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MULTI - A MULTIGROUP OR MULTIPOINT P_3 PROGRAMME FOR CALCULATING THERMAL NEUTRON SPECTRA IN A REACTOR CELL

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A B S T R A C T

Programme MULTI calculates the space energy distribution of thermal neutrons in a multizone, cylindrical, infinitely long reactor lattice cell by using the multigroup or multipoint P_3 approximation. This report presents a short description of the algorithm and the programme and gives the instructions needed for its exploatation.

1. INTRODUCTION

Programme MULTI calculates the space energy distribution of thermal neutrons in a multizone, cylindrically symmetric and infinitely high reactor lattice cell. The method applied is a combination of the P_3 approximation of the spherical harmonics procedure with either the standard multigroup scheme /1/ or the more efficient multipoint treatment /2/.

The thermal neutron flux in each zone of a reactor cell is described by a system of multigroup or multipoint integrodifferential equations in angle and space variable. To solve this system an iteration procedure is applied which makes possible to treat the equations one by one. P_3 approximation of the spherical harmonics method transforms further each of the multigroup or multipoint equations into a system of six ordinary first order differential equations in space variable only. The general solution of this system can be expressed in analytical form /3/ and contains six unknown integration constants which have to be determined so that flux moments satisfy the boundary conditions at cell zones boundaries. This means that in each iteration cycle and for each energy group or point it is necessary to form a system of algebraic equations stating the boundary conditions for a reactor cell considered, solve this system and use the solutions to calculate the space distribution of spherical

harmonics flux momentsin the given energy group, i.e. point.

The present report contains a short description of the algorithm used, describes the programme written for a ZUSE Z 23 computer and gives all the instructions needed for exploatation of the programme.

2. DESCRIPTION OF THE PROCEDURE

The space-angle-energy distribution of thermal neutrons in a zone of a cylindrical infinitely long reactor lattice cell is described by a set of multigroup /1/ or multipoint /2/ equations:

$$-\vec{\Omega}\,\mathrm{grad}\,\varphi^{j}(r,\vec{\Omega}) - \Sigma^{j}\varphi^{j}(r,\vec{\Omega}) + \sum_{\ell=1}^{J}\int_{0}^{4\pi} d\vec{\Omega}'\,\varphi^{\ell}(r,\vec{\Omega}')\,\Sigma^{j\leftarrow\ell}(\vec{\Omega}\vec{\Omega}') + S^{j}(r,\vec{\Omega}) \qquad (1)$$

$$j=1,2,\ldots,J$$

The total thermal flux $\varphi(r)$ and the reaction rate $P(r)$ are given by:

$$\varphi(r) = \sum_{j=1}^{J}\int_{0}^{4\pi}\varphi^{j}(r,\vec{\Omega})d\Omega = \sum_{j=1}^{J}\varphi^{j}_{oo}(r) \qquad (2)$$

$$P(r) = \sum_{j=1}^{J}\Sigma^{j}\,\varphi^{j}_{oo}(r) \qquad (3)$$

In the above equations ℓ and j are the indices of energy groups or points and J is the total number of groups, i.e. points in the energy range considered. Σ^{j}, $\Sigma^{j\leftarrow\ell}(\vec{\Omega}\vec{\Omega}')$ and $S^{j}(r,\vec{\Omega})$ are the imput quantities for the present calculation, having different values for each material of a cell and for each j and ℓ.

In the multigroup treatment, when the group value of the flux is defined as

$$\varphi^{j}(r,\vec{\Omega}) = \int_{E_{j-1}}^{E_j} \varphi(r,\vec{\Omega}, E)\, dE \qquad (4)$$

the group values of the total cross section Σ^{j} and the group scattering matrix $\Sigma^{j\leftarrow\ell}$ are calculated as:

$$\Sigma^{j} = \frac{\int_{E_{j-1}}^{E_j} \Sigma(E)\, M(E)\, dE}{\int_{E_{j-1}}^{E_j} M(E)\, dE} \qquad (5)$$

$$\Sigma^{j\leftarrow\ell} = \frac{\int_{E_{j-1}}^{E_j} dE \int_{E_{\ell-1}}^{E_\ell} \Sigma(E'\to E, \vec{\Omega}\cdot\vec{\Omega}')\, M(E')dE'}{\int_{E_{\ell-1}}^{E_\ell} M(E')\, dE'} \qquad (6)$$

$M(E)$ is the supposed spectrum, for instance Maxwellian or $1/E$. The group values of the source from the epithermal region are defined as:

$$S^{j}(r,\vec{\Omega}) = \int_{E_{j-1}}^{E_j} S(r,\vec{\Omega},E)\, dE \qquad (7)$$

E_j are the energy groups boundaries.

In the energy point treatment the fluxes φ^j are defined as:

$$\varphi^j(r,\vec{\Omega}) = W_j \varphi(r, \vec{\Omega}, E_j) \qquad (8)$$

Here, E_j are the integration points and W_j are the corresponding integration weights. Σ^j are exactly the values of the total cross section at the points E^j:

$$\Sigma^j = \Sigma(E_j) \qquad (9)$$

The point to point scattering matrix is most generally defined by:

$$\sum_{j=1}^{J} \varphi^j(r,\vec{\Omega}) \Sigma^{j\leftarrow l}(\vec{\Omega}\cdot\vec{\Omega}') \cong \int_0^{E^*} \varphi(r,\vec{\Omega},E)\, \Sigma(\vec{\Omega}\cdot\vec{\Omega}',E\rightarrow E_j)dE \qquad \ldots\ldots \qquad (10)$$

E^* being the upper boundary of the thermal energy range. The particular form od $\Sigma^{j\leftarrow l}$ depends on the interpolation scheme chosen to represent the energy variation of neutron flux between the integration points. A possible method for constructing the point scattering matrix is suggested in /2/, together with the consistent definition of the source S^j.

The system of equations (1) is successfully treated by the following iteration procedure /1/:

$$\vec{\Omega}\,\mathrm{grad}\,\varphi_i^j(r,\vec{\Omega}) + \Sigma^j\varphi_i^j(r,\vec{\Omega}) + \int_0^{4\pi} d\vec{\Omega}'\varphi_i^j(r,\vec{\Omega}')\Sigma^{j\leftarrow j}(\vec{\Omega}\vec{\Omega}') =$$

$$= S_i^j(r,\vec{\Omega}) + \sum_{l=1}^{j-1}\int_0^{4\pi} d\Omega'\varphi_i^l(r,\vec{\Omega}')\Sigma^{j\leftarrow l}(\vec{\Omega}\vec{\Omega}') +$$

$$+ \sum_{l=j+1}^{J}\int_0^{4\pi} d\Omega'\varphi_{i-1}^l(r,\vec{\Omega}')\Sigma^{j\leftarrow l}(\vec{\Omega}\vec{\Omega}') \qquad (11)$$

where i is the iteration index. The source term is recalculated after each iteration step so that, in spite of the calculation errors, the total absorption equals the total source in the reactor cell.

When the spherical harmonics method is applied to (11) in the standard way /4/, it reduces further to a set of differential equations in r for the spherical harmonics flux moments. In P-3 approximation and in a cylindrically symmetric system only six flux moments exist, which can be regarded as components of the flux vector:

$$F(r) = \begin{Vmatrix} \varphi_{00}(r) \\ \varphi_{20}(r) \\ \varphi_{22}(r) \\ \varphi_{11}(r) \\ \varphi_{31}(r) \\ \varphi_{33}(r) \end{Vmatrix} \qquad (12)$$

For each energy group and in each iteration cycle $F_i^j(r)$ has to be determined as a solution of an inhomogeneous system of six ordinary first order differential equations:

$$L^j(r)\, F_i^j(r) = R_i^j(r) \tag{13}$$

$L^j(r)$ is a sixth order matrix differential operator in r:

$$L^j(r) = \begin{Vmatrix} \Sigma_o^j & o & o & \frac{1}{r}\frac{d}{dr}r & o & o \\ o & 5\Sigma^j & o & -\frac{1}{r}\frac{d}{dr}r & \frac{1}{r}\frac{d}{dr}r & o \\ o & o & \frac{5}{6}\Sigma^j & r\frac{d}{dr}\frac{1}{r} & -\frac{r}{6}\frac{d}{dr}\frac{1}{r} & \frac{1}{12r^3}\frac{d}{dr}r^3 \\ \frac{d}{dr} & -\frac{d}{dr} & \frac{1}{2r^2}\frac{d}{dr}r^2 & 3\Sigma^j & o & o \\ o & \frac{d}{dr} & -\frac{1}{12r^2}\frac{d}{dr}r^2 & o & \frac{7}{6}\Sigma^j & o \\ o & o & r^2\frac{d}{dr}\frac{1}{r^2} & o & o & \frac{7}{15}\Sigma^j \end{Vmatrix} \tag{14}$$

It has been supposed here that neutron scattering is isotropic and Σ_o^j is to be calculated as:

$$\Sigma_o^j = \Sigma^j - \int_o^{4\pi} \Sigma^{j\leftarrow j}(\Omega'\to\Omega)\,d\Omega = \Sigma^j - \Sigma_o^{j\leftarrow j} \tag{15}$$

The source from the epithermal region is also considered as isotopic as well as independent of r inside a cell zone. Thus the free term vector $R_i^j(r)$ reduces to only the first component:

$$\varphi_{oo,i}^j(r) = S_{oo,i}^j + \sum_{\ell=1}^{j-1} \varphi_{oo,i}^{\ell}(r)\,\Sigma_o^{j\leftarrow\ell} + \sum_{\ell=j+1}^{J} \varphi_{oo,i-1}^{\ell}(r)\,\Sigma_o^{j\leftarrow\ell}$$

$$\ldots\ldots \tag{16}$$

It exists only in these zones of a reactor cell where the slowing down and the thermalization properties should be taken into account.

The general solution of system of equations (13) is a sum of the general solution of the corresponding homogeneous system and a particular solution existing only in the moderating zones of the reactor cell:

$$F_i^j = F_{i\ hom}^j + F_{i\ part}^j \tag{17}$$

where

$$L^j\ F_{i\ hom}^j = 0 \tag{18}$$

The solution of the homogeneous system (18) can be expressed /5/ in terms of the modified first and second order Bessel functions:

$$\varphi_{st,i,hom}^j = \sum_{k=1}^{3} A_{st}^{jk}\ \left[a_i^{jk}\ I_t(\lambda^{jk} r) + (-)^t b_i^{jk} K_t(\lambda^{jk} r)\right] \tag{19}$$

$$st = oo, 2o, 22, 11, 31, 33$$

λ^{jk} and A_{st}^{jk} are the eigenvalues and the coefficients which can be expressed in terms of the cross sections of the cell zone considered:

$$\nu^{j1} = \sqrt{p^j + \sqrt{(p^j)^2 - q^j}}$$

$$\nu^{j2} = \sqrt{p^j - \sqrt{(p^j)^2 - q^j}}$$

$$p^j = \frac{1}{18}\left[55\,\xi_o^j\,\xi^j + 35(\xi^j)^2\right] \tag{20}$$

$$q^j = \frac{35}{3}\,\xi_o^j\,(\xi^j)^3$$

$$\nu^{j3} = \xi^j\sqrt{7}$$

For $i = 1,2$:

$$A_{oo}^{ji} = 1$$

$$A_{2o}^{ji} = -\frac{1}{5}\,\frac{(\nu^{ji})^2 - 10\,\xi_o^j\,\xi^j}{(\nu^{ji})^2 - 7\,(\xi^j)^2}$$

$$A_{22}^{ji} = -3\,A_{2o}^{ji} \tag{21}$$

$$A_{11}^{ji} = \frac{\xi_o^j}{\nu^{ji}}$$

$$A_{31}^{ji} = \frac{9\,\nu^{ji}}{7\,\xi^j}\,A_{2o}^{ji}$$

$$A_{33}^{ji} = A_{31}^{ji}$$

for $i=3$:

$$A_{oo}^{j3} = 0$$

$$A_{2o}^{j3} = 1$$

$$A_{22}^{j3} = 1 \qquad (22)$$

$$A_{11}^{j3} = 0$$

$$A_{31}^{j3} = 5/\sqrt{7}$$

$$A_{33}^{j3} = -3/\sqrt{7}$$

a_i^{jk} and b_i^{jk} in (19) are the integration constants which have to be determined for each i and j by satisfying the following boundary conditions: finite flux everywhere in the cell, continuity of all the flux moments at interfaces between cell zones and zero neutron flux gradient and zero integral current at outer cell boundary.

In order to determine F_{part} each zone of the cell where $\varphi_{oo}(r)$ exists is substituted by a number of subzones and $\varphi_{oo}(r)$ is approximated by a piecewise constant function /3/

$$\varphi_{oo,i}^{j}(r) = S_{oo,i}^{j} + \sum_{l=1}^{j-1} \overline{\varphi}_{oo,i,z}^{l} \Sigma_o^{j-l} + \sum_{l=j+1}^{J} \overline{\varphi}_{oo,i-1,z}^{l} \Sigma_o^{j-l}$$

$$\text{for } r_{z-1} \leq r \leq r_z \qquad \ldots\ldots \qquad (23)$$

$\overline{\varphi}^{j}_{oo,i,z}$ being the average value of $\varphi_{oo,i,z}(r)$ in a subzone z with the outer radius r_z. Now it follows from (13) that $F^{j}_{i,part}$ has only the first component

$$\varphi^{j}_{oo,i,part} = \frac{1}{\Sigma^{j}_{o}} \left[S^{j}_{oo,i} + \sum_{l=1}^{j-1} \overline{\varphi}^{l}_{oo,i,z} \, \tau^{j-l}_{o} + \right.$$

$$\left. + \sum_{l=j+1}^{J} \overline{\varphi}_{oo,i-1,z} \, \tau^{j-l}_{o} \right] \qquad (24)$$

$$\text{for} \quad r_{z-1} \leq r \leq r_z$$

To provide that flux moments are continuous everywhere in the cell the integration constants a and b in (19) are allowed to have different values in each moderator subzone. These values are determined by stating the continuity conditions at interfaces between the subzones. Except for the central cell zone, where coefficients b in (19) must be identically equal zero, there are six unknown integration constants for each subzone of moderating zones and each zone where $\Sigma_{oo} = 0$. If z is the total number of zones and subzones in the cell, there are 6Z-3 integration constants to be determined by solving a system of 6Z-3 algebraic equations. These are 6(Z-1) equations stating the continuity of all the flux moments at interfaces between zones and subzones

$$F^{j}_{i,hom,z}(r_z) - F^{j}_{i,hom,z+1}(r_z) = - F^{j}_{i,part,z} + F^{j}_{i,part,z+1} \qquad (25)$$

$$z = 1,2,\ldots,Z-1$$

and three equations stating the zero flux gradient /6/ and zero integral current at outer boundary of a cell:

$$\frac{d}{dr} \varphi^{j}_{oo,i,Z}(r_Z) = 0$$

$$\varphi^{j}_{11,i,Z}(r_Z) = 0 \qquad (26)$$

$$\varphi^{j}_{31,i,Z}(r_Z) + \varphi^{j}_{33,i,Z}(r_Z) = 0$$

The system of equations (25) and (26), together with (17), (19) to (22) and (24), determines the space distribution of spherical harmonics flux moments at the energy group or point j in iteration cycle i for a cell with given geometry and given group, i.e. point input parameters. Consequently, the system (25), (26) has to be formed and solved J times I times, I being the number of iterations necessary to achieve the prescribed accuracy of reaction rates and thermal utilisation factor calculation.

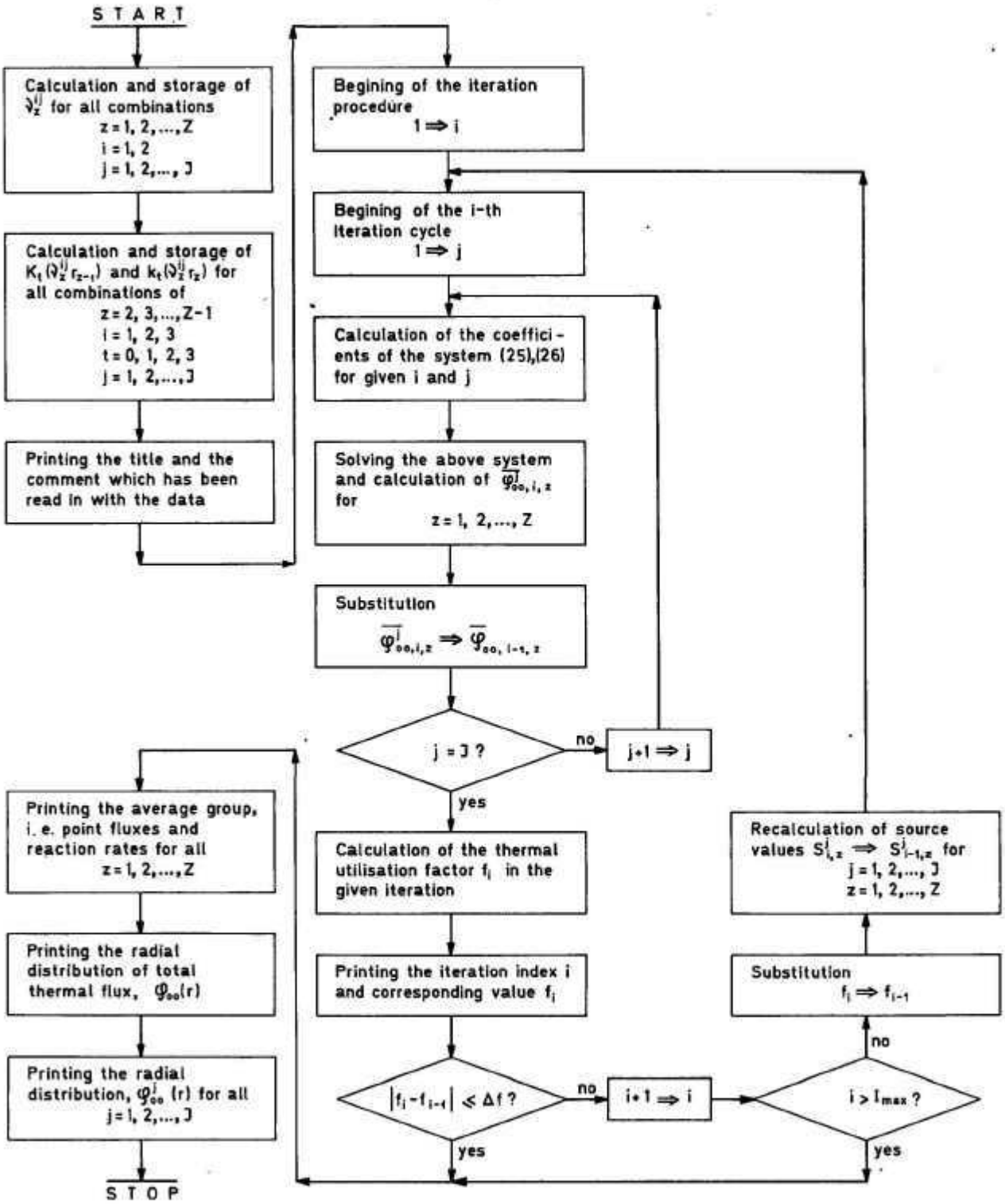
3. DESCRIPTION OF THE PROGRAMME

According to the algorithm described in the previous chapter a programme MULTI has been written for a digital computer ZUSE Z 23 in the internal language Freiburg code. The flow diagram shows the organization of the programme.

Programme MULTI supposes that the division of moderating cell zones into subzones has been performed in advance and the guess fluxes $\varphi^{j}_{oo,o,z}$ determined and read in together with the other group or point imput parameters Σ^{j}, $\Sigma^{j\leftarrow\ell}$ and S^{j}. The calculation begins with evaluation and storage of the quantities ν^{jk}_{z}, $K_t(\nu^{jk}_{z} r_{z-1})$ and $K^{jk}_{t}(\nu^{jk}_{z} r_{z})$ for all combinations of indices j, k, z and t ($j=1,2,\ldots,J$; $k=1,2,3$; $z=1,2,\ldots,Z$; $t=0,1,2,3$). In this way the repetition of these calculations during the iteration process has been avoided. The very limited storage capacity of ZUSE computer made it impossible to calculate in advance and memorize the other quantities that do not change in the iterations, as for example $A^{jk}_{st,z}$ and $I_t(\nu^{jk}_{z} r_{z})$.

The iteration process starts by stating $i = 1$. Each iteration cycle i begins by stating $j = 1$. For given i and j programme calculates the matrix of coefficients of the system (25), (26) according to (19) - (22). The right-hand side of the system is calculated according to (24) and (25). The differences between the coefficients in different columns of the system (25), (26) can be very large ($I_t(\nu r)$ and $K_t(\nu r)$ for large ν or r), what can cause considerable inaccuraces in determining the solutions. However, as the order of magnitude of the coefficients in each particular column does not vary very much, the above mentioned

FLOW DIAGRAM OF THE PROGRAMME MULTI



difficulty has been successfully avoided by normalizing the unknowns so that the difference in the order of magnitude of the coefficients in different columns is reduced to the minimum. After the system has been solved, the solutions are renormalized and than used to calculate $\overline{\varphi}^{j}_{oo,i,z}$ for all cell zones $(z=1,2,\ldots,Z)$. These values are then stored instead of the corresponding values $\overline{\varphi}^{j}_{oo,i-1,z}$ known from the previous iteration. An iteration cycle is completed after the above calculation has been repeated for all energy groups, i.e. points $(j=1,2,\ldots,J)$.

Now the programme calculates the thermal utilisation factor and compares it with the value from the previous iteration. If the difference is not less than the given number Δf, the iteration process is continued. The new values of the neutron source, $S^{j}_{i+1,z}$, are calculated so that the sum over all j and z equals the total absorption in the cell calculated with the latest flux values, $\varphi^{j}_{oo,i,z}$. The iteration index i is then increased by one and a new iteration cycle is started. This is repeated until the difference between thermal utilisation factors calculated in two successive iterations becomes less than the given number Δf. When this condition is fulfilled the iteration process is finished. The programme then calculates and prints out the average group, i.e. point fluxes and the reaction rates for all the cell zones. After that follows the space distribution of total thermal flux, $\varphi_{oo}(r)$ and the space distribution of all the group or point fluxes $\varphi^{j}_{oo}(r)$. The detailes of the programme can be seen from the statements list.

List of statements T A P E I

```
UK10850U

(TEXTA) ;


                                P 3 M U L T I

       ;0

(TEXTB) ;
         ITERATION     ;0

(TEXTC) ;
         GROUP         ;0

(TEXTD) ;

                          SPACE DISTRIBUTION OF NEUTRON FLUX

    RADIUS                    FLUX                    RADIUS                    FLUX

;0

(TEXTE) ;

                       VOLUME AVERAGED FLUXES AND ABSORBTION RATES

      GROUP          ZONE NUMBER            MEAN FLUX        RELATIVE MEAN FLUX     ABSORBTION RATE

;0

(TEXTH) ;
         THERMAL UTILIZATION FACTOR   F = ;0

(TEXTI) ;

                     SPACE DISTRIBUTION OF TOTAL THERMAL NEUTRON FLUX

     RADIUS                    FLUX                    RADIUS                    FLUX

;0
(J)     0
(N)     0
(R)     0
(Z1)    CKA19+10E A(F001) A(KJI1) 0       0          (Z2)    CKA19+10E A(F002) A(KJI2) A(KIB2) A(KOB2)
(Z3)    CKA19+10E A(F003) A(KJI3) A(KIB3) A(KOB3)    (Z4)    CKA19+10E A(F004) A(KJI4) A(KIB4) A(KOB4)
(Z5)    CKA19+10E A(F005) A(KJI5) A(KIB5) A(KOB5)    (Z6)    CKA19+10E A(F006) A(KJI6) A(KIB6) A(KOB6)
KZ7)    CKA19+10E A(F007) A(KJI7) A(KIB7) A(KOB7)    (Z8)    CKA19+10E A(F008) A(KJI8) A(KIB8) A(KOB8)
(Z9)    CKA19+10E A(F009) A(KJI9) A(KIB9) A(KOB9)    (TEXT)  ; ;0 CKA19+50E
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       -1,8892 -11,3389
(F)     1 1
(C)     1
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```
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GRV5+0 U20 GBV5+1 U21 GBV5+2 U22 GBV5+3 UK184A26 B5 CA4 UK101A26
B21 A22 U24 CS1 U25 CB(EMPTY) A21 U19
NS21 U26 BK179A26 A19 UK32A26 B20 AK180A26 UK29A26 B25 U13 0
B25 U13 0 CKA26+1 PEV26+41A26 BK32A26 A24 UK32A26 BK29A26 A24
EV26A26
BK181A26 U18 BK182A26 U23 CKB13+15 BKV64+132A26
CKB26+0 B24 NU3 PQRVYA27-41 B3 AK180A26 A19 UK61A26 B3 AK179A26
A19 UK69A26 B25 U13 0 CKB27+0 CKB13+29 BKV32+182A26 B80 E42
B25 U13 0 CKB13+30 BKV32+140A26 E32
CKA26+1 B26 S21 QQEV48A26
BK183A26 A19 UK91A26 BK184A26 CS1 U28 CKB27+0 CKB26+0 GB26+(EMPTY)
NU3 PQRVYA25-41 B3 A21 A27 0 CGU28+1 CKA26+1 B26 S21 QQEV85A26
CKA27+1 B27 S22 QQEV84A26 0
CKA27+1 B27 S21 PPE48 GKB27+80 U6 CI255 US16 PPE32 B6 U29 CI255
U16 B27 U28 E32
B26 GU28+(EMPTY) CKB27+0 GKB27+80 U6 B29 PPQQZV0A26 : GKU27+80 CKA27+1
B27 S24 QQE51 EV67A26
B27 S28 PPQQE74 GKB27+80 PPQQE75 M B31 X GKB27+160 + GKU27+160
CKA27+1 B27 S24 QQE64 E55
CKB30+0 B30 S26 PPQQE58 B30 NU3 PQRVYA25-41 B3 A18 A19 U49 B3
A23 A19 U57 B25 U13 0 CKB27+0 GKB28+160 U31 PPQQE58 E64
B25 U13 0 CKA30+1 B30 S21 QQE33 EV73A26 UV80+0
BVB0+0 BV160+0 UV160+0 GB4+0 0

CKI19+8191E U255E
(JN X )  LHCKNS2+1 CKB13+1 BVK19+14V EV19V
(YN X )  LYCKNS2+1 CKB13+1 BVK19+12V EV15V
(IN X )  LHCKNA2+1 EV13V 0,577215665 3,14159265
(KN X )  LYCKNA2+1 CKB13+1 BVK19+6V EV7V
0,499137931 12,25 0,464224130 12,25 0,349137930 5,71077955
RUK5+283V PPQQCA1 CS1 U34 NS6 U35 CKI3+1 U36 B34 U6 QM B34 X U37
B1 RA1 RCA129 U38 U39 U40 CKB41+0
B36 U3 YPEV37+26V NS35 CS5 QEV37+12V PPEV11V
B38 CA1 U6 B34 - PPEV16V B38 + PPEV289V EV167V
CA3 FV1020 B19 X X B20 + B37 QFV37+454 PFV37+451 QQEV156V PEV35+14V
CKA41+1 B41 FV1020 U3 B34 U6 B3 : B39 X U39 CKA35+1 QEV35+12R
B36 U3 YEV9V
B34 FV(LN X ) BK180A26 + CA1 NU32 LYCKB33+0 NS41
YB41 NU34 YB38 U30 B34 CKA3+1 PPQQYEV28V
CKA35+1 CKA34+1 B36 U3 YEV28V B35 FV1020 :1 B33 + U33.
B34 QQEV12R PPQQEV6V FV1020 :1 B33 + U33
B32 U6 B33 - U18
B34 PPQQEV25V NU3 PQRVYA36-41 B3 FV1020 U3 B37 U6 B3 : B40 X U40
B36 U3 YEV3V B18 X
CKI30+255 U3 CKI6+255 PPQQEV8V S3 CA30 QQEV5V
B30 + U30 EV53R
B30 U6 B39 X U30
B36 U3 B6 YEV60V
B37 U2 M U37 B41 CA1 U3 B30 U6 PYM U30 B41 PPQQEV41V
CKB32+0 FV1020 B39 X U39 B38 U34 CKB33+0
CKA33+1 B41 S33 PPQQEV17V
NU3 PQRVYA34-41 B3 FV1020 U3 B37 U6 B3 : B34 X U34 B32 + U32 EV19R
B32 U6 B38 + B39 : B37 U2 B6 PM B38 + B37 U2 PBK11A26 QCKA30+1 QB30 : E0
```

```
CKA34+1 NS35 U42 QEV37+14V
BK6+11A26 B34 : CS1 W U33 B34 M FV(EXP X) B33 X U33 EV36V
BK6+11A26 B34 X :1 CA1 W U33
NS35 LCA1 FV1020 BK11A26 X CS2 U2 B34 U6 B2 - U43 FV(SIN X) CKI36+1 CUS0 U2 B6 QM QU44 PU45
B43 FV(COS X) CKI36+1 CUS0 U2 B6 QU45 PU44 CKA34+3 CKB18+0
CKA18+1 NS18 LCA1 U3 NS35 LA3 LVU11 RS3 NU3 PQRVYA12-41 B3 U17 B18 FV1020 B34 X U11 B17 FV1020 B11 :
CKS42+1 PEV42+4V CKI6+255 CS129 PPEV27V B40 X B37 U2 QB18 QCA1 QU3 B6 QYM U40 QCKS3+1 QYEV6V
B39 + U39 QEV37+41R EV4V B41 + U41
CKI6+255 U3 CKI40+255 S3 CA30 PPEV51R
B39 U6 PEV37+10V B45 X U18 B41 U6 B44 X B18 + B33 X EV225A26
B34 M U34 CA1 FV(EXP X) CS1 U33 B38 CS2 FV(EXP X) U42 B38 U6 B35 PPQQEV10V EV3V
B35 PPQQEV5V B42 X CKA35+1 EV5R B6 U35
B42 U6 B38 X U38 :1 B38 + B34 X FV(EXP X) U18
B35 PPQQEV11V U6 B39 X U39 :1 B39 + CKS6+1 B18 X
CKI33+255 U3 CKI6+255 S3 CA30 QQEV5V
B33 + U33 EV33R
B33 PPQQCA2 CS2 U6 EV225A26

(EXP X)
CKI19+8191E
U2 CKB13+16 BVK16+43A26 CKI2+255 CUS128 PPEV38A26 U11 CA7 PPQQEV77A26 PQQNEV1009 QQQNEV75A26
CKIS2+256 RVA0 RCKB2+9 U6 PPQQEV29A26 NE19
LVA23 U6 CKB13+16 BVK16+60A26 B11 U2 CKB11+1 B6 E16
68719476736' 34359738368' 11453246123'
B1 RA1 RCA129 EV75A26
CKB13+3 BVK23+26A26 CKB2+2 CKS18+16 E19
U13 CKB11+0 CKIS2+256 PQPPQQRA0 EV12A26
YS6 LVCKS2+1 QEV33A26 LVGKA2+23 NU3 PQRVYA7-38 RVE16
2863311531' 572662306' 95443718' 13634817' 1704352' 189372' 18937' 1722' 143' 11'
CKB13+0 PQPPQQRVA0 RVB11 LCA218 S13 NU11 PE28 RVCKA2+1 B3 NU6 PQRVYA7-38 RVE16
CKIS3+512 RA11 CA128 U6 E5 CKIS2+256 PNS4 AKP1A26 EV9A26 18984232243 2'

(LN X )
CKI19+8191E
U11 PPQQNVE1009 QQNVE1009 CKB13+16 BKV16+11A26
B32 U6 CKI11+255 CS129 CKB2+0 E28
YS6 LVCKS2+1 QVE28A26 LVGKA2+23 NU3 PQRVYA7-7 RVE16
68719238988' -343510882 21' 2280105543 4' -1654310134 5' 1152110003 8' -655898577 7' 247998240 3' -44348418 8'
PPP28+128 198532846284'
U2 QNS4 PQPPQQRVA0 RVB11 RIS31 RVU6 B3 QNS4 U32
CKS21+31 CKA18+19 CKB2+7 NS6 QQNE19 NS13 QQCA352 U11 CKIS32+256 VE64A26
U6 NS13 QQCA224 U13 U11 B6 LVCKA11+346 LVA0 PQPPQQRA0 LVA32 U2 QNS4 PQPPQQRVA0
RVA0 CKIS3+512 QNS4 RS13 A11 U6 E5

(SIN X)
CKI19+8191E VE23A26

(COS X)
HEV24A26
YS6 LVCKS2+1 LVGKA2+27 QVE19A26 NU3 PQRVYA7-38 RVE16
PQLVAPPHS26-28 VE46A26
1H7944381448' 68719476736' -11453246123' 572662306' -13634817' 189372' -1723' 12'
U6 CKA19+62 CKB2+5 NE18
LVCKB11+0 YLVCKB11+1 RCKB13+16 U2 BKV16+2A26 CKB3+0 CKI2+255 CS129 QQVE40A26 CUS27 QQZ5 A23 U23
CKIS2+256 QNS4 RS25 E23
CUS1 U13 CKIS2+256 QNS4 PQPPQQRA0 EV48A26
A25 RA0 PVE53A26 CKUS3+0 PPQQVE53A26 CKS3+1 US25 U6
B3 A11 U3 U23 B6 YUS25 RVB4 YNS4 U11 U6 PPQQVE5 CKNS2+1 CKB25+0 E28
U2 QQNS4 CKB13+0 CKB3+0 PQPPQQRVA0 RVNS13 CA348 U6 CKIS3+512 QNS4 RA6 U6 E5
U6 CKS19+13 B11 E29
```

```
(START) CK114+16 NS4 UK1020 CB7 UK1030 UK1032 CB0 UK1031 CB12 UK1035 UK1036

(N1)    NSK100+(N) CKB101+(Z1) CKB99+1 CKB98+0 CKB97+0
        GBV101+1 U102
        GBV101+2 U103
        GBV101+3 U109
        GBV101+5 C1R191 U104
        GBV101+6 C1R191 U131
        GBV101+7 C1R191 U105
        GBV101+8 C1R191 U132
        GBV101+10 C1R191 U130
        GBV101+11 C1R191 CS1 U106
        GBV101+12 C1R191 CS1 U107
        GBV101+13 C1R191 CS1 U108
        B102 U6 X U20 B103 U6 X B20 - U133
(J1)    NSK110+(J) CKB111+0
        B104 A111 CGB4+0 U112
        B105 A111 CGB4+0 U113
        B112 U6 B113 X U20
        B113 U6 X U21
        B20 X BK2(NR) X U22
        B21 BK6+1(NR) X U21
        B20 BK6+(NR) X B21 + U20
        X B22 - W U21
        B20 + W U22 CGU106+1
        B102 X U114
        B20 U6 B21 - W U23 CGU106+1
        B102 X U115
        BK6+3(NR) B113 X U24
        B102 X U116
        B22 U6 B103 X U117
        B23 U6 B103 X U118
        B24 U6 B103 X U119

        B102 PPQQEV53V
        CKNS120+3 CKB121+114 CKB122+117 CKB123+1
        CKNS124+4 CKB125+10(NR)
        GBV125+0 U6 KGB121+0 FV(KN X ) PEV123+2V M CGU107+1
        BK(N) S99 PPQQEV8V
        GBV125+0 U6 KGB122+0 FV(KN X ) PEV123+2V M CGU108+1
        NS123 U123 CKA124+1 CKA125+1 QEV124+21R
        CKA120+1 CKA121+1 CKA122+1 QEV120+27R
        BK(N) S99 PPQQEV2V EV17V
        CKNS120+3 CKB122+117
        CKNS124+2 CKB125+11(NR)
        GBV125+0 U6 KGB122+0 FV(KN X ) M CGU108+1
        CKA124+1 CKA125+2 QEV124+8R
        CKA120+1 CKA122+1 QEV120+13R

        B130 A111 U20 CGB4+0 U6 B109 X GU20+0
        B131 A111 CGB4+0 U6 GB20+0 X B133 X B98 + U98
        B132 A111 CGB4+0 U6 B133 X B97 + U97

        CKA110+1 CKA111+1 QEV110+2(J1)
        CKA99+1 CKA100+1 CKA101+14 QEV100+5(N1)
        B97 U6 B98 : UK(C)

        BK(TEXTA) HD2 BK(TEXT) HD2
```

```
        CKB230+0 CKB6+6 BK(N) X' CS2 U231 CKB6+2 X' U232 CKB6+3 X' U233
(IT)    CKB234+1 CKB235+0 CKB236+0 CKB237+(END) CKB238+0 CKB242+0 CKB243+0
        BK(TEXTB) HD2 B234 D2
        NSK200+(N) CKB201+(Z1)
        GBV201+10 CIR191 CS1 U202 NSK203+(J)
        CGB202+1 U6 BK(C) X GU202+0 CKA203+1 QEV203+6R
        CKA201+14 CKA200+1 QEV200+14R

(J2)    NSK240+(J) CKB241+0
        B231 CS1 U6 B231 X' U13 CB0 UV(SYSTM)
(N2)    NSK200+(N) CKB201+(Z1) CKB202+0 CKB203+(NORM) CKS203+1
        GBV201+1 U110
        GBV201+2 U111
        GBV201+5 CIR191 A241 CGB4+0 U112
        GBV201+7 CIR191 A241 CGB4+0 U113
        GBV201+11 CIR191 A241 A241 U6 CGB4+0 U114
        CGB6+1 U115
        BK6+3(NR) B113 X U116
(ACALC) CKB120+114 CKB121+130 CKNS122+2
        KGB120+0 U6 X U20 BK6+5(NR) B113 X B113 X B20 - U21
        BK6+4(NR) B112 X B113 X B20 - B21 : BK6(NR) : U20
        BK9(NR) KGU121+0
        B20 M KGU121+1
        BK7(NR) X M KGU121+2
        B112 U6 KGB120+0 : M KGU121+3
        BK6+8(NR) KGB120+0 X B20 X B113 : KGU121+4
        BK4(NR) X M KGU121+5
        CKA120+1 CKA121+6 CKA122+1 QEV122+3(ACALC)
        CKB142+0
        BK9(NR) U143
        U144
        CKB145+0
        BK15(NR) U146
        BK16(NR) U147
(SCALC) GBV201+0 CIR191 A241 CGB4+0 U148
        GBV201+0 PPQQEV2V EV24V
        NSK120+(J)
        GBV201+10 CIR191 CS1 U121
        GBV201+9 CIR191 U20 BK6+(J) B241 X' A20 CS1 U122
        CGB121+1 U6 CGB122+1 X B148 + U148
        CKA120+1 QEV120+8R
        B148 U6 B112 : M U148

        B202 PPQQEV(CENTR) BK(N) S202 CS1 PPQQEV(OUTER) EV(INTER)

(CENTR) B231 CS1 U20 B148 GU20+(SYSTM)
        CKB120+113 CKB121+129 CKNS122+3 CKB123+0
        CKGB120+1 U6 B111 X U124
        CKB6+0 B124 FV(IN X ) U150 U151
        CK16+255 CS12R CGU203+1 U125
        CKB6+2 B124 FV(IN X ) U152
        CKB6+1 B124 FV(IN X ) U153 U154
        CKB6+3 B124 FV(IN X ) U155
        CKB126+149 CKNS127+6
        CKGB126+1 U6 CKGB121+1 X PPQQEV2V S125 GU123+(SYSTM)
        B123 A231 U123 CKA127+1 QEV127+11R
        B123 S233 CA1 U123 CKA122+1 QEV122+9(CENTR)
        EV(READY)
```

```
(INTER) B202 CS1 U6 B233 X' U20 A231 CS1 U21 A233 U22
        B148 GU22+(SYSTM) M GB21+(SYSTM) + GU21+(SYSTM)
        CKB120+113 CKB121+129 CKNS122+3 B202 CKB6+6 X' CS3 A20 U123 A233 U124
        CKGB120+1 U6 B110 X U125
        CKGB120+0 U6 B111 X U126
        CKB6+0 B125 FV(IN X ) U150 U151
        CK16+255 CS128 CGU203+1 U128
        CKB6+2 B125 FV(IN X ) U152
        CKB6+1 B125 FV(IN X ) U153 U154
        CKB6+3 B125 FV(IN X ) U155
        GBV201+12 C18191 U20 CKB6+12 B241 X' A20 U20 B122 CA3 CKB6+4 X' A20 U20
        GB20+0 U6 U160 U161 CK16+255 CS128 GU203+3 U129 GB20+2 U162 GB20+1 U163 U164 GB20+3 U165
        CKB6+0 B126 FV(IN X ) U170 U171
        CKB6+2 B126 FV(IN X ) U172
        CKB6+1 B126 FV(IN X ) U173 U174
        CKB6+3 B126 FV(IN X ) U175
        GBV201+13 C18191 U20 CKB6+12 B241 X' A20 U20 B122 CA3 CKB6+4 X' A20 U20
        GB20+0 U180 U181 GB20+2 U182 GB20+1 U183 U184 GB20+3 U185
        CKB119+149 CKNS118+6
        CKGB121+1 U127
        CKGB119+1 U6 B127 X PPQQEV2V S120 M GU123+(SYSTM)
        KGB119+10 U6 B127 X PPQQEV2V S129 M GU123+3(SYSTM)
        KGB119+20 U6 B127 X PPQQEV2V S120 GU124+(SYSTM)
        KGB119+30 U6 B127 X PPQQEV2V S129 GU124+3(SYSTM)
        B123 A231 U123 B124 A231 U124 CKA118+1 QEV118+39R
        B123 S233 CA1 U123 B124 S233 CA1 U124 CKA122+1 QEV122+28(INTER)
        CKA203+3 EV(READY)

(OUTER) B202 CS1 U6 B233 X' U20 A231 CS1 U21 B148 M GB21+(SYSTM) + GU21+(SYSTM)
        CKB120+113 CKB121+129 CKB117+133 CKNS122+3 B202 CKB6+6 X' CS3 A20 U123 A233 U124
        CKGB120+1 U6 B110 X U125
        CKGB120+0 U6 B111 X U126
        CKB6+0 B125 FV(IN X ) U150 U151
        CK16+255 CS128 CGU203+1 U128
        CKB6+2 B125 FV(IN X ) U152
        CKB6+1 B125 FV(IN X ) U153 U154
        CKB6+3 B125 FV(IN X ) U155
        GBV201+12 C18191 U20 CKB6+12 B241 X' A20 U20 B122 CA3 CKB6+4 X' A20 U20
        GB20+0 U6 U160 U161 CK16+255 CS128 GU203+3 U129 GB20+2 U162 GB20+1 U163 U164 GB20+3 U165
        CKB6+1 B126 FV(IN X ) U171
        CKB6+3 B126 FV(IN X ) U173
        GBV201+13 C18191 U20 CKB6+12 B241 X' A20 U20 B122 CA3 CKB6+2 X' A20 U20
        GB20+0 U181 GB20+1 U183
        CKB119+149 CKNS118+6
        CKGB121+1 U127
        CKGB119+1 U6 B127 X PPQQEV2V S128 M GU123+(SYSTM)
        KGB119+10 U6 B127 X PPQQEV2V S129 M GU123+3(SYSTM)
        B123 A231 U123 CKA118+1 QEV118+22R
        B171 U6 KGB120+0 X PPQQEV2V S128 GU124+(SYSTM)
        B181 U6 KGB120+0 X PPQQEV2V S129 GU124+3(SYSTM)
        B124 A231 U124
        B171 U6 KGB117+0 X PPQQEV2V S128 GU124+(SYSTM)
        B181 U6 KGB117+0 X PPQQEV2V S129 GU124+3(SYSTM)
        B124 A231 U124
        B171 U6 KGB117+1 X U20 B173 U6 KGB117+2 X B20 + PPQQE2V S128 GU124+(SYSTM)
        B181 U6 KGB117+1 X U20 B183 U6 KGB117+2 X B20 + PPQQEV2 S129 GU124+3(SYSTM)
        B123 S233 CA1 U123 B124 S232 CA1 U124 CKA117+6 CKA122+1 QEV122+26(OUTER)
```

```
(READY) CKA200+1 CKA201+14 CKA202+1 QEV200+5(N2)
        FV(SOLVE)
        NS231 CA1 U20 CKB21+0
        GB21+(SOLUT) PPQQEV2V GS21+(NORM) GU21+(SOLUT)
        CKA20+1 CKA21+1 QEV20+6R

(N3)    NSK200+(N) CKB201+(Z1) CKB202+0 CKB203+(SOLUT) CKNS206+1
        GBV201+1 U110
        GBV201+2 U111
        GBV201+4 U112
        GBV201+5 C1B191 A241 CGB4+0 U117
        GBV201+6 C1B191 A241 CGB4+0 U118
        GBV201+8 C1B191 A241 CGB4+0 U119 U113
        GBV201+10 C1B191 A241 U116
        GBV201+11 C1B191 A241 A241 U6 CGB4+0 U114
        CGB6+1 U115
        GBV201+0 PPQQEV2V EV24V
        GBV201+13 C1B191 CS1 U121
        GBV201+9 C1B191 U20 BK6+(J) B241 X' A20 CS1 U122
        NSK120+(J)
        CGB121+1 U6 CGB122+1 X B113 + U113
        CKA120+1 QEV120+8R
        B113 U6 B117 : U113
        B202 PPQQEV2V EV27V
        B111 U6 B114 X CKB6+1 FV(IN X ) GB203+0 X B114 : U120
        B111 U6 B115 X CKB6+1 FV(IN X ) GB203+1 X B115 : B120 + B111 : EV102V
        B110 U6 X U20 B111 U6 X B20 - U130
        B114 U6 B110 X U120 CKB6+1 FV(KN X ) B110 X U121
        B114 U6 B111 X U122 CKB6+1 FV(KN X ) B111 X B121 - GB203+3 X U123
        B120 CKB6+1 FV(IN X ) B110 X U121
        B122 CKB6+1 FV(IN X ) B111 X B121 - GB203+0 X B123 - B114 : U124
        B115 U6 B110 X U120 CKB6+1 FV(KN X ) B110 X U121
        B115 U6 B111 X U122 CKB6+1 FV(KN X ) B111 X B121 - GB203+4 X U123
        B120 CKB6+1 FV(IN X ) B110 X U121
        B122 CKB6+1 FV(IN X ) B111 X B121 - GB203+1 X B123 - B115 : B124 + B130 :
        PPQQCS1 CA1 U6 B113 + GU116+0

(FLUX)  B230 PPQQEV76V PEV206+14V
        BK(TEXTC) HD2 B241 CA1 D2
        BK(TEXTD) HD2 FV1002
        CB4 UK1033 CB12 UK1034 CKB239+100(END)
        B241 PPQQEV2V EV4V CKS230+1 B110 CGUV237+1
        B110 D2 B114 X U120 CKB6+0 FV(IN X ) GB203+0 X B113 + U130
        B110 U6 B115 X U121 CKB6+0 FV(IN X ) GB203+1 X B130 + U130
        B202 PPQQEV17V
        B120 CKB6+0 FV(KN X ) GB203+3 X B130 + U130
        B121 CKB6+0 FV(KN X ) GB203+4 X B130 + U130
        B130 D2 CGBV239+1 + CGUV239+0
        B110 U6 B112 + U110 B111 - QEV60R

        CKA200+1 CKA201+14 CKA203+3 B202 PPQQEV2V CKA203+3 CKA202+1 CKA206+1 QEV200+5(N3)
        B230 PPQQEV4V CNS20 FV852 FV1002
        CKA240+1 CKA241+1 QEV240+2(J2)
        B230 PPQQEV17V
        BK(TEXTI) HD2 CKB237+1
        GBV237+(END) D2 GBV237+100(END) U6 BK101(END) : D2
        CKA237+1 CKA230+1 QEV230+0R
        CNS20 FV852 FV1002
```

```
(MEAN)  CKI14+1 PPQQEV3V B230 PPQQEV(EFCE)
        BK(TEXTE) HD2 FV1002
        CB5 UK1033 CB9 UK1034 CBB UK1035

(J3)    NSK240+(J) CKB241+0
        B241 CA1 HD2

(N4)    NSK200+(N) CKB201+(Z1) CKB202+1 CKB203+40
        GBV201+6 CIB191 A241 CGB4+3 U20 GBV201+1 U6 X U21 GBV201+2 U6 X B21 - B20 X U20
        GBV201+10 CIB191 A241 CGB4+3 U21 B241 PPQQEV2V EV3V B21 CKGU203+0
        B202 HD2 CNS5 FV842
        B21 D2
        CKGB203+0 : D2
        B21 U6 B20 X D2 HFV802
        CKA200+1 CKA201+14 CKA202+1 CKA203+1 QEV200+4(N4) FV1002
        CKA240+1 CKA241+1 QEV240+2(J3) CNS20 FV852

(EFCE)  NSK240+(J) CKB241+0 NSK200+(N) CKB201+(Z1)
        GBV201+6 CIB191 A241 CGB4+3 U20
        GBV201+1 U6 X U21 GBV201+2 U6 X B21 - U21
        GBV201+8 CIB191 A241 CGB4+3 U6 B21 X B236 + U236
        GBV201+10 CIB191 A241 CGB4+0 U6 B20 X B21 X U20 B235 + U235
        GBV201+0 PPEV6V B20 U6 B243 + U243
        CKA200+1 CKA201+14 QEV200+4(EFCE)
        CKA240+1 CKA241+1 QEV240+2(EFCE)
        BK(C) U20 B236 U6 B235 : UK(C) CKA234+1
        BK(F) UK1(F)
        BK(TEXTH) HD2 B243 U6 B235 : D2 UK(F) FV1002
        B230 CS1 PPQQEV(END)
        B234 SK(IMAX) PPQQEV(LAST)
        BK6+(F) BK1(F) - QQM BK(DELTF) - QQEV(LAST)
        EV1(IT)

(LAST)  CKA230+1 EV1(IT)

(END)   ZV0


U1050U

(KJI1)  CKA19+30E   (KJI2)  CKA19+30E   (KJI3)  CKA19+30E   (KJI4)  CKA19+30E
(KJI5)  CKA19+30E   (KJI6)  CKA19+30E   (KJI7)  CKA19+30E   (KJI8)  CKA19+30E
(KJI9)  CKA19+30E

(KIB2)  CKA19+180E  (KIB3)  CKA19+180E  (KIB4)  CKA19+180E  (KIB5)  CKA19+180E
(KIB6)  CKA19+180E  (KIB7)  CKA19+180E  (KIB8)  CKA19+180E  (KIB9)  CKA19+180E

(KOB2)  CKA19+180E  (KOB3)  CKA19+180E  (KOB4)  CKA19+180E  (KOB5)  CKA19+180E
(KOB6)  CKA19+180E  (KOB7)  CKA19+180E  (KOB8)  CKA19+180E  (KOB9)  CKA19+90E

(NORM)  CKA19+60E
(SOLUT) CKA19+60E

ZV0+1E


(EMPTY) CKA19+200E
(SYSTM) 0

ZV0+1E
```

4. INSTRUCTIONS FOR THE USER

Programme MULTI requires the knowledge of the group or point values of cross sections Σ_o^j, Σ_a^j and Σ^j, scattering matrix $\Sigma^{j \leftarrow \ell}$ and source of thermal neutrons S^j for all the materials of a reactor cell considered. These values have to be either calculated by a separate programme or taken from a data library. Each block of these data must be preceded by a label. The following notation is suggested: (XSO) for a block of J values of $\Sigma_o^j = \Sigma^j - \Sigma^{j \leftarrow j}$, (XSA) for a block of J values of absorption cross sections Σ_a^j, (XST) for a block of J values of the total cross section Σ^j, (XSOO) for a block of J source values S^j and (XSLJ) for a block of J^2 scattering matrix values, but with diagonal elements substituted by zeros. Here X stands instead of one or two letters denoting a material considered, for example (HSO) for H_2O, (DSO) for D_2O, (CSO) for graphite or (USO) for uranium.

The imput quantities for the programme MULTI have to be stored in the following way: the general data for the case treated to the addresses:

(J) J = number of energy groups or energy points

(N) N = number of cell zones after the moderating zones have been devided into subzones

(R) R = effective radius of a cell

and for each zone and subzone (index z) to the address

(POD_z) indicator (-1′ for fuel, 0 for moderator, 1′ for the other materials)

r_{z-1} = inner radius of zone z 1

r_z = outer radius of zone z 2

$\bar{\varphi}_z$ = average flux in zone z obtained by a monoenergetic calculation 3

Δr_z = step for calculating radial flux distribution in zone z 4

A(XSO) 5
A(XSA) 6
A(XST) 7
A(XSOO) 8
A(XSLJ) 9
A(FOOZ) 10
A(KJ1Z) 11

after intersection these statements give the addresses of the group, i.e. point parameters for the material X of a zone z; the notation provided a rational use of computer memory for the group or point imput data have to be memorised only once even for the cases when several cell zones consist of the same material.

The programme supposes that $\Delta f = 10^{-6}$ and $I_{max} = 10'$. If other values are wanted they have to be stored with addresses (DELTF) and (IMAX). A commentor title consisting of maximum 350 characters can be memorized with address (TEXT) and will be printed before any results.

The guess fluxes for a zone z, $\overline{\varphi}^{j}_{oo,o,z}$, are calculated as a product of average flux in zone z obtained by a monoenergetic calculation, $\bar{\varphi}_z$, and group or point values of guess spectrum which for each zone z have to be denoted by a label (FOO_z).

The following pages give an example of imput for a three zone U-Al-D_2O cell, 15 energy groups and moderator devided into three subzones.

```
(US00)
 0          0          0          0          0
 0          0          0          0          0
 0          0          0          0          0
(USA)
 ,958375979/-01  ,102082755/+00  ,110256662/+00  ,119854390/+00  ,131283770/+00
 ,145124976/+00  ,162232463/+00  ,183919022/+00  ,212311400/+00  ,251098918/+00
 ,307298642/+00  ,396132645/+00  ,558202119/+00  ,953748714/+00  ,878402765/+01
(UST)
 ,492026598/+00  ,499071755/+00  ,507245662/+00  ,516843390/+00  ,528272770/+00
 ,542113976/+00  ,559221463/+00  ,580908022/+00  ,609300400/+00  ,648087918/+00
 ,704287642/+00  ,793121645/+00  ,955191119/+00  ,135073771/+01  ,918101665/+01
(US0)
 ,958375979/-01  ,102082755/+00  ,110256662/+00  ,119854390/+00  ,131283770/+00
 ,145124976/+00  ,162232463/+00  ,183919022/+00  ,212311400/+00  ,251098918/+00
 ,307298642/+00  ,396132645/+00  ,558202119/+00  ,953748714/+00  ,878402765/+01

(AS00)
 0          0          0          0          0
 0          0          0          0          0
 0          0          0          0          0
(ASA)
 ,375359475/-02  ,403184955/-02  ,435468526/-02  ,473375614/-02  ,518516966/-02
 ,573184047/-02  ,640751593/-02  ,726484594/-02  ,838542824/-02  ,991737589/-02
 ,121378341/-01  ,156456123/-01  ,228466908/-01  ,376691566/-01  ,346933011/+00
(AST)
 ,880335048/-01  ,883118496/-01  ,886346853/-01  ,890137561/-01  ,894651697/-01
 ,900118485/-01  ,906875159/-01  ,915440459/-01  ,926654282/-01  ,941973759/-01
 ,964179341/-01  ,999256123/-01  ,106326691/+00  ,121949157/+00  ,431213011/+00
(AS0)
 ,375359475/-02  ,403184955/-02  ,435468526/-02  ,473375614/-02  ,518516966/-02
 ,573184047/-02  ,640751593/-02  ,726484594/-02  ,838542824/-02  ,991737589/-02
 ,121378341/-01  ,156456123/-01  ,228466908/-01  ,376691566/-01  ,346933011/+00

(DS00)
 ,969258628/+00  ,764454453/+00  ,417010455/+00  ,377745121/+00  ,337892116/+00
 ,297265278/+00  ,255590471/+00  ,212446485/+00  ,167150963/+00  ,114409817/+00
 ,680777671/-02  ,529520229/-02  ,378248429/-22  ,226930848/-02  ,748464367/-03
(DSA)
 ,373375075/-04  ,401053451/-04  ,433166351/-04  ,470873035/-04  ,515775742/-04
 ,570153816/-04  ,637364155/-04  ,722564337/-04  ,834109729/-04  ,986494637/-04
 ,120728697/-03  ,155628992/-03  ,219301374/-03  ,374700125/-03  ,345098893/-02
(DST)
 ,332449081/+00  ,353380928/+00  ,360142569/+00  ,366255065/+00  ,373673445/+00
 ,382409073/+00  ,392648797/+00  ,404480044/+00  ,418117297/+00  ,434182967/+00
 ,453777913/+00  ,484409158/+00  ,541865336/+00  ,705922713/+00  ,228200722/+01
(DS0)
 ,258885102/+00  ,266899989/+00  ,268175489/+00  ,268226598/+00  ,268646653/+00
 ,269613007/+00  ,271187296/+00  ,273461286/+00  ,276753888/+00  ,281923307/+00
 ,298422566/+00  ,310132911/+00  ,356878529/+00  ,508843041/+00  ,196364658/+01
```

(DSLJ)

0	,284347777/-01	,280048469/-02	,429895684/-03	,828272582/-04
,189883989/-04	,486662934/-05	,131025893/-05	,363802312/-06	,103779268/-06
,306345916/-07	,957685531/-08	,281032875/-08	,154236339/-08	,219348686/-08
,837177383/-01	0	,235546915/-01	,369996517/-02	,659670679/-03
,145695859/-03	,382741881/-04	,109876502/-04	,330245818/-05	,102775398/-05
,332761913/-06	,114562678/-06	,443489726/-07	,225874638/-07	,353326665/-07
,569857589/-01	,861632643/-01	0	,273871723/-01	,492654500/-02
,102825567/-02	,259910587/-03	,773344395/-04	,249184111/-04	,842256594/-05
,298895428/-05	,112703484/-05	,480878666/-06	,270634336/-06	,463478134/-06
,380959279/-01	,575254232/-01	,887926789/-01	0	,318562626/-01
,661424863/-02	,159849594/-02	,466131567/-03	,157172157/-03	,571862290/-04
,220330562/-04	,912027497/-05	,427626118/-05	,265893295/-05	,494513976/-05
,270376265/-01	,379472221/-01	,588359776/-01	,915978464/-01	0
,374111344/-01	,895784011/-02	,250009642/-02	,842266444/-03	,323221370/-03
,134482863/-03	,686633894/-04	,311670682/-04	,212070195/-04	,428568574/-04
,193193850/-01	,262485439/-01	,375759864/-01	,584362547/-01	,945301986/-01
0	,442364707/-01	,122385987/-01	,396711125/-02	,154020053/-02
,680022764/-03	,332014068/-03	,185899146/-03	,138212397/-03	,301137039/-03
,126984542/-01	,178453996/-01	,258934917/-01	,368801642/-01	,585976708/-01
,974754782/-01	0	,526664286/-01	,168829660/-01	,637311853/-02
,287649195/-02	,149669101/-02	,987773845/-03	,733157300/-03	,170858522/-02
,729865394/-02	,189677433/-01	,160993227/-01	,235521982/-01	,357369685/-01
,583293784/-01	,188228432/+00	0	,631306892/-01	,235546997/-01
,104385046/-01	,559679066/-02	,362473861/-02	,315770239/-02	,782279700/-02
,357426726/-02	,581817476/-02	,917417034/-02	,141169990/-01	,215809653/-01
,340025995/-01	,573648005/-01	,102412730/+00	0	,762218174/-01
,326997932/-01	,177259161/-01	,118849340/-01	,110086272/-01	,287641441/-01
,146331344/-02	,259856662/-02	,445113447/-02	,738221224/-02	,119445373/-01
,191571117/-01	,315203914/-01	,553558784/-01	,103516658/+00	0
,928870353/-01	,487567868/-01	,325112929/-01	,310862479/-01	,845426434/-01
,491737709/-03	,957268521/-03	,179161300/-02	,323411515/-02	,565323486/-02
,964138754/-02	,162823334/-01	,281395720/-01	,518739389/-01	,102761365/+00
0	,115129226/+00	,757584478/-01	,718487604/-01	,198592579/+00
,132682986/-03	,284107170/-03	,583294434/-03	,115154993/-02	,219205987/-02
,404463184/-02	,728439627/-02	,129900370/-01	,237424543/-01	,464237195/-01
,900403111/-01	0	,148267582/+00	,137842119/+00	,378873404/+00
,277803570/-04	,655695348/-04	,148039135/-03	,320480975/-03	,667097140/-03
,133903988/-02	,260840316/-02	,496566338/-02	,938828400/-02	,182461300/-01
,303645809/-01	,905504164/-01	0	,213256163/+00	,588063455/+00
,418817659/-05	,108964201/-04	,270513878/-04	,642070661/-04	,146058061/-03
,319893132/-03	,672021405/-03	,137732206/-02	,276153078/-02	,552716916/-02
,115816588/-01	,265826714/-01	,734368934/-01	0	,672278626/+00
,330084052/-06	,934681224/-06	,251632113/-05	,645210136/-05	,157870622/-04
,369584498/-04	,829236794/-04	,179747112/-03	,378813184/-03	,786484329/-03
,165358634/-02	,373573408/-02	,100456957/-01	,305731990/-01	0

```
(F001)
 ,143760273/-01    ,157714171/-01    ,159995490/-01    ,280981831/-01    ,269623394/-01
 ,392860452/-01    ,612192983/-01    ,918057778/-01    ,130155871/+00    ,164554733/+00
 ,172497594/+00    ,140240863/+00    ,800335605/-01    ,255390611/-01    ,145625387/-02

(F002)
 ,143760273/-01    ,157714171/-01    ,159995490/-01    ,280981831/-01    ,269623394/-01
 ,392860452/-01    ,612192983/-01    ,918057778/-01    ,130155871/+00    ,164554733/+00
 ,172497594/+00    ,140240863/+00    ,800335605/-01    ,255390611/-01    ,145625387/-02

(F003)
 ,143760273/-01    ,157714171/-01    ,159995490/-01    ,280981831/-01    ,269623394/-01
 ,392860452/-01    ,612192983/-01    ,918057778/-01    ,130155871/+00    ,164554733/+00
 ,172497594/+00    ,140240863/+00    ,800335605/-01    ,255390611/-01    ,145625387/-02

(F004)
 ,143760273/-01    ,157714171/-01    ,159995490/-01    ,280981831/-01    ,269623394/-01
 ,392860452/-01    ,612192983/-01    ,918057778/-01    ,130155871/+00    ,164554733/+00
 ,172497594/+00    ,140240863/+00    ,800335605/-01    ,255390611/-01    ,145625387/-02

(F005)
 ,143760273/-01    ,157714171/-01    ,159995490/-01    ,280981831/-01    ,269623394/-01
 ,392860452/-01    ,612192983/-01    ,918057778/-01    ,130155871/+00    ,164554733/+00
 ,172497594/+00    ,140240863/+00    ,800335605/-01    ,255390611/-01    ,145625387/-02
```

T A P E III

```
UK(TEXT)U ;

                    U - AL - D2O  CELL

                    FUEL RADIUS                    1.25 CM
                    CLADDING THICKNESS             0.10 CM
                    CELL RADIUS                    4.51 CM
                    MODERATOR DEVIDED IN THREE SUBZONES
                    NUMBER OF ENERGY GROUPS        15

;0
UK(J)U    15'
UK(N)U    5'
UK(R)U    4,51
UK(Z1)U   -1'   0      1,25   1,199   0,05   A(US0)   A(USA)   A(UST)   A(US00)   A(USLJ)
UK(Z2)U   1'    1,25   1,35   1,427   0,05   A(AS0)   A(ASA)   A(AST)   A(AS00)   A(ASLJ)
UK(Z3)U   0     1,35   1,72   1,534   0,10   A(DS0)   A(DSA)   A(DST)   A(DS00)   A(DSLJ)
UK(Z4)U   0     1,72   2,43   1,735   0,10   A(DS0)   A(DSA)   A(DST)   A(DS00)   A(DSLJ)
UK(Z5)U   0     2,43   4,51   1,941   0,10   A(DS0)   A(DSA)   A(DST)   A(DS00)   A(DSLJ)

ZV0*(START)E
```

List of addresses for the example given here:

TAPE I

```
TEXTA 02032 K 1050'
TEXTB 02046 K 1062'
TEXTC 02053 K 1067'
TEXTD 02060 K 1072'
TEXTE 02110 K 1096'
TEXTH 02143 K 1123'
TEXTI 02153 K 1131'
J 02204 K 1156'
N 02205 K 1157'
R 02206 K 1158'
Z1 02207 K 1159'
Z2 02225 K 1173'
Z3 02243 K 1187'
Z4 02261 K 1201'
Z5 02277 K 1215'
Z6 02315 K 1229'
Z7 02333 K 1243'
Z8 02351 K 1257'
Z9 02367 K 1271'
TEXT 02405 K 1285'
DELTF 02471 K 1337'
IMAX 02472 K 1338'
NR 02473 K 1339'
F 02514 K 1356'
C 02516 K 1358'
SOLVE 02517 K 1359'
JN X  03026 K 1558'
YN X  03032 K 1562'
IN X  03036 K 1566'
KN X  03042 K 1570'
EXP X 03660 K 1968'
LN X  04002 K 2050'
SIN X 04105 K 2117'
COS X 04106 K 2118'
START 04232 K 2202'
N1 04245 K 2213'
J1 04325 K 2261'
IT 04622 K 2450'
J2 04656 K 2478'
N2 04670 K 2488'
ACALC 04730 K 2520'
SCALC 05033 K 2587'
CENTR 05107 K 2631'
INTER 05200 K 2688'
OUTER 05471 K 2873'
READY 06012 K 3082'
N3 06032 K 3098'
FLUX 06351 K 3305'
MEAN 06531 K 3417'
J3 06546 K 3430'
N4 06550 K 3435'
EFCE 06644 K 3492'
LAST 06774 K 3580'
END 06776 K 3582'
```

```
KJI1 02032  1050'
KJI2 02070  1080'
KJI3 02126  1110'
KJI4 02164  1140'
KJI5 02222  1170'
KJI6 02260  1200'
KJI7 02316  1230'
KJI8 02354  1260'
KJI9 02412  1290'
KIB2 02450  1320'
KIB3 02734  1500'
KIB4 03220  1680'
KIB5 03504  1860'
KIB6 03770  2040'
KIB7 04254  2220'
KIB8 04540  2400'
KIB9 05024  2580'
KOB2 05310  2760'
KOB3 05574  2940'
KOB4 06060  3120'
KOB5 06344  3300'
KOB6 06630  3480'
KOB7 07114  3660'
KOB8 07400  3840'
KOB9 07664  4020'
NORM 10016  4110'
SOLUT 10112  4170'
```

TAPE II

```
US00 10206  4230'
USA 10225  4245'
UST 10244  4260'
US0 10263  4275'
AS00 10302  4290'
ASA 10321  4305'
AST 10340  4320'
AS0 10357  4335'
DS00 10376  4350'
DSA 10415  4365'
DST 10434  4380'
DS0 10453  4395'
DSLJ 10472  4410'
F001 11033  4635'
F002 11052  4650'
F003 11071  4665'
F004 11110  4680'
F005 11127  4695'
```

end of TAPE I

```
EMPTY 11147  4711'
SYSTM 11457  4911'
```

The limitations of the programme due to the small computer memory capacity are: number of cell zones $N \leqslant 9$; the maximum number of groups allowed depends on N and must be determined so that the total number of data on the tape II does not exceede $3765-(6N-3)(6N-2)$.

The programme has to be stored into the computer in the following order:

1. tape I with the programme until the first stop;
2. tape II with the group or point cross sections, scattering matrices, neutron sources and guess spectra for all the materials of the cell;
3. end of tape I
4. tape III with the imput data.

The following options for printing the results are available:

$\langle 14 \rangle_1 = 0$ the average group, i.e. point fluxes and absorption rates in cell zones printed after each iteration cycle;

$\langle 14 \rangle_1 = 1$ the above quantities printed only after the whole iteration process is completed;

$\langle 14 \rangle_{16} = 0$ the results printed by the teleprinter

$\langle 14 \rangle_{16} = 1$ the results punched on a tape

After all the three tapes have been read in the calculation begins by pressing the button START.

5. REFERENCES

1. G.I.Marchuk, V.G.Turchin, V.V.Smelov, G.A.Il'yasova: Methods of Calculating Slow-Neutron Spectra, Proceedings of the Brookhaven Conference on Neutron Thermalization, Vol.II, BNL, 1962.

2. B.Fredin, T.Boševski, M.Mataušek: Discrete Energy Representation of Thermal Neutron Spectra in U-Pu Lattices, to be published.

3. M.Mataušek: Space Energy Distribution of Thermal Neutron Flux in a Heterogeneous Cylindrically Symmetric Reactor Cell, m. of sc. thesis, IBK-449.(in serbian).

4. G.I.Marchuk: Methods of Calculating Nuclear Reactors, Gosatomizdat, Moscow, 1961.(in russian).

5. B.Davison: Neutron Transport Theory, Oxford University Press, 1958.

6. W.W.Clendenin: Effect of Zero Gradient Boundary Conditions on Cell Calculations in Cylindrical Geometry, Nucl.Sci. Engng. 14 (1962) 103.