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CALCULATION OF HIGH ENERGY EVENTS IN THERMAL REACTORS

II. A COMPUTER CODE - HEETR

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II. A Computer Code - HEETR

by

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ABSTRACT

A FORTRAN code is described which computes high energy events in thermal reactors having cylindrical fuel elements. The HEETR code is based on transmission and escape probabilities. Code calculations are compared with experimental determinations of the ratio of ^{238}U to ^{235}U fissions for lattices of natural uranium tubes and rod clusters in D_2O. Good agreement is obtained for lattices of single rods, but code calculations tend to exceed experimental values for lattices of tubes and rod clusters.

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CALCULATION OF HIGH ENERGY EVENTS IN THERMAL REACTORS

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INTRODUCTION

In an earlier report(1), a multigroup technique was described for calculating high energy events in thermal reactors having cylindrical fuel regions. The neutron current leaving a region was expressed in terms of the current entering the region by transmission probabilities and in terms of sources within the region by escape probabilities. Simplifying assumptions were made so that these probabilities could be readily calculated. Some simple applications of the technique were reported; extensive applications, however, require the use of a computer. A code has been written in FORTRAN II for performing these calculations on the IBM 704.

SUMMARY

The HEETR code for computing High Energy Events in Thermal Reactors is described and the FORTRAN listing is given. The basic assumptions used in the code are:

- Scattering in the laboratory system is isotropic.
- Distribution of secondary neutrons is uniform within each region.
- Distribution of currents at interfaces is uniform over the interface.
- Number of neutrons passing through an interface per unit solid angle is proportional to the cosine of the angle that the direction of travel makes with the normal to the interface.
- The reactor is infinite.

The code has a number of options. It is not necessarily limited to the calculation of high energy events in thermal reactors, but may be used wherever the basic assumptions have sufficient validity, e.g. for fast reactors having cylindrical fuel elements. For each neutron energy group, the code computes disadvantage factors in each region of each different fuel cylinder. The spatially averaged flux integrated over energy and spatial averages of nuclear parameters are also calculated for each group.

The code was applied to lattices of tubes and rod clusters in D_2O, which were studied experimentally in the Process Development Pile at the Savannah River Laboratory. Calculations of the ratio of ^{238}U to ^{235}U fissions in these lattices were compared with the experimental values. With the cross sections, group structure, and thermal fission source distributions employed, the calculated values of this ratio generally exceeded the experimental values. For the experiments performed with tubes, there appears to be reason to ascribe at least some of the discrepancy to a lack of precision in the data, which in turn is attributable to low flux levels. In the case of rod clusters, the discrepancy is at least partly due to the fact that the basic assumptions used in the code are poorer than when cylindrical symmetry exists. For single rods, the calculations agree well with the experiments.

A series of calculations for a uranium tube show that appreciable contributions to the ratio of ^{238}U to ^{235}U fissions arise from secondary neutrons that have been scattered by moderator and from neutrons passing through moderator from one tube to another or from one portion of the inner surface to another without having a collision in the moderator.

DISCUSSION

Approximations

The assumptions on which the HEETR code is based are:

(1) Secondary neutrons resulting from fissions and from neutrons being scattered are uniformly distributed throughout each region whether the region is a cylinder, an annulus, or surrounding space. When cylindrical symmetry exists within a fuel region, this approximation can be made as good as one wishes by taking a sufficiently large number of regions.

(2) Scattering is isotropic in the laboratory frame of reference.

(3) The current is uniformly distributed over each interface between regions.

(4) At each interface the fraction of the neutrons per unit solid angle crossing in a direction making an angle θ with respect to the normal to the surface is $\frac{\cos \theta}{\pi}$. Attempting to improve the first approximation by subdividing regions may make this approximation poorer.

(5) The reactor consists of an infinite number of infinitely long cells. Where the leakage is small compared with the number of neutrons being removed from the energy range encompassed by the calculations, this approximation should be fairly good. Where leakage effects are important, axial leakage can be represented by fictitious absorption cross sections. Alternatively the reactor may be considered to consist of a single infinitely long cell containing symmetrically different types of fuel cylinders depending on their locations within the cell, but the first approximation concerning the uniformity of the source distribution in the space surrounding the fuel cylinder may be fairly poor if this approach is used. Probably the best approach is to employ the spatially averaged nuclear parameters calculated for each group in an infinite reactor by the HEETR code in a multigroup code for a homogeneous reactor that includes leakage effects.

Mathematical Basis

Within each energy group and each region, the number of neutron interactions per unit time is computed as

$$A = Q + J^- - J^+$$

where Q is the number of secondary neutrons resulting from fission and from scattering events, J^- is the total current of neutrons entering from adjacent regions, and J^+ is the total current of neutrons leaving the region. At internal interfaces the boundary conditions are continuity of the inward and outward currents. At external boundaries either a cell boundary condition may be used where the inward current equals the outward current or the Dancoff[2] approach may be used where cylinders interact through a surrounding medium.

The mathematical development employed in the code is identical with that given in Reference (1) with the following exceptions.

(1) Instead of attempting to set up and solve the matrix equations in the neutron currents, a group-by-group approach, standard in multigroup problems, is used. All secondary neutrons entering a neutron energy group as the result of scattering events in higher energy groups and all neutrons resulting from fissions in whatever group they may occur are lumped together in the source terms Q_k appearing, for example, in Equations 3-7[1]. This amounts formally to setting $c_{kj} = 0$ in these equations when $j \neq k$ (since these c_{kj} are now included in Q_k), and results in an equation of identical form for each group. The calculation for each group may thus be treated as a one-group problem. The relative numbers of events in the various regions are calculated first for the group of highest energy from an assumed spatial distribution of source neutrons arising from fissions induced by neutrons of all energies including those encompassed by this group.

The calculation then proceeds to the second highest group where the source distribution is composed of the neutrons arising from the same assumed spatial distribution of fission neutrons together with those scattered into the second group from the first group. The calculation is continued in this manner down through the group of lowest energy where again the source neutrons are supplied by fission and by neutrons scattered from the higher energy groups.

From the ratios of the fission cross sections to the total cross sections and from the relative numbers of neutron interactions calculated for each region and each group a spatial distribution of fission neutrons is calculated, which is combined with any other source that may be present (e.g., from thermal fission). The assumed source distribution is adjusted to agree with the calculated distribution, and the group-by-group calculation is repeated. Iteration is continued until the calculated distribution reproduces the assumed distribution satisfactorily. The total source of fission neutrons is normalized to unity within a cell at the start of each iteration.

(2) With the foregoing simplifications, for each group and for each annular region Equation 12[1] becomes

$$L\ J_o = R\ J_i + S \qquad (1)$$

The matrix L is

$$L = \begin{pmatrix} 1-c(1-E_o-E_i) & -T_{oo}(1-c(1-E_i))-cE_o(1-T_{io}) \\ 0 & -T_{io}(1-c(1-E_o))-cE_i(1-T_{oo}) \end{pmatrix}$$

and the matrix R is

$$R = \begin{pmatrix} T_{oi}(1-c(1-E_i))+cE_o & 0 \\ cE_i(1-T_{oi}) & -(1-c(1-E_o-E_i)) \end{pmatrix}$$

The terms T_{oo}, T_{io}, T_{oi}, E_o, and E_i represent transmission and escape probabilities characteristic of the region and group, and c represents the number of secondary neutrons per interaction resulting from a scattering event that remain in the group.

The S vector is

$$S = \begin{pmatrix} QE_o \\ QE_i \end{pmatrix}$$

The current vectors are

$$J_o = \begin{pmatrix} J_o^+ \\ J_o^- \end{pmatrix} \quad \text{and} \quad J_i = \begin{pmatrix} J_i^- \\ J_i^+ \end{pmatrix}$$

where J_o^+ and J_i^+ represent the total currents integrated over the surface (per unit axial length) leaving the outer and inner surfaces of the annulus, and J_o^- and J_i^- represent the total currents entering these surfaces.

For a central cylindrical region

$$\begin{pmatrix} 1-c(1-E_o) & -T_{oo}-c(E_o-T_{oo}) \\ 1 & -1 \end{pmatrix} \begin{pmatrix} J_o^+ \\ J_o^- \end{pmatrix} = \begin{pmatrix} QE_o \\ Q-(1-c)A \end{pmatrix}$$

which can be solved for the vector J_o, giving

$$\begin{pmatrix} J_o^+ \\ J_o^- \end{pmatrix} = \begin{pmatrix} \dfrac{E_o-T_{oo}}{1-T_{oo}} Q \\ -\dfrac{1-E_o}{1-T_{oo}} Q \end{pmatrix} + \begin{pmatrix} \dfrac{T_{oo}(1-c)+cE_o}{1-T_{oo}} A \\ \dfrac{1-c+cE_o}{1-T_{oo}} A \end{pmatrix} \tag{2}$$

Q is known from the assumed spatial distribution of fission neutrons and from the solutions obtained for higher energy groups; E_o, T_{oo}, and c can be computed from the properties of the medium contained within the region; and A is unknown. When the boundary conditions are applied at interfaces, the currents at the outermost cylindrical surface are expressed in terms of A of the innermost region and in terms of the sources in all regions. Application of the cell boundary condition then gives A in cell calculations, and an interaction calculation relating the currents at the surfaces of each symmetrically different coaxial combination of regions gives A for the central cylinder of each combination when the cell boundary condition is not used.

The latter calculation is performed by making use of the one-group version of Equation 19[1]

$$G\,J^+ + H\,J^- = EQ \tag{3}$$

where J^+ and J^- are the vectors of the currents leaving and entering the outer surface of each symmetrically different cylinder, the elements of the matrices G and H are the elements G_{kij} and H_{kij} of Reference (1) with the group index k dropped, E is the vector of the escape probabilities from the surrounding medium (e.g. moderator) into each symmetrically different cylinder, and Q is the number of source neutrons in the surrouding medium within a cell. Once A is found for each central cylinder, A for each annular region and for the surrounding medium is readily obtained from the sources within each region and from the currents entering and leaving the region. The flux within a region is then simply the ratio of A to the total macroscopic cross section.

This method of calculation is satisfactory provided the transmission probability for an annulus is not too small, as is generally the case for fast neutrons for which the code was originally intended. For completely black regions, modifications are easily made to permit the calculation to be carried out, and presumably similar modifications could be made for nearly black regions. Such modifications, however, are not presently incorporated in the code.

(3) Simpler forms for the transmission probabilities T_{oi} and T_{oo} are used:

$$T_{oi}(\alpha,\Sigma R) = \frac{2}{\pi}\int_{-1}^{1} Ki_3(\Sigma R(\sqrt{1-\alpha^2u^2} - \alpha\sqrt{1-u^2}))\,du \qquad (4)$$

$$T_{oo}(\alpha,\Sigma R) = \frac{4}{\pi}\int_{\alpha}^{1} Ki_3(2\Sigma R\sqrt{1-u^2})\,du \qquad (5)$$

where Σ is the total (or the transport) cross section, R is the outer radius, and α is the ratio of the inner and outer radius.

(4) The following form[3] is used for the Dancoff factor:

$$T_{ih}(R/d,\Sigma R) = \frac{1}{\pi^2}\int_{-1}^{1}\int_{-1}^{1} \frac{Ki_3(\Sigma R(\sqrt{(d/R)^2-(u+v)^2} - \sqrt{1-u^2} - \sqrt{1-v^2}))\,du\,dv}{\sqrt{(d/R)^2-(u+v)^2}} \qquad (6)$$

where d is the axis-to-axis separation.

Description of HEETR Code

The HEETR code listing is given in Appendix A. To permit a large number of groups and regions, the code is divided into two parts. In the first part, microscopic cross sections read from a library are combined with atomic densities to give macroscopic cross sections for each type of material and for each energy group. The fraction of the fission spectrum included in each group is also computed in this part by Subroutine FNSPM. This information together with general input data is put on a scratch tape and is called into the core after the second part of the code has been called into the core by Subroutine LTAP1. The solution to a problem is obtained in the second part of the code, which employs a number of subroutines.

In Subroutine TRP the transmission probabilities and the Dancoff factors, if required, for each region and group are computed and stored. This procedure is adopted because the computation of these probabilities is fairly time-consuming and they do not change from one iteration to another. The Dancoff factor is computed from Equation 6 by 16 point Gauss quadrature of each integral in the double integral, except when $\Sigma = 0$ for which the analytic evaluation of the integral is employed. Several different schemes were tried for evaluating the Dancoff integral before finally concluding that the 16 point quadrature gives satisfactory results, which are in fairly good agreement with Reference (3). Estimates are required for the fractions of neighboring cylinders "seen" when other cylinders intervene. For clusters such estimates are provided by extending the cluster conceptually and assuming that nearest neighbors, next nearest, etc. are "seen" completely until the sum of the fractions reaching these neighbor with $\Sigma = 0$ equals unity. More distant neighbors are then assumed to be blocked from view.

The probability of transmission from the inner to the outer surface of an annulus, T_{oi}, is computed directly from Equation 4 by 14 point Gauss quadrature except for small values of ΣR for which the K_{i_3} function is approximated by its first few terms, which are then integrated. More than 14 points were tried but were not found to give appreciably different results. The probability of transmission from the inner surface to the outer surface without passing through the inner surface, T_{oo}, is computed from Equation 5 by computing the integral from $-\alpha$ to α again by 14 point Gauss quadrature and subtracting the result from the integral from -1 to 1, which is T_{oo} for a cylinder ($\alpha = 0$) and which has been integrated[4] to give

$$T_{oo}(0,\Sigma R) = 1 - \frac{4(\Sigma R)^2}{3}\Big\{2\Sigma R\left[K_1(\Sigma R)I_1(\Sigma R) + K_o(\Sigma R)I_o(\Sigma R)\right] - 2 + \frac{K_1(\Sigma R)I_1(\Sigma R)}{\Sigma R} - K_o(\Sigma R)I_1(\Sigma R) + K_1(\Sigma R)I_o(\Sigma R)\Big\} \qquad (7)$$

The Bessel functions are evaluated by subroutines obtained from Hanford. For small and large values of ΣR, approximations[4] to Equation 7 are employed:

$$T_{oo}(0,\Sigma R) = 1 - \Sigma R(2-\Sigma R(\frac{8}{3} - \Sigma R\ (\log 2 + 5/4 - \gamma - \log \Sigma R))) \qquad 0 \leqslant \Sigma R < 0.1$$

$$T_{oo}(0,\Sigma R) = \frac{3}{16(\Sigma R)^2}\ (1 + \frac{5}{8(\Sigma R)^2}) \qquad \Sigma R \geqslant 5$$

where γ is Euler's constant. For the general case, where $\alpha > 0$, $T_{oo}(\alpha,\Sigma R)$ for $\Sigma R < 0.1$ is integrated in the same manner as T_{oi} by approximating the Ki_3 function by its first few terms. Except where it is approximated by leading terms, the Ki_3 function is computed from rational approximations[5].

The number of interactions A in each region and in each group for a particular specification of the spatial distribution of the fission source is computed in Subroutine SOLN. The solution of the simultaneous equations resulting when symmetrically different fuel regions are present is obtained with the New York University Subroutine LEQ. When Dancoff factors are used, Subroutine MOD is used to compute the elements of G, H, and E in Equation 3. Subroutine MATS computes the elements of L^{-1} and R in Equation 1 for each annular region. Subroutine JVECTR computes the terms in Equation 2 for the central cylinder, and by repeated application of boundary conditions relates the currents at the outer surface of the outermost annulus to the sources in all regions and to the interactions A in the central cylinder. Terms are saved so that when A is found for the cylinder, A is readily obtained for all regions by suitable multiplication.

In the main program, the normalization of fission sources and the iteration to a converged spatial distribution of fissions are carried out. Average fluxes and over-all average nuclear parameters are computed. The various printing options are exercised in the main program.

As presently dimensioned, each cylindrical element may consist of as many as 20 regions, the elements may belong to as many as 10 symmetry classes, the number of different materials may be as many as 9, the number of different isotopes and compounds of which the materials are composed may be as many as 25, and the number of energy groups may be as many as 20. Modifications in the dimensions are easily made. Thus, the number of groups can be increased at the expense, say, of the number of symmetry classes by a change in the DIMENSION statements in the programs and subroutines.

The amount of machine time is clearly a function of the complexity of the problem. The seven double-tube cases in Table I, the four 7-rod clusters in Table IV, and the two 19-rod clusters in Table IV took about one hour of machine time with 15 energy groups. Where many complex problems are to be run, considerable savings in machine time can probably be made by employing polynominal approximations to the transmission probabilities and Dancoff factor.

Five tape units are employed by the code. The first and second parts of the program are on Tape 1. Tape 5 is used for library data (microscopic cross sections and other nuclear parameters). Tape 8 is used for input data for running problems. Tape 2 is used for storing output from Part I. Tape 10 is used for storing output data computed by Part II.

Application of Code to PDP Lattices

The HEETR code computes spatial and energy averages of all nuclear parameters and hence furnishes information from which leakage can be computed as well as absorptions in the various materials present. About the only directly measurable parameter with which comparison can be made, however, is the ratio of ^{238}U to ^{235}U fissions in a thermal reactor. This ratio has been measured[6,7] for a number of natural uranium metal lattices of tubular elements and of rod clusters in a D_2O-moderated reactor. To check the code out and to provide some comparison with experiment, calculations were made by HEETR for these lattices to give not only this ratio, but also average values of all the nuclear parameters over the energy range lying above 2035 ev. The fast reactor cross sections compiled by Yiftah, Okrent, and Moldauer[8] were used for the cladding and for the uranium isotopes except that ν in the first four groups was reduced by 1.9% for ^{235}U and by 3.0% for ^{238}U in line with more recent data.

Cross sections for D_2O and H_2O were computed by a zero-dimensional multigroup code employing a group lethargy width of 0.05. Appendix B (a complete sample printout for the first 19-rod cluster of Table IV) gives the cross sections with the lower value of ν. The lower bound for the calculations was determined by the lower bound of the 15 group set of cross sections. The spatial distributions of fissions occurring below this energy were assumed to be those determined experimentally by thermal flux traverses.[6,9,7] In the 15 group scheme fissions in ^{238}U are confined to the first four groups; ^{235}U fissions of course occur in all groups. In the calculations, the actual physical interfaces were used and regions were not subdivided. For the clusters, estimates were made from scale drawings of the number of rods that a rod in one cluster could "see" in neighboring clusters.

Calculations were first made for 12 lattices of single and double tubes studied experimentally[6]. The description of the tubes and lattices will not be repeated here. The numbering of the lattices is the same as in the reference. Except where noted otherwise, all calculations used the transport cross section both in fuel and moderator and Dancoff factors were used. The age τ was calculated as $\tau = (\overline{1/3\Sigma_{tr}})/(\overline{\Sigma}_c+\overline{\Sigma}_f+\overline{\Sigma}_r-\nu\overline{\Sigma}_f)$. The thermal value taken for ν was 2.42.

The results calculated for the tubes are given in Table I, together with the experimental values of δ, the ratio of ^{238}U to ^{235}U fissions.

TABLE I

Average Nuclear Parameters above 2035 ev for Lattices of Natural Uranium Tubes[6]

Tube	Lattice	Σ_{tr}	Σ_c	Σ_f	ν	τ	δ Calc.	δ Exptl.
Single	1	0.274	0.00140	0.00058	2.76	56.85	0.0547	0.044±0.007
	1[a]	0.274	0.00140	0.00058	2.76	56.85	0.0543	
	1[b]	0.274	0.00140	0.00057	2.76	56.83	0.0542	
	1[c]	0.274	0.00140	0.00058	2.76	56.87	0.0553	
	2	0.273	0.00127	0.00054	2.76	56.74	0.0508	0.033±0.007
	3	0.269	0.00109	0.00047	2.76	56.88	0.0435	0.026±0.005
	4	0.263	0.00053	0.00040	2.78	56.29	0.0375	0.025±0.005
	11	0.279	0.00169	0.00069	2.76	57.04	0.0659	0.046±0.007
Double	5	0.280	0.00177	0.00070	2.76	57.01	0.0665	0.061±0.008
	6	0.275	0.00142	0.00061	2.76	56.42	0.0579	0.046±0.008
	7	0.279	0.00177	0.00069	2.76	57.49	0.0665	0.064±0.010
	8	0.278	0.00156	0.00067	2.76	56.54	0.0643	0.046±0.008
	9	0.278	0.00159	0.00069	2.76	56.56	0.0654	0.052±0.008
	10	0.266	0.00076	0.00059	2.77	56.43	0.0571	0.061±0.010
	12	0.279	0.00182	0.00079	2.76	59.06	0.0784	0.067±0.010

(a) Includes contributions from 6 nearest neighbors only.
(b) Cell boundary condition used rather than Dancoff factors.
(c) Cell boundary condition and total cross section in moderator rather than transport cross section.

In Table II values of δ are given for each tube in the double tube assemblies, although these individual ratios were not measured experimentally. Except for lattice 10 the calculated values of the over-all ratio of ^{238}U to ^{235}U fissions lie above the experimental values, and only for lattices 5, 7 and 10 are the calculated results within the quoted range of experimental error (the result for lattice 12 is close). It hardly seems likely that much of the discrepancy can lie in reasonable errors in the nuclear parameters. Lattices 4 and 10 differed respectively from lattices 3 and 9 only in the pitch, which was 14 inches for 4 and 10 rather than 7 inches as for all other lattices. The trend in the experimental values for 9 and 10 is clearly in the wrong direction.

TABLE II

Ratio of ^{238}U to ^{235}U Fissions in Each Tube of Double Tube Assemblies

Lattice	δ Inner Tube	δ Outer Tube	δ Over-All
5	0.0744	0.0635	0.0665
6	0.0662	0.0532	0.0579
7	0.0745	0.0615	0.0665
8	0.0751	0.0569	0.0643
9	0.0723	0.0600	0.0654
10	0.0645	0.0515	0.0571
12	0.1002	0.0667	0.0784

On the basis of tube dimensions one would expect δ for lattice 7 to be closer to δ for lattice 8 and δ for lattices 1 and 11 to differ more than was found experimentally. There thus appears some basis for assigning at least part of the discrepancy to a lack of precision in the experimental data, which in large part may be due to low flux levels[8].

For lattice 1, variations in the options used in the code were tried. As Table I shows, for this lattice, the cell boundary condition gives a somewhat smaller δ than is obtained with the use of Dancoff factors. When Dancoff factors are used, contributions from tubes beyond the six nearest neighbors add very little. It makes little difference whether the total cross section or the transport cross section is used in the moderator, provided c is adjusted (as it is in the code) so that when the transport cross section is used the numbers of neutrons per interaction absorbed and transferred to lower energy groups are the same as when the total cross section is used.

To investigate the origin of various contributions to δ, some calculations were set up for a hypothetical lattice of natural uranium tubes with inner and outer radii of 4.0 and 4.5 cm. These tubes are similar to those used in lattice 3, which had inner radii of 3.87 cm and outer radii of 4.39 cm. The moderator was taken to be pure D_2O. The cell radius was 9.5 cm. A cell calculation was performed in which the transport cross section was used. Results of these calculations are given in Table III and show that appreciable contributions to δ come from secondary neutrons that have had at least one interaction in the moderator and from neutrons passing through the moderator from one tube to another or from one portion of the inner surface of a tube

TABLE III

Source of Contributions to
δ in 8-cm ID, 9-cm OD Tube

Situation Considered	δ
Tube immersed in moderator (as in Table I)	0.0409
Central moderator replaced by fictitious, purely absorbing medium with same Σ_T	0.0359
Same as immediately above but Σ_T increased by a factor of 10	0.0319
Same as first case except outer moderator replaced by fictitious absorber with same Σ_T	0.0355
Both inner and outer moderator replaced by fictitious absorber with same Σ_T	0.0319
No neutrons entering inner or outer surfaces of tube	0.0283

to another without having a collision. It was not possible to perform valid calculations when the cross section of the outer fictitious absorbing medium was increased by 10, because the blackness of the annulus made the calculations insensitive to the cell boundary condition. The last δ in the table was obtained by a hand calculation using escape probabilities calculated for the tube. It should be noted that even this result is higher than one would expect from the experimental results. For this same tube a calculation was made in which the inner and outer moderator were subdivided into annuli 1 cm thick. The central moderator cylinder had a diameter of 2 cm. The value calculated for δ was 0.405 compared with 0.409 when no subdivision was made. The respective values of τ were 55.93 and 55.91 cm^2. Subdivision of the moderator, in this case at least, thus has little effect.

The next set of lattices[7] for which calculations were made consisted of 1-inch-diameter natural uranium rods and clusters of these rods containing 3, 7, and 19 rods per cluster. The Dancoff factors were used in all cases. For the 7-rod clusters there were two symmetry types, and for the 19-rod clusters, four symmetry types. Results of the calculations are given in Table IV. The experimental data also include values of δ for rods at each symmetrically different location within a cluster. These ratios are compared with the calculations in Table V.

TABLE IV

Average Nuclear Parameters Above 2035 ev for Lattices of Natural Uranium Rod Clusters[7]

Rods/ Cluster	Pitch, in.	Σ_{tr}	Σ_c	Σ_f	ν	τ	Average δ Calc.	Average δ Exptl.
1	7.00	0.263	0.00058	0.00056	2.78	57.02	0.0544	0.053
	7.00[a]	0.263	0.00058	0.00056	2.78	57.02	0.0544	
	8.08	0.262	0.00051	0.00055	2.78	57.01	0.0536	0.054
	9.33	0.261	0.00045	0.00054	2.78	57.01	0.0530	0.050
	12.12	0.260	0.00038	0.00053	2.79	57.01	0.0524	0.048
3	7.00	0.272	0.00122	0.00074	2.77	57.70	0.0729	0.063
	14.00	0.262	0.00055	0.00067	2.78	57.58	0.0666	0.062
7	12.12	0.269	0.00106	0.00086	2.78	58.33	0.0864	0.071
	14.00	0.267	0.00089	0.00084	2.78	58.30	0.0851	0.067
	18.52	0.264	0.00067	0.00083	2.79	58.29	0.0837	0.068
	18.52[b]	0.263	0.00062	0.00069	2.79	57.55	0.0689	0.057
19	14.00	0.279	0.00180	0.00102	2.77	59.18	0.1049	0.100
	18.52	0.271	0.00120	0.00098	2.78	58.97	0.1008	0.102

(a) Calculation includes effect of only the 6 nearest neighbors.
(b) Triangular pitch of 2 inches in cluster. All other clusters had a 1.5-inch pitch within the cluster.

TABLE V

Ratio of ^{238}U to ^{235}U Fissions in Rods in Symmetrically Different Locations[a]

Rods/ Cluster	Pitch, in.	δ at Rod Location 1 Calc.	1 Exptl.	2 Calc.	2 Exptl.	3 Calc.	3 Exptl.	4 Calc.	4 Exptl.
7	12.12	0.1260	0.105	0.0820	0.067				
	14.00	0.1252	0.098	0.0807	0.063				
	18.52	0.1234	0.098	0.0793	0.066				
	18.52	0.0875	0.074	0.0667	0.055				
19	14.00	0.2360	0.179	0.1681	0.152	0.0939	0.097	0.0814	0.075
	18.52	0.2089	0.167	0.1622	0.142	0.0950	0.105	0.0755	0.076

(a) Rod locations are numbered from center outward[7].

Agreement with experiment in the case of the single rods is good. The disagreement in the case of the clusters can probably be explained at least partially on the basis of a decrease in the validity of the first and third approximations. The thermal fission source is actually higher toward the outside of the cluster and this should tend to enhance the current directed outward into the moderator at the expense of the current directed toward the center of the cluster. Errors in the estimates of numbers of neighboring rods "seen" may also contribute to the discrepancy. Homogenizing the cluster and treating it as a number of coaxial annuli, as Maerkl and Fowler[10] do in a similar treatment of fast fissions, should improve the agreement between calculation and experiment since they found very good agreement between calculations and experiments for the lattices they studied.

Input to HEETR

As many cards are used for library and for problem data as are required by the information being supplied. Each card is begun at the left. The cards must be read onto the library tape (5) and the input data tape (8).

Library Data

Format	Data
14I5	NG, NM NG = No. of groups. NM = No. of isotopes or compounds.
7F10.6	(ST(J,I),J=1,NG), (STR(J,I),J=1,NG), (SC(J,I),J=1,NG), (SF(J,I),J=1,NG), (VNU(J,I),J=1,NG), (SIJ(J,I),J=1,NIJ), AWT(I) ST, STR, SC, and SF are the microscopic cross sections σ_t, σ_{tr}, σ_c, and σ_f for the Ith isotope in the Jth group. VNU is the number of neutrons per fission ν. SIJ is the microscopic cross section σ_{KJ} for transfer from group J to group K; the order of listing is σ_{11}, σ_{21}, σ_{22}, σ_{31}, σ_{32}, σ_{33}, ..., $\sigma_{(NG+1)(NG)}$. AWT is the atomic or molecular weight. The items are listed serially as indicated with no breaks; a new card is started each time I advances.
7F10.6	(EL(I),I=1,NG) EL is the lower bound of a group in Mev and is greatest for group 1.
12A6	(CC(I),I=1,NM) CC is a label of no more than 6 letters describing the Ith isotope or material.

Problem Data

Format	Data
14I5	NSC,(NR(I),I=1,NSC), (NWSC(I),I=1,NSC),NRT,NST,NSA,NSR,NCC,NP,(NOUT(I) I=1,5)

NSC is the number of symmetrically different types of fuel cylinders per cell. NR is the number of regions within each type. NWSC is the number of members of each type. NRT is the number of different materials. NST is the solution type. If $0\leqslant NST\leqslant 3$ the transport cross section is used in computing transmission and escape probabilities, and the number of secondaries remaining in a group i is given by $c = (\sigma_{tr}-\sigma_t+\sigma_{ii})/\sigma_{tr}$. If $4\leqslant NST\leqslant 7$ the total cross section is used, and $c = \sigma_{ii}/\sigma_t$. If NST=2,3,6,7 a cell boundary condition is used (available only if NSC=NWSC(NSC)=1; otherwise Dancoff factors are used. If NST is even, the fission source FS gives the actual distribution in the thermal group (NG+1); if NST is odd, FS is an estimate of the over-all source distribution resulting from fissions in all NG groups. In this case, either there is no thermal group or it is group NG. If 10 is added to NST, the solution type is unchanged but the code computes the ratio of ^{238}U to ^{235}U fissions in each uranium region. If this option is selected, NST must be even, material number 2 must be uranium, and material number 3 must be ^{238}U having the same atomic density as in the uranium. (No region will contain material number 3.) NSA is the number of different intracell axis-to-axis spacings. NSR is the number of different intercell axis-to-axis spacings. If NSC=NWSC(NSC)=1, NSR is taken to be 0, and NSA is taken to be the total number of different axis-to-axis spacings to be considered and must be $\geqslant 1$. NCC is the negative of exponent of 10 used as a convergence criterion (NCC was 4 for the calculations made for Tables I-V). NP is the problem number. NOUT specifies printout option. If NOUT(1)$\neq$0, fission sources and disadvantage factors for each region and group are printed. If NOUT(2)$\neq$0, axis-to-axis spacings, weights WTS, and weights in an infinite lattice WIL are printed. If NOUT(3)$\neq$0, all transmission probabilities and Dancoff factors are printed. If NOUT(4)$\neq$0, macroscopic cross sections for each material are printed. If NOUT(5)$\neq$0, library is printed.

7F10.6 (COMP(J,I),J=1,NM+1)

COMP(1,I) is the density of the I^{th} material and COMP(J,I) for $2 \leq J \leq NM+1$ is the weight fraction of each isotope in the library in the order listed appearing in the I^{th} material. A new card is started each time I advances. Moderator must be material number 1.

14I5 (INT(J,I),J=1,NR(I))

7F10.6 (RAD(J,I),J=1,NR(I))

7F10.6 (FS(J,I),J=1,NR(I))

INT indicates the material of which the J^{th} region in the I^{th} symmetry type is composed. RAD is the outer radius of the region. FS is the thermal fission source or the estimated source in the region depending on NST. INT, RAD, and FS each starts a new card. The cycle repeats each time I advances. There are NSC cycles.

7F10.6 UATAS,FSM,RADC,VNUTH

UATAS is the minimum axis-to-axis spacing in cm. FSM is the fission source within a cell in the region surrounding the cylinders. RADC is the cell radius in cm. VNUTH is the number of neutrons released per thermal fission.

7F10.6 (ATAS(I),I=1,NSA), (ATAS(NSA+I),I=1,NSR)

ATAS is the axis-to-axis spacing expressed as a multiple of UATAS. Those within a cell are listed first in increasing order followed by those involving more than one cell.

24F3.2 (WIL(I),I=1,NSA)

WIL is the number of elements at each intracell spacing in an infinite lattice formed by extending the cluster of elements within a cell.

24F3.2 (WTS(K,I,J),K=1,NSA+NSR)

WTS is the number of elements of symmetry type J transmitting neutrons to an element of symmetry type I separated from it by ATAS(K). A new card is started each time J advances and a new cycle (and card) is started each time I advances.

14I5 NSC,(NR(I),I=1,NSC), etc.

Cards for the next problem, which must use the same library. If NSC=0, NR(1) is interpreted as a series number for a group of problems, and tape 1 is rewound to be ready for another series using a different library.

Output from HEETR

The regular output, which may be supplemented by any or all of the five options indicated by NOUT, consists first of the problem number, a description of the type of solution as indicated by NST, and the density and composition of each material in the cell. This information is followed by optional printouts of the library and the macroscopic cross sections of each material. Next the code prints for each group the lower energy bound, the fraction of the fission spectrum included, and the spatially averaged flux integral normalized to unity for the integral over the entire energy range encompassed by all the groups. These are followed by spatial averages of Σ_t, Σ_{tr}, Σ_c, Σ_f, $\nu\Sigma_f$, and ν for each group. Spatially averaged values of the macroscopic transfer cross section Σ_{kj} are listed next. Finally if there is a thermal group not encompassed by the code, values averaged over space and over all energies encompassed by the NG groups are listed for $\overline{\Sigma}_t$, $\overline{\Sigma}_{tr}$, $1/(\overline{1/\Sigma_{tr}})$, $\overline{\Sigma}_c$, $\overline{\Sigma}_f$, $\overline{\nu}$, $\nu\overline{\Sigma}_f$, and $\overline{\Sigma}_r$ where r denotes removal below the lower bound of the group of lowest energy; an age τ is computed as $\tau = (\overline{1/\Sigma_{tr}})/(3\overline{\Sigma}_c+3\overline{\Sigma}_f+3\overline{\Sigma}_r-3\nu\overline{\Sigma}_f)$; and the fraction of the source neutrons arising from thermal fissions and the ratio of fast-to-thermal fissions are given. The ratio of ^{238}U to ^{235}U fissions in each symmetrically different uranium region and the over-all ratio for the cell follow next if this option was selected.

An optional printout then gives the outer radius, the volume fraction, the fission source, and the disadvantage factor in each group for the moderator surrounding the fuel cylinders and for each region of each symmetrically different fuel cylinder. The next optional printout gives axis-to-axis spacings and weights. The final optional printout gives Dancoff factors and transmission probabilities.

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APPENDIX A – FORTRAN LISTING

```
    PART 1     HEETR CODE          H. K. CLARK        8211-1K
301 FORMAT(14I5)
302 FORMAT(7F10.6)
303 FORMAT(/////)
304 FORMAT(24F3.2)
305 FORMAT(12A6)
310 FORMAT(50X14HPROBLEM NUMBERI5)
311 FORMAT(1H065X18HWEIGHT FRACTION OF)
312 FORMAT(30H   TYPE NO.      DENSITY(G/CC) ,2XA6,8(4XA6))
313 FORMAT(I8,F18.5,F13.6,3F10.5)
314 FORMAT(46H1PRINTOUT OF LIBRARY TAPE AND FISSION SPECTRUM)
315 FORMAT(98H1 GROUP    EL(MEV)    FISSION SOURCE    SIGMA-T      SIGMA-
   1TR    SIGMA-C     SIGMA-F       NU          A6,F16.3)
316 FORMAT(I5,1PE14.4,0PF12.5,1PE15.3,3E12.3,0PF9.3)
317 FORMAT(104H0            SIGMA-IJ (TRANSFER TO GROUP I FROM GROUP J),
   1ARRANGED AS 11, 21, 22, 31, 32, 33,...,(NG+1)(NG))
318 FORMAT(10X11F10.4)
319 FORMAT(74H1PRINTOUT OF MACROSCOPIC CROSS SECTIONS AND FISSION SPEC
   1TRUM FOR EACH TYPE)
320 FORMAT(112H1 GROUP    EL(MEV)    FISSION SOURCE    SIGMA-T      SIGMA
   1-TR    SIGMA-C      SIGMA-F     NUSIGMA-F        TYPE NUMBER I1)
321 FORMAT(I5,1PE14.4,0PF12.5,F15.7,4F12.7)
322 FORMAT(120H1HEETR CODE                          COMPUTES EVENTS IN CYLINDR
   1ICAL CELLS FROM ESCAPE AND TRANSMISSION PROBABILITIES                  )
323 FORMAT(31H1END OF LAST PROBLEM OF SERIES I2/////)
324 FORMAT(120H0SOURCE SUPPLIED FOR EACH REGION IS RELATIVE NUMBER OF
   1NEUTRONS PRODUCED BY FISSIONS OCCURRING IN GROUP NG+1.              )
325 FORMAT(120H0SOURCE SUPPLIED FOR EACH REGION IS ESTIMATE OF RELATIV
   1E NUMBER OF NEUTRONS PRODUCED BY FISSIONS OCCURRING IN NG GROUPS.)
326 FORMAT(120H0TRANSMISSION AND ESCAPE PROBABILITIES ARE COMPUTED FRO
   1M TOTAL CROSS SECTIONS.                                             )
327 FORMAT(120H0TRANSMISSION AND ESCAPE PROBABILITIES ARE COMPUTED FRO
   1M TRANSPORT CROSS SECTIONS.                                         )
328 FORMAT(120H0DANCOFF FACTORS ARE EMPLOYED FOR INTERACTION BETWEEN E
   1LEMENTS IMMERSED IN MODERATOR.                                      )
329 FORMAT(120H0THE CELL APPROXIMATION IS MADE WITH ZERO CURRENT AT TH
   1E CELL BOUNDARY.                                                    )
    DIMENSION ST(20,25),STR(20,25),SC(20,25),SF(20,25),VNU(20,25),SIJ(
   1230,25),AWT(25),COMP(26,10),EL(20),SGMT(20,10),SGMTR(20,10),SGMC(2
   20,10),SGMB(20,10),VSGMB(20,10),SGMIJ(230,10),SPRM(20),NWSC(10)
    DIMENSION NR(10),INT(20,10),RAD(20,10),FS(20,10),ATAS(24),WTS(24,1
   10,10),WIL(24),CC(25),NOUT(5)
```

NG=NO. OF GROUPS, NSC=NO. OF SYMMETRY CLASSES, NR(I)=NO. OF REGIONS IN EACH CLASS, NRT=NO. OF DIFFERENT TYPES OF REGIONS IN CELL, NM=NO. OF MATERIALS FOR WHICH DATA ARE TO BE READ, NWSC(I)= NO. OF UNITS WITHIN EACH SYMMETRY CLASS, ST(I,J)= SIGMA TOTAL OF MATERIAL J IN GROUP I. SIMILARLY STR, SC, SF, AND VNU REPRESENT SIGMA TRANSPORT, SIGMA CAPTURE, SIGMA FISSION, AND NU. SIJ(I,J) REPRESENTS TRANSFER CROSS SECTIONS OF MATERIAL J ARRANGED IN THE ORDER 11, 21, 22, 31, 32, 33,...,(NG+1)(NG). INT(J,I) IS THE

REGION TYPE INDEX FOR SYMMETRY CLASS I. INT(J,I) ASSUMES A TYPE NO. FOR EACH REGION J. AWT(I)=ATOMIC WEIGHT OF MATERIAL I. COMP(I,J)=DENSITY OF TYPE J FOLLOWED IN ORDER BY WEIGHT FRACTIONS OF VARIOUS MATERIALS I-1. RAD(I,J)=OUTER RADIUS OF REGION I OF SYMMETRY CLASS J. EL(I)=LOWER BOUND OF GROUP I IN MEV. FS(I,J)= ESTIMATED OR ACTUAL FISSION SOURCE IN EACH REGION I OF EACH SYMMETRY CLASS J. NP=PROBLEM NO. NST=SOLUTION TYPE(IF NST IS EVEN, FS IS ACTUAL SOURCE IN NG+1 GROUP. IF ODD FS IS ESTIMATE. 0 THRU 3 INDICATE TRANS. APPROX.). ATAS(I)=POSSIBLE AXIS TO AXIS SEPARATION VALUES IN INCREASING ORDER. WTS(I,J,K)=NO. OF UNITS IN SYMMETRY CLASS K TRANSMITTING NEUTRONS TO UNIT OF SYMMETRY CLASS J AT A SEPARATION ATAS(I). FSM=ACTUAL OR ESTIMATED FISSION SOURCE IN MODERATOR.

INTRACELL SPACINGS MUST BE LISTED FIRST IN INCREASING ORDER FOL-LOWED BY INTERCELL SPACINGS, EVEN IF SOME INTER ARE LESS

UATAS=UNIT AXIS TO AXIS SEPARATION. RADC=RADIUS OF CELL

IF NST=2,3,6,OR 7,(AND IF NSC=NWSC(NSC)=1) CODE USES CELL BOUNDARY

IF RATIO OF U-238 TO U-235 FISSIONS IS DESIRED, NST IS INCREASED BY 10. THE URANIUM MUST BE MATERIAL TYPE 2, AND MATERIAL TYPE 3 MUST BE PURE U-238 HAVING THE SAME ATOMIC DENSITY AS IN MATERIAL TYPE 2. THIS OPTION IS AVAILABLE ONLY WHEN NST IS EVEN.

NCC IS NEGATIVE EXPONENT OF 10 FOR CONVERGENCE CRITERION

MODERATOR REGION IS ALWAYS TYPE 1. NSA=NO. OF INTRA CELL SPACINGS.

NSR=NO. OF INTERCELL SPACINGS

NOUT SPECIFIES OUTPUT. IT CONSISTS OF 5 NUMBERS.IF FIFTH NUMBER IS NON-ZERO, LIBRARY TAPE IS PRINTED. IF FOURTH NUMBER IS NON-ZERO MACROSCOPIC SIGMAS FOR TYPES EMPLOYED ARE PRINTED. IF THIRD NUMBER IS NON-ZERO, TPOO, TPOI, AND DTP ARE PRINTED. IF SECOND NUMBER IS NON-ZERO, ATAS, WTS, AND WIL ARE PRINTED. IF FIRST NUMBER IS NON-ZERO, FISSION SOURCES AND DISADVANTAGE FACTORS ARE PRINTED.

```
      NLIB=5
      NTIN=8
      NTOUT=10
      REWIND 2
      READ INPUT TAPE NLIB,301,NG,NM
      NIJ=((NG+1)*(NG+2))/2-1
      DO 2 I=1,NM
    2 READ INPUT TAPE NLIB,302,(ST(J,I),J=1,NG),(STR(J,I),J=1,NG),(SC(J,
     1I),J=1,NG),(SF(J,I),J=1,NG),(VNU(J,I),J=1,NG),(SIJ(J,I),J=1,NIJ)
     2,AWT(I)
      READ INPUT TAPE NLIB,302,                (EL(I),I=1,NG)
      READ INPUT TAPE NLIB,305,(CC(I),I=1,NM)
      REWIND NLIB
      READ INPUT TAPE NTIN,301,NSC,(NR(I),I=1,NSC),(NWSC(I),I=1,NSC),NRT
     1,NST,NSA,NSR,NCC,NP,(NOUT(I),I=1,5)
      IF(NSC)21,21,22
   21 REWIND 1
      WRITE OUTPUT TAPE NTOUT,323,NR(1)
      CALL RETURN
   22 WRITE OUTPUT TAPE NTOUT,322
      K=NM+1
      DO 4 I=1,NRT
    4 READ INPUT TAPE NTIN,302,(COMP(J,I),J=1,K)
      DO 3 I=1,NSC
      K=NR(I)
      READ INPUT TAPE NTIN,301,(INT(J,I),J=1,K)
      READ INPUT TAPE NTIN,302,(RAD(J,I),J=1,K)
    3 READ INPUT TAPE NTIN,302,(FS(J,I),J=1,K)
      READ INPUT TAPE NTIN,302,UATAS,FSM,RADC,VNUTH
      NATAS=NSA+NSR
      READ INPUT TAPE NTIN,302,(ATAS(I),I=1,NATAS)
      READ INPUT TAPE NTIN,304,(WIL(I),I=1,NSA)
      DO 5 I=1,NSC
      DO 5 J=1,NSC
    5 READ INPUT TAPE NTIN,304,(WTS(K,I,J),K=1,NATAS)
      CALL EFM
      DO 18 I=1,NATAS
   18 ATAS(I)=UATAS*ATAS(I)
      DO 14 I=1,NRT
      DO 7 J=1,NG
      SGMT(J,I)=0.
      SGMTR(J,I)=0.
      SGMC(J,I)=0.
      SGMB(J,I)=0.
    7 VSGMB(J,I)=0.
      DO 8 J=1,NIJ
    8 SGMIJ(J,I)=0.
      DO 14 J=1,NM
      IF(COMP(J+1,I))14,14,10
   10 XN=COMP(1,I)*COMP(J+1,I)*.6023/AWT(J)
      DO 11 L=1,NG
      SGMT(L,I)=SGMT(L,I)+XN*ST(L,J)
      SGMTR(L,I)=SGMTR(L,I)+XN*STR(L,J)
      SGMC(L,I)=SGMC(L,I)+XN*SC(L,J)
      SGMB(L,I)=SGMB(L,I)+XN*SF(L,J)
   11 VSGMB(L,I)=VSGMB(L,I)+XN*SF(L,J)*VNU(L,J)
      DO 12 L=1,NIJ
   12 SGMIJ(L,I)=SGMIJ(L,I)+XN*SIJ(L,J)
   14 CONTINUE
```

```
      SM=0.
      DO 17 I=1,NG
      IF(I-1)15,15,16
   15 SPRM(I)=FNSPM(EL(I))
      GO TO 17
   16 SM=SM+SPRM(I-1)
      SPRM(I)=FNSPN(EL(I))-SM
   17 CONTINUE
      IF(NST-10)101,100,100
  100 MST=NST
      NST=MST-10
  101 WRITE OUTPUT TAPE NTOUT,303
      WRITE OUTPUT TAPE NTOUT,310,NP
      IF(FLOATF(NST/2)-FLOATF(NST)/2.+.1)23,23,24
   23 WRITE OUTPUT TAPE NTOUT,325
      GO TO 25
   24 WRITE OUTPUT TAPE NTOUT,324
   25 N=NST/4+1
      GO TO (26,27),N
   26 WRITE OUTPUT TAPE NTOUT,327
      GO TO 28
   27 WRITE OUTPUT TAPE NTOUT,326
   28 N=NST+1
      GO TO (29,29,30,30,29,29,30,30),N
   29 WRITE OUTPUT TAPE NTOUT,328
      GO TO 42
   30 WRITE OUTPUT TAPE NTOUT,329
   42 WRITE OUTPUT TAPE NTOUT,303
      NST=MST
      IF(NM-9)31,31,32
   31 N=NM
      GO TO 33
   32 N=9
   33 WRITE OUTPUT TAPE NTOUT,311
      WRITE OUTPUT TAPE NTOUT,312,(CC(I),I=1,N)
      DO 34 I=1,NRT
   34 WRITE OUTPUT TAPE NTOUT,313,I,COMP(1,I),(COMP(J+1,I),J=1,N)
      WRITE OUTPUT TAPE NTOUT,303
      IF(NM-9)45,45,35
   35 IF(NM-18)36,36,37
   36 N=NM-9
      GO TO 38
   37 N=9
   38 WRITE OUTPUT TAPE NTOUT,311
      WRITE OUTPUT TAPE NTOUT,312,(CC(I+9),I=1,N)
      DO 39 I=1,NRT
   39 WRITE OUTPUT TAPE NTOUT,313,I,COMP(1),(COMP(J+10),J=1,N)
      IF(NM-18)45,45,40
   40 N=NM-18
      WRITE OUTPUT TAPE NTOUT,303
      WRITE OUTPUT TAPE NTOUT,311
      WRITE OUTPUT TAPE NTOUT,312,(CC(I+18),I=1,N)
      DO 41 I=1,NRT
   41 WRITE OUTPUT TAPE NTOUT,313,I,COMP(1),(COMP(J+19),J=1,N)
   45 IF(NOUT(5))46,60,46
   46 WRITE OUTPUT TAPE NTOUT,314
      DO 48 I=1,NM
      WRITE OUTPUT TAPE NTOUT,315,CC(I),AWT(I)
      DO 47 J=1,NG
```

```
 47 WRITE OUTPUT TAPE NTOUT,316,J,EL(J),SPRM(J),ST(J,I),STR(J,I),SC(J,
   1I),SF(J,I),VNU(J,I)
    WRITE OUTPUT TAPE NTOUT,317
 48 WRITE OUTPUT TAPE NTOUT,318,(SIJ(II,I),II=1,NIJ)
 60 IF(NOUT(4))61,80,61
 61 WRITE OUTPUT TAPE NTOUT,319
    DO 63 I=1,NRT
    WRITE OUTPUT TAPE NTOUT,320,I
    DO 62 J=1,NG
 62 WRITE OUTPUT TAPE NTOUT,321,J,EL(J),SPRM(J),SGMT(J,I),SGMTR(J,I),
   1SGMC(J,I),SGMB(J,I),VSGMB(J,I)
    WRITE OUTPUT TAPE NTOUT,317
 63 WRITE OUTPUT TAPE NTOUT,318,(SGMIJ(II,I),II=1,NIJ)
 80 WRITE TAPE 2,SGMT,SGMTR,SGMC,SGMB,VSGMB,SGMIJ,SPRM,NG,NSC,NR,NWSC,
   1NRT,NST,EL,INT,RAD,RADC,FS,FSM,ATAS,WTS,WIL,NSA,NSR,NCC,NOUT,VNUTH
   2,NTIN,NTOUT
    REWIND 2
    CALL LTAP1
    END(2,0,0,0,0)

    FUNCTION FNSPM      H. K. CLARK
    FUNCTION FNSPM(A)

    COMPUTES FISSION SPECTRUM BY INTEGRATING F(E) FROM A TO INFINITY.

    F(E)=0.45270*EXPF(-E/0.965)*SINHF(SQRTF(2.29*E))
    Y1=1.01797*SQRTF(A)+.74328
    Y2=Y1-1.48656
    FNSPM=1.-.37953*(EXPF(-Y1**2)-EXPF(-Y2**2))-.5*(ERRORF(Y1)+ERRORF(
   1Y2))
    RETURN
    END(2,0,0,0,0)

    PART 2      HEETR CODE           H. K. CLARK       8211-1K
    DIMENSION SGMT(20,10),SGMTR(20,10),SGMC(20,10),SGMB(20,10),VSGMB(2
   10,10),SGMIJ(230,10),SPRM(20),NR(10),INT(20,10),RAD(20,10),ABT(20,1
   20,20),FS(20,10),AA(19,10),AQ(19,10),VA(2,10),ATAS(24),WTS(24,10
   3,10),WIL(24),TPOI(19,10,20),TPOO(20,10,20),DTP(24,20),NWSC(10),ABM
   4(20),VQ(2,10),V(20,10),UFS(20,10),PFS(20,10),DFS(20,10),NOUT(5),
   5PHI(20),EL(20),IH(20),FDU(20,10),FNU(20,10),DLTA(20,10),IS(7),
   6IR(7),DA(7)

    ABT(I,J,K)=ABSORPTIONS IN REGION I, SYMMETRY CLASS J, AND GROUP K.

    ABM(I)=ABSORPTIONS IN MODERATOR IN GROUP I.
301 FORMAT(40H1          PRINTOUT OF AVERAGED CONSTANTS/////)
302 FORMAT(30H0    MODERATOR    CELL RADIUS=F8.4 ,13H   VOL FRACT=F7.5
   1,19H   THRML FISS SRCE=F7.5,14H    LAST ITER=F7.5)
303 FORMAT(30H0    MODERATOR    CELL RADIUS=F8.4, 13H   VOL FRACT=F7.5
   1,19H   FINAL FISS SRCE=F7.5,14H    PREV ITER=F7.5)
304 FORMAT(7H0CLASS I1,6H  NO.=I2,7H   REGNI3,7H   TYPEI2,10H   RADIUS
   1=F8.4,13H   VOL FRACT=F7.5,19H   THRML FISS SRCE=F7.5,13H   LAST I
   2TER=F7.5)
305 FORMAT(7H0CLASS I1,6H  NO.=I2,7H   REGNI3,7H   TYPEI2,10H   RADIUS
   1=F8.4,13H   VOL FRACT=F7.5,19H   FINAL FISS SRCE=F7.5,13H   PREV I
   2TER=F7.5)
306 FORMAT(10X7HGROUP  10I10)
307 FORMAT(120H0GROUP      EL(MEV)   SPECTRUM      FLUX       SIGMA-T
   1  SIGMA-TR      SIGMA-C      SIGMA-F      NU*SIGMA-F        NU       )
```

```
308 FORMAT(I4,1PE15.3,0PF10.5,1PE13.4,0PF10.4,F12.4,F13.5,F12.5,F13.5,
   1F15.4)
309 FORMAT(104H0          SIGMA-IJ (TRANSFER TO GROUP I FROM GROUP J),
   1ARRANGED AS 11, 21, 22, 31, 32, 33,...,(NG+1)(NG))
310 FORMAT(10X11F10.4)
311 FORMAT(1H0///40X41HPARAMETERS AVERAGED OVER SPACE AND ENERGY//9H S
   1IGMA-T=F8.5,13H    SIGMA-TR=F8.5,14H    1/(TRMFP)=F8.5,12H    SIGM
   2A-C=F9.6,12H    SIGMA-F=F9.6,7H    NU=F7.4/6X11HNU*SIGMA-F=F9.6,18
   3H    SIGMA-REMOVAL=F9.6,39H    TAU (TRMFP/(3*SIGMA-(C+F+R-NU*F)))=
   4F8.3/11X58HFRACTION OF SOURCE NEUTRONS ARISING FROM THERMAL FISSIO
   5NS=F9.6/11X34HRATIO OF FAST TO THERMAL FISSIONS=F8.5)
312 FORMAT(41H1PRINTOUT OF DANCOFF FACTORS IN MODERATOR)
313 FORMAT(12H0    RADIUS=F7.4,29H     AXIS-TO-AXIS SEPARATION=F7.4)
314 FORMAT(5X15HDANCOFF FACTOR 10F10.5)
315 FORMAT(39H1PRINTOUT OF TRANSMISSION PROBABILITIES)
316 FORMAT(7H0CLASS I1,11H    REGION I2)
317 FORMAT(10X10HTPOI       10F10.5)
318 FORMAT(46H1PRINTOUT OF AXIS-TO-AXIS SPACINGS AND WEIGHTS)
319 FORMAT(30H0AXIS-TO-AXIS SEPARATION      8F11.4)
320 FORMAT(81H0WTS(I,J,K) ARRANGED WITHIN ROWS BY I. ROWS ADVANCE BY J
   1, AND GROUPS OF ROWS BY K)
321 FORMAT(24F5.1)
322 FORMAT(5X15HDISADVNTG FCTR 10F10.5)
323 FORMAT(30H NO. IN INF. REG. LATTICE     8F11.4)
324 FORMAT(10X10HTPOO       10F10.5)
325 FORMAT( 1H0///40X41HDISADVANTAGE FACTORS AND VOLUME FRACTIONS)
326 FORMAT(11X 41HOVERALL RATIO OF U-238 TO U-235 FISSIONS=F8.5)
327 FORMAT(21X 22HSYMMETRY CLASS, REGION    I5,1H,I2,6(I7,1H,I2))
328 FORMAT(21X 22H  U-238/U-235 FISSIONS 7F10.5)
    REWIND 2
    READ TAPE 2,SGMT,SGMTR,SGMC,SGMB,VSGMB,SGMIJ,SPRM,NG,NSC,NR,NWSC,
   1NRT,NST,EL,INT,RAD,RADC,FS,FSM,ATAS,WTS,WIL,NSA,NSR,NCC,NOUT,VNUTH
   2,NTIN,NTOUT
    REWIND 1
    IDA=0
    IF(NST-10)111,110,110
110 NST=NST-10
    IDA=1
111 CALL EFM
    CALL TRP(NST,NSC,NR,INT,NG,NSA,NSR,WTS,WIL,ATAS,RAD,RADC,SGMT,
   1SGMTR,TPOO,TPOI,DTP,L)
    IF(L)2,2,1
  1 FS(L,1)=FSM
  2 SUMA=0.
    DO 31 I=1,NSC
    KK=NR(I)
    DO 31 J=1,KK
 31 SUMA=SUMA+FS(J,I)*FLOATF(NWSC(I))
    IF(L)32,32,33
 32 SUMA=SUMA+FSM
    FSM=FSM/SUMA
 33 DO 34 I=1,NSC
    KK=NR(I)
    DO 34 J=1,KK
 34 FS(J,I)=FS(J,I)/SUMA
    IF(FLOATF(NST/2)-FLOATF(NST)/2.+.1)38,38,35
 35 DO 36 I=1,NSC
    KK=NR(I)
    DO 36 J=1,KK
```

```
36 DFS(J,I)=FS(J,I)
   IF(L)37,37,38
37 DFSM=FSM
38 VM=0.
   DO 7 I=1,NSC
   K=NR(I)
   DO 7 J=1,K
   IF(J-1)3,3,4
 3 V(1,I)=(RAD(1,I)/RADC)**2
   GO TO 5
 4 V(J,I)=(RAD(J,I)**2-RAD(J-1,I)**2)/RADC**2
 5 IF(L)6,6,7
 6 VM=VM+V(J,I)*FLOATF(NWSC(I))
 7 CONTINUE
   IF(L)8,8,9
 8 VM=1.-VM
 9 N=NST/4
40 CALL SOLN(L,NG,NSC,NST,NSA,NSR,NR,INT,NWSC,SGMT,SGMTR,SGMIJ,FS,FSM
  1,SPRM,DTP,TPOO,TPOI,RAD,RADC,ABT,ABM,WTS)
   DO 12 I=1,NSC
   KK=NR(I)
   DO 12 J=1,KK
   JJ=INT(J,I)
   UFS(J,I)=0.
   DO 12 K=1,NG
   IF(N)10,10,11
10 ABT(J,I,K)=ABT(J,I,K)/(SGMTR(K,JJ)*V(J,I))
   GO TO 12
11 ABT(J,I,K)=ABT(J,I,K)/(SGMT(K,JJ)*V(J,I))
12 UFS(J,I)=UFS(J,I)+VSGMB(K,JJ)*ABT(J,I,K)*V(J,I)
   IF(L)13,13,17
13 UFSM=0.
   DO 16 I=1,NG
   IF(N)14,14,15
14 ABM(I)=ABM(I)/(SGMTR(I,1)*VM)
   GO TO 16
15 ABM(I)=ABM(I)/(SGMT(I,1)*VM)
16 UFSM=UFSM+ABM(I)*VSGMB(I,1)*VM
17 IF(FLOATF(NST/2)-FLOATF(NST)/2.+.1)51,51,18
18 SUMA=0.
   DO 19 I=1,NSC
   KK=NR(I)
   DO 19 J=1,KK
   PFS(J,I)=FS(J,I)-UFS(J,I)
19 SUMA=SUMA+PFS(J,I)*FLOATF(NWSC(I))
   IF(L)20,20,21
20 PFSM=FSM-UFSM
   SUMA=SUMA+PFSM
   UFSM=UFSM/SUMA
   PFSM=PFSM/SUMA
21 SUMC=0.
   DO 22 I=1,NSC
   KK=NR(I)
   DO 22 J=1,KK
   UFS(J,I)=UFS(J,I)/SUMA
   PFS(J,I)=PFS(J,I)/SUMA
22 SUMC=SUMC+ABSF(DFS(J,I)-PFS(J,I))*FLOATF(NWSC(I))
   IF(L)23,23,24
23 SUMC=SUMC+ABSF(DFSM-PFSM)
```

```
24 IF(SUMC-10.**(-NCC))60,60,25
25 SUMC=0.
   DO 41 I=1,NSC
   KK=NR(I)
   DO 41 J=1,KK
   FS(J,I)=DFS(J,I)+UFS(J,I)
41 SUMC=SUMC+FS(J,I)*FLOATF(NWSC(I))
   IF(L)42,42,43
42 FSM=DFSM+UFSM
   SUMC=SUMC+FSM
   FSM=FSM/SUMC
43 DO 44 I=1,NSC
   KK=NR(I)
   DO 44 J=1,KK
44 FS(J,I)=FS(J,I)/SUMC
   GO TO 40
51 SUMA=0.
   SUMC=0.
   DO 52 I=1,NSC
   KK=NR(I)
   DO 52 J=1,KK
52 SUMA=SUMA+UFS(J,I)*FLOATF(NWSC(I))
   IF(L)53,53,54
53 SUMA=SUMA+UFSM
   UFSM=UFSM/SUMA
   SUMC=ABSF(FSM-UFSM)
54 DO 55 I=1,NSC
   KK=NR(I)
   DO 55 J=1,KK
   UFS(J,I)=UFS(J,I)/SUMA
55 SUMC=SUMC+ABSF(FS(J,I)-UFS(J,I))*FLOATF(NWSC(I))
   IF(SUMC-10.**(-NCC))60,60,56
56 DO 57 I=1,NSC
   KK=NR(I)
   DO 57 J=1,KK
57 FS(J,I)=UFS(J,I)
   IF(L)58,58,40
58 FSM=UFSM
   GO TO 40
60 DO 63 I=1,NG
   PHI(I)=0.
   DO 61 J=1,NSC
   KK=NR(J)
   DO 61 JJ=1,KK
61 PHI(I)=PHI(I)+ABT(JJ,J,I)*V(JJ,J)*FLOATF(NWSC(J))
   IF(L)62,62,63
62 PHI(I)=PHI(I)+ABM(I)*VM
63 CONTINUE
   DO 66 I=1,NG
   DO 64 J=1,NSC
   KK=NR(J)
   DO 64 JJ=1,KK
64 ABT(JJ,J,I)=ABT(JJ,J,I)/PHI(I)
   IF(L)65,65,66
65 ABM(I)=ABM(I)/PHI(I)
66 CONTINUE
   DO 69 I=1,NG
   SGMT(I,10)=0.
   SGMTR(I,10)=0.
```

```
      SGMC(I,10)=0.
      SGMB(I,10)=0.
      VSGMB(I,10)=0.
      DO 67 J=1,NSC
      F=FLOATF(NWSC(J))
      KK=NR(J)
      DO 67 JJ=1,KK
      LL=INT(JJ,J)
      SGMT(I,10)=SGMT(I,10)+SGMT(I,LL)*V(JJ,J)*ABT(JJ,J,I)*F
      SGMTR(I,10)=SGMTR(I,10)+SGMTR(I,LL)*V(JJ,J)*ABT(JJ,J,I)*F
      SGMC(I,10)=SGMC(I,10)+SGMC(I,LL)*V(JJ,J)*ABT(JJ,J,I)*F
      SGMB(I,10)=SGMB(I,10)+SGMB(I,LL)*V(JJ,J)*ABT(JJ,J,I)*F
   67 VSGMB(I,10)=VSGMB(I,10)+VSGMB(I,LL)*V(JJ,J)*ABT(JJ,J,I)*F
      IF(L)68,68,69
   68 SGMT(I,10)=SGMT(I,10)+SGMT(I,1)*VM*ABM(I)
      SGMTR(I,10)=SGMTR(I,10)+SGMTR(I,1)*VM*ABM(I)
      SGMC(I,10)=SGMC(I,10)+SGMC(I,1)*VM*ABM(I)
      SGMB(I,10)=SGMB(I,10)+SGMB(I,1)*VM*ABM(I)
      VSGMB(I,10)=VSGMB(I,10)+VSGMB(I,1)*VM*ABM(I)
   69 CONTINUE
      NIJ=((NG+1)*(NG+2))/2-1
      K=NG+1
      DO 72 I=1,NG
      LL=((I-1)*I)/2+1
      DO 72 J=I,K
      LL=LL+J-1
      SGMIJ(LL,10)=0.
      DO 70 II=1,NSC
      KK=NR(II)
      DO 70 JJ=1,KK
      MM=INT(JJ,II)
   70 SGMIJ(LL,10)=SGMIJ(LL,10)+SGMIJ(LL,MM)*V(JJ,II)*ABT(JJ,II,I)*FLOAT
     1F(NWSC(II))
      IF(L)71,71,72
   71 SGMIJ(LL,10)=SGMIJ(LL,10)+SGMIJ(LL,1)*VM*ABM(I)
   72 CONTINUE
      SMP=0.
      SGT=0.
      SGTR=0.
      SGC=0.
      SGB=0.
      VSGB=0.
      SGIJ=0.
      PH=0.
      DO 73 I=1,NG
      PH=PH+PHI(I)
      SGT=SGT+SGMT(I,10)*PHI(I)
      SGTR=SGTR+SGMTR(I,10)*PHI(I)
      SGC=SGC+SGMC(I,10)*PHI(I)
      SMP=SMP+PHI(I)/SGMTR(I,10)
      SGB=SGB+SGMB(I,10)*PHI(I)
      VSGB=VSGB+VSGMB(I,10)*PHI(I)
      KK=(NG*(NG+1))/2+I
   73 SGIJ=SGIJ+SGMIJ(KK,10)*PHI(I)
      PH=1./PH
      DO 74 I=1,NG
   74 PHI(I)=PHI(I)*PH
      SGT=SGT*PH
      SGTR=SGTR*PH
```

```
      SGC=SGC*PH
      SGB=SGB*PH
      VSGB=VSGB*PH
      SGIJ=SGIJ*PH
      SMP=1./(SMP*PH)
      KK=NG/11+1
      WRITE OUTPUT TAPE NTOUT,301
      WRITE OUTPUT TAPE NTOUT,307
      DO 75 I=1,NG
   75 IH(I)=I
      DO 80 I=1,NG
      VV=VSGMB(I,10)/SGMB(I,10)
   80 WRITE OUTPUT TAPE NTOUT,308,I,EL(I),SPRM(I),PHI(I),SGMT(I,10),
     1SGMTR(I,10),SGMC(I,10),SGMB(I,10),VSGMB(I,10),VV
      WRITE OUTPUT TAPE NTOUT,309
      WRITE OUTPUT TAPE NTOUT,310,(SGMIJ(I,10),I=1,NIJ)
      IF(FLOATF(NST/2)-FLOATF(NST)/2.+.1)87,87,81
   81 VV=VSGB/SGB
      FTNR=(1.-SUMA)/SUMA
      FTFR=FTNR*VNUTH/VV
      TAU=1./(3.*SMP*(SGC+SGB+SGIJ-VSGB))
      WRITE OUTPUT TAPE NTOUT,311,SGT,SGTR,SMP,SGC,SGB,VV,VSGB,SGIJ,TAU,
     1SUMA,FTFR
      IF(IDA)126,126,112
  112 DO 113 I=1,NG
      IF(SGMB(I,3))114,114,113
  113 CONTINUE
  114 NFG=I-1
      SA=0.
      SB=0.
      SC=0.
      DO 118 J=1,NSC
      NK=NR(J)
      DO 118 K=1,NK
      IF(INT(K,J)-2)118,115,118
  115 FDU(K,J)=0.
      FNU(K,J)=0.
      DO 116 I=1,NFG
  116 FDU(K,J)=FDU(K,J)+SGMB(I,3)*ABT(K,J,I)*PHI(I)
      FDU(K,J)=FDU(K,J)*V(K,J)*FLOATF(NWSC(J))*(1.-SUMA)/VSGB
      DO 117 I=1,NG
  117 FNU(K,J)=FNU(K,J)+SGMB(I,2)*ABT(K,J,I)*PHI(I)
      FNU(K,J)=FNU(K,J)*V(K,J)*FLOATF(NWSC(J))*(1.-SUMA)/VSGB
      X=DFS(K,J)*FLOATF(NWSC(J))*SUMA/VNUTH+FNU(K,J)-FDU(K,J)
      DLTA(K,J)=FDU(K,J)/X
      SA=SA+FDU(K,J)
      SB=SB+FNU(K,J)
      SC=SC+DFS(K,J)*FLOATF(NWSC(J))*SUMA
  118 CONTINUE
      DELTA=SA/(SC/VNUTH+SB-SA)
      WRITE OUTPUT TAPE NTOUT,326,DELTA
      IL=0
      I=0
      IJ=1
      IK=1
  119 DO 123 J=IJ,NSC
      NK=NR(J)
      DO 122 K=IK,NK
      IF(INT(K,J)-2)122,120,122
```

```
120 I=I+1
    IF(I-7)121,124,124
121 IS(I)=J
    IR(I)=K
    DA(I)=DLTA(K,J)
122 CONTINUE
123 IK=1
    IL=1
    IF(I)126,126,124
124 WRITE OUTPUT TAPE NTOUT,327,(IS(JJ),IR(JJ),JJ=1,I)
    WRITE OUTPUT TAPE NTOUT,328,(DA(JJ),JJ=1,I)
    IF(IL)125,125,126
125 I=0
    IJ=J
    IK=K
    GO TO 119
126 IF(NOUT(1))82,93,82
 82 WRITE OUTPUT TAPE NTOUT,325
    IF(L)83,83,85
 83 WRITE OUTPUT TAPE NTOUT,302,RADC,VM,DFSM,PFSM
    DO 84 I=1,KK
    JJ=XMINOF(NG,10*I)
    K=10*(I-1)+1
    WRITE OUTPUT TAPE NTOUT,306,(IH(J),J=K,JJ)
 84 WRITE OUTPUT TAPE NTOUT,322,(ABM(J),J=K,JJ)
 85 DO 86 I=1,NSC
    LL=NR(I)
    DO 86 J=1,LL
    MM=INT(J,I)
    WRITE OUTPUT TAPE NTOUT,304,I,NWSC(I),J,MM,RAD(J,I),V(J,I),DFS(J,I
   1),PFS(J,I)
    DO 86 JJ=1,KK
    LM=XMINOF(NG,10*JJ)
    K=10*(JJ-1)+1
    WRITE OUTPUT TAPE NTOUT,306,(IH(II),II=K,LM)
 86 WRITE OUTPUT TAPE NTOUT,322,(ABT(J,I,II),II=K,LM)
    GO TO 93
 87 IF(NOUT(1))88,93,88
 88 IF(L)89,89,91
 89 WRITE OUTPUT TAPE NTOUT,303,RADC,VM,UFSM,FSM
    DO 90 I=1,KK
    JJ=XMINOF(NG,10*I)
    K=10*(I-1)+1
    WRITE OUTPUT TAPE NTOUT,306,(IH(J),J=K,JJ)
 90 WRITE OUTPUT TAPE NTOUT,322,(ABM(J),J=K,JJ)
 91 DO 92 I=1,NSC
    LL=NR(I)
    DO 92 J=1,LL
    MM=INT(J,I)
    WRITE OUTPUT TAPE NTOUT,305,I,NWSC(I),J,MM,RAD(J,I),V(J,I),UFS(J,I
   1),FS(J,I)
    DO 92 JJ=1,KK
    LM=XMINOF(NG,10*JJ)
    K=10*(JJ-1)+1
    WRITE OUTPUT TAPE NTOUT,306,(IH(II),II=K,LM)
 92 WRITE OUTPUT TAPE NTOUT,322,(ABT(J,I,II),II=K,LM)
 93 NATAS=NSA+NSR
    IF(NOUT(2))94,98,94
 94 IF(L)994,994,98
```

```
994 WRITE OUTPUT TAPE NTOUT,318
    LM=(NSA+NSR)/9+1
    DO 96 I=1,LM
    JJ=XMINOF(NSA+NSR,8*I)
    LL=XMINOF(NSA,8*I)
    K=8*(I-1)+1
    WRITE OUTPUT TAPE NTOUT,319,(ATAS(J),J=K,JJ)
    IF(NSA-K)96,95,95
 95 WRITE OUTPUT TAPE NTOUT,323,(WIL(J),J=K,LL)
 96 CONTINUE
    WRITE OUTPUT TAPE NTOUT,320
    DO 97 K=1,NSC
    DO 97 J=1,NSC
 97 WRITE OUTPUT TAPE NTOUT,321,(WTS(I,J,K),I=1,NATAS)
 98 IF(NOUT(3))99,105,99
 99 IF(L)100,100,102
100 WRITE OUTPUT TAPE NTOUT,312
    K=NR(1)
    R=RAD(K,1)
    DO 101 LL=1,NATAS
    WRITE OUTPUT TAPE NTOUT,313,R,ATAS(LL)
    DO 101 I=1,KK
    JJ=XMINOF(NG,10*I)
    K=10*(I-1)+1
    WRITE OUTPUT TAPE NTOUT,306,(IH(J),J=K,JJ)
101 WRITE OUTPUT TAPE NTOUT,314,(DTP(LL,J),J=K,JJ)
102 WRITE OUTPUT TAPE NTOUT,315
    DO 104 I=1,NSC
    K=NR(I)
    DO 104 J=1,K
    WRITE OUTPUT TAPE NTOUT,316,I,J
    DO 104 JJ=1,KK
    LL=XMINOF(NG,10*JJ)
    MM=10*(JJ-1)+1
    WRITE OUTPUT TAPE NTOUT,306,(IH(LM),LM=MM,LL)
    IF(J-1)104,104,103
103 WRITE OUTPUT TAPE NTOUT,317,(TPOI(J-1,I,LM),LM=MM,LL)
104 WRITE OUTPUT TAPE NTOUT,324,(TPOO(J,I,LM),LM=MM,LL)
105 CALL LTAP1
    END(2,0,0,0,0)
    SUBROUTINE TRP(NST,NSC,NR,INT,NG,NSA,NSR,WTS,WIL,ATAS,RAD,RADC,
   1SGMT,SGMTR,TPOO,TPOI,DTP,KK)
    DIMENSION NR(10),INT(20,10),WTS(24,10,10),WIL(24),ATAS(24),RAD(20,
   110),SGMT(20,10),SGMTR(20,10),TPOI(19,10,20),TPOO(20,10,20),DTP(24,
   220)
    N=NST/4
    KK=NST+1
    GO TO (31,31,32,32,31,31,32,32),KK
 31 KK=0
    GO TO 25
 32 NR(1)=NR(1)+1
    KK=NR(1)
    RAD(KK,1)=RADC
    INT(KK,1)=1
 25 DO 8 I=1,NSC
    M=NR(I)
    DO 8 J=1,M
    L=INT(J,I)
    IF(J-1)2,2,1
```

```
 1 A=RAD(J-1,I)/RAD(J,I)
 2 DO 8 K=1,NG
   IF(N)3,3,4
 3 B=SGMTR(K,L)*RAD(J,I)
   GO TO 5
 4 B=SGMT(K,L)*RAD(J,I)
 5 IF(J-1)6,6,7
 6 TPOO(1,I,K)=TCYL(B)
   GO TO 8
 7 TPOO(J,I,K)=TOO(A,B)
   TPOI(J-1,I,K)=TOI(A,B)
 8 CONTINUE
   IF(KK)26,26,24
26 M=NSA+NSR
   K=NR(1)
   R=RAD(K,1)

   TO BE ABLE TO USE DANCOFF FACTOR ALL OUTERMOST RADII MUST BE EQUAL
   X=0.
   DO 16 I=1,NSA
   A=R/ATAS(I)
   Y=DCFR(A,0.)*WIL(I)
   X=X+Y
   IF(X-1.)10,10,9
 9 Y=(1.-(X-Y))/Y
10 DO 15 L=1,NG
   IF(N)11,11,12
11 B=SGMTR(L,1)*R
   GO TO 13
12 B=SGMT(L,1)*R
13 DTP(I,L)=DCFR(A,B)
   IF(X-1.)15,15,14
14 DTP(I,L)=DTP(I,L)*Y
15 CONTINUE
   IF(X-1.)16,16,17
16 CONTINUE
   GO TO 20
17 IF(I-NSA)18,20,20
18 J=I+1
   DO 19 I=J,NSA
   DO 19 L=1,NG
19 DTP(I,L)=0.
20 J=NSA+1
   IF(M-J)24,27,27
27 DO 23 I=J,M
   A=R/ATAS(I)
   DO 23 L=1,NG
   IF(N)21,21,22
21 B=SGMTR(L,1)*R
   GO TO 23
22 B=SGMT(L,1)*R
23 DTP(I,L)=DCFR(A,B)
24 RETURN
   END(2,0,1,0,0)

   FUNCTION TCYL        H. K. CLARK
   FUNCTION TCYL(B)
   IF(B-5.)1,1,2
 1 IF(B-.1)5,4,4
```

```
4 T0=BI0(B)
  T1=BI1(B)
  U0=BK0(B)
  U1=BK1(B)
  TCYL=1.-4.*B**2/3.*(2.*(B*(U1*T1+U0*T0)-1.)+U1*T1/B-U0*T1+U1*T0)
  GO TO 3
5 TCYL=1.-B*(2.-B*(2.6666667-B*(1.3659315-LOGF(B))))
  GO TO 3
2 TCYL=3./(16.*B**2)*(1.+5./(8.*B**2))
3 RETURN
  END(2,0,1,0,0)

  FUNCTION TOO        H. K. CLARK
  FUNCTION TOO(A,B)
  DIMENSION X(7),H(7)
  X(1)=.98628381
  X( 2)=.92843488
  X( 3)=.82720132
  X( 4)=.68729290
  X( 5)=.51524864
  X( 6)=.31911237
  X( 7)=.10805495
  H(1)=.035119460
  H( 2)=.080158087
  H( 3)=.12151857
  H( 4)=.15720317
  H( 5)=.18553840
  H( 6)=.20519846
  H( 7)=.21526385
  SUM=0.
  IF(B-0.1)2,2,4
2 DO 3 I=1,7
  Y=B*2.*SQRTF(1.-X(I)**2)
  Z=B*2.*SQRTF(1.-(A*X(I))**2)
3 SUM=SUM+(Y**3*(.32487747*(1.+.024358732*Y**2)-LOGF(Y)*(1.+.025*Y**
 12)/6.)-Z**3*(.32487747*(1.+.024358732*Z**2)-LOGF(Z)*(1.+.025*Z**2)
 2/6.)*A)*H(I)
  TOO=  -1.2732395*SUM
  C=SQRTF(1.-A**2)
  TERM=   A+B*(2.-1.2732395*(A*C+ATANF(A/C)))-4.*B**2*(2.-3.*A+A**3)
 1/3.
  TERM=1.-TERM
  TOO=TOO+TERM
  GO TO 5
4 DO 1 I=1,7
1 SUM=SUM+BEKI3(2.*B*SQRTF(1.-(A*X(I))**2))*H(I)
  TOO=TCYL(B)-1.2732395*A*SUM
5 RETURN
  END(2,0,1,0,1)

  FUNCTION TOI       H. K. CLARK
  FUNCTION TOI(A,B)
  DIMENSION X(7),H(7)
  X(1)=.98628381
  X( 2)=.92843488
  X( 3)=.82720132
  X( 4)=.68729290
  X( 5)=.51524864
  X( 6)=.31911237
```

```
      X( 7)=.10805495
      H(1)=.035119460
      H( 2)=.080158087
      H( 3)=.12151857
      H( 4)=.15720317
      H( 5)=.18553840
      H( 6)=.20519846
      H( 7)=.21526385
      TOI=0.
      IF(B-0.1)2,2,4
    2 DO 3 I=1,7
      Y=B*(SQRTF(1.-(A*X(I))**2)-A*SQRTF(1.-X(I)**2))
    3 TOI=TOI+Y**2*(.78539816-.32487747*Y*(1.+.024358732*Y**2)+Y*LOGF(Y)
     1*(1.+.025*Y**2)/6.)*H(I)
      TOI=TOI*1.2732395
      C=SQRTF(1.-A**2)
      TERM=B*(.63661976*(C+ATANF(A/C)/A)-A)
      TERM=1.-TERM
      TOI=TOI+TERM
      GO TO 5
    4 DO 1 I=1,7
    1 TOI=TOI+H(I)*BEKI3(B*(SQRTF(1.-(A*X(I))**2)-A*SQRTF(1.-X(I)**2)))
      TOI=TOI*1.2732395
    5 RETURN
      END(2,0,1,0,1)

      FUNCTION DCFR(R,S)          H. K. CLARK     8211-1K
      FUNCTION DCFR(R,S)

      COMPUTES DANCOFF FACTOR AS FUNCTION OF R=RADIUS/(AXIS-TO-AXIS SEP-

      ARATION) AND OF S=SIGMA*RADIUS
      RADF(U,V)=SQRTF(1./R**2-(U+V)**2)
      DANF(U,V)=BEKI3(S*(RADF(U,V)-SQRTF(1.-U**2)-SQRTF(1.-V**2)))/RADF(
     1U,V)
      DIMENSION A(8),H(8)
      A(1)=0.98940093
      A(2)=0.94457502
      A(3)=0.86563120
      A(4)=0.75540441
      A(5)=0.61787624
      A(6)=0.45801678
      A(7)=0.28160355
      A(8)=0.09501251
      H(1)=0.02715246
      H(2)=0.06225352
      H(3)=0.09515851
      H(4)=0.12462897
      H(5)=0.14959599
      H(6)=0.16915652
      H(7)=0.18260342
      H(8)=0.18945061
      IF(S)4,5,4
    4 SUM=0.
      DO 3 I=1,8
      DO 3 J=1,I
      IF(I-J)2,2,1
    1 SUM=SUM+4.*H(I)*H(J)*(DANF(A(I),A(J))+DANF(A(I),-A(J)))
      GO TO 3
```

```
2 SUM=SUM+2.*H(J)**2*(DANF(A(J),A(J))+DANF(A(J),-A(J)))
3 CONTINUE
  DCFR=.10132118*SUM
  GO TO 8
5 B=2.*R
  E=SQRTF(1.-B**2)
  IF(E)6,6,7
6 DCFR=.18169012
  GO TO 8
7 C=ATANF(B/E)
  DCFR=.31830988*(C-SINF(.5*C)/COSF(.5*C))
8 RETURN
  END(2,0,1,0,0)

  FUNCTION BEKI3(X)                H. K. CLARK          8211-1K
  FUNCTION BEKI3(X)
  IF(X-.1)1,2,2
1 BEKI3=.73665545/(.93793888+X*(1.1941916+X*(.58824515+X*(.57033719+
 1X*(-1.5791166+X*4.292469)))))
  GO TO 9
2 IF(X-.4)3,4,4
3 BEKI3=.57149776/(.72767871+X*(.92546909+X*(.47415208+X*(.25082036+
 1X*(-.025930075+X*.055707999)))))
  GO TO 9
4 IF(X-1.)5,6,6
5 BEKI3=.32724738/(.41667409+X*(.52956551+X*(.27542730+X*(.12837751+
 1X*(.011919149+X*.013920954)))))
  GO TO 9
6 IF(X-2.5)7,8,8
7 BEKI3=(.22159402+X*(-.093883791+X*(.014738215-X*.00085765003)))/(
 1.28267237+X*(.23563203+X*(.063402052+X*.013600324)))
  GO TO 9
8 Y=1./(X+3.25)
  BEKI3=1.2684458*SQRTF(Y)*EXPF(-X)/(1.0120742+Y*(-.000325432+Y*(
 1-1.1646323+Y*(1.3873864-Y*4.4655208))))
9 RETURN
  END(2,0,1,0,0)

  IDIOT BIO FUNCTION


  FUNCTION BIO (X)


  IF (X - 3.75) 2, 2, 3
2 Z = (X / 3.75)**2
  BIO = 1.0 + Z * (3.5156229 + Z * (3.0899424 + Z * (1.2067492 +
 1       Z * (0.2659732 + Z * (0.0360768 + Z * 0.0045813)))))
  GO TO 4
3 Z = 3.75 / X
  BIO = (EXPF(X) / SQRTF(X)) * (.39894228 + Z * (.013285917 + Z *
 1       (.002253187 + Z * (-.001575649 + Z * (.009162808 + Z *
 2       (-.020577063 + Z * (.026355372 + Z * (-.016476329 + Z *
 3       .003923767))))))))
4 RETURN
  END (2,0,0,0,1)

  IDIOT BI1 FUNCTION
```

```
      FUNCTION BI1 (X)


      IF (X - 3.75) 2, 2, 3
    2 Z = (X / 3.75)**2
      BI1 = (.5 + Z * (.87890594 + Z * (.51498869 + Z * (.15084934 +
     1      Z * (.02658733 + Z * (.00301532 + Z * .00032411)))))) * X
      GO TO 4
    3 Z = 3.75 / X
      BI1 = (EXPF(X) / SQRTF(X)) * (.39894228 + Z * (-.039880242 + Z *
     1       (-.003620183 + Z * (.001638014 + Z * (-.01031555 + Z *
     2       (.022829673 + Z * (-.028953121 + Z * (.017876535 - Z *
     3       .004200587))))))))
    4 RETURN
      END (2,0,0,0;1)

      IDIOT BKO FUNCTION


      FUNCTION BKO (X)


      IF (X - 2.0) 2, 2, 3
    2 Z = (X / 2.0)**2
      SERIES = -.57721566 + Z * (.4227842 + Z * (.23069756 + Z *
     1          (.0348859 + Z * (.00262698 + Z * (.0001075 + Z *
     2          .0000074)))))
      BKO = SERIES - LOGF(X / 2.0) * BIO(X)
      GO TO 4
    3 Z = 2.0 / X
      BKO = (1.2533141 + Z * (-.07832358 + Z * (.02189568 + Z *
     1       (-.01062446 + Z * (.00587872 + Z * (-.0025154 + Z *
     2       .00053208)))))) / (SQRTF(X) * EXPF(X))
    4 RETURN
      END (2,0,0,0;1)

      IDIOT BK1 FUNCTION


      FUNCTION BK1 (X)


      IF (X - 2.0) 2, 2, 3
    2 Z = (X / 2.0)**2
      SERIES = 1.0 + Z * (.15443144 + Z * (-.67278579 + Z * (-.18156897
     1          + Z * (-.01919402 + Z * (-.00110404 - Z * .00004686)))))
      BK1 = SERIES / X + LOGF(X / 2.0) * BI1(X)
      GO TO 4
    3 Z = 2.0 / X
      BK1 = (1.2533141 + Z * (.23498619 + Z * (-.0365562 + Z *
     1       (.01504268 + Z * (-.00780353 + Z * (.00325614 - Z *
     2       .00068245)))))) / (SQRTF(X) * EXPF(X))
    4 RETURN
      END (2,0,0,0;1)

      SUBROUTINE SOLN    H. K. CLARK
      SUBROUTINE SOLN(L,NG,NSC,NST,NSA,NSR,NR,INT,NWSC,SGMT,SGMTR,SGMIJ,
     IFS,FSM,SPRM,DTP,TPOO,TPOI,RAD,RADC,ABT,ABM,WTS)
```

```
      DIMENSION NR(10),INT(20,10),NWSC(10),SGMT(20,10),SGMTR(20,10),
     1SGMIJ(230,10),FS(20,10),SPRM(20),DTP(24,20),TPOO(20,10,20),
     2TPOI(19,10,20),RAD(20,10),ABT(20,10,20),ABM(20),AA(19,10),AQ(19,10
     3),VA(2,10),VQ(2,10),AUX(10,10),ANC(10,1),G(10,10),EQ(10),WTS(24,10
     4,10)
      DO 18 IG=1,NG
      IF(L)13,13,14
   13 CALL MOD(IG,NSC,NST,NSA,NSR,NR,NWSC,SGMT,SGMTR,SGMIJ,WTS,DTP,RAD,
     1RADC,ABM,SPRM,FSM,G,EQ,HII,C,Q)
   14 DO 1 ISC=1,NSC
    1 CALL JVECTR(NR,INT,IG,ISC,NST,SGMT,SGMTR,SGMIJ,SPRM,FS,TPOO,TPOI,
     1RAD,ABT,AA,AQ,VA,VQ)
      IF(L)15,15,16
   15 DO 2 I=1,NSC
      DO 2 J=1,NSC
    2 AUX(I,J)=G(I,J)*VA(1,J)
      DO 3 I=1,NSC
    3 AUX(I,I)=AUX(I,I)+HII*VA(2,I)
      DO 4 I=1,NSC
      ANC(I,1)=0.
      DO 4 J=1,NSC
    4 ANC(I,1)=ANC(I,1)+G(I,J)*VQ(1,J)
      DO 5 I=1,NSC
    5 ANC(I,1)=-ANC(I,1)-HII*VQ(2,I)+EQ(I)
      IF(NSC-1)20,20,21
   21 LA=XLOCF(AUX(1,1))
      LB=XLOCF(ANC(1,1))
      DUMMY=LEQF(LA,LB,NSC,1,10,10)
      GO TO 10
   20 ANC(1,1)=ANC(1,1)/AUX(1,1)
      GO TO 10
   16 ANC(1,1)=(VQ(2,1)-VQ(1,1))/(VA(1,1)-VA(2,1))
   10 DO 7 I=1,NSC
      K=NR(I)-1
      ABT(1,I,IG)=ANC(I,1)
      IF(K)7,7,6
    6 DO 9 J=1,K
    9 ABT(J+1,I,IG)=AA(J,I)*ANC(I,1)+AQ(J,I)
    7 CONTINUE
      IF(L)17,17,18
   17 ABM(IG)=Q
      DO 8 I=1,NSC
    8 ABM(IG)=ABM(IG)+FLOATF(NWSC(I))*(ANC(I,1)*(VA(1,I)-VA(2,I))+VQ(1,I
     1)-VQ(2,I))
      ABM(IG)=ABM(IG)/(1.-C)
   18 CONTINUE
      RETURN
      END(2,0,1,0,1)
      SUBROUTINE MOD(IG,NSC,NST,NSA,NSR,NR,NWSC,SGMT,SGMTR,SGMIJ,WTS,DTP
     1,RAD,RADC,ABM,SPRM,FSM,G,EQ,HII,C,Q)
      DIMENSION H(10),TS(10,10),SPRM(20)
      DIMENSION NR(10),RAD(20,10),SGMT(20,10),SGMTR(20,10),SGMIJ(230,10)
     1,ABM(20),NWSC(10),WTS(24,10,10),DTP(24,20),         G(10,10),EQ(10)
      M=(IG*(IG+1))/2
      K=NR(1)
      R=RAD(K,1)
      SUM=0.
      DO 1 I=1,NSC
    1 SUM=SUM+FLOATF(NWSC(I))
```

```
      V=RADC**2-SUM*R**2
      N=NST/4
      IF(N)2,2,3
    2 C=(SGMTR(IG,1)-SGMT(IG,1)+SGMIJ(M,1))/SGMTR(IG,1)
      B=SGMTR(IG,1)*R
      GO TO 4
    3 C=SGMIJ(M,1)/SGMT(IG,1)
      B=SGMT(IG,1)*R
    4 EF=.5*R**2/(B*V)
      L=NSA+NSR
      DO 6 I=1,NSC
      DO 6 J=1,NSC
      TS(I,J)=0.
      DO 6 K=1,L
      IF(WTS(K,I,J))6,6,5
    5 TS(I,J)=TS(I,J)+WTS(K,I,J)*DTP(K,IG)
    6 CONTINUE
      SUM=0.
      DO 8 I=1,NSC
      H(I)=0.
      DO 7 J=1,NSC
    7 H(I)=H(I)+TS(I,J)
    8 SUM=SUM+FLOATF(NWSC(I))*EF*(1.-H(I))
      EE=1.-C*(1.-SUM)
      HII=EE
      DO 10 I=1,NSC
   10 G(I,I)=-(EE*TS(I,I)+C*FLOATF(NWSC(I))*EF*(1.-H(I))**2)
      DO 12 I=1,NSC
      DO 12 J=1,NSC
      IF(I-J)11,12,11
   11 G(I,J)=-(EE*TS(I,J)+C*FLOATF(NWSC(J))*EF*(1.-H(I))*(1.-H(J)))
   12 CONTINUE
      Q=SPRM(IG)*FSM
      K=IG-1
      IF(K)17,17,13
   13 DO 16 I=1,K
      M=(IG*(IG+1))/2-K-1+I
      IF(N)14,14,15
   14 Q=Q+ABM(I)*SGMIJ(M,1)/SGMTR(I,1)
      GO TO 16
   15 Q=Q+ABM(I)*SGMIJ(M,1)/SGMT(I,1)
   16 CONTINUE
   17 DO 18 I=1,NSC
   18 EQ(I)=C*EF*(1.-H(I))
      RETURN
      END(2,0,1,0,0)

      SUBROUTINE JVECTR   H. K. CLARK
      SUBROUTINE JVECTR(NR,INT,IG,ISC,NST,SGMT,SGMTR,SGMIJ,SPRM,FS,TPOO,
     1TPOI,RAD,ABT,AA,AQ,VA,VQ)

      IG=GROUP INDEX, ISC=SYMMETRY CLASS INDEX,JVECTR=VA*ABSORPTION IN

      REGION 1 + VQ. ABSORPTION IN REGION I=AA*ABSORPTION IN REGION 1+AQ
      DIMENSION TPOO(20,10,20),TPOI(19,10,20),NR(10),INT(20,10),AA(19,10
     1),AQ(19,10),AUX(2),SGMT(20,10),SGMTR(20,10),SGMIJ(230,10),SPRM(20)
     2,ABT(20,10,20),VA(2,10),DMX(2,2),SIMX(2,2),FS(20,10),RAD(20,10)
     3,VQ(2,10)
      M=(IG*(IG+1))/2
```

```
      N=NST/4
      L=INT(1,ISC)
      IF(N)2,2,3
    2 C=(SGMTR(IG,L)-SGMT(IG,L)+SGMIJ(M,L))/SGMTR(IG,L)
      B=RAD(1,ISC)*SGMTR(IG,L)
      GO TO 4
    3 C=SGMIJ(M,L)/SGMT(IG,L)
      B=RAD(1,ISC)*SGMT(IG,L)
    4 X=TPOO(1,ISC,IG)
      E=(1.-X)/(2.*B)
      VA(1,ISC)=((1.-C)*X+C*E)/(1.-X)
      VA(2,ISC)=(1.-C+C*E)/(1.-X)
      Q=SPRM(IG)*FS(1,ISC)
      K=IG-1
      IF(K)9,9,5
    5 DO 8 I=1,K
      M=(IG*(IG+1))/2-K-1+I
      IF(N)6,6,7
    6 Q=Q+ABT(1,ISC,I)*SGMIJ(M,L)/SGMTR(I,L)
      GO TO 8
    7 Q=Q+ABT(1,ISC,I)*SGMIJ(M,L)/SGMT(I,L)
    8 CONTINUE
    9 VQ(1,ISC)=(E-X)*Q/(1.-X)
      VQ(2,ISC)=(E-1.)*Q/(1.-X)
      MM=NR(ISC)-1
      IF(MM)26,26,1
    1 DO 25 I=1,MM
      CALL MATS(INT,I+1,ISC,IG,NST,SGMT,SGMTR,SGMIJ,TPOO,TPOI,RAD,DMX,
     1SIMX,EO,EI,C)
      L=INT(I+1,ISC)
   10 AA(I,ISC)=(VA(1,ISC)-VA(2,ISC))/(1.-C)
      AQ(I,ISC)=(VQ(1,ISC)-VQ(2,ISC))/(1.-C)
      Q=SPRM(IG)*FS(I+1,ISC)
      IF(K)15,15,11
   11 DO 14 J=1,K
      M=(IG*(IG+1))/2-K-1+J
      IF(N)12,12,13
   12 Q=Q+ABT(I+1,ISC,J)*SGMIJ(M,L)/SGMTR(J,L)
      GO TO 14
   13 Q=Q+ABT(I+1,ISC,J)*SGMIJ(M,L)/SGMT(J,L)
   14 CONTINUE
   15 DO 16 J=1,2
      AUX(J)=0.
      DO 16 JJ=1,2
   16 AUX(J)=AUX(J)+DMX(J,JJ)*VQ(JJ,ISC)
      AUX(1)=AUX(1)+Q*EO
      AUX(2)=AUX(2)+Q*EI
      DO 17 J=1,2
      VQ(J,ISC)=0.
      DO 17 JJ=1,2
   17 VQ(J,ISC)=VQ(J,ISC)+SIMX(J,JJ)*AUX(JJ)
      DO 18 J=1,2
      AUX(J)=0.
      DO 18 JJ=1,2
   18 AUX(J)=AUX(J)+DMX(J,JJ)*VA(JJ,ISC)
      DO 19 J=1,2
      VA(J,ISC)=0.
      DO 19 JJ=1,2
   19 VA(J,ISC)=VA(J,ISC)+SIMX(J,JJ)*AUX(JJ)
```

```
      AA(I,ISC)=AA(I,ISC)+(VA(2,ISC)-VA(1,ISC))/(1.-C)
      AQ(I,ISC)=AQ(I,ISC)+(VQ(2,ISC)-VQ(1,ISC)+Q)/(1.-C)
   25 CONTINUE
   26 RETURN
      END(2,0,1,0,0)

      SUBROUTINE MATS     H. K. CLARK
      SUBROUTINE MATS(INT,I,J,K,NST,SGMT,SGMTR,SGMIJ,TPOO,TPOI,RAD,DMX,
     1SIMX,EO,EI,C)

      I,J,K ARE REGION,SYMMETRY CLASS AND GROUP INDICES. DMX IS RIGHT

      MATRIX. SIMX IS INVERSE OF LEFT MATRIX
      DIMENSION SGMT(20,10),SGMTR(20,10),SGMIJ(230,10),TPOO(20,10,20),
     1TPOI(19,10,20),INT(20,10),DMX(2,2),SIMX(2,2),RAD(20,10)
      M=(K*(K+1))/2
      N=NST/4
      L=INT(I,J)
      A=RAD(I-1,J)/RAD(I,J)
    1 IF(N)2,2,3
    2 C=(SGMTR(K,L)-SGMT(K,L)+SGMIJ(M,L))/SGMTR(K,L)
      B=RAD(I,J)*SGMTR(K,L)
      GO TO 4
    3 C=SGMIJ(M,L)/SGMT(K,L)
      B=RAD(I,J)*SGMT(K,L)
    4 X=TPOI(I-1,J,K)
      Y=TPOO(I,J,K)
      DEN=2.*B*(1.-A**2)
      G=A*X+Y
      EO=(1.-G)/DEN
      EI=(1.-X)*A/DEN
      DMX(1,1)=X*(1.-C*(1.-EI))+C*EO
      DMX(1,2)=0.
      DMX(2,1)=C*EI*(1.-X)
      DMX(2,2)=-(1.-C*(1.-EO-EI))
      SIMX(1,1)=-1./DMX(2,2)
      SIMX(2,2)=-1./(A*X*(1.-C*(1.-EO))+C*EI*(1.-Y))
      SIMX(1,2)=(Y*(1.-C*(1.-EI))+C*EO*(1.-A*X))*SIMX(1,1)*SIMX(2,2)
      SIMX(2,1)=0.
   21 RETURN
      END(2,0,1,0,0)
```

APPENDIX B – SAMPLE PRINTOUT

HEETR CODE   COMPUTES EVENTS IN CYLINDRICAL CELLS FROM ESCAPE AND TRANSMISSION PROBABILITIES

PROBLEM NUMBER 27

SOURCE SUPPLIED FOR EACH REGION IS RELATIVE NUMBER OF NEUTRONS PRODUCED BY FISSIONS OCCURRING IN GROUP NG+1.

TRANSMISSION AND ESCAPE PROBABILITIES ARE COMPUTED FROM TRANSPORT CROSS SECTIONS.

DANCOFF FACTORS ARE EMPLOYED FOR INTERACTION BETWEEN ELEMENTS IMMERSED IN MODERATOR.

		WEIGHT FRACTION OF				
TYPE NO.	DENSITY(G/OC)	D2O	H2O	U-235	U-238	AL
1	1.10420	0.997600	0.002400	-0.	-0.	-0.
2	18.90000	-0.	-0.	0.007100	0.992900	-0.
3	18.90000	-0.	-0.	-0.	0.992900	-0.
4	0.00050	1.000000	-0.	-0.	-0.	-0.
5	2.70000	-0.	-0.	-0.	-0.	1.000000

PRINTOUT OF LIBRARY TAPE AND FISSION SPECTRUM

GROUP	EL(MEV)	FISSION SOURCE	SIGMA-T	SIGMA-TR	SIGMA-C	SIGMA-F	NU	D2O	20.000
1	3.6788E 00	0.13138	5.097E 00	3.114E 00	9.707E-02	0.	0.		
2	2.2313E 00	0.21028	6.103E 00	4.365E 00	0.	0.	0.		
3	1.3534E 00	0.23119	7.650E 00	6.155E 00	0.	0.	0.		
4	8.2085E-01	0.18035	9.679E 00	8.347E 00	0.	0.	0.		
5	4.9787E-01	0.11474	9.542E 00	7.463E 00	0.	0.	0.		
6	3.0197E-01	0.06474	1.266E 01	1.041E 01	0.	0.	0.		
7	1.8316E-01	0.03401	1.027E 01	8.635E 00	0.	0.	0.		
8	1.1109E-01	0.01713	1.037E 01	8.298E 00	0.	0.	0.		
9	6.7379E-02	0.00841	1.050E 01	8.127E 00	-0.	0.	0.		
10	4.0868E-02	0.00407	1.050E 01	8.079E 00	-0.	0.	0.		
11	2.4788E-02	0.00195	1.050E 01	8.079E 00	-0.	0.	0.		
12	1.5034E-02	0.00093	1.050E 01	8.079E 00	-0.	0.	0.		
13	9.1188E-03	0.00044	1.050E 01	8.079E 00	-0.	0.	0.		
14	5.5308E-03	0.00021	1.050E 01	8.079E 00	-0.	0.	0.		
15	2.0347E-03	0.00015	1.050E 01	8.079E 00	-0.	0.	0.		

SIGMA-IJ (TRANSFER TO GROUP I FROM GROUP J), ARRANGED AS 11, 21, 22, 31, 32, 33,...,(NG+1)(NG)

2.3782	1.5405	2.6009	0.3754	1.5172	2.9160	0.3979	0.7316	2.0075	3.8013	0.3431
0.6816	1.1375	2.6072	3.6158	0.0400	0.5206	0.9477	1.4656	2.6340	5.8465	0.
0.0513	0.5902	1.1288	1.5877	3.6372	3.9955	0.	0.	0.0508	0.6266	1.1089
1.6003	3.3041	4.1688	0.	0.	0.	0.0500	0.5586	1.0276	1.5494	3.2969
4.4063	0.	0.	0.	0.	0.0372	0.5118	0.9413	1.5026	3.2608	4.4405
0.	0.	0.	0.	0.	0.0413	0.4508	0.9138	1.4508	3.2577	4.4463
0.	0.	0.	0.	0.	0.	0.0319	0.4502	0.8817	1.4369	3.2534
4.4436	0.	0.	0.	0.	0.	0.	0.	0.0346	0.4600	0.8715
1.4363	3.2554	4.4432	0.	0.	0.	0.	0.	0.	0.	0.
0.0355	0.4580	0.8711	1.4365	3.2557	4.4437	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.0354	0.4929	1.3291	2.3080	4.6919	6.0714	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.0353
0.4932	1.3644	4.4286								

GROUP	EL(MEV)	FISSION SOURCE	SIGMA-T	SIGMA-TR	SIGMA-C	SIGMA-F	NU	H2O	18.000
1	3.6788E 00	0.13138	4.960E 00	2.094E 00	9.971E-02	0.	0.		
2	2.2313E 00	0.21028	6.319E 00	2.739E 00	0.	0.	0.		
3	1.3534E 00	0.23119	8.633E 00	4.083E 00	0.	0.	0.		
4	8.2085E-01	0.18035	1.208E 01	6.215E 00	1.200E-04	0.	0.		
5	4.9787E-01	0.11474	1.401E 01	6.022E 00	2.000E-04	0.	0.		
6	3.0197E-01	0.06474	2.067E 01	1.049E 01	2.000E-04	0.	0.		
7	1.8316E-01	0.03401	2.140E 01	9.853E 00	2.000E-04	0.	0.		
8	1.1109E-01	0.01713	2.566E 01	1.098E 01	2.200E-04	0.	0.		
9	6.7379E-02	0.00841	3.004E 01	1.233E 01	4.000E-04	0.	0.		
10	4.0868E-02	0.00407	3.410E 01	1.367E 01	4.400E-04	0.	0.		
11	2.4788E-02	0.00195	3.725E 01	1.472E 01	6.000E-04	0.	0.		
12	1.5034E-02	0.00093	3.959E 01	1.551E 01	7.600E-04	0.	0.		
13	9.1188E-03	0.00044	4.122E 01	1.605E 01	9.300E-04	0.	0.		
14	5.5308E-03	0.00021	4.243E 01	1.646E 01	1.260E-03	0.	0.		
15	2.0347E-03	0.00015	4.340E 01	1.678E 01	1.830E-03	0.	0.		

SIGMA-IJ (TRANSFER TO GROUP I FROM GROUP J), ARRANGED AS 11, 21, 22, 31, 32, 33,...,(NG+1)(NG)

1.8909	1.4157	2.2525	0.6195	1.7234	3.0428	0.3691	0.9221	2.5515	4.6603	0.2221
0.5593	1.1957	3.4595	4.9939	0.1347	0.3392	0.7252	1.5591	3.9141	8.2726	0.0817
0.2057	0.4399	0.9456	2.0075	5.6190	6.6202	0.0496	0.1248	0.2668	0.5736	1.2176
2.6672	6.3485	7.5414	0.0301	0.0757	0.1618	0.3479	0.7385	1.6177	3.3183	7.6431
8.4748	0.0182	0.0459	0.0981	0.2110	0.4479	0.9812	2.0127	4.1228	8.9939	9.3304
0.0111	0.0278	0.0595	0.1280	0.2717	0.5951	1.2207	2.5006	4.9444	10.2640	9.9872
0.0067	0.0169	0.0361	0.0776	0.1648	0.3610	0.7404	1.5167	2.9989	5.7086	11.2493
10.4788	0.0041	0.0102	0.0219	0.0471	0.0999	0.2189	0.4491	0.9199	1.8189	3.4624
6.2991	11.9823	10.8204	0.0025	0.0062	0.0133	0.0286	0.0606	0.1328	0.2724	0.5582
1.1032	2.1001	3.8206	6.7392	12.4902	11.0754	0.0024	0.0060	0.0129	0.0278	0.0591
0.1294	0.2654	0.5437	1.0750	2.0463	3.7228	6.5667	11.3175	20.1432	17.8682	0.0014
0.0035	0.0075	0.0162	0.0344	0.0753	0.1545	0.3164	0.6256	1.1909	2.1666	3.8217
6.5865	11.2109	25.5334								

GROUP	EL(MEV)	FISSION SOURCE	SIGMA-T	SIGMA-TR	SIGMA-C	SIGMA-F	NU	U-235	235.000
1	3.6788E 00	C.13138	3.880E 00	3.880E 00	2.000E-02	1.210E 00	3.090		
2	2.2313E 00	0.21028	4.730E 00	4.730E 00	3.500E-02	1.290E 00	2.790		
3	1.3534E 00	0.23119	4.860E 00	4.860E 00	5.800E-02	1.310E 00	2.620		
4	8.2085E-01	0.18035	5.080E 00	5.080E 00	1.150E-01	1.270E 00	2.530		
5	4.9787E-01	0.11474	5.580E 00	5.580E 00	1.930E-01	1.220E 00	2.520		
6	3.0197E-01	0.06474	6.810E 00	6.810E 00	2.400E-01	1.290E 00	2.480		
7	1.8316E-01	0.03401	8.540E 00	8.540E 00	2.960E-01	1.420E 00	2.450		
8	1.1109E-01	C.01713	1.010E 01	1.010E 01	3.700E-01	1.620E 00	2.440		
9	6.7379E-02	C.00841	1.150E 01	1.150E 01	4.830E-01	1.860E 00	2.430		
10	4.0868E-02	C.00407	1.260E 01	1.260E 01	6.240E-01	2.150E 00	2.430		
11	2.4788E-02	0.00195	1.360E 01	1.360E 01	8.030E-01	2.510E 00	2.420		
12	1.5C34E-02	0.00093	1.430E 01	1.430E 01	1.003E 00	2.950E 00	2.420		
13	9.1188E-03	C.00044	1.510E 01	1.510E 01	1.249E 00	3.490E 00	2.420		
14	5.5308E-03	C.00021	1.870E 01	1.870E 01	1.689E 00	4.330E 00	2.420		
15	2.0347E-03	0.00015	2.230E 01	2.230E 01	2.092E 00	4.980E 00	2.420		

SIGMA-IJ (TRANSFER TO GROUP I FROM GROUP J), ARRANGED AS 11, 21, 22, 31, 32, 33,...,(NG+1)(NG)

0.6610	C.1100	1.4540	0.3370	C.2010	1.8570	0.5070	0.4210	0.3430	2.4090	0.4750
0.5200	C.6110	0.4370	3.396C	C.3010	0.4050	0.2290	0.2920	0.4350	4.7720	0.2590
0.2300	C.1860	C.2110	0.119C	C.4060	6.4010	0.	0.1740	0.0800	0.2140	0.1050
0.0730	C.3250	7.7140	0.	C.	0.1860	0.1320	0.0590	0.0220	0.0610	0.3120
8.8570	C.	C.	0.	C.	0.0530	0.0070	0.0200	0.0380	0.2460	9.6300
C.	C.	C.	0.	C.	0.	0.0160	0.0330	0.0400	0.1680	10.1510
0.	C.	0.	0.	C.	0.	0.0010	0.0090	0.0100	0.0210	0.1360
10.2130	C.	0.	0.	C.	0.	0.	0.	0.0040	0.0040	0.0070
0.	C.1340	10.2300	0.	C.	0.	0.	0.	0.	0.	0.
0.	C.	0.	0.	C.1310	12.5180	0.	0.	0.	0.	0.
0.	C.	C.	0.	C.	0.	0.	0.	0.1630	15.1600	0.
0.	C.	C.	0.	C.	0.	0.	0.	0.	0.	0.
0.	C.	0.0680								

GROUP	EL(MEV)	FISSION SOURCE	SIGMA-T	SIGMA-TR	SIGMA-C	SIGMA-F	NU	U-238	238.000
1	3.6788E 00	C.13138	3.900E 00	3.900E 00	10.000E-03	6.090E-01	3.100		
2	2.2313E 00	C.21028	4.630E 00	4.630E 00	2.200E-02	5.810E-01	2.780		
3	1.3534E 00	C.23119	4.870E 00	4.870E 00	5.700E-02	4.300E-01	2.600		
4	8.2085E-01	C.18035	5.010E 00	5.010E 00	1.290E-01	2.400E-02	2.560		
5	4.9787E-01	C.11474	5.590E 00	5.590E 00	1.390E-01	C.	0.		
6	3.0197E-01	C.06474	6.880E 00	6.880E 00	1.270E-01	C.	0.		
7	1.8316E-01	C.03401	8.480E 00	8.480E 00	1.610E-01	0.	0.		
8	1.1109E-01	C.01713	1.010E 01	1.010E 01	2.270E-01	0.	0.		
9	6.7379E-02	C.00841	1.150E 01	1.150E 01	2.900E-01	0.	0.		
10	4.0868E-02	C.00407	1.250E 01	1.250E 01	3.700E-01	0.	0.		
11	2.4788E-02	C.00195	1.360E 01	1.360E 01	4.500E-01	0.	0.		
12	1.5C34E-02	C.00093	1.430E 01	1.420E 01	5.200E-01	0.	0.		
13	9.1188E-03	C.00044	1.500E 01	1.500E 01	6.020E-01	0.	0.		
14	5.5308E-03	C.00021	1.510E 01	1.510E 01	6.600E-C1	C.	0.		
15	2.C347E-03	C.00015	1.600E 01	1.600E 01	9.300E-01	0.	0.		

SIGMA-IJ (TRANSFER TO GROUP I FROM GROUP J), ARRANGED AS 11, 21, 22, 31, 32, 33,...,(NG+1)(NG)

0.7740	C.1350	1.4830	0.4250	C.2570	2.4760	0.6400	0.5510	0.7390	3.8930	0.6000
0.6780	C.8650	0.5950	4.9210	C.3800	0.5300	0.2100	0.2720	0.5300	6.2150	0.3270
C.3010	C.0280	0.0890	0.	C.5380	7.7190	0.	0.2270	0.0650	0.0080	0.
0.	C.6000	9.2990	0.	C.	0.	0.	0.	0.	0.	0.3750
10.6700	C.	0.	0.	C.	0.	0.	0.	0.1990	0.4320	11.8740
C.	C.	0.	0.	C.	0.	0.	0.	0.0640	0.1510	12.9810
0.	C.	0.	0.	C.	0.	0.	0.	0.0440	0.0760	0.1690
13.6140	C.	0.	0.	C.	0.	0.	0.	0.	0.	0.0290
0.	C.1660	14.2240	0.	C.	0.	0.	0.	0.	0.	0.
0.	C.	0.	0.	C.1740	14.2660	0.	0.	0.	0.	0.
C.	C.	0.	0.	C.	0.	0.	0.	0.1740	15.0070	0.
0.	C.	C.	0.	C.	0.	0.	0.	0.	0.	0.
0.	C.	0.0630								

GROUP	EL(MEV)	FISSION SOURCE	SIGMA-T	SIGMA-TR	SIGMA-C	SIGMA-F	NU	AL	27.000
1	3.6788E 00	C.13138	1.370E 00	1.370E 00	2.630E-02	0.	0.		
2	2.2313E 00	C.21028	1.600E 00	1.600E 00	3.000E-04	0.	0.		
3	1.3534E 00	C.23119	2.000E 00	2.000E 00	4.000E-04	0.	0.		
4	8.2085E-01	C.18035	2.480E 00	2.480E 00	4.000E-04	0.	0.		
5	4.9787E-01	C.11474	2.970E 00	2.970E 00	7.000E-04	0.	0.		
6	3.0197E-01	C.06474	3.170E 00	3.170E 00	1.100E-03	0.	0.		
7	1.8316E-01	C.03401	3.820E 00	3.820E 00	1.700E-03	0.	0.		
8	1.1109E-01	C.01713	5.020E 00	5.020E 00	2.300E-03	0.	0.		
9	6.7379E-02	C.00841	5.980E 00	5.980E 00	3.000E-03	0.	0.		
10	4.0868E-02	C.00407	2.780E 00	2.780E 00	0.	0.	0.		
11	2.4788E-02	C.00195	6.340E 00	6.340E 00	3.900E-03	0.	0.		
12	1.5C34E-02	C.00093	7.500E-01	7.500E-01	0.	0.	0.		
13	9.1188E-03	C.00044	1.130E 00	1.130E 00	0.	0.	0.		
14	5.5308E-03	C.00021	1.510E 00	1.510E 00	9.230E-02	C.	0.		
15	2.0347E-03	C.00015	1.370E 00	1.370E 00	0.	0.	0.		

SIGMA-IJ (TRANSFER TO GROUP I FROM GROUP J), ARRANGED AS 11, 21, 22, 31, 32, 33,...,(NG+1)(NG)

0.6917	0.3050	1.0627	0.1590	C.3600	1.5696	0.0950	0.0830	0.3310	2.0916	0.0510
0.0710	C.0780	0.3460	2.5653	C.0300	0.	0.0210	0.0260	0.4040	2.7489	0.0120
0.0230	C.	0.0100	0.	C.4200	3.3343	0.	0.	0.	0.0040	0.
0.	C.4840	4.3857	0.	C.	0.	0.0020	0.	0.	0.	0.6320
5.2870	C.	C.	0.	C.	0.	0.	0.	0.	C.6900	2.4720
C.	C.	0.	0.	C.	0.	0.	0.	0.	0.3080	5.6151
C.	C.	0.	0.	C.	0.	0.	0.	0.	0.	0.7210
0.6690	C.	0.	0.	C.	0.	0.	0.	0.	0.	0.
0.	C.0810	1.0090	0.	C.	0.	0.	0.	0.	C.	0.
0.	C.	C.	0.	C.1210	1.2567	0.	0.	0.	0.	0.
C.	C.	C.	0.	C.	0.	0.	0.	0.1610	1.3193	0.
0.	C.	0.	0.	C.	0.	0.	0.	0.	0.	0.
0.	C.	C.C507								

PRINTOUT OF MACROSCOPIC CROSS SECTIONS AND FISSION SPECTRUM FOR EACH TYPE

TYPE NUMBER 1

GROUP	EL(MEV)	FISSION SOURCE	SIGMA-T	SIGMA-TR	SIGMA-C	SIGMA-F	NUSIGMA-F
1	3.6788E 00	0.13138	0.1695390	0.1034813	0.0032290	0.	0.
2	2.2313E 00	0.21028	0.2030216	0.1450275	0.	0.	0.
3	1.3534E 00	0.23119	0.2545317	0.2045512	0.	0.	0.
4	8.2085E-01	0.18035	0.3221688	0.2774413	0.0000000	0.	0.
5	4.9787E-01	0.11474	0.3177891	0.2480908	0.0000000	0.	0.
6	3.0197E-01	0.06474	0.4219599	0.3462830	0.0000000	0.	0.
7	1.8316E-01	0.03401	0.3426852	0.2873188	0.0000000	0.	0.
8	1.1109E-01	0.01713	0.3461799	0.2762562	0.0000000	0.	0.
9	6.7379E-02	0.00841	0.3508175	0.2707080	0.0000000	0.	0.
10	4.0868E-02	0.00407	0.3513424	0.2692241	0.0000000	0.	0.
11	2.4788E-02	0.00195	0.3516211	0.2693173	0.0000001	0.	0.
12	1.5034E-02	0.00093	0.3518289	0.2693868	0.0000001	0.	0.
13	9.1188E-03	0.00044	0.3519731	0.2694350	0.0000001	0.	0.
14	5.5308E-03	0.00021	0.3520809	0.2694710	0.0000001	0.	0.
15	2.0347E-03	0.00015	0.3521671	0.2694998	0.0000002	0.	0.

SIGMA-IJ (TRANSFER TO GROUP I FROM GROUP J), ARRANGED AS 11, 21, 22, 31, 32, 33,....(NG+1)(NG)

0.0791	0.0512	0.0865	0.0125	0.0505	0.0970	0.0132	0.0244	0.0668	0.1265	0.0114
0.0227	0.0378	0.0868	0.1204	0.0013	0.0173	0.0315	0.0488	0.0877	0.1947	0.0000
0.0017	0.0196	0.0375	0.0528	0.1212	0.1331	0.0000	0.0000	0.0017	0.0208	0.0369
0.0533	0.1102	0.1390	0.0000	0.0000	0.0000	0.0017	0.0186	0.0342	0.0517	0.1100
0.1469	0.0000	0.0000	0.0000	0.0000	0.0013	0.0171	0.0314	0.0502	0.1090	0.1481
0.0000	0.0000	0.0000	0.0000	0.0000	0.0014	0.0151	0.0305	0.0486	0.1090	0.1484
0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0011	0.0151	0.0295	0.0482	0.1089
0.1483	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0012	0.0154	0.0292
0.0482	0.1091	0.1484	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0013	0.0154	0.0292	0.0483	0.1091	0.1484	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	0.0000	0.0000	0.0001	0.0014	0.0167	0.0447	0.0776	0.1574	0.2030	0.0000
0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0001	0.0002	0.0015
0.0169	0.0463	0.1492								

TYPE NUMBER 2

GROUP	EL(MEV)	FISSION SOURCE	SIGMA-T	SIGMA-TR	SIGMA-C	SIGMA-F	NUSIGMA-F
1	3.6788E 00	0.13138	0.1865459	0.1865459	0.0004818	0.0293376	0.0909425
2	2.2313E 00	0.21028	0.2215060	0.2215060	0.0010568	0.0280354	0.0779429
3	1.3534E 00	0.23119	0.2329483	0.2329483	0.0027269	0.0208713	0.0542744
4	8.2085E-01	0.18035	0.2396726	0.2396726	0.0061658	0.0015765	0.0040229
5	4.9787E-01	0.11474	0.2673888	0.2673888	0.0066675	0.0004196	0.0010574
6	3.0197E-01	0.06474	0.3290741	0.3290741	0.0061138	0.0004437	0.0011003
7	1.8316E-01	0.03401	0.4056533	0.4056533	0.0077477	0.0004804	0.0011965
8	1.1109E-01	0.01713	0.4831238	0.4831238	0.0109075	0.0005572	0.0013595
9	6.7379E-02	0.00841	0.5500915	0.5500915	0.0139382	0.0006397	0.0015545
10	4.0868E-02	0.00407	0.5979599	0.5979599	0.0177860	0.0007394	0.0017968
11	2.4788E-02	0.00195	0.6505429	0.6505429	0.0216467	0.0008633	0.0020891
12	1.5034E-02	0.00093	0.6840268	0.6840268	0.0250398	0.0010146	0.0024553
13	9.1188E-03	0.00044	0.7175450	0.7175450	0.0290186	0.0012003	0.0029047
14	5.5308E-03	0.00021	0.7235321	0.7235321	0.0319244	0.0014892	0.0036039
15	2.0347E-03	0.00015	0.7675114	0.7675114	0.0440853	0.0017127	0.0041449

SIGMA-IJ (TRANSFER TO GROUP I FROM GROUP J), ARRANGED AS 11, 21, 22, 31, 32, 33,....(NG+1)(NG)

0.0370	0.0064	0.0709	0.0203	0.0123	0.1182	0.0306	0.0263	0.0352	0.1857	0.0287
0.0324	0.0413	0.0284	0.2349	0.0101	0.0253	0.0101	0.0130	0.0253	0.2968	0.0156
0.0144	0.0014	0.0043	0.0000	0.0257	0.3688	0.	0.0108	0.0031	0.0005	0.0000
0.0000	0.0286	0.4443	0.	0.	0.0001	0.0000	0.0000	0.0000	0.0000	0.0179
0.5098	0.	0.	0.	0.	0.0000	0.0000	0.0000	0.0095	0.0206	0.5672
0.	0.	0.	0.	0.	0.	0.0000	0.0000	0.0031	0.0072	0.6200
0.	0.	0.	0.	0.	0.	0.0000	0.0000	0.0021	0.0036	0.0081
0.6500	0.	0.	0.	0.	0.	0.	0.	0.0000	0.0000	0.0014
0.	0.0079	0.6790	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.0083	0.6818	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.0083	0.7179	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.0030								

TYPE NUMBER 3

GROUP	EL(MEV)	FISSION SOURCE	SIGMA-T	SIGMA-TR	SIGMA-C	SIGMA-F	NUSIGMA-F
1	3.6788E 00	0.13138	0.1852114	0.1852114	0.0004749	0.0289215	0.0896566
2	2.2313E 00	0.21028	0.2198792	0.2198792	0.0010448	0.0275917	0.0767051
3	1.3534E 00	0.23119	0.2312768	0.2312768	0.0027069	0.0204207	0.0530939
4	8.2085E-01	0.18035	0.2379255	0.2379255	0.0061262	0.0011398	0.0029178
5	4.9787E-01	0.11474	0.2654697	0.2654697	0.0066011	0.	0.
6	3.0197E-01	0.06474	0.3267320	0.3267320	0.0060312	0.	0.
7	1.8316E-01	0.03401	0.4027162	0.4027162	0.0076459	0.	0.
8	1.1109E-01	0.01713	0.4796501	0.4796501	0.0107803	0.	0.
9	6.7379E-02	0.00841	0.5461363	0.5461363	0.0137721	0.	0.
10	4.0868E-02	0.00407	0.5936264	0.5936264	0.0175713	0.	0.
11	2.4788E-02	0.00195	0.6458655	0.6458655	0.0213705	0.	0.
12	1.5034E-02	0.00093	0.6791086	0.6791086	0.0246949	0.	0.
13	9.1189E-03	0.00044	0.7123517	0.7123517	0.0285890	0.	0.
14	5.5308E-03	0.00021	0.7171007	0.7171007	0.0313435	0.	0.
15	2.0347E-03	0.00015	0.7598418	0.7598418	0.0441658	0.	0.

SIGMA-IJ (TRANSFER TO GROUP I FROM GROUP J), ARRANGED AS 11, 21, 22, 31, 32, 33,....(NG+1)(NG)

0.0368	0.0064	0.0704	0.0202	0.0122	0.1176	0.0304	0.0262	0.0351	0.1849	0.0285
0.0322	0.0411	0.0283	0.2337	0.0180	0.0252	0.0100	0.0129	0.0252	0.2952	0.0155
0.0143	0.0013	0.0042	0.	0.0255	0.3666	0.	0.0108	0.0031	0.0004	0.
0.	0.0285	0.4416	0.	0.	0.	0.	0.	0.	0.	0.0178
0.5067	0.	0.	0.	0.	0.	0.	0.	0.0095	0.0205	0.5639
0.	0.	0.	0.	0.	0.	0.	0.	0.0030	0.0072	0.6165
0.	0.	0.	0.	0.	0.	0.	0.	0.0021	0.0036	0.0080
0.6465	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.0014
0.	0.0079	0.6755	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.0083	0.6775	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.0083	0.7127	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.0030								

GROUP	EL(MEV)	FISSION SOURCE	SIGMA-T	SIGMA-TR	SIGMA-C	SIGMA-F	NUSIGMA-F	TYPE NUMBER 4
1	3.6788E 00	C.13138	0.0000767	0.0C00469	0.0000015	0.	0.	
2	2.2313E 00	C.21028	0.0000919	0.0C0C657	0.	0.	0.	
3	1.3534E 00	C.23119	0.0001152	0.0C0C927	0.	0.	0.	
4	8.2C85E-01	C.18035	0.0001457	0.0001257	0.	0.	0.	
5	4.9787E-01	C.11474	0.0001437	0.0001124	0.	0.	0.	
6	3.0197E-01	C.06474	0.0001907	0.0001568	0.	0.	0.	
7	1.8316E-01	C.03401	0.0001547	0.0C01300	0.	0.	0.	
8	1.1109E-01	C.01713	0.0001561	0.0001249	0.	0.	0.	
9	6.7379E-02	C.00841	0.0001580	0.0C01224	-0.	0.	0.	
10	4.0868E-02	C.00407	0.0001581	0.0001216	-0.	0.	0.	
11	2.4788E-02	C.00195	0.0001581	0.0001216	-0.	0.	0.	
12	1.5C34E-02	C.00093	0.0001581	0.0C01216	-0.	0.	0.	
13	9.1188E-03	C.00044	0.0001581	0.0C01216	-0.	0.	0.	
14	5.5308E-03	C.00021	0.0001581	0.0001216	-0.	0.	0.	
15	2.C347E-03	C.00015	0.0001581	0.0C01216	-0.	0.	0.	

SIGMA-IJ (TRANSFER TO GROUP I FROM GROUP J), ARRANGED AS 11, 21, 22, 31, 32, 33,...,(NG+1)(NG)

0.0000	C.0000	0.0000	0.00CC	C.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000
C.0000	C.0000	0.0000	0.0001	C.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.
0.C000	C.0000	0.C000	0.C0C0	C.00C1	0.0001	0.	0.	0.0000	0.0000	0.0000
0.0000	C.0000	0.0001	0.	C.	0.	0.0000	0.0000	0.0000	0.0000	0.0000
0.0001	C.	0.	0.	C.	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001
0.	C.	0.	0.	C.	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001
C.	C.	0.	0.	C.	0.	0.0000	0.0000	0.0000	0.0000	0.0000
0.0001	C.	0.	0.	C.	0.	0.	0.	0.0000	0.0000	0.0000
0.0000	C.0000	0.0001	0.	C.	0.	0.	0.	0.	0.	0.
0.0000	C.0000	0.0000	0.C0C0	C.000C	0.0001	0.	0.	0.	0.	0.
C.	C.	C.	0.	C.000C	0.0000	0.0000	0.0000	0.0001	0.0001	0.
0.	C.	C.	0.	C.	0.	0.	0.	0.	0.	0.0000
0.0000	C.0000	0.0001								

GROUP	EL(MEV)	FISSION SOURCE	SIGMA-T	SIGMA-TR	SIGMA-C	SIGMA-F	NUSIGMA-F	TYPE NUMBER 5
1	3.6788E 00	C.13138	0.0825151	0.0825151	0.0015840	0.	0.	
2	2.2313E 00	C.21028	0.0963680	C.0963680	0.0000181	0.	0.	
3	1.3534E 00	C.23119	0.1204600	0.1204600	0.0000241	0.	0.	
4	8.2C85E-01	C.18035	0.1493704	0.1493704	0.0000241	0.	0.	
5	4.9787E-01	C.11474	0.1788831	0.1788831	0.0000422	0.	0.	
6	3.C197E-01	C.06474	0.1909291	C.1909291	0.0000663	0.	0.	
7	1.8316E-01	C.03401	0.2300786	C.230C786	0.0001024	0.	0.	
8	1.1109E-01	C.01713	0.3023546	0.3023546	0.0C01385	0.	0.	
9	6.7379E-02	C.00841	0.3601754	0.3601754	0.0001807	0.	0.	
10	4.C868E-02	C.00407	0.1674394	0.1674394	0.	0.	0.	
11	2.4788E-02	C.00195	0.3818582	0.3818582	0.0002349	0.	0.	
12	1.5C34E-02	C.00093	0.0451725	0.0451725	0.	0.	0.	
13	9.1188E-03	C.00044	0.0680599	0.068C599	0.	0.	0.	
14	5.5308E-03	C.00021	0.0909473	0.0909473	0.0055592	0.	0.	
15	2.C347E-03	C.00015	0.0825151	0.0825151	0.	0.	0.	

SIGMA-IJ (TRANSFER TO GROUP I FROM GROUP J), ARRANGED AS 11, 21, 22, 31, 32, 33,...,(NG+1)(NG)

0.0417	0.0184	0.0640	0.0096	C.0217	0.0945	0.0057	0.0050	0.0199	0.1260	0.0031
0.0043	C.0047	0.0208	0.1545	C.0018	0.	0.0013	0.0016	0.0243	0.1656	0.0007
0.0014	C.	0.0006	0.	C.0253	0.2008	0.	0.	0.	0.0002	0.
0.	C.0292	0.2642	0.	C.	0.	0.0001	0.	0.	0.	0.0381
0.3184	C.	0.	0.	C.	0.	0.	0.	0.	0.0416	0.1489
0.	C.	0.	0.	C.	0.	0.	0.	0.	0.0186	0.3382
0.	C.	0.	0.	C.	0.	0.	0.	0.	0.	0.0434
0.0403	C.	0.	0.	C.	0.	0.	0.	0.	0.	0.
0.	C.0049	0.0608	0.	C.	0.	0.	0.	0.	0.	0.
0.	C.	0.	0.	C.0073	0.0757	0.	0.	0.	0.	0.
0.	C.	0.	0.	C.	0.	0.	0.	0.0097	0.0795	0.
0.	C.	0.	0.	C.	0.	0.	0.	0.	0.	0.
0.	C.	0.0031								

PRINTOUT OF AVERAGED CONSTANTS

GROUP	EL(MEV)	SPECTRUM	FLUX	SIGMA-T	SIGMA-TR	SIGMA-C	SIGMA-F	NU*SIGMA-F	NU
1	3.679E 00	0.13138	3.0391E-02	0.1691	0.1238	0.00239	0.00791	0.02451	3.0999
2	2.231E 00	0.21028	5.0951E-02	0.2020	0.1612	0.00027	0.00713	0.01983	2.7802
3	1.353E 00	0.23119	5.7033E-02	0.2413	0.2069	0.00074	0.00562	0.01461	2.6004
4	8.208E-01	C.18035	6.1457E-02	C.2913	0.2602	0.00162	0.00041	0.00106	2.5517
5	4.979E-01	C.11474	7.0444E-02	0.2991	0.2479	0.00152	0.0001C	0.00024	2.5200
6	3.C20E-01	0.06474	6.0976E-02	0.3968	0.3369	0.00109	0.C0008	0.00020	2.4800
7	1.832E-01	0.C3401	6.8619E-02	0.3467	0.2997	0.00100	0.00006	0.00015	2.4500
8	1.111E-01	0.C1713	6.8738E-02	0.3583	0.2973	0.00118	0.00006	0.00015	2.4400
9	6.738E-02	0.C0841	6.8106E-02	0.3672	0.2957	0.00127	0.00006	0.00014	2.4300
10	4.C87E-02	0.00407	6.8892E-02	C.3699	0.2967	0.00163	0.00007	0.00016	2.4300
11	2.479E-02	C.C0195	6.7507E-02	0.3755	0.3015	0.00183	0.00007	0.00018	2.4200
12	1.503E-02	C.C0093	6.7126E-02	0.3747	0.3006	0.00213	0.00009	0.00021	2.4200
13	9.119E-03	0.C0044	6.6227E-02	0.3770	0.3025	0.00237	0.00010	0.00024	2.4200
14	5.531E-03	0.00021	6.5499E-02	0.3774	0.3028	0.00263	0.00012	0.00029	2.4200
15	2.C35E-03	0.C0015	1.2803E-01	0.3801	0.3052	0.00352	0.00013	0.00032	2.4200

SIGMA-IJ (TRANSFER TO GROUP I FROM GROUP J), ARRANGED AS 11, 21, 22, 31, 32, 33,...,(NG+1)(NG)

0.0655	0.0374	0.0808	0.0143	0.0393	0.1014	0.0175	0.0240	0.0560	0.1405	0.0156
0.0243	0.0373	0.0684	0.1459	C.0059	0.0186	0.0244	0.0373	0.0709	0.2106	0.0042
0.0049	C.0139	0.0272	0.0389	C.1011	0.1637	0.0000	0.0028	0.0020	0.0146	0.0271
0.0422	C.0976	0.1728	0.0000	C.0000	0.0000	0.0012	0.0137	0.0271	0.0439	0.0985
0.1811	C.0000	0.0000	0.0000	C.0000	0.0009	0.0135	0.0266	0.0448	0.0996	0.1850
0.0000	0.0000	0.0000	0.00C0	0.0000	0.0011	0.0128	0.0266	0.0436	0.0980	0.1897
0.0000	0.0000	0.0000	0.0000	C.00C0	0.0000	0.0010	0.0131	0.0265	0.0432	0.0991
0.1889	C.0000	0.0000	0.0000	C.0000	0.0000	0.00C0	0.0000	0.0011	0.0138	0.0262
0.0433	0.0987	C.1901	0.0000	C.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0011	0.0137	0.0263	0.0434	C.0992	0.1899	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	0.0000	0.0000	0.0001	C.0012	0.0150	0.0401	0.0700	0.1430	0.2410	0.0000
0.0000	C.0000	0.0000	0.0000	C.0000	0.0000	0.0000	0.0000	0.0001	0.0002	0.0014
0.0153	C.0418	0.1354								

PARAMETERS AVERAGED OVER SPACE AND ENERGY

```
SIGMA-T= 0.34013    SIGMA-TR= 0.27884    1/(TRMFP)= 0.26575    SIGMA-C= 0.001796    SIGMA-F= 0.001021    NU= 2.7695
     NU*SIGMA-F= 0.002827    SIGMA-REMOVAL= 0.021204    TAU (TRMFP/(3*SIGMA-(C+F+R-NU*F)))=  59.182
        FRACTION OF SOURCE NEUTRONS ARISING FROM THERMAL FISSIONS= 0.882077
        RATIO OF FAST TO THERMAL FISSIONS= 0.11682
        OVERALL RATIO OF U-238 TO U-235 FISSIONS= 0.10493
                  SYMMETRY CLASS, REGION    1, 1      2, 1      3, 1      4, 1
                   U-238/U-235 FISSIONS  0.23597   0.16813   0.09391   0.08137
```

DISADVANTAGE FACTORS AND VOLUME FRACTIONS

```
  MODERATOR    CELL RADIUS= 18.6708   VOL FRACT=0.89555   THRML FISS SRCE=0.         LAST ITER=0.
       GROUP           1          2          3          4          5          6          7          8          9         10
   DISADVNTG FCTR   0.76556    0.78564    0.76709    0.77589    0.82121    0.88437    0.94741    0.97407    0.99610    0.99467
       GROUP          11         12         13         14         15

   DISADVNTG FCTR   1.00396    1.00328    1.00731    1.00888    1.01167

CLASS 1  NO.= 1   REGN  1   TYPE 2   RADIUS=  1.2675   VOL FRACT=0.00461   THRML FISS SRCE=0.01895   LAST ITER=0.01894
       GROUP           1          2          3          4          5          6          7          8          9         10
   DISADVNTG FCTR   2.63528    2.37233    2.47583    2.52707    2.42302    1.86422    1.39734    1.19262    1.00036    1.03752
       GROUP          11         12         13         14         15
   DISADVNTG FCTR   0.94465    0.95693    0.91454    0.89812    0.86782

CLASS 1  NO.= 1   REGN  2   TYPE 4   RADIUS=  1.3030   VOL FRACT=0.00026   THRML FISS SRCE=0.         LAST ITER=0.
       GROUP           1          2          3          4          5          6          7          8          9         10
   DISADVNTG FCTR   2.60362    2.31047    2.36762    2.33820    2.24799    1.72328    1.34067    1.16593    1.00600    1.03693
       GROUP          11         12         13         14         15
   DISADVNTG FCTR   0.95593    0.97129    0.93380    0.92038    0.89736

CLASS 1  NO.= 1   REGN  3   TYPE 5   RADIUS=  1.3843   VOL FRACT=0.00063   THRML FISS SRCE=0.         LAST ITER=0.
       GROUP           1          2          3          4          5          6          7          8          9         10
   DISADVNTG FCTR   2.56497    2.29181    2.33094    2.29585    2.20783    1.69554    1.32734    1.15796    1.00379    1.03466
       GROUP          11         12         13         14         15
   DISADVNTG FCTR   0.95428    0.97332    0.93399    0.92032    0.89895

CLASS 2  NO.= 6   REGN  1   TYPE 2   RADIUS=  1.2675   VOL FRACT=0.00461   THRML FISS SRCE=0.03031   LAST ITER=0.03031
       GROUP           1          2          3          4          5          6          7          8          9         10
   DISADVNTG FCTR   2.91623    2.68790    2.83148    2.83435    2.58470    1.99427    1.45489    1.22258    1.01756    1.04414
       GROUP          11         12         13         14         15
   DISADVNTG FCTR   0.95235    0.96159    0.92086    0.90498    0.87599

CLASS 2  NO.= 6   REGN  2   TYPE 4   RADIUS=  1.3030   VOL FRACT=0.00026   THRML FISS SRCE=0.         LAST ITER=0.
       GROUP           1          2          3          4          5          6          7          8          9         10
   DISADVNTG FCTR   2.78297    2.53182    2.62482    2.55857    2.34772    1.81083    1.37842    1.18567    1.01903    1.04106
       GROUP          11         12         13         14         15
   DISADVNTG FCTR   0.96266    0.97550    0.94000    0.92726    0.90576

CLASS 2  NO.= 6   REGN  3   TYPE 5   RADIUS=  1.3843   VOL FRACT=0.00063   THRML FISS SRCE=0.         LAST ITER=0.
       GROUP           1          2          3          4          5          6          7          8          9         10
   DISADVNTG FCTR   2.72446    2.49389    2.56776    2.49752    2.29659    1.77611    1.36110    1.17535    1.01609    1.0385[illegible]
       GROUP          11         12         13         14         15
   DISADVNTG FCTR   0.96084    0.97745    0.94017    0.92721    0.90736

CLASS 3  NO.= 6   REGN  1   TYPE 2   RADIUS=  1.2675   VOL FRACT=0.00461   THRML FISS SRCE=0.06236   LAST ITER=0.06236
       GROUP           1          2          3          4          5          6          7          8          9         10
   DISADVNTG FCTR   3.24385    3.08175    3.26417    3.15390    2.66480    2.09494    1.49711    1.24647    1.04461    1.05042
       GROUP          11         12         13         14         15
   DISADVNTG FCTR   0.96984    0.97253    0.93865    0.92517    0.90081

CLASS 3  NO.= 6   REGN  2   TYPE 4   RADIUS=  1.3030   VOL FRACT=0.00026   THRML FISS SRCE=0.         LAST ITER=0.
       GROUP           1          2          3          4          5          6          7          8          9         10
   DISADVNTG FCTR   2.80564    2.63899    2.75775    2.63727    2.27886    1.81387    1.37185    1.18383    1.03484    1.04144
       GROUP          11         12         13         14         15
   DISADVNTG FCTR   0.97765    0.98518    0.95753    0.94767    0.93131

CLASS 3  NO.= 6   REGN  3   TYPE 5   RADIUS=  1.3843   VOL FRACT=0.00063   THRML FISS SRCE=0.         LAST ITER=0.
       GROUP           1          2          3          4          5          6          7          8          9         10
   DISADVNTG FCTR   2.68293    2.53705    2.64460    2.53312    2.19994    1.75973    1.34651    1.16936    1.02994    1.03789
       GROUP          11         12         13         14         15
   DISADVNTG FCTR   0.97526    0.98696    0.95763    0.94755    0.93296

CLASS 4  NO.= 6   REGN  1   TYPE 2   RADIUS=  1.2675   VOL FRACT=0.00461   THRML FISS SRCE=0.07083   LAST ITER=0.07084
       GROUP           1          2          3          4          5          6          7          8          9         10
   DISADVNTG FCTR   3.14919    3.03632    3.23056    3.10153    2.56610    2.05120    1.47392    1.23553    1.04852    1.04877


       GROUP          11         12         13         14         15
   DISADVNTG FCTR   0.97596    0.97661    0.94649    0.93438    0.91236

CLASS 4  NO.= 6   REGN  2   TYPE 4   RADIUS=  1.3030   VOL FRACT=0.00026   THRML FISS SRCE=0.         LAST ITER=0.
       GROUP           1          2          3          4          5          6          7          8          9         10
   DISADVNTG FCTR   2.62090    2.49463    2.64141    2.52541    2.14859    1.75032    1.33915    1.16705    1.03615    1.03833
       GROUP          11         12         13         14         15
   DISADVNTG FCTR   0.98305    0.98895    0.96543    0.95704    0.94323

CLASS 4  NO.= 6   REGN  3   TYPE 5   RADIUS=  1.3843   VOL FRACT=0.00063   THRML FISS SRCE=0.         LAST ITER=0.
       GROUP           1          2          3          4          5          6          7          8          9         10
   DISADVNTG FCTR   2.47911    2.38977    2.51261    2.41070    2.06254    1.69199    1.31140    1.15216    1.03061    1.03456
       GROUP          11         12         13         14         15
   DISADVNTG FCTR   0.98066    0.99071    0.96548    0.95690    0.94489
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PRINTOUT OF AXIS-TO-AXIS SPACINGS AND WEIGHTS

AXIS-TO-AXIS SEPARATION        3.8100    6.5991    20.3200    22.4790    24.1300    25.0190    26.2382    27.8638
NO. IN INF. REG. LATTICE       6.0000    6.0000

AXIS-TO-AXIS SEPARATION       27.9400   28.7020    29.7942    30.9118

WTS(I,J,K) ARRANGED WITHIN ROWS BY I. ROWS ADVANCE BY J, AND GROUPS OF ROWS BY K
 0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.
 1.0  0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.
 0.   1.0  0.   0.   0.   0.   0.   0.   0.   0.   0.   0.
 0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.
 6.0  0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.
 2.0  2.0  0.   0.   0.   0.   0.   0.   0.   0.   0.   0.
 2.0  0.   0.   0.   0.   0.   0.1  0.   0.   0.   0.   0.
 1.0  2.0  0.   0.   0.   0.   0.   0.   0.   0.   0.   0.
 0.   6.0  0.   0.   0.   0.   0.   0.   0.   0.   0.   0.
 2.0  0.   0.   0.   0.   0.   0.1  0.   0.   0.   0.   0.
 0.   2.0  0.   0.   2.0  1.8  0.   0.   0.   0.   0.   0.
 2.0  0.   0.   2.0  0.   0.   2.0  1.4  0.   0.   0.   0.
 0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.
 1.0  2.0  0.   0.   0.   0.   0.   0.2  0.1  0.   0.   0.
 2.0  0.   0.   2.0  0.   0.   2.0  1.4  0.   0.   0.   0.
 0.   0.   1.0  0.   0.   3.6  0.   0.   2.0  0.   0.   1.4


PRINTOUT OF DANCOFF FACTORS IN MODERATOR

    RADIUS= 1.3843     AXIS-TO-AXIS SEPARATION= 3.8100
         GROUP            1         2         3         4         5         6         7         8         9        10
    DANCOFF FACTOR   0.10096   0.09381   0.08457   0.07464   0.07847   0.06647   0.07340   0.07480   0.07550   0.07569
         GROUP           11        12        13        14        15
    DANCOFF FACTOR   0.07568   0.07567   0.07567   0.07566   0.07566

    RADIUS= 1.3843     AXIS-TO-AXIS SEPARATION= 6.5991
         GROUP            1         2         3         4         5         6         7         8         9        10
    DANCOFF FACTOR   0.02594   0.02098   0.01557   0.01087   0.01255   0.00779   0.01036   0.01094   0.01124   0.01132
         GROUP           11        12        13        14        15
    DANCOFF FACTOR   0.01131   0.01131   0.01131   0.01130   0.01130

    RADIUS= 1.3843     AXIS-TO-AXIS SEPARATION=20.3200
         GROUP            1         2         3         4         5         6         7         8         9        10
    DANCOFF FACTOR   0.00245   0.00107   0.00033   0.00008   0.00014   0.00002   0.00007   0.00008   0.00009   0.00009
         GROUP           11        12        13        14        15
    DANCOFF FACTOR   0.00009   0.00009   0.00009   0.00009   0.00009

    RADIUS= 1.3843     AXIS-TO-AXIS SEPARATION=22.4790
         GROUP            1         2         3         4         5         6         7         8         9        10
    DANCOFF FACTOR   0.00173   0.00069   0.00019   0.00004   0.00007   0.00001   0.00003   0.00004   0.00004   0.00005
         GROUP           11        12        13        14        15
    DANCOFF FACTOR   0.00005   0.00005   0.00005   0.00005   0.00005

    RADIUS= 1.3843     AXIS-TO-AXIS SEPARATION=24.1300
         GROUP            1         2         3         4         5         6         7         8         9        10
    DANCOFF FACTOR   0.00133   0.00049   0.00012   0.00002   0.00004   0.00000   0.00002   0.00002   0.00003   0.00003
         GROUP           11        12        13        14        15
    DANCOFF FACTOR   0.00003   0.00003   0.00003   0.00003   0.00003

    RADIUS= 1.3843     AXIS-TO-AXIS SEPARATION=25.0190
         GROUP            1         2         3         4         5         6         7         8         9        10
    DANCOFF FACTOR   0.00116   0.00041   0.00010   0.00002   0.00003   0.00000   0.00001   0.00002   0.00002   0.00002
         GROUP           11        12        13        14        15
    DANCOFF FACTOR   0.00002   0.00002   0.00002   0.00002   0.00002

    RADIUS= 1.3843     AXIS-TO-AXIS SEPARATION=26.2382
         GROUP            1         2         3         4         5         6         7         8         9        10
    DANCOFF FACTOR   0.00096   0.00032   0.00007   0.00001   0.00002   0.00000   0.00001   0.00001   0.00001   0.00001
         GROUP           11        12        13        14        15
    DANCOFF FACTOR   0.00001   0.00001   0.00001   0.00001   0.00001

    RADIUS= 1.3843     AXIS-TO-AXIS SEPARATION=27.8638
         GROUP            1         2         3         4         5         6         7         8         9        10
    DANCOFF FACTOR   0.00075   0.00024   0.00005   0.00001   0.00001   0.00000   0.00000   0.00001   0.00001   0.00001
         GROUP           11        12        13        14        15
    DANCOFF FACTOR   0.00001   0.00001   0.00001   0.00001   0.00001

    RADIUS= 1.3843     AXIS-TO-AXIS SEPARATION=27.9400
         GROUP            1         2         3         4         5         6         7         8         9        10
    DANCOFF FACTOR   0.00074   0.00023   0.00005   0.00001   0.00001   0.00000   0.00000   0.00001   0.00001   0.00001
         GROUP           11        12        13        14        15
    DANCOFF FACTOR   0.00001   0.00001   0.00001   0.00001   0.00001

    RADIUS= 1.3843     AXIS-TO-AXIS SEPARATION=28.7020
         GROUP            1         2         3         4         5         6         7         8         9        10
    DANCOFF FACTOR   0.00067   0.00020   0.00004   0.00000   0.00001   0.00000   0.00000   0.00001   0.00001   0.00001

         GROUP           11        12        13        14        15
    DANCOFF FACTOR   0.00001   0.00001   0.00001   0.00001   0.00001

    RADIUS= 1.3843     AXIS-TO-AXIS SEPARATION=29.7942
         GROUP            1         2         3         4         5         6         7         8         9        10
    DANCOFF FACTOR   0.00057   0.00016   0.00003   0.00000   0.00001   0.00000   0.00000   0.00000   0.00000   0.00000
         GROUP           11        12        13        14        15
    DANCOFF FACTOR   0.00000   0.00000   0.00000   0.00000   0.00000

    RADIUS= 1.3843     AXIS-TO-AXIS SEPARATION=30.9118
         GROUP            1         2         3         4         5         6         7         8         9        10
    DANCOFF FACTOR   0.00048   0.00013   0.00002   0.00000   0.00001   0.00000   0.00000   0.00000   0.00000   0.00000
         GROUP           11        12        13        14        15
    DANCOFF FACTOR   0.00000   0.00000   0.00000   0.00000   0.00000
```

PRINTOUT OF TRANSMISSION PROBABILITIES

CLASS 1 REGION 1

GROUP	1	2	3	4	5	6	7	8	9	10
TPCO	0.63891	0.58998	0.57493	0.56630	0.53230	0.46487	0.39463	0.33592	0.29333	0.26677
GROUP	11	12	13	14	15					
TPCO	0.24083	0.22587	0.21200	0.20963	0.19318					

CLASS 1 REGION 2

GROUP	1	2	3	4	5	6	7	8	9	10
TPCI	1.00000	1.00000	0.99999	0.99999	0.99999	0.99999	0.99999	0.99999	0.99999	0.99999
TPCO	0.02729	0.02729	0.02729	0.02729	0.02729	0.02729	0.02729	0.02729	0.02729	0.02729
GROUP	11	12	13	14	15					
TPCI	0.99999	0.99999	0.99999	0.99999	0.99999					
TPCO	0.02729	0.02729	0.02729	0.02729	0.02729					

CLASS 1 REGION 3

GROUP	1	2	3	4	5	6	7	8	9	10
TPCI	0.98834	0.98640	0.98304	0.97903	0.97496	0.97331	0.96796	0.95819	0.95047	0.97654
TPCO	0.05501	0.05442	0.05341	0.05224	0.05107	0.05060	0.04912	0.04652	0.04457	0.05152
GROUP	11	12	13	14	15					
TPCI	0.94760	0.99358	0.99035	0.98716	0.98834					
TPCO	0.04387	0.05665	0.05564	0.05465	0.05501					

CLASS 2 REGION 1

GROUP	1	2	3	4	5	6	7	8	9	10
TPCO	0.63891	0.58998	0.57493	0.56630	0.53230	0.46487	0.39463	0.33592	0.29333	0.26677
GROUP	11	12	13	14	15					
TPCO	0.24083	0.22587	0.21200	0.20963	0.19318					

CLASS 2 REGION 2

GROUP	1	2	3	4	5	6	7	8	9	10
TPCI	1.00000	1.00000	0.99999	0.99999	0.99999	0.99999	0.99999	0.99999	0.99999	0.99999
TPCO	0.02729	0.02729	0.02729	0.02729	0.02729	0.02729	0.02729	0.02729	0.02729	0.02729
GROUP	11	12	13	14	15					
TPCI	0.99999	0.99999	0.99999	0.99999	0.99999					
TPCO	0.02729	0.02729	0.02729	0.02729	0.02729					

CLASS 2 REGION 3

GROUP	1	2	3	4	5	6	7	8	9	10
TPCI	0.98834	0.98640	0.98304	0.97903	0.97496	0.97331	0.96796	0.95819	0.95047	0.97654
TPCO	0.05501	0.05442	0.05341	0.05224	0.05107	0.05060	0.04912	0.04652	0.04457	0.05152
GROUP	11	12	13	14	15					
TPCI	0.94760	0.99358	0.99035	0.98716	0.98834					
TPCO	0.04387	0.05665	0.05564	0.05465	0.05501					

CLASS 3 REGION 1

GROUP	1	2	3	4	5	6	7	8	9	10
TPCO	0.63891	0.58998	0.57493	0.56630	0.53230	0.46487	0.39463	0.33592	0.29333	0.26677
GROUP	11	12	13	14	15					
TPCO	0.24083	0.22587	0.21200	0.20963	0.19318					

CLASS 3 REGION 2

GROUP	1	2	3	4	5	6	7	8	9	10
TPCI	1.00000	1.00000	0.99999	0.99999	0.99999	0.99999	0.99999	0.99999	0.99999	0.99999
TPCO	0.02729	0.02729	0.02729	0.02729	0.02729	0.02729	0.02729	0.02729	0.02729	0.02729
GROUP	11	12	13	14	15					
TPCI	0.99999	0.99999	0.99999	0.99999	0.99999					
TPCO	0.02729	0.02729	0.02729	0.02729	0.02729					

CLASS 3 REGION 3

GROUP	1	2	3	4	5	6	7	8	9	10
TPCI	0.98834	0.98640	0.98304	0.97903	0.97496	0.97331	0.96796	0.95819	0.95047	0.97654
TPCO	0.05501	0.05442	0.05341	0.05224	0.05107	0.05060	0.04912	0.04652	0.04457	0.05152
GROUP	11	12	13	14	15					
TPCI	0.94760	0.99358	0.99035	0.98716	0.98834					
TPCO	0.04387	0.05665	0.05564	0.05465	0.05501					

CLASS 4 REGION 1

GROUP	1	2	3	4	5	6	7	8	9	10
TPCO	0.63891	0.58998	0.57493	0.56630	0.53230	0.46487	0.39463	0.33592	0.29333	0.26677
GROUP	11	12	13	14	15					
TPCO	0.24083	0.22587	0.21200	0.20963	0.19318					

CLASS 4 REGION 2

GROUP	1	2	3	4	5	6	7	8	9	10
TPCI	1.00000	1.00000	0.99999	0.99999	0.99999	0.99999	0.99999	0.99999	0.99999	0.99999
TPCO	0.02729	0.02729	0.02729	0.02729	0.02729	0.02729	0.02729	0.02729	0.02729	0.02729
GROUP	11	12	13	14	15					
TPCI	0.99999	0.99999	0.99999	0.99999	0.99999					
TPCO	0.02729	0.02729	0.02729	0.02729	0.02729					

CLASS 4 REGION 3

GROUP	1	2	3	4	5	6	7	8	9	10
TPCI	0.98834	0.98640	0.98304	0.97903	0.97496	0.97331	0.96796	0.95819	0.95047	0.97654
TPCO	0.05501	0.05442	0.05341	0.05224	0.05107	0.05060	0.04912	0.04652	0.04457	0.05152
GROUP	11	12	13	14	15					
TPCI	0.94760	0.99358	0.99035	0.98716	0.98834					
TPCO	0.04387	0.05665	0.05564	0.05465	0.05501					