MASTER

HEAVY WATER ORGANIC COOLED REACTOR

HWOCR - SAFE: A MONTE CARLO REACTOR ANALYSIS CODE

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ATOMICS INTERNATIONAL—COMBUSTION ENGINEERING

A Joint Venture for Heavy Water Organic Cooled Reactors

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ATOMICS INTERNATIONAL-COMBUSTION ENGINEERING
A Joint Venture for Heavy Water Organic Cooled Reactors

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ABSTRACT

HWO CR-SAFE is a Monte Carlo reactor analysis code capable of completely describing proposed HWO CR lattice configurations as well as more approximate annular representations of them. It is designed to be used as a benchmark tool to check multigroup diffusion and transport calculations and to evaluate the effect of the geometric approximations necessary in such calculations. Cross section data may be treated in great detail in the thermal and epithermal energy ranges so that multigroup constants can also be checked. HWO CR-SAFE is an outgrowth of the SAFE code which was designed to evaluate the criticality of three dimensional fuel assemblies for nuclear safety studies. Versions of HWO CR-SAFE are available in FORTRAN IV for the IBM 7094 and in FORTRAN H for the IBM system 360.

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I. INTRODUCTION

The use of the Monte Carlo Method to perform practical steady-state reactor analysis at a reasonable cost has been effectively demonstrated by applying the nuclear safety code SAFE⁽¹⁾ to the HWOCR fuel cell.

HWOCR-SAFE is a Monte Carlo thermal reactor analysis code which handles the detailed geometry of proposed HWOCR Lattice configurations. Versions are available in FORTRAN IV for the IBM 7094 and in FORTRAN H for the IBM system 360.

Complete generality in geometric capability was deliberately avoided since it would lead to a loss in efficiency both in the use of computer storage for the detailed tabulation of design parameters and in calculational speed due to the unnecessary complications which would arise in the tracking procedures. Simplicity of input preparation is a further advantage gained by tailoring the code to handle a limited class of problems.

The HWOCR-SAFE code is an adaptation and extension of the SAFE code⁽¹⁾ which was developed with a similar philosophy for nuclear safety problems. The SAFE code was written to handle identical cylindrical rods in three-dimensional finite or infinite arrays. HWOCR-SAFE is restricted to two-dimensional rectangular cell calculations.

The restriction in SAFE that all rods be identical was relaxed in HWOCR-SAFE to allow up to six possible rod types (all cylindrical). The rod intersection procedures of the SAFE code are still used to the same advantage in the HWOCR-SAFE code, as described in Section III-A-3.

II. TREATMENT OF GEOMETRY IN HWOCR-SAFE

A. PERMISSIBLE GEOMETRIC CONFIGURATIONS

The HWOCR-SAFE code is a two-dimensional cell code in which the cell is assumed to be rectangular. (For clarity in reading this section, consult Figure 1.) Up to 20 material regions (zones) can be specified where one of the zones is completely described by the cell boundaries and is assigned the zone number NZCEL. All other zones lie within a cylinder described by a boundary number NBOWAL. (Note that NZCEL must be the highest zone number assigned). The region in which the fuel rods are inserted is designated as zone NZIB, and is described completely by boundary NBIWAL (Note that the value of NZIB must be equal to the number of rod zones plus one).

A zone is defined as a region of uniform material composition with the following two exceptions:

- 1) Zone NZIB is described as if it were a region of homogeneous composition contained within the cylinder described by boundary number NBIWAL. The existence of fuel rods in this medium is accounted for in the particle tracking routines, thereby avoiding the complex description of this zone which would otherwise result. The material composition used is that which surrounds fuel rods.

- 2) Zone NZCEL is described as if it were a region of homogeneous composition contained within the cell boundaries. The material composition used is that which exists in the region beyond boundary NBOWAL.

All cylindrical boundaries with index numbers NBIWAL or greater must be concentric and may be used to describe material regions such as pressure tubes, calandria tubes, or gaps. Up to 40 rods in the shape of right circular cylinders may be inserted arbitrarily in zone NZIB.

These rods may be of up to six types. A type may be distinguished by either external size, location, internal geometry, or material composition. One may wish to designate two identically constructed rods inserted in different locations as different types so that tallying of certain quantities can be distinguished.

Each rod may contain material regions or zones whose defining boundary equations have their origin at the center of the particular rod types. Rod zones must be assigned the lowest zone numbers so that they occupy the range from 1 to NZIB-1. The rod type to which each zone is assigned is entered in the IZTYPE array. All zones in a given rod type are described by concentric cylinders.

The number of zones assigned to each rod type is entered in the NZONE array.

The number of boundary equations used to describe the zones in each rod type is entered in the NBOUND array.

The outer radius of each rod type is entered in the NPHI array.

The outer zone of each rod type is entered in the NADJRZ array. (See Section V for further details regarding the input arrays described above.)

To facilitate the handling of a large number of rods, two coordinate systems are used:

- 1) The Main Coordinate System: a right-handed Cartesian coordinate system whose origin is the center of the cylinder described by boundary NBIWAL.

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Figure 1. HWOCR-SAFE Geometry

2) The Intra-Rod Coordinate System: A right-handed system in which all rod boundary equations are written. The origin is at the center of the rod.

1. Boundary Equations

The X and Y coordinates of the Ith rod in the main coordinate system are entered as CENTER (1,I) and CENTER (2,I), respectively.

The cell boundaries are assumed to be planes. Consequently, only the width in the X direction (CWIDTH) and the depth in the Y direction (CDEPTH) are required as problem input.

All other boundary equations are of the form

$$X^2 + Y^2 - R^2 = 0 \quad .$$

The value of R^2 for cylinder I is input as BK (I). Up to 25 such boundary equations are permitted in the problem description. The origin is in the intra-rod coordinate system, as can be seen from the form of the equation above. A boundary equation need not be entered more than once even though it may be assigned to several rod types. Not more than two boundaries may be used to describe a given region.

2. Annular Representation

In the annular representation, all zones must be described by concentric cylinders. This representation should be used only for purposes of comparison with transport theory codes since the actual geometry calculation can be performed with no significant change in computer time required.

The annular representation is achieved by representing the entire cell as a single rod. For this representation, NANULR must be set equal to one. The direction of a particle is reversed at the cell boundary because of the complete symmetry of the cell about its center. See Section VI for an example of an annular representation calculation.

B. TRACKING OF PARTICLES

1. Determination of Distance to a Boundary

Assume a boundary surface has an equation of the form

$$X^2 + Y^2 - R^2 = 0$$

for all X, Y on the surface of the right cylinder. Let S_b be the distance to this boundary from some point X_0, Y_0 at which the neutron is located, and let the direction of the neutron be defined by direction cosines (α, β, γ) . Then

$$X_1 = X_0 + \alpha S_b$$

$$Y_1 = Y_0 + \beta S_b$$

represents the point (X_1, Y_1) at which the neutron's path intersects the surface. It follows that

$$X_1^2 + Y_1^2 - R^2 = 0 \quad ,$$

and therefore

$$(X_0 + \alpha S_b)^2 + (Y_0 + \beta S_b)^2 - R^2 = 0 \quad .$$

Then,

$$X_0^2 + Y_0^2 - R^2 + (\alpha^2 + \beta^2) S_b^2 + 2(\alpha X_0 + \beta Y_0) S_b = 0$$

or

$$h S_b^2 + 2e S_b + r = 0 \quad ,$$

where we define

$$h = \alpha^2 + \beta^2$$

$$e = \alpha X_0 + \beta Y_0 \text{ and } r = X_0^2 + Y_0^2 - R^2 \quad .$$

We then solve for S_b from

$$S_b = \frac{-e + g \sqrt{e^2 - hr}}{h}$$

where $g = \pm 1$. For a neutron within a given zone, the appropriate value for g is such that $g \cdot r$ is negative for a zone boundary. These "g" values must be supplied as input to the problem (GAY array).

The distance a particle must travel to leave the zone in which it is located is obtained by finding the smallest, positive, real distance to a boundary in that zone. The boundary for which S_b is minimal is the boundary which would be crossed if no prior collision occurs. Care is taken in the code to avoid calculation of any S_b which would be either negative or complex.

2. Determination of Zone in Which Collision Occurs

To determine if a particle is in a given zone, the quantity, r , defined above, is evaluated for each appropriate boundary and compared with the appropriate value of g . When the product $r \cdot g$ is negative for all boundaries surrounding a given zone, the particle is in that zone. If even one such product $r \cdot g$ is positive, the particle is not in that zone and another zone must be checked until one is found to be the correct zone. Should no zone be acceptable, some minor adjustments in the

particle's position are tried and, should these fail to rectify the situation, the problem is halted and appropriate error messages are printed for the user's perusal.

Section V of this report explains how the boundaries and appropriate g values are input.

III. MONTE CARLO PROCEDURES

A DESCRIPTION OF A NEUTRON HISTORY

Neutrons are started from an initial source distribution in space, angle, and energy with a statistical weight of unity. They are followed from collision to collision until they are either captured or produce fission. K_{∞} is the average number of neutrons produced per source neutron, regarding the contribution of captured neutrons as zero. The details of the physical and geometric selection processes are discussed below.

1 Description of Source

A source particle is defined by an initial energy, an initial direction of motion expressed in the form of three direction cosines, and three spatial coordinates.

a. Selection of Initial Energy

The selection of the initial energy is accomplished by assuming a spectrum for fission neutrons and tabulating the average energy between energy points defining equal probability intervals. The Cranberg spectrum⁽²⁾ for fissions occurring in U^{235} has been tabulated and adopted for use in HWO-CR-SAFE and has the form

$$f(E) = 0.4527 e^{-(E/0.965)} \sinh \sqrt{2.29E}$$

with an average energy $\bar{E} = 1.98$ Mev. E is in units of Mev. Should there be any reason to change this spectrum, the source routine can be easily modified to accommodate an alternate spectrum.

b. Selection of Initial Direction Cosines

The emergence of a neutron from a fission reaction is isotropic in direction in the center-of-mass system. Since fissile isotopes are quite heavy, negligible error is introduced in extending this assumption to the laboratory system. The direction cosines, α , β , and γ , which serve to define the direction of particle motion are thus selected isotropically.

Since $\alpha^2 + \beta^2 + \gamma^2 = 1$, this is equivalent to picking particles on the surface of a unit sphere. We therefore set

$$\gamma = 1 - 2r_1 \quad ,$$

where r_1 is a random number. (Note: All random numbers are selected uniformly between 0 and 1.)

Then, since $\alpha^2 + \beta^2 = (1 - \gamma^2)$, we select α and β as coordinates of a point on a circle of radius $\sqrt{(1 - \gamma^2)}$. This is done by picking two more random numbers, r_2 and r_3 , and if

$$(1 - 2r_2)^2 + (1 - 2r_3)^2 \leq 1 \quad ,$$

then

$$\alpha = (1 - 2r_2) \sqrt{\frac{(1 - \gamma^2)}{(1 - 2r_2)^2 + (1 - 2r_3)^2}}$$

and

$$\beta = (1 - 2r_3) \sqrt{\frac{(1 - \gamma^2)}{(1 - 2r_2)^2 + (1 - 2r_3)^2}} .$$

If $(1 - 2r_2)^2 + (1 - 2r_3)^2 > 1$, we must reject r_2 and r_3 and pick two new values for them, etc., until the above test is passed. Since proper programming of this procedure involves the calculation of only one square root, this method turns out to be the most efficient of the commonly used methods available.

c Selection of Spatial Coordinates

One of the problems facing a Monte Carlo criticality calculation is that the spatial distribution of fission neutrons is not known, except for a few special cases. This necessitates using a self-generating type of source selection procedure, so that in the limit of a large number of histories the spatial source coordinates chosen would be distributed very similarly to the distribution of neutrons in the actual physical case. To accomplish this, HWO-CR-SAFE requires the user to input the coordinates of the starting history. He should choose these at a point where he feels the neutron production is at a maximum. Starting with this initial set, the points where succeeding fissions are produced and the accumulated neutron production occurring in each rod type are stored. The rod type is selected based on the relative cumulative production of neutrons in each rod type. Should the user have a problem in which his knowledge of the source distribution would significantly reduce the variance in K_{∞} , were this knowledge brought to bear on the calculation, he could modify or rewrite subroutine SOURCE to suit his particular case.

2. Location of Point of Next Collision

To determine where the neutron will make its next collision, we must find the mean free path of the neutron at its present energy, in the region where it is located. The distance, S , which the neutron will travel before colliding in this medium is then obtained from an exponential distribution by selecting a random number, r , and setting $S = -\lambda \ln r$, where λ is the mean free path. This distance is then compared with S_p , the maximum distance a particle having direction cosines α , β , γ could travel in this region. If S is less than this distance, then we assume the particle will collide at

$$X' = X + \alpha S$$

$$Y' = Y + \beta S$$

Should S be greater than the maximum possible distance in the region, the particle is assumed to have left the region and is placed just inside the next region, as follows:

$$X' = X + \alpha(S_b + \delta)$$

$$Y' = Y + \beta(S_b + \delta) \quad ,$$

where δ is a small distance used by the code to ensure the particle's entrance into the adjacent region. The recommended value is 10^{-4} cm, but this may be changed in the input data if the need arises. (This quantity is designated as DELTA in the input description in Section V-B.)

Once the particle is so placed in the adjacent region, a new S_b is calculated and the particle's path is followed in the same manner as described above until in some region, $S < S_b$ and a collision takes place at (X', Y') .

3 Tracking of Particles in Region Adjacent to Fuel Rods

Should the particle leave the fuel rod, it is assumed to enter the space adjacent to the rod (zone NZIB). The procedure at this point is similar in principle to the treatment given the particle within a fuel rod, but the distance to another fuel rod (if one lies in the path of the particle) must be calculated as well as the distance to the boundary NBIWAL.

In addition to the internal geometry permitted within a rod, a main coordinate system and an intra-rod coordinate system are used. This is possible because of the assumption of similarity of rods of a given type and their cylindrical shape. As a result of this innovation, the input data need contain only a description of one rod of each type and the coordinates of the centers of the rods with respect to the main coordinate system. The internal rod geometry is then input with respect to the intra-rod coordinate system.

The assumption of geometric similarity of all rods greatly speeds up that portion of the calculation devoted to geometric boundary and zone searching, since the internal boundary equations are of a simpler form, and the intersection of particle paths with rods can take full advantage of the cylindrical nature of the rods. To illustrate how one can streamline the particle tracking routines if one knows the rods are similar, consider a particle which, at some point in its history, leaves such a rod, as shown in Figure 2. It is necessary to find which of the remaining rods could be intersected first by this particle path. In the case of cylindrical rods, HWOCR-SAFE determines this by computing the mean between the two points of intersection of the trajectory with a rod boundary. This does not require the computation of a square root as would the distance to either intersection point, as will now be shown.

The distance to a given rod i is

$$S_i = \frac{-(\alpha X_0 + \beta Y_0) - \sqrt{(\alpha X_0 + \beta Y_0)^2 - (\alpha^2 + \beta^2)(X_0^2 + Y_0^2 - R_i^2)}}{(\alpha^2 + \beta^2)} \quad ,$$

Figure 2 Intersection of Particle Path with
Neighboring Rods

while the distance to reach the rod and traverse it is

$$S_1 = \frac{-(\alpha X_0 + \beta Y_0) + \sqrt{(\alpha X_0 + \beta Y_0)^2 - (\alpha^2 + \beta^2)(X_0^2 + Y_0^2 - R_1^2)}}{(\alpha^2 + \beta^2)},$$

where the direction cosines (α, β, γ) are subject to the constraint

$$\alpha^2 + \beta^2 + \gamma^2 = 1.$$

If the quantity $(\alpha X_0 + \beta Y_0)$ is positive, S_1 will be negative and need not be calculated (e. g., S_5).

If $(\alpha X_0 + \beta Y_0)^2 < (\alpha^2 + \beta^2)(X_0^2 + Y_0^2 - R_1^2)$, S_1 will be complex and again need not be calculated (e. g., S_4).

For positive, real S , the mean of S_1 and S_1 is calculated as

$$M_1 \equiv \frac{S_1 + S_1}{2} = \frac{-(\alpha X_0 + \beta Y_0)}{(\alpha^2 + \beta^2)} \equiv \frac{m_1}{(\alpha^2 + \beta^2)}.$$

For non-overlapping cylinders the rod which would be intersected first is then the one for which this mean distance is the shortest. Since dozens of rods could be involved, this constitutes a great saving in computation cost. If the rods were permitted arbitrary external shape, this procedure would not be possible.

4. Selection of Interacting Nuclear Species

If we define σ_1 as the total cross section for element 1, then the total cross section for the medium is

$$\Sigma_T = \sum_{i=1}^M N_i \sigma_i ,$$

where N_1 is the number of nuclei of element 1 per cubic centimeter present in the medium. M is the total number of elements (nuclear species) in the medium.

The probability of a neutron colliding with element j is then,

$$P_j = \frac{N_j \sigma_j}{\Sigma_T}$$

To select the type of colliding nucleus we therefore pick a random number, r , and select the j^{th} element in the medium when

$$P_1 + P_2 + \dots + P_{j-1} < r < P_j + P_{j+1} + \dots + P_m .$$

5. Selection of Type of Nuclear Reaction

When a neutron undergoes a collision with a nucleus, it may scatter, either elastically or inelastically, or it may be absorbed. The probability of elastic scattering with a nucleus of species j , is

$$P_{s_j} = \frac{\sigma_{s_j}}{\sigma_j}$$

where σ_{s_j} is the elastic scattering cross sections for material j . Similarly, for a neutron above the inelastic scattering threshold, the inelastic scattering probability is

$$P_{in_j} = \frac{\sigma_{in_j}}{\sigma_j}$$

We assume the neutron is elastically scattered if a random number, $r \leq P_{s_j}$, while for $r > P_{s_j}$ we assume it is inelastically scattered if

$$P_{s_j} < r \leq (P_{s_j} + P_{in_j}) .$$

If $r > (P_{s_j} + P_{in_j})$, the neutron is considered absorbed by the nucleus if absorption weighting is not used. Should the nucleus be of a fissionable type, then

$$\frac{W v \sigma_{f_j}}{(\sigma_j - \sigma_{s_j} - \sigma_{in_j})}$$

neutrons are assumed to have been produced by this neutron. W is the statistical weight of the neutron at the time the reaction takes place.

6. The Selective Use of Absorption Weighting

Absorption weighting is used everywhere in the fast energy range (1 kev to 10 Mev). Thus, if a particle of weight W collides with a nucleus where the absorption cross section is Σ_a and the scattering cross section is Σ_s , then the statistical weight of the particle after collision is $W \Sigma_s / (\Sigma_a + \Sigma_s)$, and absorption of the amount $W \Sigma_a / (\Sigma_a + \Sigma_s)$ is assumed to have taken place. In the resonance energy range (1 ev to 1 kev), absorption weighting is used everywhere for non-resonance absorbers. For materials designated as resonance absorbers on the cross-section library tape, the analog procedure of allowing a particle to have its history terminated by an absorption process is followed. In highly thermal reactors this is advantageous since absorption weighting in regions of high absorption probability would result in particles of very low statistical weight being followed for many collisions in the thermal region even though their importance is small.

In the thermal energy range (0 to 1 ev), absorption weighting is used in all zones for which the input quantity NSO is equal to two. If NSO is not equal to two for a given zone, absorption weighting is used in the thermal energy range until the particle weight falls below the value of the input parameter WC. This option is provided so that the possibility of reducing the variance by an appropriate choice of WC can be investigated. In the case of a heavy-water moderator which has an extremely low absorption probability, it appeared that $WC = 1.0$ was as good as any value of WC tried, but this conclusion should be regarded as preliminary since an exhaustive investigation was not made.

Note that for any zone containing fuel, NSO must be input as one so that absorption weighting will not be used for particles whose weight is below WC in fuel zones.

7. Selection of Emergent Energy and Angle

The determination of the neutron energy subsequent to a collision is, of course, strongly dependent on the type of interaction which occurred. This in turn is a function of the incident neutron energy, insofar as the reaction cross sections are energy dependent.

HWOOCR-SAFE divides the entire energy range (from 10 Mev to 0) into three subranges: fast (from 10 Mev to 1 kev); resonance range (from 1 kev to 1 ev); and thermal (from 1 ev to 0 ev).

In the fast range, there are in general two types of scattering: elastic and inelastic.

a. Elastic Collisions in Fast and Resonance Energy Ranges

The method for determining the angle and energy of a neutron emerging from an elastic scattering collision in the fast energy range applies also to the same reaction in the resonance energy range.

First, the scattering is assumed to be isotropic in the center-of-mass system. Consequently, a set of isotropic direction cosines, α'' , β'' , and γ'' are obtained as shown in Section III-A-1-b. If we define the initial direction cosines of the neutron, in the laboratory system, as α , β , and γ , then the new direction cosines in the laboratory system are:

$$\alpha' = \frac{\alpha + A\alpha''}{C} ; \beta' = \frac{\beta + A\beta''}{C} ; \gamma' = \frac{\gamma + A\gamma''}{C} ;$$

where A is the ratio of the mass of the nucleus to the mass of the neutron and

$$C \equiv \sqrt{1 + A^2 + 2A\mu} , \mu = \alpha\alpha'' + \beta\beta'' + \gamma\gamma'' .$$

The new energy, E' , is then equal to $[C/(A+1)]^2$ times the incident energy, E . For a detailed derivation of these quantities, see the section on thermal elastic scattering, III-A-7-d. We can see that for very large A, $E' \rightarrow E$ and $\alpha' \rightarrow \alpha''$, $\beta' \rightarrow \beta''$, $\gamma' \rightarrow \gamma''$. A value of A (denoted by BMASS), above which the scattering will be assumed isotropic in the laboratory system, is required as input data to the code. (Use of a large value for BMASS, say 500, will eliminate this approximation for all isotopes in the problem.)

b. Inelastic Collisions in the Fast Energy Range

At the time of this writing, the only model available for inelastic scattering is the evaporation model. Provision is made to include other models, but they have not as yet been incorporated.

The evaporation model assumes that the distribution of particles emerging from an inelastic (n-n) collision is a Maxwellian:

$$n(E') = E' e^{-E'/T} ,$$

where $0 \leq E' \leq E$ and $T = c \sqrt{E}$, E being the incident neutron energy.

The straightforward Monte Carlo procedure would be to set a random number, r , equal to

$$\frac{\int_0^{E'} n(E'') dE''}{\int_0^E n(E'') dE''} .$$

Thus we would set

$$r = \frac{1 - \left(1 + \frac{E'}{T}\right) e^{-E'/T}}{1 - \left(1 + \frac{E}{T}\right) e^{-E/T}}$$

and solve for E' given E , T , and r .

Since this is not a convenient form for Monte Carlo use, the code employs the following equivalent procedure. The random variable E'/T may be replaced by the sum of two random variables, X and Y , if

$$\int_0^x X(X - Y) Y(y) dy$$

equals the distribution function obeyed by E'/T .

If $X(x) = e^{-x}$ and $Y(y) = e^{-y}$, then

$$\int_0^x e^{-(x-y)} e^{-y} dy = \int_0^x e^{-x} dy = x e^{-x},$$

which is the distribution function from which we wish to pick E'/T .

Therefore, we pick random numbers R_1 and R_2 and set $X = -\ln R_1$, $Y = -\ln R_2$, and then set $\eta = -(\ln R_1 + \ln R_2) = -\ln(R_1 R_2)$.

Then if $\eta < E/T$, set $E = T\eta$. If $\eta \geq E/T$, pick two new random numbers and repeat the process. This procedure ignores the difference between the energy in the C.M. system and the laboratory system. For the very heavy materials for which this process is a good approximation, this is quite justified. Since, for lighter materials the evaporation model does not really apply, it seemed pointless to make this adjustment. HWOCR-SAFE was developed primarily for thermal or near-thermal systems in which inelastic scattering at high energies plays an extremely minor role. Should the need arise to apply HWOCR-SAFE to very fast systems, it will be necessary to provide a more rigorous treatment of inelastic scattering for light elements.

c. n, 2n Reactions

The Monte Carlo simulation of the $n, 2n$ reaction in deuterium which is used in the HWOCR-SAFE code is essentially that given on pages 66 and 68 in Reference 3, with the exception that particle splitting is not used and a weight of $2W$ is assigned to the emerging particle. A general $n, 2n$ reaction is also provided which is essentially the evaporation model (Section III-A-7-b) but again with a weight of $2W$ assigned to the emerging particle. For example, this model would be appropriate for $n, 2n$ reactions in beryllium.

d. Elastic Scattering in the Thermal Energy Range

Proper treatment of scattering in the thermal energy range cannot neglect the velocities of the nuclei which are involved in the collisions with the neutrons. Additional complications are introduced by molecular and crystal binding of these atoms. A rigorous treatment of all these phenomena could only be accomplished by a detailed tabulation of the energy dependent scattering kernel. Should a detailed analysis of the thermal spectrum be required, it would be necessary to use such a procedure, but for purposes of determining η , f , and the region dependent thermal fluxes, the model described below appears to be adequate.

What has been done is to use a free atom model with an effective mass assigned to each nuclear species to approximate the effect of it being part of a larger, rigid molecule. The value assigned for this effective mass is based on the work of Sachs and Teller⁽⁴⁾ as applied by Brown and St. John⁽⁵⁾ in the case of hydrogen. In other cases, it is simply based on empirical agreement with thermal spectrum measurements.

In addition, the thermal cross sections used in the library are those for the bound atom rather than for the free atom.

Given the above approximations, we then use the free atom model to determine the velocity of the target atom, after which we find the new neutron energy and direction from classical collision mechanics.

In using the free atom model, the main problem is to properly select the atom velocity and the angle between the neutron and atom velocities before collision. Assuming the atoms of the medium to be in a Maxwellian velocity distribution, the total scattering rate, R , for a neutron of velocity, v_1 , is

$$R = \int_{-1}^{+1} \frac{d\mu}{2} \int_0^{\infty} \Sigma_s(v_r) v_r \mathcal{M}(v_2) dv_2 \quad ,$$

where v_2 is the atom speed, μ is the cosine of the angle between v_1 and v_2 , and v_r is the relative speed of the neutron with respect to the atom. $\mathcal{M}(v_2)$ is the Maxwellian distribution of atom speeds

$$v_r = \sqrt{v_1^2 + v_2^2 - 2v_1v_2\mu} \quad ,$$

$$\mathcal{M}(v_2) = \frac{4}{\sqrt{\pi}} \left(\frac{M}{2kT} \right)^{3/2} v_2^2 e^{-\frac{Mv_2^2}{2kT}} \quad ,$$

where

M = the effective mass of the target nucleus,
 k = the Maxwell Boltzman constant, and
 T = the temperature of the medium.

Letting

$$\beta^2 = \frac{M}{2kT}, \quad \mathfrak{M}(v_2) = \frac{4\beta^3}{\sqrt{\pi}} v_2^2 e^{-\beta^2 v_2^2}.$$

Then

$$\mathfrak{R} = \frac{4\beta^3}{\sqrt{\pi}} \int_{-1}^1 \frac{d\mu}{2} \int_0^\infty \Sigma_s(v_r) \sqrt{v_1^2 + v_2^2 - 2v_1 v_2 \mu} v_2^2 e^{-\beta^2 v_2^2} dv_2.$$

If the scattering cross section is constant, then

$$\begin{aligned} \mathfrak{R} &= \frac{2\beta^3}{\sqrt{\pi}} \Sigma_s \int_{-1}^1 d\mu \int_0^\infty \sqrt{v_1^2 + v_2^2 - 2v_1 v_2 \mu} v_2^2 e^{-\beta^2 v_2^2} dv_2 \\ &\equiv \Sigma_s V(v_1). \end{aligned}$$

The probability that a neutron of speed v_1 has a scattering collision with a molecule of mass M and speed v_2 with an angle between $\vec{v}_1$ and $\vec{v}_2$ of $\cos^{-1} \mu$ is (when Σ_s is constant)

$$p(v_2, \mu | v_1) dv_2 d\mu = \frac{2\beta^3}{\sqrt{\pi}} \frac{d\mu dv_2 v_2^2 e^{-\beta^2 v_2^2} \sqrt{v_1^2 + v_2^2 - 2v_1 v_2 \mu}}{V(v_1)}.$$

To properly select v_2 and μ we must find another probability distribution which is independent of v_1 . First, let us replace v_r by the maximum possible value of v_r , namely $v_{r\max} = v_1 + v_2$.

Calling this function

$$g(v_2, \mu | v_1) d\mu dv_2 = \frac{2\beta^3}{\sqrt{\pi}} \frac{d\mu dv_2 v_2^2 e^{-\beta^2 v_2^2} (v_1 + v_2)}{V(v_1)},$$

we see that g is always larger than p .

It can also be shown that $V(v_1)/v_1 \geq 1$, approaching 1 at $v_1 = \infty$, and that $V(v_1)$ has a minimum (at $v_1 = 0$) of $2/(\beta \sqrt{\pi})$, since

$$V(v_1) = \frac{1}{\beta \sqrt{\pi}} e^{-\beta^2 v_1^2} + \left(\frac{1}{2\beta^2 v_1} + v_1 \right) \mathfrak{E}_1(\beta^2 v_1)$$

where

$$\xi_2(x) = \frac{2}{\sqrt{\pi}} \int_0^x e^{-t^2} dt \quad .$$

Replacing $g(v_2, \mu | v_1)$ by

$$h(v_2, \mu | v_1) = \frac{2\beta^3}{\sqrt{\pi}} v_2^2 e^{-\beta^2 v_2^2} \left(1 + \beta \frac{\sqrt{\pi}}{2} v_2 \right)$$

therefore eliminates the dependence upon v_1 , while maintaining $h > p$ everywhere.

$$\int_{-1}^1 \int_0^\infty h(v_2) dv_2 d\mu = 2 \left(\frac{2\beta^3}{\sqrt{\pi}} \right) \int_0^\infty \left[\frac{\beta\sqrt{\pi}}{2} v_2^3 + v_2^2 \right] e^{-\beta^2 v_2^2} dv_2$$

$$= 2$$

$$\therefore \int_0^{v_2} h(v') dv' = \frac{4\beta^3}{\sqrt{\pi}} \int_0^{v_2} \left[\frac{\beta\sqrt{\pi}}{2} v'^3 + v'^2 \right] e^{-\beta^2 v'^2} dv'$$

$$= \psi(v_2) \quad .$$

$$\frac{\psi(v_2)}{\psi(\infty)} = \frac{2\beta^3}{\sqrt{\pi}} \int_0^{v_2} \left[\frac{\beta\sqrt{\pi}}{2} v'^3 + v'^2 \right] e^{-\beta^2 v'^2} dv' \quad .$$

Letting $U = \beta v'$ and $dU = \beta dv'$,

$$\xi = \frac{\psi(\beta v_2)}{\psi(\infty)} = \int_0^{\beta v_2(\xi)} U^2 \left(U + \frac{2}{\sqrt{\pi}} \right) e^{-U^2} dU \quad .$$

We then can select v_2 randomly from a table of $[\beta v_2(\xi)]$ by dividing the selected tabular value by β . Random direction cosines, α'' , β'' , and γ'' , are then chosen isotropically, from which $\mu = \alpha\alpha'' + \beta\beta'' + \gamma\gamma''$ and v_r are calculated. Another random number is then picked and compared with

$$\frac{p}{h} = \frac{v_r}{v(v_1) \left(1 + \frac{\beta\sqrt{\pi}}{2} v_2 \right)} \quad .$$

If the random number, ξ_2 , is less than p/h , we accept v_2 , α'' , β'' , γ'' . If not, we select a new v_2 , etc., and repeat the process until one set of parameters is accepted. The technique just described may be found in Reference 6. An extension of it follows. If Σ_s is not a constant, but is a function of v_r , the procedure becomes a bit more complicated. We do not treat the case where Σ_s is an arbitrary function of v_r but allow it to have the following form:

$$\Sigma_s(v_r) = \Sigma_0 + \Sigma_1 e^{-\Sigma_2 v_r^2}.$$

For this case, let us define $\mathcal{R}$ as $\Sigma_0 V(v_1)$, where

$$\begin{aligned} V(v_1) = \frac{1}{\Sigma_0} & \left[\Sigma_0 \left\{ \frac{1}{\beta\sqrt{\pi}} e^{-\beta^2 v_1^2} + \left(\frac{1}{2\beta^2 v_1} + v_1 \right) \text{erf}(\beta v_1) \right\} \right. \\ & \left. + \frac{\Sigma_1 \beta^3}{(\beta^2 + \Sigma_2)^2} \left\{ e^{-\beta^2 v_1^2} + \left(\frac{\sqrt{\beta^2 + \Sigma_2}}{2\beta^2 v_1} + \frac{\beta^2 v_1}{\sqrt{\beta^2 + \Sigma_2}} \right) \text{erf} \left(\frac{\beta v_1}{\sqrt{\beta^2 + \Sigma_2}} \right) e^{-\frac{\Sigma_2 v_1^2 \beta^2}{\beta^2 + \Sigma_2}} \right\} \right] \end{aligned}$$

(A detailed derivation of $V(v_1)$ may be found in Reference 4.) Then

$$p(v_2, \mu | v_1) dv_2 d\mu = \frac{2\beta^3}{\sqrt{\pi}} d\mu dv_2 v_2^2 e^{-\beta^2 v_2^2} v_r \left(\Sigma_0 + \Sigma_1 e^{-\Sigma_2 v_r^2} \right) / \Sigma_0 V(v_1)$$

and

$$g(v_2, \mu | v_1) dv_2 d\mu = \frac{2\beta^3}{\sqrt{\pi}} \frac{v_2^2 e^{-\beta^2 v_2^2} (\Sigma_0 + \Sigma_1) (v_1 + v_2)}{\Sigma_0 V(v_1)}$$

Setting

$$h(v_2) dv_2 d\mu = \frac{2\beta^3}{\sqrt{\pi}} \frac{v_2^2 e^{-\beta^2 v_2^2}}{\Sigma_0} (\Sigma_0 + \Sigma_1) \left(1 + \frac{\beta\sqrt{\pi}}{2} v_2 \right) dv_2 d\mu$$

and

$$\frac{p}{h} = \frac{\left(\Sigma_0 + \Sigma_1 e^{-\Sigma_2 v_r^2} \right) v_r}{\left(\Sigma_0 + \Sigma_1 \right) V(v_1) \left(1 + \frac{\sqrt{\pi}}{2} \beta v_2 \right)},$$

we can select v_2 from the same table as we do for the case when Σ_s is constant, and proceed in the same manner as for that situation. To save computing time, we define Σ_0' to be $\Sigma_0/(\Sigma_0 + \Sigma_1)$ and Σ_1' to be $\Sigma_1/(\Sigma_0 + \Sigma_1)$ if and only if $\Sigma_1 \neq 0$

Then, for $\Sigma_s = \text{constant}$,

$$\frac{p}{h} = \frac{v_r}{V(v_1) \left(1 + \frac{\sqrt{\pi}}{2} \beta v_2\right)}, \quad \mathcal{R} \equiv \Sigma_s V(v_1),$$

while for

$$\Sigma_s = \Sigma_0 + \Sigma_1 e^{-\Sigma_2 v_r^2}, \quad \frac{p}{h} = \frac{\left(\Sigma_0' + \Sigma_1' e^{-\Sigma_2 v_r^2}\right) v_r}{V(v_1) \left(1 + \frac{\pi \beta}{2} v_2\right)}$$

Once v_2 , α'' , β'' , and γ'' are accepted, we obtain ω_1 , α' , β' , and γ' , the speed and direction cosines of the neutron after collision, in the following manner. From the laws of collision mechanics, we have the following information:

1) $\vec{V}_c = \vec{W}_c$ where $\vec{V}_c$ and $\vec{W}_c$ are the velocities of the center of mass before and after collision, respectively.

2) $v_r^2 = \omega_2^2$ where v_r and ω_r are the relative speeds of the neutron with respect to the colliding nucleus before and after collision, respectively.

3) $\vec{v}_r = \vec{v}_1 - \vec{v}_2$ and $\vec{\omega}_r = \vec{\omega}_1 - \vec{\omega}_2$ by definition of relative velocity.

4) $\vec{v}_1 + M_{th} \vec{v}_2 = (1 + M_{th}) \vec{V}_c$, and $\vec{\omega}_1 + M_{th} \vec{\omega}_2 = (1 + M_{th}) \vec{W}_c$ by definition of the center of mass. M_{th} is the ratio of the mass of the nucleus to the mass of the neutron.

Eliminating $\vec{\omega}_2$ by use of (3) and (4):

$$\vec{\omega}_1 = \vec{V}_c + \frac{M_{th}}{1 + M_{th}} \vec{\omega}_r.$$

Again, using (4) to eliminate $\vec{V}_c$, we have:

$$\vec{\omega}_1 = \frac{1}{1 + M_{th}} [\vec{v}_1 + M_{th} (\vec{v}_2 + \vec{\omega}_r)],$$

letting $\omega_1 = |\vec{\omega}_1|$, we have

$$\alpha' = \frac{1}{\omega_1 (1 + M_{th})} \left[v_1 \alpha + M_{th} (v_2 \alpha'' + v_r \alpha_r) \right], \text{ etc.},$$

since $|\vec{\omega}_r| = |\vec{v}_r| = v_r$, and α_r , β_r , and γ_r are selected isotropically. α' , β' , γ' are, thus, the new direction cosines of the neutron, after collision.

Since $\alpha'^2 + \beta'^2 + \gamma'^2 = 1$,

$$E' = \frac{\omega_1^2}{2} = \frac{1}{2(1 + M_{th})^2} \left\{ \begin{aligned} & [v_1 \alpha + M_{th} (v_2 \alpha'' + v_r \alpha_r)]^2 \\ & + [v_1 \beta + M_{th} (v_2 \beta'' + v_r \beta_r)]^2 \\ & + [v_1 \gamma + M_{th} (v_2 \gamma'' + v_r \gamma_r)]^2 \end{aligned} \right\}$$

while

$$\begin{aligned} \alpha' &= \frac{v_1 \alpha + M_{th} (v_2 \alpha'' + v_r \alpha_r)}{(1 + M_{th}) \sqrt{2E'}} \\ \beta' &= \frac{v_1 \beta + M_{th} (v_2 \beta'' + v_r \beta_r)}{(1 + M_{th}) \sqrt{2E'}} \\ \gamma' &= \frac{v_1 \gamma + M_{th} (v_2 \gamma'' + v_r \gamma_r)}{(1 + M_{th}) \sqrt{2E'}} \end{aligned}$$

When $v_2 \ll v_1$ on the average, we may regard v_2 as 0. v_r then becomes equal to v_1 . Then

$$\begin{aligned} \alpha' &= \frac{v_1 \alpha + M_{th} v_1 \alpha_r}{(1 + M_{th}) \sqrt{2E'}} = \frac{v_1 (\alpha + M_{th} \alpha_r)}{(1 + M_{th}) \sqrt{2E'}} \\ E' &= \frac{v_1^2}{2(1 + M_{th})^2} \left\{ \alpha^2 + \beta^2 + \gamma^2 + 2M_{th} (\alpha \alpha_r + \beta \beta_r + \gamma \gamma_r) \right. \\ &\quad \left. + M_{th}^2 (\alpha_r^2 + \beta_r^2 + \gamma_r^2) \right\} \end{aligned}$$

Therefore,

$$E' = \frac{E}{(1 + M_{th})^2} (1 + 2\mu M_{th} + M_{th}^2)$$

where $\mu = \alpha \alpha_r + \beta \beta_r + \gamma \gamma_r$. (E is the energy of the neutron prior to collision).

Then

$$\alpha' = \frac{\alpha + M_{th} \alpha_r}{\sqrt{1 + 2M_{th}\mu + M_{th}^2}} = \frac{\alpha + M_{th} \alpha_r}{C}$$

$$\beta' = \frac{\beta + M_{th} \beta_r}{C}, \gamma' = \frac{\gamma + M_{th} \gamma_r}{C}$$

Equating M_{th} to A , and $\alpha_r, \beta_r, \gamma_r$ to $\alpha'', \beta'', \gamma''$ in III-A-7-a, we obtain the coordinates of a neutron subsequent to an elastic collision in the energy ranges above thermal energies.

Note that the thermal cross-section library must contain (for any isotope for which the above thermal model is to be used) a total cross section which is equal to the effective scattering cross-section $\mathcal{R}(v)/v$ plus $\sigma_a(v)$ in order that detailed balance may be preserved. The tables for the relative velocities $V(v)$, the effective total cross sections, and the effective scattering cross sections are on the HWOCR-SAFE cross-section library tape. Note that these tables are temperature dependent.

B METHODS OF ESTIMATION

Based on the analysis of variance for collision-type estimators and track-length estimators shown in Appendix A, it appears that for regions thicker than 1.257 mfp that collision-type estimators are preferable. As a result, collision-type estimation is used in most regions of the reactor. However, for those regions (such as the tubular walls and the cladding of the fuel rods) for which collision estimators would not be satisfactory, a method was developed for estimating reaction rates which is superior to pure track-length estimation while avoiding the undersampling which would result from collision estimation.

Statistical estimation combined with the method of forced collisions was utilized to provide a collision point on every pass through a thin region. The reaction in the thin region was then processed, after which (to avoid particle splitting) the coordinates of the particle were chosen to be either those of the collision point in the region or the point of escape at the boundary of the region. This choice was randomly based on the statistical weight of the neutron subsequent to the reaction at each of the above mentioned coordinate points. The statistical weight of the neutron to be followed at either point was set equal to the sum of the statistical weights occurring subsequent to the reaction in the region and emerging from it. The detailed procedure is presented in Appendix B.

The point of this method is that it supplements pure statistical estimation with a statistically improved treatment of scattering collisions in thin regions.

IV. TALLYING PROCEDURES AND OUTPUT DESCRIPTION

In the first line of output, the quantities printed are (from left to right):

- HISTS: The number of neutron histories run to the time of printing.
- FISS: The number of neutron histories ending in a thermal fission.
- K INFINITY: The total production per neutron history.
- P: The absorption below 1 ev divided by the total absorption.
- EPSILON: The total production divided by the production below 1 ev.
- TH. UTIL: The absorption in fuel (below 1 ev) divided by the total absorption (below 1 ev).
- TOTAL ABS: The total absorption per neutron history. This will depart from unity due to multiplicative processes such as n, 2n reactions. The HWOCR-SAFE code does not treat n, 2n reactions as negative absorption. Any values of the total absorption slightly less than one are due to truncation in the tallying process.
- ETA: The thermal production (below 1 ev) divided by the thermal absorption in the fuel (below 1 ev).

One can see that K is equal to the product of P, EPSILON, ETA, TH. UTIL., and TOTAL ABS.

The volume fraction of fuel of Type I is equal to the volume of all zones J for which NSO (J) = 1 (this indicates that the zone contains fuel) and IZTYPE (J) = I, divided by the total cell volume. The printed quantity POWER is then equal to the power generated in Type I divided by the volume fraction of Type I. The power generated in Type I is the fission rate times the factor ENUCON (input to the code via the cross-section tape) for converting fission rate to power. The presently used value is unity for all fissionable isotopes so that in the sample output presented in this report, the power is identical to the fission rate.

The next section of the output gives the fission and capture (excluding fission) rates between the energy bands indicated. These energy bands are defined by the input array ECAP, where the low energy band is assumed to be bounded below by zero and the high energy band is assumed to begin at 10 Mev. Thus, the ECAP input array defines only the intermediate group boundaries. In the fuel zones, the first six of a possible eight isotopes which are specified in the IDZONE array are the six isotopes for which the fission and capture monitoring is done. For example, in the sample calculation shown in Section V-C, IDZONE (1, 1) to (3, 1) are 2, 1, and 13 respectively. These are the ID numbers read in from the cross-section tape defining U^{235} , U^{238} and carbon at 1000°F. Thus, under the heading "ISOTOPE IN FUEL,"

Isotope number 1 refers to U^{235} ;

Isotope number 2 refers to U^{238} ; and

Isotope number 3 refers to the carbon contained in the fuel.

The next section of the output gives the absorption and scattering rates by zone and energy group. The absorption rate is found by dividing the cumulative absorptions per history in a given energy group by the volume fraction of the zone. The volume fraction of a zone is found by dividing the

total volume of all regions assigned the given zone number by the total cell volume. For example, if there are 12 rods of Type 5, and Zone 10 is contained in rod Type 5, then the volume fraction of Zone 10 is 12 times the volume of Zone 10 divided by the total cell volume.

The next part of the output gives the group averaged macroscopic values of $\nu\Sigma_f$ and Σ_f for each energy group. These consist of the Monte Carlo estimates of

$$\nu\Sigma_f = \frac{\iint \nu\Sigma_f \phi \, dx \, dE}{\iint \phi \, dx \, dE}$$

and

$$\Sigma_f = \frac{\iint \Sigma_f \phi \, dx \, dE}{\iint \phi \, dx \, dE}$$

The flux ϕ is summed over the entire nonmoderator volume (the region designated as non-D₂O in the next paragraph) and not merely the volume of zones containing fuel.

The next section gives the group averaged macroscopic value of the absorption and elastic scattering cross sections, MUBAR ($\bar{\mu}$), and the group flux for each energy group for two regions defined by the headings D₂O and non-D₂O. The region referred to as D₂O is that which lies between the boundary designated as NBOWAL and the cell boundaries. The non-D₂O region lies within the boundary designated as NBOWAL. The absorption cross section is obtained by dividing the total absorptions in the given region and in the given energy band by the total flux in the same region and energy band. The elastic scattering cross section, similarly, is equal to the total elastic scatterings in the region and energy band in question divided by the total flux in the same region and energy band. The printed group flux is equal to the above mentioned total flux normalized to the volume fraction of the region in question. MUBAR is the cosine of the laboratory scattering angle for ingroup scatterings averaged over the elastic and inelastic scattering collision density in the energy group and spatial region indicated.

Next, the total scattering transfer matrices for D₂O and for non-D₂O regions are printed. These represent the scattering from incident Group I to emergent Group J normalized to the total flux in the incident Group I. Note that upscattering from the thermal energy group is included.

Next, the first four thermal spectrum velocity moments averaged over the neutron density are printed for each zone. These are obtained by observing that the neutron density is equal to the flux divided by the neutron velocity. The neutron density is thus obtained as the accumulated product of the flux and the reciprocal of the neutron velocity, V , where V is in units of (ev/amu)^{1/2}. In these units, $V_{2200} = \sqrt{2(0.0253)}$. The N^{th} thermal spectrum velocity moment is then obtained as the accumulated product of the flux and the neutron velocity raised to the $N-1$ power, normalized to the neutron density. The quantity printed in the column headed "THERMAL FLUX" is the above-mentioned thermal flux normalized to the volume fraction of the appropriate zone.

The last section of batch output is the energy deposition in the carbon and hydrogen of zone NZIB (which contains the coolant in the HWOCR design). It was of interest to know the distribution of amounts of energy deposition per collision as well as the total energy deposited. Thus, the user must input the array EDEP which specifies the energy bands into which the energy losses are tallied. NDEP (≤ 9) non-zero energies (in ev) are input in array EDEP in descending order, where the lowest energy boundary is assumed to be zero. The total energy deposited (in ev) in the moderator per source neutron is also output.

The energy deposition in hydrogen is tallied separately from that of other materials. For zones other than NZCEL, energy deposition for all other materials in a region are accumulated together and the result is printed under the "CARBON" heading. For the coolant material proposed for the HWOCR, this is an exact procedure since the coolant contains only hydrogen and carbon.

For an annular representation run, the moderator zone is still designated as NZCEL. The coolant zone (NZIB in the exact representation) may now be divided into several non-adjacent rings. By designating the input quantity IZTYPE (I) = 100 for all such coolant rings I, the total energy deposition for these zones will be accumulated and printed as energy deposited in the coolant in the manner described above.

Upon completion of the total number of histories requested, the following statistical evaluation of results is printed:

- 1) Values of K INFINITY, P, EPSILON, TH. UTIL., TOTAL ABS., and ETA which would result if the first n histories were neglected. The value n appears under the heading HISTS. This printout is of use in determining whether or not there are source settling difficulties in the problem being run.
- 2) The individual batch results for each set of NDHIST histories ending with the history number printed in the column labelled HISTS.
- 3) The value of the standard deviation for a set of NDHIST histories for the quantities appearing in the individual batch results. The standard deviation of the mean values of these quantities may be obtained by dividing these standard deviations by a quantity equal to $(\text{NHIST}/\text{NDHIST})^{1/2}$.

V. RECOMMENDED INPUT PREPARATION PROCEDURE FOR DETAILED GEOMETRIC CASES

A detailed description of the input data required to successfully utilize the HWOCR-SAFE Code and the manner in which it is to be prepared is described in this section.

As is the case with many codes designed for a specialized application, the final product may end up with more flexibility or capability than the developer had specifically in mind while creating it. Utilization of such features is encouraged (and some mention of these may appear in various places in this report), but caution should be exercised in their use and in the interpretation of such results.

Section A will assist the user in laying out his case pictorially, which should be done prior to preparing the data sheets.

Section B will list, location by location, the input data and their specific meanings. The use of sample cases prepared on standard input sheets to illustrate the discussion will enable the reader to immediately see the numerical form and the meaning of the data with a minimum of references to other parts of the report.

A. PICTORIAL LAYOUT

1) Make a reasonable sketch of the reactor cell such as shown in Figure 3.

2) Record the dimensions of the cell in centimeters. The perpendicular distance between cell boundaries perpendicular to the X-axis is known as CWIDTH. Similarly, the distance between the cell boundaries perpendicular to the Y-axis is called CDEPTH.

3) One can assign identifying numbers to the rods and record the X and Y coordinates of the centers of the rods in the main coordinate system.

4) At this point, we come to the description of individual rods of each type. Each zone should have an identifying number. The zones containing fissionable materials should have the lowest numbers for maximum operating efficiency of the code. Boundary surface equations should be written down at this time, identifying numbers assigned to them and indicated on the sketches. These equations are written in the intra-rod coordinate system and must be in the following form: $X^2 + Y^2 - BK(I) = 0$, $BK(I) > 0$.

5) Now that the boundary identification and zone identification numbers have been assigned, the user should prepare a set of numbers we shall call MUU (I, J) where MUU (I, J) is the J^{th} boundary identification number assigned to the I^{th} zone. As an example, suppose a zone with identification number 10 was defined by a set of surfaces with identification numbers 3 and 5. Then we would have the following set of MUUs for Zone 10:

$$\text{MUU}(10, 1) = 3$$

$$\text{MUU}(10, 2) = 5.$$

Another set of numbers, GAY (I, J), will also be needed and should be set up at this time. The indices I and J have the same meaning as in the MUU (I, J) set. The GAY (I, J) are evaluated as follows:

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Figure 3. Sketch of Actual Geometry Sample Case

- a) Write down boundary surface equation $MUU(I, J)$ in the form indicated in Section V. A. 4 above. In this form, the equation represents the locus of all points (X_0, Y_0) lying on the surface. For such an (X_0, Y_0) , the right-hand side of the equation is 0. For any point not on the surface, (X_1, Y_1) , then, the right-hand side will not be 0, but may, in general, be positive or negative.
- b) Evaluate the right-hand side of boundary $MUU(I, J)$ for any point (X_1, Y_1) within Zone I.
- c) If the right-hand side is positive, $GAY(I, J) = -1$. If the right-hand side is negative, $GAY(I, J) = +1$.
- d) There must be a $GAY(I, J)$ for every $MUU(I, J)$.
- 6) The code also requires a knowledge of which boundary surfaces are outer boundaries of the various rod types. This set of numbers is called $NPHI(J)$ where $NPHI(J)$ is the outer boundary of rod Type J.

B. INPUT DESCRIPTION

The first block of input data is on file with the program deck and should not, in general, be changed. These data consist of the fission spectrum and thermal atom velocity distribution tables.

The next two cards which are to be supplied by the user are:

- 1) A title card containing any identifying information the user wishes printed out.
- 2) A card containing the starting random number RDUM.

The sample load sheet on page 38 gives an example of a data input sheet for the above two cards.

Following the card containing the starting random number is a set of cards known as the "DATA" array. Each card has the relative location of the first word on the card entered, right-adjusted, in the first 12 columns of the card. The data entries on the card are entered into a set of five consecutive locations in the "DATA" array, beginning with this first location. Entries having a value of "0." need not be entered. All numerical entries should contain a decimal point in the appropriate place.

A detailed description of the meaning and location of each entry is presented on pages 34 through 37.

An important point to note is the entry of a (-) sign in column "1" of the last card to be read into the DATA array.

Standard sheets which may be submitted for keypunching are used to illustrate a sample case

<u>LOCATION IN DATA ARRAY</u>	<u>FORTRAN NAME</u>	<u>EXPLANATION</u>
DATA (1)	NHIST	Total number of histories to be run
DATA (2)	NDHIST	Number of histories between printouts (batch size) (maximum number of batches = 100)
DATA (3)	NRTYP	Number of rod types ($NRTYP \leq 6$)
DATA (4)	NROD	Number of rods ($NROD \leq 40$)
DATA (5)		<u>Not used</u>
DATA (6)	NBIWAL	Boundary number of the inner wall
DATA (7)	NBOWAL	Boundary number of the outer wall
DATA (8) to (13)	NBOUND (1) to (6)	NBOUND (I) is the number of boundary equations used for rod type I

<u>LOCATION IN DATA ARRAY</u>	<u>FORTTRAN NAME</u>	<u>EXPLANATION</u>
DATA (14) to (19)	NZONE (1) to (6)	NZONE (I) is the number of zones in rod type I
DATA (20) to (39)	IZTYPE (1) to (20)	IZTYPE (I) is the rod type containing zone I. Note: If annular representation is being used, see Section VI
DATA (40)	IZSTOR	Zone in which first history is to start
DATA (41)	IRSTOR	Rod in which first history is to start
DATA (42) to (61)	NB (1) to (20)	NB (I) is the number of boundaries defining the I th zone
DATA (62) to (101)	MUU (20, 2)	MUU (I, J) is the identification number of the J th boundary describing Zone I
DATA (102) to (107)	NPHI (1) to (6)	NPHI (I) is the outer boundary of rod Type I
DATA (108) to (113)	NADJRZ (1) to (6)	NADJRZ (I) is the outer zone of rod Type I
DATA (114) to (133)	NADJPZ (1) to (20)	NADJPZ (I) is the number of zones adjacent to Zone I
DATA (134)	IZP (2, 20)	IZP (K, I) is the K th zone adjacent to Zone I
DATA (174)	NTHRM	Number of materials for which upscattering is to be allowed (≤ 6)
DATA (175) to (180)	IDTHRM (1) to (6)	ID numbers of the upscattering materials in ascending order
DATA (181)	NM	Total number of materials in problem (≤ 18)
DATA (182)	MAT (1) to (18)	ID numbers of materials needed for this problem in ascending order
DATA (207)	NMZONE (1) to (20)	NMZONE (I) is the number of materials in Zone I (≤ 8)
DATA (227)	IDZONE (8, 20)	IDZONE (1, J) to IDZONE (8, J) are the ID numbers of the materials in Zone J
DATA (387)	NZIB	Zone number of the coolant
DATA (388)	NZCEL	Zone number of the moderator
DATA (389)	NDEP	Number of energy boundaries between 0 and 10 Mev (excluding 0 and 10 Mev) defining the energy deposition groups

<u>LOCATION IN DATA ARRAY</u>	<u>FORTTRAN NAME</u>	<u>EXPLANATION</u>
DATA (390)	NSO (1) to (20)	NSO (I) = 1: Zone I contains fuel NSO (I) = 3: statistical estimation is to be used in Zone I NSO (I) = 2: absorption weighting is to be used in Zone I NSO (I) = 0: None of the above conditions apply
DATA (410)	IRTYP (1) to (40)	IRTYP (I) is the rod type describing rod I.
DATA (450)	NPUNCH	= 0: punch restart cards after NHIST histories only = n: punch restart cards upon completion of every n x NDHIST histories (for example NPUNCH = 1 specifies that restart cards are to be punched upon completion of each batch of NDHIST histories)
DATA (451)	NSTART	= 1: restart cards are to be read in = 0: restart option is not being used
DATA (452)	NANULR	= 0: actual geometry = 1: annular representation is being used
DATA (459) to (464)	RADIUS (1) to (6)	RADIUS (I) is the radius of rod Type I
DATA (465)	DELTA	Kick factor (see page 15)
DATA (466) to (625)	CENTER (4, 40)	X and Y coordinates of the centers of the rods. (The X and Y coordinates of the I th rod are entered as CENTER (1, I) and CENTER (2, I) respectively)
DATA (626) to (665)	GAY (20, 2)	GAY (I, J) refers to the J th boundary describing Zone I. Its value is + 1. or - 1.
DATA (666) to (671)		<u>Not used</u>
DATA (672) to (696)	BK (1) to (25)	BK (I) is the square of the radius of the I th boundary
DATA (697) to (856)	DZONE (8, 20)	Atomic number densities corresponding to the ID numbers listed in the IDZONE array
DATA (857)	CRAD	Outer radius of the fuel element } Wall lies between the inner and outer radii
DATA (858)	CIRAD	
DATA (859)	CWIDTH	Width of the cell
DATA (860)	CDEPTH	Depth of the cell
DATA (861)	XSTORE	X coordinate at which first source particle is to start

<u>LOCATION IN DATA ARRAY</u>	<u>FORTTRAN NAME</u>	<u>EXPLANATION</u>
DATA (862)	YSTORE	Y coordinate at which first source particle is to start
DATA (863) to (871)	EDEP (1) to (9)	Energy deposition group boundaries (0 is assumed for the lower boundary and 10 Mev is assumed for the upper boundary. These two values should not be input)
DATA (872) to (874)	ECAP (1) to (3)	Capture and fission monitoring group boundaries (lower = 0, upper = 10 Mev are assumed and should not be input)
DATA (875) to (880)	EKT (1) to (6)	EKT (I) is the thermal temperature in ev of the I th upscatterer
DATA (881)	BMASS	Mass above which isotropic scattering in the laboratory system is assumed
DATA (882)	WC	Weight above which absorption weighting is used in the thermal energy range in regions in which NSO $\neq$ 2.

C. LOAD SHEETS FOR SAMPLE CASE

The data input sheets for the explicit geometry sample case are presented on pages 38 through 59.

FORTRAN FIXED 10 DIGIT DECIMAL DATA

DECK NO. _____ PROGRAMMER _____ DATE _____ PAGE _____ of _____ JOB NO. _____

NUMBER		IDENTIFICATION	DESCRIPTION DO NOT KEY PUNCH
1	H.W.Ø.C.R. S.A.F.E.		TITLE CARD. The first 72 columns will be printed at the beginning of the output.
13	T E.S.T. C.A.S.E.		
25	E X.P.L.I.C.I.T. G.E.Ø		
37	.N.E.W. 3.7. R.Ø.D		
49	.N.E.W. C.Ø.M.M.Ø.N	73 80	
61	1.1.-8-6.6.		
1	3 1 3 7 4 6 5 2 7 0 3 1		Starting random number. It must be in the octal number system (no digit > 7). The right most digit must be odd. The largest number usable is 343277244615. (This was prepared for the IBM 7094. For the IBM system 360 the random number must consist of 8 hexadecimal digits beginning in Column 5).
13			
25			
37			
49		73 80	
61			
1			
13			
25			
37			
49		73 80	
61			
1			
13			
25			
37			
49		73 80	
61			

FORTRAN FIXED 10 DIGIT DECIMAL DATA

Explicit
DECK NO. Geometry PROGRAMMER _____ DATE _____ PAGE 1 of 21 JOB NO. _____

NUMBER	IDENTIFICATION	DESCRIPTION DO NOT KEY PUNCH
1	1	
13	4 0 0 0 .	NHIST total number of histories to be run
25	5 0 .	NDHIST number of histories between printout (batchsize)
37	6 .	NRTYP number of rod types
49	3 7 .	NRØD number of rods
61		
1	6	
13	5 .	NBIWAL boundary number of the inner wall
25	8 .	NBØWAL boundary number of the outer wall
37	2 .	NBØUND (1) NBØUND (1) is the number of boundary
49	2 .	NBØUND (2) equations used for rod type I.
61	2 .	NBØUND (3)
1	1 1	
13	2 .	NBØUND (4)
25	2 .	NBØUND (5)
37	2 .	NBØUND (6)
49		
61		
1	1 4	
13	2 .	NZØNE (1) NZØNE (1) is the number of zones in
25	2 .	NZØNE (2) rod type I.
37	2 .	NZØNE (3)
49	2 .	NZØNE (4)
61	2 .	NZØNE (5)

FORTRAN FIXED IO DIGIT DECIMAL DATA

DECK NO. _____ PROGRAMMER _____ DATE _____ PAGE 2 of 21 JOB NO. _____

NUMBER		IDENTIFICATION	DESCRIPTION DO NOT KEY PUNCH
1	1 9		
13	2		NZONE (6)
25			
37			
49			
61		73 80	
1	2 0		
13	1 .		IZTYPE (1) IZTYPE (1) is the rod type containing
25	2 .		IZTYPE (2) zone I.
37	3 .		IZTYPE (3)
49	4 .		IZTYPE (4)
61	5 .	73 80	IZTYPE (5)
1	2 5		
13	6 .		IZTYPE (6)
25	1 .		IZTYPE (7)
37	2 .		IZTYPE (8)
49	3 .		IZTYPE (9)
61	4 .	73 80	IZTYPE (10)
1	3 0		
13	5 .		IZTYPE (11)
25	6 .		IZTYPE (12)
37			
49			
61		73 80	

FORTRAN FIXED 10 DIGIT DECIMAL DATA

DECK NO. _____ PROGRAMMER _____ DATE _____ PAGE 3 of 21 JOB NO. _____

NUMBER	IDENTIFICATION	DESCRIPTION DO NOT KEY PUNCH
1 4 0		
13 5		IZSTOR zone in which first history is to start
25 2 6		IRSTOR rod in which first history is to start
37 1		NB (1) NB(I) is the number of boundaries defining
49 1	73 80	NB (2) the 1 th zone
61 1		NB (3)
1 4 5		
13 1		NB (4)
25 1		NB (5)
37 1		NB (6)
49 2	73 80	NB (7)
61 2		NB (8)
1 5 0		
13 2		NB (9)
25 2		NB (10)
37 2		NB (11)
49 2	73 80	NB (12)
61 1		NB (13)
1 5 5		
13 2		NB (14)
25 2		NB (15)
37 2		NB (16)
49 4	73 80	NB (17)
61		

FORTRAN FIXED 10 DIGIT DECIMAL DATA

DECK NO. _____ PROGRAMMER _____ DATE _____ PAGE 4 of 21 JOB NO. _____

	NUMBER	IDENTIFICATION	DESCRIPTION DO NOT KEY PUNCH
1	6 2		MUU (I, J) is the identification number of the J th boundary
13	1 .		describing zone I. The number of boundaries describing a
25	1 .		given zone is limited to 2.
37	1 .		
49	1 .	73 .80	
61	1 .		
1	6 7		
13	3 .		
25	1 .		
37	1 .		
49	1 .	73 .80	
61	1 .		
1	7 2		
13	1 .		
25	3 .		
37	5 .		
49	5 .	73 .80	
61	6 .		
1	7 7		
13	7 .		
25			
37			
49		73 .80	
61			

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FORTRAN FIXED 10 DIGIT DECIMAL DATA

DECK NO. _____ PROGRAMMER _____ DATE _____ PAGE 5 of 21 JOB NO. _____

	NUMBER	IDENTIFICATION	DESCRIPTION DO NOT KEY PUNCH
1	8 8		
13	2 .		
25	2 .		
37	2 .		
49	2 .	73 80	
61	2 .		
1	9 3		
13	4 .		
25	0 .		
37	6 .		
49	7 .	73 80	
61	8 .		
1	1 0 2		
13	2 .		NPHI (I) is the outer boundary of rod type I
25	2 .		
37	2 .		
49	2 .	73 80	
61	2 .		
1	1 0 7		
13	4 .		
25	7 .		NADJRZ (I) is the outer zone of rod type I.
37	8 .		
49	9 .	73 80	
61	1 0 .		

FORTRAN FIXED 10 DIGIT DECIMAL DATA

DECK NO. _____ PROGRAMMER _____ DATE _____ PAGE 6 of 21 JOB NO. _____

	NUMBER	IDENTIFICATION	DESCRIPTION DO NOT KEY PUNCH
1	1 1 2		
13	1 1 .		
25	1 2 .		
37	1 .		NADJPZ (1) is the number of zones adjacent to zone 1.
49	1 .	73 80	
61	1 .		
1	1 1 7		
13	1 .		
25	1 .		
37	1 .		
49	1 .	73 80	NADJPZ (7) $\neq$ 2., since zone NZIB lies outside the rod
61	1 .		containing zone 7.
1	1 2 2		
13	1 .		
25	1 .		
37	1 .		
49	1 .	73 80	
61	1 .		NADJPZ (NZIB) does not include rods as adjacent zones.
1	1 2 7		
13	1 .		Zones lying between NZIB and NZCEL are regarded internally
25	2 .		as "wall" zones. Thus only zone 15 is "adjacent" to zone 14,
37	1 .		zone NZIB not being a "wall zone." Similarly, zone NZCEL
49		73 80	is not a "wall zone."
61			

FORTRAN FIXED 10 DIGIT DECIMAL DATA

DECK NO. _____ PROGRAMMER _____ DATE _____ PAGE 7 of 21 JOB NO. _____

	NUMBER	IDENTIFICATION	DESCRIPTION DO NOT KEY PUNCH
1	1 3 4		
13	7 .		IZP (K, I) is the K th zone adjacent to zone I.
25			
37	8 .		
49		73 80	
61	9 .		
1	1 4 0		
13	1 0 .		
25			
37	1 1 .		
49		73 80	
61	1 2 .		
1	1 4 6		
13	1 .		
25			
37	2 .		
49		73 80	
61	3 .		
1	1 5 2		
13	4 .		
25			
37	5 .		
49		73 80	
61	6 .		

FORTRAN FIXED 10 DIGIT DECIMAL DATA

DECK NO. _____ PROGRAMMER _____ DATE _____ PAGE 8 of 21 JOB NO. _____

	NUMBER	IDENTIFICATION	DESCRIPTION DO NOT KEY PUNCH
1	1 5 8		
13	1 4 .		
25			
37	1 5 .		
49		73 80	
61	1 4 .		
1	1 6 3		
13	1 6 .		
25	1 5 .		
37			
49	1 6 .	73 80	
61			
1	1 7 4		
13	6 .		NTHRM number of materials for which upscattering is to be allowed
25			
37			
49		73 80	
61			
1	1 7 5		
13	1 1 .		IDTHRM This array lists the ID numbers of the upscattering materials in ascending order.
25	1 3 .		
37	1 4 .		
49	1 5 .	73 80	
61	1 6 .		

FORTRAN FIXED 10 DIGIT DECIMAL DATA

DECK NO _____ PROGRAMMER _____ DATE _____ PAGE 9 of 21 JOB NO. _____

	NUMBER	IDENTIFICATION	DESCRIPTION DO NOT KEY PUNCH
1	1 8 0		
13	1 8 .		
25	1 1 .		NM total number of materials in problem
37	1 .		U238 (The MAT array lists the
49	2 .	73 80	U235 ID numbers needed in ascending order.)
61	1 0		Zirconium
1	1 8 5		
13	1 1 .		Carbon at coolant temperature
25	1 3 .		Carbon at fuel temperature
37	1 4 .		Hydrogen in H ₂ O at moderator temperature
49	1 5 .	73 80	Hydrogen in coolant at coolant temperature
61	1 6 .		Deuterium in D ₂ O at moderator temperature
1	1 9 0		
13	1 7 .		Aluminum
25	1 8 .		Oxygen in SAP
37	1 9 .		Oxygen in moderator
49		73 80	
61			
1	2 0 7		NMZONE (I) is the number of materials in zone I.
13	3 .		
25	3 .		
37	3 .		
49	3 .	73 80	
61	3 .		

FORTRAN FIXED 10 DIGIT DECIMAL DATA

DECK NO. _____ PROGRAMMER _____ DATE _____ PAGE 10 of 21 JOB NO. _____

	NUMBER	IDENTIFICATION	DESCRIPTION DO NOT KEY PUNCH
1	2 1 2		
13	3 .		
25	2 .		
37	2 .		
49	2 .	73 80	
61	2 .		
1	2 1 7		
13	2 .		
25	2 .		
37	2 .		
49	2 .	73 80	
61	0 .		Zone 15 is a void
1	2 2 2		
13	1 .		
25	3 .		
37			
49		73 80	
61			
1	2 2 7		IDZONE (1, J) to IDZONE (8, J) are the ID numbers of the
13	2 .		materials in zone J.
25	1 .		
37	1 3 .		Cards starting with locations 235, 243, 251, 259, 267 are
49		73 80	identical to this card representing zone 2 through 6.
61			

FORTRAN FIXED 10 DIGIT DECIMAL DATA

DECK NO. _____ PROGRAMMER _____ DATE _____ PAGE 11 of 21 JOB NO. _____

	NUMBER	IDENTIFICATION	DESCRIPTION DO NOT KEY PUNCH
1	2 7 5		
13	1 8 .		Cards starting with 283, 291, 299, 307, 315 are identical to this card representing zones 8 through 12. (Fuel rod cladding)
25	1 7 .		
37			
49		73.....80	
61			
1	3 2 3		
13	1 5 .		Zone 13 is zone NZIB and should have the materials of the medium adjacent to the rods.
25	1 1 .		
37			
49		73.....80	
61			
1	3 3 1		
13	1 8 .		
25	1 7 .		
37			
49		73.....80	
61			
1	3 4 7		Note that no entries are needed for void zones
13	1 0 .		
25			
37			
49		73.....80	
61			

FORTRAN FIXED 10 DIGIT DECIMAL DATA

DECK NO. _____ PROGRAMMER _____ DATE _____ PAGE 12 of 21 JOB NO. _____

	NUMBER	IDENTIFICATION	DESCRIPTION DO NOT KEY PUNCH
1	3.5.5		
13	1.6.		
25	1.4.		
37	1.9.		
49		73 80	
61			
1	3.8.7		
13	1.3.		NZIB
25	1.7.		NZCEL
37	6.		NDEP
49		73 80	
61			
1	3.9.0		NSO
13	1.		} Fuel zones
25	1.		
37	1.		
49	1.	73 80	
61	1.		
1	3.9.5		
13	1.		
25	3.		Statistical estimation is to be used in
37	3.		cladding zones
49	3.	73 80	
61	3.		

FORTRAN FIXED 10 DIGIT DECIMAL DATA

DECK NO. _____ PROGRAMMER _____ DATE _____ PAGE 13 of 21 JOB NO. _____

	NUMBER	IDENTIFICATION	DESCRIPTION DO NOT KEY PUNCH
1	4 0 0		
13	3 .		
25	3 .		
37	2 .		Absorption weighting is to be used in coolant
49	3 .	73	} statistical estimation is to be used in
61	3 .	80	
1	4 0 5		wall regions
13	3 .		
25	0 .		Moderator is an optically large region not containing fuel in
37			which it is desirable to end histories in an analog fashion.
49		73	
61		80	
1	4 1 0		
13	1 .		IRTYPE (I) is the rod type to which rod I belongs
25	2 .		
37	2 .		
49	2 .	73	
61	2 .	80	
1	4 1 5		
13	2 .		
25	2 .		
37	4 .		
49	3 .	73	
61	4 .	80	

FORTRAN FIXED 10 DIGIT DECIMAL DATA

DECK NO. _____ PROGRAMMER _____ DATE _____ PAGE 14 of 21 JOB NO. _____

	NUMBER	IDENTIFICATION	DESCRIPTION DO NOT KEY PUNCH
1	4 2 0		
13	3 .		
25	4 .		
37	3 .		
49	4 .	73	80
61	3 .		
1	4 2 5		
13	4 .		
25	3 .		
37	4 .		
49	3 .	73	80
61	5 .		
1	4 3 0		
13	5 .		
25	5 .		
37	5 .		
49	5 .	73	80
61	5 .		
1	4 3 5		
13	5 .		
25	5 .		
37	5 .		
49	5 .	73	80
61	5 .		

FORTRAN FIXED 10 DIGIT DECIMAL DATA

DECK NO. _____ PROGRAMMER _____ DATE _____ PAGE 15 of 21 JOB NO. _____

	NUMBER	IDENTIFICATION	DESCRIPTION DO NOT KEY PUNCH
1	4 4 0		
13	5		
25	6		
37	6		
49	6	73 80	
61	6		
1	4 4 5		
13	6		
25	6		
37			
49		73 80	
61			
1	4 5 0		
13	1		NPUNCH
25	1		NSTART
37	0		NANULR
49		73 80	
61			
1	4 5 9		RADIUS (I) is the radius of rod type I.
13	. 6 9 5 7 4 5 5		
25	. 6 9 5 7 4 5 5		
37	. 6 9 5 7 4 5 5		
49	. 6 9 5 7 4 5 5	73 80	
61	. 6 9 5 7 4 5 5		

FORTRAN FIXED 10 DIGIT DECIMAL DATA

DECK NO. _____ PROGRAMMER _____ DATE _____ PAGE 16 of 21 JOB NO. _____

NUMBER	IDENTIFICATION	DESCRIPTION DO NOT KEY PUNCH
1 4 6 4		
13 . 4 4 2 3 1 6 5		
25 . 0 0 0 1		DELTA
37		
49	73 80	
61		
1 4 6 6		The X and Y coordinates of the 1 th rod are entered as
13 0 . 0		CENTER (1, 1) and CENTER (2, 1) respectively.
25 0 . 0		
37		
49	73 80	
61		
1 4 7 0		
13 - 1 . 6 3 3 2 2 3		CENTER (1, 2)
25 0 . 0		CENTER (2, 2)
37		
49	73 80	
61		
1 4 7 4		
13 - . 8 1 6 6 1 1		CENTER (1, 3)
25 1 . 4 1 4 4 1 3		CENTER (2, 3)
37		The remainder of this array can be found in the printed
49	73 80	output in section V. E
61		

FORTRAN FIXED 10 DIGIT DECIMAL DATA

DECK NO. _____ PROGRAMMER _____ DATE _____ PAGE 17 of 21 JOB NO. _____

	NUMBER	IDENTIFICATION	DESCRIPTION DO NOT KEY PUNCH
1	6 2 6		GAY (I, J) refers to the J th boundary describing zone I.
13	1 . 0		See section V. A. Item 5
25	1 . 0		
37	1 . 0		
49	1 . 0	73	80
61	1 . 0		
1	6 3 1		
13	1 . 0		
25	- 1 . 0		
37	- 1 . 0		
49	- 1 . 0	73	80
61	- 1 . 0		
1	6 3 6		
13	- 1 . 0		
25	- 1 . 0		
37	1 . 0		
49	- 1 . 0	73	80
61	- 1 . 0		
1	6 4 1		
13	- 1 . 0		GAY (16, 1)
25			
37			
49		73	80
61			

FORTRAN FIXED 10 DIGIT DECIMAL DATA

DECK NO _____ PROGRAMMER _____ DATE _____ PAGE 18 of 21 JOB NO. _____

	NUMBER	IDENTIFICATION	DESCRIPTION DO NOT KEY PUNCH
1	6 5 2		
13	1 . 0		GAY (7, 2)
25	1 . 0		
37	1 . 0		
49	1 . 0	73	80
61	1 . 0		
1	6 5 7		
13	1 . 0		
25	0 . 0		
37	1 . 0		
49	1 . 0	73	80
61	1 . 0		
1	6 7 2		BK (I) is the square of the radius of the I th boundary
13	. 3 7 6 2 7 3 3		
25	. 4 8 4 0 6 1 8		
37	. 1 2 7 3 5 6 7		
49	. 1 9 5 6 4 3 9	73	80
61	2 6 . 6 1 2 7		
1	6 7 7		
13	2 9 . 7 1 1 7 7		
25	3 8 . 1 2 7 5 6		
37	4 0 . 0 0 0 7 2		
49		73	80
61			

FORTRAN FIXED 10 DIGIT DECIMAL DATA

DECK NO. _____ PROGRAMMER _____ DATE _____ PAGE 19 of 21 JOB NO. _____

	NUMBER	IDENTIFICATION	DESCRIPTION DO NOT KEY PUNCH
1	6 9 7		DZONE array contains the atomic number densities
13	. 0 0 0 4 0 9 5 2		corresponding to the ID numbers listed in the IDZONE array.
25	. 0 3 0 6 9 9		
37	. 0 3 2 4 4 4 3		
49		73 80	Cards starting with locations 705, 713, 721, 729, and 737 are
61			identical to this card.
1	7 4 5		
13	. 0 0 4 7 4 6 9 5		Cards starting with locations 753, 761, 769, 777, 785 are
25	. 0 5 6 9 7 9 9		identical to this card, representing the atomic number
37			densities of zones 8 through 12 (fuel rod cladding)
49		73 80	
61			
1	7 9 3		
13	. 0 3 1 3 7 6 1		
25	. 0 4 0 3 4 0 7		
37			
49		73 80	
61			
1	8 0 1		
13	. 0 0 4 7 4 6 9 5		
25	. 0 5 6 9 7 9 9		
37			
49		73 80	
61			

FORTRAN FIXED 10 DIGIT DECIMAL DATA

DECK NO. _____ PROGRAMMER _____ DATE _____ PAGE 20 of 21 JOB NO. _____

	NUMBER	IDENTIFICATION	DESCRIPTION	DO NOT KEY PUNCH
1	8.17		(Zone 15 is a void requiring no entry at 809)	
13	.0424478			
25				
37				
49		73	80	
61				
1	825			
13	.0641769			
25	.00016084			
37	.0321689			
49		73	80	
61				
1	857			
13	6.324612		CRAD	
25	5.15875		CIRAD	
37	27.94		CWIDTH	
49	27.94	73	80	CDEPTH
61	0.0		XSTORE	First source particle
1	862			will start at center of
13	0.0		YSTORE	rod IRSTOR in zone IZSTOR.
25	2. + 0.7		EDEP (Note that 0 and 10 MEV are assumed)	
37	1. + 0.7			
49	5. + 0.6	73	80	
61	2. + 0.6			

FORTRAN FIXED 10 DIGIT DECIMAL DATA

DECK NO. _____ PROGRAMMER _____ DATE _____ PAGE 21 of 21 JOB NO. _____

	NUMBER	IDENTIFICATION	DESCRIPTION DO NOT KEY PUNCH
1	8 6 7		
13	1 + 0 6		
25	5 + 0 5		
37			
49		73 80	
61			
1	8 7 2		ECAP (Note that 0 and 10 MEV are assumed
13	5 0 0 0 0		as the lower and upper boundaries)
25	2 0 0 0		
37	. 6 2 5		
49		73 80	
61			
1	8 7 5		EKT (I) is the thermal temperature in ev of the I th
13	. 0 5 3 6		upscatterer.
25	. 0 6 9 8 8		
37	. 0 3 1 1		
49	. 0 5 3 6	73 80	
61	. 0 3 1 1		
1	8 8 0		
13	. 0 5 4 0 3		
25	1 0 0		BMASS
37	1 . 0		WC
49		73 80	
61

7-27-67 UNC

7680-1039

Figure 4. Deck Setup for 360 HWO CR-SAFE Code

D. DECK SETUP

The deck setup for the IBM 360 FORTRAN H version of HWOCR-SAFE is shown in Figure 4. A listing of the DD cards for the sample calculations of this section is shown below.

```
//G.FT08F001 DD UNIT 2400,DISP OLD,VOLUME SFR WA0758, X
//          DSNNAME HSAFF.FILE1,LABEL 1,SL
//G.FT08F002 DD DISP OLD,VOLUME REF *.FT08F001, X
//          DSNNAME HSAFE.U281,LABEL 2,SL
//G.FT08F003 DD DISP OLD,VOLUME REF *.FT08F001, X
//          DSNNAME HSAFE.U251,LABEL 3,SL
//G.FT08F004 DD DISP OLD,VOLUME REF *.FT08F001, X
//          DSNNAME HSAFF.ZR01,LABEL 6,SL
//G.FT08F005 DD DISP OLD,VOLUME REF *.FT08F001, X
//          DSNNAME HSAFE.CC01,LABEL 7,SL
//G.FT08F006 DD DISP OLD,VOLUME REF *.FT08F001, X
//          DSNNAME HSAFE.CF01,LABEL 9,SL
//G.FT08F007 DD DISP OLD,VOLUME REF *.FT08F001, X
//          DSNNAME HSAFE.HM01,LABEL 10,SL
//G.FT08F008 DD DISP OLD,VOLUME REF *.FT08F001, X
//          DSNNAME HSAFF.HC01,LABEL 11,SL
//G.FT08F009 DD DISP OLD,VOLUME REF *.FT08F001, X
//          DSNNAME HSAFE.DD01,LABEL 12,SL
//G.FT08F010 DD DISP OLD,VOLUME REF *.FT08F001, X
//          DSNNAME HSAFF.AL01,LABEL 13,SL
//G.FT08F011 DD DISP OLD,VOLUME REF *.FT08F001, X
//          DSNNAME HSAFE.OO01,LABEL 14,SL
//G.FT08F012 DD DISP OLD,VOLUME REF *.FT08F001, X
//          DSNNAME HSAFF.OM01,LABEL 15,SL
```

E. OUTPUT FOR EXPLICIT GEOMETRY SAMPLE CASE

The printed output for the explicit geometry sample case is presented in this section. The first line of output is the title card. The second line gives the value of the starting random number RDUM. The first six pages list the input DATA array by location. The rest of the output is as outlined in Section IV.

HWOCR SAFE TEST CASE EXPLICIT GEO. NEW 37 ROD NEW COMMON 11-8-66
RDUM = 31374652713.

INDEX	DATA	INDEX	DATA	INDEX	DATA	INDEX	DATA
1	4.0	2	5.1	3	6	4	37
5		6	5	7	8	8	2
9		1	2	11		12	2
13		14	2	15	2	16	2
17		18	2	19	2	2	1
21	2	22	3	23	4	24	5
25	6	26	1	27	2	28	3
29	4	30	5	31	6	32	0
33		34	0	35		36	4
37		38	0	39		4	5
41	26	42	1	43	1	44	1
45	1	46	1	47	1	48	2
49	2	5	2	51	2	52	2
53	2	54	1	55	2	56	2
57	0	58	4	59		6	1
61		62	1	63	1	64	1
65	1	66	1	67	3	68	1
69	1	70	1	71	1	72	1
73	3	74	5	75	5	76	6
77	7	78	0	79	0	8	0
81		82	1	83	1	84	0
85		86		87		88	2
89		90	2	91	2	92	2
93	4	94	1	95	6	96	7
97	8	98	0	99		100	0
101		102	2	103	2	104	2
105	2	106	2	107	4	108	7
109	8	110	9	111	10	112	11
113	12	114	1	115	1	116	1
117	1	118	1	119	1	12	1
121	1	122	1	123	1	124	1
125	1	126	1	127	1	128	2
129	1	130	1	131	0	132	0
133		134	7	135		136	8
137		138	9	139	0	140	10
141		142	11	143	0	144	12

145
149
153
157
161
165
169
173
177 14
181 11
185 11
189 16
193
197
201
205
209 3
213 2
217 2
221
225
229 13
233
237 13
241
245 13
249
253 13
257
261 13
265
269 13
273
277
281
285
289
293
297
301
305
309

146 1
15 3
154 5
158 14
162 14
166 6
170 5
174 6
178 15
182 1
186 13
190 17
194
198
202
206
210 3
214 2
218 2
222
226
230
234
238
242
246
250
254
258
262
266
27
274
278
282
286
290
294
298
302
306
310

147
151
155
159
163 16
167
171
175 11
179 16
183 2
187 14
191 18
195
199
203
207 3
211 3
215
219
223
227
231
235
239
243
247
251 2
255
259 2
263
267 2
271
275 18
279
283 13
287
291 18
295
299 13
303
307 18
311

148 2
152 4
156 6
160 15
164 15
168 0
172 0
176 13
18 18
184 10
188 15
192 19
196
200
204 0
208 3
212 3
216 2
220 2
224
228 1
232 0
236 1
240
244 1
248 0
252 1
256 0
260 1
264 0
268 1
272 0
276 17
280
284 17
288
292 17
296
300 17
304
308 17
312 0

313	
317	
321	0
325	
329	
333	
337	
341	1
345	
349	
353	1
357	19
361	
365	
369	
373	
377	
381	
385	
389	6
393	1
397	3
401	3
405	3
409	
413	2
417	4
421	4
425	4
429	5
433	5
437	5
441	6
445	6
449	
453	
457	
459	.69574550
463	.69574550
467	.69574550
471	.69574550
475	-1.41441301

314	
318	
322	0
326	
330	
334	0
338	0
342	0
346	
350	
354	0
358	0
362	0
366	
370	0
374	0
378	
382	0
386	0
390	1
394	1
398	3
402	2
406	0
410	1
414	2
418	3
422	3
426	3
430	5
434	5
438	5
442	6
446	6
450	1
454	0
458	0
462	.69574550
466	.4423165
468	.0000000
472	.0000000
476	.0000000

315	18
319	
323	15
327	
331	18
335	1
339	
343	
347	1
351	
355	16
359	
363	
367	
371	0
375	
379	
383	
387	13
391	1
395	1
399	3
403	3
407	
411	2
415	2
419	4
423	4
427	4
431	5
435	5
439	5
443	6
447	1
451	1
455	
461	.69574550
465	.69574550
469	.69574550
473	.69574550
477	.69574550

316	17
320	0
324	11
328	0
332	17
336	0
340	0
344	0
348	0
352	0
356	14
360	0
364	0
368	0
372	0
376	0
380	0
384	0
388	17
392	1
396	3
400	3
404	3
408	3
412	2
416	2
420	3
424	3
428	3
432	5
436	5
440	5
444	6
448	0
452	0
456	0
462	.69574550
466	.69574550
470	-1.6332230
474	-1.8166110
478	-1.8166110

479	1.41441301	48	0.0 00000	481	0.0	482	1.6332230
483	0.0 00000	484	0.0 00000	485	0.0	486	0.8166110
487	-1.41441301	488	0.0 00000	489	0.0 00000	49	-0.8166110
491	1.41441301	492	0.0 00000	493	0.0 00000	494	-2.4498350
495	-1.41441301	496	0.0 00000	497	0.0	498	-1.6332230
499	-2.82882601	500	0.0 00000	501	0.0 00000	502	0.0 00000
503	-2.82882601	504	0.0 00000	505	0.0 00000	506	1.6332230
507	-2.82882601	508	0.0 00000	509	0.0 00000	510	2.4498350
511	-1.41441301	512	0.0 00000	513	0.0 00000	514	3.26644599
515	0.0 00000	516	0.0 00000	517	0.0 00000	518	2.4498350
519	1.41441301	520	0.0 00000	521	0.0 00000	522	1.6332230
523	2.82882601	524	0.0 00000	525	0.0 00000	526	0.0 00000
527	2.82882601	528	0.0 00000	529	0.0 00000	53	-1.6332230
531	2.82882601	532	0.0 00000	533	0.0 00000	534	-2.4498350
535	1.41441301	536	0.0 00000	537	0.0 00000	538	-3.26644599
539	0.0 00000	540	0.0 00000	541	0.0 00000	542	-4.0835800
543	-1.41441301	544	0.0 00000	545	0.0 00000	546	-4.0835800
547	1.41441301	548	0.0 00000	549	0.0 00000	550	-3.26644599
551	2.82882601	552	0.0 00000	553	0.0 00000	554	-0.8166115
555	4.24323899	556	0.0 00000	557	0.0 00000	558	0.8166115
559	4.24323899	560	0.0 00000	561	0.0 00000	562	3.26644599
563	2.82882601	564	0.0 00000	565	0.0 00000	566	4.0835800
567	1.41441301	568	0.0 00000	569	0.0 00000	57	4.0835800
571	-1.41441301	572	0.0 00000	573	0.0 00000	574	3.26644599
575	-2.82882601	576	0.0 00000	577	0.0 00000	578	0.8166115
579	-4.24323899	580	0.0 00000	581	0.0 00000	582	-0.8166115
583	-4.24323899	584	0.0 00000	585	0.0 00000	586	-3.26644599
587	-2.82882601	588	0.0 00000	589	0.0 00000	59	-2.2936250
591	-3.97267401	592	0.0 00000	593	0.0 00000	594	-4.58724898
595	0.0 00000	596	0.0 00000	597	0.0 00000	598	-2.2936250
599	3.97267401	600	0.0 00000	601	0.0 00000	602	2.2936250
603	3.97267401	604	0.0 00000	605	0.0 00000	606	4.58724898
607	0.0 00000	608	0.0 00000	609	0.0 00000	61	2.2936250
611	-3.97267401	612	0.0 00000	613	0.0 00000	614	0.0 00000
615	0.0 00000	616	0.0 00000	617	0.0 00000	618	0.0 00000
619	0.0 00000	620	0.0 00000	621	0.0 00000	622	0.0 00000
623	0.0 00000	624	0.0 00000	625	0.0 00000	626	1.0000000
627	1.00000000	628	1.00000000	629	1.00000000	63	1.0000000
631	1.00000000	632	-1.00000000	633	-1.00000000	634	-1.00000000
635	-1.00000000	636	-1.00000000	637	-1.00000000	638	1.00000000
639	-1.00000000	640	-1.00000000	641	-1.00000000	642	0.0 00000
643	0.0 00000	644	0.0 00000	645	0.0 00000	646	0.0 00000

647	0.00000000	648	0.00000000	649	0.00000000	65	0.00000000
651	0.00000000	652	1.00000000	653	1.00000000	654	1.00000000
655	1.00000000	656	1.00000000	657	1.00000000	658	0.00000000
659	1.00000000	66	1.00000000	661	1.00000000	662	0.00000000
663	0.00000000	664	0.00000000	665	0.00000000	666	0.00000000
667	0.00000000	668	0.00000000	669	0.00000000	67	0.00000000
671	0.00000000	672	0.37627330	673	0.48461800	674	0.12735670
675	0.19564390	676	26.61269999	677	29.71177006	678	38.12756140
679	4.00000000	68	0.00000000	681	0.00000000	682	0.00000000
683	0.00000000	684	0.00000000	685	0.00000000	686	0.00000000
687	0.00000000	688	0.00000000	689	0.00000000	69	0.00000000
691	0.00000000	692	0.00000000	693	0.00000000	694	0.00000000
695	0.00000000	696	0.00000000	697	0.00000000	698	0.00000000
699	0.00000000	70	0.00000000	701	0.00000000	702	0.00000000
703	0.00000000	704	0.00000000	705	0.00000000	706	0.00000000
707	0.00000000	708	0.00000000	709	0.00000000	71	0.00000000
711	0.00000000	712	0.00000000	713	0.00000000	714	0.00000000
715	0.00000000	716	0.00000000	717	0.00000000	718	0.00000000
719	0.00000000	720	0.00000000	721	0.00000000	722	0.00000000
723	0.00000000	724	0.00000000	725	0.00000000	726	0.00000000
727	0.00000000	728	0.00000000	729	0.00000000	73	0.00000000
731	0.00000000	732	0.00000000	733	0.00000000	734	0.00000000
735	0.00000000	736	0.00000000	737	0.00000000	738	0.00000000
739	0.00000000	74	0.00000000	741	0.00000000	742	0.00000000
743	0.00000000	744	0.00000000	745	0.00000000	746	0.00000000
747	0.00000000	748	0.00000000	749	0.00000000	75	0.00000000
751	0.00000000	752	0.00000000	753	0.00000000	754	0.00000000
755	0.00000000	756	0.00000000	757	0.00000000	758	0.00000000
759	0.00000000	76	0.00000000	761	0.00000000	762	0.00000000
763	0.00000000	764	0.00000000	765	0.00000000	766	0.00000000
767	0.00000000	768	0.00000000	769	0.00000000	77	0.00000000
771	0.00000000	772	0.00000000	773	0.00000000	774	0.00000000
775	0.00000000	776	0.00000000	777	0.00000000	778	0.00000000
779	0.00000000	780	0.00000000	781	0.00000000	782	0.00000000
783	0.00000000	784	0.00000000	785	0.00000000	786	0.00000000
787	0.00000000	788	0.00000000	789	0.00000000	790	0.00000000
791	0.00000000	792	0.00000000	793	0.00000000	794	0.00000000
795	0.00000000	796	0.00000000	797	0.00000000	798	0.00000000
799	0.00000000	80	0.00000000	801	0.00000000	802	0.00000000
803	0.00000000	804	0.00000000	805	0.00000000	806	0.00000000
807	0.00000000	808	0.00000000	809	0.00000000	810	0.00000000
811	0.00000000	812	0.00000000	813	0.00000000	814	0.00000000

815	0.000000	816	0.000000	817	0.424478	818	0.000000
819	0.000000	82	0.000000	821	0.000000	822	0.000000
823	0.000000	824	0.000000	825	0.06417691	826	0.00016084
827	0.03216890	828	0.000000	829	0.000000	830	0.000000
831	0.000000	831	0.000000	833	0.000000	834	0.000000
835	0.000000	836	0.000000	837	0.000000	838	0.000000
839	0.000000	84	0.000000	841	0.000000	842	0.000000
843	0.000000	844	0.000000	845	0.000000	846	0.000000
847	0.000000	848	0.000000	849	0.000000	85	0.000000
851	0.000000	852	0.000000	853	0.000000	854	0.000000
855	0.000000	856	0.000000	857	6.32461202	858	5.15875000
859	27.9400006	86	27.9400006	861	0.000000	862	0.000000
863	*****	864	*****	865	5 0.000000	866	20 0.000000
867	1.0 0.00000000	868	5 0.00000000	869	0.000000	87	0.000000
871	0.00000000	872	5.0000000000	873	2 0.00000000	874	0.62500000
875	0.05360530	876	0.06988190	877	0.0311540	878	0.05360530
879	0.0311540	88	0.054030	881	0.000000	882	1.00000000
883	0.00000000	884	0.000000	885	0.000000	886	0.000000
887	0.00000000	888	0.000000	889	0.000000	89	0.000000
891	0.00000000	892	0.00000000	893	0.000000	894	0.000000
895	0.00000000	896	0.000000	897	0.000000	898	0.000000
899	0.00000000	900	0.00000000	901	0.000000	902	0.000000
903	0.00000000	904	0.00000000	905	0.000000	906	0.000000
907	0.00000000	908	0.00000000	909	0.000000	91	0.000000
911	0.00000000	912	0.000000	913	0.000000	914	0.000000
915	0.00000000	916	0.00000000	917	0.000000	918	0.000000
919	0.00000000	92	0.00000000	921	0.000000	922	0.000000
923	0.000000	924	0.000000	925	0.000000	926	0.000000
927	0.000000	928	0.000000	929	0.000000	93	0.000000
931	0.00000000	932	0.00000000	933	0.000000	934	0.000000
935	0.00000000	936	0.00000000	937	0.000000	938	0.000000
939	0.00000000	94	0.000000	941	0.000000	942	0.000000
943	0.00000000	944	0.00000000	945	0.000000	946	0.000000
947	0.00000000	948	0.00000000	949	0.000000	950	0.000000

ZONE

1
2
3
4
5
6

VOLUME FRACTION

0.00151426
0.009 8556
0.009 8556
0.009 8556
0.01817112
0.003 7518

7	0.00043378
8	0.00260268
9	0.00260268
10	0.00260268
11	0.00520536
12	0.00164887
13	0.04198585
14	0.01247178
15	0.03386819
16	0.00753827
17	0.839 2261

HISTS FISS K EFFECTIVE P EPSILON TH UTIL TOTAL ABS ETA
 400 2560 0.12519553E 01 0.87502351E 0 0.11060813E 01 0.91686789E 0 0.1002749 E 01 0.15287473E 1

FUEL TYPE - - - 1 2 3 4 5 6
 POWER 0.49141257E 01 0.66719619E 1 0.9569 36 E 01 0.8 79 559E 1 0.13024262E 02 0.15139719E 02

ENERGY	ISOTOPE IN FUEL					
	1	2	3	4	5	6
0.1 E 08						
FISSIONS	0.21639363E-02	0.26682368E-01	0.00000000E-38	0.00000000E-38	0.00000000E-38	0.00000000E-38
CAPTURES	0.37985329E-03	0.16824800E-01	0.00000000E-38	0.00000000E-38	0.00000000E-38	0.00000000E-38
0.5 E 05						
FISSIONS	0.11982175E-02	0.00000000E-38	0.00000000E-38	0.00000000E-38	0.00000000E-38	0.00000000E-38
CAPTURES	0.42815582E-03	0.22364339E-01	0.00000000E-38	0.00000000E-38	0.00000000E-38	0.00000000E-38
0.2 E 04						
FISSIONS	0.18434918E-01	0.00000000E-38	0.00000000E-38	0.00000000E-38	0.00000000E-38	0.00000000E-38
CAPTURES	0.13431845E-01	0.96332249E-01	0.47715008E-06	0.00000000E-38	0.00000000E-38	0.00000000E-38
0.625 E 01						
FISSIONS	0.46314484E-01	0.00000000E-38	0.00000000E-38	0.00000000E-38	0.00000000E-38	0.00000000E-38
CAPTURES	0.54506756E-01	0.1948612E-01	0.17769858E-05	0.00000000E-38	0.00000000E-38	0.00000000E-38
0.0 E-38						

ZONE		0.100000E 08	0.500000E 5	0.200000E 4	0.625000E 01	0.000000E-38
1	CAPTURES	0.0811273 E 01	0.66130996E 01	0.2 495887E 01	0.71775638E 01	
	SCATTERS	0.04834998E 02	0.14615540E 02	0.162 7772E 02	0.15319486E 02	
2	CAPTURES	0.06466944E 00	0.49637409E 01	0.2 0911379E 01	0.89589549E 01	
	SCATTERS	0.0272675E 02	0.12539698E 02	0.14832833E 02	0.2 0647865E 02	
3	CAPTURES	0.0296812 E 01	0.48916148E 01	0.21110875E 01	0.13159776E 02	
	SCATTERS	0.0253 1144E 02	0.11466347E 02	0.14129200E 02	0.26868 80E 02	
4	CAPTURES	0.09948450 E 00	0.45194352E 01	0.24446742E 01	0.114 7583E 02	
	SCATTERS	0.026211431E 02	0.1 0422109E 02	0.147 2965E 02	0.26 562 E 02	
5	CAPTURES	0.08805208E 00	0.45691331E 01	0.28705283E 01	0.19147187E 02	
	SCATTERS	0.023843 034E 02	0.11198 81E 02	0.169 6779E 02	0.368 7192E 02	
6	CAPTURES	0.09356690E 00	0.53186538E 01	0.31817755E 01	0.23759980E 02	
	SCATTERS	0.02799 445E 02	0.12263319E 02	0.16317623E 02	0.4 755884E 02	
7	CAPTURES	0.03334967E- 1	0.787 01759E- 2	0.41730811E-02	0.28217345E 01	

	SCATTERS	0.1991228 E 02	0.51749464E 01	0.31497146E 01	.41271481E 01
8	CAPTURES	0.18054 1 E-01	0.56739980E-02	0.29128917E-01	.38987321E
	SCATTERS	0.19211 15E 02	0.38243890E 01	0.3 493705E 01	.48342969E 01
9	CAPTURES	0.18164816E-01	0.52741188E- 2	0.84519751E-02	.63412442E 0
	SCATTERS	0.1813127 E 02	0.33259.52E 1	0.3204.904E 01	.68914.046E 01
10	CAPTURES	0.17897138E- 1	0.5 568.34E- 2	0.15179.63E-01	.44793954E 0
	SCATTERS	0.1848431 E 02	0.32934562E 01	0.32992.66E 01	.595 3329E 01
11	CAPTURES	0.15591593E-01	0.51321377E-02	0.2149384 E-01	.74946807E 0
	SCATTERS	0.16311.083E 02	0.34248798E 1	0.34528218E 01	.91997445E 01
12	CAPTURES	0.154.4.9 E-01	0.49978557E- 2	0.13124635E-01	.91236632E 0
	SCATTERS	0.15846463E 02	0.33121881E 1	0.35075687E 01	.1.1476603E 02
13	CAPTURES	0.42512267E-02	0.32845977E-03	0.17541941E-01	.55117.91E 0
	SCATTERS	0.24066867E 02	0.14636696E 02	0.29212667E 02	.13333979E 03
14	CAPTURES	0.116.9311E-01	0.48217478E-02	0.31116221E-01	.12832154E 01
	SCATTERS	0.12967851E 02	0.31304418E 01	0.37375770E 01	.13548386E 02
15	CAPTURES	0.1 00000 E-38	0.1 000000E-38	0.1 0 0001E-38	.0 000000E-38
	SCATTERS	0.1 00000 E-38	0.1 000000E-38	0.1 0 0000E-38	.0 000000E-38
16	CAPTURES	0.1 741.07E-01	0.1 763132E-01	0.13267151E 01	.84173794E 0
	SCATTERS	0.15083875E 02	0.65896105E 01	0.11081609E 02	.36791999E 02
17	CAPTURES	0.15058335E-02	0.15571249E-05	0.39066571E-03	.14094971E-01
	SCATTERS	0.06396579E 01	0.56782817E 1	0.14011443E 02	.82855330E 02

0.100000E 08 0.500000E 05 ENERGY 0.200000E 4 0.625000E 00 0.100000E-38

NU*SIGMA F 0.06311769E-02 0.93360394E-03 0.78872077E-02 0.73369486E-01

SIGMA F 0.24273797E-02 0.38396226E-03 0.32457581E-02 0.31193207E-01

0.100000E 08 0.500000E 05 ENERGY 0.200000E 4 0.625000E 00 0.100000E-38

020 SIGMA CAPTURE 0.08572602E-04 0.92468927E-07 0.95081124E-05 0.76089961E-04

SIGMA SCATTER	0.33235656E 00	0.33720134E 01	0.34977137E 01	0.44728428E 01
FLUX	0.21959695E 02	0.16839440E 02	0.41087619E 02	0.18524787E 03
NON-D20 SIGMA CAPTURE	0.39454116E-02	0.77628865E-02	0.22526869E-01	0.51527993E-01
SIGMA SCATTER	0.23549547E 00	0.42684611E 01	0.38475882E 01	0.49845996E 01
FLUX	0.73822304E 02	0.19385735E 02	0.35282569E 02	0.95288988E 02

		ENERGY			
		0.100000E 08	0.500000E 05	0.200000E 04	0.625000E 03
D20	MUBAR	0.28355125E 00	0.29579600E 01	0.2474557E 01	0.11735079E 01
NON D20	MUBAR	0.23401997E 00	0.23175538E 01	0.29296363E 01	0.18481210E 01

THERMAL PRODUCTION = 1.12544196
 BELOW 0.625
 TOTAL PRODUCTION = 1.2519553
 $\epsilon_{0.625} = 1.1124$
 CAPTURES IN U_{235} AND U_{238} = 0.73555368
 BELOW 0.625
 $\eta_{0.625} = 1.53006$
 $\eta_f = 1.39667$

THERMAL ABS. MOD. BELOW 0.625 = 0.0118260
 THERMAL ABS. NON-MOD. BELOW 0.625 = 0.7939771
 TOTAL ABS. BELOW 0.625 = 0.8058031
 TOTAL ABS. = 1.002749
 $P_{0.625} = 0.803954$
 THERMAL ABS. IN FUEL BELOW 0.625 = 0.735555
 $f_{0.625} = 0.91282$

AI-CE-MEMO-69

D2O TRANSFER MATRIX
EMERGENT ENERGY

INCIDENT ENERGY	0.10000E 08	0.50000E 05	0.20000E 04	0.62500E 00	0.00000E 00
0.10000E 08					
0.50000E 05	0.4512826E 03	0.6411148E- 1	0.42059717E-04	0.0000000E-38	
0.20000E 04	0.0000000E-38	0.12799653E 01	0.24672765E 00	0.0000000E-38	
0.62500E 00	0.0000000E-38	0.0000000E-38	0.19452793E 01	0.1239108E 00	
0.00000E 00	0.0000000E-38	0.0000000E-38	0.38574574E-03	0.45315802E 01	

AI-CE-MEMO-69

NON D2O TRANSFER MATRIX
EMERGENT ENERGY

INCIDENT ENERGY
0.10000 E 08

0.10000 E 08 0.50000 E 05 0.20000 E 04 0.62500 E 00 0.00000 E -38

0.15772993E 00 0.96566 01E-14 0.3923961 E-03 0.0000000E-38

0.50000 E 05

0.00000000E-38 0.83517412E-01 0.178259 E-01 0.0000000E-38

0.20000 E 04

0.00000000E-38 0.0000000E-38 0.6155096E-01 0.32321328E-02

0.62500 E 00

0.0000000 E-38 0.0000000E-38 0.1668124 E-04 0.49170348E-01

0.00000 E-38

THERMAL SPECTRUM VELOCITY MOMENTS

THERMAL

ZONE NO.	FIRST	SECOND	THIRD	FOURTH	FLUX
1	0.39544734E 00	0.19264445E 00	0.11236466E 00	0.75660192E- 1	0.35264776E 02
2	0.38485613E 00	0.19387032E 00	0.1086458E 00	0.69599733E- 1	0.44637361E 02
3	0.38382682E 00	0.1750470E 00	0.9579881E-01	0.59432078E- 1	0.62619463E 02
4	0.36989253E 00	0.1796140E 00	0.97714198E-01	0.61168311E- 1	0.55794355E 02
5	0.36125962E 00	0.15647111E 00	0.80327833E-01	0.47913456E- 1	0.85471269E 02
6	0.34944432E 00	0.14885032E 00	0.76429667E-01	0.45559221E- 1	0.99845793E 02
7	0.39207816E 00	0.18758064E 00	0.10669318E 00	0.74111E- 1	0.4805049E 02
8	0.38938478E 00	0.18377685E 00	0.10104054E 00	0.63303789E- 1	0.4837104E 02
9	0.36827542E 00	0.16571173E 00	0.87984959E-01	0.53826150E- 1	0.69159717E 02
10	0.3823473E 00	0.17828020E 00	0.99681416E-01	0.64999361E- 1	0.5901732E 02
11	0.34903730E 00	0.15185081E 00	0.77167538E-01	0.45841418E- 1	0.91888885E 02
12	0.31696795E 00	0.13538883E 00	0.68677775E-01	0.4644285E- 1	0.138925 E 03
13	0.33128866E 00	0.14277029E 00	0.7313396E-01	0.43365163E- 1	0.83673691E 02
14	0.30594790E 00	0.11925746E 00	0.56234149E-01	0.31543727E- 1	0.13297561E 03
15	0.0000000E-38	0.0000000E-38	0.0000000E-38	0.0000000E-38	0.13617382E 03
16	0.3069372E 00	0.11640066E 00	0.54671730E-01	0.3760425E- 1	0.13883333E 03
17	0.28459850E 00	0.10263765E 00	0.45112086E-01	0.2414291E- 1	0.1852487E 03

ENERGY	ENERGY DEPOSITION IN	
	CARBON	HYDROGEN
0.2000000E 07	0.0000 00E-38	0.53924878E 05
0.1000000E 07	0.61353806E 04	0.58233589E 05
0.5000000E 06	0.11819286E 05	0.47746781E 05
0.2000000E 06	0.20974478E 05	0.39549445E 05
0.1000000E 06	0.83744858E 04	0.13457151E 05
0.5000000E 05	0.44934282E 04	0.77321166E 04
0.0000000E-38	0.38027496E 04	0.8482809E 04

TOTAL ENERGY DEPOSITED IN COOLANT = 0.28429203E 06

MODERATOR = 0.13152945E 07

CALCULATIONS NEGLECTING THE FIRST NO HISTORIES

HISTS	K EFFECTIVE	P	EPSILON	TH UTIL	TOTAL ABS	ETA
50	0.12494204E 01	0.8 431527E 00	0.11068349E 01	0.91638437E 00	0.10027838E 01	0.15272651E 01
10	0.12472896E 01	0.8 459823E 00	0.11071415E 01	0.916 3399E 00	0.1 028.96E 01	0.15242307E 01
15	0.12476089E 01	0.8 438659E 00	0.11074.29E 01	0.91586581E 00	0.1002598 E 01	0.15253.34E 01
20	0.12473727E 01	0.8 37828 E 00	0.11078157E 01	0.91618618E 00	0.10023876E 01	0.15253504E 01
25	0.12481451E 01	0.8 342786E 00	0.11083384E 01	0.91596693E 00	0.10024197E 01	0.15265690E 01
30	0.12469157E 01	0.8 324196E 00	0.11084358E 01	0.91547374E 00	0.10021827E 01	0.15264668E 01
35	0.12479085E 01	0.8 322731E 00	0.11083471E 01	0.91533302E 00	0.1 022129E 01	0.1528.212E 01
40	0.12468279E 01	0.8 429297E 00	0.11073501E 01	0.91570746E 00	0.1002244 E 01	0.15253883E 01
45	0.12462581E 01	0.80389684E 00	0.11072599E 01	0.91585179E 00	0.1002276 E 01	0.15252658E 01
50	0.12451710E 01	0.80350091E 00	0.11071374E 01	0.91561809E 00	0.10023 9 E 01	0.15251249E 01
55	0.12442108E 01	0.80306363E 00	0.11073616E 01	0.91545916E 00	0.10023429E 01	0.15247522E 01
60	0.12440273E 01	0.80420472E 00	0.11058120E 01	0.91626488E 00	0.10023778E 01	0.15231176E 01
65	0.12458587E 01	0.80369759E 00	0.1105764 E 01	0.91656363E 00	0.10024141E 01	0.15258221E 01
70	0.12465560E 01	0.80403402E 00	0.11055 09E 01	0.91649558E 00	0.10024515E 01	0.15264567E 01
75	0.12442 57E 01	0.80366222E 00	0.11056333E 01	0.91670239E 00	0.10024902E 01	0.15236985E 01
80	0.12428846E 01	0.80347843E 00	0.11057735E 01	0.91661902E 00	0.10025299E 01	0.15223304E 01
85	0.12428300E 01	0.80410144E 00	0.11051835E 01	0.9166.742E 00	0.10025711E 01	0.15218363E 01
90	0.124 5919E 01	0.80358461E 00	0.11057226E 01	0.91617652E 00	0.10026135E 01	0.1519982 E 01
95	0.124 2349E 01	0.8 422586E 00	0.11049607E 01	0.91566814E 00	0.10026571E 01	0.15201573E 01
100	0.12373180E 01	0.80343251E 00	0.1105406 E 01	0.91558919E 00	0.10027 24E 01	0.15175304E 01
105	0.12408696E 01	0.80267598E 00	0.11055720E 01	0.91577616E 00	0.10027493E 01	0.15227097E 01
110	0.12413424E 01	0.80258613E 00	0.11061925E 01	0.91572851E 00	0.10024531E 01	0.15231350E 01
115	0.12457421E 01	0.80269434E 00	0.11060750E 01	0.91583234E 00	0.10024972E 01	0.15282494E 01
120	0.12479379E 01	0.80438293E 00	0.11052862E 01	0.91591831E 00	0.10025428E 01	0.15286066E 01
125	0.12456375E 01	0.8 409732E 00	0.11056490E 01	0.91583914E 00	0.1 025901E 01	0.15258896E 01
130	0.12487536E 01	0.8 336258E 00	0.11058486E 01	0.9158983 E 00	0.10024111E 01	0.1531004 E 01
135	0.12488893E 01	0.80291989E 00	0.11058197E 01	0.91665550E 00	0.10024582E 01	0.15307172E 01
140	0.12471483E 01	0.80262791E 00	0.11065 25E 01	0.91649351E 00	0.10025 79E 01	0.152839.1E 01
145	0.12496095E 01	0.80370308E 00	0.11049701E 01	0.91734479E 00	0.10020636E 01	0.1530736 E 01
150	0.12474850E 01	0.8 292526E 00	0.11057932E 01	0.91748925E 00	0.10021 73E 01	0.15281679E 01
155	0.12471318E 01	0.8 435205E 00	0.11043975E 01	0.91752692E 00	0.10021531E 01	0.15268201E 01
160	0.12502995E 01	0.80594865E 00	0.11038622E 01	0.91777118E 00	0.10022 05E 01	0.15279276E 01
165	0.12519805E 01	0.8 63386 E 00	0.11047662E 01	0.91774755E 00	0.1 022501E 01	0.15289230E 01
170	0.12545348E 01	0.8 748665E 00	0.11035547E 01	0.918 6 86E 00	0.10023 14E 01	0.15299726E 01
175	0.12492762E 01	0.807661236E 00	0.11039655E 01	0.9172970E 00	0.10023054E 01	0.15258298E 01
180	0.12452991E 01	0.80597331E 00	0.11050137E 01	0.9169.015E 00	0.10024121E 01	0.15213074E 01
185	0.12410427E 01	0.80530476E 00	0.11052624E 01	0.9165.766E 00	0.10024709E 01	0.15175856E 01
190	0.12456370E 01	0.80619118E 00	0.11047170E 01	0.916 3597E 00	0.1 020575E 01	0.15236921E 01
195	0.12455415E 01	0.80657716E 00	0.11047933E 01	0.91585132E 00	0.10021007E 01	0.15229671E 01
200	0.12450339E 01	0.80556307E 00	0.11057651E 01	0.9158613.E 00	0.10021671E 01	0.15228212E 01

2050	0.12436652E 01	0.87424 11E 00	0.11069 28E 01	0.91638242E 0	0.10022761E 01	0.15211281E 01
2100	0.12471286E 01	0.87747399E 00	0.11026511E 01	0.91576122E 01	0.10022877E 01	0.15260558E 01
2150	0.12455718E 01	0.87940861E 00	0.11000437E 01	0.91511900E 00	0.10023528E 01	0.15250808E 01
2200	0.12491794E 01	0.87747153E 00	0.11010853E 01	0.91441 45E 0	0.10024216E 01	0.15329247E 01
2250	0.12494149E 01	0.87885173E 00	0.11099973 E 01	0.91442394E 0	0.10024945E 01	0.15318849E 01
2300	0.12457159E 01	0.87843169E 00	0.11007145E 01	0.91333373E 0	0.10025716E 01	0.15288191E 01
2350	0.12529.47E 01	0.87804857E 00	0.11014985E 01	0.91420155E 0	0.10026536E 01	0.15356909E 01
2400	0.12498083E 01	0.8782116 E 00	0.11005543E 01	0.91418979E 0	0.10027403E 01	0.15328068E 01
2450	0.12495329E 01	0.8780053 E 00	0.11006236E 01	0.91376368E 0	0.10022381E 01	0.15342280E 01
2500	0.12522423E 01	0.8790284 E 00	0.110999286E 01	0.91261154E 0	0.10023167E 01	0.15383996E 01
2550	0.12563823E 01	0.87884263E 00	0.11010665E 01	0.91349934E 00	0.10024 25E 01	0.15406141E 01
2600	0.12669743E 01	0.8781277145E 00	0.11002512E 01	0.91221569E 0	0.10024953E 01	0.15492720E 01
2650	0.12695173E 01	0.8781114555E 00	0.11023408E 01	0.91411228E 00	0.10018631E 01	0.15503009E 01
2700	0.12734776E 01	0.87994138E 00	0.11031478E 01	0.91288166E 00	0.10019435E 01	0.15582828E 01
2750	0.12715971E 01	0.8782228 E 00	0.11019982E 01	0.91371105E 0	0.10020324E 01	0.15593624E 01
2800	0.12730418E 01	0.878104081E 00	0.11006 9 E 01	0.91331427E 0	0.10021259E 01	0.15594206E 01
2850	0.12686 8.E 01	0.8781026 52E 00	0.110995892E 01	0.91283416E 0	0.10022284E 01	0.15563730E 01
2900	0.12626667E 01	0.87705208E 00	0.11022465E 01	0.91261182E 0	0.10015380E 01	0.15529409E 01
2950	0.12626 50E 01	0.87329525E 00	0.11048571E 01	0.91174550E 00	0.10016226E 01	0.15577884E 01
3000	0.12587747E 01	0.87301832E 00	0.11035158E 01	0.91217642E 0	0.10017157E 01	0.15547775E 01
3050	0.12596484E 01	0.87501477E 00	0.11031851E 01	0.91218767E 0	0.10018196E 01	0.15521131E 01
3100	0.12588791E 01	0.87609512E 00	0.110988428E 01	0.91223171E 0	0.10019341E 01	0.15549551E 01
3150	0.12542525E 01	0.87825613E 00	0.110984292E 01	0.91227566E 0	0.10008888E 01	0.15472197E 01
3200	0.12438222E 01	0.87586723E 00	0.11013892E 01	0.90982738E 0	0.10019575E 01	0.15387898E 01
3250	0.12413554E 01	0.87532373E 00	0.11057555E 01	0.90799765E 0	0.10010355E 01	0.15336714E 01
3300	0.12558114E 01	0.87715881E 00	0.11064196E 01	0.90882646E 0	0.10011272E 01	0.15455103E 01
3350	0.12675109E 01	0.878191036E 00	0.11092391E 01	0.90793407E 0	0.10012318E 01	0.15482087E 01
3400	0.12617172E 01	0.878383158E 00	0.11101276E 01	0.90662158E 0	0.10013531E 01	0.15383008E 01
3450	0.12680305E 01	0.878153454 E 00	0.11070561E 01	0.90888 58E 0	0.10014954E 01	0.15433437E 01
3500	0.12720102E 01	0.87791662E 00	0.11072285E 01	0.90691627E 0	0.10016661E 01	0.15461590E 01
3550	0.12643034E 01	0.878198656E 00	0.11113528E 01	0.90627489E 0	0.10018726E 01	0.15282141E 01
3600	0.12573526E 01	0.8781072218E 00	0.112 3716E 01	0.9095620 E 0	0.10021348E 01	0.15186737E 01
3650	0.12787985E 01	0.8781924985E 00	0.11186 94E 01	0.91065495E 0	0.10024702E 01	0.15285581E 01
3700	0.1281386E 01	0.8782226772E 00	0.11237305E 01	0.90923 28E 0	0.10029187E 01	0.15192945E 01
3750	0.125 9975E 01	0.8781552731E 00	0.11316194E 01	0.90531148E 0	0.10035561E 01	0.14920311E 01
3800	0.12199335E 01	0.8781295828E 00	0.11311903E 01	0.90385877E 0	0.10045 3 E 01	0.14611 15E 01
3850	0.11967370E 01	0.8781723779E 00	0.11291951E 01	0.91052301E 00	0.100460857E 01	0.14156482E 01
3900	0.11243944E 01	0.878260795E 00	0.11456628E 01	0.89816213E 0	0.100392516E 01	0.13834499E 01
3950	0.11774530E 01	0.8779796818E 00	0.1145205 E 01	0.90414162E 0	0.99980545E 00	0.14253542E 01

INDIVIDUAL BATCH RESULTS

HISTS	K	EFFECTIVE	P	EPSILON	TH	UTIL	TOTAL ABS	ETA
50	0.14522794E	01	0.88519555E	00	0.10571555E	01	0.99999876E	0.16315384E
100	0.14156234E	01	0.78218178E	00	0.10861662E	01	0.99999573E	0.1764 373E
150	0.12211667E	01	0.82061838E	00	0.10869534E	01	0.92851295E	0.14457280E
200	0.12670997E	01	0.84954422E	00	0.10773667E	01	0.893 5352E	0.15218899E
250	0.11894414E	01	0.83046864E	00	0.10681727E	01	0.93228162E	0.14382669E
300	0.13391196E	01	0.81694435E	00	0.11016684E	01	0.95122511E	0.15335997E
350	0.11744415E	01	0.80431377E	00	0.11153605E	01	0.92575639E	0.14141745E
400	0.13257126E	01	0.72632651E	00	0.118 3 62E	01	0.88596962E	0.17454777E
450	0.12872858E	01	0.83248307E	00	0.11135841E	01	0.9 53 177E	0.15339013E
500	0.13272550E	01	0.83167703E	00	0.11153678E	01	0.93237 27E	0.15346447E
550	0.13065213E	01	0.83374435E	00	0.10926 26E	01	0.92552969E	0.15496866E
600	0.12566899E	01	0.72528312E	00	0.12235 74E	01	0.85456142E	0.16572191E
650	0.11213239E	01	0.8382667 E	00	0.11086417E	01	0.897 2682E	0.13451673E
700	0.11998415E	01	0.78143745E	00	0.111241 44E	01	0.92119683E	0.14828347E
750	0.13993206E	01	0.82826272E	00	0.10979 56E	01	0.90341656E	0.17034274E
800	0.13287580E	01	0.81545477E	00	0.10973 38E	01	0.9226 557E	0.16096264E
850	0.12463231E	01	0.76412532E	00	0.1144147 E	01	0.91671611E	0.15551709E
900	0.13815951E	01	0.83622979E	00	0.10759752E	01	0.94234847E	0.16295367E
950	0.12623687E	01	0.76436325E	00	0.11533845E	01	0.94889247E	0.15090930E
1000	0.14152455E	01	0.85195921E	00	0.10820955E	01	0.9201469 E	0.16684708E
1050	0.10277762E	01	0.84819243E	00	0.10937087E	01	0.90512116E	0.12241175E
1100	0.12134454E	01	0.80779759E	00	0.10699611E	01	0.91847577E	0.14986930E
1150	0.09055958E	00	0.79640225E	00	0.11146836E	01	0.90974779E	0.12265926E
1200	0.11227772E	01	0.70788797E	00	0.11574894E	01	0.91034682E	0.15 53227E
1250	0.13744614E	01	0.82013366E	00	0.10874963E	01	0.920 9914E	0.16748096E
1300	0.10773683E	01	0.84338716E	00	0.10932981E	01	0.91282623E	0.12645 29E
1350	0.12415605E	01	0.82688405E	00	0.11073901E	01	0.87683114E	0.15464713E
1400	0.13394232E	01	0.8181437 E	00	0.10737412E	01	0.92494 98E	0.16486585E
1450	0.11216245E	01	0.749 3 14E	00	0.12011501E	01	0.87095881E	0.1396230 E
1500	0.13558359E	01	0.84268 63E	00	0.10683860E	01	0.91044697E	0.16543044E
1550	0.12647901E	01	0.73285227E	00	0.11777 41E	01	0.91545839E	0.16 1982 E
1600	0.10950856E	01	0.72753718E	00	0.11345013E	01	0.9 45 901E	0.14669300E
1650	0.11712928E	01	0.7875778 E	00	0.10937 92E	01	0.9189111 E	0.1479973 E
1700	0.1134481 E	01	0.75340 45E	00	0.11307 74 E	01	0.90226345E	0.14761435E
1750	0.14911699E	01	0.84692755E	00	0.10882877E	01	0.95085387E	0.17016846E
1800	0.14242692E	01	0.83481235E	00	0.10650958E	01	0.93422460E	0.17148601E
1850	0.14283037E	01	0.83479524E	00	0.10958 04E	01	0.93322061E	0.16733215E
1900	0.10480828E	01	0.76872364E	00	0.11331909E	01	0.93642233E	0.12591882E
1950	0.12495556E	01	0.79033083E	00	0.11016 69E	01	0.92377929E	0.15538361E
2000	0.12658439E	01	0.84723473E	00	0.10678738E	01	0.91547 93E	0.15285309E

205	0.12984114E 01	0.85727999E 00	0.10648761E 01	0.8967500E 00	0.99986459E 00	0.15862731E 01
210	0.11120572E 01	0.68175812E 00	0.13245571E 01	0.94448194E 00	0.99988699E 00	0.13053521E 01
215	0.13047299E 01	0.73571593E 00	0.12034051E 01	0.94192635E 00	0.99987936E 00	0.15647108E 01
220	0.11156974E 01	0.88171168E 00	0.10596386E 01	0.93853658E 00	0.99987268E 00	0.12725244E 01
225	0.12409391E 01	0.75664736E 00	0.11417722E 01	0.91390463E 00	0.99987173E 00	0.15719268E 01
230	0.13751817E 01	0.82317168E 00	0.10776154E 01	0.95092572E 00	0.99987364E 00	0.16304750E 01
235	0.10184844E 01	0.82110971E 00	0.1069555E 01	0.8857238E 00	0.99986649E 00	0.12976696E 01
240	0.13519878E 01	0.8313768E 00	0.1131816E 01	0.91458152E 00	0.99987841E 00	0.16287893E 01
245	0.12583470E 01	0.8141998E 00	0.10984244E 01	0.9279079E 00	0.1018311E 01	0.14903929E 01
250	0.1168251E 01	0.77723729E 00	0.11234481E 01	0.94982958E 00	0.99987745E 00	0.14087601E 01
255	0.11321816E 01	0.81442946E 00	0.10645274E 01	0.88697597E 00	0.99982882E 00	0.14725440E 01
260	0.95981549E 00	0.6985399E 00	0.11321726E 01	0.95543192E 00	0.9998045E 00	0.12705825E 01
265	0.11983147E 01	0.8559082E 00	0.10436601E 01	0.86452815E 00	0.10195632E 01	0.15219181E 01
270	0.11665487E 01	0.8425220E 00	0.1079918E 01	0.94493786E 00	0.99977255E 00	0.13571453E 01
275	0.1324908E 01	0.8530471E 00	0.11315655E 01	0.8931967E 00	0.99973249E 00	0.15320618E 01
280	0.12369251E 01	0.75565261E 00	0.11374637E 01	0.92394739E 00	0.99977636E 00	0.15578785E 01
285	0.13750181E 01	0.8138147E 00	0.1122725E 01	0.92433593E 00	0.9997716E 00	0.16285101E 01
290	0.13593177E 01	0.87974474E 00	0.1049370E 01	0.91725125E 00	0.1017417E 01	0.16242158E 01
295	0.12639608E 01	0.8869226E 00	0.1051911E 01	0.92913552E 00	0.9997606E 00	0.14622129E 01
300	0.13392115E 01	0.8884469E 00	0.1136928E 01	0.90516204E 00	0.99975872E 00	0.16181466E 01
305	0.12421741E 01	0.7650695E 00	0.11099263E 01	0.90984723E 00	0.99974203E 00	0.16082981E 01
310	0.12734957E 01	0.78552622E 00	0.11866222E 01	0.91137251E 00	0.99975967E 00	0.14994527E 01
315	0.1337532E 01	0.7703565E 00	0.11054785E 01	0.91146182E 00	0.1019743E 01	0.16905589E 01
320	0.14211378E 01	0.84652321E 00	0.10585886E 01	0.9496146E 00	0.99978828E 00	0.16703849E 01
325	0.1288228E 01	0.81402989E 00	0.10415959E 01	0.93701366E 00	0.99978828E 00	0.16124841E 01
330	0.10391121E 01	0.77959747E 00	0.10946397E 01	0.89596758E 00	0.99975204E 00	0.13593652E 01
335	0.11035776E 01	0.745298E 00	0.10659641E 01	0.92148277E 00	0.99976635E 00	0.15078031E 01
340	0.13370361E 01	0.78881939E 00	0.10992754E 01	0.9242097E 00	0.99977684E 00	0.16687287E 01
345	0.11922703E 01	0.79715105E 00	0.11473691E 01	0.88116200E 00	0.99978828E 00	0.14796777E 01
350	0.12282333E 01	0.7895849E 00	0.11052748E 01	0.92926671E 00	0.99978828E 00	0.15148281E 01
355	0.13413715E 01	0.8003389E 00	0.10734355E 01	0.91284077E 00	0.99980736E 00	0.17107533E 01
360	0.13199000E 01	0.89318637E 00	0.10471163E 01	0.88234957E 00	0.99977493E 00	0.15997952E 01
365	0.11072311E 01	0.75086826E 00	0.11348242E 01	0.90119223E 00	0.99978733E 00	0.14421846E 01
370	0.1277577E 01	0.80108581E 00	0.10886234E 01	0.91945652E 00	0.99977875E 00	0.15851520E 01
375	0.14258442E 01	0.8560987E 00	0.1093839E 01	0.92796709E 00	0.99973202E 00	0.16464655E 01
380	0.13752537E 01	0.82585209E 00	0.11331446E 01	0.9115873E 00	0.99976826E 00	0.16134276E 01
385	0.12855231E 01	0.80003844E 00	0.11367825E 01	0.88330687E 00	0.99975491E 00	0.16055940E 01
390	0.13414221E 01	0.88715542E 00	0.11026255E 01	0.93253861E 00	0.99975395E 00	0.14708817E 01
395	0.10713358E 01	0.76753259E 00	0.11461662E 01	0.8920082E 00	0.10186977E 01	0.1341129E 01
400	0.11774530E 01	0.79796818E 00	0.1145205E 01	0.90414162E 00	0.99980545E 00	0.14253542E 01

STANDARD DEVIATIONS

0.11998319E 00 .46057013E-01 .45608699E- 1 .21841446E-01 .69547858E- 2 .12941811E 0

σ_{MEAN}	= 0.01341	0.005149	0.005099	0.002442	0.0007776	0.01447
$\sigma_{\text{MEAN}}^{\%}$	= 1.071	0.6394	0.4610	0.2663	0.07755	0.9466
P. E.	= 0.009045	0.003473	0.003439	0.001647	0.0005245	0.009760
P. E. $^{\%}$	= 0.7224	0.4313	0.3109	0.1796	0.05231	0.6385

VI. RECOMMENDED INPUT PREPARATION PROCEDURE FOR AN ANNULAR REPRESENTATION OF CELL

A detailed description of the input data required for an annular representation case and the manner in which it is to be prepared is described in this section.

A. PICTORIAL LAYOUT

1) Make a reasonable sketch of the annular representation to be used. Figure 5 shows this for the sample case.

2) Assign identifying numbers to the annular zones, with the restriction that the highest number be reserved for the moderator region (NZCEL).

3) Assign boundary numbers in any convenient manner.

4) Coolant zones should have IZTYPE = 100 for each of them.

5) Assign IZTYPE for each fuel zone as if it were in a different rod type.

6) NRTYP = number of fuel zones.

7) NROD = 1.

8) With the exception of 4, 5, and 6, assume there is one rod of Type 1; thus NADJRZ (1) = outer zone number and NADJRZ (2) to NADJRZ (6) need no entry, and NBOUND (1) = total number of boundaries in cell (including outer cylindrical boundary) while no entries are needed for NBOUND (2) through NBOUND (6).

9) For further details consult comments on sample case load sheets.

ZONE	IZTYPE
1	1 FUEL
2	100 COOLANT
3	2 FUEL
4	100 COOLANT
5	3 FUEL
6	100 COOLANT
7	4 FUEL
8	100 COOLANT
9	1 PRESSURE TUBE
10	1 GAP
11	1 CALANDRIA TUBE
12	1 MODERATOR

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Figure 5. Sketch of Annular Representation Sample Case

B. LOAD SHEETS FOR ANNULAR REPRESENTATION SAMPLE CASE

The data input sheets for the annular representation sample case are presented in this section.

FORTTRAN FIXED 10 DIGIT DECIMAL DATA

Annular
 DECK NO. Representation PROGRAMMER Levitt DATE 6/1/67 PAGE 1 of 22 JOB NO. 7772-01

NUMBER	IDENTIFICATION	DESCRIPTION DO NOT KEY PUNCH
1	1	
13	4 0 0 0 .	NHIST total number of histories to be run.
25	5 0 .	NDHIST number of histories between printout (batch size)
37	4 .	NRTYP number of zones containing fuel
49	1 .	NRØD in annular rep., entire prob. is treated as one rod
61	1 0	
1	6	
13		NBIWAL not used in annular representation
25		NBØWAL not used in annular representation
37	1 2 .	NBØUND (1) 12 boundary equations are being used to describe
49		this annular representation problem; they are
61	2 0	regarded as being in one rod type.
1	1 4	
13	1 2 .	NZØNE (1) number of zones in rod type 1 which is the
25		total number of zones in the cell since this is
37		an annular representation
49		
61	3 0	
1	2 0	
13	1 .	IZTYPE zone 1 contains fuel (type 1)
25	1 0 0 .	zones containing coolant should have IZTYPE = 100.
37	2 .	zone 3 contains fuel (type 2)
49	1 0 0 .	zone 4 contains coolant
61	3 .	zone 5 contains fuel (type 3)

FORTRAN FIXED 10 DIGIT DECIMAL DATA

DECK NO. _____ PROGRAMMER _____ DATE _____ PAGE 2 of 22 JOB NO. _____

NUMBER	IDENTIFICATION	DESCRIPTION DO NOT KEY PUNCH
1 2 5		
13 1 0 0 .		zone 6 contains coolant
25 4 .		zone 7 contains fuel (type 4)
37 1 0 0 .		zone 8 contains coolant
49 1 .	73 80	zones which are neither fuel nor coolant should have
61 1 .	5 0	IZTYPE = 1.0
1 3 0		
13 1 .		
25 1 .		
37		
49	73 80	
61	6 0	
1 4 0		
13 7 .		IZSTOR first history is to start in zone 7
25 1 .		IRSTOR first history is to start in rod 1
37		
49	73 80	
61	7 0	
1 4 2		
13 1 .		NB (1) (Number of boundaries defining the 1 th zone)
25 2 .		NB (2)
37 2 .		NB (3)
49 2 .	73 80	NB (4)
61 2 .	8 0	NB (5)

FORTRAN FIXED 10 DIGIT DECIMAL DATA

DECK NO. _____ PROGRAMMER _____ DATE _____ PAGE 3 of 22 JOB NO. _____

NUMBER	IDENTIFICATION	DESCRIPTION DO NOT KEY PUNCH
1 4 7		
13 2		NB (6)
25 2		NB (7)
37 2		NB (8)
49 2	73 80	NB (9)
61 2	 9 0	NB (10)
1 5 2		
13 2		NB (11)
25 2		NB (12)
37		
49	73 80	
61	 1 0 0	
1 6 2		MUU (1, 1) is the identification number
13 1		of the first boundary describing the 1 th zone
25 1		MUU (2, 1)
37 2		MUU (3, 1)
49 3	73 80	MUU (4, 1)
61 4	 1 1 0	MUU (5, 1)
1 6 7		
13 5		MUU (6, 1)
25 6		MUU (7, 1)
37 7		MUU (8, 1)
49 8	73 80	MUU (9, 1)
61 9	 1 2 0	MUU (10, 1)

FORTRAN FIXED 10 DIGIT DECIMAL DATA

DECK NO _____ PROGRAMMER _____ DATE _____ PAGE 4 of 22 JOB NO. _____

	NUMBER	IDENTIFICATION	DESCRIPTION DO NOT KEY PUNCH
1	7 2		
13	1 0 .		MUU (11, 1)
25	1 1 .		MUU (12, 1)
37			
49		73.....80	
61		1 3 0	
1	8 2		
13			MUU (1, 2) MUU (1, 2) is the identification number of
25	2 .		MUU (2, 2) the second boundary describing the 1 th zone
37	3 .		MUU (3, 2)
49	4 .	73.....80	MUU (4, 2)
61	5 .	1 4 0	MUU (5, 2)
1	8 7		
13	6 .		MUU (6, 2)
25	7 .		MUU (7, 2)
37	8 .		MUU (8, 2)
49	9 .	73.....80	MUU (9, 2)
61	1 0 .	1 5 0	MUU (10, 2)
1	9 2		
13	1 1 .		MUU (11, 2)
25	1 2 .		MUU (12, 2)
37			
49		73.....80	
61		1 6 0	

FORTRAN FIXED 10 DIGIT DECIMAL DATA

DECK NO. _____ PROGRAMMER _____ DATE _____ PAGE 5 of 22 JOB NO. _____

	NUMBER	IDENTIFICATION	DESCRIPTION DO NOT KEY PUNCH
1	1 0 2		
13	1 2 .		NPHI (1) the outer boundary of the first rod type is 12.0
25			
37			
49		73 80	
61		1 7 0	
1			
13			
25			
37			
49		73 80	
61			
1			
13			
25			
37			
49		73 80	
61			
1			
13			
25			
37			
49		73 80	
61			

FORTRAN FIXED 10 DIGIT DECIMAL DATA

DECK NO. _____ PROGRAMMER _____ DATE _____ PAGE 6 of 22 JOB NO. _____

	NUMBER	IDENTIFICATION	DESCRIPTION DO NOT KEY PUNCH
1	1 0 8		
13	1 2		NADJRZ the outer zone of rod type 1 is zone number 12
25			
37			
49		73 80	
61		1 8 0	
1	1 1 4		
13	1		NADJPZ (1) NADJPZ (1) indicates the number of zones adjacent
25	2		NADJPZ (2) to zone 1.
37	2		NADJPZ (3)
49	2	73 80	NADJPZ (4)
61	2	1 9 0	NADJPZ (5)
1	1 1 9		
13	2		NADJPZ (6)
25	2		NADJPZ (7)
37	2		NADJPZ (8)
49	2	73 80	NADJPZ (9)
61	2	2 0 0	NADJPZ (10)
1	1 2 4		
13	2		NADJPZ (11)
25	1		NADJPZ (12)
37			
49		73 80	
61		2 1 0	

FORTRAN FIXED 10 DIGIT DECIMAL DATA

DECK NO. _____ PROGRAMMER _____ DATE _____ PAGE 7 of 22 JOB NO. _____

NUMBER	IDENTIFICATION	DESCRIPTION DO NOT KEY PUNCH
1 3 4		
2		IZP (1, 1) IZP (K, I) is the K th zone adjacent to zone I.
3		IZP (2, 1)
4		IZP (1, 2)
1 73 80		IZP (2, 2)
2 2 0		IZP (1, 3)
1 3 9		
2		IZP (2, 3)
5		IZP (1, 4)
3		IZP (2, 4)
6 73 80		IZP (1, 5)
4 2 3 0		IZP (2, 5)
1 4 4		
7		IZP (1, 6)
5		IZP (2, 6)
8		IZP (1, 7)
6 73 80		IZP (2, 7)
9 2 4 0		IZP (1, 8)
1 4 9		
7		IZP (2, 8)
1 0		IZP (1, 9)
8		IZP (2, 9)
1 1 73 80		IZP (1, 10)
9 2 5 0		IZP (2, 10)

FORTRAN FIXED 10 DIGIT DECIMAL DATA

DECK NO. _____ PROGRAMMER _____ DATE _____ PAGE 8 of 22 JOB NO. _____

	NUMBER	IDENTIFICATION	DESCRIPTION DO NOT KEY PUNCH
1	1 5 4		
13	1 2 .		IZP (1, 11)
25	1 0 .		IZP (2, 11)
37	1 1 .		IZP (1, 12)
49		73 80	IZP (2, 12)
61		2 6 0	
1	1 7 4		
13	6 .		NTHRM number of materials for which upscattering is allowed
25	1 1 .		IDTHRM (1) IDTHRM gives the ID numbers of the
37	1 3 .		IDTHRM (2) upscattering materials in ascending
49	1 4 .	73 80	IDTHRM (3) order
61	1 5 .	2 7 0	IDTHRM (4)
1	1 7 9		
13	1 6 .		IDTHRM (5)
25	1 8 .		IDTHRM (6)
37	1 1 .		NM total number of materials in this problem is 11.
49	1 .	73 80	MAT (1) U238 (MAT array lists the ID numbers
61	2 .	2 8 0	MAT (2) U235 of materials in this problem in
1	1 8 4		ascending order)
13	1 0 .		MAT (3) Zr
25	1 1 .		MAT (4) C (at coolant temperature)
37	1 3 .		MAT (5) C (at fuel temperature)
49	1 4 .	73 80	MAT (6) H (at moderator temperature)
61	1 5 .	2 9 0	MAT (7) H (at coolant temperature)

FORTRAN FIXED 10 DIGIT DECIMAL DATA

DECK NO _____ PROGRAMMER _____ DATE _____ PAGE 9 of 22 JOB NO. _____

	NUMBER	IDENTIFICATION	DESCRIPTION DO NOT KEY PUNCH
1	1 8 9		
13	1 6 .		MAT (8) Deuterium
25	1 7 .		MAT (9) Al
37	1 8 .		MAT (10) O (at coolant temperature)
49	1 9 .	73 80	MAT (11) O (at moderator temperature)
61		3 0 0	
1	2 0 7		
13	3 .		NMZONE(1) NMZONE (1) is the number of materials
25	4 .		NMZONE(2) in zone I.
37	3 .		NMZONE(3)
49	4 .	73 80	NMZONE(4)
61	3 .	3 1 0	NMZONE(5)
1	2 1 2		
13	4 .		NMZONE(6)
25	3 .		NMZONE(7)
37	4 .		NMZONE(8)
49	2 .	73 80	NMZONE(9)
61	0 .	3 2 0	NMZONE(10)
1	2 1 7		
13	1 .		NMZONE(11)
25	3 .		NMZONE(12)
37			
49		73 80	
61		3 3 0	

FORTRAN FIXED 10 DIGIT DECIMAL DATA

DECK NO. _____ PROGRAMMER _____ DATE _____ PAGE 10 of 22 JOB NO. _____

NUMBER	IDENTIFICATION	DESCRIPTION DO NOT KEY PUNCH
1.....2.2.7		
13 2.....		IDZONE(1, 1) ID numbers of the materials in zone 1
25 1.....		IDZONE(2, 1)
37 1.3.....		IDZONE(3, 1)
49.....73.....80		
61.....3.4.0		
1.....2.3.5		
13 1.5.....		IDZONE(1, 2) ID numbers of the materials in zone 2
25 1.1.....		IDZONE(2, 2)
37 1.7.....		IDZONE(3, 2)
49 1.8.....73.....80		IDZONE(4, 2)
61.....3.5.0		
1.....2.4.3		
13 2.....		IDZONE(1, 3) ID numbers of the materials in zone 3
25 1.....		IDZONE(2, 3)
37 1.3.....		IDZONE(3, 3)
49.....73.....80		
61.....3.6.0		
1.....2.5.1		
13 1.5.....		IDZONE(1, 4) ID numbers of the materials in zone 4
25 1.1.....		IDZONE(2, 4)
37 1.7.....		IDZONE(3, 4)
49 1.8.....73.....80		IDZONE(4, 4)
613.7.0		

FORTRAN FIXED 10 DIGIT DECIMAL DATA

DECK NO. _____ PROGRAMMER _____ DATE _____ PAGE 11 of 22 JOB NO. _____

NUMBER	IDENTIFICATION	DESCRIPTION DO NOT KEY PUNCH
1 2 5 9		ID numbers of the materials in zone 5
13 2 .		IDZONE(1, 5)
25 1 .		IDZONE(2, 5)
37 1 3 .		IDZONE(3, 5)
49	73 80	
61	3 8 0	
1 2 6 7		ID numbers of the materials in zone 6
13 1 5 .		IDZONE(1, 6)
25 1 1 .		IDZONE(2, 6)
37 1 7 .		IDZONE(3, 6)
49 1 8 .	73 80	IDZONE(4, 6)
61	3 9 0	
1 2 7 5		ID numbers of the materials in zone 7
13 2 .		IDZONE(1, 7)
25 1 .		IDZONE(2, 7)
37 1 3 .		IDZONE(3, 7)
49	73 80	
61	4 0 0	
1 2 8 3		ID numbers of the materials in zone 8
13 1 5 .		IDZONE(1, 8)
25 1 1 .		IDZONE(2, 8)
37 1 7 .		IDZONE(3, 8)
49 1 8 .	73 80	IDZONE(4, 8)
61	4 1 0	

FORTRAN FIXED 10 DIGIT DECIMAL DATA

DECK NO. _____ PROGRAMMER _____ DATE _____ PAGE 12 of 22 JOB NO. _____

	NUMBER	IDENTIFICATION	DESCRIPTION DO NOT KEY PUNCH
1	2 9 1		ID numbers of the materials in zone 9
13	1 7 .		IDZONE(1, 9)
25	1 8 .		IDZONE(2, 9)
37			
49		73 80	
61		4 2 0	
1	2 9 9		ID number of material in zone 10
13	0 . 0		IDZONE(1, 10) (Zone 10 is void)
25			
37			
49		73 80	
61		4 3 0	
1	3 0 7		ID number of material in zone 11
13	1 0 .		IDZONE(1, 11)
25			
37			
49		73 80	
61		4 4 0	
1	3 1 5		ID numbers of materials in zone 12
13	1 6 .		IDZONE(1, 12)
25	1 9 .		IDZONE(2, 12)
37	1 4 .		IDZONE(3, 12)
49		73 80	
61		4 5 0	

FORTTRAN FIXED 10 DIGIT DECIMAL DATA

DECK NO. _____ PROGRAMMER _____ DATE _____ PAGE 13 of 22 JOB NO. _____

NUMBER	IDENTIFICATION	DESCRIPTION DO NOT KEY PUNCH
1 13 25 37 49 61 3 8 7 0 . . 0	73 80 4 6 0	NZIB not used in annular representation
1 13 25 37 49 61 3 8 8 1 2 .	73 80 4 7 0	NZCEL Moderator zone (should be the highest zone number in problem)
1 13 25 37 49 61 3 8 9 6 . . 1 . . 2 . . 1 . . 2 . .	73 80 4 8 0	Number of energy boundaries between 0 and 10 MEV NDEP (excluding 0 and 10 MEV) def. the energy deposition groups NSØ(1) = 1.0: indicates zone 1 contains fuel. NSØ(2) = 2.0: absorption weighting is to be used in zone 2. NSØ(3) = 1.0: zone 3 contains fuel NSØ(4) = 2.0: absorption weighting is to be used in zone 4.
1 13 25 37 49 61 3 9 4 1 . . 2 . . 1 . . 2 . . 3 . .	73 80 4 9 0	NSØ(5) = 1.0: zone 5 contains fuel NSØ(6) = 2.0: absorption weighting is to be used in zone 6 NSØ(7) = 1.0: zone 7 contains fuel NSØ(8) = 2.0: absorption weighting is to be used in zone 8 NSØ(9) = 3.0: statistical estimation is to be used in zone 9.

FORTRAN FIXED 10 DIGIT DECIMAL DATA

DECK NO. _____ PROGRAMMER _____ DATE _____ PAGE 14 of 22 JOB NO. _____

NUMBER	IDENTIFICATION	DESCRIPTION DO NOT KEY PUNCH
1	3 9 9	
13	3 .	NSQ(10) = 3.0: statistical estimation is to be used in zone 10
25	3 .	NSQ(11) = 3.0: statistical estimation is to be used in zone 11
37	0 .	NSQ(12) = 0.0: non fuel optically thick region in which no
49	73 80	absorption weighting takes place in thermal region
61	5 0 0	for neutrons whose statistical weight W is less than WC.
1	4 1 0	
13	1 .	IRTYP(1) = 1.0: indicates that rod 1 is of rod type 1.
25		
37		
49	73 80	
61	5 1 0	
1	4 5 0	
13	1 .	NPUNCH = 1.0: punch restart cards upon completion of each
25	1 .	batch of NDHIST histories.
37	1 .	NSTART = 1.0: restart cards are to be read in
49	73 80	NANULR = 1.0: annular representation
61	5 2 0	
1		
13		
25		
37		
49	73 80	
61		

FORTRAN FIXED 10 DIGIT DECIMAL DATA

DECK NO. _____ PROGRAMMER _____ DATE _____ PAGE 15 of 22 JOB NO. _____

	NUMBER	IDENTIFICATION	DESCRIPTION DO NOT KEY PUNCH
1	4 5 9		
13	1 5 . 7 6 3 5 3		RADIUS(1)
25			
37			
49		73 80	
61		5 3 0	
1	4 6 5		
13	. 0 0 0 1		DELTA kick factor
25	0 . 0		CENTER (1, 1) X coordinate } of the center
37	0 . 0		CENTER (2, 1) Y coordinate } of rod 1.
49		73 80	
61		5 4 0	
1	6 2 6		
13	1 . 0		GAY(1, 1) GAY(I, J) refers to the J th boundary
25	- 1 . 0		GAY(2, 1) describing zone I. Its value is +1. or -1.
37	- 1 . 0		GAY(3, 1) See page 31 .
49	- 1 . 0	73 80	GAY(4, 1)
61	- 1 . 0	5 5 0	GAY(5, 1)
1	6 3 1		
13	- 1 . 0		GAY(6, 1)
25	- 1 . 0		GAY(7, 1)
37	- 1 . 0		GAY(8, 1)
49	- 1 . 0	73 80	GAY(9, 1)
61	- 1 . 0	5 6 0	GAY(10, 1)

FORTRAN FIXED 10 DIGIT DECIMAL DATA

DECK NO. _____ PROGRAMMER _____ DATE _____ PAGE 16 of 22 JOB NO. _____

	NUMBER	IDENTIFICATION	DESCRIPTION DO NOT KEY PUNCH
1	6 3 6		
13	- 1 . 0		GAY(11, 1)
25	- 1 . 0		GAY (12, 1)
37			
49		73	
61		5 7 0	
1	6 4 6		
13			GAY(1, 2)
25	1 . 0		GAY(2, 2)
37	1 . 0		GAY(3, 2)
49	1 . 0	73	GAY(4, 2)
61	1 . 0	5 8 0	GAY(5, 2)
1	6 5 1		
13	1 . 0		GAY(6, 2)
25	1 . 0		GAY(7, 2)
37	1 . 0		GAY(8, 2)
49	1 . 0	73	GAY(9, 2)
61	1 . 0	5 9 0	GAY(10, 2)
1	6 5 6		
13	1 . 0		GAY(11, 2)
25	1 . 0		GAY(12, 2)
37			
49		73	
61		6 0 0	

FORTRAN FIXED 10 DIGIT DECIMAL DATA

DECK NO. _____ PROGRAMMER _____ DATE _____ PAGE 17 of 22 JOB NO. _____

	NUMBER	IDENTIFICATION	DESCRIPTION DO NOT KEY PUNCH
1	6 7 2		
13	. . 3 7 6 2 7 2 8		BK(1) BK(1) is the square of the radius of the 1 th boundary
25	1 . . 6 5 8 0 7 7		BK(2)
37	3 . . 9 1 5 6 4 8		BK(3)
49	7 . . 1 6 7 5 9 4	73.....80	BK(4)
61	1 1 . . 6 8 2 8 2	6 1 0	BK(5)
1	6 7 7		
13	1 6 . . 4 5 8 1 3		BK(6)
25	2 1 . . 7 3 7 6 1		BK(7)
37	2 6 . . 6 1 2 6 0		BK(8)
49	2 9 . . 7 1 1 7 7	73.....80	BK(9)
61	3 8 . . 1 2 7 5 6	6 2 0	BK(10)
1	6 8 2		
13	4 0 . . 0 0 0 7 2		BK(11)
25	2 4 8 . . 4 8 8 9		BK(12)
37	.....		
49	.....	73.....80	
61	.....	.....6 3 0	
1	6 9 7		
13	. 4 0 9 5 1 6 - 0 3		DZØNE(1, 1) Atomic number densities
25	. 3 0 6 9 9 - 0 1		(2, 1) Corresponding to the ID numbers listed
37	. 3 2 4 4 4 3 - 0 1		(3, 1) in the IDZØNE array
49	.....	73.....80	
61	.....	.....6 4 0	

FORTRAN FIXED 10 DIGIT DECIMAL DATA

DECK NO. _____ PROGRAMMER _____ DATE _____ PAGE 18 of 22 JOB NO. _____

	NUMBER	IDENTIFICATION	DESCRIPTION DO NOT KEY PUNCH
1	7 0 5		
13	. 2 3 0 7 6 4 - 0 1		DZONE (1, 2)
25	. 2 9 6 6 9 8 - 0 1		(2, 2)
37	. 1 5 0 7 2 2 - 0 1		(3, 2)
49	. 1 2 5 5 6 6 - 0 2	73	(4, 2)
61		80	
		6 5 0	
1	7 1 3		
13	. 4 0 9 5 1 6 - 0 3		
25	. 3 0 6 9 9 - 0 1		
37	. 3 2 4 4 4 3 - 0 1		
49		73	
61		80	
		6 6 0	
1	7 2 1		
13	. 2 3 0 7 6 4 - 0 1		
25	. 2 9 6 6 9 8 - 0 1		
37	. 1 5 0 7 2 2 - 0 1		
49	. 1 2 5 5 6 6 - 0 2	73	
61		80	
		6 7 0	
1	7 2 9		
13	. 4 0 9 5 1 6 - 0 3		
25	. 3 0 6 9 9 - 0 1		
37	. 3 2 4 4 4 3 - 0 1		
49		73	
61		80	
		6 8 0	

FORTRAN FIXED 10 DIGIT DECIMAL DATA

DECK NO. _____ PROGRAMMER _____ DATE _____ PAGE 19 of 22 JOB NO. _____

	NUMBER	IDENTIFICATION	DESCRIPTION DO NOT KEY PUNCH
1	7.3.7		
13	..2.3.0.7.6.4. - 0 1		
25	. 2 9 6 6 9 8. - 0 1		
37	..1.5.0.7.2.2. - 0 1		
49	. 1 2 5 5 6 6. - 0 2	73.....80	
61	.....	.....6.9.0	
1	7.4.5		
13	. 4 0 9 5 1 6. - 0 3		
25	. 3 0 6 9 9. - 0 1		
37	. 3 2 4 4 4 3. - 0 1		
49	.....	73.....80	
61	.....	.....7.0.0	
1	7.5.3		
13	. 2 3 0 7 6 4. - 0 1		
25	. 2 9 6 6 9 8. - 0 1		
37	. 1 5 0 7 2 2. - 0 1		
49	. 1 2 5 5 6 6. - 0 2	73.....80	
61	.....	.....7.1.0	
1	7.6.1		
13	. 5 6 9 7 9 9. - 0 1		A1
25	. 4 7 4 6 9 5. - 0 2		Oxygen
37	.....		
49	.....	73.....80	
61	.....	.....7.2.0	

FORTRAN FIXED 10 DIGIT DECIMAL DATA

DECK NO. _____ PROGRAMMER _____ DATE _____ PAGE 20 of 22 JOB NO. _____

	NUMBER	IDENTIFICATION	DESCRIPTION DO NOT KEY PUNCH
1	7 6 9		
13	0 . 0		
25			
37			
49		73 80	
61		7 3 0	
1	7 7 7		
13	. 4 2 4 4 7 8 - 0 1		Zr
25			
37			
49		73 80	
61		7 4 0	
1	7 8 5		
13	. 6 4 1 7 6 9 - 0 1		D
25	. 3 2 1 6 8 9 - 0 1		Q
37	. 1 6 0 8 4 0 - 0 3		H
49		73 80	
61		7 5 0	
1			
13			
25			
37			
49		73 80	
61			

FORTTRAN FIXED 10 DIGIT DECIMAL DATA

DECK NO. _____ PROGRAMMER _____ DATE _____ PAGE 21 of 22 JOB NO. _____

	NUMBER	IDENTIFICATION	DESCRIPTION DO NOT KEY PUNCH
1	8 6 1		
13	4 . 3 5 9 6 1		XSTORE } X and Y coordinates at which first particle
25	0 . 0		YSTORE } history is to start.
37	2 . 0 + 0 6		EDEP(1) Energy deposition group boundaries
49	1 . 0 + 0 6	73 80	EDEP(2)
61	. 5 + 0 6	7 7 0	EDEP(3)
1	8 6 6		
13	. 2 + 0 6		EDEP(4)
25	. 1 + 0 6		EDEP(5)
37	. 0 5 + 0 6		EDEP(6)
49		73 80	
61		7 8 0	
1	8 7 2		
13	5 0 0 0 0 .		ECAP(1) Capture and fission
25	2 0 0 0 .		ECAP(2) Monitoring group boundaries
37	. 6 2 5		ECAP(3)
49		73 80	
61		7 9 0	
1	8 7 5		
13	. 0 5 3 0 6		EKT(1) EKT(I) is the thermal temperature (in electron
25	. 0 6 9 8 2		EKT(2) volts) of the 1 th upscatterer.
37	. 0 3 1 5 2 7		EKT(3)
49	. 0 5 3 0 6	73 80	EKT(4)
61	. 0 3 9 8 2 7	8 0 0	EKT(5)

FORTRAN FIXED 10 DIGIT DECIMAL DATA

DECK NO. _____ PROGRAMMER _____ DATE _____ PAGE 22 of 22 JOB NO. _____

NUMBER	IDENTIFICATION	DESCRIPTION DO NOT KEY PUNCH
1		
13		
25		
37		
49		
61		
1		
13		
25		
37		
49		
61		
1		
13		
25		
37		
49		
61		
1		
13		
25		
37		
49		
61		
1		
13		
25		
37		
49		
61		

114-C-17

AI-CE-MEMO-69

C. OUTPUT FOR ANNULAR REPRESENTATION SAMPLE CASE

The printed output for the annular representation sample case is presented in this section. The first line of output is the title card. The second line gives the value of the starting random number RDUM. The first six pages list the input DATA array by location. The rest of the output is as outlined in Section IV.

HWOCR SAFE TEST CASE ANNULAR GEO.

RDUM = 313746527031

INDEX	DATA	INDEX	DATA	INDEX	DATA	INDEX	DATA
1	400	2	50	3	4	4	1
5		6		7		8	12
9		10		11		12	0
13		14	12	15		16	0
17		18		19		20	1
21	10	22	2	23	10	24	3
25	10	26	4	27	100	28	1
29	1	30	1	31	1	32	0
33		34		35		36	0
37		38		39		40	7
41	1	42	1	43	2	44	2
45	2	46	2	47	2	48	2
49	2	50	2	51	2	52	2
53		54		55		56	0
57		58		59		60	0
61		62	1	63	1	64	2
65	3	66	4	67	5	68	6
69	7	70	8	71	9	72	10
73	11	74		75		76	0
77		78		79		80	0
81		82		83	2	84	3
85	4	86	5	87	6	88	7
89	8	90	9	91	10	92	11
93	12	94	0	95		96	0
97		98		99		100	0
101		102	12	103		104	0
105		106		107		108	12
109		110		111		112	0
113		114	1	115	2	116	2
117	2	118	2	119	2	120	2
121	2	122	2	123	2	124	2
125	1	126		127		128	0
129		130		131		132	0
133		134	2	135		136	3
137		138	4	139	2	140	5
141	3	142	6	143	4	144	7

145	5	146	8	147	6	148	9
149	7	150	9	151	8	152	11
153	9	154	12	155	1	156	11
157		158	9	159		160	
161		162	9	163		164	9
165		166	9	167		168	9
169		170	9	171		172	9
173		174	6	175	11	176	13
177	14	178	15	179	16	180	18
181	11	182	1	183	2	184	15
185	11	186	13	187	14	188	15
189	16	190	7	191	18	192	19
193		194		195		196	9
197		198		199		200	9
201		202	9	203		204	
205		206		207	3	208	4
209	3	210	4	211	3	212	4
213	3	214	4	215	2	216	
217	1	218	3	219		220	
221		222		223		224	
225		226		227	2	228	1
229	13	230		231		232	
233		234		235	15	236	11
237	17	238	18	239		240	9
241		242		243	2	244	1
245	13	246	9	247		248	9
249		250		251	15	252	11
253	17	254	18	255		256	
257		258		259	2	260	1
261	13	262		263		264	
265		266		267	15	268	11
269	17	270	18	271		272	
273		274		275	2	276	1
277	13	278		279		280	
281		282		283	15	284	11
285	17	286	18	287		288	
289		290		291	17	292	18
293		294		295		296	
297		298		299		300	
301		302		303		304	
305		306	9	307	1	308	
309		310		311		312	

313
 317 14
 321
 325
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 333
 337
 341
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 349
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 361
 365
 369
 373
 377
 381
 385
 389 6
 393 2
 397 2
 401
 405
 409
 413
 417
 421
 425
 429
 433
 437
 441
 445
 449
 453
 457
 459 15.76353002
 463 1.00000000
 467 0.00000000
 471 0.00000000
 475 0.00000000

314
 318
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 326
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 334
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 342
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 464
 468
 472
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315 16
 319
 323
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 331
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 371
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 391 2
 395 2
 399
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316 19
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 324
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 364
 368
 372
 376
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 384
 388
 392 12
 396
 400
 404
 408
 412
 416
 42
 424
 428
 432
 436
 44
 444
 448
 452
 456
 462
 466
 47
 474
 478

479	0.00000000	480	0.0 0.0000	481	0.0 0.0000	482	0.0 0.0000
483	0.00000000	484	0.0 0.0000	485	0.0 0.0000	486	0.0 0.0000
487	0.00000000	488	0.0 0.0000	489	0.0 0.0000	490	0.0 0.0000
491	0.00000000	492	0.0 0.0000	493	0.0 0.0000	494	0.0 0.0000
495	0.00000000	496	0.0 0.0000	497	0.0 0.0000	498	0.0 0.0000
499	0.00000000	500	0.0 0.0000	501	0.0 0.0000	502	0.0 0.0000
503	0.00000000	504	0.0 0.0000	505	0.0 0.0000	506	0.0 0.0000
507	0.00000000	508	0.0 0.0000	509	0.0 0.0000	510	0.0 0.0000
511	0.00000000	512	0.0 0.0000	513	0.0 0.0000	514	0.0 0.0000
515	0.00000000	516	0.0 0.0000	517	0.0 0.0000	518	0.0 0.0000
519	0.00000000	520	0.0 0.0000	521	0.0 0.0000	522	0.0 0.0000
523	0.00000000	524	0.0 0.0000	525	0.0 0.0000	526	0.0 0.0000
527	0.00000000	528	0.0 0.0000	529	0.0 0.0000	530	0.0 0.0000
531	0.00000000	532	0.0 0.0000	533	0.0 0.0000	534	0.0 0.0000
535	0.00000000	536	0.0 0.0000	537	0.0 0.0000	538	0.0 0.0000
539	0.00000000	540	0.0 0.0000	541	0.0 0.0000	542	0.0 0.0000
543	0.00000000	544	0.0 0.0000	545	0.0 0.0000	546	0.0 0.0000
547	0.00000000	548	0.0 0.0000	549	0.0 0.0000	550	0.0 0.0000
551	0.00000000	552	0.0 0.0000	553	0.0 0.0000	554	0.0 0.0000
555	0.00000000	556	0.0 0.0000	557	0.0 0.0000	558	0.0 0.0000
559	0.00000000	560	0.0 0.0000	561	0.0 0.0000	562	0.0 0.0000
563	0.00000000	564	0.0 0.0000	565	0.0 0.0000	566	0.0 0.0000
567	0.00000000	568	0.0 0.0000	569	0.0 0.0000	570	0.0 0.0000
571	0.00000000	572	0.0 0.0000	573	0.0 0.0000	574	0.0 0.0000
575	0.00000000	576	0.0 0.0000	577	0.0 0.0000	578	0.0 0.0000
579	0.00000000	580	0.0 0.0000	581	0.0 0.0000	582	0.0 0.0000
583	0.00000000	584	0.0 0.0000	585	0.0 0.0000	586	0.0 0.0000
587	0.00000000	588	0.0 0.0000	589	0.0 0.0000	590	0.0 0.0000
591	0.00000000	592	0.0 0.0000	593	0.0 0.0000	594	0.0 0.0000
595	0.00000000	596	0.0 0.0000	597	0.0 0.0000	598	0.0 0.0000
599	0.00000000	600	0.0 0.0000	601	0.0 0.0000	602	0.0 0.0000
603	0.00000000	604	0.0 0.0000	605	0.0 0.0000	606	0.0 0.0000
607	0.00000000	608	0.0 0.0000	609	0.0 0.0000	610	0.0 0.0000
611	0.00000000	612	0.0 0.0000	613	0.0 0.0000	614	0.0 0.0000
615	0.00000000	616	0.0 0.0000	617	0.0 0.0000	618	0.0 0.0000
619	0.00000000	620	0.0 0.0000	621	0.0 0.0000	622	0.0 0.0000
623	0.00000000	624	0.0 0.0000	625	0.0 0.0000	626	0.0 0.0000
627	-1.00000000	628	-1.00000000	629	-1.00000000	630	-1.00000000
631	-1.00000000	632	-1.00000000	633	-1.00000000	634	-1.00000000
635	-1.00000000	636	-1.00000000	637	-1.00000000	638	-1.00000000
639	0.00000000	640	0.00000000	641	0.00000000	642	0.00000000
643	0.00000000	644	0.00000000	645	0.00000000	646	0.00000000

647 1.000000
651 1.000000
655 1.000000
659 1.000000
663 1.000000
667 1.000000
671 1.000000
675 7.16759402
679 26.61260009
683 248.48889923
687 0.00000000
691 0.00000000
695 0.00000000
699 0.03244430
703 0.00000000
707 0.01507220
711 0.00000000
715 0.03244430
719 0.00000000
723 0.01507220
727 0.00000000
731 0.03244430
735 0.00000000
739 0.01507220
743 0.00000000
747 0.03244430
751 0.00000000
755 0.01507220
759 0.00000000
763 0.00000000
767 0.00000000
771 0.00000000
775 0.00000000
779 0.00000000
783 0.00000000
787 0.00000000
791 0.00000000
795 0.00000000
799 0.00000000
803 0.00000000
807 0.00000000
811 0.00000000

648 1.000000
652 1.000000
656 1.000000
660 1.000000
664 1.000000
668 1.000000
672 0.37627280
676 11.68281996
680 29.71177006
684 0.00000000
688 0.00000000
692 0.00000000
696 0.00000000
700 0.00000000
704 0.00000000
708 0.01255660
712 0.00000000
716 0.00000000
720 0.00000000
724 0.01255660
728 0.00000000
732 0.00000000
736 0.00000000
740 0.01255660
744 0.00000000
748 0.00000000
752 0.00000000
756 0.01255660
760 0.00000000
764 0.00000000
768 0.00000000
772 0.00000000
776 0.00000000
780 0.00000000
784 0.00000000
788 0.00000000
792 0.00000000
796 0.00000000
800 0.00000000
804 0.00000000
808 0.00000000
812 0.00000000

649 1.000000
653 1.000000
657 1.000000
661 1.000000
665 1.000000
669 1.000000
673 1.65817700
677 16.45812988
681 38.12756014
685 0.00000000
689 0.00000000
693 0.00000000
697 0.00000000
701 0.00000000
705 0.23076400
709 0.00000000
713 0.00000000
717 0.00000000
721 0.23076400
725 0.00000000
729 0.00000000
733 0.00000000
737 0.23076400
741 0.00000000
745 0.00000000
749 0.00000000
753 0.23076400
757 0.00000000
761 0.56979900
765 0.00000000
769 0.00000000
773 0.00000000
777 0.42447800
781 0.00000000
785 0.64176900
789 0.00000000
793 0.00000000
797 0.00000000
801 0.00000000
805 0.00000000
809 0.00000000
813 0.00000000

65 1.000000
654 1.000000
658 1.000000
662 1.000000
666 1.000000
670 1.000000
674 3.91564801
678 21.73761000
682 40.00000000
686 0.00000000
690 0.00000000
694 0.00000000
698 0.00000000
702 0.00000000
706 0.02966980
710 0.00000000
714 0.00000000
718 0.00000000
722 0.02966980
726 0.00000000
730 0.00000000
734 0.00000000
738 0.02966980
742 0.00000000
746 0.00000000
750 0.00000000
754 0.02966980
758 0.00000000
762 0.00000000
766 0.00000000
770 0.00000000
774 0.00000000
778 0.00000000
782 0.00000000
786 0.03216890
790 0.00000000
794 0.00000000
798 0.00000000
802 0.00000000
806 0.00000000
810 0.00000000
814 0.00000000

815	0.00000000	816	0.00000000	817	0.00000000	818	0.00000000
819	0.00000000	820	0.00000000	821	0.00000000	822	0.00000000
823	0.00000000	824	0.00000000	825	0.00000000	826	0.00000000
827	0.00000000	828	0.00000000	829	0.00000000	830	0.00000000
831	0.00000000	832	0.00000000	833	0.00000000	834	0.00000000
835	0.00000000	836	0.00000000	837	0.00000000	838	0.00000000
839	0.00000000	840	0.00000000	841	0.00000000	842	0.00000000
843	0.00000000	844	0.00000000	845	0.00000000	846	0.00000000
847	0.00000000	848	0.00000000	849	0.00000000	850	0.00000000
851	0.00000000	852	0.00000000	853	0.00000000	854	0.00000000
855	0.00000000	856	0.00000000	857	15.7655312	858	5.15873998
859	0.00000000	860	0.00000000	861	4.3596102	862	0.00000000
863	*****	864	*****	865	5.00000000	866	20.00000000
867	1.00000000	868	0.00000000	869	0.00000000	870	0.00000000
871	0.00000000	872	0.00000000	873	2.00000000	874	0.62500000
875	0.05360530	876	0.06988190	877	0.31254000	878	0.05360530
879	0.03110540	880	0.05360530	881	0.00000000	882	1.00000000
883	0.00000000	884	0.00000000	885	0.00000000	886	0.00000000
887	0.00000000	888	0.00000000	889	0.00000000	890	0.00000000
891	0.00000000	892	0.00000000	893	0.00000000	894	0.00000000
895	0.00000000	896	0.00000000	897	0.00000000	898	0.00000000
899	0.00000000	900	0.00000000	901	0.00000000	902	0.00000000
903	0.00000000	904	0.00000000	905	0.00000000	906	0.00000000
907	0.00000000	908	0.00000000	909	0.00000000	910	0.00000000
911	0.00000000	912	0.00000000	913	0.00000000	914	0.00000000
915	0.00000000	916	0.00000000	917	0.00000000	918	0.00000000
919	0.00000000	920	0.00000000	921	0.00000000	922	0.00000000
923	0.00000000	924	0.00000000	925	0.00000000	926	0.00000000
927	0.00000000	928	0.00000000	929	0.00000000	930	0.00000000
931	0.00000000	932	0.00000000	933	0.00000000	934	0.00000000
935	0.00000000	936	0.00000000	937	0.00000000	938	0.00000000
939	0.00000000	940	0.00000000	941	0.00000000	942	0.00000000
943	0.00000000	944	0.00000000	945	0.00000000	946	0.00000000
947	0.00000000	948	0.00000000	949	0.00000000	950	0.00000000

ZONE

1
2
3
4
5
6

VOLUME FRACTION

0.00151424
0.00515840
0.00985200
0.01386880
0.01817074
0.01921740

1.-2124634
2.-1961854
3.-0124727
4.-03386787
5.-0753827
6.839 2412

7
8
9
10
11
12

HISTS FISS K EFFECTIVE P EPSILON TH UTIL TOTAL ABS ETA
 4 2598 1.12814326E 11 .84993495E .11151977E .11348565E .1 222636E 1 .15516217E 1
 FUEL TYPE - - - 1 2 3 4 5 6
 POWER 7.62198235E 1 7.66 93544E 1 8.88964932E 1 1.13768326E 2 .0000437E-38 .0000184E-38

ENERGY ISOTOPE IN FUEL
 1 2 3 4 5 6
 7.10000E-08
 FISSIONS .25735915E-02 0.27195859E-01 0.0000000E-38 0.0000000E-38 0.0000000E-38 0.0000000E-38
 CAPTURES .35348893E-03 0.1767470E-01 0.0000000E-38 0.0000000E-38 0.0000000E-38 0.0000000E-38
 0.50000E-05
 FISSIONS .11683320E-02 0.0000000E-38 0.0000000E-38 0.0000000E-38 0.0000000E-38 0.0000000E-38
 CAPTURES .38124010E-03 0.19540139E-01 0.0000000E-38 0.0000000E-38 0.0000000E-38 0.0000000E-38
 0.20000E-04
 FISSIONS .22137049E-01 0.0000000E-38 0.0000000E-38 0.0000000E-38 0.0000000E-38 0.0000000E-38
 CAPTURES .13991930E-01 0.8861809E-01 .48184953E-06 0.0000000E-38 0.0000000E-38 0.0000000E-38
 0.62500E-03
 FISSIONS .47067351E-01 0.0000000E-38 0.0000000E-38 0.0000000E-38 0.0000000E-38 0.0000000E-38
 CAPTURES .55476164E-01 0.1825121E-01 .86179341E-06 0.0000000E-38 0.0000000E-38 0.0000000E-38
 0.00000E-38

TOTAL FISSIONS = 0.52364834

ZONE ENERGY
 .10000E-08 .50000E-05 .20000E-04 .62500E-03 0.00000E-38
 1 CAPTURES 0.99243715E 01 0.37043126E 01 0.2233172E 01 .8165317E 01
 SCATTERS 0.27960979E 02 0.1069577E 02 0.11020049E 02 0.16206913E 02
 2 CAPTURES 0.7215934E-02 0.88959426E-01 0.1359819E-01 .27303362E 01
 SCATTERS .24547699E 02 0.1441455E 02 .18918181E 02 .49463934E 02
 3 CAPTURES 0.1158365E 01 .37341417E 01 0.175586E 01 .91581575E 01
 SCATTERS 0.25167705E 02 0.97621300E 01 0.13167801E 02 0.18343266E 02
 4 CAPTURES 0.64035266E-02 0.14045610E-02 0.13166174E-01 .35482267E 01
 SCATTERS 0.2305184E 02 0.10192615E 02 0.19487522E 02 .63522771E 02
 5 CAPTURES 0.77547871E 00 0.4267947E 01 0.2345978E 01 .12365981E 02
 SCATTERS 0.26194892E 02 0.97029755E 01 0.14088162E 02 0.26164723E 02
 6 CAPTURES 0.7680664E-02 0.17017310E-02 0.14016532E-01 .55477927E 01
 SCATTERS 0.22507262E 02 0.12355336E 02 0.2796893E 02 0.93854458E 02
 7 CAPTURES 0.91745863E 00 0.45774104E 01 0.28762682E 01 0.19605189E 02

	SCATTERS	0.24745804E 02	0.10879380E 02	0.15612836E 02	0.37448255E 02
8	CAPTURES	0.41631759E-02	0.18475831E-02	0.28328432E-01	0.91510774E 01
	SCATTERS	0.18175223E 02	0.11754395E 02	0.22836379E 02	0.14979191E 03
9	CAPTURES	0.10535905E-01	0.54043631E-02	0.22057904E-01	0.13567643E 01
	SCATTERS	0.12565734E 02	0.34567803E 01	0.37939638E 01	0.14223293E 02
10	CAPTURES	0.10000000E-38	0.00000000E-38	0.00000000E-38	0.00000000E-38
	SCATTERS	0.00000000E-38	0.00000000E-38	0.00000000E-38	0.00000000E-38
11	CAPTURES	0.2433777E-01	0.1852332E-01	0.90159941E-01	0.77339449E 01
	SCATTERS	0.14885209E 02	0.67354256E 01	0.11094716E 02	0.38187359E 02
12	CAPTURES	0.1802704E-02	0.14618946E-05	0.11575704E-03	0.14809756E-01
	SCATTERS	0.05951075E 01	0.57937959E 01	0.14188662E 02	0.85851999E 02

		0.100000E 08	0.500000E 05	ENERGY 0.200000E 04	0.625000E 00	0.100000E-38
NU* <td></td> <td>0.08986981E-02</td> <td>0.85997086E-03</td> <td>0.97269680E-02</td> <td>0.72273224E-01</td> <td></td>		0.08986981E-02	0.85997086E-03	0.97269680E-02	0.72273224E-01	
SIGMA F		0.25259067E-02	0.35368392E-03	0.41028643E-02	0.29742076E-01	

		0.100000E 08	0.500000E 05	ENERGY 0.200000E 04	0.625000E 00	0.100000E-38
D20	SIGMA CAPTURE	0.84197174E-04	0.85639455E-07	0.27531797E-05	0.77401493E-04	
	SIGMA SCATTER	0.30802993E 00	0.33940717E 01	0.33745265E 00	0.44869565E 00	
	FLUX	0.21410606E 02	0.17070340E 02	0.42046380E 02	0.19133682E 03	
NON-D20	SIGMA CAPTURE	0.41232958E-02	0.7307266E-02	0.22518663E-01	0.5171309E-01	
	SIGMA SCATTER	0.23409968E 00	0.41731594E 01	0.37222257E 00	0.49012601E 00	
	FLUX	0.73213758E 02	0.18764202E 02	0.34354850E 02	0.98307730E 02	

		0.100000E 08	0.500000E 05	ENERGY 0.200000E 04	0.625000E 00	0.100000E-38
D20	MUBAR	0.28023244E 00	0.28346397E 00	0.25118676E 00	0.11818171E 00	
NON D20	MUBAR	0.23309409E 00	0.23956114E 00	0.29921629E 00	0.18012395E 00	

D20 TRANSFER MATRIX
EMERGENT ENERGY

INCIDENT ENERGY	0.100000E 08	0.500000E 05	0.200000E 04	0.625000E 00	0.000000E -38
0.100000E 08					
0.500000E 05	0.4441904E 01	.65803976E-01	0.000000E-38	0.00000000E-38	
0.200000E 04	0.000000E-38	0.13516730E 01	0.25769738E 0	0.00000000E-38	
0.625000E 00	0.000000E-38	0.000000E-38	0.2258567E 01	0.12679617E 0	
0.000000E -38	0.000000E-38	0.000000E-38	0.33254412E-03	0.45513975E 01	

THERMAL PRODUCTION
BELOW 0.625 = 1.14374

TOTAL PRODUCTION = 1.28143

$\epsilon_{0.625} = 1.12039$

CAPTURES IN U_{235} AND U_{238} = 0.7365629
BELOW 0.625

$\eta_{0.625} = 1.55281$

$\eta_f = 1.41833$

THERMAL ABS. MOD. BELOW 0.625 = 0.0124257

THERMAL ABS. NON-MOD. BELOW 0.625 = 0.7939697

TOTAL ABS. BELOW 0.625 = 0.8063954

TOTAL ABS. = 1.0022636

$P_{0.625} = 0.80457$

THERMAL ABS. IN FUEL
BELOW 0.625 = 0.7365637

$f_{0.625} = 0.91340$

AI-CE-MEMO-69

NON D20 TRANSFER MATRIX
EMERGENT ENERGY

INCIDENT ENERGY	0.10000E-38	0.50000E-35	0.20000E-14	0.62500E-00	0.00000E-38
0.10000E-38	0.000000000E-38	0.000000000E-38	0.000000000E-38	0.000000000E-38	0.000000000E-38
0.50000E-35	0.000000000E-38	0.000000000E-38	0.000000000E-38	0.000000000E-38	0.000000000E-38
0.20000E-14	0.000000000E-38	0.000000000E-38	0.000000000E-38	0.000000000E-38	0.000000000E-38
0.62500E-00	0.000000000E-38	0.000000000E-38	0.000000000E-38	0.000000000E-38	0.000000000E-38
0.00000E-38	0.000000000E-38	0.000000000E-38	0.000000000E-38	0.000000000E-38	0.000000000E-38

THERMAL SPECTRUM VELOCITY MOMENTS

ZONE NO.	FIRST	SECOND	THIRD	FOURTH	FLUX
1	0.37667408E-00	0.1916557E-00	0.11523648E-00	0.66610622E-01	0.36004941E-02
2	0.37605666E-00	0.17389621E-00	0.94841034E-01	0.6028599E-01	0.42621259E-02
3	0.47632116E-00	0.17979528E-00	0.95961596E-01	0.5861298E-01	0.44831087E-02
4	0.37686615E-00	0.1778999E-00	0.97291204E-01	0.6153840E-01	0.55154763E-02
5	0.39137554E-00	0.18285423E-00	0.99467017E-01	0.62100055E-01	0.60293376E-02
6	0.36404959E-00	0.16284557E-00	0.85737610E-01	0.52239510E-01	0.79548925E-02
7	0.35993783E-00	0.15631152E-00	0.80184329E-01	0.47719353E-01	0.86806935E-02
8	0.3174908E-00	0.12888148E-00	0.62509975E-01	0.35814589E-01	0.11801679E-03
9	0.3049492E-00	0.11497082E-00	0.5335128E-01	0.29464462E-01	0.13956150E-03
10	0.0000000E-38	0.0000000E-38	0.0000000E-38	0.0000000E-38	0.14233739E-03
11	0.29967534E-00	0.11353013E-00	0.51731563E-01	0.2878903E-01	0.14348037E-03
12	0.28239012E-00	0.1116531E-00	0.4448508E-01	0.23563914E-01	0.19133682E-03

ENERGY	ENERGY DEPOSITION IN	
	CARBON	HYDROGEN
0.2000000E 07	0.78474927E 03	0.64249819E 05
0.10000000E 07	0.42433842E 04	0.64981805E 05
0.50000000E 06	0.17323442E 05	0.44784191E 05
0.20000000E 06	0.2639 839E 05	0.38010931E 05
0.10000000E 06	0.12591231E 05	0.13951 75E 05
0.50000000E 05	0.78245565E 04	0.75120574E 04
0.00000000E-38	0.65821434E 04	0.7 388784E 04

TOTAL ENERGY DEPOSITED IN COOLANT = 0.31226909E 06 → 0.5963336 MEV/FISSION

MODERATOR = 0.12774630E 07 → 2.43954 MEV/FISSION

TOTAL FISSIONS = 0.52364834

CALCULATIONS NEGLECTING THE FIRST NO HISTORIES

HISTS	K EFFECTIVE	P	EPSILON	TH UTIL	TOTAL ABS	ETA
50	0.12824144E 01	0.87901471E 00	0.11149405E 01	0.91358288E 00	0.10022922E 01	0.15526657E 01
100	0.12838274E 01	0.87874812E 00	0.11157961E 01	0.91353410E 00	0.10020986E 01	0.15540799E 01
150	0.12835987E 01	0.87807861E 00	0.11169954E 01	0.91373353E 00	0.10021267E 01	0.1553391E 01
200	0.12834347E 01	0.87708185E 00	0.11173499E 01	0.91365447E 00	0.10021541E 01	0.15506865E 01
250	0.12823993E 01	0.87663741E 00	0.11173249E 01	0.91359976E 00	0.10021829E 01	0.15540486E 01
300	0.12802418E 01	0.87639317E 00	0.11169594E 01	0.91352691E 00	0.10019428E 01	0.15529001E 01
350	0.12806049E 01	0.87693787E 00	0.11159312E 01	0.91351196E 00	0.10017332E 01	0.15540744E 01
400	0.12819738E 01	0.87734616E 00	0.11160128E 01	0.91327978E 00	0.10017576E 01	0.15538929E 01
450	0.12803185E 01	0.87737006E 00	0.11164657E 01	0.91297244E 00	0.10017827E 01	0.15529906E 01
500	0.12814078E 01	0.87747615E 00	0.11173153E 01	0.91272313E 00	0.10018185E 01	0.15533441E 01
550	0.12810133E 01	0.87735262E 00	0.11171184E 01	0.91263475E 00	0.10018351E 01	0.15534519E 01
600	0.12795505E 01	0.87740872E 00	0.11168917E 01	0.91216964E 00	0.10018624E 01	0.15526483E 01
650	0.12795630E 01	0.87710559E 00	0.11168123E 01	0.9117107E 00	0.10018907E 01	0.15540823E 01
700	0.12839288E 01	0.87708380E 00	0.11165567E 01	0.91152544E 00	0.10019201E 01	0.15599336E 01
750	0.12821593E 01	0.87727057E 00	0.11160291E 01	0.91133171E 00	0.10019503E 01	0.15585643E 01
800	0.12802262E 01	0.87673562E 00	0.11170861E 01	0.91126984E 00	0.10019815E 01	0.15558295E 01
850	0.12796785E 01	0.87687168E 00	0.11164787E 01	0.91099586E 00	0.10020138E 01	0.15561657E 01
900	0.12793635E 01	0.87689329E 00	0.11163034E 01	0.91116181E 00	0.10020472E 01	0.15556518E 01
950	0.12803474E 01	0.87687064E 00	0.11150972E 01	0.91081754E 00	0.10020814E 01	0.15555711E 01
1000	0.12828658E 01	0.876856721E 00	0.11146908E 01	0.91031132E 00	0.10021168E 01	0.15602813E 01
1050	0.12829539E 01	0.876833394E 00	0.11155486E 01	0.91000135E 00	0.10021535E 01	0.15611108E 01
1100	0.12857364E 01	0.876064136E 00	0.11150493E 01	0.90966975E 00	0.10021913E 01	0.15622518E 01
1150	0.12833346E 01	0.8761021150E 00	0.11149570E 01	0.90971058E 00	0.10022307E 01	0.15581633E 01
1200	0.12814318E 01	0.87670865E 00	0.11159372E 01	0.90999605E 00	0.10022716E 01	0.15568212E 01
1250	0.12786475E 01	0.876003401E 00	0.11143509E 01	0.90965284E 00	0.10019777E 01	0.15541462E 01
1300	0.12810150E 01	0.876056651E 00	0.11133403E 01	0.90922645E 00	0.10018405E 01	0.15575604E 01
1350	0.12840583E 01	0.876023043E 00	0.11122128E 01	0.90920555E 00	0.10018768E 01	0.15642848E 01
1400	0.12808367E 01	0.87696455E 00	0.11126195E 01	0.90853592E 00	0.10015305E 01	0.15625931E 01
1450	0.12799117E 01	0.87681916E 00	0.11121491E 01	0.90812190E 00	0.10015625E 01	0.15615251E 01
1500	0.12756807E 01	0.87611686E 00	0.11123721E 01	0.90737989E 00	0.10015957E 01	0.15556044E 01
1550	0.12791934E 01	0.876051382E 00	0.11130442E 01	0.90813603E 00	0.10016308E 01	0.15588517E 01
1600	0.12814819E 01	0.876112269E 00	0.11123934E 01	0.90784915E 00	0.10016669E 01	0.15618182E 01
1650	0.12861116E 01	0.876152705E 00	0.11134905E 01	0.90855446E 00	0.10017149E 01	0.15638618E 01
1700	0.12851830E 01	0.876997276E 00	0.11145076E 01	0.90837698E 00	0.10013131E 01	0.15652205E 01
1750	0.12818825E 01	0.8761021816E 00	0.11142031E 01	0.90863987E 00	0.10013448E 01	0.15616535E 01
1800	0.12802929E 01	0.876000718E 00	0.11151156E 01	0.90882798E 00	0.10013781E 01	0.15574879E 01
1850	0.12770632E 01	0.8760892889E 00	0.11161411E 01	0.90870736E 00	0.10014131E 01	0.15543387E 01
1900	0.12772012E 01	0.8760961812E 00	0.11148037E 01	0.90831569E 00	0.10014493E 01	0.15556609E 01
1950	0.12752424E 01	0.8760984161E 00	0.11161381E 01	0.90875653E 00	0.10014871E 01	0.15501789E 01
2000	0.12699277E 01	0.8760944838E 00	0.11143705E 01	0.90860231E 00	0.10015271E 01	0.15471189E 01

2050	0.12710173E	01	0.81102325E	00	0.11124874E	01	0.90846463E	00	0.10013264E	01	0.15486038E	01
2100	0.12717865E	01	0.81216108E	00	0.11126472E	01	0.90774960E	00	0.1001364E	01	0.15483811E	01
2150	0.12730073E	01	0.81309145E	00	0.11118572E	01	0.90705842E	00	0.10014035E	01	0.15512371E	01
2200	0.12720234E	01	0.81278247E	00	0.11115310E	01	0.90641163E	00	0.10014452E	01	0.1551124E	01
2250	0.12693885E	01	0.81350634E	00	0.11101876E	01	0.90616363E	00	0.1001490E	01	0.15487596E	01
2300	0.12728612E	01	0.81534184E	00	0.11096355E	01	0.90631366E	00	0.1001537E	01	0.1549942E	01
2350	0.12719903E	01	0.81621340E	00	0.11083833E	01	0.90775902E	00	0.10015865E	01	0.15464329E	01
2400	0.12688477E	01	0.81658325E	00	0.11091178E	01	0.90849585E	00	0.10016395E	01	0.15395613E	01
2450	0.12677142E	01	0.81655244E	00	0.11069172E	01	0.91044759E	00	0.10016962E	01	0.15379108E	01
2500	0.12697148E	01	0.81499353E	00	0.11079956E	01	0.91158038E	00	0.10017561E	01	0.15397748E	01
2550	0.12685534E	01	0.81372312E	00	0.11086408E	01	0.91060350E	00	0.10014988E	01	0.15434598E	01
2600	0.12724013E	01	0.81360600E	00	0.11088342E	01	0.91165474E	00	0.10015241E	01	0.15462702E	01
2650	0.12702251E	01	0.81531974E	00	0.11079735E	01	0.91172433E	00	0.10015497E	01	0.15414205E	01
2700	0.12666580E	01	0.81365846E	00	0.11084579E	01	0.91101260E	00	0.10015791E	01	0.15417147E	01
2750	0.12690966E	01	0.81499751E	00	0.11081645E	01	0.91095802E	00	0.10016185E	01	0.15415998E	01
2800	0.12629637E	01	0.81264908E	00	0.11101490E	01	0.91086064E	00	0.99980960E	00	0.15372245E	01
2850	0.12641918E	01	0.81067672E	00	0.11126593E	01	0.91173446E	00	0.99980984E	00	0.15375076E	01
2900	0.12610727E	01	0.80961738E	00	0.11100545E	01	0.91180011E	00	0.99980998E	00	0.15392136E	01
2950	0.12539797E	01	0.80876452E	00	0.11107197E	01	0.91222198E	00	0.99980988E	00	0.1535446E	01
3000	0.12548599E	01	0.81115746E	00	0.11113836E	01	0.91195258E	00	0.99980888E	00	0.15266407E	01
3050	0.12539660E	01	0.81082351E	00	0.11121853E	01	0.9136656E	00	0.99980843E	00	0.15222227E	01
3100	0.12523961E	01	0.80965652E	00	0.11131608E	01	0.91298193E	00	0.99981038E	00	0.15223102E	01
3150	0.12372571E	01	0.8107388E	00	0.11135380E	01	0.91136951E	00	0.99980938E	00	0.15040499E	01
3200	0.12419505E	01	0.81001613E	00	0.11118398E	01	0.91179733E	00	0.99980897E	00	0.15127009E	01
3250	0.12419746E	01	0.81043703E	00	0.11115469E	01	0.90979278E	00	0.99980742E	00	0.15156774E	01
3300	0.12246316E	01	0.81011495E	00	0.11142683E	01	0.90885445E	00	0.99980817E	00	0.14929939E	01
3350	0.12164391E	01	0.80985091E	00	0.11168185E	01	0.90690666E	00	0.99980845E	00	0.14832806E	01
3400	0.12119742E	01	0.80422105E	00	0.11168006E	01	0.9039296E	00	0.99980974E	00	0.14931489E	01
3450	0.12191343E	01	0.80747774E	00	0.11221891E	01	0.90438141E	00	0.99981117E	00	0.14879397E	01
3500	0.12014147E	01	0.80669782E	00	0.11232908E	01	0.90605412E	00	0.99981098E	00	0.14635845E	01
3550	0.11968446E	01	0.80987757E	00	0.11185430E	01	0.90697376E	00	0.99980927E	00	0.14569807E	01
3600	0.11855308E	01	0.80092217E	00	0.1121730E	01	0.90877745E	00	0.99981022E	00	0.14523093E	01
3650	0.11990810E	01	0.80073325E	00	0.1122083E	01	0.90752715E	00	0.99981485E	00	0.14706455E	01
3700	0.12071118E	01	0.80801427E	00	0.11173838E	01	0.9070110E	00	0.99981562E	00	0.14743278E	01
3750	0.11800360E	01	0.80900624E	00	0.11213229E	01	0.90612416E	00	0.99981289E	00	0.14358406E	01
3800	0.11564968E	01	0.79557543E	00	0.11261922E	01	0.90336719E	00	0.99981833E	00	0.14291083E	01
3850	0.11700567E	01	0.82322185E	00	0.11145203E	01	0.89677943E	00	0.99981753E	00	0.14223144E	01
3900	0.11731777E	01	0.81395790E	00	0.11266799E	01	0.8920000E	00	0.99981403E	00	0.1434423E	01
3950	0.12054768E	01	0.89139442E	00	0.11040813E	01	0.90600567E	00	0.99980068E	00	0.1352208E	01

INDIVIDUAL BATCH RESULTS

HISTS	K EFFECTIVE	P	EPSILON	TH UTIL	TOTAL ABS	ETA
50	0.12038722E 01	0.80261934E 00	0.11284262E 01	0.90572648E 00	0.99999871E 00	0.14675782E 01
100	0.11721949E 01	0.82949623E 00	0.10464342E 01	0.91723546E 00	0.1173929E 01	0.14471594E 01
150	0.13014403E 01	0.86041113E 00	0.10316609E 01	0.899 8256E 00	0.99999273E 00	0.163 7404E 01
200	0.15263400E 01	0.88399594E 00	0.10948505E 01	0.91922991E 00	0.99999 91E 00	0.17156392E 01
250	0.11308323E 01	0.84048738E 00	0.11194842E 01	0.9176 201E 00	0.99998820E 00	0.13097844E 01
300	0.14420354E 01	0.82439181E 00	0.11418745E 01	0.91877994E 00	0.10199566E 01	0.16346721E 01
350	0.12537321E 01	0.76723636E 00	0.11993541E 01	0.91473199E 00	0.10172395E 01	0.14642361E 01
400	0.12590869E 01	0.77748811E 00	0.11099909E 01	0.93082675E 00	0.99997592E 00	0.15674154E 01
450	0.13224583E 01	0.80564722E 00	0.10857374E 01	0.93518613E 00	0.99997747E 00	0.16166797E 01
500	0.12040652E 01	0.79993028E 00	0.10566 58E 01	0.932 3796E 00	0.99997652E 00	0.1528486 E 01
550	0.13786512E 01	0.816 1568E 00	0.11307795E 01	0.91737982E 00	0.99997 67E 00	0.15460155E 01
600	0.13804647E 01	0.80353010E 00	0.11322410E 01	0.94447447E 00	0.99997938E 00	0.16065824E 01
650	0.12787149E 01	0.82775743E 00	0.11215545E 01	0.94225 77E 00	0.99996722E 00	0.14618338E 01
700	0.99802065E 00	0.80854616E 00	0.11390133E 01	0.92389698E 00	0.99995816E 00	0.11730168E 01
750	0.13923423E 01	0.79492 24E 00	0.11490313E 01	0.92433883E 00	0.99994957E 00	0.16492303E 01
800	0.14058771E 01	0.84157606E 00	0.10576973E 01	0.91513532E 00	0.99995315E 00	0.17259477E 01
850	0.13147366E 01	0.79814598E 00	0.11556426E 01	0.92875588E 00	0.99994731E 00	0.15348085E 01
900	0.12992 63E 01	0.80552985E 00	0.11272807E 01	0.90072935E 00	0.99994493E 00	0.15885247E 01
950	0.12193437E 01	0.69605852E 00	0.11994048E 01	0.93554147E 00	0.99996 42E 00	0.15612366E 01
1000	0.11292467E 01	0.81707621E 00	0.11435156E 01	0.94099811E 00	0.99995375E 00	0.12844450E 01
1050	0.12776682E 01	0.82236031E 00	0.1066123 E 01	0.92826790E 00	0.99995589E 00	0.15699813E 01
1100	0.11215680E 01	0.67420466E 00	0.11497794E 01	0.93317837E 00	0.99995780E 00	0.155 5043E 01
1150	0.14226358E 01	0.83525643E 00	0.11198169E 01	0.9074 776E 00	0.99994707E 00	0.16762831E 01
1200	0.13898933E 01	0.89451 46E 00	0.10665903E 01	0.89522387E 00	0.99993849E 00	0.16273968E 01
1250	0.14345675E 01	0.73699158E 00	0.11996489E 01	0.9304 732E 00	0.10184381E 01	0.17123656E 01
1300	0.12048016E 01	0.78149385E 00	0.1195084 E 01	0.93335954E 00	0.10093868E 01	0.13692569E 01
1350	0.10657191E 01	0.82841367E 00	0.11692673E 01	0.91000898E 00	0.99991632E 00	0.12087297E 01
1400	0.14515848E 01	0.84009967E 00	0.10934159E 01	0.94216002E 00	0.10198822E 01	0.16445668E 01
1450	0.13280134E 01	0.74968883E 00	0.11362401E 01	0.93141 81E 00	0.99990 82E 00	0.1673991 E 01
1500	0.14914613E 01	0.79331612E 00	0.11027009E 01	0.94612144E 00	0.99989963E 00	0.18022071E 01
1550	0.11035547E 01	0.84331047E 00	0.10754774E 01	0.87170757E 00	0.99988 55E 00	0.13960023E 01
1600	0.11693487E 01	0.78123712E 00	0.11483879E 01	0.92245841E 00	0.99989319E 00	0.14130976E 01
1650	0.10638847E 01	0.79208256E 00	0.10534226E 01	0.87362440E 00	0.99988 79E 00	0.14593152E 01
1700	0.13288283E 01	0.88173069E 00	0.10700456E 01	0.91591801E 00	0.10197339E 01	0.15079474E 01
1750	0.14337 39E 01	0.79891373E 00	0.11269 11E 01	0.89636245E 00	0.99988270E 00	0.17768103E 01
1800	0.13518276E 01	0.81951508E 00	0.10778488E 01	0.90044674E 00	0.99988 31E 00	0.16998104E 01
1850	0.14191675E 01	0.85644512E 00	0.10764621E 01	0.91373426E 00	0.99987411E 00	0.16848845E 01
1900	0.12712660E 01	0.77993619E 00	0.11756516E 01	0.92581 55E 00	0.99989223E 00	0.14976950E 01
1950	0.13575149E 01	0.80440260E 00	0.10657322E 01	0.88999961E 00	0.99989939E 00	0.1788222 1E 01
2000	0.14878311E 01	0.82559705E 00	0.11800424E 01	0.91481442E 00	0.99988794E 00	0.16695658E 01

205	0.12274332E	01	0.748517 7E	00	0.11961379E	01	0.91437384E	0	0.1 093517E	01	0.14854176E	01
210	0.12417874E	01	0.76772165E	00	0.11063 43E	01	0.939 4877E	0	0.99989939E	0	0.15571296E	01
215	0.12266164E	01	0.7776861 00	00	0.11438562E	01	0.93275364E	0	0.9999.129E	0	0.14784577E	01
220	0.13084273E	01	0.82423192E	00	0.11233941E	01	0.930 5487E	0	0.9999.129E	0	0.15195757E	01
225	0.13642435E	01	0.78740579E	00	0.1157130 0E	01	0.91539399E	0	0.99988 31E	0	0.16358936E	01
230	0.11513176E	01	0.75099681E	00	0.11313486E	01	0.90061602E	0	0.99988985E	0	0.15047653E	01
235	0.13016724E	01	0.78653217E	00	0.11515921E	01	0.85673377E	0	0.99990511E	0	0.16774843E	01
240	0.13725529E	01	0.80435753E	00	0.1087787 0E	01	0.88378721E	0	0.99989 33E	0	0.1776311 0E	01
245	0.13039842E	01	0.81753987E	00	0.111798 38E	01	0.84795494E	0	0.99988 79E	0	0.15945296E	01
250	0.12076964E	01	0.86340674E	00	0.10739004E	01	0.87832 12E	0	0.99989939E	00	0.14830268E	01
255	0.13033972E	01	0.85049674E	00	0.10900898E	01	0.93769 35E	0	0.1 382161E	01	0.14440912E	01
260	0.116 8114E	01	0.81700487E	00	0.11027366E	01	0.88126989E	0	0.99979258E	0	0.14623334E	01
265	0.13311596E	01	0.7673 196E	00	0.11314804E	01	0.90965691E	0	0.99983.68E	0	0.16858240E	01
270	0.13629675E	01	0.8585471 00	00	0.10963954E	01	0.92927583E	0	0.99978685E	00	0.15584831E	01
275	0.12056932E	01	0.78015666E	00	0.11162353E	01	0.91243890E	0	0.99984407E	00	0.15176204E	01
280	0.14162865E	01	0.87025608E	00	0.1067330 0E	01	0.91309779E	0	0.10197811E	01	0.16374991E	01
285	0.12347183E	01	0.85801346E	00	0.10541444E	01	0.89187129E	0	0.99980402E	0	0.15309345E	01
290	0.13328123E	01	0.83398235E	00	0.11697987E	01	0.91033254E	0	0.99980688E	0	0.15010142E	01
295	0.14100246E	01	0.82752754E	00	0.10977754E	01	0.90314184E	0	0.99981213E	01	0.17189228E	01
300	0.12363758E	01	0.76990652E	00	0.10974118E	01	0.9179656 0E	0	0.99982977E	00	0.1613233 0E	01
305	0.12718439E	01	0.81750254E	00	0.1096576 0E	01	0.87967136E	0	0.99981737E	0	0.16131132E	01
310	0.12822247E	01	0.83183008E	00	0.10953104E	01	0.92564385E	0	0.99977350E	0	0.15207111E	01
315	0.15097589E	01	0.79125806E	00	0.11079325E	01	0.94106752E	0	0.99982738E	00	0.18303341E	01
320	0.11621628E	01	0.82230158E	00	0.11433997E	01	0.90462679E	0	0.99981594E	0	0.13666215E	01
325	0.12415895E	01	0.80370278E	00	0.11162526E	01	0.9421168 0E	00	0.99983215E	0	0.14692248E	01
330	0.14847755E	01	0.81494625E	00	0.10810597E	01	0.92285156E	0	0.99979687E	0	0.18265793E	01
335	0.13311348E	01	0.81354740E	00	0.10848397E	01	0.934 6 81E	0	0.9998045 0E	0	0.16150403E	01
340	0.1270176E	01	0.87741031E	00	0.11170227E	01	0.93994505E	0	0.99979305E	0	0.13788989E	01
345	0.11332130E	01	0.76839682E	00	0.10567515E	01	0.89837211E	0	0.99979401E	0	0.15537686E	01
350	0.13963308E	01	0.81527690E	00	0.11127985E	01	0.88783 51E	0	0.99981308E	0	0.17338750E	01
355	0.12425451E	01	0.77808057E	00	0.11662 30E	01	0.89743911E	0	0.99982643E	0	0.15261029E	01
360	0.12873554E	01	0.88152204E	00	0.10956108E	01	0.89386356E	0	0.99980164E	0	0.14915023E	01
365	0.10906792E	01	0.80224411E	00	0.11180631E	01	0.91751335E	0	0.99977779E	00	0.13255872E	01
370	0.11508961E	01	0.75704684E	00	0.11535517E	01	0.91083831E	0	0.99981.22E	0	0.14471629E	01
375	0.13424911E	01	0.80305456E	00	0.11003946E	01	0.91147258E	0	0.99982929E	0	0.16670493E	01
380	0.12741928E	01	0.86273 92E	00	0.11039933E	01	0.91629387E	00	0.99979115E	0	0.146 3242E	01
385	0.11158171E	01	0.71263644E	00	0.11645584E	01	0.92619721E	0	0.99982 71E	0	0.14519047E	01
390	0.11638145E	01	0.84174955E	00	0.10907865E	01	0.90602260E	0	0.99982452E	0	0.13992596E	01
395	0.11408787E	01	0.73652344E	00	0.11515854E	01	0.87504978E	0	0.99982738E	0	0.15374427E	01
400	0.12054768E	01	0.89139442E	00	0.11040813E	01	0.9060 567E	0	0.99983.68E	0	0.13522080E	01

STANDARD DEVIATIONS

0.11572668E-01 0.43017430E-01 0.40319562E-01 0.27817975E-01 0.68386782E-02 0.13697670E-01

$\sigma_{\text{MEAN}} = 0.01294$ 0.004809 0.004508 0.002328 0.0007646 0.01531

VII. COMPARISON OF HWOCR-SAFE RESULTS WITH HAMMER RESULTS

Excellent agreement with transport codes has been obtained using HWOCR-SAFE, while the speed of convergence of k_{∞} has been quite encouraging. Probable errors in k_{∞} of 0.7% have been obtained in less than 1 hr on a standard IBM 7094

The table below presents a comparison of k_{∞} and the four factors as calculated by HWOCR-SAFE and a multigroup transport code HAMMER.^(7,8)

The geometric representation in HAMMER was restricted to annular rings, so two Monte Carlo calculations were performed (4000 histories each).

The first used the annular representation permitted in HAMMER and the second used the actual geometry. The estimated probable errors are shown to the right of each Monte Carlo result.

The agreement between the HAMMER results and the annular Monte Carlo results is quite good, especially considering the fact that independently prepared cross-section libraries were used for each code. The differences shown in the actual geometry SAFE calculation, wherever they exceed the estimated probable errors, must therefore be regarded as significant, showing the utility of a Monte Carlo reactor analysis calculation.

COMPARISON OF HWOCR-SAFE RESULTS FROM 4000 HISTORIES WITH HAMMER CALCULATIONS

	HAMMER	HWOCR-SAFE USING HAMMER GEOMETRY	HWOCR-SAFE USING ACTUAL GEOMETRY
K_{∞}	1 2672	1 2814 $\pm$ 0 00873	1.2520 $\pm$ 0 00905
P	0 80156	0 80457 $\pm$ 0 00324	0 80395 $\pm$ 0 00347
ϵ	1 1123	1 1204 $\pm$ 0 00304	1 1124 $\pm$ 0 00344
η	1 5592	1 5528 $\pm$ 0 0103	1 5301 $\pm$ 0.0098
f	0 91154	0 91340 $\pm$ 0 00157	0 91282 $\pm$ 0 00165

7 00 115 12

VIII. CROSS-SECTION LIBRARY

A. TYPES OF CROSS SECTIONS

All materials on the library tape have a total cross section in barns, tabulated as a function of energy. In addition, there are elastic and inelastic scattering cross sections tabulated as a function of energy. In the fast and resonance energy regions these numbers, however, are actually elastic scattering and inelastic scattering probabilities, obtained by normalizing these cross sections to the total cross section for the material in question.

For example, if σ_t is the total cross section at a given energy point for a particular material, then the value at the corresponding point for the elastic scattering cross section is σ_s/σ_t , where σ_s is the elastic scattering cross section in barns.

Similarly, the inelastic scattering cross section, as it appears on the library tape, is actually σ_{in}/σ_t .

If σ_a is defined as $\sigma_t - \sigma_s - \sigma_{in}$, and σ_f is the fission cross section, in barns, then the fission cross section on the library tape is $\nu\sigma_f/\sigma_a$.

The reason for using these forms of cross sections is that computing time is saved in the internal operation of the code.

In the thermal energy region, elastic scattering and $\nu\sigma_f$ are tabulated as cross sections rather than probabilities so that linear interpolation between energy points can be validly used.

B. THERMAL SCATTERING PARAMETERS

In addition to the above-mentioned cross sections, tables of the effective relative velocity of a neutron in a Maxwellian distribution of atoms of a given material are provided for materials whose thermal velocities may be significant. In addition, a value for the thermal effective mass is provided. Should the user request thermal upscattering for a material for which no such data exist on the tape, he will receive a message to that effect when he tries to run his problem.

C. TREATMENT OF ENERGY GRID

The fast energy range uses the same energy grid for all materials, and uses the group concept, in which the same cross section applies for all neutron energies lying between two group boundaries.

In the resonance region, however, each material classified as a resonance absorber has its own arbitrary set of energy points and an appropriate scheme for interpolating for energies between two tabulated values. This is necessary to describe the sharp fluctuations in the cross sections of such materials without having to introduce a grid structure containing several thousand points. Some materials, however, have no significant variation in cross section in the resonance region and so their total and scattering cross sections have been regarded as constant in this energy range.

The thermal energy range uses the same energy grid for all materials but does not use the group concept. It regards the cross sections as existing at the energy points at which they are entered, and uses linear interpolation for obtaining cross sections intermediate to the tabulated values.

D. PRESENT LIST OF ELEMENTS ON CROSS-SECTION LIBRARY TAPE

When specifying the specific nuclear materials for a particular case, the user should consult the following chart for the proper ID. No. to call in the correct cross sections.

<u>ID. NO.</u>	<u>NUCLEAR SPECIES</u>
1	U238
2	U235
3	Not Yet Assigned
4	Not Yet Assigned
5	Not Yet Assigned
6	Not Yet Assigned
7	Not Yet Assigned
8	Ni
9	Cr
10	Zr
11	C in the coolant
12	Fe
13	C in the fuel
14	H in the moderator
15	H in the coolant
16	Deuterium
17	Al
18	O in the SAP
19	O in the moderator
20	H (in H ₂ O)

When requesting materials to be read from the library tape it is necessary to request them in ascending order of ID. No.

Instructions for remaking the cross-section library tape may be obtained from the authors.

APPENDIX A VARIANCE ANALYSIS

In the development of the HWOCR-SAFE code, the question arose as to the choice of estimator type to be used, particularly in optically thin regions which are susceptible to undersampling. To aid in this determination, the variance of collision and track-length type estimators was investigated.

The variance of the expected value Z of the quantity is given by

$$\sigma^2 = \overline{(Z - \bar{Z})^2} \quad \dots (A1)$$

The distribution of path lengths S between collisions is given by $f(S) dS \propto e^{-\Sigma_t S} dS$ where $S \geq 0$. Since $\int_0^\infty f(S) dS = 1$, $f(S) = \Sigma_t e^{-\Sigma_t S}$.

Let us consider a reaction defined by Σ where Σ/Σ_t is the probability of the reaction occurring, given that a collision has taken place. For the collision method, the estimator is given by

$$\begin{aligned} Z_c &= W \frac{\Sigma}{\Sigma_t} \text{ for } 0 < S < S_{\max} ; \\ &= 0 \text{ for } S_{\max} < S , \end{aligned} \quad \dots (A2)$$

where W is the statistical weight of the incident neutron.

The expected value of Z_c is defined as

$$\bar{Z}_c = \int_0^\infty Z_c f(S) dS \quad \dots (A3)$$

Making use of Equation A2,

$$\bar{Z}_c = \int_0^{S_{\max}} W \frac{\Sigma}{\Sigma_t} \left(\Sigma_t e^{-\Sigma_t S} \right) dS = \frac{W \Sigma}{\Sigma_t} \left(1 - e^{-\Sigma_t S_{\max}} \right) \quad \dots (A4)$$

Thus,

$$\begin{aligned}
 Z_c - \bar{Z}_c &= W \frac{\Sigma}{\Sigma_t} e^{-\Sigma_t S_{\max}} \text{ for } 0 < S < S_{\max} \\
 &= -W \frac{\Sigma}{\Sigma_t} \left(1 - e^{-\Sigma_t S_{\max}} \right) \text{ for } S_{\max} < S
 \end{aligned} \quad \dots (A5)$$

Substituting A5 into A1 yields

$$\begin{aligned}
 \sigma_c^2 &= \int_0^{S_{\max}} W^2 \frac{\Sigma^2}{\Sigma_t^2} e^{-2\Sigma_t S_{\max}} \left(\Sigma_t e^{-\Sigma_t S} dS \right) + \int_{S_{\max}}^{\infty} W^2 \frac{\Sigma^2}{\Sigma_t^2} \left(1 - e^{-\Sigma_t S_{\max}} \right) \left(\Sigma_t e^{-\Sigma_t S} dS \right) \\
 &= W^2 \frac{\Sigma^2}{\Sigma_t^2} e^{-\Sigma_t S_{\max}} \left(1 - e^{-\Sigma_t S_{\max}} \right)
 \end{aligned} \quad \dots (A6)$$

For the track length method, the estimator for the reaction in question is given by

$$\begin{aligned}
 Z_f &= W \Sigma \text{ for } 0 < S < S_{\max} \\
 &= W S_{\max} \Sigma \text{ for } S_{\max} < S
 \end{aligned} \quad \dots (A7)$$

By substituting A7 into A3 and carrying out the integrations, it can be seen that $\bar{Z}_f = \bar{Z}_c$. Thus

$$Z_f - \bar{Z}_f = W \Sigma \left[S - \frac{1 - e^{-\Sigma_t S_{\max}}}{\Sigma_t} \right] ; 0 < S < S_{\max}$$

Therefore,

$$\begin{aligned}
 &= W \Sigma \left[S_{\max} - \frac{1 - e^{-\Sigma_t S_{\max}}}{\Sigma_t} \right] ; S_{\max} < S \\
 \sigma_f^2 &= \int_0^{S_{\max}} W^2 \Sigma^2 \left[S - \frac{1 - e^{-\Sigma_t S_{\max}}}{\Sigma_t} \right]^2 \Sigma_t e^{-\Sigma_t S} dS \\
 &+ \int_{S_{\max}}^{\infty} W^2 \Sigma^2 \left[S_{\max} - \frac{1 - e^{-\Sigma_t S_{\max}}}{\Sigma_t} \right]^2 \Sigma_t e^{-\Sigma_t S} dS
 \end{aligned} \quad \dots (A9)$$

Performing the indicated integration and rearranging terms allows us to express the variance using track-length estimation as

$$\sigma_f^2 = W^2 \frac{\Sigma_t^2}{\Sigma_t^2} \left(1 - e^{-\Sigma_t S_{\max}} \right) \left(e^{-\Sigma_t S_{\max}} + \frac{1 - 2\Sigma_t S_{\max} e^{-\Sigma_t S_{\max}}}{1 - e^{-\Sigma_t S_{\max}}} \right) \dots (A10)$$

From A6 and A10, one obtains

$$\sigma_f^2 = \sigma_c^2 + W^2 \frac{\Sigma_t^2}{\Sigma_t^2} \left(1 - e^{-\Sigma_t S_{\max}} - 2\Sigma_t S_{\max} e^{-\Sigma_t S_{\max}} \right) \dots (A11)$$

Therefore

$$\sigma_f^2 < \sigma_c^2 \text{ when } 1 - e^{-\Sigma_t S_{\max}} - 2\Sigma_t S_{\max} e^{-\Sigma_t S_{\max}} < 0 \dots (A12)$$

Let $D \equiv \Sigma_t S_{\max}$.

$$1 - e^{-D_0} - 2D_0 e^{-D_0} = 0 \text{ where } D = D_0 \text{ when } \sigma_f^2 = \sigma_c^2 \dots (A13)$$

Solving (A13), one obtains

$$D_0 \cong 1.257 \text{ mfp} \dots (A14)$$

When $D < D_0$, $\sigma_f^2 < \sigma_c^2$.

When $D > D_0$, $\sigma_f^2 > \sigma_c^2$.

Using A6 and A10 yields

$$\frac{\sigma_f^2}{\sigma_c^2} = \frac{e^D - e^{-D} - 2D}{1 - e^{-D}} \dots (A15)$$

APPENDIX B
METHOD OF ESTIMATION IN OPTICALLY THIN REGIONS

Consider a neutron of statistical weight W entering a thin region with phase space coordinates $(X, Y, \alpha, \beta, \gamma, E)$. Let $S_{\max}$ be the distance the neutron could travel in the thin region were it to traverse it without colliding. Let

$$W = W_1 + W_2 + W_3 \quad \dots(B1)$$

where

W_1/W = the probability of absorption in the thin region;

W_2/W = the probability of scattering in the thin region; and

W_3/W = the probability that the neutron will traverse the thin region without colliding

Let

$$W' = W - W_1 = W_2 + W_3 \quad \dots(B2)$$

Then

$$W_1 = W \left(1 - e^{-S_{\max} \Sigma_t} \right) \frac{\Sigma_a}{\Sigma_t} \quad \dots(B3)$$

All necessary tallies involving absorption in the thin region are made assuming W_1 neutrons have been absorbed in this region.

Tallies involving scattering are made assuming W_2 neutrons have scattered where

$$W_2 = W \left(1 - e^{-S_{\max} \Sigma_t} \right) \frac{\Sigma_s}{\Sigma_t} \quad \dots(B4)$$

The flux in the thin region for this event is obtained by tallying the track length $W_3 S_{\max}$ due to the traversal of the region by W_3 neutrons plus the track length $(W_1 + W_2) S_c$, where S_c is the distance to a collision point in the thin region selected from an exponential distribution of track lengths in the range $(0, S_{\max})$. To determine S_c , a random number R is selected.

Setting

$$R = \frac{\int_0^{S_c} \Sigma_t e^{-S' \Sigma_t} dS'}{\int_0^{S_{\max}} \Sigma_t e^{-S' \Sigma_t} dS'} = \frac{1 - e^{-S_c \Sigma_t}}{1 - e^{-S_{\max} \Sigma_t}}, \quad \dots (B5)$$

one obtains

$$\begin{aligned} S_c &= -\frac{1}{\Sigma_t} \ln \left[1 - R \left(1 - e^{-S_{\max} \Sigma_t} \right) \right] \\ &= -\frac{1}{\Sigma_t} \ln \left[1 - R \frac{W_1 + W_2}{W} \right] \end{aligned}$$

The weight of the neutron subsequent to the event is $W' = W_2 + W_3$. A single particle is then followed starting from coordinates $(X_0, Y_0, \alpha_0, \beta_0, \gamma_0, E_0)$ which are chosen as follows:

Select a random number R' .

$$\begin{aligned} X_0 &= X + \alpha S_{\max} ; Y_0 = Y + \beta S_{\max} ; E_0 = E \\ \text{If } R' &\leq \frac{W_3}{W'} , & \alpha_0 &= \alpha \\ & & \beta_0 &= \beta \\ \text{If } R' &> \frac{W_3}{W'} , & \gamma_0 &= \gamma \\ X_0 &= X + \alpha S_c ; Y_0 = Y + \beta S_c \end{aligned}$$

and $\alpha_0, \beta_0, \gamma_0$, and E_0 are determined in the same manner as described on page 27 assuming that a scattering collision has taken place.

The expected number of neutrons being followed from a point in the thin region is

$$W' \left(\frac{W_2}{W'} \right) = W_2$$

Similarly, the expected number of neutrons being followed as if they had not collided in the thin region is $W' [W_3/W'] = W_3$.

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