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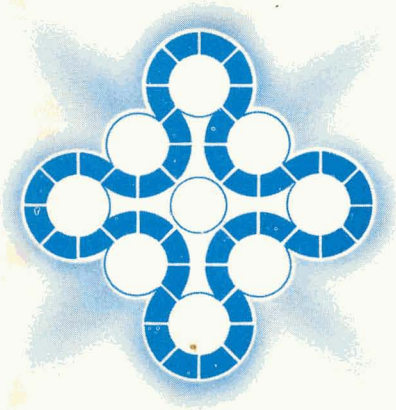

Aerojet Nuclear Company

NATIONAL REACTOR TESTING STATION

Idaho Falls, Idaho — 83401

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ABSTRACT

The RAFFLE code is a three-dimensional general purpose Monte Carlo program for the solution of static neutron transport problems. It is written in FORTRAN IV and is presently operational on the IBM 360/75 computer. Either fission source iteration or external source problems can be solved. The external sources can be distributed volume sources or current sources defined on specified surfaces, and these sources can optionally generate fission daughters. Groupwise reaction rates and fluxes for up to 100 energy groups can be obtained for all regions of interest. Instead of reaction rates, cell averaged groupwise cross sections together with P_0 and P_1 transfer matrices can be obtained in addition to the fluxes. Multiplication factors, lifetimes, and generation times are also computed. For each RAFFLE estimate, the fractional probable error is also given. Optional multiple thermal groups make RAFFLE suitable for studies of complex thermal or coupled fast-thermal systems. Groupwise currents from any region to any adjacent region can be calculated. RAFFLE has the capability of handling all practical geometrical models. Detailed spatial information can be produced by use of small regions, or edits can be obtained for sets of regions to show averaged behavior. In the same way, groups can be combined into group sets. RAFFLE can use either multigroup or pointwise cross section data. A combination of the two types can also be used. Hence, cross section data can be extremely detailed if required, or they can be very coarse. Inelastic discrete level and evaporation model scattering; resolved resonance absorption, scattering, and fission; and elastic scattering with any degree of anisotropic angular scattering can all be treated. Three scoring techniques and a number of biasing options can be selected to make the Monte Carlo procedures of RAFFLE effective for a wide variety of problems.

SUMMARY

The types of neutron transport problems solved, the scoring and biasing options, the reactor physics treatment, and the output data are reviewed in an introduction that acquaints the user with the capabilities of the RAFFLE general purpose Monte Carlo program.

The transport and collision events that comprise a neutron history are discussed with emphasis on the relations between the Monte Carlo and reactor physics aspects of the simulation. This presentation includes physically oriented explanations of the various scoring and biasing options available in the code. Selection of a scoring technique and effective use of the biasing options are first considered in relation to the type of problem being solved. Then more specific guidelines are given to assist the user in preparing the input data to select biasing options and parameters that yield reliable answers in a reasonable amount of computer time.

RAFFLE uses regions defined by surfaces to describe the geometrical model for a problem. A second geometry consisting of regularly shaped zones is used to reduce the computational time for assigning events to regions; four zone geometries are available. The procedures for using these geometrical descriptions and selection of the proper zone geometry so that the program can perform efficiently are thoroughly explained.

Detailed instructions for preparation of the problem input data are presented. The use of these instructions is clarified by three sample problems together with a step by step explanation of their preparation. The formats for the cross section data are presented, the use of cross section data in the RAFFLE calculations discussed, and the numerous options for the problem cross section libraries considered.

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THE RAFFLE GENERAL PURPOSE MONTE CARLO CODE

I. INTRODUCTION

The RAFFLE Code is a general purpose Monte Carlo neutron transport code. RAFFLE can solve iteration type problems to obtain the multiplication factor (k) and normal mode fluxes, or it can solve external source problems. The external sources may be distributed volume sources of any shape or may be incoming current sources specified on particular surfaces. The current sources may have any energy and angular distributions. For external source problems, fission daughters can be subsequently generated from the source neutrons. For any type of problem, the neutron slowing down treatment can be as detailed as desired. Inelastic discrete level and evaporation model scattering; resolved resonance absorption, scattering, and fission; and elastic scattering with any degree of anisotropic angular scattering can all be treated. Multiple thermal energy groups are optional and can be used for thermal systems. Also, for resonance problems, temperature can be spatially dependent.

The output edits from RAFFLE can be quite detailed for those problems where detail is of interest. Multiplication factors, lifetimes, and generation times are obtained for iteration type problems and external source with fission problems. Groupwise fluxes, absorption rates (resonance and nonresonance), and fission rates (resonance and non-resonance) are output for all regions of interest. The groupwise structure is quite arbitrary and the regions may be made as small as necessary to obtain fine spatial detail. The regions and groups may be lumped into region and group sets to account for symmetry or to obtain integrated or average behavior. Groupwise currents from any region to any other region may be obtained. For cell type problems, the cell averaged absorption cross sections, fission cross sections, and total scattering cross sections can be obtained. These cell cross sections can be obtained with regard to any group structure. In addition, for these cell problems the complete groupwise P_0 and P_1 transfer matrices can be obtained. For all the output quantities edited, associated fractional probable errors are also printed out.

A specific RAFFLE computer run is terminated either by satisfaction of a convergence criteria or by satisfaction of a maximum run time. A problem can be run until the fractional error on the multiplication factor, a region flux, or a region and group flux decreases below a specified input value. A problem can also be terminated when the maximum fractional error of a set of fluxes decreases below the input value. Instead of terminating upon convergence criteria, a particular computer run can be terminated when a given run time is achieved. For this type of termination, a complete output edit is given

upon termination. A combination of termination criteria may also be used, where the computer run terminates, either when convergence criteria are satisfied or when the given run time is achieved.

The geometrical capability of the code is restricted to decrease computer time, but retains enough flexibility so that all practical geometrical models can be handled. After an arbitrary reference coordinate axis is selected by the user, any of the following surface types can be combined to describe the particular model.

1. Plane surfaces parallel to the z axis. These include plane surfaces perpendicular to the x or y axis and plane surfaces perpendicular to the x, y plane, but oriented at any angle.

2. Plane surfaces perpendicular to the z axis.

3. Cylindrical surfaces of any radii, with their axes parallel to the z axis.

4. Spherical surfaces of any radii.

On the exterior surfaces of the problem, albedos may be set equal to 0.0 or may be set equal to 1.0. For those surfaces with albedo 0.0, the neutrons escape into the surrounding space and do not reenter. For those surfaces with albedo 1.0, the neutrons reflect back into the pertinent region, the neutron having no energy change but having simply a new direction that is a mirror reflection of the incident direction.

Unlike most other Monte Carlo Codes which contain only one scoring technique, the RAFFLE Monte Carlo Code has the feature of containing three scoring techniques, any of which may be used for a particular problem. The path technique uses a Richtmeyer-type estimator, which is essentially an averaged path length estimator, and is the scoring technique well suited to most problems. The second scoring technique which may be used is the ray technique, where flux contributions are computed to all regions along the scattered direction of the neutron. The last scoring technique available is the KENO technique, in which cross sections of all regions are made equal and delta-type scattering is allowed. The flexibility of containing three scoring techniques allows the RAFFLE Code to solve a wide class of problems in the most efficient manner. Use of the correct scoring technique may save 50% computer time in particular problems.

For the neutron transport calculations, the RAFFLE Code uses both multigroup cross sections and pointwise cross sections. Multigroup macroscopic cross sections are used to determine the locations of collisions of the neutrons, and are used to determine the

particular isotopes off which the neutrons scatter. If the problem contains inelastic scattering, pointwise microscopic cross sections (in energy) are then used to determine whether the scattering is elastic or inelastic, and if inelastic, the particular discrete level or evaporation level involved. For the pointwise cross sections, linear interpolation is used between the values read in. This pointwise treatment is used only in those energy ranges containing inelastic scattering; if the problem contains no inelastic scattering, the algorithm determining the mode of scattering is bypassed and transfer is made directly to the elastic scattering subroutine.

As a result of this combined use of multigroup and pointwise cross sections, the spatial effects are in essence determined from the multigroup cross sections while spectrum effects are determined from the pointwise cross sections. The use of multigroup and pointwise data combines the efficiency gained in computer time from use of multigroup data with the accuracy and fine detail gained in spectrum effects from the use of pointwise data. The treatment of fine spectrum, or scattering effects is particularly important in fast reactor calculations and resonance calculations. Furthermore, as up to 100 groups can be used, there is no appreciable loss of accuracy in the multigroup portion of the treatment.

Along with the spatial coordinates, a continuous energy, direction, and time variable is associated with each neutron. With use of the pointwise cross section representation, discrete level inelastic scattering is handled precisely. Evaporation model scattering, with an allowable energy-dependent temperature, is also handled. For either type of inelastic scattering, isotropic scattering in the laboratory frame is assumed. The (n,2n) type interactions can also be handled, with a separate evaporation model spectrum used for the energy of the two emitted neutrons. For the elastic model of scattering, any degree of anisotropic scattering can be treated. The actual cosine scattering distribution, in either the center of mass or laboratory frame, is line-fitted to as fine a detail as desired. Since the energy variable is continuous, the scattered energy is exactly determined once the scattering cosine is determined.

RAFFLE treats the resolved resonance interactions by use of the single level Breit-Wigner formula for the pointwise cross sections which are then Doppler-broadened using a Maxwellian distribution for the nucleus velocity. This resonance treatment can be applied for scattering cross sections, absorption cross sections, and for fission cross sections. In addition to a resonance contribution, a cross section may also have a smooth contribution. Since a continuous energy is associated with each neutron, the resonance contributions, from all isotopes within the material, are exactly computed at every neutron energy point. Each isotope may have an arbitrarily large number of resolved resonances, and

at a particular neutron energy contributions may be computed from as many neighboring resonances as deemed necessary. At present, RAFFLE has no special unresolved resonance treatment; unresolved resonances, if present, can be treated analogously to the resolved treatment, or can be treated by a pointwise representation of the cross sections, or they can be added to the smooth contribution.

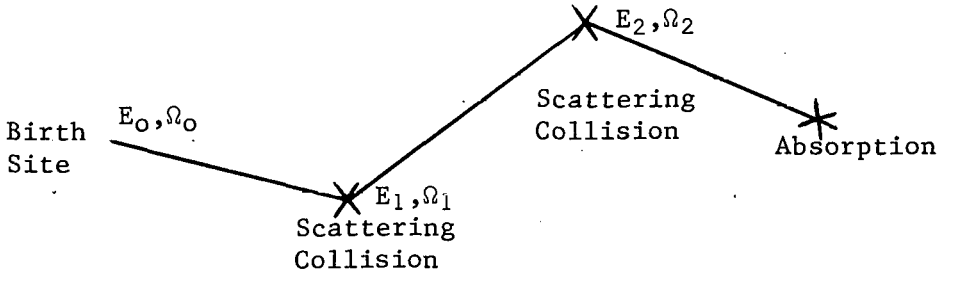
Finally, the RAFFLE Code contains standard biasing techniques which may be used for particular problems to decrease the computer running time. Weight reduction, in which at a collision a neutron always undergoes a scattering, may be used. Neutron splitting may be used in those regions where more accurate, detailed information is desired. Russian roulette may be used in those regions of little concern, or may be used in those regions with high scattering properties. In RAFFLE, Russian roulette may be played in various degrees, dependent upon the particular group and region.

Many of the geometrical routines in RAFFLE were taken directly from the PMC general purpose Monte Carlo program written by R. A. Grimesey, C. W. Berner, and S. Tong[1]. General references for this report are Cashwell and Everett[2], Spanier and Gelbard[3], and Wilks[4].

II. THE MONTE CARLO OF RAFFLE

1. NEUTRON TRANSPORT TECHNIQUES

In RAFFLE individual neutrons are followed from their birth to their death, where a death is an absorption or leakage from the system. The following of a neutron incorporates (a) the choosing of sites of collision for the individual neutron, (b) at the collision sites choosing the type of interaction undergone by the neutron, and (c) at the scattering collisions choosing the scattered energy and direction for the neutron. The complete "trace" of an individual neutron is called the neutron history; the neutron history is thus the individual neutron collision sites, the individual interactions undergone by the neutron at the collision sites, and the new directions and energies at the scattering collision sites.



A Neutron History

The Monte Carlo technique selects a particular neutron history for an individual source neutron, a source neutron simply being a neutron born at some site. The particular neutron history is selected by means of probability distributions which are determined from the reactor physics of the problem, and the particular neutron history yields particular values for the fluxes, reaction rates, etc. These particular values are termed estimates. After a particular neutron history is determined and followed, a new source neutron and a new neutron history are then chosen and likewise followed. The new neutron history yields second estimates for the fluxes, reaction rates, etc. A large number of source neutrons and associated neutron histories are analyzed in this manner and the resulting individual estimates are averaged to yield the final results from the Monte Carlo simulation.

The first task in determining a particular neutron history is to select a birth site and the source neutron energy and direction. Let the neutron source distribution be $S(\bar{r},E,\bar{\Omega})$,

where $\bar{r}$ is the spatial coordinate (x, y, z), E the energy, and $\bar{\Omega}$ the angular direction[a]. The source distribution is that which would be used in the reactor physics calculation for the problem and is given. It may be a specified external source or may be the fission source from the previous k iteration. By a simple selection, a particular set of source neutron coordinates $(\bar{r}_o, E_o, \bar{\Omega}_o)$ is chosen from the normalized source distribution $\delta(\bar{r}, E, \bar{\Omega})$

$$\delta(\bar{r},E,\bar{\Omega}) = \frac{S(\bar{r},E,\bar{\Omega})}{\int_V dV \int_0^{E_o} dE \int_{4\pi} d\Omega\, S(\bar{r},E,\bar{\Omega})} .$$

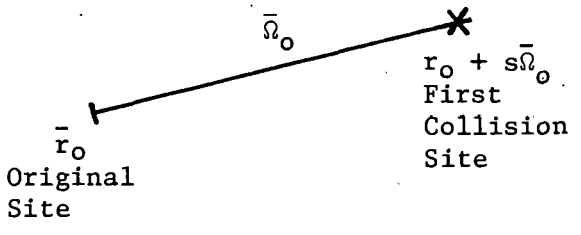
This selection of particular values from a distribution is done by means of numerical algorithms in the same way as, for example, a particular number is chosen from a normal distribution. The particular coordinates chosen $(\bar{r}_o, E_o, \bar{\Omega}_o)$ are the birth site $\bar{r}_o$, the source neutron energy E_o, and the source neutron direction $\bar{\Omega}_o$ for the beginning of the particular neutron history.

From the reactor physics, given an original position $\bar{r}_o$, and energy E_o, and a direction $\bar{\Omega}_o$, the probability that the neutron has its first collision at some distance s from this original site f(s)ds is

$$f(s)ds = \exp\left(-\int_o^s \Sigma(s')ds'\right) \Sigma(s)ds$$

where $\Sigma(s')$ is the total macroscopic cross section at distance s' from $\bar{r}_o$ along the direction $\bar{\Omega}_o$,

$$\Sigma(s') = \Sigma(\bar{r}_o + s'\bar{\Omega}_o) .$$

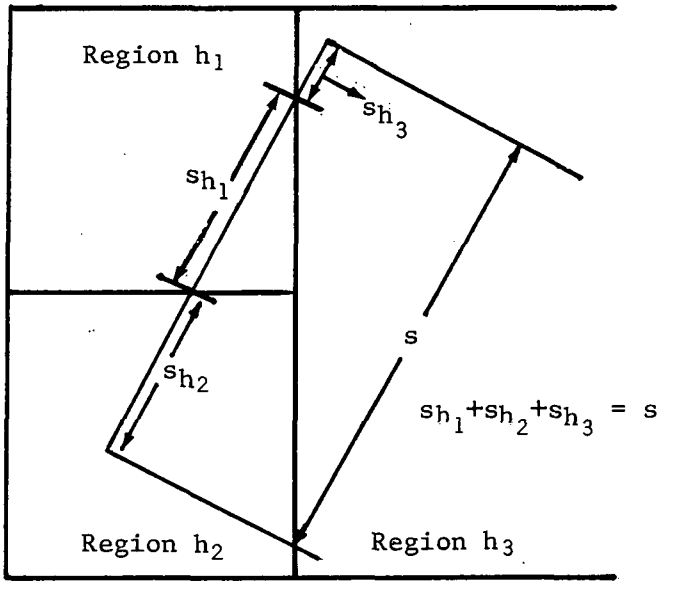


Since the macroscopic cross section $\Sigma(s')$ is basic data and is known, f(s) is known and a particular distance s may be chosen from f(s)ds by use of numerical algorithms. Given a particular distance value s, the neutron is advanced to the site of its first collision $r_o + s\Omega_o$.

---

[a] Time independence is assumed.

From reactor physics again, the neutron flux ϕ is defined to be the total number of path lengths in a unit volume per unit time; $\phi dV\ dt = nv\ dV\ dt$. The quantity v dt is the path length of a neutron in time dt, and this quantity times the total number of neutrons in dV gives the total flux in dt and dV. The neutron flux is therefore physically the neutron path length. In the neutron transport from $\bar{r}_o$ to $\bar{r}_o + s\bar{\Omega}_o$, its path length is the particular chosen distance s and, hence, the flux contribution is s. In the RAFFLE Code, fluxes are computed regionwise (integrated over the region volume) and groupwise (integrated over group energy limits). Therefore, the group g corresponding to E_o is first determined by RAFFLE, $E_g < E_o \leq E_{g+1}$, where E_g are the group cutoffs input by the user. Those individual regions, h, traversed by the neutron is going from $\bar{r}_o$ to $\bar{r}_o + s\bar{\Omega}_o$ are noted and the portion of s, s_h, in each region is determined. Each contribution s_h is stored as the estimate for the regionwise and groupwise flux ϕ_{gh}. Analogously, the regionwise and groupwise reaction rates estimates are $s_h\Sigma$, where Σ is the pertinent reaction rate macroscopic cross section in region h.



s_{h_1} is the flux ϕ_{gh_1}

s_{h_2} is the flux ϕ_{gh_2}

s_{h_3} is the flux ϕ_{gh_3}

For all the path lengths of a neutron history and for all the neutron histories processed, these flux estimates s_h and reaction rate estimates $s_h\Sigma$ are cumulatively added in the proper region h and group g storage locations. The sum tallies divided by the number of neutron histories processed gives the final fluxes ϕ_{gh} printed out by RAFFLE.

Returning to the individual neutron history, with the flux estimates tallied for the first transit, the neutron coordinates are updated to the values $\bar{r}_o + s\bar{\Omega}_o$, E_o, $\bar{\Omega}_o$; i.e., the neutron is now at the site of its first collision. At this collision point, the type of interaction the neutron undergoes must be determined, and if the interaction is a scattering, the new scattered energy and direction must be chosen. It should again be emphasized at this point that the interaction chosen and the new energy and direction if the neutron scatters are all

particular values. There is no generalization here; the Monte Carlo techniques choose distinct values to simulate one example of neutron trajectory. Many individual examples are simulated and averages are taken of the individual flux and reaction rate contributions to yield the final results.

Let us proceed with our one neutron history. The algorithms used to choose the particular interaction and possible scattered energy and direction at the site $\bar{r}_o + s\bar{\Omega}_o$ are discussed in the next section. However, one can see that if the interaction chosen is an absorption interaction, the neutron history is simply terminated and a new source neutron is chosen [from $\delta(\bar{r},E,\bar{\Omega})$], which is the beginning of a new neutron history.

Let us assume a scattering interaction has been determined as the type of interaction undergone and assume a particular new scattered direction $\bar{\Omega}_1$ and energy E_1 have been chosen for the neutron. The new coordinates of the neutron are now $\bar{\Omega}_1$, E_1, and $\bar{r}_1 = \bar{r}_o + s\bar{\Omega}_o$. This scattered neutron can be treated precisely as the source neutron in determining the site of its next collision (now the second collision). The distribution f(s)ds is used to determine a particular value s and the neutron is advanced to the site $\bar{r}_1 + s\bar{\Omega}_1$ of its second collision. Flux estimates are obtained from this new path length in exactly the same way as for the first path length. At this new interaction site, decisions are made as to the type of interaction undergone, and so forth. The whole Monte Carlo process thus repeats itself, with the energy and direction updated at every scattering collision and with the position coordinate updated from f(s)ds.

The remainder of this section deals with the particular algorithms used in RAFFLE for the distribution f(s)ds. For a general understanding of the Monte Carlo techniques in RAFFLE the reader may skip this remaining discussion and may go to the next section which describes the treatment of the collisions within a neutron history. There will be no loss of continuity.

The particular algorithms used in RAFFLE to choose a distance of value s from f(s)ds are simplified because of the allowable region descriptions. A region is simply a particular three-dimensional volume; all individual regions in RAFFLE must be homogeneous in composition. Any two regions may have different isotope concentrations, but in one given defined region the concentration must be constant. Hence, the macroscopic cross sections in a region are constant with regard to position. For a constant cross section f(s)ds becomes

$$f(s)ds = \exp(-\Sigma_h s)\ \Sigma_h\ ds$$

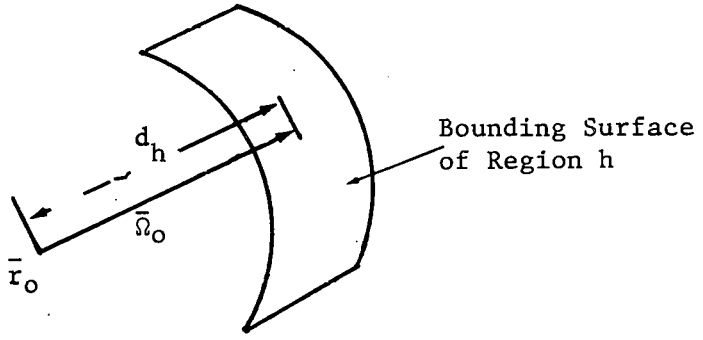
where Σ_h is the constant total cross section for region h.

Therefore, in RAFFLE, after choosing the source coordinate values $\bar{r}_o$, E_o, $\bar{\Omega}_o$, the particular region h in which $\bar{r}_o$ is located is determined. The cross sections used by RAFFLE are groupwise and hence the group g corresponding to E_o is next determined. The total cross section for the region and group $\Sigma_{h,g}$ is then retrieved from storage. The distribution which will be used to determine s is thus finally

$$f(s)ds = \exp(-\Sigma_{h,g}\, s)\ \Sigma_{h,g}\, ds \quad .$$

If the problem contains resonances, the resonance contribution to the total cross section is incorporated in $\Sigma_{h,g}$.

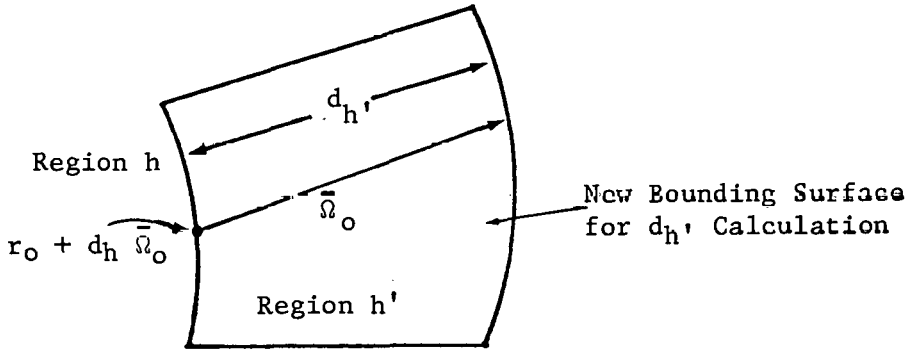
Before the distance to the collision is chosen from f(s)ds, the distance to boundary must be first calculated to determine whether the neutron totally escapes the region for a particular value of s. Now, the particular region h, in which $\bar{r}_o$ is located, is bounded by various defined surfaces (the surfaces are defined by the user as the later sections explain). Given the boundary surfaces for the region h, the distance to boundary d_h is simply that distance $\bar{r}_o$, along the direction $\bar{\Omega}_o$, to the corresponding boundary surface.



This distance to boundary d_h is the furthermost distance the neutron can travel before it escapes region h. With the bounding surfaces for region h known, the distance to boundary d_h is straightforwardly computed by means of standard vector analysis.

Once d_h is computed, the algorithm determining the neutron's distance to collision proceeds as follows. A particular value s is chosen from the f(s)ds distribution (using $\Sigma_{h,g}$). If this value s is smaller than d_h, the decision is made that the neutron has a collision in region h, at the point $\bar{r}_o + s\bar{\Omega}_o$. The computation for the neutron history then proceeds to the algorithm treating a neutron collision (described in the next section). If the value s is greater than or equal to d_h the neutron position is advanced to $\bar{r}_o + d_h\,\bar{\Omega}_o$ and the neutron has no collision in region h. For either of these possibilities a flux contribution is tallied for region h; for $s < d_h$, the flux contribution (ϕ_{gh}) is s, and for $s \geq d_h$ the flux contribution is d_h.

For $s \geq d_h$, after the neutron position is advanced to $\bar{r}_1 = \bar{r}_o + d_h \bar{\Omega}_o$, the neutron of new coordinates $\bar{r}_1$, E_o, $\bar{\Omega}_o$ is treated exactly like the original source neutron (coordinates $\bar{r}_o$, E_o, $\bar{\Omega}_o$). The new region in which the neutron is located h', is first determined (h' is the region "on the other side" of the bounding surface to which the neutron was advanced). The distance to boundary for this region, $d_{h'}$, is next computed.



A distance to collision value s' is chosen from the distribution f(s')ds', where now

$$f(s')ds' = \exp(-\Sigma_{h',g} s') \Sigma_{h',g} ds' \quad .$$

If $s' < d_{h'}$, the neutron is advanced to the point $\bar{r}_1 + s' \bar{\Omega}_o$ and the neutron has a collision in region h'. Computations proceed to the collision treatment algorithm. If $s' \geq d_{h'}$, the neutron is advanced to the new position $\bar{r}_1 + s' \bar{\Omega}_o$ and suffers no collision in region h'. The distance to collision computations proceed in this manner until the neutron eventually undergoes a collision or eventually escapes from the system.

2. COLLISION TREATMENT TECHNIQUES

For the treatment of a particular collision in a neutron history, the neutron has coordinate value $\bar{r}$, E, $\bar{\Omega}$ entering the collision. For a source neutron undergoing its first collision, the coordinates $\bar{r}$, E, $\bar{\Omega}$ are the values $\bar{r}_o + s\bar{\Omega}_o$, E_o, $\bar{\Omega}_o$. In general, the particular values $\bar{r}$, E, $\bar{\Omega}$ are those determined by the previous computations. From reactor physics, for a neutron with incident coordinates $\bar{r}$, E, $\bar{\Omega}$, the probability that it undergoes a scattering collision p_s is

$$p_s = \frac{\Sigma_s(\bar{r},E)}{\Sigma(\bar{r},E)}$$

where $\Sigma_s(\bar{r},E)$ is the scattering macroscopic cross section and $\Sigma(\bar{r},E)$ is the total collision macroscopic cross section (scattering plus absorption). The probability that the neutron undergoes an absorption, p_a, is

$$p_a = \frac{\Sigma_a(\bar{r},E)}{\Sigma(\bar{r},E)}$$

where $\Sigma_a(\bar{r},E)$ is the macroscopic absorption cross section at $\bar{r}$ and E. Since the neutron must either scatter or be absorbed

$$p_a + p_s = 1 \quad .$$

Therefore, considering p_s and p_a, an analog procedure can be simply used to select either a scattering interaction or an absorption interaction for the neutron. This analog procedure simply consists of selecting a random number ρ from a uniform distribution over the interval from 0 to 1. If $\rho \leq p_s$, the neutron undergoes a scattering; if $\rho > p_s$, it is absorbed. If an absorption interaction is selected, the neutron history is terminated at this point and a new neutron history is followed. If a scattering interaction is selected, the particular isotope off which the neutron scatters must next be determined.

Instead of using an analog procedure to select the type of interaction, absorption or scattering, "weight factors" can be used. To understand the use of a weight factor, assume that instead of one neutron undergoing a collision, one had N neutrons undergoing a collision, all having the same incident coordinates $\bar{r}$, E, $\bar{\Omega}$. Out of these N neutrons, an average of Np_s neutrons would undergo scattering collisions. This same number of scattering collisions Np_s would be obtained if one assumed all N neutrons underwent scatterings, but only a portion of each neutron, p_s, emerged from every scattering. Since averages are computed in a Monte Carlo simulation, this average reasoning is valid.

By the above reasoning one can therefore say that whenever the individual neutron undergoes a collision it always undergoes a scattering and never is absorbed. The neutron "weight" emerging from the collision is, however, not unity but p_s. For the weight treatment, a neutron weight w is thus associated with the neutron as it proceeds along its history, and is updated after every collision. The source neutron is initially assigned a weight of unity, $w_o = 1$. The weight of the neutron emerging from its first collision is p_s, which can be written as $w_o p_s$, where $w_o = 1$ is the incident neutron weight (i.e., the original source neutron weight). After the first collision, the weight of the neutron is $w_1 = w_o p_s$. At the second collision, the weight of the neutron emerging is $w_1 p_s$, where p_s now is the value at the coordinates of the second collision. In general, the weight of the neutron emerging from a collision is wp_s, where w is the incident neutron weight and p_s is the probability of scattering at the collision. With this weighting technique, the individual flux contributions are then ws_h, instead of s_h, where s_h is the path length described in the previous section and where w is the neutron weight currently assigned the neutron.

This collision weight treatment for the individual neutron histories can be rigorously proven to involve no approximations in the final results obtained. For slowing down type

problems, the advantage of the weight treatment is that a neutron history is never terminated due to the neutron being absorbed[a]. Hence, each neutron history will yield flux and reaction rate contributions at low energies relative to the source energy. The analog method (choosing whether the neutron was absorbed or scattered), on the other hand, will usually terminate the neutron history before reaching these lower energies.

In RAFFLE, the user has the option of either using the analog method or the weight treatment method for the collisions of the individual histories. For problems in which lower energy fluxes contribute to the results, it is best to use the weight treatment techniques (e.g., epithermal, thermal, or resonance problems). For problems in which the source fluxes contribute most, it is best to use the analog technique (e.g., small fast spectrum systems). In general, the weight technique is efficient for all classes of problems and is the "safest" technique to use for any problem. Even for small fast spectrum systems, ideally suited to the analog method, the weight technique is still reasonably efficient.

Whether the weight technique or the analog technique is used, given the neutron has a scattering, the next task is to determine the particular isotope off which the neutron scatters. From reactor physics again, given a scattering of the neutron with incident coordinates $\bar{r}$, E, $\bar{\Omega}$, the probability that the neutron scatters off isotope i, p_i, is

$$p_i = \frac{\Sigma_i(\bar{r},E)}{\Sigma_s(\bar{r},E)} \quad .$$

The quantity $\Sigma_i(\bar{r},E)$ is the macroscopic scattering cross section for isotope i at the point r. All the isotopes which are present at the point $\bar{r}$ must be considered, and since the neutron must scatter off one isotope, given it does scatter,

$$p_{i_1} + p_{i_2} + \ldots + p_{i_n} = 1$$

where i_1, i_2, etc., refer to the isotopes present at point $\bar{r}$. Since the values $p_{i_1}, \ldots p_{i_n}$ are given from the cross section data, a straightforward selection algorithm is used in RAFFLE to determine the particular isotope off which the neutron scatters. This analog selection procedure consists of selecting a random number ρ from a uniform distribution on the interval from 0 to 1. The random number is then successively compared to the values p_{i_1}, $p_{i_1} + p_{i_2}$, $p_{i_1} + p_{i_2} + p_{i_3}, \ldots$. When $\rho \leq p_{i_1} + p_{i_2} + \ldots + p_{i_k}$, the isotope i_k is then chosen as the isotope off which the neutron scatters.

Once the isotope is chosen, say isotope i has been chosen, then a decision must be made whether the scattering is inelastic or elastic. The probability of an inelastic scattering off isotope i, p_{in}, is

$$p_{in} = \frac{\sigma_{in}(E)}{\sigma_s(E)}$$

[a] In practice and for efficiency, the neutron is terminated when its weight drops below a "cutoff" value. In RAFFLE, Russian roulette is used which involves no loss of information when the neutron is terminated. This procedure is discussed in the next section.

and the probability of an elastic scattering, p_{el}, is

$$p_{el} = \frac{\sigma_{el}(E)}{\sigma_s(E)} \quad .$$

The quantities $\sigma_{in}(E)$, $\sigma_{el}(E)$, and $\sigma_s(E)$ are the microscopic inelastic, elastic, and scattering cross section, respectively, for isotope i at neutron energy E. Another simple selection algorithm incorporating p_{in} and p_{el} is therefore used to select the mode of scattering off isotope i.

If an elastic scattering is chosen, a value for the scattered energy E' of the neutron and a value for the scattered direction $\overline{\Omega}'$ of the neutron can finally be determined. The scattering cosine μ in the center of mass frame is first chosen from the distribution $f(\mu)d\mu$ where $f(\mu)d\mu$ is part of the basic data which is input for the isotope. In RAFFLE, there are no isotropic approximations needed for $f(\mu)d\mu$; it can be dependent upon the incident energy E and can be of any anisotropic form. The $f(\mu)d\mu$ distributions input to RAFFLE can be taken directly from basic ENDF data.

Once a value for the scattered cosine is chosen, say μ, a value for the scattered azimuthal angle ϕ (in the center of mass frame) is chosen from an isotropic distribution $d\phi/2\Pi$. In RAFFLE, values for ϕ and μ are selected by means of direct sampling procedures, analogous to the previous procedures described. For μ, $f(\mu)d\mu$ is used directly and no polynominal expansions are used. Given μ and ϕ values and given the neutron incident direction $\overline{\Omega}$, the scattered direction of the neutron $\overline{\Omega}'$ is thus determined. Likewise, the scattered neutron energy E' is determined by means of the formula

$$E' = \frac{E(A^2 + 2A\mu + 1)}{(A + 1)^2} \quad ,$$

where E is the neutron incident energy E and A is the mass number of isotope i. For an elastic scattering, the scattered energy and direction are thus determined and the collision treatment is completed.

If an inelastic scattering is chosen, a further decision must be made as to whether the inelastic scattering is an evaporation model type or a discrete level type. The ratios $\sigma_{ev}(E)/\sigma_{in}(E)$ and $\sigma_L(E)/\sigma_{in}$ are consequently used for still another analog selection procedure, where $\sigma_{ev}(E)$ and $\sigma_L(E)$ are the microscopic evaporation model and discrete level cross sections, respectively, for isotope i. At this stage, the scattered energy and direction of the neutron can be determined.

If an evaporation model scattering is chosen, the final energy E' is chosen from the distribution $f_{ev}(E')dE'$, where

$$f_{ev}(E')dE' = \frac{E'}{T} e^{-E'/T} dE' \quad ,$$

where T is the energy dependent temperature for the isotope. The scattered direction $\overline{\Omega}'$ is then chosen from an isotropic distribution in the lab frame. Both these selections are made by means of analog procedures similar to those previously discussed.

If the inelastic scattering is a discrete level type, the particular level involved in the scattering is determined from the ratios $\sigma_{\ell}(E)/\sigma_L(E)$, where $\sigma_{\ell}(E)$ is the microscopic cross section for level ℓ of isotope i;

$$\sum_{\ell}^{L} \sigma_{\ell}(E) = \sigma_L(E) \quad .$$

The ratio $\sigma_{\ell}(E)/\sigma_L(E)$ is the probability that the neutron scatters by means of the particular level ℓ. Using the same type algorithm as for the previous analog selections, a particular level ℓ_o is chosen. Given ℓ_o, its associated discrete energy change ΔE_{ℓ_o} is given as basic data and the scattered energy of the neutron E' is consequently given;

$$E' = E - \Delta E_{\ell_o} \quad .$$

The scattered direction $\overline{\Omega}'$ is finally chosen from a distribution which is isotropic in the lab frame.

Values for the scattered energy and for the scattered direction, E' and $\overline{\Omega}'$, are thus determined for the neutron, whether it has undergone an evaporation model scattering, a discrete level scattering, or an elastic scattering. The collision treatment is thus completed for any mode of scattering decided upon[a].

[a] The above discussion assumes no n,2n type reactions. The incorporation of this interaction follows along the same lines as discussed above. RAFFLE can handle n,2n type interactions, with a weight treatment used for the multiplication.

III. GEOMETRICAL DESCRIPTION OF THE PROBLEM

1. PHYSICAL VOLUME DEFINITION

To set up a RAFFLE Monte Carlo run, the geometrical surfaces and regions of the problem must first be described. All problems are three-dimensional; one- and two-dimensional problems must still be viewed as three-dimensional. For these one- and two-dimensional problems, albedos on particular surfaces are set equal to 1 to account for the one- and two-dimensionality of the problem. For example, problems of infinite extent in the Z direction would still be given a finite Z height and albedos on the two Z surfaces would simply be set equal to 1 to account for the infiniteness. Problems containing symmetry can be treated by considering only a symmetrical portion of the problem with albedos set equal to 1.0 on the surfaces of symmetry.

To set up a problem, the user must define the *complete three-dimensional physical volume* of the problem. The complete physical volume is the geometrical extent of the problem, incorporating the various regions and surfaces of the arrangement to be analyzed. It is recommended that a three-dimensional illustration of the problem be drawn by the user. This may include projected views, cross section illustrations, or any other drawings which aid the user in describing the problem. To illustrate the physical volume description, consider a cell of a single rod surrounded by moderator as shown in Figure 1. The cell is infinite in the Z direction. The rectangular volume would be the complete physical volume for the problem. Albedos of 1 would be assigned to the x, y, and z plane surfaces to account for symmetry and infiniteness in the z-direction. The actual z-height of the rectangle can be

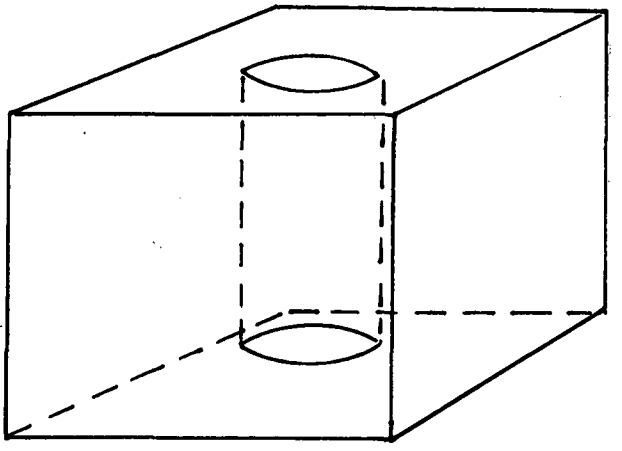


Fig. 1 Physical volume of a cell problem.

arbitrarily assigned because of the unit albedos; however, a finite definite height must be assigned, and the complete physical three-dimensional value for the problem would again be the solid rectangular volume illustrated. For a complete reactor problem, the three-dimensional physical volume of the problem would be the complete three-dimensional physical volume of the reactor.

2. SURROUNDING VACUUM REGION DESCRIPTION

After the physical volume of the problem is defined, a *vacuum region* surrounding the physical volume must be defined. This vacuum (or "fictitious" region) is needed solely because of the search algorithm used in RAFFLE; the neutrons, for example, will never enter this vacuum region if albedos are set equal to 1.0 on the outer surfaces of the physical volume. For this cell problem, a surrounding vacuum region could be defined as shown in Figure 2. The vacuum region in Figure 2 is the rectangular volume surrounding the physical volume (the larger rectangular volume minus the physical rectangular volume). The outer plane surfaces define the extent of the vacuum region.

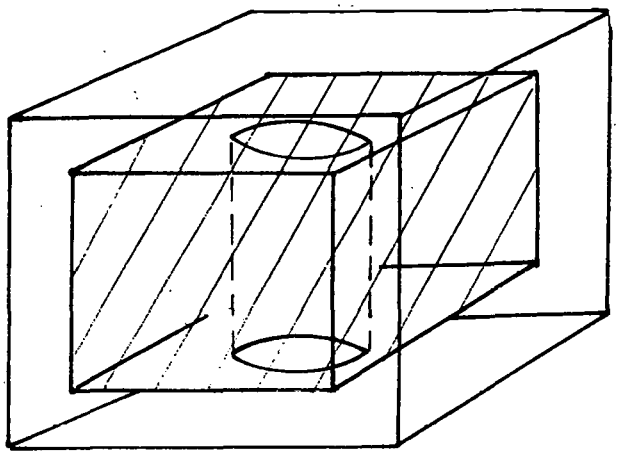


Fig. 2 Vacuum region for the cell problem.

The vacuum region may be of any shape as defined by its outer surfaces, but it must totally enclose the physical volume of the problem. For ease of input description, the vacuum region should be a simple shape, such as the box-shaped region shown in Figure 2. All dimensions in RAFFLE are in centimeters (cm), and the vacuum region outer surfaces (the outer plane surfaces of Figure 2) should be at least 1 cm from the physical volume surfaces (that is, the vacuum region's thickness should be at least 1 cm).

As another example of defining the physical volume and surrounding vacuum region, consider the GODIVA spherical reactor as a problem. The physical volume would be the

GODIVA reactor itself. A suitable, simple surrounding vacuum region would consist of a sphere of larger radius as shown in Figure 3. The actual vacuum region is that portion of space contained between the GODIVA outer spherical surface and the spherical surface of radius R. The radius R may be of any size, as long as it is at least 1 cm greater than the radius of GODIVA. The shape of the vacuum region is again of no consequence; instead of a larger spherical region, GODIVA could have been enclosed in a box-shaped vacuum region as in Figure 2.

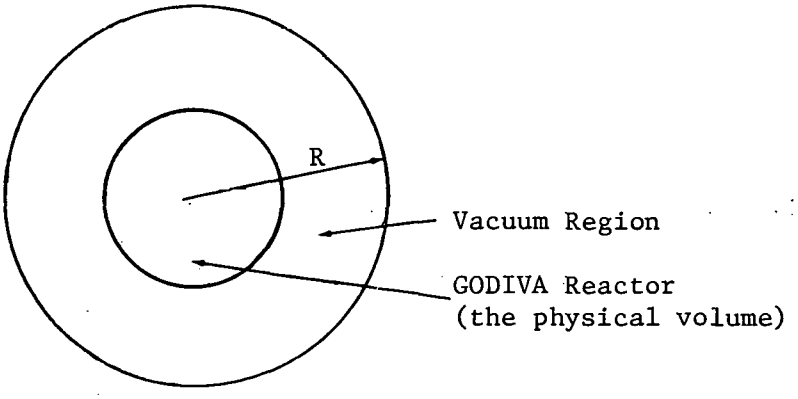


Fig. 3 A spherical reactor with a spherical vacuum region.

3. COORDINATE AXIS CHOICE

Once the physical volume and vacuum region have been identified, a set of coordinate axes must be chosen for the problem. The coordinate axes must be chosen such that the physical volume and surrounding vacuum region are in the first octant of the coordinate system. That is, all points (x,y,z) within the physical volume and vacuum region and all points (x,y,z) on the outer surfaces of the vacuum region must be such that $x \geq 0, y \geq 0, z \geq 0$.

Figure 4 depicts a possible choice of coordinate axes for the cell problem configuration of Figure 2. Any choice of coordinates is correct as long as the entire problem volume (physical plus vacuum) lies in the positive coordinate octant. Usually, for convenience, the coordinate axes (0,0,0) coincide with an outer point of the vacuum region. Figure 5 illustrates this possible choice of coordinate axes for the cell problem.

In the succeeding detailed definitions of the surfaces and regions of the problem, all representations will be made with respect to these coordinate axes chosen; the coordinate axes will serve as the coordinate system by which all surfaces and regions in the physical volume and vacuum region are described.

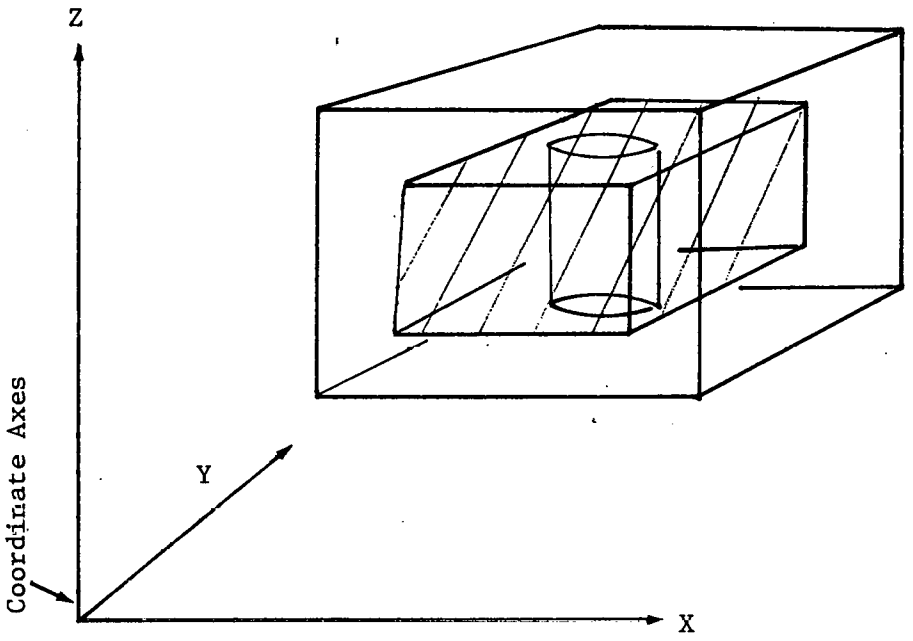


Fig. 4 Coordinate axes for a cell problem.

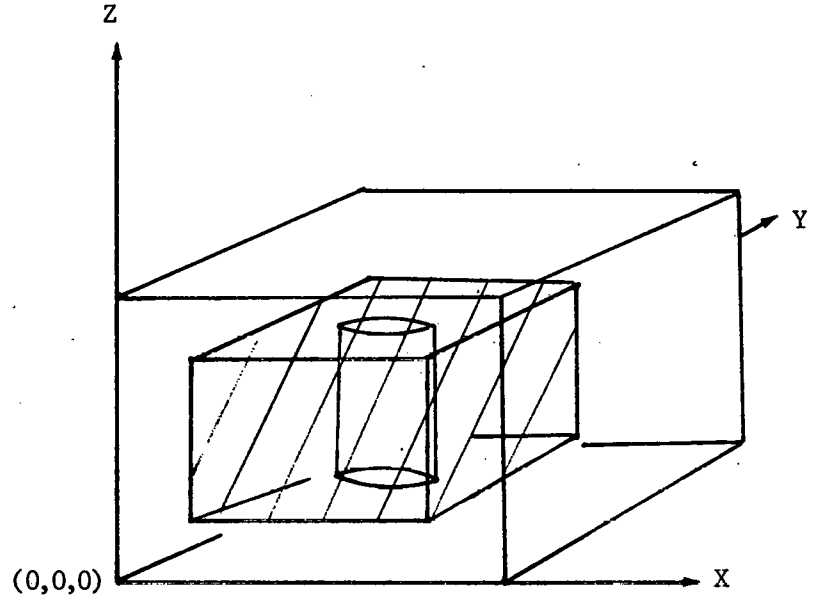


Fig. 5 The conventional rectangular coordinate system.

4. SURFACE DESCRIPTIONS

Once the physical volume, surrounding vacuum region, and coordinate axis have been defined, the geometrical surfaces of the problem must be defined. The list below gives those types of surfaces which may be used to define the region boundaries of the problem. All dimensions are in centimeters and the coordinate frame is that chosen by the user and previously described.

Surface Type 1 Plane surfaces perpendicular to either the x, y, or z axis of the coordinate axes chosen:

$$Ax = D \qquad (\text{or } x = D_1) \tag{1}$$

$$By = D \qquad (\text{or } y = D_2) \tag{2}$$

$$Cz = D \qquad (\text{or } z = D_3), \tag{3}$$

where A, B, C, D, D_1, D_2, D_3 are arbitrary constants.

Surface Type 2 Plane surfaces perpendicular to the x, y plane, but oriented at any angle. The general equation of these plane surfaces is

$$Ax + By = D, \tag{4}$$

where A, B, and D are arbitrary constants.

Surface Type 3 Cylindrical surfaces whose axes are perpendicular to the z-axis of the coordinate frame chosen. The general equation of these surfaces is given by

$$(x - x_o)^2 + (y - y_o)^2 = R^2, \tag{5}$$

where x_o, y_o is the center line of the cylinder and R is the radius. R, x_o, and y_o may have any values greater than or equal to zero.

Surface Type 4 Spherical surfaces, whose general equation is given by

$$(x - x_o)^2 + (y - y_o)^2 + (z - z_o)^2 = R^2 \tag{6}$$

where x_o, y_o, and z_o is the center point of the sphere and R is the radius. R may have any value greater than or equal to zero.

Inputting the surface descriptions to RAFFLE is straightforward. For plane surfaces, either perpendicular or oriented at any angle, the general equation

$$Ax + By + Cz = D, \tag{7}$$

is used by RAFFLE. To input perpendicular plane surfaces (Type 1 surfaces in the above list), two of the constants A, B, and C are given values of 0.0, and the remaining constant and D are given their respective values. For example, to describe a plane surface perpendicular to the x-axis, one would read in the values

$$B = 0.0 \tag{8}$$

$$C = 0.0, \tag{9}$$

and A and D would be given their respective values. A could also be set equal to 1.0 and D given the value D_1 in describing this surface in the form $x = D_1$. For a plane surface of Type 2 in the above list (Equation 4), which is perpendicular to the x,y plane, but oriented in any direction, the value of C = 0.0 would be read in and the values A, B, and D would be read in as their particular values. For a cylindrical surface, the center point x_o,y_o and the radius R (all in centimeters) are read in. For a spherical surface, the center point x_o,y_o,z_o and the radius R would be input (again, all in centimeter units). Whenever a cylindrical or spherical surface is read in, the corresponding center line or point must also be read in as a surface of zero radius. Therefore, if a cylindrical surface exists in a problem and its parameters of x_o,y_o and R are read in, the corresponding center line of the cylinder must also be read in as an additional cylindrical surface with parameters x_o,y_o and R = 0.0. Similarly, if a spherical surface is read in with parameters x_o,y_o,z_o and radius R, the corresponding center point of the sphere must also be read in as an additional spherical surface with parameters x_o,y_o,z_o and radius R = 0.0.

All surfaces in the problem, both those in the physical volume and those surrounding the vacuum region, must be defined by one of the above surface formulas. Any combination of the above surface types may be used in a problem. The user may use planar, spherical, and cylindrical surfaces to describe the region boundaries. Each unique surface in the problem is assigned a *corresponding unique index* to identify the surface, and these indices must range consecutively from 1 to the total number of surfaces; the surfaces can be numbered in any way the user desires. In numbering the surfaces, the user must bear in mind that a surface has an infinite extent so that if two or more regions are bounded by the same surface, this surface is only described once and given one unique number (index).

As an example of describing and numbering the surfaces in a problem, consider again the cell problem example (Figure 1). The unique surfaces and their numbers (arbitrarily chosen) for the physical volume are shown in Figure 6. The corresponding surface formulas and the values of the constants read in for each surface are given beneath the figure. The formulas and constants are with reference to the coordinate frame in Figure 5.

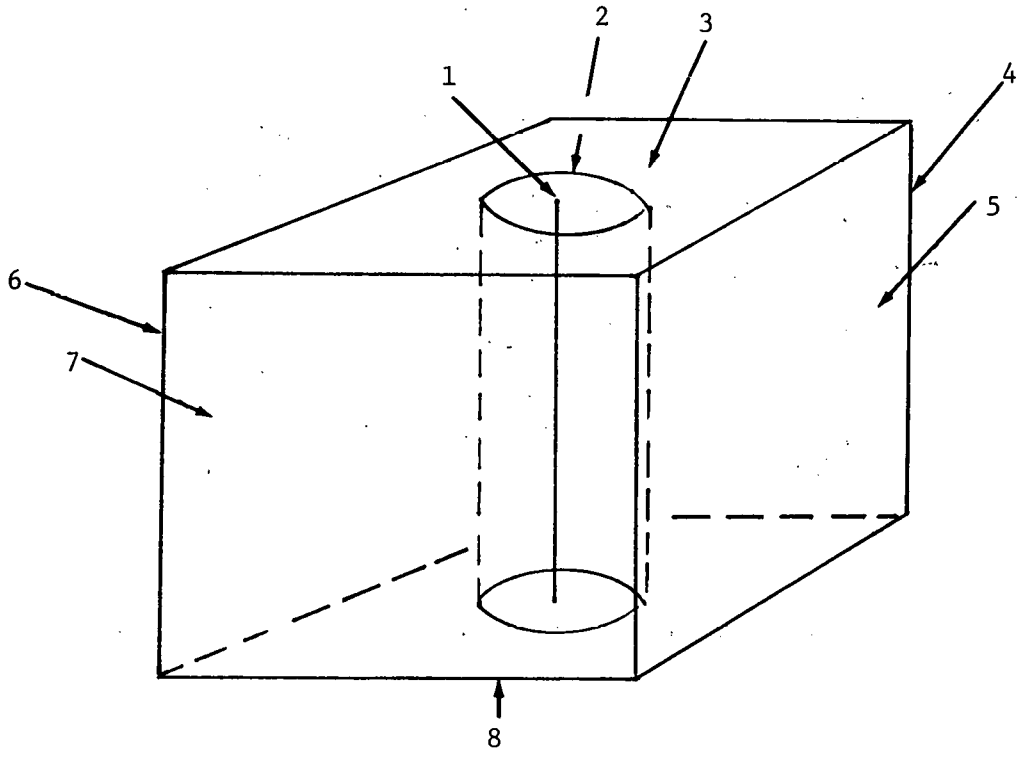


Fig. 6 Surface numbers for a cell problem.

Surface Number	Surface Formula	Surface Constants Read In
1	$(x - x_o)^2 + (y - y_o)^2 = 0$ (cyl)	x_o, y_o, 0.0
2	$(x - x_o)^2 + (y - y_o)^2 = R^2$ (cyl)	x_o, y_o, R
3	$z = D_1$ (plane)	A=0.0, B=0.0, C=1.0, D=D_1
4	$y = D_2$ (plane)	A=0.0, B=1.0, C=0.0, D=D_2
5	$x = D_3$ (plane)	A=1.0, B=0.0, C=0.0, D=D_3
6	$x = D_4$ (plane)	A=1.0, B=0.0, C=0.0, D=D_4
7	$y = D_5$ (plane)	A=0.0, B=1.0, C=0.0, D=D_5
8	$z = D_6$ (plane)	A=0.0, B=0.0, C=1.0, D=D_6

In the preceding surface descriptions, x_o, y_o, R, D_1, D_2, D_3, etc., would be the appropriate values, in centimeters, for this problem. As previously discussed in the above surface descriptions, it is noted that the center line axis of the cylinder must be defined as a cylindrical surface of radius 0.0 (Surface 1).

For the cell problem example, in addition to the surfaces of the physical volume, all the surfaces of the surrounding vacuum region must be described and numbered. The numbering of the vacuum region surfaces is shown in Figure 7, and the surface descriptions are given beneath the figure. It is noted that the first surface number must be 9 to continue the sequence of surface numbers from the physical volume.

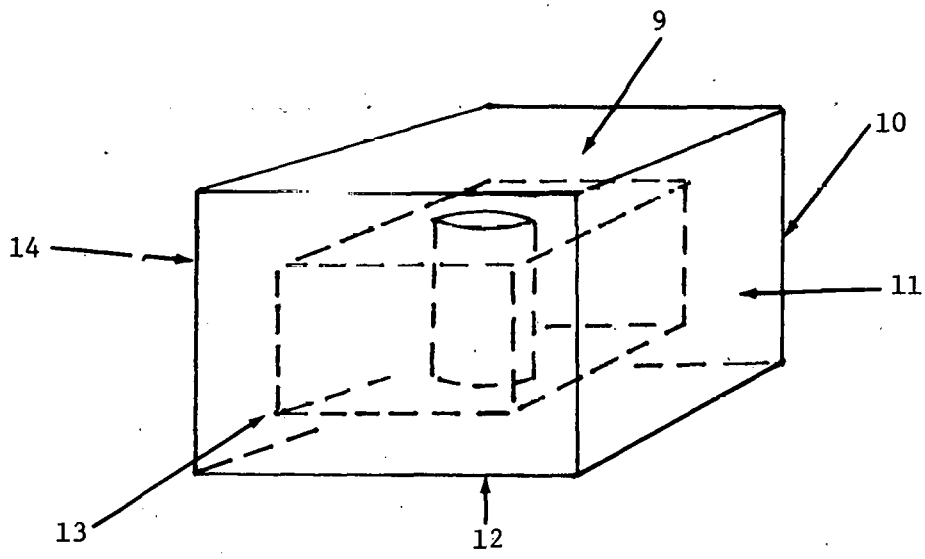


Fig. 7 Surface numbers for a cell problem with an enclosing vacuum region.

Surface Number	Surface Formula	Surface Constants Read In
9	$z = D_7$	A=0.0, B=0.0, C=1.0, D=D_7
10	$y = D_8$	A=0.0, B=1.0, C=0.0, D=D_8
11	$x = D_9$	A=1.0, B=0.0, C=0.0, D=D_9
12	$z = D_{10}$	A=0.0, B=0.0, C=1.0, D=D_{10}
13	$y = D_{11}$	A=0.0, B=1.0, C=0.0, D=D_{11}
14	$x = D_{12}$	A=1.0, B=0.0, C=0.0, D=D_{12}

Again, in the preceding surface descriptions D_7 D_8, etc., would be the appropriate values for the chosen vacuum region.

The vacuum region was separated from the physical volume for this example of describing and numbering the surfaces merely for ease of illustration. In an actual problem, the user may wish to do this or he may number and describe all the surfaces on one illustration. Also in the cell problem example, the vacuum region surfaces were given the highest surface numbers. This is not necessary; the surface numbering is completely arbitrary as long as one unique number corresponds to one unique surface and the numbers

run consecutively. Whatever the user wishes to do, he should plainly number the surfaces on his three-dimensional illustration and he should construct a list of the surface numbers and their respective formula descriptions.

5. REGION DESCRIPTIONS

5.1 Region Types

With the surfaces of the problem defined, all the regions of the problem must be labeled as to the type of region. This includes labeling of the individual regions in the surrounding vacuum region. A region is defined as a particular three-dimensional volume completely enclosed by a set of surfaces; the set of enclosing surfaces are then the boundaries of that region. The type of region is defined by the types of surfaces that enclose it, or serve as its boundaries, and only particular combinations of these surface types may be used to describe a region. There are four combinations of surface types that may be used to define a region, and hence there are four region types allowed.

Regardless of the region type all regions must be homogeneous and contain only one material. The material may consist of any mixture of isotopes; however, the isotope number densities must be constant throughout a region. The regions defined for a problem may not only be those physical regions with one material, but additional smaller regions may be defined to obtain flux detail. The RAFFLE Monte Carlo code obtains groupwise, volume integrated fluxes, absorption rates, etc., for only those regions defined in the problem. Therefore, if one wants spatial flux detail in say a large homogeneous region, he should subdivide this region into smaller regions in which detail is desired[a].

As was previously stated, the particular combination of surface types, which bound and define a region, determines the *type* of region. The four allowable types of regions are given below and are denoted by Region Type 1, Region Type 2, Region Type 3, and Region Type 4. In general, the region types are classified as to how many plane surfaces and how many curved surfaces are their boundaries.

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[a] This division will entail adding extra surfaces (other than the physical surfaces of the problem) to define these smaller regions. Also, because of the limitation of region types, additional surfaces may need to be added to conform to the four region types allowed.

Region Type 1

This type of region has no curved surfaces (i.e., no spherical or cylindrical surfaces). Plane surfaces (Surface Types 1 and/or 2 in the previous section) completely enclose the region, and the region may have from *five to eight* of these plane surfaces. Any combination of plane surfaces of Type 1 and Type 2 described in the preceding section may enclose the region. Examples of regions of Type 1 are shown in Figure 8. In these examples, the plane surfaces must be defined as surfaces of the problem and must be indexed as described in the preceding section.

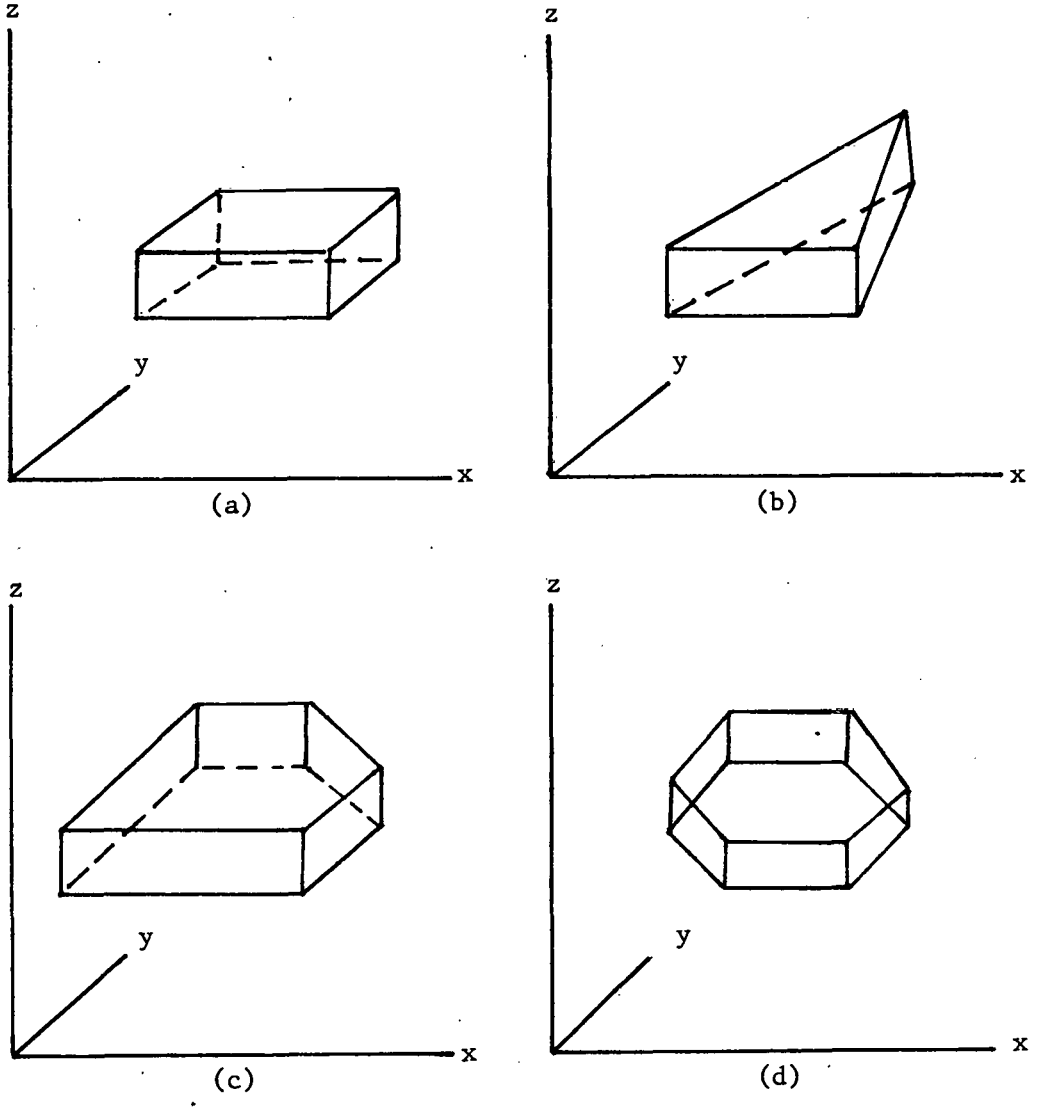


Fig. 8 Examples of Type 1 regions.

Region Type 2

Type 2 regions have *one curved surface* and from *five to seven* plane surfaces. With reference to the preceding section, this type of region has a curved surface of Type 3 or 4 (cylindrical or spherical) and from five to seven plane surfaces of Type 1 or 2 (any combination of Types 1 and 2). Figure 9 shows examples of these region types, where the shaded portion is the region of Type 2. In each of the above figures, the z-axis extends perpendicularly out of the page. Each darkened region illustrated is thus actually three-dimensional with a perpendicular height in the z-direction and having two plane surfaces of $z = C_1$, and $z = C_2$, where C_1 and C_2 are constants. The straight lines and perimeter of the circle are thus actually the plane surfaces and curved surface which bound

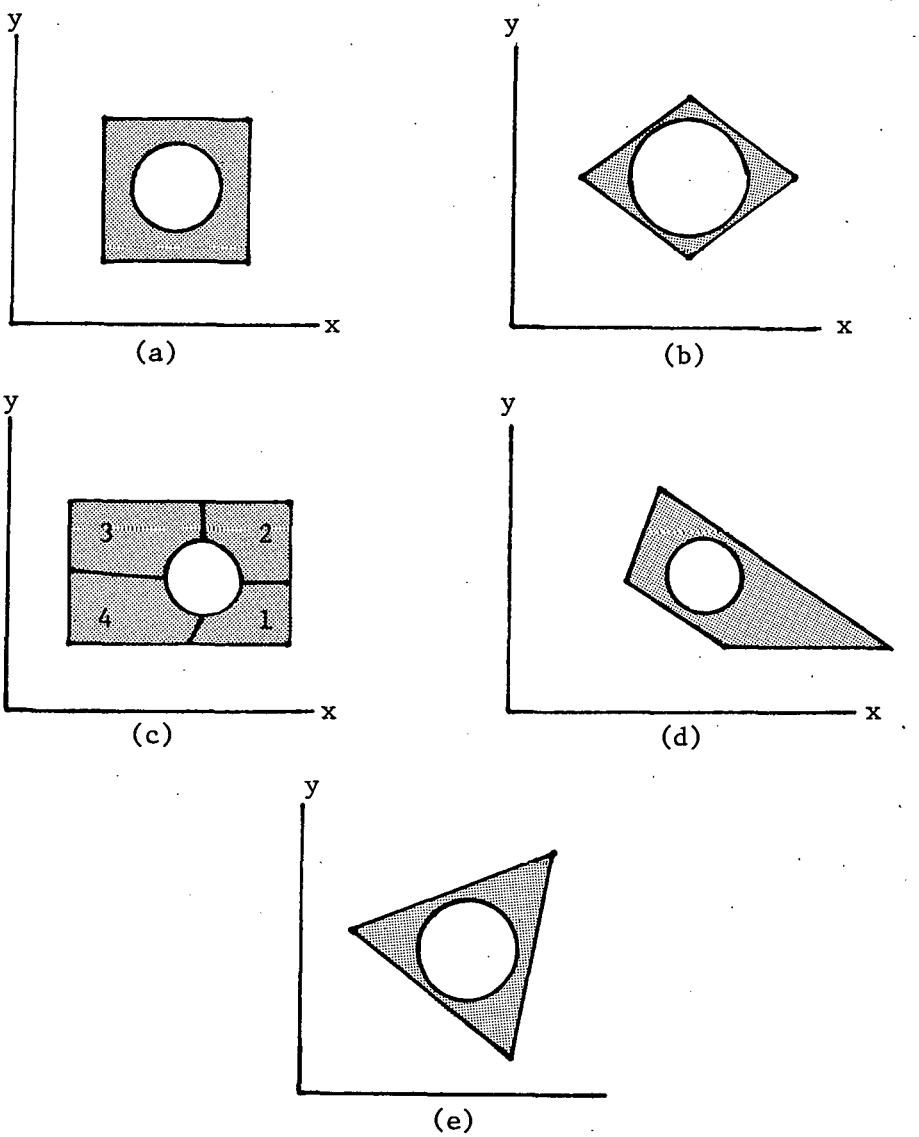


Fig. 9 Examples of Type 2 regions.

the region and define the region type. In the illustrations, the curved surface may either be a cylindrical surface or a spherical surface.

Region Type 3

This particular type of region has *two curved surfaces* and from *two to six plane surfaces*. With reference to the surface types described in the previous section, a region of Type 3 has two surfaces of Type 3 or Type 4 (cylindrical or spherical) and has from two to six plane surfaces of Type 1 or 2 (any combination). Figure 10 illustrates a few examples of regions of Type 3; the shaded portion is again the region of Type 3.

In Figure 10, the z-axis extends out of the page for Examples (c) through (g), and hence the regions represented are actually three-dimensional. The plane surfaces and curved surfaces (depicted as lines and circles in these two-dimensional illustrations) must of course be defined as surfaces within the problem, and they must be numbered as described in the previous section. For Example (a), the solid cylinder is a region of Type 3 since the center line of the cylinder must be represented as a cylindrical surface of zero radius as was previously discussed. The curved surfaces in Examples (c) through (g) must be either two cylindrical surfaces with the same axis (i.e., concentric) or two spherical surfaces with the same center point (concentric spheres). If the surfaces are not concentric or if there is a spherical surface within a cylindrical surface (and vice versa), then additional plane surfaces must be added to make the regions Type 2 regions (with one curved surface).

The regions in Example (d) are of Type 3 because the center line (or center point for a sphere) must be considered a curved surface of zero radius. In Examples (c) through (g) the shaded regions are Type 3 regions and not Type 2 regions (one curved surface) since the center line or point is considered a surface for these regions. Thus, a zero radius surface outside the physical volume of a Type 3 region may be required to define it.

Region Type 4

A region of Type 4 has *two concentric spherical surfaces*, and has no plane surfaces or cylindrical surfaces. This type of region has two surfaces of Type 4, with the same center point, x_o, y_o, and z_o, as was described in the preceding section. For this type of region, there are no different possibilities--only two spherical surfaces with the same center point. This type of region is either a solid sphere or an annulus of a sphere. The two examples of Type 4 regions are shown in Figure 11.

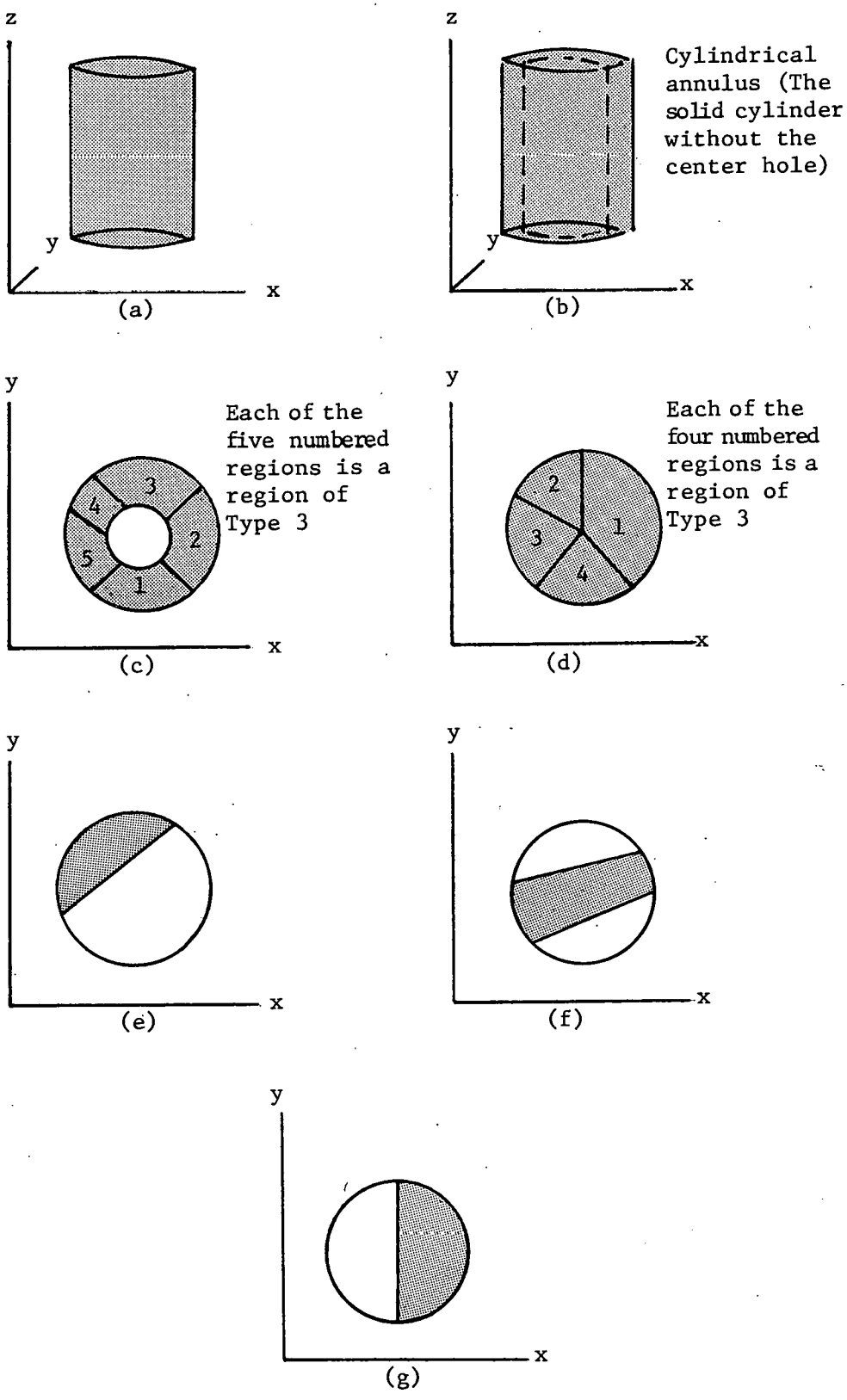


Fig. 10 Examples of Type 3 regions.

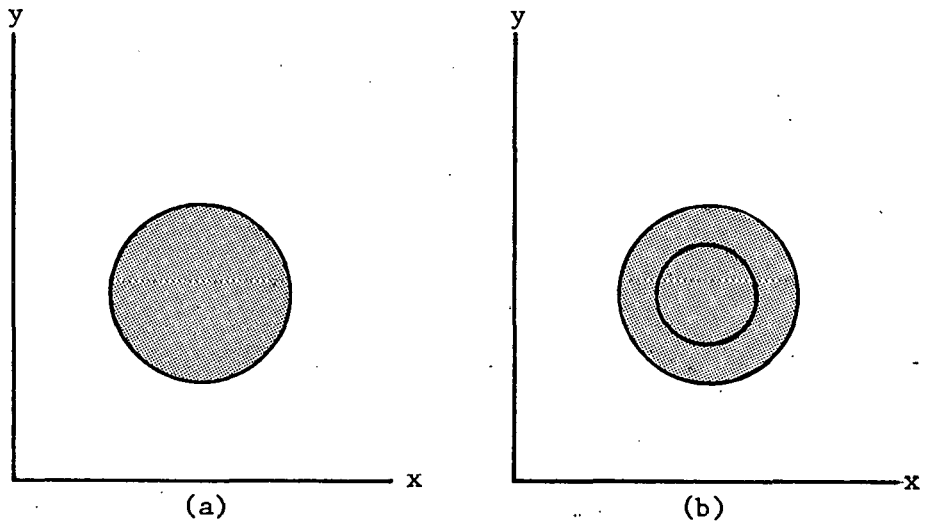


Fig. 11 Examples of Type 4 regions.

5.2 Indexing Regions

Once the regions have been defined, they must be assigned indices for the purposes of identification. This assigning of indices (i.e., numbering the regions) is completely analogous to the numbering of surfaces which was described earlier. Each unique region in the problem, both those in the physical volume and those in the surrounding vacuum region, must be assigned a unique index. For the regions in the physical volume, the indices must range consecutively from 1 to the total number of regions in the physical volume. The regions in the physical volume can be numbered in any way the user desires, but one number (index) must correspond to one region in the physical volume and the numbers must range consecutively from 1 to the total number of regions in the physical volume.

Each individual region in the surrounding vacuum region must be likewise assigned a unique number (index). *If there are N total regions in the physical volume, then the individual vacuum region numbers must begin at N+1 and increase consecutively*. Any assignment of indices to the vacuum regions is permissible, but, again emphasizing the above restriction, these vacuum region numbers must continue the sequence of the physical volume numbers. Thus, if there were eight regions in the physical volume, the individual regions in the vacuum region would be numbered 9, 10, 11,... This numbering of the vacuum regions in sequence after the real regions is used in RAFFLE to identify the vacuum regions.

Returning to the cell problem example (Figure 2), the figures on the next two pages show one possible numbering scheme. For the regions in the physical volume and

surrounding vacuum region, the region numbers assigned are those in *brackets* while the other numbers in circles are the surface numbers which have been previously assigned (Figures 6 and 7). The surface numbers on "lines" refer to those plane surfaces represented by these lines. There are two regions defined in the physical volume. In Figure 12, "Region 1", ([1]) is the surrounding moderator region while "Region 2" ([2]) is the cylindrical rod. The individual vacuum regions are shown in Figure 13. These vacuum regions were chosen to conform to regions of Type 1; any other region description is valid as long as the individual regions defined conform to the permissible region types. The numbering scheme illustrated in Figures 12 and 13 is of course only one possibility. The cylindrical rod might have been denoted as Region 1 and the moderator region as Region 2, and any other numbering combination might have been used for the vacuum regions. However, to obey the general numbering rules, in all of these particular numbering schemes, the two regions in the physical volume must have indices of 1 and 2 and the vacuum regions must have indices beginning at 3 and progressing consecutively.

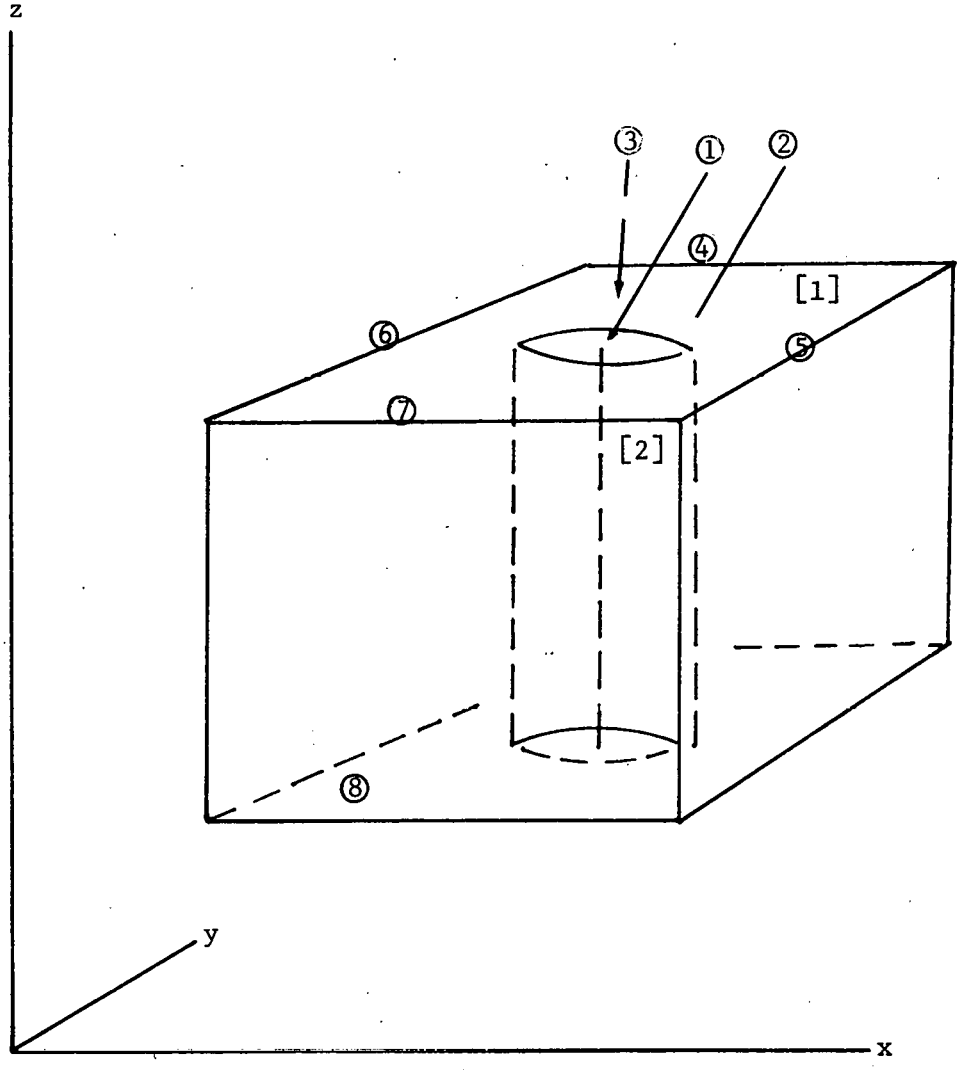


Fig. 12 Region and surface numbers for a cell problem.

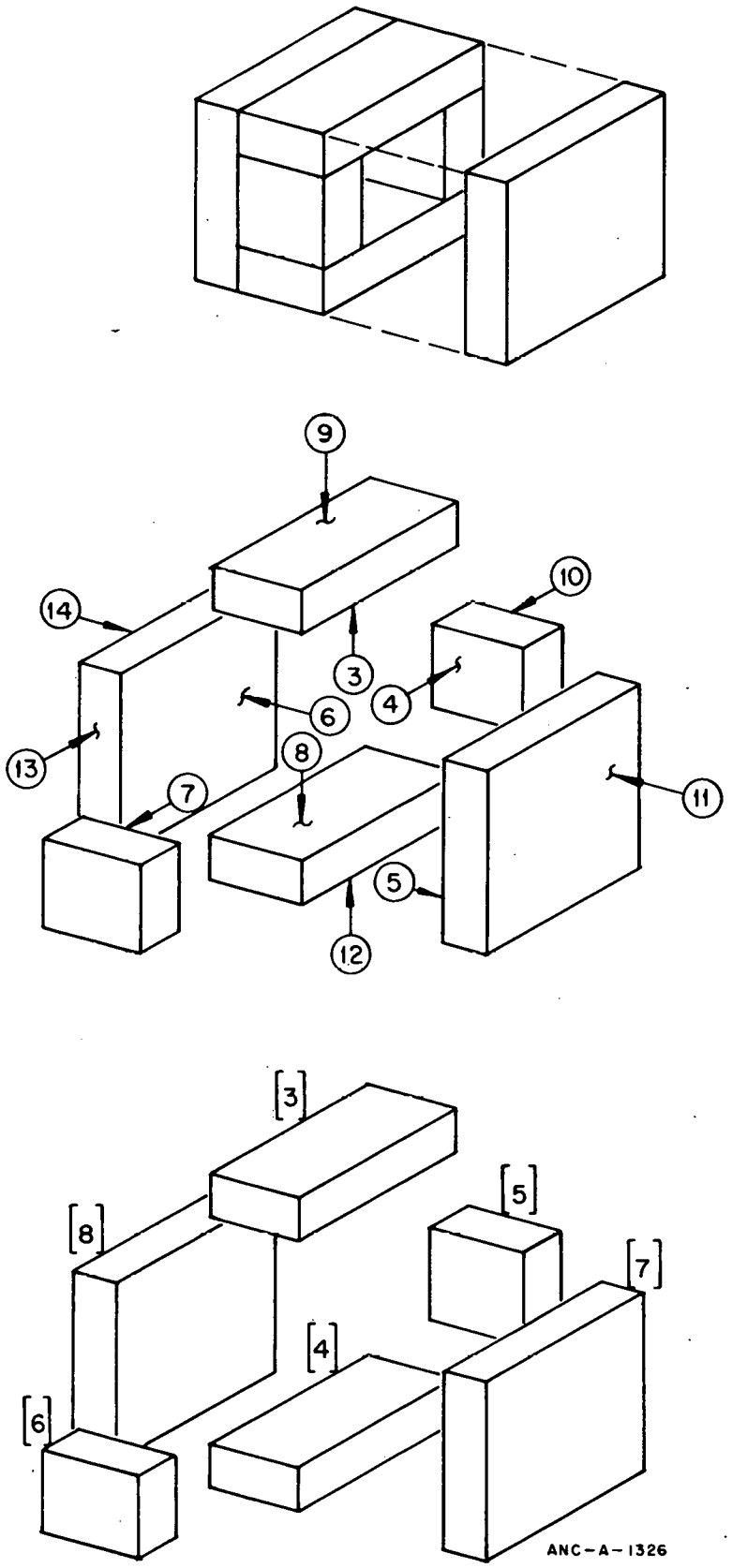


Fig. 13 Region numbers for a cell with an enclosing vacuum region.

In assigning the region numbers in Figure 12, Region 1 and Region 2 are assumed to be homogeneous regions with no spatial variation in properties. Since volume integrated reaction rates are obtained only for the regions defined, with this definition of the two regions, volume integrated groupwise fluxes and reaction rates would be obtained for the rod and for the surrounding moderator.

If more spatial detail of the flux and reaction rates is desired, then additional surfaces and regions would need to be defined for the problem. For example, if more detail in the rod were desired, then additional concentric cylindrical surfaces could be placed in the rod and the corresponding additional regions could be indexed as shown in Figure 14. Groupwise, volume integrated fluxes and reaction rates would then be obtained for each of the four defined regions in the rod (plus the moderator region). With this new region description, the vacuum region numbers would now begin at 5 and progress consecutively.

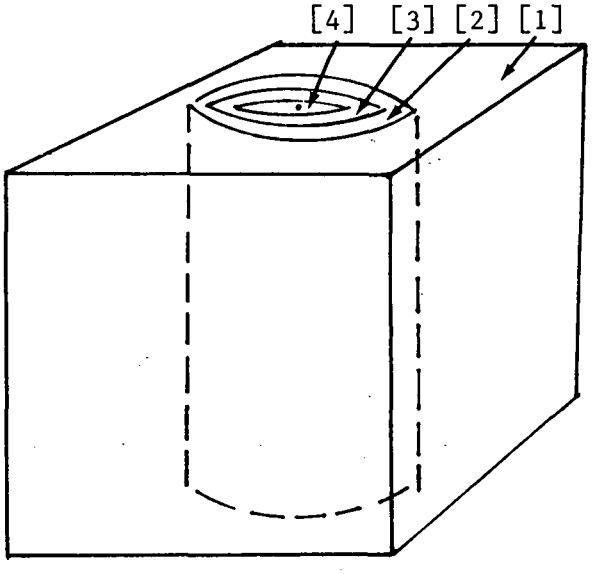


Fig. 14 Subdivision of the fuel rod into four regions.

In Figure 13, which depicts the numbering scheme used for the vacuum regions, the bottom illustration depicts the same regions as in the upper illustration, but the regions are isolated for a clearer view. The surface numbers previously defined are shown in the top illustration in circles. In defining these individual vacuum regions, it must be remembered that surfaces are of infinite extent. Hence, no new surfaces are needed to define the individual regions and the surfaces shown in Figures 12 and 13 are those previously defined in Figures 6 and 7. It is of no significance that a region is intersected by another surface which is not one of its boundaries (for example, in Figure 13, Surface 7 would intersect Region 3 if extended). One need only select as region boundaries those particular surfaces

which define a region conforming to one of the four region types previously defined. Any other surfaces which intersect this region can be ignored.

5.3 Assigning Region Types

After the regions of the problem have been numbered (indexed), each region must then be defined as to its region type, and the surface numbers which are the boundaries of each region must be defined. The four types of regions, Region Type 1, Region Type 2, Region Type 3, and Region Type 4, have been previously discussed. To each numbered region, its corresponding region type (whether Type 1, Type 2, etc.) must be associated. Also, to each numbered region, the corresponding surface numbers which are its defined boundaries must also be associated. These surface numbers refer to the numbering scheme the user has chosen for the surfaces, which was discussed earlier. Each region number, its corresponding region type, and its boundary surface numbers will then be input to RAFFLE.

An effective procedure to describe the regions is to construct a table with "REGION NUMBER" as one column, "REGION TYPE" as another column, and "BOUNDING SURFACES" as another column. For each region, its index (number), region type (whether 1, 2, 3, or 4), and its bounding surface numbers should then be listed. In addition, another column "REGION MATERIAL" should be included in the list. The numbers in this column will identify the material in each region. This material description will be discussed later. The list so constructed by the user will give a complete description of each region and the numbers on this list will then be essentially input to RAFFLE. For the cell problem, using the region and surface indexing previously assigned, the list describing the regions is given in Table I.

5.4 Sign Convention for Plane Surfaces

With regard to the region descriptions of the problem, the final task is to assign a plus (+) or minus (-) sign to each of the plane surfaces bounding each region. In the previous region descriptions, the surface numbers bounding each region were listed (the last column in Table I). To those surface numbers which are *plane surfaces* (surfaces of Type 1 or 2), a plus or minus sign must be prefixed to the number. Curved surfaces (surface Types 3 and 4) need no signs.

TABLE I

REGION DESCRIPTIONS FOR THE CELL PROBLEM

Region No.	Region Type	Region Material	Bounding Surfaces
1	2		2, 4, 5, 6, 7, 3, 8
2	3		1, 2, 3, 8
3	1		9, 3, 5, 6, 10, 13
4	1		8, 12, 10, 13, 5, 6
5	1		3, 8, 4, 10, 5, 6
6	1		3, 8, 7, 13, 5, 6
7	1		5, 11, 9, 12, 10, 13
8	1		9, 12, 6, 14, 10, 13

In general, a plane surface has a plus sign (+) if the region lies to the *right* of, or *above*, the surface, and it has a minus sign (-) if the region lies to the *left* of, or *below*, the surface. As an example of this assigning of plus or minus signs, consider the illustration below. In the illustration, the z axis extends out of the page. The x plane $x = D_1$, Surface 8, has a plus sign since the region lies to the right of the surface. The x plane $x = D_2$, Surface 9, has a minus sign since the region lies to the left of the surface. The y plane $y = D_3$, Surface 2, has a plus sign since the region lies above it, and the y plane $y = D_4$, Surface 3, has a minus sign since

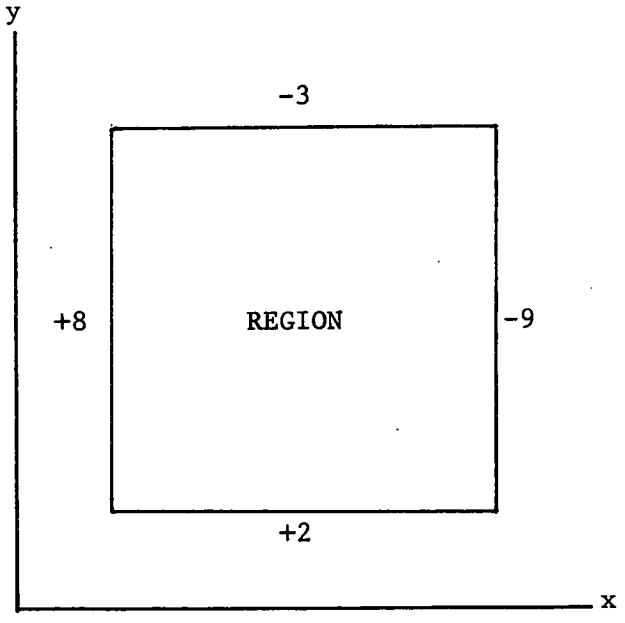


Fig. 15 Sign convention for Type 1 surfaces.

the region lies below it. Similar conventions hold for the z surfaces bounding this region; the top surface, $z = D_5$, would have a minus sign and the bottom surface, $z = D_6$, would have a plus sign ($D_6 < D_5$).

Instead of using the left-right, below-above guidelines, the sign of the plane surface can be analytically determined as follows. Take the equation of the plane surface, $Ax + By + Cz = D$, where A, B, C, and D are the constants chosen to define this surface. Insert the coordinates of any point (x_o, y_o, z_o) within the region and determine $Ax_o + By_o + Cz_o - D$. If this quantity is negative, then the sign of this surface is negative, if it is positive the sign of the surface is positive.

This analytical determination of the sign is particularly applicable to slanted plane surfaces, where there may be ambiguity as to the left-right, below-above rule. Consider, for example, Figure 16 depicting a region with a slanted surface. Surface 1 is defined (and input) as $x = 4.0$, and Surface 2 is defined (and input) as $y = 1.0$. For these particular surfaces, there is no ambiguity of sign. Surface 1 has a minus sign (-1) since the region is to the left of the surface and Surface 2 has a plus sign (+2) since the region is above this surface. The signs of these two surfaces could also be determined from the analytical rule.

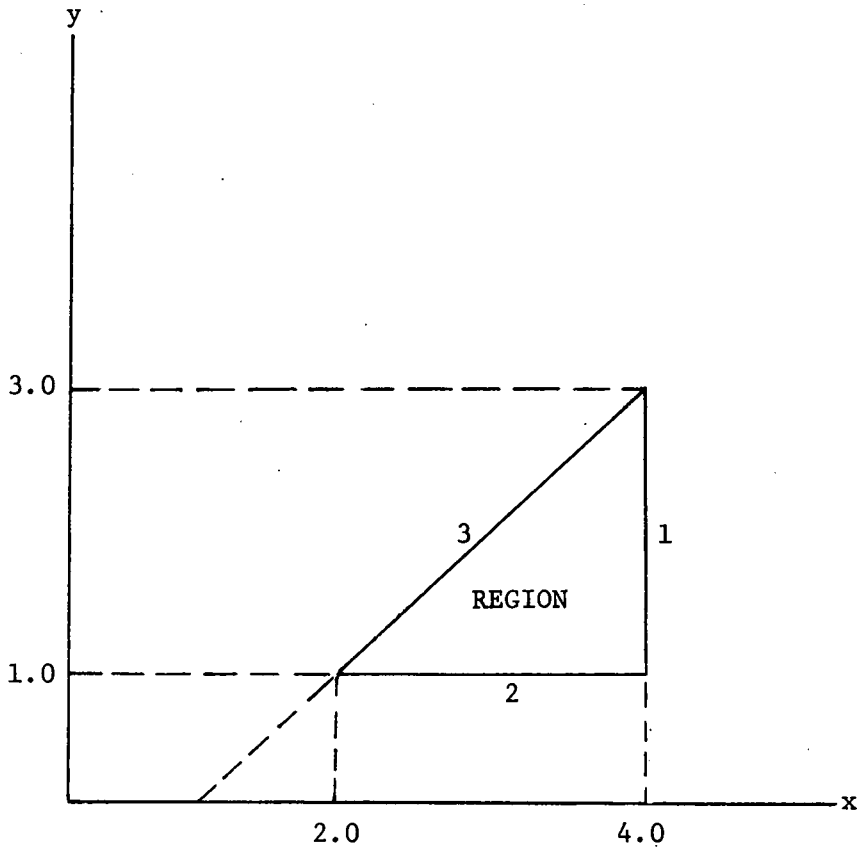


Fig. 16 Sign convention for Type 2 surfaces.

Since the x coordinate (x_o) of any point in the region is less than 4.0, the quantity x_o - 4.0 is negative and hence Surface 1 has a minus sign. Similarly, the y coordinate (y_o) of any point in the region is greater than 1.0 and hence the quantity y_o - 1.0 is positive and Surface 2 has a plus sign.

Surface 3 is the ambiguous surface with regard to the left-right, below-above rule and its sign must be determined from the analytical substitution method. Assume this surface is defined as x - y = 1.0. The point (3.0, 1.1) is clearly within the region. Substituting these coordinates into the defined equation, one obtains 3.0 - 1.1 - 1.0 = 0.9 which is greater than zero and hence Surface 3 has a plus sign. Surface 3 could also be equivalently defined as y - x = -1.0. With this definition of the surface, substituting the point (3.0, 1.1), one obtains 1.1 - 3.0 + 1.0 = -0.9 which is negative and hence Surface 3 has a negative sign.

As seen from the preceding illustration, the analytical substitution rule unambiguously gives the correct sign for any plane surface. The user should only take care that the form of surface equation used is that exactly as defined and is input to RAFFLE. *Whenever there is a question as to the sign of a plane surface, the analytical substitution rule should be used.*

In the previous section, it was recommended that the user prepare a table describing the region type and bounding surfaces of each region. Using the rules defined, he can now affix plus or minus signs to every plane surface bounding each region. Because of coding algorithms, the plus signs can be ignored when input; however, the user must have determined that the signs were plus and not minus. This table with the signs affixed to each plane surface will be the final format of the inputs needed to define each region in a RAFFLE problem.

For the cell problem, Table I was prepared defining each region of this example problem. This table with the correct signs now affixed to the surface numbers is shown as Table II.

TABLE II

REGION DESCRIPTIONS FOR THE CELL PROBLEM,
WITH SIGNS AFFIXED TO THE PLANE SURFACES

Region No.	Region Type	Region Material	Bounding Surfaces
1	2		2, -4, -5, +6, +7, -3, +8
2	3		1, 2, -3, +8
3	1		-9, +3, -5, +6, -10, +13
4	1		8, -12, 10, +13, -5, +6
5	1		-3, +8, +4, -10, -5, +6
6	1		-3, +8, -7, +13, -5, +6
7	1		+5, -11, -9, +12, -10, +13
8	1		-9, +12, -6, +14, -10, +13

6. REGION MATERIAL DESCRIPTIONS

As previously stated, each region must be homogeneous and contain only one material, where a material is a particular mixture of isotopes. The material descriptions are defined separately and once the user has defined the materials, he assigns one material number to each defined region in the physical volume. The individual regions in the surrounding vacuum region are not assigned any material since they are only "fictitious" regions for use by the RAFFLE algorithms.

Each material in the problem must be assigned a unique material number, where the numbers range from 1 to the total number of materials. Any assignment of these identifying numbers is valid as long as the numbers begin at 1 and increase in succession (1, 2, ...). If a material appears in several regions these different regions will simply have the same material number. To define a material, the isotopes and corresponding isotope number densities are given for the material. An illustration of defined materials with their corresponding material numbers is given below.

Material No.	Isotope, Isotope Number Density
1	(U-238, 0.04518)(U-235, 0.01559)
2	(Na, 0.01304)

The number densities defined and input to RAFFLE are in units of 10^{24} nuclei/cm^3. In the above illustration, Material 1 contains U-238 at a concentration of 0.04518 x 10^{24}

nuclei/cm^3 and U-235 at a concentration of 0.01559 x 10^{24} nuclei/cm^3. Material 2 contains Na at a concentration of 0.01304 x 10^{24} nuclei/cm^3.

It is wise to construct a table, as illustrated above, for the problem being analyzed. The input to RAFFLE will essentially be the entries in this table, with the simple modification that isotope identifying numbers will be used in place of the symbols (U-238, etc.). The isotope identification numbers and the microscopic isotope data are discussed in Sections V, VI, and VII. If a true vacuum region exists for the problem, then a "vacuum material" must be defined for this region (or regions). The true vacuum regions are to be distinguished from the surrounding vacuum region in that these true vacuum regions are contained within the physical volume of the problem. If such regions exist within the physical volume, a vacuum material is defined by assigning it any isotope with a zero concentration.

After the materials and corresponding material numbers are defined, each individual region in the physical volume must be assigned a material number. In the previous section, it was recommended that a table be constructed for the region descriptions, where one column of this table was titled "REGION MATERIAL". In this column, the corresponding material numbers should now be listed.

For the cell example problem assume the center rod consists of Material 1 and the surrounding moderator region of Material 2, where Materials 1 and 2 refer to the material definition illustration given in this section. The listing of these material numbers, is shown in Table III. The table is simply Table II with the appropriate material numbers inserted. It is noted that no material numbers are assigned to Regions 3 through 8 since these are regions in the surrounding vacuum region. This table is now complete with respect to region descriptions and its entries would be simply input to RAFFLE.

TABLE III

REGION DESCRIPTIONS FOR THE CELL PROBLEM,
THE COMPLETE TABLE WITH REGION MATERIALS ASSIGNED

Region No.	Region Type	Region Material	Bounding Surfaces
1	2	2	2, -4, -5, +6, +7, -3, +8
2	3	1	1, 2, -3, +8
3	1		-9, +3, -5, +6, -10, +13
4	1		-8, +12, -10, +13, -5, +6
5	1		-3, +8, +4, -10, -5, +6
6	1		-3, +8, -7, +13, -5, +6
7	1		+5, -11, -9, +12, -10, +13
8	1		-9, +12, -6, +14, -10, +13

7. ZONE GEOMETRY CONSTRUCTION

7.1 General Description

The final task in the geometrical description is the construction of a zone geometry overlay for the problem. This section describes the general concepts of the zone overlay; later sections will describe the detailed input required for RAFFLE. The zone geometry is a simplified mesh superimposed over the regions to aid in the geometric description of the problem; the zone geometry overlay reflects the spatial regularities and symmetries of the problem. One of four permissible zone geometries can be used for a particular problem:

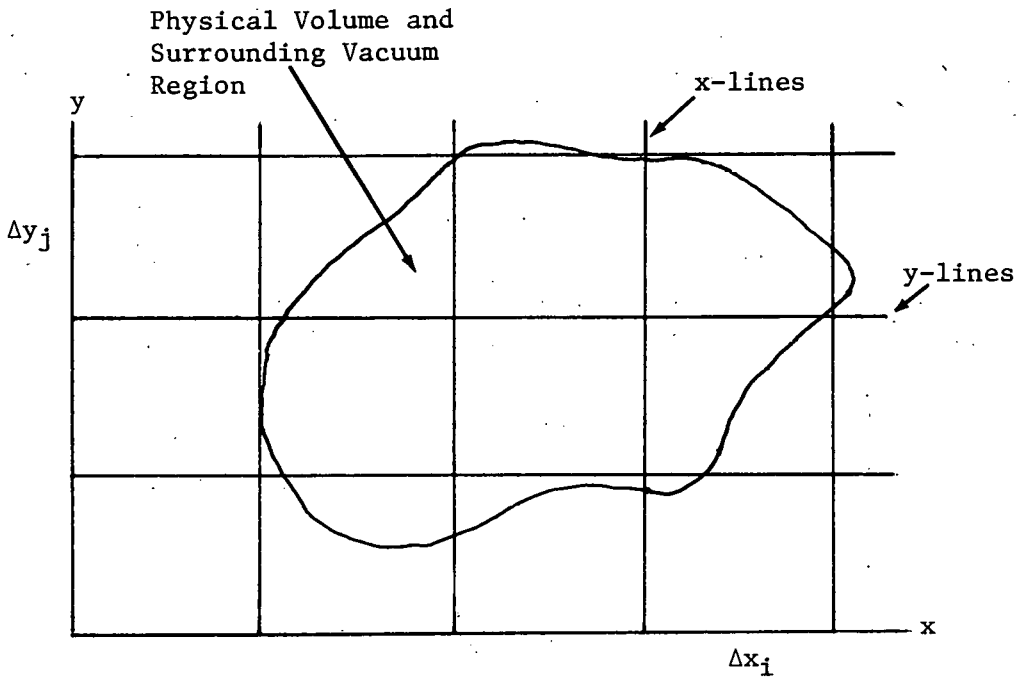
(1) The rectangular x, y, z zone geometry, which is a rectangular x, y, z mesh

(2) The cylindrical r, z zone geometry, which is a cylindrical r, z mesh

(3) The cylindrical r, Θ, z zone geometry, which is a cylindrical r, Θ, z mesh

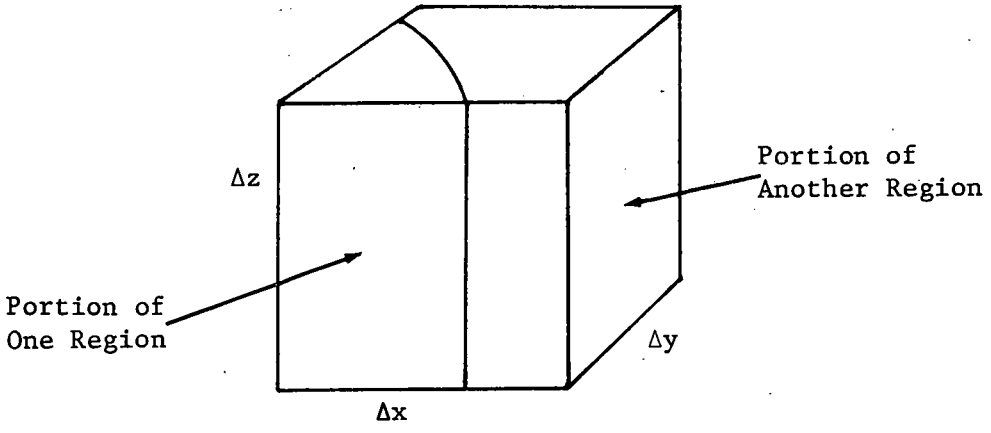
(4) The spherical r zone geometry, which is a spherical radial mesh.

If the rectangular zone geometry is used then x, y, z lines are overlayed on the spatial description of the problem. These x, y, z lines form a mesh of solid rectangles (boxes) having volumes $\Delta x_i \Delta y_j \Delta z_k$ where Δx_i, Δy_j, and Δz_k are the spacings between adjacent x, y, and z lines, respectively.



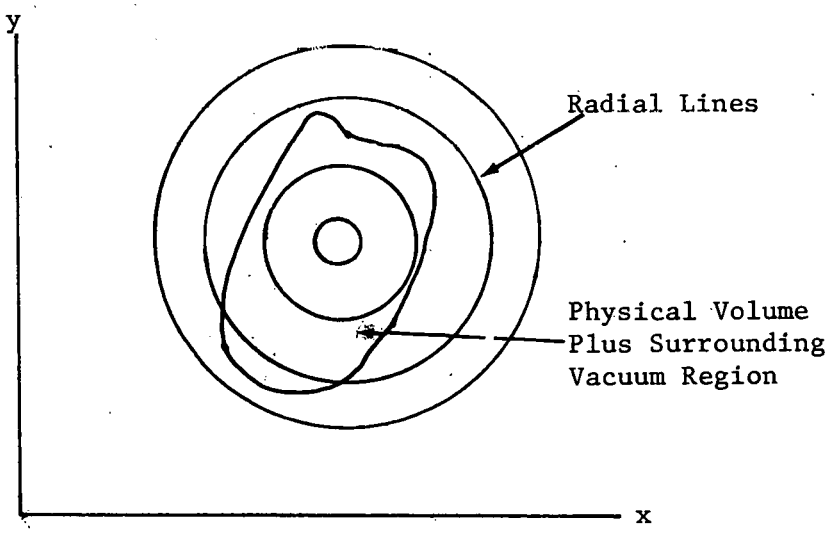
The figure above depicts the x, y lines overlayed on a problem; these lines must overlay the physical volume plus surrounding vacuum region. In the above figure, the z axis extends out of the page and hence the figure illustrates a cross section perpendicular to the z axis. The z lines would give each of the above $\Delta x_i \Delta y_j$ rectangles a height of Δz_k.

Within each solid rectangle $\Delta x_i \Delta y_j \Delta z_k$, called a "zone", one or more regions of the problem are contained, where the region or regions in the zone are those which have been previously defined. Instead of totally containing one or more regions, a zone may contain only portions of a region or regions.



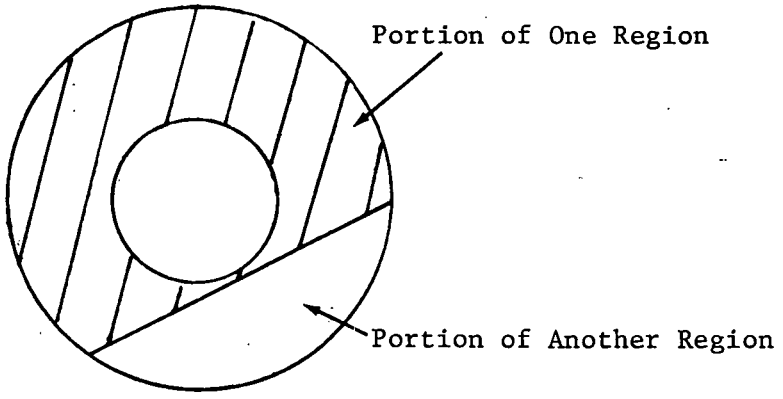
The preceding illustration depicts a zone (the box) containing portions of two regions, where these regions have been earlier defined for the problem. For the x, y, z rectangular zone geometry, every region of the problem must be contained in one or more of the zones, and thus the zone overlay encompasses the physical volume and surrounding vacuum region.

If the cylindrical r, z zone geometry is used, z lines and cylindrical radial (r) lines are overlayed on the problem. The overlay thus creates individual zones having volumes $\Pi(r_2^2 - r_1^2)\Delta z$, where r_2 and r_1 are adjacent radial lines and where Δz is a spacing between adjacent z lines. The individual zones are thus annuli of solid cylinders of height Δz.

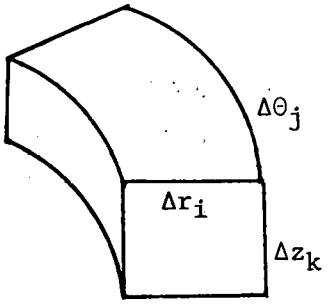


In above figure, the z axis extends out of the page and thus the figure illustrates a cross sectional view. Each of the circular annuli have heights of Δz_i.

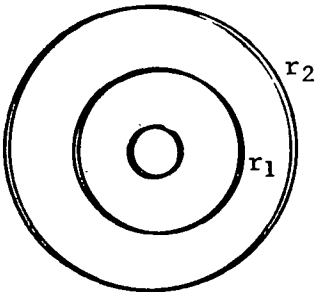
Each cylindrical zone contains one or more of the regions in either the physical volume or the surrounding vacuum region. As for any type zone geometry, an individual zone may contain regions in the physical volume and regions in the vacuum region. As for the rectangular zone geometry, the r, z zone overlay must encompass the total physical volume and surrounding vacuum region.



The r, Θ, z zone geometry is analogous to the r, z zone geometry, with the r, Θ, z geometry simply having additional angular lines (Θ lines) which divide the cylindrical annuli into angular sectors. For the r, Θ, z zone geometry, a zone is the solid space contained with the limits r_i to $r_i + \Delta r_i$, $\Theta_j + \Delta\Theta_j$, and z_k to $z_k + \Delta z_k$.



The last type of zone overlay which may be used is the spherical zone overlay. This simply consists of a series of concentric spherical annuli, where each zone has a volume of the type $\frac{4}{3}\Pi(r_2^3 - r_1^3)$, where r_2 and r_1 are adjacent radii of the sphere.



7.2 General Recommendations

Only one zone geometry type can be used to overlay a particular problem. Any one of the four zone geometries can be used for any problem; however, the judicious choice of a zone geometry can save computer time. The optimum choice of a zone geometry is such that each zone contains only one region where the region may extend to any number of zones. If the regions are of such shape that one region per zone is not possible, then the zone geometry should be chosen such that as few regions as possible are in each zone. In those zones containing more than one region, there optimally should be one dominant region consuming most of the volume of the zone. In essence then, the zone geometry should be chosen to reflect the symmetries of the problem. If the problem consists entirely of, or almost entirely of rectangular regions, then the x, y, z rectangular zone geometry should be used. If it consists of cylindrical regions, then the r, z zone geometry should be chosen; if there is spatial variation in the Θ direction, then the r, Θ, z zone geometry should

be used, and so forth. Practicality must, of course, be the guiding factor since the user does not want to spend an extreme amount of time in setting up the zone geometry, particularly since the difference in computer time is generally negligible between the optimum, but difficult, and the near optimum, but more simply constructed.

7.3 Zone Construction

This section describes the actual construction of the zone overlays. The zone lines once constructed in the manner to be described will be the complete set of information needed by RAFFLE and hence can simply be transferred to input cards.

7.3.1 *Construction of the Rectangular Zone Description.* All zone lines (x, y, z lines) must be with reference to a zone geometry center point. Therefore a zone geometry center point, or reference coordinate point (x_o, y_o, z_o), is first chosen and the x, y, z lines are given values with respect to this center point; the x, y, z lines thus represent the relative distances of these lines from the center point. The x direction, y direction, and z direction here are with reference to the original coordinate frame chosen by the user. As for all the distance units used in RAFFLE, all values for the x, y, z lines are in centimeters.

To begin construction of the x, y, z zone geometry, the entire problem, i.e., physical volume plus surrounding vacuum region, is first enclosed in a solid rectangular "box". This box (rectangular solid) represents the total extent of the zone geometry description.

Since all position coordinates must be in the first octant of the original reference frame, the zone geometry point must be such that $x_o \geq 0$, $y_o \geq 0$, and $z_o \geq 0$. If $x_o = y_o = z_o = 0$, then the zone geometry center point coincides with the origin of the original reference frame chosen by the user. All x, y, and z lines must be *nonnegative* with respect to the zone center point (x_o, y_o,z_o). Hence, the zone center point must lie on the lower left hand corner of the solid as illustrated in Figure 17. *For rectangular zone geometry the zone geometry center point must coincide with the origin of the original reference frame.*

Once the zone extent, i.e., rectangular solid, is constructed (or mentally visualized) the "z lines" (z planes) are first assigned by the user. These z lines (Figure 18) are completely arbitrary, but optimally should coincide with the z symmetry of the problem and the lines will quite often coincide with certain of the z plane surfaces of the problem.

The first z line, z_1, always has a value of 0.0 since it must coincide with z_o. The other z line values are then assigned with respect to z_1. There may be any number of lines

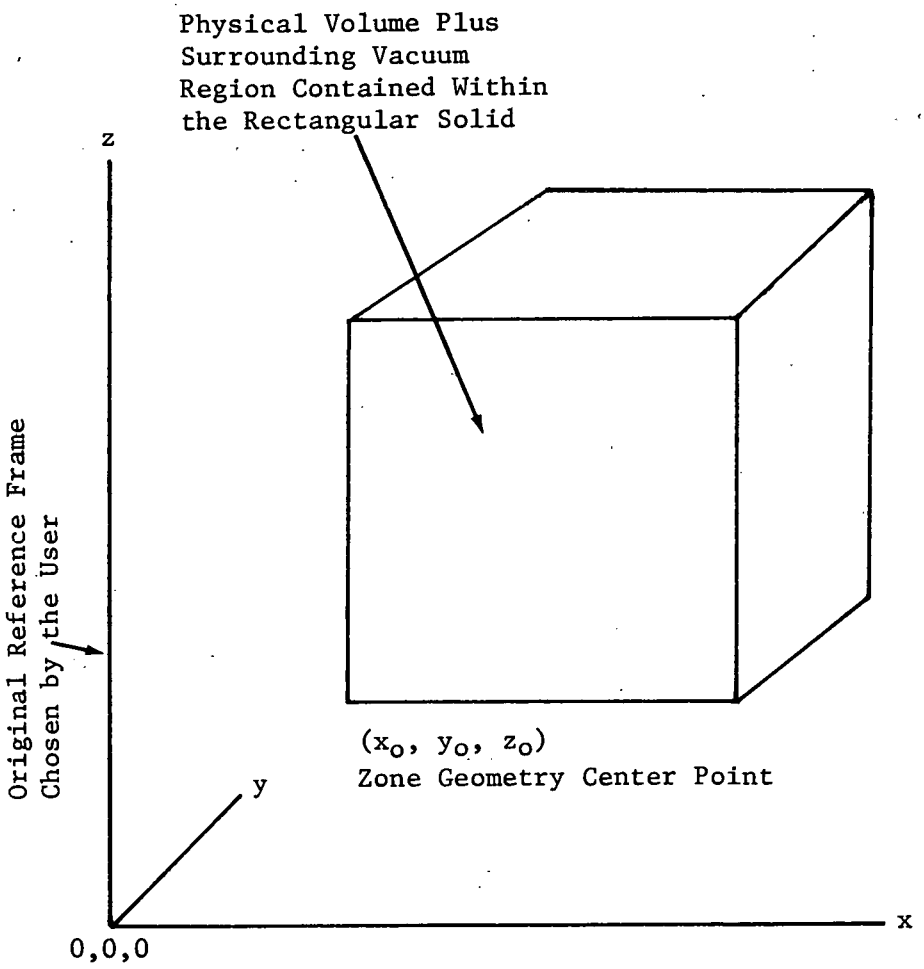
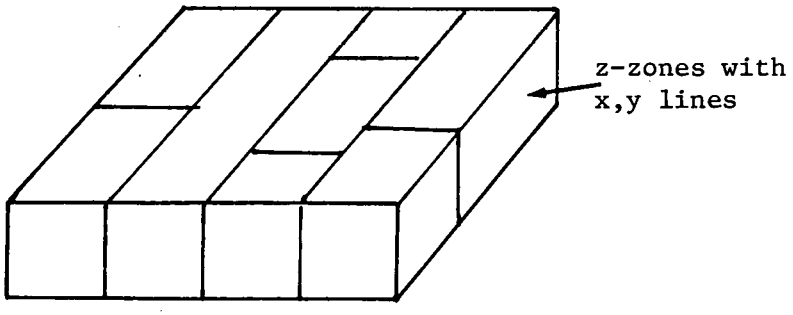


Fig. 17 Zone geometry coordinate system.

assigned; however, there must be a minimum of two z lines for every problem $z_1 = 0.0$ and the "top" z line (i.e., the bottom and top z surfaces of the total zone extent).

The z lines, which define z planes, will form "z zones", as illustrated in Figure 18. These z zones are solid rectangular "layers" of height Δz_i, and are numbered from bottom up as shown in Figure 18. In each of these z zones, x, y lines will be constructed to form the individual rectangular zones (of volume $\Delta x_i \Delta y_j \Delta z_k$) and the z zone numbers will be used to reference these individual x, y zones.



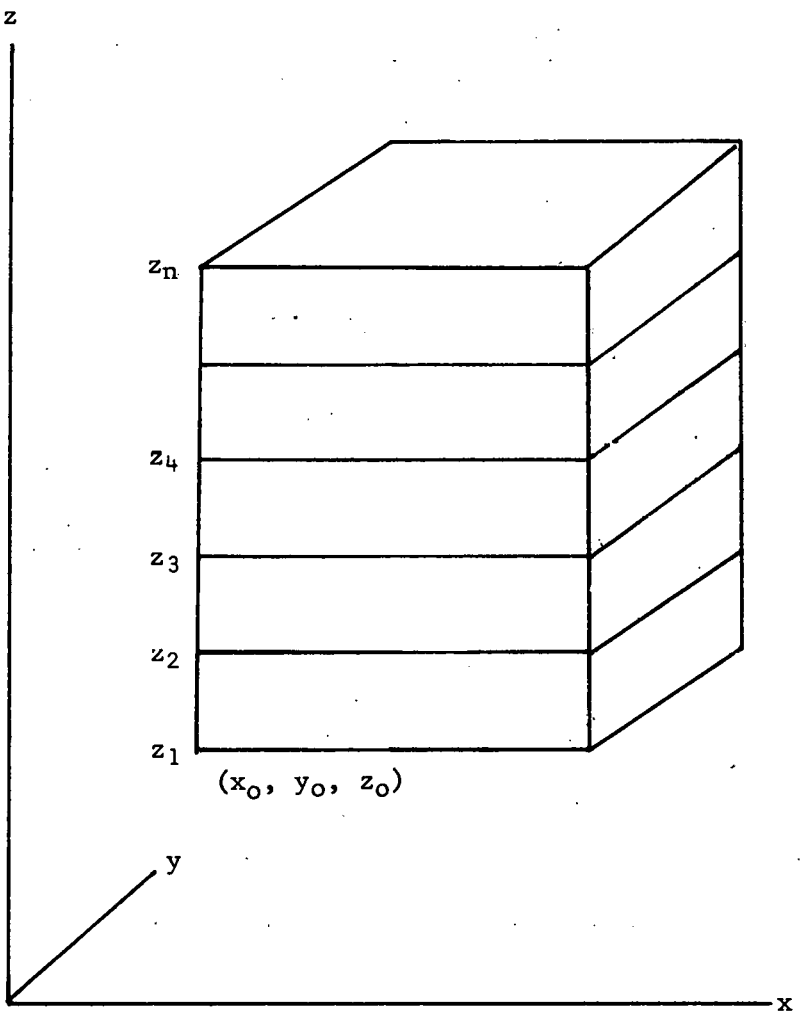


Fig. 18 Numbering of the z zones and z lines.

Consider a problem in which the physical volume is rectangular solid, then four z lines can be chosen to efficiently describe the z zone overlay.

As depicted in Figure 19, the zone center point (x_o, y_o, z_o) coincides with the "lower left hand corner" of the surrounding vacuum region. The z lines coincide with the z plane surfaces of the problem, and the z lines, z_1 and z_4, coincide with the bottom and top surfaces bounding the surrounding vacuum region. The zone geometry extent equals the total volume of the problem, physical volume plus surrounding vacuum region volume.

For the problem illustrated in Figure 19, if the user had divided the physical volume into two stacked regions to obtain more spatial detail in the fluxes, then an additional z line should be included to coincide with this additional z surface in the physical volume. The z line construction shown in Figure 19 could still be used; however, this construction would not be as efficient since it would eventually result in more than one region existing per zone.

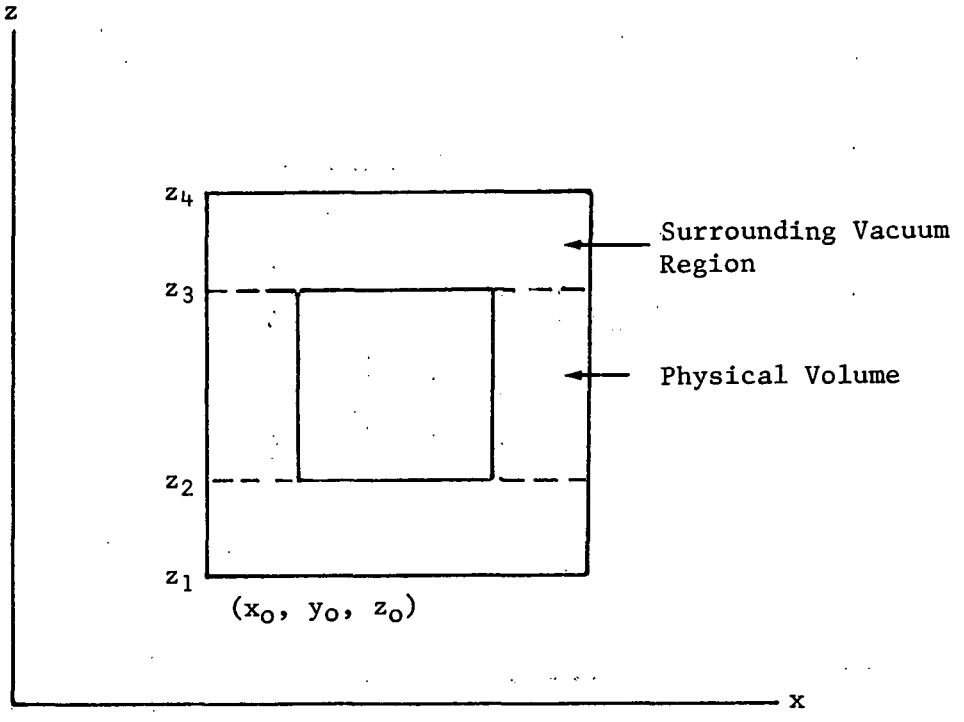


Fig. 19 Z zone selection for a rectangular physical volume.

After the z lines and corresponding z zones have been constructed, the x and y lines must be defined for each z zone. Each z zone has its own unique x, y lines, and the x, y lines are first constructed for z zone 1 then z zone 2, etc., through the total number of z zones. For a particular z zone, the x lines are first constructed forming "columns" (or x zones as shown in Figure 20) within the z zone.

The x lines can be arbitrarily spaced; however, the first x line, x_1, must be 0.0 since it must coincide with x_o, the zone center point x coordinate. The remaining x lines are assigned values with respect to x_1 (i.e., x_o), and hence, their values are their relative distances (in centimeters) from x_1. There may be any number of x lines per z zone; however, there must be a minimum of two x lines per z zone, $x_1 = 0.0$ and the "right hand" x line (defining the left and right surfaces of the total zone extent). Since the entire zone geometry extent must be a rectangular solid, all final x lines of all the z zones must have the same value.

After the x lines are constructed for a z zone, the y lines (Figure 21) must finally be defined for each x zone.

In Figure 21, twelve y lines have been defined for the four x zones. For a particular problem, any number of y lines may be assigned to each x zone. The first y line of each x

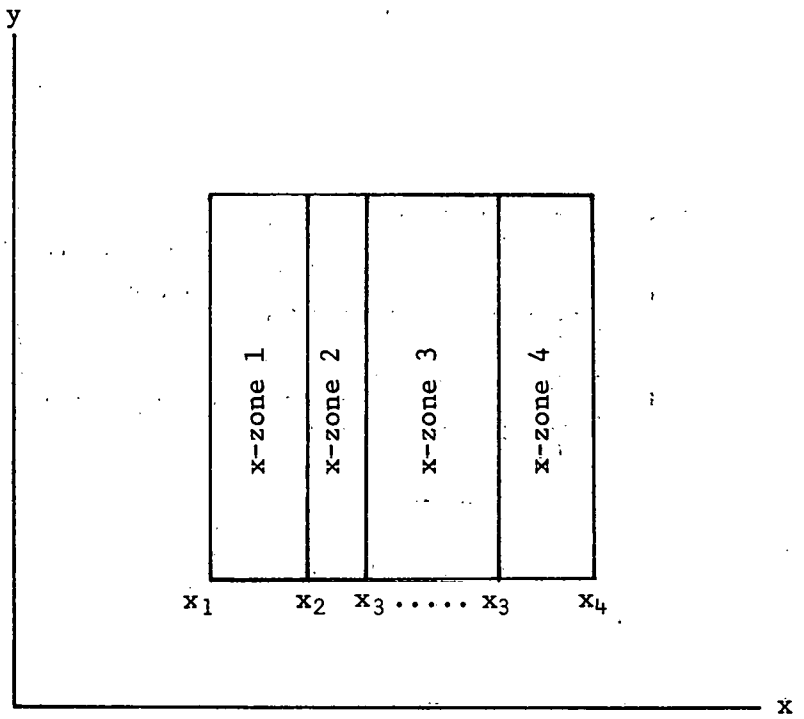


Fig. 20 Assignment of x lines to a z zone.

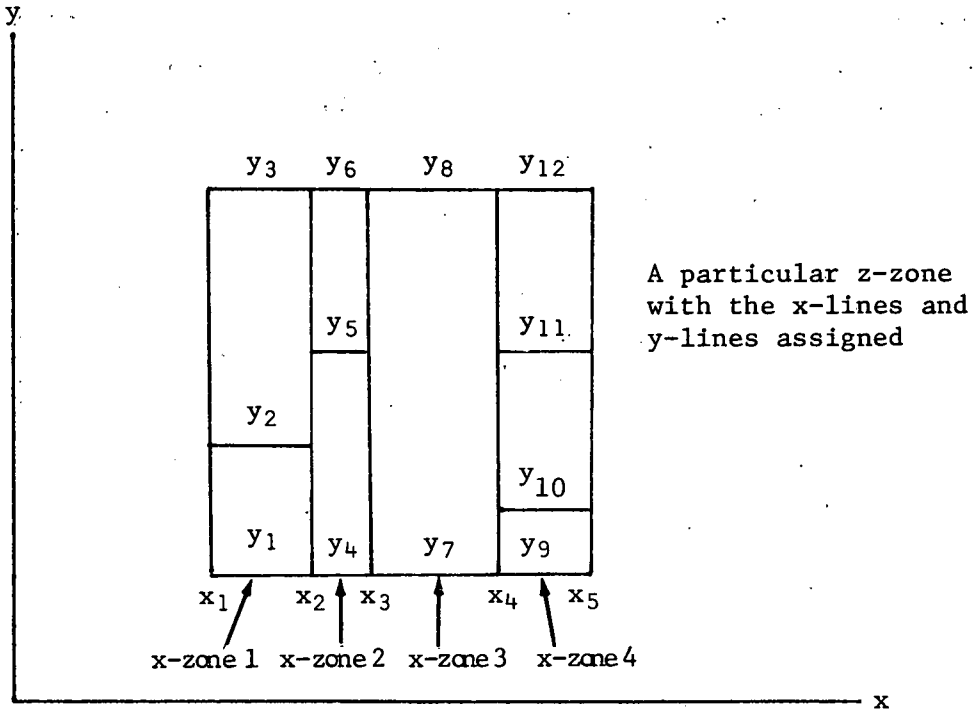


Fig. 21 Assignment of y lines.

zone must be y = 0.0 and the remaining y line values in an x zone are with respect to the first y line. For Figure 21, the y_2 value would be relative to y_1, etc., the y_5 value relative to y_4, and so forth. For each x zone, there must be a minimum of two y lines, y = 0.0 and the top y line of each x zone. Furthermore, all the top y lines of every x zone must have the same value (in Figure 21 this means $y_3 = y_6 = y_8 = y_{12}$).

The construction of the x and y lines must be repeated for every z zone. Not only must the final (i.e., top) y lines have the same value for each x zone of a z zone, but the final y lines of all z zones must be the same. Thus, for Figure 21, if other x and y lines were constructed for other z zones, the final bounding y lines of each x zone must equal y_3 ($y_6 = y_8 = y_{12}$). The requirement that all final x lines be the same and all final y lines be the same simply means that the entire zone geometry extent is a solid rectangular box. Irregular stacking as depicted on the next page is not allowed.

As for the z lines, the x and y lines should be chosen to closely coincide with the region descriptions. A particular zone is then the rectangular volume contained between adjacent x, y, and z lines; it is that volume in an x zone contained within adjacent y lines for that x zone.

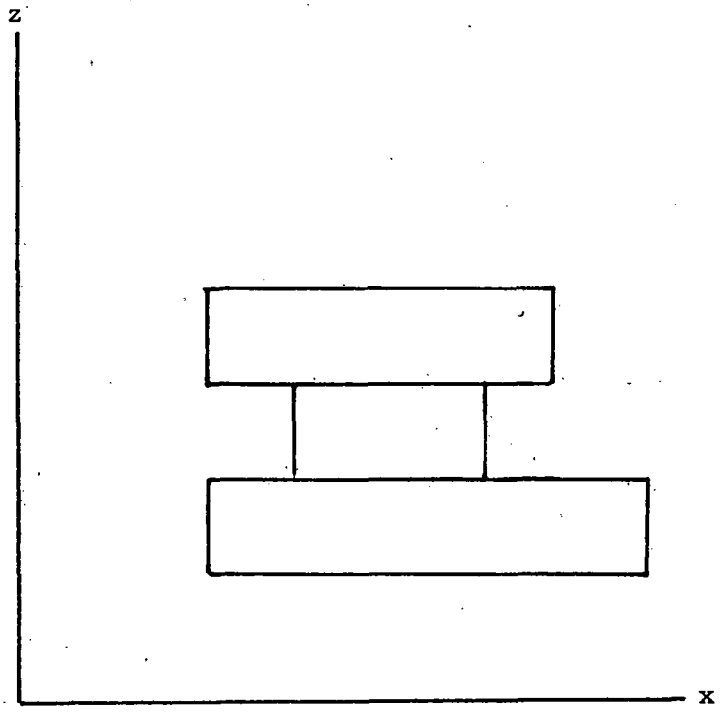
Figure 22 depicts the individual zones for the sample zone setup (each individual zone is denoted by the word "zone"). Each zone illustrated is a rectangular volume bounded by the two z lines forming the particular z zone. Since optimal assignment of the x, y lines creates a minimum number of regions per zone, the x, y lines chosen should, in general, coincide with the x, y plane surfaces of the problem. *For any zone construction, the x and y lines must be chosen such that no zone contains more than seven regions (or portions of seven regions).*

7.3.2 *Format of Input for the x, y, z Lines.* Once the z lines and x, y lines for each z zone are defined, they can now be input to RAFFLE. All the z lines are input as a group, all the x lines as a group, and all the y lines as a group. The z lines, in centimeters, are input in increasing order of value:

$$z_1, z_2, \ldots z_n$$

with

$$z_1 = 0.0$$



Example of Invalid Irregular Stacking.

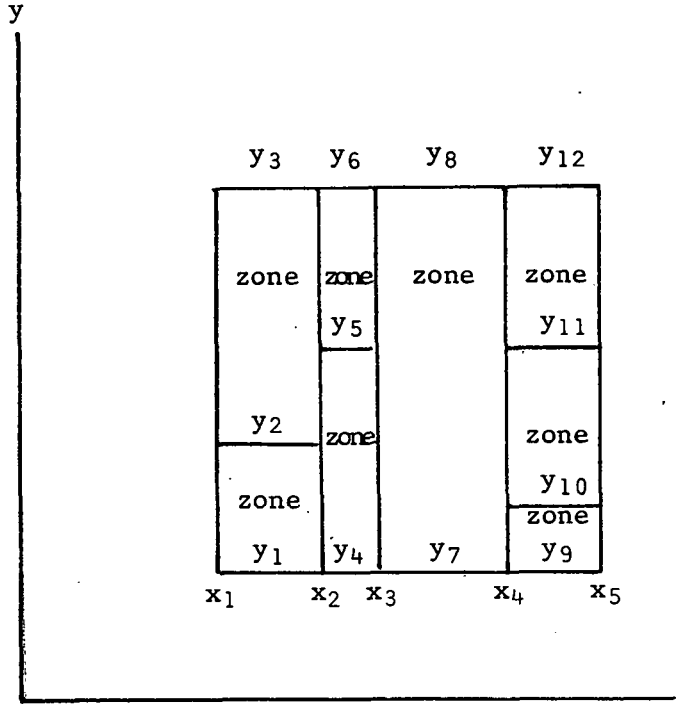


Fig. 22 Subdivision of a z zone into the individual zones.

and

$$z_1 < z_2 < \ldots < z_n \quad .$$

The z values are relative to z_1 (i.e., relative to z_o, the z coordinate of the zone geometry center point) and there must be minimum of two z lines read in.

The x lines are input in order of z zone number; the x lines for z zone 1 come first, then those for z zone 2, etc. The x lines are thus grouped from bottom z zone to top z zone. The x lines, in centimeters, are thus input in the order

$$x_1^{(1)}, x_2^{(1)}, \ldots, x_{n_1}^{(1)}, x_1^{(2)}, x_2^{(2)}, \ldots x_{n_2}^{(2)}, \ldots$$

where the superscript denotes the z zone number. The first x line of each z zone must be zero.

$$x_1^{(1)} = x_1^{(2)} = \ldots = 0.0$$

and the final x lines of each z zone must be equal,

$$x_{n_1}^{(1)} = x_{n_2}^{(2)} = \ldots$$

Finally, for a given z zone, the x lines must be arranged in increasing order

$$x_1^{(1)} < x_2^{(1)} < \ldots < x_{n_1}^{(1)}$$

$$x_1^{(2)} < x_2^{(2)} < \ldots < x_{n_2}^{(2)} \quad .$$

The y lines are input in order of z zone and within each z zone, they are arranged in order of increasing x zone. The y lines are thus read in from bottom z zone to top z zone; for a given z zone, the y lines are read in from left x zone to right x zone. Within the x zone, the y lines are arranged in increasing order. Thus, the y lines, again in centimeters, are input in the format

$$\underbrace{\underbrace{y_1^{(1)}, \ldots y_{m_1}^{(1)}}_{\text{x zone 1}}, \underbrace{y_1^{(1)}, \ldots y_{m_2}^{(1)}}_{\text{x zone 2}}, \ldots}_{\text{z zone 1}} \quad \underbrace{\underbrace{y_1^{(2)}, \ldots y_{n_1}^{(2)}}_{\text{x zone 1}}, \underbrace{y_1^{(2)}, \ldots y_{n_2}^{(2)}}_{\text{x zone 2}}, \ldots}_{\text{z zone 2}}$$

where "x zone 1", "x zone 2" denote the x zones (i.e., columns) taken from left to right. The first y value for each x zone must be zero

$$y_1^{(1)} = \ldots = y_1^{(2)} = \ldots = 0.0$$

and the final y values for all the x zones, in all the z zones, must be equal,

$$y_{m_1}^{(1)} = y_{m_2}^{(1)} = \ldots\ y_{n_1}^{(2)} = y_{n_2}^{(2)} = \ldots$$

Finally, within an x zone, the y line values must be in increasing order, e.g.,

$$\underbrace{y_1^{(1)} < y_2^{(1)}, \ \ldots < y_{m_1}^{(1)}}_{\text{x zone 1}}, \text{ etc.}$$

The card formats for the above input sequences of the x, y, and z lines are described in Section V.

7.3.3 *Numbering the Individual Rectangular Zones.* The zones are the individual rectangular volumes formed by the x, y, and z lines; the zones must be numbered, or indexed, for input to RAFFLE. In any problem, the total number of zones will always equal the total number of y lines minus the number of y = 0.0 lines. The zones are numbered in exactly the same way as the y lines are read into RAFFLE. The numbering starts at 1. Beginning with the first z zone, the bottom z zone, the individual zones are numbered consecutively from the bottom of the first x zone to the top of the first x zone. The numbering is continued to the second x zone, from bottom to top, and so forth. After the first z zone has been completely numbered in this manner, the numbering continues in exactly the same way for the second and remaining z zones.

In the previous illustrations, if the z zone depicted was the first z zone, the zone numbers would be assigned as shown in Figure 23. The numbering would continue in this manner for the remaining z zones, with the zone numbers continuing in sequence.

After the zones are numbered, the individual regions within each zone are determined. A region is to be considered in a zone if any portion of the region is in that zone. Thus, one region may appear in several zones. The input required for RAFFLE are the region numbers within each zone. These region numbers are those previously assigned to each region in the physical volume and surrounding vacuum region. A maximum of seven regions per zone is allowed. An individual zone may contain regions, some of which are in the physical volume and the others in the surrounding vacuum region, and this maximum of seven regions applies to the sum total of regions in the zone.

To avoid error, it has been found to be a good practice to construct a table with two columns headed by "Zone Number" and "Regions in the Zone". In the "Zone Number"

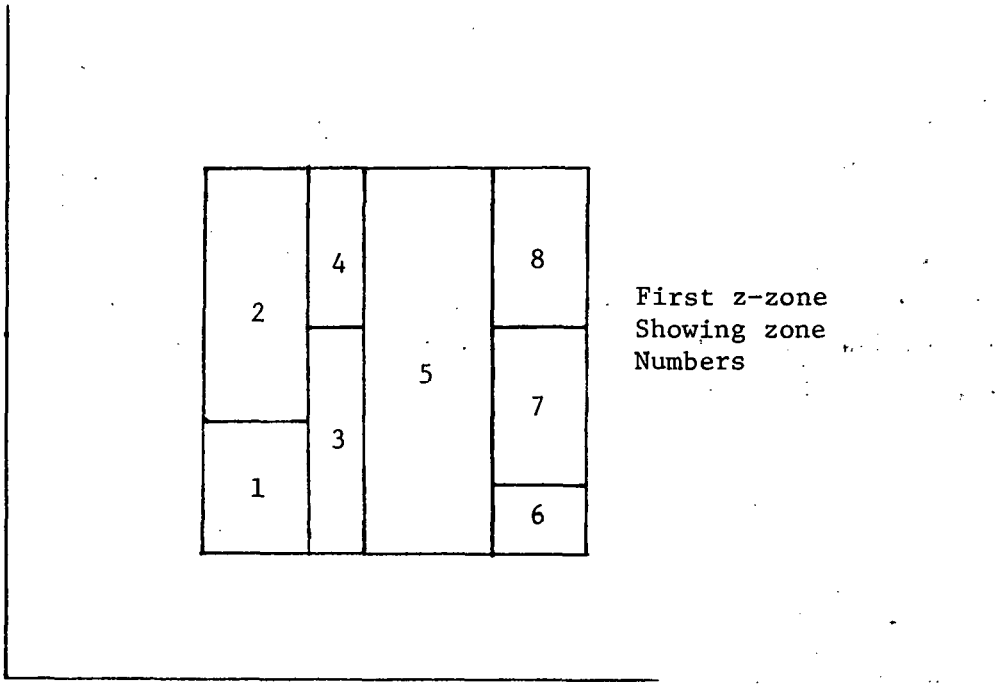


Fig. 23 Zone numbers for first z zone.

column, the zone numbers are listed and in the "Regions in the Zone" column, the corresponding regions are listed. This table will be precisely the input required by RAFFLE for describing the regions contained in the zones.

"Zone Number"	"Regions in the Zone"
1	$n_1, n_2, \ldots$
2	$n_1, \ldots$
⋮	⋮

If there is more than one region per zone, the region numbers for the zone should optimally be arranged in order of decreasing region volume contained within the zone. Thus, the first region number should be for the region occupying most of the individual zone volume, the second region number for the region occupying the second greatest portion of the zone volume, and so forth. (The ordering here, for the table and input cards, is from left to right, with the first region number being the leftmost, etc.) RAFFLE searches the regions in order of input by the user, and this arrangement minimizes computer time.

7.3.4 *Construction of the Cylindrical r, z Zone Description.* As for all the zone descriptions, the center point, or reference coordinate point (x_o, y_o, z_o), must first be chosen to describe the r, z zone overlay. All the radial (r) and z lines will be assigned values relative to this zone coordinate origin. To select the zone center point, and to begin the zone description, the entire volume of the problem (physical volume plus surrounding

vacuum region) is first enclosed by a right circular cylinder, as shown in Figure 24. This cylinder is the zone geometry extent, and the zone geometry center point is the bottom point on the axis of the cylinder as depicted in Figure 24. The axis of the cylinder must be parallel to the z axis of the original reference frame chosen by the user. The total zone cylinder can be larger than the total volume of the problem; however, the cylinder must be entirely in the first octant of this original coordinate frame as illustrated above. Hence, $z_o \geq 0$, and x_o, y_o, must both be greater than zero and must have values such that the entire cylinder lies in the first octant. To have a minimum number of regions per zone, the r, z overlay should be used when the problem has cylindrical symmetry, and the axis of the cylinder should be chosen to coincide with the axis of symmetry.

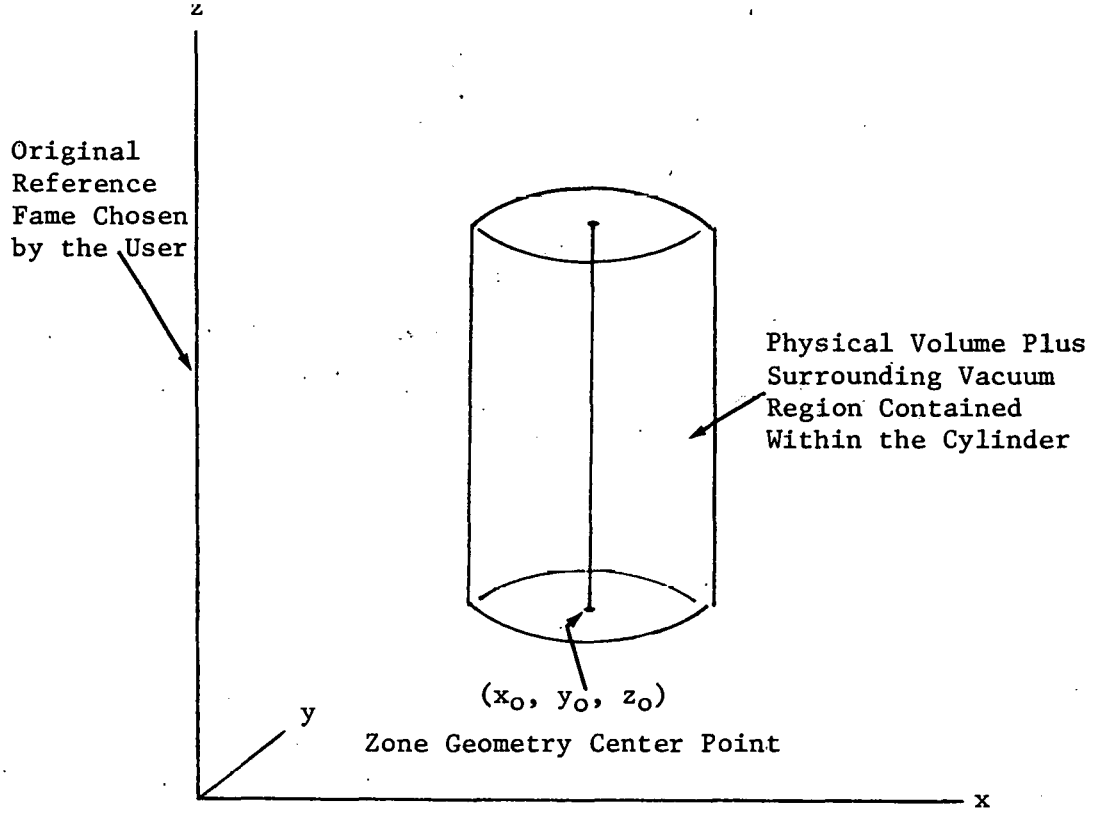


Fig. 24 Coordinate system for cylindrical zones.

Once the zone extent is defined (or mentally visualized), the z planes ("z lines") must be assigned. The first z line is the bottom of the zone extent cylinder and the last z line is the top of the cylinder. There may be any number of additional z lines assigned between these two planes and they may be arbitrarily spaced. The first z line, the bottom of the cylinder, has a value z = 0.0 (since it coincides with z_o) and the other z values are relative to this first z line (z plane). For any problem, there must be a minimum of two z planes defined, the bottom and top z planes of the total zone cylinder.

As depicted in Figure 25, the z lines which are planes perpendicular to the z axis, divide the cylinder into stacked cylinders called "z zones". The z zones are numbered from bottom up. Each z zone will contain cylindrical annuli which are the individual zones, and this z zone numbering will be used in referring to these individual zones.

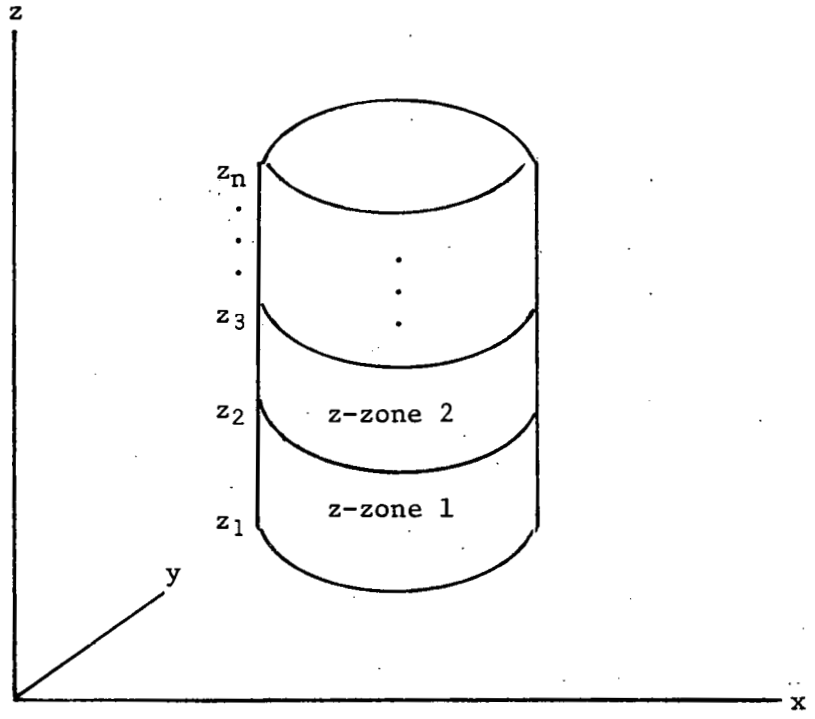
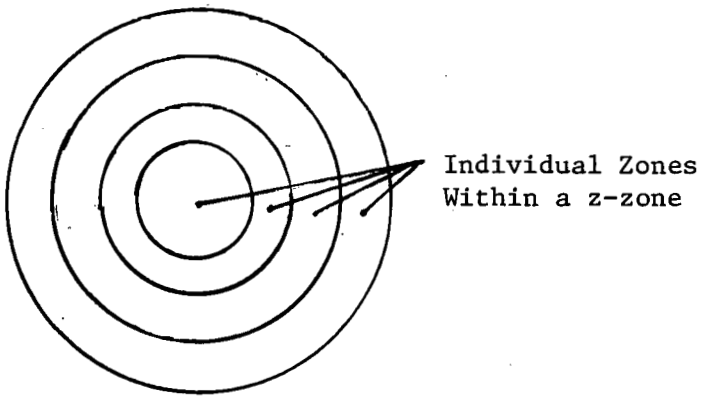
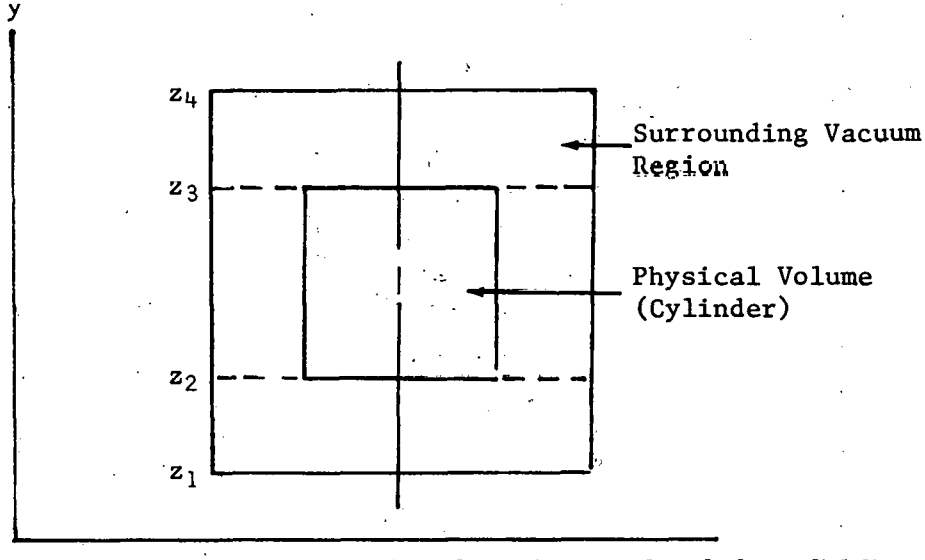


Fig. 25 Cylindrical z zones.



To have a minimum number of regions per zone, the z lines should be chosen to coincide with the z plane surfaces of the problem. For example, if the physical volume is a cylindrical reactor, four z lines can be used efficiently to partition the zone cylinder. After the z lines have been defined, which in turn defines the z zones, the radial lines for each z zone must be defined. Each z zone has its own independent radial lines. For a particular z



zone (Figure 26), the radial lines may be arbitrarily spaced and the radial lines assigned values with respect to the axis of the zone cylinder.

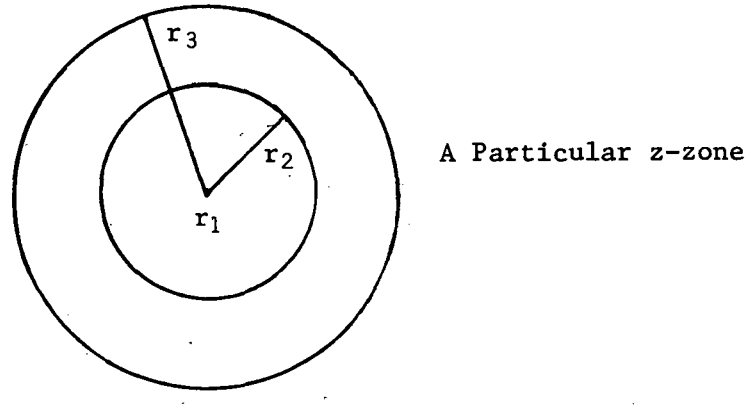


Fig. 26 Radial lines in a cylindrical z zone.

The first radial line, or radius, must always be r = 0.0 (the center line) and all the outermost radial lines of every z zone must have the same value. In the above example, the radial lines r_1, r_2, and r_3 divide the particular z zone into two cylindrical annuli, with r_1 = 0.0. If r_3 is the outer radial line of this z zone, then all the other outermost radial lines of the other z zones must equal r_3.

The radial lines thus define the individual zones for the r, z zone geometry. An individual zone is the volume in a z zone between two adjacent radial lines with width $r_{i+1} - r_i$ and having a height of $z_{k+1} - z_k$, where z_{k+1} and z_k are the two adjacent z lines forming a z zone. For the previous illustration (Figure 26), the individual zones are shown in Figure 27, where each individual zone is denoted by the word "zone". Analogous to this z zone each of the other z zones can have its own unique annular zones.

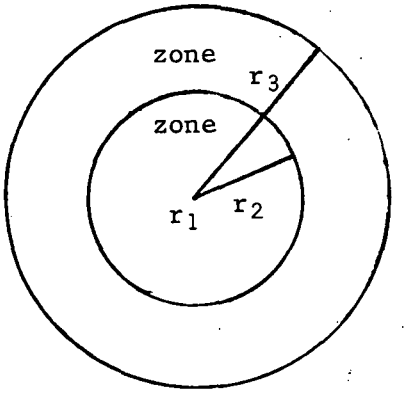


Fig. 27 Individual zones for a particular z zone.

For optimal zone overlay, the radial lines should be chosen to coincide with the radial surfaces of the problem so that one cylindrical-annular region is contained in one cylindrical-annular zone. The zones should thus be defined to contain one region per zone or one dominant region per zone, filling most of the zone volume. Every region, in both the physical volume and surrounding vacuum region, must be contained in one or more of the individual zones. *As with the rectangular overlay there can be no more than seven regions contained in one individual zone.*

7.3.5 *Format of Input for the r, z Lines.* All the z lines, defining the z zones, are input in one group to the RAFFLE code. The z lines, in centimeters, are input in increasing order,

$$z_1, z_2, \ldots z_n$$

with

$$z_1 = 0.0$$

and

$$z_1 < z_2 < z_3 < \ldots < z_n \quad .$$

The z values are relative to z_1 and there must be a minimum of two z lines input.

After the z lines, all the radial lines are then input in one group. The radial lines, in centimeters, are input in order of increasing z zone (from bottom to top z zone), and within each z zone the radial lines are arranged in increasing order of value;

$$r_1^{(1)},\ r_2^{(1)},\ \ldots\ r_{n_1}^{(1)},\ r_1^{(2)},\ r_2^{(2)},\ \ldots\ r_{n_2}^{(2)},\ \ldots$$

where the superscript denotes the z zone number. The first radial line of each z zone must be zero,

$$r_1^{(1)} = r_1^{(2)} = \ldots = 0.0$$

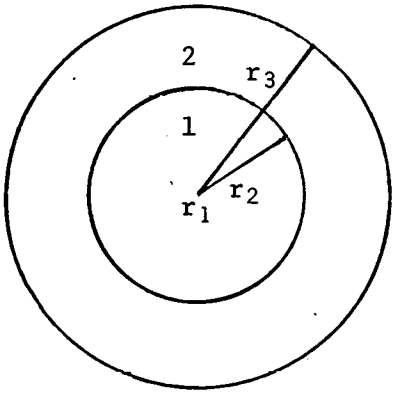
and the outer radial lines of each z zone must be equal,

$$r_{n_1}^{(1)} = r_{n_2}^{(2)} = \ldots \quad .$$

There must be a minimum of two radial lines read in per z zone. The input card formats for this sequence are defined in Section V.

7.3.6 *Numbering the Individual r, z Zones.* After the zone overlay has been defined, each individual zone must then be assigned a unique zone number, with the zone numbers running consecutively from 1 to the total number of individual zones. The zones are numbered according to increasing z zone number and within a z zone according to increasing radial line; the zone numbers run consecutively from one z zone to the next higher z zone. In the previous illustration (Figure 27), if the z zone pictured was the first z zone (the bottom z zone), the two zones would be numbered as shown below. The numbering would continue in this manner, from inner to outer annulus, for the other z zones with the first zone of the second z zone having the number 3.

The zones are numbered to identify the individual regions in a particular zone, where a region is to be considered in a zone if any portion of it is contained within the individual zone volume.



First z-zone Showing Zone Numbers

RAFFLE requires the region numbers contained within each zone number, where the region numbers are those previously assigned to the individual regions. All individual regions, in both the physical volume and the surrounding vacuum region, must be assigned to one or more zones as stated previously, and a maximum of seven regions per zone is allowed.

Analogous to the rectangular overlay, it is a good practice to construct a table listing the zone numbers and region numbers per corresponding zone number.

"Zone Number"	"Regions in the Zone"
1	$n_1, n_2, \ldots$
2	$n_1, \ldots$
⋮	⋮

Once constructed, this table need merely be transferred to cards for the required input to RAFFLE. If there is more than one region per zone, the region numbers in a zone should be arranged in order of decreasing zone volume occupied by the region. The first region number (the leftmost) should be for that region occupying most of the individual zone volume, the second region number for the region occupying the next greatest volume, and so forth.

7.3.7 *Construction of the Cylindrical r, Θ, z Zone Description.* The cylindrical r, Θ, z zone description is analogous to the cylindrical r, z zone description with angular Θ lines merely being added to describe variations in the angular direction. Because of the similarity between the r, Θ, z zone description and r, z zone description, the r, Θ, z zone description will be brief with references being made to r, z description.

For the r, Θ, z description, the entire volume of the problem is first enclosed in a right cylindrical volume. This right cylinder, which is the zone geometry extent, must encompass both the physical volume and surrounding vacuum region. The outer surfaces of this cylinder usually coincide with the outer surfaces of the surrounding vacuum region (for optimal zone descriptions), but the cylinder may have greater extent. Analogous with the r, z zone description, for the r, Θ, z zone descriptions:

(1) The entire cylinder must lie in the first octant of the originally defined coordinate frame, and its axis must be parallel to the z axis of the frame.

(2) The zone geometry center point (x_o, y_o, z_o) must lie on the axis of the cylinder, on its bottom z plane.

For optimal zone description, the axis of the cylinder should coincide with the cylindrical axis of symmetry of the problem.

The z plane surfaces, z lines, are first defined for this zone cylinder. Analogous with the r, z zone descriptions:

(1) The z lines may be arbitrarily spaced, cutting the zone cylinder at any heights.

(2) The first z plane must be z = 0.0 and all the other z values are with respect to this first plane.

(3) For a problem, there may be any number of z lines defined; however, there must always be a minimum of two z lines, the bottom and the top z planes of the cylinder.

The z planes ("z lines") divide the cylinder into stacked z zones, and as for the r, z geometry, the z zones are numbered from bottom to top. For optimal zone description, the z planes should coincide with the z surfaces of the problem.

Once the z planes, and hence z zones, have been defined, the radial and angular lines are then defined for each z zone. Each z zone has its own unique radial and angular lines. The radial lines are defined in the same as for the r, z zone description; the first radial line of every z zone must be r = 0.0 and the outermost radial lines of every z zone must all be equal. The radial line values are the actual radii from the cylinder axis. A z zone may have any number of radial lines, but for any problem there must always be a minimum of two radial lines defined for a z zone ($r_1 = 0$ and the outermost radius).

Once the radial lines have been defined, angular (Θ) lines must additionally be defined for each circular annulus. The circular annuli are denoted as "radial zones" for future reference. For each radial zone, Θ lines are assigned such that the angles (Θ) range from values greater than 0 to 360^o. The angles are in degrees and are with reference to the x axis of the originally defined coordinate frame. *For each radial zone, the angles 90^o, 180^o, 270^o, and 360^o must always be included*; in addition to these four angles, other values may be arbitrarily assigned by the user.

Figure 28 illustrates an example of Θ lines defined for a particular radial zone in a particular z zone. It is noted that the mandatory angles 90^o, 180^o, 270^o, and 360^o are defined plus additional angles to account for angular variation. It is also noted that 0^o is treated as 360^o; the first angle is Θ_1 (or 90^o if there is no intermediary angle) and is not 0^o.

The individual zones for the r, Θ, z description are the volumes contained within adjacent Θ lines, for a given radial zone and z zone. The zones for the previous illustration are depicted in Figure 29.

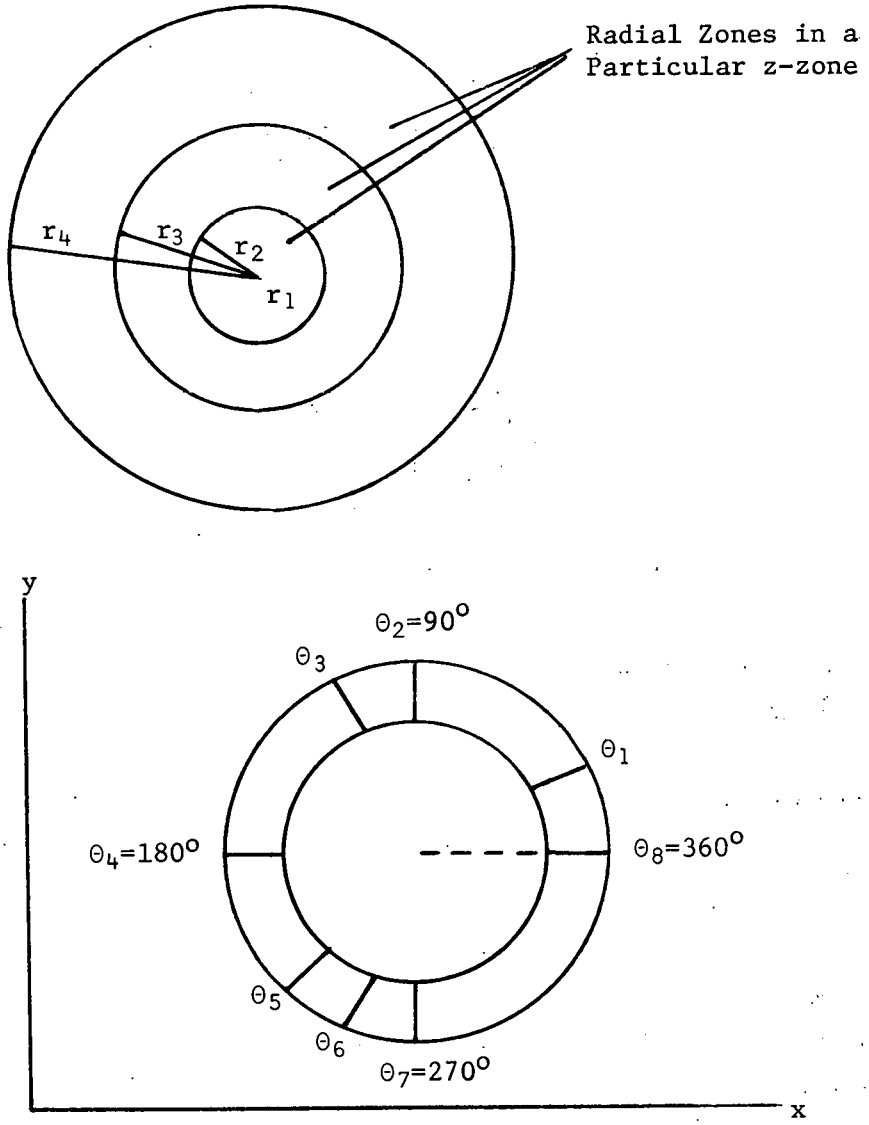


Fig. 28 Theta lines in a radial zone.

7.3.8 *Format of Input for the r, Θ, z Lines.* For RAFFLE input, all the z lines are input in one group, all the radial lines are input in one group, and all the Θ lines are input in one group. The z lines, in centimeters, are input in increasing order of value;

$$z_1,\ z_2, \ldots z_n$$

with

$$z_1 = 0.0$$

and

$$z_1 < z_2 < \ldots < z_n \quad .$$

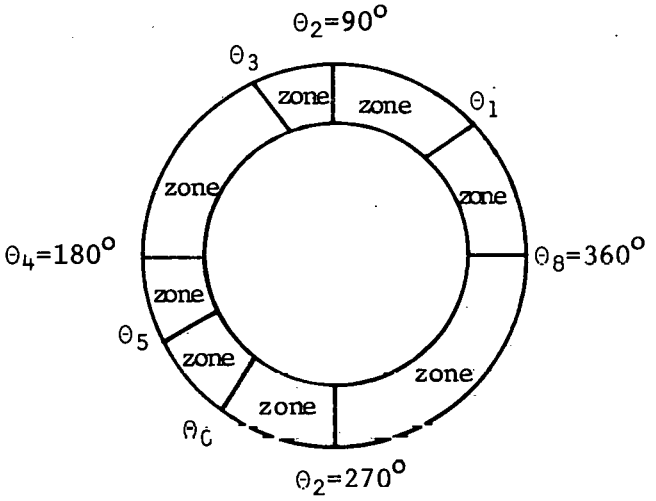


Fig. 29 Individual zones for a given radial zone.

The z lines have values relative to z_1, and there must be a minimum of two z line values read in for any problem.

The radial lines are input in exactly the same order as for the r, z zone description, from bottom to top z zone and from inner to outer value for a given z zone;

$$r_1^{(1)},\ r_2^{(1)},\ \ldots\ r_{n_1}^{(1)},\ r_1^{(2)},\ r_2^{(2)},\ \ldots\ r_{n_2}^{(2)},\ \ldots\ ,$$

where the superscript denotes the z zone number. The first radial line of each z zone must be zero and the outer radial lines must be equal for all the z zones. For a given z zone, the radial lines must be arranged in increasing order of value, and there must always be a minimum of two radial lines for each z zone, $r_1 = 0$ and the outermost radius.

The Θ lines are input in increasing value for a given radial zone, from inner radial zone to outer radial zone, and from bottom z zone to top z zone. The Θ lines values are in degrees, with reference to the x coordinate axis of the originally defined coordinate frame.

$$\Theta_1,\ \Theta_2,\ldots\Theta_{m_1}\ ,\ \Theta_1,\ \Theta_2,\ldots\Theta_{m_2}\ \ldots\quad \Theta_1,\ \Theta_2,\ldots\Theta_{n_1}\ ,\ \Theta_1,\ \Theta_2,\ldots\Theta_{n_2}\ \ldots$$

Radial Zone 1 Radial Zone 2 | Radial Zone 1 Radial Zone 2

z Zone 1 | z Zone 2

In the above input illustration, the "radial zone" numbers increase from inner radial zone to outer radial zone (i.e., radial zone numbers increase as radial line values increase). For each radial zone, the angles 90^o, 180^o, 270^o, and 360^o must always be included and any

additional angles must be input such that the values are arranged in increasing order.The value 0^o is never input since this values corresponds to 360^o.

7.3.9 *Numbering the Individual r, Θ, z Zones.* The individual zones are numbered in the same order that the Θ lines are input. The zone numbers must begin with 1 and increase consecutively to the total number of individual zones. For a given radial zone, the zones are numbered in order of increasing angle; the numbering is thus counterclockwise. The numbering is continued to the next outer adjacent radial zone, and when all the radial zones of a given z zone have been assigned indices, the numbering continues to the next higher z zone. An example of zone numbering is shown in Figure 30, where the z zone depicted is z zone 1. The numbering would continued in this manner for z zone 2 and the higher z zones.

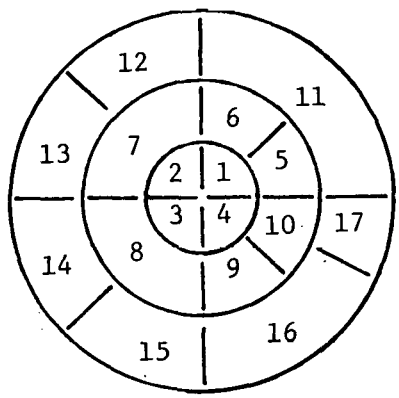


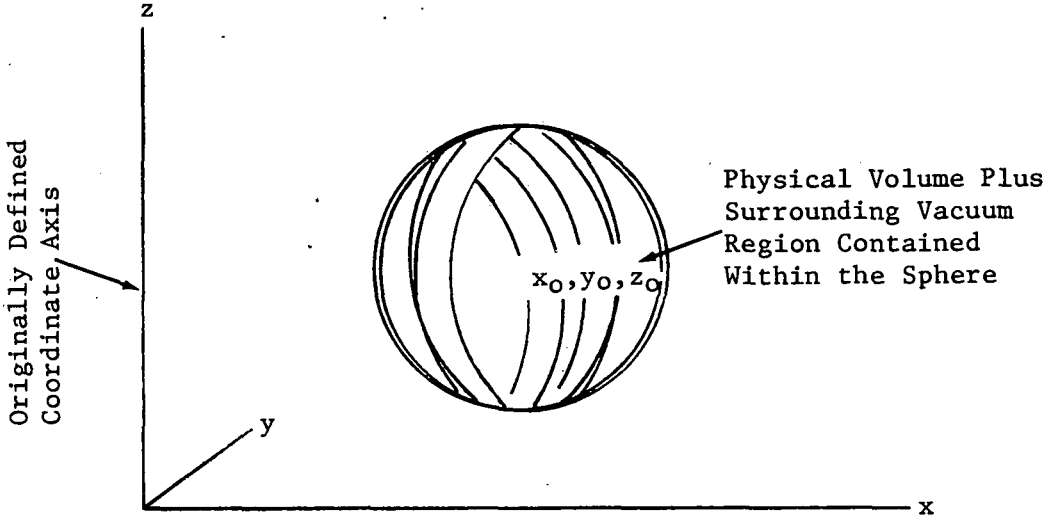
Fig. 30 First z zone showing the zone numbers.

After the zones are numbered, the individual regions, or portions of individual regions, within each zone must be determined. The input needed for RAFFLE are the region numbers within each zone number. For this data, it is wise to construct a table listing the zone numbers and corresponding region numbers in each zone. The table then can be simply transferred to cards. All the defined regions must appear in one or more zones and a maximum of seven regions per zone is allowed. As for the r, z zone descriptions, if there is more than one region per zone, the region numbers should be optimally arranged in order of decreasing zone volume occupied.

7.3.10 *Construction of the Spherical Zone Description.* The spherical zone description is the simplest to set up, but, for optimal zone overlay, should only be used when the problem has spherical symmetry. For the spherical zone description, the entire volume of the problem (physical volume plus surrounding vacuum region) is first enclosed in a sphere. The sphere represents the total zone extent and the total volume of the zone description. The zone geometry center point x_o, y_o, z_o must be the center of the sphere, where x_o, y_o,

z_o are with respect to the originally defined coordinate axis. The sphere must lie entirely in the first octant of this coordinate axis; consequently, the zone geometry center point x_o, y_o, z_o must be such that $x_o > 0$, $y_o > 0$, $z_o > 0$.

With the zone sphere defined (or mentally visualized), the radial lines for the sphere must be defined. These radial lines are simply the radii of spherical surfaces that subdivide the sphere into spherical annuli, and these spherical annuli are the individual zones for the spherical zone description. There may be any number of radial lines assigned and these radial lines may be spaced arbitrarily. The first radial lines, r_1, must be 0.0, and there must always be a minimum of two radial lines defined for any problem; that is $r_1 = 0.0$ and the outer radius of the sphere. These radial lines, or radii, will be input to RAFFLE to define the spherical zone geometry description.



In Figure 31, illustrating an example of radial lines assigned, the four radial lines $r_1 = 0.0$, r_2, r_3, and r_4 subdivided the sphere into three spherical annuli, which are individual zones. The outer radial line r_4 is the outer radius of the total zone sphere and must be such that the physical volume plus surrounding vacuum region is contained totally within the sphere.

To have a minimum number of regions contained within an individual zone, the spherical surfaces defined by the radial lines should coincide with the spherical surfaces previously defined for the problem. Thus, the spherical zone description is optimal when all the regions are spherical annuli and when each region coincides with one individual zone. As for all the zone descriptions, when one region per zone is not possible, then the individual spherical annular zones should be chosen such that one region is dominant, filling most of an individual zone volume.

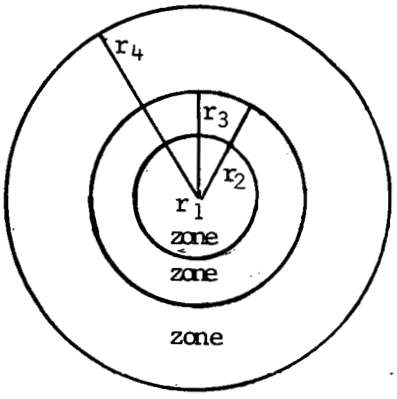


Fig. 31 Illustration of the spherical zone description.

7.3.11 *Format of Input for the Radial Lines.* For the spherical zone description, the radial lines, in centimeters, are input to RAFFLE in order of increasing value, with the first value always 0.0; that is

$$r_1, r_2, \ldots r_n$$

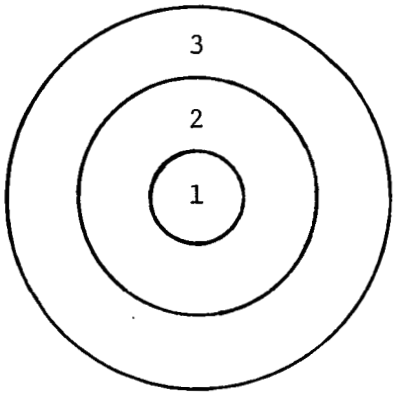
with

$$r_1 = 0.0$$

and

$$r_1 < r_2 < \ldots < r_n \quad .$$

7.3.12 *Numbering the Individual Spherical Annular Zones.* The spherical annular zones are numbered from inner spherical annulus to outer spherical annulus. The first zone, nearest the sphere center point, has the number 1 and the numbers then increase consecutively to the outer spherical annulus. For the previous illustration (Figure 31), the zone numbering is shown below.



The Zone Numbers for The Spherical Zone Illustrated

After the individual zones are numbered, the individual regions within each zone must be identified. As for the other zone descriptions, this is best done if a table is constructed with the individual zone numbers and the region numbers contained in the zone.

"Zone Number"	"Regions in the Zone"
1	$n_1, n_2, \ldots$
2	$n_1, \ldots$
⋮	⋮

Again, as for all zone descriptions, a maximum of seven regions per zone is allowed. Also, if there is more than one region per zone, the regions in a zone should optimally be arranged in order of decreasing zone volume occupied.

IV. APPLICATION TO NEUTRON TRANSPORT PROBLEMS

This section describes the types of problems solved by RAFFLE and presents guidelines for the selection of options and the use of biasing techniques. The mnemonic names of the RAFFLE input data are capitalized to aid cross reference with Section V where the rules for preparing the input data are given.

Proper selection of options and use of biasing techniques can often save considerable computer time. However, improper use can produce misleading results by introducing systematic errors. The purpose of the guidelines given in this section is to assist the user in getting reliable answers in a reasonable amount of computer time. Optimization requires detailed consideration of the physics of each problem. In many cases if reasonable choices are made the computer time changes slowly about its minimum as the biasing parameters vary. It is recommended that the user read Section II, "THE MONTE CARLO OF RAFFLE", before using the guidelines presented in the present section.

RAFFLE can be used to solve two classes of problems, where the class of problem is associated with the type of information obtained. These two classes of problems are: (a) problems for which multigroup, volume integrated fluxes and reaction rates are desired, and (b) problems for which the averaged groupwise cross sections and P_0 and P_1 transfer matrices are desired. In a given computer run, only one class of information can be obtained (i.e., one class of problem can be solved). The flag in RAFFLE that the user must set is ITRAGG; if ITRAGG = 0, Class 1 information is obtained, and if ITRAGG = 1, Class 2 information is obtained. For a given problem, the user may, of course, make two computer runs with ITRAGG having its value changed for each run (with certain other changes needed). However, this is not the usual case, since the user generally desires only one class of information. These two classes of problems, or equivalently the two classes of information obtained, will be discussed separately. Since the cross section type problems involve only a few simple modifications of the flux and reaction rate problems, the reader should read the flux and reaction rate sections first.

1. PROBLEMS FOR WHICH FLUXES AND REACTION RATES ARE DESIRED (ITRAGG = 0)

1.1 General Problem Description

This is the usual class of problem solved and includes iteration problems and external source problems. An iteration problem, IXTERN = 1, is the standard eigenvalue (k) problem

in which, in addition to k, the fundamental mode fluxes and reaction rates are obtained. An external source problem, IXTERN = 2 or 3, is one in which a defined source (or sources) generates the subsequent neutron fluxes and reaction rates. In an external source problem, the source neutrons may undergo fissions and generate fission neutrons. If there is no fission in the external source problem, or if the flux contribution from the fission neutrons is not included, then the problem is said to be "an external source type with fission daughters not being followed" and IXTERN = 2. If there is inclusion of the flux contribution from the fission generated neutrons, called "fission daughters", then the problem is said to be "an external source type with fission daughters followed" and IXTERN = 3. (In an eigenvalue problem, IXTERN = 1, the flux contribution from fission generated neutrons is always included.)

1.2 Iteration Problems

NIVO neutrons are stored to start a generation for an iteration problem. An initial source distribution for the first generation is entered as part of the input data, and a value of 1.0 is assumed for k. A stored neutron is processed as described in Section II until its history terminates. At each collision in a region containing a fissionable material a contribution to the weight for a daughter neutron is generated. At each collision the generated contribution is added to the sum of all previous contributions since the start of the history or the storage of the previous daughter. At the collision where the accumulated weight equals or exceeds the estimate of k as updated at the end of the previous generation, a daughter neutron is stored with a weight of k and with the coordinates of this collision. The updated k includes results for all previous tallied generation. This stored neutron will be used as part of the source for the next generation where the daughters are processed sequentially. The accumulated weight is decreased by k and the above process repeated until the history terminates. At the end of the history it may be necessary to store a neutron with a weight less than the estimated k. Source neutrons for the present generation are processed until NIVO neutrons have been stored for the next generation. If necessary, processing of the source neutrons is repeated until NIVO daughters have been stored.

For an iteration problem, the errors on the RAFFLE estimates of k are meaningful only after the neutron distribution has reached equilibrium. Therefore, enough generations to achieve equilibrium should be processed before the actual tallies started. The number of initial generations to process is specified by INNGEN.

The number of generations needed to reach equilibrium is highly dependent on the reactor properties. For thermal reactors where the average number of collisions per neutron history is high, it has been found that three to five generations with about 30 neutrons per

generation, NIVO = 30, are often sufficient to reach equilibrium. When running thermal problems, the user is advised to run initial problems with NIVO small and RTIME = 0.0 to check the running time (see Section IV.1.5). For fast reactors where, on the average, a neutron makes only a few collisions before being lost, 10 to 25 generations with NIVO = 256 are usually needed. Again the user is cautioned that any general guidelines can be misleading in some cases. If INNGEN is too small, a systematic error can result; if it too large, computer time is lost.

For iteration problems difficulties arise when an attempt is made to find the flux distribution among uncoupled regions. If the degree of coupling between two identical regions is very small, the ratio of the fluxes for the two regions may become very large. Combining the two regions into one region-set gives a valid answer for the sum of the fluxes in the two regions.

1.3 Additional Constants Obtained for Iteration (k) Problems

The eigenvalue, or generation factor, k obtained by RAFFLE is a generation-based value;

$$k = \frac{\int_V dV \int_o^{E_o} dE\ \nu\Sigma_f\phi(\bar{r},E)}{\int_V dV \int_o^{E_o} dE\ \Sigma_a\phi(\bar{r},E) + \oint_S dS \int_o^{E_o} dE\ J(\bar{r},E)}$$

where V is the total volume and $J(\bar{r},E)$ is the outward current. E_o is the maximum energy of the problem, taken to be 10 MeV. The eigenvalue is thus the average number of fission neutrons generated from one original fission source neutron. The RAFFLE code computes k in two different ways and combines the two computations into a value having the minimum statistical error. The two individually computed values and the best combined value are all printed out with their associated fractional probable errors ($\delta k/k$ where δk is the respective probable error). These k values differ only in the statistical estimation techniques used and the statistical error associated with each value; all three values are theoretically given by the one equation above. (The "best" value of k is thus the one with the smallest fractional probable error, since no value involves any physical approximations.)

In addition to k, a "lifetime" t_L and a "generation" time t_g are also printed out by RAFFLE. For the computation of these values, all fission neutrons for a particular generation are taken to be born at t = 0.0. Also, the total fission source strength for the generation is normalized to unity. The lifetime t_L is then defined as

$$t_L = \int_V dV \int_0^{E_0} dE \int_0^{\infty} dt\ t\ \Sigma_a\phi(\bar{r},E,t) + \oint_S dS \int_0^{E_0} dE \int_0^{\infty} dt\ t\ J(\bar{r},E,t) ,$$

where $J(\bar{r},E,t)$ is the outward current. The lifetime t_L is thus the true average time of life for the fission source neutron -- the interval of time from birth to absorption or leakage. The generation time t_g is defined as

$$t_g = \frac{\int_V dV \int_0^{E_0} dE \int_0^{\infty} dt\ t\ \nu\Sigma_f\phi(\bar{r},E,t)}{\int_V dV \int_0^{E_0} dE \int_0^{\infty} dt\ \nu\Sigma_f\phi(\bar{r},E,t)}$$

and is the true average of time to the birth of the next generation daughter. These lifetime and generation time values will be printed out with their corresponding fractional probable errors ($\delta t_L/t_L$ and $\delta t_g/t_g$).

1.4 Fixed Source Problems

In a fixed source problem in which the contributions from fission daughters to the fluxes or reaction rates cannot be neglected, the fission daughters must be followed. In this instance failure to set IXTERN = 3 will produce a systematic error. In addition to setting IXTERN = 3 when following the fission daughters, values must be entered for MAFIS, IAFIS, and perhaps CFISK. MAFIS specifies the maximum number of fission daughters that can be stored for a neutron history. The uses of the flag IAFIS that determines the method of storing daughters and the weight CFISK are explained below.

As a neutron passes through a fissionable material a fractional fission daughter weight is generated at each collision. Consider first the option where the flag IAFIS = 1. In this case a value must be entered for CFISK. At each collision the generated fission daughter weight is added to the sum of the previous weights for the history. At the collision where this sum equals or exceeds CFISK, a fission daughter is stored with a weight of CFISK and with the coordinates of this collision. After a daughter is stored the accumulated weight is decreased by CFISK and the process repeated until MAFIS fission daughters have been stored or the history terminates. When a history terminates, a daughter is stored with the weight accumulated up to that time. When the termination occurs in a nonfissionable material the daughter is stored at the site of the last collision in a fissionable material. If the option IAFIS = 2 is used, a daughter of generated weight is stored at each collision until the limit set by MAFIS is reached or the history terminates. In this case no entry is needed for CFISK. In either case, at the end of a history the stored daughters are processed in the same way as a source neutron. The maximum number of daughters that can be stored per source neutron is MAFIS.

If MAFIS is too small, the answers may be biased because significant fission daughters are neglected; if MAFIS is too large, computer time may be wasted on daughters that do not make appreciable contributions to the answers. Note that the maximum value for MAFIS is 200. For problems where fine details of the fission process are not important, a satisfactory procedure is to use 10 for MAFIS, set IAFIS to 1, and enter a value of 1.0 for CFISK. The particular choice for MAFIS is not critical in this case. An example of such a problem is one where only the total fission power is wanted.

If details of the fission process are of interest, the amount of information per source problem can be increased by using a small value of CFISK. Then a large number of daughters of low weight are produced per history; the effect is similar to splitting neutrons. MAFIS must be large enough to prevent bias from failure to store fission daughters. When using this procedure, it must be remembered that sufficient source particles must be processed to give a valid distribution of the collisions producing fissions.

If the problem is an external source type and the contributions from the subsequently generated fission neutrons are included in the flux and reaction rates, IXTERN = 3, then a "multiplication factor" k is computed for the problem. This multiplication factor is computed according to the formula

$$k = \frac{\int_V dV \int_0^{E_0} dE\ \nu\Sigma_f\phi(\bar{r},E)}{S}$$

where S is the total external source strength (integrated over energy, direction, and space). The multiplication factor is thus the average number of fission neutrons generated per external source neutron. As for the iteration type problems, this multiplication factor is statistically estimated in two different ways and optimally combined to obtain a third value, having the smallest statistical error. The fractional probable errors are printed out along with each of the three values. The symbol k is printed out by RAFFLE for the multiplication factor, which is the same symbol used by RAFFLE for the eigenvalue, or generation factor, for iteration type problems. There should be no confusion, however, as long as the definitions are kept in mind.

For external source problems with fission, in addition to the multiplication factor, a "lifetime" t_L and "generation time" t_g are also printed. To compute these values, as for the iteration case all neutrons are taken to be born at t = 0.0 and the total source is normalized to unity. The lifetime t_L is then calculated from the formula

$$t_L = \int_V dV \int_0^{E_0} dE \int_0^{\infty} dt\ t\ \Sigma_a\phi(\bar{r},E,t) + \oint_S dS \int_0^{E_0} dE \int_0^{\infty} dt\ t\ J(\bar{r},E,t)$$

where $\phi(\bar{r},E,t)$ is the flux from external sources and from generated fission neutrons. $J(\bar{r},E,t)$ is the outward current. The lifetime t_L is consequently the average time of life, from birth to absorption or leakage. The generation time t_g is given by the formula

$$t_g = \frac{\int_V dV \int_0^{E_0} dE \int_0^{\infty} dt\ t\ \nu\Sigma_f\phi(\bar{r},E,t)}{\int_V dV \int_0^{E_0} dE \int_0^{\infty} dt\ \nu\Sigma_f\phi(\bar{r},E,t)}$$

and represents an average time for fission neutron generation. These two quantities are usually of minor interest in the problem, but since their computation requires negligible computer time, they are output by RAFFLE with their associated fractional standard deviations.

1.5 Convergence and Batching Options

RAFFLE checks for convergence after each generation, where a generation is that number of histories required to produce NIVO new generation source daughters[a]. The batching option is described below. At the start of a generation NIVO neutrons are available for processing; the actual number processed may differ somewhat from NIVO. For fixed source problems computer time is usually saved by using 256, the default and maximum value, for NIVO. Exceptions may occur for problems which converge very quickly. The choice of NIVO for iteration problems is discussed in Section IV.1.2. As described in Section I, there is considerable flexibility in the criteria available for convergence and for terminating a problem. The fractional error which must be reached for convergence is entered as CHECK. Since the default value for CHECK is 1.0, a smaller value must be entered or execution will terminate the first time convergence is checked. The maximum CPU time allowed for the RAFFLE Monte Carlo calculations is specified by RTIME. Note, however, that the total CPU time required for a problem exceeds RTIME. Usually the total does not exceed RTIME by more than a minute. If the total CPU time allowed is too short, the problem may terminate without printing the results. When RTIME is reached before convergence the tallies are processed, the probable errors are computed, and the output data are printed just as if the problem converged. If a value of 0.0 is entered for RTIME, results are printed after each generation. Termination is then only by satisfaction of convergence or by exceeding maximum CPU time. This option may be useful for establishing the validity of iteration problems. The user may want to use a value of less than 256 for NIVO in order to

[a] It can be shown that NIVO is the expected number of histories required to produce NIVO daughters, and hence there is a stable iteration.

obtain more frequent checks on the changes between generations. The user is cautioned that when RTIME = 0.0 a large amount of data may be printed and that the maximum CPU time must be controlled external to RAFFLE.

RAFFLE tallies are processed as accumulated when batching is not used, IBAT = 0, or at the end of each generation if batching is used, IBAT = 1. The use of batching saves computer time, but the program does not properly account for "lost" neutrons when this option is used. If there are many collisions per history, say 50 or more, then the fractional time saved by batching is small while the error introduced by a lost neutron may be high. Thus, in this case it is usually desirable not to use batching. Typically, thermal systems and very large systems fall in the above category. On the other hand, high leakage fast systems often have only few collisions per history and batching saves considerable computer time without introducing appreciable nonrandom errors. Of course, batching may always be used when the number of lost neutrons is negligible.

1.6 Russian Roulette Cutoff Weights

The available scoring and cutoff options and their selection for a particular problem are discussed in Sections I and II. The scoring technique is selected by ISCORE and the cutoff option by NEXCUT. For a large class of problems, standard path scoring (ISCORE = 1) using standard Russian roulette (NEXCUT = 1) below WNCUT is effective, even when not the optimum choice. In addition to the flags and parameter above, the Russian roulette decision weight COMPR can be varied. The discussion below considers problems with ISCORE = 1, NEXCUT = 1.

At each collision the weight of a neutron is updated (see Section II.2), and when the weight drops below WNCUT Russian roulette is played to decide whether the history is terminated or the weight of the neutron is increased. To make the Russian roulette decision, a random number ρ is selected from a uniform distribution over the interval from 0 to 1. If ρ is greater than COMPR the history is terminated. Otherwise the weight is multiplied by the inverse of COMPR and the processing of the history continues. The default value of 0.5 for COMPR is satisfactory, even when not optimum, for most problems. If a value of 1.0 or greater is used for COMPR, a neutron history will never terminate from a reduction in weight. If a value of 0.0 or less is used the history will always terminate when the weight drops below WNCUT. This latter choice may be useful for problems where the neutrons are of no interest after their weight is below WNCUT.

The selection of a satisfactory value for WNCUT is quite problem dependent and only general guidelines are given. If values averaged over energy are used, the number of collisions, N, to reach WNCUT can be found by solving $(\bar{\Sigma}_s/\bar{\Sigma}_t)^N$ = WNCUT. In general, WNCUT should be set to give an acceptable average number of collisions to the lowest energy of interest before termination by Russian roulette.

If WNCUT is too low computer time can be wasted in following neutrons after they no longer influence the behavior of the system. On the other hand, setting WNCUT too high can result in so few neutrons reaching the lower energies that the values for the probable errors are not reliable. In extreme cases a correct choice of WNCUT is crucial. For instance, with a pure scatterer of infinite extent a solution can be obtained only if WNCUT = 1.0. For any other choice the first history will never terminate. However, for many problems as WNCUT is varied from its best value the computer time changes slowly, and the probable errors are reliable over a wide range of values on either side of the best value of WNCUT.

For a number of fast systems a value of 0.2 for WNCUT has been satisfactory as has 0.02 for a number of thermal systems. Again the user is cautioned that in particular extreme cases the above values may not be satisfactory. It is recommended that when in doubt the user make some estimate of WNCUT and run short problems with WNCUT at 2.0, 1.0, and 0.5 times the estimated value. Then the results can be used to decide whether further iteration is necessary.

For problems using multiple thermal groups (see Sample Problem III in Section VII), values are required for NTHCUT and NCOL2. If a neutron makes NTHCUT plus NCOL2 thermal collisions, Russian roulette is then played exactly as previously described. If the neutron survives, Russian roulette is subsequently played at each subsequent NCOL2th collision. The other cutoff procedures previously described apply to all neutrons, thermal or not. Thus, if NEXCUT = 1 Russian roulette is played whenever the weight drops below WNCUT.

If a satisfactory value is entered for WNCUT, the default values of 800 for NTHCUT and five for NCOL2 are always acceptable. For some problems, other choices may reduce computer time.

1.7 Uniform Interval Number Tables

RAFFLE uses uniform interval number tables to eliminate computation of logarithms, sines, or cosines in the course of the neutron's transport. The size of these tables is set by MEXP; for each variable specifying the direction and location of the neutron there are

2^{MEXP} entries in the corresponding number table. The size of these tables imposes a limit on the resolution in RAFFLE. The default and maximum value of nine for MEXP gives 512 entries per table and always provides adequate resolution.

1.8 Flux and Reaction Rate Information

For either the iteration k problem or the external source problem, the user must input as part of the data the energy cutoffs E_g. These cutoffs define the group structure for the problem, with group g defined to be the energy range from E_g to E_{g+1}, $E_{g+1} < E_g$. As explained in Section VII, groupwise microscopic cross sections must be input for each isotope in the problem according to this same group structure definition. In addition to being used for the groupwise cross section data, the group structure defines the maximum obtainable energy resolution; the procedure for using group sets to obtain less detailed information is described in Section IV.1.9. Since the group structure is completely arbitrary, any particular detailed flux and reaction-rate information can be obtained; however, the information will only be obtained groupwise for the group (group set) structure defined.

The maximum spatial resolution obtainable is the groupwise and flux reaction rates integrated over the defined regions of the problem. The coalescing of regions into region sets is also described in Section IV.1.9. Since the regions must have homogeneous properties, but otherwise can be arbitrarily defined (see Region Descriptions, Section III.5), any spatial detail is obtainable; however, the groupwise fluxes and reaction rates can only be obtained in a volume-integrated form, for the individual regions defined by the user for the problem.

Thus, for both the iteration type and external source type problems, if E_g is the defined group structure and V_h is the volume of an individual region, the fluxes ϕ_{gh} and reaction rates R_{gh} obtained will be:

$$\phi_{gh} = \frac{\int_{V_h} dV \int_{E_{g+1}}^{E_g} dE\ \phi(E,\bar{r})}{S}, \quad g = 1, 2, \ldots G, \quad h = 1, \ldots, H$$

$$R_{gh} = \frac{\int_{V_h} dV \int_{E_{g+1}}^{E_g} dE\ R(E,\bar{r})}{S}, \quad g = 1, 2, \ldots G, \quad h = 1, \ldots, H \quad ,$$

where $R(E,\bar{r})$ is the particular pointwise reaction rate and $\phi(E,\bar{r})$ is the pointwise scalar flux. This information can be obtained for all the groups defined G and for all regions defined H.

(The H regions are those in the physical volume of the problem.) The normalization constant S is the total source strength. For iteration (k) problems,

$$S = \int_V dV \int_o^{E_o} dE \; \nu\Sigma_f\phi(E,\bar{r})$$

where V is the total (physical) volume of the problem and E_o is the maximum energy of the problem, taken to be 10 MeV. For external source problems, S is the total integrated external source intensity,

$$S = \int_V dV \int_o^{E_o} dE \; S(\bar{r},E)$$

where $S(\bar{r},E)$ is the defined pointwise source intensity. For external source problems with current sources, S is the total number of incoming neutrons (i.e., the source currents integrated over surfaces, energy, and direction). If the external sources (volume or current) generate fission neutrons, S is still only the original total source intensity and does not include the generated fission neutron intensity. For either type problem, the fluxes and reaction rates are thus given in units of "per source neutron".

For either iteration or external source problems, the particular groupwise and regionwise reaction rates obtained are:

$(\Sigma_a\phi)_{g,h}$, the groupwise and regionwise absorption rate

$(\upsilon\Sigma_f\phi)_{g,h}$, the groupwise and regionwise fission source rates.

If the problem includes resonance, these reaction rates are subdivided into the resonance contribution and the total contribution (resonance plus smooth).

All of the groupwise and regionwise reaction rates and fluxes will be printed with their associated fractional probable errors. If $\delta\phi_{gh}$ and δR_{gh} are the flux and reaction rate probable errors, respectively, then the errors printed out will be $\delta\phi_{gh}/\phi_{gh}$ and $\delta R_{gh}/R_{gh}$.

1.9 Coalescing the Groups and Regions into Group Sets and Region Sets

As an overlay on the defined group structure and the defined regions, the user must specify a group set structure and a region set structure. This simply involves collecting the groups and regions into unique sets. With this set structure defined, "group set" and "region set" fluxes will be obtained, i.e., the regionwise and groupwise fluxes will be summed over the groups and regions in the particular group set and region set. This collecting, or

coalescing, of groups and regions into broader groups and into larger regions is thus used only for the structure of output desired. Even if coalesced broad group information is wanted, a finer group structure E_g is desirable since the microscopic isotope group cross sections are input according to this original finer group structure, and the neutron transport is computed with these finer groups as data. Likewise, the finer region definition may be necessary because of the physical inhomogeneities of the problem, even though no spatial information is desired.

Let G be the group set numbers, G = 1, 2,...,G_T where G_T is the total number of group sets. Analogously, let H be the region set numbers, H = 1, 2,...,H_T, where H_T is the total number of region sets. A particular group set G is defined by assigning various groups to be in it;

$$G = \{g_1, g_2, \ldots, g_n\} .$$

A particular region set H is defined by assigning various regions to be in it;

$$H = \{h_1, h_2, \ldots, h_m\} .$$

Each group and region must be in some group set and region set, respectively; however, a particular group or region cannot appear in more than one group set or region set. With these restrictions observed, any allocation of the groups and regions to the group sets and region sets is permissible. (Usually adjacent groups are combined in a group set; this is not necessary, though.) To define the group sets and region sets for the RAFFLE input, a group set number and a region set number are simply assigned to each group and region, respectively, where these set numbers increase consecutively from 1.

With the group sets and region sets defined, the fluxes and reaction rates are printed out for this overlay structure; fluxes and reaction rates are always printed out by RAFFLE according to group and region set. These group set and region set fluxes and reaction rates are simply summations of the groupwise and regionwise fluxes and reaction rates, summed over the groups and regions in the group sets and region sets. The fluxes and reaction rates printed out are thus ϕ_{GH} and R_{GH};

$$\phi_{GH} = \sum_{\substack{g \in G \\ h \in H}} \phi_{gh}$$

$$R_{GH} = \sum_{\substack{g \in G \\ h \in H}} R_{gh} .$$

The numbers G and H are the particular group set number and region set number, respectively. The quantities ϕ_{gh} and R_{gh} are the groupwise and regionwise fluxes and reaction rates defined in the previous section, and the summation is over all groups in group set G and over all regions in region set H. If one group is assigned to the group set G, and one region corresponds to the region set H, then the group set and region set flux and reaction rate simply correspond to the groupwise and regionwise flux and reaction rate.

The fractional errors printed out by RAFFLE are for the region and group set fluxes and reaction rates. Thus, the fractional errors printed out are $\delta\phi_{GH}/\phi_{GH}$ and $\delta R_{GH}/R_{GH}$, where $\delta\phi_{GH}$ and δR_{GH} are the associated group set and region set probable errors.

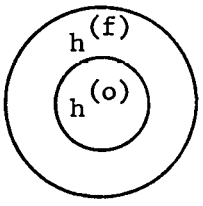
The group set and region set overlay must be assigned for every problem. If the user desires the detailed groupwise and regionwise fluxes and reaction rates, he merely assigns one group to one group set and one region to one region set. However, because of symmetry or because particular regions and groups are not of interest, certain groups and regions can be lumped into one group set and region set, while the other groups and regions can be assigned one to a set.

1.10 The Option of Obtaining Directional Currents

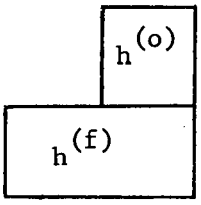
For iteration type problems and external source problems, the user has the option of obtaining directional currents across desired surfaces. To obtain the neutron currents, a group structure must be defined that can be independent of the group structure defined for the group cross sections and fluxes. This current group structure is defined by assigning energy cutoffs that determine the group energy limits. Groupwise currents, integrated in energy over the group structure, are then obtained.

The groupwise currents are sorted into "incoming" currents and "outgoing" currents by specifying the originating regions and the final regions. An originating region number $h^{(o)}$ is specified and a final region number $h^{(f)}$ is specified, where the region numbers refer to those previously assigned the regions (see Region Descriptions). The final region number $h^{(f)}$ must correspond to a region adjacent to the originating region $h^{(o)}$, otherwise assignment of originating and final regions is completely arbitrary. With an originating and final region designated, the groupwise currents crossing from $h^{(o)}$ to $h^{(f)}$ will then be determined. This "region-to-region" current is a sum, over all common surfaces, of the surface currents crossing from $h^{(o)}$ to $h^{(f)}$. If the two regions have only one common surface, then the region-to-region current corresponds to the common surface current from $h^{(o)}$ to $h^{(f)}$.

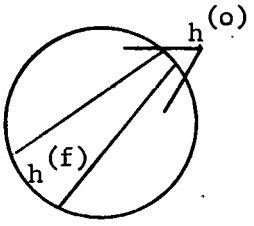
Shown below are examples of the groupwise region-to-region currents obtained by RAFFLE.



Two concentric cylinders. Groupwise currents will be obtained crossing the common cylindrical surface from $h^{(o)}$ to $h^{(f)}$ ($h^{(f)}$ may be the surrounding vacuum region).



Two rectangular solids. Groupwise currents will be obtained from $h^{(o)}$ to $h^{(f)}$, crossing the portion of the common surface.



A segment within a cylinder. Groupwise currents will be obtained from $h^{(o)}$ to $h^{(f)}$, crossing the two common surfaces.

Any number of originating regions may be assigned, and any number of final regions may be assigned for an originating region. Hence, any degree of spatial detail can be obtained for the groupwise currents. Furthermore, the final regions may include regions in the surrounding vacuum region and, consequently, groupwise leakage currents can be obtained.

As for the flux and reaction rate output, the region-to-region currents output by RAFFLE are normalized to units of neutrons per source neutron. (The normalization factor S is identical to that used for the fluxes and reaction rates, Section IV.1.8.) The errors for the region-to-region currents are not printed out; however, they can be simply computed from the binomial formula

$$\frac{\delta J_g}{J_g} = \frac{0.6745}{\sqrt{NJ_g}}$$

where

J_g = groupwise current from $h^{(o)}$ to $h^{(f)}$ printed out by RAFFLE

$\frac{\delta J_g}{J_g}$ = the fractional probable error for the current

N = the total number of histories followed by RAFFLE (which it prints out).

2. PROBLEMS FOR WHICH AVERAGED GROUPWISE CROSS SECTIONS ARE DESIRED (ITRAGG = 1)

2.1 General Problem Description

The major difference between the cross section class of problem and the flux and reaction rate class of problem is that *all the regions of the physical volume of the problem must be coalesced into one region set if cross sections are desired.* The cross section class of problem includes iteration (k) problems and external source problems with or without fission daughters being generated. As for the flux and reaction rate problem, a group structure is defined for the groupwise information to be obtained. Unlike the flux type problems, however, instead of obtaining region and group fluxes and reaction rates, averaged groupwise cross sections are obtained for the problem. These groupwise cross sections are obtained by taking the ratios of the total groupwise reaction rates to the total groupwise fluxes for the entire physical volume of the problem. The computation of the cross sections is performed in a correlated manner in the RAFFLE code to minimize the statistical errors associated with the cross sections. The averaged groupwise cross sections obtained include the absorption cross sections, the υ times the fission cross sections, the scattering cross sections, and the complete P_0 and P_1 transfer matrices.

2.2 Problems for Which Elastic Cross Sections are Desired

To calculate elastic cross sections, the flag IELGG must be set 1 or 2. When IELGG = 1, the scattering angle is found once for each collision, and thus for each collision the P_0 and P_1 scattering cross sections are calculated only once. This option is effective where the number of collisions per history is large, e.g., thermal problems. When IELGG = 2, the scattering angle is determined NFGG times at a collision and thus the P_0 and P_1 scattering cross sections calculated NFGG times. The effect is similar to splitting neutrons. This option is well suited to problems with only a few collisions, say five or less, e.g., some fast systems. A value of five for NFGG is satisfactory for the general problem.

2.3 Averaged Cross Section Information Obtained

Like the flux and reaction rate problem, the user must input an energy cutoff structure, E_g, which defines the basic group structure of the problem. The energy cutoffs E_g are the lower energies of the groups. The group structure will be used for the isotope group cross sections and will be used as the first group structure for which the averaged cross

sections can be obtained. Overlayed on the group structure will be a group set structure allowing coalescing of the groups. As for the flux type problems, even if the groups are coalesced to a few broad group sets, in order to obtain few group cross sections, a finer original group structure E_g is still desired since the isotope microscopic group cross sections are input according to the finer structure.

Let the group cutoffs be E_g for a total of G groups defined. Also, neglect for the present the group set overlay, since this merely "sums" the basic group structure. The averaged groupwise cross sections obtained are then given by the formula

$$\bar{\Sigma}_g = \frac{\int_V dV \int_{E_g}^{E_{g+1}} dE\ \Sigma(\bar{r},E)\ \phi(\bar{r},E)}{\int_V dV \int_{E_g}^{E_{g+1}} dE\ \phi(\bar{r},E)}$$

where $\phi(\bar{r},E)$ is the pointwise scalar flux. The spatial integrals are over the entire physical volume of the problem, for example, the entire cell. The macroscopic cross sections $\Sigma(\bar{r},E)$ are either absorption, scattering, or υ-fission. Hence, the average absorption, scattering, and υ-fission cross sections are obtained. If the problem contains resonance, the absorption and υ-fission cross sections are subdivided into the resonance contribution and the total value (resonance plus smooth). These average cross sections with their associated fractional probable errors ($\delta\Sigma_g/\Sigma_g$) are obtained by RAFFLE.

In addition to the groupwise averaged cross sections, the groupwise averaged P_o and P_1 transfer matrices can also be obtained by RAFFLE. If $\Sigma_o(g\to g')$ is an element in the P_o transfer matrix, then $\Sigma_o(g\to g')$ is given by the formula

$$\bar{\Sigma}_o(g\to g') = \frac{\int_V dV \int_{E_g}^{E_{g+1}} dE \int_{E_{g'}}^{E_{g'+1}} dE'\ \phi(\bar{r},E)\ \Sigma_s(E\to E',\bar{r})}{\int_V dV \int_{E_g}^{E_{g+1}} dE\ \phi(\bar{r},E)}$$

where $\Sigma_s(E\to E',\bar{r})$ is the macroscopic scattering cross section from energy E to energy E'. The spatial integrals again are over the entire physical volume of the problem. For these P_o coefficients, the user has the option of obtaining the elastic P_o's, the inelastic P_o's, or the total scattering P_o's (elastic plus inelastic). The P_1 transfer elements $\bar{\Sigma}_1(g\to g')$ are analogously given by the formula

$$\bar{\Sigma}_l(g\to g') = \frac{\int_V dV \int_{E_g}^{E_{g+1}} dE \int_{E_{g'}}^{E_{g'+1}} dE'\ \phi(r,E)\ \mu(E,E')\ \Sigma_s(E\to E',\bar{r})}{\int_V dV \int_{E_g}^{E_{g+1}} dE \int_{E_{g'}}^{E_{g'+1}} dE'\ \phi(\bar{r},E)}$$

where $\mu(E,E')$ is the cosine of the scattering angle in the lab frame. Since inelastic scattering is assumed isotropic in the lab frame, the P_1 transfer cross sections are entirely elastic P_1 cross sections. These transfer cross sections with their associated fractional probable errors are printed out by RAFFLE.

2.4 Coalescing the Regions and Groups

As stated, to obtain the averaged cross sections and transfer matrices all regions in the physical volume must be assigned to one region set. There is no option here; the user must assign all the regions, in the physical volume, to region set 1. In the RAFFLE input, this merely involves assigning one (1) as the region set number to all the regions in the physical volume.

As stated previously, the basic group structure E_g can be overlayed by a group set structure in order to obtain broader group cross sections and transfer matrices. The defining of group sets is exactly the same as for the flux type problems: a group set G is defined by defining the groups which are coalesced in the group set. For the RAFFLE input format, each group is assigned one group set number, where the group set numbers must increase consecutively from one to the total number of group sets.

Averaged cross sections and transfer matrices are always printed out according to group set. If R_g is the group reaction rate,

$$R_g = \int_V dV \int_{E_g}^{E_{g+1}} dE\ \Sigma(\bar{r},E)\ \phi(\bar{r},E)$$

and ϕ_g is the group flux,

$$\phi_g = \int_V dV \int_{E_g}^{E_{g+1}} dE\ \phi(\bar{r},E) \quad .$$

The averaged group set cross sections obtained, $\bar{\Sigma}_G$, will be

$$\bar{\Sigma}_G = \frac{\sum_{g\epsilon G} R_g}{\sum_{g\epsilon G} \phi_g} \quad .$$

G is the group set number and the summations are over all groups g in G. If G consists of one group, the averaged group set cross section is that defined in the previous section ($\bar{\Sigma}_G = \bar{\Sigma}_g$).

The group set transfer matrices are computed in the same way as the group set averaged cross sections. If $R_o(g \to g')$ is the scattering transfer rate from group g to g',

$$R_o(g \to g') = \int_V dV \int_{E_g}^{E_{g+1}} dE \int_{E_{g'}}^{E_{g'+1}} dE' \; \phi(\bar{r},E) \; \Sigma_s(E \to E', \bar{r})$$

then the group set P_o transfer cross section $\bar{\Sigma}(G \to G')$ is

$$\bar{\Sigma}_o(G \to G') = \frac{\sum_{g \in G} \sum_{g' \in G'} R_o(g \to g')}{\sum_{g \in G} \phi_g} .$$

If group sets G and G' consist of one group, the group set P_o cross section is simply the group P_o cross section $[\bar{\Sigma}_o(G \to G') = \bar{\Sigma}_o(g \to g')]$. The P_1 group set transfer cross section $\Sigma_1(G \to G')$ is, analogously,

$$\bar{\Sigma}_1(G \to G') = \frac{\sum_{g \in G} \sum_{g' \in G'} R_1(g \to g')}{\sum_{g \in G} \phi_g}$$

where

$$R_1(g \to g') = \int_V dV \int_{E_g}^{E_{g+1}} dE \int_{E_{g'}}^{E_{g'+1}} dE' \; \phi(\bar{r},E) \; \mu(E,E') \; \Sigma_s(E \to E'; \bar{r}) \quad .$$

The fractional probable errors printed out by RAFFLE are for the group set cross sections and transfer matrices. The fractional errors printed out by RAFFLE are thus $\delta\bar{\Sigma}_G/\bar{\Sigma}_G$, $\delta\bar{\Sigma}_o(G \to G')/\bar{\Sigma}_o(G \to G')$, and $\delta\bar{\Sigma}_1(G \to G')/\bar{\Sigma}_1(G \to G')$, where "$\delta$" denotes the probable error.

As for the flux type problem, the group set structure must be defined for every cross section type problem. This requirement of a group set structure for every problem causes the user no great trouble since it is simple to define and input. Furthermore, it adds considerable flexibility. If the user desires the original group cross sections and transfer matrices, he simply assigns one group to one group set. If he desires broad group information, of any structure, he simply coalesces the groups into a few group set.

2.5 Additional Information Obtained for Cross Section Type Problems

In addition to the averaged cross sections and transfer matrices, the group set volume integrated fluxes ϕ_G are always obtained;

$$\phi_G = \sum_{g \epsilon G} \phi_g$$

where the group sets refer to those defined for the cross sections and transfer matrices. The group set fluxes, with their associated fractional probable errors $\delta\phi_G/\phi_G$, are printed out by RAFFLE. Additional constants are obtained, depending upon whether the problem is of an iteration type or of an external source type. For an iteration type problem, the eigenvalue, or generation factor k, the lifetime t_L, and the generated time t_g are all obtained with their associated fractional errors. The reader is referred to Section IV.1.2 of the previous flux and reaction rate problem discussion since the quantities are exactly the same as discussed there. For external source problems with fission daughters followed, the "multiplication factor", "lifetime", and "generation time" are additionally obtained. For the discussion of these quantities, the reader is referred to Section IV.1.3 of the flux and reaction rate problem discussion. Finally, for either iteration or external source type problems for which cross sections and transfer matrices are obtained, the user has the option also of obtaining the region-to-region currents. For this information on currents the reader is referred to Section IV.1.10 of the previous discussion.

3. GENERAL GUIDELINES FOR PREPARING RAFFLE PROBLEMS

3.1 Initial Checkout of RAFFLE Problems

It is strongly recommended that the execution time, as set by RTIME, be kept short until a RAFFLE problem has been thoroughly checked. Failure to observe this precaution can result in wasted computer time. Two types of mistakes can occur in the RAFFLE input data: (a) violation of the rules as stated in Section V for the input data, and (b) failure to describe properly the model as desired by the user. Many, but not all, of the first type are detected and execution of the Monte Carlo routines bypassed. The program has no way of checking for the second type.

Among the errors that can cause RAFFLE to terminate because of excessive CPU time are:

(1) The control on CPU time external to RAFFLE was not sufficiently longer than RTIME. It is recommended that initially the limit on CPU time exceed RTIME by one minute.

(2) RTIME was too small to allow INNGEN+1 generations to be processed and edited. No results are available for first INNGEN generations.

(3) No fission spectra, data type IFM, are assigned to a material with fission data (a material containing one or more fissionable isotopes).

(4) The regions are not entirely within the upper right hand quadrant.

(5) There is one region per zone, and the region to zone assignment is incorrect.

The following errors can cause an addressing error, such as a 0C5 error on an IBM 360. The numerical limits are those in effect at the time of this report.

(1) A material number less than one or greater than NMAT is assigned to a real region.

(2) A material contains an isotope with fission data, but the number of the fission spectrum assigned to the material is zero or negative. As noted above, this error sometimes produces a loop so that the program terminates because of excessive CPU time.

(3) An isotope contains fission data, but no spectrum index, data type ISPECT.

(4) The storage for leakage edits has been exceeded. This error can sometimes result in excessive CPU time. The limit is

$$2 * \text{NREG} + \sum_{\text{IH}=1}^{\text{NREG}} \left[(\text{LGRP}+1) * (\text{NEXIT}(\text{IH}) \right] \leq 500 \ .$$

(5) The number of surfaces, NSUR, exceeds 200.

(6) The storage for tallies is exceeded. The limit is

$$(\text{NGRPST}+1) * \text{NREGST} \leq 1050 \ .$$

(7) The number of region sets is too large. The limit is

$$\text{NREGST} \leq 100 \ .$$

When TXREG = 1, the failure to specify a nonzero temperature for a material containing an isotope with resonance data can cause an attempt to calculate the square root of a negative number.

The fractional probable errors from a short problem can be used to estimate the CPU time needed to achieve any desired errors. If E_1 is the initial error obtained with a RTIME of T_1 and E_2 is the desired error then

$$T_2 = T_1 \left(\frac{E_1}{E_2}\right)^2$$

where T_2 is RTIME for the second problem. If the running time is very short the initial errors may be incorrect; however, the above equation is usually satisfactory if the initial fractional error is less than 0.2.

After all errors detected during the input edit have been eliminated the program may terminate with the message 'PROGRAM STOP -- SEARCH HAS FAILED 100 TIMES IN LOCATING SOURCE PARTICLES'. When this occurs the locations and region extents of the sources should be checked. If these are correct, check the geometry as discussed below. After the program succeeds in locating the source particles it may terminate with the message 'PROGRAM TERMINATED BECAUSE 10*IRRBOX IS GREATER THAN TOTAL NUMBER OF COLLISIONS', where X is 1, 2, or 3.

Even with correct descriptions of the region and zone geometries, some neutrons with unusual histories may be lost because the program algorithms cannot assign them to a region. However, if the lost neutrons exceed 0.1 percent of the histories, a mistake in the region or zone descriptions should be considered.

A message such as 'LOST NEUTRON (COUNTED IN IRRB01) -- THE NEUTRON WAS LOST IN TRYING TO CROSS TO AN ADJACENT REGION' is printed every time a neutron is lost. The lost neutrons, divided into three categories, are totaled on the line labeled ERROR -- TALLY BOX COUNTS near the start of the output data.

Among the items that should be checked when neutrons are lost are:

(1) NSUR, the number of surfaces.

(2) NREG, the number of real regions.

(3) NFREG, the number of vacuum regions.

(4) NNZONE, the total number of zones.

(5) KOBN, the external boundary numbers. Note, the external boundaries are those at the exterior of the *real* regions.

If the problem persists, the assignment of regions to zones, IZONE, the region types, IIRT, the region boundaries, KBN, the boundary coefficients, A, and the edited zone description should be checked. The fraction of lost neutrons is problem dependent, and even with correct region zone descriptions the fraction may be about 1.0 percent of the histories. This is acceptable; however, to be conservative the user should carefully examine the input data before accepting more than 0.1 percent lost neutrons.

Although not specifically stated in the rules for region descriptions, all regions must be convex in the sense that no planar surface may extend into a region for which it is a boundary. This problem can be eliminated by using more regions.

3.2 Combining RAFFLE Estimates

If a Monte Carlo program processes a sufficiently large number of events, roundoff can cause the statistical errors to be incorrect. RAFFLE uses double precision arithmetic for the tallies in order to extend the limit on the number of events that can be correctly processed. While this limit has not been determined, RAFFLE problems using four hours CPU time on an IBM 360/75 and processing 1,600,000 collisions have been run successfully.

Because RAFFLE does not possess restart capabilities, the user may want to combine results from several RAFFLE runs rather than make one very long run. When combining results, a different value for the number of random numbers initially rejected, NREJEC, must be entered for each individual run. If the values of NREJEC differ by more than about 1,000 the correlation between two runs will be negligible. To combine N uncorrelated RAFFLE estimates of the same quantity:

let

X_i be one of the estimates to be combined

δ_i be the corresponding fractional error

$S_i = (X_i\delta_i)^2$

$\bar{X}$ be the best estimate in the sense of having the minimum fractional errors

$\delta_{\bar{X}}$ be the fractional error for the best estimate.

Then

$$\bar{X} = \frac{\sum_{i=1}^{N} \frac{X_i}{S_i}}{\sum_{i=1}^{N} \frac{1}{S_i}}$$

$$S_{\bar{X}} = \frac{1}{\sum_{i=1}^{N} \frac{1}{S_i}}$$

$$\delta_{\bar{X}} = \frac{\sqrt{S_{\bar{X}}}}{\bar{X}}$$

For N=2

$$\bar{X} = \frac{S_2 X_1 + S_1 X_2}{S_1 + S_2}$$

$$S_{\bar{X}} = \frac{S_1 S_2}{S_1 + S_2}$$

$$\delta_{\bar{X}} = \frac{\sqrt{S_{\bar{X}}}}{\bar{X}}$$

RAFFLE gives the fractional probable error for each estimate. If X is the value given for the estimate and δ_X the fractional probable error, then the actual value of X has a 50 percent chance of lying in the interval $(X-\delta_X X, X+\delta_X X)$; this is a useful if not precise interpretation of δ_X. Multiplying a RAFFLE fractional probable error by 1.483 gives the corresponding fractional standard deviation.

V. PREPARATION OF RAFFLE INPUT DATA

This section presents the detailed instructions for preparing the RAFFLE input data except for the cross section libraries which are discussed in Section VII. In this section, the existence on auxiliary storage of the required cross section libraries is assumed and instructions for their use presented. RAFFLE reads from the libraries into main storage the data for only those isotopes requested for a particular problem.

1. ORDER OF DATA SETS

The input data for RAFFLE can be considered as consisting of a number of data sets. Table IV shows the order of these data sets.

TABLE IV

ORDER OF DATA SETS

1	Problem title card
2	General integer data
3	General floating point data
4	Fast and one thermal group cross section library
5	Multigroup thermal cross section library
6	Surface source data

Notes: Data sets 5 and 6 are optional

Data set 4 may be optionally read in on FORTRAN logical unit 15

Data set 5 may be optionally read in on FORTRAN logical unit 11

2. DATA SET FORMATS

2.1 Problem Title Card

The FORTRAN format of the problem title card is A1, A3, 19A4.

Column 1 Input copy flag

0-Do not list input cards

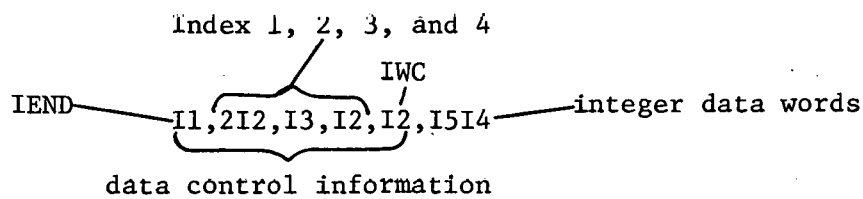
1-List input cards

Columns 2-80	Any identifying Hollerith characters can be punched here

This card *must* head the input data for each problem; it can be blank.

2.2 Preparation of the Integer Data

The FORTRAN format for an integer data card, except in the surface source data sets described in Section 2.4 is:



The first 12 columns of an integer data card are devoted to the identification of the data on the cards as follows:

Column 1	IEND	Zero or blank means other integer data cards follow. 1 punched means this is the last integer data card.
Columns 2-3	INDEX 1	The value of these four indices identify the integer data punched on the card; hence, the card order is irrevelant.
Columns 4-5	INDEX 2	
Columns 6-8	INDEX 3	
Columns 9-10	INDEX 4	
Columns 11-12	IWC	This word tells the number of integer words punched on the card (1 to 15). If IWC is zero or blank, a value of 15 is assumed.

There must be at least one integer data card per problem.

The value of IWC specifies the number of successive words of data given on the card, excluding the data control information in card column 1 to 12.

The integer data cards can be in any order so long as the last card has a 1 punched in card column 1, but the integer data deck must follow the problem title card and precede the floating point data deck.

Each integer data word must be right adjusted; that is, the number must end in the extreme right column of the 4 column field.

The single word input data (starting with INEDIT and ending with IFRST) can be punched in the order of increasing INDEX 3 values across a card (provided the INDEX 3 value in card columns 6-8 is that of the first data word on the card).

TABLE V

DESCRIPTION OF GENERAL INTEGER DATA

Index 1 Card Cols. 2-3 Format I2	Index 2 Card Cols. 4-5 Format I2	Index 3 Card Cols. 6-8 Format I3	Index 4 Card Cols. 9-10 Format I2	Mnemonic Name of Data	Notes on Application of Data	Default Value
		1		INEDIT	Edit Flag 1-Edit input only 2-Edit input and execute problem	1
		2		IED	Isotope Edit Flag 0-Print macroscopic cross sections 1-Print macroscopic and microscopic cross sections 2-Used for debugging 3-Do not print any cross sections	0
		3		NGRP	Number of cross section broad groups	
		4		NREG	Number of real regions	
		5		NFREG	Number of vacuum (fictitious) regions	
		6		NMAT	Number of materials	
		7		IZØNGE	Zone Geometry Type 1-Stacked rectangular 2-Spherical 3-Stacked cylindrical (R,Z) 4-Stacked R, Z, Ø	
		8		NSUR	Number of surface equations	

TABLE V (Cont'd)

DESCRIPTION OF GENERAL INTEGER DATA

Index 1 Card Cols. 2-3 Format I2	Index 2 Card Cols. 4-5 Format I2	Index 3 Card Cols. 6-8 Format I3	Index 4 Card Cols. 9-10 Format I2	Mnemonic Name of Data	Notes on Application of Data	Default Value
		9		NFSP	Number of spectra	
		10		NSCAT	Number of isotopes in problem	
		11		NIC	Number of isotopes in fast library	
		12		LABGRP	Angular data for group LABGRP and below are in the lab system (not used with multiple thermal groups, MACRO≠0)	NGRP
		13		LSCAT	No energy change from elastic scatter is computed for group LSCAT and below (not used with multiple thermal groups, MACRO≠0)	NGRP
		14		IXTERN	Eigenvalue or fixed source flag 1-Eigenvalue (iteration) problem 2-Fixed source problem, fission daughters not followed 3-Fixed source problem, fission daughters followed	
		15		NIVØ	Number of histories per generation or batch (maximum value is 256)	256

TABLE V (Cont'd)

DESCRIPTION OF GENERAL INTEGER DATA

Index 1 Card Cols. 2-3 Format I2	Index 2 Card Cols. 4-5 Format I2	Index 3 Card Cols. 6-8 Format I3	Index 4 Card Cols. 9-10 Format I2	Mnemonic Name of Data	Notes on Application of Data	Default Value
		16		ISCØRE	Scoring Flag 1-Standard path scoring 2-KENO method (isotopes used in problem must not contain resonance data) 3-Ray method	1
		17		NNZØNE	Total number of zones	
		18		NNXZL	Number of radial lines (not used for IZØNGE=1)	
		19		NNYZL	Number of theta values (used only for IZØNGE=4)	
		20		NNZZL	Number of zone z-lines for stacked zone geometries (not used for IZØNGE=2)	
		21		NGRPST	Number of group sets (if not read in, group sets correspond to groups)	NGRP
		22		NREGST	Number of region sets (if not read in, region sets correspond to real regions)	NREG
		23		NEXCUT	Cutoff option 1-Standard Russian roulette below WNCUT 2-No weight reduction, compare with Σ_S/Σ_T 3-Russian roulette below region and group dependent cutoffs WGT(J,IR)	1

TABLE V (Cont'd)

DESCRIPTION OF GENERAL INTEGER DATA

Index 1 Card Cols. 2-3 Format I2	Index 2 Card Cols. 4-5 Format I2	Index 3 Card Cols. 6-8 Format I3	Index 4 Card Cols. 9-10 Format I2	Mnemonic Name of Data	Notes on Application of Data	Default Value
		24		ISPLT	Splitting Flag 1-No splitting 2-Splitting by integer multiples 3-Splitting by weight comparison	1
		25		JTAPE	Fast Library Flag 0-Read fast library from cards (Unit 5) 1-Not used 2-Read fast library from tape or disk (Unit 15)	0
		26			Not Used	
		27		MEXP	Exponent of 2 which determines size of random number table (maximum is 9)	9
		28		NREJEC	NREJEC random numbers are initially rejected so that the sequence starts with the NREJEC+1th random number $1 \leq NREJEC \leq 9999$	
		29		NSØRCS	Number of external or initial fission sources (used if ICURR=0)	
		30		IVSPEC	Index number of the spectrum used for all the sources ($1 \leq IVSPEC \leq NFSP$)	

TABLE V (Cont'd)

DESCRIPTION OF GENERAL INTEGER DATA

Index 1 Card Cols. 2-3 Format I2	Index 2 Card Cols. 4-5 Format I2	Index 3 Card Cols. 6-8 Format I3	Index 4 Card Cols. 9-10 Format I2	Mnemonic Name of Data	Notes on Application of Data	Default Value
		31		INNGEN	Number of generations processed before tallies are started	1
		32		ICURR	Volume or surface source flag (see Section 2.4 for description of source types) 0-Volume source problem 1-Planar surface source problem 2-Cylindrical surface source problem	0
		33		LGRP	Number of groups for which leakage tally is made	
		34		IVERGE	Convergence Flag 1-Convergence on k 2-Convergence on region flux 3-Convergence on region and group flux (IVERGE=1 not allowed when ICURR>0)	
		35		MAXCNT	Maximum number of times to split per history (used if ISPLT=2 or 3)	6
		36		NEXREG	Region Convergence Flag 0 All region sets are checked for convergence N (N≥1) N region sets are checked for convergence (the index numbers of these region sets must be entered in ICHREG) (used only if IVERGE=2 or 3)	

TABLE V (Cont'd)

DESCRIPTION OF GENERAL INTEGER DATA

Index 1 Card Cols. 2-3 Format I2	Index 2 Card Cols. 4-5 Format I2	Index 3 Card Cols. 6-8 Format I3	Index 4 Card Cols. 9-10 Format I2	Mnemonic Name of Data	Notes on Application of Data	Default Value
		37		NEXGRP	Region and group convergence flag 0 All group sets checked for convergence M (M≥1) M group sets checked for convergence (group sets of region sets specified in NEXREG) (the index numbers of these group sets must be entered in ICHGRP) (used only if IVERGE=3)	
		38			Not Used (do not enter 0)	
		39			Not Used (do not enter 0)	
		40		IBAT	Batching flag 0-No batching 1-Batching	0
		41		TXREG	Flag for input of temperature (°K) for resolved resonance calculation 0-Temperature input by isotope in cross section library 1-Temperature input for each region containing a material with a resonant isotope (in REGTEM)	0
		101		NTHRM	Number of thermal groups	

TABLE V (Cont'd)

DESCRIPTION OF GENERAL INTEGER DATA

Index 1 Card Cols. 2-3 Format I2	Index 2 Card Cols. 4-5 Format I2	Index 3 Card Cols. 6-8 Format I3	Index 4 Card Cols. 9-10 Format I2	Mnemonic Name of Data	Notes on Application of Data	Default Value
		102		MACRO	Structure of thermal library ±1-1 to 99 thermal groups, cross sections by material 2 1 to 99 thermal groups, cross sections by isotope If MACRØ is positive, read in thermal library on unit 11 (disk or-tape) If MACRØ is -1, read in on unit 5 (cards)	
		103		NTHCUT	Russian roulette after NTHCUT thermal	800
		104		NCØL2	and after NCØL2 subsequent thermal collisions	5
		105		IFRST	Group number (as punched on thermal cards) to use as first RAFFLE thermal group	
	1	IR		MATRL(IR)	Index number of material in region IR	
	2	IR		IIRT(IR)	Region type for region IR 1-No curved boundaries, 5 to 8 plane boundaries 2-One curved, 5 to 7 plane boundaries 3-Two concentric curved, 2 to 6 plane boundaries 4-Two concentric spherical boundaries	
	3	I		ICHREG(I)	List of the region sets to be checked for convergence (not required if IVERGE=1, or if NEXREG=0)	

TABLE V (Cont'd)

DESCRIPTION OF GENERAL INTEGER DATA

Index 1 Card Cols. 2-3 Format I2	Index 2 Card Cols. 4-5 Format I2	Index 3 Card Cols. 6-8 Format I3	Index 4 Card Cols. 9-10 Format I2	Mnemonic Name of Data	Notes on Application of Data	Default Value
	4	I		ICHGRP(I)	List of the group sets to be checked for convergence (not required if IVERGE=1, or if NEXREG=0)	
	5	IC		ITYPE(IC)	Source type for volume source IC (used if ICURR=0) 0-Rectangular solid source or plane source 1-Cylindrical-shell, ring, or line source 2-Spherical-shell, or point source	
	6	IR		NØGEN(IR)	Splitting multiples for region IR (used when ISPLT=2)	
	7				Not Used	
	8	J		IGRPST(J)	If NGRPST is greater than 1 and less than NGRP, enter the group set number for each group J	
	9	IR		IREGST(IR)	If NREGST is greater than 1 and less than NREG, enter the region set number for each region IR	
	10	I		KØBN(I)	List of the unsigned external boundary numbers in any order. (The index numbers of the surfaces bounding the real regions)	
	11	IM		IFM(IM)	The number of fission spectra for material IM	

TABLE V (Cont'd)

DESCRIPTION OF GENERAL INTEGER DATA

Index 1 Card Cols. 2-3 Format I2	Index 2 Card Cols. 4-5 Format I2	Index 3 Card Cols. 6-8 Format I3	Index 4 Card Cols. 9-10 Format I2	Mnemonic Name of Data	Notes on Application of Data	Default Value
	12	ID		NAFTAL(ID)	List of the identification numbers in order of increasing magnitude, for the isotopes used in the problem from the fast library	
	13	ID		ISPECT(ID)	For each isotope in NAFTAL, list the index number of its fission spectrum, if the isotope is not fissionable enter zero or blank	
	14	ID		IDTHERM(ID)	If any of the thermal and fast isotope identification numbers differ, list the thermal ID's here. If a thermal ID is 0 that isotope is assumed to have zero thermal contribution. (Used only if MACRØ=2)	
	15	ID		IMØRE(ID)	Temporary changes to cross section data for the isotope with sequence number ID. (The data in the cross section library is not changed, and these changes are effective only for the problem being run. The multi-thermal group data cannot be changed by this procedure.) 0-No changes 1-Update data for isotope ID 2-Temporarily add isotope ID to library or completely replace data for isotope ID	

TABLE V (Cont'd)

DESCRIPTION OF GENERAL INTEGER DATA

Index 1 Card Cols. 2-3 Format I2	Index 2 Card Cols. 4-5 Format I2	Index 3 Card Cols. 6-8 Format I3	Index 4 Card Cols. 9-10 Format I2	Mnemonic Name of Data	Notes on Application of Data	Default Value
1	IM	ID		MIX(ID,IM)	The isotopes with identification numbers listed form material IM. (Use the fast library identification numbers.)	
2		IR		KBN(IR)	List of the signed boundary numbers for region IR	
3		IZL		IZØNE(IZL)	List of regions in zone IZL (The index numbers for the vacuum regions must start with NREG+1) (Not more than 7 regions per zone)	
4	IR	IH		IHEXIT(IH,IR)	List of regions for which current from region IR is desired (Regions in list must be adjacent to region IR. Not used if LGRP=0)	
5	IC	I		IREG(I,IC)	List of the exempt regions, in any order, for source IC	
6		1		MAFIS	Maximum number of fission daughters to store (Not to exceed 200) (Required only when IXTERN=3)	
6		2		IAFIS	Flag for storage of fission daughter weights 1-Store CFISK 2-Store entire generated weight (Required when IXTERN=3)	

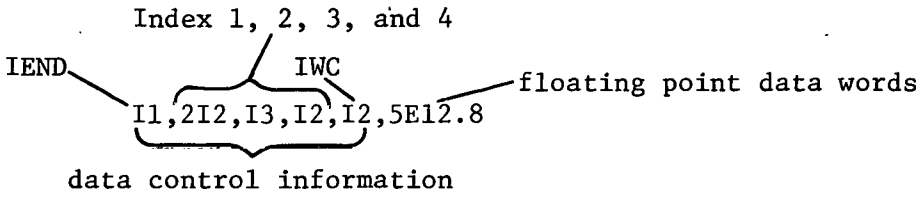
TABLE V (Cont'd)

DESCRIPTION OF GENERAL INTEGER DATA

Index 1 Card Cols. 2-3 Format I2	Index 2 Card Cols. 4-5 Format I2	Index 3 Card Cols. 6-8 Format I3	Index 4 Card Cols. 9-10 Format I2	Mnemonic Name of Data	Notes on Application of Data	Default Value
6		3		ITRAGG	Reaction rate or cross section flag 0-Calculate fluxes and reaction rates 1-Calculate fluxes and transfer cross sections	
6		4		IINGG	Flag for inelastic cross sections 0-Do not calculate inelastic cross sections 1-Calculate inelastic cross sections (Required when ITRAGG=1)	
6		5		IELGG	Flag for elastic cross sections 0-Do not calculate elastic cross sections 1-Calculate elastic cross sections and calculate P(0) and P(1) values once per collision 2-Calculate elastic cross sections and calculate P(0) and P(1) values NFGG times per collision	
6		6		NFGG	Make P(0) and P(1) estimations NFGG times per collision (Must be specified when IELGG=2)	

2.3 Preparation of the Floating Point Data

The FORTRAN format for a floating point data card, except in the current source data sets described in Section 2.4, is:



The first 12 columns of a floating point data card are devoted to the identification of the data on the card.

Column 1	IEND	Zero or blank means other floating point data cards follow. A 1 punched means this is the last floating point data card
Columns 2-3	INDEX 1	The values of these four indices identify the floating point data punched on the card; hence, the card order is irrelevant.
Columns 4-5	INDEX 2	
Columns 6-8	INDEX 3	
Columns 9-10	INDEX 4	
Columns 11-12	IWC	This word tells the number of floating point words punched on the card (1 to 5). If IWC is zero or blank, a value of 5 is assumed.
Columns 13-72		1 to 5 floating point words of format E12.8 can be punched in these columns

There must be at least one floating point data card per problem.

The value of IWC specifies the number of successive words of data given on the card excluding the data control information in card columns 1-12.

The floating point data cards can be in any order so long as the last card has a 1 punched in card column 1. The floating point data deck must follow the general integer data deck.

The single word input data (starting with RTIME and ending with CØMPR) can be punched in the order of increasing Index 3 values across a card (provided the Index 3 value in card columns 6-8 corresponds to the data word in the first floating point data field on the card).

TABLE VI

DESCRIPTION OF GENERAL FLOATING POINT DATA

Index 1 Card Cols. 2-3 Format I2	Index 2 Card Cols. 4-5 Format I2	Index 3 Card Cols. 6-8 Format I3	Index 4 Card Cols. 9-10 Format I2	Mnemonic Name of Data	Notes on Application of Data	Default Value
		1		RTIME	Maximum CPU time. If exceeded, code completes current generation, edits and terminates. If 0.0, the code edits each generation with no time check.	0.0
		2		WNCUT	The cutoff weight when NEXCUT=1	
		3		CHECK	Fractional convergence error	1.0
		4		XØP	X-Coordinate of zone geometry center point or origin (must be 0.0 if rectangular zone geometry, IZØNGE=1)	
		5		YØP	Y-Coordinate of zone geometry center point or origin (must be 0.0 if rectangular zone geometry, IZØNGE=1)	
		6		ZØP	Z-Coordinate of zone geometry center point or origin (must be 0.0 if rectangular zone geometry, IZØNGE=1)	
		7			Reserved for future use	
		8		WSTØP	Relative weight at which program quits following ray (used if ISCØRE=3)	10^{-6}
		9		CFISK	Weight for fission daughter storage (used if IAFIS=1)	0.5

TABLE VI (Cont'd)

DESCRIPTION OF GENERAL FLOATING POINT DATA

Index 1 Card Cols. 2-3 Format I2	Index 2 Card Cols. 4-5 Format I2	Index 3 Card Cols. 6-8 Format I3	Index 4 Card Cols. 9-10 Format I2	Mnemonic Name of Data	Notes on Application of Data	Default Value
		106		CØMPR	Russian roulette decision weight for multiple thermal groups (used if MACRO=±1 or 2)	0.5
	1	J		GV(J)	Lower cutoffs for energy groups in eV. Entered in decreasing order. Value for last group must be 0.0	
	2	IR		REGTEM(IR)	For each region containing a material with a resonant isotope enter the temperature, in degrees Kelvin, for the resolved resonance calculation (used only if TXREG=1)	
	3	IR		XØGEN(IR)	Region dependent weights for region IR (used when ISPLT=3)	
	4	I		ALBEDØ(I)	For each external boundary KØBN(I) list the corresponding albedo (the external boundaries are those bounding the real regions of the model)	

TABLE VI (Cont'd)

DESCRIPTION OF GENERAL FLOATING POINT DATA

Index 1 Card Cols. 2-3 Format I2	Index 2 Card Cols. 4-5 Format I2	Index 3 Card Cols. 6-8 Format I3	Index 4 Card Cols. 9-10 Format I2	Mnemonic Name of Data	Notes on Application of Data	Default Value
	5	IX		XLINE(IX)	The zone X-lines for parallelepiped zone geometry. The zone R-lines for the other geometries (for the stacked geometries, the first value is 0.0 for the first Z-zone. The values proceed to the largest for the first Z-zone and then start with 0.0 for the second Z-zone, etc. A minimum of two X-lines or R-lines are required for each Z-zone. IZØNGE=1, 3, or 4) (For spherical geometry the values proceed from 0.0 to the largest value. IZØNGE=2)	
	6	IY		YLINE(IY)	The zone Y-lines for parallelepiped geometry, IZØNGE=1. The zone θ-lines for R,θ,Z geometry, IZØNGE=4 (not used for IZØNGE=2, or 3) (For parallelepiped geometry, the Y-line values start with 0.0 in the first X-zone of the first Z-zone. At least two values, the first being 0.0, are required for each X-zone. The values proceed from the first X-zone of the first Z-zone to the last X-zone of the last Z-zone) (For R,θ,Z geometry, the values of the θ-lines are in degrees. For each R-zone four values 90.0, 180.0, 270.0, 360.0 degrees must be specified. Any other θ-lines, $0<\theta<360$, may be entered in any R-zone. The values start with the inner R-zone in the bottom Z-zone and end in the outer R-zone of the top Z-zone)	

TABLE VI (Cont'd)

DESCRIPTION OF THE GENERAL FLOATING POINT DATA

Index 1 Card Cols. 2-3 Format I2	Index 2 Card Cols. 4-5 Format I2	Index 3 Card Cols. 6-8 Format I3	Index 4 Card Cols. 9-10 Format I2	Mnemonic Name of Data	Notes on Application of Data	Default Value
	7	IZZ		ZLINE(IZZ)	The zone Z-lines increasing in order from 0.0, the first value, to the height of the top Z-plane (not used for IZØNGE=2, spherical zone geometry)	
	8	JL		GVL(JL)	Lower energy cutoffs (eV) for the leakage groups (not used if LGRP=0)	
	9	IC		XTENS(IC)	Relative source intensity integrated over the volume of source IC not including exempt regions (used if ICURR=0)	
1	IM	II		DENS(II,IM)	The number density (in units of 10^{24}) for isotope II in material IM. Listed in same order as in MIX(II,IM)	
2	IR	J		WGT(J,IR)	The Russian roulette cutoff weights for region IR and group J (used when NEXCUT=3)	

TABLE VI (Cont'd)

DESCRIPTION OF GENERAL FLOATING POINT DATA

Index 1 Card Cols. 2-3 Format I2	Index 2 Card Cols. 4-5 Format I2	Index 3 Card Cols. 6-8 Format I3	Index 4 Card Cols. 9-10 Format I2	Mnemonic Name of Data	Notes on Application of Data	Default Value
5	IC	I		DEL(IC)	The location point (X_1, X_2, X_3) and the respective dimensions (ΔX_1, ΔX_2, ΔX_3) for volume source IC (used if ICURR=0) For ITYPE=0, the source particles are generated uniformly with respect to x, y, and z, excluding the exempt regions. For a plane source one of the values Δx, Δy, or Δz is read in as zero.* The point X,Y,Z is with respect to the fixed reference frame for the problem. The data is read in as X,Y,Z,Δx,Δy,Δz. For ITYPE=1, the source particles are generated uniformly with respect to r and z in the volume r to r+Δr, z to z+Δz, excluding the exempt regions. For a ring source Δz is read in as zero.* For a solid cylindrical source r is read in as zero. For a line source r and Δr are read in as zero. The point X,Y,Z is with respect to the fixed reference frame for the problem. The data is read in as X,Y,Z,r,Δr,Δz. *See Section 2.4 for a discussion of the current from a surface source obtained by reducing a dimension of a volume source to zero.	
				DEL(IC)	continued on next page	

TABLE VI (Cont'd)

DESCRIPTION OF GENERAL FLOATING POINT DATA

Index 1 Card Cols. 2-3 Format I2	Index 2 Card Cols. 4-5 Format I2	Index 3 Card Cols. 6-8 Format I3	Index 4 Card Cols. 9-10 Format I2	Mnemonic Name of Data	Notes on Application of Data	Default Value
5	IC	I		DEL(IC)	For ITYPE=2, the source particles are generated uniformly with respect to r in the volume r to r+Δr, excluding the exempt regions. For Δr read in as zero the source particles are generated uniformly on the spherical surface r.* For a point source, r and Δr are read in as zero. The point X,Y,Z is with respect to the fixed reference frame for the problem. The data is read in as X,Y,Z,r,Δr,0.0. *See Section 2.4 for a discussion of the current from a surface source obtained by reducing a dimension of a volume source to zero.	
6	ISPEC	JF		FSPEC(JF)	The normalized intensity of spectrum ISPEC in spectrum group JF. (Spectrum group structure specified by GVTAB(JF) or by GV(JF).)	

TABLE VI (Cont'd)

DESCRIPTION OF GENERAL FLOATING POINT DATA

Index 1 Card Cols. 2-3 Format I2	Index 2 Card Cols. 4-5 Format I2	Index 3 Card Cols. 6-8 Format I3	Index 4 Card Cols. 9-10 Format I2	Mnemonic Name of Data	Notes on Application of Data	Default Value
7		IS	N	A(IS)	Coefficients I determining the equation of boundary IS. N=1 for planes; N=2 for cylinders and spheres. Each equation is of the form Ax+By+Cz=d for planes, $(x-x_o)^2+(y-y_o)^2=r^2$ for cylinders, and $(x-x_o)^2+(y-y_o)^2+(z-z_o)^2=r^2$ for spheres, where x_o,y_o,z_o are with respect to the origin of the coordinate system for the region geometry. For planes, the data are entered in the order A,B,C,D. For cylinders the data are entered in the order $0.0,r,x_o,y_o$. For the spheres, the order is $1.0,r,x_o,y_o,z_o$. Only the following types of planes are allowed: Ax=D i.e. B=C=0 By=D i.e. A=C=0 Cz=D i.e. A=B=0 Ax+By=D i.e. C=0	
8		JF		GVTAB(JF)	Lower energy cutoff (eV) for fission spectra group JF. (Required only if group structure for fission spectra differs from that for cross sections)	

2.4 Preparation of the Data for RAFFLE Sources

The section describes the preparation of the data to specify the external sources for fixed source problems, or to specify the initial fission sources for eigenvalue problems. The term "source" is used in two senses: (a) the volume or surface where the neutrons are generated, and (b) the current of neutrons entering the system from a source in the first sense.

RAFFLE provides three types of external sources designated as (a) volume sources, (b) planar surface sources, and (c) cylindrical surface sources. Only one type may be used in a given problem, and the selection is made by setting ICURR in the general integer data of Table V to 0, 1, or 2 for volume sources, planar surface sources, or cylindrical surface sources, respectively. The input data for volume sources is described in Tables V and VI, that for planar surface sources in Table VII, and that for cylindrical surface sources in Table VIII. As discussed later the extent of a volume source can be reduced to a surface, line, or point and that of a surface source to a line or point.

In the description of the input data it is necessary to distinguish between an angular flux, $f(\bar{r},\bar{\Omega})$, and the angular distribution of the current crossing a surface element ds. The angular current is $f(\bar{r},\bar{\Omega})x\ \bar{n}\cdot\bar{\Omega}$, where $\bar{n}$ is the normal to ds and $\bar{\Omega}$ is the neutron direction. The angular flux is defined as the number of neutrons traveling in direction $\bar{\Omega}$ crossing a unit area normal to $\bar{\Omega}$ per unit time and per unit solid angle. Since $\bar{n}\cdot\bar{\Omega}$ is the cosine of the angle between the normal vector $\bar{n}$ and the neutron direction $\bar{\Omega}$, the angular distribution of the current is the number of neutrons traveling in direction $\bar{\Omega}$ crossing a unit area normal to $\bar{n}$ (i.e., crossing a unit area of the surface of which ds is an element) per unit time per solid angle.

For a volume source, ICURR=0, particles are generated with an isotropic angular distribution and a uniform spatial distribution over the source volume with the exempt regions excluded. The intensity of a volume source, as input by data type XTENS, can be interpreted as the number of neutrons generated per unit time in the entire volume of the source. However, since RAFFLE normalizes the total number of particles generated per unit time in all volume sources to 1.0, only the relative values of the intensities are significant. The strength of a source, in terms of total particles emitted per unit time, is therefore not reduced when the source volume is decreased by the use of exempt regions.

When a volume source is reduced to a surface, line, or point source, the isotropic angular distribution is maintained. As a result, when a surface source is obtained by reducing

the thickness of volume source to zero, the angular current distribution tends to be uniform rather than cosine. Also, the emission of the source is over both hemispheres. Surface sources obtained as the limiting case of a volume source should be used with caution, particularly as boundary sources representing the flow of neutrons into the system. A typical use of volume sources is the representation of the fission sources from an array of fuel rods. Volume sources are used to specify the initial fission source in an iteration problem, IVERGE=1.

For each type of source the spatial distributions that may be specified directly are quite limited. However, a wide range of source shapes can be obtained by the use of exempt regions. Any external source must lie entirely within the real regions of the problem. If some of these regions are specified as exempt regions for a source, then that sources does not generate any particles in these exempt regions. The use of exempt regions to obtain a source distributed over a volume with a hexagonal cross section is shown in Figure 32. In view A of Figure 32 a plan view of the real regions near the source is shown. View B shows a cross section of a source occupying a cylindrical region. The regions designated as exempt are shown in C. Finally, D shows a cross section of the resulting source. This method can be used with any of the three types of sources.

The surface sources, ICURR=1 or ICURR=2, are intended for use as boundary sources describing the flow of neutrons into the system. These sources emit particles from the surface into only one hemisphere. A uniform angular flux distribution, that is, a cosine angular current distribution, can be selected. Alternatively, angular fluxes can be input to specify a nonisotropic angular flux distribution. The total strength of a surface source and its energy distribution are determined by inputting a value of the hemispherical current for each energy group. When the spatial distribution is uniform these currents are in units of neutrons per square centimeter per second. Since RAFFLE fluxes and reaction rates are per source particle, multiplying all the groupwise currents in a problem by the same constant does not change the results. When surface sources are used, convergence on the eigenvalue is not allowed, and thus IVERGE, Table V, must equal 2 or 3. The energy group structure for the surface sources is specified independently of that used for the Monte Carlo calculations of collision events. While the same cutoffs for the energy groups are used for all sources in a problem, the groupwise intensities that determine the spectral distribution are specified independently for each source. Within each group the distribution is assumed to be uniform with respect to energy.

The preparation of the input data for planar surface sources is described in Table VII. Each planar surface source has a uniform spatial distribution over a rectangle (excluding any

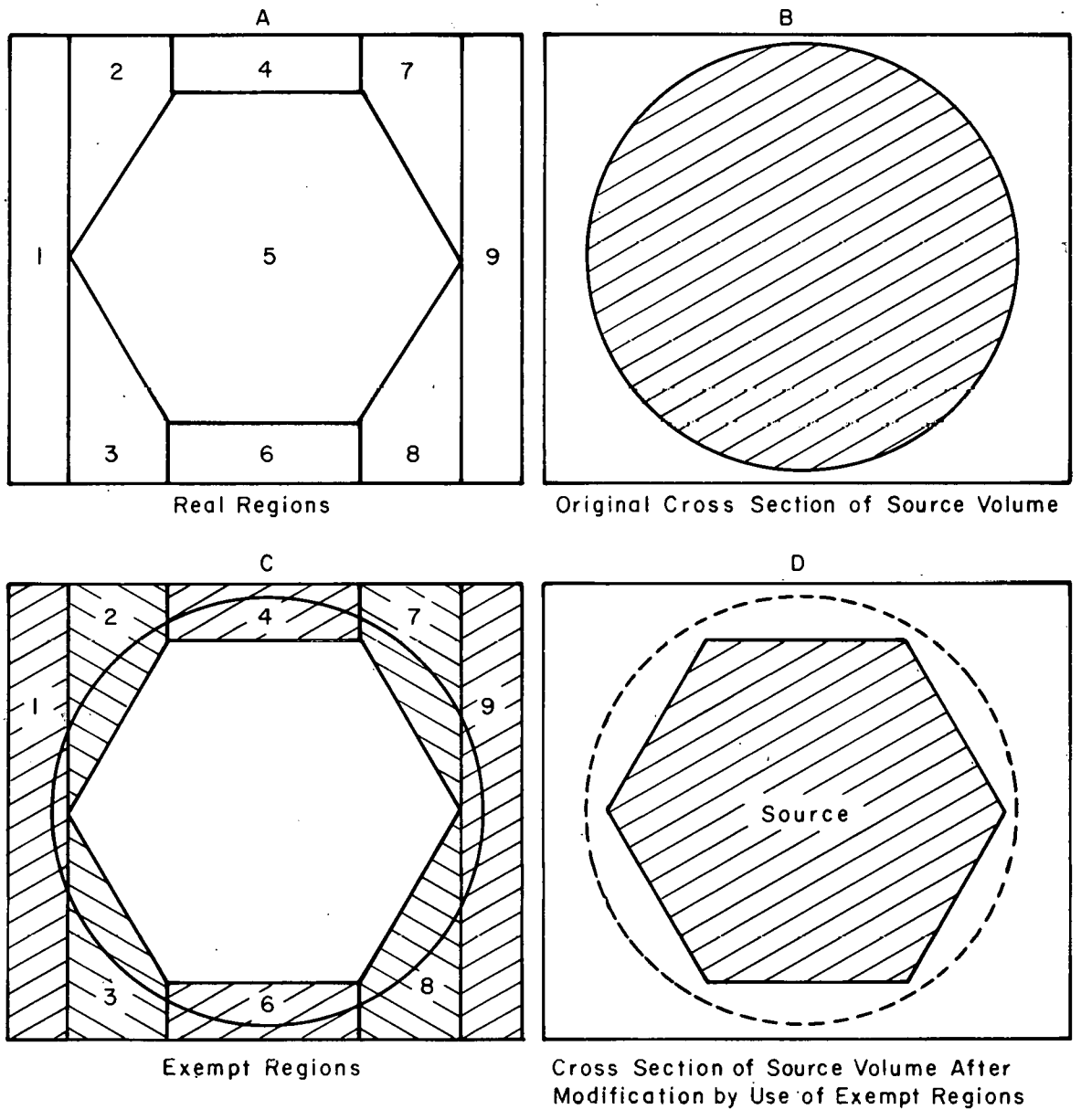


Fig. 32 Modification of source geometry by exempt regions.

portions lying in exempt regions) whose location and extent are determined as shown in Figure 33. The plane on which the neutron source is spatially distributed must be parallel to one of the xy, xz, or yz planes. A nonisotropic distribution of the angular flux with respect to the angle between the direction of the source neutrons and the normal to the plane may be read in. For a planar surface source the angular distribution always has axial symmetry about the normal to the plane.

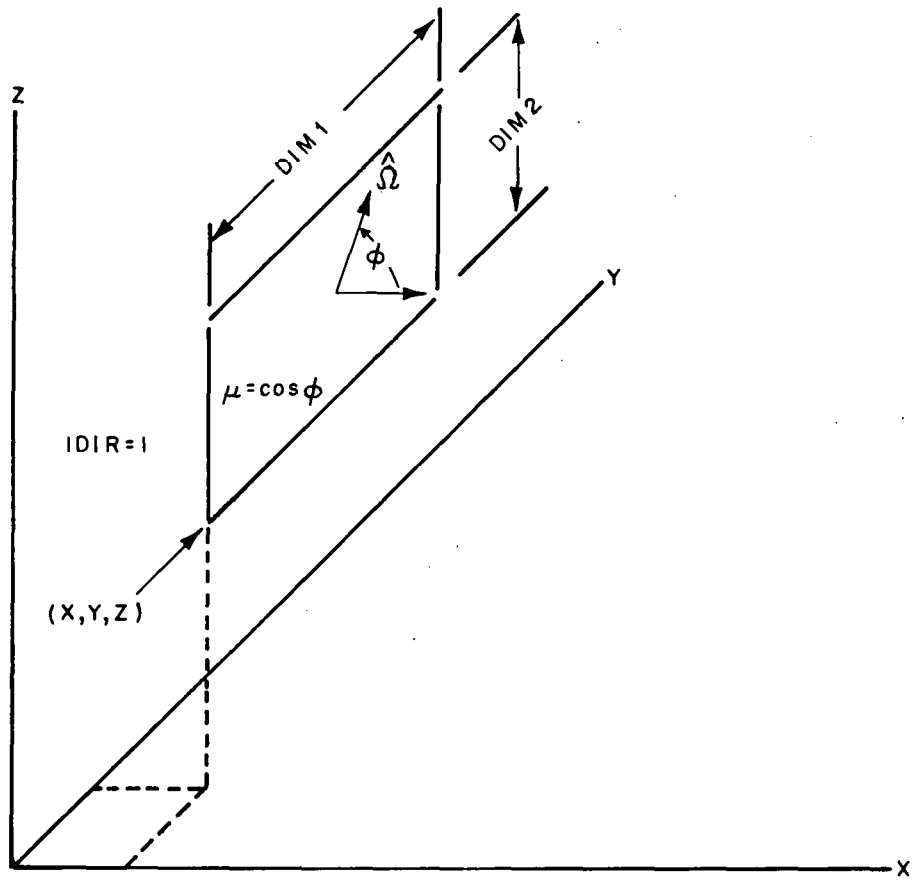


Fig. 33 Coordinates for a planar current source into the positive x hemisphere.

The preparation of the input data for cylindrical surface sources is described in Table VIII. For a cylindrical source a nonuniform distribution of the angular flux with respect to both the normal and azimuthal directions may be read in. The set of angles used to define the angular flux distribution is shown in Figure 34. If a nonisotropic distribution is used, the input data specifies it for only one quadrant of the hemisphere, with symmetry assumed about μ=0 and ϕ=0. In the z direction the spatial distribution may be uniform or of the form Acos(Bz + C); in the tangential direction the spatial distribution is always uniform. The cylinder on which the source is produced must have its axis parallel to the z axis of the coordinate system for the region geometry.

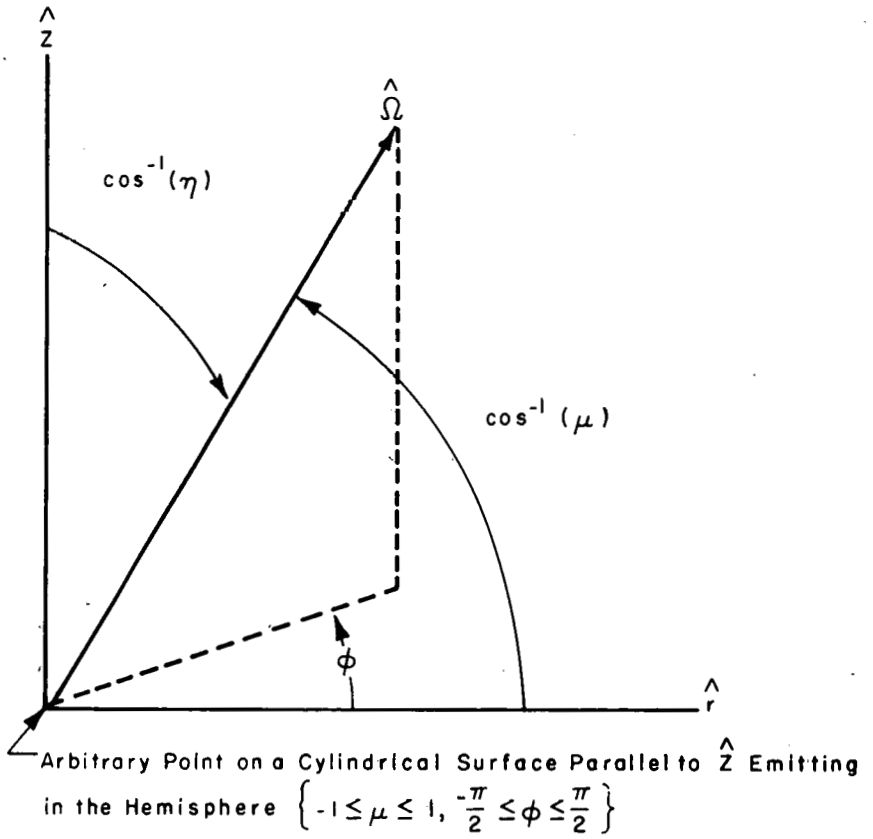


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Fig. 34 Angles for defining a nonisotropic angular flux for a cylindrical surface source.

TABLE VII

DESCRIPTION OF DATA FOR PLANAR SURFACE SOURCES
(Used when ICURR=1)

Card Type 1	Format 15I5	6 Entries
NSORCS Columns 1-5	Number of planar surface sources	
NCURGP Columns 6-10	Number of energy groups for the surface sources	
ICURBS Columns 11-15	Importance weighting flag 0-No importance weighting 1-*Equal importances assigned to each group 2-Read in group importances *For equal importances, the groups are chosen uniformly with appropriate weighting performed	
ICURIS Columns 16-20	Nonisotropic source flag 0-Use isotropic angular flux distribution (0 is the default value) 1-Read in a nonisotropic distribution with respect to the normal direction to the plane of the source (The distribution is assumed to have axial symmetry with respect to the normal to the plane of the source)	
NCURMU Columns 21-25 (Used if ICURIS=1)	Number of normal cosines μ used to describe the nonisotropic distribution (NCURMU$\geq$2 since the end values 1.0 and 0.0 are required)	
ICURMU Columns 26-30	Sampling Flag 0-Sample from the nonisotropic angular flux distribution that is read in 2-Sample from an isotropic angular flux distribution (The angular current is then proportional to μ, and appropriate weighting is performed by RAFFLE)	
Card Type 2	Format 5F15.0	NCURGP + 1 Entries
GRP(IG)	Enter energy cutoffs, 5 values per card, in floating point format. Values, in eV, start with the upper energy of highest energy group and are entered in order of increasing group number, that is, decreasing energy. The last value is that for the lower energy cutoff of the last group.	

TABLE VII (Cont'd)

DESCRIPTION OF DATA FOR PLANAR SURFACE SOURCES
(Used when ICURR=1)

Card Type 3 Format 5F15.0 NCURGP Entries

IMP(IG) (Used if ICURBS=2)	Enter group importances in order of increasing group number. The distribution used is proportional to the importances, after suitable normalization by RAFFLE.

Card Type 4 Format 5F15.0 NCURMU Entries

CØSPØ(I) (Used if ICURIS=1)	Enter normal cosines in order of decreasing value. The cosines are with respect to the normal axis to the plane.

Card Types 5, 6, 7, 8, 9 One set required for each source

Card Type 5 Format 15I5 3 Entries

ITYPE	Source type (Must be 0 to indicate a planar source)
IDIR	Source direction flag 1-Positive x direction -1-Negative x direction 2-Positive y direction -2-Negative y direction 3-Positive z direction -3-Negative z direction The direction designates the hemisphere into which the current flows. Use only one direction for a given source.
NEXREG	Number of exempt regions

Card Type 6 Format 15I5 NEXREG Entries

EXREG(K) (Used if NEXREG>0)	List the exempt regions in any order

Card Type 7 Format 5F15.0 5 Entries

XCØR	X coordinate locating planar source
YCØR	Y coordinate locating planar source
ZCØR	Z coordinate locating planar source

(Card Type 7 continued on next page)

TABLE VII (Cont'd)

DESCRIPTION OF DATA FOR PLANAR SURFACE SOURCES
(Used when ICURR=1)

Card Type 7 (Cont'd)

DIM1	Y dimension if IDIR=±1 X dimension if IDIR=±2 or ±3	DIM1 and DIM2 are simply the non-zero values of the sequence ΔX, ΔY, ΔZ
DIM2	Z dimension if IDIR=±1 or ±2 Y dimension if IDIR=±3	

Note: The source coordinates XCØR, YCØR, ZCØR must be such that DIM1≥0 and DIM2≥0. For either DIM1=0 or DIM2=0 a line source will result. For both DIM1=0 and DIM2=0 a point source will result.

Card Type 8 Format 5F15.0 NCURGP Entries

SØRVAL(IG)	Hemispherical groupwise currents per unit area in order of increasing group number, decreasing energy

Note: The current source will have a uniform spatial distribution over the rectangle on which it is defined. The total intensity for a plane source is thus $\Delta_1\Delta_2 J$ where Δ_1 and Δ_2 are equal to DIM1 and DIM2 respectively and J is the sum of the input hemispherical groupwise currents.

Card Type 9 Format 5F15.0 NCURMU Entries for each of NCURGP Groups

F(I,IG) (Use if ICURIS=1)	For each group, proceeding from the highest numbered to the lowest numbered group, enter NCURMU values of the angular fluxes in order of decreasing value of the normal cosine. Start a new card for each group. The angular fluxes entered are assumed to have axial symmetry about the normal to the plane. Normalization is not required.

Note: Repeat Card Types 5, 6, 7, 8, and 9 until all sources have been described.

Note: Do not enter a 1 in the first column of the last card of this data set.

TABLE VIII

DESCRIPTION OF DATA FOR CYLINDRICAL SURFACE SOURCES

Card Type 1	Format 15I5	6 Entries
NSORCS Columns 1-5	Number of cylindrical surface sources	
NCURGP Columns 6-10	Number of energy groups for the surface sources	
ICURBS Columns 11-15	Importance weighting flag 0-No importance weighting 1-*Equal importances assigned to each group 2-Read in group importances *For equal importances, the groups are chosen uniformly with appropriate weighting performed to account for group-to-group variation of the current intensities	
ICURIS Columns 16-20	Nonisotropic source flag 0-Use isotropic angular flux distribution 1-Read in a nonisotropic distribution with respect to both the normal and azimuthal directions	
NCURMU Columns 21-25 (Used if ICURIS=1)	Number of polar cosines η, including $\eta=1$, used to describe the nonisotropic distribution	
NCURAZ Columns 26-30 (Used if ICURIS=1)	Number of azimuthal angles ϕ, including end points, to describe the nonisotropic distribution	
Card Type 2	Format 5F15.0	NCURGP + 1 Entries
GRP(IG)	Enter energy cutoffs, 5 values per card, in floating point format. Values, in eV, start with the upper energy of the highest energy group and are entered in order of increasing group number, that is, decreasing energy. The last value is that for the lower energy cutoff of the last group.	
Card Type 3	Format 5F15.0	NCURGP Entries
IMP(IG) (Used if ICURBS=2)	Enter group importances in order of increasing group number. The distribution used is proportional to the importances, after suitable normalization by RAFFLE.	

TABLE VIII (Cont'd)

DESCRIPTION OF DATA FOR CYLINDRICAL SURFACE SOURCES

Card Type 4 Format 5F15.0 NCURMU Entries	
CØSPØ(I) (Used if ICURBS=2)	Enter the polar cosines η in order of increasing value (Must include η_1=0.0 and η_{NCURMU}=1.0)
Card Type 5 Format 5F15.0 NCURAZ Entries	
AZ(J) (Used if ICURIS=1)	Enter the asimuthal angles, in degrees, in order of increasing value (Must include both end points, 0° and 90°) See Figure 34.
Card Types 6, 7, 8, 9, 10, and 11	One set required for each source
Card Type 6 Format 15I5	4 Entries
ITYPE	Source type (Must be 1 to indicate a cylindrical source)
IDIR	Source direction flag +1-Outward current -1-Inward current
IBIAS	Z biasing flag 0-Uniform spatial distribution in the Z direction (0 is the default value) 1-The spatial distribution in the Z direction is given by Acos(Bz + C)
	Note: The spatial distribution in the tangential direction is always assumed to be uniform. For IBIAS=1 the current source, for a surface, will have the distribution JAcos(Bz + C)dϕdZ where J is the sum of the input hemispherical group currents. The total strength will then be $2\pi RJ \int_{Z_o}^{Z_o+\Delta Z} A\cos(Bz + C)$ where Z_o and ΔZ are the input Z dimensions for the source and R the input radius
NEXEM	Number of exempt regions

TABLE VIII (Cont'd)

DESCRIPTION OF DATA FOR CYLINDRICAL SURFACE SOURCES

Card Type 7	Format 5F15.0	3 Entries
A,B,C (Used if IBIAS=1)	Biasing parameters for Acos(Bz + C)	
Card Type 8	Format 5F15.0	NEXEM Entries
EXREG(K) (Used if NEXEM>0)	List of exempt regions in any order	
Card Type 9	Format 5F15.0	5 Entries
X_o,Y_o,Z_o,R,DELZ	Source dimensions X_o, Y_o, Z_o locate the bottom of the axis of the cylindrical source with respect to the coordinate system for the region geometry R specifies radius of the source DELZ specifies the extent (height) of the source in the Z direction Note: All dimensions are in centimeters For DELZ=0 a ring source will result	
Card Type 10	Format 5F15.0	NCURGP Entries
SØRVAL(IG)	Hemispherical groupwise currents per unit area in order of increasing group number, decreasing energy	
Card Type 11	Format 5F15.0	NCURAZ*NCURMU*NCURGP Entries
F(J,I,IG) (Used if ICURIS=1)	For each of the polar cosine values η_i, beginning with the minimum η, read in NCURAZ values of the angular flux in order of increasing azimuthal angle ϕ_j, $(\psi(\eta_i,\phi_j),j=1,NCURAZ)$; where ψ is the angular flux). Repeat this input for each of the polar cosines in order of increasing polar cosine value (start the data for each polar cosine on a new card) This block of input will be the angular fluxes for a particular group. Repeat this input for each of the NCURGP current groups in order of increasing group number	

(Card Type 11 continued on next page)

TABLE VIII (Cont'd)

DESCRIPTION OF DATA FOR CYLINDRICAL SURFACE SOURCES

Card Type 11 (Cont'd)

$\psi(\eta_1,\phi_j)$, j=1, NCURAZ

$\psi(\eta_2,\phi_j)$, j=1, NCURAZ

⋮

$\psi(\eta_{(NCURMU-1)},\phi_j)$, j=1, NCURAZ

$\psi(\eta_{NCURMU},\phi_j)$, j=1, NCURAZ

} Group 1

η_1=0.0

η_{CURMU}=1.0

$\psi(\eta_1,\phi_j)$, j=1, NCURAZ

⋮

$\psi(\eta_{NCURMU},\phi_j)$, j=1, NCURAZ

} Group 2

etc.

Note: For each group it is recommended that the value input for the angular flux at η_1 be the same as that for η_2 if the user has no better value. For each group the value input for the angular flux at η_{CURMU} must be the same as that for $\eta_{(CURMU-1)}$

VI. SAMPLE PROBLEMS

This section describes the preparation of the input data, other than the cross section data, for three RAFFLE problems that illustrate a number of the major options available. The geometry is the same for all of the problems with two cylindrical fuel pins surrounded by coolant in a rectangular cell. The first problem iterates on a fission source with convergence on k and calculates reaction rates. The second problem uses fixed current sources with convergence on groupset fluxes and calculates cross sections for the reactor cell. Sodium is used as the coolant for the above problems, and thus they apply to fast reactor systems. The third problem uses multiple thermal groups and demonstrates the application of RAFFLE to a thermal reactor system. For this problem the coolant is water.

In describing the preparation of the input data, familiarity with Section V is assumed. The geometry common to all three problems is described and then individual problems discussed. Output listings are presented but are not discussed. The primary intent of this section is to provide concrete examples of how to prepare the input data for RAFFLE problems. Cutoff values, choice of options, etc., should not be considered as recommendations; Section IV provides guidelines for selecting options and biasing techniques. In the present section the existence of the required cross section libraries is assumed. Preparation of cross section data is discussed in Section VII.

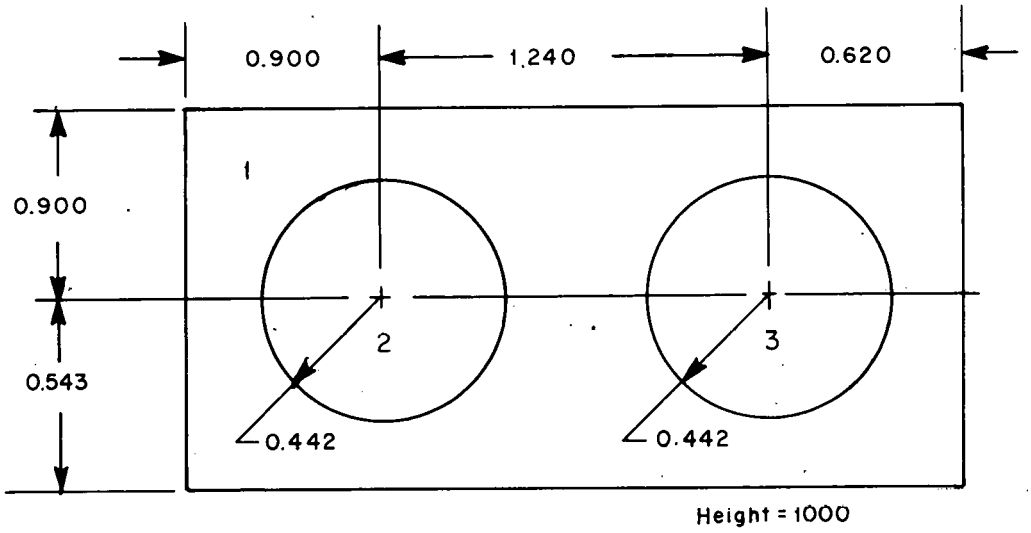
1. GEOMETRY OF THE REACTOR CELL

A top view of the reactor cell is shown in Figure 35. The 1000 cm high rectangular cell has two cylindrical fuel pins, one of high and one of low enrichment fuel, surrounded by coolant. The cell thus consists of three materials.

For a RAFFLE problem two independent geometrical descriptions are required. The first uses surfaces and regions to describe the actual geometry of the system, with perhaps some approximations, in a form suitable for the computer. The second defines zones that are used to reduce the computer time required to determine in which region an event occurs. The region model is discussed first and then the zone model.

The region and surface numbers for the model are shown in Figure 36, the dimensions in Figures 36 and 37. Detailed discussions of the use of surfaces and regions to describe a system are presented in Sections III.4 and III.5. While the reactor cell contains only three materials, the restrictions on region types make it necessary to use four real regions to describe the cell for RAFFLE calculations. In addition, six vacuum regions are used to

Note: All Dimensions in Centimeters



Region	Material
1	1 Coolant
2	2 High Enrichment Fuel Pin
3	3 Low Enrichment Fuel Pin

ANC-A-640

Fig. 35 Reactor cell for sample problems.

TABLE IX

ASSIGNMENT OF MATERIALS TO REGIONS*

Region Index Number	Material Index Number
1	1
2	1
3	2
4	3
5	-*
6	-
7	-
8	-
9	-
10	-

*A material is not assigned to a vacuum region

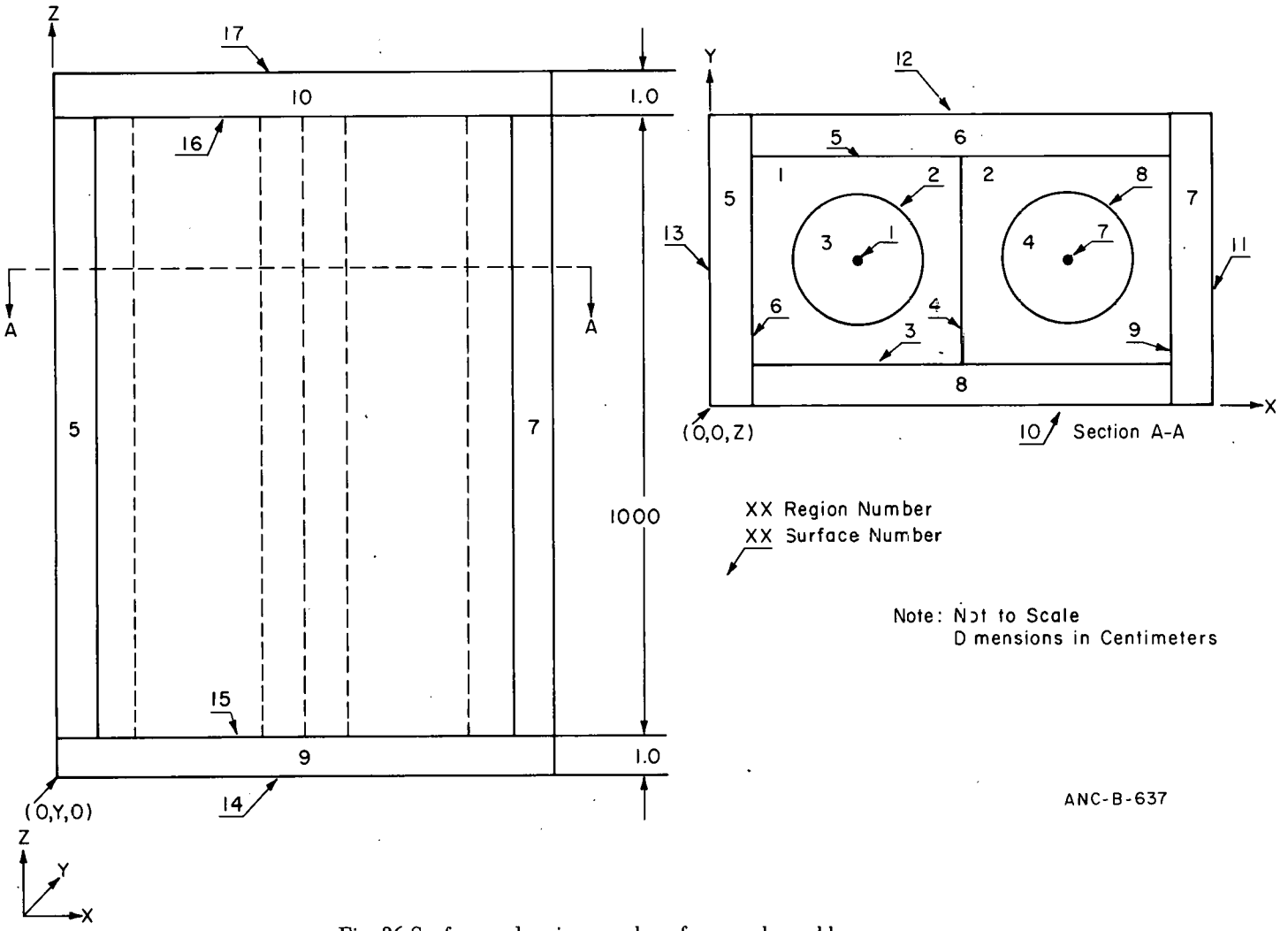


Fig. 36 Surface and region numbers for sample problems.

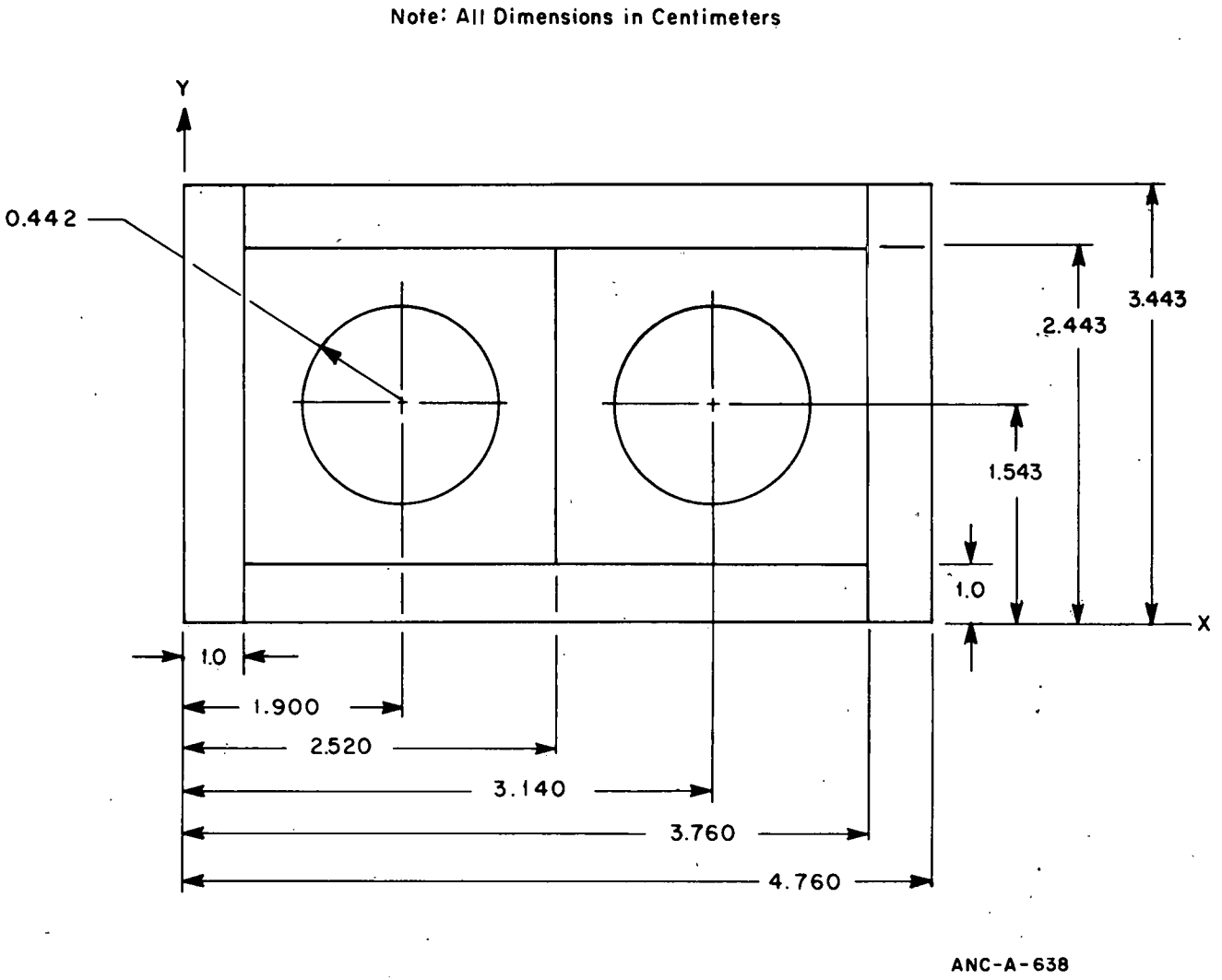


Fig. 37 Dimensions of RAFFLE model for sample problems.

enclose the real regions. Note that the region numbers for the vacuum regions follow in progression the number for the real regions. The correspondence between materials and regions is given in Table IX. Regions 3 and 4 each contain a volume source in Problem I. For Problem II the sources of regions 3 and 4 are replaced by planar surface sources as shown in Figure 38. Note that the surface sources are placed so that they are contained entirely within real regions. Except for the differences in the sources the region model for Problem II is identical with that for Problem I.

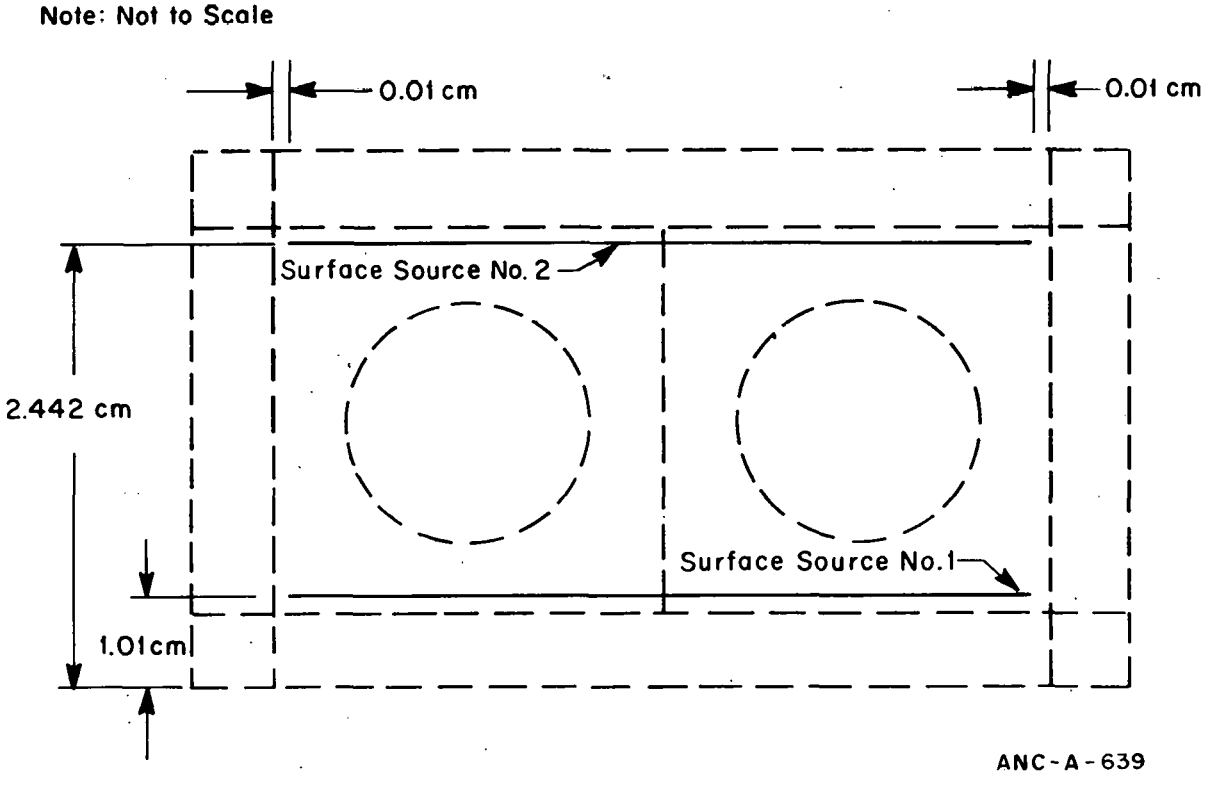


Fig. 38 Placement of surface sources for sample problem II.

The zone geometry as shown in Figure 39 is identical for all three problems. For efficient calculations, it is desirable to have one region per zone. The cylindrical regions make it impossible to achieve this objective with any of the available zone geometries. However, the stacked rectangular zones have been selected to keep the number of regions per zone small.

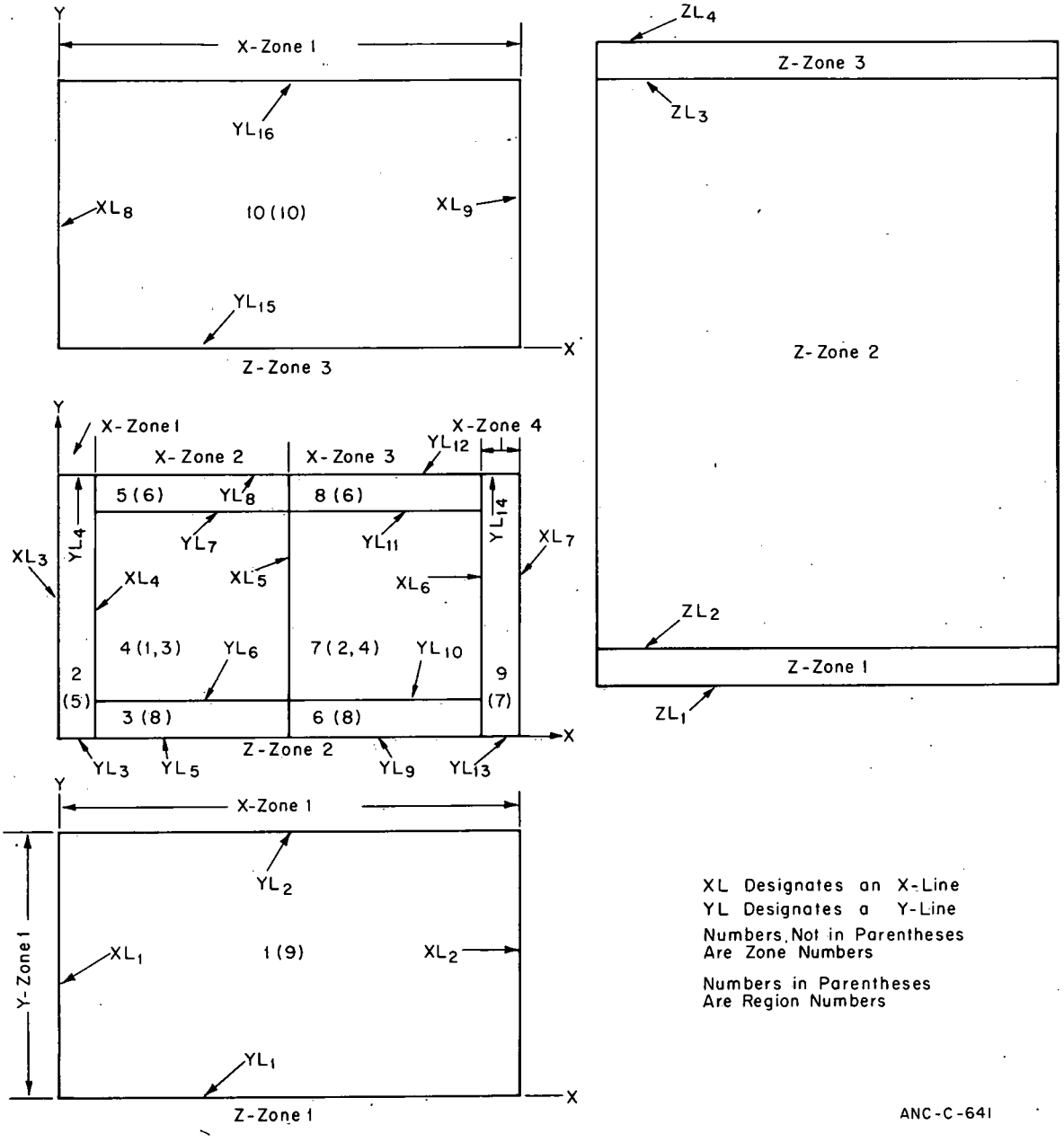


Fig. 39 Zone description for sample problems.

2. SAMPLE PROBLEM I

Problem I is an eigenvalue problem with the fluxes and reaction rates calculated for a system consisting of an infinite three-dimensional array of the cells of Figure 37. The integer data set with references to the mnemonic names of the data types and comments on their usage is listed and numbered by card in Table X. Table XI lists the floating point data in similar form. The data types are described in Section V. The input data, other than the cross section library, in card image form are given and numbered in Table XII. Form ANC-1755, *Reactor Codes Input Form*, is designed for entering the general fixed and floating point data sets. The first card for the problem is a title card.

The first entry in the integer data set, INEDIT, is set to 2 so that the problem will be executed. The value of 69 for NGRP is imposed by the cross section library used. The first fifteen items are entered on Card 2 as shown in Table XII. The 1 in column 8 indicates that Index 3 has a value of 1 for the first entry on the card. The 15 in columns 11 and 12 shows that fifteen words are entered on the card. Fifteen separate cards could have been used for these entries; in this case each card would contain the value of Index 3 in column 8 and 1 in column 12. The next fifteen words or values are entered on Card 3. Note the 16 in columns 7 and 8 and the inclusion of blanks for the words with Index 3 equal to 18, 19, and 26. The remainder of the single entries are entered on Card 4.

The first multiple index entry specifies the assignment of materials to regions as shown in Table IX. Referring to Table X, the 1 in Index 2 designates the data type. The 1 in Index 3 shows the first word of data on the card contains the material number for region 1. Note that no assignment is needed for the vacuum regions. A region may contain only one material. However, the same material can be used in any number of regions.

The entries on the next card specify the region type for each region, including the vacuum regions. The allowable region types are described in Section III.5.1. Referring to Figure 36 it is seen that regions 1 and 2 each have one curved boundary and thus are Type 2. The first two data entries on Card 6, therefore, each have a value of 2. Regions 3 and 4 each have two curved boundaries; note that surfaces 1 and 7 are cylinders with zero radii and are Type 3. The remaining regions have no curved boundaries and are Type 1. Since convergence is on k, IVERGE=1, data types ICHREG and ICHGRP are not used.

A source type must be specified for each of the two sources, which are cylinders occupying the same volumes as the fuel pins, regions 3 and 4. In the present case, the sources are cylinders of Type 1.

TABLE X

INTEGER DATA FOR SAMPLE PROBLEM I

Index 1 Card Cols. 2-3 Format I2	Index 2 Card Cols. 4-5 Format I2	Index 3 Card Cols. 6-8 Format I3	Index 4 Card Cols. 9-10 Format I2	Mnemonic Name of Data	Data Card Columns 13-72 Format 1514														Comments	Card No.
		1		INEDIT	2														Execute Problem	2
		2		IED		3													Do not print cross section data	2
		3		NGRP			69												Number of cross section broad groups	2
		4		NREG				4											Number of real regions	2
		5		NFREG					6										Number of enclosing vacuum regions	2
		6		NMAT						3									Number of materials	2
		7		IZØNGE							1								Stacked parallelepiped zone geometry	2
		8		NSUR								17							Number of surfaces	2
		9		NFSP									1						Number of fission spectra	2
		10		NSCAT										6					Number of isotopes in problem	2
		11		NIC											18				Number of isotopes in cross section library	2
		12		LABGRP												69			Group 69 angular data in lab system	2
		13		LSCAT													69		No elastic energy change in group 69	2
		14		IXTERN														1	Eigenvalue problem	2
		15		NIVØ														16	Histories per generation	2
		16		ISCØRE	1														Standard path scoring	3
		17		NNZØNE		10													Total number of zones	3
		20		NNZZL					4										Number of z-lines	3
		21		NGRPST						27									Number of groupsets	3
		22		NREGST							2								Number of region sets	3
		23		NEXCUT								1							Standard Russian roulette	3
		24		ISPLT									1						No splitting	3
		25		JTAPE										2					Read cross section library from unit 15	3
		27		MEXP												9			Sets size of random number table	3
		28		NREJEC													5		Random numbers initially rejected	3
		29		NSØRCS														2	Number of initial fission sources	3
		30		IVSPEC														1	Fission spectrum #1 used for the source	3
		31		INNGEN	3														Number of generations processed before tally	4
		32		ICURR		0													Volume source problem	4
		33		LGRP			0												No leakage tallies	4
		34		IVERGE				1											Convergence on k	4
	1	1		MATRL(IR)	1	1	2	3											Assigns materials to regions	5
	2	1		IIRT(IR)	2	2	3	3	1	1	1	1	1	1					Specifies region types	6
	5	1		ITYPE(IC)	1	1													Specific cylindrical volume sources	7

TABLE X (Cont'd)

INTEGER DATA FOR SAMPLE PROBLEM I

Index 1 Card Cols. 2-3 Format I2	Index 2 Card Cols. 4-5 Format I2	Index 3 Card Cols. 6-8 Format I3	Index 4 Card Cols. 9-10 Format I2	Mnemonic Name of Data	Data Card Columns 13-72 Format 15I4															Comments	Card No.
	8	1		IGRPST(J)	1	1	2	2	3	3	4	4	5	5	6	6	7	7	8	}	8
	8	16		IGRPST(J)	8	9	9	10	10	11	11	12	12	13	13	14	14	15	15	} Establishes correspondence between	9
	8	31		IGRPST(J)	16	16	17	17	18	18	19	19	20	20	21	21	22	22	22	} group and group set energy structures	10
	8	46		IGRPST(J)	22	23	23	23	23	24	24	24	24	25	25	25	25	26	26	}	11
	8	61		IGRPST(J)	26	26	27	27	27	27	27	27	27							}	12
	9	1		IREGST(IR)	2	2	1	1												Collapses regions into region sets	13
	10	1		KØBN(I)	3	9	5	6	15	16										External boundaries or surfaces	14
	11	2		IFM(IM)	1	1														Number of fission spectra by material	15
	12	1		NAFTAL(ID)	12	14	15	23	29	141										List of isotope identification numbers	16
	13	1		ISPECT(ID)	1	1	1	0	0	0										Assigns fission spectra to isotopes	17
1	1	1		MIX(ID,1)	29	141														Isotopes in Material 1	18
1	2	1		MIX(ID,2)	12	14	15	23												Isotopes in Material 2	19
1	3	1		MIX(ID,3)	12	14	15	23												Isotopes in Material 3	20
2		1		KBN(IS,1)	2	6	3	-4	-5	15	-16									Signed boundaries for Region 1	21
2		2		KBN(IS,2)	8	4	3	-9	-5	15	-16									Signed boundaries for Region 2	22
2		3		KBN(IS,3)	1	2	15	-16												Signed boundaries for Region 3	23
2		4		KBN(IS,4)	7	8	15	-16												Signed boundaries for Region 4	24
2		5		KBN(IS,5)	13	10	-6	-12	15	-16										Signed boundaries for Region 5	25
2		6		KBN(IS,6)	6	5	-9	-12	15	-16										Signed boundaries for Region 6	26
2		7		KBN(IS,7)	9	10	-11	-12	15	-16										Signed boundaries for Region 7	27
2		8		KBN(IS,8)	6	10	-9	-3	15	-16										Signed boundaries for Region 8	28
2		9		KBN(IS,9)	13	10	-11	-12	14	-15										Signed boundaries for Region 9	29
2		10		KBN(IS,10)	13	10	-11	-12	16	-17										Signed boundaries for Region 10	30
3		1		IZØNE(1)	9															Regions in Zone 1	31
3		2		IZØNE(2)	5															Regions in Zone 2	32
3		3		IZØNE(3)	8															Regions in Zone 3	33
3		4		IZØNE(4)	1	3														Regions in Zone 4	34
3		5		IZØNE(5)	6															Regions in Zone 5	35
3		6		IZØNE(6)	8															Regions in Zone 6	36
3		7		IZØNE(7)	2	4														Regions in Zone 7	37
3		8		IZØNE(8)	6															Regions in Zone 8	38
3		9		IZØNE(9)	7															Regions in Zone 9	39
3		10		IZØNE(10)	10															Regions in Zone 10	40
6		3		ITRAGG	0															Calculate reaction rates	41

TABLE XI

FLOATING POINT DATA FOR SAMPLE PROBLEM I

Index 1 Card Cols. 2-3 Format I2	Index 2 Card Cols. 4-5 Format I2	Index 3 Card Cols. 6-8 Format I3	Index 4 Card Cols. 9-10 Format I2	Mnemonic Name of Data	Data Card Columns 13-72					Comments	Card No.
		1		RTIME	1.0					Maximum time for Monte Carlo calculations	42
		2		WNCUT	0.2					Cutoff weight	43
		3		CHECK		0.1				Criteria for convergence on k	44
		4		XØP	0.0					Origin of zone geometry coordinate system	44
		5		YØP		0.0					44
		6		ZØP			0.0				44
	1	1		GV(J)	7.79 +6	6.07 +6	4.72 +6	3.68 +6	2.87 +6	Lower cutoffs (eV) for energy broad groups	45
	1	6		GV(J)	2.23 +6	1.74 +6	1.35 +6	1.05 +6	8.21 +5		46
	1	11		GV(J)	6.39 +5	4.98 +5	3.88 +5	3.02 +5	2.35 +5		47
	1	16		GV(J)	1.83 +5	1.43 +5	1.11 +5	8.65 +4	6.74 +4		48
	1	21		GV(J)	5.25 +4	4.09 +4	3.18 +4	2.48 +4	1.93 +4		49
	1	26		GV(J)	1.50 +4	1.17 +4	9.12 +3	7.10 +3	5.53 +3		50
	1	31		GV(J)	4.31 +3	3.36 +3	2.61 +3	2.04 +3	1.59 +3		51
	1	36		GV(J)	1.23 +3	961.1	748.5	582.9	454.0		52
	1	41		GV(J)	353.6	275.4	214.5	167.0	130.1		53
	1	46		GV(J)	101.3	78.9	61.4	47.9	37.3		54
	1	51		GV(J)	29.0	22.6	17.6	13.7	10.68		55
	1	56		GV(J)	8.32	6.48	5.04	3.93	3.06		56
	1	61		GV(J)	2.38	1.86	1.44	1.125	0.876		57
	1	66		GV(J)	0.683	0.532	0.414	0.0			58
	4	1		ALBEDØ(I)	1.0	1.0	1.0	1.0	1.0	Albedos for surfaces 3, 9, 5, 6, 15	59
	4	6		ALBEDØ(I)	1.0					Albedo for surface 16, see KØBN	60
	5	1		XLINE(IX)	0.0	4.760	0.0	1.0	2.520	Distances of x-zone-lines from origin	61
	5	6		XLINE(IX)	3.760	4.760	0.0	4.760			62
	6	1		YLINE(IY)	0.0	3.443	0.0	3.443	0.0		63
	6	6		YLINE(IY)	1.0	2.443	3.443	0.0	1.0	Distances of y-zone-lines from origin	64
	6	11		YLINE(IY)	2.443	3.443	0.0	3.443	0.0		65
	6	16		YLINE(IY)	3.443						66
	7	1		ZLINE(IZ)	0.0	1.0	1001.0	1002.0		Distances of z-zone-lines from origin	67
	9	1		XTENS(IC)	1.0	1.0				Source intensities	68
1	1	1		DENS(II,1)	1.671 -2	1.301 -2				Isotopic concentrations for coolant	69
1	2	1		DENS(II,2)	1.559 -2	5.801 -3	7.689 -4	4.518 -2		Concentrations for high enrichment pin	70
1	3	1		DENS(II,3)	1.901 -2	2.901 -3	3.845 -4	4.528 -2		Concentrations for low enrichment pin	71
5	1	1		DEL(IC,1)	1.900	1.543	1.0	0.0	0.442	Dimensions and location for source 1	72
5	1	6		DEL(IC,1)	1000.0						73

TABLE XI (Cont'd)

FLOATING POINT DATA FOR SAMPLE PROBLEM I

Index 1 Card Cols. 2-3 Format I2	Index 2 Card Cols. 4-5 Format I2	Index 3 Card Cols. 6-8 Format I3	Index 4 Card Cols. 9-10 Format I2	Mnemonic Name of Data	Data Card Columns 13-72					Comments	Card No.
5	2	1		DEL(IC,2)	3.140	1.543	1.0	0.0	0.442	Dimensions and location for Source 2	74
5	2	6		DEL(IC,2)	1000.0						75
6	1	1		FSPEC(1)	.0071790	.0203770	.0425630	.0698340	.0947739		76
6	1	6		FSPEC(1)	.1108400	.1153600	.1096000	.0969729	.0811549		77
6	1	11		FSPEC(1)	.0650310	.0503760	.0380050	.0280890	.0204290		78
6	1	16		FSPEC(1)	.0146730	.0073677	.0051703	.0036117	.0025138		79
6	1	21		FSPEC(1)	.0025138	.0017448	.0012084	.0008355	.0005769	Normalized fission spectrum	80
6	1	26		FSPEC(1)	.0003979	.0002743	.0001889	.0001301	.0000895		81
6	1	31		FSPEC(1)	.0000616	.0000424	.0000291	.0000200	.0000138		82
6	1	36		FSPEC(1)	.0000095	.0000065	.0000045	.0000031	.0000021		83
6	1	41		FSPEC(1)	.0000014	.0000010					84
7		1	2	A(I,1)	0.0	0.0	1.900	1.543		Coefficients for Surface 1	85
7		2	2	A(I,2)	0.0	0.442	1.900	1.543		Coefficients for Surface 2	86
7		3	1	A(I,3)	0.0	1.0	0.0	1.0		Coefficients for Surface 3	87
7		4	1	A(I,4)	1.0	0.0	0.0	2.520		Coefficients for Surface 4	88
7		5	1	A(I,5)	0.0	1.0	0.0	2.443		Coefficients for Surface 5	89
7		6	1	A(I,6)	1.0	0.0	0.0	1.0		Coefficients for Surface 6	90
7		7	2	A(I,7)	0.0	0.0	3.140	1.543		Coefficients for Surface 7	91
7		8	2	A(I,8)	0.0	0.442	3.140	1.543		Coefficients for Surface 8	92
7		9	1	A(I,9)	1.0	0.0	0.0	3.760		Coefficients for Surface 9	93
7		10	1	A(I,10)	0.0	1.0	0.0	0.0		Coefficients for Surface 10	94
7		11	1	A(I,11)	1.0	0.0	0.0	4.760		Coefficients for Surface 11	95
7		12	1	A(I,12)	0.0	1.0	0.0	3.443		Coefficients for Surface 12	96
7		13	1	A(I,13)	1.0	0.0	0.0	0.0		Coefficients for Surface 13	97
7		14	1	A(I,14)	0.0	0.0	1.0	0.0		Coefficients for Surface 14	98
7		15	1	A(I,15)	0.0	0.0	1.0	1.0		Coefficients for Surface 15	99
7		16	1	A(I,16)	0.0	0.0	1.0	1001.0		Coefficients for Surface 16	100
7		17	1	A(I,17)	0.0	0.0	1.0	1002.0		Coefficients for Surface 17	101

TABLE XII

LISTING OF CARD INPUT FOR SAMPLE PROBLEM I

```
CARD
NO.
  1        RAFFLE MONTE CARLO PROGRAM  SAMPLE PROBLEM I     AN ITERATION PROBLEM
  2           1  15   2   3  69    4   6   3   1  17   1   6  18  69  69   1  16
  3          16  15   1  10            4  27   2   1   1   2      9   5   2   1
  4          31   4   3   0   0   1
  5        1  1   4   1   1   2   3
  6        2  1  10   2   2   3   3   1   1   1   1   1   1
  7        5  1   2   1   1
  8        8  1  15   1   1   2   2   3   3   4   4   5   5   6   6   7   7   8
  9        8 16  15   8   9   9  10  10  11  11  12  12  13  13  14  14  15  15
 10        8 31  15  16  16  17  17  18  18  19  19  20  20  21  21  22  22  22
 11        8 46  15  22  23  23  23  23  24  24  24  24  25  25  25  25  26  26
 12        8 61   9  26  26  27  27  27  27  27  27  27
 13        9  1   4   2   2   1   1
 14       10  1   6   3   9   5   6  15  16
 15       11  2   2   1   1
 16       12  1   6  12  14  15  23  29 141
 17       13  1   6   1   1   1   0   0   0
 18     1 1  1   2  29 141
 19     1 2  1   4  12  14  15  23
 20     1 3  1   4  12  14  15  23
 21     2    1   7   2   6   3  -4  -5  15 -16
 22     2    2   7   8   4   3  -9  -5  15 -16
 23     2    3   4   1   2  15 -16
 24     2    4   4   7   8  15 -16
 25     2    5   6  13  10  -6 -12  15 -16
 26     2    6   6   6   5  -9 -12  15 -16
 27     2    7   6   9  10 -11 -12  15 -16
 28     2    8   6   6  10  -9  -3  15 -16
 29     2    9   6  13  10 -11 -12  14 -15
 30     2   10   6  13  10 -11 -12  16 -17
 31     3    1   1   9
 32     3    2   1   5
 33     3    3   1   8
 34     3    4   2   1   3
 35     3    5   1   6
 36     3    6   1   8
 37     3    7   2   2   4
 38     3    8   1   6
 39     3    9   1   7
 40     3   10   1  10
 41   1 6    3   1   0
 42            1   1  1.0
 43            2   2  0.2          0.1
 44            4   3  0.0          0.0          0.0
 45        1   1   5  7.79   +6    6.07   +6    4.72   +6   3.68   +6   2.87   +6
 46        1   6   5  2.23   +6    1.74   +6    1.35   +6   1.05   +6   8.21   +5
 47        1  11   5  6.39   +5    4.98   +5    3.88   +5   3.02   +5   2.35   +5
 48        1  16   5  1.83   +5    1.43   +5    1.11   +5   8.65   +4   6.74   +4
 49        1  21   5  5.25   +4    4.09   +4    3.18   +4   2.48   +4   1.93   +4
 50        1  26   5  1.50   +4    1.17   +4    9.12   +3   7.10   +3   5.53   +3
 51        1  31   5  4.31   +3    3.36   +3    2.61   +3   2.04   +3   1.59   +3
 52        1  36   5  1.23   +3    961.1        748.5        582.9        454.0
 53        1  41   5  353.6        275.4        214.5        167.0        130.1
 54        1  46   5  101.3         78.9         61.4         47.9         37.3
 55        1  51   5   29.0         22.6         17.6         13.7         10.68
 56        1  56   5    8.32         6.48         5.04         3.93         3.06
 57        1  61   5    2.38         1.86         1.44         1.125        0.876
 58        1  66   4   0.683        0.532        0.414        0.0
 59        4  1    5  1.0          1.0          1.0          1.0          1.0
 60        4  6    1  1.0
 61        5  1    5  0.0          4.760        0.0          1.0          2.520
 62        5  6    4  3.760        4.760        0.0          4.760
 63        6  1    5  0.0          3.443        0.0          3.443        0.0
 64        6  6    5  1.0          2.443        3.443        0.0          1.0
 65        6 11    5  2.443        3.443        0.0          3.443        0.0
 66        6 16    1  3.443
 67        7  1    4  0.0          1.0          1001.0       1002.0
 68        9  1    2  1.0          1.0
 69     1 1  1   2  1.671  -2    1.301  -2
 70     1 2  1   4  1.559  -2    5.801  -3    7.689  -4    4.518  -2
 71     1 3  1   4  1.901  -2    2.901  -3    3.845  -4    4.528  -2
 72     5 1  1   5  1.900        1.543        1.0          0.0          0.442
 73     5 1  6   1  1000.0
 74     5 2  1   5  3.140        1.543        1.0          0.0          0.442
 75     5 2  6   1  1000.0
 76     6 1  1   5 .0071790     .0203770     .0425630     .0698340     .0947739
 77     6 1  6   5 .1108400     .1153600     .1096000     .0969729     .0811549
```

TABLE XII (Cont'd)

LISTING OF CARD INPUT FOR SAMPLE PROBLEM I

CARD NO.										
78		6	1	11	5	.0650310	.0503760	.0380050	.0280890	.0204290
79		6	1	16	5	.0146730	.0104730	.0073677	.0051703	.0036117
80		6	1	21	5	.0025138	.0017448	.0012084	.0008355	.0005769
81		6	1	26	5	.0003979	.0002743	.0001889	.0001301	.0000895
82		6	1	31	5	.0000616	.0000424	.0000291	.0000200	.0000138
83		6	1	36	5	.0000095	.0000065	.0000045	.0000031	.0000021
84		6	1	41	2	.0000014	.0000010			
85		7		1	2	4 0.0	0.0	1.900	1.543	
86		7		2	2	4 0.0	0.442	1.900	1.543	
87		7		3	1	4 0.0	1.0	0.0	1.0	
88		7		4	1	4 1.0	0.0	0.0	2.520	
89		7		5	1	4 0.0	1.0	0.0	2.443	
90		7		6	1	4 1.0	0.0	0.0	1.0	
91		7		7	2	4 0.0	0.0	3.140	1.543	
92		7		8	2	4 0.0	0.442	3.140	1.543	
93		7		9	1	4 1.0	0.0	0.0	3.760	
94		7		10	1	4 0.0	1.0	0.0	0.0	
95		7		11	1	4 1.0	0.0	0.0	4.760	
96		7		12	1	4 0.0	1.0	0.0	3.443	
97		7		13	1	4 1.0	0.0	0.0	0.0	
98		7		14	1	4 0.0	0.0	1.0	0.0	
99		7		15	1	4 0.0	0.0	1.0	1.0	
100		7		16	1	4 0.0	0.0	1.0	1001.0	
101	1	7		17	1	4 0.0	0.0	1.0	1002.0	

The next data types discussed are NGRPST which specifies the number of groupsets and IGRPST which establishes a correspondence between the energy group structure, as determined by the cross section library, and the energy structure of the groupsets. The groupsets determine the group structure for the output data, and thus provide a transformation from the library group structure to another group structure. Table XIII shows the correspondence between groups and groupsets. It should be noted that while several groups can be combined into one groupset, the reverse is not allowed. The data for IGRPST are on Cards 8 through 12.

Data type IREGST, Card 13, specifies the correspondence between regions and region sets. In the present problem, the two fuel pin regions are combined into the first region set and the two coolant regions into the second region set. With NREGST=1 all of the real regions are combined into one region, the output data are average values for the entire cell, and no entries are required for IREGST.

Data type KOBN, Card 14, lists the external boundary or surface numbers in any order. Signs are not required on the numbers. The external boundaries are defined by the limits of the real regions, see Figure 36.

The number of fission spectra for each material is listed in data type IFM. Note that since material 1 does not contain a fissionable isotope, an entry is not required for this material. Thus, on Card 15, Index 3 is set to 2 so that the first data word applies to material 2.

TABLE XIII

CORRESPONDENCE BETWEEN GROUPS AND GROUPSETS

Group	Groupset	Group	Groupset
1	1	35	18
2	1	36	18
3	2	37	19
4	2	38	19
5	3	39	20
6	3	40	20
7	4	41	21
8	4	42	21
9	5	43	22
10	5	44	22
11	6	45	22
12	6	46	22
13	7	47	23
14	7	48	23
15	8	49	23
16	8	50	23
17	9	51	24
18	9	52	24
19	10	53	24
20	10	54	24
21	11	55	25
22	11	56	25
23	12	57	25
24	12	58	25
25	13	59	26
26	13	60	26
27	14	61	26
28	14	62	26
29	15	63	27
30	15	64	27
31	16	65	27
32	16	66	27
33	17	67	27
34	17	68	27
		69	27

In data type NAFTAL, with Index 2 equal to 12, the identification numbers of all the isotopes used in the problem are listed in order of increasing magnitude. In data type ISPECT with Index 2 equal to 13, the index number of the fission spectrum for each isotope is listed in the same order as the isotope identification numbers in NAFTAL. A zero or blank is entered for nonfissionable isotopes. The identification numbers for the isotopes

used in this problem are in Table XIV. U-238, PU-239, and PU-240 are the only fissionable isotopes and the same fission spectrum is used for all of them.

Data type MIX lists the identification numbers of the isotopes comprising each material. At least one card is required for each material. Table XIV shows the isotopes in each material. Index 2 on Card 18 is equal to 1 to show that the data apply to the material 1.

TABLE XIV

MATERIAL COMPOSITIONS FOR RAFFLE SAMPLE PROBLEMS I AND II

Material 1 Coolant-Structure

Isotope	Identification Number	Concentration (Units of 10^{24} atoms/cm^3)
Fe	29	0.01671
Na-23	141	0.01301

Material 2 High Enrichment Fuel Pin

Isotope	Identification Number	Concentration (Units of 10^{24} atoms/cm^3)
U-238	12	0.01559
PU-239	14	0.005801
Pu-240	15	0.0007689
Oxygen	23	0.04518

Material 3 Low Enrichment Fuel Pin

Isotope	Identification Number	Concentration (Units of 10^{24} atoms/cm^3)
U-238	12	0.01901
PU-239	14	0.002901
PU-240	15	0.0003845
Oxygen	23	0.04528

Regions are defined by the surfaces which bound them, and data type KBN gives the surfaces, as identified by the surface numbers, bounding each region. One card is used for each region. The boundaries for the regions are shown in Figure 36. The surface boundary numbers must be signed as described in Section III.5.4. A positive sign need not be entered. Cylindrical or spherical surfaces always have a positive sign.

For regions having all plane boundaries parallel to one of the planes defined by the coordinate system, the signs can be determined by a straightforward convention. For the surfaces parallel to the X=0 plane, the region boundary surface closest to this plane is positive and the other surface is negative. The same convention applies to planes parallel to the Y=0 and Z=0 planes. From Figure 36 it is seen that region 1 is bounded by surfaces 2, 6, 3, 4, 5, 15, and 16. Surface 2 is cylindrical and thus has a positive sign. By the convention described above, surfaces 4, 5, and 16 are negative with respect to region 1. The data for region 1 are entered on Card 21. Proceeding to region 2, Card 22, it is seen that surface 4 is positive with respect to region 2.

The regions belonging to each zone, as shown in Table XV or Figure 39, are specified by data type IZONE. The zones are ordered starting with the first y-zone in the first x-zone of the first z-zone. The zone numbering is shown in Figure 39. A detailed discussion of the zone geometries is given in Section III.6. The zones that determine NNZONE and the ordering sequence for IZONE are actually the y-zones in parallelepiped geometry. One card is required for each zone. A zone may not have more than seven regions in it. However, there is no such restriction on the number of zones that a region may belong to.

TABLE XV

ASSIGNMENT OF REGIONS TO ZONES

Zone	Regions
1	9
2	5
3	8
4	1, 3
5	6
6	8
7	2, 4
8	6
9	7
10	10

The present problem has no exit regions and no exempt regions so that data types IHEXIT and IREG are not needed. Similarly, since IXTERN=1, MAFIS and IAFIS are not needed. ITRAGG=0 so that reaction rates rather than cross sections are output. IINGG, IELGG, and NFFG are not needed when ITRAGG=0. This entry on Card 41 ends the fixed point data for Problem I as indicated by the "1" in column 1.

The floating point data and the names of the associated data types are shown in Tables XI and XII. In Table XII the floating point data starts with Card 42. The first

floating point entry RTIME is set to 1.0 so that the Monte Carlo calculations terminate when the CPU time equals one minute. The available CPU time must exceed RTIME or the problem will terminate without printing all, or perhaps any, of the results. While the additional time required is problem dependent, it is recommended that one minute be allowed. However, for most problems the actual editing time will be less than one minute. On Cards 43 and 44, note the use of indexing to group the data for related items in Table XII.

The lower energy cutoffs in electron volts for the cross section broad groups are next entered as data type GV. This group structure is imposed by the cross section library used. The data are entered on Cards 45 through 58. Data type XOGEN is not used since ISPLT=-1. Since the system consists of an infinite 3-D array of cells, the albedo has a value of 1.0 at each of the six external surfaces, Cards 59 and 60.

The data that dimensions the zone geometry are entered next, Cards 61 through 67. All dimensions are in centimeters. In the present case of stacked rectangular geometry, each dimension gives the perpendicular distance of a plane from the origin of the coordinate system for the zone geometry. For rectangular zone geometry the origins of the region and zone geometries must coincide. The sequence in which the values for the x-lines, data type XLINES, are entered is shown by the subscripts of the "XL's" in Figure 39. The distances are found by references to Figures 36 and 37. For each z-zone the value for the first x-line must be 0.0. Data type GVL is not used since LGRP=0. A relative intensity of 1.0 is entered for each of the two sources as data type XTENS on Card 68.

The next data type, DENS, establishes the concentrations of the isotopes in each material. These concentrations are given in units of 10^{24} atoms per cubic centimeter. The ordering sequence for the isotopes in the materials is established by fixed point data type MIX. The concentrations are taken from Table XIV. Since NEXCUT=1, data type WGT is not needed.

Data type DEL specifies the volumes occupied by each of the sources. In this problem there are two cylindrical sources each of radius 0.442 cm and extending from 1.0 cm above the x-y plane to 1001.0 cm above it. The locations of the axes are shown in Figure 37. The geometries have been specified as cylindrical by setting ITYPE=1 for each of the sources. On Card 72 the first two data entries place the axis of the cylinder for the source 1.900 cm in the x direction and 1.543 cm in the y direction from the origin of the region geometry. The axis of a cylindrical source is assumed by the program to be parallel to the z-axis. The third data element places the bottom of the cylindrical volume at 1.0 cm above the x-y plane. The

fourth entry being 0.0 indicates that the source is a solid cylinder rather than a cylindrical shell. The fifth entry specifies that the radius of the cylinder is 0.442 cm. The data entry on Card 73 shows that the length of the cylinder is 1000 cm.

The normalized fission or initial source spectra are specified in data type FSPEC. The fractions of particles emitted in each energy group are entered in order of increasing group number, i.e., decreasing energy. For each spectrum the entries should sum to 1, to the number of significant figures used in entering the fractions. In the present problem, data are needed for only one spectrum, i.e., the U-235 fission spectrum, which is used for all three fissionable isotopes and also for the initial distributions in the two cylindrical sources.

The region geometry is established by specifying in data type A the coefficients that determine the equations for the surfaces that bound the regions (see Section III.4). Seventeen surfaces are required to define the reactor cell and the enclosing vacuum regions as shown in Figure 36. One card is required for each surface. The surface number is entered as Index 3, Cards 85 through 101.

For the planar surfaces Index 4 has a value of 1. The cylindrical surfaces are identified by a value of 2 for Index 4 and a value of 0.0 for the first data entry. Consider first the data for surface 2, Card 86, Index 4 and the first data entry identify this surface as cylindrical. The second data entry shows the radius to be 0.442 cm, and the third and fourth data items give values of 1.900 cm and 1.543 cm, respectively, for the x and y coordinates of the axis. For a planar surface the four data entries are the coefficients in the equation AX+BY+CZ=D which defines the surface. This data set completes the input, other than the cross section data, for Problem I. The computer output for this problem is listed in Table XVI at the end of Section VI, starting on page 166.

3. SAMPLE PROBLEM II

Problem II is presented primarily to demonstrate the calculation of cross sections for a cell problem and the use of surface sources. In addition, some of the convergence options differ from those of Problem I. The geometry of the reactor cell and the material compositions are the same as for Problem I. A listing of the input data, other than the cross section library, is shown in Table XVII.

TABLE XVII

LISTING OF INPUT CARDS FOR SAMPLE PROBLEM II

CARD NO.																		
1	RAFFLE	MONTE	CARLO	PROGRAM			SAMPLE	PROBLEM	II		A	CURRENT	SOURCE	PROBLEM				
2		1	15	2	3	69	4	6	3	1	17	1	6	18	69	69	3	16
3		16	13	1	10			4	27	1	2	1	2		9	5		
4		31	7	0	1	0	3		0	2								
5		40	1	1														
6	1	1	4	1	1	2	3											
7	2	1	10	2	2	3	3	1	1	1	1	1	1					
8	4	1	2	7	8													
9	8	1	15	1	1	2	2	3	3	4	4	5	5	6	6	7	7	8
10	8	16	15	8	9	9	10	10	11	11	12	12	13	13	14	14	15	15
11	8	31	15	16	16	17	17	18	18	19	19	20	20	21	21	22	22	22
12	8	46	15	22	23	23	23	23	24	24	24	24	25	25	25	25	26	26
13	8	61	9	26	26	27	27	27	27	27	27	27						
14	10	1	6	3	9	5	6	15	16									
15	11	2	2	1	1													
16	12	1	6	12	14	15	23	29	141									
17	13	1	6	1	1	1	0	0	0									
18	1 1	1	2	29	141													
19	1 2	1	4	12	14	15	23											
20	1 3	1	4	12	14	15	23											
21	2	1	7	2	6	3	-4	-5	15	-16								
22	2	2	7	8	4	3	-9	-5	15	-16								
23	2	3	4	1	2	15	-16											
24	2	4	4	7	8	15	-16											
25	2	5	6	13	10	-6	-12	15	-16									
26	2	6	6	6	5	-9	-12	15	-16									
27	2	7	6	9	10	-11	-12	15	-16									
28	2	8	6	6	10	-9	-3	15	-16									
29	2	9	6	13	10	-11	-12	14	-15									
30	2	10	6	13	10	-11	-12	16	-17									
31	3	1	1	9														
32	3	2	1	5														
33	3	3	1	8														
34	3	4	2	1	3													
35	3	5	1	6														
36	3	6	1	8														
37	3	7	2	2	4													
38	3	8	1	6														
39	3	9	1	7														
40	3	10	1	10														
41	1 6	1	6	4	2	1	1	2	9									
42		1	1	1.0														
43		2	2	0.2			0.01											
44		4	3	0.0			0.0			0.0								
45	1	1	5	7.79		+6	6.07		+6	4.72		+6	3.68		+6	2.87		+6

TABLE XVII (Cont'd)

LISTING OF INPUT CARDS FOR SAMPLE PROBLEM II

```
CARD
NO.
 46      1  6  5  2.23   +6  1.74   +6  1.35   +6  1.05   +6  8.21   +5
 47      1 11  5  6.39   +5  4.98   +5  3.88   +5  3.02   +5  2.35   +5
 48      1 16  5  1.83   +5  1.43   +5  1.11   +5  8.65   +4  6.74   +4
 49      1 21  5  5.25   +4  4.09   +4  3.18   +4  2.48   +4  1.93   +4
 50      1 26  5  1.50   +4  1.17   +4  9.12   +3  7.10   +3  5.53   +3
 51      1 31  5  4.31   +3  3.36   +3  2.61   +3  2.04   +3  1.59   +3
 52      1 36  5  1.23   +3  961.1      748.5      582.9      454.0
 53      1 41  5  353.6      275.4      214.5      167.0      130.1
 54      1 46  5  101.3       78.9       61.4       47.9       37.3
 55      1 51  5   29.0       22.6       17.6       13.7       10.68
 56      1 56  5    8.32       6.48       5.04       3.93       3.06
 57      1 61  5    2.38       1.86       1.44       1.125      0.876
 58      1 66  4    0.683      0.532      0.414      0.0
 59      4  1  5  0.0        1.0        0.0        1.0        1.0
 60      4  6  1  1.0
 61      5  1  5  0.0        4.760      0.0        1.0        2.520
 62      5  6  4  3.760      4.760      0.0        4.760
 63      6  1  5  0.0        3.443      0.0        3.443      0.0
 64      6  6  5  1.0        2.443      3.443      0.0        1.0
 65      6 11  5  2.443      3.443      0.0        3.443      0.0
 66      6 16  1  3.443
 67      7  1  4  0.0        1.0        1001.0     1002.0
 68  1   1  1  2  1.671  -2  1.301  -2
 69  1   2  1  4  1.559  -2  5.801  -3  7.689  -4   4.518  -2
 70  1   3  1  4  1.901  -2  2.901  -3  3.845  -4  4.528  -2
 71      6  1  1  5 .0071790    .0203770    .0425630    .0698340    .0947739
 72      6  1  6  5 .1108400    .1153600    .1096000    .0969729    .0811549
 73      6  1 11  5 .0650310    .0503760    .0380050    .0280890    .0204290
 74      6  1 16  5 .0146730    .0104730    .0073677    .0051703    .0036117
 75      6  1 21  5 .0025138    .0017448    .0012084    .0008355    .0005769
 76      6  1 26  5 .0003979    .0002743    .0001889    .0001301    .0000895
 77      6  1 31  5 .0000616    .0000424    .0000291    .0000200    .0000138
 78      6  1 36  5 .0000095    .0000065    .0000045    .0000031    .0000021
 79      6  1 41  2 .0000014    .0000010
 80      7     1 2 4  0.0        0.0        1.900      1.543
 81      7     2 2 4  0.0        0.442      1.900      1.543
 82      7     3 1 4  0.0        1.0        0.0        1.0
 83      7     4 1 4  1.0        0.0        0.0        2.520
 84      7     5 1 4  0.0        1.0        0.0        2.443
 85      7     6 1 4  1.0        0.0        0.0        1.0
 86      7     7 2 4  0.0        0.0        3.140      1.543
 87      7     8 2 4  0.0        0.442      3.140      1.543
 88      7     9 1 4  1.0        0.0        0.0        3.760
 89      7    10 1 4  0.0        1.0        0.0        0.0
 90      7    11 1 4  1.0        0.0        0.0        4.760
```

TABLE XVII (Cont'd)

LISTING OF INPUT CARDS FOR SAMPLE PROBLEM II

```
CARD
 NO.

 91     7   12 1 4  0.0          1.0          0.0          3.443
 92     7   13 1 4  1.0          0.0          0.0          0.0
 93     7   14 1 4  0.0          0.0          1.0          0.0
 94     7   15 1 4  0.0          0.0          1.0          1.0
 95     7   16 1 4  0.0          0.0          1.0          1001.0
 96   1 7   17 1 4  0.0          0.0          1.0          1002.0
 97       2   27    2    0
 98          1.000E+07       6.070E+06       3.680E+06       2.230E+06       1.350E
 99          8.210E+05       4.980E+05       3.020E+05       1.830E+05       1.110E
100          6.740E+04       4.090E+04       2.480E+04       1.500E+04       9.120E
101          5.530E+03       3.360E+03       2.040E+03       1.230E+03       7.480E
102          4.540E+02       2.750E+02       1.010E+02       3.730E+01       1.370E
103          5.040E+00       6.830E-01       0.0
104   1.0  1.5  1.5  1.5  2.0  3.0  3.0  3.0  3.0  3.0  2.0  1.5  1.5  1.5  1
105   1.0  1.0  1.0  1.0  1.0  0.7  0.7  0.5  0.5  0.5  0.5  0.5
106      0    2    0
107   1.01          1.01          1.01          2.740          999.98
108          5.806E-06       2.290E-05       4.981E-05       7.574E-05       1.061E
109          1.797E-04       2.008E-04       2.034E-04       1.704E-04       1.403E
110          1.023E-04       7.249E-05       4.708E-05       3.144E-05       1.542E
111          7.280E-06       2.612E-06       8.656E-06       4.392E-06       1.939E
112          5.051E-07       3.225E-07       2.723E-08       1.983E-09       2.446E
113          7.991E-11       1.556E-14
114      0   -2    0
115   1.01          2.433         1.01          1.423          99.98
116          3.478E-06       1.430E-05       3.186E-05       4.828E-05       6.778E
117          1.225E-04       1.378E-04       1.493E-04       1.391E-04       1.123E
118          8.541E-05       6.287E-05       4.277E-05       2.956E-05       1.502E
119          7.276E-06       2.631E-06       8.823E-06       4.629E-06       2.254E
120          6.962E-07       5.894E-07       1.106E-07       1.468E-08       3.252E
121          6.293E-10       6.158E-14
```

The integer entries that are not the same as those of Problem I are given in Table XVIII. As a result of these changes, Problem II uses external planar surface sources, follows

TABLE XVIII

CHANGES IN INTEGER DATA FOR PROBLEM II

Index 1	Index 3	Name	Problem I	Problem II
-	14	IXTERN	1	3
-	22	NREGST	2	1
-	23	NEXCUT	1	2
-	29	NSØRCS	2	-
-	30	IVSPEC	1	-
-	31	INNGEN	3	0
-	32	ICURR	0	1
-	34	IVERGE	1	3
-	37	NEXGRP	-	2
-	40	IBAT	0	1
6	1	MAFIS	-	4
6	2	IAFIS	-	2
6	3	ITRAGG	0	1
6	4	IINGG	-	1
6	5	IELGG	-	2
6	6	NFGG	-	9

fission daughters, and calculates macroscopic cross sections for the reactor cell. Since there are few collisions per history, IBAT is set to 1 so that the tallies are batched to save computer time. For the calculation of cell cross sections all the real regions must be assigned to the same region set, which is accomplished by setting NREGST to 1. In this case, data type IREGST is not needed. These changes are reflected in Cards 2, 3, 4, 5, and 41 of Table XVII. The placement of the current sources is shown in Figure 38 which illustrates the requirement that the current sources lie entirely within real regions. The use of the current sources requires that the albedos for surfaces 3 and 5 be set to 0.0 as shown by Card 59. Thus, the system consists of a slab of infinite extent in the x and z directions with current sources on both sides of the slab. Floating point data types XTENS and DEL are not used with surface sources. The input data for the surface sources are specified by Cards 97 through 121 of Table XVII. Detailed instructions for preparing the data for surface sources are given in Section V.2.4. Card 97 shows two surface sources with 27 energy groups using input importances and an isotropic distribution. Cards 98 through 103 specify the cutoff energies that define the energy groups. Note that 28 values are given since the first value

gives the upper energy limit of the first group, and the last value gives the lower energy limit for the last group. The number of energy groups and the cutoff energies for a source need not correspond to those used for the Monte Carlo calculations. The importances are listed on Cards 104 and 105. Card 106 shows the first source to be planar and emitting in the positive y direction without any exempt regions. Card 107 gives the origin and extent of the first source. Cards 108 through 113 give the group source intensities. Cards 114 through 121 contain the data for the second source. Note that this data set does not have a "1" in column 1 of the last card. The data for cylindrical surface sources are similar to that for planar current sources (see Section V.2.4 for details). The computer output for this problem is listed in Table XIX at the end of Section VI, starting on page 181.

4. SAMPLE PROBLEM III

Sample Problem III demonstrates the use of multiple group thermal cross sections, that is, more than one energy group in the thermal neutron energy range. The use of multiple thermal groups is recommended for most thermal reactor calculations, particularly since computer time is usually not increased and may be decreased. When multiple thermal groups are used, two cross section libraries are required as described in Section VII. The geometry for Problem III is identical to that for Problem I. However, in Problem III water is used as the coolant since the use of multiple thermal groups is only appropriate for a thermal system. The isotopic compositions of the materials for this problem are given in Table XX.

The input data, other than the cross section libraries, are listed in Table XXI; the changes in control parameters from Problem I are listed in Table XXII. The change of NIC from 18 to 15 reflects the use of a different cross section library for Problem III. Items LABGRP and LSCAT are not required when multiple thermal groups are used. NTHRM specifies 27 energy groups in the thermal cross section library. The upper two of these groups overlap and replace the bottom two groups of the 69 group library. Thus there are 67 above thermal groups for a total of 94. MACRO=2 specifies that the thermal cross sections are entered by isotope and read in on logical unit 11.

The identification numbers of the isotopes for the above thermal groups are entered on Card 19, Table XXI and those for the thermal groups on Card 21. In order to represent water in the thermal energy region as a molecule rather than as a mixture of hydrogen and oxygen, the following procedure is used: Oxygen is included twice in the fast library, once

TABLE XX

MATERIAL COMPOSITIONS FOR RAFFLE SAMPLE PROBLEM III

Material 1 Water

Fast Library

Isotope	Identification Number	Concentration (Units of 10^{24} atoms/cm^3)
H	1	0.066
O	601	0.033

Thermal Library

Molecule	Identification Number	Concentration (Units of 10^{24} molecules/cm^3)
H_2O	601	0.033

Material 2 High Enrichment Fuel Pin

Isotope	Identification Number	Concentration (Units of 10^{24} atoms/cm^3)
U-235	10	0.00217
U-238	12	0.0195
Oxygen	23	0.0434

Material 3 Low Enrichment Pin

Isotope	Identification Number	Concentration (Units of 10^{24} atoms/cm^3)
U-235	10	0.00110
U-238	12	0.0206
Oxygen	23	0.0434

with identification number 23 and once with identification number 601. Isotope 23 is used in the fuel and isotope 601 in the water. In the thermal library "isotope" 601 contains data for the water molecule, then the "0" as the first data entry on Card 21 designates that isotope 1, hydrogen, is not used in the thermal library.

TABLE XXI

LISTING OF INPUT CARDS FOR SAMPLE PROBLEM III

CARD NO.																			
1	RAFFLE	MONTE	CARLO	PROGRAM	SAMPLE	PROBLEM	III	MULTI-THERMAL	GROUPS										
2		1	15	2	3	94	4	6	3	1	17	1	5	15				1	16
3		16	15	1	10			4	28	2	1	1	2		4	5	2	1	
4		31	4	1	0	0	1												
5		101	5	27	2	900		1											
6	1	1	4	1	1	2	3												
7	2	1	10	2	2	3	3	1	1	1	1	1	1						
8	5	1	2	1	1														
9	8	1	15	1	1	2	2	3	3	4	4	5	5	6	6	7	7	8	
10	8	16	15	8	9	9	10	10	11	11	12	12	13	13	14	14	15	15	
11	8	31	15	16	16	17	17	18	18	19	19	20	20	21	21	22	22	22	
12	8	46	15	22	23	23	23	23	24	24	24	24	25	25	25	25	26	26	
13	8	61	7	26	26	27	27	27	27	27									
14	8	68	15	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	
15	8	83	12	28	28	28	28	28	28	28	28	28	28	28					
16	9	1	4	2	2	1	1												
17	10	1	6	3	9	5	6	15	16										
18	11	2	2	1	1														
19	12	1	5	1	10	12	23	601											
20	13	1	5	0	1	1	0	0											
21	14	1	5	0	10	12	23	601											
22	1 1	1	2	1	601														
23	1 2	1	3	10	12	23													
24	1 3	1	3	10	12	23													
25	2	1	7	2	6	3	-4	-5	15	-16									
26	2	2	7	8	4	3	-9	-5	15	-16									
27	2	3	4	1	2	15	-16												
28	2	4	4	7	8	15	-16												
29	2	5	6	13	10	-6	-12	15	-16										
30	2	6	6	6	5	-9	-12	15	-16										
31	2	7	6	9	10	-11	-12	15	-16										
32	2	8	6	6	10	-9	-3	15	-16										
33	2	9	6	13	10	-11	-12	14	-15										
34	2	10	6	13	10	-11	-12	16	-17										
35	3	1	1	9															
36	3	2	1	5															
37	3	3	1	8															
38	3	4	2	1	3														
39	3	5	1	6															
40	3	6	1	8															
41	3	7	2	2	4														
42	3	8	1	6															
43	3	9	1	7															
44	3	10	1	10															
45	1 6	3	1	0															

TABLE XXI (Cont'd)

LISTING OF INPUT CARDS FOR SAMPLE PROBLEM III

CARD NO.													
46		1	1	1.0									
47		2	2	0.05		0.07							
48		4	3	0.0		0.0		0.0					
49	1	1	5	7.79	+6	6.07	+6	4.72	+6	3.68	+6	2.87	+6
50	1	6	5	2.23	+6	1.74	+6	1.35	+6	1.05	+6	8.21	+5
51	1	11	5	6.39	+5	4.98	+5	3.88	+5	3.02	+5	2.35	+5
52	1	16	5	1.83	+5	1.43	+5	1.11	+5	8.65	+4	6.74	+4
53	1	21	5	5.25	+4	4.09	+4	3.18	+4	2.48	+4	1.93	+4
54	1	26	5	1.50	+4	1.17	+4	9.12	+3	7.10	+3	5.53	+3
55	1	31	5	4.31	+3	3.36	+3	2.61	+3	2.04	+3	1.59	+3
56	1	36	5	1.23	+3	961.1		748.5		582.9		454.0	
57	1	41	5	353.6		275.4		214.5		167.0		130.1	
58	1	46	5	101.3		78.9		61.4		47.9		37.3	
59	1	51	5	29.0		22.6		17.6		13.7		10.68	
60	1	56	5	8.32		6.48		5.04		3.93		3.06	
61	1	61	5	2.38		1.86		1.44		1.125		0.876	
62	1	66	5	0.683		0.532		0.49		0.475		0.46	
63	1	71	5	0.43		0.414		0.36		0.34		0.32	
64	1	76	5	0.30		0.28		0.26		0.24		0.22	
65	1	81	5	0.18		0.14		0.10		0.09		0.08	
66	1	86	5	0.07		0.06		0.04		0.0253		0.015	
67	1	91	4	0.008		0.005		0.002		0.0			
68	4	1	5	1.0		1.0		1.0		1.0		1.0	
69	4	6	1	1.0									
70	5	1	5	0.0		4.760		0.0		1.0		2.520	
71	5	6	4	3.760		4.760		0.0		4.760			
72	6	1	5	0.0		3.443		0.0		3.443		0.0	
73	6	6	5	1.0		2.443		3.443		0.0		1.0	
74	6	11	5	2.443		3.443		0.0		3.443		0.0	
75	6	16	1	3.443									
76	7	1	4	0.0		1.0		1001.0		1002.0			
77	9	1	2	1.0		1.0							
78	1	1	2	0.066		0.033							
79	1	2	1	3	0.00217		0.0195		0.0434				
80	1	3	1	3	0.00110		0.0206		0.0435				
81	5	1	1	5	1.900		1.543		1.0		0.0		0.442
82	5	1	6	1	1000.0								
83	5	2	1	5	3.140		1.543		1.0		0.0		0.442
84	5	2	6	1	1000.0								
85	6	1	1	5	.0071790		.0203770		.0425630		.0698340		.0947739
86	6	1	6	5	.1108400		.1153600		.1096000		.0969729		.0811549
87	6	1	11	5	.0650310		.0503760		.0380050		.0280890		.0204290
88	6	1	16	5	.0146730		.0104730		.0073677		.0051703		.0036117
89	6	1	21	5	.0025138		.0017448		.0012084		.0008355		.0005769
90	6	1	26	5	.0003979		.0002743		.0001889		.0001301		.0000895

TABLE XXI (Cont'd)

LISTING OF INPUT CARDS FOR SAMPLE PROBLEM III

CARD NO.										
91		6	1	31	5	.0000616	.0000424	.0000291	.0000200	.0000138
92		6	1	36	5	.0000095	.0000065	.0000045	.0000031	.0000021
93		6	1	41	2	.0000014	.0000010			
94		7		1	2	4	0.0	0.0	1.900	1.543
95		7		2	2	4	0.0	0.442	1.900	1.543
96		7		3	1	4	0.0	1.0	0.0	1.0
97		7		4	1	4	1.0	0.0	0.0	2.520
98		7		5	1	4	0.0	1.0	0.0	2.443
99		7		6	1	4	1.0	0.0	0.0	1.0
100		7		7	2	4	0.0	0.0	3.140	1.543
101		7		8	2	4	0.0	0.442	3.140	1.543
102		7		9	1	4	1.0	0.0	0.0	3.760
103		7		10	1	4	0.0	1.0	0.0	0.0
104		7		11	1	4	1.0	0.0	0.0	4.760
105		7		12	1	4	0.0	1.0	0.0	3.443
106		7		13	1	4	1.0	0.0	0.0	0.0
107		7		14	1	4	0.0	0.0	1.0	0.0
108		7		15	1	4	0.0	0.0	1.0	1.0
109		7		16	1	4	0.0	0.0	1.0	1001.0
110	1	7		17	1	4	0.0	0.0	1.0	1002.0

TABLE XXII

CHANGES IN CONTROL PARAMETERS FOR PROBLEM III

Index 3	Name	Problem I	Problem III
3	NGRP	69	94
10	NSCAT	6	5
11	NIC	18	15
12	LABGRP	69	--
13	LSCAT	69	--
21	NGRPST	27	28
101	NTHRM	--	27
102	MACRØ	--	2
103	NTHCUT	--	900
104	NCØL2	--	0
105	IFRST	--	1

Card 20 reflects the different fissionable isotopes for Problem III as compared to Problem I. Other changes are the material compositions, Cards 22 through 24 and 78 through 80; the assignment of groups to groupsets, Cards 13 through 15; and the extension of the cutoff energies to 94 groups, Cards 62 through 67. Table XXIII lists the output data for this problem.

TABLE XXIII

LISTING OF OUTPUT FROM PROBLEM III


```
        RAFFLE MONTE CARLO PROGRAM  SAMPLE PROBLEM III  MULTI-THERMAL GROUPS

            EDIT OF INPUT DATA


   EIGENVALUE PROBLEM
   REACTION RATES AND FLUXES CALCULATED
   VOLUME SOURCE PROBLEM
   CONVERGENCE ON K
   STANDARD CROSS SECTION LIBRARY USED
   STANDARD PATH SCORING
   BATCHING NOT USED



INPUT EDIT FLAG. IF INEDIT=1, THE INPUT IS ONLY PROCESSED AND EDITED.
IF INEDIT=2, THE ENTIRE PROGRAM IS EXECUTED.
FOR THIS RUN INEDIT = 2
NO. HISTORIES TO PROCESS PER GENERATION--NIVO=   16
MAXIMUM EXECUTION TIME (NO EFFECT IF =0.0)--RTIME=   1.00000


NO. OF GROUPS =  94
NO. OF REAL REGIONS =   4
NO. OF FICTITIOUS REGIONS =   6
NO. OF MATERIALS =   3
ZONE GEOMETRY TYPE = 1
NO. OF BOUNDARY EQUATIONS =   17
NO. OF FISSION TABLES =  1
NO. OF SCATTERING ISOTOPES =   5


OPTIONAL THERMAL XSECT INPUT USED--THERMAL XSECTS READ IN BY ISOTOPE

ISOTOPE  1 THERMAL ID=    0
ISOTOPE  2 THERMAL ID=   10
ISOTOPE  3 THERMAL ID=   12
ISOTOPE  4 THERMAL ID=   23

ISOTOPE  5 THERMAL ID=  601
ISOTOPE

NO. THERMAL GROUPS=  27
RUSSIAN ROULETTE PLAYED AFTER 900 THERMAL COLLISIONS AND AFTER  0 SUBSEQUENT COLLISIONS
THE FIRST THERMAL GROUP USED IN RAFFLE CORRESPONDS TO GROUP  1 AS PUNCHED ON THE THERMAL LIBRARY CARDS


ISOTOPE LIST USED IN THIS PROBLEM

ISOTOPE  1 ID=    1
ISOTOPE  2 ID=   10
ISOTOPE  3 ID=   12
ISOTOPE  4 ID=   23
```

TABLE XXIII (Cont'd)

LISTING OF OUTPUT FROM PROBLEM III

ISOTOPE 5 ID= 601

EXTERNAL SOURCE FLAG (IXTERN).
IF IXTERN=1 THERE ARE NO EXTERNAL SOURCES (AN EIGENVALUE PROBLEM),
IF IXTERN=2 THERE ARE EXTERNAL SOURCES BUT FISSION DAUGHTERS ARE NOT FOLLOWED,
IF IXTERN=3 THERE ARE EXTERNAL SOURCES AND FISSION DAUGHTERS ARE FOLLOWED.
FOR THIS PROBLEM IXTERN = 1

SCORING FLAG. IF ISCOR=1 PATH SCORING IS USED,
IF ISCOR=2 THE BOUNDRY-ELIMINATION METHOD IS USED,
IF ISCOR=3 THE COLLISION-CONTRIBUTION METHOD IS USED.
FOR THIS PROBLEM ISCOR = 1

TRANSFER COMPUTATION POINTERS
INELASTIC FLAG (=1 TO COMPUTE INELASTIC) = 0
ELASTIC FLAG (=1 TO COMPUTE ONCE, =2 TO COMPUTE N TIMES) = 0

LIBRARY FLAG(=0 IF READ FROM CARDS, =2 IF READ FROM LOGICAL UNIT 15) JTAPE = 2
NIC = 15 ISOTOPES IN LIBRARY

GROUP	LOWER ENERGY CUTOFF (EV)
1	7.7900E 06
2	6.0700E 06
3	4.7200E 06
4	3.6800E 06
5	2.8700E 06
6	2.2300E 06
7	1.7400E 06
8	1.3500E 06
9	1.0500E 06
10	8.2100E 05
11	6.3900E 05
12	4.9800E 05
13	3.8800E 05
14	3.0200E 05
15	2.3500E 05
16	1.8300E 05
17	1.4300E 05
18	1.1100E 05
19	8.6500E 04
20	6.7400E 04
21	5.2500E 04
22	4.0900E 04
23	3.1800E 04
24	2.4800E 04
25	1.9300E 04
26	1.5000E 04
27	1.1700E 04
28	9.1200E 03
29	7.1000E 03
30	5.5300E 03
31	4.3100E 03
32	3.3600E 03
33	2.6100E 03

TABLE XXIII (Cont'd)

LISTING OF OUTPUT FROM PROBLEM III

34	2.0400E 03
35	1.5900E 03
36	1.2300E 03
37	9.6110E 02
38	7.4850E 02
39	5.8290E 02
40	4.5400E 02
41	3.5360E 02
42	2.7540E 02
43	2.1450E 02
44	1.6700E 02
45	1.3010E 02
46	1.0130E 02
47	7.8900E 01
48	6.1400E 01
49	4.7900E 01
50	3.7300E 01
51	2.9000E 01
52	2.2600E 01
53	1.7600E 01
54	1.3700E 01
55	1.0680E 01
56	8.3200E 00
57	6.4800E 00
58	5.0400E 00
59	3.9300E 00
60	3.0600E 00
61	2.3800E 00
62	1.8600E 00
63	1.4400E 00
64	1.1250E 00
65	8.7600E-01
66	6.8300E-01
67	5.3200E-01
68	4.9000E-01
69	4.7500E-01
70	4.6000E-01
71	4.3000E-01
72	4.1400E-01
73	3.6000E-01
74	3.4000E-01
75	3.2000E-01
76	3.0000E-01
77	2.8000E-01
78	2.6000E-01
79	2.4000E-01
80	2.2000E-01
81	1.8000E-01
82	1.4000E-01
83	1.0000E-01
84	9.0000E-02
85	8.0000E-02
86	7.0000E-02
87	6.0000E-02
88	4.0000E-02
89	2.5300E-02

TABLE XXIII (Cont'd.)

LISTING OF OUTPUT FROM PROBLEM III

90	1.5000E-02
91	8.0000E-03
92	5.0000E-03
93	2.0000E-03
94	0.0

NO CM TO LAB TRANSFORMATION IS MADE FOR GROUP 94 AND LOWER GROUPS
NO ENERGY CHANGE IS MADE FOR ELASTIC SCATTER EVENT FOR GROUP 94 AND LOWER GROUPS

GROUP SET INFORMATION -

ENERGY GROUPS IN GROUP SET 1
1 2

ENERGY GROUPS IN GROUP SET 2
3 4

ENERGY GROUPS IN GROUP SET 3
5 6

ENERGY GROUPS IN GROUP SET 4
7 8

ENERGY GROUPS IN GROUP SET 5
9 10

ENERGY GROUPS IN GROUP SET 6
11 12

ENERGY GROUPS IN GROUP SET 7
13 14

ENERGY GROUPS IN GROUP SET 8
15 16

ENERGY GROUPS IN GROUP SET 9
17 18

ENERGY GROUPS IN GROUP SET 10
19 20

ENERGY GROUPS IN GROUP SET 11
21 22

ENERGY GROUPS IN GROUP SET 12
23 24

ENERGY GROUPS IN GROUP SET 13
25 26

ENERGY GROUPS IN GROUP SET 14
27 28

ENERGY GROUPS IN GROUP SET 15
29 30

TABLE XXIII (Cont'd)

LISTING OF OUTPUT FROM PROBLEM III


```
ENERGY GROUPS IN GROUP SET   16
   31    32

ENERGY GROUPS IN GROUP SET   17
   33    34

ENERGY GROUPS IN GROUP SET   18
   35    36

ENERGY GROUPS IN GROUP SET   19
   37    38

ENERGY GROUPS IN GROUP SET   20
   39    40

ENERGY GROUPS IN GROUP SET   21
   41    42

ENERGY GROUPS IN GROUP SET   22
   43    44    45    46

ENERGY GROUPS IN GROUP SET   23
   47    48    49    50

ENERGY GROUPS IN GROUP SET   24
   51    52    53    54

ENERGY GROUPS IN GROUP SET   25
   55    56    57    58

ENERGY GROUPS IN GROUP SET   26
   59    60    61    62

ENERGY GROUPS IN GROUP SET   27
   63    64    65    66    67

ENERGY GROUPS IN GROUP SET   28
   68    69    70    71    72    73    74    75    76    77    78    79    80    81    82
   83    84    85    86    87    88    89    90    91    92    93    94

ENERGY BREAKPOINTS FOR THE GROUP SETS

   1.00000E 07    6.07000E 06    3.68000E 06    2.23000E 06    1.35000E 06    8.21000E 05
   4.98000E 05    3.02000E 05    1.83000E 05    1.11000E 05    6.74000E 04    4.09000E 04
   2.48000E 04    1.50000E 04    9.12000E 03    5.53000E 03    3.36000E 03    2.04000E 03
   1.23000E 03    7.48500E 02    4.54000E 02    2.75400E 02    1.01300E 02    3.73000E 01
   1.37000E 01    5.04000E 00    1.86000E 00    5.32000E-01    0.0

MATERIAL      NO. OF FISSION SPECTRA      NO. OF ISOTOPES
    1                   0                       2
    2                   1                       3
    3                   1                       3

THE CUTOFF FLAG. IF NEXCUT=1 THE CONSTANT CUTOFF WEIGHT METHOD IS USED,
IF NEXCUT=2 THERE IS NO WEIGHT REDUCTION
IF NEXCUT=3 BOUNDED DOUBLE VALUE ROULETTE IS PLAYED.
```

TABLE XXIII (Cont'd)

LISTING OF OUTPUT FROM PROBLEM III

FOR THIS PROBLEM NEXCUT = 1

WNCUT = 5.0000E-02

SPLITTING FLAG. IF ISPLT =1 THERE IS NO SPLITTING, IF ISPLT =2 SPLITTING IS BY INTEGER MULTIPLES, IF ISPLT =3 SPLITTING IS BY WEIGHT COMPARISON.
FOR THIS PROBLEM ISPLT = 1

MATERIAL NO.=	1	NO. OF ISOTOPES =	2				
ISOTOPE NO.	DENSITY	ISOTOPE NO.	DENSITY	ISOTOPE NO.	DENSITY	ISOTOPE NO.	DENSITY
1	6.6000E-02	601	3.3000E-02				

MATERIAL NO.=	2	NO. OF ISOTOPES =	3				
ISOTOPE NO.	DENSITY	ISOTOPE NO.	DENSITY	ISOTOPE NO.	DENSITY	ISOTOPE NO.	DENSITY
10	2.1700E-03	12	1.9500E-02	23	4.3400E-02		

MATERIAL NO.=	3	NO. OF ISOTOPES =	3				
ISOTOPE NO.	DENSITY	ISOTOPE NO.	DENSITY	ISOTOPE NO.	DENSITY	ISOTOPE NO.	DENSITY
10	1.1000E-03	12	2.0600E-02	23	4.3500E-02		

ALL MATERIALS(ISOTOPES) FOUND IN THERMAL XSECT INPUT

FISSION SPECTRUM NO. = 1

GROUP	INTENSITY	GROUP	INTENSITY	GROUP	INTENSITY	GROUP	INTENSITY	GROUP	INTENSITY
1	7.1790E-03	2	2.0377E-02	3	4.2563E-02	4	6.9834E-02	5	9.4774E-02
6	1.1084E-01	7	1.1536E-01	8	1.0960E-01	9	9.6973E-02	10	8.1155E-02
11	6.5031E-02	12	5.0376E-02	13	3.8005E-02	14	2.8089E-02	15	2.0429E-02
16	1.4673E-02	17	1.0473E-02	18	7.3677E-03	19	5.1703E-03	20	3.6117E-03
21	2.5138E-03	22	1.7448E-03	23	1.2084E-03	24	8.3550E-04	25	5.7690E-04
26	3.9790E-04	27	2.7430E-04	28	1.8890E-04	29	1.3010E-04	30	8.9500E-05
31	6.1600E-05	32	4.2400E-05	33	2.9100E-05	34	2.0000E-05	35	1.3800E-05
36	9.5000E-06	37	6.5000E-06	38	4.5000E-06	39	3.1000E-06	40	2.1000E-06
41	1.4000E-06	42	1.0000E-06	43	0.0	44	0.0	45	0.0
46	0.0	47	0.0	48	0.0	49	0.0	50	0.0
51	0.0	52	0.0	53	0.0	54	0.0	55	0.0
56	0.0	57	0.0	58	0.0	59	0.0	60	0.0
61	0.0	62	0.0	63	0.0	64	0.0	65	0.0
66	0.0	67	0.0	68	0.0	69	0.0	70	0.0
71	0.0	72	0.0	73	0.0	74	0.0	75	0.0
76	0.0	77	0.0	78	0.0	79	0.0	80	0.0
81	0.0	82	0.0	83	0.0	84	0.0	85	0.0
86	0.0	87	0.0	88	0.0	89	0.0	90	0.0
91	0.0	92	0.0	93	0.0	94	0.0		

BOUNDARY EQUATION PARAMETERS

NO.	N	TYPE	A	B	C	D	R	XO	YO	ZO
1	2	CYLINDER					0.0	1.9000E 00	1.5430E 00	
2	2	CYLINDER					4.4200E-01	1.9000E 00	1.5430E 00	
3	1	PLANE	0.0	1.0000E 00	0.0	1.0000E 00				
4	1	PLANE	1.0000E 00	0.0	0.0	2.5200E 00				
5	1	PLANE	0.0	1.0000E 00	0.0	2.4430E 00				
6	1	PLANE	1.0000E 00	0.0	0.0	1.0000E 00				
7	2	CYLINDER					0.0	3.1400E 00	1.5430E 00	

TABLE XXIII (Cont'd)

LISTING OF OUTPUT FROM PROBLEM III

8	2	CYLINDER					4.4200E-01	3.1400E 00	1.5430E 00
9	1	PLANE	1.0000E 00	0.0	0.0	3.7600E 00			
10	1	PLANE	0.0	1.0000E 00	0.0	0.0			
11	1	PLANE	1.0000E 00	0.0	0.0	4.7600E 00			
12	1	PLANE	0.0	1.0000E 00	0.0	3.4430E 00			
13	1	PLANE	1.0000E 00	0.0	0.0	0.0			
14	1	PLANE	0.0	0.0	1.0000E 00	0.0			
15	1	PLANE	0.0	0.0	1.0000E 00	1.0000E 00			
16	1	PLANE	0.0	0.0	1.0000E 00	1.0010E 03			
17	1	PLANE	0.0	0.0	1.0000E 00	1.0020E 03			

NO.OF EXTERNAL BOUNDARIES = 6

EXTERNAL BOUNDARY NO.	ALBEDO
3	1.0000E 00
9	1.0000E 00
5	1.0000E 00
6	1.0000E 00
15	1.0000E 00
16	1.0000E 00

REGION DESCRIPTIONS

REGION NO.	REGION TYPE	MATERIAL	NO.OF BOUNDARIES	
	SIGNED BOUNDARY NO.S---			
1	2	1	7	
	2 6 3 -4 -5 15 -16			
2	2	1	7	
	8 4 3 -9 -5 15 -16			
3	3	2	4	
	1 2 15 -16			
4	3	3	4	
	7 8 15 -16			
5	1	0	6	
	13 10 -6 -12 15 -16			
6	1	0	6	
	6 5 -9 -12 15 -16			
7	1	0	6	
	9 10 -11 -12 15 -16			
8	1	0	6	
	6 10 -9 -3 15 -16			
9	1	0	6	
	13 10 -11 -12 14 -15			
10	1	0	6	
	13 10 -11 -12 16 -17			

TABLE XXIII (Cont'd)

LISTING OF OUTPUT FROM PROBLEM III


```
REGION SET INFORMATION -

REGIONS IN REGION SET     1
    3     4

REGIONS IN REGION SET     2
    1     2
```

TABLE XXIII (Cont'd)

LISTING OF OUTPUT FROM PROBLEM III


```
                ZONE GEOMETRY DESCRIPTION
STACKED RECTANGULAR ZONE GEOMETRY, IZONGE = 1


TOTAL NUMBER OF ZONES = 10
NUMBER OF Z-LINES =  4

Z-LINES
     0.0          1.00000  1001.00000  1002.00000

*****************************************************************************************************************
INFORMATION FOR Z-ZONE  1

XLINES
     0.0          4.76000

Y-LINES FOR X-ZONE  1
     0.0          3.44300

*****************************************************************************************************************
INFORMATION FOR Z-ZONE  2

XLINES
     0.0          1.00000      2.52000      3.76000      4.76000

Y-LINES FOR X-ZONE  1
     0.0          3.44300

Y-LINES FOR X-ZONE  2
     0.0          1.00000      2.44300      3.44300

Y-LINES FOR X-ZONE  3
     0.0          1.00000      2.44300      3.44300

Y-LINES FOR X-ZONE  4
     0.0          3.44300

*****************************************************************************************************************
INFORMATION FOR Z-ZONE  3

XLINES
     0.0          4.76000

Y-LINES FOR X-ZONE  1
     0.0          3.44300
```

TABLE XXIII (Cont'd)

LISTING OF OUTPUT FROM PROBLEM III

ZONE	NO. OF REGIONS	REGION NO.S	
1	1	9	
2	1	5	
3	1	8	
4	2	1	3
5	1	6	
6	1	8	
7	2	2	4
8	1	6	
9	1	7	
10	1	10	

LEAKAGE FLAG. IF NEXCUR=1 NO LEAKAGE IS COMPUTED, IF NEXCUR=2 LEAKAGE IS COMPUTED.
NEXCUR = 1

CONVERGENCE FLAG. IF IVERGE=1 CONVERGENCE IS ON K, IF IVERGE=2 CONVERGENCE IS ON REGION SET FLUXES
AND IF IVERGE=3 CONVERGENCE IS ON REGION AND GROUP SET FLUXES.
THE VALUE OF IVERGE FOR THIS PROBLEM IS 1

THE FRACTIONAL ERROR FOR CONVERGENCE IS 7.0000E-02

SCORING INITIALIZATION.
THE NUMBER OF GENERATIONS TO PROCESS BEFORE SCORING IS BEGUN = 1

RANDOM VARIABLE TABLE INFORMATION
NO. OF ENTRIES IN EACH TABLE = 512 (EXPONENT OF 2 = 9) NO OF RANDOM NO.S INITIALLY REJECTED = 5

INITIAL SOURCE INFORMATION
NO. OF SOURCES = 2 FISSION SPECTRUM NO. TO USE = 1
VOLUME SOURCE PROBLEM, ICURR = 0

SOURCE NO.	SOURCE TYPE	INTENSITY	NO. OF EXEMPT REGIONS		
	LIST OF EXEMPT REGIONS- CENTER POINT (X,Y,Z) AND SOURCE DIMENSIONS				
1	1	1.0000E 00	0		
	1.9000E 00	1.5430E 00	1.0000E 00	0.0	4.4200E-01 1.0000E 03
2	1	1.0000E 00	0		
	3.1400E 00	1.5430E 00	1.0000E 00	0.0	4.4200E-01 1.0000E 03

VARIABLE INPUT
NCHECK = 1 MAXCNT = 6 IBUMAX = 24 XKENO = 3.3000E-01 WSTOP = 1.0000E-06

7156 STORAGE LOCATIONS IN BULK USED BEFORE LOCATIONS RESERVED FOR OUTPUT TALLIES

8040 STORAGE LOCATIONS USED IN BULK

TABLE XXIII (Cont'd)

LISTING OF OUTPUT FROM PROBLEM III

(RAFFLE/005 R.S. MARSDEN 5/ 5/72) A GENERAL PURPOSE MONTE CARLO PROGRAM 10/24/72

RAFFLE MONTE CARLO PROGRAM SAMPLE PROBLEM III MULTI-THERMAL GROUPS

RAFFLE OUTPUT DATA

SOURCE DISTRIBUTION FOR THE NEXT GENERATION

1	0.0	2	0.0	3	5.0000E-01	4	5.0000E-01

TABLE XXIII (Cont'd)

LISTING OF OUTPUT FROM PROBLEM III


```
ZTIME,RTIME=    0.27178664E-01    0.10000000D 01
ZTIME,RTIME=    0.72938621E-01    0.10000000D 01
ZTIME,RTIME=    0.72938621E-01    0.10000000D 01
```

TABLE XXIII (Cont'd)

LISTING OF OUTPUT FROM PROBLEM III

CONVERGED OUTPUT**********

TOTAL DATA PROCESSED. 1 GENERATIONS 16 HISTORIES 867 COLLISIONS

ERROR TALLY-BOX COUNTS. 0 IN IRRBO1 0 IN IRRBO2 0 IN IRRBO3

DATA FOR THE GENERATION JUST PROCESSED. 16 DAUGHTERS INITIALLY STORED 16 DAUGHTERS PROCESSED

EIGENVALUE (K) RESULTS.
K FROM COLLISIONS = 1.4863E 00 (6.2023E-02) K FROM PATHS = 1.5552E 00 (1.4449E-01)
BEST COMBINED K = 1.4904E 00 (6.1246E-02)

LIFETIME AND GENERATION TIME (IN MICROSECONDS).
GENERATION TIME = 1.2937D 01 (2.1463E-01) LIFETIME = 1.0892D 01 (2.3063E-01)

FLUX OF MAXIMUM FRACTIONAL ERROR. FLUX = 4.5217E-02 (6.5308E-01) REGION SET = 1 GROUP SET = 14

CONVERGENCE ERROR CHECK.
FRACTIONAL ERROR FOR BEST COMBINED K = 6.1246E-02 FRACTIONAL ERROR DESIRED = 7.0000E-02

FLUXES BY REGION SET (REGSET) AND GROUP SET (GRSET)

GPSET	REGSET 1	REGSET 2	REGSET
1	0.0	0.0	
2	2.7018E-01	6.5065E-01	
3	4.3456E-01	1.0027E 00	
4	6.8200E-01	1.3520E 00	
5	9.5594E-01	1.8548E 00	
6	8.6791E-01	2.0990E 00	
7	5.8532E-01	1.1009E 00	
8	2.3120E-01	9.4054E-01	
9	3.6444E-02	4.6138E-01	
10	3.3857E-01	4.7834E-01	
11	5.7176E-02	5.0132E-01	
12	2.4648E-01	4.5521E-01	
13	1.6759E-01	3.4500E-01	
14	4.5217E-02	2.5694E-01	
15	8.7482E-02	2.5941E-01	
16	1.2106E-01	1.4043E-01	
17	2.3476E-01	4.0787E-01	
18	1.6594E-01	4.2257E-01	
19	2.6793E-02	3.9026E-01	
20	1.9016E-01	2.9997E-01	
21	1.0642E-01	5.0773E-01	
22	4.6525E-01	6.6141E-01	
23	5.1666E-01	6.9359E-01	
24	2.3202E-01	7.1234E-01	
25	2.0575E-01	3.8364E-01	
26	4.5964E-01	6.7712E-01	
27	2.0612E-01	7.1595E-01	
28	1.1901E 00	3.7875E 00	

TABLE XXIII (Cont'd)

LISTING OF OUTPUT FROM PROBLEM III

FLUXES BY REGION SET (REGSET)

REGSET	REGSET FLUX
1	9.1268E 00
2	2.1558E 01

FRACTIONAL ERRORS FOR THE REGION AND GROUP SET FLUXES

GRSET	REGSET 1	REGSET 2	REGSET
1	0.0	0.0	
2	6.5308E-01	6.5308E-01	
3	4.4882E-01	4.2088E-01	
4	3.6656E-01	3.5383E-01	
5	2.9909E-01	2.9437E-01	
6	2.2364E-01	2.3498E-01	
7	2.2010E-01	2.1519E-01	
8	4.0197E-01	2.2627E-01	
9	6.5308E-01	3.5567E-01	
10	3.6956E-01	2.5847E-01	
11	4.8663E-01	2.2778E-01	
12	3.3188E-01	2.4906E-01	
13	3.6473E-01	1.8490E-01	
14	6.5308E-01	2.7239E-01	
15	6.5308E-01	2.8881E-01	
16	6.5308E-01	3.9094E-01	
17	3.0998E-01	2.3920E-01	
18	4.5662E-01	3.0461E-01	
19	6.5308E-01	2.7603E-01	
20	3.1338E-01	2.4649E-01	
21	4.7863E-01	2.2963E-01	
22	2.7391E-01	1.8438E-01	
23	3.2130E-01	2.4222E-01	
24	2.5496E-01	2.4029E-01	
25	3.0376E-01	2.2162E-01	
26	3.4690E-01	1.8360E-01	
27	3.2111E-01	1.7857E-01	
28	1.0865E-01	1.6621E-01	

FRACTIONAL ERRORS FOR THE REGION SET FLUXES

REGSET	ERROR
1	4.8213E-02
2	4.2767E-02

TABLE XXIII (Cont'd)

LISTING OF OUTPUT FROM PROBLEM III

ABSORPTION AND NU*FISSION RATES FOR EACH GROUP AND REGION SET

****

* REGION SET 1 *

****

	GROUP SET 1	GROUP SET 2	GROUP SET 3	GROUP SET 4	GROUP SET 5
RES ABSORPTION	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
TOT ABSORPTION	0.0 (0.0)	3.9863E-03 (0.6531)	5.4327E-03 (0.4460)	5.6115E-03 (0.3654)	5.2126E-03 (0.2940)
RES NU*FISSION	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
TOT NU*FISSION	0.0 (0.0)	9.8180E-03 (0.6531)	1.4689E-02 (0.4476)	1.3919E-02 (0.3651)	6.2970E-03 (0.2829)

	GROUP SET 6	GROUP SET 7	GROUP SET 8	GROUP SET 9	GROUP SET 10
RES ABSORPTION	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
TOT ABSORPTION	4.1116E-03 (0.2281)	2.8200E-03 (0.2207)	1.4170E-03 (0.3991)	2.2333E-04 (0.6531)	2.7628E-03 (0.3775)
RES NU*FISSION	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
TOT NU*FISSION	3.6447E-03 (0.2361)	2.7580E-03 (0.2267)	1.5122E-03 (0.4062)	1.5142E-04 (0.6531)	2.3205E-03 (0.4022)

	GROUP SET 11	GROUP SET 12	GROUP SET 13	GROUP SET 14	GROUP SET 15
RES ABSORPTION	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
TOT ABSORPTION	5.9793E-04 (0.4866)	1.5738E-03 (0.3538)	8.9806E-04 (0.4105)	2.0221E-04 (0.6531)	1.9870E-07 (0.6531)
RES NU*FISSION	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
TOT NU*FISSION	6.0504E-04 (0.4866)	2.6265E-03 (0.3575)	1.5271E-03 (0.4130)	3.4967E-04 (0.6531)	0.0 (0.0)

	GROUP SET 16	GROUP SET 17	GROUP SET 18	GROUP SET 19	GROUP SET 20
RES ABSORPTION	2.5836E-03 (0.6531)	8.2529E-04 (0.5915)	4.2876E-03 (0.5594)	1.3892E-05 (0.6531)	1.7273E-02 (0.6505)
TOT ABSORPTION	3.2055E-03 (0.6531)	2.4782E-03 (0.3356)	5.2959E-03 (0.5328)	1.7126E-04 (0.6531)	1.8045E-02 (0.6262)
RES NU*FISSION	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
TOT NU*FISSION	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)

	GROUP SET 21	GROUP SET 22	GROUP SET 23	GROUP SET 24	GROUP SET 25
RES ABSORPTION	1.3740E-04 (0.5757)	4.4284E-02 (0.6228)	2.7844E-02 (0.3704)	1.0429E-01 (0.3662)	3.4859E-02 (0.3734)
TOT ABSORPTION	4.4757E-04 (0.4474)	4.4709E-02 (0.6185)	3.0449E-02 (0.3452)	1.0317E-01 (0.3687)	3.0725E-02 (0.3815)
RES NU*FISSION	0.0 (0.0)	0.0 (0.0)	4.4080E-02 (0.4455)	4.7607E-02 (0.4057)	5.5416E-02 (0.3969)
TOT NU*FISSION	0.0 (0.0)	0.0 (0.0)	4.7906E-02 (0.4143)	4.6291E-02 (0.4072)	4.9051E-02 (0.4019)

	GROUP SET 26	GROUP SET 27	GROUP SET 28	TOTAL OVER ALL GROUPS
RES ABSORPTION	9.3032E-03 (0.5065)	5.1021E-03 (0.4852)	0.0 (0.0)	2.5080E-01 (0.1906)
TOT ABSORPTION	1.8748E-02 (0.3563)	1.4665E-02 (0.3060)	6.7378E-01 (0.1107)	9.8174E-01 (0.0581)
RES NU*FISSION	1.3602E-02 (0.5064)	9.3597E-03 (0.4924)	0.0 (0.0)	1.7006E-01 (0.1791)
TOT NU*FISSION	2.2948E-02 (0.3720)	2.4559E-02 (0.3106)	1.3077E 00 (0.1118)	1.5587E 00 (0.0893)

****

* REGION SET 2 *

****

	GROUP SET 1	GROUP SET 2	GROUP SET 3	GROUP SET 4	GROUP SET 5
TOT ABSORPTION	0.0 (0.0)	1.0804E-03 (0.6531)	4.7030E-06 (0.4453)	3.0843E-06 (0.3538)	4.2240E-06 (0.2942)

	GROUP SET 6	GROUP SET 7	GROUP SET 8	GROUP SET 9	GROUP SET 10
TOT ABSORPTION	5.0468E-06 (0.2340)	3.1223E-06 (0.2202)	3.4986E-06 (0.2273)	2.5349E-06 (0.3558)	3.7969E-06 (0.2773)

	GROUP SET 11	GROUP SET 12	GROUP SET 13	GROUP SET 14	GROUP SET 15
TOT ABSORPTION	5.3979E-06 (0.2255)	6.3838E-06 (0.2461)	7.1739E-06 (0.1878)	7.5506E-06 (0.2672)	1.0024E-05 (0.2868)

TABLE XXIII (Cont'd)

LISTING OF OUTPUT FROM PROBLEM III

	GROUP SET 16	GROUP SET 17	GROUP SET 18	GROUP SET 19	GROUP SET 20
TOT ABSORPTION	7.5000E-06 (0.3909)	2.6283E-05 (0.2357)	3.5698E-05 (0.2983)	4.3548E-05 (0.2809)	4.2250E-05 (0.2452)
	GROUP SET 21	GROUP SET 22	GROUP SET 23	GROUP SET 24	GROUP SET 25
TOT ABSORPTION	9.4737E-05 (0.2281)	1.7559E-04 (0.1817)	3.0555E-04 (0.2380)	5.4646E-04 (0.2308)	4.9860E-04 (0.2360)
	GROUP SET 26	GROUP SET 27	GROUP SET 28	TOTAL OVER ALL GROUPS	
TOT ABSORPTION	1.3683E-03 (0.1781)	2.4841E-03 (0.1825)	4.8608E-02 (0.1897)	5.5383E-02 (0.1719)	

****

TABLE XVI

LISTING OF OUTPUT FROM PROBLEM I


```
RAFFLE MONTE CARLO PROGRAM  SAMPLE PROBLEM I     AN ITERATION PROBLEM

    EDIT OF INPUT DATA


   EIGENVALUE PROBLEM
   REACTION RATES AND FLUXES CALCULATED
   VOLUME SOURCE PROBLEM
   CONVERGENCE ON K
   STANDARD CROSS SECTION LIBRARY USED
   STANDARD PATH SCORING
   BATCHING NOT USED



INPUT EDIT FLAG. IF INEDIT=1, THE INPUT IS ONLY PROCESSED AND EDITED.
IF INEDIT=2, THE ENTIRE PROGRAM IS EXECUTED.
FOR THIS RUN INEDIT = 2
NO. HISTORIES TO PROCESS PER GENERATION--NIVO=   16
MAXIMUM EXECUTION TIME (NO EFFECT IF =0.0)--RTIME=   1.00000


NO. OF GROUPS =  69
NO. OF REAL REGIONS =   4
NO. OF FICTITIOUS REGIONS =   6
NO. OF MATERIALS =   3
ZONE GEOMETRY TYPE = 1
NO. OF BOUNDARY EQUATIONS =   17
NO. OF FISSION TABLES =  1
NO. OF SCATTERING ISOTOPES =   6


ISOTOPE LIST USED IN THIS PROBLEM

ISOTOPE  1 ID=   12
ISOTOPE  2 ID=   14
ISOTOPE  3 ID=   15
ISOTOPE  4 ID=   23
ISOTOPE  5 ID=   29

ISOTOPE  6 ID=  141
ISOTOPE

EXTERNAL SOURCE FLAG (IXTERN).
IF IXTERN=1 THERE ARE NO EXTERNAL SOURCES (AN EIGENVALUE PROBLEM),
IF IXTERN=2 THERE ARE EXTERNAL SOURCES BUT FISSION DAUGHTERS ARE NOT FOLLOWED,
IF IXTERN=3 THERE ARE EXTERNAL SOURCES AND FISSION DAUGHTERS ARE FOLLOWED.
FOR THIS PROBLEM IXTERN = 1

SCORING FLAG. IF ISCOR=1 PATH SCORING IS USED,
IF ISCOR=2 THE BOUNDRY-ELIMINATION METHOD IS USED,
IF ISCOR=3 THE COLLISION-CONTRIBUTION METHOD IS USED.
FOR THIS PROBLEM ISCOR = 1
```

TABLE XVI (Cont'd)

LISTING OF OUTPUT FROM PROBLEM I

TRANSFER COMPUTATION POINTERS
INELASTIC FLAG (=1 TO COMPUTE INELASTIC) = 0
ELASTIC FLAG (=1 TO COMPUTE ONCE, =2 TO COMPUTE N TIMES) = 0

LIBRARY FLAG(=0 IF READ FROM CARDS, =2 IF READ FROM LOGICAL UNIT 15) JTAPE = 2
NIC = 18 ISOTOPES IN LIBRARY

GROUP	LOWER ENERGY CUTOFF (EV)
1	7.7900E 06
2	6.0700E 06
3	4.7200E 06
4	3.6800E 06
5	2.8700E 06
6	2.2300E 06
7	1.7400E 06
8	1.3500E 06
9	1.0500E 06
10	8.2100E 05
11	6.3900E 05
12	4.9800E 05
13	3.8800E 05
14	3.0200E 05
15	2.3500E 05
16	1.8300E 05
17	1.4300E 05
18	1.1100E 05
19	8.6500E 04
20	6.7400E 04
21	5.2500E 04
22	4.0900E 04
23	3.1800E 04
24	2.4800E 04
25	1.9300E 04
26	1.5000E 04
27	1.1700E 04
28	9.1200E 03
29	7.1000E 03
30	5.5300E 03
31	4.3100E 03
32	3.3600E 03
33	2.6100E 03
34	2.0400E 03
35	1.5900E 03
36	1.2300E 03
37	9.6110E 02
38	7.4850E 02
39	5.8290E 02
40	4.5400E 02
41	3.5360E 02
42	2.7540E 02
43	2.1450E 02
44	1.6700E 02
45	1.3010E 02
46	1.0130E 02
47	7.8900E 01
48	6.1400E 01

TABLE XVI (Cont'd)

LISTING OF OUTPUT FROM PROBLEM I

49	4.7900E 01
50	3.7300E 01
51	2.9000E 01
52	2.2600E 01
53	1.7600E 01
54	1.3700E 01
55	1.0680E 01
56	8.3200E 00
57	6.4800E 00
58	5.0400E 00
59	3.9300E 00
60	3.0600E 00
61	2.3800E 00
62	1.8600E 00
63	1.4400E 00
64	1.1250E 00
65	8.7600E-01
66	6.8300E-01
67	5.3200E-01
68	4.1400E-01
69	0.0

NO CM TO LAB TRANSFORMATION IS MADE FOR GROUP 69 AND LOWER GROUPS
NO ENERGY CHANGE IS MADE FOR ELASTIC SCATTER EVENT FOR GROUP 69 AND LOWER GROUPS

GROUP SET INFORMATION -

ENERGY GROUPS IN GROUP SET 1
1 2

ENERGY GROUPS IN GROUP SET 2
3 4

ENERGY GROUPS IN GROUP SET 3
5 6

ENERGY GROUPS IN GROUP SET 4
7 8

ENERGY GROUPS IN GROUP SET 5
9 10

ENERGY GROUPS IN GROUP SET 6
11 12

ENERGY GROUPS IN GROUP SET 7
13 14

ENERGY GROUPS IN GROUP SET 8
15 16

ENERGY GROUPS IN GROUP SET 9
17 18

ENERGY GROUPS IN GROUP SET 10

TABLE XVI (Cont'd)

LISTING OF OUTPUT FROM PROBLEM I


```
   19    20

ENERGY GROUPS IN GROUP SET   11
   21    22

ENERGY GROUPS IN GROUP SET   12
   23    24

ENERGY GROUPS IN GROUP SET   13
   25    26

ENERGY GROUPS IN GROUP SET   14
   27    28

ENERGY GROUPS IN GROUP SET   15
   29    30

ENERGY GROUPS IN GROUP SET   16
   31    32

ENERGY GROUPS IN GROUP SET   17
   33    34

ENERGY GROUPS IN GROUP SET   18
   35    36

ENERGY GROUPS IN GROUP SET   19
   37    38

ENERGY GROUPS IN GROUP SET   20
   39    40

ENERGY GROUPS IN GROUP SET   21
   41    42

ENERGY GROUPS IN GROUP SET   22
   43    44    45    46

ENERGY GROUPS IN GROUP SET   23
   47    48    49    50

ENERGY GROUPS IN GROUP SET   24
   51    52    53    54

ENERGY GROUPS IN GROUP SET   25
   55    56    57    58

ENERGY GROUPS IN GROUP SET   26
   59    60    61    62

ENERGY GROUPS IN GROUP SET   27
   63    64    65    66    67    68    69

ENERGY BREAKPOINTS FOR THE GROUP SETS

   1.00000E 07    6.07000E 06    3.68000E 06    2.23000E 06    1.35000E 06    8.21000E 05
```

TABLE XVI (Cont'd)

LISTING OF OUTPUT FROM PROBLEM I

4.98000E 05	3.02000E 05	1.83000E 05	1.11000E 05	6.74000E 04	4.09000E 04
2.48000E 04	1.50000E 04	9.12000E 03	5.53000E 03	3.36000E 03	2.04000E 03
1.23000E 03	7.48500E 02	4.54000E 02	2.75400E 02	1.01300E 02	3.73000E 01
1.37000E 01	5.04000E 00	1.86000E 00	0.0		

MATERIAL	NO. OF FISSION SPECTRA	NO. OF ISOTOPES
1	0	2
2	1	4
3	1	4

THE CUTOFF FLAG. IF NEXCUT=1 THE CONSTANT CUTOFF WEIGHT METHOD IS USED,
IF NEXCUT=2 THERE IS NO WEIGHT REDUCTION
IF NEXCUT=3 BOUNDED DOUBLE VALUE ROULETTE IS PLAYED.
FOR THIS PROBLEM NEXCUT = 1

WNCUT = 2.0000E-01

SPLITTING FLAG. IF ISPLT =1 THERE IS NO SPLITTING, IF ISPLT =2 SPLITTING IS BY INTEGER MULTIPLES, IF ISPLT =3 SPLITTING IS BY WEIGHT COMPARISON.
FOR THIS PROBLEM ISPLT = 1

MATERIAL NO.= 1 NO. OF ISOTOPES = 2

ISOTOPE NO.	DENSITY	ISOTOPE NO.	DENSITY	ISOTOPE NO.	DENSITY	ISOTOPE NO.	DENSITY
29	1.6710E-02	141	1.3010E-02				

MATERIAL NO.= 2 NO. OF ISOTOPES = 4

ISOTOPE NO.	DENSITY	ISOTOPE NO.	DENSITY	ISOTOPE NO.	DENSITY	ISOTOPE NO.	DENSITY
12	1.5590E-02	14	5.8010E-03	15	7.6890E-04	23	4.5180E-02

MATERIAL NO.= 3 NO. OF ISOTOPES = 4

ISOTOPE NO.	DENSITY	ISOTOPE NO.	DENSITY	ISOTOPE NO.	DENSITY	ISOTOPE NO.	DENSITY
12	1.9010E-02	14	2.9010E-03	15	3.8450E-04	23	4.5230E-02

FISSION SPECTRUM NO. = 1

GROUP	INTENSITY	GROUP	INTENSITY	GROUP	INTENSITY	GROUP	INTENSITY	GROUP	INTENSITY
1	7.1790E-03	2	2.0377E-02	3	4.2563E-02	4	6.9834E-02	5	9.4774E-02
6	1.1084E-01	7	1.1536E-01	8	1.0960E-01	9	9.6973E-02	10	8.1155E-02
11	6.5031E-02	12	5.0376E-02	13	3.8005E-02	14	2.8089E-02	15	2.0429E-02
16	1.4673E-02	17	1.0473E-02	18	7.3677E-03	19	5.1703E-03	20	3.6117E-03
21	2.5138E-03	22	1.7448E-03	23	1.2084E-03	24	8.3550E-04	25	5.7690E-04
26	3.9790E-04	27	2.7430E-04	28	1.8890E-04	29	1.3010E-04	30	8.9500E-05
31	6.1600E-05	32	4.2400E-05	33	2.9100E-05	34	2.0000E-05	35	1.3800E-05
36	9.5000E-06	37	6.5000E-06	38	4.5000E-06	39	3.1000E-06	40	2.1000E-06
41	1.4000E-06	42	1.0000E-06	43	0.0	44	0.0	45	0.0
46	0.0	47	0.0	48	0.0	49	0.0	50	0.0
51	0.0	52	0.0	53	0.0	54	0.0	55	0.0
56	0.0	57	0.0	58	0.0	59	0.0	60	0.0
61	0.0	62	0.0	63	0.0	64	0.0	65	0.0
66	0.0	67	0.0	68	0.0	69	0.0		

BOUNDARY EQUATION PARAMETERS

NO.	N	TYPE	A	B	C	D	R	XO	YO	ZO
1	2	CYLINDER					0.0	1.9000E 00	1.5430E 00	
2	2	CYLINDER					4.4200E-01	1.9000E 00	1.5430E 00	

TABLE XVI (Cont'd)

LISTING OF OUTPUT FROM PROBLEM I

3	1	PLANE	0.0	1.0000E 00	0.0	1.0000E 00			
4	1	PLANE	1.0000E 00	0.0	0.0	2.5200E 00			
5	1	PLANE	0.0	1.0000E 00	0.0	2.4430E 00			
6	1	PLANE	1.0000E 00	0.0	0.0	1.0000E 00			
7	2	CYLINDER					0.0	3.1400E 00	1.5430E 00
8	2	CYLINDER					4.4200E-01	3.1400E 00	1.5430E 00
9	1	PLANE	1.0000E 00	0.0	0.0	3.7600E 00			
10	1	PLANE	0.0	1.0000E 00	0.0	0.0			
11	1	PLANE	1.0000E 00	0.0	0.0	4.7600E 00			
12	1	PLANE	0.0	1.0000E 00	0.0	3.4430E 00			
13	1	PLANE	1.0000E 00	0.0	0.0	0.0			
14	1	PLANE	0.0	0.0	1.0000E 00	0.0			
15	1	PLANE	0.0	0.0	1.0000E 00	1.0000E 00			
16	1	PLANE	0.0	0.0	1.0000E 00	1.0010E 03			
17	1	PLANE	0.0	0.0	1.0000E 00	1.0020E 03			

NO.OF EXTERNAL BOUNDARIES = 6

EXTERNAL BOUNDARY NO.	ALBEDO
3	1.0000E 00
9	1.0000E 00
5	1.0000E 00
6	1.0000E 00
15	1.0000E 00
16	1.0000E 00

REGION DESCRIPTIONS

REGION NO.	REGION TYPE	MATERIAL	NO.OF BOUNDARIES	SIGNED BOUNDARY NO.S---					
1	2	1	7	2	6	3	-4	-5	15	-16
2	2	1	7	8	4	3	-9	-5	15	-16
3	3	2	4	1	2	15	-16			
4	3	3	4	7	8	15	-16			
5	1	0	6	13	10	-6	-12	15	-16	
6	1	0	6	6	5	-9	-12	15	-16	
7	1	0	6	9	10	-11	-12	15	-16	
8	1	0	6	6	10	-9	-3	15	-16	
9	1	0	6	13	10	-11	-12	14	-15	

TABLE XVI (Cont'd)

LISTING OF OUTPUT FROM PROBLEM I


```
   10                1                0                6
        13      10     -11     -12      16     -17

REGION SET INFORMATION -

REGIONS IN REGION SET     1
     3      4

REGIONS IN REGION SET     2
     1      2
```

TABLE XVI (Cont'd)

LISTING OF OUTPUT FROM PROBLEM I


```
                ZONE GEOMETRY DESCRIPTION
STACKED RECTANGULAR ZONE GEOMETRY, IZONGE = 1


TOTAL NUMBER OF ZONES = 10
NUMBER OF Z-LINES =  4

Z-LINES
     0.0          1.00000   1001.00000   1002.00000
*****************************************************************************************************************
INFORMATION FOR Z-ZONE  1

XLINES
     0.0          4.76000

Y-LINES FOR X-ZONE  1
     0.0          3.44300
*****************************************************************************************************************
INFORMATION FOR Z-ZONE  2

XLINES
     0.0          1.00000      2.52000      3.76000      4.76000

Y-LINES FOR X-ZONE  1
     0.0          3.44300

Y-LINES FOR X-ZONE  2
     0.0          1.00000      2.44300      3.44300

Y-LINES FOR X-ZONE  3
     0.0          1.00000      2.44300      3.44300

Y-LINES FOR X-ZONE  4
     0.0          3.44300
*****************************************************************************************************************
INFORMATION FOR Z-ZONE  3

XLINES
     0.0          4.76000

Y-LINES FOR X-ZONE  1
     0.0          3.44300
```

TABLE XVI (Cont'd)

LISTING OF OUTPUT FROM PROBLEM I

ZONE	NO. OF REGIONS	REGION NO.S	
1	1	9	
2	1	5	
3	1	8	
4	2	1	3
5	1	6	
6	1	8	
7	2	2	4
8	1	6	
9	1	7	
10	1	10	

LEAKAGE FLAG. IF NEXCUR=1 NO LEAKAGE IS COMPUTED, IF NEXCUR=2 LEAKAGE IS COMPUTED.
NEXCUR = 1

CONVERGENCE FLAG. IF IVERGE=1 CONVERGENCE IS ON K, IF IVERGE=2 CONVERGENCE IS ON REGION SET FLUXES
AND IF IVERGE=3 CONVERGENCE IS ON REGION AND GROUP SET FLUXES.
THE VALUE OF IVERGE FOR THIS PROBLEM IS 1

THE FRACTIONAL ERROR FOR CONVERGENCE IS 1.0000E-01

SCORING INITIALIZATION.
THE NUMBER OF GENERATIONS TO PROCESS BEFORE SCORING IS BEGUN = 3

RANDOM VARIABLE TABLE INFORMATION
NO. OF ENTRIES IN EACH TABLE = 512 (EXPONENT OF 2 = 9) NO OF RANDOM NO.S INITIALLY REJECTED = 5

INITIAL SOURCE INFORMATION
NO. OF SOURCES = 2 FISSION SPECTRUM NO. TO USE = 1
VOLUME SOURCE PROBLEM, ICURR = 0

SOURCE NO. SOURCE TYPE INTENSITY NO. OF EXEMPT REGIONS
LIST OF EXEMPT REGIONS-
CENTER POINT (X,Y,Z) AND SOURCE DIMENSIONS

1	1	1.0000E 00	0				
	1.9000E 00	1.5430E 00	1.0000E 00	0.0	4.4200E-01	1.0000E 03	
2	1	1.0000E 00	0				
	3.1400E 00	1.5430E 00	1.0000E 00	0.0	4.4200E-01	1.0000E 03	

VARIABLE INPUT
NCHECK = 1 MAXCNT = 6 IBUMAX = 24 XKEND = 3.3000E-01 WSTOP = 1.0000E-06

12313 STORAGE LOCATIONS IN BULK USED BEFORE LOCATIONS RESERVED FOR OUTPUT TALLIES

13334 STORAGE LOCATIONS USED IN BULK

TABLE XVI (Cont'd)

LISTING OF OUTPUT FROM PROBLEM I

(RAFFLE/005 R.S. MARSDEN 5/ 5/72) A GENERAL PURPOSE MONTE CARLO PROGRAM 12/12/72

RAFFLE MONTE CARLO PROGRAM SAMPLE PROBLEM I AN ITERATION PROBLEM

RAFFLE OUTPUT DATA

SOURCE DISTRIBUTION FOR THE NEXT GENERATION

1	0.0	2	0.0	3	5.0000E-01	4	5.0000E-01

TABLE XVI (Cont'd)

LISTING OF OUTPUT FROM PROBLEM I


```
ZTIME,RTIME=    0.18803197E 00    0.100000000D 01
ZTIME,RTIME=    0.48311460E 00    0.100000000D 01
ZTIME,RTIME=    0.48311460E 00    0.100000000D 01
ZTIME,RTIME=    0.74075723E 00    0.100000000D 01
ZTIME,RTIME=    0.75462389E 00    0.100000000D 01
ZTIME,RTIME=    0.10461006E 01    0.100000000D 01
```

TABLE XVI (Cont'd)

LISTING OF OUTPUT FROM PROBLEM I

CONVERGED OUTPUT**********

TOTAL DATA PROCESSED. 1 GENERATIONS 17 HISTORIES 1543 COLLISIONS

ERROR TALLY-BOX COUNTS. 0 IN IRRB01 0 IN IRRB02 0 IN IRRB03

DATA FOR THE GENERATION JUST PROCESSED. 16 DAUGHTERS INITIALLY STORED 17 DAUGHTERS PROCESSED

EIGENVALUE (K) RESULTS.
K FROM COLLISIONS = 1.5022E 00 (4.0646E-02) K FROM PATHS = 1.4712E 00 (3.5259E-02)
BEST COMBINED K = 1.4825E 00 (3.1575E-02)

LIFETIME AND GENERATION TIME (IN MICROSECONDS).
GENERATION TIME = 5.1004D-01 (1.3926E-01) LIFETIME = 7.2685D-01 (1.9535E-01)

FLUX OF MAXIMUM FRACTIONAL ERROR. FLUX = 8.7381E-02 (6.5436E-01) REGION SET = 1 GROUP SET = 21

CONVERGENCE ERROR CHECK.
FRACTIONAL ERROR FOR BEST COMBINED K = 3.1575E-02 FRACTIONAL ERROR DESIRED = 1.0000E-01

FLUXES BY REGION SET (REGSET) AND GROUP SET (GRSET)

GPSET	REGSET 1	REGSET 2	REGSET
1	0.0	0.0	
2	4.0955E-01	1.1986E 00	
3	1.3609E 00	2.6593E 00	
4	1.6811E 00	4.7301E 00	
5	3.3366E 00	8.0835E 00	
6	5.0663E 00	1.2445E 01	
7	4.7414E 00	9.0249E 00	
8	4.9708E 00	1.0844E 01	
9	6.9347E 00	1.3138E 01	
10	6.9030E 00	1.5066E 01	
11	6.0413E 00	1.2978E 01	
12	3.3869E 00	7.8700E 00	
13	4.4077E 00	1.1009E 01	
14	3.5527E 00	8.7255E 00	
15	1.9459E 00	4.8098E 00	
16	8.3678E-01	1.7733E 00	
17	2.4296E-01	5.5757E-01	
18	8.6057E-01	1.8426E 00	
19	5.0828E-01	8.0768E-01	
20	2.6668E-01	7.2155E-01	
21	8.7381E-02	4.1470E-01	
22	0.0	0.0	
23	0.0	0.0	
24	0.0	0.0	
25	0.0	0.0	
26	0.0	0.0	
27	0.0	0.0	

TABLE XVI (Cont'd)

LISTING OF OUTPUT FROM PROBLEM I

FLUXES BY REGION SET (REGSET)

REGSET	REGSET FLUX
1	5.7541E 01
2	1.2870E 02

FRACTIONAL ERRORS FOR THE REGION AND GROUP SET FLUXES

GRSET	REGSET 1	REGSET 2	REGSET
1	0.0	0.0	
2	4.5219E-01	4.6181E-01	
3	3.1223E-01	3.2600E-01	
4	2.3859E-01	2.2551E-01	
5	1.8900E-01	1.7456E-01	
6	2.1487E-01	2.1688E-01	
7	1.6236E-01	1.5516E-01	
8	1.2887E-01	1.5639E-01	
9	1.6212E-01	1.6206E-01	
10	1.0295E-01	1.1681E-01	
11	8.5857E-02	9.5556E-02	
12	1.0191E-01	1.0395E-01	
13	1.1390E-01	1.2519E-01	
14	1.4689E-01	1.3105E-01	
15	1.3626E-01	1.5336E-01	
16	1.6293E-01	1.7814E-01	
17	2.7584E-01	2.4106E-01	
18	3.1900E-01	3.2151E-01	
19	3.1898E-01	3.0525E-01	
20	4.4256E-01	5.3577E-01	
21	6.5436E-01	6.5436E-01	
22	0.0	0.0	
23	0.0	0.0	
24	0.0	0.0	
25	0.0	0.0	
26	0.0	0.0	
27	0.0	0.0	

FRACTIONAL ERRORS FOR THE REGION SET FLUXES

REGSET	ERROR
1	3.0290E-02
2	3.3448E-02

TABLE XVI (Cont'd)

LISTING OF OUTPUT FROM PROBLEM I

ABSORPTION AND NU*FISSION RATES FOR EACH GROUP AND REGION SET

****

* REGION SET 1 *

****

	GROUP SET 1	GROUP SET 2	GROUP SET 3	GROUP SET 4	GROUP SET 5
RES ABSORPTION	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
TOT ABSORPTION	0.0 (0.0)	8.2827E-03 (0.4516)	2.6651E-02 (0.2993)	3.1266E-02 (0.2411)	3.7048E-02 (0.1895)
RES NU*FISSION	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
TOT NU*FISSION	0.0 (0.0)	2.4108E-02 (0.4539)	7.7149E-02 (0.2933)	8.4991E-02 (0.2417)	8.7430E-02 (0.1905)

	GROUP SET 6	GROUP SET 7	GROUP SET 8	GROUP SET 9	GROUP SET 10
RES ABSORPTION	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
TOT ABSORPTION	4.8761E-02 (0.2174)	4.5008E-02 (0.1649)	4.9900E-02 (0.1273)	7.3529E-02 (0.1549)	8.6290E-02 (0.0982)
RES NU*FISSION	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
TOT NU*FISSION	1.0521E-01 (0.2188)	9.3985E-02 (0.1664)	9.7821E-02 (0.1275)	1.3250E-01 (0.1521)	1.4909E-01 (0.0956)

	GROUP SET 11	GROUP SET 12	GROUP SET 13	GROUP SET 14	GROUP SET 15
RES ABSORPTION	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
TOT ABSORPTION	9.2844E-02 (0.0857)	6.0640E-02 (0.1003)	9.3480E-02 (0.1149)	9.2046E-02 (0.1456)	6.3791E-02 (0.1384)
RES NU*FISSION	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
TOT NU*FISSION	1.3304E-01 (0.0887)	7.5746E-02 (0.1011)	9.6991E-02 (0.1186)	8.9499E-02 (0.1460)	5.7179E-02 (0.1413)

	GROUP SET 16	GROUP SET 17	GROUP SET 18	GROUP SET 19	GROUP SET 20
RES ABSORPTION	2.9473E-03 (0.5063)	3.2548E-03 (0.4437)	1.8326E-02 (0.2778)	5.7849E-03 (0.4278)	1.1739E-02 (0.4820)
TOT ABSORPTION	3.4339E-02 (0.1581)	1.2447E-02 (0.2717)	5.2976E-02 (0.2872)	3.1384E-02 (0.3234)	3.1068E-02 (0.4403)
RES NU*FISSION	3.9766E-07 (0.4216)	4.6842E-04 (0.6503)	6.3426E-05 (0.3520)	8.5880E-06 (0.4251)	7.6789E-06 (0.6368)
TOT NU*FISSION	2.8836E-02 (0.1722)	1.1934E-02 (0.2816)	4.9334E-02 (0.3195)	3.8759E-02 (0.3153)	3.0196E-02 (0.4272)

	GROUP SET 21	GROUP SET 22	GROUP SET 23	GROUP SET 24	GROUP SET 25
RES ABSORPTION	3.7497E-03 (0.6544)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
TOT ABSORPTION	9.6319E-03 (0.6544)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
RES NU*FISSION	6.0799E-04 (0.6544)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
TOT NU*FISSION	9.1026E-03 (0.6544)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)

	GROUP SET 26	GROUP SET 27	TOTAL OVER ALL GROUPS
RES ABSORPTION	0.0 (0.0)	0.0 (0.0)	4.5801E-02 (0.2602)
TOT ABSORPTION	0.0 (0.0)	0.0 (0.0)	9.8138E-01 (0.0520)
RES NU*FISSION	0.0 (0.0)	0.0 (0.0)	1.1565E-03 (0.4433)
TOT NU*FISSION	0.0 (0.0)	0.0 (0.0)	1.4729E 00 (0.0331)

****

* REGION SET 2 *

****

	GROUP SET 1	GROUP SET 2	GROUP SET 3	GROUP SET 4	GROUP SET 5
RES ABSORPTION	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
TOT ABSORPTION	0.0 (0.0)	5.5335E-04 (0.4511)	3.5669E-04 (0.2978)	2.1988E-04 (0.2381)	4.7326E-04 (0.1792)

	GROUP SET 6	GROUP SET 7	GROUP SET 8	GROUP SET 9	GROUP SET 10
RES ABSORPTION	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	5.6711E-07 (0.3815)	1.7908E-07 (0.1195)
TOT ABSORPTION	1.0886E-03 (0.2168)	7.4876E-04 (0.1557)	1.1727E-03 (0.1565)	1.4900E-03 (0.1618)	4.8517E-03 (0.1179)

TABLE XVI (Cont'd)

LISTING OF OUTPUT FROM PROBLEM I

	GROUP SET 11	GROUP SET 12	GROUP SET 13	GROUP SET 14	GROUP SET 15
RES ABSORPTION	3.2386E-07 (0.0966)	5.7693E-07 (0.1018)	3.8607E-06 (0.1267)	1.3243E-05 (0.1236)	4.8906E-05 (0.1819)
TOT ABSORPTION	5.4390E-03 (0.0973)	4.5303E-03 (0.1044)	3.5518E-03 (0.1234)	3.6080E-03 (0.1293)	5.1784E-03 (0.1509)
	GROUP SET 16	GROUP SET 17	GROUP SET 18	GROUP SET 19	GROUP SET 20
RES ABSORPTION	1.7744E-04 (0.2009)	6.5507E-04 (0.2172)	3.7195E-04 (0.3213)	8.7925E-05 (0.3029)	3.4851E-05 (0.6059)
TOT ABSORPTION	7.2985E-04 (0.1804)	7.3500E-04 (0.2202)	6.8401E-04 (0.3191)	2.6612E-03 (0.3524)	2.3351E-04 (0.5321)
	GROUP SET 21	GROUP SET 22	GROUP SET 23	GROUP SET 24	GROUP SET 25
RES ABSORPTION	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
TOT ABSORPTION	1.6441E-04 (0.6544)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
	GROUP SET 26	GROUP SET 27	TOTAL OVER ALL GROUPS		
RES ABSORPTION	0.0 (0.0)	0.0 (0.0)	1.3950E-03 (0.2290)		
TOT ABSORPTION	0.0 (0.0)	0.0 (0.0)	3.8470E-02 (0.0583)		

****

TABLE XIX

LISTING OF OUTPUT FROM PROBLEM II


```
RAFFLE MONTE CARLO PROGRAM  SAMPLE PROBLEM II   A CURRENT SOURCE PROBLEM

    EDIT OF INPUT DATA


  EXTERNAL SOURCE PROBLEM, FISSION DAUGHTERS FOLLOWED
  TRANSFER CROSS SECTIONS AND FLUXES CALCULATED
  PLANAR SURFACE SOURCE PROBLEM
  CONVERGENCE ON A REGION AND GROUP FLUX
  STANDARD CROSS SECTION LIBRARY USED
  STANDARD PATH SCORING
  BATCHING USED



INPUT EDIT FLAG. IF INEDIT=1, THE INPUT IS ONLY PROCESSED AND EDITED.
IF INEDIT=2, THE ENTIRE PROGRAM IS EXECUTED.
FOR THIS RUN INEDIT = 2
NO. HISTORIES TO PROCESS PER GENERATION--NIVO=   16
MAXIMUM EXECUTION TIME (NO EFFECT IF =0.0)--RTIME=   1.00000


NO. OF GROUPS =  69
NO. OF REAL REGIONS =   4
NO. OF FICTITIOUS REGIONS =   6
NO. OF MATERIALS =   3
ZONE GEOMETRY TYPE = 1
NO. OF BOUNDARY EQUATIONS =   17
NO. OF FISSION TABLES =  1
NO. OF SCATTERING ISOTOPES =   6


ISOTOPE LIST USED IN THIS PROBLEM

ISOTOPE  1 ID=   12
ISOTOPE  2 ID=   14
ISOTOPE  3 ID=   15
ISOTOPE  4 ID=   23
ISOTOPE  5 ID=   29

ISOTOPE  6 ID=  141
ISOTOPE

EXTERNAL SOURCE FLAG (IXTERN).
IF IXTERN=1 THERE ARE NO EXTERNAL SOURCES (AN EIGENVALUE PROBLEM),
IF IXTERN=2 THERE ARE EXTERNAL SOURCES BUT FISSION DAUGHTERS ARE NOT FOLLOWED,
IF IXTERN=3 THERE ARE EXTERNAL SOURCES AND FISSION DAUGHTERS ARE FOLLOWED.
FOR THIS PROBLEM IXTERN = 3

SCORING FLAG. IF ISCOR=1 PATH SCORING IS USED,
IF ISCOR=2 THE BOUNDRY-ELIMINATION METHOD IS USED,
IF ISCOR=3 THE COLLISION-CONTRIBUTION METHOD IS USED.
FOR THIS PROBLEM ISCOR = 1
```

TABLE XIX (Cont'd)

LISTING OF OUTPUT FROM PROBLEM II

TRANSFER COMPUTATION POINTERS
INELASTIC FLAG (=1 TO COMPUTE INELASTIC) = 1
ELASTIC FLAG (=1 TO COMPUTE ONCE, =2 TO COMPUTE N TIMES) = 2
NUMBER OF COMPUTE TIMES (FOR ELASTIC FLAG =2) = 9

LIBRARY FLAG(=0 IF READ FROM CARDS, =2 IF READ FROM LOGICAL UNIT 15) JTAPE = 2
NIC = 18 ISOTOPES IN LIBRARY

GROUP	LOWER ENERGY CUTOFF (EV)
1	7.7900E 06
2	6.0700E 06
3	4.7200E 06
4	3.6800E 06
5	2.8700E 06
6	2.2300E 06
7	1.7400E 06
8	1.3500E 06
9	1.0500E 06
10	8.2100E 05
11	6.3900E 05
12	4.9800E 05
13	3.8800E 05
14	3.0200E 05
15	2.3500E 05
16	1.8300E 05
17	1.4300E 05
18	1.1100E 05
19	8.6500E 04
20	6.7400E 04
21	5.2500E 04
22	4.0900E 04
23	3.1800E 04
24	2.4800E 04
25	1.9300E 04
26	1.5000E 04
27	1.1700E 04
28	9.1200E 03
29	7.1000E 03
30	5.5300E 03
31	4.3100E 03
32	3.3600E 03
33	2.6100E 03
34	2.0400E 03
35	1.5900E 03
36	1.2300E 03
37	9.6110E 02
38	7.4850E 02
39	5.8290E 02
40	4.5400E 02
41	3.5360E 02
42	2.7540E 02
43	2.1450E 02
44	1.6700E 02
45	1.3010E 02
46	1.0130E 02
47	7.8900E 01

TABLE XIX (Cont'd)

LISTING OF OUTPUT FROM PROBLEM II

48	6.1400E 01
49	4.7900E 01
50	3.7300E 01
51	2.9000E 01
52	2.2600E 01
53	1.7600E 01
54	1.3700E 01
55	1.0680E 01
56	8.3200E 00
57	6.4800E 00
58	5.0400E 00
59	3.9300E 00
60	3.0600E 00
61	2.3800E 00
62	1.8600E 00
63	1.4400E 00
64	1.1250E 00
65	8.7600E-01
66	6.8300E-01
67	5.3200E-01
68	4.1400E-01
69	0.0

NO CM TO LAB TRANSFORMATION IS MADE FOR GROUP 69 AND LOWER GROUPS.
NO ENERGY CHANGE IS MADE FOR ELASTIC SCATTER EVENT FOR GROUP 69 AND LOWER GROUPS.

GROUP SET INFORMATION -

ENERGY GROUPS IN GROUP SET 1
1 2

ENERGY GROUPS IN GROUP SET 2
3 4

ENERGY GROUPS IN GROUP SET 3
5 6

ENERGY GROUPS IN GROUP SET 4
7 8

ENERGY GROUPS IN GROUP SET 5
9 10

ENERGY GROUPS IN GROUP SET 6
11 12

ENERGY GROUPS IN GROUP SET 7
13 14

ENERGY GROUPS IN GROUP SET 8
15 16

ENERGY GROUPS IN GROUP SET 9
17 18

TABLE XIX (Cont'd)

LISTING OF OUTPUT FROM PROBLEM II


```
ENERGY GROUPS IN GROUP SET   10
   19    20

ENERGY GROUPS IN GROUP SET   11
   21    22

ENERGY GROUPS IN GROUP SET   12
   23    24

ENERGY GROUPS IN GROUP SET   13
   25    26

ENERGY GROUPS IN GROUP SET   14
   27    28

ENERGY GROUPS IN GROUP SET   15
   29    30

ENERGY GROUPS IN GROUP SET   16
   31    32

ENERGY GROUPS IN GROUP SET   17
   33    34

ENERGY GROUPS IN GROUP SET   18
   35    36

ENERGY GROUPS IN GROUP SET   19
   37    38

ENERGY GROUPS IN GROUP SET   20
   39    40

ENERGY GROUPS IN GROUP SET   21
   41    42

ENERGY GROUPS IN GROUP SET   22
   43    44    45    46

ENERGY GROUPS IN GROUP SET   23
   47    48    49    50

ENERGY GROUPS IN GROUP SET   24
   51    52    53    54

ENERGY GROUPS IN GROUP SET   25
   55    56    57    58

ENERGY GROUPS IN GROUP SET   26
   59    60    61    62

ENERGY GROUPS IN GROUP SET   27
   63    64    65    66    67    68    69

ENERGY BREAKPOINTS FOR THE GROUP SETS
```

TABLE XIX (Cont'd)

LISTING OF OUTPUT FROM PROBLEM II


```
   1.00000E 07    6.07000E 06    3.68000E 06    2.23000E 06    1.35000E 06    8.21000E 05
   4.98000E 05    3.02000E 05    1.83000E 05    1.11000E 05    6.74000E 04    4.09000E 04
   2.48000E 04    1.50000E 04    9.12000E 03    5.53000E 03    3.36000E 03    2.04000E 03
   1.23000E 03    7.48500E 02    4.54000E 02    2.75400E 02    1.01300E 02    3.73000E 01
   1.37000E 01    5.04000E 00    1.86000E 00    0.0
```

MATERIAL	NO. OF FISSION SPECTRA	NO. OF ISOTOPES
1	0	2
2	1	4
3	1	4

THE CUTOFF FLAG. IF NEXCUT=1 THE CONSTANT CUTOFF WEIGHT METHOD IS USED,
IF NEXCUT=2 THERE IS NO WEIGHT REDUCTION
IF NEXCUT=3 BOUNDED DOUBLE VALUE ROULETTE IS PLAYED.
FOR THIS PROBLEM NEXCUT = 2

SPLITTING FLAG. IF ISPLT =1 THERE IS NO SPLITTING, IF ISPLT =2 SPLITTING IS BY INTEGER MULTIPLES, IF ISPLT =3 SPLITTING IS BY WEIGHT COMPARISON.
FOR THIS PROBLEM ISPLT = 1

MATERIAL NO.= 1 NO. OF ISOTOPES = 2

ISOTOPE NO.	DENSITY	ISOTOPE NO.	DENSITY	ISOTOPE NO.	DENSITY	ISOTOPE NO.	DENSITY
29	1.6710E-02	141	1.3010E-02				

MATERIAL NO.= 2 NO. OF ISOTOPES = 4

ISOTOPE NO.	DENSITY	ISOTOPE NO.	DENSITY	ISOTOPE NO.	DENSITY	ISOTOPE NO.	DENSITY
12	1.5590E-02	14	5.8010E-03	15	7.6890E-04	23	4.5180E-02

MATERIAL NO.= 3 NO. OF ISOTOPES = 4

ISOTOPE NO.	DENSITY	ISOTOPE NO.	DENSITY	ISOTOPE NO.	DENSITY	ISOTOPE NO.	DENSITY
12	1.9010E-02	14	2.9010E-03	15	3.8450E-04	23	4.5280E-02

FISSION SPECTRUM NO. = 1

GROUP	INTENSITY	GROUP	INTENSITY	GROUP	INTENSITY	GROUP	INTENSITY	GROUP	INTENSITY
1	7.1790E-03	2	2.0377E-02	3	4.2563E-02	4	6.9834E-02	5	9.4774E-02
6	1.1084E-01	7	1.1536E-01	8	1.0960E-01	9	9.6973E-02	10	8.1155E-02
11	6.5031E-02	12	5.0376E-02	13	3.8005E-02	14	2.8089E-02	15	2.0429E-02
16	1.4673E-02	17	1.0473E-02	18	7.3677E-03	19	5.1703E-03	20	3.6117E-03
21	2.5139E-03	22	1.7448E-03	23	1.2084E-03	24	8.3550E-04	25	5.7690E-04
26	3.9790E-04	27	2.7430E-04	28	1.8890E-04	29	1.3010E-04	30	8.9500E-05
31	6.1600E-05	32	4.2400E-05	33	2.9100E-05	34	2.0000E-05	35	1.3800E-05
36	9.5000E-06	37	6.5000E-06	38	4.5000E-06	39	3.1000E-06	40	2.1000E-06
41	1.4000E-06	42	1.0000E-06	43	0.0	44	0.0	45	0.0
46	0.0	47	0.0	48	0.0	49	0.0	50	0.0
51	0.0	52	0.0	53	0.0	54	0.0	55	0.0
56	0.0	57	0.0	58	0.0	59	0.0	60	0.0
61	0.0	62	0.0	63	0.0	64	0.0	65	0.0
66	0.0	67	0.0	68	0.0	69	0.0		

BOUNDARY EQUATION PARAMETERS

NO.	N	TYPE	A	B	C	D	R	XO	YO	ZO
1	2	CYLINDER					0.0	1.9000E 00	1.5430E 00	
2	2	CYLINDER					4.4200E-01	1.9000E 00	1.5430E 00	
3	1	PLANE	0.0	1.0000E 00	0.0	1.0000E 00				

TABLE XIX (Cont'd)

LISTING OF OUPTUT FROM PROBLEM II

4	1	PLANE	1.0000E 00	0.0	0.0	2.5200E 00			
5	1	PLANE	0.0	1.0000E 00	0.0	2.4430E 00			
6	1	PLANE	1.0000E 00	0.0	0.0	1.0000E 00			
7	2	CYLINDER					0.0	3.1400E 00	1.5430E 00
8	2	CYLINDER					4.4200E-01	3.1400E 00	1.5430E 00
9	1	PLANE	1.0000E 00	0.0	0.0	3.7600E 00			
10	1	PLANE	0.0	1.0000E 00	0.0	0.0			
11	1	PLANE	1.0000E 00	0.0	0.0	4.7600E 00			
12	1	PLANE	0.0	1.0000E 00	0.0	3.4430E 00			
13	1	PLANE	1.0000E 00	0.0	0.0	0.0			
14	1	PLANE	0.0	0.0	1.0000E 00	0.0			
15	1	PLANE	0.0	0.0	1.0000E 00	1.0000E 00			
16	1	PLANE	0.0	0.0	1.0000E 00	1.0010E 03			
17	1	PLANE	0.0	0.0	1.0000E 00	1.0020E 03			

NO.OF EXTERNAL BOUNDARIES = 6

EXTERNAL BOUNDARY NO.	ALBEDO
3	0.0
9	1.0000E 00
5	0.0
6	1.0000E 00
15	1.0000E 00
16	1.0000E 00

REGION DESCRIPTIONS

REGION NO.	REGION TYPE	MATERIAL	NO.OF BOUNDARIES	SIGNED BOUNDARY NO.S---					
1	2	1	7	2	6	3	-4	-5	15	-16
2	2	1	7	8	4	3	-9	-5	15	-16
3	3	2	4	1	2	15	-16			
4	3	3	4	7	8	15	-16			
5	1	0	6	13	10	-6	-12	15	-16	
6	1	0	6	6	5	-9	-12	15	-16	
7	1	0	6	9	10	-11	-12	15	-16	
8	1	0	6	6	10	-9	-3	15	-16	
9	1	0	6	13	10	-11	-12	14	-15	

TABLE XIX (Cont'd)

LISTING OF OUTPUT FROM PROBLEM II


```
10                  1                  0                  6
     13     10    -11    -12     16    -17

REGION SET INFORMATION -

REGIONS IN REGION SET    1
   1     2     3     4
```

TABLE XIX (Cont'd)

LISTING OF OUTPUT FROM PROBLEM II


```
                ZONE GEOMETRY DESCRIPTION
STACKED RECTANGULAR ZONE GEOMETRY, IZONGE = 1


TOTAL NUMBER OF ZONES = 10
NUMBER OF Z-LINES =  4

Z-LINES
     0.0          1.00000  1001.00000  1002.00000

*****************************************************************************************************************
INFORMATION FOR Z-ZONE  1

XLINES
     0.0          4.76000

Y-LINES FOR X-ZONE  1
     0.0          3.44300

*****************************************************************************************************************
INFORMATION FOR Z-ZONE  2

XLINES
     0.0          1.00000      2.52000      3.76000      4.76000

Y-LINES FOR X-ZONE  1
     0.0          3.44300

Y-LINES FOR X-ZONE  2
     0.0          1.00000      2.44300      3.44300

Y-LINES FOR X-ZONE  3
     0.0          1.00000      2.44300      3.44300

Y-LINES FOR X-ZONE  4
     0.0          3.44300

*****************************************************************************************************************
INFORMATION FOR Z-ZONE  3

XLINES
     0.0          4.76000

Y-LINES FOR X-ZONE  1
     0.0          3.44300
```

TABLE XIX (Cont'd)

LISTING OF OUTPUT FROM PROBLEM II

ZONE	NO. OF REGIONS	REGION NO.S	
1	1	9	
2	1	5	
3	1	8	
4	2	1	3
5	1	6	
6	1	8	
7	2	2	4
8	1	6	
9	1	7	
10	1	10	

LEAKAGE FLAG. IF NEXCUR=1 NO LEAKAGE IS COMPUTED, IF NEXCUR=2 LEAKAGE IS COMPUTED.
NEXCUR = 1

CONVERGENCE FLAG. IF IVERGE=1 CONVERGENCE IS ON K, IF IVERGE=2 CONVERGENCE IS ON REGION SET FLUXES
AND IF IVERGE=3 CONVERGENCE IS ON REGION AND GROUP SET FLUXES.
THE VALUE OF IVERGE FOR THIS PROBLEM IS 3

THE FRACTIONAL ERROR FOR CONVERGENCE IS 1.0000E-02

FLAGS FOR IVERGE = 3. IF NEXREG = 0 ALL REGION SETS ARE TO BE CHECKED. IF NEXGRP = 0, ALL GROUP SETS ARE TO BE CHECKED
FOR NEXREG = N AND/OR NEXGRP = M, THE N REGION AND/OR M GROUP SETS SPECIFIED BELOW ARE TO BE CHECKED
FOR THIS PROBLEM NEXREG = 0 AND NEXGRP = 2

GROUP SET NO.S TO CHECK ARE -
7 8

RANDOM VARIABLE TABLE INFORMATION
NO. OF ENTRIES IN EACH TABLE = 512 (EXPONENT OF 2 = 9) NO OF RANDOM NO.S INITIALLY REJECTED = 5

CURRENT SOURCE INFORMATION

NO. OF CURRENT SOURCES = 2
NO. OF CURRENT GROUPS = 27
GROUP BIASING FLAG (=1 FOR EQUAL PROBABILITIES, =2 FOR INPUT IMPORTANCES) = 2
NON-ISOTROPIC FLAG (=1 FOR NON-ISOTROPIC ANGULAR FLUX) = 0

ENERGY CUTOFFS FOR THE CURRENT GROUPS (IN ORDER OF INCREASING GROUP AND DECREASING ENERGY)

1.0000E 07	6.0700E 06	3.6800E 06	2.2300E 06	1.3500E 06	8.2100E 05	4.9800E 05	3.0200E 05
1.8300E 05	1.1100E 05	6.7400E 04	4.0900E 04	2.4800E 04	1.5000E 04	9.1200E 03	5.5300E 03
3.3600E 03	2.0400E 03	1.2300E 03	7.4800E 02	4.5400E 02	2.7500E 02	1.0100E 02	3.7300E 01
1.3700E 01	5.0400E 00	6.8300E-01	0.0				

GROUP IMPORTANCES FOR ICURBS=2 (IN ORDER OF INCREASING GROUP)

1.0000E 00	1.5000E 00	1.5000E 00	1.5000E 00	2.0000E 00	3.0000E 00	3.0000E 00	3.0000E 00
3.0000E 00	3.0000E 00	2.0000E 00	1.5000E 00	1.5000E 00	1.5000E 00	1.5000E 00	1.0000E 00
1.0000E 00	1.0000E 00	1.0000E 00	1.0000E 00	7.0000E-01	7.0000E-01	5.0000E-01	5.0000E-01

TABLE XIX (Cont'd)

LISTING OF OUTPUT FROM PROBLEM II

5.0000E-01 5.0000E-01 5.0000E-01

INFORMATION FOR CURRENT SOURCE NO. 1

SOURCE TYPE = 0 SOURCE DIRECTION = 2 NO. OF EXEMPT REGIONS = 0

SOURCE DIMENSIONS (X,Y,Z AND NON-ZERO DX,DY,DZ) - 1.0100E 00 1.0100E 00 1.0100E 00 2.7400E 00 9.9998E 02

HEMISPHERICAL GROUP-WISE CURRENTS (IN ORDER OF INCREASING GROUP NO.)

5.8060E-06	2.2900E-05	4.9810E-05	7.5740E-05	1.0610E-04	1.7970E-04	2.0080E-04	2.0340E-04
1.7040E-04	1.4030E-04	1.0230E-04	7.2490E-05	4.7080E-05	3.1440E-05	1.5420E-05	7.2800E-06
2.6120E-06	8.6560E-06	4.3920E-06	1.9390E-06	5.0510E-07	3.2250E-07	2.7230E-08	1.9830E-09
2.4460E-10	7.9910E-11	1.5560E-14					

INFORMATION FOR CURRENT SOURCE NO. 2

SOURCE TYPE = 0 SOURCE DIRECTION = -2 NO. OF EXEMPT REGIONS = 0

SOURCE DIMENSIONS (X,Y,Z AND NON-ZERO DX,DY,DZ) - 1.0100E 00 2.4330E 00 1.0100E 00 1.4230E 00 9.9980E 01

HEMISPHERICAL GROUP-WISE CURRENTS (IN ORDER OF INCREASING GROUP NO.)

3.4780E-06	1.4300E-05	3.1860E-05	4.8280E-05	6.7780E-05	1.2250E-04	1.3780E-04	1.4930E-04
1.3910E-04	1.1230E-04	8.5410E-05	6.2870E-05	4.2770E-05	2.9560E-05	1.5020E-05	7.2760E-06
2.6310E-06	8.8230E-06	4.6290E-06	2.2540E-06	6.9620E-07	5.8940E-07	1.1060E-07	1.4680E-08
3.2520E-09	6.2930E-10	6.1580E-14					

STONE DEBUG

ENERGY CUTOFFS

1.0000E 07	6.0700E 06	3.6800E 06	2.2300E 06	1.3500E 06	8.2100E 05	4.9800E 05	3.0200E 05
1.8300E 05	1.1100E 05	6.7400E 04	4.0900E 04	2.4800E 04	1.5000E 04	9.1200E 03	5.5300E 03
3.3600E 03	2.0400E 03	1.2300E 03	7.4800E 02	4.5400E 02	2.7500E 02	1.0100E 02	3.7300E 01
1.3700E 01	5.0400E 00	6.8300E-01	0.0				

NORMALIZED IMPORTANCES

2.5381E-02	3.8071E-02	3.8071E-02	3.8071E-02	5.0761E-02	7.6142E-02	7.6142E-02	7.6142E-02
7.6142E-02	7.6142E-02	5.0761E-02	3.8071E-02	3.8071E-02	3.8071E-02	3.8071E-02	2.5381E-02
2.5381E-02	2.5381E-02	2.5381E-02	2.5381E-02	1.7766E-02	1.7766E-02	1.2690E-02	1.2690E-02
1.2690E-02	1.2690E-02	1.2690E-02					
2.5381E-02	6.3452E-02	1.0152E-01	1.3959E-01	1.9036E-01	2.6650E-01	3.4264E-01	4.1878E-01

TABLE XIX (Cont'd)

LISTING OF OUTPUT FROM PROBLEM II


```
 4.9492E-01      5.7107E-01      6.2183E-01      6.5990E-01      6.9797E-01      7.3604E-01      7.7411E-01      7.9949E-01
 8.2487E-01      8.5025E-01      8.7563E-01      9.0101E-01      9.1878E-01      9.3655E-01      9.4924E-01      9.6193E-01
 9.7462E-01      9.8731E-01      1.0000E 00

INDIVIDUAL SOURCE INFORMATION WITH THE FOLLOWING FORMAT
TYPE,INTENSITY,DIRECTION,EXEMPT REG.
LIST OF EXEMPT REG.
X,Y,Z,DX,DY,DZ
CUM. GP PROBABILITIES (OR WEIGHTS IF ICBS=1,2)
AND IF ICURIS=1, GPWISE J0,F1,J1,...FN,JN WHERE N=NCURMU-1


INFO FOR SOURCE NO.   1

    0       3.9713E 00          2          0

 1.0100E 00      1.0100E 00      1.0100E 00      2.7400E 00      9.9998E 02

 1.5783E-01      4.1500E-01      9.0267E-01      1.3726E 00      1.4421E 00      1.6283E 00      1.8195E 00      1.8430E 00
 1.5440E 00      1.2713E 00      1.3904E 00      1.3137E 00      8.5319E-01      5.6976E-01      2.7944E-01      1.9789E-01
 7.1003E-02      2.3530E-01      1.1939E-01      5.2708E-02      1.9615E-02      1.2524E-02      1.4804E-03      1.0781E-04
 1.3298E-05      4.3444E-06      8.4594E-10


INFO FOR SOURCE NO.   2

    0       1.5498E-01         -2          0

 1.0100E 00      2.4330E 00      1.0100E 00      1.4230E 00      9.9980E 01

 1.2579E-01      3.4480E-01      7.6821E-01      1.1641E 00      1.2257E 00      1.4769E 00      1.6613E 00      1.8000E 00
 1.6770E 00      1.3539E 00      1.5446E 00      1.5159E 00      1.0313E 00      7.1276E-01      3.6216E-01      2.6316E-01
 9.5159E-02      3.1911E-01      1.6742E-01      8.1523E-02      3.5972E-02      3.0454E-02      8.0004E-03      1.0619E-03
 2.3524E-04      4.5521E-05      4.4545E-09

VARIABLE INPUT
NCHECK =     1  MAXCNT =     0  IBUMAX =  24  XKENO =   3.3000E-01  WSTOP =   1.0000E-06

 12313 STORAGE LOCATIONS IN BULK USED BEFORE LOCATIONS RESERVED FOR OUTPUT TALLIES

 12992 STORAGE LOCATIONS USED IN BULK
```

TABLE XIX (Cont'd)

LISTING OF OUTPUT FROM PROBLEM II

(RAFFLE/005 R.S. MARSDEN 5/ 5/72) A GENERAL PURPOSE MONTE CARLO PROGRAM 12/14/72

RAFFLE MONTE CARLO PROGRAM SAMPLE PROBLEM II A CURRENT SOURCE PROBLEM

RAFFLE OUTPUT DATA

TABLE XIX (Cont'd)

LISTING OF OUTPUT FROM PROBLEM II


```
 ZTIME,RTIME=   0.55466630E-02   0.10000000D 01
 ZTIME,RTIME=   0.10538660E-01   0.10000000D 01
 ZTIME,RTIME=   0.18303990E-01   0.10000000D 01
 ZTIME,RTIME=   0.23850653E-01   0.10000000D 01
 ZTIME,RTIME=   0.33834651E-01   0.10000000D 01
 ZTIME,RTIME=   0.44927981E-01   0.10000000D 01
 ZTIME,RTIME=   0.56575980E-01   0.10000000D 01
 ZTIME,RTIME=   0.65450609E-01   0.10000000D 01
 ZTIME,RTIME=   0.70719898E-01   0.10000000D 01
 ZTIME,RTIME=   0.75711846E-01   0.10000000D 01
 ZTIME,RTIME=   0.79594493E-01   0.10000000D 01
 ZTIME,RTIME=   0.85141122E-01   0.10000000D 01
 ZTIME,RTIME=   0.90410411E-01   0.10000000D 01
 ZTIME,RTIME=   0.96234381E-01   0.10000000D 01
 ZTIME,RTIME=   0.10039437E 00   0.10000000D 01
 ZTIME,RTIME=   0.10954636E 00   0.10000000D 01
 ZTIME,RTIME=   0.11842102E 00   0.10000000D 01
 ZTIME,RTIME=   0.12396765E 00   0.10000000D 01
 ZTIME,RTIME=   0.12923694E 00   0.10000000D 01
 ZTIME,RTIME=   0.13755691E 00   0.10000000D 01
 ZTIME,RTIME=   0.14338088E 00   0.10000000D 01
 ZTIME,RTIME=   0.15031421E 00   0.10000000D 01
 ZTIME,RTIME=   0.15586084E 00   0.10000000D 01
 ZTIME,RTIME=   0.16445816E 00   0.10000000D 01
 ZTIME,RTIME=   0.17361015E 00   0.10000000D 01
 ZTIME,RTIME=   0.18026614E 00   0.10000000D 01
 ZTIME,RTIME=   0.18636745E 00   0.10000000D 01
 ZTIME,RTIME=   0.19635141E 00   0.10000000D 01
 ZTIME,RTIME=   0.20383936E 00   0.10000000D 01
 ZTIME,RTIME=   0.21077269E 00   0.10000000D 01
 ZTIME,RTIME=   0.21521002E 00   0.10000000D 01
 ZTIME,RTIME=   0.22602600E 00   0.10000000D 01
 ZTIME,RTIME=   0.23157263E 00   0.10000000D 01
 ZTIME,RTIME=   0.24349791E 00   0.10000000D 01
 ZTIME,RTIME=   0.24765790E 00   0.10000000D 01
 ZTIME,RTIME=   0.25986052E 00   0.10000000D 01
 ZTIME,RTIME=   0.26512980E 00   0.10000000D 01
 ZTIME,RTIME=   0.27483642E 00   0.10000000D 01
 ZTIME,RTIME=   0.28038305E 00   0.10000000D 01
 ZTIME,RTIME=   0.28870302E 00   0.10000000D 01
 ZTIME,RTIME=   0.29314035E 00   0.10000000D 01
 ZTIME,RTIME=   0.29868698E 00   0.10000000D 01
 ZTIME,RTIME=   0.30367893E 00   0.10000000D 01
 ZTIME,RTIME=   0.31310821E 00   0.10000000D 01
 ZTIME,RTIME=   0.32475621E 00   0.10000000D 01
 ZTIME,RTIME=   0.33363086E 00   0.10000000D 01
 ZTIME,RTIME=   0.33973217E 00   0.10000000D 01
 ZTIME,RTIME=   0.34832948E 00   0.10000000D 01
 ZTIME,RTIME=   0.35637212E 00   0.10000000D 01
 ZTIME,RTIME=   0.36496943E 00   0.10000000D 01
**********************************************************************************************************************
                                    LOST NEUTRON (COUNTED IN IRRB01)
REGION NO. IN WHICH NEUTRON WAS LOCATED =   8          A FICTITIOUS REGION WAS ENTERED BUT NO EXTERNAL BOUNDARY WAS FOUND
**********************************************************************************************************************
 ZTIME,RTIME=   0.37218004E 00   0.10000000D 01
```

TABLE XIX (Cont'd)

LISTING OF OUTPUT FROM PROBLEM II


```
   ZTIME,RTIME=    0.37717199E 00    0.10000000D 01
   ZTIME,RTIME=    0.38687861E 00    0.10000000D 01
   ZTIME,RTIME=    0.39048392E 00    0.10000000D 01

 (X,Y,Z)=     1.90187E 00     1.54665E 00     4.75433E 01 ZONE=     4 REGIONS IN ZONE=     1     3     0     0     0     0     0     2

**********************************************************************************************************************
                                        LOST NEUTRON (COUNTED IN IRRB01)
REGION NO. IN WHICH NEUTRON WAS LOCATED =    3              THE NEUTRON WAS LOST IN TRYING TO CROSS TO AN ADJACENT REGION
**********************************************************************************************************************
   ZTIME,RTIME=    0.39547586E 00    0.10000000D 01
   ZTIME,RTIME=    0.40490514E 00    0.10000000D 01
   ZTIME,RTIME=    0.41350245E 00    0.10000000D 01
   ZTIME,RTIME=    0.42265445E 00    0.10000000D 01
   ZTIME,RTIME=    0.42875576E 00    0.10000000D 01
   ZTIME,RTIME=    0.43624371E 00    0.10000000D 01
   ZTIME,RTIME=    0.44179034E 00    0.10000000D 01
   ZTIME,RTIME=    0.44567299E 00    0.10000000D 01
   ZTIME,RTIME=    0.45177430E 00    0.10000000D 01
   ZTIME,RTIME=    0.45759827E 00    0.10000000D 01
   ZTIME,RTIME=    0.46120358E 00    0.10000000D 01
   ZTIME,RTIME=    0.47007823E 00    0.10000000D 01
   ZTIME,RTIME=    0.48533154E 00    0.10000000D 01
   ZTIME,RTIME=    0.49254215E 00    0.10000000D 01
   ZTIME,RTIME=    0.50058478E 00    0.10000000D 01
   ZTIME,RTIME=    0.50696343E 00    0.10000000D 01
   ZTIME,RTIME=    0.51251006E 00    0.10000000D 01
   ZTIME,RTIME=    0.51833403E 00    0.10000000D 01
   ZTIME,RTIME=    0.52471268E 00    0.10000000D 01
   ZTIME,RTIME=    0.53802466E 00    0.10000000D 01
   ZTIME,RTIME=    0.54384863E 00    0.10000000D 01
   ZTIME,RTIME=    0.55105925E 00    0.10000000D 01
   ZTIME,RTIME=    0.55549657E 00    0.10000000D 01
   ZTIME,RTIME=    0.56298453E 00    0.10000000D 01
   ZTIME,RTIME=    0.57074982E 00    0.10000000D 01
   ZTIME,RTIME=    0.57906979E 00    0.10000000D 01
   ZTIME,RTIME=    0.59016311E 00    0.10000000D 01
   ZTIME,RTIME=    0.59903777E 00    0.10000000D 01
   ZTIME,RTIME=    0.60680306E 00    0.10000000D 01
   ZTIME,RTIME=    0.61512303E 00    0.10000000D 01
   ZTIME,RTIME=    0.61983764E 00    0.10000000D 01
   ZTIME,RTIME=    0.62482959E 00    0.10000000D 01
   ZTIME,RTIME=    0.62954420E 00    0.10000000D 01
   ZTIME,RTIME=    0.63758683E 00    0.10000000D 01
   ZTIME,RTIME=    0.64424282E 00    0.10000000D 01
   ZTIME,RTIME=    0.65145344E 00    0.10000000D 01
   ZTIME,RTIME=    0.66005075E 00    0.10000000D 01
   ZTIME,RTIME=    0.66920274E 00    0.10000000D 01
   ZTIME,RTIME=    0.67474937E 00    0.10000000D 01
   ZTIME,RTIME=    0.67890936E 00    0.10000000D 01
   ZTIME,RTIME=    0.68584269E 00    0.10000000D 01
   ZTIME,RTIME=    0.69249868E 00    0.10000000D 01
   ZTIME,RTIME=    0.70220530E 00    0.10000000D 01
   ZTIME,RTIME=    0.71052527E 00    0.10000000D 01
   ZTIME,RTIME=    0.71579456E 00    0.10000000D 01
```

TABLE XIX (Cont'd)

LISTING OF OUTPUT FROM PROBLEM II


```
 ZTIME,RTIME=   0.72217321E 00   0.10000000D 01
 ZTIME,RTIME=   0.73160249E 00   0.10000000D 01
 ZTIME,RTIME=   0.73520780E 00   0.10000000D 01
 ZTIME,RTIME=   0.74352777E 00   0.10000000D 01
 ZTIME,RTIME=   0.75101572E 00   0.10000000D 01
 ZTIME,RTIME=   0.75683969E 00   0.10000000D 01
 ZTIME,RTIME=   0.76044500E 00   0.10000000D 01
 ZTIME,RTIME=   0.76821029E 00   0.10000000D 01
 ZTIME,RTIME=   0.77403426E 00   0.10000000D 01
 ZTIME,RTIME=   0.78429556E 00   0.10000000D 01
 ZTIME,RTIME=   0.79372483E 00   0.10000000D 01
 ZTIME,RTIME=   0.80093545E 00   0.10000000D 01
 ZTIME,RTIME=   0.81230611E 00   0.10000000D 01
 ZTIME,RTIME=   0.82145810E 00   0.10000000D 01
 ZTIME,RTIME=   0.83643407E 00   0.10000000D 01
 ZTIME,RTIME=   0.83976203E 00   0.10000000D 01
 ZTIME,RTIME=   0.85057801E 00   0.10000000D 01
 ZTIME,RTIME=   0.85723400E 00   0.10000000D 01
 ZTIME,RTIME=   0.86666328E 00   0.10000000D 01
 ZTIME,RTIME=   0.87193257E 00   0.10000000D 01
 ZTIME,RTIME=   0.87553787E 00   0.10000000D 01
 ZTIME,RTIME=   0.87942052E 00   0.10000000D 01
 ZTIME,RTIME=   0.88829517E 00   0.10000000D 01
 ZTIME,RTIME=   0.89356446E 00   0.10000000D 01
 ZTIME,RTIME=   0.90077507E 00   0.10000000D 01
 ZTIME,RTIME=   0.90881771E 00   0.10000000D 01
 ZTIME,RTIME=   0.91741502E 00   0.10000000D 01
 ZTIME,RTIME=   0.92434835E 00   0.10000000D 01
 ZTIME,RTIME=   0.93239099E 00   0.10000000D 01
 ZTIME,RTIME=   0.93876964E 00   0.10000000D 01
 ZTIME,RTIME=   0.94903094E 00   0.10000000D 01
 ZTIME,RTIME=   0.95485491E 00   0.10000000D 01
 ZTIME,RTIME=   0.96040154E 00   0.10000000D 01
 ZTIME,RTIME=   0.96705753E 00   0.10000000D 01
 ZTIME,RTIME=   0.97232682E 00   0.10000000D 01
 ZTIME,RTIME=   0.98092413E 00   0.10000000D 01
 ZTIME,RTIME=   0.98758012E 00   0.10000000D 01
 ZTIME,RTIME=   0.99451345E 00   0.10000000D 01
 ZTIME,RTIME=   0.10072699E 01   0.10000000D 01

TOTAL DATA PROCESSED.          138 GENERATIONS          3387 HISTORIES          2191 COLLISIONS

ERROR TALLY-BOX COUNTS.          2 IN IRRB01          0 IN IRRB02          0 IN IRRB03

DATA FOR THE GENERATION JUST PROCESSED.          16 DAUGHTERS INITIALLY STORED          37 DAUGHTERS PROCESSED

EIGENVALUE (K) RESULTS.
K FROM COLLISIONS = 2.3877E-02 ( 3.6708E-02 )          K FROM PATHS = 2.3606E-02 ( 2.0601E-02 )
BEST COMBINED K = 2.3602E-02 ( 2.0600E-02 )

LIFETIME AND GENERATION TIME (IN MICROSECONDS).
GENERATION TIME = 5.7044D-03 ( 7.4962E-02 )          LIFETIME = 6.2775D-03 ( 2.1753E-02 )

FLUX OF MAXIMUM FRACTIONAL ERROR.          FLUX = 3.3402E-08 ( 2.5512E-01 )     REGION SET =   1     GROUP SET =  27
```

TABLE XIX (Cont'd)

LISTING OF OUTPUT FROM PROBLEM II

CONVERGENCE ERROR CHECK.
REGION AND GROUP SET FLUX OF MAXIMUM FRACTIONAL ERROR = 4.1126E-01 REGION SET = 1 GROUP SET = 8
FRACTIONAL ERROR = 5.9682E-02 FRACTIONAL ERROR DESIRED = 1.0000E-02

FLUXES BY REGION SET (REGSET) AND GROUP SET (GRSET)

GPSET	REGSET 1 REGSET
1	1.5887E-02
2	4.9519E-02
3	1.0917E-01
4	1.2503E-01
5	1.9819E-01
6	3.4539E-01
7	3.8857E-01
8	4.1126E-01
9	3.1644E-01
10	2.8030E-01
11	1.7086E-01
12	1.7956E-01
13	1.0363E-01
14	6.8911E-02
15	2.8584E-02
16	1.0863E-02
17	4.7218E-03
18	1.8022E-02
19	7.6890E-03
20	3.5086E-03
21	9.9254E-04
22	4.5586E-04
23	5.9430E-05
24	4.4892E-06
25	3.1186E-07
26	5.7600E-08
27	3.3402E-08

FLUXES BY REGION SET (REGSET)

REGSET	REGSET FLUX
1	2.8376E 00

FRACTIONAL ERRORS FOR THE REGION AND GROUP SET FLUXES

GRSET	REGSET 1 REGSET
1	1.0483E-01
2	8.5399E-02
3	8.1910E-02
4	7.3376E-02
5	6.4355E-02
6	6.7970E-02
7	5.0239E-02

TABLE XIX (Cont'd)

LISTING OF OUTPUT FROM PROBLEM II

8	5.9682E-02
9	6.8761E-02
10	5.6039E-02
11	7.1702E-02
12	8.2948E-02
13	1.3658E-01
14	8.1022E-02
15	8.7881E-02
16	1.0573E-01
17	1.0755E-01
18	1.2780E-01
19	1.5929E-01
20	1.1395E-01
21	1.4201E-01
22	1.4610E-01
23	2.1604E-01
24	1.9137E-01
25	1.5940E-01
26	2.0163E-01
27	2.5512E-01

FRACTIONAL ERRORS FOR THE REGION SET FLUXES

REGSET	ERROR
1	1.3901E-02

TABLE XIX (Cont'd)

LISTING OF OUTPUT FROM PROBLEM II

ABSORPTION AND NU*FISSION CROSS SECTIONS FOR EACH GROUP (REGSET=1)

****

* REGION SET 1 *

****

	GROUP SET 1	GROUP SET 2	GROUP SET 3	GROUP SET 4	GROUP SET 5
RES ABSORPTION	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
TOT ABSORPTION	6.1772E-03 (0.0297)	6.5628E-03 (0.0334)	6.1082E-03 (0.0272)	5.9444E-03 (0.0320)	3.9575E-03 (0.0281)
RES NU*FISSION	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
TOT NU*FISSION	3.3351E-02 (0.0417)	1.7980E-02 (0.0363)	1.7551E-02 (0.0278)	1.5997E-02 (0.0325)	9.4716E-03 (0.0300)

	GROUP SET 6	GROUP SET 7	GROUP SET 8	GROUP SET 9	GROUP SET 10
RES ABSORPTION	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	1.4557E-05 (0.6192)	8.4080E-09 (0.0393)
TOT ABSORPTION	3.4765E-03 (0.0270)	3.0957E-03 (0.0324)	3.3154E-03 (0.0303)	3.5509E-03 (0.0333)	4.2940E-03 (0.0293)
RES NU*FISSION	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
TOT NU*FISSION	7.5133E-03 (0.0296)	6.4209E-03 (0.0355)	6.2704E-03 (0.0329)	6.2447E-03 (0.0364)	6.8963E-03 (0.0341)

	GROUP SET 11	GROUP SET 12	GROUP SET 13	GROUP SET 14	GROUP SET 15
RES ABSORPTION	1.3958E-08 (0.0291)	5.7372E-08 (0.0304)	2.3482E-07 (0.0430)	1.0315E-06 (0.0354)	5.3975E-06 (0.0534)
TOT ABSORPTION	5.2562E-03 (0.0364)	6.6570E-03 (0.0360)	5.7651E-03 (0.0703)	8.8954E-03 (0.0390)	1.1224E-02 (0.0439)
RES NU*FISSION	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
TOT NU*FISSION	6.9108E-03 (0.0430)	7.6577E-03 (0.0421)	6.1345E-03 (0.0809)	8.4148E-03 (0.0427)	9.2475E-03 (0.0563)

	GROUP SET 16	GROUP SET 17	GROUP SET 18	GROUP SET 19	GROUP SET 20
RES ABSORPTION	5.7341E-04 (0.4065)	5.0218E-03 (0.2039)	5.9136E-03 (0.3024)	4.1618E-03 (0.1993)	1.2590E-02 (0.2555)
TOT ABSORPTION	1.3585E-02 (0.0616)	1.6668E-02 (0.0888)	1.7970E-02 (0.1106)	2.4365E-02 (0.0620)	4.1699E-02 (0.0896)
RES NU*FISSION	3.8243E-06 (0.3851)	7.6174E-06 (0.1827)	2.9243E-05 (0.2521)	2.1968E-05 (0.4124)	2.0633E-05 (0.2011)
TOT NU*FISSION	1.2094E-02 (0.0653)	1.3699E-02 (0.0747)	1.6902E-02 (0.0699)	2.4744E-02 (0.0763)	4.7007E-02 (0.0779)

	GROUP SET 21	GROUP SET 22	GROUP SET 23	GROUP SET 24	GROUP SET 25
RES ABSORPTION	1.8477E-02 (0.3627)	4.6754E-02 (0.2643)	4.4172E-02 (0.2900)	8.1343E-02 (0.4114)	6.2095E-02 (0.5122)
TOT ABSORPTION	4.4923E-02 (0.1635)	5.2605E-02 (0.2375)	4.7427E-02 (0.2700)	8.5373E-02 (0.3924)	6.8302E-02 (0.4674)
RES NU*FISSION	9.7237E-03 (0.4515)	4.2198E-02 (0.3672)	8.0892E-02 (0.3796)	4.1948E-02 (0.2757)	6.9025E-02 (0.5121)
TOT NU*FISSION	5.2587E-02 (0.0968)	5.4327E-02 (0.2903)	8.7321E-02 (0.3515)	4.8986E-02 (0.2450)	7.9700E-02 (0.4468)

	GROUP SET 26	GROUP SET 27	TOTAL OVER ALL GROUPS
RES ABSORPTION	3.7418E-03 (0.2287)	1.4864E-01 (0.3679)	9.1709E-05 (0.1332)
TOT ABSORPTION	2.6629E-02 (0.1467)	1.9467E-01 (0.2870)	4.6843E-03 (0.0128)
RES NU*FISSION	2.6916E-03 (0.1271)	9.5131E-04 (0.1891)	1.2247E-05 (0.1710)
TOT NU*FISSION	4.3874E-02 (0.1781)	8.1722E-02 (0.1665)	8.3752E-03 (0.0140)

****

TOTAL SCATTERING CROSS-SECTIONS

GROUP	X-SECT	FRACTIONAL ERROR
1	1.0944E-01	1.2406E-02
2	1.3064E-01	1.2543E-02
3	1.3295E-01	9.4706E-03
4	1.3456E-01	1.1772E-02
5	1.8670E-01	1.2799E-02

TABLE XIX (Cont'd)

LISTING OF OUTPUT FROM PROBLEM II

6	1.9865E-01	7.7227E-03
7	2.5151E-01	1.5977E-02
8	2.1141E-01	1.3480E-02
9	2.0844E-01	1.4535E-02
10	2.3461E-01	1.3148E-02
11	2.5595E-01	1.3371E-02
12	4.0414E-01	2.1558E-02
13	1.7855E-01	3.6808E-02
14	2.4816E-01	1.9097E-02
15	3.4942E-01	1.1533E-02
16	3.8864E-01	3.1029E-02
17	8.8829E-01	4.8847E-02
18	2.9864E-01	2.1176E-02
19	2.9630E-01	2.8751E-02
20	3.0573E-01	2.1061E-02
21	3.1465E-01	3.5549E-02
22	3.1256E-01	7.4323E-02
23	2.8475E-01	2.5385E-02
24	3.1227E-01	1.1453E-01
25	2.7545E-01	1.7181E-02
26	2.9041E-01	2.0293E-02
27	3.0182E-01	3.1126E-02

PO SCATTERING MATRIX (THE INTEGERS IN PARENTHESES ARE THE GROUPS SCATTERED TO)

PO FROM GROUP 1

(1) 7.7574E-02 (2) 8.3894E-03 (3) 8.9841E-03 (4) 9.3416E-03 (5) 7.6557E-03 (6) 5.0756E-03 (7) 2.6886E-03 (8) 1.2535E-03
(9) 5.3351E-04 (10) 2.1465E-04 (11) 8.3717E-05 (12) 3.1915E-05 (13) 1.1986E-05 (14) 3.7026E-06 (15) 1.2379E-06 (16) 0.0
(17) 0.0 (18) 0.0 (19) 0.0 (20) 0.0 (21) 0.0 (22) 0.0 (23) 0.0 (24) 0.0
(25) 0.0 (26) 0.0 (27) 2.6561E-04 (

PO FROM GROUP 2

(2) 9.6663E-02 (3) 1.3886E-02 (4) 8.9431E-03 (5) 8.4565E-03 (6) 5.6686E-03 (7) 3.1277E-03 (8) 1.4898E-03 (9) 6.4335E-04
(10) 2.6524E-04 (11) 1.0515E-04 (12) 4.0494E-05 (13) 1.5336E-05 (14) 5.6475E-06 (15) 1.9088E-06 (16) 0.0 (17) 0.0
(18) 0.0 (19) 0.0 (20) 0.0 (21) 0.0 (22) 0.0 (23) 0.0 (24) 0.0 (25) 0.0
(26) 0.0 (27) 0.0 (

PO FROM GROUP 3

(3) 9.6040E-02 (4) 1.4801E-02 (5) 5.3909E-03 (6) 5.2725E-03 (7) 3.9555E-03 (8) 2.0229E-03 (9) 9.4758E-04 (10) 3.4743E-04
(11) 1.3342E-04 (12) 5.1932E-05 (13) 1.9816E-05 (14) 7.3562E-06 (15) 2.7618E-06 (16) 5.9049E-07 (17) 0.0 (18) 0.0
(19) 0.0 (20) 0.0 (21) 0.0 (22) 0.0 (23) 0.0 (24) 0.0 (25) 0.0 (26) 0.0
(27) 0.0 (

PO FROM GROUP 4

(4) 8.9522E-02 (5) 2.0425E-02 (6) 8.1706E-03 (7) 4.5907E-03 (8) 1.6183E-03 (9) 4.9808E-04 (10) 1.4864E-04 (11) 4.8371E-05
(12) 1.7777E-05 (13) 7.1614E-06 (14) 2.3380E-06 (15) 4.3841E-07 (16) 1.6143E-07 (17) 0.0 (18) 0.0 (19) 0.0
(20) 0.0 (21) 0.0 (22) 0.0 (23) 0.0 (24) 0.0 (25) 0.0 (26) 0.0 (27) 0.0

TABLE XIX (Cont'd)

LISTING OF OUTPUT FROM PROBLEM II

PO FROM GROUP 5

(5) 1.5400E-01 (6) 2.4676E-02 (7) 6.5407E-03 (8) 4.4608E-03 (9) 2.0654E-03 (10) 9.0985E-04 (11) 4.1930E-04 (12) 2.3321E-04
(13) 3.8435E-05 (14) 6.5444E-06 (15) 7.7990E-07 (16) 5.5241E-08 (17) 0.0 (18) 0.0 (19) 0.0 (20) 0.0
(21) 0.0 (22) 0.0 (23) 0.0 (24) 0.0 (25) 0.0 (26) 0.0 (27) 0.0 (

PO FROM GROUP 6

(6) 1.8742E-01 (7) 2.7211E-02 (8) 1.3309E-03 (9) 5.9240E-04 (10) 3.1416E-04 (11) 1.0362E-04 (12) 2.7650E-05 (13) 8.4934E-06
(14) 2.8321E-06 (15) 9.5632E-07 (16) 8.6151E-08 (17) 2.6574E-10 (18) 0.0 (19) 0.0 (20) 0.0 (21) 0.0
(22) 0.0 (23) 0.0 (24) 0.0 (25) 0.0 (26) 0.0 (27) 0.0 (

PO FROM GROUP 7

(7) 2.2372E-01 (8) 2.9522E-02 (9) 1.9382E-04 (10) 4.2591E-05 (11) 5.0187E-05 (12) 1.1812E-05 (13) 4.6289E-06 (14) 1.0765E-06
(15) 2.9774E-07 (16) 1.3165E-07 (17) 4.5211E-08 (18) 3.0816E-09 (19) 0.0 (20) 0.0 (21) 0.0 (22) 0.0
(23) 0.0 (24) 0.0 (25) 0.0 (26) 0.0 (27) 0.0 (

PO FROM GROUP 8

(8) 1.8917E-01 (9) 2.2412E-02 (10) 1.6273E-04 (11) 6.0977E-05 (12) 7.8906E-06 (13) 8.6416E-08 (14) 5.5239E-07 (15) 2.5325E-07
(16) 6.4704E-08 (17) 2.7159E-08 (18) 9.8289E-09 (19) 0.0 (20) 0.0 (21) 0.0 (22) 0.0 (23) 0.0
(24) 0.0 (25) 0.0 (26) 0.0 (27) 0.0 (

PO FROM GROUP 9

(9) 1.8377E-01 (10) 2.4723E-02 (11) 9.4258E-05 (12) 1.4753E-05 (13) 1.1583E-05 (14) 3.6950E-06 (15) 1.4081E-06 (16) 7.5577E-07
(17) 2.6625E-07 (18) 7.3263E-08 (19) 0.0 (20) 0.0 (21) 0.0 (22) 0.0 (23) 0.0 (24) 0.0
(25) 0.0 (26) 0.0 (27) 0.0 (

PO FROM GROUP 10

(10) 1.9509E-01 (11) 2.8653E-02 (12) 6.8020E-04 (13) 6.1895E-05 (14) 4.3856E-06 (15) 9.9227E-08 (16) 5.2114E-08 (17) 2.7787E-08
(18) 4.4991E-09 (19) 3.0497E-09 (20) 2.1221E-10 (21) 0.0 (22) 0.0 (23) 0.0 (24) 0.0 (25) 0.0
(26) 0.0 (27) 0.0 (

PO FROM GROUP 11

(11) 2.3524E-01 (12) 1.8866E-02 (13) 3.1237E-04 (14) 1.3939E-04 (15) 6.3815E-05 (16) 2.2914E-05 (17) 4.1920E-06 (18) 5.1982E-07
(19) 2.1917E-08 (20) 5.3247E-07 (21) 1.4329E-07 (22) 0.0 (23) 0.0 (24) 0.0 (25) 0.0 (26) 0.0
(27) 0.0 (

PO FROM GROUP 12

(12) 3.9518E-01 (13) 3.9338E-02 (14) 0.0 (15) 0.0 (16) 0.0 (17) 0.0 (18) 0.0 (19) 0.0
(20) 0.0 (21) 0.0 (22) 0.0 (23) 0.0 (24) 0.0 (25) 0.0 (26) 0.0 (27) 0.0

PO FROM GROUP 13

(13) 1.5957E-01 (14) 8.7545E-03 (15) 2.3160E-05 (16) 0.0 (17) 0.0 (18) 0.0 (19) 0.0 (20) 0.0
(21) 0.0 (22) 0.0 (23) 0.0 (24) 0.0 (25) 0.0 (26) 0.0 (27) 0.0 (

PO FROM GROUP 14

(14) 2.7287E-01 (15) 3.0921E-02 (16) 3.9833E-05 (17) 1.4054E-05 (18) 5.4283E-06 (19) 7.2971E-07 (20) 0.0 (21) 0.0
(22) 0.0 (23) 0.0 (24) 0.0 (25) 0.0 (26) 0.0 (27) 0.0 (

TABLE XIX (Cont'd)

LISTING OF OUTPUT FROM PROBLEM II


```
                                                    PO FROM GROUP  15
(15) 3.0073E-01 (16) 1.5093E-02 (17) 0.0        (18) 0.0        (19) 4.6890E-06 (20) 1.2985E-06 (21) 5.0864E-07 (22) 1.0404E-07
(23) 9.5350E-09 (24) 0.0        (25) 0.0        (26) 0.0        (27) 0.0        (

                                                    PO FROM GROUP  16
(16) 3.4087E-01 (17) 5.4436E-02 (18) 0.0        (19) 0.0        (20) 0.0        (21) 0.0        (22) 0.0        (23) 0.0
(24) 0.0        (25) 0.0        (26) 0.0        (27) 0.0        (

                                                    PO FROM GROUP  17
(17) 8.1702E-01 (18) 9.5855E-02 (19) 0.0        (20) 0.0        (21) 0.0        (22) 0.0        (23) 0.0        (24) 0.0
(25) 0.0        (26) 0.0        (27) 0.0        (

                                                    PO FROM GROUP  18
(18) 2.5488E-01 (19) 3.1406E-02 (20) 0.0        (21) 0.0        (22) 0.0        (23) 0.0        (24) 0.0        (25) 0.0
(26) 0.0        (27) 0.0        (

                                                    PO FROM GROUP  19
(19) 2.8937E-01 (20) 2.3198E-02 (21) 0.0        (22) 0.0        (23) 0.0        (24) 0.0        (25) 0.0        (26) 0.0
(27) 0.0        (

                                                    PO FROM GROUP  20
(20) 2.7083E-01 (21) 1.8703E-02 (22) 0.0        (23) 0.0        (24) 0.0        (25) 0.0        (26) 0.0        (27) 0.0

                                                    PO FROM GROUP  21
(21) 3.3105E-01 (22) 5.3145E-02 (23) 0.0        (24) 0.0        (25) 0.0        (26) 0.0        (27) 0.0        (

                                                    PO FROM GROUP  22
(22) 3.2654E-01 (23) 5.4727E-03 (24) 0.0        (25) 0.0        (26) 0.0        (27) 0.0        (

                                                    PO FROM GROUP  23
(23) 2.5820E-01 (24) 3.7216E-03 (25) 0.0        (26) 0.0        (27) 0.0        (

                                                    PO FROM GROUP  24
(24) 3.2292E-01 (25) 0.0        (26) 0.0        (27) 0.0        (

                                                    PO FROM GROUP  25
(25) 1.6352E-01 (26) 8.4943E-03 (27) 0.0        (

                                                    PO FROM GROUP  26
(26) 2.9298E-01 (27) 1.1269E-02 (

                                                    PO FROM GROUP  27
(27) 2.9158E-01 (
```

TABLE XIX (Cont'd)

LISTING OF OUTPUT FROM PROBLEM II

P1 SCATTERING MATRIX (THE INTEGERS IN PARENTHESES ARE THE GROUPS SCATTERED TO)

P1 FROM GROUP 1

(1) 5.3434E-02 (2)-1.4883E-04 (3) 0.0 (4) 0.0 (5) 0.0 (6) 0.0 (7) 0.0 (8) 0.0
(9) 0.0 (10) 0.0 (11) 0.0 (12) 0.0 (13) 0.0 (14) 0.0 (15) 0.0 (16) 0.0
(17) 0.0 (18) 0.0 (19) 0.0 (20) 0.0 (21) 0.0 (22) 0.0 (23) 0.0 (24) 0.0
(25) 0.0 (26) 0.0 (27) 0.0 (

P1 FROM GROUP 2

(2) 6.4707E-02 (3)-2.1140E-03 (4) 0.0 (5) 0.0 (6) 0.0 (7) 0.0 (8) 0.0 (9) 0.0
(10) 0.0 (11) 0.0 (12) 0.0 (13) 0.0 (14) 0.0 (15) 0.0 (16) 0.0 (17) 0.0
(18) 0.0 (19) 0.0 (20) 0.0 (21) 0.0 (22) 0.0 (23) 0.0 (24) 0.0 (25) 0.0
(26) 0.0 (27) 0.0 (

P1 FROM GROUP 3

(3) 4.3323E-02 (4)-7.2514E-04 (5) 0.0 (6) 0.0 (7) 0.0 (8) 0.0 (9) 0.0 (10) 0.0
(11) 0.0 (12) 0.0 (13) 0.0 (14) 0.0 (15) 0.0 (16) 0.0 (17) 0.0 (18) 0.0
(19) 0.0 (20) 0.0 (21) 0.0 (22) 0.0 (23) 0.0 (24) 0.0 (25) 0.0 (26) 0.0
(27) 0.0 (

P1 FROM GROUP 4

(4) 4.0011E-02 (5)-5.0431E-03 (6) 0.0 (7) 0.0 (8) 0.0 (9) 0.0 (10) 0.0 (11) 0.0
(12) 0.0 (13) 0.0 (14) 0.0 (15) 0.0 (16) 0.0 (17) 0.0 (18) 0.0 (19) 0.0
(20) 0.0 (21) 0.0 (22) 0.0 (23) 0.0 (24) 0.0 (25) 0.0 (26) 0.0 (27) 0.0

P1 FROM GROUP 5

(5) 5.0143E-02 (6)-7.2174E-03 (7) 0.0 (8) 0.0 (9) 0.0 (10) 0.0 (11) 0.0 (12) 0.0
(13) 0.0 (14) 0.0 (15) 0.0 (16) 0.0 (17) 0.0 (18) 0.0 (19) 0.0 (20) 0.0
(21) 0.0 (22) 0.0 (23) 0.0 (24) 0.0 (25) 0.0 (26) 0.0 (27) 0.0 (

P1 FROM GROUP 6

(6) 5.1811E-02 (7)-6.5925E-04 (8) 0.0 (9) 0.0 (10) 0.0 (11) 0.0 (12) 0.0 (13) 0.0
(14) 0.0 (15) 0.0 (16) 0.0 (17) 0.0 (18) 0.0 (19) 0.0 (20) 0.0 (21) 0.0
(22) 0.0 (23) 0.0 (24) 0.0 (25) 0.0 (26) 0.0 (27) 0.0 (

P1 FROM GROUP 7

(7) 4.8999E-02 (8)-9.7826E-03 (9) 0.0 (10) 0.0 (11) 0.0 (12) 0.0 (13) 0.0 (14) 0.0
(15) 0.0 (16) 0.0 (17) 0.0 (18) 0.0 (19) 0.0 (20) 0.0 (21) 0.0 (22) 0.0
(23) 0.0 (24) 0.0 (25) 0.0 (26) 0.0 (27) 0.0 (

P1 FROM GROUP 8

(8) 2.2679E-02 (9)-5.1410E-03 (10) 0.0 (11) 0.0 (12) 0.0 (13) 0.0 (14) 0.0 (15) 0.0
(16) 0.0 (17) 0.0 (18) 0.0 (19) 0.0 (20) 0.0 (21) 0.0 (22) 0.0 (23) 0.0
(24) 0.0 (25) 0.0 (26) 0.0 (27) 0.0 (

P1 FROM GROUP 9

(9) 3.1944E-02 (10)-5.1976E-03 (11) 0.0 (12) 0.0 (13) 0.0 (14) 0.0 (15) 0.0 (16) 0.0

TABLE XIX (Cont'd)

LISTING OF OUTPUT FROM PROBLEM II

(17) 0.0 (18) 0.0 (19) 0.0 (20) 0.0 (21) 0.0 (22) 0.0 (23) 0.0 (24) 0.0
(25) 0.0 (26) 0.0 (27) 0.0 (

P1 FROM GROUP 10

(10) 1.9081E-02 (11)-8.9501E-03 (12) 0.0 (13) 0.0 (14) 0.0 (15) 0.0 (16) 0.0 (17) 0.0
(18) 0.0 (19) 0.0 (20) 0.0 (21) 0.0 (22) 0.0 (23) 0.0 (24) 0.0 (25) 0.0
(26) 0.0 (27) 0.0 (

P1 FROM GROUP 11

(11) 2.1544E-02 (12)-6.1646E-03 (13) 0.0 (14) 0.0 (15) 0.0 (16) 0.0 (17) 0.0 (18) 0.0
(19) 0.0 (20) 0.0 (21) 0.0 (22) 0.0 (23) 0.0 (24) 0.0 (25) 0.0 (26) 0.0
(27) 0.0 (

P1 FROM GROUP 12

(12) 3.1051E-02 (13)-1.6396E-02 (14) 0.0 (15) 0.0 (16) 0.0 (17) 0.0 (18) 0.0 (19) 0.0
(20) 0.0 (21) 0.0 (22) 0.0 (23) 0.0 (24) 0.0 (25) 0.0 (26) 0.0 (27) 0.0

P1 FROM GROUP 13

(13) 9.9706E-03 (14)-1.8191E-03 (15) 0.0 (16) 0.0 (17) 0.0 (18) 0.0 (19) 0.0 (20) 0.0
(21) 0.0 (22) 0.0 (23) 0.0 (24) 0.0 (25) 0.0 (26) 0.0 (27) 0.0 (

P1 FROM GROUP 14

(14) 5.8149E-03 (15)-9.9896E-03 (16) 0.0 (17) 0.0 (18) 0.0 (19) 0.0 (20) 0.0 (21) 0.0
(22) 0.0 (23) 0.0 (24) 0.0 (25) 0.0 (26) 0.0 (27) 0.0 (

P1 FROM GROUP 15

(15) 1.1236E-02 (16)-5.1640E-03 (17) 0.0 (18) 0.0 (19) 0.0 (20) 0.0 (21) 0.0 (22) 0.0
(23) 0.0 (24) 0.0 (25) 0.0 (26) 0.0 (27) 0.0 (

P1 FROM GROUP 16

(16) 3.0649E-02 (17)-8.5177E-03 (18) 0.0 (19) 0.0 (20) 0.0 (21) 0.0 (22) 0.0 (23) 0.0
(24) 0.0 (25) 0.0 (26) 0.0 (27) 0.0 (

P1 FROM GROUP 17

(17) 4.6549E-02 (18)-3.0085E-02 (19) 0.0 (20) 0.0 (21) 0.0 (22) 0.0 (23) 0.0 (24) 0.0
(25) 0.0 (26) 0.0 (27) 0.0 (

P1 FROM GROUP 18

(18) 1.6036E-02 (19)-9.7875E-03 (20) 0.0 (21) 0.0 (22) 0.0 (23) 0.0 (24) 0.0 (25) 0.0
(26) 0.0 (27) 0.0 (

P1 FROM GROUP 19

(19) 5.9580E-03 (20)-1.0654E-02 (21) 0.0 (22) 0.0 (23) 0.0 (24) 0.0 (25) 0.0 (26) 0.0
(27) 0.0 (

TABLE XIX (Cont'd)

LISTING OF OUTPUT FROM PROBLEM II


```
                                                    P1 FROM GROUP  20
(20) 1.4569E-02 (21)-8.9557E-03 (22) 0.0        (23) 0.0        (24) 0.0        (25) 0.0        (26) 0.0        (27) 0.0

                                                    P1 FROM GROUP  21
(21)-2.4499E-03 (22)-8.6467E-03 (23) 0.0        (24) 0.0        (25) 0.0        (26) 0.0        (27) 0.0        (

                                                    P1 FROM GROUP  22
(22) 2.2840E-02 (23) 2.1387E-04 (24) 0.0        (25) 0.0        (26) 0.0        (27) 0.0        (

                                                    P1 FROM GROUP  23
(23) 6.9270E-03 (24)-3.3141E-03 (25) 0.0        (26) 0.0        (27) 0.0        (

                                                    P1 FROM GROUP  24
(24)-1.1330E-03 (25) 0.0        (26) 0.0        (27) 0.0        (

                                                    P1 FROM GROUP  25
(25) 1.0295E-02 (26) 1.5014E-03 (27) 0.0        (

                                                    P1 FROM GROUP  26
(26) 1.8196E-02 (27)-7.8691E-03 (

                                                    P1 FROM GROUP  27
(27)-4.7446E-02 (
```

PO FRACTIONAL ERROR MATRIX (THE INTEGERS IN PARENTHESES ARE THE GROUPS SCATTERED TO)

```
                                                    PO ERRORS FROM GROUP   1
( 1) 1.4393E-01 ( 2) 7.9901E-02 ( 3) 1.6850E-02 ( 4) 1.6632E-02 ( 5) 2.0019E-02 ( 6) 2.4763E-02 ( 7) 2.7644E-02 ( 8) 2.9191E-02
( 9) 2.9967E-02 (10) 3.0435E-02 (11) 3.0707E-02 (12) 3.0869E-02 (13) 3.1112E-02 (14) 4.0777E-02 (15) 5.0911E-02 (16) 0.0
(17) 0.0        (18) 0.0        (19) 0.0        (20) 0.0        (21) 0.0        (22) 0.0        (23) 0.0        (24) 0.0
(25) 0.0        (26) 0.0        (27) 7.8410E-02 (

                                                    PO ERRORS FROM GROUP   2
( 2) 6.8376E-02 ( 3) 6.8769E-02 ( 4) 5.8975E-03 ( 5) 1.3057E-02 ( 6) 2.0089E-02 ( 7) 2.8231E-02 ( 8) 2.8024E-02 ( 9) 2.9902E-02
(10) 3.0326E-02 (11) 3.0559E-02 (12) 3.0692E-02 (13) 3.0775E-02 (14) 3.1176E-02 (15) 3.6333E-02 (16) 0.0        (17) 0.0
(18) 0.0        (19) 0.0        (20) 0.0        (21) 0.0        (22) 0.0        (23) 0.0        (24) 0.0        (25) 0.0
(26) 0.0        (27) 0.0        (

                                                    PO ERRORS FROM GROUP   3
( 3) 7.9248E-02 ( 4) 6.6000E-02 ( 5) 2.1342E-02 ( 6) 2.0114E-02 ( 7) 2.2239E-02 ( 8) 2.7071E-02 ( 9) 3.0572E-02 (10) 2.9623E-02
(11) 2.7706E-02 (12) 2.7734E-02 (13) 2.7746E-02 (14) 2.7748E-02 (15) 2.7766E-02 (16) 5.5391E-02 (17) 0.0        (18) 0.0
(19) 0.0        (20) 0.0        (21) 0.0        (22) 0.0        (23) 0.0        (24) 0.0        (25) 0.0        (26) 0.0
```

TABLE XIX (Cont'd)

LISTING OF OUTPUT FROM PROBLEM II

(27) 0.0 (

PO ERRORS FROM GROUP 4

(4) 8.7898E-02 (5) 8.0755E-02 (6) 3.2940E-02 (7) 4.0833E-02 (8) 5.4258E-02 (9) 5.4841E-02 (10) 5.3159E-02 (11) 7.6084E-02
(12) 8.7270E-02 (13) 1.0227E-01 (14) 1.3596E-01 (15) 4.7724E-02 (16) 4.7913E-02 (17) 0.0 (18) 0.0 (19) 0.0
(20) 0.0 (21) 0.0 (22) 0.0 (23) 0.0 (24) 0.0 (25) 0.0 (26) 0.0 (27) 0.0

PO ERRORS FROM GROUP 5

(5) 6.6650E-02 (6) 1.2854E-01 (7) 3.6748E-02 (8) 4.1463E-02 (9) 5.7296E-02 (10) 1.0027E-01 (11) 1.1468E-01 (12) 1.5532E-01
(13) 2.9685E-01 (14) 1.4822E-01 (15) 2.0429E-01 (16) 8.4750E-02 (17) 0.0 (18) 0.0 (19) 0.0 (20) 0.0
(21) 0.0 (22) 0.0 (23) 0.0 (24) 0.0 (25) 0.0 (26) 0.0 (27) 0.0 (

PO ERRORS FROM GROUP 6

(6) 6.2612E-02 (7) 1.3801E-01 (8) 5.3869E-02 (9) 5.2163E-02 (10) 5.8453E-02 (11) 9.0461E-02 (12) 1.5348E-01 (13) 1.9646E-01
(14) 2.5815E-01 (15) 3.1369E-01 (16) 4.5666E-01 (17) 4.9059E-01 (18) 0.0 (19) 0.0 (20) 0.0 (21) 0.0
(22) 0.0 (23) 0.0 (24) 0.0 (25) 0.0 (26) 0.0 (27) 0.0 (

PO ERRORS FROM GROUP 7

(7) 5.3548E-02 (8) 1.3072E-01 (9) 7.7214E-02 (10) 5.5828E-02 (11) 8.5715E-02 (12) 6.9326E-02 (13) 1.0013E-01 (14) 1.4201E-01
(15) 1.8271E-01 (16) 2.3836E-01 (17) 2.3164E-01 (18) 3.6416E-01 (19) 0.0 (20) 0.0 (21) 0.0 (22) 0.0
(23) 0.0 (24) 0.0 (25) 0.0 (26) 0.0 (27) 0.0 (

PO ERRORS FROM GROUP 8

(8) 5.7327E-02 (9) 1.2830E-01 (10) 7.6918E-02 (11) 9.8655E-02 (12) 2.5942E-01 (13) 3.6338E-01 (14) 2.2824E-01 (15) 2.6442E-01
(16) 4.1718E-01 (17) 3.2492E-01 (18) 4.3209E-01 (19) 0.0 (20) 0.0 (21) 0.0 (22) 0.0 (23) 0.0
(24) 0.0 (25) 0.0 (26) 0.0 (27) 0.0 (

PO ERRORS FROM GROUP 9

(9) 6.2605E-02 (10) 2.4370E-01 (11) 2.7891E-01 (12) 1.7558E-01 (13) 1.3837E-01 (14) 2.1380E-01 (15) 1.9864E-01 (16) 2.2554E-01
(17) 2.6129E-01 (18) 4.1368E-01 (19) 0.0 (20) 0.0 (21) 0.0 (22) 0.0 (23) 0.0 (24) 0.0
(25) 0.0 (26) 0.0 (27) 0.0 (

PO ERRORS FROM GROUP 10

(10) 5.7984E-02 (11) 1.2425E-01 (12) 6.9688E-02 (13) 2.2954E-01 (14) 1.3529E-01 (15) 2.5729E-01 (16) 2.3583E-01 (17) 2.1370E-01
(18) 4.5918E-01 (19) 3.0525E-01 (20) 7.2540E-01 (21) 0.0 (22) 0.0 (23) 0.0 (24) 0.0 (25) 0.0
(26) 0.0 (27) 0.0 (

PO ERRORS FROM GROUP 11

(11) 7.6159E-02 (12) 2.3535E-01 (13) 9.5321E-02 (14) 1.5597E-01 (15) 1.2165E-01 (16) 2.1892E-01 (17) 2.8954E-01 (18) 3.1789E-01
(19) 6.7869E-01 (20) 3.1289E-01 (21) 4.3310E-01 (22) 0.0 (23) 0.0 (24) 0.0 (25) 0.0 (26) 0.0
(27) 0.0 (

PO ERRORS FROM GROUP 12

(12) 5.0854E-02 (13) 1.4954E-01 (14) 0.0 (15) 0.0 (16) 0.0 (17) 0.0 (18) 0.0 (19) 0.0
(20) 0.0 (21) 0.0 (22) 0.0 (23) 0.0 (24) 0.0 (25) 0.0 (26) 0.0 (27) 0.0

TABLE XIX (Cont'd)

LISTING OF OUTPUT FROM PROBLEM II


```
                                                                  PO ERRORS FROM GROUP  13
(13) 1.0511E-01 (14) 4.9517E-01 (15) 2.9292E-01 (16) 0.0        (17) 0.0        (18) 0.0        (19) 0.0        (20) 0.0
(21) 0.0        (22) 0.0        (23) 0.0        (24) 0.0        (25) 0.0        (26) 0.0        (27) 0.0        (

                                                                  PO ERRORS FROM GROUP  14
(14) 7.5966E-02 (15) 3.0861E-01 (16) 1.0080E-01 (17) 1.3442E-01 (18) 2.1557E-01 (19) 6.4082E-01 (20) 0.0        (21) 0.0
(22) 0.0        (23) 0.0        (24) 0.0        (25) 0.0        (26) 0.0        (27) 0.0        (

                                                                  PO ERRORS FROM GROUP  15
(15) 7.3012E-02 (16) 2.6284E-01 (17) 0.0        (18) 0.0        (19) 1.7282E-01 (20) 1.7894E-01 (21) 3.2361E-01 (22) 5.0250E-01
(23) 6.2114E-01 (24) 0.0        (25) 0.0        (26) 0.0        (27) 0.0        (

                                                                  PO ERRORS FROM GROUP  16
(16) 9.4868E-02 (17) 2.8103E-01 (18) 0.0        (19) 0.0        (20) 0.0        (21) 0.0        (22) 0.0        (23) 0.0
(24) 0.0        (25) 0.0        (26) 0.0        (27) 0.0        (

                                                                  PO ERRORS FROM GROUP  17
(17) 9.0646E-02 (18) 1.3853E-01 (19) 0.0        (20) 0.0        (21) 0.0        (22) 0.0        (23) 0.0        (24) 0.0
(25) 0.0        (26) 0.0        (27) 0.0        (

                                                                  PO ERRORS FROM GROUP  18
(18) 8.8236E-02 (19) 1.9442E-01 (20) 0.0        (21) 0.0        (22) 0.0        (23) 0.0        (24) 0.0        (25) 0.0
(26) 0.0        (27) 0.0        (

                                                                  PO ERRORS FROM GROUP  19
(19) 9.4261E-02 (20) 2.7422E-01 (21) 0.0        (22) 0.0        (23) 0.0        (24) 0.0        (25) 0.0        (26) 0.0
(27) 0.0        (

                                                                  PO ERRORS FROM GROUP  20
(20) 1.0076E-01 (21) 2.2811E-01 (22) 0.0        (23) 0.0        (24) 0.0        (25) 0.0        (26) 0.0        (27) 0.0

                                                                  PO ERRORS FROM GROUP  21
(21) 1.0593E-01 (22) 5.1362E-01 (23) 0.0        (24) 0.0        (25) 0.0        (26) 0.0        (27) 0.0        (

                                                                  PO ERRORS FROM GROUP  22
(22) 1.4701E-01 (23) 8.0032E-01 (24) 0.0        (25) 0.0        (26) 0.0        (27) 0.0        (

                                                                  PO ERRORS FROM GROUP  23
(23) 1.3437E-01 (24) 4.6893E-01 (25) 0.0        (26) 0.0        (27) 0.0        (

                                                                  PO ERRORS FROM GROUP  24
(24) 1.8911E-01 (25) 0.0        (26) 0.0        (27) 0.0        (

                                                                  PO ERRORS FROM GROUP  25
```

TABLE XIX (Cont'd)

LISTING OF OUTPUT FROM PROBLEM II

(25) 1.6598E-01 (26) 5.7669E-01 (27) 0.0 (

P0 ERRORS FROM GROUP 26

(26) 2.0679E-01 (27) 4.8903E-01 (

P0 ERRORS FROM GROUP 27

(27) 1.1500E-01 (

P1 FRACTIONAL ERROR MATRIX (THE INTEGERS IN PARENTHESES ARE THE GROUPS SCATTERED TO)

P1 ERRORS FROM GROUP 1

(1) 1.4358E-01 (2) 1.8247E 00 (3) 0.0 (4) 0.0 (5) 0.0 (6) 0.0 (7) 0.0 (8) 0.0
(9) 0.0 (10) 0.0 (11) 0.0 (12) 0.0 (13) 0.0 (14) 0.0 (15) 0.0 (16) 0.0
(17) 0.0 (18) 0.0 (19) 0.0 (20) 0.0 (21) 0.0 (22) 0.0 (23) 0.0 (24) 0.0
(25) 0.0 (26) 0.0 (27) 0.0 (

P1 ERRORS FROM GROUP 2

(2) 6.9239E-02 (3) 2.9630E-01 (4) 0.0 (5) 0.0 (6) 0.0 (7) 0.0 (8) 0.0 (9) 0.0
(10) 0.0 (11) 0.0 (12) 0.0 (13) 0.0 (14) 0.0 (15) 0.0 (16) 0.0 (17) 0.0
(18) 0.0 (19) 0.0 (20) 0.0 (21) 0.0 (22) 0.0 (23) 0.0 (24) 0.0 (25) 0.0
(26) 0.0 (27) 0.0 (

P1 ERRORS FROM GROUP 3

(3) 8.4613E-02 (4) 5.8046E-01 (5) 0.0 (6) 0.0 (7) 0.0 (8) 0.0 (9) 0.0 (10) 0.0
(11) 0.0 (12) 0.0 (13) 0.0 (14) 0.0 (15) 0.0 (16) 0.0 (17) 0.0 (18) 0.0
(19) 0.0 (20) 0.0 (21) 0.0 (22) 0.0 (23) 0.0 (24) 0.0 (25) 0.0 (26) 0.0
(27) 0.0 (

P1 ERRORS FROM GROUP 4

(4) 1.0978E-01 (5) 2.2438E-01 (6) 0.0 (7) 0.0 (8) 0.0 (9) 0.0 (10) 0.0 (11) 0.0
(12) 0.0 (13) 0.0 (14) 0.0 (15) 0.0 (16) 0.0 (17) 0.0 (18) 0.0 (19) 0.0
(20) 0.0 (21) 0.0 (22) 0.0 (23) 0.0 (24) 0.0 (25) 0.0 (26) 0.0 (27) 0.0

P1 ERRORS FROM GROUP 5

(5) 9.7111E-02 (6) 1.7680E-01 (7) 0.0 (8) 0.0 (9) 0.0 (10) 0.0 (11) 0.0 (12) 0.0
(13) 0.0 (14) 0.0 (15) 0.0 (16) 0.0 (17) 0.0 (18) 0.0 (19) 0.0 (20) 0.0
(21) 0.0 (22) 0.0 (23) 0.0 (24) 0.0 (25) 0.0 (26) 0.0 (27) 0.0 (

P1 ERRORS FROM GROUP 6

(6) 6.5025E-02 (7) 2.2156E 00 (8) 0.0 (9) 0.0 (10) 0.0 (11) 0.0 (12) 0.0 (13) 0.0
(14) 0.0 (15) 0.0 (16) 0.0 (17) 0.0 (18) 0.0 (19) 0.0 (20) 0.0 (21) 0.0
(22) 0.0 (23) 0.0 (24) 0.0 (25) 0.0 (26) 0.0 (27) 0.0 (

TABLE XIX (Cont'd)

LISTING OF OUTPUT FROM PROBLEM II

(7) 6.8553E-02 (8) 1.3242E-01 (9) 0.0
(10) 0.0 (11) 0.0 (12) 0.0 (13) 0.0 (14) 0.0
(15) 0.0 (16) 0.0 (17) 0.0 (18) 0.0 (19) 0.0
(20) 0.0 (21) 0.0 (22) 0.0 (23) 0.0 (24) 0.0
(25) 0.0 (26) 0.0 (27) 0.0

P1 ERRORS FROM GROUP 7

(8) 1.4090E-01 (9) 1.8265E-01 (10) 0.0
(11) 0.0 (12) 0.0 (13) 0.0 (14) 0.0 (15) 0.0
(16) 0.0 (17) 0.0 (18) 0.0 (19) 0.0 (20) 0.0
(21) 0.0 (22) 0.0 (23) 0.0 (24) 0.0 (25) 0.0
(26) 0.0 (27) 0.0

P1 ERRORS FROM GROUP 8

(9) 8.9065E-02 (10) 3.3767E-01 (11) 0.0
(12) 0.0 (13) 0.0 (14) 0.0 (15) 0.0 (16) 0.0
(17) 0.0 (18) 0.0 (19) 0.0 (20) 0.0 (21) 0.0
(22) 0.0 (23) 0.0 (24) 0.0 (25) 0.0 (26) 0.0
(27) 0.0

P1 ERRORS FROM GROUP 9

(10) 1.6217E-01 (11) 1.1811E-01 (12) 0.0
(13) 0.0 (14) 0.0 (15) 0.0 (16) 0.0 (17) 0.0
(18) 0.0 (19) 0.0 (20) 0.0 (21) 0.0 (22) 0.0
(23) 0.0 (24) 0.0 (25) 0.0 (26) 0.0 (27) 0.0

P1 ERRORS FROM GROUP 10

(11) 1.9967E-01 (12) 2.2770E-01 (13) 0.0
(14) 0.0 (15) 0.0 (16) 0.0 (17) 0.0 (18) 0.0
(19) 0.0 (20) 0.0 (21) 0.0 (22) 0.0 (23) 0.0
(24) 0.0 (25) 0.0 (26) 0.0 (27) 0.0

P1 ERRORS FROM GROUP 11

(12) 1.5301E-01 (13) 1.4576E-01 (14) 0.0
(15) 0.0 (16) 0.0 (17) 0.0 (18) 0.0 (19) 0.0
(20) 0.0 (21) 0.0 (22) 0.0 (23) 0.0 (24) 0.0
(25) 0.0 (26) 0.0 (27) 0.0

P1 ERRORS FROM GROUP 12

(13) 3.6419E-01 (14) 6.4633E-01 (15) 0.0
(16) 0.0 (17) 0.0 (18) 0.0 (19) 0.0 (20) 0.0
(21) 0.0 (22) 0.0 (23) 0.0 (24) 0.0 (25) 0.0
(26) 0.0 (27) 0.0

P1 ERRORS FROM GROUP 13

(14) 7.5659E-01 (15) 3.5695E-01 (16) 0.0
(17) 0.0 (18) 0.0 (19) 0.0 (20) 0.0 (21) 0.0
(22) 0.0 (23) 0.0 (24) 0.0 (25) 0.0 (26) 0.0
(27) 0.0

P1 ERRORS FROM GROUP 14

(15) 4.6297E-01 (16) 2.8267E-01 (17) 0.0
(18) 0.0 (19) 0.0 (20) 0.0 (21) 0.0 (22) 0.0
(23) 0.0 (24) 0.0 (25) 0.0 (26) 0.0 (27) 0.0

P1 ERRORS FROM GROUP 15

(16) 2.3113E-01 (17) 3.3547E-01 (18) 0.0
(19) 0.0 (20) 0.0 (21) 0.0 (22) 0.0 (23) 0.0
(24) 0.0 (25) 0.0 (26) 0.0 (27) 0.0

P1 ERRORS FROM GROUP 16

P1 ERRORS FROM GROUP 17

TABLE XIX (Cont'd)

LISTING OF OUTPUT FROM PROBLEM II


```
(17) 3.5798E-01 (18) 1.4983E-01 (19) 0.0        (20) 0.0        (21) 0.0        (22) 0.0        (23) 0.0        (24) 0.0
(25) 0.0        (26) 0.0        (27) 0.0        (

                                                P1 ERRORS FROM GROUP  18
(18) 2.9652E-01 (19) 2.4505E-01 (20) 0.0        (21) 0.0        (22) 0.0        (23) 0.0        (24) 0.0        (25) 0.0
(26) 0.0        (27) 0.0        (

                                                P1 ERRORS FROM GROUP  19
(19) 6.3515E-01 (20) 2.4610E-01 (21) 0.0        (22) 0.0        (23) 0.0        (24) 0.0        (25) 0.0        (26) 0.0
(27) 0.0        (

                                                P1 ERRORS FROM GROUP  20
(20) 3.4610E-01 (21) 2.2148E-01 (22) 0.0        (23) 0.0        (24) 0.0        (25) 0.0        (26) 0.0        (27) 0.0

                                                P1 ERRORS FROM GROUP  21
(21) 3.2869E 00 (22) 4.4703E-01 (23) 0.0        (24) 0.0        (25) 0.0        (26) 0.0        (27) 0.0        (

                                                P1 ERRORS FROM GROUP  22
(22) 3.2740E-01 (23) 4.3441E 00 (24) 0.0        (25) 0.0        (26) 0.0        (27) 0.0        (

                                                P1 ERRORS FROM GROUP  23
(23) 5.6871E-01 (24) 4.7079E-01 (25) 0.0        (26) 0.0        (27) 0.0        (

                                                P1 ERRORS FROM GROUP  24
(24) 1.0427E 01 (25) 0.0        (26) 0.0        (27) 0.0        (

                                                P1 ERRORS FROM GROUP  25
(25) 4.6397E-01 (26) 5.7669E-01 (27) 0.0        (

                                                P1 ERRORS FROM GROUP  26
(26) 4.9074E-01 (27) 4.9015E-01 (

                                                P1 ERRORS FROM GROUP  27
(27) 1.9464E-01 (
```

*** END OF RAFFLE OUTPUT ***

VII. RAFFLE CROSS SECTION DATA

The use of cross section data by RAFFLE is discussed in Section VII.1, the formal rules for the preparation of the cross section in Section VII.2, and the procedures for processing ENDF data into the formats required by RAFFLE in Section VII.3. RAFFLE can optionally use two cross section libraries. The first of these is always required, and it is designated the fast library even though it can contain data for one thermal group. The second library, designated thermal, is optional and contains data for multiple thermal groups. RAFFLE reads from the libraries into main storage the data for only those isotopes requested for a problem.

While a problem may require a large amount of cross section data, often only a few changes are required from problem to problem. Master cross section libraries for RAFFLE are kept in files that can be readily copied with insertions, deletions, and changes to provide user's libraries. In addition, temporary changes that are in effect for only one problem can be read in on cards as described in Section VII.4.

1. THE USE OF CROSS SECTION DATA BY RAFFLE

Four major types of cross section data can be provided for each isotope in the RAFFLE fast cross section library. The first type consists of the broad group cross sections and is used for every isotope. The broad group data must be consistent with the group energy structure that is input in the integer data of Table V as data type GV. A maximum of 100 groups, including both fast and thermal groups, can be used. For each isotope, the complete set of data for a broad group consists of:

(1) The microscopic absorption cross section including the n-2n contribution

(2) Nu times the microscopic fission section

(3) The microscopic elastic scattering cross section

(4) The microscopic inelastic scattering cross section

(5) The microscopic n,2n cross section

(6) The data specifying the histogram that describes the angular distribution of the scattered neutrons

(7) The microscopic P_1 elastic scattering cross section.

Any of these that are not appropriate may be omitted. For instance (2) is included only for fissionable isotopes, and then values need be entered only for groups having a nonzero fission cross section.

RAFFLE contains an option to calculate the total elastic scattering cross sections from the histograms rather than entering them separately. Alternatively, an option permits calculation of the angular scattering distribution from the total and P_1 elastic cross sections. This option may be selected independently for each isotope on a groupwise basis.

When the "histogram" option is used, RAFFLE requires the data needed to approximate the spectrum averaged groupwise angular scattering distribution, $f_g(\mu)$, by a straight line and a number of histograms as shown in Figure 40. Here μ is the scattered cosine in the center of mass system. This option permits treatment of elastic scattering with any degree of anisotropic scattering.

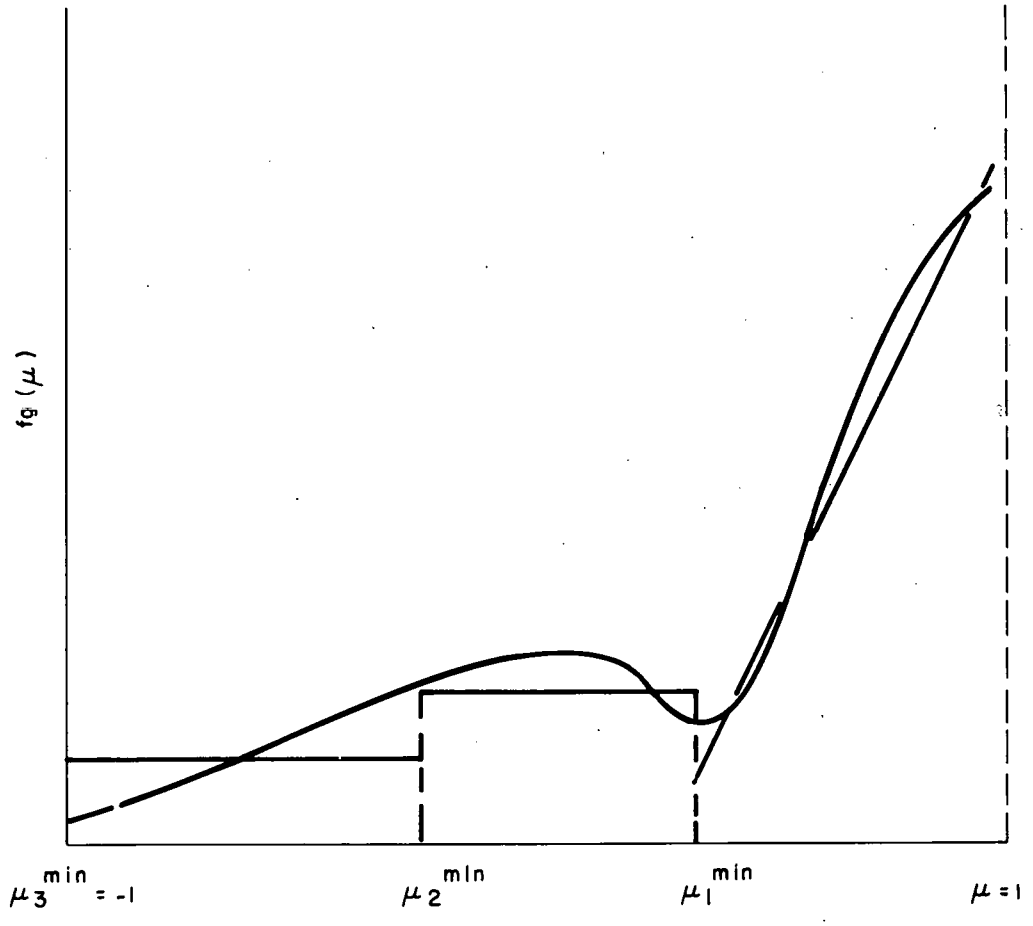


Fig. 40 Histogram fit to angular scattering distribution.

The second major data type uses a fine group structure to provide a more detailed description of a scattering event in the energy range where nonelastic scattering occurs. These fine group data are optional and are not used to determine path lengths, but only the mode of scatter and the secondary energy for nonelastic scatter. Pointwise values of the elastic, n-2n, the inelastic at each discrete level, and the evaporation model cross sections are read in at each fine group break point, and linearity is assumed between points. For scatter off an individual level, a definite energy loss is assigned. In the region where the levels are not resolved, the evaporation model is used to determine the scattered neutron energy. Figure 41 shows the fit to an inelastic scheme with two discrete levels up to a cutoff above which an evaporation model is assumed.

The third major type of cross section data consists of the resonance parameters and the auxiliary data needed to calculate the resonance cross sections from the parameters. This type is optional by isotope.

The fourth type, which is optional by isotope, consists of pointwise data. For each isotope pointwise data for the absorption, elastic scattering, and nu-fission, cross sections may be input over an energy range specified for that isotope. One of five available interpolation schemes is used to determine the cross sections at the energy of a collision event, and these interpolated cross sections are added to the appropriate broad group cross sections. The energy range can be broken into not more than five interpolation regions and any one of the available interpolation schemes used over a region.

The fast library is limited to one thermal group, does not allow upscattering, and contains microscopic cross sections. The thermal library can have the data entered as microscopic cross sections by isotope or as macroscopic cross sections by material. The energy ranges of the two libraries can overlap, and in this overlapping range the data from the thermal library replaces that from the fast library. When a thermal library is used, the change of energy for a scattering event in the thermal range is determined by a transfer matrix, and upscattering is permitted.

Before proceeding with the Monte Carlo calculations, RAFFLE calculates the broad group macroscopic cross sections for each material in the problem. A somewhat simplified version of how RAFFLE uses cross section data in evaluating a collision event is shown in Figure 42. When a collision occurs, it is characterized by the energy of the incoming neutron and by the material in which the collision occurs, in addition to its spatial location. If the material contains no isotopes with a resonance or pointwise contribution at energy E, the

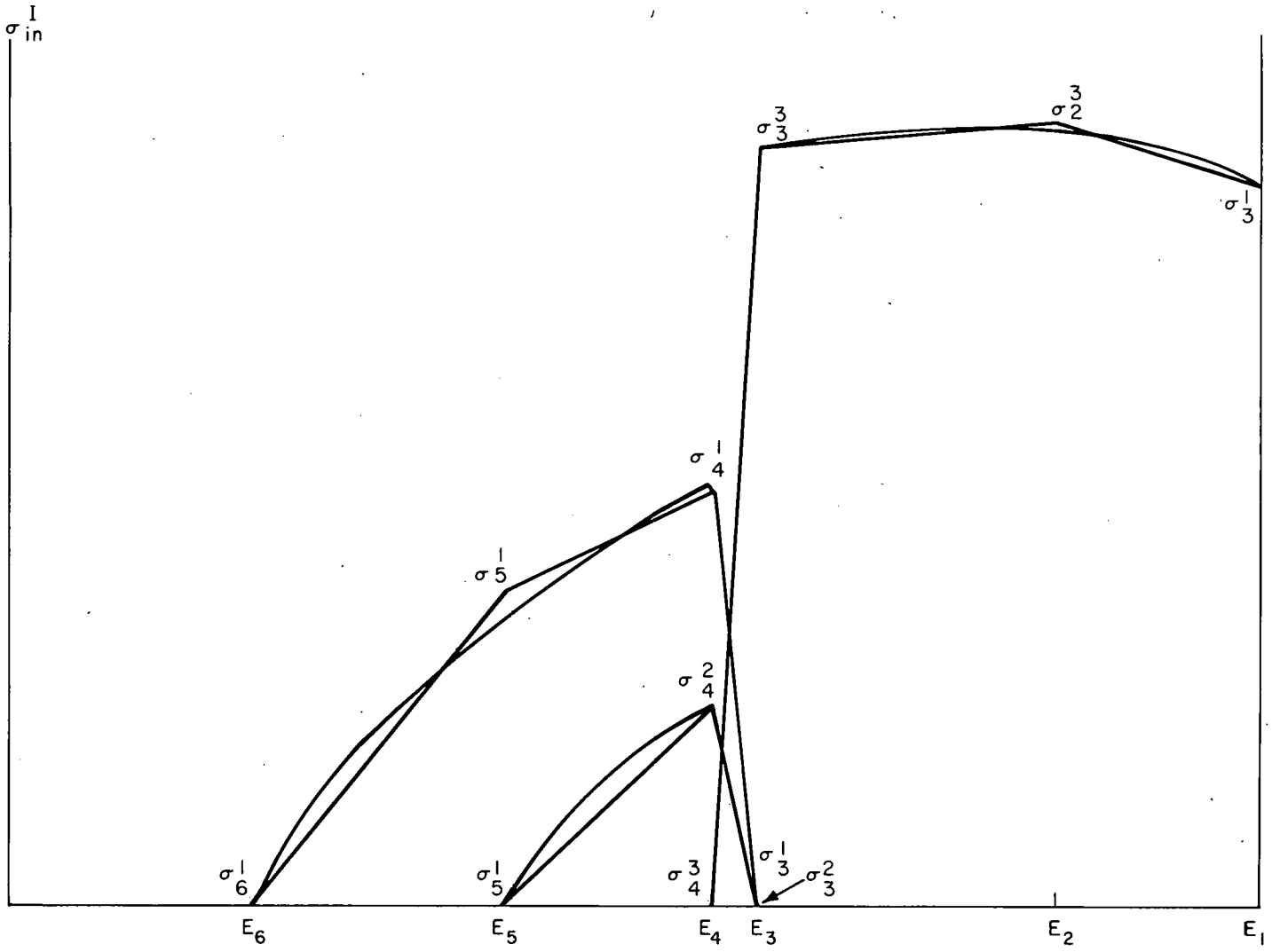


Fig. 41 Inelastic level fitting scheme.

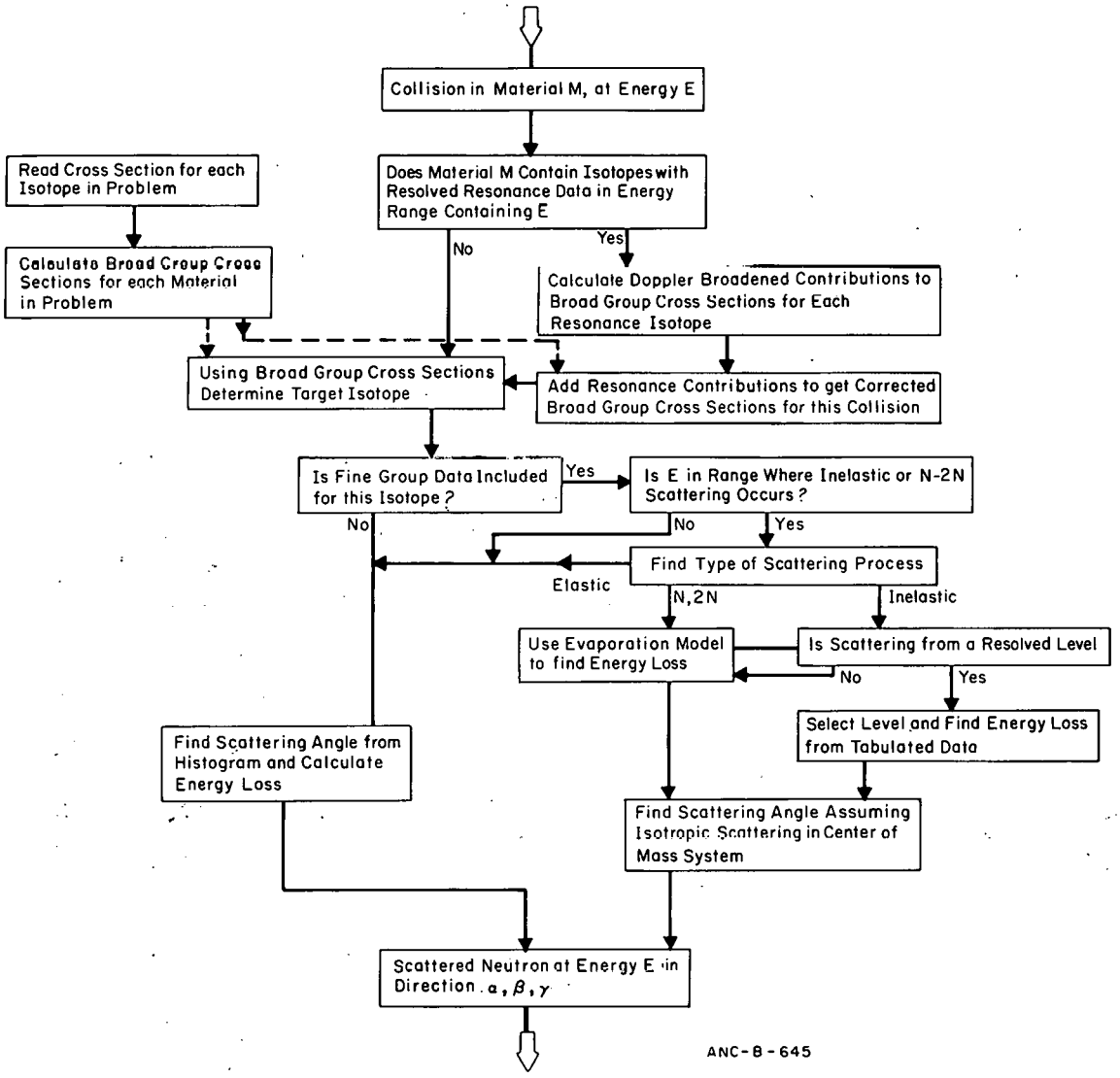


Fig. 42 Use of cross section data by RAFFLE.

broad group cross sections are used without modification. If the material does contain one or more such isotopes, the broad group cross sections must be modified. For an isotope with resolved resonance data in the applicable energy range, the resonance nearest in energy to E is found along with a specified number of the nearest adjacent resonances. The contribution to the Doppler broadened capture, fission, and scattering cross sections for a resonance at energy E_o is given for a neutron at energy, E, by

$$\sigma_C(E) = \frac{4\pi\hbar^2}{2m} \frac{g}{\sqrt{E_o E}} \left(\frac{A+1}{A}\right) \frac{\Gamma_n \Gamma_\gamma}{\Gamma^2} \psi(X,\theta)$$

$$\sigma_F(E) = \sigma_C(E) \frac{\Gamma_F}{\Gamma_\gamma}$$

$$\sigma_S(E) = \frac{4\pi\hbar^2}{2m} \frac{g}{E_o} \left(\frac{A+1}{A}\right) \frac{\Gamma_n^2}{\Gamma^2} \psi(X,\theta) + 2g \sqrt{\frac{4\pi\hbar^2}{2m} \frac{\sigma_p}{E_o} \frac{\Gamma_n}{\Gamma}} \chi(X,\theta) + \sigma_p$$

where

$$\Gamma = \Gamma_n + \Gamma_\gamma + \Gamma_F$$

$$g = \frac{1}{2} \left(\frac{2J+1}{2I+1}\right) \qquad J = I \pm \frac{1}{2} \quad .$$

The Doppler line functions $\psi(X,\Theta)$ and $\chi(X,\Theta)$ are given by

$$\psi(X,\theta) = \frac{1}{2\sqrt{\pi\theta}} \int_{-\infty}^{\infty} \frac{e^{-(X-Y)^2/4\theta}}{1+Y^2} dY$$

$$\chi(X,\theta) = \frac{1}{2\sqrt{\pi\theta}} \int_{-\infty}^{\infty} \frac{Ye^{-(X-Y)^2/4\theta}}{1+Y^2} dY$$

$$\theta = \frac{4EKT}{AT^2}$$

$$X = \frac{E-E_o}{\Gamma/2} \quad .$$

K is Boltzmann's constant and the temperature T is input in degrees Kelvin. This process is repeated for each resonant isotope in the material. The results are then used to modify the broad group cross sections so that they include the contributions from the appropriate resonances. This process is carried out every time a collision involving resonances occurs.

Using the broad group cross sections, modified by the contributions from resonance reactions and the pointwise cross sections if necessary, a random number selection is made to determine the isotope with which the neutron collides. The program then determines whether the cross section data for this isotope contains fine group constants in the appropriate energy range. If not, the collision is assumed to be elastic. If so, an analog determination of the type of collision, elastic or inelastic, is made by the procedure described in Section II.2. When an inelastic collision occurs, an analog procedure is used to select the level from which the scattering occurs or to specify use of the evaporation model, again as described in Section II.2. When this choice has been made, the energy loss can be found from the input data or calculated if the evaporation model is used. The direction of the scattered neutron is found assuming isotropic scattering in the center of mass system. If the scattering is elastic, the direction of the scattered neutron is found from the histogram for the proper isotope and energy group. The angle of scattering having been found, the energy loss is then calculated by the program.

2. PREPARATION OF CROSS SECTION DATA

RAFFLE searches through the fast cross section library and reads into the core only the data for those isotopes requested by the problem. For each isotope in this library a title card, an integer data set, and a floating data set are required, in that order. These data may be updated at execution time by additional input cards as described in Section VII.4. The data must be arranged in order of increasing isotope identification number. The formats for the integer and for the floating point data are the same as those described in Sections V.2.2 and V.2.3. The description of the title card is given in Table XXIV; the descriptions of the integer and floating point data for an isotope in the fast library are given in Tables XXV and XXVI.

TABLE XXIV

PREPARATION OF TITLE CARD FOR CROSS SECTION DATA
FOR EACH ISOTOPE OR MATERIAL

Word	Card Columns	Description
MATLNØ	6-8	Identification Number
TITLE	9-80	Any Alphanumeric Information

TABLE XXV

INTEGER DATA FOR RAFFLE FAST CROSS SECTION LIBRARY

Index 1 Card Cols. 2-3 Format I2	Index 2 Card Cols. 4-5 Format I2	Index 3 Card Cols. 6-8 Format I3	Index 4 Card Cols. 9-10 Format I2	Mnemonic Name of Data	Notes on Application of Data
1		J		JELAS(J)	Elastic scattering cross section flag 0-The elastic scattering cross section for group J, SIGPO(J), is read in 1-SIGPO(J) is set equal to 2π times the area under the histogram curve 2-SIGPO(J) and SIGPI(J) as read in are used to determine the histogram for group J
2		J		NHIS(J)	The number of lower μ cutoff points determining the histogram for group J
14		1		JGRP	The number of fine groups
14		2		LEVEL	The number of inelastic levels
14		3		IEVAPT	Nuclear temperature for evaporation model 0-Computed as $C\sqrt{E}$ 1-Read in as a function of E
15		1		NER	Flag for pointwise data 0-No pointwise range 1-Pointwise data input (Data with Index 1=16)

TABLE XXV (Cont'd)

INTEGER DATA FOR RAFFLE FAST CROSS SECTION LIBRARY

Index 1 Card Cols. 2-3 Format I2	Index 2 Card Cols. 4-5 Format I2	Index 3 Card Cols. 6-8 Format I3	Index 4 Card Cols. 9-10 Format I2	Mnemonic Name of Data	Notes on Application of Data
15		2		IR	Overlap flag 0-Pointwise and resonance parameter ranges do not overlap in energy 1-Ranges overlap
15		3		NEIGH	Number of neighboring resonances used in resolved calculation. In addition to the nearest resonance, NEIGH upper and NEIGH lower resonances contribute to the cross section at each energy point
15		4		LIS	Resolved scattering cross section 0-Calculate from resonance parameters 1-Set to 0.0
15		5		LAG	Resonance Calculation 0-No effect 1-Store precomputed values for use in resonance calculation (Default value is LAG=1)
15		6		NRS	Number of resolved resonances
15		7		LGW	Statistical factor 0-A constant statistical factor is used 1-A value of the statistical factor is input for each resonance

TABLE XXV (Cont'd)

INTEGER DATA FOR RAFFLE FAST CROSS SECTION LIBRARY

Index 1 Card Cols. 2-3 Format I2	Index 2 Card Cols. 4-5 Format I2	Index 3 Card Cols. 6-8 Format I3	Index 4 Card Cols. 9-10 Format I2	Mnemonic Name of Data	Notes on Application of Data
15		8		LCW	Capture width 0-A constant value is used 1-Input by resonance
15		9		LFW	Fissionable isotope flag 0-No fission 1-Input fission width by resonance
16		1		LEW	Energy spacing for pointwise data 0-Equal energy spacing (read in endpoints of pointwise range 1-Tabulated energy spacing (Read in energy points)
16		3		LAW	Type of pointwise data for absorption cross sections 0-No pointwise absorption cross section 1-Tabulated absorption cross section 2-σ_a=CA 3-σ_a=CA/$\sqrt{E}$
16		4		LSW	Type of pointwise data for scattering cross sections 0-No pointwise scattering cross sections 1-Tabulated scattering cross sections 2-σ_s=CS

TABLE XXV (Cont'd)

INTEGER DATA FOR RAFFLE FAST CROSS SECTION LIBRARY

Index 1 Card Cols. 2-3 Format I2	Index 2 Card Cols. 4-5 Format I2	Index 3 Card Cols. 6-8 Format I3	Index 4 Card Cols. 9-10 Format I2	Mnemonic Name of Data	Notes on Application of Data
16		5		LFW	Type of pointwise data for nu*fission cross sections 0-No pointwise nu*fission cross sections 1-Tabulated $\nu\sigma_f$ 2-$\nu\Sigma_f$=CF 3-$\nu\Sigma_f$=CF/$\sqrt{E}$
16		6		NE	Number of energy points in range
16		7		NR	Number of interpolation regions spanning pointwise range (5 maximum, default value is 1)
16		JR		NBT(JR)	Index of upper energy point for interpolation region JR (Default value is NE, which is for NR=1) (Indices run from 1 to NE)
16		JR		INT(JR)	Interpolation scheme for region JR 1-σ is constant in E (constant) 2-σ is linear in E (linear-linear) 3-σ is linear in ln E (linear-log) 4-ln σ is linear in E (log-linear) 5-ln σ is linear in ln E (log-log) These are the ENDF interpolation schemes. Reference: M. K. Drake, Data Formats and Procedures for the ENDF Neutron Cross Section Library, Section 4.3, BNL 50274

TABLE XXVI

FLOATING POINT DATA FOR RAFFLE FAST CROSS SECTION LIBRARY

Index 1 Card Cols. 2-3 Format I2	Index 2 Card Cols. 4-5 Format I2	Index 3 Card Cols. 6-8 Format I3	Index 4 Card Cols. 9-10 Format I2	Mnemonic Name of Data	Notes on Application of Data
		1		AMI	Atomic mass
1		J	2	SIGA(J)	Absorption cross section for group J
1		J	3	SIGNU(J)	Nu times fission cross section for group J
1		J	6	SIGP0(J)	Elastic scatter cross section for group J (Used if JELAS(J)=0 or 2)
1		J	7	SIGP1(J)	P_1 component of elastic scatter cross section (Used to generate the histogram if JELAS(J)=2)
7	J	I		F(I,J)	The differential scattering values determining the histogram for group J (Not used if JELAS(J)=2)
8	J	I		U(I,J)	The lower breakpoint values of mu of the histogram for group J (Not used if JELAS(J)=2) (Not necessary to input the mu=-1.0 point)
9		J		SIGIN(J)	Inelastic scattering cross section for group J
10		J		SIGN2n(J)	N-2N scattering cross section for group J
14		JF	1	EFINE(JF)	Energy breakpoints (eV) in decreasing order for the fine groups

TABLE XXVI (Cont'd)

FLOATING POINT DATA FOR RAFFLE FAST CROSS SECTION LIBRARY

Index 1 Card Cols. 2-3 Format I2	Index 2 Card Cols. 4-5 Format I2	Index 3 Card Cols. 6-8 Format I3	Index 4 Card Cols. 9-10 Format I2	Mnemonic Name of Data	Notes on Application of Data
14		JF	2	SIGEL(JF)	Pointwise value of the elastic scattering cross section at point JF
14		JF	3	SIGINL(JF)	Pointwise value of the total inelastic cross section at point JF
14		JF	4	SIG2N(JF)	Pointwise value of the n-2n cross section at point JF (Only the non-zero values need be entered)
14		L	5	Q(L)	Value in eV of the discrete energy loss for inelastic level L
14	L	JF		SIGL(JF,L)	Pointwise value of the inelastic scatter cross section for level L at point JF
14	LEVEL +1	JF		SIGEVP(JF)	Pointwise value of the inelastic cross section for the evaporation model at point JF
14		JF	6	TVAP(JF)	Pointwise value of the nuclear temperature for the evaporation model (Used only if IEVAPT=1)
15		1		TEMP	Temperature (°K) for the resolved resonance calculation
15		2		ELØW	Lower energy of the resolved resonance range

TABLE XXVI (Cont'd)

FLOATING POINT DATA FOR RAFFLE FAST CROSS SECTION LIBRARY

Index 1 Card Cols. 2-3 Format I2	Index 2 Card Cols. 4-5 Format I2	Index 3 Card Cols. 6-8 Format I3	Index 4 Card Cols. 9-10 Format I2	Mnemonic Name of Data	Notes on Application of Data
15		3		EUP	Upper energy of the resolved resonance range
15		4		AI	Atomic mass (AI repeats AMI but must be entered)
15		5		C1	Constants used to compute number of neutrons per fission in the resolved range ν=C1 + C2*E
15		6		C2	
15		7		EL	Lower energy of the resolved resonance range
15		8		EH	Upper energy of the resolved resonance range
15		9		G	Statistical factor (Used only if LGW=0)
15		10		GAMG	Capture width (Used only if LCW=0)
15		11		SPØ	The potential scattering cross section
15	1	IRR		ER(IRR)	Energy of resonance IRR in eV
15	2	IRR		AG(IRR)	Statistical factor for resonance IRR (Used only if LGW=1)
15	3	IRR		GN(IRR)	Neutron width for resonance IRR in eV

TABLE XXVI (Cont'd)

FLOATING POINT DATA FOR RAFFLE FAST CROSS SECTION LIBRARY

Index 1 Card Cols. 2-3 Format I2	Index 2 Card Cols. 4-5 Format I2	Index 3 Card Cols. 6-8 Format I3	Index 4 Card Cols. 9-10 Format I2	Mnemonic Name of Data	Notes on Application of Data
15	4	IRR		GG(IRR)	Capture width for resonance IRR in eV (Used only if LCW=1)
15	5	IRR		GF(IRR)	Fission width for resonance IRR in eV (Used only if LFW=1)
16		2		CA	Constant defining pointwise absorption cross section (See LAW in Table 25)
16		3		CS	Constant defining pointwise scattering cross section (See LSW in Table 25)
16		4		CF	Constant defining pointwise nu*fission cross section (See LFW in Table 25)
16		JF	1	EPT(JF)	Energy (eV) of point JF in pointwise range if LEW=1. If LEW=0, EPT(1) is the lower cutoff energy and EPT(2) the upper cutoff energy in eV of the pointwise range. (LEW is described in Table 25) (Energy points must be in order of increasing energy)
16		JF	2	SIGAP(JF)	Absorption cross section for point JF (Used if LAW=1, Table 25)
16		JF	3	SIGS(JF)	Scattering cross section for point JF (Used if LSW=1, Table 25)

TABLE XXVI (Cont'd)

FLOATING POINT DATA FOR RAFFLE FAST CROSS SECTION LIBRARY

Index 1 Card Cols. 2-3 Format I2	Index 2 Card Cols. 4-5 Format I2	Index 3 Card Cols. 6-8 Format I3	Index 4 Card Cols. 9-10 Format I2	Mnemonic Name of Data	Notes on Application of Data
16		JF	4	SIGNUP(JF)	Nu*fission cross section for point JF (Used if LFW=1, Table 25)

The data for the thermal library can be entered by isotope as microscopic cross sections or by material as macroscopic cross sections, and no ordering of data sets by isotope, with respect to identification number, is required. The format of the title card is given in Table XXIV. No integer data are used in the thermal library, and the description of the floating point data is given in Table XXVIII.

3. PROCESSING ENDF DATA FOR RAFFLE CROSS SECTION LIBRARIES

With only a few exceptions, the data in the RAFFLE cross section libraries are derived from the ENDF files[5]. The processing into the RAFFLE formats of all the ENDF data required for a problem can require considerable effort and computer time. However, for a particular sequence of problems often only a few changes in cross section data are needed from problem to problem. The following procedures are used to reduce the effort needed to prepare cross section libraries for RAFFLE problems. Master fast and thermal libraries are kept on easily modified tape files created by the UPD program[6]. For a sequence of problems, user libraries, with the data for only the isotopes actually used and with any needed modifications, are created from the master libraries and stored on tape or disk. Changes in the cross section data from problem to problem are read in on cards along with the problem data as described in Section VII.4. The up-to-date status of the master libraries is reported in Aerojet Nuclear Company internal documents.

The types of data in the RAFFLE cross section libraries are described in Section VII.1. Much of the broad group data for the fast library is obtained directly from the PHROG[7] library. As a result, the broad group energy structure of the RAFFLE master fast library, as given in Table XXVII, is the same as that of the PHROG fine group energy structure. In the PHROG library a distinction is made between isotopes for which resonance data are provided and isotopes for which such data are not included. In either case the groupwise microscopic total inelastic and n-2n cross sections are read from the PHROG library and output in RAFFLE format by the RAFSIG3 program[8].

If the PHROG library includes resonance data for an isotope, the only resonance contributions to the absorption and nu-fission cross sections are the flat or background cross sections. In the RAFFLE master fast library, isotopes with resonance data are handled as follows. The resolved and unresolved resonance ranges are treated separately. Over the energy range of the resolved cross sections, the broad group absorption and nu-fission cross sections are used without modification as read from the PHROG library. The resolved

resonance parameters are read from the ENDF files by the RAFSIG5 program[9] and output in RAFFLE format. "Infinite dilute" unresolved resonance contributions are obtained by a PHROG calculation. These contributions are added to the background group cross sections from the PHROG library and output in RAFFLE format by the RAFSIG4 program[10]. Since incorporating the unresolved contributions into the RAFFLE broad group cross sections makes them problem dependent, it is expected that the user will use PHROG and RAFSIG4 to modify the group cross sections when creating a user's library. RAFFLE can optionally calculate the contributions to the scattering cross sections from the resolved resonance parameters. When this option is used only the background resonance contributions must be included with the RAFFLE broad group elastic scattering cross sections.

For some RAFFLE problems, the CPU time can be substantially reduced by incorporating averaged resolved resonance cross sections into the broad group cross sections. In particular, this procedure *must* be used when the KENO scoring technique is used. To use this option, the user obtains the groupwise resolved resonance cross sections from a PHROG calculation and adds the results to the background using RAFSIG4.

A user's library can use pointwise data obtained from the C-SURE program[11] to describe the unresolved resonance contributions to the cross sections. However, in the form provided by C-SURE, these pointwise data are problem dependent.

In the master fast library, the "histogram" option is used to describe the angular distribution of neutrons undergoing elastic scattering. The ASED program[12] reads the differential scattering cross sections from the ENDF files, averages them over a specified spectrum, fits the spectral averaged data to the required histogram form, and outputs the data in the formats required for the RAFFLE library. It is expected that only a few unusual problems will require changes from the histogram data in the master library.

The master fast library contains "fine group" data for all isotopes having inelastic scattering data in the ENDF files. The RAFSIG1 program[13] reads the data from the ENDF files and fits the inelastic scattering data to the same pointwise energy structure as that used for the elastic scattering data. The RAFSIG2 program[14] then fits the data from RAFSIG1 to a representation using fewer points and in the form required for the RAFFLE fine group data. Again, it is expected only a few unusual problems will require changes from the fine group data in the master library.

By putting the appropriate thermal cross sections into group 69, thermal reactor calculations can be made using only the fast library. However, it is recommended that a separate multigroup thermal library be used whenever events at thermal energies warrant it. The use of multiple thermal groups usually does not increase the CPU time for a RAFFLE problem. A multigroup library is created by using INCITE[15] which outputs the library in RAFFLE format and can store it on disk, tape, or cards.

4. TEMPORARY CHANGES TO THE FAST LIBRARY

Data type IMØRE(ID) in the general integer data, Table V, can be used to indicate temporary changes in the fast cross section data if the library is read from FORTRAN logical unit 15. These changes are effective only for the problem being run, and the data in the library are not changed. ID is the sequence number of the isotope. Consider a library containing isotopes with identification numbers 1, 10, 12, and 23; the sequence numbers are then 1, 2, 3, 4. An example of the input for IMØRE to indicate that temporary changes will be made to the data for the isotopes with identification numbers 10 and 23 is shown below.

col. 2-3	col. 4-5	col. 6-8	col. 9-10	col. 11-12	col. 13-16	col. 17-20	col. 21-24	col. 25-28
	15	1		4	0	1	0	1

The changes are input on change cards that immediately follow the general floating point data (Table VI). The data on the change cards override the corresponding data in the fast library. For each isotope with changed data, a title card, at least one fixed point card, and at least one floating point card must be included in that order. The last fixed point card and the last floating point card must each have a "1" in column 1. The formats for the change cards are the same as those for the permanent library and are given in Tables XXIV, XXV, and XXVI. The change cards must be entered in order of increasing isotope identification number.

TABLE XXVII

BROAD GROUP ENERGY STRUCTURE FOR RAFFLE
MASTER FAST CROSS SECTION LIBRARY

Group Number	Lower Lethargy	Lower Energy (eV)	Group Number	Lower Lethargy	Lower Energy (eV)
1	0.25	7.79×10^6	23	5.75	3.18×10^4
2	0.50	6.07×10^6	24	6.00	2.48×10^4
3	0.75	4.72×10^6	25	6.25	1.93×10^4
4	1.00	3.68×10^6	26	6.50	1.50×10^4
5	1.25	2.87×10^6	27	6.75	1.17×10^4
6	1.50	2.23×10^6	28	7.00	9.12×10^3
7	1.75	1.74×10^6	29	7.25	7.10×10^3
8	2.00	1.35×10^6	30	7.50	5.53×10^3
9	2.25	1.05×10^6	31	7.75	4.31×10^3
10	2.50	8.21×10^5	32	8.00	3.36×10^3
11	2.75	6.39×10^5	33	8.25	2.61×10^3
12	3.00	4.98×10^5	34	8.50	2.04×10^3
13	3.25	3.88×10^5	35	8.75	1.59×10^3
14	3.50	3.02×10^5	36	9.00	1.23×10^3
15	3.75	2.35×10^5	37	9.25	961.1
16	4.00	1.83×10^5	38	9.50	748.5
17	4.25	1.43×10^5	39	9.75	582.9
18	4.50	1.11×10^5	40	10.00	454.0
19	4.75	8.65×10^4	41	10.25	353.6
20	5.00	6.74×10^4	42	10.50	275.4
21	5.25	5.25×10^4	43	10.75	214.5
22	5.50	4.09×10^4	44	11.00	167.0

Continued on next page

TABLE XXVII (Cont'd)

BROAD GROUP ENERGY STRUCTURE FOR RAFFLE
MASTER FAST CROSS SECTION LIBRARY

Group Number	Lower Lethargy	Lower Energy (eV)	Group Number	Lower Lethargy	Lower Energy (eV)
45	11.25	130.1	57	14.25	6.48
46	11.50	101.3	58	14.50	5.04
47	11.75	78.9	59	14.75	3.93
48	12.00	61.4	60	15.00	3.06
49	12.25	47.9	61	15.25	2.38
50	12.50	37.3	62	15.50	1.86
51	12.75	29.0	63	15.75	1.44
52	13.00	22.6	64	16.00	1.125
53	13.25	17.6	65	16.25	0.876
54	13.50	13.7	66	16.50	0.683
55	13.75	10.68	67	16.75	0.532
56	14.00	8.32	68	17.00	0.414
			69	∞	0.000

TABLE XXVIII

FLOATING POINT DATA FOR RAFFLE THERMAL LIBRARY

Index 1 Card Cols. 2-3 Format I2	Index 2 Card Cols. 4-5 Format I2	Index 3 Card Cols. 6-8 Format I3	Index 4 Card Cols. 9-10 Format I2	Mnemonic Name of Data	Notes on Application of Data
1		J	2	SIGA(J)	Absorption cross section for thermal group J
1		J	3	SIGNU(J)	Nu times fission cross section for thermal group J
2		J	N	TRMAT(J,J+N)	Optional specification of the isotropic scattering cross sections $\Sigma^{\ell}_{so\ j\rightarrow j'}$=TRMAT(J,J+N) for the isotropic scattering of neutrons from thermal energy group j=J to group j'=J+N. For specifying the scattering cross sections from group J to a group J+1, for example, the optional format corresponding to INDEX 1=2 may be much more convenient than the format of INDEX 1=3, below. (This format is particularly convenient when there is ingroup scattering and scattering from a given group to the next group only.) The first data word on the card is the value of the cross section $\Sigma^{\ell}_{so\ j\rightarrow j'}$ for scattering neutrons from energy group j=J to group j'=J+N, the next word on the card is the cross section for scattering from group j=J+1 to group j'=J+N+L, etc. N may be zero or negative to accommodate ingroup scatter terms and upscatter terms.

TABLE XXVIII (Cont'd)

FLOATING POINT DATA FOR RAFFLE THERMAL LIBRARY

Index 1 Card Cols. 2-3 Format I2	Index 2 Card Cols. 4-5 Format I2	Index 3 Card Cols. 6-8 Format I3	Index 4 Card Cols. 9-10 Format I2	Mnemonic Name of Data	Notes on Application of Data
3		J	K	TRMAT(J,K)	Specification of the isotropic scattering cross sections $\Sigma^{\ell}_{so\ j\to j'}$=TRMAT(J,K) for scattering neutrons from thermal energy group j J to group j'=K. The first data word on a card is the value of the cross section $\Sigma^{\ell}_{so\ j\to j'}$ for scattering neutrons from energy group j=J (Index 3) to group j'=K+1, the next is value is for scattering from group j=J to group J' K+1, the next is for scattering from group j=J to group j'=K+2, etc. K may be equal to or less than J to accommodate ingroup scatter terms and upscatter terms.
5		J	N	TRMAT1(J,J+N)	Optional specification of the first moment scattering cross sections $\Sigma^{\ell}_{s1\ j\to j'}$=TRMAT1(J,J+N) for the linear anisotropic scattering of neutrons from thermal energy group j=J to group j'=J+N. The first data word on the card is the value for the first moment cross section $\Sigma^{\ell}_{s1\ j\to j'}$ for the linear anisotropic transfer of neutrons from group j=J to group j'=J+N, the next word is for group j=J+1 to group j'=J+1+N, etc. N may be zero or negative to accomodate linear anisotropic transfer within group and to higher energies.

TABLE XXVIII (Cont'd)

FLOATING POINT DATA FOR RAFFLE THERMAL LIBRARY

Index 1 Card Cols. 2-3 Format I2	Index 2 Card Cols. 4-5 Format I2	Index 3 Card Cols. 6-8 Format I3	Index 4 Card Cols. 9-10 Format I2	Mnemonic Name of Data	Notes on Application of Data
6		J	K	TRMAT1(J,K)	Specification of the first moment scattering cross sections $\Sigma_{s1\ j\to j'}$=TRMAT1(J,K) for the linear anisotropic scattering of neutrons from thermal energy group j=J to group j'=K. The first data word on a card is the value of the first moment cross section $\Sigma_{s1\ j\to j'}$ for the linear anisotropic transfer of neutrons from group j=J to group j'=K, the next word is for group j=J to group j'=K+1, etc. K may be equal to or less than J to accomodate linear anisotropic transfer within group to higher energies.

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