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ABSTRACT

The nine Reactor Statics Modules are designed to introduce students to the use of numerical methods and digital computers for calculation of neutron flux distributions in space and energy which are needed to calculate criticality, power distribution, and fuel burnup for both slow neutron and fast neutron fission reactors. The last module, RS-9, includes a separate program, WANDIC (one-dimensional diffusion code with three energy-group representation), for the calculations of neutron spectra and group constants for use in fast breeder reactor calculations. It can be used with the criticality programs in RS-2 and RS-8. The reactor is divided into several concentric annular regions and it is assumed that those regions can be represented fairly well by their average properties. The previous modules show how these properties are found. The set of nine modules is intended to supplement textbooks and other lecture material generally available to students in their course work. It is assumed that students are familiar with elementary nuclear structure, neutron-nuclei interactions, and introductory material on fission chain reactors. (Author/SK)

REACTOR STATICS MODULE, RS-9

MULTIGROUP DIFFUSION PROGRAM USING AN EXPONENTIAL ACCELERATION TECHNIQUE

by

Victor C. Macek

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Reactor Statics Module, RS-9

Multigroup Diffusion Program Using an Exponential Acceleration Technique

9.1 Introduction

A reactor physicist or a nuclear engineer designing a power reactor needs to know the number of neutrons present within the system. This information is necessary for the calculation of the power distribution in a reactor from which further vital information on other related physical quantities needed to assure a successful operation of the reactor can be derived.

Previous modules discussed a broad area of problems which are encountered in reactor physics design. The basic input for calculations consists of engineering specifications and nuclear data. The former provide quantities like power density, fuel composition and a geometric description of the reactor. This information varies from one design to another. On the other hand, the nuclear data contains detailed cross-section information.

This input starts a rather long string of calculations before one can obtain results in a form which is suitable for engineering application.

The detailed treatment of space-energy physical phenomena in the entire reactor represents a very difficult task. Therefore, the problem is usually divided into several different stages and the flow of calculations passes from the detailed analysis of the neutron balance in an elementary fuel pin cell to the reactor as a whole consisting of assemblies which are represented by their average properties. In this procedure, the spatial and energy effects are reduced in detail; the former through the "homogenization", the latter through the group condensation. Of course, care must be taken in these simplifications. For example, neutron balance must be conserved.

The code WANDIC (one-dimensional diffusion code with a three energy-group representation) which is described in this module can be used to perform the global reactor calculations. The reactor is divided into several concentric annular regions and it is assumed that we can represent those regions fairly well by their average properties. The previous modules show how these properties are found.

Features of WANDIC

9.2 General Description

The program solves the three group diffusion equations

$$D_g \nabla^2 \phi^g - \Sigma_T \phi^g + S^g = 0 \quad \text{for } g = 1,2,3 \tag{9.2.1}$$

where the source term consisting of fission neutrons appears in the highest energy group only. The source terms in the lower groups are due to scattered neutrons from the adjacent upper group. The source S^g is given as

$$S^g = \frac{\delta_{1g}}{K} \sum_{g=1}^{3} (\nu\Sigma_f)^g \phi^g + \Sigma_s^{g-1,g} \phi^{g-1} \tag{9.2.2}$$

where δ_{1g} is Kronecker's delta; $\delta_{1g} = 1$ for $g = 1$, zero otherwise. The group diffusion equations are solved for cylindrical geometry with θ and β symmetries by using a finite difference technique which is described in module RS-2. Fluxes in each group and each mesh-point are calculated by solving a system of linear equations.

$$\begin{array}{rcl}
b_1^g \phi_1^g - a_1 \phi_2^g & = & S_1^g \\
\hdashline
-c_n^g \phi_{n-1}^g + b_n^g \phi_n^g - a_n^g \phi_n^g & = & S_n^g \\
\hdashline
-c_M^g \phi_{M-1} + b_M^g \phi_M^g & = & S_{M-1}^g
\end{array} \tag{9.2.3}$$

where indices 1, M denote mesh-points at the center and outer boundary of the reactor respectively. S_n is the source at the point n.

In matrix form the system (9.2.3) can be written as

$$A^g \phi^g = S^g \tag{9.2.4}$$

where ϕ^g is a vector representing fluxes ϕ_n^g at all mesh-points. The source term is a vector whose components are

$$S_n^g = h_n(\Sigma_{sn}^{g-1,g}\phi_n^{g-1} + \frac{\delta_{1g}}{K}\sum_{j=1}^{3}(\nu\Sigma_f)_n^j\phi_n^j)$$

where h_n is volume of the mesh-interval. In matrix notation S_n^g can be written as

$$S^g = E^g\phi + \frac{\delta_{1g}}{K}F\phi, \tag{9.2.5}$$

where

δ_{1g} is the Kronecker delta and

$$\phi = \begin{bmatrix}\phi^1\\ \phi^2\\ \phi^3\end{bmatrix} \qquad \begin{array}{l} E^g = (E^{1g}\ E^{2g}\ 0) \\ F\ = (F^1\ F^2\ F^3)\ . \end{array}$$

The vector ϕ^j is formed from the elements ϕ_n^j, the diagonal matrix E^{jg} is formed from the elements $\Sigma_{sn}^{g-1,g}$, and the diagonal matrix F^j is formed from the elements $(\nu\Sigma_{fn})^j$.

Finally, the assembly of group euqations may also be regarded as a matrix problem, which may be written as

$$\underline{\underline{A}}\ \underline{\phi} = \underline{S}, \tag{9.2.6}$$

where

$$\underline{\underline{A}} = \begin{bmatrix} A^1 & 0 & 0 \\ 0 & A^2 & 0 \\ 0 & 0 & A^3 \end{bmatrix} \qquad \underline{S} = \underline{E}\ \underline{\phi} + \frac{1}{k}\ \underline{F}\ \underline{\phi}$$

$$\underline{F} = \begin{bmatrix} F^1 \\ F^2 \\ F^3 \end{bmatrix}^T \qquad \underline{E} = \begin{bmatrix} E^1 \\ E^2 \\ E^3 \end{bmatrix}^T .$$

9.3 The Inner Iteration

The inner iteration allows calculation of spatial dependence of fluxes with respect to the boundary conditions. For simple one-dimensional geometries the inner iteration can be avoided and fluxes at each mesh-point calculated by a direct procedure such as Thomas algorithm which is described in Module RS-2, Chapter 2. This algorithm is used in this code.

9.4 The Outer Iteration

The overall matrix problem to be solved is expressed in Eq. (9.2.6) as

$$\underline{\underline{A}}\ \underline{\phi} = \underline{S} \qquad (9.4.1)$$

in which

$$\underline{S} = \underline{E}\ \underline{\phi} + \frac{1}{k}\ \underline{F}\ \underline{\phi} . \qquad (9.4.2)$$

The normal procedure is to begin the solution of the group equations in the highest energy group by using a flux guess for the calculation of the fission source. In the highest group there are no slowing-down scattering terms. Proceeding to the next group, the slowing-down part of the source can be calculated from the new fluxes in group 1; since fission source in this model appears only in the highest group, the fission part of the source in group 2 is zero. The calculation can proceed in this fashion to thermal energy. At the end of the outer iteration we have a completely new flux vector, so that the fission source $\underline{F}\ \underline{\phi}$ may be recalculated and the whole process may be repeated.

The equation which must be solved is

$$(A - E)\phi = \frac{1}{k} F\ \phi. \qquad (9.4.3)$$

The iteration process proceeds by defining a vector

$$\psi = \frac{1}{k} F\phi = \frac{1}{k} S \qquad (9.4.4)$$

where

$$S = F\phi. \qquad (9.4.5)$$

(Note that S denotes the fission source only.)

The iteration is defined by the relation

$$(A - E)\phi^{(p)} = \psi^{(p-1)}. \qquad (9.4.6)$$

From Eq. (9.4.5) we can write

$$S^{(p)} = F\phi^{(p)}. \qquad (9.4.7)$$

By combining Eqs. (9.4.5) and (1.4.7), the p-th iterate of the source reactor is given by

$$\frac{1}{k^{(p)}} S^{(p)} = \psi^{(p - 1)}. \tag{9.4.7}$$

To estimate the eigenvalue one utilizes the fact that when a convergence is being approached, the fission source for one iteration should equal the fission source for the next. In this code the estimate of the eigenvalue is determined in the following fashion. The iteration starts with $k^{(0)}$ equal to 1 and $S^{(0)}$ such that

$$\int_{(\text{vol of core})} S^{(0)} dv = 1 \tag{9.4.8}$$

Then from (1.4.7) and (1.4.4),

$$k^{(1)} = \int_{(\text{vol of core})} S^{(1)} dv, \tag{9.4.9}$$

and similarly

$$k^{(p)} = \int S^{(p)} dv. \tag{9.4.9}$$

The iteration continues until convergence of the eigenvalue $k^{(p)}$ is obtained, i.e.,

$$\left| \frac{k^{(p)} - k^{(p-1)}}{k^{(p)}} \right| < \varepsilon . \tag{9.4.10}$$

The single power iteration described above tends to converge rather slowly and acceleration techniques are used to improve the convergence rate. If we denote the unaccelerated fission source for iteration p by $S^{*(p)}$, then we calculate an accelerated fission source from

$$S^{(p)} = S^{(p-1)} + \omega(S^{*(p)} - S^{(p-1)}). \tag{9.4.11}$$

This form of acceleration is referred to as a first order acceleration. The Chebyshev polynomial method is described Reactor Statics Module, RS-8. The optimum value of ω requires a knowledge of the maximum eigenvalue of the matrix $(A - E)F^{-1}$. Generally this eigenvalue is not known. One of the methods to solve this problem is described in the following section.

9.5 The Exponential Over-Relaxation Technique

The program uses a special technique for the calculation of the source introduced for the subsequent iteration step.

Fission sources are computed from the calculated fluxes at each mesh point as follows

$$S^*_n = \sum_j (\nu\Sigma_f)^j_n \phi^j_n \qquad \begin{array}{l} j = 1,2,3 \\ n = 1,2,\ldots \end{array} \quad . \tag{9.5.1}$$

For the first iteration the initial source-guess will be, e.g.,

$$S^{(0)} = \frac{1}{\Pi R^2} , \tag{9.5.2}$$

where R is the radius of the core. The source for the p-th iteration will be given by formula

$$S_n^{(p)} = S_n^{(p-1)} + \omega(S^*_n - S_n^{(p-1)} , \tag{9.5.3}$$

where ω is the relaxation factor whose optimal value lies between 1 and 2.

The equation (9.5.3) can be rewritten as

$$\begin{aligned} S_n^{(p)} &= S_n^{(p-1)} [1 + \omega(\frac{S^*_n}{S_n^{(p-1)}} - 1)] \\ S_n^p &\approx S_n^{(p-1)} \exp[\omega(\frac{S^*_n}{S_n^{(p-1)}} - 1] \end{aligned} \tag{9.5.4}$$

for $(\omega\frac{S^*_n}{S_n^{(p-1)}} -1) \ll 1$.

The optimal value of the relaxation factor ω is automatically computed during the calculation.

Letting,

$$Q' = \frac{S^*_n}{S_n^{(p-1)}} -1, \tag{9.5.5}$$

we can have two cases:

1) $Q' > 0$.

The exponential function can be expressed as

$$\exp[\omega(\frac{S^*_n}{S_n^{(p-1)}} -1] \simeq 1 + \omega(\frac{S_n}{S_n^{(p-1)}} -1)$$

$$\simeq 2 - (1 - \omega(\frac{S^*_n}{S_n^{(p-1)}} -1)) \tag{9.5.6}$$

$$\simeq 2 - e^{-Q} \quad ,$$

where

$$Q = \omega^* \left| \frac{S^*_n}{S_n^{(p-1)}} -1 \right| . \tag{9.5.7}$$

2) $Q' < 0$.

In this case we have

$$\exp[\omega(\frac{S^*_n}{S_n^{(p-1)}} -1)] = e^{-Q} . \tag{9.5.8}$$

The calculation of the exponential function in the core is speeded up by the following approximations:

For $Q > 0.1 \quad \bar{e}^{Q} \rightarrow \exp[-Q]$

$0.001 < Q \leq 0.1 \quad \bar{e}^{Q} \rightarrow \frac{1 - Q/2}{1 + Q/2}$

$Q < 0.001 \quad \bar{e}^{Q} \rightarrow 1 - Q$.

In order to find the optimum value of ω it is necessary to scan the maximum relative error at each iteration given by the expression

$$\varepsilon^{(p)}(S) = \max_{i}\left(\frac{S_i^{(p)} - S_i^{(p-1)}}{S_i^{(p-1)}}\right) , \qquad (9.5.9)$$

where i runs through all mesh-points. The computation is normally started with ω equal to 1.9. At the end of 20 iterations the convergence ratio is tested. If the convergence is fast enough, let us say, if

$$\frac{\varepsilon^{(10)}(S)}{\varepsilon^{(20)}(S)} > 1.5 , \qquad (9.5.10)$$

the iteration with unchanged ω is continued for another 20 iterations. If the convergence is slow with respect to the above criterion, i.e., the inequality is reversed and if the relative point-wise error oscillates which can be described by the inequality

$$\left|\frac{\varepsilon^{(20)}}{\varepsilon^{(19)}}\left[1 + \left|\varepsilon^{(19)}(S)\right|\right]\right| > 1.0, \qquad (9.5.11)$$

ω is reduced by 0.1 and with this new value of ω the iteration process is continued in the same manner as described above.

9.6 Accuracy Criteria

In this code two criteria for the outer iteration are adopted. The convergence of the multiplication factor k will be reached when the following holds.

$$\left| \frac{k^{(p)} - k^{(p-1)}}{k^{(p)}} \right| < \frac{\varepsilon_1}{5.0} , \qquad (9.6.1)$$

where $k^{(p-1)}$ is the eigenvalue obtained in the previous iteration. Once criticality is obtained, the program proceeds to obtain the pointwise convergence of neutron group fluxes which will be reached when the following condition is fulfilled.

$$\left| \frac{\phi_n^{(p)} - \phi_n^{(p-1)}}{\phi_n^{(p-1)}} \right|_{\max} < \varepsilon_2 . \qquad (9.6.2)$$

With the poison search another convergence criterion must be included which is discussed further.

9.7 Control Search

The program does a control search on a poison or any fictitious material which adjusts the reactor to the critical condition. Let the multiplier of the poison concentration be denoted by X. In general, the parameter X can be applied to any other type of control. By changing X the program finds k, then changes X, finds k again, and so on. In the early stages of the process the k calculations stop when both criteria (9.6.1) and (9.6.2) are satisfied. Then the criterion to guarantee criticality is applied, i.e.,

$$|k(\text{converged}) - k_c| < \varepsilon_1, \tag{9.7.1}$$

if k_c is chosen to be unity, the reactor is critical. Clearly k_c also can be chosen to take into account the presence of other reactivity controls.

The initial guess for the multiplication factor proceeds according to the following formulas:

a) If the first guess for the multiplication factor X is zero, the second guess is

$$X_2 = \Delta X *\{\text{of sign of } (1.0 - k_1)\} \; . \tag{9.7.2}$$

b) If the first guess is non-zero the second guess is given by

$$X_2 = 1.0 + \Delta X *\{[\text{sign of } (1.0 - k_1)]\}* X, \tag{9.7.2}$$

where k is the converged eigenvalue and ΔX is an increment in the parameter X. This formula tries to ensure that X moves in the right direction: it assumes that if X is negative, an increase of X decreases the reactivity, and the converse of this if X is positive (this would be applied, e.g., for the search of fissile isotopic composition). The programs finishes when three conditions (9.6.1), (9.6.2), and (9.7.1) are satisfied.

With the quantities X_1 and X_2 the search is begun and X is varied in order to make k equal to unity. It is easy enough then to make a simple, search procedure such as ordinary "regula falsi," but these processes appear to be very inefficient in this context. The difficulty is that given X, we can find k but the more accurately we require it, the greater the number of iterations is required. One way to go is to improve "regula falsi" process so that the search is accelerated. In ordinary "regula falsi" at each stop, it is one of the limits (a, b) which is used and the last approximation of the root. Instead of that we can use the last two approximations which are closer to the root which is searched for than the limits of the interval (a, b). The formula which is used has the form given by Equation (9.7.5) and is illustrated in Figure 1.

$$a_{n+1} = a_n - f(a_n) * \frac{a_n - a_{n-1}}{f(a_n) - f(a_{n-1})} . \qquad (9.7.4)$$

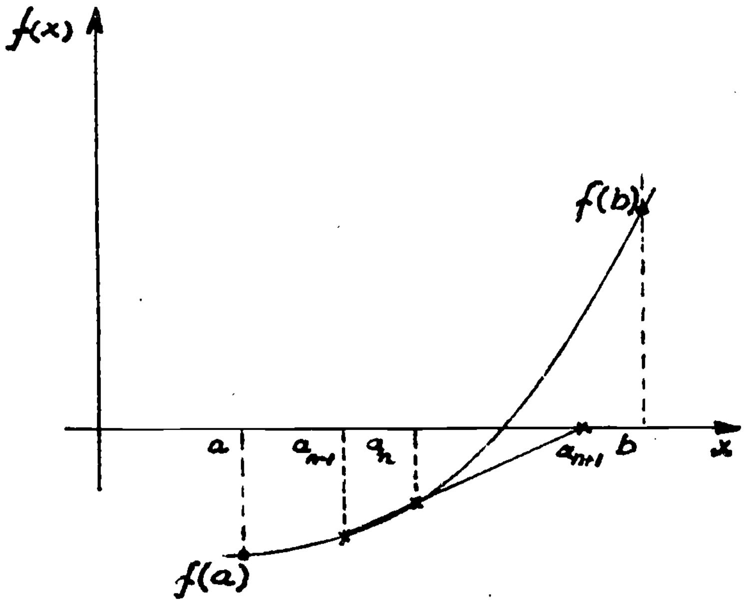


Fig. 1.

The a_1 is found from the formula

$$a_1 = b - f(b)\,\frac{b - a}{f(b) - f(a)}\,. \qquad (9.7.5)$$

Depending on the sign of f(a), f(b), and $f(a_1)$, a_2 is computed from the formula (9.7.6) if $f(a) < 0$, $f(b) > 0$ and $f(a_1) < 0$; if $f(a_1) > 0$ from the formula (9.7.7),

$$a_2 = a_1 - f(a_1)\,\frac{b - a_1}{f(b) - f(a_1)} \qquad (9.7.6)$$

and

$$a_2 = a_1 - f(a_1)\,\frac{a_1 - a}{f(a_1) - f(a)}\,. \qquad (9.7.7)$$

If perchance the point a_3 will appear outside the interval (a, b) then in the following step it will be necessary to consider the closer limit instead of the point a_3. It can be shown that convergence of this method is faster than the ordinary "regular falsi".

9.8 Power Normalization of Neutron Fluxes

The source-normalized power at the point $\vec{r}$ is given by the expression

$$p(\vec{r}) = \sum_1 \kappa_j \Sigma_f^j(\vec{r})\Phi^j(\vec{r}) \quad j = 1,2,3 \tag{9.8.1}$$

where $_j$ stands for energy produced per fission reaction, $\Phi^j(r)$ is the source-normalized flux. In order to get fluxes normalized to the total power output of the reactor we have to multiply the source normalized fluxes by the normalization factor γ given by the formula

$$\gamma = \frac{P|H}{\int_0^R p(\vec{r})\underline{dr}}, \tag{9.8.2}$$

where $\underline{dr} = 2\pi\, rdr$ and H is the height of the reactor. The power-normalized flux Φ' is then given by

$$\Phi_j'(\vec{r}) = \gamma\Phi_j(r). \tag{9.8.3}$$

9.9 Organization of the Program

The code WANDIC has the following limitations:

a) Number of energy groups is three

b) The reactor can be divided into four regions from which the outer one is non-multiplicative. If use of fewer regions is desired, the the entry data for some of these regions will be identical.

c) Memory array space is provided for up to 300 mesh-points.

d) Number of intervals dividing each region must be even.

The code consists of a number of subprograms which perform different parts of calculation and are controlled by the main program.

9.10 The Role of Different Subprograms

PLOT: The subprogram participating in preparation of the output and plotting the related results on the printer.

SIMP: The subprogram performing the integration of functions over the core volume by SIMQSON'S rule.

ZERO: The subprogram which employs the accelerated "regula falsi" technique.

9.11 Flow-Chart

Besides its role as the manager of subprograms, the main program is in charge of entry of data for calculation of fluxes and preparation of results for the output. In Figure 2 the flow-chart of the sequence of calculation is presented.

FLOW-CHART A

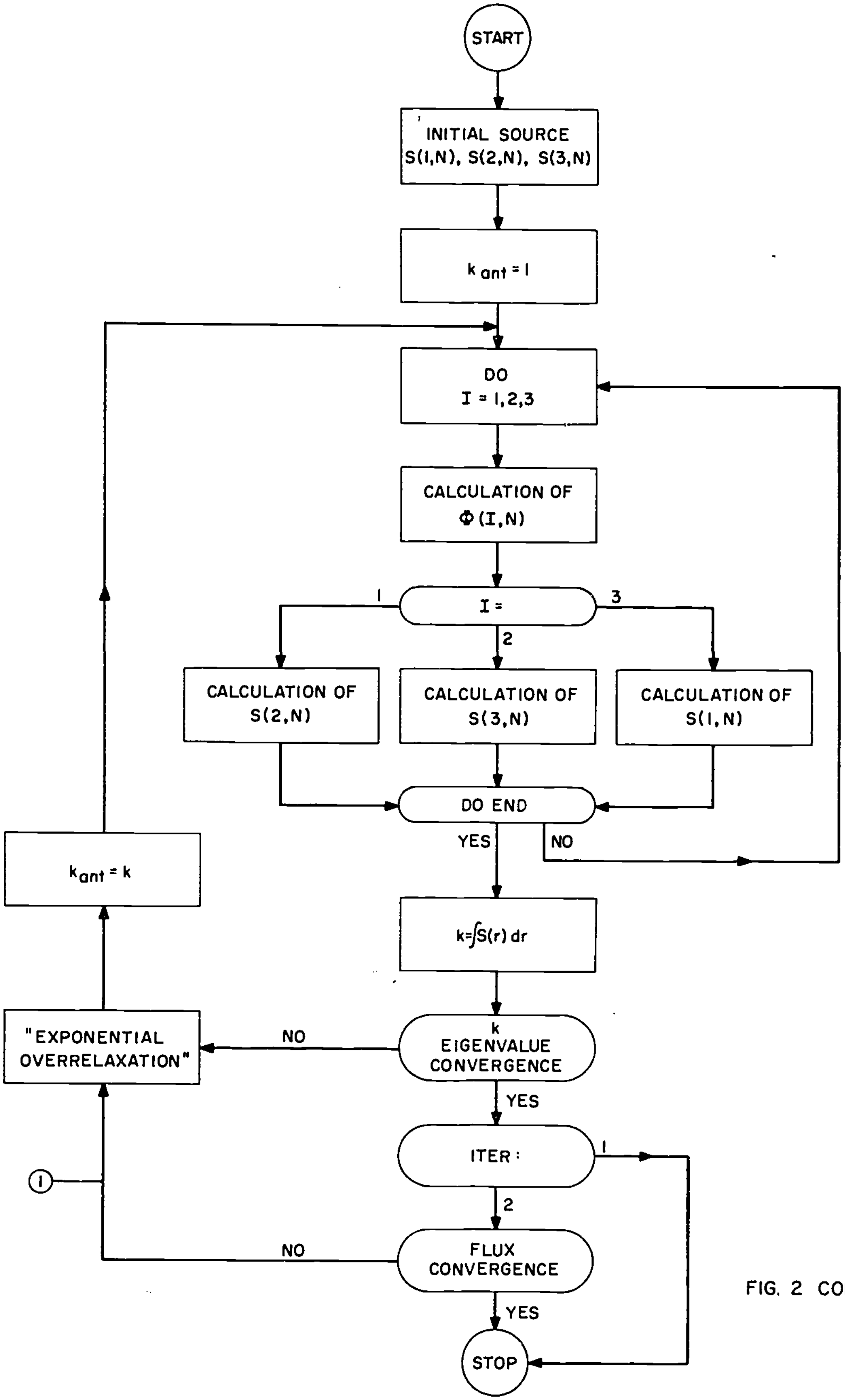


FIG. 2 CON'T.

GENERAL FLOW-CHART OF THE PROGRAM

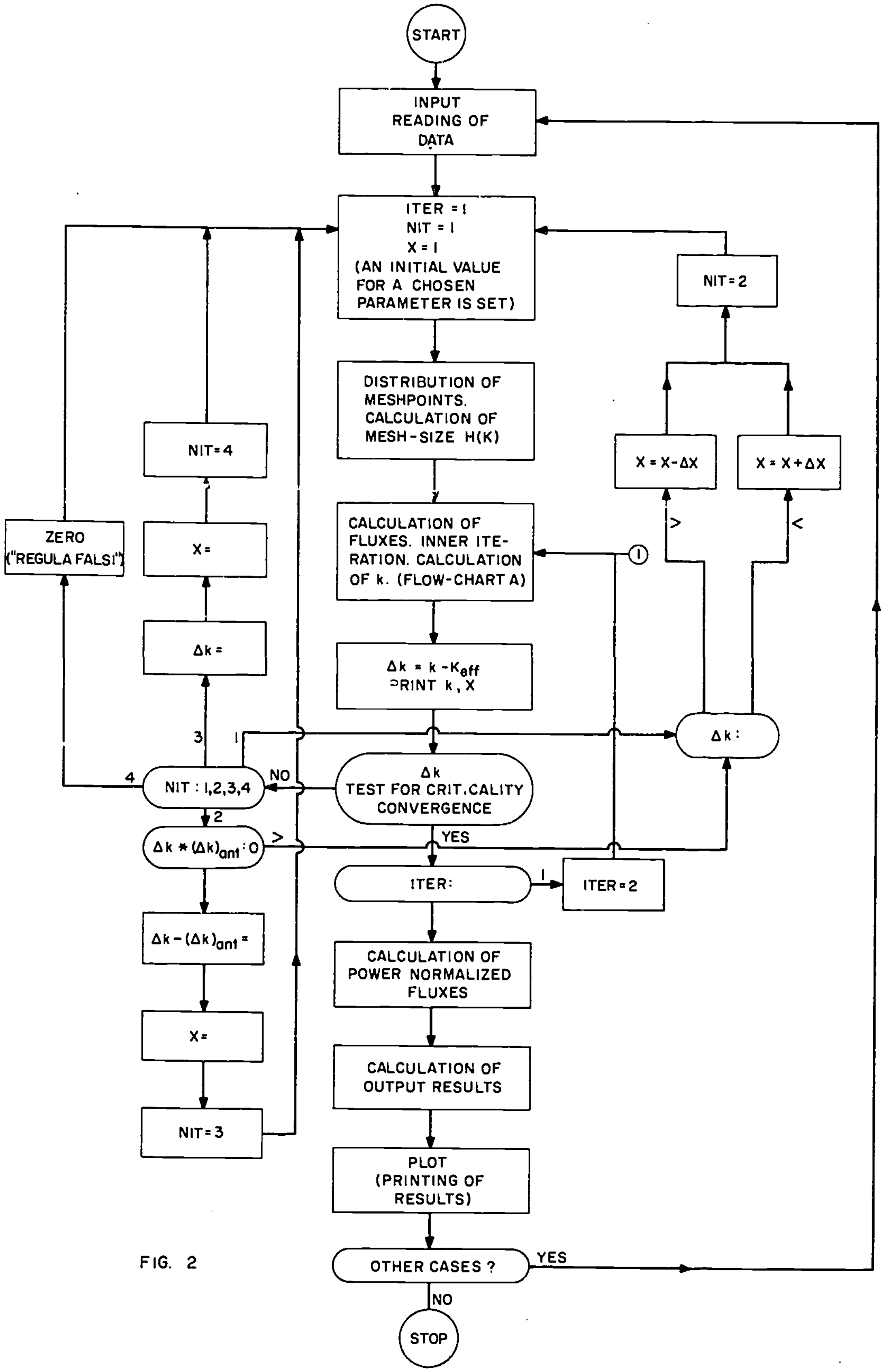


FIG. 2

9.12 Output

The output of the program are:

a) source normalized group fluxes versus radius

b) relative magnitudes of fluxes at each mesh-point with respect to the flux at the symmetry axis of the core

c) ratio of group fluxes

d) eigenvalue of the unpoisoned reactor

e) poison concentration needed for criticality

f) power normalized group fluxes

g) power generated in each fueled region with respective power densities

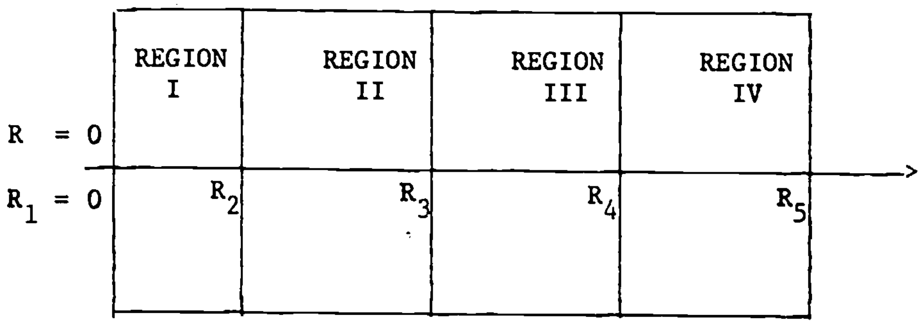
h) for user who wants to watch the iteration process, printing of eigenvalue K computed at each iteration is provided.

9.13 Names of Principal Variables Used by the Program

H(K):	mesh-size of the region K
FLUX(I,N):	neutron flux of the group I at the mesh-point N
SDS(N):	slowing-down source at the mesh-point N
FS(N):	fission source at the mesh-point N
S(N):	source at the mesh-point N
EPS(P):	maximun relative error for the source on the p-th iteration
FME:	$K_c = 1$
XP:	multiplication factor for the control poison cross-section
FMANT:	eigenvalue of the preceding iteration
FPR(K):	power density of the region K.

9.14 Use of the Program for a Simple Problem. Presentation of Entry of Data

The data introduced here are for illustration purposes only. Consider a cylindrical reactor consisting of three different fissionable regions and a reflector (see figure below). The outer radius of the first region is $R_2 = 87.7$ cm, the second $R_3 = 124.00$ cm, $R_4 = 152.00$ cm, $R_5 = 159$ cm.



The data for the problem would start:

1 card: symbols used for reading are

OVREL CONV PREC BH2 SCP POW NINT(1) NINT(2) NINT(3) NINT(4) ICP ICC

where

OVREL: the relaxation factor (Sec. 1.5). This factor for a new problem is put equal to 1.9. Once an "optimum" factor is found, this may be introduced into a set of similar problems (e.g., with the same mesh-point distribution).

CONV: the pointwise flux convergence accuracy number (ε_2). (See Eq. (9.6.2)

PREC: the accuracy (ε_1) for the eigenvalue convergence. (See Eq. (9.6.1).

BH2: axial buckling.

SCP: microscopic cross-section of a poison material for the third group energy level in barns.

POW: thermal output of the reactor in watts.

NINT(K): number of intervals per region K.

ICP: control search parameter. If its value is

1...control poison is considered in region 1

2...region 2

3...region 3

4...all fueled regions

5...regions 1 and 2

6...regions 2 and 3

ICC: is the case control parameter (equal to zero, if only one case is to be treated; positive, if otherwise)

The three group diffusion equations in one of the multiplicative powers assumes, in general, the following form

$$D_1\Delta^2\Phi_1 - (\Sigma_{a_1} + \Sigma_{S_1 1\to 2})\Phi_1 + \sum_{i=1}^{3} \frac{(\nu\Sigma_f)_i\Phi_i}{k} = 0$$

$$D_2\Delta^2\Phi_2 - (\Sigma_{a_2} + \Sigma_{S_1 2\to 3})\Phi_2 + \Sigma_{S_1 1\to 2}\Phi_1 = 0$$

$$D_3\Delta^2\Phi_3 - \Sigma_{a_3}\Phi_3 \qquad + \Sigma^1_{S_1 2\to 3}\Phi_2 = 0$$

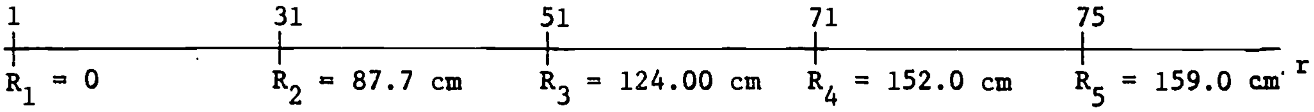
For example, with calculated macroscopic cross-sections

$$1.7\,\Delta^2\Phi_1 - (0.004 + 0.06)\Phi_1 + \frac{1}{k}(0.43\,\Phi_1 + 0.015\,\Phi_2 + .16\,\Phi_3 = 0$$

$$0.85\,\Delta^2\Phi_2 - (0.025 + 0.05)\Phi_2 + 0.06\,\Phi_1 \qquad = 0$$

$$0.39\,\Delta^2\Phi_3 - 0.13\,\Phi_3 \qquad + 0.05\,\Phi_2 \qquad\qquad\qquad = 0$$

Let us divide the region I into 30 equal intervals, the regions II and III into 20 intervals and region IV into 4 intervals. The mesh-points in the radial direction will be numbered as shown in the figure below.



Let us assume that the axial buckling BH2 = $1.56 * 10^{-3}\text{cm}^2$; we shall use poison search in all fissionable regions, ICP = 4, the microscopic absorption cross-section of the poison material σ = 2109 bn, and this will be the only case to be treated. The power output of the reactor is 2441 MW.

OVREL	CONV	PREC	BH2	SCP	POW
1.9E - 01	1.E - 02	1.E - 04	156.E - 05	2109.E 00	2441.E + 06
N_1	N_2	N_3	N_4	ICP	ICC
30	20	20	04	04	0

<u>2, 3, 4th Cards</u>:

The second card carries physical data for the first region--group 1, the third those for group 2, the fourth for group 3. Data are read in the following order (the symbols are self-explanatory; means $\frac{\text{watts}}{\text{fission}}$).

$$D_j \quad \Sigma_{aj} \quad \Sigma_{r_1 j\to j+1} \quad (\nu\Sigma_f)_j \quad (\ \Sigma_f)_j$$

2nd:	17.E - 1	4.E - 3	6.E - 2	43.E - 2	93.E - 15
3rd:	85.E - 2	25.E - 3	5.E - 2	1.E - 2	19.E - 14
4th:	39.E - 2	13.E - 2	0.E + 0	16.E - 2	21.E - 13

Other 6 cards carry the similar data for regions II and III.

<u>11, 12, 13th Cards</u>:

These cards carry the data for the outer non-fissionable region in order of groups 1, 2, 3. These data are

$$D_j \quad \Sigma_{aj} \quad \Sigma_{S\ j \to j+1}$$

Let the reflector have the following data in order of groups 1, 2, 3

11th:	19.E - 1	36.E - 5	26.E - 3
12th:	92.E - 2	57.E - 5	28.E - 3
13th:	31.E - 2	85.E - 4	0.E 0

<u>14th Card</u>:

This card carries outer radii of regions with increasing order

R_2	R_3	R_4	R_5
877.E - 1	124.E 0	152.E 0	159.E 0

15th Card:

The value carried by this card is the increment of the multiplier adjusting the poison concentration at early stages of control search.

PP

0.05

9.15 Rules for Card Punching

The format of data read is fixed: real variables are read with the format E 10.0, the integer ones with the format I2 with one blank space separating them. On the last card PP, variable is read with the format F5.3.

```
                    C      MAIN PROGRAM
                    C     PROGRAM WANDIC
                    C
                    C
                    C     THE PROGRAM SOLVES THE THREE-GROUP DIFFUSION EQUATIONS
                    C     FOR A CYLINDRICAL REACTOR CONSISTING OF THREE FUELED REGIONS
                    C     AND A REFLECTOR
                    C
                    C
                    C     INPUT-MEANING OF SYMBOLS
                    C
                    C     NINT...NUMBER OF INTERVALS FOR EACH REGION
                    C     OVREL...OVERRELAXATION FACTOR
                    C     CONV...PRECISION FOR THE POINTWISE FLUX CONVERGENCE
                    C     X...MULTIPLIER FOR THE CONTROL SEARCH PARAMETER
                    C     D...DIFFUSION COEFFICIENT
                    C     SCA...MACROSCOPIC ABSORPTION CROSS-SECTION
                    C     XNF...MACROSCOPIC FISSION CROSS-SECTION*NU
                    C     XKF...MACROSCOPIC FISSION CROSS-SECTION*KAPPA
                    C     SR...SCATTERING CROSS-SECTION INTO THE LOWER ADJACENT GROUP
                    C     BH2...TRANSVERSE BUCKLING
                    C     RR...OUTER RADIUS OF THE REGIONS 1,2,3,4
                    C     POW...POWER OUTPUT OF THE REACTOR
                    C     SCP...MICROSCOPIC CROSS-SECTION OF THE CONTROL POISON
                    C     ICP...COTROL PARAMETER FOR THE POISON SEARCH
                    C     1...REGION 1
                    C     2...REGION 2
                    C     3...REGION 3
                    C     4...ALL FUELED REGIONS
                    C     5...REGIONS 1&2
                    C     6...REGIONS 2&3
                    C     ICC...PROGRAM CONTROL INDICATING THE NUMBER OF CASES
                    C           POSITIVE INTEGER...SEVERAL CASES TO BE TREATED
                    C           0...ONLY ONE CASE
                    C
                    C
                    C     LIMITATIONS OF THE CODE
                    C
                    C     1ST:NINT(K) MUST BE EVEN NUMBER
                    C     2ND: TOTAL NUMBER OF MESH-POINTS BE LESS THAN 301
                    C
0001                      SUBROUTINE PLOT (LI,N,LP)
0002                      REAL MX,MN,PRNT(6,9),DISP(6),DY,X(300),Y(3,300),H(4)
0003                      INTEGER LI,LP,PT,STRG(101),BLK,PER(21),AST,I,N,NINT(4)
0004                      COMMON Y,H,NINT
0005                      DATA PRNT/4HFAST,4H FLU,4HX - ,4HGROU,4HP 1 ,1H ,4HRESO,4HNANC,4HE
                         1 FL,4HUX -,4HGROU,4HP 2 ,4HSLOW,4H FLU,4HX - ,4HGROU,4HP 3 ,1H ,4H
                         2GROU,4HP 1 ,1H ,1H ,1H ,1H ,4HGROU,4HP 2 ,1H ,1H ,1H ,1H ,4HGROU,4
                         3HP 3 ,1H ,1H ,1H ,1H ,4HGROU,4HP 1 ,4H/ GR,4HOUP ,4H3   ,1H ,4HGRO
                         4U,4HP 2 ,4H/ GR,4HOUP ,4H3   ,1H ,4HGROU,4HP 1 ,4H/ GR,4HOUP ,4H2
                         5  ,1H /,BLK,AST/1H ,1H*/,PER/21*'.'/
0006                      DO 1 I=1,101
0007                1     STRG(I)=BLK
                    C
                    C     CALCULATION OF RADII CORRESPONDING TO THE MESH-POINTS
                    C
0008                      X(1)=0.0
0009                      K=1
```

```
 0010               DO 2 I=2,N                                                  A  59
 0011               X(I)=X(I-1)+H(K)                                            A  60
 0012               IF (I.EQ.NINT(K)) K=K+1                                     A  61
 0013        2      CONTINUE                                                    A  62
 0014               WRITE (6,9) (PRNT(I,LP),I=1,6)                              A  63
 0015               MN=Y(LI,1)                                                  A  64
 0016               MX=MN                                                       A  65
 0017               DO 6 I=2,N                                                  A  66
 0018               IF (MX-Y(LI,I)) 3,4,4                                       A  67
 0019        3      MX=Y(LI,I)                                                  A  68
 0020               GO TO 6                                                     A  69
 0021        4      IF (MN-Y(LI,I)) 6,6,5                                       A  70
 0022        5      MN=Y(LI,I)                                                  A  71
 0023        6      CONTINUE                                                    A  72
 0024               DY=(MX-MN)/100                                              A  73
 0025               DO 7 I=1,6                                                  A  74
 0026        7      DISP(I)=MN+(I-1)*20*DY                                      A  75
 0027               WRITE (6,10) DISP                                           A  76
 0028               WRITE (6,11) (PER(I),I=1,21)                                A  77
 0029               DO 8 I=1,N                                                  A  78
 0030               PT=(Y(LI,I)-MN)/DY+1.5                                      A  79
 0031               STRG(PT)=AST                                                A  80
 0032               WRITE (6,12) X(I),STRG                                      A  81
 0033        8      STRG(PT)=BLK                                                A  82
 0034               RETURN                                                      A  83
             C                                                                  A  84
 0035        9      FORMAT (1H1,45X,7HPLOT OF,1X,6A4,//,57X,6HZ-AXIS)           A  85
 0036        10     FORMAT (11X,6(E10.3,10X))                                   A  86
 0037        11     FORMAT (16X,21(A1,4X),/,7H R-AXIS)                          A  87
 0038        12     FORMAT (E11.3,5X,101A1)                                     A  88
 0039               END                                                         A  89
```

```
FORTRAN IV G LEVEL  21                    MAIN              DATE = 74327          12/56/19

                     C      INTEGRATION SIMPSON FOR N POINTS. N MUST BE EVEN.                 B   1
                     C      N MUST BE WITHIN 4 AND 100                                        B   2
  0001                      FUNCTION SIMP (DX,XX,N,J1)                                        B   3
  0002                      DIMENSION XX(100), DX(4)                                          B   4
  0003                      SIMP=XX(1)+XX(N)+4.*XX(N-1)                                       B   5
  0004                      J=(N-3)/2                                                         B   6
  0005                      DO 1 I=1,J                                                        B   7
  0006               1      SIMP=SIMP+4.*XX(2*I)+2.*XX(2*I+1)                                 B   8
  0007                      SIMP=SIMP*DX(J1)/3.                                               B   9
  0008                      RETURN                                                            B  10
  0009                      END                                                               B  11
```

```
FORTRAN IV G LEVEL  21                 MAIN              DATE = 74327           12/56/19

C     ACCELERATED 'REGULA FALSI'
C
C
      SUBROUTINE ZERO (A1,A2,F1,F2,A10,A20,DF1,DF2,RAD)
    1 RAD=A2-F2*(A2-A1)/(F2-F1)
      VARA=A2-F2*(A2-A1)/(F2-F1)
      HH=ABS(A20-A10)
      H1=ABS(VARA-A10)
      H2=ABS(VARA-A20)
      IF (H1-H2) 2,8,3
    2 TEMP=H2
      L=2
      GO TO 4
    3 TEMP=H1
      L=1
    4 IF (TEMP-HH) 8,5,5
    5 GO TO (6,7), L
    6 A2=A20
      F2=DF2
      GO TO 1
    7 A2=A10
      F2=DF1
      GO TO 1
    8 RETURN
      END
```

```
                C      ENTRY OF DATA AND DIMENSIONS OF ARRAYS                                  D    1
 0001                  DIMENSION NINT(4), RR(5), H(4), EPS(30), SCAO(3,3)                      D    2
 0002                  DIMENSION SCA(3,4), SR(3,4), D(3,4), XNF(3,3), XKF(3,3)                 D    3
 0003                  DIMENSION SANT(300), DFMAX(3), FS(300), SUM(300), SDS(300), AIDD(3      D    4
                     1,300)                                                                    D    5
 0004                  DIMENSION ALFA(300), BETA(300), S(300), FLUX(3,300), GX(100), FPR(      D    6
                     13)                                                                       D    7
 0005                  COMMON AIDD,H,NINT                                                      D    8
 0006           1      READ (5,142) OVREL,CONV,PREC,BH2,SCP,POW,NINT,ICP,ICC                   D    9
 0007                  READ (5,143) ((D(I,K),SCA(I,K),SR(I,K),XNF(I,K),XKF(I,K),I=1,3),K=      D   10
                     11,3)                                                                     D   11
 0008                  READ (5,144) (D(I,4),SCA(I,4),SR(I,4),I=1,3)                            D   12
 0009                  READ (5,145) (RR(K),K=2,5)                                              D   13
 0010                  READ (5,146) PP                                                         D   14
                C                                                                              D   15
                C      PRINTING OF DATA                                                        D   16
                C                                                                              D   17
 0011                  RR(1)=0.0                                                               D   18
 0012                  WRITE (6,147)                                                           D   19
 0013                  WRITE (6,148)                                                           D   20
 0014                  WRITE (6,149) (RR(L),L=1,5)                                             D   21
 0015                  WRITE (6,150) NINT,OVREL,PREC,CONV                                      D   22
 0016                  WRITE (6,151) BH2,SCP                                                   D   23
 0017                  WRITE (6,152) ((SCA(I,K),I=1,3),K=1,4)                                  D   24
 0018                  WRITE (6,153) ((D(I,K),I=1,3),K=1,4)                                    D   25
 0019                  WRITE (6,154) ((SR(I,K),I=1,3),K=1,4)                                   D   26
 0020                  WRITE (6,155) ((XNF(I,K),I=1,3),K=1,3)                                  D   27
 0021                  WRITE (6,156) ((XKF(I,K),I=1,3),K=1,3)                                  D   28
 0022                  WRITE (6,157) POW                                                       D   29
 0023                  WRITE (6,158)                                                           D   30
                C                                                                              D   31
                C      NUMBERING OF MESH-POINTS                                                D   32
                C                                                                              D   33
 0024                  PI=3.14159265                                                           D   34
 0025                  CF=1.6021E-13                                                           D   35
 0026                  TEMP=1.0                                                                D   36
 0027                  ITER=1                                                                  D   37
 0028                  NIT=1                                                                   D   38
 0029                  NINT(1)=NINT(1)+1                                                       D   39
 0030                  N1=NINT(1)                                                              D   40
 0031                  DO 2 K=2,4                                                              D   41
 0032           2      NINT(K)=NINT(K)+NINT(K-1)                                               D   42
 0033                  N2=NINT(2)                                                              D   43
 0034                  N3=NINT(3)                                                              D   44
 0035                  N3M1=N3-1                                                               D   45
 0036                  N4=NINT(4)                                                              D   46
 0037                  N4M1=N4-1                                                               D   47
 0038                  XP=1.                                                                   D   48
 0039                  JJ=1                                                                    D   49
 0040                  DO 3 K=1,4                                                              D   50
 0041                  DO 3 I=1,3                                                              D   51
 0042           3      SCA(I,K)=SCA(I,K)+SR(I,K)+BH2*D(I,K)                                    D   52
 0043                  DO 4 K=1,3                                                              D   53
 0044           4      SCAO(3,K)=SCA(3,K)                                                      D   54
 0045                  DO 5 N=1,N4M1                                                           D   55
 0046                  FS(N)=0.0                                                               D   56
 0047           5      SUM(N)=0.0                                                              D   57
                C                                                                              D   58
```

```
              C      CALCULATION OF H(K)                                          D  59
              C                                                                   D  60
0048                 DO 8 K=1,4                                                   D  61
0049                 IF (K-1) 8,6,7                                               D  62
0050          6      TEMP=NINT(1)-1                                               D  63
0051                 GO TO 8                                                      D  64
0052          7      TEMP=NINT(K)-NINT(K-1)                                       D  65
0053          8      H(K)=(RR(K+1)-RR(K))/TEMP                                    D  66
              C                                                                   D  67
              C      POISON CONTROL BLOCK                                         D  68
              C                                                                   D  69
0054          9      GO TO (10,10,10,11,12,13), ICP                               D  70
0055          10     SCA(3,ICP)=SCA0(3,ICP)*XP                                    D  71
0056                 GO TO 16                                                     D  72
0057          11     KF=1                                                         D  73
0058                 KL=3                                                         D  74
0059                 GO TO 14                                                     D  75
0060          12     KF=1                                                         D  76
0061                 KL=2                                                         D  77
0062                 GO TO 14                                                     D  78
0063          13     KF=2                                                         D  79
0064                 KL=3                                                         D  80
0065          14     DO 15 K=KF,KL                                                D  81
0066          15     SCA(3,K)=SCA0(3,K)*XP                                        D  82
0067                 JJ=1                                                         D  83
              C                                                                   D  84
              C      GENERATION OF THE INITIAL FAST SOURCE                        D  85
              C                                                                   D  86
0068          16     S(1)=1./(RR(4)*RR(4)*PI)                                     D  87
0069                 ITC=1                                                        D  88
0070                 SANT(1)=S(1)                                                 D  89
0071                 DO 21 N=2,N4                                                 D  90
0072                 IF (N-N3) 18,19,17                                           D  91
0073          17     S(N)=0.0                                                     D  92
0074                 GO TO 21                                                     D  93
0075          18     S(N)=S(1)                                                    D  94
0076                 GO TO 20                                                     D  95
0077          19     S(N3)=S(1)*H(3)/(H(3)+H(4))                                  D  96
0078          20     SANT(N)=S(N)                                                 D  97
0079          21     CONTINUE                                                     D  98
0080                 FMANT=1.0                                                    D  99
              C                                                                   D 100
              C                                                                   D 101
              C      CALCULATION OF FLUXES                                        D 102
              C                                                                   D 103
0081          22     DO 58 I=1,3                                                  D 104
0082                 TEMP=H(1)*H(1)*SCA(I,1)+4.*D(I,1)                            D 105
0083                 ALFA(2)=4.*D(I,1)/TEMP                                       D 106
0084                 BETA(2)=S(1)*H(1)*H(1)/TEMP                                  D 107
0085                 R=0.0                                                        D 108
0086                 K=1                                                          D 109
0087                 DO 26 N=2,N4M1                                               D 110
0088                 IF (N-NINT(K)) 23,24,23                                      D 111
0089          23     R=R+H(K)                                                     D 112
0090                 AN=(1.+H(K)/(2.*R))*D(I,K)/(H(K)*H(K))                       D 113
0091                 CN=(1.-H(K)/(2.*R))*D(I,K)/(H(K)*H(K))                       D 114
0092                 BN=AN+CN+SCA(I,K)                                            D 115
0093                 GO TO 25                                                     D 116
```

```
 0094         24     K=K+1                                                                  D 117
 0095                R=RR(K)                                                                D 118
 0096                TEMP=(H(K-1)+H(K))*.5                                                  D 119
 0097                AN=(1.+H(K)/(2.*R))*D(I,K)/(H(K)*TEMP)                                 D 120
 0098                CN=(1.-H(K-1)/(2.*R))*D(I,K-1)/(H(K-1)*TEMP)                           D 121
 0099                BN=AN+CN+(SCA(I,K)*H(K)+SCA(I,K-1)*H(K-1))/(H(K)+H(K-1))               D 122
 0100         25     TEMP=BN-CN*ALFA(N)                                                     D 123
 0101                ALFA(N+1)=AN/TEMP                                                      D 124
 0102         26     BETA(N+1)=(S(N)+CN*BETA(N))/TEMP                                       D 125
 0103                BM=CN*(3.+H(4)/(1.066*D(I,4)))-AN                                      D 126
 0104                CM=4.*CN-BN                                                            D 127
 0105                GO TO (28,27), ITER                                                    D 128
 0106         27     TEMP=FLUX(I,N4)                                                        D 129
 0107         28     FLUX(I,N4)=(S(N4M1)+CM*BETA(N4))/(BM-CM*ALFA(N4))                      D 130
 0108                GO TO (30,29), ITER                                                    D 131
 0109         29     DFMAX(I)=ABS((TEMP-FLUX(I,N4))/TEMP)                                   D 132
 0110         30     DO 35 N=1,N4M1                                                         D 133
 0111                L=N4-N                                                                 D 134
 0112                GO TO (32,31), ITER                                                    D 135
 0113         31     TEMP=FLUX(I,L)                                                         D 136
 0114         32     FLUX(I,L)=ALFA(L+1)*FLUX(I,L+1)+BETA(L+1)                              D 137
 0115                GO TO (35,33), ITER                                                    D 138
 0116         33     DFMAX(I)=ABS((TEMP-FLUX(I,L))/TEMP)                                    D 139
 0117                IF (DFMAX(I)-TEMP) 34,35,35                                            D 140
 0118         34     DFMAX(I)=TEMP                                                          D 141
 0119         35     CONTINUE                                                               D 142
              C                                                                             D 143
              C      CALCULATION OF SOURCE FOR THE FOLLOWING GROUP                          D 144
              C                                                                             D 145
 0120                K=1                                                                    D 146
 0121                DO 58 N=1,N4M1                                                         D 147
 0122                IF (N.GT.NINT(3)) GO TO 40                                             D 148
 0123                IF (N-NINT(K)) 36,40,36                                                D 149
 0124         36     GO TO (38,38,37), I                                                    D 150
 0125         37     SDS(N)=0.0                                                             D 151
 0126                GO TO 39                                                               D 152
 0127         38     SDS(N)=SR(I,K)*FLUX(I,N)                                               D 153
 0128         39     FS(N)=XNF(I,K)*FLUX(I,N)                                               D 154
 0129                GO TO 53                                                               D 155
 0130         40     K=K+1                                                                  D 156
 0131                IF (K-4) 45,41,50                                                      D 157
 0132         41     GO TO (43,43,42), I                                                    D 158
 0133         42     SDS(N)=0.0                                                             D 159
 0134                TEMP1=0.0                                                              D 160
 0135                GO TO 44                                                               D 161
 0136         43     SDS(N)=SR(I,K)*FLUX(I,N)                                               D 162
 0137                TEMP1=SR(I,K-1)*FLUX(I,N)                                              D 163
 0138         44     TEMP2=XNF(I,K-1)*FLUX(I,N)                                             D 164
 0139                FS(N)=0.0                                                              D 165
 0140                GO TO 49                                                               D 166
 0141         45     GO TO (47,47,46), I                                                    D 167
 0142         46     SDS(N)=0.0                                                             D 168
 0143                TEMP1=0.0                                                              D 169
 0144                GO TO 48                                                               D 170
 0145         47     SDS(N)=SR(I,K)*FLUX(I,N)                                               D 171
 0146                TEMP1=SR(I,K-1)*FLUX(I,N)                                              D 172
 0147         48     FS(N)=XNF(I,K)*FLUX(I,N)                                               D 173
 0148                TEMP2=XNF(I,K-1)*FLUX(I,N)                                             D 174
```

```
0149          49     TEMP=H(K)+H(K-1)                                            D 175
0150                 SDS(N)=(SDS(N)*H(K)+TEMP1*H(K-1))/TEMP                      D 176
0151                 FS(N)=(FS(N)*H(K)+TEMP2*H(K-1))/TEMP                        D 177
0152                 GO TO 53                                                    D 178
0153          50     GO TO (52,52,51), I                                         D 179
0154          51     SDS(N)=0.0                                                  D 180
0155                 GO TO 54                                                    D 181
0156          52     SDS(N)=SR(I,4)*FLUX(I,N)                                    D 182
0157                 GO TO 54                                                    D 183
0158          53     SUM(N)=SUM(N)+FS(N)                                         D 184
0159          54     GO TO (56,56,55), I                                         D 185
0160          55     IF (N.GT.NINT(3)) GO TO 57                                  D 186
0161                 S(N)=SUM(N)                                                 D 187
0162                 SUM(N)=0.0                                                  D 188
0163                 GO TO 58                                                    D 189
0164          56     S(N)=SDS(N)                                                 D 190
0165                 GO TO 58                                                    D 191
0166          57     S(N)=0.0                                                    D 192
0167          58     CONTINUE                                                    D 193
              C                                                                  D 194
              C      INTEGRATION OF THE SOURCE                                   D 195
              C                                                                  D 196
0168                 FMULT=S(N3)*RR(4)*H(4)/3.                                   D 197
0169                 DO 63 K=1,3                                                 D 198
0170                 GO TO (59,60,60), K                                         D 199
0171          59     L=0                                                         D 200
0172                 GO TO 61                                                    D 201
0173          60     L=NINT(K-1)-1                                               D 202
0174          61     M=NINT(K)-L                                                 D 203
0175                 R=RR(K)                                                     D 204
0176                 DO 62 N=1,M                                                 D 205
0177                 ITEMP=N+L                                                   D 206
0178                 GX(N)=S(ITEMP)*R                                            D 207
0179          62     R=R+H(K)                                                    D 208
0180          63     FMULT=FMULT+SIMP(H,GX,M,K)                                  D 209
0181                 FMULT=FMULT*2.*PI                                           D 210
0182                 WRITE (6,159) FMULT                                         D 211
0183                 IF (ABS(FMULT-FMANT)/FMULT-PREC/5.) 85,64,64                D 212
              C                                                                  D 213
              C      PREPARATION OF ITERATIONS                                   D 214
              C                                                                  D 215
0184          64     RPSP=0.0                                                    D 216
0185                 DO 66 N=1,N3                                                D 217
0186                 S(N)=S(N)/FMULT                                             D 218
0187                 EMAX=ABS((S(N)-SANT(N))/SANT(N))                            D 219
0188                 IF (EMAX-RPSP) 66,66,65                                     D 220
0189          65     RPSP=EMAX                                                   D 221
0190          66     CONTINUE                                                    D 222
0191                 EPS(JJ)=RPSP                                                D 223
0192                 IF (JJ-20) 72,67,67                                         D 224
0193          67     IF (ABS(EPS(10)/EPS(20))-1.5) 68,71,71                      D 225
0194          68     IF (ABS(EPS(20)/EPS(19)*(1.+ABS(EPS(19))))-1.) 71,69,69     D 226
0195          69     GO TO (70,71), ITER                                         D 227
0196          70     OVREL=OVREL-0.1                                             D 228
0197          71     JJ=1                                                        D 229
0198          72     DO 84 N=1,N3                                                D 230
0199                 Q=S(N)/SANT(N)-1.                                           D 231
0200                 IF (Q) 73,74,74                                             D 232
```

```
0201     73    K1=1                                                        D 233
0202           GO TO 75                                                    D 234
0203     74    K1=2                                                        D 235
0204     75    Q=ABS(Q)*CVREL                                              D 236
0205           IF (Q-0.1) 77,76,76                                         D 237
0206     76    Q=1.0/EXP(Q)                                                D 238
0207           GO TO 80                                                    D 239
0208     77    IF (Q-.001) 79,78,78                                        D 240
0209     78    Q=(1.-Q/2.)/(1.+Q/2.)                                       D 241
0210           GO TO 80                                                    D 242
0211     79    Q=1.-Q                                                      D 243
0212     80    GO TO (81,82), K1                                           D 244
0213     81    S(N)=SANT(N)*Q                                              D 245
0214           GO TO 83                                                    D 246
0215     82    S(N)=SANT(N)*(2.-Q)                                         D 247
0216     83    SANT(N)=S(N)                                                D 248
0217     84    CONTINUE                                                    D 249
0218           FMANT=FMULT                                                 D 250
0219           JJ=JJ+1                                                     D 251
0220           ITC=ITC+1                                                   D 252
0221           IF (ITC.GT.400) GO TO 140                                   D 253
0222           GO TO 22                                                    D 254
0223     85    GO TO (89,86), ITER                                         D 255
0224     86    DFMM=0.0                                                    D 256
0225           DO 88 I=1,3                                                 D 257
0226           IF (DFMAX(I)-DFMM) 88,88,87                                 D 258
0227     87    DFMM=DFMAX(I)                                               D 259
0228     88    CONTINUE                                                    D 260
0229           IF (DFMM-CONV) 89,64,64                                     D 261
0230     89    FME=1.                                                      D 262
0231           DFMUL=FMULT-FME                                             D 263
0232           WRITE (6,160) XP,FMULT                                      D 264
0233           IF (XP.EQ.1.0) EIGEN=FMULT                                  D 265
0234           IF (ABS(DFMUL)-PREC) 104,90,90                              D 266
0235     90    GO TO (91,92,99,103), NIT                                   D 267
0236     91    DFM1=DFMUL                                                  D 268
0237           NIT=2                                                       D 269
0238           GO TO 93                                                    D 270
0239     92    IF (DFMUL*DFM1) 95,104,93                                   D 271
0240     93    IF (DFMUL) 94,104,94                                        D 272
0241     94    X1=XP                                                       D 273
0242           XP=XP+PP*DFMUL/ABS(DFMUL)
0243           DFM1=DFMUL
0244           GO TO 9                                                     D 275
0245     95    IF (DFMUL) 96,104,97                                        D 276
0246     96    DF2=DFM1                                                    D 277
0247           DF1=DFMUL                                                   D 278
0248           A20=X1                                                      D 279
0249           A10=XP                                                      D 280
0250           XP=X1-DFM1*(X1-XP)/(DFM1-DFMUL)                             D 281
0251           GO TO 98                                                    D 282
0252     97    DF2=DFMUL                                                   D 283
0253           DF1=DFM1                                                    D 284
0254           A20=XP                                                      D 285
0255           A10=X1                                                      D 286
0256           XP=XP-DFMUL*(XP-X1)/(DFMUL-DFM1)                            D 287
0257     98    NIT=3                                                       D 288
0258           X1=XP                                                       D 289
```

```
 0259                    DFM1=DFMUL                                                          D 290
 0260                    GO TO 9                                                             D 291
 0261          99        NIT=4                                                               D 292
 0262                    DFM1=DFMUL                                                          D 293
 0263                    X1=XP                                                               D 294
 0264                    IF (DFMUL) 100,104,101                                              D 295
 0265          100       XP=X1-DFM1*(A20-X1)/(DF2-DFM1)                                      D 296
 0266                    GO TO 102                                                           D 297
 0267          101       XP=X1-DFM1*(X1-A10)/(DFM1-DF1)                                      D 298
 0268          102       XANT=XP                                                             D 299
 0269                    GO TO 9                                                             D 300
 0270          103       CALL ZERO (X1,XANT,DFM1,DFMUL,A10,A20,DF1,DF2,XP)                   D 301
 0271                    X1=XANT                                                             D 302
 0272                    XANT=XP                                                             D 303
 0273                    DFM1=DFMUL                                                          D 304
 0274                    GO TO 9                                                             D 305
 0275          104       GO TO (105,106), ITER                                               D 306
 0276          105       ITER=2                                                              D 307
 0277                    WRITE (6,161) ITER                                                  D 308
 0278                    GO TO 64                                                            D 309
               C                                                                             D 310
               C         PREPARATION OF OUTPUT                                               D 311
               C         CALCULATION OF POWER NORMALIZED FLUXES                              D 312
               C                                                                             D 313
 0279          106       FP=0.0                                                              D 314
 0280                    DO 107 N=1,N3                                                       D 315
 0281          107       SUM(N)=0.0                                                          D 316
 0282                    K=1                                                                 D 317
 0283                    DO 110 I=1,3                                                        D 318
 0284                    DO 110 N=1,N3M1                                                     D 319
 0285                    IF (N-NINT(K)) 108,109,108                                          D 320
 0286          108       FS(N)=XKF(I,K)*FLUX(I,N)                                            D 321
 0287                    GO TO 110                                                           D 322
 0288          109       K=K+1                                                               D 323
 0289                    TEMP=XKF(I,K-1)*FLUX(I,N)                                           D 324
 0290                    FS(N)=XKF(I,K)*FLUX(I,N)                                            D 325
 0291                    FS(N)=(FS(N)*H(K)+TEMP*H(K-1))/(H(K)+H(K-1))                        D 326
 0292          110       SUM(N)=SUM(N)+FS(N)                                                 D 327
 0293                    TEMP=H(3)/(H(3)+H(4))                                               D 328
 0294                    DO 111 I=1,3                                                        D 329
 0295          111       SUM(N3)=SUM(N3)+XKF(I,3)*FLUX(I,N3)*TEMP                            D 330
 0296                    DO 119 K=1,3                                                        D 331
 0297                    GO TO (112,113,113), K                                              D 332
 0298          112       L=0                                                                 D 333
 0299                    GO TO 114                                                           D 334
 0300          113       L=NINT(K-1)-1                                                       D 335
 0301          114       M=NINT(K)-L                                                         D 336
 0302                    R=RR(K)                                                             D 337
 0303                    DO 115 N=1,M                                                        D 338
 0304                    ITEMP=N+L                                                           D 339
 0305                    GX(N)=SUM(ITEMP)*R                                                  D 340
 0306          115       R=R+H(K)                                                            D 341
 0307                    FP=FP+SIMP(H,GX,M,K)                                                D 342
 0308                    IF (K.EQ.3) FP=FP+SUM(N3)*RR(4)*H(4)/3.                             D 343
 0309                    GO TO (116,117,118), K                                              D 344
 0310          116       FPR(K)=FP                                                           D 345
 0311                    GO TO 119                                                           D 346
 0312          117       FPR(K)=(FP-FPR(K-1))                                                D 347
```

```
0313            GO TO 119                                              D 348
0314      118   FPR(K)=(FP-FPR(K-1)-FPR(K-2))                          D 349
0315      119   CONTINUE                                               D 350
0316            FP=0.0                                                 D 351
0317            DO 120 K=1,3                                           D 352
0318            FPR(K)=2.*PI*FPR(K)                                    D 353
0319      120   FP=FP+FPR(K)                                           D 354
0320            GAM=POW/FP                                             D 355
0321            TEMP=PI/SQRT(BH2)                                      D 356
0322            GAM=GAM/TEMP                                           D 357
0323            WRITE (6,162)                                          D 358
0324            WRITE (6,163) (RR(L),L=1,5)                            D 359
0325            WRITE (6,164) EIGEN                                    D 360
0326            WRITE (6,165)                                          D 361
0327            GO TO (121,121,121,122,123,124), ICP                   D 362
0328      121   WRITE (6,166) ICP                                      D 363
0329            GO TO 125                                              D 364
0330      122   WRITE (6,167)                                          D 365
0331            GO TO 125                                              D 366
0332      123   WRITE (6,168)                                          D 367
0333            GO TO 125                                              D 368
0334      124   WRITE (6,169)                                          D 369
0335      125   DO 126 K=1,3                                           D 370
0336      126   SCA(3,K)=SCA(3,K)-D(3,K)*BH2                           D 371
0337            GO TO (127,128,129,127,127,128), ICP                   D 372
0338      127   K=1                                                    D 373
0339            GO TO 130                                              D 374
0340      128   K=2                                                    D 375
0341            GO TO 130                                              D 376
0342      129   K=3                                                    D 377
0343      130   TEMP=SCA(3,K)-SCAO(3,K)                                D 378
0344            WRITE (6,170) TEMP                                     D 379
0345            TEMP=TEMP/SCP*1.E+24                                   D 380
0346            WRITE (6,171) TEMP                                     D 381
0347            WRITE (6,172)                                          D 382
0348            WRITE (6,173) (FLUX(1,N),N=1,N4)                       D 383
0349            WRITE (6,174) (FLUX(2,N),N=1,N4)                       D 384
0350            WRITE (6,175) (FLUX(3,N),N=1,N4)                       D 385
          C                                                            D 386
          C     CALCULATION OF POWER NORMALIZED FLUXES                 D 387
          C                                                            D 388
0351            DO 131 I=1,3                                           D 389
0352            DO 131 N=1,N4                                          D 390
0353            FLUX(I,N)=FLUX[illegible]*GAM                          D 391
0354      131   AIDD(I,N)=FLUX([illegible]                             D 392
0355            WRITE (6,176)                                          D 393
0356            WRITE (6,177) (AIDD(1,N),N=1,N4)                       D 394
0357            WRITE (6,178) (AIDD(2,N),N=1,N4)                       D 395
0358            WRITE (6,179) (AIDD(3,N),N=1,N4)                       D 396
0359            DO 132 LI=1,3                                          D 397
0360            LP=LI                                                  D 398
0361            CALL PLOT (LI,N4,LP)                                   D 399
0362      132   CONTINUE                                               D 400
0363            WRITE (6,180)                                          D 401
0364            DO 133 I=1,3                                           D 402
0365            TEMP=FLUX(I,1)                                         D 403
0366            DO 133 N=1,N4                                          D 404
0367      133   AIDD(I,N)=FLUX(I,N)/TEMP                               D 405
```

```
0368                WRITE (6,181) (AIDD(1,N),N=1,N4)                                        D 406
0369                WRITE (6,182) (AIDD(2,N),N=1,N4)                                        D 407
0370                WRITE (6,183) (AIDD(3,N),N=1,N4)                                        D 408
0371                DO 134 LI=1,3                                                           D 409
0372                LP=LI+3                                                                 D 410
0373                CALL PLOT (LI,N4,LP)                                                    D 411
0374          134   CONTINUE                                                                D 412
0375                DO 135 I=1,2                                                            D 413
0376                DO 135 N=1,N4                                                           D 414
0377          135   AIDD(I,N)=FLUX(I,N)/FLUX(3,N)                                           D 415
0378                WRITE (6,184)                                                           D 416
0379                WRITE (6,185) (AIDD(1,N),N=1,N4)                                        D 417
0380                WRITE (6,186) (AIDD(2,N),N=1,N4)                                        D 418
0381                DO 136 LI=1,2                                                           D 419
0382                LP=6+LI                                                                 D 420
0383                CALL PLOT (LI,N4,LP)                                                    D 421
0384          136   CONTINUE                                                                D 422
0385                DO 137 N=1,N4                                                           D 423
0386          137   AIDD(1,N)=FLUX(1,N)/FLUX(2,N)                                           D 424
0387                WRITE (6,187) (AIDD(1,N),N=1,N4)                                        D 425
0388                CALL PLOT (1,N4,9)                                                      D 426
              C                                                                             D 427
              C     CALCULATION OF POWER GENERATED IN EACH REGION                           D 428
              C                                                                             D 429
0389                DO 138 K=1,3                                                            D 430
0390                TEMP=PI/SQRT(BH2)                                                       D 431
0391                FPR(K)=FPR(K)*TEMP*GAM                                                  D 432
0392          138   CONTINUE                                                                D 433
0393                WRITE (6,188) (FPR(K),K=1,3)                                            D 434
0394                DO 139 K=1,3                                                            D 435
0395                FPR(K)=FPR(K)/TEMP                                                      D 436
0396                TEMP=PI*(RR(K+1)*RR(K+1)-RR(K)*RR(K))                                   D 437
0397                FPR(K)=FPR(K)/TEMP                                                      D 438
0398          139   CONTINUE                                                                D 439
0399                WRITE (6,189) (FPR(K),K=1,3)                                            D 440
0400                WRITE (6,190) OVREL                                                     D 441
0401                IF (ICC.GT.0) GC TO 1                                                   D 442
0402                GO TO 141                                                               D 443
0403          140   WRITE (6,191)                                                           D 444
0404          141   STCP                                                                    D 445
              C                                                                             D 446
0405          142   FORMAT (6E10.0,6(1X,I2))                                                D 447
0406          143   FORMAT (5E10.0)                                                         D 448
0407          144   FORMAT (3E10.0)                                                         D 449
0408          145   FORMAT (4E10.0)                                                         D 450
0409          146   FORMAT (F5.3)                                                           D 451
0410          147   FORMAT (1H1)                                                            D 452
0411          148   FORMAT (16H PROGRAM WAN DIC,///,26H REGIONS IN ORDER 1,2,3,4,//)        D 453
0412          149   FORMAT (17H RADII OF REGIONS,//,2X,8HREGION 1,4X 8HREGION 2,4X,8HR      D 454
                   1EGION 3,4X,8HREGION 4,4X,8HREGION 5,//,2X,5(F8.2,4X))                   D 455
0413          150   FORMAT (7H NINT =,4(I2,1X),/,7H OVREL=,F6.2,6X,6H PREC=,E9.2,6X,6H      D 456
                   1 CONV=,E9.2)                                                            D 457
0414          151   FORMAT (//,6H BH2 =,E12.5,6X,28H POISON MICRO CROSS-SECTION=,1X,E1      D 458
                   12.5,//)                                                                 D 459
0415          152   FORMAT (26H ABSORPTION CROSS-SECTIONS,//,5X,7HGROUP 1,7X,7HGROUP 2      D 460
                   1,7X,7HGROUP 3,/,3(2X,E12.5),/)                                          D 461
0416          153   FORMAT (//,23H DIFFUSION COEFFICIENTS,//,3(2X,E12.5),/)                 D 462
0417          154   FORMAT (//,26H TRANSFER CROSS-SECTIONS  ,//,3(2X,E12.5),/)              D 463
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0418          155   FORMAT (//,23H NU-FISSION            ,//,3(2X,E12.5),/)                D 464
0419          156   FORMAT (//,14H KAPPA-FISSION,//,3(2X,E12.5),/)                         D 465
0420          157   FORMAT (13H POWER (W) = ,E12.5)                                        D 466
0421          158   FORMAT (1H1)                                                           D 467
0422          159   FORMAT (1X,4H  K=,F10.6)                                               D 468
0423          160   FORMAT (//,5H XP= ,E12.5,5X,15H EIGENVALUE K =,E12.5)                  D 469
0424          161   FORMAT (7H ITER= ,I2)                                                  D 470
0425          162   FORMAT (1H1,8H RESULTS,///)                                            D 471
0426          163   FORMAT (17H RADII OF REGIONS,//,2X,8HREGION 1,4X,8HREGION 2,4X,8HR     D 472
                   1EGION 3,4X,8HREGION 4,4X,8HREGION 5,//,2X,5(F8.2,4X))                  D 473
0427          164   FORMAT (//,41H EIGENVALUE OF THE UNPOISONED REACTOR K =,E12.5)         D 474
0428          165   FORMAT (//,49H CONTROL POISON WAS USED IN THE FOLLOWING REGIONS,/)     D 475
0429          166   FORMAT (9H REGION  ,I2)                                                D 476
0430          167   FORMAT (21H ALL FISSION REGIONS )                                      D 477
0431          168   FORMAT (17H REGIONS 1 AND 2 )                                          D 478
0432          169   FORMAT (17H REGIONS 2 AND 3 )                                          D 479
0433          170   FORMAT (//,36H MACRO CROSS-SECTION OF THE POISON= ,E12.5)              D 480
0434          171   FORMAT (//,24H POISON CONCENTRATION = ,E12.5)                          D 481
0435          172   FORMAT (////,28H FLUXES NORMALIZED TO SOURCE)                          D 482
0436          173   FORMAT (//,19H FAST FLUX-GROUP 1 ,/,5(2X,E12.5))                       D 483
0437          174   FORMAT (//,24H RESONANCE FLUX-GROUP 2 ,/,5(2X,E12.5))                  D 484
0438          175   FORMAT (//,19H SLOW FLUX-GROUP 3 ,/,5(2X,E12.5))                       D 485
0439          176   FORMAT (////,28H FLUXES NORMALIZED TO POWER )                          D 486
0440          177   FORMAT (//,19H FAST FLUX-GROUP 1 ,/,5(2X,E12.5))                       D 487
0441          178   FORMAT (//,24H RESONANCE FLUX-GROUP 2 ,/,5(2X,E12.5))                  D 488
0442          179   FORMAT (//,19H SLOW FLUX-GROUP 3 ,/,5(2X,E12.5))                       D 489
0443          180   FORMAT (///,16H RELATIVE FLUXES)                                       D 490
0444          181   FORMAT (//,9H GROUP 1 ,/,5(2X,E12.5))                                  D 491
0445          182   FORMAT (//,9H GROUP 2 ,/,5(2X,E12.5))                                  D 492
0446          183   FORMAT (//,9H GROUP 3 ,/,5(2X,E12.5))                                  D 493
0447          184   FORMAT (///,35H RATIOS OF FLUXES TO THE SLOW FLUX )                    D 494
0448          185   FORMAT (//,19H GROUP 1 / GROUP 3 ,/,5(2X,E12.5))                       D 495
0449          186   FORMAT (//,19H GROUP 2 / GROUP 3 ,/,5(2X,E12.5))                       D 496
0450          187   FORMAT (//,19H GROUP 1 / GROUP 2 ,//,5(2X,E12.5))                      D 497
0451          188   FORMAT (//,31H POWER OUTPUT IN REGIONS  1,2,3,//,2X,3(E12.5,5X))       D 498
0452          189   FORMAT (//,42H POWER DENSITY IN REGIONS 1,2,3 (KW/LITER),//,2X,3(E     D 499
                   112.5,5X))                                                              D 500
0453          190   FORMAT (//,33H COMPUTED OVERRELAXATION FACTOR= ,F6.3)                  D 501
0454          191   FORMAT (22H # OF ITERATIONS > 400)                                     D 502
0455                END                                                                    D 503
```
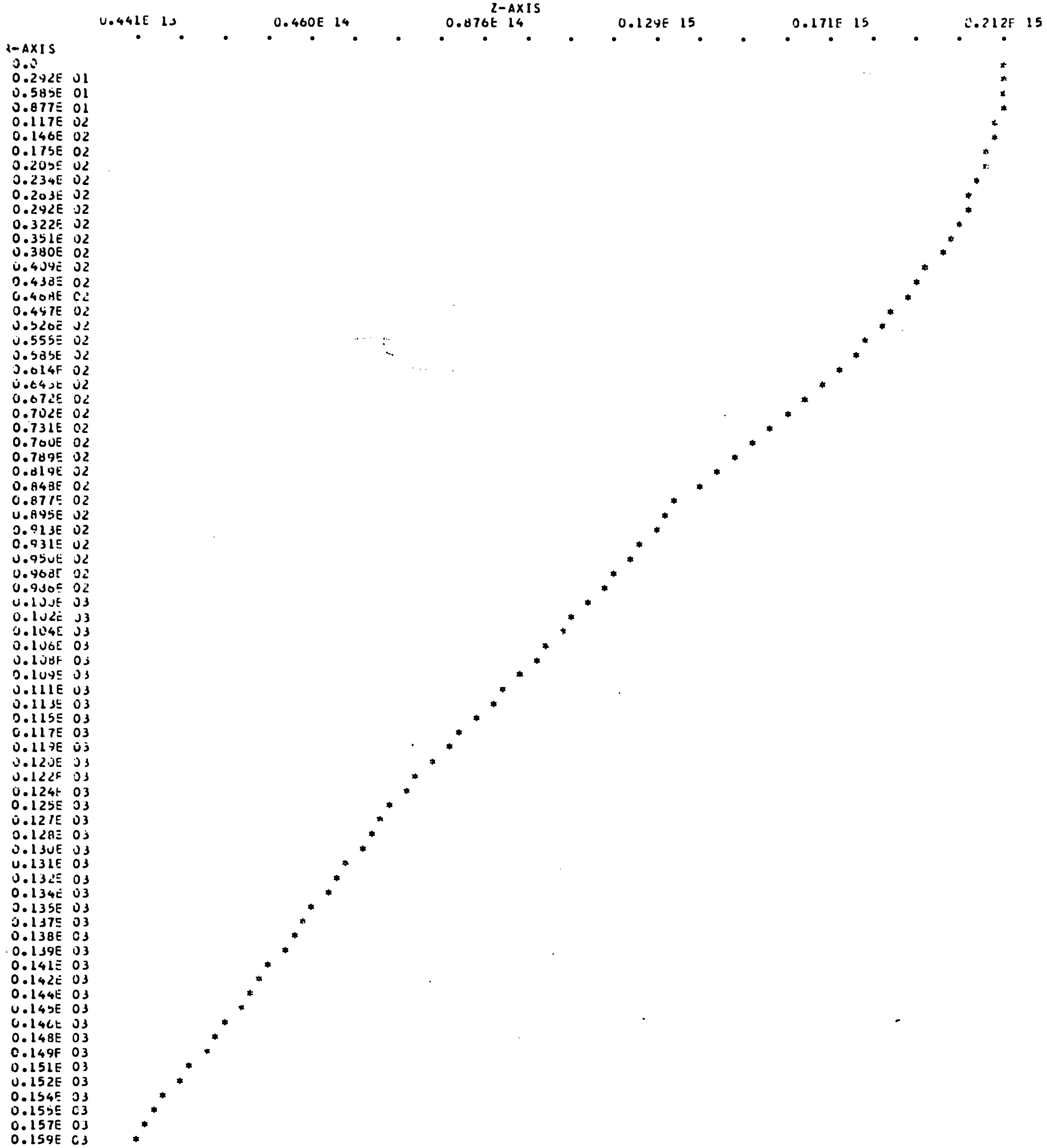

```
PROGRAM WAN DIC


REGIONS IN ORDER 1,2,3,4,


RADII OF REGIONS

 REGION 1     REGION 2     REGION 3     REGION 4     REGION 5

     0.0          87.70        124.00       152.00       159.00
NINT =30 20 20   4
OVREL=  1.90         PREC= 0.10E-03         CONV= 0.10E-01


BH2 = 0.73800E-04        POISON MICRO CROSS-SECTION=  0.21090E 04


ABSORPTION CROSS-SECTICNS

    GROUP 1        GROUP 2        GROUP 3
  0.35410E-02    0.25680E-01    0.13870E 00

  0.35410E-02    0.25680E-01    0.13870E 00

  0.35410E-02    0.25680E-01    0.13870E 00

  0.36220E-03    0.57220E-03    0.84730E-02



DIFFUSION COEFFICIENTS

  0.17070E 01    0.85360E 00    0.39510E 00

  0.17070E 01    0.85360E 00    0.39510E 00

  0.17070E 01    0.85360E 00    0.39510E 00

  0.19300E 01    0.91730E 00    0.31470E 00



TRANSFER CROSS-SECTIONS

  0.61130E-01    0.49440E-01    0.0

  0.61130E-01    0.49440E-01    0.0

  0.61130E-01    0.49440E-01    0.0

  0.26280E-01    0.28110E-01    0.0



NU-FISSION

  0.42920E-02    0.15060E-01    0.16400E 00

  0.42920E-02    0.15060E-01    0.16400E 00

  0.42920E-02    0.15060E-01    0.16400E 00



KAPPA-FISSION

  0.93280E-13    0.19010E-12    0.21290E-11

  0.93280E-13    0.19010E-12    0.21290E-11

  0.93280E-13    0.19010E-12    0.21290E-11

POWER (W) =  0.24410E 10
```

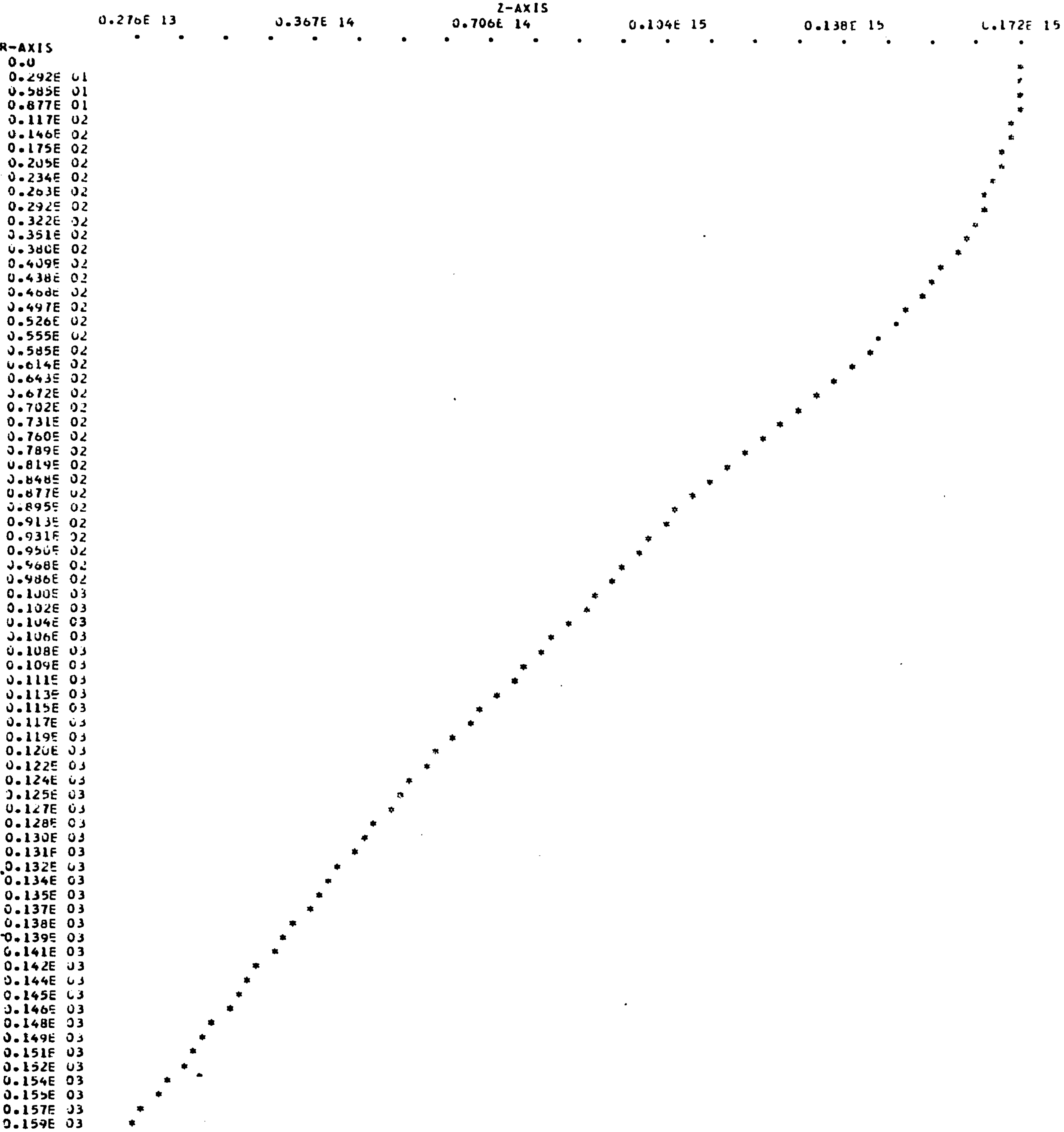
```
RESULTS


RADII OF REGIONS

 REGION 1     REGION 2     REGION 3     REGION 4     REGION 5

     0.0          87.70       124.00       152.00       159.00

EIGENVALUE OF THE UNPOISONED REACTOR K = 0.97971E 00

CONTROL POISON WAS USED IN THE FOLLOWING REGIONS

ALL FISSION REGIONS

MACRO CROSS-SECTION OF THE POISON= -0.37987E-02

POISON CONCENTRATION = -0.18012E 19



FLUXES NORMALIZED TO SOURCE


FAST FLUX-GROUP 1
   0.42922E-03    0.42904E-03    0.42848E-03    0.42755E-03    0.42625E-03
   0.42457E-03    0.42253E-03    0.42012E-03    0.41734E-03    0.41420E-03
   0.41070E-03    0.40683E-03    0.40261E-03    0.39804E-03    0.39312E-03
   0.38785E-03    0.38224E-03    0.37629E-03    0.37002E-03    0.36342E-03
   0.35650E-03    0.34927E-03    0.34173E-03    0.33390E-03    0.32578E-03
   0.31737E-03    0.30870E-03    0.29977E-03    0.29059E-03    0.28117E-03
   0.27153E-03    0.26543E-03    0.25925E-03    0.25300E-03    0.24667E-03
   0.24027E-03    0.23381E-03    0.22728E-03    0.22069E-03    0.21404E-03
   0.20734E-03    0.20059E-03    0.19379E-03    0.18696E-03    0.18008E-03
   0.17317E-03    0.16623E-03    0.15926E-03    0.15228E-03    0.14527E-03
   0.13825E-03    0.13282E-03    0.12740E-03    0.12197E-03    0.11654E-03
   0.11111E-03    0.10569E-03    0.10027E-03    0.94856E-04    0.89454E-04
   0.84063E-04    0.78686E-04    0.73325E-04    0.67980E-04    0.62653E-04
   0.57341E-04    0.52038E-04    0.46722E-04    0.41343E-04    0.35784E-04
   0.29774E-04    0.23213E-04    0.17707E-04    0.13012E-04    0.89179E-05


RESONANCE FLUX-GROUP 2
   0.34819E-03    0.34804E-03    0.34759E-03    0.34683E-03    0.34577E-03
   0.34441E-03    0.34275E-03    0.34080E-03    0.33854E-03    0.33599E-03
   0.33314E-03    0.33001E-03    0.32658E-03    0.32287E-03    0.31887E-03
   0.31459E-03    0.31004E-03    0.30521E-03    0.30012E-03    0.29476E-03
   0.28914E-03    0.28327E-03    0.27716E-03    0.27080E-03    0.26421E-03
   0.25739E-03    0.25036E-03    0.24311E-03    0.23566E-03    0.22802E-03
   0.22019E-03    0.21525E-03    0.21023E-03    0.20516E-03    0.20003E-03
   0.19484E-03    0.18959E-03    0.18429E-03    0.17895E-03    0.17356E-03
   0.16812E-03    0.16265E-03    0.15714E-03    0.15159E-03    0.14602E-03
   0.14041E-03    0.13478E-03    0.12913E-03    0.12347E-03    0.11778E-03
   0.11209E-03    0.10769E-03    0.10329E-03    0.98890E-04    0.94487E-04
   0.90086E-04    0.85687E-04    0.81293E-04    0.76904E-04    0.72522E-04
   0.68149E-04    0.63786E-04    0.59433E-04    0.55091E-04    0.50761E-04
   0.46441E-04    0.42132E-04    0.37833E-04    0.33548E-04    0.29291E-04
   0.25108E-04    0.20280E-04    0.15418E-04    0.10537E-04    0.55811E-05


SLOW FLUX-GROUP 3
   0.12748E-03    0.12742E-03    0.12726E-03    0.12698E-03    0.12659E-03
   0.12609E-03    0.12549E-03    0.12477E-03    0.12394E-03    0.12301E-03
   0.12197E-03    0.12082E-03    0.11956E-03    0.11820E-03    0.11674E-03
   0.11517E-03    0.11351E-03    0.11174E-03    0.10987E-03    0.10791E-03
   0.10586E-03    0.10371E-03    0.10147E-03    0.99139E-04    0.96725E-04
   0.94229E-04    0.91653E-04    0.89000E-04    0.86272E-04    0.83474E-04
   0.80609E-04    0.78797E-04    0.76962E-04    0.75105E-04    0.73225E-04
   0.71325E-04    0.69405E-04    0.67466E-04    0.65509E-04    0.63535E-04
   0.61545E-04    0.59541E-04    0.57524E-04    0.55494E-04    0.53452E-04
   0.51401E-04    0.49340E-04    0.47272E-04    0.45197E-04    0.43117E-04
   0.41033E-04    0.39423E-04    0.37812E-04    0.36200E-04    0.34588E-04
   0.32977E-04    0.31367E-04    0.29758E-04    0.28152E-04    0.26548E-04
   0.24948E-04    0.23353E-04    0.21764E-04    0.20186E-04    0.18625E-04
   0.17100E-04    0.15647E-04    0.14350E-04    0.13391E-04    0.13176E-04
   0.14593E-04    0.16797E-04    0.14841E-04    0.99331E-05    0.30294E-05
```

```
FLUXES NORMALIZED TO POWER


FAST FLUX-GROUP 1
  0.21237E 15    0.21228E 15    0.21200E 15    0.21154E 15    0.21090E 15
  0.21007E 15    0.20906E 15    0.20787E 15    0.20649E 15    0.20494E 15
  0.20320E 15    0.20129E 15    0.19920E 15    0.19694E 15    0.19451E 15
  0.19190E 15    0.18912E 15    0.18618E 15    0.18308E 15    0.17981E 15
  0.17639E 15    0.17281E 15    0.16908E 15    0.16520E 15    0.16119E 15
  0.15703E 15    0.15274E 15    0.14832E 15    0.14378E 15    0.13912E 15
  0.13435E 15    0.13133E 15    0.12827E 15    0.12518E 15    0.12205E 15
  0.11888E 15    0.11568E 15    0.11245E 15    0.10919E 15    0.10590E 15
  0.10259E 15    0.99247E 14    0.95885E 14    0.92502E 14    0.89100E 14
  0.85681E 14    0.82248E 14    0.78801E 14    0.75343E 14    0.71876E 14
  0.68402E 14    0.65719E 14    0.63034E 14    0.60347E 14    0.57661E 14
  0.54975E 14    0.52291E 14    0.49610E 14    0.46933E 14    0.44260E 14
  0.41593E 14    0.38932E 14    0.36279E 14    0.33635E 14    0.30999E 14
  0.28371E 14    0.25747E 14    0.23117E 14    0.20456E 14    0.17705E 14
  0.14731E 14    0.11485E 14    0.87612E 13    0.64379E 13    0.44124E 13


RESONANCE FLUX-GROUP 2
  0.17228E 15    0.17220E 15    0.17198E 15    0.17160E 15    0.17108E 15
  0.17041E 15    0.16959E 15    0.16862E 15    0.16750E 15    0.16624E 15
  0.16483E 15    0.16328E 15    0.16159E 15    0.15975E 15    0.15777E 15
  0.15565E 15    0.15340E 15    0.15101E 15    0.14849E 15    0.14584E 15
  0.14306E 15    0.14016E 15    0.13713E 15    0.13399E 15    0.13073E 15
  0.12735E 15    0.12387E 15    0.12029E 15    0.11660E 15    0.11282E 15
  0.10895E 15    0.10650E 15    0.10402E 15    0.10151E 15    0.98969E 14
  0.96400E 14    0.93805E 14    0.91185E 14    0.88540E 14    0.85872E 14
  0.83184E 14    0.80475E 14    0.77748E 14    0.75005E 14    0.72246E 14
  0.69473E 14    0.66688E 14    0.63893E 14    0.61089E 14    0.58277E 14
  0.55460E 14    0.53284E 14    0.51107E 14    0.48929E 14    0.46750E 14
  0.44572E 14    0.42396E 14    0.40222E 14    0.38050E 14    0.35882E 14
  0.33719E 14    0.31560E 14    0.29406E 14    0.27258E 14    0.25115E 14
  0.22978E 14    0.20846E 14    0.18719E 14    0.16599E 14    0.14493E 14
  0.12423E 14    0.10034E 14    0.76287E 13    0.52137E 13    0.276[illegible]E 13


SLOW FLUX-GROUP 3
  0.63073E 14    0.63046E 14    0.62963E 14    0.62826E 14    0.62635E 14
  0.62388E 14    0.62088E 14    0.61733E 14    0.61324E 14    0.60862E 14
  0.60347E 14    0.59778E 14    0.59158E 14    0.58485E 14    0.57761E 14
  0.56986E 14    0.56161E 14    0.55286E 14    0.54363E 14    0.53392E 14
  0.52375E 14    0.51311E 14    0.50203E 14    0.49052E 14    0.47858E 14
  0.46623E 14    0.45348E 14    0.44035E 14    0.42686E 14    0.41301E 14
  0.39883E 14    0.38987E 14    0.38079E 14    0.37160E 14    0.36230E 14
  0.35290E 14    0.34340E 14    0.33380E 14    0.32412E 14    0.31436E 14
  0.30451E 14    0.29460E 14    0.28461E 14    0.27457E 14    0.26447E 14
  0.25432E 14    0.24412E 14    0.23389E 14    0.22363E 14    0.21333E 14
  0.20302E 14    0.19506E 14    0.18708E 14    0.17911E 14    0.17114E 14
  0.16316E 14    0.15520E 14    0.14724E 14    0.13929E 14    0.13135E 14
  0.12344E 14    0.11554E 14    0.10768E 14    0.99874E 13    0.92153E 13
  0.84606E 13    0.77418E 13    0.70999E 13    0.66258E 13    0.65193E 13
  0.72204E 13    0.83110E 13    0.73431E 13    0.49147E 13    0.14989E 13
```

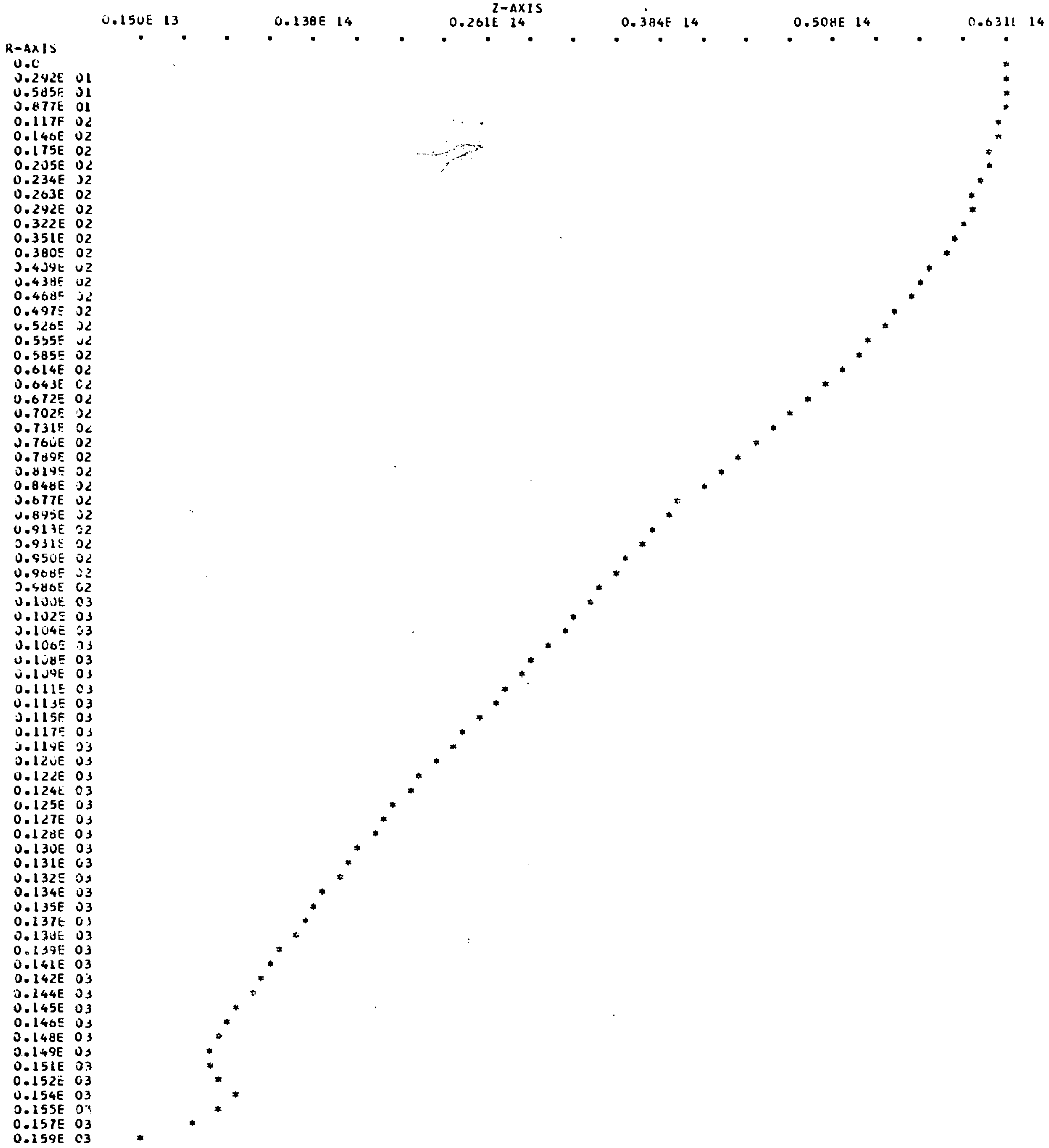
PLOT OF FAST FLUX - GROUP 1



PLOT OF RESONANCE FLUX -GROUP 2

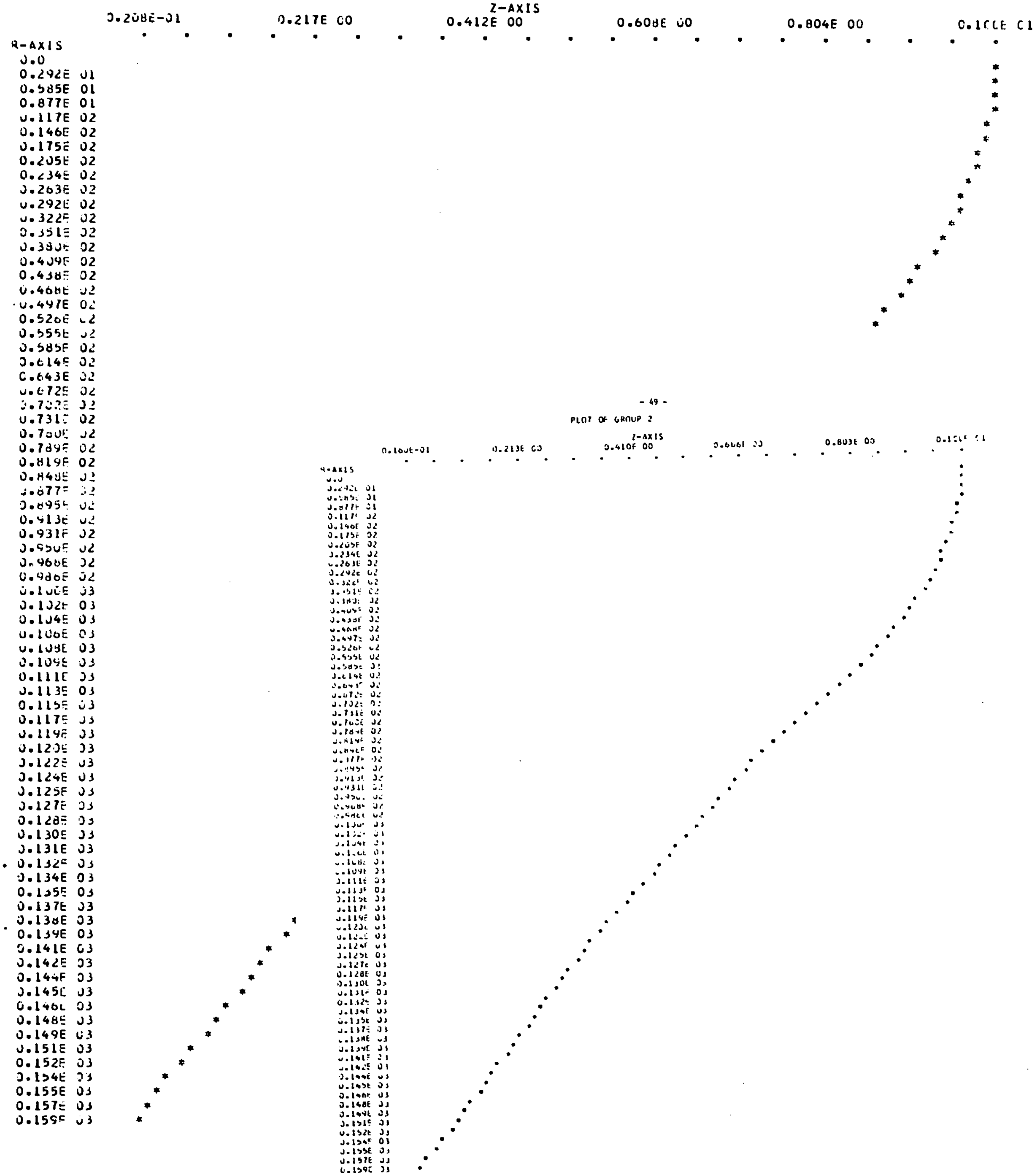


PLOT OF SLOW FLUX - GROUP 3



```
RELATIVE FLUXES


GROUP 1
  0.10000E 01    0.99957E 00    0.99826E 00    0.99609E 00    0.99306E 00
  0.98916E 00    0.98440E 00    0.97879E 00    0.97232E 00    0.96500E 00
  0.95683E 00    0.94783E 00    0.93800E 00    0.92735E 00    0.91588E 00
  0.90360E 00    0.89053E 00    0.87668E 00    0.86206E 00    0.84668E 00
  0.83056E 00    0.81371E 00    0.79616E 00    0.77791E 00    0.75899E 00
  0.73942E 00    0.71921E 00    0.69841E 00    0.67702E 00    0.65507E 00
  0.63260E 00    0.61839E 00    0.60400E 00    0.58943E 00    0.57469E 00
  0.55978E 00    0.54472E 00    0.52950E 00    0.51415E 00    0.49866E 00
  0.48305E 00    0.46733E 00    0.45150E 00    0.43557E 00    0.41955E 00
  0.40345E 00    0.38728E 00    0.37105E 00    0.35477E 00    0.33845E 00
  0.32209E 00    0.30945E 00    0.29681E 00    0.28416E 00    0.27151E 00
  0.25886E 00    0.24623E 00    0.23360E 00    0.22099E 00    0.20841E 00
  0.19585E 00    0.18332E 00    0.17083E 00    0.15838E 00    0.14597E 00
  0.13359E 00    0.12124E 00    0.10885E 00    0.96321E-01    0.83369E-01
  0.69366E-01    0.54081E-01    0.41254E-01    0.30314E-01    0.20777E-01


GROUP 2
  0.10000E 01    0.99957E 00    0.99826E 00    0.99609E 00    0.99305E 00
  0.98915E 00    0.98439E 00    0.97876E 00    0.97229E 00    0.96496E 00
  0.95679E 00    0.94778E 00    0.93794E 00    0.92727E 00    0.91580E 00
  0.90351E 00    0.89043E 00    0.87657E 00    0.86194E 00    0.84655E 00
  0.83042E 00    0.81356E 00    0.79600E 00    0.77774E 00    0.75881E 00
  0.73923E 00    0.71902E 00    0.69821E 00    0.67682E 00    0.65487E 00
  0.63239E 00    0.61818E 00    0.60379E 00    0.58922E 00    0.57447E 00
  0.55957E 00    0.54450E 00    0.52929E 00    0.51394E 00    0.49846E 00
  0.48285E 00    0.46713E 00    0.45130E 00    0.43537E 00    0.41936E 00
  0.40326E 00    0.38710E 00    0.37087E 00    0.35460E 00    0.33828E 00
  0.32192E 00    0.30930E 00    0.29666E 00    0.28401E 00    0.27137E 00
  0.25873E 00    0.24609E 00    0.23347E 00    0.22087E 00    0.20828E 00
  0.19572E 00    0.18319E 00    0.17069E 00    0.15822E 00    0.14578E 00
  0.13338E 00    0.12100E 00    0.10866E 00    0.96349E-01    0.84124E-01
  0.72109E-01    0.58245E-01    0.44281E-01    0.30263E-01    0.16029E-01


GROUP 3
  0.10000E 01    0.99957E 00    0.99826E 00    0.99609E 00    0.99305E 00
  0.98915E 00    0.98438E 00    0.97876E 00    0.97228E 00    0.96495E 00
  0.95678E 00    0.94776E 00    0.93792E 00    0.92725E 00    0.91577E 00
  0.90349E 00    0.89041E 00    0.87654E 00    0.86191E 00    0.84652E 00
  0.83038E 00    0.81352E 00    0.79596E 00    0.77770E 00    0.75877E 00
  0.73918E 00    0.71897E 00    0.69816E 00    0.67677E 00    0.65482E 00
  0.63234E 00    0.61813E 00    0.60373E 00    0.58916E 00    0.57442E 00
  0.55951E 00    0.54445E 00    0.52924E 00    0.51388E 00    0.49840E 00
  0.48279E 00    0.46707E 00    0.45125E 00    0.43532E 00    0.41931E 00
  0.40321E 00    0.38705E 00    0.37083E 00    0.35455E 00    0.33823E 00
  0.32188E 00    0.30925E 00    0.29662E 00    0.28397E 00    0.27133E 00
  0.25869E 00    0.24606E 00    0.23344E 00    0.22084E 00    0.20826E 00
  0.19571E 00    0.18319E 00    0.17073E 00    0.15835E 00    0.14611E 00
  0.13414E 00    0.12274E 00    0.11257E 00    0.10505E 00    0.10336E 00
  0.11448E 00    0.13177E 00    0.11642E 00    0.77920E-01    0.23764E-01
```

PLOT OF GROUP 1



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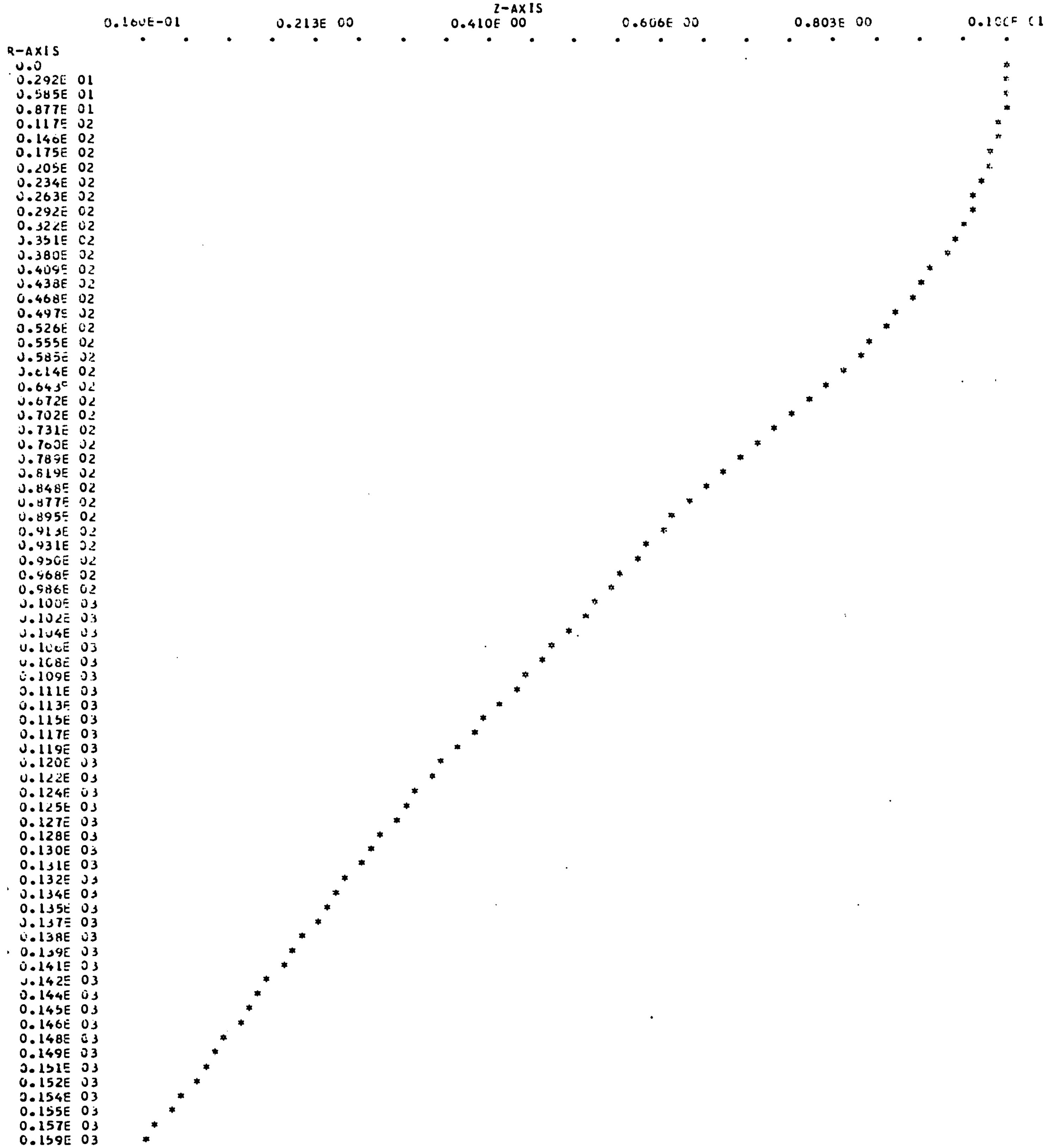
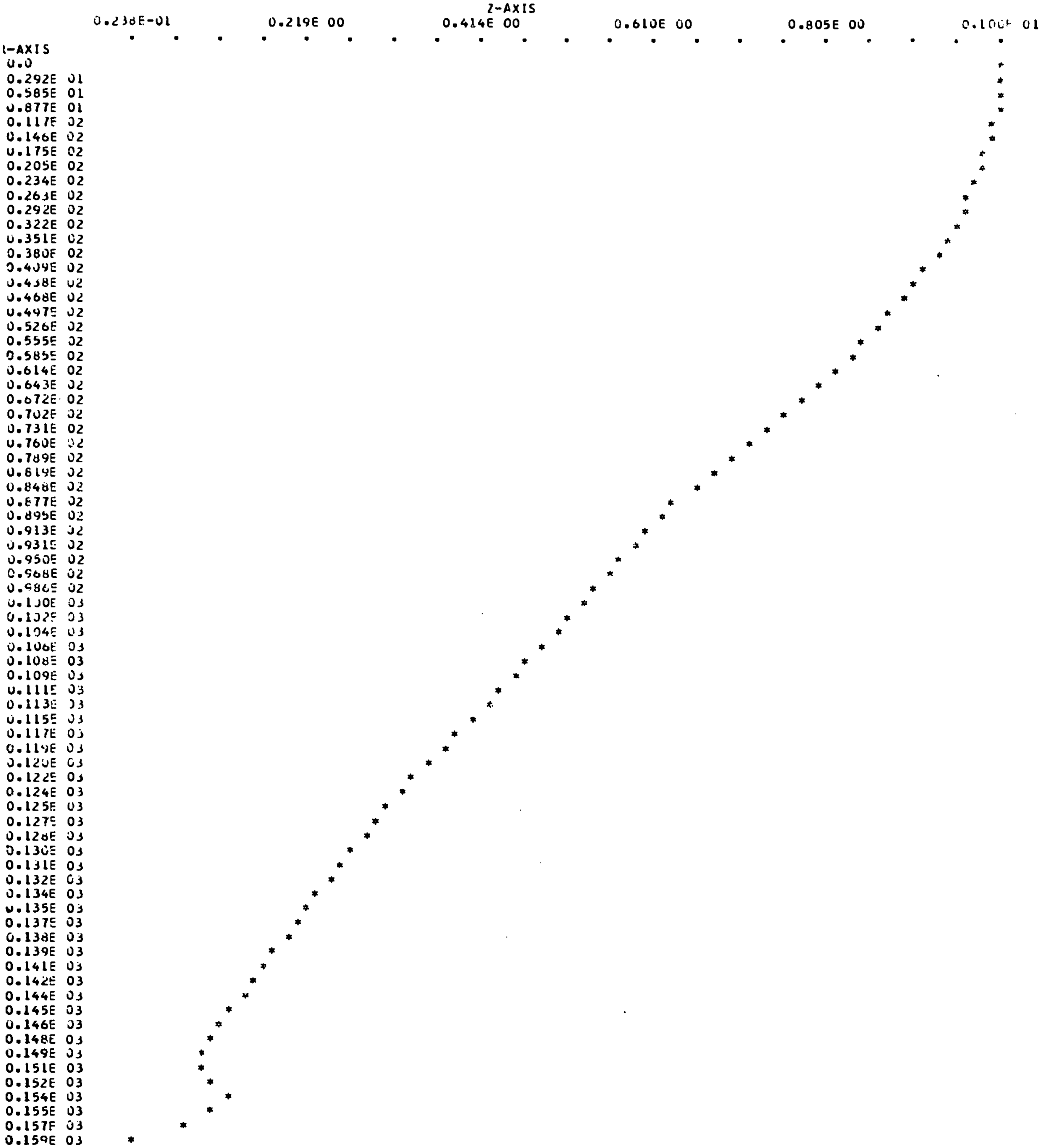
PLOT OF GROUP 2

PLOT OF GROUP 2

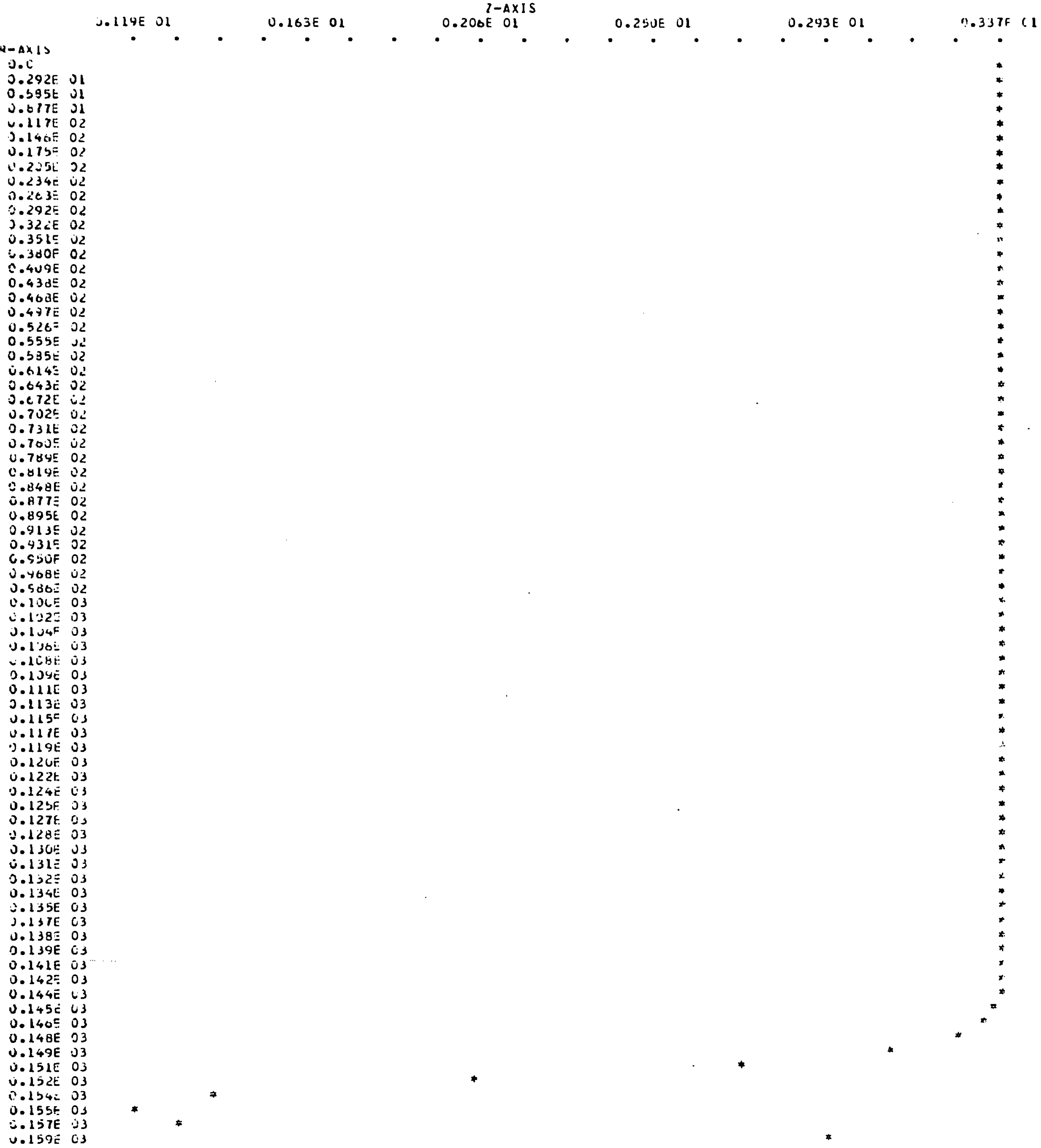


PLOT OF GROUP 3

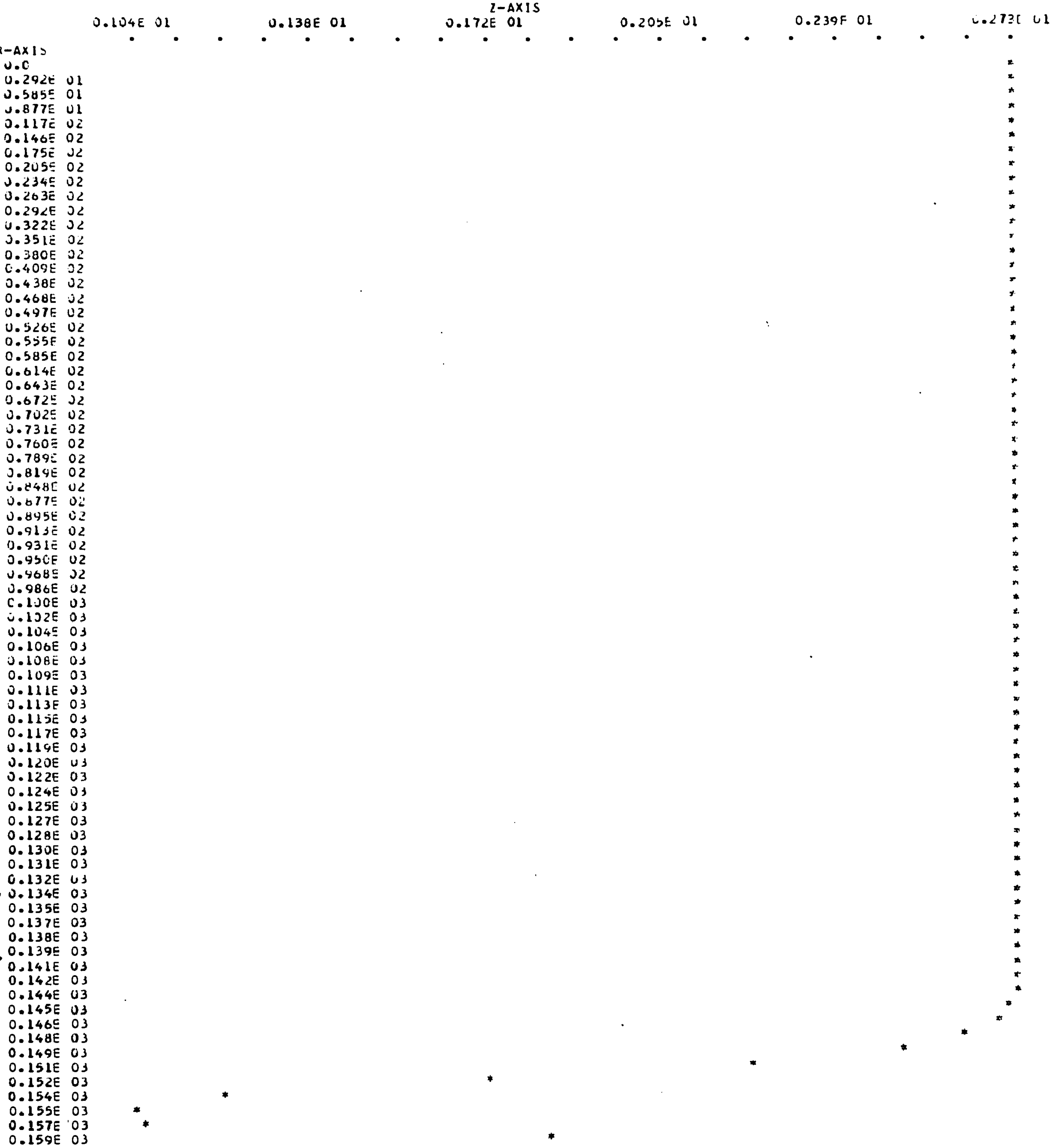


```
RATIOS OF FLUXES TO THE SLOW FLUX


GROUP 1 / GROUP 3
  0.33671E 01    0.33671E 01    0.33671E 01    0.33671E 01    0.33671E 01
  0.33671E 01    0.33671E 01    0.33672E 01    0.33672E 01    0.33672E 01
  0.33673E 01    0.33673E 01    0.33673E 01    0.33674E 01    0.33674E 01
  0.33675E 01    0.33675E 01    0.33676E 01    0.33677E 01    0.33677E 01
  0.33678E 01    0.33679E 01    0.33679E 01    0.33680E 01    0.33680E 01
  0.33681E 01    0.33682E 01    0.33683E 01    0.33683E 01    0.33684E 01
  0.33685E 01    0.33685E 01    0.33686E 01    0.33686E 01    0.33686E 01
  0.33687E 01    0.33687E 01    0.33688E 01    0.33688E 01    0.33688E 01
  0.33689E 01    0.33689E 01    0.33689E 01    0.33690E 01    0.33690E 01
  0.33690E 01    0.33691E 01    0.33691E 01    0.33691E 01    0.33692E 01
  0.33692E 01    0.33692E 01    0.33693E 01    0.33693E 01    0.33693E 01
  0.33693E 01    0.33694E 01    0.33694E 01    0.33694E 01    0.33695E 01
  0.33695E 01    0.33695E 01    0.33691E 01    0.33677E 01    0.33639E 01
  0.33533E 01    0.33257E 01    0.32559E 01    0.30873E 01    0.27158E 01
  0.20403E 01    0.13819E 01    0.11931E 01    0.13099E 01    0.29438E 01


GROUP 2 / GROUP 3
  0.27314E 01    0.27314E 01    0.27314E 01    0.27314E 01    0.27314E 01
  0.27314E 01    0.27314E 01    0.27314E 01    0.27314E 01    0.27314E 01
  0.27314E 01    0.27314E 01    0.27314E 01    0.27314E 01    0.27315E 01
  0.27315E 01    0.27315E 01    0.27315E 01    0.27315E 01    0.27315E 01
  0.27315E 01    0.27315E 01    0.27315E 01    0.27315E 01    0.27316E 01
  0.27316E 01    0.27316E 01    0.27316E 01    0.27316E 01    0.27316E 01
  0.27316E 01    0.27316E 01    0.27316E 01    0.27316E 01    0.27317E 01
  0.27317E 01    0.27317E 01    0.27317E 01    0.27317E 01    0.27317E 01
  0.27317E 01    0.27317E 01    0.27317E 01    0.27317E 01    0.27317E 01
  0.27317E 01    0.27317E 01    0.27317E 01    0.27317E 01    0.27317E 01
  0.27317E 01    0.27318E 01    0.27318E 01    0.27318E 01    0.27318E 01
  0.27318E 01    0.27318E 01    0.27318E 01    0.27318E 01    0.27317E 01
  0.27316E 01    0.27314E 01    0.27308E 01    0.27292E 01    0.27254E 01
  0.27159E 01    0.26927E 01    0.26365E 01    0.25052E 01    0.22230E 01
  0.17205E 01    0.12074E 01    0.10389E 01    0.10608E 01    0.18423E 01
```

PLOT OF GROUP 1 / GROUP 3



PLOT OF GROUP 2 / GROUP 3



GROUP 1 / GROUP 2

```
0.12327E 01   0.12327E 01   0.12327E 01   0.12327E 01   0.12327E 01
0.12327E 01   0.12327E 01   0.12328E 01   0.12328E 01   0.12328E 01
0.12328E 01   0.12328E 01   0.12328E 01   0.12328E 01   0.12328E 01
0.12329E 01   0.12329E 01   0.12329E 01   0.12329E 01   0.12329E 01
0.12329E 01   0.12330E 01   0.12330E 01   0.12330E 01   0.12330E 01
0.12330E 01   0.12331E 01   0.12331E 01   0.12331E 01   0.12331E 01
0.12331E 01   0.12331E 01   0.12332E 01   0.12332E 01   0.12332E 01
0.12332E 01   0.12332E 01   0.12332E 01   0.12332E 01   0.12332E 01
0.12333E 01   0.12333E 01   0.12333E 01   0.12333E 01   0.12333E 01
0.12333E 01   0.12333E 01   0.12333E 01   0.12333E 01   0.12333E 01
0.12333E 01   0.12334E 01   0.12334E 01   0.12334E 01   0.12334E 01
0.12334E 01   0.12334E 01   0.12334E 01   0.12334E 01   0.12335E 01
0.12335E 01   0.12336E 01   0.12337E 01   0.12339E 01   0.12343E 01
0.12347E 01   0.12351E 01   0.12349E 01   0.12324E 01   0.12217E 01
0.11858E 01   0.11446E 01   0.11485E 01   0.12348E 01   0.15979E 01
```

```
                                             PLOT OF GROUP 1 / GROUP 2

                                                        Z-AXIS
           0.114E 01           0.124E 01           0.133E 01           0.142E 01           0.151E 01           0.160E 01
               .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    .
R-AXIS
 0.0                              *
 0.292E 01                        *
 0.585E 01                        *
 0.877E 01                        *
 0.117E 02                        *
 0.146E 02                        *
 0.175E 02                        *
 0.205E 02                        *
 0.234E 02                        *
 0.263E 02                        *
 0.292E 02                        *
 0.322E 02                        *
 0.351E 02                        *
 0.380E 02                        *
 0.409E 02                        *
 0.438E 02                        *
 0.468E 02                        *
 0.497E 02                        *
 0.526E 02                        *
 0.555E 02                        *
 0.585E 02                        *
 0.614E 02                        *
 0.643E 02                        *
 0.672E 02                         *
 0.702E 02                         *
 0.731E 02                         *
 0.760E 02                         *
 0.789E 02                         *
 0.819E 02                         *
 0.848E 02                         *
 0.877E 02                         *
 0.895E 02                         *
 0.913E 02                         *
 0.931E 02                         *
 0.950E 02                         *
 0.968E 02                         *
 0.986E 02                         *
 0.100E 03                         *
 0.102E 03                         *
 0.104E 03                         *
 0.106E 03                         *
 0.108E 03                         *
 0.109E 03                         *
 0.111E 03                         *
 0.113E 03                         *
 0.115E 03                         *
 0.117E 03                         *
 0.119E 03                         *
 0.120E 03                         *
 0.122E 03                         *
 0.124E 03                         *
 0.125E 03                         *
 0.127E 03                         *
 0.128E 03                         *
 0.130E 03                         *
 0.131E 03                         *
 0.132E 03                         *
 0.134E 03                         *
 0.135E 03                         *
 0.137E 03                         *
 0.138E 03                         *
 0.139E 03                         *
 0.141E 03                         *
 0.142E 03                         *
 0.144E 03                         *
 0.145E 03                         *
 0.146E 03                         *
 0.148E 03                         *
 0.149E 03                        *
 0.151E 03                      *
 0.152E 03              *
 0.154E 03     *
 0.155E 03      *
 0.157E 03                         *
 0.159E 03                                                                                                                 *


POWER OUTPUT IN REGIONS  1,2,3

  0.13406E 10      0.77863E 09      0.32180E 09


POWER DENSITY IN REGIONS 1,2,3 (KW/LITER)

  0.15171E 03      0.13348E 01      0.54903E 00


    UTED OVERRELAXATION FACTOR=  1.900
```