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TP2 - A Computer Program for the Calculation of Reactivity and Kinetic Parameters by the Two-Dimensional Neutron Transport Perturbation Theory

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Abstract

TP2 is a FORTRAN-IV program for the calculation of the reactivity, effective delayed neutron fractions and mean generation time by the perturbation theory using the angular fluxes calculated by a two-dimensional S_n transport code. Group cross sections, delayed neutron fractions and spectra, isotope dependent prompt neutron spectrum, and direct and adjoint angular fluxes are read from disk files. This code can treat x-y, r-z and r-θ geometry in two dimensions, and the code structure is nearly the same as the TP1 code for the one-dimensional geometry.

As in the TP1 code, there are two main options. One is for the exact perturbation calculation of the reactivity where the direct and adjoint angular fluxes are used for unperturbed and perturbed systems respectively. The other option is for the first order perturbation calculation of the probe reactivity in which usually unperturbed direct and adjoint angular fluxes are used. In both cases, reactivities for each reaction process are printed in the energy and space dependent form according to the input specification.

The criticality factor calculated by the S_n transport code using an isotope independent fission spectrum can be corrected by the TP2 code by taking into account an isotope dependency of the prompt fission spectrum and delayed neutron spectrum.

Numerical examples are presented to demonstrate the accuracy of the reactivity, the effect of the number of mesh points and the order of the S_n method. Comparisons with the diffusion method are given.

TP2, Ein Programm zur Berechnung von Reaktivitäten und Kinetik-Parametern basierend auf zweidimensionaler Neutronen-Transport-Störungstheorie

Zusammenfassung

TP2 ist ein FORTRAN-IV Störungstheorie-Programm zur Berechnung von Reaktivitäten, effektiven verzögerten Neutronenanteilen und mittleren Generationszeiten; TP2 benutzt die Information aus Winkelflüssen eines zweidimensionalen S_N Codes. Gruppenkonstanten, verzögerte Neutronenanteile und Spektren, isotopabhängiges promptes Neutronenspektrum und direkte und adjungierte Winkelflüsse werden als Plattendateien übergeben. Das Programm ist für zweidimensionale x-y, r-z und r-θ Geometrie und besitzt eine ähnliche Struktur wie das eindimensionale Programm TP1.

Wie in TP1 gibt es zwei Hauptoptionen. Die erste ist exakte Störungstheorie, d. h. für die Berechnung der Reaktivität werden die direkten Winkelflüsse des ungestörten Systems und die adjungierten Winkelflüsse des gestörten Systems verwendet. Die zweite ist Störungstheorie 1. Ordnung, die direkte und adjungierte Winkelflüsse des ungestörten Systems benutzt. Bei beiden Optionen werden für jeden Reaktionstyp die Reaktivitäten energie- und ortsabhängig ausgegeben.

Der mit isotopunabhängigem Spaltspektrum berechnete Kritikalitätsfaktor des S_N Programmes kann von TP2 - unter Berücksichtigung eines isotopabhängigen prompten Spaltspektrums und eines verzögerten Neutronenspektrums - korrigiert werden.

Numerische Beispiele geben einen Eindruck von der erreichbaren Genauigkeit für Reaktivitäten, dem Effekt der Anzahl der Ortspunkte und der Ordnung der S_N Quadratur. Darüberhinaus ist ein Vergleich mit Diffusionsmethoden beschrieben.

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I INTRODUCTION

The transport perturbation theory is described in Ref. /1/ for the calculation of reactivity, effective delayed neutron fraction and mean neutron generation time. In Chap. II, only the results of the perturbation theory, the explicit expressions of these quantities are given, which are used in TP2 code. The structure of TP2 code and input and output of the code are almost the same as those of TP1 code /1/.

The code TP2 reads the direct and adjoint angular fluxes which are calculated by the two dimensional S_n transport code SNOW /2/, and group cross section table used in S_n code. Fission cross sections and delayed neutron fraction for each fissile isotope are read separately. Isotope dependent prompt neutron fission spectra and delayed neutron spectra are read to calculate a criticality factor which is corrected for the dependence of prompt fission neutron spectra on the individual fissile isotopes and the spectrum difference between the prompt and delayed neutrons. This has to be done in TP2 code because the present version of the transport code SNOW can use only an isotope independent fission neutron spectrum.

In Chap. III details of the program and input description are given. If all input data described in Chap. III, which are read by each subroutine, are available, TP2 code can be used with any other S_n transport code.

In Chap. IV sample calculations are given to demonstrate the accuracy of the reactivity and criticality factor with respect to the number of mesh points and the order of S_n method. Comparison with the diffusion theory is also given there. Summary of the present work is given in Chap. V.

II FORMULAS

1. Explicit Expression of Reactivity

The derivation of the reactivity by the perturbation theory is given in Ref. /1/. Here, only the final results are given in the following.

The reactivity for each reaction process is given as follows:

$$\rho_{cg}(\vec{r}) = -\delta\hat{\Sigma}_{cg}\sum_{m}\Delta\vec{\Omega}_{m}\, f^{+}_{kg}(\vec{r},\vec{\Omega}_{m})f_{kog}(\vec{r},\vec{\Omega})/[F], \qquad \text{(capture)} \qquad (1)$$

$$\rho_{fg}(\vec{r}) = -\delta\Sigma_{fg}\sum_{m}\Delta\vec{\Omega}_{m}\, f^{+}_{kg}(\vec{r},\Omega_{m})f_{kog}(\vec{r},\vec{\Omega})/[F], \qquad \text{(fission)} \qquad (2)$$

$$\rho_{rg}(\vec{r}) = -\delta\hat{\Sigma}_{tg}\sum_{m}\Delta\vec{\Omega}_{m}\, f^{+}_{kg}(\vec{r},\vec{\Omega}_{m})f_{kog}(\vec{r},\vec{\Omega})/[F], \qquad \text{(removal)} \qquad (3)$$

$$\rho_{sog}(\vec{r}) = -\delta\Sigma_{sg}\sum_{m}\Delta\vec{\Omega}_{m}\, f^{+}_{kg}(\vec{r},\vec{\Omega}_{m})f_{kog}(\vec{r},\vec{\Omega})/[F], \qquad \text{(scattering out)} \qquad (4)$$

$$\rho_{sig}(\vec{r}) = \sum_{g'=1}^{g-1}\sum_{l=0}^{I_s}\frac{2l+1}{4\pi}\,\Sigma_{sl}(g\leftarrow g')\sum_{m=0}^{l}\varepsilon_{m}\left(f^{+lm}_{kgc}(\vec{r}_i)f^{lm}_{kog'c}(\vec{r}_i)+f^{+lm}_{kgs}(\vec{r}_i)f^{lm}_{kog's}(\vec{r}_i)\right)/[F]$$

$$\text{(scattering in)} \qquad (5)$$

$$\rho_{oig}(\vec{r}_i) = \rho_{sog}(\vec{r}_i) + \rho_{sig}(\vec{r}_i) \qquad \text{(scattering out + scattering in)} \qquad (6)$$

$$\rho_{g\leftarrow g-1}(\vec{r}_i) = \sum_{l=0}^{I_s}\frac{2l+1}{4\pi}\,\Sigma_{sl}(g\leftarrow g-1)\sum_{m=0}^{l}\varepsilon_{m}\left(f^{+lm}_{kgc}(\vec{r}_i)f^{lm}_{kog-1c}(\vec{r}_i)+f^{+lm}_{kgs}(\vec{r}_i)f^{lm}_{kog-1s}(\vec{r}_i)\right)/[F]$$

$$\text{(scattering in from g-1 to g)} \qquad (7)$$

$$\rho_{fsg}(\vec{r}_i) = f^{+oo}_{kg}(\vec{r}_i)\left(\sum_{j}\chi^{j}_{g}\sum_{g'=1}^{G}\delta(\nu_p\Sigma_f)^{j}_{g'}+\sum_{i}\chi_{ig}\sum_{g'=1}^{G}\delta(\nu^{i}_{d}\Sigma_f)_{g'}\right)f^{oo}_{kog'}(\vec{r}_i)/4\pi k_o\,[F]$$

$$\text{(fission source)} \qquad (8)$$

$$\rho_{afg}(\vec{r}_i) = \sum_{g'=1}^{G}f^{+oo}_{kg'}(\vec{r}_i)\left(\sum_{j}\chi^{j}_{g'}\delta(\nu_p\Sigma_f)^{j}_{g}+\sum_{i}\chi_{ig'}\delta(\nu^{i}_{d}\Sigma_f)_{g}\right)f^{oo}_{kog}(\vec{r}_i)/4\pi k_o\,[F]$$

$$\text{(adjoint fission source)} \qquad (9)$$

$$\rho_{g}(\vec{r}) = \rho_{rg}(\vec{r}) + \rho_{sig}(\vec{r}) + \rho_{fsg}(\vec{r}) \qquad \text{(total)} \qquad (10)$$

$$[F] = \frac{1}{4\pi}\sum_{p}\Delta V_p\sum_{g=1}^{G}f^{+oo}_{kg}(\vec{r}_p)\left(\sum_{i}\chi^{j}_{g}\sum_{g'=1}^{G}(\nu_p\Sigma_f)^{j}_{g'}+\sum_{i}\chi_{ig}\sum_{g'=1}^{G}(\nu^{i}_{d}\Sigma_f)_{g'}\right)f^{oo}_{kog'}(\vec{r}_p) \qquad (11)$$

where $\varepsilon_0 = 1$, $\varepsilon_1 = \varepsilon_2 = \varepsilon_3 = \ldots = 2$, and

$$\hat{\Sigma}_{tg} = \hat{\Sigma}_{ag} + \Sigma_{sg}, \quad *) \tag{12}$$

$$\hat{\Sigma}_{ag} = \Sigma_{absg} + D_g B_g^2. \tag{13}$$

The mean generation time $\bar{\Lambda}$ is

$$\bar{\Lambda} = \sum_p \Delta V_p \sum_{g=1}^{G} \frac{1}{vg} \left(\sum_m \Delta\vec{\Omega}_m \, f^+_{kg}(\vec{r}_p,\vec{\Omega}_m) f_{kog}(\vec{r}_p,\vec{\Omega}_m) \right) / \, [F] \tag{14}$$

The effective delayed neutron fractions $\bar{\beta}_i^j$ are

$$\bar{\beta}_i^j = \sum_p \Delta V_p \sum_{g=1}^{G} \left(f^{+oo}_{kog}(\vec{r}_p)\chi_{ig} \right) \sum_{g'=1}^{G} \left((\nu^i_d \Sigma_f)^j_{g'}, \, f^{oo}_{kog'}, (\vec{r}_p) \right) / \, [F] \tag{15}$$

$$\bar{\beta}_i = \sum_j \bar{\beta}_i^j \tag{16}$$

$$\bar{\beta}^j = \sum_i \bar{\beta}_i^j \tag{17}$$

The index g denotes energy group, and $f_{ko}(\vec{r},\vec{\Omega})$ and $f^+_{kg}(\vec{r},\vec{\Omega})$ are unperturbed direct and perturbed adjoint angular fluxes respectively. The indices j and i denote the isotope and the delayed neutron group respectively. The effective delayed neutron fractions are calculated for each mixture.

The spherical harmonics moments are defined by

$$f^{ln}(\vec{r}) = \sum_m \Delta\vec{\Omega}_m \, Y^*_{ln}(\vec{\Omega}_m) f(\vec{r},\vec{\Omega}_m) \equiv f^{ln}_c(\vec{r}) - i f^{ln}_s(\vec{r}) \tag{18}$$

Then

$$f^{ln}_c(\vec{r}) = \sum_m \Delta\vec{\Omega}_m \left[\frac{(1-n)!}{(1+n)!} \right]^{1/2} P_{ln}(\cos\theta_m) \cos n\phi_m \tag{19}$$

$$f^{ln}_s(\vec{r}) = \sum_m \Delta\vec{\Omega}_m \left[\frac{(1-n)!}{(1+n)!} \right]^{1/2} P_{ln}(\cos\theta_m) \sin n\phi_m \tag{20}$$

In the TP2 code, the factor ε_m in Eq. (7) is included in the spherical harmonics function. Namely, the spherical harmonics function $\hat{Y}^c_{ln}(\theta_m,\phi_m)$ and $\hat{Y}^s_{ln}(\theta_m,\phi_m)$ are defined as

$$\hat{Y}^c_{ln}(\theta_m,\phi_m) = \left[\varepsilon_n \frac{(1-n)!}{(1+n)!} \right]^{1/2} P_{ln(\cos\theta_m)} \cos n\phi_m \tag{21}$$

---

*) This relation which is used to determine Σ_{sg} is essential for taking into account (n,2n) reactions (see also /1/ p.12).

$$\hat{Y}^{s}_{ln}(\theta_m,\phi_m) = \left[\frac{\epsilon_n(1-n)!}{(1+n)!}\right]^{1/2} P_{ln}(\cos\theta_m)\sin n\phi_m \tag{22}$$

Summing up the energy and space dependent reactivities over energy group, we obtain space dependent reactivities,

$$\rho_\alpha(\vec{r}) = \sum_g \rho_{\alpha g}(\vec{r}) \tag{23}$$

where α denotes each reaction process. By integrating them over space, we obtain energy dependent reactivities,

$$\rho_{\alpha g} = \sum_{ij} \Delta V_{ij}\, \rho_{\alpha g}\,(\vec{r}_{ij}) \tag{24}$$

Summing them up over energy group and integrating over space, we obtain the reactivities for the whole reactor,

$$\rho_\alpha = \sum_g \sum_{i,j} \Delta V_{ij}\, \rho_{\alpha g}\,(\vec{r}_{ij}) \tag{25}$$

Volume element is given as in the following.

a) x-y geometry

$$\Delta V_{ij} = \Delta x_i \Delta y_j \tag{26}$$

b) r-z geometry

$$\Delta V_{ij} = \pi(r_{i+1}^2 - r_i^2)\Delta z_j \tag{27}$$

c) r-θ geometry

$$\Delta V_{ij} = \frac{1}{2}(r_{i+1}^2 - r_i^2)\Delta\theta_j \tag{28}$$

2. Symmetry of the Angular Flux

In the case of two dimensional geometry shown in Fig. 1, there is the following symmetry for the angular flux:

$$f_g(\vec{r},\theta,\phi) = f_g(\vec{r},\pi-\theta,\phi) \tag{29}$$

Since the angular flux is expanded in the form (Ref. /1/ Eq. (42)),

$$f_g(\vec{r},\vec{\Omega}) = \frac{1}{4\pi} \sum_{l=0}^{\infty} (2l+1) \sum_{m=-l}^{l} f_g^{lm}(\vec{r}) Y_{lm}(\vec{\Omega}) \tag{30}$$

then

$$f_g(\vec{r},\pi-\theta,\phi) = \frac{1}{4\pi} \sum_{l=0}^{\infty} (2l+1) \sum_{m=-l}^{l} f_g^{lm}(\vec{r}) Y_{lm}(\pi-\theta,\phi)$$

$$= \frac{1}{4\pi} \sum_{l=0}^{\infty} (2l+1) \sum_{m=-l}^{l} f_g^{lm}(\vec{r}) (-1)^{l+m} Y_{lm}(\theta,\phi) \tag{31}$$

Therefore,

$$(-1)^{l+m} f_g^{lm}(\vec{r}) = f_g^{lm}(\vec{r}) \tag{32}$$

Then $$f_g^{lm}(\vec{r}) = f_g^{clm}(\vec{r}) - i f_g^{slm}(\vec{r}) = 0, \quad \text{for } l+m = \text{odd}. \tag{33}$$

III COMPUTER PROGRAM

1. Problem Solved by TP2 Code

The two dimensional S_n transport perturbation code TP2 calculates two cases: exact perturbation and first order perturbation due to probe substitution according to input specification to the TP2 code. TP2 code reads direct and adjoint angular fluxes and the group cross section table from the disk (ISNOW). In the case of exact perturbation calculation, the direct equation should be solved using the unperturbed cross section and the adjoint equation using the perturbed cross section. In this case, perturbation is simply the difference of two cross section sets used for direct and adjoint equations. In the case of first order perturbation, the same cross section set should be used for direct and adjoint equation. The perturbation is the difference of the original cross sections and the substituted probe cross sections.

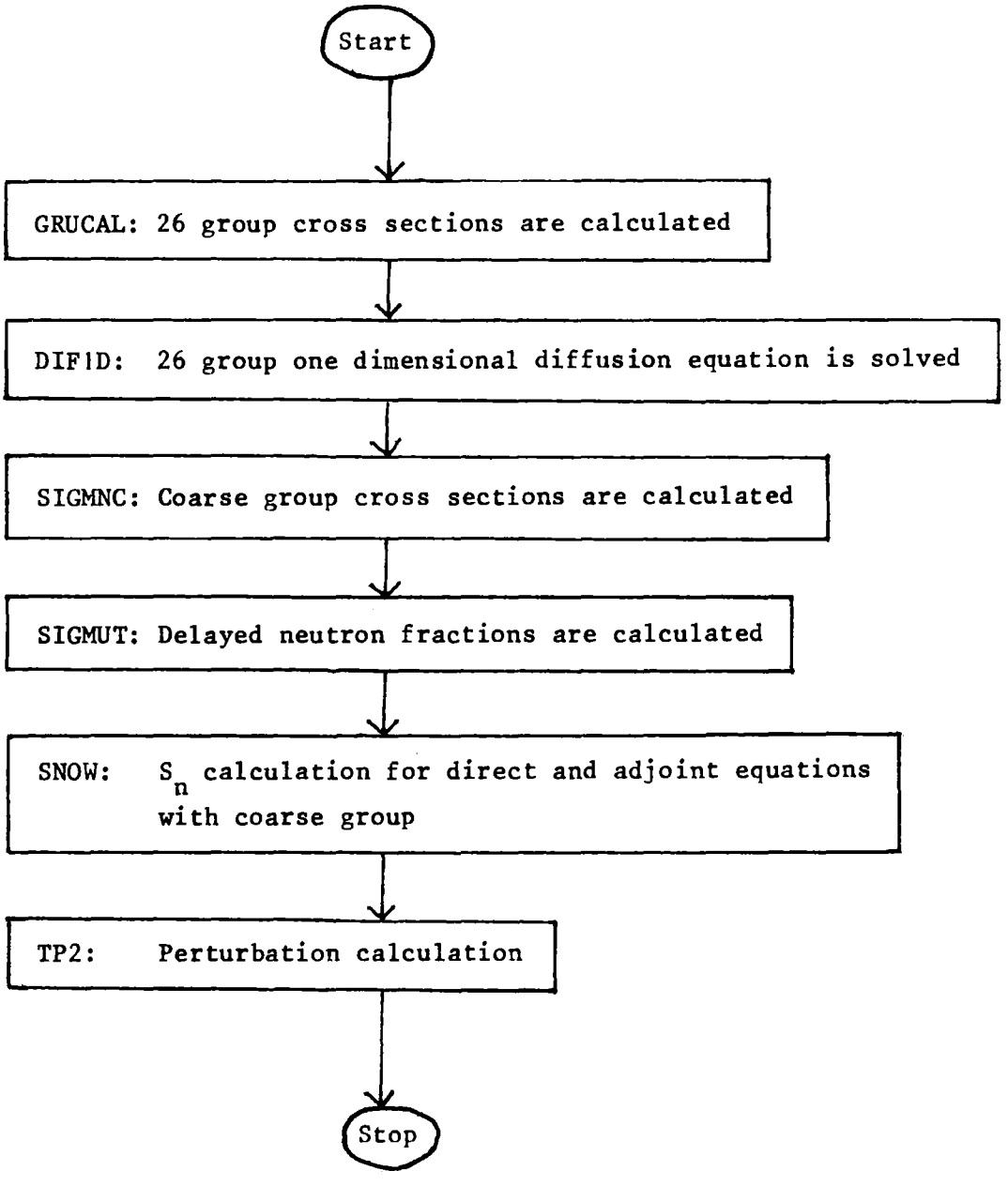
The perturbation code TP2 can be also used together with any other S_n transport

code, if all input data, which are read by several subroutines, are supplied. Therefore, for this purpose, it is only necessary to replace or to rewrite some subroutines for reading input data which are described in detail in the following.

2. Program Chain and Data Flow for TP2 Calculation

The perturbation calculation is performed by using GRUCAL /3/, DIF1D /4/, SIGMUT /6/ and SNOW which are modules of the KAPROS system and the transport perturbation code TP2 in the following order.

Flow diagram of whole perturbation calculation



1) GRUCAL computes all group cross sections in the form of SIGMN file for the unperturbed and perturbed systems.

2) DIFID solves one dimensional diffusion equation using 26 group cross sections computed by GRUCAL and integrates zonewise the 26 group fluxes.

3) SIGMNC condenses the 26 group cross sections into appropriate coarse groups using the one dimensional integrated fluxes as weighting functions. This procedure is supposed to be sufficient for the present purpose. For other cases it might be more appropriate to use improved weighting functions coming e.g. from two dimensional diffusion calculation.

4) SIGMUT reads the delayed neutron data from card input and computes delayed fission cross section and adds this to SIGMN-block. The complete condensed SIGMN-file is written on the disk IGRUC by using KAPROS utility UTKS.

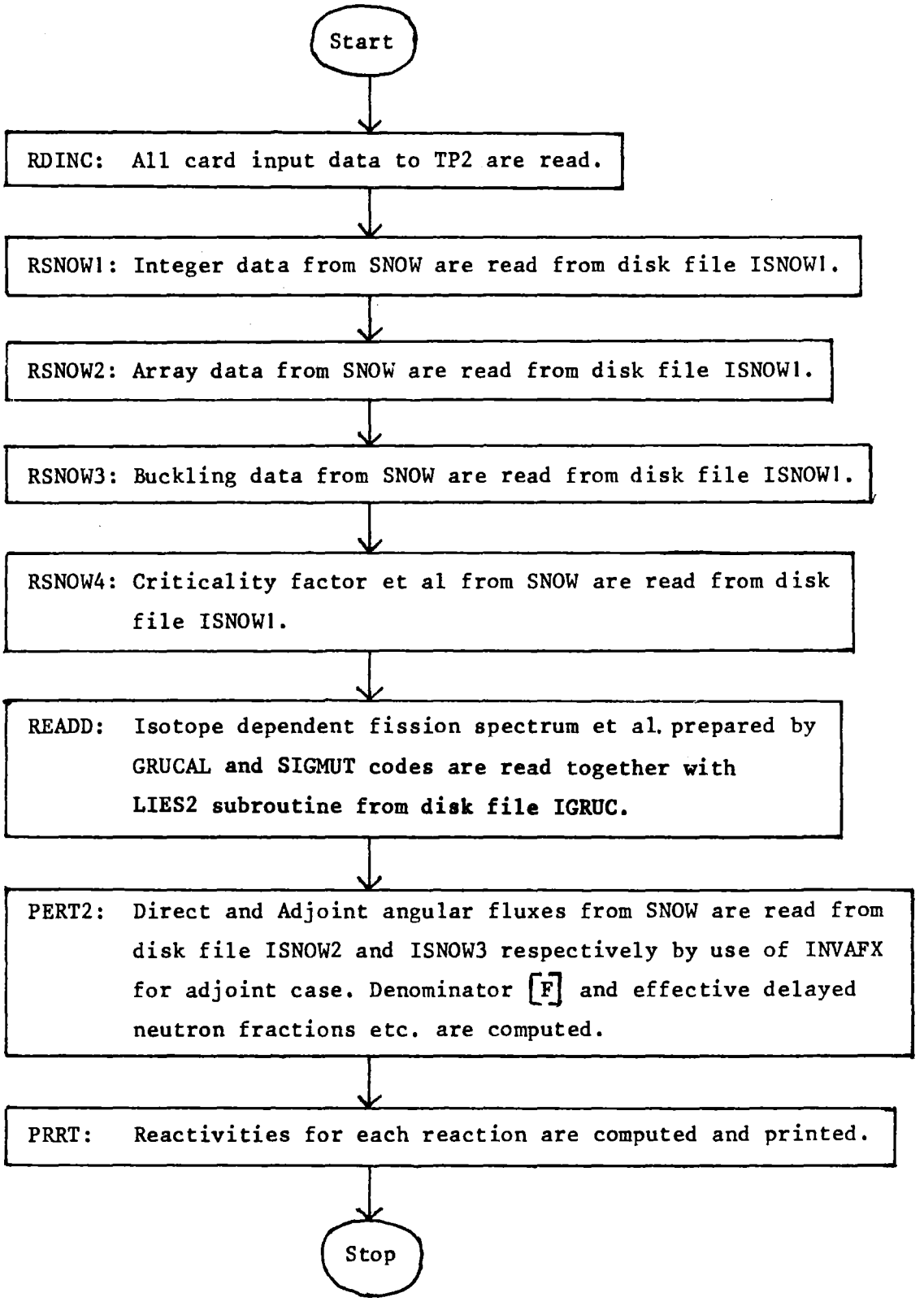
5) SNOW reads cross sections from the SIGMN file on a disk IGRUC and computes first the direct angular flux and criticality factor and then the adjoint angular flux and criticality factor, and writes them on a disk in three files, ISNOW1, ISNOW2 and ISNOW3. This interface file is created only by the latest version of SNOW within KAPROS system.

6) TP2 reads the direct and adjoint angular fluxes, cross section table written by SNOW, isotope dependent fission cross sections and fission spectra and delayed neutron data available in the SIGMN-block.

3. Explanation of the program TP2

1) Flow diagram and subroutines of TP2

Flow diagram of the TP2 program is shown in the following.



The following subroutines are used in TP2.

a) DIMENS: Dimension of a working array A which contains integer and real number is declared.

b) RDINC: All card input data to TP2 are read.

c) RSNOW1: Following data are read from the disk ISNOW1 as a first record written by SNOW code. After reading, these are printed. All notations given here and in the following follow closely those of the SNOW code /2/.

ISCT: Order of anisotropic scattering,
ISN: Order of S_n, 2, 4, 6, 8.
IGE: Geometry (1/2/3 = x-y/r-z/r-θ),
IGM: Number of groups,
IXM: Number of zones in x (or r) coordinate,
IYM: Number of zones in y (or z or θ) coordinate,
IM: Number of intervals in x (or r) coordinate,
JM: Number of intervals in y (or z or θ) coordinate,
MBK: =0 , No buckling,
=1 , Buckling correction using height Ho,
=±2, Group dependent buckling,
=±3, Group and zone dependent buckling,
BF: = Ho; The height Ho for buckling correction, when MBK = 1,
RLOG: = 10^{-10}, (This is not used in TP2 code.)
MT: Length of cross section table,
MTP: Number of mixtures,
MM: = ISN(ISN+4)/2, Number of angular directions,
IHS: Location of $\Sigma_{so}(g \leftarrow g)$ in cross section table,
IHT: Location of total cross section in cross section table,
IHM: Length of cross section table,

After reading the above quantities, IS = ISCT+1 is computed.

d) RSNOW2: Following data are read from the disk ISNOW1 as a second record successively to the data read by RSNOW1.

V(IM,IYM): = ΔV_{ij}, volume element,

RX(IMP): = x_i, x coordinate, IMP = IM+1,

RY(JMP): =y_j, y coordinate, JMP = JM+1,

MAI(IM): zone index in x-coordinate,

MAJ(JM): zone index in y-coordinate,

IMAT(MTP): Index for mixtures,

W(MM): = w_m, weight of quadrature formula over solid angle,

TW(IS,IS,MM): spherical harmonics function multiplied by weight w_m,

C(IHM,IGM,MT): cross section table, IHM = IGM+5,

$C(1,G,N) = \Sigma^m_{trg}$, $C(2,G,N) = \Sigma^m_{fg}$

$C(3,G,N) = \Sigma^m_{ag}$, $C(4,G,N) = \nu\Sigma^m_{fg}$, IHS = 6

$C(5,G,N) = \Sigma^m_{tg}$, $C(IHS+G-G',G,N) = \Sigma^m_{so}(g\leftarrow g')$

$C(IHS+G-G',N+L) = \Sigma^m_{sl}(g\leftarrow g')$ for $1 \le L \le ISCT \le 6$,

where m is the mixture index and N = |MZ(IX,JY)|,
IX=MAI(I), JY=MAJ(J).

e) RSNOW3: Buckling values are read from the disk ISNOW1,

B(IBM): B_g^2 or $D_gB_g^2$ first for direct equation and later for adjoint equation. Here,

IBM=0, if MBK=0 or 1 (Read statement is skipped.)

IBM=IGM, if MBK=±2

IBM=IXMxIYMxIGM, if MBK=±3

If MBK = 1, BF = H_o should be read in by RSNOW1, and

$$D_gB^2 = \frac{1}{3\Sigma_{trg}}\left[\frac{\pi}{H_o+2Z_o\lambda_{trg}}\right]^2 = \frac{\Sigma_{trg}}{3}\left[\frac{\pi}{H_o\Sigma_{trg}+2Z_o}\right]^2$$

This D_gB^2 can be dependent on group and zone.

If MBK = 2, B_g^2 is read as (B(G), G=1, IGM)

=-2, $D_gB_g^2$ is read.

If MBK = 3, $B_g^2(\vec{r}_{ij})$ is read as

(((B(G,I,J),G=1,IGM),I=1,IXM),J=1,IYM).

= -3, $D_g B_g^2(\vec{r}_{ij})$ is read.

f) RSNOW4: Following data are read from the disk ISNOW1 first for direct equation and later for adjoint equation.

MZ(IXM,IYM): Location of the o-th moment of scattering cross section in the cross section table.

RK: Criticality factor

After reading MZ(IXM,IYM), MZT(IXM,IYM) is calculated which is the mixture index denoting which material is in each zone.

g) FCT(N): = N! for the normalization of the spherical harmonics function.

h) SPHF: Spherical harmonics function is stored in the following form in SNOW code.

$$\left.\begin{aligned} T(L,N,M) &= P_{l-1,n-1}(\xi_m)\cos(n-1)\phi_m \\ &= 0 \end{aligned}\right\} \quad \begin{aligned} &\text{for } L=1\sim IS,\ N=1\sim L,\ L+N=\text{even}, \\ &\qquad\qquad L+N=\text{odd}. \end{aligned}$$

$$\left.\begin{aligned} T(L,N,M) &= P_{n-1,1}(\xi_m)\cos 1\phi_m \\ &= 0 \end{aligned}\right\} \quad \begin{aligned} &\text{for } L=1\sim(IS-1),\ N=(L+1)\sim IS, \\ &\qquad\qquad L+N+1=\text{even}, \\ &\qquad " \qquad\qquad L+N+1=\text{odd}. \end{aligned}$$

$$TW(N,J,M) = W_m \times T(N,J,M),\ N=1,\sim IS,\ J=1\sim IS,\ M=1\sim MM.$$

In this subroutine, the array TW is multiplied by the constant such that

$$TW(L,N,M) = W_m\left[\frac{2(1-n)!}{(1-1+n-1)!}\right]^{1/2} P_{1-1,n-1}(\xi_m)\cos(n-1)\phi_m, \quad \text{for } 2\le N\le L \quad 2\le L\le IS,$$

$$TW(L,N,M) = W_m\left[\frac{2(n-1-1)!}{(n-1+1)!}\right]^{1/2} P_{n-1,1}(\xi_m)\sin 1\phi_m, \quad \text{for } L+1\le N\le IS \quad 1\le L\le IS-1.$$

i) READD: This subroutine is the same as the one used in TP1 code. Following data are read from the core memory prepared usually by GRUCAL, SIGMNC and SIGMUT codes.

SNFTJ(IGM,IFM,MTP) = $(\nu\Sigma_f)_g^j$; Number of total fission neutrons times fission cross section of j-isotope,

SNFDJ(IGM,IDM,IFM,MTP) = $(\nu_d{}^i\Sigma_f)_g^j$; Number of ith-group delayed neutrons times fission cross section of j-isotope,

XKIJ(IGM,IFM,MTP) = χ_g^j; Prompt fission spectrum of j-isotope,

DKI(IGM,IDM) = χ_{ig}; Delayed neutron spectrum of i-th delayed neutron group,

where MTP, IFM and IDM are number of mixtures, number of fissile isotope and number of delayed neutron groups, respectively. After reading these data, following cross sections are computed.

SNFP(IGM,MTP) = $(\nu_p\Sigma_f)_g = \sum_j (\nu_p\Sigma_f)_g^j$

SNFPJ(IGM,IFM,MTP) = $(\nu_p\Sigma_f)_g^j$

SNFD(IGM,IDM,MTP) = $(\nu_d^i\Sigma_f)_g = \sum_j (\nu_d^i\Sigma_f)_g^j$

j) LIES2: This subroutine is taken from DTK code and is rewritten such that the program for the preparation of cross section table C is deleted and the SIGMN file prepared by GRUCAL and SIGMUT is read from the disk file IGRUC to the core memory to prepare only the delayed neutron data for READD.

k) WQORG: This subroutine is the same as that used in the DTK code. This code is used in READD to read cross section from SIGMN file.

l) CLEAR: This subroutine is used to make an array set zero.

m) PRINT1: Print one dimensional array,

n) PRINT2: Print two dimensional array,

o) PRINT3: Print three dimensional array,

p) PERT2: Denominator $[\bar{F}]$, mean generation time and effective delayed neutron fractions are computed.

q) RUIS: Higher order spherical harmonics components and a reactivity due to the higher order scattering are computed.

r) PRRT: Reactivities for each reaction are computed and printed.

s) INVAFX: Adjoint angular flux is read from the disk ISNOW3 and re-ordered inversely with respect to the group index. The order with respect to the angular index must also be changed because in the SNOW code, the adjoint equation is solved by replacing $\vec{\Omega}_m$ by $-\vec{\Omega}_m$. Therefore, the order of angular flux is rearranged such that $-\vec{\Omega}_m = \vec{\Omega}_{m'}$. The following indexes show that, for example, $f_g^+(\vec{r}_i,-\vec{\Omega}_6)$ in S_2 case is transferred to the second place as $f_g^+(\vec{r}_i,\vec{\Omega}_2)$. The rearranged adjoint angular flux is stored in the disk IDSK1. The place where no index is given has the zero weight for w_m. Therefore those terms give no contribution to the integral over angular variable.

S2

M 1, 2, 3, 4, 5, 6,
M' -, 6, 5, -, 3, 2,

S4

M 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16
M' -, 13, 12, 11, 10, -, 16, 15, -, 5, 4, 3, 2, -, 8, 7

S6

M 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16,
M' -, 22, 21, 20, 19, 18, 17, -, 27, 26, 25, 24, -, 30, 29, -,

M 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30,
M' 7, 6, 5, 4, 3, 2, -, 12, 11, 10, 9, -, 15, 14,

S8

M 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15,
M' -, 33, 32, 31, 30, 29, 28, 27, 26, -, 40, 39, 38, 37, 36,

M 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30,
M' 35, -, 45, 44, 43, 42, -, 48, 47, -, 9, 8, 7, 6, 5,

M 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48,
M' 4, 3, 2, -, 16, 15, 14, 13, 12, 11, -, 21, 20, 19, 18, -, 24, 23,

2) Arrays used in TP2

A(LAENGE): Master array,

NAIST(2IFMP): Name of fissile isotopes, IFMP = IFM+1

MAI(IM): Zone index in x coordinate,

MAJ(JM): Zone index in y coordinate,

IMAT(MTP): Index for mixtures,

MZT(IXM,IYM): Mixture index denoting which mixture is in each zone,

MZ(IXM,IYM): Location of the o-th moment of scattering cross section in the cross section table for each zone,

MZTP(IXM,IYM): MZT(IXM,IYM) for adjoint equation,

MZP(IXM,IYM): MZ(IXM,IYM) for adjoint equation,

IPLATZ(MTP): Location of the o-th moment of scattering cross section in the cross section table,

V(IM,IYM): = ΔV, Volume element

RX(IMP): = x_i, IMP = IM+1,

RY(JMP): = y_j, JMP = JM+1,

W(MM): = w_m, Weight of angular quadrature,

TW(IS,IS,MM): Spherical harmonics function multiplied by weight w,

B(IBM): IBM = 0, if MBK = 0 or 1,
IBM = IGM, if MBK = ±2,
IBM = IXMxIYMxIGM, if MBK = ±3,

BP(IBM): B(IBM) for adjoint equation,

VE(IGM): $= \frac{1}{v_g}$, v_g is group dependent neutron velocity,

KAI(IGM): $= \chi_g$, Isotope independent fission spectrum used in SNOW code,

C(IHM,IGM,MT): Cross section table, IHM=IHS+IGM-1, IHS=6

SNFDJ(IGM,IDM,IFM,MTP): $= (\nu_d{}^i\Sigma_f)_g^i$

SNFD(IGM,IDM,MTP): $= (\nu_d{}^i\Sigma_f)_g = \sum_j (\nu_d{}^i\Sigma_f)_g^j$

SNFTJ(IGM,IFM,MTP: $= (\nu\ \Sigma_f)_g^j = \sum_i (\nu_d{}^i\Sigma_f)_g + (\nu_p\Sigma_f)_g$

SNFPJ(IGM,IFM,MTP): $= (\nu_p\Sigma_f)_g^j$

SNFP(IGM,MTP): $= (\nu_p\Sigma_f)_g = \sum_j (\nu_p\Sigma_f)_g^j$

XKIJ(IGM,IFM,MTP): $= \chi_g{}^j$, Isotope dependent fission spectrum,

DKI(IGM,IDM): $= \chi_{ig}$, Delayed neutron spectrum,

FKO(IM,JM): $= f_{kog}(\vec{r}_i,\vec{\Omega}_m)$, Angular flux for some direction, Temporary.

FKD(JM,JM): $= f^+_{kg}(\vec{r}_i,\vec{\Omega}_m)$, Adjoint angular flux for some direction, Temporary.

FTKO(IM,JM,IGM): $= f^{oo}_{kog}(\vec{r})$, Total flux for direct equation,

FTKD(IM,JM,IGM): $= f^{+oo}_{kg}(\vec{r})$, Total flux for adjoint equation,

AFKOD(IM,JM,IGM): $= \sum_m w_m\ f^+_{kg}(\vec{r},\vec{\Omega}_m) f_{kog}(\vec{r},\vec{\Omega}_m)$,

SDK(IDM): Temporary,

SMFD(IDM): Temporary,

SMDFD(IDM): Temporary,

SMXD(IDM): Temporary,

SMXP(IFM): Temporary,

SMFDJ(IDM,IFM): Temporary,

SMFP(IFM): Temporary,

SMDFP(IFM): Temporary,

SMK(IFM): Temporary,

BETAJ(IFMP,IDMP,MTP): $= \bar{\beta}_i^j$, Mixture dependent effective delayed neutron fraction, IFMP=IFM+1, IDMP=IDM+1,

RG(10,IGM): $= \rho_{\alpha g}$, Reactivity for each reaction,

RSI(IB): Reactivity due to the anisotropic scattering. If ISCT = 0, IB = 0, if ISCT $\geq$ 1, IB = IM×JM×IGM,

U(IRIS): Temporary, for cross section preparation in LIES2 code,

IU(IRIS): Temporary, for cross section preparation in LIES2 code.

3) Total number of a core memory for TP2

The total number of a core memory is reserved in the subroutine DIMENS by the array A(LAENGE). The number of the core storage can be roughly calculated by

LAENGE = LMAX + IRIS

LMAX = 3•IM•JM•IGM + IHM•IGM•MT

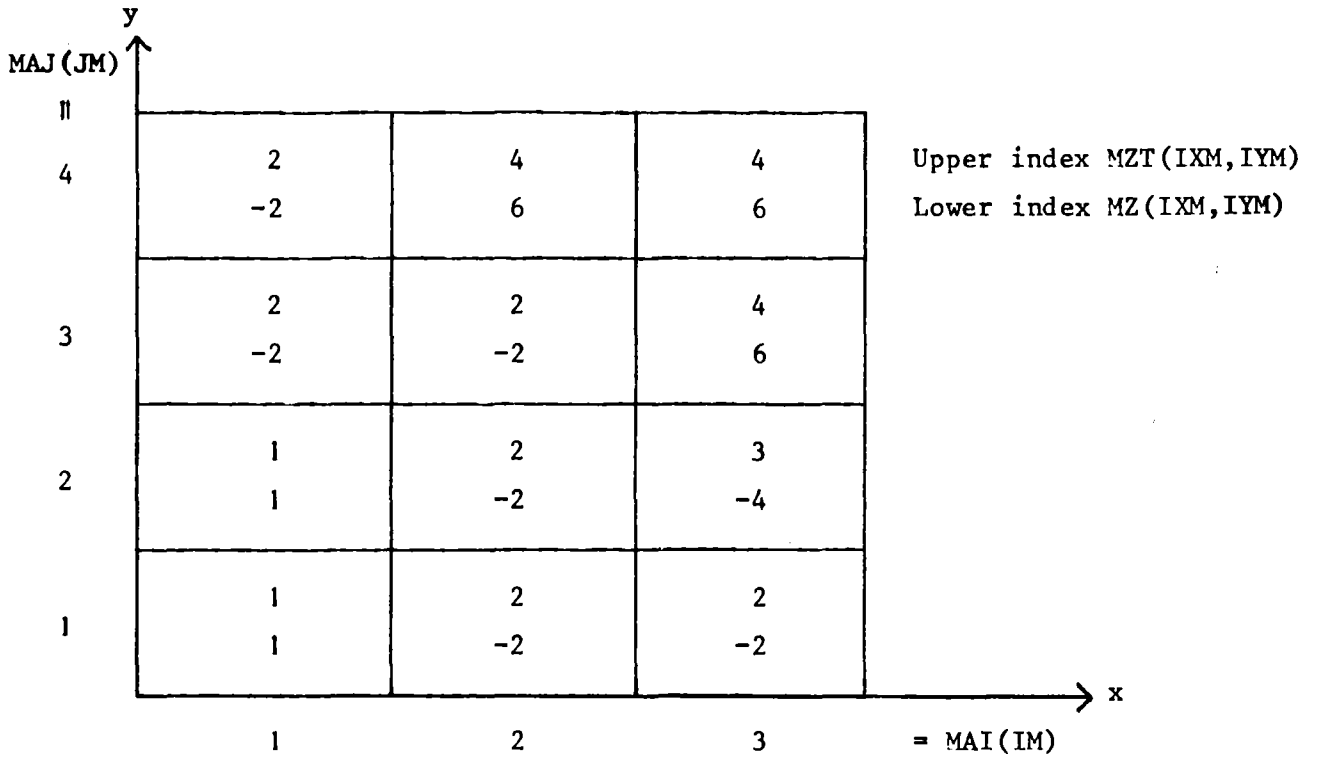
The last IRIS words of the array A are used by the WQORG as working array to prepare the cross section table C(IHM,IGM,MT). Therefore, IRIS calculated as a difference between LAENGE and actually needed core storage should not be too small.

4) Example of input data to SNOW code for the perturbation calculation

ISCT = 1:
IM = 18:
JM = 16:
MU = 4: Number of zone,
MT = 7: Total number of cross section table,
MTP = 5: Number of mixtures,
IXM = 3: Number of zone in x-coordinate,
IYM = 4: Number of zone in y-coordinate,

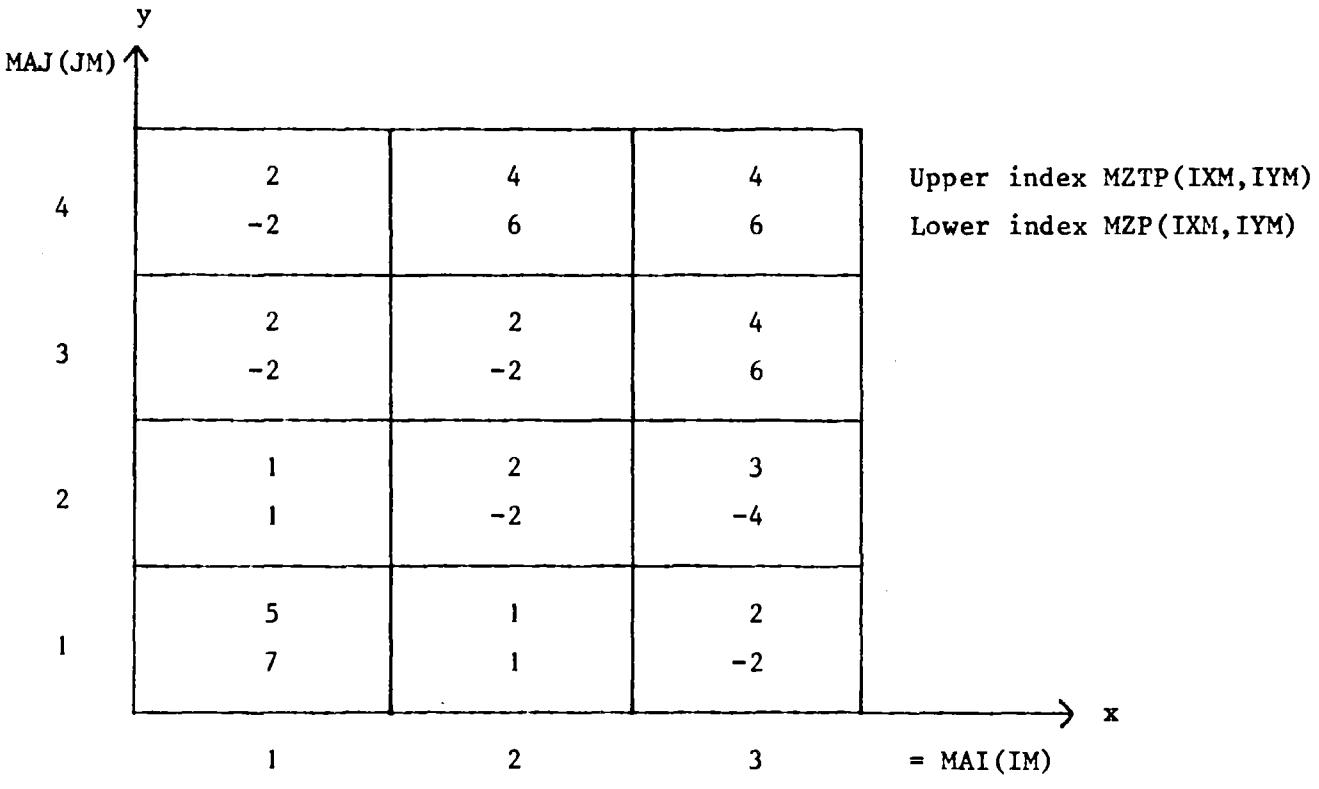
IMAT(MTP): = 1, -2, -3, 4, 5
IPLATZ(MTP): = 1, 2, 4, 6, 7

For direct equation
((MZT(I,J),I=1,IXM),J=1,IYM): = 1, 2, 2, 1, 2, 3, 2, 2, 4, 2, 4, 4,
((MZ(I,J),I=1,IXM),J=1,IYM): = 1, -2, -2, 1, -2, -4, -2, -2, 6, -2, 6, 6,



For adjoint equation

((MZTP(I,J),I=1,IXM),J=1,IYM): = 5, 1, 2, 1, 2, 3, 2, 2, 4, 2, 4, 4
((MZP(I,J),I=1,IXM),J=1,IYM): = 7, 1, -2, 1, -2, -4, -2, -2, 6, -2, 6, 6



Minus sign of the index means that the mixture has anisotropic scattering component.

5) Management of angular flux from the disk

In the disk files ISNOW2 and ISNOW3, direct and adjoint angular fluxes are stored respectively by the SNOW code. The angular fluxes are read in the subroutine PERT2 by the following program.

```
REWIND ISNOW2

DØ 1 IG = 1, IGM

DO 1 M = 1, MM
```

```
READ (ISNOW2) FKO (IM,JM)
(Here, direct total flux is computed.)
1 CONTINUE
```

The order of the adjoint angular flux is rearranged with respect to the group and angular indexes and then it is written in the IDSK1 by calling the subroutine INVAFX.

```
CALL   INVAFX(FKD,IM,JM)

REWIND  IDSK1

DO 3 IG=1,IGM

DO 3 M=1,MM

READ(IDSK1) FKD(IM,JM)
(Here, adjoint total flux is computed.)
3  CONTINUE
```

In the following routine, the product of direct and adjoint angular flux are computed.

```
REWIND ISNOW2
REWIND IDSK1
DO 18 IG=1, IGM

DO 19 M=1, MM

READ(ISNOW2) FKO(IM,JM)

READ(IDSK1) FKD(IM,JM)
(Here, the product of direct and adjoint angular flux are computed.)
19  CONTINUE

18  CONTINUE
```

If anisotropic scattering is included, subroutine RUIS is called by the subroutine PERT2. In the subroutine RUIS, the reactivity due to the anisotropic

scattering is computed by reading the angular flux in the following way.

```
REWIND IDSK2
WRITE (IDSK2)FTKO,FTKD
DO 31 L=1,IS
DO 32 N=1,IS
REWIND ISNOW2
REWIND IDSK1
DO 33 IG=1,IGM
DO 34 M=1,MM
READ(ISNOW2) FKO
READ(IDSK1) FKD
34  CONTINUE
33  CONTINUE
32  CONTINUE
31  CONTINUE
REWIND IDSK2
READ(IDSK2) FTKO,FTKD
```

4. Comment on input data

1) Input data to GRUCAL

Types CHI, NUSF, SCAPT, SFISS, SBE, SREM, STR, STRTR, 1/v, STOT and SMTOT are necessary. Isotope dependent quantities for the fissile isotopes are produced by using the GRUCAL-option 'AUSWERT' with the three 'ZUSATZ'-types CHI (microscopic), NUSF (macroscopic) and SFISS (macroscopic). All fissile isotopes are supposed to be contained in all mixtures because isotope dependent fission spectrum and cross sections are stored in the arrays XKIJ(IGM,IFM,MTP), SNFDJ (IGM,IDM,IFM,MTP) and SNFTJ(IGM,IFM,MTP). The option of microscopic fission spectrum is necessary for the CHI. The input example is shown in the Appendix II.

2) Input data to DIF1D

For the condensation of 26 group cross section from GRUCAL code, we can choose appropriate one dimensional model to obtain weighting flux. Input data can be written by referring to the Ref. /4/.

3) Input data to SIGMNC

The 26 group cross section is condensed by using the one dimensional flux obtained above. Input data can be written by referring to the Ref. /5/.

4) Input data to SIGMUT

The isotope independent delayed neutron spectrum for each delayed group and the delayed neutron fraction for each isotope should be read from cards for SIGMUT code /6/.

5) Input data to SNOW

The option of k_{eff} computation and ITH=-2 for direct and ITH=-1 for adjoint case should be chosen to create the interface file to TP2. An error criterion of 10^{-5} is desirable for the criticality factor and for the flux.

5. Input Description of TP2 Code

(All input data should be provided in formatted form.)

Card	Variable		Meaning
K1(18A4)	TITLE(18):		Information Text
K2(24I3)	IFM:		Number of fissile isotope
	IDM:		Number of delayed neutron groups
	IFEX:	1	Exact perturbation is calculated.
		0	This is not done.
	IFFP:	1	The first order perturbation by the probe is calculated.
		0	This is not done.
	IFPG:	1	Global input of perturbed region (K4)
		0	Pointwise input of perturbed region (K5)
			If IFFP=0, this integer has no meaning.
	IFGS:	1	Group and space dependent reactivity is printed.
		0	This is not done.
	IFS:	1	Space dependent reactivity is printed.
		0	This is not done.
	IFG:	1	Group dependent reactivity is printed.
		0	This is not done.
	IFK:	1	Corrected criticality factor for isotope dependent fission spectrum is printed.
		0	This is not done.
	IPAF:	1	Direct and adjoint angular flux are printed.
		0	This is not done.
	IPFX:	1	Direct and adjoint total flux are printed.
		0	This is not done.

IPCS: 1 Group cross sections are printed according to the arrays defined in Chap. III, 3.
0 This is not done.

K3 NAIST(IFM) (9A8) Names of fissile isotopes

S1 End of TP2 input for IFFP=0.
If IFFP=1 and IFPG=1, K4, if IFFP=1 and IFPG=0, K5 is read repeatedly for all cases as needed.

K4(24I3) NPR: Mixture index of the probe which replaces the mixture of unperturbed system,

IL: Left mesh index of x coordinate,

IR: Right mesh index of x coordinate,

JL: Lower mesh index of y coordinate,

JU: Upper mesh index of y coordinate, where the probe is inserted.

S2 End of TP2 input for IFFP=1 and IFPG=1.

K5(24I3) NPR: Mixture index of the probe which replaces the mixture of the unperturbed system at IPT mesh boxes.*

IPT: Total number of mesh boxes.

(IPX(I),IPY(I),I=1,IPT): Indices of mesh boxes for x and y coordinates, where the probe is inserted.

S3 End of TP2 input for IFFP=1 and IFPG=0.

* A mesh box of the two dimensional spatial discretization grid is characterized by the grid indices of the lower left corner.

6. Output Description of TP2 Code

The effective neutron generation time and the delayed neutron fraction for each fissile isotope and for each mixture are always printed. The criticality factor corrected for the isotope dependency of fission spectrum and delayed neutron spectrum is printed according to the input specification. The space and energy dependent reactivities are printed according to the input specification in the

following order: mesh indices ,group index, reactivities due to capture $\rho_{cg}(\vec{r}_{ij})$, absorption by fission $\rho_{fg}(\vec{r}_{ij})$, removal $\rho_{rg}(\vec{r}_{ij})$, scattering out $\rho_{sog}(\vec{r}_{ij})$, scattering in $\rho_{sig}(\vec{r}_{ij})$, scattering out + in $\rho_{sog}(\vec{r}_{ij}) + \rho_{sig}(\vec{r}_{ij})$, scattering in from g-1, $\rho_{sig\leftarrow g-1}(\vec{r}_{ij})$, fission source $\rho_{fsg}(\vec{r}_{ij})$, adjoint fission source $\rho_{afg}(\vec{r}_{ij})$ and total $\rho_{g}(\vec{r}_{ij})$. SUM means summation over energy groups and INTEGRAL means integration over space. The reactivity by probe perturbation is printed as an integral over the specified mesh box. Output example is shown in Appendix III. The integral reactivity value divided by the volume of the mesh box, therefore, represents an average value which should be attributed to the center of the corresponding mesh box. This is different from diffusion theory results, obtained e.g. by DXPERT, which refer really to the spatial position corresponding to the grid indices specified in the input. This difference (mesh-edge-diffusion values versus mesh-centered-transport values) has to be taken into account when comparing diffusion and transport local perturbation reactivities.

IV NUMERICAL EXAMPLES

1. Test Calculation for TP2 Code

Exact perturbation calculations are performed for VERA-11A /7/, a plutonium-plus-graphite critical assembly with a fairly small core region to check the accuracy of perturbation code TP2. The 26 group cross section set is computed by the GRUCAL code using the number density given in Table 1 of Ref. /7/ and composition (a). Since the present data used in GRUCAL code does not include isotopes Sn and Ga, isotope Sn is simply replaced by isotope Zr with the same number density as isotope Sn. The isotope Ga is approximated by two isotopes Cu and Nb with number density 0.78×number of Ga atom = 0.00035022 and 0.22 × number of Ga atom = 0.00009878 respectively.

The 26 group constant is condensed into 4 group by using the flux from the diffusion calculation to reduce the CPU time in S_n transport calculation. For this purpose, the spherical model given in Fig. 1 of Ref. /7/ is used. Core region of the spherical model is artificially divided into two regions: the first region is from 0 to 5 cm and the second is from 5 cm to 13.99 cm, and number of mesh intervals of 10 and 18 is used for each region.

For the blanket region, the number of mesh intervals of 86 is used from 13.99 cm to 56.99 cm. Using these region-integrated fluxes for three regions, 26 group cross sections are condensed into 4 groups, from 1 to 4, from 5 to 8, from 9 to 12 and from 13 to 26 groups. Mixture indexes 1 and 2 used in Tables 1 ∿ 4 are those for the core regions; the former are obtained using the flux for the first region and the latter for the second region. Mixture 3 is that for the blanket. As a perturbed cross section, mixture 4 is obtained by multiplying the number density of Pu^{239} in mixture 1 by 1.25.

For the two dimensional S_n calculation, the two dimensional R-Z model given in Fig. 2 of Ref. /7/ is used. Here, again the core region is artificially divided into two regions: the first region is $0 \leq r \leq 4$ cm and $0 \leq z \leq 4$ cm, and the second region is the remaining region of the core region. Mixture index 1, 2, 3 shown in Tables 1∿4 means that mixtures 1 and 2 are used for the first and the second region of the core region respectively and mixture 3 for the blanket. Similarly, mixture 4, 2, 3 means that mixtures 4 and 2 are used for the first and the second region of the core region respectively and the mixture 3 for the blanket. Number of mesh intervals 12 × 12 shown in the Tables means that 2+4+6 and 2+3+7 mesh intervals are used for x and y or r and z coordinate respectively and, for example, 2 mesh intervals for the first region, 4 for the second region, 6 for the blanket in x direction. For the case of 24×24, all the numbers of mesh intervals are doubled.

In all calculations, the error criterion of 10^{-5} is used for the criticality factor and the total flux. Option of Tschebyscheff acceleration is used for the inner and outer iterations, and the maximum number of inner iteration per outer iteration is limited to 10.

In the Tables, four reactivities are shown which are calculated using the criticality factor calculated by SNOW code:

$$\rho_{kok^+} = \frac{1}{k_o} - \frac{1}{k^+}$$

$$\rho_{kok} = \frac{1}{k_o} - \frac{1}{k}$$

$$\rho_{kk_o^+} = \frac{1}{k} - \frac{1}{k_o^+}$$

$$\rho_{k^+k_o^+} = \frac{1}{k^+} - \frac{1}{k_o^+}$$

where

k_o: the criticality factor of direct equation for unperturbed system,

k_o^+: the criticality factor of adjoint equation for unperturbed system,

k: the criticality factor of direct equation for perturbed system,

k^+: the criticality factor of adjoint equation for perturbed system.

ρ_p is the reactivity calculated by the TP2 code and $\bar{k}$ is the criticality factor which is corrected for the isotope dependency of the fission spectrum and the delayed neutron spectrum using ρ' (Ref. /1/);

$$\bar{k} = \frac{k_o}{1-\rho' k_o}$$

However, for the calculations shown in Tables 1∿4, an isotope independent fission spectrum is used in SNOW and TP2 calculations. Therefore, the correction is only done for the delayed neutron spectrum in those sample calculations.

In Table 1 are shown the results by the S_2 method for the x-y geometry in which the input index only for the specification of geometry to the S_n transport code SNOW is replaced from R-Z by x-y geometry. As seen in Table 1, the criticality factor of the direct equation has a difference of 4×10^{-4} from that of the adjoint equation in cases 1 and 2, however, this difference decreases to less than 5×10^{-5} by increasing the number of space mesh points as shown in cases 3 ∿ 6. The reactivity calculated by the TP2 code is almost independent of the number of mesh intervals, namely, the difference between them is only 1×10^{-5}. Agreement of the reactivities obtained from the criticality factors and the perturbation calculation is also good, the difference is about 1×10^{-5}.

In Table 2 are shown the results for VERA-11A of r-z geometry by S_2 method. There are large differences, about 1×10^{-3} between the criticality factors of direct and adjoint equation for the same system. This is due to the non-adjointness of the discretized adjoint equation to the direct equation with respect to the angular variable as in the one dimensional case. This difference decreases as the order of S_n increases, about 2×10^{-4} for S_4 method and 3×10^{-5} for S_8 method as seen in cases 5 and 6 of Tables 3 and 4.

This difference introduces a large error to the reactivity calculated from k_o and k^+ or k and k_o^+ in lower S_n order; there are about 4×10^{-3} ∿ 1×10^{-3} difference between $\rho_{kok}{}^+$ and $\rho_{kko}{}^+$ in S_2 method. On the other hand, the difference between the absolute values of ρ_{kok} and $\rho_k{}^+{}_{ko}{}^+$ is small, and they become close, about 9.38×10^{-3}, as the number of mesh intervals increases even in S_2 method. However, there is a large difference of 0.32×10^{-3} between ρ_{kok} and ρ_p in S_2 method. This difference becomes small as the order n of S_n increases, 0.08×10^{-3}

for S_4 and 0.04×10^{-3} for S_8 as seen in Tables 3 and 4. Therefore, we can assume that as the order n of S_n increases, the reactivities from the criticality factors and from the perturbation calculation become closer.

The difference of ρ_p between S_2 and S_8 method is small for this sample calculation, only 1.6 %. However the difference between ρ_{kok} by S_2 method and ρ_p by S_8 method is 5.3 %. Therefore, the reactivity calculated by the perturbation method is most probably more accurate than that by the criticality factor. The reason for this fact is not completely clear. One possible explanation is as follows: since the core (with high source density) is very small compared with the blanket (with fairly low source density), there may be a ray effect for the flux in a blanket region in S_2 method. The influence of the ray effect may be different for the direct and adjoint solutions leading to an error for the criticality factors and hence the reactivity derived from direct and adjoint cases. However, in the perturbation calculation of bilinear form of direct and adjoint angular fluxes, there may be a possibility of cancellation of the error due to the ray effect because of the difference in the boundary condition for the angular fluxes; outgoing direct and incoming adjoint fluxes vanish at the outermost boundary. This could lead to a situation at a certain position where the ray effect causes an overprediction of the direct flux and an underprediction of the adjoint flux for the same angular direction, thus resulting in a partial cancellation of the ray effect error in perturbation calculation.

In all cases of r-z geometry given in Tables 2 $\sim$ 4, the criticality factors become smaller, as the number of space mesh intervals increases. Kiefhaber /8/ calculated also the same case as the present case, and in his case, the criticality factors become larger as the number of mesh intervals increases. There are small differences in geometry and in group cross sections between both cases. However, this small difference may not cause such a difference in convergence characteristic of the criticality factor, and the reason is not clear at present.

Conclusion

1. For x-y geometry, the reactivity calculated from the criticality factor agrees well with that calculated by the perturbation method within the error of 3×10^{-5} in the case of S_2 method.
2. For r-z geometry, there is a difference of about 3×10^{-4} between the reactivities obtained from the criticality factors and the perturbation method by

the S_2 method. This difference decreases to 4×10^{-5}, if S_8 method is used.

3. The perturbation method gives higher accuracy for the reactivity by the S_2 method in r-z geometry, which gives an error of 1.6 %, than the reactivity from the criticality factors which has an error of 5.3 % compared with the reactivity of S_8 method.

2. Comparison with the Results of the Diffusion Calculation

Sample calculations are also performed using the two dimensional diffusion code DIXY /9/ and diffusion perturbation code DXPERT /10/ for the same reactor as performed in Tables 2 ∿ 4. The same 4 group cross sections are used except the transport cross section. GRUCAL code calculates two kinds of transport cross sections named as STR and STRTR. In the transport calculation, the transport cross section STRTR is used for the total cross section. On the other hand, in the diffusion calculation, the transport cross section STR is used to obtain the diffusion coefficient.

In addition to 4 group case, 11 group case is also calculated to check the effect of group condensation, where the lower group boundaries are 3, 4, 5, 6, 7, 8, 9, 10, 12, 16 and 26. Computation is performed first for the coarse mesh case (2+8+9)×(2+7+10) mesh intervals with 4 group and the error criterions of 10^{-2} and 5×10^{-2} for the source term and flux respectively. Then, using the fission source thus obtained, fine mesh case (5+13+21)×(5+11+19) mesh intervals with 4 group is calculated using the error criterion of 10^{-4} and 2×10^{-4} for the source term and flux and the 11 group case with the same mesh intervals and the error criterion. The results are shown in Table 5.

The criticality factor by 4 group calculation in case 2 for unperturbed reactor is 0.95686 and the difference from S_8 method is -6.2 % which is larger than the difference of the criticality factor by S_2 method from S_8 method, -2.0 % The difference of the criticality factor with 4 group from that with 11 group is 1.1 % which is not small. The reactivity calculated from the difference of the criticality factors agrees well with that by the perturbation method within an error of 0.3 % *. The deviation between diffusion- and S_8-reactivity is smaller than that between S_2- and S_8-reactivity.

---

*) The reactivities calculated by the DXPERT code of the present version (16.11.1978) are 9.040×10^{-3} and 9.110×10^{-3} for 4 and 11 groups respectively. They are calculated by the equation,

$$\rho = \text{ABSORPTION} + \text{DIFFUSION} + \frac{1}{k_o}\,\text{FISSION} + \text{DEGRADATION}$$

(Footnote continued on p. 29)

The difference from S_8 method is only 0.1 %. However this agreement may be fortuitous because the criticality factor determined by the diffusion method shows a larger difference to the S_8 method than the criticality factor of the S_2 calculation.

The transport correction to the criticality factor is fairly large. To check the effect of using the transport cross section STRTR in SNOW calculation, the same case as given in case 3 of Table 4 is recalculated by replacing STRTR by the transport cross section STR which is used in the diffusion calculation. The result is shown in Table 4 as case 7. Only in this case, isotope dependent fission spectra are used for TP2 calculation. For SNOW calculation, use is made of an average fission spectrum which is calculated in GRUCAL code by using the weighting factors proportioned to atomic number density, i.e. it is essentially the Pu239 fission spectrum. (All other cases, an isotope independent fission spectrum which is provided by the GRUCAL codes is used for SNOW and TP2 calculation.) However, the effect of using isotope dependent fission spectrum is small compared to the transport effect. The change of the criticality factor is about 0.1 % as can be seen by comparing k_o and $\bar{k}$ for case 7 of Table 4.

The criticality factor for unperturbed reactor is 1.00885, which is smaller than that obtained by using the transport cross section STRTR, by 1.2 %**), and this criticality factor is a little bit closer to that obtained by using the diffusion method. Namely, the transport correction to the criticality factor from the diffusion method becomes smaller, 5.2 % instead of the previous case of 6.3 %.

As a conclusion, it can be said that the transport correction to the criticality factor from the diffusion method is large for this assembly with a small core region, however, the reactivity by the uniform change of the number density of ^{239}Pu in the central part of the core can be well calculated by the diffusion method.

---

where k_o is a criticality factor of the direct equation for unperturbed system and other terms correspond to the output quantities from DXPERT code. It is found that the reactivity should be calculated by the equation,

$$\rho = -(\text{ABSORPTION} + \text{DIFFUSION} + \frac{1}{k^+}\,\text{FISSION} + \text{DEGRADATION})$$

where k^+ is a criticality factor of adjoint equation for perturbed system, and this reactivity is given in Table 5.

The author wishes to express his thanks to Drs. Höbel and Kiefhaber for their help in obtaining correct value from DXPERT calculation.

**) Part of this difference may be due to inconsistencies in the resonance self-shielding factors (f-factors) taken from the KFKINR-group constant set to determine STR and STRTR respectively.

3. Material worths; Results for Assembly VERA-11A

Material worths at the center of VERA-11A are calculated for U^{235}, U^{238} and Pu^{239} by TP2 and DXPERT using the first order perturbation option and they are given in Table 6. Use is made of the direct and adjoint angular fluxes for the unperturbed system. As a perturbation, the number density of each material in the central mesh interval of the core region is increased by $0.000072\times10^{24}/cm^3$, which is about 1 % of that of Pu^{239}. For TP2 calculation, S_8 method and the number of spatial mesh intervals of $(4+8+12)\times(4+6+14)$ are used. As a comparison, the material worths by the diffusion method are also calculated by using DXPERT code. In this case 11 group calculation is also performed as well as 4 group. In Table 6 the experimental value taken from Ref. /7/ which is normalized to that of U^{235} is also shown.

As seen in Table 6, the material worth for Pu^{239} calculated by the diffusion theory is nearly the same as that by the transport method, the difference is less than 2 %. In this case, the difference between 4 group and 11 group by the diffusion theory is also small, about 0.6 %. However, there is about 9 % difference from experimental value.

The material worth for U^{238} by the diffusion method is larger by 58 % and by 128 % than that by the transport method in the case of 4 group and 11 group respectively. Therefore, the effect of group condensation from 11 group to 4 group is nearly the same as the transport correction. The experimental worth for U^{238} is nearer to the transport worth, the difference is about 11 %, than the diffusion value. However, this may be fortuitous because the effect of group condensation is large, and many group transport calculations should be performed.

To see the spatial dependency of the material worth of U^{238}, the material worth is calculated along the radial direction at the middle plane in axial direction by changing the number density of U^{238} at each mesh interval by $0.72\times10^{20}/cm^3$, and the result is shown in Fig. 2 and 3. The increase of material worth from the core center to core blanket boundary is due to the reflector effect of the U^{238}. Neutrons may be scattered back into the core region by the U^{238}. This is directly observed in the DXPERT calculation, in which the positive reactivity of the diffusion term increases from the center of the core to the boundary of the core and blanket, on the other hand, all other terms of absorption and creation by fission decrease monotonically from the core center to the outer boundary

of the core. As expected, the difference of the transport value from the diffusion value becomes larger at the boundary of the core and blanket. **(see Fig. 3)**
As a conclusion, it can be said that it is necessary to use a transport perturbation method with sufficient energy groups to obtain the material worth of U^{238} with a good accuracy for this small assembly with hard neutron spectrum.

V SUMMARY

TP2 is a FORTRAN-IV program for the calculation of the reactivity, effective delayed neutron fractions and mean generation time by the transport perturbation theory.

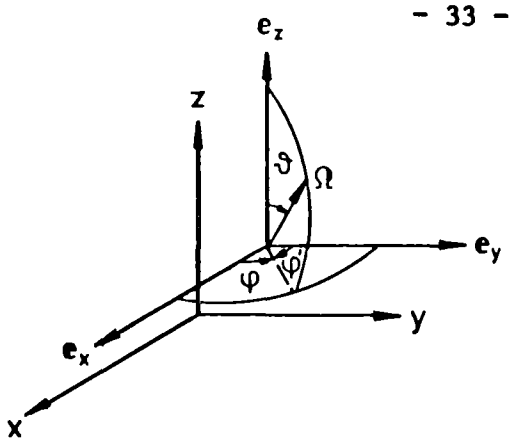
This code has two main options. One is for the exact perturbation calculation of the reactivity where the direct and adjoint angular fluxes are used for unperturbed and perturbed systems respectively. The other option is for the first order perturbation calculation of the probe reactivity in which usually unperturbed direct and adjoint angular fluxes are used.

The criticality factor calculated by S_n transport code using an isotope independent fission spectrum can be corrected by TP2 code by taking into account an isotope dependency of the prompt fission spectrum and delayed neutron spectra.

Sample calculations are performed to check the accuracy of TP2 code for VERA-11A, a small plutonium-plus-graphite critical assembly. The conclusions are as follows:

1. For x-y geometry, the reactivity calculated from the criticality factor agrees well with that calculated by the exact perturbation method independent of the order of S_n.
2. For r-z geometry, there is an appreciable difference between the reactivities obtained from criticality factors and the exact perturbation method by the S_2 method. This difference decreases as the order of S_n method increases.
3. The reactivity by the perturbation method with S_2 method has higher accuracy than the reactivity from the criticality factor with S_2 method in r-z geometry.

4. The transport correction to the criticality factor from the diffusion method is large for this assembly with a small core region. However, the material worth of Pu^{239} in the center of the core can be well calculated by the diffusion method.
5. The material worth of U^{238} by the transport perturbation method is largely different from that by the diffusion method. It is necessary to use a transport perturbation method with a sufficient number of energy groups to obtain the material worth of U^{238} with good accuracy.
6. A typical CPU time by IBM 370/168 is 25 min. with S_8 method, 24 x 24 mesh intervals and 4 group for both direct and adjoint S_n calculation using SNOW code. Number of core memory used is 26 K words. For TP2 calculation, CPU time is 10 sec and number of core memory is 9.6 K words.

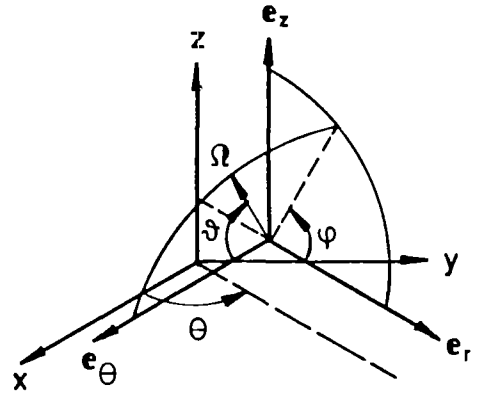


$\mu = \Omega \cdot e_x = \sin\vartheta \cos\varphi$

$\eta = \Omega \cdot e_y = \sin\vartheta \sin\varphi$

$\xi = \Omega \cdot e_z = \cos\vartheta$

x-y and triangular geometries on x-y plane

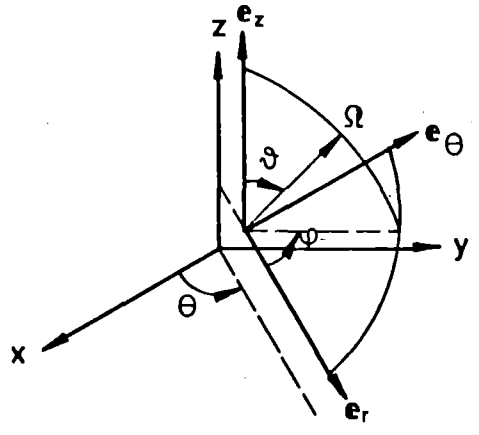


$\mu = \Omega \cdot e_r = \sin\vartheta \cos\varphi$

$\eta = \Omega \cdot e_z = \sin\vartheta \sin\varphi$

$\xi = \Omega \cdot e_\theta = \cos\vartheta$

r-z geometry



$\mu = \Omega \cdot e_r = \sin\vartheta \cos\varphi$

$\eta = \Omega \cdot e_\theta = \sin\vartheta \sin\varphi$

$\xi = \Omega \cdot e_z = \cos\vartheta$

r-θ geometry

Fig.1 Coordinate system for two dimensional geometry

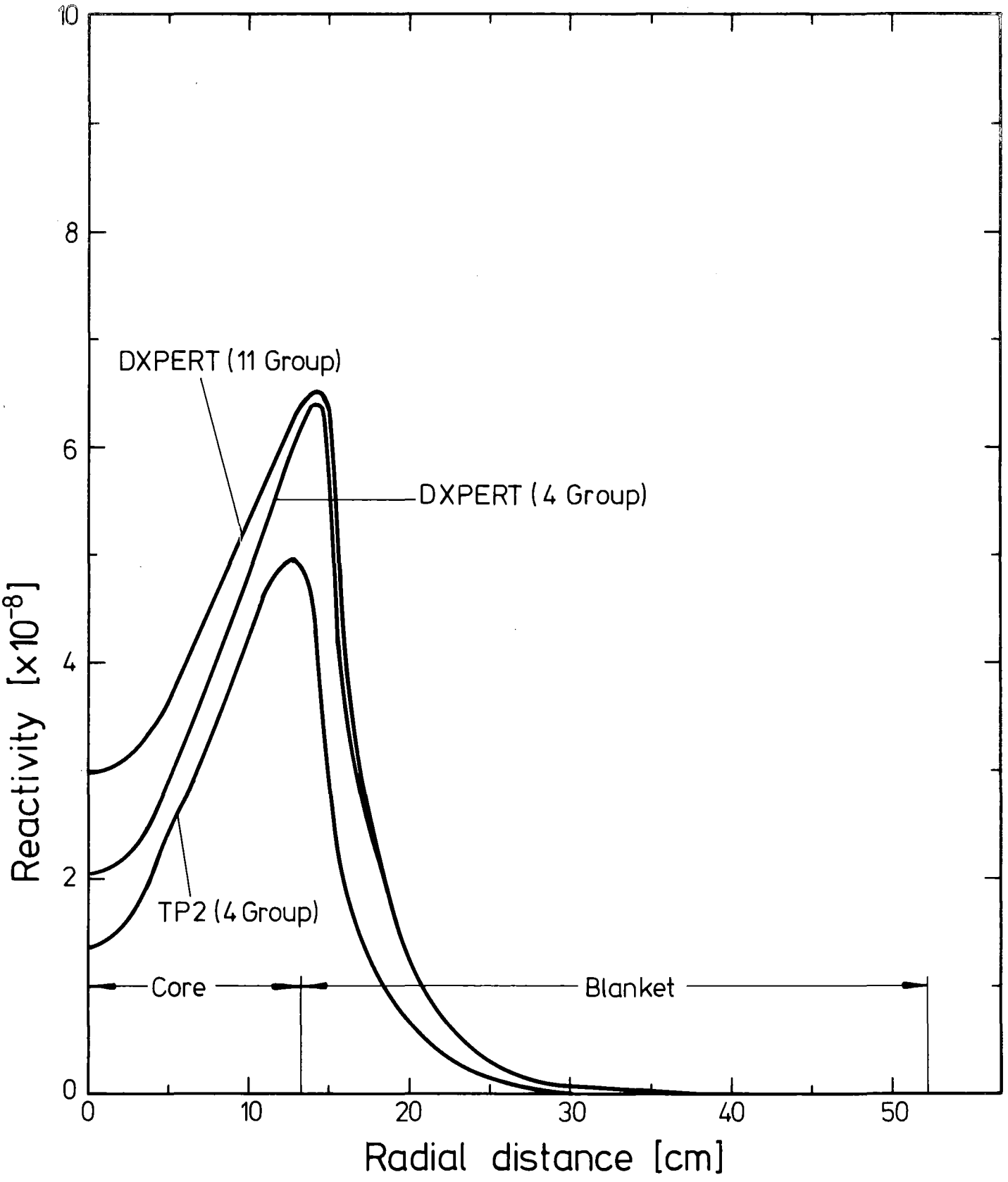


Fig. 2 Reactivity traverse $\rho(\vec{r}_i)$ by the increase of the number density of U^{238} by $0.72\times10^{20}/cm^3$ along radial coordinate of the center horizontal plane

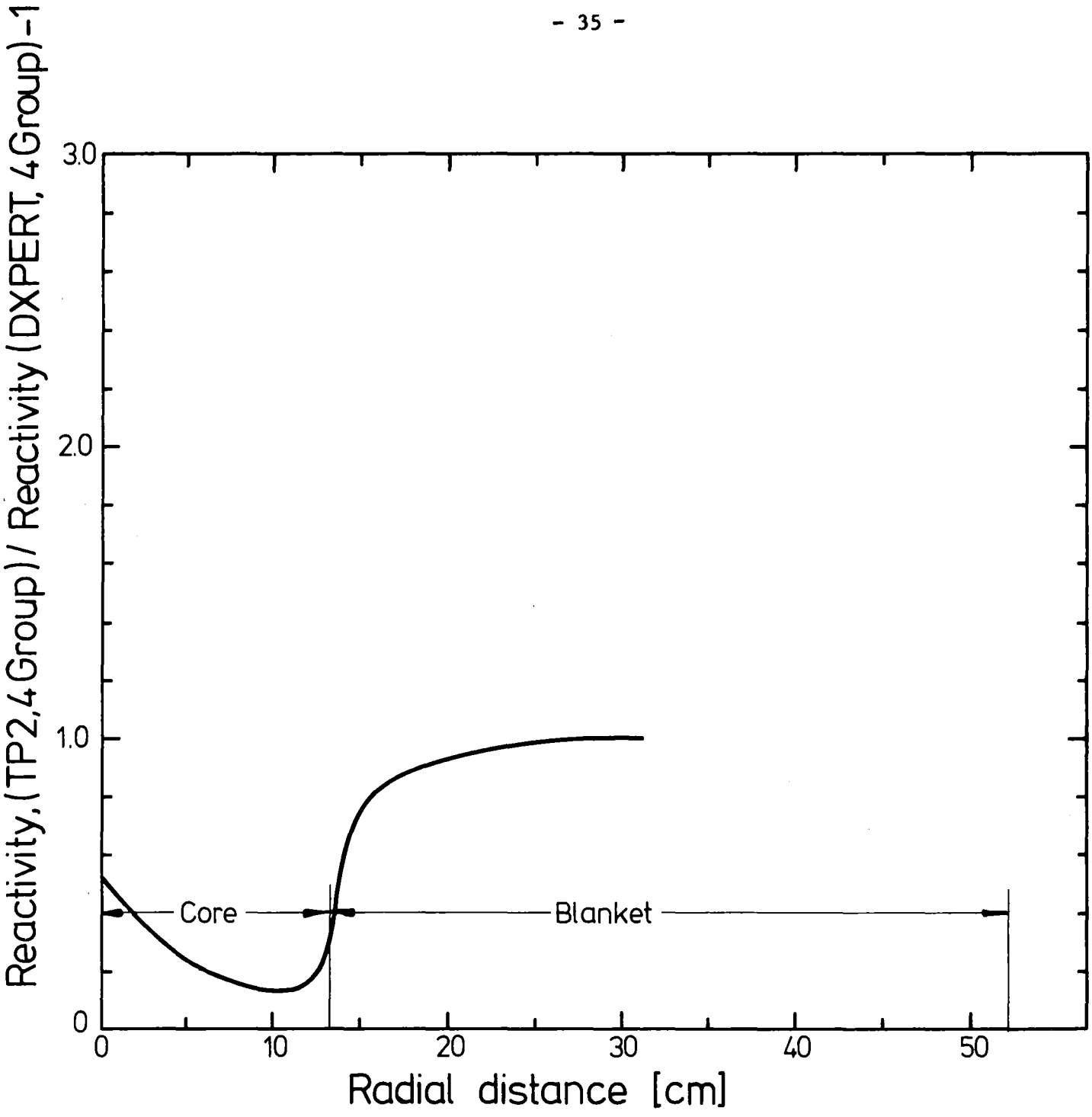


Fig. 3 Ratio of reactivities by the diffusion and transport methods along radial coordinate of the center horizontal plane SHOWN IN FIG. 2

Table 1. Reactivity [1] for x-y geometry by SNOW and TP2 codes with S_2 method by the exact perturbation method

		SNOW							TP2				
case	Number of mesh intervals (x coordinate × y coordinate)	k_o k^+ k $k_o{}^+$	Mixture index	CPU time (min)	Number of outer iteration	Number of inner iteration	Number of core memory (K words)	ρ_{kok^+} ρ_{kok} ρ_{kko^+} $\rho_{k^+k_o^+}$ $(\times 10^{-2})$	ρ_p $(\times 10^{-2})$	$\bar{k}$	ρ' $(\times 10^{-4})$	CPU time (sec)	Number of core memory (K words)
1	12 × 12	1.36201	1, 2, 3		14	411	3.3	1.353	1.373	1.36172	-1.58	1.7	3.4
		1.38759	4, 2, 3		14	467		1.374					
2	12 × 12	1.38799	4, 2, 3		13	426	3.3	-1.395	-1.373	1.38768	-1.62	1.7	3.4
		1.36162	1, 2, 3		16	516		-1.375					
3	24 × 24	1.36278	1, 2, 3		15	461	9.0	1.373	1.372	1.36249	-1.57	3.4	9.5
		1.38878	4, 2, 3		18	612		1.372					
4	24 × 24	1.38875	4, 2, 3		14	444	9.0	-1.371	-1.372	1.38844	-1.61	3.4	9.5
		1.36280	1, 2, 3		20	655		-1.373					
5	48 × 48	1.36317	1, 2, 3	8.5	22	681	29.0	1.369	1.372	1.36288	-1.57	11	33.9
		1.38910	4, 2, 3	6.6	16	530		1.371					
6	48 × 48	1.38913	4, 2, 3	6.1	16	489	29.0	-1.373	-1.372	1.38882	-1.61	11	33.9
		1.36312	1, 2, 2	6.8	17	546		-1.372					

1) Reactivity caused by an increase of the number density of Pu^{239} by 25 % in the central core region of 4 cm × 4 cm.

Table 2. Reactivity [1] for VERA-11A of r-z geometry by SNOW and TP2 with S_2 method by the exact perturbation method

		SNOW							TP2				
case	Number of mesh intervals (r coordinate × z coordinate)	k_o $k\pm$ k k_o^+	Mixture index	CPU time (min)	Number of outer iterations	Number of inner iterations	Number of core memory (k words)	ρ_{kok^+} ρ_{kok} ρ_{kko^+} $\rho_{k^+ko^+}$ ($\times 10^{-3}$)	ρ_p ($\times 10^{-3}$)	$\bar{k}$	ρ' ($\times 10^{-4}$)	CPU time (sec)	Number of core memory (k words)
1	12 × 12	1.04330	1, 2, 3	0.6	21	722	3.3	7.13	8.913	1.04296	-3.11	1.7	3.4
		1.05112	4, 2, 3	0.4	15	478		9.46					
2	12 × 12	1.05370	4, 2, 3	0.6	21	727	3.3	-11.83	-8.903	1.05335	-3.16	1.7	3.4
		1.04073	1, 2, 3	0.4	15	475		-9.50					
3	24 × 24	1.04038	1, 2, 3	2.3	21	717	9.0	8.46	9.033	1.04005	-3.05	3.5	9.5
		1.04961	4, 2, 3	1.6	15	474		9.40					
4	24 × 24	1.05066	4, 2, 3	2.3	19	700	9.0	-10.36	-9.027	1.05032	-3.09	3.5	9.5
		1.03935	1, 2, 3	1.5	14	462		-9.41					
5	48 × 48	1.03994	1, 2, 3	7.8	18	621	29.0	8.47	9.056	1.03961	-3.04	10.5	33.9
		1.04918	4, 2, 3	8.0	16	623		9.38					
6	48 × 48	1.05019	4, 2, 3	9.6	21	765	29.0	-10.30	-9.051	1.04985	-3.08	10.5	33.9
		1.03895	1, 2, 3	7.9	16	624		-9.39					

1) Reactivity caused by an increase of the number density of Pu^{239} by 25 % in the central core region of 4 cm × 4 cm.

Table 3. Reactivity [1] for VERA-11A of r-z geometry by SNOW and TP2 with S_4 method by the exact perturbation method

		SNOW							TP2				
case	Number of mesh intervals (r coordinate × z coordinate)	k_o k^+ k k_o^+	Mixture index	CPU time (min)	Number of outer iterations	Number of inner iterations	Number of core memory (k words)	ρ_{kok^+} ρ_{kok} ρ_{kko^+} $\rho_{k^+k_o^+}$ ($\times 10^{-3}$)	ρ_p ($\times 10^{-3}$)	$\bar{k}$	ρ' ($\times 10^{-4}$)	CPU time (sec)	Number of core memory (k words)
1	12 × 12	1.03087	1, 2, 3	1.3	19	648	5.4	2.389	8.601	1.03068	-1.74	2.1	3.4
		1.03341	4, 2, 3	1.0	16	503		8.792					
2	12 × 12	1.04030	4, 2, 3	1.6	22	738	5.4	-15.438	-8.595	1.03994	-3.33	2.1	3.4
		1.02385	1, 2, 3	0.9	14	435		-9.035					
3	24 × 24	1.02258	1, 2, 3	5.8	23	752	13.1	8.683	8.841	1.02225	-3.14	4.8	9.5
		1.03174	4, 2, 3	3.4	14	440		8.969					
4	24 × 24	1.03205	4, 2, 3	5.9	23	763	13.1	-9.252	-8.839	1.03171	-3.19	4.8	9.5
		1.02228	1, 2, 3	3.3	14	428		8.966					
5	48 × 48	1.02210	1, 2, 3	22.2	20	694	37.1	8.732	8.865	1.02177	-3.13	15.8	33.9
		1.03130	4, 2, 3	14.1	14	441		8.950					
6	48 × 48	1.03153	4, 2, 3	22.2	21	705	37.1	-9.164	-8.864	1.03120	-3.18	15.8	33.9
		1.02187	1, 2, 3	13.8	14	439		-8.946					

1) Reactivity caused by an increase of the number density of Pu^{239} by 25 % in the central core region of 4 cm × 4 cm.

Table 4. Reactivity [1] for VERA-11A of r-z geometry by SNOW and TP2 with S_8 method by the exact perturbation method (In cases 1-6, an isotope independent fission spectrum is used in SNOW and TP2.)

		SNOW							TP2				
case	Number of mesh intervals (r coordinate × z coordinate)	k_o k^+ k k_o^+	Mixture index	CPU time (min)	Number of outer iterations	Number of inner iterations	Number of core memory (k words)	$\rho k o k^+$ $\rho k o k$ $\rho k k o^+$ $\rho k^+ k o^+$ $(\times 10^{-3})$	ρ_p $(\times 10^{-3})$	$\bar{k}$	ρ' $(\times 10^{-4})$	CPU time (sec)	Number of core memory (k words)
1	12 × 12	1.02772	1, 2, 3	3.9	19	650	12.1	3.45	8.664	1.02737	-3.28	3.7	3.5
		1.03137	4, 2, 3	2.5	14	430		8.81					
2	12 × 12	1.03711	4, 2, 3	4.5	22	734	12.1	-14.38	-8.660	1.03675	-3.33	3.8	3.5
		1.02186	1, 2, 3	2.9	14	452		-9.02					
3	24 × 24	1.02083	1, 2, 3	15.3	20	676	26.3	8.40	8.876	1.02050	-3.16	10.1	9.6
		1.02965	4, 2, 3	10.1	14	445		8.94					
4	24 × 24	1.03023	4, 2, 3	15.6	20	687	26.3	-9.52	-8.875	1.02989	-3.21	10.0	9.6
		1.02023	1, 2, 3	10.4	14	461		-8.97					
5	48 × 48	1.01988	1, 2, 3	73.4	24	787	63.4	8.87	8.910	1.01956	-3.15	35.8	34.0
		1.02920	4, 2, 3	46.2	15	501		8.95					
6	48 × 48	1.02927	4, 2, 3	71.7	23	778	63.4	-9.02	-8.910	1.02894	-3.20	35.3	34.0
		1.01981	1, 2, 3	46.3	15	504		-8.95					
7 [2]	24 × 24	1.00885	1, 2, 3	14.2	18	608	26.3	8.53	8.973	1.00778	-10.54	10.4	9.9
		1.01761	4, 2, 3	10.5	15	455							

1) Reactivity caused by an increase of the number density of Pu^{239} by 25 % in the central core region of 4 cm × 4 cm.

2) Transport cross section STR is used instead of STRTR. Only in this case, isotope dependent fission spectra are used.

Table 5. Reactivity [1] for VERA-11A of r-z geometry by the diffusion theory and the exact perturbation method

case	Number of energy group	Number of mesh intervals (r coordinate × z coordinate)	DXDIFF					DXPERT	
			k_o(upper) k^+(lower)	Mixture index	CPU time (sec)	Number of outer iterations	ρ_{kok^+} ($\times 10^{-3}$)	Reactivity ρ_p ($\times 10^{-3}$)	CPU time (sec)
1	4	(2+8+9) × (2+7+10)	0.95055 0.95876	1, 2, 3 4, 2, 3	7 7	11 11			
2	4	(5+13+21) × (5+11+19)	0.95686 0.96506	1, 2, 3 4, 2, 3	59 57	15 16	8.89	8.920	1.3
3	11	(5+13+21) × (5+11+19)	0.94623 0.95434	1, 2, 3 4, 2, 3	137 152	9 9	8.98	8.989	1.2

1) Reactivity caused by an increase of the number density of Pu^{239} by 25 % in the central core region of 4 cm × 4 cm.

Table 6. Material worth at the core center of VERA-11A by an increase of the number density of $0.72\times10^{20}/cm^3$

Material	Experiment [1] ratio	Diffusion (4 group) ratio		Diffusion (11 group) ratio		Transport (4 group) ratio	
U^{235}	1.000	1.150×10^{-6}	1.000	1.151×10^{-6}	1.000	1.101×10^{-6}	1.000
U^{238}	1.262×10^{-2}	2.061×10^{-8}	1.793×10^{-2}	2.992×10^{-8}	2.598×10^{-2}	1.379×10^{-8}	1.138×10^{-2}
Pu^{239}	1.814	1.885×10^{-6}	1.640	1.900×10^{-6}	1.650	1.836×10^{-6}	1.669

1) Experimental values are normalized to 1901 mb for U^{235} in Ref. /7/.

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APPENDIX I Structure of the Interface Files from SNOW Code

The following data are read from the interface file ISNOW1.
(Detailed explanations of the meaning of the various quantities are given in Chapter III.3)

1st record: ISCT, ISN, IGE, IGM, IXM, IYM, IM, JM, MBK, BF, RLØG, MT, MTP, MM, IHS, IHT, IHM

2nd record: V(IM,IYM), RX(IM), RY(JM), MAI(IM), MAJ(JM), IMAT(MTP), W(MM), TW(IS,IS,MM), C(IHM,IGM,MT)

3rd record: B(IBM), if MBK = ±2 or MBK = ±3

4th record: MZ(IXM,IYM), RK

5th record: BP(IBM)

6th record: MZP(IXM,IYM), RKP

2) The direct angular fluxes are read from the interface file ISNOW2 in the following program in subroutine PERT2.

```
  DØ 1 IG=1, IGM
  DØ 1 M=1, MM
1 READ (ISNOW2) FKØ(IM,JM)
```

3) The adjoint angular fluxes are read from the interface file ISNOW3 by a subroutine INVAFX with inverse order with respect to the group and angular index. This adjoint angular fluxes are written by the SNOW code in the following order.

```
DO 1 IG=1, IGM
DØ 1 M=1, MM
1 WRITE(ISNOW3) FKD(IM,JM)
```

APPENDIX II Sample Problem Input Data

Input data for VERA-11A of r-z geometry is given in the following for the calculation of the reactivity caused by an increase of the number density of Pu^{239} by 25 % in the central core region of 4 cm × 4 cm by the exact perturbation method. In the input data to SIGMUT code, an option is used to replace the transport cross section STRTR by STR which is read from input cards. In the SNOW calculation, S_2 method and a number of spatial mesh intervals of (2+4+6)×(2+3+7) are used.

The first part (job INR65920) concerns the preparation of the complete condensed SIGMN block (Here the old NUSYS-version (06731) of the code DIF1D has been applied together with the code 02761 to generate the weighting functions. Presently, the KAPROS-program-chain DIF1D,FLINT1 would be more appropriate for that purpose.). The second part of the sample input concerns the SNOW- and TP2-calculations.

```
//INR65920 JOB (0659,101,P6M2B),KOBAYASHI,
//  REGION=800K
//*MAIN LINES=10
//*FORMAT PR,DDNAME=FT42F001                                                    00000100
//*FORMAT PR,DDNAME=SYSPRINL                                                    00000110
//*FORMAT PR,DDNAME=,FORMS=REPRO
// EXEC PGM=IEFBR14
//SIGMN DD UNIT=3330,VOL=SER=TSTLIB,
// DISP=(OLD,DELETE),DSN=DATA.INR659.SIGMN4
//KAPSNOW EXEC KSCLG                                                            00000120
//K.FT44F001 DD UNIT=SYSDA,SPACE=(3064,200)                                     00000130
//K.FT01F001 DD UNIT=3330,VOL=SER=KAPROS,DISP=SHR,DSN=KSDA.GRUBA.KFKINR         00000140
//K.FT09F001 DD UNIT=3330,VOL=SER=KAPROS,DISP=SHR,DSN=KSDA.JBGRUC               00000150
//K.FT04F001 DD DSN=GROUCO,VOL=SER=KAPROS,UNIT=3330,DISP=SHR                    00000160
//K.FT10F001 DD UNIT=3330,VOL=SER=KAPROS,DISP=SHR,DSN=GRSTAB                    00000170
//K.FT11F001 DD UNIT=3330,VOL=SER=KAPROS,DISP=SHR,DSN=F26                       00000180
//K.FT16F001  DD UNIT=3330,DSN=DATA.INR659.SIGMN4,SPACE=(TRK,(5,1)),
//   DISP=(NEW,KEEP),DCB=(RECFM=VBS,BLKSIZE=13030),VOL=SER=TSTLIB
//K.FT38F001 DD UNIT=SYSDA,DSN=&&INTFAC,DISP=(NEW,PASS),                        00000220
//    DCB=(RECFM=VBS,BLKSIZE=13030),SPACE=(TRK,(50,10))                         00000230
//K.FT37F001 DD UNIT=SYSDA,DSN=&&ANGFLR,DISP=(NEW,PASS),                        00000220
//    DCB=(RECFM=VBS,BLKSIZE=13030),SPACE=(TRK,20)
//K.FT36F001 DD UNIT=SYSDA,DSN=&&ANGFLA,DISP=(NEW,PASS),                        00000220
//    DCB=(RECFM=VBS,BLKSIZE=13030),SPACE=(TRK,20)
//K.FT39F001 DD UNIT=SYSDA,SPACE=(TRK,10)                                       00000240
//K.FT14F001 DD UNIT=SYSDA,SPACE=(TRK,200)                                      00000250
//K.SYSIN DD *                                                                  00000300
*COMPILE G                                                                      00000310
      SUBROUTINE STR                                                            00000320
C                                                                               00000330
      REAL*4 GR(4),SIG(4),SC(4),S26(4),S11(4),UT(4),CO(4)                       00000340
      REAL*4 SA(4),SP(4),NU(4),TO(4),SU(4),SO(4)                                00000350
C                                                                               00000360
      DATA                                                                      00000370
     *  GR/'GRUC','AL  ','    ','    '/,                                       00000380
     *  SIG/'SIGM','N   ','    ','    '/,                                       00000390
     *  S26/'SIG ','26  ','    ','    '/,                                       00000400
     *  S11/'SIG ','11  ','    ','    '/,                                       00000410
     *  UT/'INPU','T UT','KS  ','    '/,                                       00000420
     *  SC/'SIGM','NC  ','    ','    '/,                                       00000430
     *  CO/'COND','ENSA','TION','    '/                                        00000440
      DATA                                                                      00000450
     *  SA/'SIGM','A   ',2*'    '/,                                           00000460
     *  SP/'SPEK','T   ',2*'    '/,                                           00000470
     *  NU/'NUDA','BL  ',2*'    '/,                                           00000480
     *  TO/'INUM','ORD ',2*'    '/,                                           00000490
     *  SU/'INPU','T SI','GMUT','    '/,
     *  SO/'SIGM','N NE','W   ','    '/
C                                                                               00000500
      CALL KSINIT(N1,N2,N3,N4,N5)                                               00000510
C                                                                               00000520
      CALL KSEXEC ('GRUCAL  ',2,0,                                              00000530
```

```
     * GR,GR,SIG,S26,IQ)                                                    00000540
C                                                                          00000550
      CALL KSEXEC ('CCSNTO  ',3,0,                                         00000560
     * TO,TO,SIG,S26,SA,SA,IQ)                                            00000570
C                                                                          00000580
      CALL KSEXEC ('NUSYS   ',3,0,                                         00000590
     * NU,NU,SA,SA,SP,SP,IQ)                                              00000600
C                                                                          00000610
      CALL KSEXEC ('SIGMNC  ',4,0,                                         00000620
     * CO,CO,SP,SP,SIG,S26,SC,S11,IQ)                                     00000630
C                                                                          00000640
      CALL KSEXGC('SIGMUT  ',3,0,SU,SU,SO,SO,S11,S11,IQ)
      CALL KSDLT(S26,1,IQ)                                                 00000650
      CALL KSDLT(SA,1,IQ)                                                  00000660
      CALL KSDLT(SP,1,IQ)                                                  00000670
C                                                                          00000680
      CALL KSEXEC ('UTKS    ',2,0,                                         00000690
     * UT,UT, SO, SO,IQ)                                                  00000700
C                                                                          00000710


      RETURN                                                               00000740
      END                                                                  00000750
*$*$                                                                       00000760
*LINK MAP,LIST                                                            00000770
 ENTRY STR                                                                 00000780
 NAME STR                                                                  00000790
*$*$                                                                       00000800
*KSIOX DBN=GRUCAL,TYP=CARD,PMN=PRGRUC                                     00000950
'GRUCAL  '                                                                 00000960
'KFKINR  ' 'SN-RECH.' '        '                                         00000970
 10 11                                                                     00000980
'MISCH   '                                                                 00000990
4
13           'KFKINR  '   '        '   '        '                              1
'PU239   '       300.       0.007213                                        2
'PU240   '       300.       0.000370                                        3
'PU241   '       300.       0.000028                                        4
'NB      '       300.       9.878E-5                                        5
'C       '       300.       0.046204                                        6
'FE      '       300.       0.006084                                        7
'CR      '       300.       0.001579                                        8
'NI      '       300.       0.000665                                        9
'CU      '       300.       0.00775222                                      10
'PB      '       300.       0.000035                                        11
'ZR      '       300.       0.000043                                        12
'U 235   '       300.       0.0                                             13
'U 238   '       300.       0.0                                             14
13           'KFKINR  '   '        '   '        '                              1
'PU239   '       300.       0.007213                                        2
'PU240   '       300.       0.000370                                        3
'PU241   '       300.       0.000028                                        4
'NB      '       300.       9.878E-5                                        5
'C       '       300.       0.046204                                        6
'FE      '       300.       0.006084                                        7
'CR      '       300.       0.001579                                        8
'NI      '       300.       0.000665                                        9
'CU      '       300.       0.00775222                                      10
'PB      '       300.       0.000035                                        11
'ZR      '       300.       0.000043                                        12
'U 235   '       300.       0.0                                             13
'U 238   '       300.       0.0                                             14
```

```
8              'KFKINR  '    '          '    '          '                          1
'FE      '        300.        0.0065                                               2
'CR      '        300.        0.0017                                               3
'NI      '        300.        0.00071                                              4
'U 235   '        300.        0.00025                                              5
'U 238   '        300.        0.03440                                              6
'PU239   '        300.        0.0                                                  7
'PU240   '        300.        0.0                                                  8
'PU241   '        300.        0.0                                                  9
13             'KFKINR  '    '          '    '          '                          1
'PU239   '        300.        0.00901625                                           2
'PU240   '        300.        0.000370                                             3
'PU241   '        300.        0.000028                                             4
'NB      '        300.        9.878E-5                                             5
'C       '        300.        0.046204                                             6
'FE      '        300.        0.006084                                             7
'CR      '        300.        0.001579                                             8
'NI      '        300.        0.000665                                             9
'CU      '        300.        0.00775222                                           10
'PB      '        300.        0.000035                                             11
'ZR      '        300.        0.000043                                             12
'U 235   '        300.        0.0                                                  13
'U 238   '        300.        0.0                                                  14
'GEW.CHI '
4
5
'PU239   '  0.007213
'PU240   '  0.000370
'PU241   '  0.000028
'U 235   '  0.00
'U 238   '  0.0
5
'PU239   '  0.007213
'PU240   '  0.000370
'PU241   '  0.000028
'U 235   '  0.00
'U 238   '  0.0
5
'U 235   '  0.00025
'U 238   '  0.03440
'PU239   '  0.0
'PU240   '  0.0
'PU241   '  0.0
5
'PU239   '  0.007213
'PU240   '  0.000370
'PU241   '  0.000028
'U 235   '  0.00
'U 238   '  0.0
'TYP     '                                                                       00001230
'ALLEIN  '  11                                                                  00001240
'CHI     '                                                                       00001250
 'NUSF    '                                                                     00001260
 'SCAPT   '                                                                     00001270
 'SFISS   '                                                                     00001280
 'SBE     '                                                                     00001290
 'SREM    '                                                                     00001300
 'STR     '                                                                     00001310
 'STRTR   '                                                                     00001320
 '1/V     '                                                                     00001330
 'STOT    '                                                                     00001340
 'SMTOT   '                                                                     00001350
'AUSWERT '                                                                      00001360
```

```
'ZUSATZ  ' 4                                                                    00001370
'SFISS   ' ' '        ' 0 0                                                     00001380
'CHI     ' ' '        ' 1 0
'SCAPT   ' ' '        ' 0 0                                                     00001390
'NUSF    ' ' '        ' 0 0                                                     00001400
                                                                               00001410
'GRUCEND '                                                                     00001420
*$*$                                                                           00001430
*KSIOX DBN=INPUT SIGMUT,TYP=CARD,PMN=PRSIGM                                    00001420
'BETA'                                                                         00001430
'SIG 11          ' 'SIGMN NEW       '   4  4  6  5                            00001440
'FISS' '    '                                                                  00001450
0.0 0.73 0.27 0.0
0.0 0.90 0.10 0.0
0.0 0.86 0.14 0.0
0.07 0.83 0.10 0.0
0.04 0.90 0.06 0.0
0.04 0.90 0.06 0.0
'PU239   ' 0.2523E-3 1.8592E-3 1.4343E-3 2.1779E-3 0.6839E-3 0.2324E-3        00001580
'PU240   ' 0.2688E-3 2.6208E-3 1.8432E-3 3.3600E-3 1.2288E-3 0.2784E-3        00001590
'PU241   ' 0.160E-3 3.664E-3 2.768E-3 6.240E-3 2.112E-3 0.256E-3              00001600
'U 235   ' 0.6449-3 3.6146-3 3.1904-3 6.9068-3 2.1721-3 0.4412-3
'U 238   ' 0.0586-2 0.6176-2 0.7303-2 1.7491-2 1.0143-2 0.3381-2
'MODI' 'SIGMN NEW       ' 'MVAL' 'STRTR            '   0
 1 4 1 0.149540 2 0.245060 3 0.394132 4 0.457284
                           'MVAL' 'STRTR            '   0
 2 4 1 0.149241 2 0.248647 3 0.392745 4 0.457149
                           'MVAL' 'STRTR            '   0
 3 4 1 0.169595 2 0.270228 3 0.480603 4 0.458323
                           'MVAL' 'STRTR            '   0
 4 4 1 0.158265 2 0.257396 3 0.417921 4 0.484601
'ENDM'
   'LIST' 'SIGMN NEW       '
'END'                                                                          00001630
*$*$
*KSIOX DBN=INUMORD,TYP=CARD,PMN=KETT,IND=1                                     00001440
'SIGMA   '                                                                     00001450
'ZUSATZ  ' 1 'STRTR   ' ' '        '                                           00001460
'ENDE    '                                                                     00001470
*$*$                                                                           00001480
*KSIOX DBN=NUDABL,TYP=CARD,PMN=KETT,IND=1                                      00001490
0                                                                              00001500
 00397                                                                         00001510
06731  0     0     0                                                          00001520
 ENDE                                                                          00001530
 06731                                                                         00001540
02761  0      0     4                                                         00001550
 FLUX1GEO  SPAQ1BUCK1                                                          00001560
0     0     0     23    26    0    1.0E-04    1.0E-03                         00001570
 GEO                                                                           00001580
2  3  0.  5.0  10  1 13.99      18  2 56.99    86  3                          00001590
 SPAQ1                                                                         00001600
1                                                                              00001610
1.0  0.500  0.474  0.474  0.105  0.0255  0.000029                             00001620
 END31                                                                         00001630
 02761                                                                         00001640
0       0    0    -1    1   +4    0                                          00001650
1    2    3   12                                                            00001660
 NUFIN                                                                         00001670
*$*$                                                                           00001680
*KSIOX DBN=CONDENSATION,IND=1,TYP=CARD,PMN=NUTEST                              00001690
26 4 4 1 -1                                                                    00001700
    4    8    12    26                                                       00001720
1 2 3 1                                                                        00001730
*$*$                                                                           00001740
*KSIOX DBN=INPUT UTKS,PMN=PRUTKS,TYP=CARD,IND=1                               00001750
```

```
'BWRITE' 'SIGMN NEW        ' 16  'STRUC1NU'                                  00001760
'END UTKS'                                                                   00001770
*$*$                                                                        00001780
*GO SM=STR                                                                  00002060
/*
//                                                                                //
```

```
//INR659TP JOB (0659,101,P6M2B),KOBAYASHI,
//  REGION=1023K,TIME=9
//*MAIN SYSTEM=M168
//*MAIN LINES=4                                                          00000090
//*FORMAT PR,DDNAME=FT42F001                                             00000100
//*FORMAT PR,DDNAME=SYSPRINL                                             00000110
//*FORMAT PR,DDNAME=,FORMS=REPRO
//KAPSNOW EXEC KSCLG                                                     00000120
//K.FT44F001 DD UNIT=SYSDA,SPACE=(3064,200)                              00000130
//K.FT01F001 DD UNIT=3330,VOL=SER=KAPROS,DISP=SHR,DSN=KSDA.GRUBA.KFKINR 00000140
//K.FT09F001 DD UNIT=3330,VOL=SER=KAPROS,DISP=SHR,DSN=KSDA.JBGRUC        00000150
//K.FT04F001 DD DSN=GROUCO,VOL=SER=KAPROS,UNIT=3330,DISP=SHR             00000160
//K.FT10F001 DD UNIT=3330,VOL=SER=KAPROS,DISP=SHR,DSN=GRSTAB             00000170
//K.FT11F001 DD UNIT=3330,VOL=SER=KAPROS,DISP=SHR,DSN=F26                00000180
//K.FT16F001  DD UNIT=3330,DSN=DATA.INR659.SIGMN4,SPACE=(TRK,10),
//   DISP=SHR,VOL=SER=TSTLIB
//K.FT38F001 DD UNIT=SYSDA,DSN=&&INTFAC,DISP=(NEW,PASS),                 00000220
//    DCB=(RECFM=VBS,BLKSIZE=13030),SPACE=(TRK,(50,10))                  00000230
//K.FT37F001 DD UNIT=SYSDA,DSN=&&ANGFLR,DISP=(NEW,PASS),                 00000220
//    DCB=(RECFM=VBS,BLKSIZE=13030),SPACE=(TRK,150)
//K.FT36F001 DD UNIT=SYSDA,DSN=&&ANGFLA,DISP=(NEW,PASS),                 00000220
//    DCB=(RECFM=VBS,BLKSIZE=13030),SPACE=(TRK,150)
//K.FT39F001 DD UNIT=SYSDA,SPACE=(TRK,10)                                00000240
//K.FT14F001 DD UNIT=SYSDA,SPACE=(TRK,200)                               00000250
//K.SYSIN DD *                                                           00000300
*COMPILE G
      SUBROUTINE DUMMY
      COMMON NACOM,A(100000)
      NACOM=100000
      COMMON /FIX/NICOM,IA(1000)
      NICOM=1000
      RETURN
      END
*$*$
*LINK MAP,LIST
 INCLUDE KSBIB(KASNOW)
 ENTRY KASNOW
 NAME KASNOW
*$*$
*KSIOX DBN=KASNOW,LMN=READSN,PMN=CHECK,TYP=CARD,IND=1                    00001790
VERA-11A ZWEIDIMENSIONALE SN-RECHNUNG  ZYLINDERGEOMETRIE (REELL)         00001800
000001    -2     2     1     0     1     4     1     3     3     4    4000001810
    10    10    -1     0   -16     0     1     0     0     0     0     00001820
     1     0     1     0     0     0                       1     1    000001830
                                                           3          00001840
                                                                      00001850
     1.0E-05         1.0           0.          0.          0.        0.00001990
     2     4     6                                                        1870
     2     3     7                                                        1880
         4.0     13.22       52.22                                        1890
         4.0     10.875      58.875                                       1900
     1     2     3     2     2     3     3     3     3                   00001910
                                                                      00001920
VERA-11A ZWEIDIMENSIONALE SN-RECHNUNG  ZYLINDERGEOMETRIE (ADJUNGIERT)   00001930
000001    -1     2     1     0     1     4     1     3     3     4    4000001940
    10    10    -1     0   -16     0     1     0     0     0     0     00001950
     1     0     1     0     0     0                       1          000001960
```

```
                                                                    3       00001970
                                                                            00001980
     1.0E-05          1.0           0.          0.          0.          0.00001990
     2     4     6                                                            1870
     2     3     7                                                            1880
         4.0     13.22       52.22                                            1890
         4.0     10.875      58.875                                           1900
     4     2     3     2     2     3     3     3     3                        00001910
99999                                                                       00002050
*GO SM=KASNOW                                                               00002060
//  EXEC FGCLG
//C.SYSIN DD  *
C      MAIN PROGRAM                                                          MAIN
C      COMPUTATION OF REACTIVITY,NEUTRON MEAN GENERATION TIME AND EFFECTI    MAIN
C      VE DELAYED NEUTRON FRACTION BY THE PERTURBATION METHOD USING TWO      MAIN
C      DIMENSIONAL SN CODE SNOW AND GROUP CONSTANT CODE GRUCAL.              MAIN
C      THE CODE IS MADE BY KEISUKE KOBAYASHI ON 15.11.1977                   MAIN



//G.SYSIN DD  *
 TEST DATA FOR TP2  (13.1.1978)
  5  6  1  0  0  1  1  1  1  0  0  0
PU239   PU240   PU241    U 235   U 238
  4  1 24  1  1
/*                                                                          //
//
```

APPENDIX III Sample Problem Output

Output from TP2 code is shown in the following for the input data given in Appendix II. The present case is different from the case 1 of Table 2 with two respects; the transport cross section STR is used instead of STRTR, and an average fission spectrum derived from isotope dependent fission spectra is used in SNOW calculation and isotope dependent fission spectra are used to calculate the correction factor of the criticality factor in TP2.

```
 REACTIVITY,MEAN GENERATION TIME AND EFFECTIVE DELAYEDNEUTRON FRACTION BY TRANSPORT PERTURBATION CODE TP2


 TEST DATA FOR TP2  (13.1.1978)

NUMBER OF FISSILE ISOTOPE            IFM=  5
NUMBER OF DELAYED NEUTRONS GROUPS    IGM=  6

NAME OF ISOTOPE      PU239   PU240   PU241   U 235   U 238

INPUT DATA FROM SNOW
   ISCT=  0        ISN=  2        IGE=  1        IGM=  4        IXM=  3        IYM=  3        IM= 12        JM= 12
    MBK=  0         MT=  4        MTP=  4         MM=  6        IHS=  6        IHT=  5        IHM=  9

     BF=   0.0              RLOG=   9.999999E-11

LAENGE=  100000         LAST=    3652         IRIS=   96348

RX(IMP)
   0.0          2.0000E+00   4.0000E+00   6.3050E+00   8.6100E+00   1.0915E+01   1.3220E+01   1.9720E+01   2.6220E+01   3.2720E+01
   3.9220E+01   4.5720E+01   5.2220E+01

RY(JMP)
   0.0          2.0000E+00   4.0000E+00   6.2917E+00   8.5833E+00   1.0875E+01   1.7732E+01   2.4585E+01   3.1446E+01   3.8304E+01
   4.5161E+01   5.2018E+01   5.8875E+01

 **** ALS TOTALER WIRKUNGSQUERSCHNITT WIRD DER NUSYS-TYP &STRTR&  STATT &STR& BENUETZT ****

CROSS SECTIONS CORRECTLY PREPARED

**********************************************************************************************************************

FLUXES AND ADJOINTS FOR ALL FOLLOWING PERTURBATION CALUCULATIONS ARE OBTAINED BY USING THE FOLLOWING COMPOSITIONS

**********************************************************************************************************************

FOR DIRECT EQUATION

MZ(IXM,IYM)=

  1  2  3
  2  2  3
  3  3  3

MZT(IXM,IYM)=

  1  2  3
  2  2  3
  3  3  3

FOR ADJOINT EQUATION

MZ(IXM,IYM)=

  4  2  3
  2  2  3
  3  3  3

MZT(IXM,IYM)=

  4  2  3
  2  2  3
  3  3  3


CRITICALITY FACTOR FOR DIRECT EQUATION          1.031608E+00
CRITICALITY FACTOR FOR ADJOINT EQUATION         1.039451E+00
REACTIVITY FROM THE CRITICALITY FACTOR          7.314146E-03
```

DENOMINATOR= 4.339828E+04

CORRECTION TO THE CRITICALITY FACTOR OF SNOW WHERE AN ISOTOPE INDEPENDENT FISSION SPECTRUM IS USED FOR PROMPT AND DELAYED FISSION NEUTRONS
CORRECTED CRITICALITY FACTOR FOR DIRECT EQUATION 1.030524E+00 (RO=-1.019E-03)

NEUTRON MEAN GENERATION TIME RAMDA= 6.94444E-08SEC

EFFECTIVE DELAYED NEUTRON FRACTION FOR EACH ISOTOPE AND MIXTURE

MIXTURE INDEX= 1

GROUP	PU239	PU240	PU241	U 235	U 238	ROW SUM
1	0.0	0.0	0.0	0.0	0.0	0.0
2	0.0	0.0	0.0	0.0	0.0	0.0
3	0.0	0.0	0.0	0.0	0.0	0.0
4	0.0	0.0	0.0	0.0	0.0	0.0
5	0.0	0.0	0.0	0.0	0.0	0.0
6	0.0	0.0	0.0	0.0	0.0	0.0
SUM	0.0	0.0	0.0	0.0	0.0	0.0

MIXTURE INDEX= 2

GROUP	PU239	PU240	PU241	U 235	U 238	ROW SUM
1	6.12952E-05	1.28403E-06	1.78620E-07	0.0	0.0	6.27620E-05
2	4.48795E-04	1.24363E-05	4.06865E-06	0.0	0.0	4.65299E-04
3	3.46758E-04	8.76017E-06	3.07837E-06	0.0	0.0	3.59596E-04
4	5.29614E-04	1.60599E-05	6.58057E-06	0.0	0.0	5.52654E-04
5	1.65533E-04	5.84603E-06	3.24235E-06	0.0	0.0	1.74621E-04
6	5.62506E-05	1.32449E-06	2.85046E-07	0.0	0.0	5.78601E-05
SUM	1.60825E-03	4.57110E-05	1.78338E-05	0.0	0.0	1.67179E-03

MIXTURE INDEX= 3

GROUP	PU239	PU240	PU241	U 235	U 238	ROW SUM
1	0.0	0.0	0.0	3.77009E-06	1.42526E-05	1.80227E-05
2	0.0	0.0	0.0	2.21223E-05	1.54927E-04	1.77049E-04
3	0.0	0.0	0.0	1.93202E-05	1.81886E-04	2.01207E-04
4	0.0	0.0	0.0	4.35222E-05	4.49684E-04	4.93206E-04
5	0.0	0.0	0.0	1.36588E-05	2.59883E-04	2.73542E-04
6	0.0	0.0	0.0	2.77437E-06	8.66273E-05	8.94017E-05
SUM	0.0	0.0	0.0	1.05168E-04	1.14726E-03	1.25243E-03

MIXTURE INDEX= 4

GROUP	PU239	PU240	PU241	U 235	U 238	ROW SUM
1	6.02826E-06	1.09814E-07	1.38692E-08	0.0	0.0	6.15194E-06
2	4.38991E-05	1.05808E-06	3.13865E-07	0.0	0.0	4.52710E-05
3	3.39614E-05	7.46228E-07	2.37777E-07	0.0	0.0	3.49454E-05
4	5.15781E-05	1.36057E-06	5.36129E-07	0.0	0.0	5.34748E-05
5	1.61304E-05	4.95551E-07	2.49174E-07	0.0	0.0	1.68752E-05
6	5.48138E-06	1.12273E-07	2.19054E-08	0.0	0.0	5.61556E-06
SUM	1.57079E-04	3.88251E-06	1.37272E-06	0.0	0.0	1.62334E-04

SUM OVER MIXTURE

GROUP	PU239	PU240	PU241	U 235	U 238	ROW SUM
1	6.73274E-05	1.39385E-06	1.92689E-07	3.77009E-06	1.42526E-05	8.69367E-05
2	4.92694E-04	1.34944E-05	4.38251E-06	2.21223E-05	1.54927E-04	6.37620E-04
3	3.80719E-04	9.50639E-06	3.31615E-06	1.93202E-05	1.81886E-04	5.94748E-04
4	5.81192E-04	1.74205E-05	7.51670E-06	4.35222E-05	4.49684E-04	1.09933E-03
5	1.81663E-04	6.34158E-06	3.49156E-06	1.36588E-05	2.59883E-04	4.65038E-04
6	6.17320E-05	1.43676E-06	3.06951E-07	2.77437E-06	8.66273E-05	1.52877E-04
SUM	1.76533E-03	4.95935E-05	1.92065E-05	1.05168E-04	1.14726E-03	3.08655E-03

EXACT PERTURBATION

I	J	GROUP	CAPTURE	FISSION	REMOVAL	SCATT.OUT	SCATT.IN	OUT+IN	G-I TO G	FISS.SOURCE	AD.FISS.SOURCE	TOTAL
1	1	1	-3.0217E-08	-7.3536E-06	-1.3711E-05	-1.1328E-05	6.4247E-06	-4.9030E-06	0.0	4.5614E-05	2.3060E-05	3.3327E-05
1	1	2	-9.1854E-07	-1.3213E-05	-5.6174E-05	-4.2042E-05	4.5814E-05	3.7711E-06	4.5201E-06	3.1495E-05	3.8803E-05	2.1134E-05
1	1	3	-1.7325E-06	-5.4891E-06	-4.3016E-05	-3.5794E-05	3.6870E-05	1.0763E-06	8.2101E-07	1.1345E-06	1.4677E-05	-5.0108E-06
1	1	4	-5.5005E-07	-6.9315E-07	-3.0711E-06	-1.8279E-06	1.8934E-06	6.5582E-08	6.2608E-08	0.0	1.7041E-06	-1.1776E-06
1	1	SUM	-3.2313E-06	-2.6749E-05	-1.2097E-04	-9.0992E-05	9.1002E-05	9.9735E-09	5.4037E-06	7.8244E-05	7.8244E-05	4.8273E-05
1	2	1	-2.7621E-08	-6.7218E-06	-1.7104E-05	-1.0354E-05	5.9014E-06	-4.4530E-06	0.0	4.2492E-05	2.1164E-05	3.1290E-05
1	2	2	-8.5576E-07	-1.2310E-05	-5.2335E-05	-3.9169E-05	4.2691E-05	3.5222E-06	4.1435E-06	2.9280E-05	3.6265E-05	1.9637E-05
1	2	3	-1.6277E-06	-5.1571E-06	-4.0414E-05	-3.3629E-05	3.4652E-05	1.0228E-06	7.6580E-07	1.0538E-06	1.3826E-05	-4.7081E-06
1	2	4	-5.0538E-07	-6.3686E-07	-2.9217E-06	-1.6794E-06	1.7428E-06	6.3418E-08	5.8824E-08	0.0	1.5716E-06	-1.0788E-06
1	2	SUM	-3.0165E-06	-2.4826E-05	-1.1267E-04	-8.4832E-05	8.4987E-05	1.5549E-07	4.9681E-06	7.2827E-05	7.2827E-05	4.5140E-05
2	1	1	-2.8219E-08	-6.8674E-06	-1.7474E-05	-1.0579E-05	6.0198E-06	-4.5589E-06	0.0	4.2916E-05	2.1578E-05	3.1462E-05
2	1	2	-8.6069E-07	-1.2381E-05	-5.2636E-05	-3.9394E-05	4.2971E-05	3.5771E-06	4.2221E-06	2.9541E-05	3.6477E-05	1.9876E-05
2	1	3	-1.6311E-06	-5.1677E-06	-4.0497E-05	-3.3698E-05	3.4723E-05	1.0244E-06	7.6856E-07	1.0615E-06	1.3883E-05	-4.7129E-06
2	1	4	-5.0742E-07	-6.3944E-07	-2.8331E-06	-1.6862E-06	1.7493E-06	6.3113E-08	5.8964E-08	0.0	1.5803E-06	-1.0837E-06
2	1	SUM	-3.0274E-06	-2.5056E-05	-1.1344E-04	-8.5357E-05	8.5463E-05	1.0567E-07	5.0496E-06	7.3519E-05	7.3519E-05	4.5541E-05
2	2	1	-2.6033E-08	-6.3352E-06	-1.6120E-05	-9.7589E-06	5.5774E-06	-4.1815E-06	0.0	4.0255E-05	1.9966E-05	2.9712E-05
2	2	2	-8.0638E-07	-1.1600E-05	-4.9315E-05	-3.6908E-05	4.0268E-05	3.3594E-06	3.8998E-06	2.7623E-05	3.4296E-05	1.8577E-05
2	2	3	-1.5374E-06	-4.8708E-06	-3.8171E-05	-3.1763E-05	3.2741E-05	9.7792E-07	7.2039E-07	9.9129E-07	1.3135E-05	-4.4390E-06
2	2	4	-4.7036E-07	-5.9273E-07	-2.6261E-06	-1.5630E-06	1.6238E-06	6.0733E-08	5.5584E-08	0.0	1.4714E-06	-1.0024E-06
2	2	SUM	-2.8402E-06	-2.3399E-05	-1.0623E-04	-7.9993E-05	8.0210E-05	2.1659E-07	4.6757E-06	6.8870E-05	6.8870E-05	4.2847E-05
INTEGRAL		1	-5.5441E-06	-1.3492E-03	-3.4331E-03	-2.0784E-03	1.1842E-03	-8.9415E-04	0.0	8.4853E-03	4.2439E-03	6.2364E-03
INTEGRAL		2	-1.7029E-04	-2.4496E-03	-1.0414E-02	-7.7941E-03	8.5004E-03	7.0630E-04	8.3012E-04	5.8375E-03	7.2228E-03	3.9239E-03
INTEGRAL		3	-3.2335E-04	-1.0245E-03	-8.0282E-03	-6.6804E-03	6.8842E-03	2.0372E-04	1.5214E-04	2.0577E-04	2.7535E-03	-9.3431E-04
INTEGRAL		4	-1.0025E-04	-1.2633E-04	-5.5571E-04	-3.3313E-04	3.4571E-04	1.2580E-05	1.1689E-05	0.0	3.1242E-04	-2.1400E-04
INTEGRAL		SUM	-5.9943E-04	-4.9496E-03	-2.2435E-02	-1.6686E-02	1.6914E-02	2.8456E-05	9.9395E-04	1.4533E-02	1.4533E-02	9.0121E-03