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EXPANDA-75

One-Dimensional Diffusion Code for Multi-Region Plate Lattice Heterogeneous System

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日本原子力研究所

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JAERI レポート

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JAERI 1239

EXPANDA-75: One-Dimensional Diffusion Code for Multi-Region Plate Lattice Heterogeneous System

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(Received May 12, 1975)

An advanced treatment has been developed for analyzing a multi-region plate lattice heterogeneous system using the coarse group constants set provided for a homogeneous system. The essential points of this treatment are modification of effective admixture cross sections and improvement of effective elastic removal cross sections. By this treatment the heterogeneity effects for flux distributions and effective cross sections in the unit cell can be reproduced accurately in comparison with the ultra fine group treatment which consumes huge amounts of computing time. Based on the present treatment and using the JAERI-Fast set, a one-dimensional diffusion code, EXPANDA-75, was developed for extensive use for analyses of fast critical experiments. The user's guide is also presented in this report.

*IBM Japan

EXPANDA－75

板状セル非均質体系用一次元拡散コード

日本原子力研究所東海研究所

菊池康之，桂木　学，荻津　実*，鈴木友雄

（1975年5月12日受理）

均質体系用に開発された小数群群定数を用いて，板状非均質体系を解析する方法を開発した．この方法の特徴は，実効アドミクスチャー断面積の取扱い方と，弾性除去断面積の補正とにある．これにより，単位セル内の中性子束分布及び各板の実効断面積を，極めて正確にかつ短時間に求めることができる．その精度は，超詳細スペクトルコードの結果と比較して実証された．この方法に基いて，JAERI-Fast set を用いる一次元拡散コードEXPANDA－75を開発した．その使用説明も本報告に含めてある．

* 日本IBM

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1. Introduction

Correction of heterogeneity effect is essential in analyzing the experimental data obtained from critical assemblies, since many of fast critical assemblies, for example, FCA, ZEBRA and ZPPR, are constructed with the plate lattice fuel. A precise analysis of a multi-region plate lattice heterogeneous system requires a fine spectrum calculation and a lot of codes with 2,000 $\sim$ 200,000 group structure have been developed. Such a fine spectrum calculation needs, however, a considerable computing time and is therefore very expensive.

On the other hand, we have developed a simple but enough accurate calculation system which can be used both for analysis of experiments and for design works of fast reactors. The JAERI-Fast set[1,2] was prepared as the principal library and many computer codes using this set have been so far developed. Though the JAERI-Fast set was originally developed for analysis of homogeneous system, it was found to be applicable to a two-region hexagonal lattice heterogeneous system and a one-dimensional diffusion code, EXPANDA-5[3], was developed.

Bearing the above situation in mind, we have tried to apply the JAERI-Fast set of 70 group structure to calculation of the plate lattice heterogeneous systems[4] and have developed a one-dimensional diffusion code EXPANDA-75. This report describes the method developed for this code.

EXPANDA-75 was developed from EXPANDA-70D[5], a one-dimensional diffusion code for homogeneous system. The same method is adopted for the diffusion calculations, and the detail

is not described here. The flux heterogeneity is obtained by solving the multi-group integral transport equation with the process described in section 2.

Estimation of resonance self-shielding effect is one of the most difficult problems in treating a multi-region plate lattice heterogeneous system. A reasonable extension of the equivalence relation was adopted in this code. This problem is discussed in section 3.

The correct elastic removal cross sections are calculated near the 2.85 keV resonance of sodium. A simple analytical expression of the collision density was developed and was already published[6]. Therefore only the brief explanation is given in section 4.

Another one-dimensional diffusion code for heterogeneous systems, named SLAROM[7], was recently developed independently. This code also uses the JAERI-Fast set as the library. Comparing these two codes, EXPANDA-75 has the advantage as follows;

1) The correct elastic removal cross sections are used near the 2.85 keV sodium resonance.
2) The material buckling of the cell is automatically calculated, while they must be given as an input in SLAROM.
3) The treatment of the resonance self-shielding effect is different. EXPANDA-75 takes account of the effects from all the plates in the cell, while SLAROM adopted the Menegetti's equation based on the black resonance assumption.

On the other hand, SLAROM has the following advantages;

1) The pin lattice system can be treated.
2) The anisotropic diffusion coefficient can be optionally used.
3) The cell averaged cross sections can be stored in PDS file and can be referred later. This makes, on the other hand, SLAROM a machine-dependent code.

These two codes should be selected according to the problems, considering the characteristics of each code above described.

The structure of EXPANDA-75, Input format, Output format and Job Control Language are also included in this report for user's guide.

2. Calculation of Flux Heterogeneity

The flux distribution in a unit cell is calculated, by solving the multi-group integral transport equation. The neutron balance of a unit cell for the energy group g can be expressed approximately as

$$\left(\Sigma^g_{ti} + D^g B_m^2 \frac{\Sigma^g_{ti}}{\Sigma^g_t} \right) \phi^g_i V_i = \underset{j}{\text{Sum}} P^g_{ji} Q^g_j , \qquad (1)$$

where the suffices i and j specify a plate composing the unit cell, V is the volume of a plate, Q the neutron source in a plate, P_{ji} the probability that a neutron produced in the plate j has its first collision in the plate i. D^g and Σ^g_t are cell averaged values of diffusion coefficient and total macroscopic cross section and B_m^2 is the material buckling of the cell.

The left-hand side of Eq.(1) denotes the total collision in the plate i. The second term is the correction for the net neutron leakage from the cell because of the finite system. With this correction $\underset{i}{\text{Sum}} P_{ji}$ can be normalized to unity. This term can be considered as the pseudo-absorption in the plate i.

The right-hand side of Eq.(1) represents the total number of neutrons which have the collision in the plate i. The source Q is composed of the slowing down source Q_s and the fission source Q_f;

$$Q^g_{sj} = \underset{g' \leq g}{\text{Sum}} \Sigma^{g' \to g}_{sj} \phi^{g'}_j V_j \qquad (2)$$

$$Q_{fj}^{g} = \chi^{g} \underset{g'}{\text{Sum}} \nu_{g'} \Sigma_{fj}^{g'} \phi_{j}^{g'} V_{j}, \tag{3}$$

where $\Sigma_{s}^{g' \to g}$ is the transfer cross section from the group g' to g, χ^{g} the fission spectrum for the group g and $\nu_{g'}$ the mean number of emitted neutrons due to fission by a neutron of the energy group g'.

For simplicity, we define the cell integrated flux, its partition for the plate i and the correction factor of pseudo-absorption as,

$$\Phi^{g} \equiv \underset{i}{\text{Sum}} \phi_{i}^{g} V_{i} \tag{4}$$

$$\zeta_{i}^{g} \equiv \phi_{i}^{g} V_{i} / \Phi^{g} \tag{5}$$

$$\gamma^{g} \equiv (1+D^{g} B_{m}^{2}/\Sigma_{t}^{g}). \tag{6}$$

It should be noted that ζ_{i} becomes the volume ratio in case of no flux heterogeneity. Inserting Eqs. (2)$\sim$(6), we have

$$\gamma^{g} \Sigma_{ti}^{g} \zeta_{i}^{g} \Phi^{g} = \underset{j}{\text{Sum}} P_{ji} \left(\underset{g' \leq g}{\text{Sum}} \Sigma_{sj}^{g' \to g} \zeta_{j}^{g'} \Phi^{g'} + \chi^{g} \underset{g'}{\text{Sum}} \nu_{g'} \Sigma_{fj}^{g'} \zeta_{j}^{g'} \Phi^{g'} \right) \tag{7}$$

The effective cross sections must be known first for each plate. The self-shielding factors of heterogeneous system are calculated with the method[4,8] described in section 3. It should be noted that the flux heterogeneity affects the self-shielding factor and therefore the effective cross sections are recalculated after the flux heterogeneity is obtained.

The first flight collision probability P_{ji} is expressed as

$$P_{ji} = \frac{\int_{V_i} d\vec{r} \int_{V_j} d\vec{r}' \; P(\vec{r}' \to \vec{r})}{\int_{V_j} d\vec{r}'} \tag{8}$$

where $P(r' \to r)$ is the probability that a neutron generated at r' has its first collision at r and expressed as

$$P(\vec{r}' \to \vec{r}) = \frac{\Sigma_t(r)}{4\pi |\vec{r}' - \vec{r}|^2} \exp\left[-\tau(\vec{r}, \vec{r}')\right], \tag{9}$$

where τ is the optical length between $\vec{r}$ and $\vec{r}'$.
Integrating along the plate by assuming the infinitely large geometry, Eq.(9) becomes

$$P(x' \to x) = \Sigma_t(x) \frac{1}{2} E_1\left(\left|\int_{x'}^{x} \Sigma_t(x'')\, dx''\right|\right) \tag{10}$$

$$E_n(\tau) = \int_1^{\infty} \frac{e^{-\tau t}}{t^n}\, dt \;,$$

where x is the projection of $\vec{r}$ to the axis normal to the plate surface. The numerical integration is carried out by the same method as used in the FASTOS code[9]. Neutrons comming from the neighboring cells are correctly added to the neutrons which come from the corresponding plate in the unit cell, as far as the optical length reaches 6. The symmetic cell pattern can be treated as well as the periodic cell pattern.

The material buckling is calculated as well as the fundamental mode spectrum so as to attain the neutron balance in the cell.*

---

* The heterogeneous region must contain at least one fissionable nuclide, in order to calculate the fundamental mode spectrum.

The cell averaged cross sections are first calculated as

$$\Sigma_x^g = \underset{i}{\text{Sum}}\ \zeta_i^g\ \Sigma_{xi}^g$$

$$D^g = \underset{i}{\text{Sum}}\ \zeta_i^g\ \frac{1}{\Sigma_{tr,i}^g}\ , \tag{11}$$

then the neutron balance of the cell is expressed as

$$(B_m^2\ D^g + \Sigma_t^g - \Sigma_s^{g\to g})\,\phi^g$$

$$= \frac{1}{k}\chi^g(\underset{g'}{\text{Sum}}\ \nu^{g'}\ \Sigma_f^{g'}\ \phi^{g'}) + \underset{g'\leq g}{\text{Sum}}\ \Sigma_s^{g'\to g}\ \phi^{g'}, \tag{12}$$

where k is the reactivity eigenvalue of the cell. B_m^2 and ϕ^g(g=1, ---,70) are determined by iterative procedure so that k becomes unity with the convergence criterion

$$|k-1\ | < \varepsilon, \tag{13}$$

where ε is the input value.

If the effective cross sections, the material buckling, the fundamental mode spectrum, P_{ij} and the fission source term are known, then Eq.(1) or Eq.(7) can be solved in order from the highest energy group. It should be noted, however, that the flux heterogeneity (ζ_i) must be known in order to obtain these values, as shown in Eqs.(3) and (12) and Eq.(14) in the next section. Therefore the following iterative method is adopted.

1) The effective cross sections are calculated for the homogenized cell, i.e., P_{ij}=1 and ζ_i=V_i in Eq.(14). The cell averaged cross sections are calculated by

putting $\zeta_i=V_i$ in Eq.(11).

2) The material buckling and the fundamental mode spectrum are calculated with the cell averaged cross sections (for homogenized cell).

3) The fission sources are calculated with the fundamental mode spectrum, neglecting the flux heterogeneity ($\zeta_i=V_i$).

4) The first flight collision probability P_{ij} is calculated.

5) Then Eq.(1) is solved in order from the highest energy group and ζ_i is obtained.

6) The effective cross sections for each plate are recalculated by using ζ_i and P_{ij} in Eq.(14). Then the cell averaged cross sections are calculated with Eq.(11).

7) If necessary, the material buckling, the fundamental mode spectrum and the fission sources are recalculated with the new cell averaged cross sections and ζ_i, and then the process from 4) to 6) is repeated. It was found from the preliminary study, however, that this iteration was not necessary under most of conditions.

After the cell averaged macroscopic cross sections are obtained, the usual one-dimensional diffusion calculation is carried out. This part of EXPANDA-75 is the same as that of EXPANDA-70D[5].

3. Self-shielding Factor in Heterogeneous System

The resonance self-shielding effect is complicated in the plate lattice heterogeneous cell, as the configuration of plates is generally irregular and there exists the same resonance absorber in other plates within a unit cell. The influence of the nuclides contained in other plates must be considered in calculating the self-shielding factor. Considering such an interference effect between the plates we proposed Eq.(14)[4] as the effective admixture cross section of nuclide n in the plate i,

$$\sigma_{oi}^{n} = \frac{\underset{m\neq n}{\text{Sum}}\left(\underset{j}{\text{Sum}}\ N_j^m\ \sigma^m \frac{P_{ji}}{P_{ii}}\ \zeta_j\right)}{\underset{j}{\text{Sum}}\ N_j^n \frac{P_{ji}}{P_{ii}}\ \zeta_j}, \qquad (14)$$

where N_i^m is the number density of nuclide m in the plate i, P_{ij} the first flight collision probability and ζ_i the flux heterogeneity defined as Eq.(5).

Eq.(14) was derived on the basis of the following observations:

1) This equation gives the correct value when the cell is treated as homogeneous. (P_{ij}=1 and ζ_i=V_i).
2) The effect of the flux distortion due to resonance absorption must be weaker as the distance between the plates is more remote. Hence the contribution from a given plate was assumed to be proportional to the probability that one neutron generated in the plate arrives at the plate of interest.

3) The well-known equivalence relation assumes that the asymptotic flux has the same intensity in all the plates. This assumption is not valid, however, near wide scattering resonances. If the flux of a plate is higher than that of the other plates in such an energy region, the flux depression of this plate must have more prominent effects on the flux of the considered plate.

It was proved[8] that Eq.(14) agrees with the results of the well-known equivalence relation in cases of simple configulation. It should be noted that the flux heterogeneity affects the self-shielding factors with this approximation.

4. Elastic Removal Cross Section

One of drawbacks of the JAERI-Fast set exists in the treatment of elastic removal cross sections. The spectrum deviates from the asymptotic 1/E form near wide scattering resonances. This affects the elastic removal cross section of light elements. This effect is ignored in the JAERI-Fast set and 1/E spectrum is used in calculating the elastic removal cross sections. Hence the results with the JAERI-Fast set is rather poor near wide scattering resonances. This is especially severe near the 2.85 keV resonance of sodium.

We have developed a simple analytical expression of collision density near wide scattering resonances. A subroutine named COLLIS is provided for correcting the elastic removal cross sections. The detailed description concerning COLLIS were already published[6], and only the brief description is given here.

The collision density of a mixture is expressed as

$$F(E) = \sum_i \frac{1}{(1-\alpha_i)} \int_E^{E/\alpha_i} \frac{h_i(E')}{E'} F(E')dE', \qquad (15)$$

where h_i is the scattering ratio of nuclide i. The values of h_i are constant at off-resonance energy, and F takes its asymptotic $1/\xi E$ form. Near a wide scattering resonance, however, h_i has a peak for the resonance scatterer and has a valley for the other nuclides. Thus the collision density deviates from its asymptotic form.

Taking account of the behavior above described, we treat the mixture as a pseudo-nuclide which gives the correct collision density with appropriate α and h as,

$$F(E) = \frac{1}{1-\alpha}\int_{E}^{E/\alpha} \frac{h(E')}{E'} F(E')dE' \qquad (16)$$

The value of α is approximately obtained from the following relation,

$$\underset{i}{\text{Sum}} \frac{1}{1-\alpha}\int_{E/\alpha}^{E/\alpha_i} \frac{h_i(E')}{E'} F(E')dE'=0 \qquad (17)$$

Then h(E) is expressed with this α as

$$h(E) = \underset{i}{\text{Sum}} \frac{1-\alpha_i}{1-\alpha} h_i(E) \qquad (18)$$

The approximate α value can be obtained analytically, by taking it into account that α_i resembles each other. It should be noted that α is weakly dependent on energy. The value of h(E) is near unity, as $\underset{i}{\text{Sum}}\, h_i(E)$ is normalized to unity and α is not very different from any α_i. Assuming the single-level Breit-Wigner formula for resonance scatterer and a constant cross sections for the other nuclides, h(E) is analytically expressed as

$$h(E) = A + B\left(\frac{A^+}{E-\gamma^+} + \frac{A^-}{E-\gamma^-}\right), \qquad (19)$$

where A and B are real constants, and $A^{\pm}$ and $\gamma^{\pm}$ complex constants which are determined by the resonance parameters and

the macroscopic cross sections of each nuclide. The first-order solution of Eq.(16) may be $1/\xi E$, as h(E) stays always near unity. ξ is defined here as

$$\xi = 1 + \frac{\alpha}{1-\alpha} \log \alpha \tag{20}$$

and thus ξ depends on energy through α. This first-order solution is inserted in Eq.(16) and neglecting the energy dependence of ξ through integration we have

$$F(E) = \frac{\bar{h}}{E\xi}, \tag{21}$$

where

$$\bar{h} = \int_{E}^{E/\alpha} \frac{h(E')}{(E')^2} dE'. \tag{22}$$

Then the flux is expressed as

$$\phi(E) = \frac{\bar{h}}{E\xi\Sigma} \tag{23}$$

This method gives very good results for a mixture composed of sodium and lighter nuclides. As for a mixture containing iron, however, the error is considerably large. It was also found that the asymptotic $1/\xi E$ was fairly good for a mixture containing iron and that the collision density became flat for a mixture in which the effective ξ of the constant scatterers equals to ξ of the resonance scatterer. Therefore the present expression, Eq.(21), or the conventional $1/\xi E$ expression is automatically selected in COLLIS according to the effective ξ

of the constant scatterers.

The drawback of the present method for a mixture containing iron will be further investigated. However, the improvement of elastic removal cross section is excellent with the present correction. Hence, it can be concluded from the practical point of view, that the shortcoming of the JAERI-Fast set is well fixed up.

5. General Description of Flow

EXPANDA-75 is constructed by adding a function of heterogeneity calculation to the EXPANDA-70D code. The perturbation routine is omitted in order to save the core memories. The block-diagram of EXPANDA-75 is illustrated in Fig. 1. The structures of important subroutines are shown in Fig. 2. The flux heterogeneity is calculated in the subroutine ZEETA, and the effective microscopic cross sections are calculated in MICRO. The heterogeneity calculation is iterated for NZETA times determined by input. After the ζ_i is obtained, the effective cross sections are recalculated, and a diffusion calculation is carried out. The functions of each subroutine are as follows:

°READTP

The library tape of J-FAST-70-U[10] system is converted to the temporary library system common for EXPANDA-70D and EXPANDA-75. The temporary library is stored in the disk of logical unit number 4.

°INPUT

The input data are read in this subroutine, and blank check is carried out for some input data. (See section 6).

°MICRO

The library data are read from the disk of logical unit number 4. First the effective admixture cross section σ_o is

calculated for each nuclide, taking account of flux heterogeneity as described in Section 3. In EXPANDA-75, it should be noted that the same nuclides in the different plates are treated as the different nuclides. Then the subroutine SHIELD, which calls ALPHA and BETA, is called for calculating the resonance self-shielding factors. The effective admixture cross sections are recalculated with taking account of self-shielding factors, and the iteration for obtaining the self-shielding factors is carried out until the convergence is attained. After the self-shielding factors are obtained, the subroutine COLLIS is called and the elastic removal cross sections are corrected by taking acount of the flux depression near the 2.85 keV sodium resonance with the method described in section 4. Finally the effective microscopic cross sections are stored in the disk of logical unit number 2.

°ZEETA

This subroutine calculates the flux heterogeneity in the unit cell by solving the integral transport equation. The detailed discussion is given in section 2. The microscopic cross sections are read from the disk of logical unit number 2. The P_{ij} is calculated in the subroutine GEOM. The disks of logical unit numbers 31 to 30+K are required for storing the temporary values and for transfering P_{ij} to subroutine MICRO, where K is the number of the heterogeneous regions.

°SLABK

This subroutine has two functions. When called at the

first time in the main program, SLABK makes the table of E3-function calculated in the function EI at appropriate mesh points. When called from the subroutine GEOM, the value of E3-function is obtained at the actual optical length by interpolation.

°ONEDIM

This subroutine is just the same as in EXPANDA-70. The cell averaged macroscopic cross sections are calculated from the effective microscopic cross sections read from the disk of logical unit number 2. The fluxes and the adjoint fluxes are calculated at each spatial mesh point in the subroutine EXPAND. The criticality adjustment is carried out in the subroutine REGION. SIMPS is the subroutine for Simpson integration. The disk of logical unit number 18 is used as a scratch to save the core memories.

°EDIT

The capture and absorption rates are calculated for each nuclide, using the effective microscopic cross sections read from the disk of logical unit number 2. Then the macroscopic cross sections of each region are collapsed to any group structure (less than 70 groups). The collapsed cross sections are stored in a tape or disk of logical unit number 1.

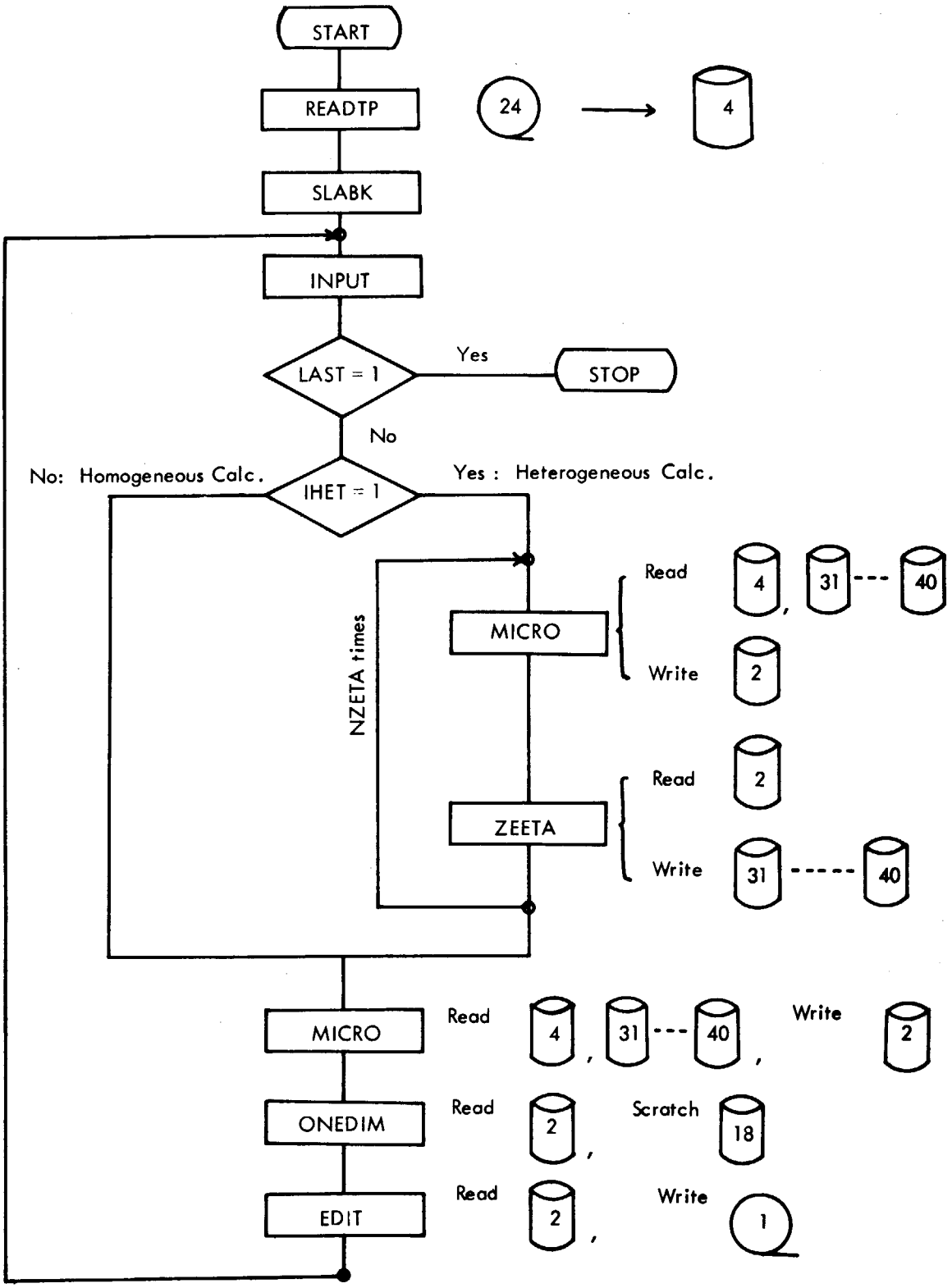

Fig. 1 Block diagram and auxiliary memories of EXPANDA-75

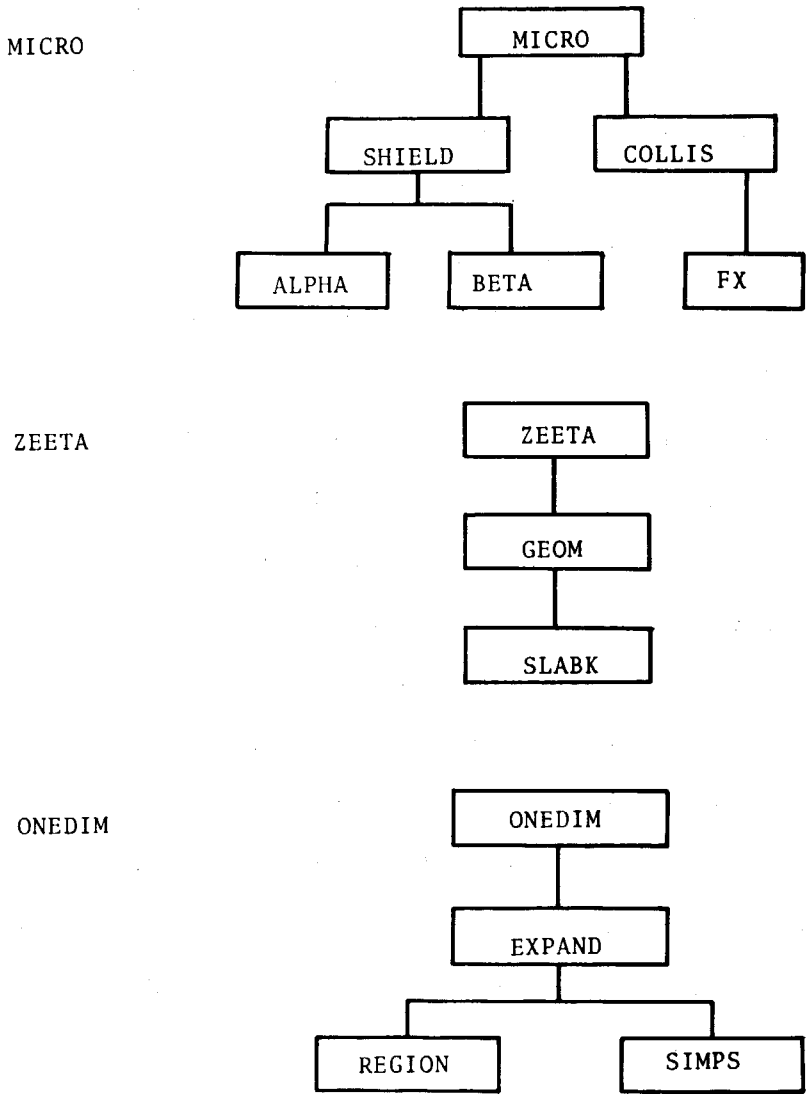

Fig. 2 Structure of important subroutines

6. Input Format

The input data format is kept to be the same as that of EXPANDA-70D as far as possible in order to avoid unnecessary confusion, and several cards are added for heterogeneity calculation. Some input data of EXPANDA-70D are not necessary for EXPANDA-75, which does not have a perturbation routine and uses only the group constants of 70 group structure. These unused values are set appropriately in the code and therefore any values are allowed for the columns which are specified as Dummy. The structure of input cards is shown in Fig. 3. The cards # 101, # A and # END are required only one time for each job and the cards # 0 to # H3 should be repeated when many cases are run in one job.

The cards # 0 to # 8 are of the same format as in EXPANDA-70D. The blank check system is adopted for these cards in order to minimize the number of input cards. When many cases are run in one job, the values once given are kept through the succeeding cases, and therefore only the data changed are required in the succeeding cases. The selection of the necessary input cards is controlled in # 0 card. The cards # H0 to # H3 are added for heterogeneity calculation. These cards must be repeated each case, for the blank check is not performed for them.

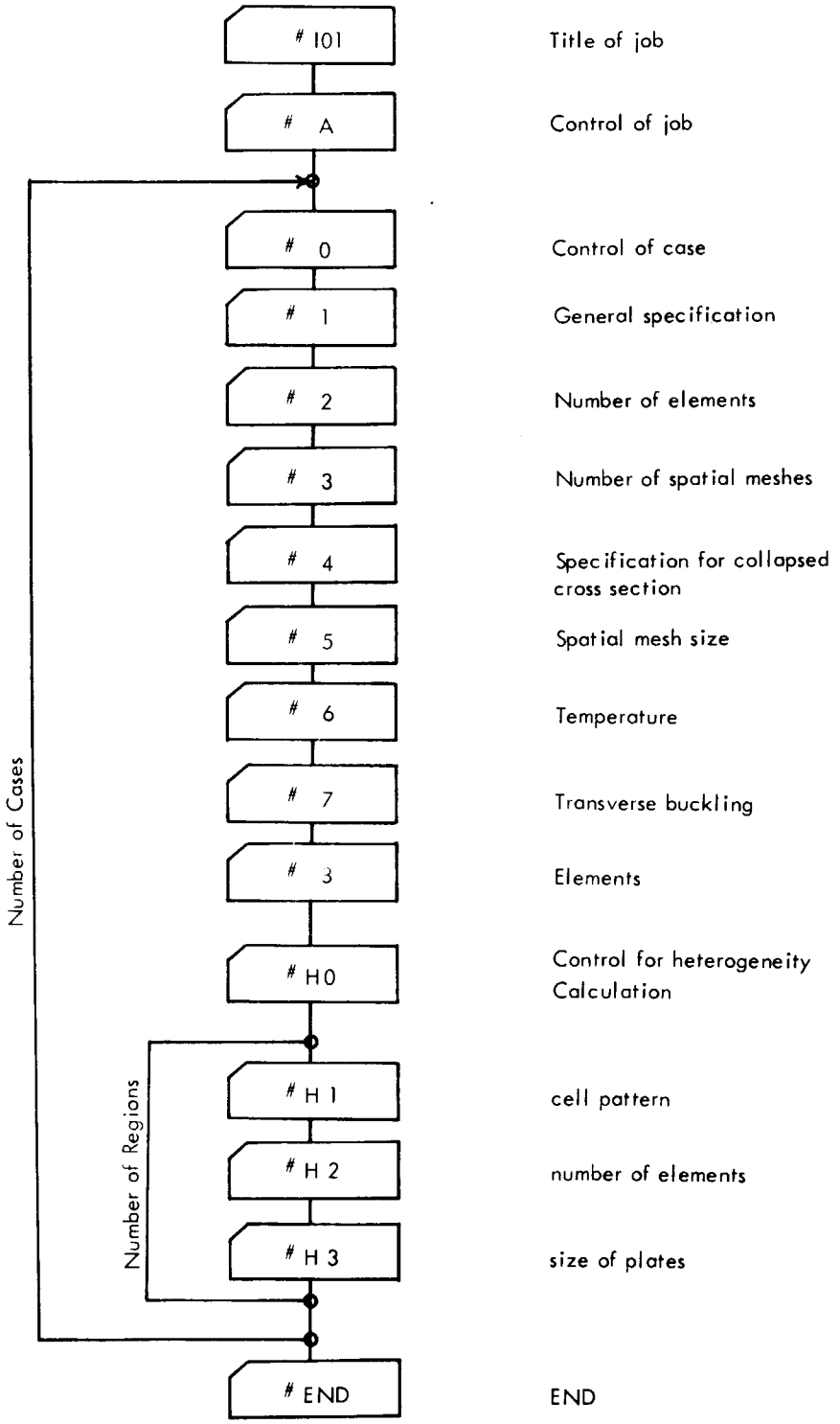

Fig. 3 Structure of input cards of EXPANDA-75

101 (20A4) HEAD
Title of this job

A (10I6)
NS, IFX, NP, IMX, ISKIPD, ISIGP, MPMIN, MPMAX, I7, ITPE

° NS Col. 1-6 Dummy (set as 0)

° IFX Col. 7-12 Dummy (set as 1)

° NP Col. 13-18
≠0 : fluxes and adjoint fluxes are punched out.
=0 : no punch out.

° IMX Col. 19-24 Dummy (set as 70)
IMX is the number of energy group*.

° ISKIPD Col. 25-30 Dummy (set as 0)

° ISIGP Col. 31-36
≠0 : the collapsed cross sections are written on the tape of logical unit number 1.
=0 : no write-out on tape.

° MPMIN Col. 37-42
The first group number from which the effective microscopic cross sections of each nuclide are printed out with a table of the self-shielding factors. If MPMIN≤0, MPMIN is set as 70.

° MPMAX Col. 43-48
The last group until which the effective microscopic cross sections are printed out. If MPMAX≤0, MPMAX is set as 1. If MPMAX<MPMIN, print-out is skipped.**

° I7 Col. 49-54
≠0 : macroscopic cross sections are punched out.
=0 : no punch out.

° ITPE Col. 55-60 Dummy (set as 0)
ITPE is the option for library tape. EXPANDA-75 uses only the library produced by J-FAST-70-U system.

The following cards must be repeated for each case.

---

* If you need another group structure, the subroutine COLLIS must be also modified.

** See also NCHK(7) ~ NCHK(9) in # H0 card!

0 (I1, I6, 9I1, 2I3, 14A4, I2)
LAST, NPROB, (ICARD(I), I=1,9), ICARD8, ICARD9, (TITLE(I), I=1, 14), ICARD4

°LAST Col. 1 Identification of # 0 card
=0

°NPROB Col. 2-7 Problem Number
≥0 : the input value of Δr is used.
<0 : the Δr obtained in the criticality adjustment of the previous case is used.

° (ICARD(I), I=1, 9) Columns 8 to 16 (9I1)
The item numbers for input cards # 1 to # 8 which should be given for this case. The item number of the cards # 1, # 2, --- # 8 are 1, 2, --- 8 respectively. They must be punched from column 8 successively without blank. In the first case, all the items except # 4 and # 7 are required. In the succeeding cases, on the other hand, only the cards containing the data changed are required. The values in the previous case are kept without change for the undefined data. # 9 card is not used in this code.

° ICARD8 Col. 17-19
Number of cards belonging to the item 8.

° ICARD9 Col. 20-22 Dummy

° (TITLE(I), I=1, 14) Col. 23-78 (14A4)
Title of this case

° ICARD4 Col. 79-80
Number of cards beloging to the item 4.

Only the cards whose item is requested as ICARD(I) in # 0 card must be put after # 0 card. The identification number of the item (NO) and the changed data must be put, and the other unchanged data may be left blank. Therefore you connot use blank as 0 in these cards. For the first case, naturally, all the values must be provided. If more than one cards are necessary for the same item, the identification (NO) must be punched for all the cards.

1 (13I3, 5E6.0)
NO, KMAX, ISYM, IMAX, ICRIT, ISW, IDS, KREG, IP, NADJ, IBR, IBSQM, LAPSE, EPS1, EPS2, DRMIN, DRMAX, RAM2

° NO Col. 1-3 Identification of # 1 card
=1

° KMAX Col. 4-6 Number of regions
≤10

° ISYM Col. 7-9
The boundary condition at the origin of spatial coordinate.

=+1 : $\frac{d}{dr}\phi(r)\Big|_{r=0} = 0$

=-1 : $\phi(0)=0$

For slab geometry, the numerical integration is extended to the image part if ISYM=+1.

° IMAX Col. 10-12 Dummy (set as 70)
IMAX is the number of energy group.

° ICRIT Col. 13-15 Option for criticality adjustment
=+1 : Δr of a region is adjusted to attain the criticality specified by RAM2 in this card.
= 0 : No criticality adjustment.

° ISW Col. 16-18 Option for print-out
=+2 : Σ, ϕ, Φ, (reaction rates, collapsed cross sections, ϕ^*)
=+1 : Σ, ϕ, (reaction rates, collapsed cross sections, ϕ^*)
= 0 : ϕ, (reaction rates, collapsed cross sections, ϕ^*)
=-1 : (reaction rates, collapsed cross sections, ϕ^*)

ϕ, ϕ^* and Φ are the flux, the adjoint flux, and the neutron spectrum at each mesh point. For the values in the parenthesis, the selection is given as an input.

° IDS Col. 19-21 Dummy (set as 29)
IDS is maximum number of energy groups into which down scattering is allowed.

° KREG Col. 22-24
Region number of the region where Δr is adjusted to attain the criticality.

° IP Col. 25-27 Geometry condition of the reactor
=0 : slab,
=1 : cylinder,
=2 : sphere.

° NADJ Col. 28-30 Option for adjoint flux
=+1 : adjoint fluxes are calculated.
=-1 : not calculated.

° IBR Col. 31-33 Option for reaction rate
=+1 : reaction rates are calculated.
=-1 : not calculated.

° IBSQM Col. 34-36 Dummy (set as 0)

° LAPSE Col. 37-39 Option for collapsed cross section
=N : the cross sections are collapsed to N group structure ($1 \leq N \leq 70$).
=0 : not collapsed.

The maximum group number into which the down-scattering is allowed is limitted to be less than 29. The collapsed cross sections are written on the tape of logical unit number 1, unless ISIGP=0.

° EPS1 Col. 40-45 (E6.0)
The convergence criterion used in calculating the eigenvalue λ and the material buckling B_m^2 (normally 1.E-5 ~ 5.E-5).

° EPS2 Col. 46-51 (E6.0)
Pointwise source convergence criterion (normally 1. E-4).

° DRMIN Col. 52-57 (E6.0)
The minimum value for Δr_{KREG} to be varied in criticality adjustment.

° DRMAX Col. 58-63 (E6.0)
The maximum value for Δr_{KREG} to be varied.

° RAM2 Col. 64-69 (E6.0)
The value of k_{eff} to which criticality adjustment is carried out.

2 (I3, 10I6) NO, (MM(K), K=1, KMAX)

° NO Col. 1-3 Identification of # 2 card
=2

° (MM(K), K=1, KMAX)
Number of elements in each region ($MM(K) \leq 100$). The same elements contained in different plates are treated as the different elements for heterogeneous system.

3 (I3, 10I6) NO, (INTER(K), K=1, KMAX)

° NO Col. 1-3 Identification of # 3 card
=3

° (INTER(K), K=1, KMAX)
Mesh number of the outer boundary of region K. The meshes are numberd as 0, 1, ---, INTER(KMAX) from the spatial origin. INTER(K) must be even number for every K. $INTER(KMAX) \leq 100$.

4* (I3, 12I6, 4X, I1)
NO, (IX(J), J=(KN-1) x 12+1, Min(KN x 12, LAPSE)), KN

° NO Col. 1-3 Identification of # 4 cards
=4

° IX(J)
The last number of energy group of 70 group structure corresponding to the coarse group J.
$1 \leq IX(1) < IX(2) < \cdots\cdots < IX(LAPSE) \leq 70$.
The coarse group J corresponds with the groups IX(j-1)+1 to IX(J) in the original 70 group structure.

° KN Col. 80
The sequential number of # 4 cards. If KN is left blank, # 4 cards must be put in order.

5 (I3, 10E6.0) NO, (DR(K), K=1, KMAX)

° NO Col. 1-3 Identification of # 5 cards
=5

° (DR(K), K=1, KMAX)
Spatial mesh size for region K in cm unit.

6 (I3, 10E6.0) NO, (T(K), K=1, KMAX)

° NO Col. 1-3 Identification of # 6 card
=6

° (T(K), K=1, KMAX)
Temperature for region K in Kelvin unit. $T(k) \geq 300°K$.

7** (I3, 5E12.5, 15X, 2I1)
NO, (BSQ(K), K=1+L, Min(5+L, KMAX)), M, NC

° NO Col. 1-3 Identification of # 7 cards
=7

° BSQ(K)
Transverse buckling $B_\perp^2$ for region K.

° M Col. 79 (I1) The last card identification
=1 : this card is the last # 7 card
=0 : this card is not the last # 7 card

---

* # 4 cards are not necessary if LAPSE=0.

** # 7 cards are not necessary for spherical geometry.

° NC Col. 80 (I1) Sequential number of # 7 cards

If 1≤KMAX≤5, there is only one # 7 card with L=0, M=1, NC=1.

If 5<KMAX≤10, there are two #7 cards;
with L=0, M=0, NC=1 for the first card,
with L=5, M=1, NC=2 for the second card.

8 (I3, 5(I3, E12.5), I1, A1)
NO, (MCODE(M,K), AN(M,K), M=1+L, Min(5+L,MM(K)), K, NC

° NO Col. 1-3 Identification of # 8 cards
=8

° (MCODE(M,K), AN(M,K), M=1+L, Min(5+L,MM(K)))
MCODE(M,K) : Nuclide code number for the M-th nuclide in region K. Nuclide code number is given in Table 1.
AN(M,K) : Number density of nuclide M in region K in 10^{24} atoms/cm^3 unit.

The same nuclides in different plates are treated as different nuclides. Therefore the same nuclide code number may appear several times in a region. It is not allowed, however, to define the same nuclide twice in the same plate. MCODE and AN are put successively from the first nuclide in the first plate (M=1) to the last nuclide in the last plate (M=MM(K)). The assignment of nuclides to each plate is specified in # H2 card. The # 8 cards are repeated for each region.

Table 1. Nuclide Code Number

Nuclide	Code Number	Nuclide	Code Number
Pu-239	949	Na	11
Pu-240	940	Al	13
Pu-241	941	Cr	24
U-234	924	Mn	25
U-235	925	Fe	26
U-238	928	Ni	28
B-10	105	Cu	29
B-11	115	Mo	42
C	6	FP(Pu-239)	999
O	8	FP(U-235)	995

° K Col. 79 (I1) Region number
K=0 for the 10th region.

° NC Col. 80 (A1) Sequential number for each region
The relation between NC and L is given as:

NC	L	NC	L	NC	L	NC	L
1	0	6	25	B	50	G	75
2	5	7	30	C	55	H	80
3	10	8	35	D	60	I	85
4	15	9	40	E	65	J	90
5	20	A	45	F	70	K	95

The following cards (# HO ~ # H3) are for heterogeneity calculation. The blank check system is not applied for them. Therefore they must be put for each case.

HO (12I6) NZETA,(NCHK(I), I=1, 10)

° NZETA Col. 1-6
Number of iteration for ZEETA. If NZETA=0, all the regions are calculated as homogeneous.

° (NCHK(I), I=1, 10) Option for check print
=1 : The following quantities are printed out
=0 : deleted

NCHK(1) : Collision densities and fluxes near 2.85 keV sodium resonance, calculated in COLLIS.

Necessary pages = 7 x KMAX x (NZETA + 1)

NCHK(2) : Coefficient matrix of Eq.(7) for obtaining ζ_i in ZEETA.

$$\text{Necessary lines} = \text{NZETA} \times \sum_{K=1}^{KMAX} [70\times(NRX(K)+2) + 5]$$

NCHK(3) : χ^g, ϕ^g, D^g, Σ_t^g, Σ_{ti}^g, $\sum_{g'} \Sigma_{si}^{g'\to g}$ and P_{ij} in ZEETA.

$$\text{Necessary lines} = \text{NZETA} \times \sum_{K=1}^{KMAX} [70\times(NRX(K)+3) + 2]$$

NCHK(4) : Macroscopic cross sections for each plate, when MICRO is called at the first time. They are printed out from MPMIN group to MPMAX group (defined in # A card)

Necessary pages = KMAX x (MPMAX-MPMIN+1)

NCHK(5) : Macroscopic cross sections, when MICRO is called at the second time.

NCHK(6) : Macroscopic cross sections, when MICRO is called at the third time.

NCHK(7) : Effective microscopic cross sections for each nuclide from MPMIN group to MPMAX group, when MICRO is called at the first time.

$$\text{Necessary lines} = 11 + \sum_{K=1}^{KMAX} [11+NRX(K) + 2 \times MM(K)]$$

NCHK(8) : Effective microscopic cross sections, when MICRO is called at the second time.

NCHK(9) : Effective microscopic cross sections, when MICRO is called at the third time.

Note : When MICRO is called at the last time, print out of the effective microscopic cross sections are controlled only by MPMIN and MPMAX in spite of the values of NCHK(7) to NCHK(9).

Sets of the following cards (# H1 ~ # H3) must be repeated for each region.

H1 (2I6) IPERIO(K), NRX(K)

° IPERIO(K) Col. 1-6 Cell pattern
=0 : symmetric cell
=1 : periodic cell

° NRX(K) Col. 7-12
Number of plates composing the unit cell in region K.
If NRX(K)=1, # H2 and # H3 cards are omitted.

H2 (10I6) (MMM(J,K), J=1, NRX(K))

° MMM(J,K)
Number of nuclides contained in the plate J of the unit cell in region K. $\sum_{J} MMM(J,K)=MM(K)$.

H3 (6E12.5) (RX(J,K), J=1, JMAX)

° RX(J,K)
Thickness of the plate J of the unit cell in region K in cm unit.

If more than one cases are run in one job, sets of the cards # 0 to # H3 are repeated. After all the cases are processed, # END card is put.

END (I1) LAST

° LAST Col. 1 Identification of # END card
=1

7. Output

The output formats are nearly the same as those of EXPANDA-70D. In this section, σ denotes the microscopic cross section in an infinitely dilute system, $\bar{\sigma}$ the effective cross section, σ_0 the effective admixture cross section and f the self-shielding factor. Many suffices used in this section are tabulated below:

m	:	nuclide
i, j	:	energy group in 70 group structure
n, l	:	energy group in the collapsed group structure
k	:	region number
p	:	plate number in the unit cell
f	:	fission
c	:	capture
e	:	elastic scattering
in	:	inelastic scattering
t	:	total
er	:	elastic removal
r	:	total removal
a	:	absorption
tr	:	transport.

7.1 Print-out

0 Description of Input Data

1 Heterogeneity calculation

The followings are printed out for each heterogeneous region. They are repeated for NZETA times.

° OUTPUT FROM ZEETA FOR REGION K

° BSQM : Material buckling obtained from Eq.(12).

° PHI : Fundamental mode spectrum obtained from Eq.(12).

° Q(J) : Fission source for each plate.

° ZETA IN REGION K

$$i,\ \Phi^i(\zeta_p^i,\ p=1,\ NRX(K))$$

$$(\zeta_p/V_p,\ p=1,\ NRX(K)),$$

where ζ_p^i and Φ^i are obtained by solving Eq.(7), V_p the volume of plate.

° AVERAGE : $\underset{i}{\text{Sum}}\ \Phi^i\ \zeta_p^i / \text{Sum}\Phi^i$

Necessary Pages = 3 x Number of heterogeneous region x NZETA

2 Effective microscopic cross sections

The effective cross sections ($\bar{\sigma}_f^m$, $\bar{\sigma}_c^m$, $\bar{\sigma}_e^m$ and $\bar{\sigma}_{er}^m$) are printed out with a table of the self-shielding factors from MPMIN group to MPMAX group.

Necessary Pages = $(\underset{k}{\text{Sum}}\ MM(K))/25$ x (MPMAX-MPMIN)

3 Macroscopic cross sections

The effective macroscopic cross sections are printed out for each region, if ISW≥1 in # 1 card.

° D : Diffusion Coefficient

$$D = \frac{1}{\underset{m}{\text{Sum}}\ N^m \bar{\sigma}_D^m},$$

$$\bar{\sigma}_D = [\bar{\sigma}_t - (\bar{\sigma}_r - \bar{\sigma}_e)](1-\mu_e) + (\bar{\sigma}_r - \bar{\sigma}_e)$$

$$\bar{\sigma}_r = \bar{\sigma}_a + \bar{\sigma}_{er} + \sigma_{in} - \sigma_{in}^{i\to i}$$

° TRANSPORT

$$\Sigma_{tr} = \underset{m}{\text{Sum}}\ N^m \bar{\sigma}_{tr}^m$$

$$\bar{\sigma}_{tr} = \bar{\sigma}_r - \mu_e \bar{\sigma}_e$$

° ABSORPTION

$$\Sigma_a = \underset{m}{\text{Sum}}\ N^m (\bar{\sigma}_f^m + \bar{\sigma}_c^m)$$

° SCATTERING

$$\Sigma_s = \underset{m}{\text{Sum}}\ N^m\ (\bar{\sigma}_e^m + \sigma_{in}^m)$$

° TOTAL REMOVAL

$$B_\perp^2\ D + \underset{m}{\text{Sum}}\ N^m\ \bar{\sigma}_t^m\ ,$$

where $B_\perp^2$ is the transverse buckling in the region.

° YIELD

$$\nu\ \Sigma_f = \underset{m}{\text{Sum}}(\nu^m\ \bar{\sigma}_f^m)\ N_m$$

° FISSION

$$\Sigma_f = \underset{m}{\text{Sum}}\ N^m\ \bar{\sigma}_f^m$$

° SCATTERING TRANSFER

$$\Sigma_s^{i\to i+j} = \underset{m}{\text{Sum}}\ N^m\ \bar{\sigma}_s^{m,\ i\to i+j},\ j=0,\ ---29,$$

where $\sigma_s^{i\to i+j}$ is the elastic and inelastic transfer cross section from the group i to i+j. j=0 means the transfer to the same energy group.

Necessary pages = 70

4 Flux (printed out, when ISW≥0 in # 1 card)

° FLUX CALCULATION

° LAMDA : the eigen value for each inner iteration.

$$\lambda = k_{eff} = \int \underset{i}{\text{Sum}}\ (\nu\Sigma_f)^i(r)\phi^i(r)\ dv$$

° CONTROLLED DELTA R:
spatial mesh size of the adjusted region after the criticality is attained.

° SOURCE : source at each spatial mesh

$$S(r) = \frac{1}{\lambda}\ \underset{i}{\text{Sum}}(\nu\Sigma_f)^i(r)\phi^i(r)$$

° INTEGRATED SOURCE

$$SR = \int_{\text{Region}} S(r)\ dV$$

° REGION VOLUME :

$$V = \int_{Region} dV$$

The following three quantities are given for every energy group.

° FLUX : $\phi^i(r)$ at each spatial mesh, the solution of

$$-D^i(r)\nabla^2\phi^i(r) + \Sigma_t^i(r)\phi^i(r) = \chi^i S(r) + \sum_{j=1}^{i-1} \Sigma_s^{j\to i}(r)\,\phi^j(r).$$

° INTEGRATED FLUX : Φ^i, Φ_k^i

$$\Phi^i = \int_{Reactor} \phi^i(r)\, dV$$

$$\Phi_k^i = \int_{Region} \phi^i(r)\, dV$$

° REGION CHECKS : $RCH2^i(K)$, $PCH1^i(k)$

$$RCH2^i = \int_{Region} (\chi^i S(r) + \sum_{j=1}^{i-1} \Sigma_s^{j\to i}\,\phi^j(r) - \Sigma_t^i\phi^i(r))\, dV$$

$$RCH1^i = -\int_{Region} D^i(r)\nabla^2\phi^i(r)\, dV$$

The accuracy of difference approximation in solving the diffusion equation can be checked by comparing RCH1 and RCH2. If they do not agree with each other, the mesh size of that region must be decreased.

The followings are printed out, if ISW=+2 in # 1 card.

° POINT WISE EDITING

° FLUX SUMMED OVER GROUPS

$$\Phi(r) = \sum_i \Phi^i(r)$$

° NORMALIZED FLUXES

$$\phi^i(r) = \phi^i(r)/\Phi(r)$$

° NORMALIZED SPECTRUM

$\Phi^i(r)/\Delta U_i$,

where ΔU_i is the lethargy width of the group i.

° REGION INTEGRATED FLUX SUMMED OVER GROUPS

$\int \Phi(r)\, dV$

Necessary pages ~36 for ISW=+1
~72 for ISW=+2

5 Adjoint flux (printed our when NADJ=+1 in # 1 card)

° ADJOINT FLUX CALCULATION

° LAMDA : the eigenvalue λ^*

$$\lambda^* = \int_{\text{Reactor}} \sum_i \chi^i \phi^{*i}(r)\, dV$$

° SOURCE : $S^*(r) = \frac{1}{\lambda} \sum_i \chi^i \phi^{*i}(r)$

° INTEGRATED SOURCE : $SR = \int_{\text{Reactor}} S^*(r)\, dV$

° ADJOINT FLUX : $\phi^*(r)$ at each spatial mesh, the solution of

$$-D^i(r)\nabla^2\phi^{*i}(r) + \Sigma_t^i(r)\phi^{*i}(r) = (\nu\Sigma_f)^i(r) + \sum_{j=i+1}^{70} \Sigma_s^{i\to j}(r)\,\phi^{*j}(r)$$

° INTEGRATED ADJOINT FLUXES : Φ^*, Φ^*_k

$$\Phi^{*i} = \int_{\text{Reactor}} \phi^{*i}(r)\, dV$$

$$\Phi^{*i}_k = \int_{\text{Region}} \phi^{*i}(r)\, dV$$

Necessary pages ~36

6 Reaction rates (printed out when IBR=+1 in # 1 card)

REACTION-RATE GROUP I

° REGION K

° CAPTURE FOR EACH NUCLIDE
The capture rates are tabulated for each plate and for the region with the nuclide code numbers.

$$\Sigma_c^{m,i}\ \Phi_k^i\ \zeta_p^i = \Sigma_c^{m,i} \int_{\text{Region}} \phi^i(r)\ dV \times \zeta_p^i$$

$$\Sigma_c^{mi}\ \Phi_k^i$$

° ABSORPTION FOR EACH NUCLIDE

$$\Sigma^{mi}\ \phi_k^i\ \zeta_p^i \quad \text{and} \quad \Sigma_a^{mi}\ \Phi_k^i$$

° TOTAL ABSORPTION, TOTAL FISSION, TOTAL CAPTURE

$$\underset{m}{\text{Sum}}\ \Sigma_a^{mi}\ \Phi_k^i,\ \underset{m}{\text{Sum}}\ \Sigma_f^{mi}\ \Phi_k^i,\ \underset{m}{\text{Sum}}\ \Sigma_c^{mi}\Phi_k^i$$

They are repeated for all the energies and finally the values summed over energy groups are given.

° MASS FOR EACH NUCLIDE
masses of each nuclide are given in gram unit for each plate of all the regions.

$$\text{Necessary lines} = 71 \times \underset{k}{\text{Sum}}(12 + 2 \times \text{NRX}(K))$$

7 Collapsed macroscopic cross sections (printed out when LAPSE=0 in # 1 card)

The macroscopic cross sections are collapsed to LAPSE group structure (LAPSE≤70), using the calculated fluxes as weights. The group structure is defined in # 4 cards. The flux of the n-th collapsed group is defined as

$$\Phi_k^n = \underset{i\in n}{\text{Sum}} \int_{\text{Region}} \phi^i(r)\ dV = \underset{i\in n}{\text{Sum}}\ \Phi_k^i\ ,$$

where $\underset{i\in n}{\text{Sum}}$ means summation over i corresponding to the n-th collapsed group. The collapsed cross sections (and diffusion

coefficient) are defined except for the scattering transfer cross section as

$$\Sigma^n_{x,k} = \underset{i\in n}{\text{Sum}}\ \Sigma^i_{x,k} \int_{\text{Region}} \phi^i(r)\ dV/\Phi^n_k \ .$$

The scattering transfer cross section is difined as

$$\Sigma^{n\to\ell}_{s,k} = \underset{i\in n}{\text{sum}} \int_{\text{Region}} \phi^i(r)\ \left(\underset{j\in\ell}{\text{Sum}}\ \Sigma^{i\to j}_{s,k}\right) dV/\Phi^n_k .$$

The maximum number of energy groups into which down scattering is allowed is limitted to be less than 30.

° DIFFUSION : D^n_k

° SIGMA-TR : Σ^n_{tr}

° SIGMA-A : Σ^n_a

° SIGMA-S : Σ^n_s

° SIGMA-T : Σ^n_t

° NU-SIGMA-F: $\nu\Sigma^n_f$

° SIGMAS TO N+0-----N+MINO(LAPSE-1, 29)

$\Sigma^{n\to n+\ell}_s$ (ℓ=0,1---min(LAPSE-1, 29))

Necessary Pages = $\frac{3}{4}$x LAPSE

7.2 Card Output

° Macroscopic cross sections, if I7≠0 in # A card.

FORMAT (6E12.5)

(χ^i, i=1, 70)

```
DO      k=1, KMAX
 DO     i=1, 70
        Σ^i_{f,k}, Σ^i_{a,k}, νΣ^i_{f,k}, Σ^i_{t,k}, (Σ_s^{i→i+j}, j=0, 29)
CONTINUE
```

° Fluxes and adjoint fluxes, if NP≠0 in # A card

FORMAT (5E 15.8)

```
DO      i=1, 70
 DO     k=1, KMAX
        (φ_k^i(N), N=N1(k), N2(k))
 CONTINUE,
```

where N1(k) and N2(k) are the boundary mesh of region k.

The format for the adjoint fluxes is the same.

7.3 Output on Tape

The collapsed cross sections are stored on tape of logical unit number 1 in the binary form, if ISIGP=0 in # A card.

```
DO      k=1, KMAX
(D_k^n, Σ_tr,k^n, Σ_a,k^n, Σ_t,k^n, νΣ_f,k^n, Σ_f,k^n, (Σ_sk^{n→n+ℓ}, ℓ=0,---),
n=1, LAPSE)
CONTINUE
```

8. Job Control

8.1 Overlay structure

EXPANDA-75 needs core memories of 85K words with overlay and of 173K words without overlay. The overlay structure is shown in Fig 4. The names in the parenthesis are those of the labled common.

8.2 Auxiliary memories

EXPANDA-75 uses a lot of scratch disks in order to save the core memories. The logical unit numbers and their specifications are given in Table 2. The library tape is common for EXPANDA-70D.

Table 2. Auxiliary Memories Used in EXPANDA-75

Logical Number	Write-in Subroutine	Read-out Subroutine	Number of tracks	Comments
1	EDIT		100	collapsed cross sections
2	MICRO	ONEDIM, ZEEIA, EDIT	*	effective microscopic cross sections
4	READTP	MICRO	500	temporary library
18	ONEDIM	ONEDIM	30	scratch
24		READTP		library tape
31**	ZEETA	ZEETA, MICRO	75	scratch
⋮	〃	〃	〃	〃
⋮	〃	〃	〃	〃
40	〃	〃	75	〃

* $\sum_{K=1}^{KMAX} [\ 70 \times N(K)\ ]$,

where N(K) = 40 x MM(K)/Buffer length.

** Each disk of logical unit number 31 to 40 corresponds to each heterogeneous region. If 5 heterogenius regions are calculated, then only the disks of unit number 31 to 35 are required.

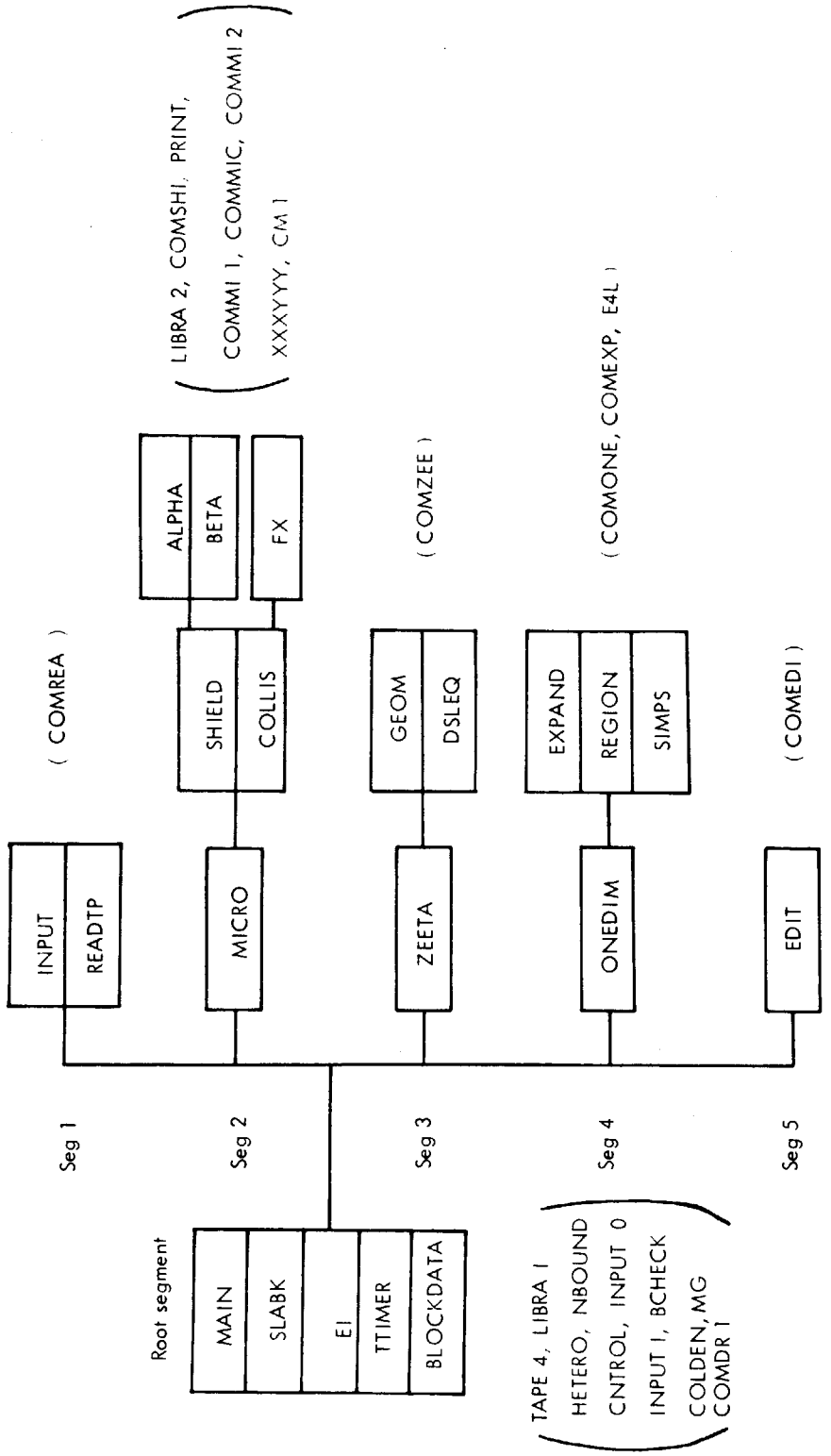

Fig. 4 Overlay structure of EXPANDA-75. Names in parenthesis are those of labled common.

9. Example

The criticality of two region reactor is calculated as an example. The core region is composed of four-plates lattice heterogeneous system whose specification is given in Table 3, and the reflector is homogeneous system composed of iron. The calculation was carried out as follows: First the core was homogenized and the core volume was adjusted so as to attain k_{eff}=1. Then fixing the core volume thus obtained, the effective multiplication factor (k_{eff}) was calculated by taking account of the heterogeneity of the core. The heterogeneity calculation was performed for two times, i.e., without fission source iteration (NZETA=1) and with one time iteration (NZETA=2), so as to know the effect of fission source iteration. Input data of this job are given in Appendix 1. Samples of output format are given in Appendix 2.

The effective multiplication factors (k_{eff}) are 1.00000 for homogeneous approximation, 1.01152 for NZETA=1 and 1.01161 for NZETA=2. This means that the heterogeneity effect on k_{eff} is 1.15 $\sim$ 1.16% for this reactor. It is proved that the iteration of fission source term little affects k_{eff}.

The ζ values of each plate are shown in Fig. 5. The difference due to fission source iteration is negligible. They are compared with the results calculated with ESELEM-4[11] a fine group spectrum code of 0.008 lethargy interval. The agreement is excellent, and the errors are 2% at most. This is indebted to the correction of elastic removal cross sections near the 2.85 keV resonance of sodim, since the agreement was

rather poor without correction.[4,12].

The effective microscopic cross sections are compared in Fig. 6 with the exact ones obtained with SDR[13,14], an ultra-fine group spectrum code of 200,000 group structure. The agreement is also good except for the capture cross section of ^{238}U below 465 eV. This drawback is common for EXPANDA-70D and is caused by the interpolation of self-shielding factor with the quadratic function, since the self-shielding factor of ^{238}U depends strongly on the admixture cross section in this energy range. More precise interpolation using hyperbolic tangent function was proposed[15]. However, this method requires considerable computing time, as the iteration is required. Taking it into account that the energy range below 500 eV is not very important for most of fast reactors, we decided not to change the present interpolation method at this moment.

The collapsed macroscopic cross sections to 11 group structure are tabulated as well as the diffusion coefficients in Table 4. It can be said from this table:

1) Fission cross sections and capture cross sections are changed by 15% at most when heterogeneity is taken into account. The collapsed fission cross sections are illustrated in Fig. 7.
2) Diffusion coefficients and scattering cross sections are less affected.
3) The results with NZETA=2 are little different from those with NZETA=1.

It is concluded that the heterogeneity effect of multi-region plate lattice system can be calculated accurately enough

without fission source iteration, i.e., with NZETA=1.

Table 3. Number Density of the System

	Core				Reflector
Plate	1	2	3	4	Homogeneous
Component	UO_2	Pu	UO_2	Na	Fe
No. Density ($\times 10^{23}/cm^3$)	^{238}U: 0.016 O: 0.032	Pu: 0.016	^{238}U: 0.016 O: 0.032	0.017	0.071
Thickness (cm)	0.6279	0.3256	0.6279	1.8555	

Table 4. Collapsed Cross Sections

Group	Lower Boundary	NZETA*	D cm^{-1}	Σ ($10^{-2}cm^{-2}$)		
				Capture	Scattering	Fission
1	4 (MeV)	0	6.62	0.121	7.95	0.674
		1	6.54	0.124	8.06	0.711
		2	6.54	0.124	8.06	0.711
2	1.4 (MeV)	0	5.31	0.0268	8.94	0.590
		1	5.27	0.0271	8.99	0.614
		2	5.27	0.0271	8.99	0.614
3	400 (keV)	0	2.94	0.0934	14.4	0.260
		1	2.94	0.0939	14.4	0.268
		2	2.94	0.0939	14.4	0.268
4	100 (keV)	0	2.27	0.124	15.3	0.247
		1	2.27	0.124	15.3	0.247
		2	2.27	0.124	15.3	0.247
5	21.5 (keV)	0	1.97	0.276	17.2	0.264
		1	1.98	0.259	17.2	0.261
		2	1.98	0.259	17.2	0.261
6	4.65 (keV)	0	1.80	0.523	19.1	0.302
		1	1.81	0.518	19.0	0.296
		2	1.81	0.518	19.0	0.296
7	1.0 (keV)	0	1.26	0.979	37.8	0.541
		1	1.30	0.900	36.9	0.491
		2	1.29	0.901	36.9	0.492
8	215 (eV)	0	2.01	1.110	16.1	1.032
		1	2.07	1.007	15.8	0.914
		2	2.06	1.008	15.8	0.916
9	46.5 (eV)	0	1.75	1.73	16.1	2.29
		1	1.82	1.52	15.8	1.89
		2	1.82	1.52	15.8	1.90
10	10 (eV)	0	2.02	3.55	15.4	1.87
		1	2.09	3.06	15.1	1.49
		2	2.09	3.07	15.1	1.49
11	0.215 (eV)	0	2.02	2.00	13.7	2.31
		1	2.05	1.88	13.5	2.02
		2	2.05	1.83	13.5	2.02

* NZETA=0 means homogeneous approximation.

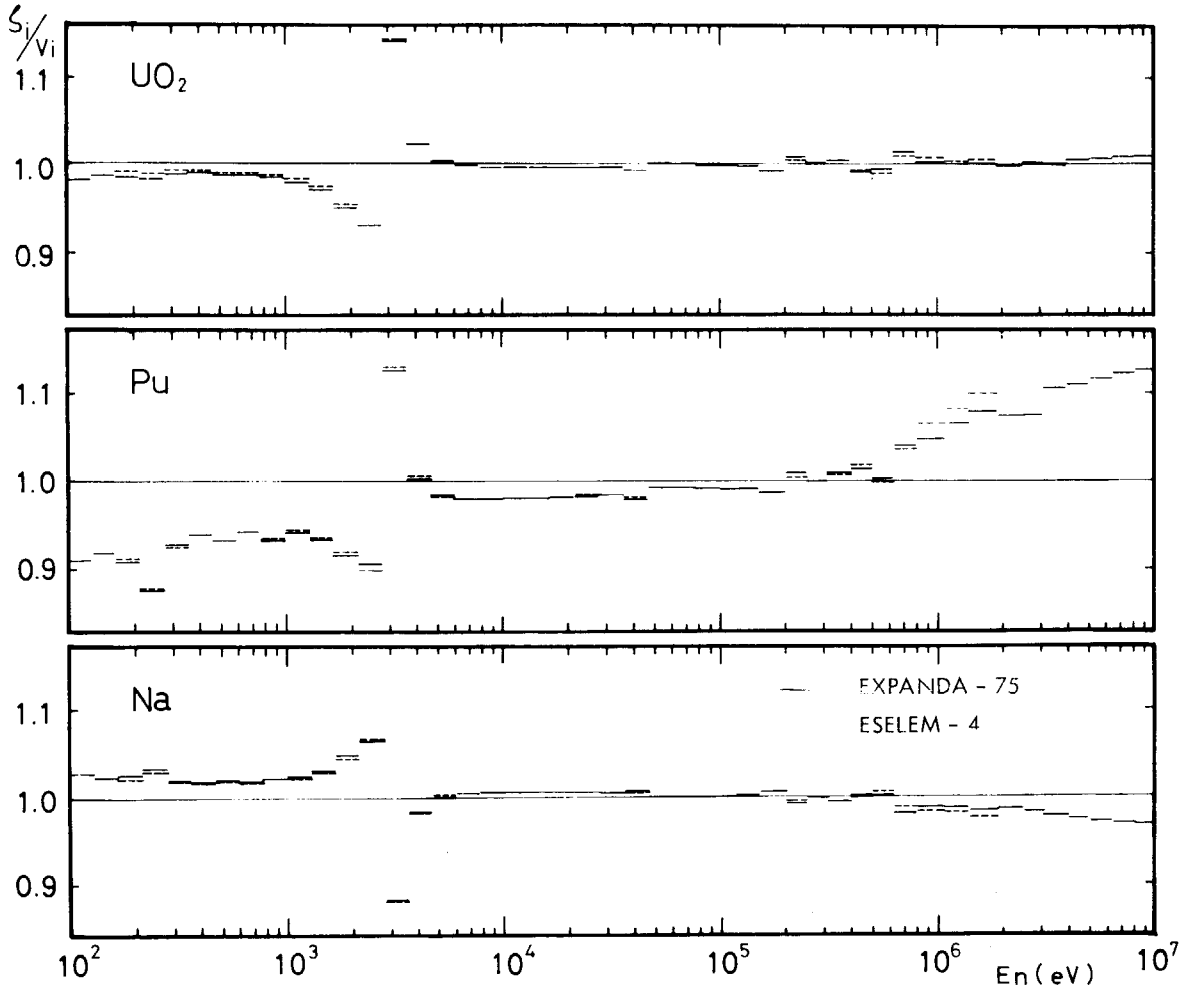

Fig. 5 Flux heterogeneity of UO_2, Pu and Na plates

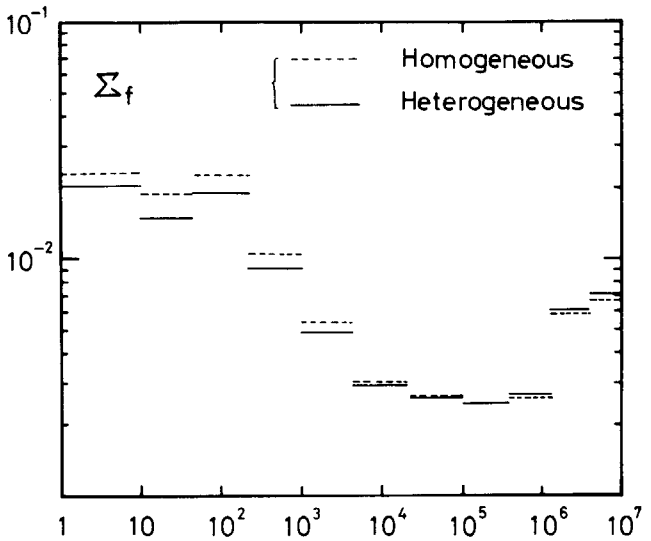

Fig. 7 Collapsed macroscopic cross sections

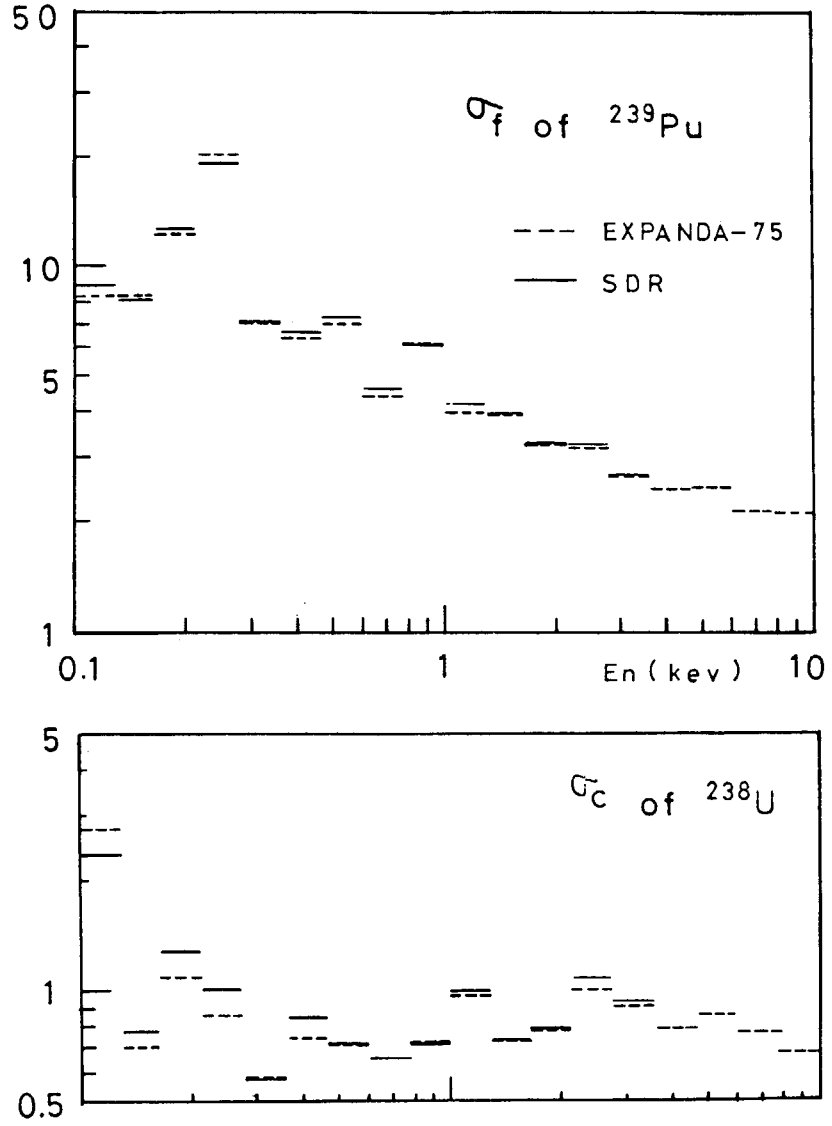

Fig. 6 Effective fission cross section of ^{239}Pu and effective capture cross section of ^{238}U.

Acknowledgment

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References

1) KATSURAGI, S., TONE, T. and HASEGAWA, A. : JAERI Fast Reactor Group Constants Systems Part I, JAERI 1195 (1970)

2) KATSURAGI, S., ISHIGURO, Y., TAKANO, H. and NAKAGAWA, M.: JAERI Fast Reactor Group Constants Systems , Part II-1, JAERI 1199 (1970)

3) SUZUKI, T. and KATSURAGI, S. : EXPANDA-5, JAERI 1210 (1972)

4) KIKUCHI, Y., KATSURAGI, S. and TAKANO, H. : Proceedings of AESJ 1973 Topical Meeting on Fast Reactor Physics, p. 60 (1973) (in Japanese)

5) HASEGAWA, A., KATSURAGI, S. and TONE, T. : EXPANDA-70 D, JAERI-M 4953 (1972) (in Japanese)

6) KIKUCHI, Y. and KATSURAGI, S. : Approximate Expression of Collision Density and Correction of Group Elastic Removal Cross Section near a Wide Scattering Resonance, JAERI-M 5963 (1975)

7) NAKAGAWA, M and TSUCHIHASHI, K. : SLAROM, JAERI-M 5916 (1974) (in Japanese)

8) KIKUCHI, Y. : J. Nucl. Sci. Technol., 11 (1974) 26

9) SUZUKI, T. and ISHIGURO, Y. : FASTOS, JAERI-memo 1914 (1965) (in Japanese)

10) HASEGAWA, A. and KATSURAGI, S. : J-FAST-70U, JAERI-M 5381 (1973) (in Japanese)

11) NAKAGAWA, M., KATSURAGI, S. and NARITA, H. : to be published

12) KIKUCHI, Y. and KATSURAGI, S. : REACTOR ENGINEERING DIVISION ANNUAL REPORT (April 1, 1973 to March 31, 1974) p.24, JAERI -M 5955 (1975)

13) BRISSENDEN, R. J. and DURSTON, C. : "Calculation of Neutron Spectra in the Doppler Region", ANL-7050, p. 51 (1971)

14) In JAERI, SDR was modified for two region cylindrical cell by T. SUZUKI in 1971 : SUZUKI, T. : JAERI-M 4481 (1971) (in Japanese)

15) KIDMAN, R. B., SCHENTER, R. E., HARDIE, R. W. and LITTLE, W. W. : Nucl. Sci. Eng., 48 (1972) 179

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Appendix 1 Sample of Input Data

Appendix 2 Samples of Output Format

#0 List of input data for the first case (homogeneous)

#1 Heterogeneity for the second case (NDETA = 1)

#2 Effective microscopic cross sections of the first case

#3 Macroscopic cross sections of the first case

#4 Flux calculation of the first case

#5 Reaction rates of the first case

#6 Collapsed cross sections of the first case

Appendix 1 Sample of Input Data

```
....*....1....*....2....*....3....*....4....*....5....*....6....*....7....*....8

 HETERO CASE NO 4 AND FE REFLECTOR
                    0     70            0     31     46     0
0     11234568     3 0   HOMOGENEOUS , CRITICAL SEARCH                          1
  1  2 +1 70 +1 +1 29  1  2 -1 +1  0 11 1.E-5 1.E-4  0.   10.   1.0
  2     6     1
  3    30    40
  4     4     8    13    19    25    31    37    43    49    55    70           1
  5  2.0   2.0
  6 300.  300.
  8928 0.016         8 0.032       949 0.016       928 0.016         8 0.032       11
  8 11 0.017                                                                     12
  8 26 0.073                                                                     21
     0
     1     4
     2     1     2     1
  0.6279       0.3256       0.6279       1.8555
     1     1
0    -11           0 0   HETERO   NZETA=1
  1             0  0              -1
     1
     1     4
     2     1     2     1
  0.6279       0.3256       0.6279       1.8555
     1     1
0    -2            0 0   HETERO   NZETA=2
     2
     1     4
     2     1     2     1
  0.6279       0.3256       0.6279       1.8555
     1     1
1
```

Appendix 2 #0 List of input data for the first case (homogeneous)

```
                    HETERO CASE NO 4 AND FE REFLECTOR

GENERAL CONTROL OF JOB

     NS       IFX      NP       IMX     ISKIPD   ISIGP    MPMIN    MPMAX      I7       ITPE
      0        1        0        70       0        0        31       46        0        0

                IMX * ITPE  = 70 GROUP JAERI FAST SET

                NS * IFX * ISKIPD = DUMMY VALUES


           OPTION FOR OUTPUT (IF 0 THEN SKIP)

                EFFECTIVE MICROSCOPIC CROSS SECTIONS PRINT-OUT    1

                MACROSCOPIC CROSS SECTIONS PUNCH-OUT              0

                FLUX AND ADJOINT FLUX PUNCH-OUT                   0

                COLLAPSED CROSS SEDTION ON TAPE UNIT 1            0


DATA FOR COLLIS ( DEFINED IN BLOCKDATA )
 COLLISION DENSITY IS CULCULATED FROM  31 GROUP TO  37 GROUP
 MESH NUMBERS FOR INTEGRATION    30
 PEAK-V                      5.69620E 02
 RESONANCE WIDTH             4.16788E 02
 RESONANCE ENERGY            2.85000E 03
 NUCLIDE   NUCLIDES REPRESENTED BY THE LEFT
  OXYGEN        8     6     4     5   105     0     0
  SODIUM       11     0     0     0     0     0     0
  IRON         13    24    26    28    29    40    42
 *** END INITIAL       TIME=  22.00(SEC)
```

```
      PROB.     1            HOMOGENEOUS , CRITICAL SEARCH

INPUT DATA LIST

REGIONS   SYMMETRY   GROUPS     CRIT   SIG.PRINT  DOWN-SC. CONT.REG.  GEOMETRY  ADJOINT   REACT-RT     BSQM     COLLAPSE
   2          1         70        1         1         29         1         2        -1         1          0         11

INPUT FOR CONVERGENCE CRITERION AND CRITICALITY SEARCH

      EPS1                EPS2                DR-MIN              DR-MAX              LAMBDA2
      1.000000E-05        1.000000E-04        0.0                 1.000000E 01        1.000000E 00

CROSS SECTIONS ARE COLLAPSED TO 11 STRUCTURE

    LAST GROUPS FOR COLLAPSE
       4         8        13        19        25        31        37        43        49        55        70

SPECIFICATION OF SYSTEM

 GEOMETRY  2     ( 0=SLAB , 1=CYLINDER , 2=SPHERE )

 REGION    NO OF     INTERFACE    MESH SIZE     TEMPERATURE    TRANSVERSE
   NO     ELEMENTS    POINT                                   BUCKLING

    1         6         30       2.00000E 00    3.000E 02
    2         1         40       2.00000E 00    3.000E 02


NZETA    0     ( IF 0 THEN HOMOGENEOUS APPROXIMATION )


SPECIFICATION OF EACH REGION

REGION 1     NUMBER OF PLATES=  4

  CELL PATERN  1 ( 0=SYMMETRIC , 1=PERIODIC )

  PLATE MMM THICKNESS  VOL-RATIO          NUMBER DENSITY

    1    2  6.279E-01  1.827E-01   928 1.60000E-02     8 3.20000E-02
    2    1  3.256E-01  9.474E-02   949 1.60000E-02
    3    2  6.279E-01  1.827E-01   928 1.60000E-02     8 3.20000E-02
    4    1  1.856E 00  5.399E-01    11 1.70000E-02

REGION 2     NUMBER OF PLATES=  1

  NUMBER DENSITY                   26 7.30000E-02

 *** END INPUT          TIME=  23.00(SEC)
```

Appendix 2 #1 Heterogeneity for the second case (NDETA = 1)

OUTPUT FROM ZEETA FOR REGION 1

BSQM
0.1591E-02

PHI
0.9980E-01 0.3206E+00 0.7332E+00 0.1363E+01 0.2182E+01 0.2778E+01 0.3756E+01 0.4477E+01 0.4001E+01 0.6615E+01
0.5962E+01 0.7252E+01 0.4183E+01 0.6820E+01 0.6332E+01 0.5762E+01 0.7620E+01 0.5375E+01 0.4100E+01 0.4938E+01
0.4377E+01 0.3767E+01 0.3502E+01 0.2872E+01 0.2271E+01 0.1823E+01 0.1363E+01 0.1012E+01 0.7523E+00 0.5299E+00
0.3376E+00 0.1751E+00 0.3759E-01 0.6289E-01 0.1926E+00 0.2241E+00 0.1810E+00 0.1204E+00 0.7560E-01 0.4299E-01
0.2519E-01 0.1369E-01 0.5479E-02 0.2568E-02 0.1260E-02 0.5804E-03 0.2381E-03 0.6427E-04 0.1620E-04 0.6465E-05
0.3809E-05 0.1202E-05 0.3472E-06 0.7887E-07 0.1944E-07 0.8350E-08 0.1004E-08 0.4484E-09 0.2734E-09 0.1631E-09
0.8985E-10 0.4493E-10 0.1886E-10 0.6699E-11 0.1812E-11 0.3385E-12 0.3624E-13 0.8538E-15 0.4320E-17 0.2764E-18

D(J)
0.6964E-01 0.8607E+00 0.6964E-01 0.0

ZETA IN REGION 1

GROUP	PHI	PLATE 1	2	3	4
1	9.8239E-02	1.850E-01	1.068E-01	1.850E-01	5.283E-01
		1.012	1.127	1.012	0.967
2	3.1515E-01	1.848E-01	1.065E-01	1.848E-01	5.240E-01
		1.011	1.124	1.011	0.971
3	7.2053E-01	1.844E-01	1.058E-01	1.844E-01	5.255E-01
		1.009	1.117	1.009	0.973
4	1.3402E+00	1.840E-01	1.052E-01	1.840E-01	5.267E-01
		1.007	1.111	1.007	0.976
5	2.1473E+00	1.832E-01	1.049E-01	1.832E-01	5.287E-01
		1.003	1.107	1.003	0.979
6	2.7355E+00	1.834E-01	1.020E-01	1.834E-01	5.312E-01
		1.004	1.076	1.004	0.984
7	3.7109E+00	1.825E-01	1.018E-01	1.825E-01	5.331E-01
		0.999	1.075	0.999	0.987
8	4.4231E+00	1.830E-01	1.022E-01	1.830E-01	5.318E-01
		1.002	1.079	1.002	0.985
9	3.9592E+00	1.829E-01	1.010E-01	1.829E-01	5.332E-01
		1.001	1.066	1.001	0.988
10	6.5486E+00	1.833E-01	9.928E-02	1.833E-01	5.342E-01
		1.003	1.048	1.003	0.989
11	5.8971E+00	1.855E-01	9.866E-02	1.855E-01	5.303E-01
		1.015	1.041	1.015	0.982
12	7.2141E+00	1.818E-01	9.508E-02	1.818E-01	5.414E-01
		0.995	1.004	0.995	1.003
13	4.1768E+00	1.813E-01	9.615E-02	1.813E-01	5.413E-01
		0.992	1.015	0.992	1.003
14	6.7547E+00	1.836E-01	9.568E-02	1.836E-01	5.371E-01
		1.005	1.010	1.005	0.995
15	6.2849E+00	1.830E-01	9.482E-02	1.830E-01	5.391E-01
		1.002	1.001	1.002	0.999
16	5.7039E+00	1.845E-01	9.563E-02	1.845E-01	5.353E-01
		1.010	1.009	1.010	0.992
17	7.6030E+00	1.816E-01	9.356E-02	1.816E-01	5.433E-01

		0.994	0.988	0.994	1.006
18	5.3529E+00	1.825E-01	9.394E-02	1.825E-01	5.411E-01
		0.999	0.992	0.999	1.002
19	4.0825E+00	1.827E-01	9.398E-02	1.827E-01	5.406E-01
		1.000	0.992	1.000	1.001
20	4.9190E+00	1.827E-01	9.394E-02	1.827E-01	5.406E-01
		1.000	0.992	1.000	1.001
21	4.3590E+00	1.830E-01	9.403E-02	1.830E-01	5.400E-01
		1.002	0.993	1.002	1.000
22	3.7510E+00	1.833E-01	9.405E-02	1.833E-01	5.394E-01
		1.003	0.993	1.003	0.999
23	3.5045E+00	1.816E-01	9.285E-02	1.816E-01	5.439E-01
		0.994	0.980	0.994	1.008
24	2.8735E+00	1.823E-01	9.331E-02	1.823E-01	5.420E-01
		0.998	0.985	0.998	1.004
25	2.2767E+00	1.821E-01	9.309E-02	1.821E-01	5.428E-01
		0.997	0.983	0.997	1.005
26	1.8298E+00	1.821E-01	9.306E-02	1.821E-01	5.427E-01
		0.997	0.982	0.997	1.005
27	1.3706E+00	1.821E-01	9.293E-02	1.821E-01	5.428E-01
		0.997	0.981	0.997	1.005
28	1.0186E+00	1.823E-01	9.296E-02	1.823E-01	5.425E-01
		0.998	0.981	0.998	1.005
29	7.5889E-01	1.822E-01	9.280E-02	1.822E-01	5.428E-01
		0.997	0.980	0.997	1.006
30	5.3524E-01	1.824E-01	9.281E-02	1.824E-01	5.423E-01
		0.999	0.980	0.999	1.005
31	3.4146E-01	1.835E-01	9.321E-02	1.835E-01	5.397E-01
		1.005	0.984	1.005	1.000
32	1.7857E-01	1.869E-01	9.496E-02	1.869E-01	5.312E-01
		1.023	1.002	1.023	0.984
33	4.2303E-02	2.082E-01	1.063E-01	2.082E-01	4.774E-01
		1.139	1.122	1.139	0.884
34	6.0489E-02	1.696E-01	8.506E-02	1.696E-01	5.758E-01
		0.928	0.898	0.928	1.067
35	1.9485E-01	1.737E-01	8.650E-02	1.737E-01	5.662E-01
		0.951	0.913	0.951	1.049
36	2.3298E-01	1.777E-01	8.832E-02	1.777E-01	5.563E-01
		0.973	0.932	0.973	1.030
37	1.9134E-01	1.791E-01	8.904E-02	1.791E-01	5.527E-01
		0.980	0.940	0.980	1.024
38	1.2983E-01	1.800E-01	8.816E-02	1.800E-01	5.519E-01
		0.985	0.931	0.985	1.022
39	8.2921E-02	1.805E-01	8.900E-02	1.805E-01	5.499E-01
		0.988	0.939	0.988	1.019
40	4.8234E-02	1.807E-01	8.805E-02	1.807E-01	5.506E-01
		0.989	0.929	0.989	1.020
41	2.8802E-02	1.810E-01	8.872E-02	1.810E-01	5.494E-01
		0.991	0.936	0.991	1.018
42	1.6085E-02	1.809E-01	8.759E-02	1.809E-01	5.507E-01
		0.990	0.925	0.990	1.020
43	6.8801E-03	1.798E-01	8.279E-02	1.798E-01	5.576E-01
		0.984	0.874	0.984	1.033
44	3.3588E-03	1.801E-01	8.549E-02	1.801E-01	5.544E-01
		0.986	0.902	0.986	1.027
45	1.7030E-03	1.805E-01	8.654E-02	1.805E-01	5.525E-01

		0.988	0.914	0.988	1.023
46	8.1476E-04	1.793E-01	8.536E-02	1.793E-01	5.561E-01
		0.981	0.901	0.981	1.030
47	3.5120E-04	1.797E-01	8.439E-02	1.797E-01	5.562E-01
		0.984	0.891	0.984	1.030
48	1.0857E-04	1.772E-01	7.506E-02	1.772E-01	5.705E-01
		0.970	0.792	0.970	1.057
49	3.2706E-05	1.784E-01	7.270E-02	1.784E-01	5.705E-01
		0.976	0.767	0.976	1.057
50	1.3632E-05	1.776E-01	8.402E-02	1.776E-01	5.608E-01
		0.972	0.887	0.972	1.039
51	8.0365E-06	1.810E-01	9.105E-02	1.810E-01	5.469E-01
		0.991	0.961	0.991	1.013
52	2.8039E-06	1.785E-01	7.878E-02	1.785E-01	5.642E-01
		0.977	0.832	0.977	1.045
53	8.5136E-07	1.754E-01	8.276E-02	1.754E-01	5.664E-01
		0.960	0.874	0.960	1.049
54	2.3406E-07	1.786E-01	7.111E-02	1.786E-01	5.717E-01
		0.978	0.751	0.978	1.059
55	6.9701E-08	1.785E-01	7.219E-02	1.785E-01	5.708E-01
		0.977	0.762	0.977	1.057
56	3.1656E-08	1.797E-01	8.402E-02	1.797E-01	5.565E-01
		0.984	0.887	0.984	1.031
57	4.6628E-09	1.609E-01	6.192E-02	1.609E-01	6.164E-01
		0.880	0.654	0.880	1.142
58	2.0487E-09	1.786E-01	8.819E-02	1.786E-01	5.546E-01
		0.978	0.931	0.978	1.027
59	1.2565E-09	1.813E-01	9.002E-02	1.813E-01	5.474E-01
		0.992	0.950	0.992	1.014
60	7.6119E-10	1.814E-01	8.952E-02	1.814E-01	5.476E-01
		0.993	0.945	0.993	1.014
61	4.2913E-10	1.813E-01	8.835E-02	1.813E-01	5.491E-01
		0.992	0.933	0.992	1.017
62	2.2257E-10	1.810E-01	8.656E-02	1.810E-01	5.515E-01
		0.991	0.914	0.991	1.021
63	9.8984E-11	1.805E-01	8.398E-02	1.805E-01	5.550E-01
		0.988	0.886	0.988	1.028
64	3.8613E-11	1.799E-01	8.036E-02	1.799E-01	5.599E-01
		0.985	0.848	0.985	1.037
65	1.2214E-11	1.790E-01	7.476E-02	1.790E-01	5.673E-01
		0.980	0.789	0.980	1.051
66	2.9971E-12	1.780E-01	6.579E-02	1.780E-01	5.781E-01
		0.975	0.695	0.975	1.071
67	5.5473E-13	1.774E-01	4.915E-02	1.774E-01	5.960E-01
		0.971	0.519	0.971	1.104
68	8.1606E-14	1.794E-01	1.303E-02	1.794E-01	6.281E-01
		0.982	0.137	0.982	1.164
69	1.1559E-14	1.796E-01	2.936E-03	1.796E-01	6.378E-01
		0.983	0.031	0.983	1.181
70	1.9022E-15	1.793E-01	3.723E-03	1.793E-01	6.376E-01
		0.982	0.039	0.982	1.181
AVERAGE		1.829E-01	9.630E-02	1.829E-01	5.380E-01
		1.001	1.017	1.001	0.997

*** END ZEETA(NO. 1) TIME= 24.00(SEC)

Appendix 2 #2 Effective microscopic cross sections of the first case

** EFFECTIVE MICRO SIGMA **

** GROUP I = 31

GROUP	REGION	MCODE	SIGO	FISSION	CAPTURE	ELASTIC	ELASTIC.REMOVAL
31	1						
	== PLATE NO.	1 ==					
		928	2.97804E+01	0.0	8.62126E-01	1.34918E+01	5.30692E-01
				1.0000	0.8286	0.7924	0.5649
		8	1.83717E+01	0.0	0.0	3.70000E+00	1.63526E+00
				1.0000	1.0000	1.0000	1.0000
	== PLATE NO.	2 ==					
		949	9.91797E+01	2.53865E+00	1.82515E+00	1.13150E+01	2.97189E-01
				0.9795	0.9660	0.9849	0.7125
	== PLATE NO.	3 ==					
		928	2.97804E+01	0.0	8.62126E-01	1.34918E+01	5.30692E-01
				1.0000	0.8286	0.7924	0.5649
		8	1.83717E+01	0.0	0.0	3.70000E+00	1.63526E+00
				1.0000	1.0000	1.0000	1.0000
	== PLATE NO.	4 ==					
		11	1.64524E+01	0.0	3.25239E-03	1.28954E+01	4.50423E+00
				1.0000	0.9900	0.9893	0.9893
GROUP	REGION	MCODE	SIGO	FISSION	CAPTURE	ELASTIC	ELASTIC.REMOVAL
31	2						
	== PLATE NO.	1 ==					
		26	0.0	0.0	2.55394E-02	7.51909E+00	6.44696E-01
				1.0000	0.9025	0.8995	0.8935

Appendix 2 #3 Macroscopic cross sections of the first case

PROB. 1

MACROSCOPIC CROSS-SECTIONS FOR GROUP 1

D
7.7408909E+00 2.7418031E+00

TRANSPORT
4.3064032E-02 1.2159451E-01

ABSORPTION
1.3737992E-02 4.3187158E-03

SCATTERING
5.7512619E-02 2.3018124E-01

TOTAL REMOVAL
3.7905690E-02 1.1140874E-01

YIELD
3.6610543E-02 0.0

FISSION
9.5714268E-03 0.0

SCATTERING TRANSFER TO $I+0$ ---- $I+2^9$

REGION 1

3.3344922E-02	5.3895212E-03	1.4045473E-03	2.3241562E-03	7.5555559E-03	6.3807084E-03
6.6767433E-03	9.5340997E-04	6.1976397E-04	6.3850715E-04	3.4915436E-04	2.5243579E-04
1.8876353E-04	1.3749392E-04	8.1437516E-05	5.6222862E-05	4.6440960E-05	2.2618566E-05
1.2666338E-05	1.1890791E-05	7.2561286E-06	4.3557029E-06	2.0932982E-06	2.1646584E-06
7.7662727E-07	4.7198292E-07	0.0	0.0	0.0	0.0

REGION 2

1.2309121E-01	9.9203652E-03	3.6705495E-03	6.7210298E-03	1.0376731E-02	1.0724576E-02
1.4548316E-02	1.4925580E-02	9.8485032E-03	9.8881421E-03	5.2670597E-03	3.6216615E-03
2.4148035E-03	1.8919629E-03	1.0847289E-03	7.5590040E-04	6.1980724E-04	2.9778452E-04
1.6180012E-04	1.4800020E-04	8.8227071E-05	5.1988703E-05	3.1854281E-05	1.9237982E-05
1.1421288E-05	0.0	0.0	0.0	0.0	0.0

Appendix 2 #4 Flux calculation of the first case

```
FLUX CALCULATION

 CONTROLLED DELTA-R = 2.0000000E+00

  LAMBDA  1 = 0.98840094
  LAMBDA  2 = 1.00177166
  LAMBDA  3 = 1.00849998
  LAMBDA  4 = 1.00863275
  LAMBDA  5 = 1.00867221
  LAMBDA  6 = 1.00866359
  LAMBDA  7 = 1.00866625

 CONTROLLED DELTA-R = 1.9653350E+00

  LAMBDA  1 = 0.99599649
  LAMBDA  2 = 0.99587204
  LAMBDA  3 = 0.99581105
  LAMBDA  4 = 0.99581037
  LAMBDA  5 = 0.99581006

 CONTROLLED DELTA-R = 1.9766326E+00

  LAMBDA  1 = 0.99996711
  LAMBDA  2 = 1.00000814
  LAMBDA  3 = 1.00002831
  LAMBDA  4 = 1.00002867
  LAMBDA  5 = 1.00002870

 CONTROLLED DELTA-R = 1.9765558E+00

  LAMBDA  1 = 1.00000098
  LAMBDA  2 = 1.00000072
  LAMBDA  3 = 1.00000060

  SOURCE

    2.1085554E-06       2.1063683E-06       2.0998147E-06       2.0889191E-06       2.0737223E-06       2.0542813E-06
    2.0306692E-06       2.0029736E-06       1.9712983E-06       1.9357616E-06       1.8964960E-06       1.8536480E-06
    1.8073771E-06       1.7578561E-06       1.7052689E-06       1.6498120E-06       1.5916922E-06       1.5311265E-06
    1.4683423E-06       1.4035756E-06       1.3370723E-06       1.2690869E-06       1.1998839E-06       1.1297370E-06
    1.0589318E-06       9.8776826E-07       9.1656536E-07       8.4567176E-07       7.7549264E-07       7.0657424E-07
    6.4006498E-07

    0.0                 0.0                 0.0                 0.0                 0.0                 0.0
    0.0                 0.0                 0.0                 0.0                 0.0

  INTEGRATED SOURCE

    9.9999999E-01       0.0

  REGION VOLUMES

    8.7333247E+05       1.2152592E+06
```

FLUXES GROUP 1

2.0914115E-07	2.0891902E-07	2.0825329E-07	2.0714629E-07	2.0560186E-07	2.0362532E-07
2.0122348E-07	1.9840456E-07	1.9517818E-07	1.9159529E-07	1.8754810E-07	1.8317002E-07
1.7843557E-07	1.7336027E-07	1.6796061E-07	1.6229384E-07	1.5625794E-07	1.4999144E-07
1.4347330E-07	1.3672277E-07	1.2975917E-07	1.2260175E-07	1.1526952E-07	1.0778094E-07
1.0015373E-07	9.2404548E-08	8.4548692E-08	7.6599660E-08	6.8568683E-08	6.0464069E-08
5.2290166E-08					
5.2290166E-08	3.3877627E-08	2.1960926E-08	1.4234288E-08	9.2116998E-09	5.9330283E-09
3.7755673E-09	2.3327566E-09	1.3356730E-09	6.0166157E-10	0.0	

INTEGRATED FLUXES

1.0671263E-01

9.4756328E-02 1.1956299E-02

REGION CHECKS

1.1302595E-04 -1.0600007E-04

1.1304876E-04 -1.0798996E-04

FLUXES GROUP 2

6.7194371E-07	6.7122974E-07	6.6908990E-07	6.6553169E-07	6.6056734E-07	6.5421392E-07
6.4649315E-07	6.3743134E-07	6.2705922E-07	6.1541174E-07	6.0252789E-07	5.8845048E-07
5.7322578E-07	5.5690330E-07	5.3953549E-07	5.2117728E-07	5.0188575E-07	4.8171968E-07
4.6073909E-07	4.3900475E-07	4.1657754E-07	3.9351793E-07	3.6988524E-07	3.4573687E-07
3.2112747E-07	2.9610791E-07	2.7072416E-07	2.4501588E-07	2.1901479E-07	1.9274241E-07
1.6620652E-07					
1.6620652E-07	1.0887992E-07	6.8774394E-08	4.4258743E-08	2.8437892E-08	1.8193042E-08
1.1505438E-08	7.0700722E-09	4.0307300E-09	1.8106103E-09	0.0	

INTEGRATED FLUXES

3.4118523E-01

3.0380900E-01 3.7376224E-02

REGION CHECKS

3.4495357E-04 -3.2439407E-04

3.4502640E-04 -3.3067280E-04

Appendix 2 #5 Reaction rates of the first case

```
                                        PROB.     1          EDITTING

REACTION RATES  GROUP  1

 REGION  1

  CAPTURE FOR EACH NUCLIDE
    PLATE  1    928  2.192373E-06      8  1.537447E-04
    PLATE  2    949  1.482752E-07
    PLATE  3    928  2.192373E-06      8  1.537447E-04
    PLATE  4     11  8.278591E-05

    REGION      928  4.384747E-06    949  1.482752E-07      8  3.074895E-04     11  8.278591E-05

  ABSORPTION FOR EACH NUCLIDE
    PLATE  1    928  2.840554E-04      8  1.537447E-04
    PLATE  2    949  3.433754E-04
    PLATE  3    928  2.840554E-04      8  1.537447E-04
    PLATE  4     11  8.278591E-05

    REGION      928  5.681109E-04    949  3.433754E-04      8  3.074895E-04     11  8.278591E-05

   TOTAL ABSORPTION  1.3018E-03      TOTAL FISSION  9.0695E-04      TOTAL CAPTURE  3.9481E-04

 REGION  2

  CAPTURE FOR EACH NUCLIDE
    PLATE  1     26  5.163586E-05

    REGION       26  5.163586E-05

  ABSORPTION FOR EACH NUCLIDE
    PLATE  1     26  5.163586E-05

    REGION       26  5.163586E-05

   TOTAL ABSORPTION  5.1636E-05      TOTAL FISSION  0.0             TOTAL CAPTURE  5.1636E-05

REACTION RATES  GROUP  2

 REGION  1

  CAPTURE FOR EACH NUCLIDE
    PLATE  1    928  8.800097E-06      8  3.185295E-04
    PLATE  2    949  5.248042E-07
    PLATE  3    928  8.800097E-06      8  3.185295E-04
    PLATE  4     11  1.169337E-04

    REGION      928  1.760019E-05    949  5.248042E-07      8  6.370590E-04     11  1.169337E-04

  ABSORPTION FOR EACH NUCLIDE
    PLATE  1    928  8.559298E-04      8  3.185295E-04
    PLATE  2    949  9.887263E-04
    PLATE  3    928  8.559298E-04      8  3.185295E-04
    PLATE  4     11  1.169337E-04
```

```
   REGION      928  1.711860E-03    949  9.887263F-04      8  6.370590E-04     11  1.169337E-04

  TOTAL ABSORPTION  3.4546E-03      TOTAL FISSION  2.6825E-03      TOTAL CAPTURE  7.7212E-04

REGION  2

 CAPTURE FOR EACH NUCLIDE
   PLATE  1     26  8.478733E-05

   REGION       26  8.478733E-05

 ABSORPTION FOR EACH NUCLIDE
   PLATE  1     26  8.478733E-05

   REGION       26  8.478733E-05

  TOTAL ABSORPTION  8.4787E-05      TOTAL FISSION  0.0             TOTAL CAPTURE  8.4787E-05
```

Appendix 2 #6 Collapsed cross sections of the first case

```
CALLAPSED MACRO SIGMAS FOR GROUP  1

    DIFFUSION
      6.6236987E+00       2.3953322E+00

    SIGMA-TR
      5.0747849E-02       1.3961213E-01

    SIGMA-A
      7.9753404E-03       7.8198704E-04

    SIGMA-S
      7.9533648E-02       2.6573730E-01

    SIGMA-T (ABSORPTION + SCATTERING AWAY(NET))
      3.4631832E-02       1.0528506E-01

    NU-SIGMA-F
      2.2437953E-02       0.0

    SIGMA-F
      6.7359876E-03       0.0

    SIGMA-S TO N+0 ---- N+10

      REGION  1
      5.2877157E-02       1.3625357E-02       1.0421921E-02       3.2784594E-03       3.2118044E-04       1.4429578E-05
      4.5134264E-09       0.0                 0.0                 0.0                 0.0

      REGION  2
      1.6123423E-01       5.2764594E-02       4.2996041E-02       8.0852122E-03       6.4609898E-04       1.1194087E-05
      0.0                 0.0                 0.0                 0.0                 0.0

CALLAPSED MACRO SIGMAS FOR GROUP  2

    DIFFUSION
      5.3054895E+00       1.9993054E+00

    SIGMA-TR
      6.4212069E-02       1.6819161E-01

    SIGMA-A
      6.1629867E-03       2.0305342E-04

    SIGMA-S
      8.9393420E-02       2.2361962E-01

    SIGMA-T (ABSORPTION + SCATTERING AWAY(NET))
      2.7873239E-02       4.6755071E-02

    NU-SIGMA-F
      1.7261366E-02       0.0
```

```
SIGMA-F
  5.8951842E-03        0.0

SIGMA-S TO N+0 ---- N+10

  REGION  1
  6.7683168E-02        1.5728114E-02        4.7908445E-03        1.1407987E-03        4.9591253E-05        9.1086312E-07
  0.0                  0.0                  0.0                  0.0                  0.0

  REGION  2
  1.7706761E-01        4.3690705E-02        2.4999995E-03        3.4020264E-04        2.1133343E-05        0.0
  0.0                  0.0                  0.0                  0.0                  0.0
```