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Two Codes for Calculating Space Dependent Fast Neutron Spectra

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S O P H I E AND C E C I L Y

TWO CODES FOR CALCULATING SPACE DEPENDENT FAST NEUTRON SPECTRA

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SUMMARY

The codes SOPHIE and CECILY are generalized versions of the asymptotic slowing down code GRACE developed at our Institute. Both codes are used for the calculation of the slowing down neutron spectrum in one-dimensional /slab, cylindrical, spherical/ geometries. The code SOPHIE is a criticality code, while CECILY solves the space-dependent slowing down problem within the elementary cell of the infinite fuel lattice. All three codes need the file called REACTOR TAPE, containing the nuclear data.

KIVONAT

A SOPHIE és CECILY kódok a szintén intézetünkben kifejlesztett, aszimptotikus közelitésben müködő GRACE kód általánositásai egydimenziós geometriára / sik, henger, gömb/. Mindkét kód lassulási neutronspektrum számitására szolgál. A SOPHIE kód kritikussági számitásokra alkalmas, mig a CECILY kód a térfüggő lassulási problémát a végtelen fütőelemrács elemi celláján belül oldja meg. Mindhárom kód müködéséhez a REACTOR TAPE nevü file használata szükséges, amely a nukleáris adatokat tartalmazza.

РЕЗЮМЕ

Программы **SOPHIE** и **CECILY** являются обобщениями асимптотической программы замедления **GRACE**, развитой тоже в нашем Институте. Обе программы разработаны для расчета нейтронного спектра замедления в одномерных /плоской, цилиндрической, сферической/ геометриях. Программа **SOPHIE** служит расчетом критичности, а программа **CECILY** решает проблему замедления, зависящую от пространственной координаты в элементарной ячейке бесконечной решетки ТВЭЛ-ов. Для работы обеих программ нужна магнитная лента **REACTOR TAPE**, содержащая необходимые ядерные данные.

I. INTRODUCTION

The codes SOPHIE and CECILY solve the energy dependent one-dimensional -equations approximating the neutron transport equation in the fast energy range. The differential equations are substituted by a finite difference scheme in the space variable. The multigroup picture is used with a fixed 40 lethargy group structure up to 10 MeV. The space interval corresponding to the actual system is divided by mesh points /max. 70 in SOPHIE and 25 in CECILY/ and into regions /max. 15 and 6 resp./ containing certain material compositions.

The codes work in three geometries, namely in the slab, cylindrical and spherical ones. The two codes are developed on the same basis as the multigroup zero-dimensional code RJG1-GRACE [1]. Quite similarly to it, the present versions of the codes do not take into account the thermal spectrum variation in space immanently, but make use of the results of a previous THERMOS [3] run, condensing the thermal energy range into one lethargy group.

The homogenized cross-sections for resonance materials in their resonance region should be given in input requiring a previous run of the code RIFFRAFF [2]. Another way of treating resonances is available in the codes, i.e. by using Hellstrand's single pin resonance integrals and mutual shielding factors [1, 4] as input data and lethargy group distributions of the resonance integrals /taken from a library/.

The purpose of developing these codes was twofold.

Firstly they are suitable to make theoretical investigations, e.g.

- study of some currently used approximations /fast advantage factors, mutual shielding factors/;
- study of the validity of the asymptotic reactor theory especially the energy-dependent buckling approximation for the reflectors /used in GRACE [1]/.

Secondly they may be used to calculate few-group diffusion constants in systems of a high number of different material regions.

It is worth to mention, that the code SOPHIE may be used for criticality calculations in cases where the asymptotic approximation is sufficient for taking into account the effect of axial leakage.

The codes SOPHIE and CECILY were written in ICL-FORTRAN. Typical running times on the ICL-1905 computer are in the range of 5 to 10 minutes.

II. BASIC EQUATIONS AND CALCULATIONAL METHOD

1. Basic equations

The equations solved by the codes SOPHIE and CECILY can be written in the following form

$$\frac{1}{r^{\alpha}} \frac{\partial r^{\alpha} J^{r}(r,u)}{\partial r} + B\, J^{z}(r,u) + \Sigma^{T}(r,u)\, \phi(r,u) = L_{o}(r,u) + S(r,u) + I(r,u) \qquad /1a/$$

$$\frac{1}{3} \frac{\partial \phi(r,u)}{\partial r} + \Sigma^{T}(r,u)\, J_{1}^{r}(r,u) = L_{1}^{r}(r,u) \qquad /1b/$$

$$-\frac{B}{3} \phi(r,u) + \Sigma^{T}(r,u)\, J^{z}(r,u) = L_{1}^{z}(r,u) \qquad /1c/$$

Notations

u - lethargy

r - space variable

α - geometry indicator, 0 for slab geometry
1 for cylindrical geometry
2 for spherical geometry

$\phi(r,u)$ - direction integrated flux:

$$2\pi \int_{-1}^{1} \varphi(r,u,\mu)\, d\mu$$

$J^{r}(r,u)$ - "radial" current:

$$2\pi \int_{-1}^{1} \mu\, \varphi(r,u,\mu)\, d\mu$$

$S(r,u)$ - fission source:

$$\frac{1}{2} \chi(u) \int_{o}^{\infty} \nu\Sigma_{f}(r,u')\, \phi(r,u')\, du'$$

$L_{o}(r,u)$ - isotropic elastic scattering rate

$I(r,u)$ - inelastic slowing down rate

$L_{1}^{r}(r,u)$ - "radial" component of the anisotropic elastic scattering rate

$L_{1}^{z}(r,u)$ - "axial" component of the anisotropic elastic scattering rate.

The exact meaning of L_o, L_1^r L_1^z and I is given in ref. [1].

$\Sigma^T(r,u)$- total cross section.

The codes SOPHIE and CECILY calculate the space dependence of the neutron flux only in one spatial variable, which is called the "radial" variable. Space dependence on the other spatial co-ordinates is taken into account by the "axial" quantities: axial current $J^z(r,u)$ and axial buckling B .

The axial leakage is calculated asymptotically, quite similarly to the leakage calculation in GRACE [1]. Actually, one of the main differences between the multiregion codes SOPHIE and CECILY is in the way of handling the axial leakage. The code SOPHIE is meant to calculate the criticality and the fast spectrum of core-reflector systems. The user may give different axial bucklings for different regions and the set of equations /1/ is solved by taking the actual value of $\Sigma^T(r,u)$ at every point r . The code CECILY is meant for cell calculations and the same buckling must be used for all regions of the cell. Practice has shown that in regions with small Σ^T this method fails, therefore in eq./1c/ $\Sigma^T(r,u)$ is not the actual total cross section at point r , but a cell-averaged value. Consequently, eq./1c/ must be rewritten in case of CECILY as

$$-\frac{B}{3}\,\phi(r,u) + \frac{\int_{cell} \Sigma^T(r,u)\,\phi(r,u)\,dV}{\int_{cell} \phi(r,u)\,dV}\, J^z(r,u) = L_1^z(r,u)$$

The same averaging procedure is carried out for all cross-sections appearing in L_1^z.

The formalism described in the following holds for both codes with minor differences. Therefore the derivations follow the line coresponding to SOPHIE. When necessary, the differences between the two codes are indicated.

The elastic slowing down source is approximated in the same way as in GRACE [1]. For elements having mass numbers greater than the aluminium /F-elements/ the Fermi-age approximation is used, while for aluminium and the lighter elements /f-elements/ the Greatling-Goertzel approximation is used. The anisotropic slowing down source is taken into account for hydrogene, deuterium and beryllium /h-elements/ accounting for a linear anisotropy in the laboratory system.

2. The multigroup equations

The continuous energy-dependence of the neutron flux and current is substituted by a multigroup picture. The group structure is identical with that of GRACE [1]. The j^{th} groups has the lethargy limits u_{j-1} and u_j, and lethargy width $\Delta u_j = u_j - u_{j-1}$. The subscript j of the thermal group is denoted by j_{th}. As this is the last energy group, j_{th} = NTH, i.e. The group integrals of flux and current are the total number of energy groups /$\leq$ 40/

$$\phi_j(r) = \int_{u_{j-1}}^{u_j} \phi(r,u)\, du \qquad \text{and}$$

$$J_j^{r,z}(r) = \int_{u_{j-1}}^{u_j} J^{r,z}(r,u)\, du$$

while the other quantities are averaged for lethargy groups in the same way as in GRACE /see eqs./21/ - /33/, /35/ - /40/, /42/ of ref. [1]/. After simple transformations, eqs./1/ can be written as follows:

$$\frac{dr^\alpha J_j^r(r)}{dr} + r^\alpha A_j(r)\,\phi_j(r) = r^\alpha B_j(r) \qquad /2a/$$

$$\frac{1}{3}\frac{d\phi_j(r)}{dr} + C_j^r(r)\, J_j^r(r) = D_j^r(r) \qquad /2b/$$

$$-\frac{B}{3}\phi_j(r) + C_j^z(r)\, J_j^z(r) = D_j^z(r) \qquad /2c/$$

where

$$A_j(r) = \Sigma_j^A + A\Sigma_j^I + \sum_f \frac{N_f\, \Xi^*_{fj}}{\Gamma_{fj} + \frac{\Delta u_j}{2}} + \frac{1}{\Delta u_j} \sum_F N_F\, \Xi_{Fj} + \frac{B^2}{3C_j^z(r)}$$

$$B_j(r) = S_j + I_j + q_{Fj-1} + \sum_f \frac{\Delta u_j}{\Gamma_{fj} + \frac{\Delta u_j}{2}}\, q_{fj-1} - \frac{\sum_h B\, p^z_{hj-1}}{C_j^z(r)} - RA_j$$

$$C_j^z(r) = C_j^r(r) = \Sigma_j^T - \sum_k N_k M_{kj} + \sum_h \frac{N_h H_{kj}}{Z_{hj} + \frac{\Delta u_j}{2}}$$

$$D_j^{r,z}(r) = \sum_h \frac{\Delta u_j}{Z_{hj} + \frac{\Delta u_j}{2}}\, p^{r,z}_{hj-1} - \frac{RA_j}{\phi_{j-1}(r)}\, J^{r,z}_{j-1}(r)$$

The nomenclature is given in ref. [1].

The r-dependence of the cross-section, slowing down densities and the BIGG-type resonance absorption rate RA_j is not written here explicitly. Equations /2a-c/ are completed now with the slowing down equations:

$$q_{fj}(r) = \frac{N_f \, \Xi^*_{fj}}{\Gamma_{fj} + \frac{\Delta u_j}{2}} \phi_j(r) + \frac{\Gamma_{fj} - \frac{\Delta u_j}{2}}{\Gamma_{fj} + \frac{\Delta u_j}{2}} q_{fj-1}(r) \qquad /3a/$$

$$q_{Fj}(r) = \frac{1}{\Delta u_j} \sum_F N_F \, \Xi_{Fj} \, \phi_j(r) \qquad /3b/$$

$$p^{r,z}_{hj}(r) = \frac{N_h \, H_{hj}}{Z_{hj} + \frac{u_j}{2}} J^{r,z}_j(r) + \frac{Z_{hj} - \frac{u_j}{2}}{Z_{hj} + \frac{u_j}{2}} p^{r,z}_{h,j-1}(r) \qquad /3c/$$

The expressions of $C_j^z(r)$ and $p^z_{hj}(r)$ are modified in CECILY:

$$C^z_j = C^z_j(r) = \frac{\int_{cell} \left[\Sigma^T_j - \sum_k N_k \, M_{kj} + \sum_h \frac{N_h \, H_{hj}}{Z_{hj} + \frac{\Delta u_j}{2}} \right] \phi_j(r) \, dV}{\int_{cell} \phi_j(r) \, dV}$$

$$P^z_{hj}(r) = \frac{\int_{cell} \frac{N_h \, H_{hj}}{Z_{hj} + \frac{\Delta u_j}{2}} \phi_j(r) \, dV}{\int_{cell} \phi_j(r) \, dV} J^z_j(r) + \frac{Z_{hj} - \frac{\Delta u_j}{2}}{Z_{hj} + \frac{\Delta u_j}{2}} p^z_{h,j-1}(r)$$

Equations /2a/ - /2c/ and /3a/ - /3c/ are valid for every fast energy group /j = 1,2....NTH-1/ with the initial conditions

$$q_{fj}(r) = q_{Fj}(r) = P_{hj}{}^{r,Z}(r) = 0 \qquad \text{for } j = 0$$

The equations of the thermal group are:

$$\frac{dr^\alpha \, J^{r,z}_{j_{th}}(r)}{dr} + r^\alpha \left[\Sigma^A_{j_{th}}(r) + \frac{B^2}{3C^z_{j_{th}}(r)} \right] \phi_{j_{th}}(r) =$$

$$r^\alpha \left[\sum_f q_{fj_{th}-1}(r) + q_{Fj_{th}-1}(r) - \frac{\sum_h B \, P^z_{hj_{th}-1}(r)}{C^z_{j_{th}}(r)} \right] \qquad /4a/$$

$$\frac{1}{3} \frac{d\phi_{j_{th}}(r)}{dr} + C^r_{j_{th}}(r) \, J^r_{j_{th}}(r) = \sum_h p^r_{hj_{th}-1}(r) \qquad /4b/$$

$$- \frac{B}{3} \phi_{j_{th}}(r) + C^z_{j_{th}}(r) \, J^z_{j_{th}}(r) = \sum_h p^z_{hj_{th}-1}(r) \qquad /4c/$$

where

$$C^z_{j_{th}}(r) = C^r_{j_{th}}(r) = \Sigma^T_{j_{th}}(r) - \mu_{j_{th}} \Sigma^S_{j_{th}}(r)$$

or in CECILY

$$C^z_{j_{th}} = C^z_{j_{th}}(r) = \frac{\int_{cell} \left[\Sigma^T_{j_{th}}(r) - \mu_{j_{th}} \Sigma^S_{j_{th}}(r)\right] \phi_{j_{th}}(r)\, dV}{\int_{cell} \phi_{j_{th}}(r)\, dV}$$

3. Finite differencing of the multigroup equations

The differential equations /2/, /3/, /4/ are defined on the space interval $0 \leq r \leq R$, where R is the radius of the cylinder or sphere, or the thickness of a slab /half-thickness of a symmetric slab/. The $(P_1$-) boundary conditions for every group j are specified as

a./ at the middle point of a symmetric slab, cylinder or sphere:

$$J^r_j(0) = 0 \qquad /5a/$$

b./ at the left hand side of an asymmetric slab:

$$J^r_j(0) = -\frac{1}{2}\phi_j(0) \qquad /5b/$$

c./ at the right hand side of a slab, cylinder or sphere in the case of zero current /symmetry/ condition:

$$J^r_j(R) = 0 \qquad /5c/$$

d./ at the right hand side of a slab, cylinder or sphere in the case of a vacuum boundary:

$$J^r_j(R) = \frac{1}{2}\phi_j(R) \qquad /5d/$$

Obviously, in CECILY always the conditions a./ and c./ apply.

In order to form a finite difference scheme from eqs. /2/ and /3/ the interval $(0,R)$ is divided by $N + 1$ mesh points and the equations are integrated for suitably chosen mesh intervals. The first mesh point r_1 is at $r = 0$, while the last one r_{N+1} is at $r = R$. The middle point of the interval (r_K, r_{K+1}) is denoted by $r_{K+1/2}$. The left and right boundaries lie at different mesh points depending on the bound-

ary conditions. The left boundary lies at r_1 in case a./ while at $r_{3/2}$ in case b./. The right boundary lies at r_{N+1} in case c./, while at $r_{N+1/2}$ in case d./. It is noted, the points r_1 and/or r_{N+1} are fictitious points when boundary conditions b./ and/or d./ apply.

The mesh must be chosen in such a way, that the boundary of different material compositions lies at the middle point of one of the mesh intervals /i.e. at some $r_{K+1/2}$/.

Now integrating eqs. /2a/ and /2c/ between $r_{K-1/2}$ and $r_{K+1/2}$ /K = 2,3,...N/, the following set of equations are obtained:

$$r^{\alpha}_{K+1/2}\, J^{r}_{j,K+1/2} - r^{\alpha}_{K-1/2}\, J^{r}_{j,K-1/2} + r^{\alpha}_{K}\, \frac{r_{K+1} - r_{K-1}}{2}\, A_{j,K(\ell)} \phi_{j,K} =$$

$$= r^{\alpha}_{K}\, \frac{r_{K+1} - r_{K-1}}{2}\, B_{j,K(\ell)} \qquad /K=2,3,...N/ \qquad /6a/$$

$$\frac{1}{3}\, \phi_{j,K+1} - \frac{1}{3}\, \phi_{j,K} + \frac{r_{K+1} - r_{K}}{2}\, \frac{C^{r}_{j,K+1(\ell')} + C^{r}_{j,K(\ell)}}{2}\, J^{r}_{j,K+1/2} =$$

$$\frac{r_{K+1} - r_{K}}{2}\, \frac{D^{r}_{j,K+1(\ell')} + D^{r}_{j,K(\ell)}}{2} \qquad /K=1,2,...N/ \qquad /6b/$$

$$-\frac{B}{3}\, \frac{r_{K+1} - r_{K-1}}{2}\, \phi_{j,K} + \frac{r_{K+1} - r_{K-1}}{2}\, C^{z}_{j,K(\ell)}\, J^{z}_{j,K} = \frac{r_{K+1} - r_{K-1}}{2}\, D^{z}_{j,K(\ell)} \qquad /6c/$$

$$/K = 2,3,...N/$$

where

$$A_{j,K(\ell)} = \Sigma^{A}_{j,\ell} + A\Sigma^{I}_{j,\ell} + \sum_{f} \frac{N_f\, \Xi^{*}_{fj,\ell}}{\Gamma_{fj,\ell} + \frac{\Delta u_j}{2}} + \frac{1}{\Delta u_j} \sum_{F} N_F\, \Xi_{Fj,\ell} + \frac{B^2}{3C^{z}_{j,K(\ell)}}$$

$$C^{z}_{j,K(\ell)} = C^{r}_{j,K(\ell)} = \Sigma^{T}_{j,\ell} - \sum_{k} N_k\, M_{kj,\ell} + \sum_{h} \frac{N_h\, H_{hj,\ell}}{Z_{hj,\ell} + \frac{\Delta u_j}{2}}$$

$$B_{j,K(\ell)} = S_{j,k} + I_{j,K} + q_{Fj-1,K} = \sum_{f} \frac{\Delta u_j}{\Gamma_{fj,\ell} + \frac{\Delta u_j}{2}}\, q_{fj-1,K} - \frac{\sum_{h} B\, p^{z}_{hj-1,K}}{C^{z}_{j,K(\ell)}} - RA_{j,K}$$

$$D^r_{j,K(\ell)} = \sum_h \frac{\Delta u_j}{Z_{hj,\ell} + \frac{\Delta u_j}{2}} p^r_{hj-1,K+1/2} - \frac{RA_{j,K}}{\phi_{j-1,K}} J^r_{j-1,K+1/2}$$

$$D^z_{j,K(\ell)} = \sum_h \frac{\Delta u_j}{Z_{hj,\ell} + \frac{\Delta u_j}{2}} p^z_{hj-1,K} - \frac{RA_{j,K}}{\phi_{j-1,K}} J^z_{j-1,K}$$

$$D^r_{j,K+1(\ell')} = \sum_h \frac{\Delta u_j}{Z_{hj,\ell'} + \frac{\Delta u_j}{2}} p^r_{hj-1,K+1/2} - \frac{RA_{j,K+1}}{\phi_{j-1,K+1}} J^r_{j-1,K+1/2}$$

Here ℓ and ℓ' indicate the material compositions at the mesh points K and K + 1 respectively.

The expression of $C^Z_{j,K(\ell)}$ is modified in CECILY as

$$C^z_j = C^z_{j,K(\ell)} = \frac{\sum_{K=1}^{N+1} \left[\Sigma^T_{j,K(\ell)} - \sum_k N_k M_{kj,\ell} + \sum_h \frac{N_h H_{hj,\ell}}{Z_{hj,\ell} + \frac{\Delta u_j}{2}} \right] \phi_{j,K} \frac{r_{K+1} - r_{K-1}}{2}}{\sum_{K=1}^{N+1} \phi_{j,K} \frac{r_{K+1} - r_{K-1}}{2}}$$

Now we introduce some quantities in order to get a well arranged set of equations

$$Al(J,K) = \frac{-r^\alpha_{K+1/2}}{3 \frac{r_{K+1} - r_K}{2} \frac{C^r_{j,K+1(\ell')} - C^r_{j,K(\ell)}}{2}} \qquad /K = 1,2,...N/$$

$$AO(J,K) = -Al(J,K) - Al(J,K-1) + r^\alpha_K \frac{r_{K+1} - r_{K-1}}{2} A_{j,K(\ell)} \qquad /K = 2,3,...N/$$

$$AV(J,K) = r^\alpha_K \frac{r_{K+1} - r_{K-1}}{2} B_{j,K(\ell)} - r^\alpha_{K+1/2} \frac{D^r_{j,K+1(\ell')} + D^r_{j,K(\ell)}}{C^r_{j,K+1(\ell')} + C^r_{j,K(\ell)}} +$$

$$r_{K-1/2} \frac{D^r_{j,K(\ell')} + D^r_{j,K-1(\ell)}}{C^r_{j,K(\ell')} + C^r_{j,K-1(\ell)}} \qquad /K = 2,3,...N/$$

$$FI(J,K) = \phi_{j,K} \qquad /K = 1,2,...N+1/$$

$$Y(J,K) = J^{r}_{j,K+1/2} \qquad /K = 1,2,...N/$$

$$YY(J,K) = J^{z}_{j,K} \qquad /K = 1,2,...N+1/$$

Substituting /6b/ to /6a/ and using the notations in eq./7/ the following equation is obtained

$$Al(J,K)*FI(J,K+1) + AO(J,K)*FI(J,K) + Al(J,K-1)*FI(J,K-1) = AV(J,K)$$
$$/K = 2,3,...N;\ J = 1,2,...NTH-1/ \qquad /8/$$

In the thermal group, one gets the same set of equations, using the notations

$$A_{j_{th},K(\ell)} = \Sigma^{A}_{j_{th},\ell} + \frac{B^2}{3C^{z}_{j_{th},K(\ell)}}$$

$$B_{j_{th},K(\ell)} = \sum_{f} q_{fj_{th}-1,K} + q_{Fj_{th}-1,K} - \frac{\sum_{h} B\, p^{z}_{hj_{th}-1,K}}{C^{z}_{j_{th},K(\ell)}}$$

$$C^{z}_{j_{th},K(\ell)} = C^{r}_{j_{th},K(\ell)} = \Sigma^{T}_{j_{th},\ell} - \mu_{j_{th}}\, \Sigma^{S}_{j_{th},\ell}$$

$$D^{r}_{j_{th},K+1(\ell')} = D^{r}_{j_{th},K(\ell)} = \sum_{h} p^{r}_{hj_{th}-1,K+1/2}$$

$$D^{z}_{j_{th},K(\ell)} = \sum_{h} p^{z}_{hj_{th}-1,K}$$

In CECILY, the expression of $C_{jth,K(\ell)}$ is modified to

$$C^{z}_{j_{th}} = C^{z}_{j_{th},K(\ell)} = \frac{\sum_{K=1}^{N+1} \left[\Sigma^{T}_{j_{th},\ell} - \mu_{j_{th}}\, \Sigma^{S}_{j_{th},\ell}\right] \phi_{j_{th},K}\, \frac{r_{K+1} - r_{K-1}}{2}}{\sum_{K=1}^{N+1} \phi_{j_{th},K}\, \frac{r_{K+1} - r_{K-1}}{2}}$$

Equations /3/ are integrated in the same way as eqs./2/ and /4/, i.e. eqs./3a/ and /3b/ and the axial component of eq./3c/ from $r_{K-1/2}$ to $r_{K+1/2}$ $(K = 2,3,...N)$, and the radial component of eq./3c/ between r_K and r_{K+1} $(K = 1,2,...N)$, giving

$$q_{fj,K} = \frac{N_f\, \Xi^{*}_{fj,K(\ell)}}{\Gamma_{fj,K(\ell)} + \frac{\Delta u_j}{2}}\, FI(J,K) + \frac{\Gamma_{fj,K(\ell)} - \frac{\Delta u_j}{2}}{\Gamma_{fj,K(\ell)} + \frac{\Delta u_j}{2}}\, q_{fj-1,K} \qquad /9a/$$

$$/K = 1,2,...N+1/$$

$$q_{Fj,K} = \frac{1}{\Delta u_j} \sum_F N_F \, \Xi_{Fj,K(\ell)} \quad FI(J,K) \qquad /K = 1,2,...N+1/ \qquad /9b/$$

$$p^r_{hj,K+1/2} = \frac{1}{2}\left[\frac{N_h \, H_{hj,K(\ell)}}{Z_{hj,K(\ell)} + \frac{\Delta u_j}{2}} + \frac{N_h \, H_{hj,K+1(\ell')}}{Z_{hj,K+1(\ell')} + \frac{\Delta u_j}{2}}\right] Y(J,K) +$$

$$\frac{1}{2}\left[\frac{Z_{hj,K(\ell)} - \frac{\Delta u_j}{2}}{Z_{hj,K(\ell)} + \frac{\Delta u_j}{2}} + \frac{Z_{hj,K+1(\ell')} - \frac{\Delta u_j}{2}}{Z_{hj,K+1(\ell')} + \frac{\Delta u_j}{2}}\right] p^r_{hj-1,K+1/2} \qquad /K=1,2,...N/ \quad /9c/$$

$$p^z_{hj,K} = \frac{N_h \, H_{hj,K(\ell)}}{Z_{hj,K(\ell)} + \frac{\Delta u_j}{2}} YY(J,K) + \frac{Z_{hj,K(\ell)} - \frac{\Delta u_j}{2}}{Z_{hj,K(\ell)} + \frac{\Delta u_j}{2}} p^z_{hj-1,K} \qquad /9d/$$

$$/K = 1,2,...N+1/$$

where

$$Y(J,K) = \frac{A1(J,K)}{r^{\alpha}_{K+1/2}}\left(FI(J,K+1) - FI(J,K)\right) + \frac{D^r_{j,K+1(\ell')} + D^r_{j,K(\ell)}}{C^r_{j,K+1(\ell')} + C^r_{j,K(\ell)}} \qquad /9e/$$

$$/K = 1,2,...N/$$

$$YY(J,K) = \frac{B}{3C_{j,K(\ell)}} \, FI(J,K) + \frac{D^z_{j,K(\ell)}}{C^z_{j,k(\ell)}} \qquad /K = 1,2,...N+1/ \qquad /9f/$$

In CECILY, of course

$$p^z_{hj,K} = \frac{\sum_{K=1}^{N+1} \frac{N_h \, H_{hj,K(\ell)}}{Z_{hj,K(\ell)} + \frac{\Delta u_j}{2}} \phi_{j,K} \frac{r_{K+1} - r_{K-1}}{2}}{\sum_{K=1}^{N+1} \phi_{j,K} \frac{r_{K+1} - r_{K-1}}{2}} YY(J,K) + \frac{Z_{hj,K(\ell)} - \frac{\Delta u_j}{2}}{Z_{hj,K(\ell)} + \frac{\Delta u_j}{2}} p^z_{hj-1,K}$$

$$/K = 1,2,...N+1/ \qquad /9g/$$

These latter expressions of currents and slowing down densities are valid for $j = 1, 2,...$ NTH-1, with the initial values

$$q_{fo,K} = q_{Fo,K} = p^r_{ho,K+1/2} = p^z_{ho,K} = 0 \qquad /9h/$$

Before detailed considerations on solving eqs. /8/ - /9/, we have to take into account the boundary conditions, which make the system of equations complete.

4. Boundary conditions

Two types of boundary conditions were specified in II.4. at both ends of the interval (O,R). A finite difference form of these conditions may be obtained in the following way.

a./ If $r = 0$ is the middle point of a symmetric slab, cylinder or sphere, then eq. /2a/ is integrated between r_1 and $r_{3/2}$. Using eq./5a/ and the notations

$$AO(J,1) = Al(J,1) + \frac{r_{3/2}^{\alpha+1}}{\alpha+1} A_{j,2(\ell)} \qquad /j=1,2,...NTH/$$

$$AV(J,1) = \frac{r_{3/2}^{\alpha+1}}{\alpha+1} B_{j,1(\ell)} - r_{3/2}^{\alpha} \frac{D^r_{j,2(\ell)}}{C^r_{j,2(\ell)}}$$

the following equation is obtained:

$$Al(J,1) * FI(J,2) + AO(J,1) * FI(J,1) = AV(J,1) \qquad /10a/$$

$$(J = 1, 2, \ldots NTH)$$

b./ If $r_{3/2}$ is the left boundary of an asymmetric slab, one may write that

$$\frac{FI(J,1) + FI(J,2)}{2} = -2\, Y(J,1)$$

An equation formally identical to eq./10a/ can be obtained with the notations

$$AO(J,1) = \left[1 - 4 \frac{Al(J,1)}{r_{3/2}^{\alpha}}\right] \frac{Al(J,1)}{1+4 \frac{Al(J,1)}{r_{3/2}^{\alpha}}}$$

and

$$AV(J,1) = -\frac{4Al(J,1)}{1+4\frac{Al(J,1)}{r_{3/2}^{\alpha}}} \frac{D^r_{j,2(\ell)}}{C^r_{j,2(\ell)}} \qquad (J = 1,2,...NTH)$$

c./ If $r = R$ is a symmetry boundary, then integrating eq./2a/ between $r_{N+1/2}$ and r_N using eq./5c/ and the definitions

$$AO(J,N+1) = - Al(J,N) + \frac{r^{\alpha}_{N+1} - r^{\alpha}_{N+1/2}}{\alpha + 1} A_{j,N(\ell)}$$

$$(J = 1,2,...NTH)$$

$$AV(J,N+1) = \frac{r^{\alpha}_{N+1} - r^{\alpha}_{N+1/2}}{\alpha + 1} B_{j,N(\ell)} + r^{\alpha}_{N+1/2} \frac{D^{r}_{j,N(\ell)}}{C^{r}_{j,N(\ell)}}$$

one obtains that

$$AO(J,N+1) * FI(J,N+1) + Al(J,N)*FI(J,N) = AV(J,N+1) \qquad /10b/$$

$$(J = 1, 2, \ldots NTH)$$

d./ In case of a vacuum boundary at $r = r_{N+1/2}$, one can proceede in an analogous way as in case b./ to get formally the same equation as eq. /10b/ with

$$AO(J,N+1) = \left[1 - 4 \frac{Al(J,N)}{r^{\alpha}_{N+1/2}} \right] \frac{Al(J,N)}{1+4 \frac{Al(J,N)}{r^{\alpha}_{N+1/2}}}$$

$$/J = 1, 2, \ldots NTH/$$

$$AV(J,N+1) = 4 \frac{Al(J,N)}{1+4 \frac{Al(J,N)}{r^{\alpha}_{N+1/2}}} \frac{D_{j,N(\ell)}}{C^{r}_{j,N(\ell)}}$$

Equations /10a/ and /10b/ together with eqs. /8/ give NTH by /N+1/ equations for the NTH by /N+1/ unknown FI/K,J/ flux values. This set of equations can be rewritten as

$$\underline{\underline{A}}(J)\ \underline{\phi}\ (J) = \underline{V}(J) \qquad (J = 1, 2, \ldots NTH) \qquad /11/$$

where the elements of the column vectors $\underline{\phi}(J)$ and $\underline{V}(J)$ are the FI/J,K/ and AV/J,K/ quantities (K = 1,2,...N+1), while the /N+1/ by /N+1/ matrix $\underline{\underline{A}}(J)$ has the form

$$\begin{bmatrix} AO(J,1) & A1(J,1) & O & & O \\ A1(J,1) & AO(J,2) & A1(J,2) & & O \\ O & & & & \\ & & & & \\ & & & & \\ & & & & \\ & & & & \\ O & & & A1(J,N-1) & AO(J,N) \quad A1(J,N) \\ O & & & O & A1(J,N) \quad AO(J,N+1) \end{bmatrix}$$

Eq. /11/ coupled with eqs. /9/ can be solved starting from J = 1 and going on group by group to the thermal energy group.

5. Solution of the equations

The solution of eq. /11/ is quite straightforward by factorizing the matrix A as

$$\underline{\underline{A}}(J) = \underline{\underline{B}}(J)\ \underline{\underline{C}}(J)$$

Here

$$\underline{\underline{B}}(J) = \begin{bmatrix} BO(J,1) & & & O \\ A1(J,1) & BO(J,2) & & \\ & & & \\ & & & \\ & & & \\ O & & & A1(J,N) \quad BO(J,N+1) \end{bmatrix}$$

where

$$BO(J,1) = AO(J,1)$$

$$BO(J,K) = AO(J,K) - \frac{A1(J,K-1) * A1(J,K-1)}{BO(J,K-1)} \qquad /12a/$$

$$(K = 2,3,\ldots N+1)$$

and

$$\underline{\underline{C}}(J) = \begin{bmatrix} 1 & Cl(J,1) & & & 0 \\ & 1 & & & \\ & & & & \\ & & & & Cl(J,N) \\ 0 & & & & 1 \end{bmatrix}$$

where

$$Cl(J,K) = \frac{Al(J,K)}{BO(J,K)} \qquad /K = 1, 2, \ldots N/ \qquad /12b/$$

The equation

$$\underline{\underline{B}}(J)\ \underline{\underline{C}}(J)\ \underline{\phi}(J) = \underline{\underline{B}}(J)\ \underline{\psi}(J) = \underline{V}(J)$$

is inverted in two steps as /denoting the components of $\psi(J)$ by PSI(J,K)/

$$PSI(J,1) = \frac{AV(J,1)}{BO(J,1)}$$

$$PSI(J,K) = \frac{AV(J,K) - Al(J,K-1) * PSI(J,K-1)}{BO(J,K)} \qquad /12c/$$

$$/K = 2, 3, \ldots N+1/$$

and

$$FI(J,N+1) = PSI(J,N+1)$$

$$FI(J,N+1-L) = PSI(J,N+1-L) - Cl(J,N+1-L) * FI(J,N+2-L) \qquad /12d/$$

$$/L = 1, 2, \ldots N/$$

for every J /J = 1, 2, ... NTH/.

The numerical operations necessary to get the final solution given by eq. /12d/ are carried out in the following order /assuming the source distribution $S_{j,K}$ to be known/:

a./ First the quantities AO/J,K/ and Al/J,K/ are caluclated; they depend on the microscopic cross-sections, number densities and geometry only.

b./ AV/1,K/ is calculated, then using eqs./12/ the flux distribution FI/J,K/ is determined in the first microgroup.

c./ By the help of eqs./9/ the slowing down densities and then the AV/J,K/ are calculated for the next microgroup, and this procedure is repeated until the thermal group is reached/including this, too/.

The only problem remained is that the source distribution is not known as it can be calculated only from the FI/J,K/ flux distribution. Therefore a source iteration must be applied which gives the flux and source distributions at the end of the procedure. As far as CECILY is concerned, a further problem of calculating the flux averaged value of the total cross sections occurs there. /See II. 7./.

6. Source iteration

In the code GRACE [1] the energy distribution of the source was given by

$$S(u) = f(u)$$

i.e. by the fission spectrum, because of the normalization

$$\int_0^\infty \nu\Sigma_f(u)\ \phi\ (u)du = k_{eff}$$

where k_{eff} is the effective multiplication factor of the system. As in the present one-dimensional space dependent codes the source is not constant in space but is given by

$$S(r,u) = \frac{f(u)}{k_{eff}} \int_0^\infty \nu\Sigma_f\ (r,u')\ \phi\ (r,u')\ du' \qquad /13/$$

an iteration procedure is necessary. The iteration formula reads as

$$S^{(i)}_{(r,u)} = \frac{f(u)}{k^{(i-1)}_{eff}} \int_0^\infty \nu\Sigma_f(r,u')\phi^{(i-1)}(r,u')\ du' \ ,$$

or in terms of the finite differenced multigroup quantities:

$$S^{(i)}(J,K) = \frac{f_J}{k^{i-1}_{eff}} \sum_{J'=1}^{NTH} \nu\Sigma_{fJ',K(\ell)}\ FI(J',K)^{(i-1)} \qquad /14a/$$

where

$$k_{eff}^{(i)} = \int_{V_{system}} dV \int_{o}^{\infty} \nu\Sigma_f(r,u')\ \phi^{(i)}(r,u')\ du' \qquad /14b/$$

and with the initial value

$$FI(J,K)^{(o)} \equiv 1 \qquad /J=1,2,...NTH;\ K=1,2,...N+1/ \qquad /14c/$$

Thus the source distribution is normalized to unity and the maximum deviation of the source values from those computed in the previous iteration step gives the degree of convergence as

$$\varepsilon_i = \max_K \left| 1 - \frac{\sum_J S^{(i-1)}(J,K)}{\sum_J S^{(i)}(J,K)} \right|$$

The source iteration is terminated, if the value of ε_i is less than a small ε specified in the input.

It is worth to remark, that the code calculates the total destruction rate

$$L^{(i)} = \int_{o}^{\infty} \left[\int_{F} df\ J^{r(i)}(r_f,u') + B \int_{V} dV\ J^{z(i)}(r,u') + \int_{V} dV\ \Sigma_a(r,u')\ \phi^{(i)}(r,u') \right] du'$$

where V is the volume of the system, while F is the outer surface of it and r_f is some point of this surface /obviously if there is any vacuum boundary of the system/. The total destruction rates must be equal to unity in every iteration step because of the normalization /14/, providing a test of the calculation.

7. Calculation of the axial leakage in CECILY

As it was mentioned above, in the equation for the axial current /see eq./2c// the cross sections are averaged over the cell. Strictly speaking, an inner iteration would be necessary in each source iteration step to get the shape of the flux in each group. It has been found, however, that it is sufficient to calculate the cross section averages using the flux shapes obtained in the previous source iteration step. The convergence rate of the source iteration is practically not effected by that.

The user must specify an axial buckling value in the input which may be zero. As a first step the code solves the problem for this value of the buckling.

At the user's option a SEARCH routine can be switched on which finds the material buckling of the given fuel lattice, i.e. such a B value for which $k_{eff} = 1$. The user is warned, that the code is not protected from cases where $k_{\infty} < 1$.

8. Determination of the critical sizes in SOPHIE

The code SOPHIE permits to calculate the k_{eff}, the flux distribution and few-group constants of a given core-reflector system. If the user is interested in the critical value of some parameters, a successive change of the size of one or more regions is carried out by the SEARCH routine until $k_{eff} = 1$ is reached. Of course, this criticality iteration can also be carried out by changing the buckling values of one or more regions in SOPHIE.

9. Some remarks on treating resonances

The user of both codes SOPHIE and CECILY has the option to make use of the two methods for treating resonances that were described in GRACE [1] in detail.

The first method consists in using the homogenized absorption, fission and scattering cross sections of resonance elements in their resonance regions, given by a RIFFRAFF [2] calculation. The output of RIFFRAFF contains not only the cell-homogenized values of these cross sections, but their values in the fuel rod as well.

The so called BIGG-type resonance treatment [1, 4] making use of Hellstrand's resonance integrals and their energy group distributions are obviously usable only in SOPHIE. In CECILY, further detailed considerations concerning the ψ-function library, etc. are necessary. Here the question of mutual shielding factors and fast adventage factor does not arise at all, because the code itself accounts for the lattice structure of the system.

III. ORGANIZATION OF THE CODES

In this section a short account on the organization of the codes SOPHIE and CECILY is briefly given. The flow diagram can be seen in Appendix 1.

First of all it seems to be obvious, that this type of calculation needs not only a well-arranged overlay structure of subroutines, but a suitable common block structure because of the enormously high number of the variables to be stored. Practically, 40 matrices $\underline{\underline{A}}$ /see II.4/ ought to be stored each with 141 elements /in the case of 70 mesh points, which is actually permitted in SOPHIE/, along with the computed quantities /flux, current, etc./, each with 40 * 70 elements. This is impossible, unless magnetic tapes are used for storing the coefficients of the equations to be solved and the computed quantities. The storage is organized in such a way that one or two records correspond to each microgroup.

The overlay structure and the order of subroutine calls satisfy the requirements of economizing the running time.

The subroutines may be divided into three groups. The MASTER segment calls the input-output subroutines INPUT, TAPEMAKER and ANITRA. The INPUT subroutine reads in the basic option data, the geometry, and the energy group limits.

The TAPEMAKER subroutine reads in the element-wise nuclear densities, the resonance and thermal data. Afterwards it reads in the microgroup cross-sections for each element occuring in the actual problem from the GRACE LIBRARY TAPE and prepares the magnetic tape MT1 containing all mixture dependent quantities needed for the solution of the equations, using two records for each microgroup.

For saving with storage, TAPEMAKER writes the Hellstrand-type resonance data on the magnetic tape MT2, and afterwards it reads them in from there.

This subroutine sets also the initial source value. After executing the subroutine group controlled by SOLVEIG /i.e. the source iteration and the whole calculation/ subroutine ANITRA prints out all the interesting quantities which can be obtained from the solution contained by the magnetic tape MT2. The ANITRA calculation needs both the tapes MT1 and MT2. If the criticality search option is used, the control is given to subroutine SEARCH. It carries out the outer iteration to $k_{eff} = 1$ /changing the sizes in the case of SOPHIE and changing the axial buckling in the case of CECILY/. In each outer iteration step subroutine SOLVEIG is called, and upon finishing the outer iteration, subroutine SEARCH calls the output subroutine ANITRA.

Any number of problems can be solved one after the other, the whole procedure being repeated starting with subroutine INPUT.

Last but not least some words are necessary on the most important block of the codes, controlled by subroutine SOLVEIG. For each microgroup this subroutine reads in the homogenized mixture data from the magnetic tape MT1 prepared by subroutine TAPEMAKER, then calls subroutine FLUX, which solves the space dependent equations with the actual source distribution.

From the solution obtained for the actual microgroup, subroutine SOLVEIG calculates the contribution of this microgroup to the source distribution of the next source iteration step. Then it turns to the next microgroup destroying the solution obtained for the previous one.

Finally a new source distribution is set and /only in the case of CECILY/ the flux averaged values of the total cross sections are computed. If the source iteration converged, the subroutine SOLVEIG makes an extra run, in order to produce the magnetic tape MT2, containing the computed flux, current, etc. distributions /one record for each microgroup/. The tape MT2 is produced only after the outer iteration converged, if SOLVEIG is called by subroutine SEARCH.

IV. USER'S MANUAL, INPUT-OUTPUT DESCRIPTION

Both codes are written for the ICL-1905 computer in ICL-FORTRAN. Both SOPHIE and CECILY require the whole memory capacity /32 K/ of the computer, as they consist of four overlay units. The input data may be read in from paper tape or cards, while the whole output appears on the line printer. The codes make use of a library tape and two scratch tapes for temporary data storage.

The input-output systems of both codes are very similar, so they are treated together. The input data can be easily prepared, usually they do not require any calculation by hand. However, in the present versions of the codes, a previous THERMOS [3] run and optionally a previous RIFFRAFF [2] run have to precede the SOPHIE or CECILY runs giving the thermal and resonance data of mixtures containing fissionable elements.

The output of the code is very abundant, and some not too significant parts of the output can be obtained by switching on some switches /see later/.

1. Input data

1st card /10A8/ : title of the actual run

2nd card /2L4, E6.3, I3, 9I2, 6I4/ : option parameters

char. 1-4 /L4/ : TRUE - this is the last problem
FALSE - this is not the last problem

char. 5-8 /L4/ : TRUE - complete output of input data
FALSE - short output of input data

char. 9-14 /E6.3/ : ε_1 the convergence limit of the source iteration /practically 1.E-5/

char. 15-17 /I3/ : number of mesh points
/in SOPHIE maximum 70, in CECILY 25/

char. 18-19 /I2/ 0: the code does not call the SEARCH subroutine
1: critical size determination by SEARCH
2: critical buckling determination by SEARCH

char. 20-21 /I2/ number of regions
/in SOPHIE maximum 15, in CECILY 6/

char. 22-23 /I2/ number of mixtures
/in SOPHIE maximum 8, while in CECILY 6, but resonance isotopes may be present only in the first 4 mixtures/

char. 24-25 /I2/ 2: RIFFRAFF data for every mixture containing resonance isotopes
1: BIGG-type data for every mixture containing resonance isotopes
0: type of resonance data is determined separately for each mixture containing resonance isotopes

char. 26-27 /I2/ 0: vacuum boundary from left
1: symmetry boundary from left

char. 28-29 /I2/ 0: vacuum boundary from right
1: symmetry boundary from right

char. 30-31 /I2/ 0: slab geometry
1: cylindrical geometry
3: spherical geometry

char. 32-33 /I2/ maximum number of source iteration steps

char. 34-35 /I2/ number of macrogroups /max.6/

char. 36-59 /6I4/ upper boundaries of macrogroups.

3rd card /I3, 2E.3, 15I3/: SEARCH data

This card is to be omitted if no search calculation is requested.

char. 1-3 /I3/ maximum number of outer iteration steps

char. 4-9 /E6.3/ convergence limit of the outer iteration /usually 1.E-5/

char. 10-15 /E6.3/ an overall changing factor /EV/

char. 16-60 /15 I3/(S) regionwise modification factor
16-39/8 I3/ (C) /MOD/NR//

In order to understand the meaning of these last two quantities, we write the outer iteration formula /e.g. for regionwise buckling iteration/

$$B(NR)^{(n+1)} = B(NR)^{(n)} \quad \frac{1 + MOD(NR) * VOL^{(n+1)}}{1 + MOD(NR) * VOL^{(n)}}$$

where $VOL^{(1)} = EV$ and the later values of $VOL^{(n)}$ are calculated from the k_{eff} value and the previous $VOL^{(n-1)}$ value. Here, NR specifies one of the regions.

4th card /8/E6.3,I3// mesh point data

char. 1-72 8/E6.3,I3/ The mesh points are specified by pairs of data. The first number or a pair gives in cm the distance of two mesh points following each other, while the second number gives the mesh point, where this distance changes. If one card is not sufficient, continue on the next cards.

5th card /15/I2, I3/ or 6/I2, I3//: region specification is given by a pair of data

char. 1-75 15/I2, I3/ (S)
char. 1-30 6/I2, I3/ (C) The first number of a pair gives the number of the mixture in the region, while the second one gives the first mesh point right to the region boundary /which is at the midpoint of a mesh interval/

6th card /8E10.5/ : buckling values

This is needed only if a slab or cylindrical geometry calculation is carried out.

char. 1-80	/8E 10.5/	the values of axial buckling in the order of regions. If one card is not sufficient, continue on the next one.

In the case of CECILY:

char. 1-10	/E10.5/	the value of axial buckling

7th card /8E10.5/ : buckling iteration initial guess

This card is to pe punched only if a SEARCH iteration is needed for the determination of the critical buckling value. This card has the same format as the previous one.

These cards form the first part of input data, read in by subroutine INPUT. A lot of small tests are built in the codes in order to protect them from input errors. If an error is detected the problem is aborted. The second part of input data are read in by TAPEMAKER with a similar care. After such an abortion, the run of an eventual next problem remains possible. The subroutine TAPEMAKER reads in the mixture cards and the resonance and thermal data cards.

Mixture cards: the following is repeated for each mixture

1st card /I2, E6.3, L4/ : mixture identification

char. 1-2	/I2/	mixture number
char. 3-8	/E6.3/	fast advantage factor in SOPHIE, where cell--homogenized nuclear densities are to be given. In CECILY it has no direct meaning, but it is used to characterize mixtures. Namely, it has the value + 1.0 for mixtures in fuel; any positive number for mixtures in cladding; any negative number for mixtures in moderator.
char. 9-12	/L4/	it is an indicator of resonance treatment. It is TRUE for BIGG-type treatment and FALSE for RIFFRAFF-type treatment.

It has to be noticed that resonance isotopes may be present only in mixtures having a mixture number less or equal 4. For each element present in this mixture prepare a 2nd mixture card.

2nd mixture card /A8, E8.4, I2/ : element data./The elements are to be listed in the order of increasing mass numbers/

char. 1-8 /A8/ : element identifier, corresponding to the element identifier list of the GRACE LIBRARY

char. 9-16 /E8.4/ : nuclear density of this element

char. 17-18 /I2/ : it has the value
2: for fissile elements
1: for fertile elements
0: in SOPHIE for every other element, in CECILY for every other element except for H, D and Be.

In CECILY a list is made from all elements present in the system according to the order of the GRACE LIBRARY. For H, D and Be, the user must give the number of this element in this list with a negative sign. E.g. if the system contains H and Be, punch -1 for H and -2 for Be.

This card has to be repeated as many times as there are elements in the actual mixture. The maximum number of elements in a mixture is restricted to 12, among these maximum 3 may be lighter than Be /including Be/, 6 may be lighter than Al, /including Al/ and 9 may have a mass number greater than that of Al. The total number of different elements in the system is limited to 18, while no more than 7 different resonance elements may be treated in a problem. After the element data, a blank card follows, indicating the end of element data for the mixture. Depending on the resonance treatment cards of the type 3/A/ or 3/B/ follow.

If there are no resonance elements in this mixture, these cards are omitted.

In the case of BIGG-type resonance treatment, the data for resonance calculation follow now.

3rd mixture card /A/ /2/2E8.4, I2// : BIGG-type resonance treatment data

char. 1-36 2/2E.8.4, I2/ Single pin resonance integral for the total energy range, mutual shielding factor and index of ψ -function are to be given here for absorption and for fission. In CECILY, the mutual shielding factors must be equal to unity/see II.9/

This card has to be repeated for each resonance isotope in the mixture, in the order of increasing mass numbers.

In the case of RIFFRAFF-type treatment, only one card is to be read in here for this mixture:

3rd mixture card /B/ /2I3/ : RIFFRAFF group limits

char. 1-3 /I3/ the first microgroup, where RIFFRAFF treatment is to be used in the actual mixture

char. 4-6 /I3/ the last microgroup, where this treatment is applied.

This ends the mixture cards for one mixture. After the last mixture follow the resonance cards for RIFFRAFF data, going again through all the mixtures. These cards are omitted for mixtures not containing resonance isotopes or if a BIGG-type calculation is applied.

These cards have an order which may appear artificial but this order permits to save considerable storage. Resonance data are given microgroupwise, in increasing order of microgroup index. For a given microgroup resonance data are given for all mixtures with RIFFRAFF treatment in the order of increasing mixture number. For a given mixture a resonance card is prepared for each resonance isotope in the order of increasing mass number.

Resonance card /3E12.6/: RIFFRAFF data

char. 1-36 /3E12.6/ resonance absorption, ν times fission and scattering cross section for the actual element for the actual mixture and microgroup.

As to these cards the following remarks have to be observed. On mixture cards 3/B/ RIFFRAFF group limits were specified mixturewise. Therefore

- for microgroups lying outside the RIFFRAFF group limits of all mixtures no resonance card is given;
- for a given microgroup only those mixtures are mentioned, the group limits of which enclose this microgroup /limits included, of course/
- if a mixture is mentioned for a microgroup, a separate card has to be punched for each resonance element. For an element having no resonances in the microgroup a blank card is given.

After the last resonance card the mixturewise thermal data are to be specified in increasing order of the mixture number /1 or 3 cards by mixture/.

Thermal cards

1st card /4E8.4/ : cross sections

char. 1-8	/E8.4/	Homogenized absorption cross section for the mixture
char. 9-16	/E8.4/	homogenized scattering cross section
char. 17-24	/E8.4/	the homogenized value of $\mu\Sigma^s$
char. 25-32	/E8.4/	homogenized ν times fission cross section

2nd card /7E8.4/ : absorption in resonance elements

char. 1-56	/7E8.4/	elementwise absorption in the order of increasing mass numbers

3rd card - the same as the previous one for fission in resonance elements without ν /.

These last two cards are to be read in only if the mixture contains any resonance element.

2. Output description

The output of SOPHIE and CECILY are very similar but CECILY gives the cell-homogenized values of some quantities, as well. As a matter of fact, this is the main difference between the codes.

First of all the codes print out the input data. Switching on the switches 1 and/or 2 one has a detailed information on the content of MT2

in the case of BIGG-type resonance treatment and/or the content of MT1, i.e. the mixture coefficients for the flux calculation. Both of these outputs might be necessary only in the course of testing the codes.

The codes give a short information after each source iteration step on the actual value of k_{eff}, on its deviation from the previous value and on the quantity ε_i defined in Sec. II.6.

At the user's option, the detailed space distribution of flux, currents and slowing down densities are printed out for each microgroup. If switch 3 is on, we get the print-out for flux, current, total slowing down density and axial current in each mesh point on a separate page for each microgroup. If also switch 4 is on, one can get two more output pages for each microgroup, which contain the values of total slowing down density for Greuling-Goertzel elements /first page/, and the values of absorption, fission and scattering rates for BIGG-type treatment of resonances and the values of anisotropic slowing down densities for H, D and Be.

Usually these 120 pages of information is too abundant. The next part of output contains the pointwise macrogroup averages of certain quantities. They are defined as follows /using the notations of Sec.II./

Diffusion constant:

$$D_K(I) = - \frac{\sum_{J\varepsilon I} \left[Y_J(K) * \left(0.5 * \left(R(K)+R(K+1)\right)\right)^{\alpha} - Y_J(K-1) * \left(0.5 * \left(R(K-1)+R(K)\right)\right)^{\alpha} \right]}{\sum_{J\varepsilon I} \left[\left(FI_J(K+1) - FI_J(K)\right) * \frac{\left(0.5 * \left(R(K)+R(K+1)\right)\right)^{\alpha}}{R(K+1) - R(K)} - \left(FI_J(K) - FI_J(K-1)\right) * \frac{\left(0.5 * \left(R(K)+R(K-1)\right)\right)^{\alpha}}{R(K) - R(K-1)} \right]}$$

and for taking into account the effect of axial leakage the expression

$$\sum_{J\varepsilon I} B * YY_J(K) * R(K)^{\alpha} \; \frac{R(K+1) - R(K-1)}{2}$$

is to be added to the denominator and the expression

$$\sum_{J\varepsilon I} B^2 * FI_J(K) * R(K)^{\alpha} * \frac{R(K+1) - R(K-1)}{2}$$

is to be subtracted from the numerator. Here I denotes the actual macrogroup consisting of microgroups $J\varepsilon I$.

Absorption cross section:

$$\Sigma_{a_K}(I) = \frac{\sum_{J\epsilon I} \left[\Sigma_{a_J}(K(\ell)) * FI_J(K) * R(K)^{\alpha} \frac{R(K+1) - R(K-1)}{2} + RAA_J(K) \right]}{\sum_{J\epsilon I} FI_J(K) * R(K)^{\alpha} \frac{R(K+1) - R(K-1)}{2}}$$

where $RAA_J(K)$ is the absorption rate for microgroups where a BIGG-type calculation was carried out.

Fission and ν fission cross sections

They are computed in the same way as absorption, substituting $\Sigma a_K(I)$, $\Sigma a_J(K(\ell))$ and $RAA_J(K)$ by the corresponding expressions.

Removal cross section ($\Sigma_R(I)$)

It is calculated by a consequent extension to the space dependent case of the method written in detail in ref. [1].

1/v cross section ($\Sigma_v(I)$)

The calculation of it is quite similar to that of ref. [1].

Pointwise macrogroup flux

$$\Phi_K(I) = \sum_{J\epsilon I} FI_J(K)$$

These quantities are printed out on one page for each macrogroup after the optional printouts of the last microgroup of this macrogroup. $\Sigma_R(I)$ and $\Sigma_v(I)$ are equal to zero in the thermal group, of course. If the calculation of a homogeneous system symmetric from left and right was carried out and axial leakage was not allowed, the diffusion constant is not computed.

Following the optional microgroup and the macrogroup printouts the space distributions of the spectrum indices are printed. These printouts are pointwise for regions containing resonance elements. These quantities have the same meaning as in ref. [1].

Now the most important output follows, i.e. the regionwise macrogroup averages of the quantities listed above, namely that of the diffusion

constant, removal, absorption, fission, ν . fission, 1/v cross sections and flux. The values of elements of energy exchange matrix /see ref. [1]/ are calculated only for regions, and printed out here, followed only by the volume of the region.

These quantities form the input data for an eventual multi-dimensional diffusion calculation in the case of SOPHIE. It is worth to mention here again, that the unchanged input thermal data gives the regionwise thermal cross sections in both codes, because they are used only to permit a criticality calculation.

In the case of CECILY two pages for the lattice cell-homogenized cross sections follow now. The first of these pages have the same structure as used for the regionwise quantities. It is directly comparable to the results of a GRACE-calculation of the lattice. It is important, that the thermal cross sections will not agree any more, because they are modified by the new disadvantage factors.

The second of these pages contains the values of non-leakage probability, resonance escape probability, fast fission factor, thermal utilization, thermal η and initial conversion ratio, calculated in a similar way as in ref. [1]. It is followed by the moderator and clad disadvantage factors, /calculated for each macrogroup/ by the homogenized values of the spectrum indices δ and ρ for each resonance element and, finally, by the iterated value of k_{eff} and the value calculated by the four-factor formula and from the non-leakage probability.

In both codes, a separate page is printed out with the space distribution of the energy-integrated source.

At last the SEARCH subroutine has its own printouts. It gives short, but sufficient information on the stage of the criticality search. At the end of this search, the parameter values making the system critical are printed out. /These latter may be the critical size or the axial buckling (s)/. All the quantities listed above are printed out again.

V. SAMPLE PROBLEM

In order to show a typical input and output list the one-dimensional model of a real zero-power assembly was chosen as a sample problem. This zero-power assembly consist of core and light water reflector, both of cylindrical shape as the radial dimensions are concerned. The critical radius of the core is 18,35 cm, while the outer radius of the reflector is 46,35 cm. The resonance integrals of the uranium isotopes, the mutual

shielding and fast advantage factors were determined by a previous GRACE [1] run, while the thermal data were obtained by THERMOS [3]. The axial bucklings are iterated values.

The input list of this sample problem is given in Appedix 2. The short output was obtained with all switches off. The content of this output is quite self-explanatory and it is given in Appendix 3.

LIST OF REFERENCES

[1] Z. Szatmáry , J. Valkó: GRACE - a multigroup fast neutron spectrum code, report KFKI-14 /1970/

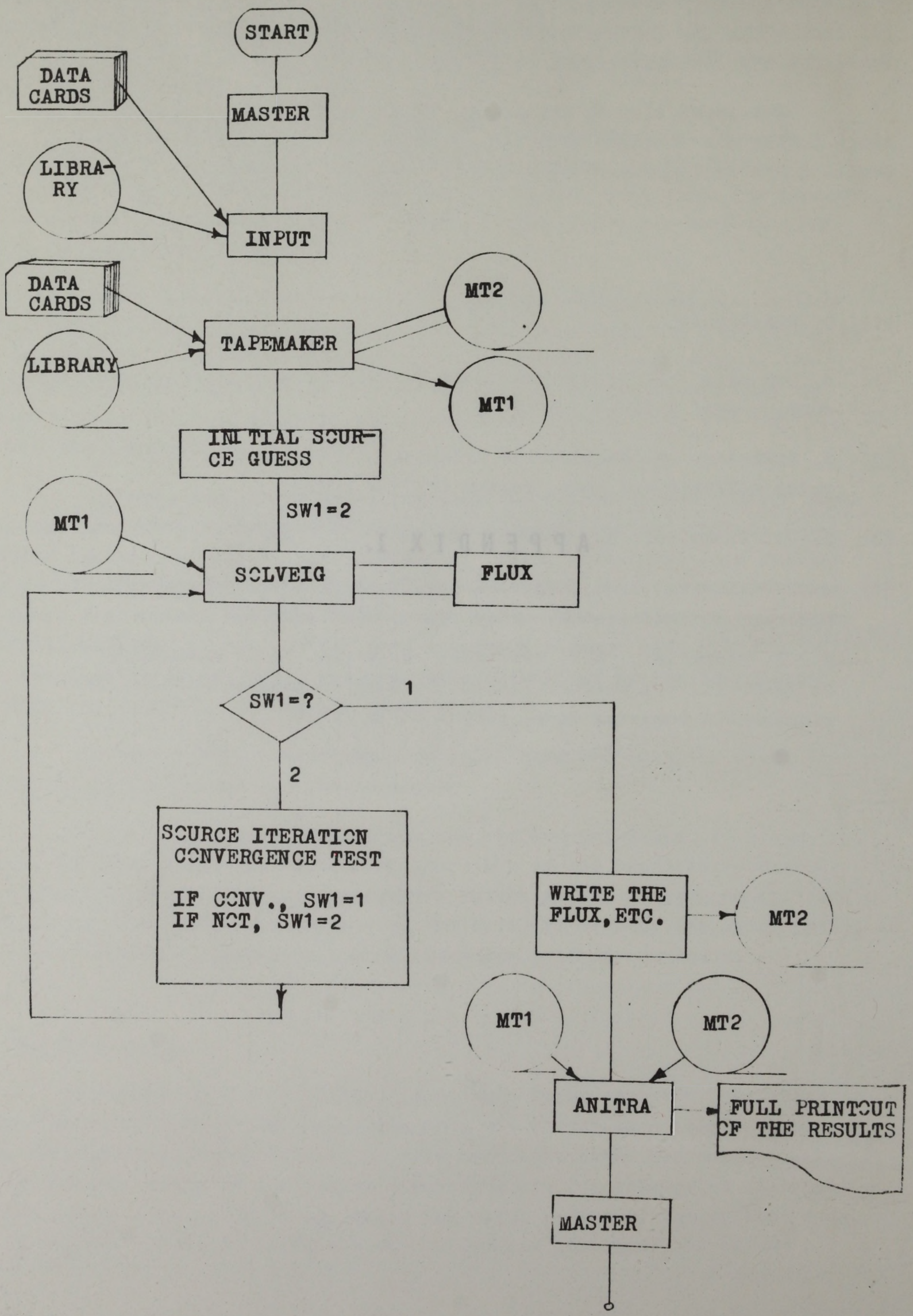
[2] Z. Szatmáry, A. Bagyinszki: Calculation of resonance integrals - codes RIFFRAFF and RA04, report KFKI-12 /1970/

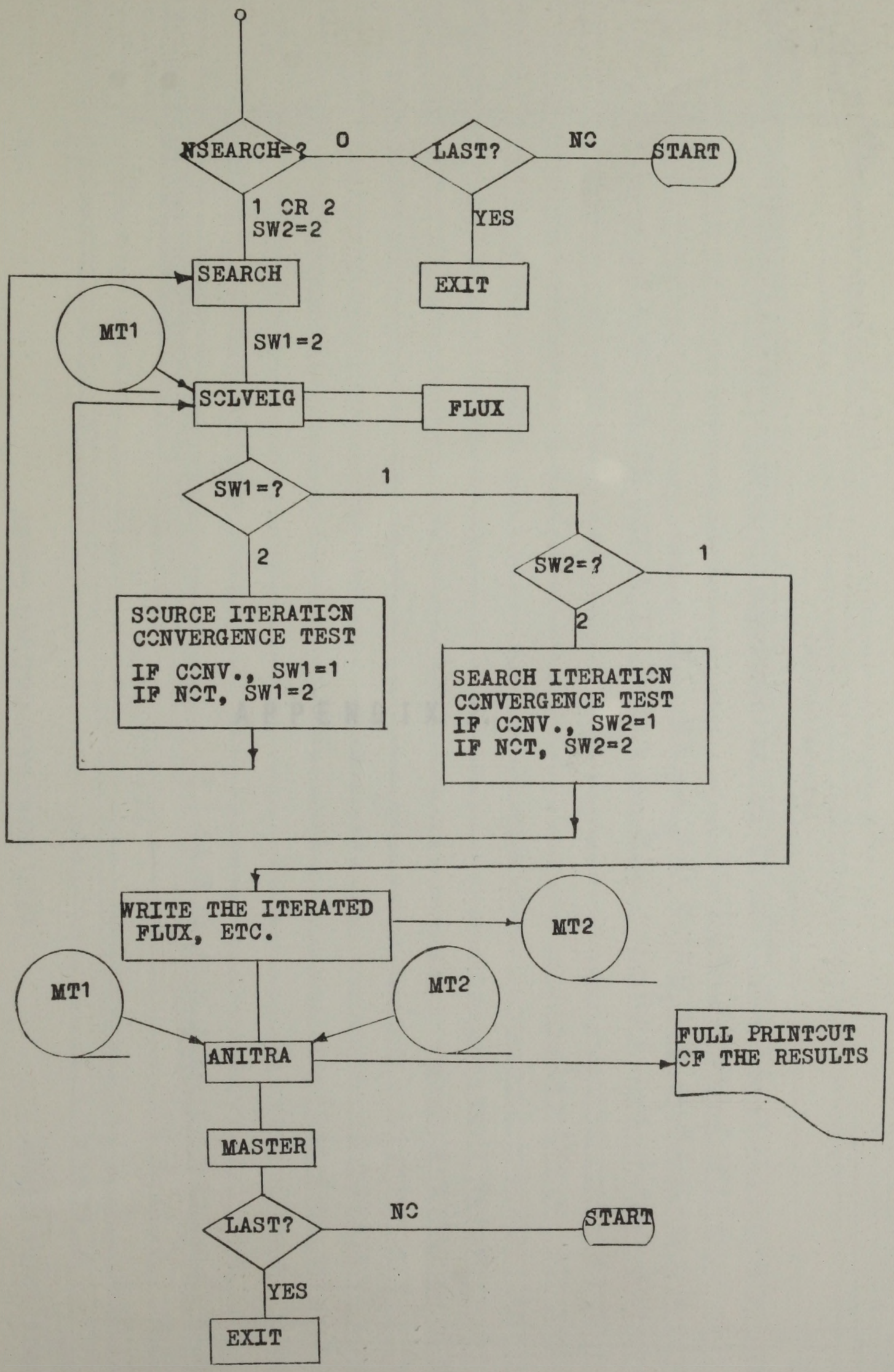
[3] R.J.J. Stamm'ler: K-7 THERMOS, report KR-47 /1963/

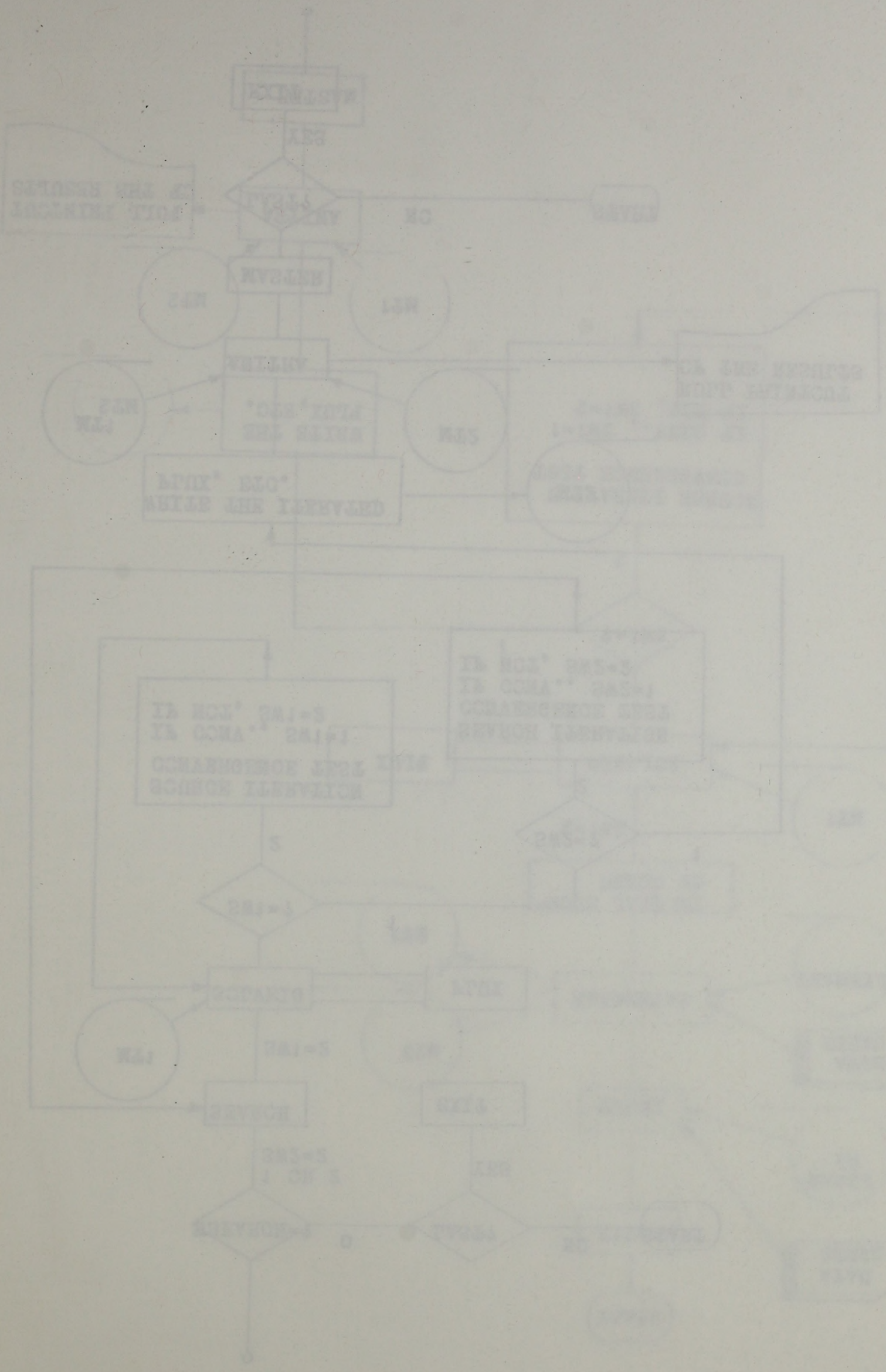
[4] O.P. Tverbakk, J. M. Døderlein: BIGG II. - a multigroup neutron spectrum and criticality code, report KR-75 /1965/

R.J.J. Stamm'ler, O.P. Tverbakk, Z. Weiss, J.M. Døderlein: DATAPREP II. - a reactor lattice homogenization and BIGG II. data preparation computer code, report KR-78 /1964/

APPENDIX 1.


START
DATA CARDS
MASTER
LIBRARY
INPUT
DATA CARDS
MT2
TAPEMAKER
LIBRARY
MT1
INITIAL SOURCE GUESS
MT1
SW1=2
SOLVEIG
FLUX
SW1=?
1
2
SOURCE ITERATION CONVERGENCE TEST
IF CONV., SW1=1
IF NOT, SW1=2
WRITE THE FLUX, ETC.
MT2
MT1
MT2
ANITRA
FULL PRINTOUT OF THE RESULTS
MASTER


NSEARCH=?
0
LAST?
NO
START
1 OR 2
SW2=2
YES
SEARCH
EXIT
MT1
SW1=2
SOLVEIG
FLUX
SW1=?
1
2
SW2=?
1
2
SOURCE ITERATION
CONVERGENCE TEST
IF CONV., SW1=1
IF NOT, SW1=2
SEARCH ITERATION
CONVERGENCE TEST
IF CONV., SW2=1
IF NOT, SW2=2
WRITE THE ITERATED
FLUX, ETC.
MT2
MT1
MT2
ANITRA
FULL PRINTOUT
OF THE RESULTS
MASTER
LAST?
NO
START
YES
EXIT



APPENDIX 2.

TITLE SOPHIE SAMPLE PROBLEM

I.C.T. FORTRAN CODING SHEET

SHEET 1 /

PROGRAMMER

DATE / /

C STATEMENT NUMBER (1–5)	CONT. (6)	FORTRAN STATEMENT (7–72)	IDENTIFICATION AND SEQUENCE No. (73–80)
		SOPHIE SAMPLE PROBLEM	
T		F 1.E-2 28 0 2 2 1 1 0 1 15 2 37 38	
3.000	0	2 3.450 5 1.000 10 1.E-6 11 1.000 17 2.000 27 4.000 28	
1 11		2 28	
0.05	5	5 0.055	
1 1.	1	46 T	
H-1		4.998-2	
C-12		1.179-4	
O-16		2.768-2	
AL-27		1.300-2	
U-235		1.296-4 2	
U-238		1.167-3 1	
329.	2	0.9909 7 213.2 0.9923 7	
34.	8	1 0.9548 27	
2 1.	0	00 0 T	
H-1		6.674-2	

FORM 1/542 (8.64)

TITLE SOPHIE SAMPLE PROBLEM

I.C.T. FORTRAN CODING SHEET

SHEET 2 /

PROGRAMMER _____

DATE __/__/__

C STATEMENT NUMBER	CONT.	FORTRAN STATEMENT	IDENTIFICATION AND SEQUENCE No.
1 2 3 4 5	6	7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72	73 74 75 76 77 78 79 80
C-16		3.337-2	
6.845-	2	2.168 0.459 0.1068	
5.185	-2	1.916-3	
4.394	-2		
2.203	-2	3.582 0.7657	

FORM 1/542 (8.64)

APPENDIX 3.

SOPHIE SAMPLE PROBLEM

OPTION DATA

BIGG-TYPE RESONANCE TREATMENT

CYLINDRICAL GEOMETRY

SYMMETRIC FROM LEFT HAND SIDE

ASYMMETRIC FROM RIGHT-HAND SIDE

SOURCE ITERATION DATA.

EPS FOR MAXIMAL R SID.: 1.000E-02
MAXIMAL NUMBER OF ITERATIONS: 15

MACROGROUP DATA

NUMBER OF MACROGROUPS: 2
BOUNDARIES AT MIGROGROUPS - 37 - 38 -

DELTA R BETWEEN MESH POINTS

3.0000E 00 2 3.4500E 00 5 1.0000E 00 10 1.0000E-06 11 1.0000E 00 17 2.0000E 00 27 4.0000E 00 28

VALUES OF MESH POINT COORDINATES IN CM

0.000 3.000 6.450 9.900 13.350 16.350 15.350 14.350 17.350
18.350 18.350 19.350 20.350 21.350 22.350 23.350 24.350 26.350
28.350 30.350 32.350 34.350 36.350 38.350 40.350 42.350 44.350
48.350

REGION BOUNDARIES IN CM

0.000E-01 1.835E 01 4.635E 01

REGIONWISE BUCKLING VALUES

5.500E-02 5.500E-02

COMPOSITION NUMBER: 1
FAST ADVANTAGE FACTOR: 0.1146E 01

ELEMENT DATA

ELEMENT	DENSITY	RES.INT. (ABS)	DANK F. (ABS)	PSI (ABS)		RES.INT. (FIS)	DANK.F. (FIS)	PSI (FIS)	
H-1	4.998E-02								
C-12	1.179E-04								
O-16	2.768E-02								
AL-27	1.300E-02								
U-235	1.296E-04	3.292E 02	9.[illegible]0E-01		7	2.1[illegible]2E 02	9.923E-01		7
U-238	1.167E-03	3.481E 01	9.5[illegible]8E-01		27	0.000E-01	0.000E-01		0

COMPOSITION NUMBER: 2
FAST ADVANTAGE FACTOR: 0.1000E 01

ELEMENT DATA

ELEMENT	DENSITY
H-1	6.674E-02
O-16	3.337E-02

LIBRARY CROSS SECTIONS ARE USED FOR THE FOLLOWING ELEMENTS:

H-1

C-12

O-16

AL-27

U-235

U-238

THERMAL CROSS SECTIONS (1/CM)

ABSORPTION:	6.845E-02
SCATTERING:	2.158E 00
FISSION:	1.0A3E-01
M:	4.500E-01

	ABS:	FISSION:
U-235	5.185E-02	4.394E-02
U-238	1.916E-03	0.000E-01

THERMAL CROSS SECTIONS (1/CM)

ABSORPTION:	2.20?E-02
SCATTERING:	3.582E 00
FISSION:	0.00?E-01
M:	7.657E-01

	ABS:	FISSION:

SOPHIE SAMPLE PROBLEM

ITERATION FOR KEFF

IT.NO	SOURCE CONV.	KEFF CONV.	KEFF SOURCE	KEFF NORMAL
1	2.06730E-01	9.68412E-01	3.15881E-02	0.58913E-01
2	8.52507E-02	2.13786E-02	1.02134E 00	0.19484E-01
3	3.08595E-02	8.26940E-03	1.00827E 00	0.87618E-01
4	1.10412E-02	2.98304E-03	1.00298E 00	0.90575E-01
5	3.95052E-03	1.07070E-03	1.00107E 00	0.91640E-01
6	1.41410E-03	3.83796E-04	1.00038E 00	0.92022E-01

POINTWISE QUANTITIES IN MACROGROUP: 1

K	DIFF. COEFF.	ABSORPTION	FISSION	NU*FISSION	REMOVAL	1/V	FLUX
1	1.29290E 00	3.63008E-03	1.18112E-03	2.76847E-03	3.27533E-02	5.98638E-08	1.02272E-01
2	1.29218E 00	3.62987E-03	1.18106E-03	2.76832E-03	3.27480E-02	5.98555E-08	1.58818E-01
3	1.28850E 00	3.62863E-03	1.18068E-03	2.76748E-03	3.27197E-02	5.98110E-08	1.46935E-01
4	1.27708E 00	3.62290E-03	1.17933E-03	2.76367E-03	3.26156E-02	5.96394E-08	1.26941E-01
5	1.27043E 00	3.60264E-03	1.17364E-03	2.75157E-03	3.25549E-02	5.91625E-08	1.00388E-01
6	1.30812E 00	3.59736E-03	1.17271E-03	2.74960E-03	3.23678E-02	5.91309E-08	9.16453E-02
7	1.38239E 00	3.59783E-03	1.17372E-03	2.75264E-03	3.25123E-02	5.92971E-08	8.24861E-02
8	1.51573E 00	3.61545E-03	1.17990E-03	2.76827E-03	3.29494E-02	5.99381E-08	7.28986E-02
9	1.71864E 00	3.67327E-03	1.19749E-03	3.01151E-03	3.39741E-02	6.15768E-08	6.28330E-02
10	1.37622E 00	3.81934E-03	1.23907E-03	3.11139E-03	3.61457E-02	6.52692E-08	5.21624E-02
11	4.65217E 00	5.13189E-04	0.00000E-01	0.00000E-01	4.81607E-02	6.52693E-08	5.21623E-02
12	1.65939E 00	5.37546E-04	0.00000E-01	0.00000E-01	5.16644E-02	6.96704E-08	4.13337E-02
13	1.44600E 00	5.60539E-04	0.00000E-01	0.00000E-01	5.46633E-02	7.33139E-08	3.24385E-02
14	1.31525E 00	5.81414E-04	0.00000E-01	0.00000E-01	5.70429E-02	7.61715E-08	2.52745E-02
15	1.23502E 00	5.99969E-04	0.00000E-01	0.00000E-01	5.87933E-02	7.81194E-08	1.95937E-02
16	1.18510E 00	6.16361E-04	0.00000E-01	0.00000E-01	5.99476E-02	7.93981E-08	1.51402E-02
17	1.15433E 00	6.31048E-04	0.00000E-01	0.00000E-01	6.06665E-02	8.00980E-08	1.16750E-02
18	1.14013E 00	6.52909E-04	0.00000E-01	0.00000E-01	6.06354E-02	7.98416E-08	7.04111E-03
19	1.15131E 00	6.71321E-04	0.00000E-01	0.00000E-01	5.98137E-02	7.87064E-08	4.28507E-03
20	1.17424E 00	6.88341E-04	0.00000E-01	0.00000E-01	5.87037E-02	7.72785E-08	2.63570E-03
21	1.20127E 00	7.05082E-04	0.00000E-01	0.00000E-01	5.75753E-02	7.58601E-08	1.63807E-03
22	1.22844E 00	7.22028E-04	0.00000E-01	0.00000E-01	5.65368E-02	7.45659E-08	1.02749E-03
23	1.25449E 00	7.39361E-04	0.00000E-01	0.00000E-01	5.56013E-02	7.34028E-08	6.49678E-04
24	1.28114E 00	7.57193E-04	0.00000E-01	0.00000E-01	5.47060E-02	7.22919E-08	4.12771E-04
25	1.31717E 00	7.75850E-04	0.00000E-01	0.00000E-01	5.35382E-02	7.09745E-08	2.62544E-04
26	1.39764E 00	7.96854E-04	0.00000E-01	0.00000E-01	5.17185E-02	6.86122E-08	1.64969E-04
27	1.71628E 00	8.29156E-04	0.00000E-01	0.00000E-01	4.67489E-02	6.23912E-08	9.80401E-05

POINTWISE QUANTITIES IN MACROGROUP: 2

X	DIFF. COEFF.	ABSORPTION	FISSION	NU*FISSION	REMOVAL	1/V	FLUX
1	1.99816E-01	6.84500E-02	4.39400E-02	1.06800E-01	0.00000E-01	0.00000E-01	8.41620E-02
2	1.99844E-01	6.84500E-02	4.39400E-02	1.06800E-01	0.00000E-01	0.00000E-01	7.08246E-01
3	2.00059E-01	6.84500E-02	4.39400E-02	1.06800E-01	0.00000E-01	0.00000E-01	1.50592E 00
4	2.01517E-01	6.84500E-02	4.39400E-02	1.06800E-01	0.00000E-01	0.00000E-01	1.99579E 00
5	2.37255E-01	6.84500E-02	4.39400E-02	1.06800E-01	0.00000E-01	0.00000E-01	1.39320E 00
6	1.70237E-01	6.84500E-02	4.39400E-02	1.06800E-01	0.00000E-01	0.00000E-01	6.52805E-01
7	1.83700E-01	6.84500E-02	4.39400E-02	1.06800E-01	0.00000E-01	0.00000E-01	6.43562E-01
8	1.86595E-01	6.84500E-02	4.39400E-02	1.06800E-01	0.00000E-01	0.00000E-01	6.70696E-01
9	1.87407E-01	6.84500E-02	4.39400E-02	1.06800E-01	0.00000E-01	0.00000E-01	7.35919E-01
10	1.06963E-01	6.84500E-02	4.39400E-02	1.06800E-01	0.00000E-01	0.00000E-01	4.39083E-01
11	2.07648E-01	2.20300E-02	0.00000E-01	0.00000E-01	0.00000E-01	0.00000E-01	4.39083E-01
12	1.17557E-01	2.20300E-02	0.00000E-01	0.00000E-01	0.00000E-01	0.00000E-01	1.08273E 00
13	1.17220E-01	2.20300E-02	0.00000E-01	0.00000E-01	0.00000E-01	0.00000E-01	1.14662E 00
14	1.16910E-01	2.20300E-02	0.00000E-01	0.00000E-01	0.00000E-01	0.00000E-01	1.12025E 00
15	1.14814E-01	2.20300E-02	0.00000E-01	0.00000E-01	0.00000E-01	0.00000E-01	1.04032E 00
16	1.05631E-01	2.20300E-02	0.00000E-01	0.00000E-01	0.00000E-01	0.00000E-01	9.32893E-01
17	1.29196E-01	2.20300E-02	0.00000E-01	0.00000E-01	0.00000E-01	0.00000E-01	1.22381E 00
18	1.21074E-01	2.20300E-02	0.00000E-01	0.00000E-01	0.00000E-01	0.00000E-01	1.17747E 00
19	1.19911E-01	2.20300E-02	0.00000E-01	0.00000E-01	0.00000E-01	0.00000E-01	8.15066E-01
20	1.19423E-01	2.20300E-02	0.00000E-01	0.00000E-01	0.00000E-01	0.00000E-01	5.50220E-01
21	1.19105E-01	2.20300E-02	0.00000E-01	0.00000E-01	0.00000E-01	0.00000E-01	3.66399E-01
22	1.19009E-01	2.20300E-02	0.00000E-01	0.00000E-01	0.00000E-01	0.00000E-01	2.42247E-01
23	1.18940E-01	2.20300E-02	0.00000E-01	0.00000E-01	0.00000E-01	0.00000E-01	1.59618E-01
24	1.18906E-01	2.20300E-02	0.00000E-01	0.00000E-01	0.00000E-01	0.00000E-01	1.04615E-01
25	1.18906E-01	2.20300E-02	0.00000E-01	0.00000E-01	0.00000E-01	0.00000E-01	6.74927E-02
26	1.18954E-01	2.20300E-02	0.00000E-01	0.00000E-01	0.00000E-01	0.00000E-01	4.12667E-02
27	1.19723E-01	2.20300E-02	0.00000E-01	0.00000E-01	0.00000E-01	0.00000E-01	3.09462E-02

SPECTRUM INDICES

REGION NUMBER: 1

K	CONV.RATIO	K	CONV.RATIO	K	CONV.RATIO	K	CONV.RATIO	K	CONV.RATIO	K	CONV.RATIO
1	9.18888E-02	2	9.14956E-02	3	9.19146E-02	4	9.18473E-02	5	9.07171E-02	6	8.71744E-02
7	8.63906E-02	8	8.19591E-02	9	7.53064E-02	10	6.26383E-02				

FISSILE ELEMENT:U-235

K	DELTAFISS	ROFISS	K	DELTAFISS	ROFISS	K	DELTAFISS	ROFISS
1	4.97327E-02	1.41090E-01	2	4.97386E-02	1.41106E-01	3	4.97542E-02	1.41142E-01
4	4.96842E-02	1.40901E-01	5	4.86256E-02	1.37702E-01	6	4.71335E-02	1.33583E-01
7	4.46226E-02	1.26204E-01	8	4.05187E-02	1.14617E-01	9	3.43619E-02	9.74234E-02
10	2.63737E-02	7.53087E-02						

FERTILE ELEMENT:U-238

K	DELTAFERT	ROFERT	K	DELTAFERT	ROFERT	K	DELTAFERT	ROFERT
1	8.16720E-03	1.64498E 00	2	8.16958E-03	1.64519E 00	3	8.17968E-03	1.64579E 00
4	8.20006E-03	1.64361E 00	5	8.14431E-03	1.60768E 00	6	7.95715E-03	1.55469E 00
7	7.59229E-03	1.47128E 00	8	6.92034E-03	1.33288E 00	9	5.80943E-03	1.12755E 00
10	4.25055E-03	8.64303E-01						

REGIONWISE MACROGROUP DATA

NUMBER OF REGION: 1

I	U	E	D	SIGMA R	SIGMA A	SIGMA F	NU*SIGMA F	SIGMA 1/V	FLUX
1	1.6536E 01	6.2500E-01	1.3569E 00	3.2731E-02	3.6255E-03	1.1806E-03	2.9[illegible]E-03	5.[illegible]E-08	[illegible].6683E-02
2	1.2000E 02	0.0000E-01	1.3315E-01	0.0000E-01	6.8450E-02	4.5940E-02	[illegible].0[illegible]E-01	0.0000E-01	[illegible].3277E-03

SCATTERING (ENERGY EXCHANGE) MATRIX (2ND TO 1ST)

F(1,1)= 0.0000E-01 S(2,1)= 1.0000E 00 E(
F(1,2)= 0.0000E-01 S(2,2)= 0.0000E-01 E(

REGIONWISE MACROGROUP DATA
NUMBER OF REGION: 2

I	U	F	D	SIGMA R	SIGMA A	SIGMA F	NU*SIGMA F	SIGMA 1/V	FLUX
1	1.6580E 01	6.2500E-01	1.3637E 00	5.4015E-02	5.9650E-04	0.0000E-01	0.0000E-01	7.4662E-13	8.3877E-04
2	1.2000E 02	0.0000E-01	1.3812E-01	0.0000E-01	2.2030E-02	0.0000E-01	0.0000E-01	0.0000E-01	1.8522E-03

SCATTERING (ENERGY EXCHANGE) MATRIX (P0 TO 1ST)

F(1,1)= 0.0000E-01 F(2,1)= 1.0000E 00 F(
F(1,2)= 0.0000E-01 F(2,2)= 0.0000E-01 F(

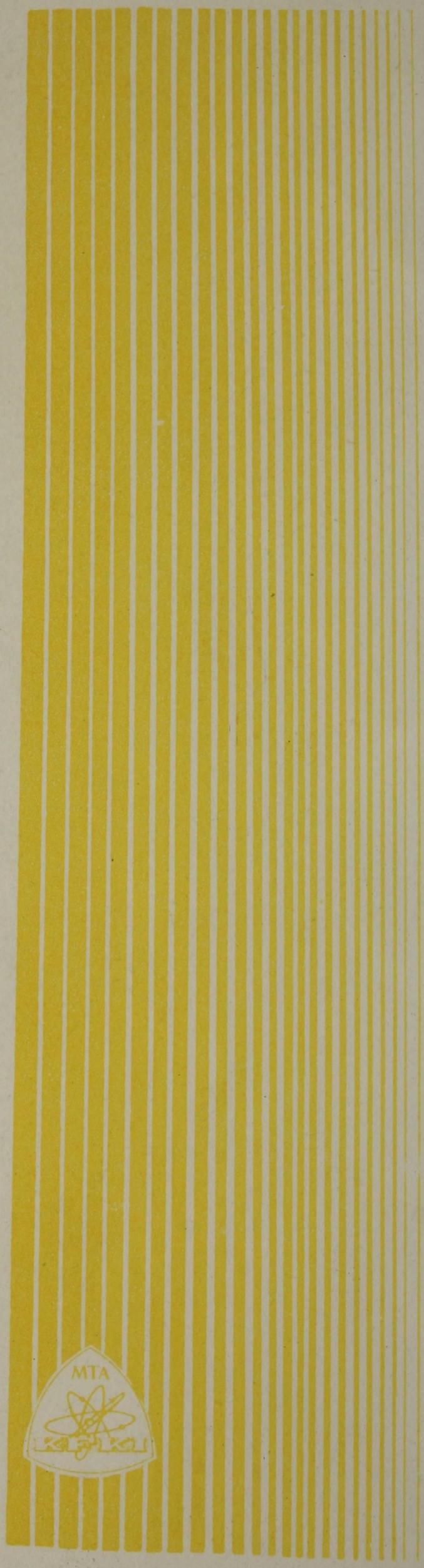
50
1

SOURCE DISTRIBUTION IN SPACE

K	SOURCE	K	SOURCE	K	SOURCE	K	SOURCE	K	SOURCE	K	SOURCE
1	8.52925E-03	2	8.34611E-03	3	7.71590E-03	4	6.66203E-03	5	5.34174E-03	6	5.01394E-03
7	4.75344E-03	8	4.62880E-03	9	4.75144E-03	10	5.30933E-03	11	0.00000E-01	12	0.00000E-01
13	0.00000E-01	14	0.00000E-01	15	0.00000E-01	16	0.00000E-01	17	0.00000E-01	18	0.00000E-01
19	0.00000E-01	20	0.00000E-01	21	0.00000E-01	22	0.00000E-01	23	0.00000E-01	24	0.00000E-01
25	0.00000E-01	26	0.00000E-01	27	0.00000E-01	28	0.00000E-01				

TIME ELAPSED: 1.08667E 01 MINUTES.

END OF SOPHIE



Kiadja a Központi Fizikai Kutató Intézet
Felelős kiadó: Szabó Ferenc igazgatóhelyettes
Szakmai lektor: Valkó János,
Gellai Borbála
Nyelvi lektor: Szabó Zoltán
Példányszám: 180 Törzsszám: 72-7456
Készült a KFKI sokszorosító üzemében
Budapest, 1972. december hó