
23	40.868 (KeV)	31.828 (KeV)	0.250	60	3.9279 (eV)	3.0590 (eV)	0.25
24	31.828 (KeV)	24.788 (KeV)	0.250	61	3.0590 (eV)	2.3824 (eV)	0.25
25	24.788 (KeV)	19.305 (KeV)	0.250	62	2.3824 (eV)	1.8554 (eV)	0.25
26	19.305 (KeV)	15.034 (KeV)	0.250	63	1.8554 (eV)	1.6374 (eV)	0.125
27	15.034 (KeV)	11.709 (KeV)	0.250	64	1.6374 (eV)	1.4450 (eV)	0.125
28	11.709 (KeV)	9.1188 (KeV)	0.250	65	1.4450 (eV)	1.2752 (eV)	0.125
29	9.1188 (KeV)	7.1017 (KeV)	0.250	66	1.2752 (eV)	1.1254 (eV)	0.125
30	7.1017 (KeV)	5.5308 (KeV)	0.250	67	1.1254 (eV)	0.99312 (eV)	0.125
31	5.5308 (KeV)	4.3074 (KeV)	0.250	68	0.99312 (eV)	0.87642 (eV)	0.125
32	4.3074 (KeV)	3.3546 (KeV)	0.250	69	0.87642 (eV)	0.77344 (eV)	0.125
33	3.3546 (KeV)	2.6126 (KeV)	0.250	70	0.77344 (eV)	0.68256 (eV)	0.125
34	2.6126 (KeV)	2.0347 (KeV)	0.250	71	0.68256 (eV)	0.60236 (eV)	0.125
35	2.0347 (KeV)	1.5846 (KeV)	0.250	72	0.60236 (eV)	0.53158 (eV)	0.125
36	1.5846 (KeV)	1.2341 (KeV)	0.250	73	0.53158 (eV)	0.46912 (eV)	0.125
37	1.2341 (KeV)	0.96112 (KeV)	0.250	74	0.46912 (eV)	0.41399 (eV)	0.125

TABLE 4 Computing times for the production of group constants with the TIMS-1 code from ENDF/B-IV

Material	Upper energy	ARCFIT-3	CPU times (sec) of FACOM 230/75					
			MCROSS-2				PEACO-7	
							A=1.0	A=30
U-234	1.0KeV	2	165	167	171	175	117	128
U-235	21.5KeV	408	986	988	1002	1003	263	278
U-236	1.0KeV	18	170	173	174		119	129
U-238	46.5KeV	33	605	617	630	638	300	326
Pu-239	21.5KeV	120	612	616	622	626	254	277
Pu-240	21.5KeV	92	778	786	789	792	256	278
Pu-241	46.5KeV	502	1049	1057	1069	1069	300	327
Th-232	46.5KeV	47	487	494	500	510	300	328

## 4.1 Input Preparation of TIMS-1

The user's input cards are prepared as described below.

Card 1 (18A4)—Title

TITLE ; Descriptive information.

Card 2 (I5)—Material.

MATNO ; Material number defined in ENDF/B or JENDL.

Card 3 (6(A8, 2X))—Designation.

(IOP(I), I=1, 6) ; Calculating flow is designated by input of some data of eight letters as follows ; FILEREAD, ARCFIT-2, ARCFIT-3, MCROSSbb, PEACObb and XSPLITbb where b means a blank. These designation data mean the performance content shown in TABLE 5.

Card 4 (namelist)—FILEREAD.

NAM1 : Namelist name.

MPRINT : Print control of nuclear data file (Default value=1).

≠0, print the nuclear data of ENDF/B or JENDL.

=0, no effect.

IRONLY : Control for resolved and unresolved region (Default value=0).

=0, unresolved and resolved regions are processed.

≠0, only resolved region is processed.

Card 5 (namelist)—ARCFIT-2.

NAM2 : Namelist name.

TABLE 5 Performance contents for designation cards of calculating flow

Designation	Input card no.	Performance	Logical unit number
FILEREAD	①~④	Resonance parameters and smooth data are read from the ENDF/B or JENDL file, and data files for TIMS-1 are produced.	F01~F03, F08, F10
ARCFIT-2	①~③, ⑤	Average resonance cross sections are calculated in the unresolved region.	F01~F03, F08, F10
ARCFIT-3	①~③, ⑤~⑪	Production of a ladder of resonance parameters.	F01~F03, F08, F10, F20~F22 F30~F32, F40~F42
MCROSS	①~③, ⑫, ⑬	Calculation of temperature dependent cross section at ultrafine group	F01~F03, F08, F10, F40~F42 F50~F54
PEACO	①~③, ⑭~⑯	Calculation of neutron spectra and group constants	F50~F54, F60, F80
XSPLIT	⑰~⑲	Plotting for temperature dependent cross sections	F50~F52, F58, F59

IOUT	: Print control of average cross sections (Default value=0). ≠0, $\langle\sigma_x, i, j\rangle$ are printed. =0, $\langle\sigma_x\rangle$ ( $=\sum_{i,j} \langle\sigma_x, i, j\rangle$ ) are printed.
ICON1	: Collapse control for average cross sections (Default value=2). =2, $\langle\sigma_x\rangle_g$ are defined for the new energy range $\Delta E_g$ ( $=\sum_i \Delta E_i$ ) / $D_{l=0}$ ≥ REON, i.e., $\langle\sigma_x\rangle_g = \sum_i \langle\sigma_x\rangle_i \Delta E_i / \sum_i \Delta E_i$ . =0, no collapse
ICFT	: Fissile or fertile material option (Default value=1). =1, fertile material =2, fissile material
IPOPT	: (u, v) parameters control (Default value=0). =1, (u, v) parameters for s-wave neutron are generated. =0, no generation
IEPXS	: Permissible error control of average cross sections (Default value=0). =0, $\varepsilon_\sigma$ of Eq. (1) has the default value 0.05 (5%). =1, group independent $\varepsilon_\sigma$ is read. =2, group dependent $\varepsilon_\sigma$ are read.
IPARA	: Permissible error control of average resonance parameters (Default value=0). =0, $\varepsilon_r$ is the default value 0.1. =1, group independent $\varepsilon_r$ is read. =2, group dependent $\varepsilon_r$ are read.
IPSET	: Random number starter control (Default value=0). =0, random number starter is fixed. =1, random number starter is not fixed.
REON	: Number of resonance parameters to be considered for the collapse of average cross sections (Default value=200.0).
Card 6	(3E10. 4)—If IEPXS=1, the following data are read: (DE(I), I=1, ICFT+1): Permissible errors $\varepsilon_{\sigma_c}$ , $\varepsilon_{\sigma_n}$ and $\varepsilon_{\sigma_f}$ .
Card 7	(I5)—If IEPXS=2, the following data are read: ISET : Number of different permissible errors for average cross sections.
Card 8	(2I5, 3E10. 4)—If IPARA=1, the following data are read: IS : Group number for upper energy boundary. IE : Group number for lower energy boundary. (DE(I), I=1, ICFT+1): Permissible errors independent on group energy among IS and IE energy group. Card 8 is repeated by ISET times.
Card 9	(3E10. 4)—If IPARA=2, the following data are read: (DP(I), I=1, NOL): Permissible errors $\varepsilon_r$ ( $l=0$ ). $\varepsilon_r(l=1)$ and $\varepsilon_r(l=2)$ for strength functions and fission widths.
Card 10	(I5)—If IPARA=2, the following data are read: ISET : Number of different errors for average resonance parameters.
Card 11	(2I5, 3E10. 4)—If IPARA=2, the following data are read: IS : Group number of upper energy boundary. IE : Group number of lower energy boundary. (DP(I), I=1, NOL): Permissible errors independent on the group energy between the IS- and IE-th energy groups. Card 11 is repeated by ISET times.
Card 12	(namelist)—MCROSS-2. NAM3 : Namelist name. NT : No. of temperatures ( $\leq 5$ ) (Default value=1).

**TABLE 6** Name of nuclide and default values for input variables in Card 13

Nuclide	CASE	N	NMP	NMD	IMP*	IMD*
<sup>232</sup> Th	TH-232bb	10	10	10	6	1
<sup>233</sup> U	U-233bbb	25	20	20	8	1
<sup>234</sup> U	U-234bbb	10	10	10	7	1
<sup>235</sup> U	U-235bbb	25	20	20	8	1
<sup>236</sup> U	U-236bbb	10	10	10	7	1
<sup>238</sup> U	U-238bbb	10	10	10	10	4
<sup>239</sup> Pu	PU-239bb	20	15	15	7	1
<sup>240</sup> Pu	PU-240bb	10	10	10	5	4
<sup>241</sup> Pu	PU-241bb	25	20	20	8	1

\* These integers are the group no. shown in TABLE 1

- MVOGT : Single and multi level expression control (Default value=0).  
     =0, single-level Breit-Wigner formula.  
     =1, Vogt's multilevel formula.  
     =2, (u, v) multilevel parameters.
- NOMS : Group number for upper energy group shown in TABLE 1.
- CASE : Name of nuclide to be processed, which are defined by eight letters as shown in TABLE 6.
- INTRP : 0, floor correction cross sections are calculated by the interpolation method given in ENDF/B-4 or JENDL (Default value=0).  
     =1, floor correction cross sections are neglected.
- TT : Temperature (°K) (Default values=300, 800, 2100 and 4500).
- Card 13 (namelist)—MCROSS-2.
- NAM4 : Namelist name.
- IOUT : Print control of ultrafine group cross sections (Default value=0).  
     =1, print ultrafine group cross sections.  
     =0, no effect.
- N : No. of the s-wave neutron resonance levels  $\lambda$  to be summed up by  $\sigma_x(E) = \sum_{\lambda=1}^{2N} \sigma_{x\lambda}(E)$  ( $\leq 50$ ) (See TABLE 6 as to default value).
- NMP : No. of the p-wave neutron resonance levels  $\lambda$  to be summed up ( $\leq 50$ ) (See TABLE 6 as to the default value).
- NMD : No. of the d-wave neutron resonance levels to be summed up ( $\leq 50$ ) (See TABLE 6 as to the default value).
- IMP : The p-wave neutron cross sections are neglected for the lower energies than the IMP-th energy group boundary. (See TABLE 6 as to the default value).
- IMD : The d-wave neutron cross sections are neglected for the lower energies than the IMD-th energy group boundary (See TABLE 6 as to the default value).
- NSS, NPP and NDD : Total sums of the s-, p- and d-wave neutron resonance levels generated by ARCFIT-3. Therefore when ARCFIT-3 is processed these data are not required.  
     When users restart from MCROSS-2 these must be read.
- Card 14 (namelist)—PEACO
- NAM5 : Namelist name.
- NTEMP : No. of temperatures ( $\leq 5$ ) (Default value=4).
- KRAT : No. of the atomic density ratio, R-values ( $\leq 5$ ) (Default value=1).
- KSIGM : No. of  $\sigma_0$ -values ( $\leq 10$ ) (Default value=8).
- KRES : No. of resonant materials ( $\leq 2$ ) (Default value=1).
- NPLOT : Plot control (Default value=0).  
     =0, neutron spectra are plotted.

=0, no plotting.

NPRINT : Print control (Default value=0).

=0, only the results for resonant material of interest are printed.

=1, also the results for background resonant material are printed.

KMOD : Upper energy group number of JFS or SRAC type group structure (See TABLES 2 and 3).  
As for SRAC type, KMOD=100+group no.

#### Card 15 (namelist)—PEACO

NAME6 : Namelist name.

KBG : No. of energy groups (Default value=0). When the users want to calculate the group constants for a different structure from JFS or SRAC type, (KBG+1) energy boundaries should be read for EN ( $\leq 60$ ).

EN : Group energy boundaries (eV) (Default values are shown in TABLES 2 and 3).

SIGM :  $\sigma_0$ -values (Default values=0, 1, 10,  $10^2$ ,  $10^3$ ,  $10^4$ ,  $10^5$ ,  $10^6$ ).

RATIO : R-values (Default values are shown in TABLE 7 for Pu-239 and U-238).

NUCLID : Material name read with 4 letters ( $\leq 3$ ). For example, NUCLID (1)=‘U238’ and NUCLID (2)=‘A30’. If two resonant materials are considered, NUCLID=‘U238’, ‘U235’, ‘A30’.

TEMP : Temperature (°K) (Default values=300, 800, 2100 and 4500).

AMASS : Average mass for background moderator nuclide (Default value=30).

#### Card 16 (10A4/10A4/10A4)—If NPLOT $\neq 0$ , the following data are read:

XTITL : Title of  $x$  coordinate.

YTITL : Title of  $y$  coordinate.

TITLE : Figure caption.

These cards are repeated by (KRAT $\times$ KSIGM) times.

#### Card 17 (3I5)—XSPLT

NCFN : Reaction type option.

=0,  $\sigma_c$ ,  $\sigma_f$ ,  $\sigma_s$ ,  $\sigma_t$ .

=1,  $\sigma_c$ .

=2,  $\sigma_t$ .

=3,  $\sigma_n$ .

=4,  $\sigma_t$ .

NTT : No. of temperatures ( $\leq 3$ ).

NEN : No. of energy groups.

#### Card 18 (6E12. 4)—XSPLT

EL : Lower energy boundary to be plotted.

EH : Upper energy boundary to be plotted.

WX : Length of  $x$  coordinate (mm) (Default value=230).

WY : Length of  $y$  coordinate (mm) (Default value=160). Maximum size is 250 mm.

RX : Linear or log scale control for  $x$  coordinate (Default value=1.0). If RX is less than Max. ( $x_i$ )/Min. ( $x_i$ ), the scale of  $x$  coordinate is linear, and if not so, log scale.

RY : Linear or log scale control for  $y$  coordinate (Default value=1.0).

#### Card 19 (10A4/10A4/10A4)—XSPLT

XTITLE : Title of  $x$  coordinate.

TABLE 7 Values of atomic number density ratio of Pu-239 to U-238

$\sigma_0$	0	1	10	$10^2$	$10^3$	$10^4$	$10^5$	$10^6$
R <sub>1</sub>	0.0	5.0	1.0	0.2	0.02	$2 \times 10^{-3}$	$2 \times 10^{-4}$	$2 \times 10^{-5}$
R <sub>2</sub>	0.0	2.5	0.5	0.1	0.01	$1 \times 10^{-3}$	$1 \times 10^{-4}$	$1 \times 10^{-5}$

YTITLE : Title of  $y$  coordinate.

TITLE : Figure caption.

If NCFN $\neq 0$ , Cards 18 and 19 are repeated by NEN times, and if NCFN=0, Cards 18 and 19 are repeated by  $4 \times$ NEN times.

#### 4.2 Output Formats

Relationship among many disk-files used in each subprogram are shown in Fig. 3. These files may be kept to perform the restart calculations. The output formats for each disk-file are as follows:

(1) The generated resonance parameters libraries

F40 ; ( $E_\lambda, g_{J\lambda}, \Gamma_{n\lambda}^0, \Gamma_{\gamma\lambda}, \Gamma_{t\lambda}, \Gamma_{in1,\lambda}^0, \Gamma_{in2,\lambda}^0, (\xi_{\lambda c}, c=1, MF), \lambda=1, K$ ), for  $l=0$

F41 and F42 ; ( $E_\lambda, g_{J\lambda}, \Gamma_{n\lambda}^0, \Gamma_{\gamma\lambda}, \Gamma_{t\lambda}, \Gamma_{in1\lambda}^0, \Gamma_{in2\lambda}^0, \lambda=1, K$ ), for  $l=1$  and 2

F23 ; ( $E_\lambda, g_{J\lambda}, \Gamma_{n\lambda}^0, \Gamma_{\gamma\lambda}, \Gamma_{t\lambda}, \Gamma_{in1\lambda}^0, \Gamma_{in2\lambda}^0, u_{t\lambda}, v_{t\lambda}, u_{it\lambda}, v_{it\lambda}, \lambda=1, K$ )

where each file is repeated by NOR=N (total number of resonances)/100+1.

(2) Doppler-broadened cross section libraries

F50—F54; ① TEMP, MATNO, AM, NOMESH, BOUND(1), (BOUND(I+1), UIGP(I), NOIG(I), NFI(I), I=1, NOMESH), NFII

② (XS(1, J), XS(2, J), XS(3, J), J=1, NFI(I))

This file is repeated by  $\sum_{I=1}^{NOMESH} NOIG(I)$ .

TEMP : Temperature (°K).

MATNO : Material number.

AM : Atomic mass.

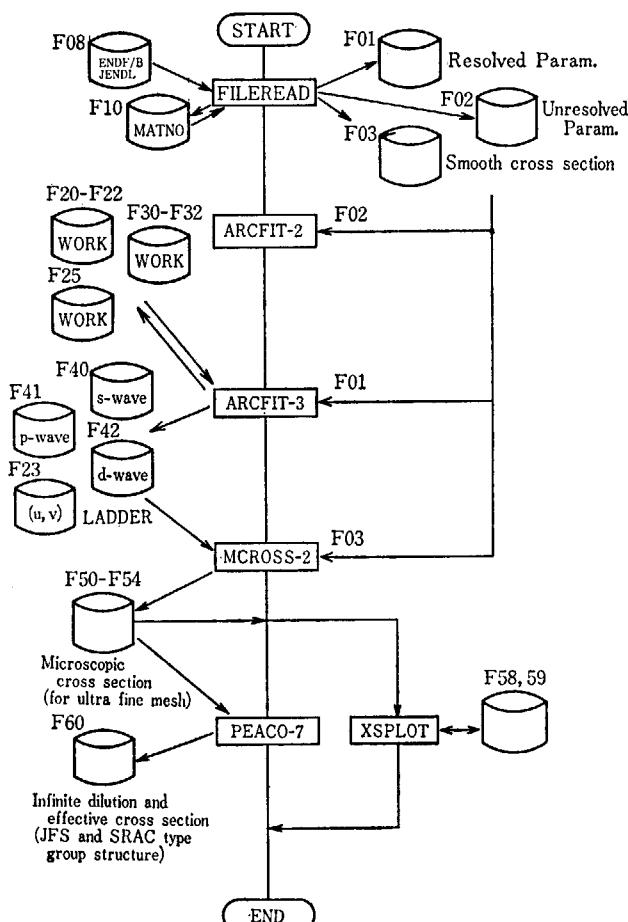


Fig. 3 Logical unit number of data-files used in the subprogram of TIMS-1

NOMESH : No. of broad energy groups as shown in TABLE 1.  
 BOUND : Energy boundary (eV) as shown in TABLE 1.  
 UIGP : Lethargy width of fine group.  
 NOIG : No. of fine group in a broad group.  
 NFI : No. of ultrafine group in a fine group.  
 NEII : Maximum no. of ultrafine group in a fine group.  
 XS(1, J) : Capture cross section.  
 XS(2, J) : Fission cross section.  
 XS(3, J) : Elastic scattering cross section.

These files (F50, 51, 52, 53, 54) are produced at each temperature.

(3) Group constant library (This file must be kept).

```
F60;      ① MATNO, NTEMP, KRES, KSIGM, KRAT, KBG
          ② (TEMP(I), I=1, NTEMP), (SIGM(I), I=1, KSIGM), (RATIO(I, J), I=1, KRAT), J=1,
             KSIGM)
          ┌── N=1, NTEMP
          ┌── K=1, KRAT
          ┌── L=1, KSIGM
          ┌── I=1, KBG
          ┌── if L=1 and K=1
          └─③ FINF(I, N), CINF(I, N), SINF(I, N), TINF(I, N), RINF(I, IV), DU(I)
          └─④ RIF(I, L, K, N), RIC(I, L, K, N), RIS(I, L, K, N), RIT(I, L, K, N), RIR(I, L, K, N),
             SPECT(I, L, K, N)
```

where

MATNO : Material No.  
 NTEMP : No. of temperatures.  
 KRES : No. of resonant nuclei.  
 KSIGM : No. of  $\sigma_0$ -values.  
 KRAT : No. of R-values.  
 KBG : No. of energy groups.  
 TEMP : Temperature (°K).  
 SIGM :  $\sigma_0$  (barn).  
 RATIO : R-value.  
 FINF : Infinite dilute fission cross section,  $\sigma_f(\infty)$ .  
 CINF : Infinite dilute capture cross section,  $\sigma_c(\infty)$ .  
 SINF : Infinite dilute elastic scattering cross section,  $\sigma_n(\infty)$ .  
 TINF : Infinite dilute total cross section,  $\sigma_t(\infty)$ .  
 RINF : Infinite dilute elastic removal cross section,  $\sigma_{er}(\infty)$ .  
 DU : Lethargy of broad group.  
 RIF : Effective fission cross section,  $\bar{\sigma}_f$ .  
 RIC : Effective capture cross section,  $\bar{\sigma}_c$ .  
 RIS : Effective elastic scattering cross section,  $\bar{\sigma}_n$ .  
 RIT : Effective total cross section,  $\bar{\sigma}_t$ .  
 RIR : Effective elastic removal cross section,  $\bar{\sigma}_{er}$ .  
 SPECT : Neutron spectrum,  $\phi_g$ .

## 5. Sample Problems

### 5.1 Fluctuation of Self-shielding Factors by Random Sampling

In the unresolved resonance region, the group constants are calculated by using a ladder of resonance parameters generated with Monte Carlo method. Therefore, the generated group constants depend on random number starters. If the starter-dependence is remarkable, the resonance parameters should be generated so many times and the calculated group constants should be averaged. If this averaging process is required, however, the computing costs will be very expensive. In the TIMS-1 code, a ladder of resonance parameters is selected as satisfying the conditions of Eqs. (1) and (2). The errors  $\varepsilon_\sigma$  and  $\varepsilon_r$  were assumed 5% and 10% respectively. The six ladders satisfying the conditions were selected for  $^{235}\text{U}$  and  $^{238}\text{U}$  by using JENDL-2, and the self-shielding factors were calculated. The magnitude of the fluctuation among the calculated self-shielding factors are shown in TABLE 8 and 9. These tables show very small fluctuation for each reaction and energy group. Thus, we can conclude that the group constants may be calculated by using only one ladder satisfying the conditions of Eqs. (1) and (2) under the assumed errors.

TABLE 8 Fluctuation of self-shielding factors of

$$^{238}\text{U} ; \chi_f = \sqrt{\frac{1}{N} \sum_{i=1}^N (f_i - \bar{f})^2} / \bar{f} (\%)$$

Energy (KeV)	$\chi_{\text{fc}}$	$\chi_{\text{fs}}$	$\chi_{\text{ft}}$	$\chi_{\text{fer}}$
46.5-36.0	0.008	0.007	0.016	0.118
36.0-27.8	0.008	0.014	0.027	0.0273
27.8-21.5	0.006	0.019	0.037	0.124
21.5-16.6	0.019	0.024	0.046	0.203
16.6-12.9	0.027	0.031	0.058	0.089
12.9-10.0	0.038	0.132	0.248	0.127
10.0-7.73	0.027	0.043	0.075	0.449
7.73-5.98	0.024	0.076	0.142	1.107
5.98-4.65	0.064	0.059	0.110	0.106
4.65-3.60	0.066	0.052	0.091	0.021

TABLE 9 Fluctuation of self-shielding factors of

$$^{235}\text{U} ; \chi_f = \sqrt{\frac{1}{N} \sum_{i=1}^N (f_i - \bar{f})^2} / \bar{f} (\%)$$

Energy (KeV)	$\chi_{\text{ff}}$	$\chi_{\text{fc}}$	$\chi_{\text{fs}}$	$\chi_{\text{ft}}$	$\chi_{\text{fer}}$
4.65-3.60	0.01	0.13	0.03	0.08	0.31
3.60-2.78	0.06	0.25	0.06	0.10	0.35
2.78-2.15	0.09	0.48	0.07	0.05	0.09
2.15-1.66	0.42	0.10	0.10	0.02	0.10
1.66-1.29	0.19	0.26	0.08	0.37	0.43
1.29-1.00	0.18	0.12	0.30	0.20	1.01
1.00-0.773	0.50	0.74	0.35	0.90	0.79
0.773-0.598	0.14	0.23	0.06	0.04	2.33
0.598-0.465	0.50	0.70	0.30	0.77	1.90

### 5.2 Collapse of Average Cross Sections in the Unresolved Region

The energy boundaries for the average cross sections are defined as shown in Fig. 4, i.e., for energy point  $E_i$  given in ENDF/B-IV or JENDL, the upper and lower energy boundaries of the average cross section are given as follows :

$$E_{iu} = \begin{cases} \frac{1}{2}(E_i + E_{i-1}), & \text{for } 1 < i \leq N \\ E_i + \frac{1}{2}(E_i + E_{i+1}), & \text{for } i = 1 \end{cases}$$

$$E_{it} = \begin{cases} \frac{1}{2}(E_i + E_{i+1}), & \text{for } 1 \leq i < N \\ E_i, & \text{for } i = N \end{cases}$$

However when  $(E_{iu} - E_{it})/D$  is very small, that is, the number of levels included in a specified energy interval is small, a ladder of resonance parameters which satisfies two conditions of Eqs. (1) and (2) can not easily be found in the small energy range. In the TIMS-1 code, for such a case, the conditions can be examined for the modified interval  $\Delta E = ND$ , where  $N$  is an integer. The TIMS-1 code assumes the default value 200 for the integer  $N$ .

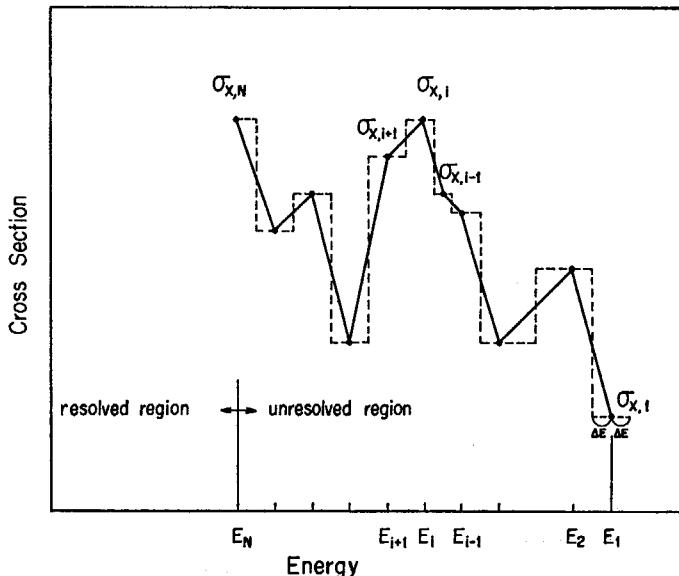


Fig. 4 Energy boundary for the calculation of average cross sections

### 5.3 Sample Data of Input and Output

In order to produce the libraries of the JFS and SRAC type from the evaluated nuclear data file of ENDF/B-IV, JENDL-1 or JENDL-2, many production run of TIMS-1 were performed using FACOM-230/75. Several examples of input and output data used in these productions are shown in this section.

TABLE 10 Sample data for calculating the group constants of  $^{238}\text{U}$  in the resolved and unresolved region

---

\$DATA					
NEW TIMS TEST RUN U-238					
1262					
FILEREAD	ARCFIT-2	ARCFIT-3	MCROSS	PEACO	-Designation
\$NAM1 \$					
\$NAM2 ICFT=1 \$					
\$NAM3 NOMS=2, CASE='U-238', TT(1)=300.0 \$					
\$NAM4 \$					
\$NAM5 NTEMP=1, KMOD=23 \$					
\$NAM6 NUCLID='U238', AMASS=30.0, TEMP(1)=300.0 \$					

---



---

\$JEND

---

TABLE 11 Sample data for calculating the group constants of  $^{238}\text{U}$  in the resolved region

---

\$DATA					
NEW TIMS TEST RUN U-238					
1262					
FILEREAD	ARCFIT-2	ARCFIT-3	MCROSS	PEACO	-Designation
\$NAM1 IRONLY=1 \$					
\$NAM2 ICFT=1 \$					
\$NAM3 NOMS=6, CASE='U-238' \$					
\$NAM4 \$					
\$NAM5 NTEMP=1, KMOD=138 \$					
\$NAM6 NUCLID='U238', AMASS=30.0 \$					

---

\$JEND

---

TABLE 10 shows an input data for processing the data of  $^{238}\text{U}$  from the ENDF/B-IV file (F08). The material number of  $^{238}\text{U}$  is 1262. The group constants for the temperature 300°K and eight default values of  $\sigma_0$  are calculated with the group structure of JFS, where the energy range is 46.5 KeV to 0.215 eV. The calculated temperature dependent cross sections are shown in Fig. 5. This figure was drawn with the use of XSPLT. Furthermore, the neutron spectrum calculated for  $\sigma_0=100$  barns and average moderator mass A=30 is shown in Fig. 6. The main output lists are shown in Appendix B.

TABLE 11 shows an input data for calculating the group constants of  $^{238}\text{U}$  in the energy range below the resolved region, where the group constants of the SRAC type are calculated for the temperature 300°K and average mass A=30.0.

Figure 7 shows the comparison of temperature dependent cross sections of  $^{239}\text{Pu}$  drawn with XSPLT using the data-files (F50, 51, 52) produced by MCROSS-2, where JENDL-1 was used as the input file.

TABLE 12 Job Control Cards in TIMS-1 for FACOM-230/75 computer

```

1 *NO 2031,T,4C,3W,1P,0,PLT
2 VM *GJOB 4112031,H1,TAKANO,431,1G,TIMS
3 VM *HLIED RFNAME=J2031,TIMSHMRB,GRFD=CN,PLTLIB=CALL
SGMT SEG0
SELECT (FTMAIN,BLOCKD,PAGE)
SGMT SEG1
SELECT (READFL,PREFL,FINDPT)
SGMT SEG01,CHN=SEG0
SELECT (RONLY)
SGMT SEG2,CHN=SEG0
SELECT (ARCF2,MOLDER,CLPSD)
SGMT SEG3,CHN=SEG0
SELECT (ARCF3,FPORT,FUGO,IMAX,PORTER)
SGMT SEG31
SELECT (BBLINP,BBLOUT,JFSDXS,FBLOCK,MKFFILE,RESOLV)
SGMT SEG32,CHN=SEG3
SELECT (PARAUV)
SGMT SEG33,CHN=SEG3
SELECT (RESINT,OUTPUT)
SGMT SEG4,CHN=SEG0
SELECT (MCROSS1,INTRD,INTB4)
SGMT SEG41
SELECT (SX,NBROAD)
SGMT SEG42,CHN=SEG4
SELECT (BROAD,ENMESH)
SGMT SEG5,CHN=SEG0
SELECT (PEAC06)
SGMT SEG51
SELECT (INPUT,FMESH)
SGMT SEG52,CHN=SEG3
SELECT (DATA)
SGMT SEG53,CHN=SEG5
SELECT (OUTPT1)
SGMT SEG54,CHN=SEG5
SELECT (AVERAG,FLXCAL,OUTPT2)
SGMT SEG6,CHN=SEG0
SELECT (XSPLT,SEARCH)
FIN
4 VM *HRUN  SIZE=20
5 VM *PLOT
6 VM *TPDISK F01,J2031,A,TMOD=9,RSIZE=80,BSIZE=3200
7 VM *TPDISK F02,J2031,B,TMOD=9,RSIZE=80,BSIZE=3200
8 VM *TPDISK F03,J2031,C,TMOD=9,RSIZE=80,BSIZE=3200
9 VM *DISKTO F08,J1615,ENDFB404
10 VM #DISK F09
11 VM *TPDISK F10,J2031,DATA,TMOD=9,RSIZE=80,BSIZE=3200
12 VM #DISK F20
13 VM #DISK F21
14 VM #DISK F22
15 VM #DISK F23
16 VM #DISK F25
17 VM #DISK F30
18 VM #DISK F31
19 VM #DISK F32
20 VM #DISK F40
21 VM #DISK F41
22 VM #DISK F42
23 VM *TAPE F50,J2031,B4UBR30,OLD,021673
24 VM #DISK F60
25 VM *DATA
26 *JEND

```

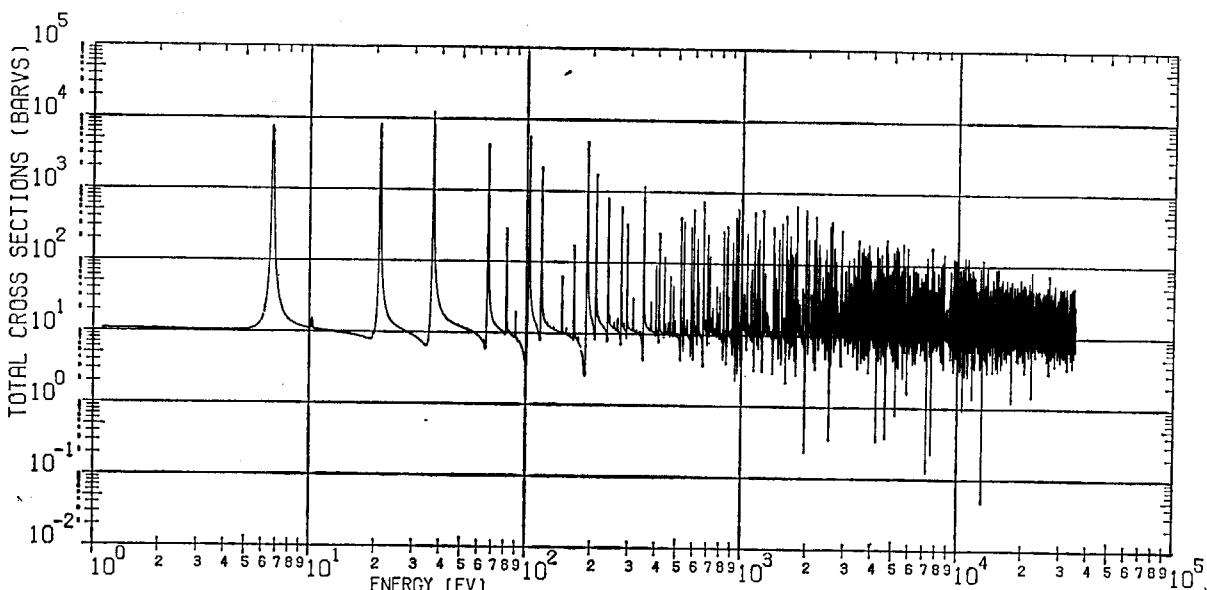


Fig. 5 Doppler broadened cross sections of  $^{238}\text{U}$  in the energy range from 0.215 eV to 46.5 keV

TABLES 12 and 13 show the Job-Control-Cards for the FACOM 230/75 and M 200 computer, respectively. The selection of necessary or unnecessary files can be seen from the relation between the data-files and calculation flow shown in Fig. 3.

TABLE 13 Job Control Cards and input data in TIMS-1 for FACOM-M 200 computer

```

L //JCLG JOB
// EXEC JCLG
//SYSIN DD DATA,DLM='++'
// JUSER 41102031.HI.TAKAN0.0431.100.TIMS
T.5 C.3 W.4 P.0 I.4 PLT
OPTP MSGCLASS=I,MSGLEVEL=(1,1),NOTIFY=J2031
// EXEC FORTHE,S0=J2031.TIMSHM,A=NOSOURCE,ELM(*),LINECOUNT(0)*,
// SYSOUT=I
// EXEC LKED,GRLIB=PLT,A=LET,XREF,BVLY*,
// SYSUT=I
//LINK.SYSIN DD *
OVERLAY SEGO
INSERT READFL,PREFL,FINDPT
OVERLAY SEGO
INSERT RONLY
OVERLAY SEGO
INSERT ARCF2,MGLDER,CLPSD
OVERLAY SEGO
INSERT ARCF3,FP0RT,FUG0,IMAX,P0RTER
OVERLAY SEGS3
INSERT BBLINP,BBL0UT,JFSOXS,FBL0CK,MKFIL0,RESOLV
OVERLAY SEGS3
***  

INSERT PARAV
OVERLAY SEGS3
INSERT RESINT,B0PUTPUT
OVERLAY SEGO
INSERT MCROSS,INTRD,INTB4
OVERLAY SEG4
INSERT SX,NBROAD
OVERLAY SEG4
INSERT BROAD,ENMESH
OVERLAY SEGO
INSERT PEAC06
OVERLAY SEGS5
INSERT INPUT,FNMESH
OVERLAY SEGS5
INSERT DATA
OVERLAY SEGS5
INSERT B0PT1
OVERLAY SEGS5
INSERT AVERAG,FLXCAL,B0PT2
OVERLAY SEGO
INSERT XSPLT,SRCH
ENTRY MAIN
NAME TIMSHM
***  

/*  

// EXEC G0.PNM=TIMSHM,SYSCUT=I  

// EXPAND TPDISK,DDN=FT01F001,DSN='J2031A'  

// EXPAND TPDISK,DDN=FT02F001,DSN='J2031B'  

// EXPAND TPDISK,DDN=FT03F001,DSN='J2031C'  

// EXPAND DISKT0,DDN=FT08F001,DSN='J1615.ENDFB409'  

// EXPAND DISK,DDN=FT09F001  

// EXPAND TPDISK,DDN=FT10F001,DSN='J2031DA'  

// EXPAND DISK,DDN=FT20F001
// EXPAND DISK,DDN=FT21F001
// EXPAND DISK,DDN=FT25F001
// EXPAND DISK,DDN=FT30F001
// EXPAND DISK,DDN=FT31F001
// EXPAND DISK,DDN=FT40F001
// EXPAND DISK,DDN=FT41F001
// EXPAND DISK,DDN=FT42F001
// EXPAND DISK,DDN=FT50F001
// EXPAND DISK,DDN=FT51F001
// EXPAND DISK,DDN=FT52F001
// EXPAND DISK,DDN=FT80F001
//SYSIN DD *
NEW TIMS TEST RUN U-238
1262
FILEREAD ARCFIT-2 ARCFIT-3 MCROSS PEAC0
&NAME1 &END
&NAME2 ICFT=1 &END
&NAME3 NOMS=4,CASE='U-238' &END
&NAME4 &END
&NAME5 NTEMP=1,KM0D=130 &END
&NAME6 NUCLID='U238','A30' &END
/*
++
//  

KE0525001 END OF DATA SET

```

```

L //JCLG JOB
// EXEC JCLG
//SYSIN DD DATA,DLM='++'
// JUSER 41102031.HI.TAKAN0.0431.100.TIMS
T.5 C.3 W.4 P.0 I.4 PLT
OPTP MSGCLASS=I,MSGLEVEL=(1,1),NOTIFY=J2031
// EXEC LMG0,LM=J2031.TIMS1',PNM=TIMS,SYSCUT=I
// EXPAND TPDISK,DDN=FT01F001,DSN='J2031A'  

// EXPAND TPDISK,DDN=FT02F001,DSN='J2031B'  

// EXPAND DISKT0,DDN=FT08F001,DSN='J2031C'  

// EXPAND DISK,DDN=FT09F001,DSN='J1615.ENDFB409'  

// EXPAND TPDISK,DDN=FT10F001,DSN='J2031DA'  

// EXPAND DISK,DDN=FT20F001
// EXPAND DISK,DDN=FT21F001
// EXPAND DISK,DDN=FT25F001
// EXPAND DISK,DDN=FT30F001
// EXPAND DISK,DDN=FT31F001
// EXPAND DISK,DDN=FT40F001
// EXPAND DISK,DDN=FT41F001
// EXPAND DISK,DDN=FT42F001
// EXPAND DISK,DDN=FT50F001
// EXPAND DISK,DDN=FT51F001
// EXPAND DISK,DDN=FT52F001
// EXPAND DISK,DDN=FT80F001
//SYSIN DD *
NEW TIMS TEST RUN U-238
1262
FILEREAD ARCFIT-2 ARCFIT-3 MCROSS PEAC0
&NAME1 &END
&NAME2 ICFT=1 &END
&NAME3 NOMS=4,CASE='U-238' &END
&NAME4 &END
&NAME5 NTEMP=1,KM0D=130 &END
&NAME6 NUCLID='U238','A30' &END
/*
++
//  

KE0525001 END OF DATA SET

```

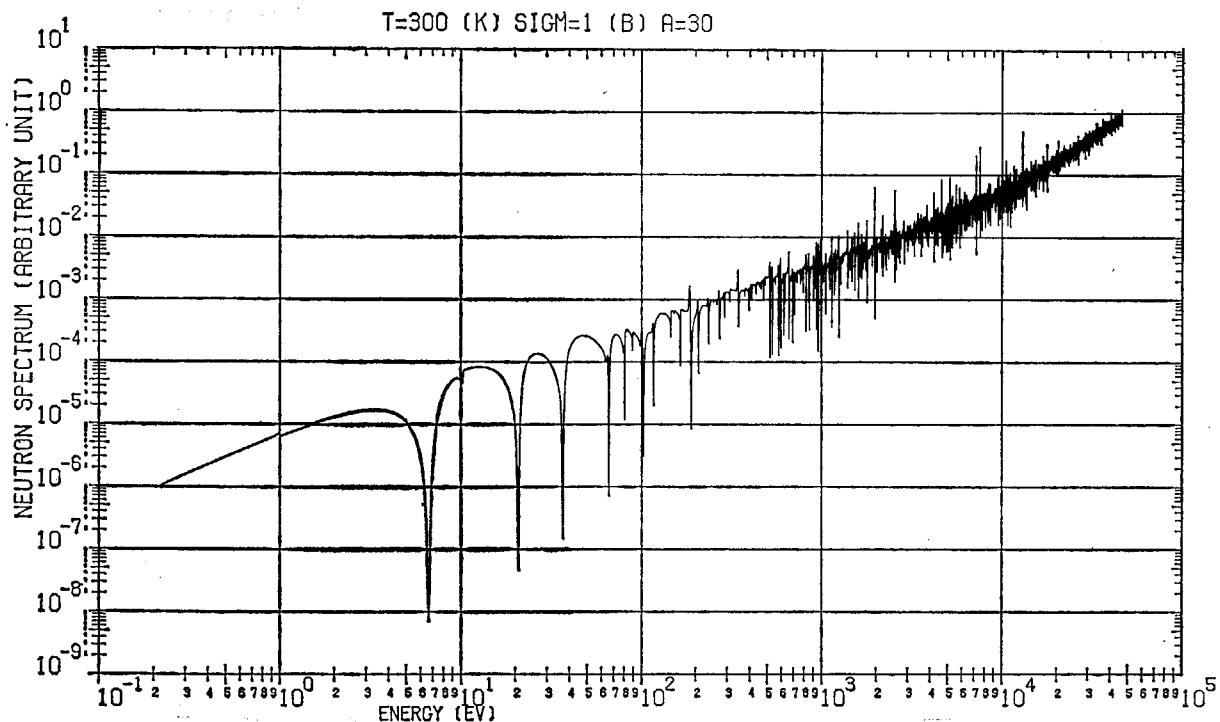
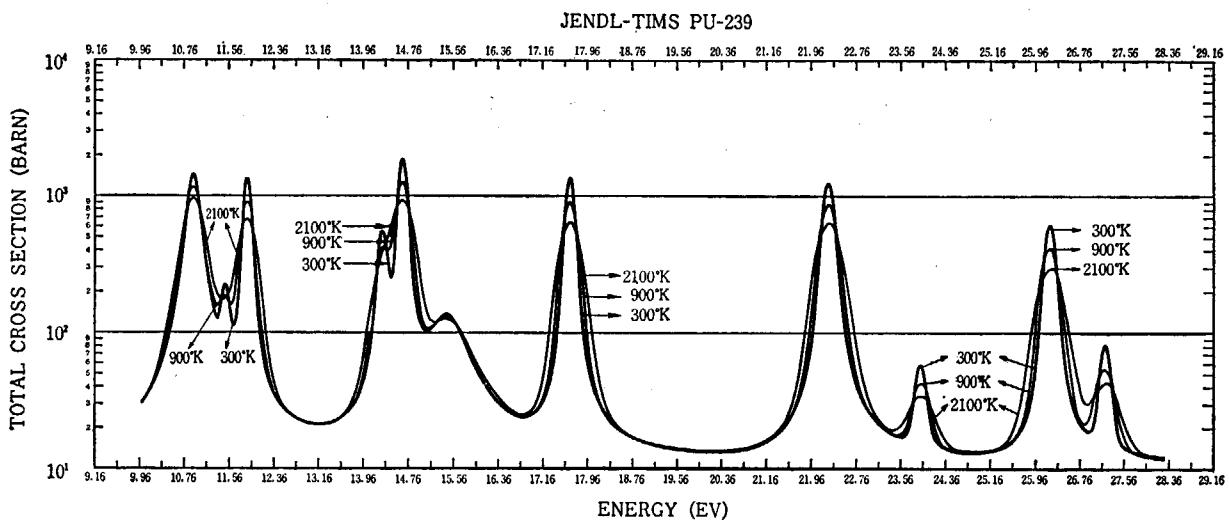


Fig. 6 Neutron spectra calculated with TIMS-1

Fig. 7 Temperature dependent cross sections of  $^{239}\text{Pu}$  in the energy range from 9.96 to 27.8 eV drawn with XSPL0T

## 6. Comparison Between Group Constants Produced by Processing Codes ETOX and TIMS-1

In this chapter, we study the influence of two different group cross sections sets on some integral quantities: One was produced by using the processing codes PROF-GROUH-G-II and ETOX, and another was produced by PROF-GROUCH-G-II and TIMS-1. The evaluated unclear data of JENDL-1<sup>26)</sup> were used in these calculations. The codes ETOX and TIMS-1 calculate the group cross sections of heavy resonant nuclides in the resonance energy regions. In the two sets, the group constants of light and medium nuclei and of heavy nuclei in smooth region above resonance energy have been calculated by the PROF-GROUCH-G-II code. Thus, the effects of different methods between TIMS and ETOX on integral quantities can be studied by performing the neutronics calculation using two group constants sets.

In the ETOX code, the effective group cross sections are calculated by assuming the constancy of collision density. Moreover, the isolated narrow resonance approximation is used in the unresolved resonance region. On the other hand, in order to avoid the calculational errors<sup>9)</sup> caused from these approximations, the TIMS-1 code calculates the effective cross sections by directly solving the neutron slowing down equation using the recurrence formula for slowing down source. For this purpose, the TIMS-1 code generates a ladder of resonance levels and parameters by using Monte Carlo method in the unresolved resonance region.

The self-shielding factors calculated with two codes TIMS-1 and ETOX are compared and some integral quantities, such as effective multiplication factors and Doppler reactivity worths were calculated by using these different group constants sets, and compared with the experimental results.

### 6.1 Comparison Between Self-Shielding Factors Calculated with the TIMS-1 and ETOX Codes

The self-shielding factors calculated with the TIMS-1 and ETOX codes are compared for some typical energy groups in Figs. 8 to 10. In these figures, the quantity  $\sigma_0$  expresses the admixture background scattering cross section of Bondarenko's type.

Figure 8 shows the comparison of the self-shielding factors for fission cross sections of  $^{235}\text{U}$ . The differences between the self-shielding factors obtained by the codes TIMS-1 and ETOX are considerably observed from this figure. The composition dependence of the self-shielding factors calculated by the TIMS-1 code is larger than that by the ETOX code. The temperature coefficients of the self-shielding factors are also different

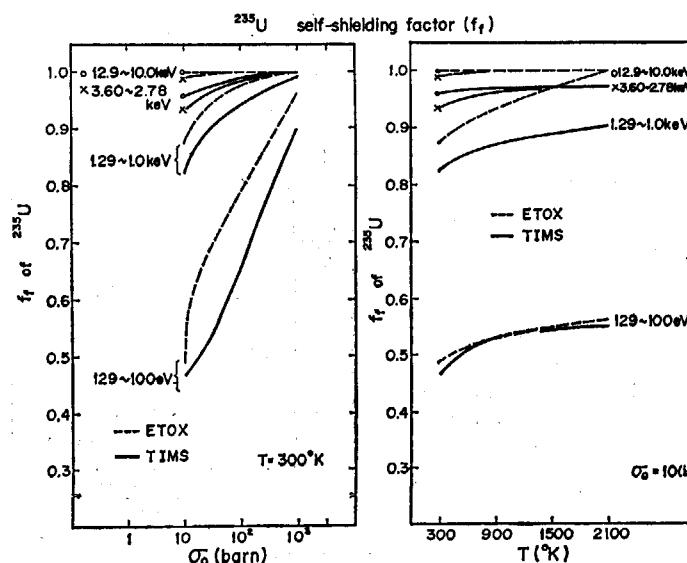


Fig. 8 Comparison of fission self-shielding factors of  $^{235}\text{U}$  calculated with the TIMS-1 and ETOX codes

between the results of TIMS-1 and ETOX.

In Fig. 9, the self-shielding factors for capture cross sections of  $^{238}\text{U}$  are compared for several energy groups. The discrepancies between the self-shielding factors depend on the compositions, i. e.  $\sigma_0$ -values. Here, a small  $\sigma_0$ -value corresponds to the  $\sigma_0$ -value for high enriched fuel systems, where the  $1/E$  neutron spectrum assumed in the ETOX code differ considerably from the accurate spectrum calculated by the TIMS-1 code. Hence, the discrepancies between the self-shielding factors may be mostly attributed to the difference in the neutron spectra assumed for the calculation.

Fig. 10 shows the self-shielding factors for fission cross sections of  $^{239}\text{Pu}$  for several energy groups. The results compared between the self-shielding factors can be similarly summarised to those observed for  $^{235}\text{U}$  and  $^{238}\text{U}$  as mentioned above.

In the next section, thus, we study the effects of the differences between the self-shielding factors on the integral quantities in fast reactor systems.

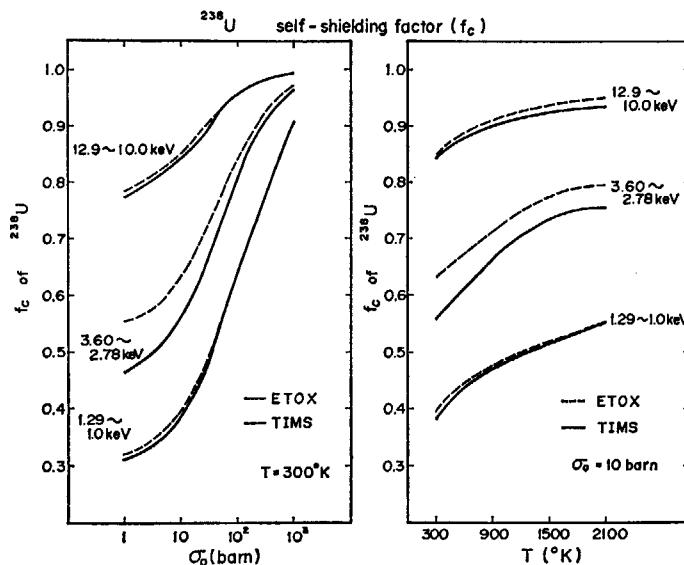


Fig. 9 Comparison of capture self-shielding factors of  $^{238}\text{U}$  calculated with the TIMS-1 and ETOX codes

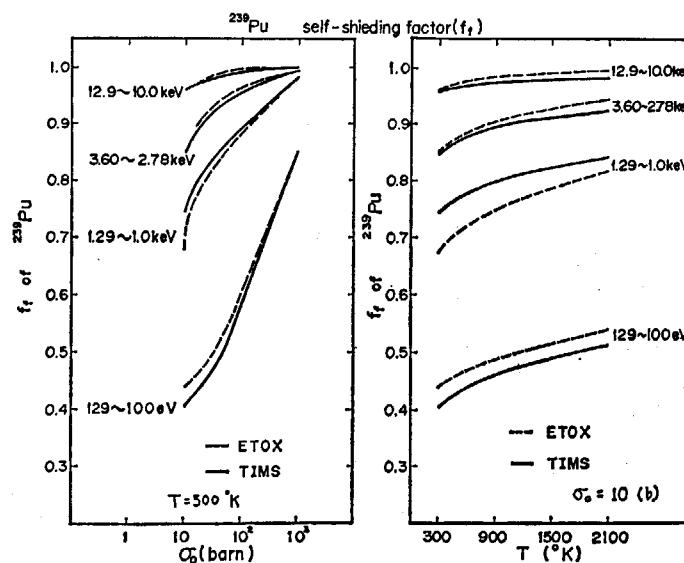


Fig. 10 Comparison of fission self-shielding factors of  $^{239}\text{Pu}$  calculated with the TIMS-1 and ETOX codes

### 6.2 Comparison of Integral Quantities Calculated by Using Two Multigroup Cross Section Sets

The differences between the two cross-section sets produced by the TIMS-1 and ETOX codes exist only in the effective cross sections of heavy nuclides in the resonance energy regions. As integral quantities to be studied, we selected the effective multiplication factor ( $k_{\text{eff}}$ ), Doppler reactivity effect and sodium void reactivity effect. The neutronics calculation were performed with the use of diffusion theory code.

Main characteristics of fast reactor critical assemblies used for the neutronics calculations are summarized in TABLE 14. Assembly FCA-VI-1 is the physics mockup core of JOYO (Experimental Fast Reactor). The SEFOR assembly is the testing core for both static power reactivity and rapid super-prompt-critical reactivity measurements. The benchmark specification model<sup>24)</sup> was used in the present calculation. The assemblies ZPPR-2 and ZPR-6-7 are the demonstration fast reactor benchmark core to provide physics data necessary for LMFBR design.

TABLE 14 Main Characteristics of Fast Reactor Critical Assemblies

Assembly	Fuel	R=Fertile/Fissile		Core volume (l)
		Inner core	Outer core	
FCA-VI-1	Pu U	4.3	3.0	473
SEFOR	Pu	4.3		558
ZPPR-2	Pu	6.5	4.0	2400
ZPR-6-7	Pu	6.5	6.5	2920
LMFBR*	Pu	8.7	6.6	9950

\* Large sodium-cooled fast breeder reactor for an international comparison calculation

#### Effective Multiplication Factor

The effective multiplication factors calculated with the two-dimensional R-Z homogeneous model are shown in TABLE 15. The differences between the effective multiplication factors calculated by using the two sets are negligibly small for FCA-VI-1 and SEFOR, but are larger than 0.1 percent for the other ones. These results cannot be ignored, compared with the value 0.2% that is the accuracy<sup>25)</sup> of goal requested from design study for a large fast breeder reactor.

#### Sodium Void Reactivity Effect

The experimental results of sodium void reactivity effect in ZPPR assembly 2 have been analyzed with one-dimensional spherical homogeneous model. The sodium-voided zone consists of 93 matrix positions with all voided 12 inches each half core. In the present analysis, some corrections such as two-dimensional, cell-heterogeneity and neutron streaming effects were not considered, because the present aim lies only in studying the influence of two different calculational methods for group constants on sodium void reactivity worth.

TABLE 16 shows the comparison of the sodium void reactivity separated in each component term. The difference between the two different sets is -3% for the total reactivity,  $0.0075(\Delta k/k)$ , though the differences by 6.5% and 11% are observed for " $\Sigma_r$ " and " $v\Sigma_i$ " components, respectively. The difference in the total reactivity  $2.4 \times 10^{-4}(\Delta k/k)$  is not small in comparison with the goal accuracy 0.3%<sup>25)</sup>.

TABLE 15 Effective Multiplication Factors Calculated with the Code 2-Dimensional R-Z Diffusion

Set Assembly	TIMS-1	ETOX	TIMS/ETOX
FCA-VI-1	0.99797	0.99819	0.9998
ZPPR-2 L-90 (normal)	0.99135	0.99275	0.9986
ZPR-6-7 (H 240)	0.99022	0.99134	0.9989
LMFBR (Na-in)	1.02372	1.02494	0.9988
SEFOR	1.02327	1.02332	0.9999

TABLE 16 Central Na-void Reactivity by 70-Group 1-Dimensional 1st Order Perturbation Calculation in ZPPR-2 Assembly

Set Component \ Set	TIMS-1	ETOX	Difference between TIMS-1 and ETOX
$\Delta k$ by $\nu\Sigma_f$	-3.632-5	-3.281-5	-3.51-6
$\Delta k$ by $\Sigma_e$	3.556-3	3.340-3	2.16-4
$\Delta k$ by $\Sigma_a$	1.134-3	1.112-3	2.20-5
$\Delta k$ by $\Sigma_{is}$	3.340-3	3.326-3	1.40-5
$\Delta k$ by $D$	-4.884-4	-4.826-4	-5.80-6
Total reactivity ( $\Delta k/k$ )	7.505-3	7.262-3	2.43-4

#### Doppler Reactivity Effect

The experiment in ZPPR assembly 2 was the sample Doppler reactivity measurement for the natural  $UO_2$  ( $NUO_2$ ), and in SEFOR assembly was the measurement of the isothermal Doppler coefficient for the full core.

The results analysed for the  $NUO_2$  sample Doppler experiment in ZPPR-2 are shown in TABLE 17. The calculation was performed with the one-dimensional first-order perturbation theory. Both the results calculated for the two-sets are larger than the experimental values by 10-14%, though either result is in good agreement with each other. However, the comparison of the groupwise Doppler reactivity worth in Fig. 11 indicates remarkable discrepancies between the calculated results. It is observed that the results of ETOX are larger than ones of TIMS-1 in the unresolved resonance region and reversely small in the resolved region. This tendency produces an accidental cancellation between the results of ETOX and TIMS-1 for the total Doppler reactivity and the results give nothing but good agreement.

The results analysed for the Doppler reactivity measurement of full core in SEFOR assembly are compared in TABLE 18 and Figs. 12 and 13. This analysis was performed with the first-order perturbation theory using two-dimensional R-Z benchmark model. In both the results of ETOX and TIMS-1, the positive Doppler reactivity by fission component term is more than about 30% of the negative one by capture. The differences

TABLE 17 Comparison of Doppler Reactivity Effects Calculated with One-Dimensional First Order Perturbation Code using Two Different Cross Sections Sets in ZPPR-2

T (°K)	Exp. ( $\times 10^{-6} \Delta k/k$ )	Calculation ( $\times 10^{-6} \Delta k/k$ )	
		TIMS-1	ETOX
300-500	-2.41	-2.656 (1.10)	-2.690 (1.12)
300-800	-4.93	-5.497 (1.12)	-5.547 (1.13)
300-1100	-6.76	-7.540 (1.12)	-7.589 (1.14)

The C/E-values are shown in the parentheses

TABLE 18 Comparison between Reactivity Components Calculated with Two-Dimensional First Order Perturbation Code in SEFOR Assembly

	Exp.	Calculation ( $\times 10^{-3} \Delta k/k$ )		
		TIMS-1	ETOX	ETOX/TIMS-1
$\nu\Sigma_f$		3.817	3.388	0.89
$\Sigma_e$		-10.19	-9.983	0.98
Total		-6.326	-6.537	1.03
$T\frac{\Delta k}{k}$	-8.10	-9.610 (1.19)	-9.981 (1.23)	1.04

The C/E-values are shown in the parentheses

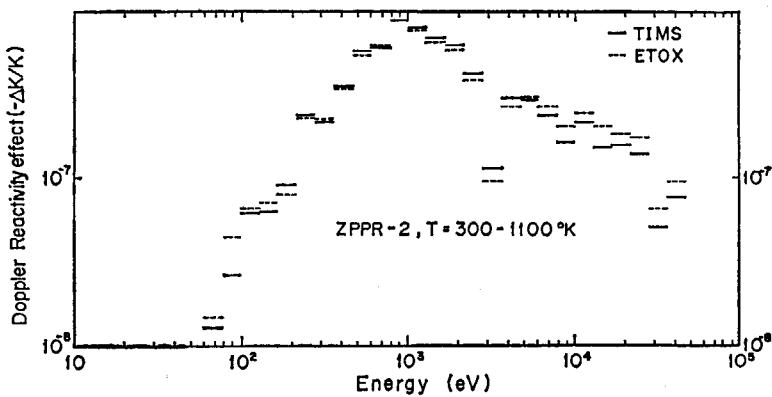


Fig. 11 Energy group-wise contribution of Doppler reactivity effect calculated by one-dimensional first order perturbation code in ZPPR assembly 2.

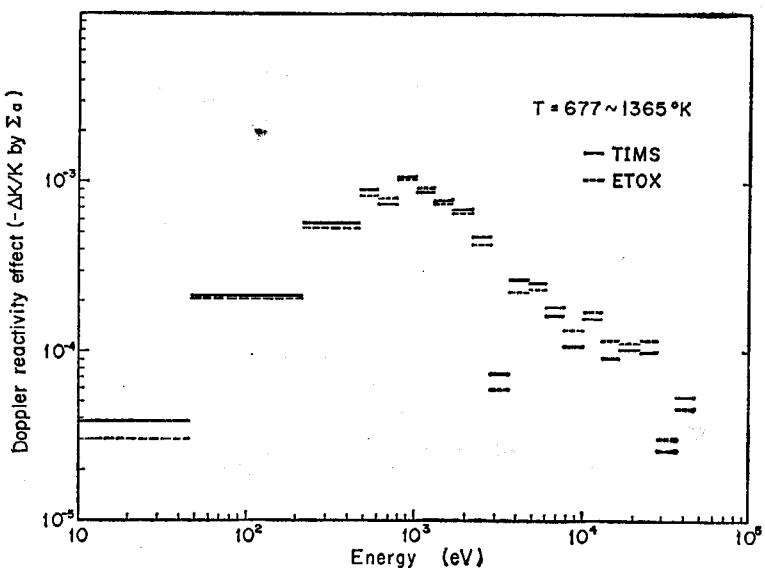


Fig. 12 Energy group-wise contribution of fission Doppler reactivity effect calculated by two-dimensional first order perturbation code in SEFOR assembly

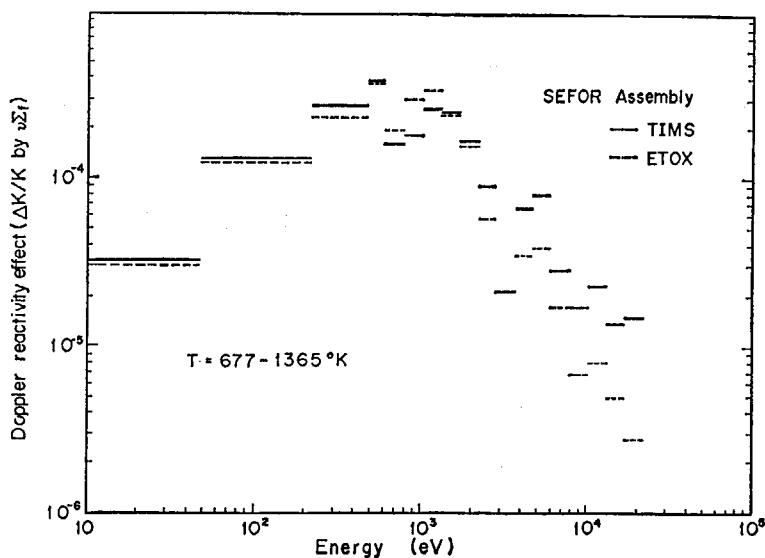


Fig. 13 Energy group-wise contribution of capture Doppler reactivity effect calculated by two-dimensional first order perturbation code in SEFOR assembly

in the group-wise fission component terms between TIMS-1 and ETOX is remarkable as seen from Fig. 12, and the result of TIMS-1 is larger than the one of ETOX, especially in the unresolved region. The differences between the capture component terms show a similar tendency also in the results of the NUO<sub>2</sub> sample Doppler analysis indicated in Fig. 13. The different tendencies for the fission and capture terms between the results of TIMS-1 and ETOX can be estimated simply from the fact that the temperature dependence of the self-shielding factors differs between the results of TIMS-1 and ETOX, depending on the  $\sigma_0$ -values. The discrepancy between TIMS-1 and ETOX for the total Doppler reactivity worth is -4% while the goal accuracy<sup>25)</sup> for Doppler effect is 7%.

### 6.3 Conclusions

The temperature and composition dependence of effective group cross sections calculated with the processing code ETOX differ considerably from those calculated with the TIMS-1 code. Particularly as for the Doppler effect of the shielding factors, the difference between the results of TIMS-1 and ETOX depends strongly on the energy groups and the compositions. The effects of these differences on the effective multiplication factor, Na-void effect and Doppler effect were studied and were no more than 0.15%, -3% and -4% respectively. These values are not so small as to be ignored compared with the goal accuracy requested from design study in a large fast breeder reactor.

### 7. Conclusions

The very severe accuracies of goal for important nuclear characteristics are required from the design study on a large fast breeder reactor. In order to satisfy the goal accuracies, there are many problems to be studied in detail. It is one of them that errors caused by the conventional approximations should not be included in the group constants used for reactor calculations. For this purpose, we were developed the TIMS-1 code which calculates the group average cross sections by solving numerically the neutron slowing down equation. This code prepares also a very useful tool to calculate the mutual shielding factors.

The analyses for several fast critical assemblies were performed by the use of the group constants generated by TIMS-1 and ETOX. It was concluded from the computational results that the rigorous treatment for the group constants were needed for the reactor calculations. Especially, it will be so for reaction rate calculation because of a softer neutron spectrum at blanket region in a large fast reactor.

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**Appendix A. Code Abstract (in Nucl. Sci. Eng. Format)**

1. Program Identification : TIMS-1 is a code for calculating the group constants of heavy resonant nuclei by using ENDF/B-IV format data.
2. Function : This code<sup>1)</sup> calculates infinitely dilute cross sections and self-shielding factors as a function of composition  $\sigma_0$ , temperature  $T$  and  $R$ -parameter, where  $R$  is the ratio of atomic number density of two different resonant nuclei.
3. Method of Solution : In the unresolved resonance region, a ladder of resonance parameters and levels is generated with Monte Carlo method. The temperature dependent cross sections are calculated with the Breit-Wigner single-level and multi-level formula<sup>2)</sup>. The neutron spectrum is accurately calculated by solving numerically the neutron slowing down equation using a recurrence formula for neutron slowing down source<sup>3)</sup>.
4. Related Material : The ENDF/B-IV or JENDL nuclear data file is adopted as input data.
5. Restrictions : The maximum numbers of energy groups, temperatures and compositions are 60, 4 and 10 respectively.
6. Computer : This code has been run on FACOM 230-model 75 and M-200.
7. Running Time : The computation time depends considerably on the materials to be calculated and the permissible errors to be assumed for the generated cross sections in the unresolved region. The computation times are about 12 minutes for the production of group constants of  $^{238}\text{U}$  for one temperature and 8 composition variables using FACOM 230/75.
8. Programming Language : FORTRAN language is used for the source deck of about 6000 cards.
9. Operating System : FACOM-230 M-V operating system is used with FORTRAN IV H-level compiler.
10. Machine Requirements : A 97000 word core is needed, and larger memory of auxiliary disk storage is required.
11. Material Available : FORTRAN source deck card images and documentation are available to users from the Computer Center at JAERI.
12. References :
  1. H. Takano, Y. Ishiguro and Y. Matsui, "TIMS-1 : A Processing Code for Production of Group Constants of Heavy Resonant Nuclei" JAERI 1267, 1980.
  2. H. Takano, Y. Ishiguro ; J. Nucl. Sci. Technol., 14 [9], 627, 1977.
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### Appendix B. Sample Output Lists of TIMS-1

MATERIAL NO. TO BE CALCULATED = 1262  
OPTION IDENTIFICATION FOR TIMS2-CODE  
FILEREAD ARCFIT-2 ARCFIT-3 MCROSS PEACO  
THIS CALCULATION THROUGH FOLLOWING SUBROUTINE  
##### FILEREAD #####  
##### ARCFIT-2 #####  
##### ARCFIT-3 #####  
##### MCROSS #####  
##### PEACO #####

START SUBROUTINE ##FILEREAD## \*\*\*\*NEW TIMS TEST RUN U-238

\*\*\*\*\*

LOGICAL UNIT = 1  
\*\*\*\*\* RESOLVED PARAMETER \*\*\*\*\*

SLBW PARAMETERS

LOGICAL UNIT = 2  
\*\*\*\*\* UNRESOLVED PARAMETER \*\*\*\*\*

ALL PARAMETERS ARE ENERGY DEPENDENT

LOGICAL UNIT = 3  
\*\*\*\*\* SMOOTH PART CROSS SECTION \*\*\*\*\*

FILE PROCESSING NORMAL END

START SUBROUTINE ##ARCFIT-2## \*\*\*\*NEW TIMS TEST RUN U-238

\*\*\*\*\*

CHECK WRITE OPTION = 0  
COLAPSED OPTION = 2

#### SUMMARY OF RESULTS

ENERGY	SIGTF	SIGTG	SIGTN	ALPHA	SIGIN	SIGTP	SIGTT
45000.0	0.0	0.3386	12.4722	0.0	0.0	9.5590	12.8108
40000.0	0.0	0.3582	12.5236	0.0	0.0	9.6079	12.8818
35000.0	0.0	0.3836	12.6278	0.0	0.0	9.6651	13.0114
30000.0	0.0	0.4174	12.7912	0.0	0.0	9.7317	13.2086
25000.0	0.0	0.4646	13.0286	0.0	0.0	9.8089	13.4931
20000.0	0.0	0.5136	13.2833	0.0	0.0	9.8986	13.7969
15000.0	0.0	0.5952	13.7132	0.0	0.0	10.0036	14.3084
12000.0	0.0	0.6490	14.0526	0.0	0.0	10.0758	14.7016
10000.0	0.0	0.7076	14.3854	0.0	0.0	10.1289	15.0930
8500.0	0.0	0.7286	14.6621	0.0	0.0	10.1718	15.3907
7500.0	0.0	0.7890	14.9428	0.0	0.0	10.2023	15.7317
6500.0	0.0	0.8615	15.2762	0.0	0.0	10.2345	16.1377
5500.0	0.0	0.9327	15.6708	0.0	0.0	10.2687	16.6035
4500.0	0.0	1.0200	16.1800	0.0	0.0	10.3055	17.2000
4125.0	0.0	1.0528	16.4118	0.0	0.0	10.3201	17.4646

\*\*\*\*\* GROUP NUMBER \*\*\*\*\* 15  
\*\*\*\*\* COLLAPSED GROUP NUMBER \*\*\*\*\* 9

START CHECK  
1 2 3 4 5 6 7 8 10  
4.7500E+04 4.2500E+04 3.7500E+04 3.2500E+04 2.7500E+04 2.2500E+04 1.7500E+04 1.3500E+04 1.1000E+04 9.2500E+03  
8.0000E+03 7.0000E+03 6.0000E+03 5.0000E+03 4.2500E+03 4.0000E+03

```

START SUBROUTINE ##ARCFIT-3## **** NEW TIMS TEST RUN U-238 ****

N TYPES      NGRD
2          9

OPTION LIST
NOPT1    ICFT   ISTART   LCPT   IROPT   IPOPT   IEPXS   IPARA   IPSET
0        1       1         0       1       0       0       0       0

ENERGY BOUNDARIES
4.7500E+04  4.2500E+04  3.7500E+04  3.2500E+04  2.7500E+04  2.2500E+04
1.7500E+04  1.2500E+04  9.2500E+03  4.0000E+03

CROSS SECTIONS AND ERRORS
***** CAPTURE ***** ***** SCATTERING *****
3.38562E-01  5.0000CE-02  1.24722E+01  5.00000E-02
3.58221E-01  5.00000E-02  1.25236E+01  5.00000E-02
3.83555E-01  5.00000E-02  1.26278E+01  5.00000E-02
4.17410E-01  5.00000E-02  1.27912E+01  5.00000E-02
4.64554E-01  5.00000E-02  1.30266E+01  5.00000E-02
5.13580E-01  5.00000E-02  1.32833E+01  5.00000E-02
5.95168E-01  5.00000E-02  1.37132E+01  5.00000E-02
6.73177E-01  5.00000E-02  1.41896E+01  5.00000E-02
8.61362E-01  5.00000E-02  1.53248E+01  5.00000E-02

NUMBER OF WAVE TYPES = 2

ATOMIC MASS NUMBER (A.M.U) = 2.36010E+02
ATOMIC RADIUS (FERMIS) = 9.18400E-01
MAX. NO. OF FISSION CHANNELS = 0
MAX. NO. OF 1ST INELASTIC CHANNELS = 1

ENERGY OF 1-ST INELASTIC CHANNELS = 2.00000E+07

EVALUATED AND GENERATED CROSS SECTIONS
GROUP NO. ENERGY RANGE (EV) SIGMA-C (BARN) SIGMA-S (BARN)
          EVA.     CAL.     CAL./EVA.     EVA.     CAL.     CAL./EVA.
1      47500.00  42500.00  0.33856  0.34947  1.03222  12.47225  12.26059  0.98303
2      42500.00  37500.00  0.35822  0.35585  0.99338  12.52360  12.63141  1.00861
3      37500.00  22500.00  0.38355  0.38729  1.00975  12.62785  12.55292  0.99407
4      32500.00  27500.00  0.41741  0.41328  0.99010  12.79123  12.82664  1.00277
5      27500.00  22500.00  0.46455  0.47460  1.02163  13.02656  13.15120  1.00942
6      22500.00  17500.00  0.51259  0.51118  0.99532  13.28332  12.89464  0.97075
7      17500.00  13500.00  0.59517  0.59421  0.99838  13.71324  13.74762  1.00251
8      13500.00  9250.00   0.67318  0.64361  0.95608  14.18959  14.03802  0.98932
9      9250.00   4000.00   0.86136  0.86228  1.00107  15.32481  15.40446  1.00520

DIFFERENCE OF CROSS SECTION WITH J.F.S. TYPE ENERGY BOUNDARY
GROUP START END DELTA X-SECTION
NO. ENERGY ENERGY (BARN)
           CAPTURE ELASTIC
23  4.6500E+04  3.6000E+04 -3.55998E-03  4.00011E-02
24  3.6000E+04  2.7800E+04  7.72764E-04  1.16860E-02
25  2.7800E+04  2.1500E+04 -7.39866E-03  -3.74228E-02
26  2.1500E+04  1.6600E+04  2.13742E-03  3.10814E-01
27  1.6600E+04  1.2900E+04  5.60155E-03  -4.22186E-03
28  1.2900E+04  1.0000E+04  2.95669E-02  1.51570E-01
29  1.0000E+04  7.7300E+03  9.15265E-03  -3.25493E-03
30  7.7300E+03  5.9800E+03 -9.20177E-04  -7.96490E-02
31  5.9800E+03  4.6500E+03 -9.20177E-04  -7.96490E-02
32  4.6500E+03  3.6000E+03 -5.69633E-04  -4.93065E-02

```

GRCP	NO.	AVERAGE CROSS SECTION AND RESONANCE PARAMETER				D-BAR	GAMMA-N <u>o</u>	GAMMA-FF	STR.F
		L	J	SIGMA-C	SIGMA-F				
1	0	0.50	0.08467	0.0	1.70964	18.72658	0.00173	0.0	9.24323E-05
1	0.50	0.06477	0.0	0.37408		18.79698	0.00322	0.0	1.71432E-04
1	1.50	0.20003	0.0	0.61765		9.86193	0.00158	0.0	1.60077E-04
	TOTAL		0.34947	0.0	12.26059				
	POTENTIAL SCATTERING				9.55902				
2	0	0.50	0.09859	0.0	2.10410	16.65671	0.00200	0.0	1.07267E-04
1	0.50	0.07034	0.0	0.31079		17.92114	0.00279	0.0	1.55757E-04
1	1.50	0.18692	0.0	0.60658		10.77586	0.00175	0.0	1.62567E-04
	TOTAL		0.35585	0.0	12.63141				
	POTENTIAL SCATTERING				9.60794				
3	0	0.50	0.11197	0.0	2.12059	18.45010	0.00167	0.0	1.01380E-04
1	0.50	0.07265	0.0	0.25680		19.23076	0.00273	0.0	1.41738E-04
1	1.50	0.20267	0.0	0.51038		10.35197	0.00159	0.0	1.53366E-04
	TOTAL		0.38729	0.0	12.55292				
	POTENTIAL SCATTERING				9.66514				
4	0	0.50	0.12066	0.0	2.48655	19.37984	0.00213	0.0	1.09917E-04
1	0.50	0.06853	0.0	0.19991		20.16129	0.00247	0.0	1.22735E-04
1	1.50	0.22409	0.0	0.40049		10.35197	0.00150	0.0	1.44802E-04
	TOTAL		0.41328	0.0	12.82664				
	POTENTIAL SCATTERING				9.73169				
5	0	0.50	0.15808	0.0	2.71813	17.66783	0.00195	0.0	1.10578E-04
1	0.50	0.07776	0.0	0.21917		19.30501	0.00283	0.0	1.46450E-04
1	1.50	0.23877	0.0	0.40513		10.42841	0.00165	0.0	1.59077E-04
	TOTAL		0.47469	0.0	13.15128				
	POTENTIAL SCATTERING				9.80586				
6	0	0.50	0.17923	0.0	2.50252	19.08397	0.00177	0.0	9.27566E-05
1	0.50	0.09298	0.0	0.19438		19.15707	0.00299	0.0	1.56062E-04
1	1.50	0.23897	0.0	0.29937		10.89325	0.00160	0.0	1.46657E-04
	TOTAL		0.51118	0.0	12.89484				
	POTENTIAL SCATTERING				9.89856				
7	0	0.50	0.23125	0.0	3.33902	19.70442	0.00213	0.0	1.08082E-04
1	0.50	0.11018	0.0	0.16129		18.43317	0.00204	0.0	1.65181E-04
1	1.50	0.25278	0.0	0.24374		10.69519	0.00152	0.0	1.51350E-04
	TOTAL		0.59421	0.0	13.74762				
	POTENTIAL SCATTERING				10.00356				
8	0	0.50	0.27677	0.0	3.70640	19.95305	0.00206	0.0	1.03320E-04
1	0.50	0.09541	0.0	0.09997		19.95305	0.00272	0.0	1.36278E-04
1	1.50	0.27143	0.0	0.15584		10.73232	0.00161	0.0	1.50144E-04
	TOTAL		0.64361	0.0	14.03802				
	POTENTIAL SCATTERING				10.07581				
9	0	0.50	0.47099	0.0	5.07420	20.50781	0.00222	0.0	1.08034E-04
1	0.50	0.12246	0.0	0.08056		20.42801	0.00380	0.0	1.85951E-04
1	1.50	0.26084	0.0	0.07785		11.02941	0.00172	0.0	1.55864E-04
	TOTAL		0.86228	0.0	15.40446				
	POTENTIAL SCATTERING				10.12967				
***** AVERAGE *****									
					19.07056	0.00198	0.0	1.03684E-04	
					19.24776	0.00296	0.0	1.53725E-04	
					10.55568	0.00162	0.0	1.53897E-04	

```

START SUBROUTINE ##MCCROSS ## ****NEW TIMS TEST RUN U-238 ****
MICROSCOPIC CROSS SECTIONS OF 236 ARE CALCULATED BY SINGLELEVEL FORMULA

NO. OF FISSION CHANNELS = 0

NO. OF RESONANCE PARAMETERS ----
    S-WAVE PARAMETERS ---- 25 100 71
    P-WAVE PARAMETERS ---- 57 100 1
    D-WAVE PARAMETERS ---- 0 100 0

NO. OF S-WAVE RESONANCES IN THE SUMMATIONS = 20      S-S INTERFERENCE EFFECT ----VOGT = 0
NO. OF P-WAVE RESONANCES IN THE SUMMATIONS = 20      NO. OF IMP = 8

TEMPERATURES (K) 200.000
ATOMIC RADIUS = 0.6401 SCATTERING RADIUS = 0.9184

ENERGY BOUNDARIES, MESH WIDTHS AND NO. OF MESH POINTS
1.0000E+04 4.6500E+03 9.99632D-05 766 10 100
4.6500E+03 1.00000E+03 2.00113D-04 768 10 100
1.0000E+03 4.65000E+02 1.99926D-04 283 10 100
4.6500E+02 1.00000E+02 2.4987D-04 615 10 100
1.0000E+02 4.65000E+01 2.4941D-04 307 10 100
4.6500E+01 1.00000E+01 4.98982D-04 308 10 100
1.0000E+01 4.65000E+00 5.00469D-04 153 10 100
4.6500E+00 2.00000E-01 4.9941D-04 630 10 100

***** FLOWER XS ENERGY RANGE *****
FROM = 0.45000E+05 TO 1.00000E+01

```

UPPER E	LOWER E	TOTAL	CAPTURE	ELASTIC	FISSION	MULTI.F	MULTI.N
1.0000E+04	4.6500E+03	1.5948E+01	8.2555E+01	1.5123E+01	9.0539E-06	0.0	0.0
4.6500E+03	1.00000E+03	2.0122E+01	1.5264E+00	1.8596E+01	6.2145E-05	0.0	0.0
1.0000E+03	4.65000E+02	2.3434E+01	3.3232E+00	2.0110E+01	5.7743E-04	0.0	0.0
4.6500E+02	1.00000E+02	5.6445E+01	1.2606E+01	4.3839E+01	0.0	0.0	0.0
1.0000E+02	4.65000E+01	4.2543E+01	1.6550E+01	2.5986E+01	0.0	0.0	0.0
4.6500E+01	1.00000E+01	6.2460E+02	6.2444E+01	0.0	5.6359E+01	0.0	0.0
1.0000E+01	4.65000E+00	1.8966E+02	1.6972E+02	1.9960E+01	0.0	0.0	0.0
4.6500E+00	2.00000E-01	1.0042E+01	6.4522E-01	9.3964E+00	0.0	0.0	0.0

```

START SUBROUTINE ##PEACO ## ****NEW TIMS TEST RUN U-238 ****

```

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

```

1 8 1 45 0 0
0.0 1.00000E+00 1.00000E+01 1.00000E+02 1.00000E+03 1.00000E+04
1.00000E+05 1.00000E+06
3.00000E+02
7.10170E+03 5.52080E+03 4.30740E+03 3.25460E+03 2.61260E+03 2.03470E+03
1.58460E+03 1.23410E+03 9.61120E+02 7.48520E+02 5.82950E+02 4.54000E+02
3.52580E+02 2.75360E+02 2.14450E+02 1.67020E+02 1.30070E+02 1.01300E+02
7.88920E+01 6.14420E+01 4.78510E+01 3.72670E+01 2.90220E+01 2.26020E+01
1.76030E+01 1.37100E+01 1.06770E+01 8.31520E+00 6.47600E+00 5.04350E+00
3.92790E+00 3.05900E+00 2.32240E+00 1.85540E+00 1.63740E+00 1.44500E+00
1.27520E+00 1.12540E+00 9.93140E-01 8.76420E-01 7.73440E-01 6.82560E-01
6.02360E-01 5.21560E-01 4.69110E-01 4.13990E-01

```

\*\* OUTPUT FROM LIBRARY TAPE \*\*

NUCLID *** 1262	TAPE NO./TEMPT(NT)/KREST/NOXG/EXG(1)/MAXNFI ***	50	300.00	236.0100	8	10000.00	10
EXG/UIGP/NCIG/NFI ***	4650.00	0.0010	766	10			
EXG/UIGP/NCIG/NFI ***	1000.00	0.0020	768	10			
EXG/UIGP/NCIG/NFI ***	465.00	0.0020	283	10			
EXG/UIGP/NOIG/NFI ***	100.00	0.0025	615	10			
EXG/UIGP/NOIG/NFI ***	46.50	0.0025	307	10			
EXG/UIGP/NCIG/NFI ***	10.00	0.0050	308	10			
EXG/UIGP/NOIG/NFI ***	4.65	0.0050	153	10			
EXG/UIGP/NCIG/NFI ***	0.20	0.0050	630	10			

## \*\*\*\*\* LIST OF INFORMATION ON GROUP STRUCTURE FOR X-SECTION AVERAGE \*\*\*\*\*

NO.	EN(N)	EN(N+1)	DELTA-U	NBG(N)	NIB(N)
1	7104.375	5527.844	0.25091	252	252
2	5527.844	4300.552	0.25098	464	212
3	4300.852	3249.031	0.25014	589	125
4	3249.031	2613.080	0.24814	713	124
5	2613.080	2034.779	0.25014	828	125
6	2034.779	1584.461	0.25014	963	125
7	1584.461	1233.804	0.25014	1068	125
8	1233.804	960.786	0.25010	1212	125
9	960.786	748.327	0.24991	1338	125
10	748.327	582.650	0.24991	1463	125
11	582.850	453.511	0.25091	1586	123
12	453.511	353.232	0.24990	1626	100
13	353.232	275.126	0.24990	1766	100
14	275.126	214.291	0.24990	1866	100
15	214.291	166.908	0.24990	1966	100
16	166.908	130.002	0.24990	2066	100
17	130.002	101.256	0.24990	2166	100
18	101.256	78.902	0.24944	2266	100
19	78.902	61.331	0.25191	2387	101
20	61.331	47.792	0.24942	2487	100
21	47.792	37.147	0.25198	2543	56
22	37.147	28.945	0.24949	2593	50
23	28.945	22.554	0.24949	2643	50
24	22.554	17.574	0.24949	2693	50
25	17.574	12.694	0.24949	2743	50
26	12.694	10.670	0.24949	2793	50
27	10.670	8.309	0.25004	2843	50
28	8.309	6.470	0.25023	2893	50
29	6.470	5.028	0.25023	2943	50
30	5.028	3.924	0.24968	2993	50
31	3.924	3.057	0.24971	3043	50
32	3.057	2.381	0.24971	3093	50
33	2.381	1.655	0.24971	3143	50
34	1.655	1.637	0.12465	3166	25
35	1.637	1.445	0.12485	3193	25
36	1.445	1.276	0.12465	3218	25
37	1.276	1.126	0.12485	3243	25
38	1.126	0.919	0.12965	3269	26
39	0.919	0.873	0.12485	3294	25
40	0.873	0.770	0.12485	3319	25
41	0.770	0.680	0.12485	3344	25
42	0.680	0.600	0.12485	3369	25
43	0.600	0.530	0.12465	3394	25
44	0.530	0.467	0.12465	3419	25
45	0.467	0.413	0.12485	3444	25

\*\*\*\*\* NEUTRON SPECTRUM \*\*\*\*\*

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SIGMA0 =      0.0
1.32139E-01 2.80922E-02 2.15152E-02 1.48463E-02 1.32129E-02 1.20980E-02 7.56056E-03 5.19954E-03
4.63081E-03 2.26445E-03 3.07822E-03 2.09841E-03 1.93100E-03 1.19443E-03 8.74772E-04 7.71062E-04
4.62954E-04 3.32627E-04 2.03386E-04 3.05062E-04 2.32126E-04 1.20447E-05 7.17667E-06 1.01258E-03 9.11006E-04
1.01663E-04 1.04859E-04 5.66224E-05 1.20447E-05 7.17667E-06 1.01703E-05 2.05147E-05 1.84682E-05
1.52125E-05 6.37908E-06 5.62444E-05 4.93434E-05 4.31310E-06 2.94472E-06 3.58212E-06 3.00996E-06
2.58074E-06 2.21844E-06 1.90502E-06 1.63317E-06 1.39775E-06

SIGMA0 =      1.00
1.56982E-01 6.74754E-02 3.52769E-02 2.12717E-02 1.63390E-02 1.29672E-02 9.52189E-03 6.58214E-03
5.53905E-03 4.00897E-03 2.58743E-03 2.26362E-03 1.50919E-03 1.01258E-03 9.11006E-04
5.56189E-04 3.68870E-04 2.56392E-04 3.03814E-04 2.49865E-04 9.56348E-05 1.59999E-04 3.37631E-05
9.51294E-05 1.09634E-04 6.90016E-05 1.59606E-05 7.16520E-06 1.83312E-05 2.17032E-05 2.03494E-05
1.72279E-05 7.32544E-06 6.49977E-06 5.72923E-06 5.02380E-06 4.59826E-06 4.08401E-06 3.51630E-06
3.03393E-06 2.61095E-06 2.24140E-06 1.91988E-06 1.64116E-06

SIGMA0 =     10.00
2.15952E-01 1.65924E-01 1.30567E-02 1.22922E-01 2.11109E-01 2.01256E-01 1.89429E-01 1.79556E-01 1.67902E-01
2.59984E-02 1.94255E-02 1.52812E-02 1.15709E-02 9.17939E-03 6.75152E-03 4.51636E-03 3.54943E-03
2.35896E-03 1.48212E-03 9.44525E-04 6.90563E-04 5.65633E-04 1.69432E-04 2.21450E-04 6.54882E-05
9.51441E-05 1.24340E-04 1.19159E-04 5.02914E-04 8.89199E-06 2.06564E-05 2.76766E-05 3.04689E-05
2.03158E-05 1.44867E-05 1.38221E-05 1.30516E-05 1.22115E-05 1.18264E-05 1.06367E-05 9.79603E-06
8.95733E-06 8.13277E-06 7.23411E-06 6.57063E-06 5.84909E-06

SIGMA0 =    100.00
2.44736E-01 2.435607E-01 2.22922E-01 2.11109E-01 2.01256E-01 1.89429E-01 1.79556E-01 1.67902E-01
1.55790E-01 1.45076E-01 1.34932E-01 1.24807E-01 1.15985E-01 1.05104E-01 9.23094E-02 8.55312E-02
7.35818E-02 6.45004E-02 5.41764E-02 4.69703E-02 4.34446E-02 2.51025E-02 2.49534E-02 1.32924E-02
1.14676E-02 1.11621E-02 1.06552E-02 7.11403E-03 1.92558E-03 1.76575E-03 1.73122E-03 1.69519E-03
1.65131E-03 8.06841E-04 7.93204E-04 7.78848E-04 7.63873E-04 7.78598E-04 7.33798E-04 7.18322E-04
7.02407E-04 6.86132E-04 6.69548E-04 6.52699E-04 6.35619E-04

SIGMA0 =   1000.00
2.50079E-01 2.48874E-01 2.46200E-01 2.42045E-01 2.41225E-01 2.37979E-01 2.35091E-01 2.315E6E-01
2.27096E-01 2.23329E-01 2.19768E-01 2.15180E-01 2.10512E-01 2.04518E-01 1.95776E-01 1.92104E-01
1.81888E-01 1.74840E-01 1.66146E-01 1.56876E-01 1.54945E-01 1.26441E-01 1.26934E-01 1.00338E-01
9.51519E-02 9.34311E-02 9.17322E-02 7.69750E-02 5.07243E-02 4.84725E-02 4.73847E-02 4.64022E-02
4.54635E-02 2.23892E-02 2.21649E-02 2.19434E-02 2.17244E-02 2.23653E-02 2.12904E-02 2.10805E-02
2.08720E-02 2.06649E-02 2.04590E-02 2.02543E-02 2.00505E-02

SIGMA0 =  10000.00
2.50730E-01 2.50484E-01 2.49017E-01 2.46056E-01 2.46746E-01 2.45196E-01 2.43550E-01 2.41689E-01
2.39548E-01 2.37716E-01 2.36729E-01 2.33924E-01 2.31728E-01 2.29164E-01 2.25596E-01 2.23172E-01
2.19354E-01 2.15077E-01 2.12667E-01 2.06587E-01 2.05987E-01 1.91154E-01 1.89711E-01 1.76075E-01
1.71781E-01 1.68966E-01 1.66437E-01 1.56368E-01 1.39588E-01 1.36033E-01 1.33321E-01 1.30850E-01
1.28503E-01 6.34075E-02 6.28575E-02 6.23175E-02 6.17869E-02 6.37050E-02 6.07319E-02 6.02262E-02
5.97274E-02 5.92351E-02 5.07486E-02 5.82663E-02 5.77931E-02

SIGMA0 = 100000.00
2.50789E-01 2.50652E-01 2.49308E-01 2.46471E-01 2.47326E-01 2.45970E-01 2.44461E-01 2.42785E-01
2.40940E-01 2.39344E-01 2.38889E-01 2.36333E-01 2.34513E-01 2.34290E-01 2.32235E-01 2.29910E-01 2.27617E-01
2.25014E-01 2.22086E-01 2.21570E-01 2.16717E-01 2.16288E-01 2.09698E-01 2.06895E-01 2.02107E-01
1.98672E-01 1.95418E-01 1.92543E-01 1.88107E-01 1.82356E-01 1.78543E-01 1.75023E-01 1.71777E-01
1.68719E-01 6.32602E-02 8.25463E-02 8.18461E-02 8.11588E-02 8.36889E-02 7.97931E-02 7.91397E-02
7.84957E-02 7.76606E-02 7.72343E-02 7.66158E-02 7.60047E-02

SIGMA0 = 1000000.00
2.50783E-01 2.50667E-01 2.49337E-01 2.46510E-01 2.47382E-01 2.46047E-01 2.44550E-01 2.42894E-01
2.41079E-01 2.39507E-01 2.38889E-01 2.36333E-01 2.34513E-01 2.34290E-01 2.32235E-01 2.29910E-01 2.27617E-01
2.25704E-01 2.22288E-01 2.22607E-01 2.17915E-01 2.17502E-01 2.12296E-01 2.09262E-01 2.05903E-01
2.02610E-01 1.99290E-01 1.96361E-01 1.92909E-01 1.89112E-01 1.85234E-01 1.81561E-01 1.78215E-01
1.75044E-01 8.62822E-02 8.56421E-02 8.49165E-02 8.42044E-02 8.68303E-02 8.27892E-02 8.21123E-02
8.14453E-02 8.07679E-02 8.01390E-02 7.94985E-02 7.88659E-02

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GROUP NO.	SIGMA-F ** SHIELDING FACTOR									
	0.	1.	10.	100.	1000.	10000.	100000.	1000000.	10000000.	
1	0.0	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
2	0.0	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
3	0.0	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
4	0.0	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
5	0.0	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
6	0.0	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
7	0.064E-05	0.9264	0.9257	0.9371	0.9382	0.9960	0.9985	0.9988	0.9988	0.9988
8	0.275E-03	0.5672	0.6009	0.7147	0.9206	0.9943	1.0021	1.0029	1.0029	1.0029
9	0.852E-05	0.9266	0.9476	0.9703	0.9969	0.9996	0.9996	0.9996	0.9996	0.9996
10	0.1755E-02	0.7923	0.8207	0.9417	1.0000	1.0053	1.0030	1.0026	1.0026	1.0026
11	0.1725E-05	1.0309	1.0367	1.0520	1.0127	1.0031	1.0017	1.0015	1.0015	1.0015
12	0.0	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
13	0.0	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
14	0.0	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
15	0.0	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
16	0.0	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
17	0.0	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
18	0.0	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
19	0.0	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
20	0.0	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
21	0.0	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
22	0.0	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
23	0.0	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
24	0.0	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
25	0.0	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
26	0.0	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
27	0.0	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
28	0.0	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
29	0.0	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
30	0.0	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
31	0.0	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
32	0.0	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
33	0.0	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
34	0.0	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
35	0.0	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
36	0.0	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
37	0.0	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
38	0.0	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
39	0.0	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
40	0.0	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
41	0.0	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
42	0.0	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
43	0.0	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
44	0.0	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
45	0.0	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000

GROUP NO.	SIGMA-A ** SHIELDING FACTOR									
	0.	1.	10.	100.	1000.	10000.	100000.	1000000.	10000000.	
1	0.8238E+00	0.6264	0.6583	0.7463	0.9070	0.9859	0.9987	1.0001	1.0003	
2	0.1099E+01	0.6289	0.6430	0.7228	0.8962	0.9337	0.9984	1.0000	1.0001	
3	0.1068E+01	0.5184	0.5289	0.6061	0.8194	0.9683	0.9966	0.9997	1.0000	
4	0.1183E+01	0.5500	0.5634	0.6407	0.8450	0.9733	0.9972	0.9999	1.0002	
5	0.1481E+01	0.3260	0.4070	0.4898	0.7308	0.9420	0.9934	0.9996	1.0002	
6	0.1779E+01	0.2839	0.3189	0.3974	0.6434	0.9082	0.9883	0.9987	0.9998	
7	0.1697E+01	0.3351	0.3452	0.4165	0.6545	0.9098	0.9885	0.9987	0.9997	
8	0.2308E+01	0.3021	0.3113	0.3735	0.5899	0.8687	0.9814	0.9982	1.0000	
9	0.3032E+01	0.1967	0.2061	0.2740	0.5347	0.8744	0.9849	0.9992	1.0007	
10	0.2636E+01	0.1802	0.1870	0.2386	0.4681	0.8313	0.9767	0.9972	0.9994	
11	0.3280E+01	0.1580	0.1661	0.2238	0.4725	0.8454	0.9816	0.9987	1.0005	
12	0.2404E+01	0.2101	0.2195	0.2912	0.5922	0.9126	0.9907	0.9998	1.0008	
13	0.4681E+01	0.1156	0.1212	0.1561	0.3300	0.7232	0.9561	0.9962	1.0005	
14	0.6675E+01	0.0930	0.0963	0.1261	0.2924	0.7220	0.9602	0.9970	1.0009	
15	0.1604E+02	0.0583	0.0648	0.0878	0.1674	0.4464	0.8463	0.9819	0.9996	
16	0.2511E+01	0.2054	0.2090	0.2996	0.6286	0.9426	0.9986	1.0029	1.0032	
17	0.4465E+02	0.0280	0.0309	0.0475	0.1219	0.3833	0.8077	0.9722	0.9946	
18	0.5268E+01	0.1931	0.2077	0.2604	0.4897	0.8641	0.9206	0.9949	0.9964	
19	0.4516E+02	0.0261	0.0281	0.0426	0.1085	0.3578	0.8036	0.9730	0.9953	
20	0.1378E+00	0.9582	0.9710	0.9961	1.0034	1.0003	1.0005	1.0006	1.0006	
21	0.4370E+01	0.1905	0.2177	0.3266	0.6375	0.9132	0.9850	0.9936	0.9945	
22	0.1668E+03	0.0103	0.0134	0.0375	0.0867	0.2488	0.6636	0.9497	1.0003	
23	0.7187E+00	0.8497	0.8907	0.9729	0.9861	0.9962	0.9973	0.9975	0.9975	
24	0.2476E+03	0.0182	0.0223	0.0434	0.1000	0.2909	0.7241	0.9618	0.9987	
25	0.4418E+00	0.9651	0.9711	0.9620	1.0026	1.0017	1.0015	1.0015	1.0015	
26	0.2938E+00	0.9962	0.9979	1.0013	0.9996	0.9998	0.9998	0.9998	0.9998	
27	0.6950E+00	0.9489	0.9463	0.9668	0.9942	0.9995	1.0000	1.0001	1.0001	
28	0.5066E+03	0.0095	0.0096	0.0150	0.0548	0.2451	0.7003	0.9502	0.9887	
29	0.1177E+02	0.3961	0.4070	0.5681	1.1629	1.0808	1.0248	1.0082	1.0060	
30	0.1122E+01	0.9761	0.9733	0.9865	1.0017	1.0016	1.0014	1.0014	1.0013	
31	0.6515E+00	1.0009	0.9996	0.9955	1.0006	1.0006	1.0006	1.0006	1.0006	
32	0.5224E+00	1.0019	1.0015	0.9997	1.0003	1.0003	1.0003	1.0003	1.0003	
33	0.4602E+00	1.0008	1.0002	1.0001	1.0001	1.0001	1.0002	1.0001	1.0001	
34	0.4734E+00	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	
35	0.4767E+00	0.9999	0.9999	0.9999	1.0000	1.0000	1.0000	1.0000	1.0000	
36	0.4642E+00	0.9998	0.9998	0.9999	1.0000	1.0000	1.0000	1.0000	1.0000	
37	0.4952E+00	0.9997	0.9997	0.9998	1.0000	1.0000	1.0000	1.0000	1.0000	
38	0.5102E+00	0.9999	0.9998	0.9999	1.0000	1.0000	1.0000	1.0000	1.0000	
39	0.5344E+00	0.9994	0.9995	0.9998	0.9999	1.0000	1.0000	1.0000	1.0000	
40	0.5553E+00									

GROUP NO.	SIGMA-S ** SHIELDING FACTOR									
	0.	1.	10.	100.	1000.	10000.	100000.	1000000.	10000000.	
1	0.1533E+02	0.6593	0.6940	0.7588	0.8903	0.9809	0.9981	1.0001	1.0003	
2	0.1619E+02	0.6552	0.6749	0.7350	0.8697	0.9745	0.9973	0.9999	1.0002	
3	0.1701E+02	0.6554	0.6641	0.7136	0.8551	0.9724	0.9970	0.9997	1.0000	
4	0.1513E+02	0.7508	0.7565	0.7931	0.8926	0.9780	0.9975	0.9998	1.0000	
5	0.2054E+02	0.4634	0.5103	0.5857	0.7467	0.9344	0.9923	0.9995	1.0003	
6	0.2442E+02	0.2024	0.3919	0.4817	0.6487	0.8867	0.9852	0.9987	1.0001	
7	0.1784E+02	0.5555	0.5924	0.6304	0.7507	0.9250	0.9901	0.9985	0.9997	
8	0.2245E+02	0.4969	0.5029	0.5402	0.6587	0.8689	0.9797	0.9975	0.9996	
9	0.1901E+02	0.5300	0.5085	0.5490	0.6852	0.9045	0.9863	0.9996	1.0008	
10	0.2054E+02	0.5397	0.5453	0.5751	0.6822	0.8864	0.9837	0.9981	0.9996	
11	0.1534E+02	0.6554	0.6589	0.6824	0.7756	0.9339	0.9921	0.9996	1.0004	
12	0.1254E+02	0.5518	0.6026	0.9093	0.9453	0.9875	0.9986	0.9999	1.0001	
13	0.2147E+02	0.5217	0.5259	0.5471	0.6271	0.8268	0.9714	0.9921	1.0010	
14	0.2029E+02	0.6243	0.6250	0.6372	0.7109	0.8867	0.9837	0.9987	1.0003	
15	0.9159E+02	0.1166	0.1257	0.1548	0.2302	0.4671	0.8395	0.9799	0.9987	
16	0.1049E+02	0.9828	0.9816	0.9769	0.9880	0.9979	0.9998	0.9999	0.9999	
17	0.1120E+03	0.1344	0.1365	0.1489	0.2105	0.4272	0.8111	0.9718	0.9942	
18	0.8032E+01	0.9685	0.9455	0.6592	0.5454	0.9840	0.9965	0.9987	0.9959	
19	0.5930E+02	0.2163	0.2135	0.2167	0.2643	0.4694	0.8378	0.9778	0.9963	
20	0.1058E+02	1.0169	1.0152	1.0013	0.9995	0.9999	0.9998	0.9993	0.9998	
21	0.2427E+02	0.6576	0.6745	0.7371	0.8669	0.9693	0.9944	0.9973	0.9977	
22	0.2017E+03	0.0328	0.0399	0.0507	0.0901	0.2492	0.6634	0.9495	1.0001	
23	0.1146E+02	0.9689	0.9790	0.9962	0.9970	0.9992	0.9994	0.9994	0.9994	
24	0.6546E+02	0.1140	0.1260	0.1593	0.1984	0.3603	0.7503	0.9656	0.9991	
25	0.8787E+01	1.0263	1.0079	1.0072	0.9996	0.9998	0.9998	0.9993	0.9998	
26	0.9973E+01	0.9925	0.9993	1.0011	0.9998	1.0000	0.9999	0.9999	0.9999	
27	0.1098E+02	0.9937	0.9944	0.9987	0.9995	0.9999	0.9999	0.9993	0.9999	
28	0.4298E+02	0.3015	0.3026	0.3161	0.3621	0.4960	0.7998	0.9667	0.9924	
29	0.6996E+01	1.1323	1.1295	1.0940	0.9708	0.9868	0.9959	0.9985	0.9988	
30	0.9190E+01	1.0204	1.0027	1.0031	0.9999	0.9999	0.9999	0.9999	0.9959	
31	0.9664E+01	1.0000	1.0001	1.0005	1.0000	1.0000	1.0000	1.0000	1.0000	
32	0.9895E+01	0.9999	0.9999	1.0001	1.0000	1.0000	1.0000	1.0000	1.0000	
33	0.1033E+02	0.9998	0.9999	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	
34	0.1011E+02	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	
35	0.1015E+02	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	
36	0.1018E+02	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	
37	0.1021E+02	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	
38	0.1010E+02	0.9993	0.9994	0.9995	1.0000	1.0001	1.0001	1.0001	1.0001	
39	0.8835E+01	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	
40	0.8650E+01	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	
41	0.8863E+01	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	
42	0.8875E+01	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	
43	0.8885E+01	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	
44	0.8893E+01	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	
45	0.8901E+01	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	

GROUP NO.	SIGMA-T ** SHIELDING FACTOR									
	0.	1.	10.	100.	1000.	10000.	100000.	1000000.	10000000.	
1	0.1615E+02	0.2548	0.5365	0.6655	0.8215	0.9540	0.9982	1.0001	1.0003	
2	0.1729E+02	0.4248	0.5261	0.6365	0.7935	0.9444	0.9974	0.9999	1.0002	
3	0.1808E+02	0.5488	0.5627	0.6185	0.7678	0.9423	0.9970	0.9998	1.0000	
4	0.1632E+02	0.6581	0.6674	0.7120	0.8285	0.9526	0.9975	0.9998	1.0001	
5	0.2202E+02	0.1302	0.3200	0.4760	0.6328	0.8756	0.9994	0.9995	1.0003	
6	0.2620E+02	0.0402	0.1809	0.3712	0.5250	0.8022	0.9862	0.9987	1.0001	
7	0.1953E+02	0.4796	0.4928	0.5420	0.6501	0.8601	0.9945	0.9968	0.9997	
8	0.2475E+02	0.3990	0.4106	0.4556	0.5554	0.7777	0.9725	0.9976	0.9995	
9	0.2204E+02	0.3745	0.3897	0.4360	0.5470	0.8170	0.9878	0.9996	1.0008	
10	0.2418E+02	0.4204	0.4288	0.4631	0.5487	0.7675	0.9762	0.9980	0.9996	
11	0.1872E+02	0.5159	0.5201	0.5425	0.6239	0.8476	0.9902	0.9995	1.0004	
12	0.1504E+02	0.7579	0.7594	0.7703	0.8346	0.9488	0.9974	0.9999	1.0002	
13	0.2615E+02	0.3995	0.4050	0.4277	0.4860	0.6878	0.9478	0.9977	1.0009	
14	0.2696E+02	0.4554	0.4566	0.4665	0.5152	0.7350	0.9640	0.9983	1.0004	
15	0.1076E+03	0.0621	0.0686	0.0933	0.1382	0.2798	0.7074	0.9802	0.9969	
16	0.1300E+02	0.8015	0.8015	0.8077	0.8726	0.9661	0.9995	1.0005	1.0006	
17	0.1567E+03	0.0879	0.0885	0.0927	0.1198	0.2381	0.6620	0.9594	0.9685	
18	0.1330E+02	0.5737	0.5706	0.5843	0.6803	0.8821	0.9518	0.9972	0.9979	
19	0.1045E+02	0.1133	0.1122	0.1152	0.1366	0.2418	0.6776	0.9722	0.9958	
20	0.1072E+02	1.0091	1.0058	0.9961	0.9995	0.9926	0.9998	0.9998	0.9998	
21	0.2864E+02	0.5267	0.5470	0.5895	0.7281	0.9189	0.9886	0.9968	0.9972	
22	0.3685E+02	0.0224	0.0225	0.0242	0.0341	0.0904	0.4212	0.8688	0.9857	
23	0.1218E+02	0.9409	0.9526	0.9795	0.9929	0.9954	0.9993	0.9993	0.9993	
24	0.3370E+02	0.0305	0.0305	0.0450	0.0667	0.1419	0.5230	0.9205	0.9876	
25	0.9229E+01	1.0028	1.0041	1.0044	0.9994	0.9966	0.9999	0.9999	0.9999	
26	0.1027E+02	0.9977	0.9987	1.0007	0.9995	0.9973	0.9999	0.9999	0.9999	
27	0.1188E+02	0.9855	0.9864	0.9936	0.9983	0.9976	0.9999	0.9999	0.9999	
28	0.5496E+03	0.0285	0.0288	0.0316	0.0460	0.1242	0.5253	0.9158	0.9809	
29	0.1877E+02	0.6276	0.6313	0.6798	0.9882	1.0329	1.0141	1.0046	1.0034	
30	0.1031E+02	0.9995	0.9994	0.9993	1.0000	1.0036	1.0001	1.0001	1.0001	
31	0.1032E+02	1.0000	1.0001	1.0002	0.9999	1.0035	1.0001	1.0000	1.0000	
32	0.1042E+02	0.9999	1.0000	1.0001	0.9999	1.0036	1.0001	1.0000	1.0000	
33	0.1051E+02	0.9999	0.9999	1.0000	0.9999	1.0036	1.0001	1.0000	1.0000	
34	0.1058E+02	1.0000	1.0000	1.0000	0.9999	1.0010	1.0000	1.0000	1.0000	
35	0.1062E+02	1.0000	1.0000	1.0000	0.9999	1.0011	1.0000	1.0000	1.0000	
36	0.1066E+02	1.0000	1.0000	1.0000	0.9999	1.0011	1.0000	1.0000	1.0000	
37	0.1070E+02	1.0000	1.0000	1.0000	0.9999	1.0010	1.0000	1.0000	1.0000	
38	0.1061E+02	0.9977	0.9980	0.9991	0.9998	1.0011	1.0001	1.0001	1.0001	
39	0.9363E+01	0.9999	1.0000	1.0000	0.9999	1.0014	1.0000	1.0000	1.0000	
40	0.9405E+01	1.0000	1.0000	1.0000	0.9998	1.0011	1.0000	1.0000	1.0000	
41	0.9442E+01	1.0000	1.0000	1.0000	0.9999	1.0011	1.0000	1.0000	1.0000	
42	0.9480E+01	1.0000	1.0000	1.0000	0.9999	1.0008	1.0000	1.0000	1.0000	
43	0.9519E+01	1.0000	1.0000</							

GROUP NO.	SIGMA-R	SHIELDING FACTOR								
		0.	1.	10.	100.	1000.	10000.	100000.	1000000.	
1	0.4391E+00	0.4103	0.5608	0.7864	0.9122	0.9827	0.9980	0.9998	1.0000	
2	0.4076E+00	0.5924	0.6130	0.8023	0.9527	0.9937	0.9988	0.9994	0.9994	
3	0.4737E+00	0.6923	0.6326	0.7401	0.9190	0.9880	0.9976	0.9986	0.9987	
4	0.5513E+00	0.6435	0.6345	0.7616	0.9451	0.9922	0.9975	0.9981	0.9981	
5	0.4454E+00	0.6661	0.7108	0.8238	0.9698	0.9946	0.9974	0.9976	0.9977	
6	0.1354E+01	0.1795	0.2175	0.2476	0.4442	0.8160	0.9733	0.9949	0.9971	
7	0.1554E+01	0.2076	0.2076	0.2310	0.4084	0.7882	0.9683	0.9941	0.9968	
8	0.4899E+00	0.7185	0.7168	0.7552	0.9421	0.9900	0.9961	0.9968	0.9968	
9	0.3622E+00	0.8416	0.8658	0.8954	0.9805	0.9950	0.9968	0.9970	0.9970	
10.	0.3419E+00	0.9962	0.9936	0.9674	1.0274	1.0099	0.9987	0.9972	0.9970	
11.	0.3522E+00	0.7817	0.8163	0.8760	0.9771	0.9943	0.9966	0.9969	0.9969	
12.	0.4865E+00	0.6889	0.8771	0.8703	0.9702	0.9933	0.9963	0.9966	0.9967	
13.	0.4996E+00	0.6654	0.7202	0.8179	0.9572	0.9913	0.9957	0.9961	0.9962	
14.	0.5408E+00	0.8651	0.8553	0.8592	0.9631	0.9899	0.9950	0.9957	0.9958	
15.	0.2077E+00	1.1519	1.0807	0.9318	0.9721	0.9870	0.9934	0.9952	0.9954	
16.	0.4052E+00	1.1196	1.0851	0.9466	0.9810	0.9933	0.9949	0.9952	0.9952	
17.	0.2222E+02	0.0076	0.0096	0.0219	0.0828	0.3057	0.7581	0.9629	0.9919	
18.	0.3302E+00	0.5125	0.6005	0.7461	0.9413	0.9844	0.9930	0.9947	0.9949	
19.	0.2698E+00	0.7689	0.7878	0.7621	0.9076	0.9673	0.9857	0.9940	0.9947	
20.	0.4221E+00	1.1705	1.1661	1.0091	0.9865	0.9943	0.9947	0.9947	0.9947	
21.	0.4560E+01	0.0411	0.0550	0.1299	0.4687	0.8654	0.9783	0.9921	0.9935	
22.	0.3169E+00	1.7711	1.7363	1.2360	1.0124	1.0106	0.9994	0.9942	0.9934	
23.	0.5396E+00	0.4952	0.5977	0.8623	0.9518	0.9883	0.9924	0.9928	0.9929	
24.	0.2648E+00	2.2429	1.9177	1.1053	0.9007	0.9684	0.9870	0.9918	0.9925	
25.	0.3208E+00	1.1101	1.1486	1.1897	0.9883	0.9917	0.9923	0.9923	0.9923	
26.	0.3622E+00	0.8749	0.9273	1.0491	0.9848	0.9911	0.9920	0.9921	0.9921	
27.	0.4048E+00	0.6922	0.7085	0.9051	0.9685	0.9891	0.9915	0.9917	0.9917	
28.	0.1509E+00	0.0146	0.0128	0.0213	0.1300	0.5440	0.9239	0.9835	0.9908	
29.	0.3031E+00	1.9432	1.9242	1.7056	0.9320	0.9740	0.9876	0.9906	0.9910	
30.	0.3301E+00	1.1253	1.1498	1.2022	0.9907	0.9893	0.9907	0.9907	0.9907	
31.	0.3413E+00	0.9713	0.9928	1.0698	0.9908	0.9908	0.9911	0.9911	0.9911	
32.	0.3473E+00	0.9189	0.9334	1.0105	0.9885	0.9902	0.9914	0.9914	0.9914	
33.	0.3513E+00	0.8957	0.9046	0.9762	0.9859	0.9904	0.9916	0.9917	0.9917	
34.	0.7055E+00	0.9447	0.9478	0.9806	0.9925	0.9954	0.9960	0.9961	0.9961	
35.	0.7079E+00	0.9424	0.9446	0.9757	0.9919	0.9955	0.9961	0.9961	0.9962	
36.	0.7100E+00	0.9405	0.9422	0.9715	0.9914	0.9955	0.9961	0.9962	0.9962	
37.	0.7117E+00	0.9391	0.9402	0.9677	0.9909	0.9955	0.9961	0.9962	0.9962	
38.	0.6016E+00	1.0420	1.0290	1.0060	0.9968	0.9960	0.9961	0.9961	0.9961	
39.	0.6160E+00	0.9169	0.9306	0.9662	0.9910	0.9956	0.9962	0.9963	0.9963	
40.	0.6170E+00	0.9306	0.9347	0.9612	0.9901	0.9955	0.9962	0.9963	0.9963	
41.	0.6179E+00	0.9328	0.9336	0.9579	0.9896	0.9955	0.9962	0.9963	0.9963	
42.	0.6186E+00	0.9325	0.9325	0.9548	0.9891	0.9955	0.9963	0.9964	0.9964	
43.	0.6193E+00	0.9319	0.9315	0.9519	0.9887	0.9955	0.9963	0.9964	0.9964	
44.	0.6198E+00	0.9311	0.9306	0.9490	0.9882	0.9954	0.9963	0.9964	0.9964	
45.	0.6203E+00	0.9304	0.9298	0.9462	0.9877	0.9954	0.9963	0.9964	0.9964	