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VIM-1
A NON-MULTIGROUP MONTE CARLO CODE
FOR
ANALYSIS OF FAST CRITICAL ASSEMBLIES

AEC Research and Development Report

Atoms International
North American Rockwell

P.O. Box 309
Canoga Park, California 91304

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By
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ABSTRACT

VIM-1 is the first of a series of Monte Carlo codes designed for analysis of fast critical experiments and fast reactor design. It has been expressly prepared for the analysis of fast critical assemblies of the plate-drawer type. It is written in Fortran, for use on either CDC or IBM computers of the 6600 or 360-75 and up class. Special versions for handling bare and reflected spheres and reflected cylinders are also available, primarily for performing comparisons of heterogeneous and homogeneous calculations.

The library uses point cross-section data, rather than multi-group constants. Angular data is in the form of cumulative distribution functions, at energies tailored to the needs of each isotope. Computation times range from three minutes to one hour on the CDC 6600 (depending on the size and spectrum of the assembly) to obtain probable statistical errors in the eigenvalue of less than 0.5%, thus providing a powerful tool for reactor design and experimental analysis at a reasonable cost.

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I. INTRODUCTION

The applicability of the results of fast critical experiments to fast reactor design rests, to a great extent, on analytic tools usable both for the experimental analysis and for design studies. Since the geometric capabilities of conventional analytic methods are restricted to simple geometric shapes, the interpretation of the experimental data by such methods is open to question, particularly in the area of heterogeneity effects. The assumptions made in the generation of multi-group data pose yet another area of difficulty. Only one method exists which has the potential capability of avoiding the compromising assumptions required by conventional methods, namely, Monte Carlo. Several problems exist, however, which may serve to dampen the enthusiasm of those who regard it as a pancea. Monte Carlo calculations require more computation time, hence higher cost. Their general complexity has created a degree of apprehension on the part of those used to more conventional methods, particularly when some of their options permit spurious results to be obtained. The VIM series of codes, of which VIM-1 is the first to be released, should eliminate the causes of confusion while minimizing computation costs. They are tailored to specific classes of problems, preserving simplicity of operation while maintaining flexibility within each class of problem. For example, VIM-1, the subject of this report, has been designed to handle plate-drawer type critical assemblies. The input preparation and geometric tracking routines are not those used in general geometry codes, and are more efficient as a result of their restricted nature.

The use of multigroup data has been avoided. Point cross-section data is used in all energy ranges for most isotopes, the only exception being the region of unresolved resonances for a few isotopes. The problem of storing the enormous amount of data in the high-speed computer core memory was solved by careful inspection of the available data, eliminating unnecessary detail, and packing the data in linear arrays, storing the beginning and end points for each isotope. This is, in effect, a variable dimensioning scheme, permitting more efficient use of the core memory. As a result, VIM does not tax software systems on any of the large computers on which it may be used. It uses one library tape and a small amount of card input data. (Source and data decks together occupy less than one full box of punched cards.) Thus, conversion from one large

computer to another requires only a minimal effort. It is written in Fortran, permitting easy modification for special tasks.

In the internal portions of the code, again, unnecessary complexity has been avoided. For example, in the spatial generation of source neutrons from one generation to another, the use of splitting, "born" storage for secondary neutrons, or non-unit starting weights, has been avoided. A thorough investigation of these techniques, along with the one used in VIM, was made on small, monoenergetic bare spheres. It was found that the variance per unit of computer time was as good or better, for the method used in VIM, than for any of the more complex methods. The extension of these findings to actual problems was verified by application of a spherical version of VIM-1 to GODIVA and JEZEBEL calculations. The importance of source settling in fast reactor and critical assembly calculations is much greater than for comparable thermal problems because of the presence of high neutron flux at energies near those of the source spectrum. This suggests that prolonging neutron histories through splitting, or even absorption weighting, may increase the variance per unit cost. Our investigation, in fact, showed this to be true. Consequently, although the code permits absorption weighting, we recommend the use of analog histories for eigenvalue calculations. Of course, for problems in which the source distribution is fixed, this argument does not hold. This is an example of where the best method for one type of problem would be a poor choice for another type, even for the same assembly.

The use of cumulative distribution functions of the center-of-mass scattering angle to describe angular distributions, instead of Legendre coefficients, is another area where unnecessary complexity and numerical difficulty has been avoided, while improving the computational speed of the selection process.

Overall computing times will vary considerably from one assembly to another. The spherical mockup of JEZEBEL requires a little over 3 minutes for 50,000 neutron histories on the CDC 6600, with a probable statistical error in k_{eff} of 0.004. At what is probably the other extreme, the heterogeneous mockup of ZPR 3-48 will run at the rate of 35,000 histories per hour, with a probable statistical error of 0.005 in that time.

In the body of this report, the CDC 6600 version of VIM-1 is described, including the physical models, library information, and instructions for users. The code has been converted to the IBM System 360 Models 75 and 85 as well, and production versions of these decks will be made available to the Argonne Code Center in the near future. At that time, any modifications made to VIM-1, subsequent to the issue date of this report, will be described in a revised user's manual included as a part of the code package.

II. TREATMENT OF GEOMETRY IN THE VIM-1 THREE-DIMENSIONAL CRITICAL ASSEMBLIES CODE

A. PERMISSIBLE GEOMETRIC CONFIGURATIONS

The VIM-1 code is a three-dimensional code designed to describe and analyze plate-drawer type critical assemblies, such as ZPR and ZEBRA, in complete geometric detail. All geometric boundaries of material regions are restricted to planes, any one of which is either parallel or perpendicular to any other plane of the system. The geometric tracking procedures for such a system are considerably faster and simpler than those required for more general geometric systems.

Analogous to the actual critical assembly being studied, the basic geometric unit will be known as a drawer. In this drawer will be zones describing the plates in the actual critical assembly, the cladding of these plates, the structural members of the drawer, as well as the matrix tubes into which these drawers are placed. Thus the one difference between a drawer in the actual critical assembly and its description in VIM-1 is the incorporation of the grid material as an outer zone of the drawer, making a drawer, as described in VIM-1, actually touch its neighbor. This eliminates the highly improbable, yet logically possible, neutron trajectory which does not intersect the nearest neighbor of the drawer from which it is emerging. Such a trajectory will be regarded as not having left its present drawer, and there will be no need to search for which drawer it would then enter. Those drawers which are identical in every respect except geometric location are regarded as being of the same drawer type. In this way, zones of such a drawer, and all related properties of these zones (such as material composition), need be described only once in the input. The only distinguishing feature of an individual drawer of a given type is then its geometric locations, described by the input quantity $MATRIX(I,J)$, which is the drawer type number of the I^{th} row and J^{th} column of a rectangular array of drawers describing the critical assembly. All drawers are assumed to have identical outer dimensions $XMAX$, $YMAX$, and $ZMAX$.

B. TRACKING OF PARTICLES

1. Determination of Distance to a Boundary

A region is defined by six boundary equations defining the surrounding planes. For Region I, they are:

$$X = XLO(I)$$

$$X = XHI(I)$$

$$Y = YLO(I)$$

$$Y = YHI(I)$$

$$Z = ZLO(I)$$

$$Z = ZHI(I).$$

Let the direction of the neutron be defined by direction cosines α , β , and γ . Depending on the signs of α , β , and γ , the neutron trajectory will intersect three of the six bounding planes. The distances to these boundaries from some point (X_o, Y_o, Z_o) , at which the neutron is located, are:

$$S_x = \frac{XLO(I) - X_o}{\alpha}, \quad \alpha < 0$$

$$S_x = \frac{X_o - XHI(I)}{\alpha}, \quad \alpha > 0$$

$$S_y = \frac{YLO(I) - Y_o}{\beta}, \quad \beta < 0$$

$$S_y = \frac{Y_o - YHI(I)}{\beta}, \quad \beta > 0$$

$$S_z = \frac{ZLO(I) - Z_o}{\gamma}, \quad \gamma < 0$$

$$S_z = \frac{Z_o - ZHI(I)}{\gamma}, \quad \gamma > 0.$$

The distance a particle must travel to leave the zone in which it is located is obtained by finding the smallest of these distances. The boundary used to calculate this minimal distance is the boundary which would be crossed if no prior collision occurs.

2. Determination of Zone in Which Collision Occurs

A particle is considered to be in zone I if its coordinates (X_o , Y_o , Z_o) satisfy the following set of inequalities:

$$XLO(I) < X_o < XHI(I)$$

$$YLO(I) < Y_o < YHI(I)$$

$$ZLO(I) < Z_o < ZHI(I).$$

Note that this does not permit one to define a zone which completely surrounds another zone, as this would cause an ambiguity in zone determination. It is always possible to eliminate such an ambiguity by breaking up a region of uniform material composition into two or more adjacent regions of the same composition when necessary. When a particle has left one zone and entered another, an exhaustive search of all possible zones would be highly inefficient. This has been avoided by the use of array IADJ(IZONE,I) which specifies the six zones adjacent to zone IZONE. Care should be exercised by the user in preparing this array. Where more than six zones are adjacent to the given zone, the six most probable zones should be entered, since the program will search these six zones before proceeding with an exhaustive search of the remaining zones. In addition, provision has been made for designation of outer zones of a given drawer type as IDOUTZ(ITYPE,IZONE). When a particle is entering a drawer for the first time, use of this array eliminates needless searching of interior zones of the drawer. It is possible for the user to maximize the efficiency of this procedure by listing these outer zones in descending order of probability that a randomly directed incident neutron would enter that zone.

III. MONTE CARLO PROCEDURES

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 captured, escape from the system, or produce fission. k_{eff} 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 in the following sections.

A. 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.

1. Selection of Initial Energy

The spectrum for fission neutrons in VIM-1 is expressed in the form

$$f(E) = \frac{2}{(kT)^{3/2} \sqrt{\pi}} E^{1/2} \exp(-E/kT) \quad , \quad \dots (1)$$

where E is the energy in ev.

By setting $df(E)/dE = 0$, we obtain

$$f_{\text{max}} = f\left(\frac{kT}{2}\right) = \frac{\sqrt{2} \exp(-1/2)}{kT \sqrt{\pi}} \quad \dots (2)$$

Then, by defining

$$f^*(E) \equiv \frac{f(E)}{f_{\text{max}}} = \sqrt{2E/kT} \exp\left[-\left(\frac{E}{kT} - \frac{1}{2}\right)\right] \quad \dots (3)$$

in the range $0 < E \leq 10^7$ ev, E may be selected by a rejection technique as follows:

- 1) Pick two random numbers, R_1 and R_2 .
- 2) Set $\eta = 10^7 R_1$.

3) a) If $R_2 \leq f^*(\eta)$, $E = \eta$.

b) If $R_2 > f^*(\eta)$ return to step 1 and repeat process.

Should there be any reason to change this spectrum, the source routine can easily accommodate an alternate spectrum in tabular form. The number of tabulated energy points is entered as ISPECT in the input data. (If a maxwellian is to be used for each isotope, enter 0 for ISPECT.)

The energy grid for this table is entered into the SE array, while the tabulated function is entered into the Q array. The energies are to be entered in descending order. The elements of the Q array should be:

$$Q(I) = \int_0^{SE(I)} f(E) dE \quad \dots (4)$$

Then, if a random number, r , lies between $Q(I)$ and $Q(I + 1)$, where $SE(I) > SE(I + 1)$, the energy, E , is obtained from:

$$E = SE(I + 1) + [SE(I) - SE(I + 1)] \left[\frac{Q(I + 1) - r}{Q(I + 1) - Q(I)} \right] \quad \dots (5)$$

Stratified sampling of neutron source energies is provided in VIM-1 to ensure that the selected energies are an adequate representation of the input distribution. The number of energy bands to be sampled with equal frequency is input as NEF. The energy boundaries are determined as follows:

$$\int_0^E f(E) dE = \frac{2}{(kT)^{3/2} \sqrt{\pi}} \int_0^E E'^{1/2} \exp(-E'/kT) dE' = \frac{\gamma\left(\frac{3}{2}, \frac{E}{kT}\right)}{\Gamma\left(\frac{3}{2}\right)} = P\left(\frac{2E}{kT} \mid 3\right) \quad \dots (6)$$

where $P(\chi^2 \mid \nu)$ is the probability integral of the χ^2 -distribution.

Let $E(I) = (kT/2)E_{FISS}(I)$ when $1 - P(E_{FISS}(I) \mid 3) = I/NEF$.

The $E_{FISS}(I)$ and the $CK(J)$ ($\equiv kT$ for isotope J) are to be input. For $NEF = 10$, the $E_{FISS}(I)$ are:

<u>I</u>	<u>E_{FISS}(I)</u>	<u>I</u>	<u>E_{FISS}(I)</u>	<u>I</u>	<u>E_{FISS}(I)</u>	<u>I</u>	<u>E_{FISS}(I)</u>	<u>I</u>	<u>E_{FISS}(I)</u>
1	6.2514	3	3.67	5	2.3660	7	1.43	9	0.5844
2	4.64	4	2.95	6	1.87	8	1.02	10	0

For other values of NEF, $1 - P(\chi^2|\nu)$ is tabulated on pages 978 to 983 of Reference 1.

2. 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 in the following manner.

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

$$\alpha = (1 - 2r_2) \sqrt{\frac{1 - \gamma^2}{(1 - 2r_2)^2 + (1 - 2r_3)^2}} \quad , \quad \dots (7)$$

and

$$\beta = (1 - 2r_3) \sqrt{\frac{1 - \gamma^2}{(1 - 2r_2)^2 + (1 - 2r_3)^2}} \quad . \quad \dots (8)$$

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

3. Spatial Distribution of Source

Monte Carlo criticality calculations are different from other types of Monte Carlo calculations in that the spatial distribution from which source particle coordinates are selected is not part of the problem input, but is itself determined by the calculation being performed.

Starting from some initial guess (or input distribution), a set of neutrons are followed until they terminate in either a capture, fission, leakage from the system, or (in rare cases) slowing down below an arbitrary energy cutoff. The spatial coordinates where fission occurs, along with the number of neutrons produced at each point, provide the basis for determining the source distribution for the next generation. VIM-1 actually regards this set of weighted source points as a distribution function from which the source neutron starting points are selected, each with initial statistical weight of unity. This method was found to be both simpler and more effective than schemes which follow the entire set sequentially using non-unit weights.

When absorption weighting is used during the neutron history, the number of weighted source points generated has no theoretical limit. The procedure adopted in VIM-1 is to use no more than one source point per neutron history, just as in the base of analog Monte Carlo. The source point at which the largest number of neutrons is produced in a given history is the one which is preserved, along with a weight equal to the number produced at that point. Test problems using this method produced results in statistical agreement with the analog method discussed previously, but it is not entirely clear that any non-analog method is completely unbiased in problems in which the source distribution is not fixed. Present test results also indicate that the variance in k_{eff} is lower, using the analog method, for a given amount of computation time in fast critical assemblies. This is probably due to the sensitivity of these calculations to the spatial source distribution, a sensitivity much greater than that usually encountered in thermal criticality calculations. The analog method clearly samples the source more frequently per unit of computation time. This should not be regarded as a postulate or a theorem, but rather as a physically intuitive explanation of an observed fact, which in no way precludes the possibility that an exception may arise. This is precisely the reason for allowing not merely absorption weighting, but a scheme which permits a variable amount of it to enable the user to attempt to optimize the procedure.

4. Estimation of k_{eff}

Each generation in VIM contains the same number of source neutrons. This number is determined by the input data, and may not exceed 1000. For any single generation, the estimate of k_{eff} is given by the total number of neutrons produced by the source neutrons of that generation, divided by the number of source neutrons. The average estimate of k_{eff} at any time is given by the total number of neutrons produced in all generations, divided by the total number of source neutrons followed (total number of histories). Since this estimate includes contributions from the early generations, which are influenced by the initial guess, one may wish to evaluate k_{eff} starting with some generation other than the first. VIM-1 prints out k_{eff} neglecting the first m generations, where m goes from 1 to $N-1$, in an N -generation calculation. In addition, VIM prints out the value of k_{eff} for each generation. Inspection of these two sets of results should enable the user to determine the best value of k_{eff} generated by the calculation.

B. 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_b , the maximum distance a particle having direction cosines α , β , and γ could travel in this region. If S is less than this distance, then we assume the particle will collide at:

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

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

$$Z' = Z + \gamma S$$

Should S be greater than the maximum possible distance in the region, S_b , the mean free path in the adjacent region is calculated and the particle is moved the appropriate distance in mean free paths, as follows:

- 1) Let L_1 be the distance in mean free paths in region 1 to the boundary between two adjacent regions, 1 and 2.

2) Let L_t be the total distance in mean free paths to be traversed by the particle. Then

$$X' = X + \alpha \left(\frac{L_1}{\lambda_1} + \frac{L_t - L_1}{\lambda_2} + \delta \right), \quad \dots (9)$$

where λ_1 and λ_2 are the mean free paths in regions 1 and 2 respectively.

Should the particle traverse n boundaries, then

$$X' = X + \alpha \left(\frac{L_1}{\lambda_1} + \frac{L_2}{\lambda_2} + \dots + \frac{L_t - \sum_{i=1}^{n+1} L_i}{\lambda_{n+1}} + n\delta \right), \quad \dots (10)$$

where $S_{bi} \equiv L_i/\lambda_i$, and δ is a small distance used by the code to ensure the particle's entrance into the adjacent region. The recommended value is 10^{-6} cm, but this may be changed in the input data if the need arises. (This quantity is designated as DELTA in the input description.)

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

C. SELECTION OF INTERACTING NUCLEAR SPECIES

If we define σ_i as the total microscopic cross section for element i , then the total macroscopic cross section for the medium is

$$\Sigma_T = \sum_{i=1}^M N_i \sigma_i, \quad \dots (11)$$

where N_i is the number of atoms of element i , 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

$$P_j = \frac{N_j \sigma_j}{\Sigma_T}, \quad \dots (12)$$

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

$$P_1 + P_2 + \dots + P_{j-1} < r < P_j + P_{j+1} + \dots + P_m \quad \dots (13)$$

D. 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

$$P_{s_j} = \frac{\sigma_{s_j}}{\sigma_j} \quad , \quad \dots (14)$$

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

$$P_{in_j} = \frac{\sigma_{in_j}}{\sigma_j} \quad \dots (15)$$

The probability the neutron survives the collision is then

$$P_{\text{surv}} = P_{s_j} + P_{in_j} = \frac{\sigma_{s_j} + \sigma_{in_j}}{\sigma_j} \quad \dots (16)$$

For purposes of variance reduction, let us instead use

$$P_{\text{surv}}^* = 1 - (1 - \beta)P_{\text{abs}} \quad ,$$

where

$$P_{\text{abs}} \equiv 1 - P_{\text{surv}} \quad \dots (17)$$

Therefore,

$$P_{\text{surv}}^* = P_{\text{surv}} + \beta(1 - P_{\text{surv}}) \quad \dots (18)$$

Let the neutron survive if a random number $r < P_{\text{surv}}^*$.

A weight factor of $P_{\text{surv}}/P_{\text{surv}}^*$ must then be applied to the neutron's statistical weight to remove the bias.

When $\beta = 0$, the weight factor is unity, and termination of a history by absorption occurs if a random number $r < P_{\text{surv}}$. This procedure generates neutron histories analogous to those in the physical assembly. When $\beta = 1$, $P_{\text{surv}}^* = 1$, and no history is terminated by absorption. Instead, a weight factor, P_{surv} , is introduced into the statistical weight of the particle at each collision. This procedure is sometimes known as absorption weighting. When this procedure is used, there is only one natural way to terminate a history (i.e., leakage out of the system). However, since this code is designed for use in fast systems exclusively, it is quite satisfactory to terminate a history when the energy of the particle drops below some preassigned value, $\text{ECUT} \geq 10 \text{ ev}$. Since the statistical weight of a particle can become quite low using this method of termination, a third method, Russian Roulette, is used to terminate a history when the statistical weight falls below some preassigned value, $\text{WCUT} \leq 1$. It is implemented as follows:

Let W be the particle weight emerging from a collision. Then, if $W > \text{WCUT}$, the history proceeds normally; but if $W \leq \text{WCUT}$, a random number, r , is generated. Then, if $r > W$, the history is terminated, while if $r \leq W$, W is reset to unity and the history is allowed to proceed.

Once it has been determined that the particle has survived a collision, it is assumed to have been scattered elastically if a random number $\eta \leq P_{s_j}/P_{\text{surv}}$. Otherwise an inelastic scattering collision is presumed to have occurred.

This method can be very effective in fixed source problems, but it is not completely clear that any absorption weighting scheme is unbiased in generating the spatial source distribution. Furthermore, in problems in which k_{eff} is very sensitive to the spatial source distribution, the analog method ($\beta = 0$) samples the source more frequently per unit of computation time, and appears to give a lower variance than absorption weighting procedures per unit cost. We therefore recommend the use of $\beta = 0$ in criticality calculations using VIM-1.

The quantities $\text{OMB}(I,J)$ referred to in the input data are values of $(1 - \beta)$ for energy range I , of isotope J . If NOMB is set equal to 1, all $\text{OMB}(I,J)$ will be set equal to 1, and analog Monte Carlo will be used. If $\text{NOMB} = 0$, all $\text{OMB}(I,J)$

will be 0, and pure absorption weighting will be used. Setting NOMB = 2 requires all OMB(I,J) to be input by the user. For NOMB = 1, WCUT must also be input by the user.

E. 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.

There are, in general, two types of scattering: elastic and inelastic.

1. Elastic Collisions

For any isotope, there exists an energy threshold below which 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-2. 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:

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

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

$$C \equiv \sqrt{1 + A^2 + 2A\mu} , \quad \dots (19)$$

where

$$\mu = \alpha\alpha'' + \beta\beta'' + \gamma\gamma'' . \quad \dots (20)$$

The new energy, E' , is then equal to $[C/(A+1)]^2$ times the incident energy, E . We can see that, for very large A, $E' \rightarrow E$, $\alpha' \rightarrow \alpha''$, $\beta' \rightarrow \beta''$, and $\gamma' \rightarrow \gamma''$. 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, ~ 500 , will eliminate this approximation for all isotopes in the problem.)

Above this threshold, the angle-energy relationship for elastic scattering is obtained through the use of energy dependent angular distributions. VIM permits each isotope to have its own energy grid for describing the angular distributions. The angular distributions themselves are described by tabulating, at each designated energy,

$$P_i = \frac{\int_{-1}^{\mu_i} \sigma_{el}(\mu) d\mu}{\int_{-1}^{+1} \sigma_{el}(\mu) d\mu}, \quad \dots (21)$$

where $\mu_i = -1 + i/10$ represents the cosine of the scattering angle in the center-of-mass system. In this way, the scattering angle is selected from the cumulative angular distribution by finding a random number

$$P_{i-1} < r < P_i \quad ; \quad i = 1, \dots, 20, \quad \dots (22)$$

and setting

$$\mu = \mu_{i-1} + \frac{r - P_{i-1}}{P_i - P_{i-1}} \times 0.1 \quad \dots (23)$$

By adopting this procedure, the complexities and numerical difficulties of sampling from Legendre data are avoided. The distribution at the energy closest to the particle collision energy will be the one used. It is felt that interpolation in energy is not warranted by the present accuracy of the data, and would reduce the computational efficiency of the code. This could easily be changed at a later date, when either the data improve or a given calculation is thought to be particularly sensitive to this data.

To obtain new direction cosines, α' , β' , and γ' , and energy, E' , for a neutron emerging from an anisotropic elastic collision, the following procedure is used:

- 1) Obtain μ as shown.
- 2) Let $C^2 \equiv A^2 + 1 + 2A\mu$, where A is the mass number of the nucleus.
- 3) Let $\alpha^* \equiv (1 + A\mu)/C^2$.

- 4) Pick random numbers, η_1 and η_2 . Let $R_1 \equiv 1 - 2\eta_1$ and $R_2 \equiv 1 - 2\eta_2$.
 5) Then, if $R_1^2 + R_2^2 > 1$, pick new η_1 and η_2 and repeat Steps 4 and 5.
 6) If $R_1^2 + R_2^2 \leq 1$, set

$$\beta^* \equiv R_1 \sqrt{\frac{1 - \alpha^{*2}}{R_1^2 + R_2^2}}$$

and

$$\gamma^* \equiv R_2 \sqrt{\frac{1 - \alpha^{*2}}{R_1^2 + R_2^2}}$$

- 7) Then

$$\alpha' = \alpha^* \alpha + \beta^* \sqrt{1 - \alpha^2} \quad ,$$

$$\beta' = \alpha^* \beta + (\gamma^* \gamma - \alpha \beta \beta^*) / \sqrt{1 - \alpha^2} \quad ,$$

$$\gamma' = \alpha^* \gamma - (\gamma^* \beta + \alpha \gamma \beta^*) / \sqrt{1 - \alpha^2} \quad ,$$

and

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

where α , β , and γ are the neutron's incident direction cosines and E is the neutron's precollision energy.

2. Inelastic Collisions

The inelastic scattering model incorporates both an evaporation model and a discrete excitation level approach. The use of these two models has not been made mutually exclusive, so that the total inelastic scattering cross section at a given energy will consist of the sum of the individual excitation level cross sections and the continuum cross section.

a. Evaporation Model

The evaporation model assumes that the distribution of particles emerging from an inelastic (n, n') collision has the form

$$n(E') = E' \exp(-E'/T) ,$$

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

$$r = \frac{1 - (1 + E'/T) \exp(-E'/T)}{1 - (1 + E/T) \exp(-E/T)} ,$$

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 $X(x) = \exp(-x)$ and $Y(y) = \exp(-y)$, then

$$\int_0^x \exp[-(x-y)] \exp(-y) dy = \int_0^x \exp(-x) dy = x \exp(-x) , \quad \dots (24)$$

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 center-of-mass system and the laboratory system. For the very heavy materials for which this process is a good approximation, this is quite justified.

b. Discrete Excitation Levels

The evaporation model is applicable in energy ranges where the excitation levels are so close together as to be virtually indistinguishable from a continuum. When this is not the case, the probabilities of exciting discrete levels are sampled in the same manner as the probabilities for selecting the type of colliding nucleus. The total inelastic cross section for a given nuclear species is made up of an evaporation model cross section and a set of discrete excitation-level cross sections:

$$\sigma_{in,J}(E) = \sigma_{ev,J}(E) + \sum_{k=1}^{n_J} \sigma_{k,J}(E) \quad ,$$

where n_J is the total number of levels defined for the J^{th} material.

To select the appropriate reaction, a random number, r , is compared with $\sigma_{1,J}(E)/\sigma_{in,J}(E)$ etc., in the manner shown in Section III-C, until either a level or evaporation model is chosen (if $r > \sum_{k=1}^{n_J} \sigma_{k,J}(E)$, the evaporation model is chosen). For discrete excitation levels, the scattering is assumed to be isotropic in the center-of-mass frame.

The procedure for obtaining α' , β' , γ' , and E' is as follows:

- 1) Let $A' \equiv A \sqrt{1 - \epsilon/E}$,

where ϵ is the neutron energy in the lab frame below which the reaction cannot take place.

- 2) Obtain center-of-mass direction cosines, α'' , β'' , and γ'' isotropically.

- 3) Let $C' \equiv \sqrt{1 + A'^2 + 2A'\mu}$,

where $\mu = \alpha\alpha'' + \beta\beta'' + \gamma\gamma''$.

- 4) Then

$$\alpha' = \frac{\alpha + A'\alpha''}{C'} \quad , \quad \beta' = \frac{\beta + A'\beta''}{C'} \quad , \quad \gamma' = \frac{\gamma + A'\gamma''}{C'} \quad , \text{ and}$$

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

Note the similarity to elastic scattering, isotropic in the center-of-mass frame. In fact, when $\epsilon = 0$, $A' = A$, and $C' = C$, the scattering law reduces to that for isotropic elastic scattering.

3. (n,2n) Reactions

The present treatment of the (n,2n) reaction is essentially the evaporation model (see Section III-E-2-a), but with a weight of $2W$ assigned to the particle, which emerges with one-half the available energy. It is felt that this model is adequate for fast critical assemblies of the type for which the code was designed. It would be a minor matter, however, to insert a more rigorous model for specialized problems when the need arises.

IV. RECOMMENDED INPUT PREPARATION PROCEDURE AND SAMPLE CASES

A detailed description of the input data required by the VIM-1 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 lists, location by location, the input data and their specific meanings. The use of a sample case, 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 sketch of the critical assembly and each of the drawer types, as shown in Figures 1, 2, and 3 which illustrate the representation of the ZPR-3-48 critical assembly used as a sample case for this report. Load sheets for the ZPR-3-48 sample case are shown in Section IV-C.
- 2) Assign an identifying number to each drawer type and each zone of the assembly. The ZPR-3-48 representation contains 26 zones in drawer type 1 and 5 zones (zone numbers 26 through 31) in drawer type 2.
- 3) Now that the zone and drawer type identification numbers have been assigned, the user can proceed to input the required arrays listed in Section IV-B. The order of entry of the IADJ(I,J) array (zones adjacent to zone J) should, whenever possible, list those zones first which have a higher probability of being entered from zone I. For example, zones 6 and 8 will be entered more frequently from zone 7 than zones 3, 4, and 26. [See IADJ(7,J) in Section IV-B.]

- a. Type 1 – Standard Core Drawer, Which Includes Axial Blanket at Both Ends
(Zone 26 not shown in drawing)

Figure 1. Assembly Drawer Types

b. Type 2 - Radial Blanket Drawer

Figure 1. Assembly Drawer Types

Figure 3. Representation of Drawer Dimensions in the Intra-Drawer Coordinate System

- 4) In order to specify the MAT and IDZONE arrays, the user must refer to Section VI for a listing of the identification numbers used on the cross-section library tape.
- 5) Record the dimensions of the zones in centimeters. All drawer types are assumed to have the same dimensions, namely XMAX, YMAX, and ZMAX, as illustrated in Figure 1. A value of XLO, XHI, YLO, YHI, ZLO, ZHI must be specified for each zone in the intra-drawer coordinate system in which 0,0,0 appears on the lower left hand corner of the front face of the drawer (see Figure 3).
- 6) The MATRIX(I,J) array specifies the drawer type number of the Ith row and Jth column, as illustrated for the ZPR-3-48 representation in Figure 1. When a neutron enters a drawer whose type number is zero, it is considered to have leaked from the assembly.

B. INPUT DESCRIPTION FOR VIM-1 (Heterogeneous Version)

The first three input cards must contain the following 15 fixed point variables entered in a 6I12 format:

1st Card	{	NTHIST	total number of histories to be run
		NPHIST	number of histories between printouts (batch size)
		NTYPE	number of drawer types (NTYPE ≤ 6)
		NROW	number of rows (NROW ≤ 30) in the critical assembly matrix
		NCOL	number of columns (NCOL ≤ 30) in the critical assembly matrix
2nd Card	{	NM	number of materials in problem (NM ≤ 13)
		NPUNCH	not used, leave blank
		NSTART	not used, leave blank
		ISTYPE	designates drawer type which contains fuel
		NZTYPE	number of fuel zones in drawer type ISTYPE
		ISPECT	if = 0: input CK array
			if > 0: number of entries in fission spectrum table
		NOMB	= 0: set all OMB = 0 (pure absorption weighting) = 1: set all OMB = 1 (analog) = 2: read in OMB array (See Section III-D for a discussion of the use of the OMB array.)

3rd Card	{	NSIZE	must equal NPHIST
		NWRITE	= 0: do not print data read in from cross-section tape = 1: do print data read in from cross-section tape
		NCK	the number of Maxwellian fission temperatures to be input (must equal the number of fissile or fertile isotopes in this problem, if ISPECT = 0).

The following arrays are then entered in a 6I12 format in the following order (note that only elements of the same array may appear on any given card, start next array on first location of the next card):

(NZONE(I),I=1,NTYPE)	NZONE(I) is the number of zones in drawer type I
(NADJ(I),I=1,NTZONE)	NADJ(I) is the number of zones adjacent to zone I
((IADJ(I,J),J=1,6),I=1,NTZONE)	IADJ(I,J) is the J th zone adjacent to zone I
(MAT(I),I=1,NM)	ID numbers of materials used in this problem, including those needed for monitoring purposes only
(NMZONE(I),I=1,NTZONE)	NMZONE(I) is the number of materials in zone I
(IZTYPE(I),I=1,NTZONE)	IZTYPE(I) is the drawer type containing zone I
((IDOUTZ(I,J),J=1,6),I=1,NTYPE)	zone numbers of the outer zones of drawer type I
((IDZONE(I,J),I=1,NMZONE(J)),J=1,NTZONE)	ID numbers of the materials in zone J
(NSO(I),I=1,NTZONE)	used as index to designate special properties of zone. Set NSO(I) = 1, if initial generation source particles may be selected from zone I.

The following array is entered in a 30I1 format, one card per column (i.e., begin new card for each column J):

((MATRIX(I,J),I=1,NROW)	MATRIX(I,J) is the drawer type number of the I th row and J th column of the critical assembly matrix (see Figure 2).
for J = 1	
= 2	
.	
.	
.	
NCOL	

The following quantities are to be input in a 6E12.8 format:

one card	XMAX	dimensions (in cm) of drawers.
	YMAX	All drawer types must have the
	ZMAX	same outer dimensions
	DELTA	small distance used by the code
		to ensure the particle's entrance
		into the adjacent region (recom-
		ended value is 10^{-6} cm) (see
		Section III-B)
	BMASS	mass number above which scat-
		tering is isotropic in lab system
	ECUT	energy below which neutron his-
		tory ends (≥ 10 ev)
	(XLO(I),XHI(I),I=1,NTZONE)	coordinates of the six planes
	(YLO(I),YHI(I),I=1,NTZONE)	which bound the I th zone (in the
	(ZLO(I),ZHI(I),I=1,NTZONE)	intradrawer coordinate system)
	((DZONE(I,J),I=1,NMZONE(J)),J=1,NTZONE)	DZONE(I,J) is the number den-
		sity (in atoms/cm ³) $\times 10^{-24}$ of
		the I th material in the J th zone

If ISPECT = 0, skip to Section A (do not input Q and SE arrays)

If ISPECT > 0, input:

(SE(I),I = 1,ISPECT) energy grid for tabular fis-

sion spectrum

(Q(I),I = 1,ISPECT) fission spectrum tabulated

function (see Section III-A-1)

skip to Section B

Section A

CK(I),I = 1,NCK Maxwellian fission spectrum

temperatures (in ev) (see Section III-A-1)

Section B

If NOMB = 2, input the following (otherwise, skip

to Section C):

((OMB(I,J),I=1,4),J=1,NM) OMB(I,J) is the value of the absorption weighting

parameter, $1 - \beta$, for energy range I of isotope J

(see section III-D)

Section C

If NOMB $\neq$ 1,INPUT: WCUT = value of weight

cutoff for absorption weighting (see Section III-D)

Format I12: NGROUP = number of groups for the monitoring of integrated

group fluxes

Format 6E12.8: (EGROUP(I),I = 1,NGROUP) lower energy group boundaries for

integrated flux monitoring (enter high energy to low energy, in ev)

Format I12: NEF = the number of energy bands for the stratified sampling

of neutron source energies

Format 6E12.8: (EFISS(I), I = 1, NEF) the lower group boundaries of the energy bands for stratified sampling of neutron source energies (high energy to low energy, in Mev)

Format 6I12: NRAT, (NURAT(I), I = 1, NRAT) where NRAT-1 = the number of central fission ratios to be computed, and NURAT(I) is the material number for the Ith central fission ratio:

$$\frac{\sigma_f(\text{NURAT}(I))}{\sigma_f(\text{NURAT}(\text{NRAT}))}$$

Note that NURAT(NRAT) is the ID number of the base material, against which the NURAT(I), I = 1, ..., NRAT-1 are being compared.

If the user wishes to override the cross sections on the tape for the unresolved resonance region, provision has been made for input of smooth self-shielded cross sections for the unresolved resonance region: (Format 2I12) NTMTOT, NSET where NTMTOT = the number of isotopes with at least one unresolved set and NSET = the total number of unresolved sets.

If NTMTOT = 0, the rest of the input is to be skipped.

(Format 6I12) NTMAT(I), I = 1, NTMTOT: identification numbers of the isotopes with unresolved sets

For each of the isotopes with unresolved sets, input the following three card sets (i.e., for I = 1, NTMTOT):

(Format 2E12.8) EUPPER(I), ELOWER(I): the upper and lower energy boundaries for the unresolved range for material number NTMAT(I)

(Format 3I12) MATSET(I, J), J = 1, 3 zone number of the zone containing material NTMAT(I), using set number MSET(I, J)

(Format 3I12) MSET(I, J), J = 1, 3 data set numbers for isotope NTMAT(I).

For each of the unresolved sets, input the following card sets (i.e., for I = 1, NSET):

(Format I12) NTM(I) the number of points in the Ith unresolved set

For K = 1 to NTM(I), input:

(Format 4E12.8) EC(I, K), AT(I, K), AS(I, K), AF(I, K) the energy, total cross section, scattering cross section, and fission cross section respectively for the Kth point of the Ith set.

C. LOAD SHEETS FOR ZPR-3-48 SAMPLE CASE

FORTRAN FIXED 10 DIGIT DECIMAL DATA

DECK NO.	PROGRAMMER	DATE	PAGE 1 of 53	JOB NO.
NUMBER	IDENTIFICATION	DESCRIPTION	DO NOT KEY PUNCH	
1	1 0 0 0 0	NTHIST total number of histories to be run		
13	4 0 0	NPHIST number of histories between printouts		
25	2	NTYPE number of drawer types		
37	2 7	NROW number of rows in the critical assembly matrix		
49	2 7	NCOL number of columns in the critical assembly matrix		
61	1 2	NM number of materials in problem		
1		NPUNCH not used		
13		NSTART not used		
25	1	ISTYPE designates drawer type which contains fuel		
37	2	NZTYPE number of fuel zones in Drawer Type I		
49	8 8	ISPECT		
61	1	NOMB (=1:analogue)		
1	4 0 0	NSIZE size of source array		
13	0	NWRITE (=0: do not print data read from cross section tape		
25	0	NCK		
37				
49				
61				
1	2 6	NZONE(I), I = 1, NTYPE		
13	5			
25		NZONE(I) is the number of zones in Drawer Type I		
37				
49				
61				

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FORTRAN FIXED 10 DIGIT DECIMAL DATA

DECK NO.		PROGRAMMER		DATE	PAGE 2 of 53	JOB NO.
NUMBER		IDENTIFICATION		DESCRIPTION DO NOT KEY PUNCH		
1		5		1 NADJ(I), I = 1, NTZONE		
13		3		2		
25		6		3 NADJ(I) is the number of zones adjacent to Zone I		
37		6		4		
49		6		5		
61		6	5 0	6		
1		6		NADJ(7)		
13		6				
25		6				
37		6				
49		6				
61		6	6 0			
1		6		NADJ(13)		
13		6				
25		6				
37		6				
49		6				
61		6	7 0			
1		6		NADJ(19)		
13		6				
25		6				
37		6				
49		6				
61		6	8 0			

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FORTRAN FIXED 10 DIGIT DECIMAL DATA

DECK NO. _____ PROGRAMMER _____ DATE _____ PAGE 3 of 53 JOB NO. _____

NUMBER	IDENTIFICATION	DESCRIPTION DO NOT KEY PUNCH
1	6	
13	6	
25	3	
37	3	
49	3 73	80
61	3	9 0
1	4	NADJ(31) (last)
13		
25		
37		
49	73	80
61		1 0 0
1		
13		
25		
37		
49	73	80
61		
1		
13		
25		
37		
49	73	80
61		

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FORTRAN FIXED 10 DIGIT DECIMAL DATA

DECK NO. _____ PROGRAMMER _____ DATE _____ PAGE 4 of 53 JOB NO. _____

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

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FORTRAN FIXED 10 DIGIT DECIMAL DATA

DECK NO. _____ PROGRAMMER _____ DATE _____ PAGE 5 of 53 JOB NO. _____

	NUMBER	IDENTIFICATION	DESCRIPTION DO NOT KEY PUNCH
1	1		(IADJ(I,J),J=1,6), I = 5
13	6		
25	3		
37	4		
49	2 5	73	80
61	2 6	1 5 0	
1	5		(IADJ(I,J),J=1,6), I = 6
13	7		
25	3		
37	4		
49	2 5	73	80
61	2 6	1 6 0	
1	6		(IADJ(I,J),J=1,6), I = 7
13	8		
25	3		
37	4		
49	2 5	73	80
61	2 6	1 7 0	
1	7		(IADJ(I,J),J=1,6), I = 8
13	9		
25	3		
37	4		
49	2 5	73	80
61	2 6	1 8 0	

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FORTRAN FIXED 10 DIGIT DECIMAL DATA

DECK NO. _____ PROGRAMMER _____ DATE _____ PAGE 6 of 53 JOB NO. _____

	NUMBER	IDENTIFICATION	DESCRIPTION DO NOT KEY PUNCH
1	8		(IADJ(I,J),J=1,6), I = 9
13	1 0		
25	3		
37	4		
49	2 5	73	80
61	2 6	1 9 0	
1	9		(IADJ(I,J),J=1,6), I = 10
13	1 1		
25	3		
37	4		
49	2 5	73	80
61	2 6	2 0 0	
1	1 0		(IADJ(I,J),J=1,6), I = 11
13	1 2		
25	3		
37	4		
49	2 5	73	80
61	2 6	2 1 0	
1	1 1		(IADJ(I,J),J=1,6), I = 12
13	1 3		
25	3		
37	4		
49	2 5	73	80
61	2 6	2 2 0	

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FORTRAN FIXED 10 DIGIT DECIMAL DATA

DECK NO. PROGRAMMER DATE PAGE 7 of 53 JOB NO.

NUMBER	IDENTIFICATION	DESCRIPTION DO NOT KEY PUNCH
1 2		(IADJ(I,J),J=1,6),I = 13
13 1 4		
25 3		
37 4		
49 2 5		
61 2 6	2 3 0	
1 1 3		(IADJ(I,J),J=1,6),I = 14
13 1 5		
25 3		
37 4		
49 2 5		
61 2 6	2 4 0	
1 1 4		(IADJ(I,J),J=1,6),I = 15
13 1 6		
25 3		
37 4		
49 2 5		
61 2 6	2 5 0	
1 1 5		(IADJ(I,J),J=1,6),I = 16
13 1 7		
25 3		
37 4		
49 2 5		
61 2 6	2 6 0	

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FORTRAN FIXED 10 DIGIT DECIMAL DATA

DECK NO. PROGRAMMER DATE PAGE 8 of 53 JOB NO.

NUMBER	IDENTIFICATION	DESCRIPTION DO NOT KEY PUNCH
1 6		(IADJ(I,J),J=1,6),I = 17
13 1 8		
25 3		
37 4		
49 2 5		
61 2 6	2 7 0	
1 1 7		(IADJ(I,J),J=1,6),I = 18
13 1 9		
25 3		
37 4		
49 2 5		
61 2 6	2 8 0	
1 1 8		(IADJ(I,J),J=1,6),I = 19
13 2 0		
25 3		
37 4		
49 2 5		
61 2 6	2 9 0	
1 1 9		(IADJ(I,J),J=1,6),I = 20
13 2 1		
25 3		
37 4		
49 2 5		
61 2 6	3 0 0	

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FORTRAN FIXED 10 DIGIT DECIMAL DATA

DECK NO.		PROGRAMMER		DATE		PAGE 9 of 53		JOB NO.	
NUMBER		IDENTIFICATION		DESCRIPTION		DO NOT KEY PUNCH			
1	2 0			(IADJ(I,J),J=1,6),I = 21					
13	2 2								
25	3								
37	4								
49	2 5			73 80					
61	2 6	3 1 0							
1	2 1			(IADJ(I,J),J=1,6),I = 22					
13	2 3								
25	3								
37	4								
49	2 5			73 80					
61	2 6	3 2 0							
1	2 2			(IADJ(I,J),J=1,6),I = 23					
13	2 4								
25	3								
37	4								
49	2 5			73 80					
61	2 6	3 3 0							
1	2			(IADJ(I,J),J=1,6),I = 24					
13	2 3								
25	3								
37	4								
49	2 5			73 80					
61	2 6	3 4 0							

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FORTRAN FIXED 10 DIGIT DECIMAL DATA

DECK NO.		PROGRAMMER		DATE		PAGE 10 of 53		JOB NO.	
NUMBER		IDENTIFICATION		DESCRIPTION		DO NOT KEY PUNCH			
1		1		(IADJ(I,J),J=1,6),I = 25					
13		2							
25		3							
37		4							
49		1 8	73	80					
61		2 0	3 5 0						
1		1		(IADJ(I,J),J=1,6),I = 26					
13		2							
25		3							
37		4							
49		1 8	73	80					
61		2 0	3 6 0						
1		3 1		(IADJ(I,J),J=1,6),I = 27					
13		2 9							
25		3 0							
37									
49			73	80					
61			3 7 0						
1		3 1		(IADJ(I,J),J=1,6),I = 28					
13		2 9							
25		3 0							
37									
49			73	80					
61			3 8 0						

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FORTRAN FIXED 10 DIGIT DECIMAL DATA

DECK NO.		PROGRAMMER		DATE		PAGE 11 of 53		JOB NO.	
NUMBER		IDENTIFICATION		DESCRIPTION		DO NOT KEY PUNCH			
1	3 1			(IADJ(I,J),J=1,6), I = 29					
13	2 7								
25	2 8								
37									
49		73		80					
61		3 9 0							
1	3 1			(IADJ(I,J),J=1,6), I = 30					
13	2 7								
25	2 8								
37									
49		73		80					
61		4 0 0							
1	2 7			(IADJ(I,J),J=1,6), I = 31					
13	2 8								
25	2 9								
37	3 0								
49		73		80					
61		4 1 0							
1									
13									
25									
37									
49		73		80					
61									

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FORTRAN FIXED 10 DIGIT DECIMAL DATA

DECK NO.		PROGRAMMER		DATE		PAGE 12 of 53		JOB NO.	
NUMBER		IDENTIFICATION		DESCRIPTION		DO NOT KEY PUNCH			
1		1		MAT	U238	(ID numbers of materials used			
13		2			U235	in this problem)			
25		3			Pu239				
37		4			Pu240				
49		5			Pu241				
61	1 1		4 2 0		Na23				
1		1 2			C12				
13		1 3			Fe				
25		1 4			Cr				
37		1 5			Ni				
49		1 6			Mo				
61	1 7		4 3 0		Al				
1		3		Zone 1	NMZONE(I) is the number of materials in				
13		3		Zone 2	Zone I				
25		3		Zone 3					
37		3		Zone 4					
49		1		Zone 5					
61	3		4 4 0	Zone 6					
1		1		Zone 7	(NMZONE)				
13		3		Zone 8					
25		2		Zone 9					
37		3		Zone 10					
49		4		Zone 11					
61	3		4 5 0	Zone 12					

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FORTRAN FIXED 10 DIGIT DECIMAL DATA

DECK NO.	PROGRAMMER	DATE	PAGE 13 of 53	JOB NO.
NUMBER	IDENTIFICATION	DESCRIPTION	DO NOT KEY PUNCH	
1	2	Zone 13	(NMZONE)	
13	1	Zone 14		
25	3	Zone 15		
37	1	Zone 16		
49	3 73	Zone 17		
61	1 4 6 0	Zone 18		
1	3	Zone 19	(NMZONE)	
13	6	Zone 20		
25	3	Zone 21		
37	1	Zone 22		
49	3 73	Zone 23		
61	1 4 7 0	Zone 24		
1	2	Zone 25		
13	2	Zone 26		
25	3	Zone 27		
37	3	Zone 28		
49	3 73	Zone 29		
61	3 4 8 0	Zone 30		
1	2	Zone 31	(NMZONE)	
13				
25				
37				
49				
61	4 9 0			

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FORTRAN FIXED 10 DIGIT DECIMAL DATA

DECK NO.	PROGRAMMER	DATE	PAGE 14 of 53	JOB NO.
NUMBER	IDENTIFICATION	DESCRIPTION	DO NOT KEY PUNCH	
1	1	IZTYPE (1)	Is the drawer type containing Zone I	
13	1			
25	1			
37	1			
49	1 73			
61	1 5 0 0			
1	1	IZTYPE (7)		
13	1			
25	1			
37	1			
49	1 73			
61	1 5 1 0			
1	1	IZTYPE (13)		
13	1			
25	1			
37	1			
49	1 73			
61	1 5 2 0			
1	1	IZTYPE (19)		
13	1			
25	1			
37	1			
49	1 73			
61	1 5 3 0			

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FORTRAN FIXED 10 DIGIT DECIMAL DATA

DECK NO. _____ PROGRAMMER _____ DATE _____ PAGE 15 of 53 JOB NO. _____

NUMBER	IDENTIFICATION	DESCRIPTION	DO NOT KEY PUNCH
1	1	IZTYPE(25)	
13	1		
25	2		
37	2		
49	2 73		
61	2 5 4 0		
1	2	IZTYPE(31)	
13			
25			
37			
49	73		
61	5 5 0		
1	1	(IDOUTZ(I,J),J=1,6),I = 1	
13	2		
25	3	(Zone numbers of the outer	
37	4	zones of Drawer Type I)	
49	2 5 73		
61	2 6 5 6 0		
1	2 7	(IDOUTZ(I,J),J=1,6),I = 2	
13	2 8		
25	2 9		
37	3 0		
49	3 1 73		
61	3 1 5 7 0		

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FORTRAN FIXED 10 DIGIT DECIMAL DATA

DECK NO. _____ PROGRAMMER _____ DATE _____ PAGE 16 of 53 JOB NO. _____

NUMBER	IDENTIFICATION	DESCRIPTION	DO NOT KEY PUNCH
1	1 3	Zone 1 IDZONE(I,J)	
13	1 4		
25	1 5		
37			
49	73		
61	5 8 0		
1	1 3	Zone 2 IDZONE(I,J)	
13	1 4		
25	1 5		
37			
49	73		
61	5 9 0		
1	1 3	Zone 3 IDZONE(I,J)	
13	1 4		
25	1 5		
37			
49	73		
61	6 0 0		
1	1 3	Zone 4 IDZONE(I,J)	
13	1 4		
25	1 5		
37			
49	73		
61	6 1 0		

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FORTRAN FIXED 10 DIGIT DECIMAL DATA

DECK NO.		PROGRAMMER		DATE		PAGE 17 of 53		JOB NO.	
NUMBER		IDENTIFICATION		DESCRIPTION		DO NOT KEY PUNCH			
1	1 2			Zone 5		IDZONE(I,J)			
13									
25									
37									
49									
61		71 80							
		6 2 0							
1	1 3			Zone 6					
13	1 4								
25	1 5								
37									
49									
61		71 80							
		6 3 0							
1	1 1			Zone 7					
13									
25									
37									
49									
61		71 80							
		6 4 0							
1	1 3			Zone 8					
13	1 4								
25	1 5								
37									
49									
61		71 80							
		6 5 0							

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FORTRAN FIXED 10 DIGIT DECIMAL DATA

DECK NO.		PROGRAMMER		DATE		PAGE 18 of 53		JOB NO.	
NUMBER		IDENTIFICATION		DESCRIPTION		DO NOT KEY PUNCH			
1		1		Zone 9	IDZONE(I,J)				
13		2							
25									
37									
49									
61		73		80					
			6 6 0						
1		1 3		Zone 10					
13		1 4							
25		1 5							
37									
49									
61		73		80					
			6 7 0						
1		3		Zone 11					
13		4							
25		5							
37		1 7							
49									
61		73		80					
			6 8 0						
1		1 3		Zone 12					
13		1 4							
25		1 5							
37									
49									
61		73		80					
			6 9 0						

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FORTRAN FIXED 10 DIGIT DECIMAL DATA

DECK NO.		PROGRAMMER		DATE		PAGE 19 of 53		JOB NO.	
NUMBER		IDENTIFICATION		DESCRIPTION		DO NOT KEY PUNCH			
1		1		Zone 13		IDZONE(I,J)			
13		2							
25									
37									
49									
61		73	80						
		7 0 0							
1		1 2		Zone 14					
13									
25									
37									
49									
61		73	80						
		7 1 0							
1		1 3		Zone 15					
13		1 4							
25		1 5							
37									
49									
61		73	80						
		7 2 0							
1		1 1		Zone 16					
13									
25									
37									
49									
61		73	80						
		7 3 0							

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FORTRAN FIXED 10 DIGIT DECIMAL DATA

DECK NO.		PROGRAMMER		DATE		PAGE 20 of 53		JOB NO.	
NUMBER		IDENTIFICATION		DESCRIPTION		DO NOT KEY PUNCH			
1	1 3			Zone 17		IDZONE(I,J)			
13	1 4								
25	1 5								
37									
49		73	80						
61		7 4 0							
1	1 2			Zone 18					
13									
25									
37									
49		73	80						
61		7 5 0							
1	1 3			Zone 19					
13	1 4								
25	1 5								
37									
49		73	80						
61		7 6 0							
1	1			Zone 20					
13	2								
25	3								
37	4								
49	5	73	80						
61	1 6	7 7 0							

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FORTRAN FIXED 10 DIGIT DECIMAL DATA

DECK NO. _____		PROGRAMMER _____		DATE _____		PAGE 21 of 53		JOB NO. _____	
NUMBER		IDENTIFICATION		DESCRIPTION		DO NOT KEY PUNCH			
1	1 3			Zone 21		IDZONE(I,J)			
13	1 4								
25	1 5								
37									
49									
61		73	80						
		7 8 0							
1	1 1			Zone 22					
13									
25									
37									
49									
61		73	80						
		7 9 0							
1	1 3			Zone 23					
13	1 4								
25	1 5								
37									
49									
61		73	80						
		8 0 0							
1	1 2			Zone 24					
13									
25									
37									
49									
61		73	80						
		8 1 0							

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FORTRAN FIXED 10 DIGIT DECIMAL DATA

DECK NO. _____		PROGRAMMER _____		DATE _____		PAGE 22 of 53		JOB NO. _____	
NUMBER		IDENTIFICATION		DESCRIPTION		DO NOT KEY PUNCH			
1	1			Zone 25		IDZONE(I,J)			
13	2								
25									
37									
49									
61		73	80						
		8 2 0							
1	1			Zone 26					
13	2								
25									
37									
49									
61		73	80						
		8 3 0							
1	1 3			Zone 27					
13	1 4								
25	1 5								
37									
49									
61		73	80						
		8 4 0							
1	1 3			Zone 28					
13	1 4								
25	1 5								
37									
49									
61		73	80						
		8 5 0							

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FORTRAN FIXED 10 DIGIT DECIMAL DATA

DECK NO.		PROGRAMMER	DATE	PAGE 23 of 53	JOB NO.
NUMBER		IDENTIFICATION	DESCRIPTION	DO NOT KEY PUNCH	
1	1 3		Zone 29	IDZONE(I,J)	
13	1 4				
25	1 5				
37					
49					
61		73	80		
			8 6 0		
1	1 3		Zone 30		
13	1 4				
25	1 5				
37					
49					
61		73	80		
			8 7 0		
1	1		Zone 31		
13	2				
25					
37					
49					
61		73	80		
			8 8 0		
1	0		NSO(I)	is used as an index to designate special	
13	0			properties of Zone I.	
25	0			If NSO(I) = 1, initial generation source	
37	0			particles may be selected from Zone I.	
49	0				
61	0	13	80		
			8 9 0		

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FORTRAN FIXED 10 DIGIT DECIMAL DATA

DECK NO.		PROGRAMMER		DATE		PAGE 24 of 53		JOB NO.	
NUMBER		IDENTIFICATION		DESCRIPTION		DO NOT KEY PUNCH			
1	0			NSO(7)					
13	0								
25	0								
37	0								
49	1								
61	0	73		80		9 0 0			
1	0			NSO(13)					
13	0								
25	0								
37	0								
49	0								
61	0	73		80		9 1 0			
1	0			NSO(19)					
13	1								
25	0								
37	0								
49	0								
61	0	73		80		9 2 0			
1	0			NSO(25)					
13	0								
25	0								
37	0								
49	0								
61	0	73		80		9 3 0			

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FORTRAN FIXED 10 DIGIT DECIMAL DATA

DECK NO.	PROGRAMMER	DATE	PAGE 25 of 53	JOB NO.
NUMBER	IDENTIFICATION	DESCRIPTION	DO NOT KEY PUNCH	
1	0	NSO(31)		
13				
25				
37				
49	73	80		
61	9 4 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				

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FORTRAN FIXED 10 DIGIT DECIMAL DATA

DECK NO.	PROGRAMMER	DATE	PAGE 26 of 53	JOB NO.
NUMBER	IDENTIFICATION	DESCRIPTION	DO NOT KEY PUNCH	
1	0 0 0 0 0 0 0 0 0 0 ? ? ?	MATRIX(1,1) → MATRIX(27,1)		
13	2 2 2 2 2 2 0 0 0 0 0 0	MATRIX(I,J)	is the drawer type number of the drawer	
25	0 0 0		in the I th row and J th column of the critical	
37			assembly matrix.	
49	73	80		
61				
1	0 0 0 0 0 0 0 2 2 2 2 2	MATRIX(1,2) →		
13	2 2 2 2 2 2 2 2 0 0 0 0			
25	0 0 0	MATRIX(27,2)		
37				
49	73	80		
61				
1	0 0 0 0 0 2 2 2 2 2 2 2	MATRIX(1,3) →		
13	2 2 2 2 2 2 2 2 2 2 0 0			
25	0 0 0	MATRIX(27,3)		
37				
49	73	80		
61				
1	0 0 0 0 2 2 2 2 2 2 2 2	MATRIX(1,4) →		
13	2 2 2 2 2 2 2 2 2 2 2 0			
25	0 0 0	MATRIX(27,4)		
37				
49	73	80		
61				

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FORTRAN FIXED 10 DIGIT DECIMAL DATA

DECK NO.		PROGRAMMER	DATE	PAGE 27 of 53	JOB NO.
NUMBER			IDENTIFICATION	DESCRIPTION	DO NOT KEY PUNCH
1	0	0 0 2 2 2 2 2 2 2 2 2 2		MATRIX(1,5) →	
13	2	2 2 2 2 2 2 2 2 2 2 2 2			
25	0	0 0		MATRIX(27,5)	
37					
49			73	80	
61					
1	0	0 2 2 2 2 2 2 2 2 2 2 2		MATRIX(1,6) →	
13	2	2 2 2 2 2 2 2 2 2 2 2 2			
25	2	0 0		MATRIX(27,6)	
37					
49			73	80	
61					
1	0	0 2 2 2 2 2 2 2 2 2 2 1		MATRIX(1,7) →	
13	1	1 1 1 2 2 2 2 2 2 2 2 2			
25	2	0 0		MATRIX(27,7)	
37					
49			73	80	
61					
1	0	2 2 2 2 2 2 2 2 2 2 1 1		MATRIX(1,8) →	
13	1	1 1 1 1 1 1 2 2 2 2 2 2			
25	2	2 0		MATRIX(27,8)	
37					
49			73	80	
61					

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FORTRAN FIXED 10 DIGIT DECIMAL DATA

DECK NO.		PROGRAMMER		DATE	PAGE 28 of 53	JOB NO.									
NUMBER				IDENTIFICATION	DESCRIPTION	DO NOT KEY PUNCH									
1	0	2	2	2	2	2	2	1	1	1	1	1		MATRIX(1,9) →	
13	1	1	1	1	1	1	1	2	2	2	2	2			
25	2	2	0											MATRIX(27,9)	
37															
49															
61															
1	2	2	2	2	2	2	2	2	1	1	1	1	1	MATRIX(1,10) →	
13	1	1	1	1	1	1	1	1	2	2	2	2			
25	2	2	2											MATRIX(27,10)	
37															
49															
61															
1	2	2	2	2	2	2	2	2	1	1	1	1	1	MATRIX(1,11) →	
13	1	1	1	1	1	1	1	1	2	2	2	2			
25	2	2	2											MATRIX(27,11)	
37															
49															
61															
1	2	2	2	2	2	2	2	2	1	1	1	1	1	MATRIX(1,12) →	
13	1	1	1	1	1	1	1	1	2	2	2	2			
25	2	2	2											MATRIX(27,12)	
37															
49															
61															

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FORTRAN FIXED 10 DIGIT DECIMAL DATA

DECK NO.	PROGRAMMER	DATE	PAGE 29 of 53	JOB NO.
NUMBER	IDENTIFICATION	DESCRIPTION	DO NOT KEY PUNCH	
1 2 2 2 2 2 2 1 1 1 1 1 1		MATRIX(1,13) →		
13 1 1 1 1 1 1 1 1 2 2 2				
25 2 2 2		MATRIX(27,13)		
37				
49				
61				
1 2 2 2 2 2 2 1 1 1 1 1 1		MATRIX(1,14) →		
13 1 1 1 1 1 1 1 1 2 2 2				
25 2 2 2		MATRIX(27,14)		
37				
49				
61				
1 2 2 2 2 2 2 1 1 1 1 1 1		MATRIX(1,15) →		
13 1 1 1 1 1 1 1 1 2 2 2				
25 2 2 2		MATRIX(27,15)		
37				
49				
61				
1 2 2 2 2 2 2 1 1 1 1 1 1		MATRIX(1,16) →		
13 1 1 1 1 1 1 1 1 2 2 2				
25 2 2 2		MATRIX(27,16)		
37				
49				
61				

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FORTRAN FIXED 10 DIGIT DECIMAL DATA

DECK NO.	PROGRAMMER	DATE	PAGE 30 of 53	JOB NO.
NUMBER	IDENTIFICATION	DESCRIPTION	DO NOT KEY PUNCH	
1 2 2 2 2 2 2 1 1 1 1 1 1		MATRIX(1,17) →		
13 1 1 1 1 1 1 1 1 2 2 2				
25 2 2 2		MATRIX(27,17)		
37				
49				
61				
1 2 2 2 2 2 2 1 1 1 1 1 1		MATRIX(1,18) →		
13 1 1 1 1 1 1 1 1 2 2 2				
25 2 2 2		MATRIX(27,18)		
37				
49				
61				
1 0 2 2 2 2 2 2 1 1 1 1 1		MATRIX(1,19) →		
13 1 1 1 1 1 1 1 1 2 2 2				
25 2 2 0		MATRIX(27,19)		
37				
49				
61				
1 0 2 2 2 2 2 2 1 1 1 1 1		MATRIX(1,20) →		
13 1 1 1 1 1 1 1 1 2 2 2				
25 2 2 0		MATRIX(27,20)		
37				
49				
61				

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FORTRAN FIXED 10 DIGIT DECIMAL DATA

DECK NO.	PROGRAMMER	DATE	PAGE 31 of 53	JOB NO.
NUMBER	IDENTIFICATION	DESCRIPTION	DO NOT KEY PUNCH	
1 0 0 2 2 2 2 2 2 2 2 1		MATRIX(1,21) →		
13 1 1 1 2 2 2 2 2 2 2 2				
25 2 0 0		MATRIX(27,21)		
37				
49	73	80		
61				
1 0 0 2 2 2 2 2 2 2 2 2		MATRIX(1,22) →		
13 2 2 2 2 2 2 2 2 2 2 2				
25 2 0 0		MATRIX(27,22)		
37				
49	73	80		
61				
1 0 0 0 2 2 2 2 2 2 2 2		MATRIX(1,23) →		
13 2 2 2 2 2 2 2 2 2 2 2				
25 0 0 0		MATRIX(27,23)		
37				
49	73	80		
61				
1 0 0 0 0 2 2 2 2 2 2 2		MATRIX(1,24) →		
13 2 2 2 2 2 2 2 2 2 2 0				
25 0 0 0		MATRIX(27,24)		
37				
49	73	80		
61				

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FORTRAN FIXED 10 DIGIT DECIMAL DATA

DECK NO.	PROGRAMMER	DATE	PAGE 32 of 53	JOB NO.
NUMBER	IDENTIFICATION	DESCRIPTION	DO NOT KEY PUNCH	
1 0 0 0 0 0 2 2 2 2 2 2		MATRIX(1,25) →		
13 2 2 2 2 2 2 2 2 2 2 0				
25 0 0 0		MATRIX(27,25)		
37				
49	73	80		
61				
1 0 0 0 0 0 0 2 2 2 2 2		MATRIX(1,26) →		
13 2 2 2 2 2 2 2 2 0 0 0				
25 0 0 0		MATRIX(27,26)		
37				
49	73	80		
61				
1 0 0 0 0 0 0 0 2 2 2 2		MATRIX(1,27) →		
13 2 2 2 2 2 2 0 0 0 0 0				
25 0 0 0		MATRIX(27,27)		
37				
49	73	80		
61				
1				
13				
25				
37				
49	73	80		
61				

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FORTRAN FIXED 10 DIGIT DECIMAL DATA

DECK NO.	PROGRAMMER	DATE	PAGE 33 of 53	JOB NO.
NUMBER	IDENTIFICATION	DESCRIPTION	DO NOT KEY PUNCH	
1	5 . 5 4 6 0 9	XMAX		
13	5 . 5 2 5 7 7	YMAX		
25	1 3 7 . 3 1 2 4	ZMAX		
37	1 . 0 - 0 6	DELTA		
49	5 0 0 .	BMASS		
61	1 0 .	ECUT		
1				
13				
25				
37				
49				
61				
1				
13				
25				
37				
49				
61				
1				
13				
25				
37				
49				
61				

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FORTRAN FIXED 10 DIGIT DECIMAL DATA

DECK NO.	PROGRAMMER	DATE	PAGE 34 of 53	JOB NO.
NUMBER	IDENTIFICATION	DESCRIPTION	DO NOT KEY PUNCH	
1	0 . 0	XLO(1)		
13	1 . 2 3 3 0 4 5	XHI(1)		
25	5 . 3 1 3 0 4 5	XLO(2)		
37	5 . 5 4 6 0 9	XHI(2)		
49	0 . 0	XLO(3)		
61	5 . 5 4 6 0 9	XHI(3)		
1	0 . 0	XLO(4)		
13	5 . 5 4 6 0 9	XHI(4)		
25	1 . 2 3 3 0 4 5	XLO(5)		
37	1 . 5 5 0 5 4 5	XHI(5)		
49	1 . 5 5 0 5 4 5	XLO(6)		
61	1 . 5 8 8 6 4 5	XHI(6)		
1	1 . 5 8 8 6 4 5	XLO(7)		
13	1 . 1 4 7 4 4 5	XHI(7)		
25	1 . 1 4 7 4 4 5	XLO(8)		
37	1 . 1 8 5 5 4 5	XHI(8)		
49	1 . 1 8 5 5 4 5	XLO(9)		
61	1 . 5 0 3 0 4 5	XHI(9)		
1	1 . 5 0 3 0 4 5	XLO(10)		
13	1 . 5 3 3 5 2 5	XHI(10)		
25	1 . 5 3 3 5 2 5	XLO(11)		
37	1 . 7 9 0 0 6 5	XHI(11)		
49	1 . 7 9 0 0 6 5	XLO(12)		
61	1 . 8 2 0 5 4 5	XHI(12)		

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FORTRAN FIXED 10 DIGIT DECIMAL DATA

DECK NO.	PROGRAMMER	DATE	PAGE 35 of 53	JOB NO.
NUMBER	IDENTIFICATION	DESCRIPTION	DO NOT KEY PUNCH	
1 . 8 2 0 5 4 5		XLO(13)		
13 2 . 1 3 8 0 4 5		XHI(13)		
25 2 . 1 3 8 0 4 5		XLO(14)		
37 2 . 4 5 5 5 4 5		XHI(14)		
49 2 . 4 5 5 5 4 5	73	XLO(15)	80	
61 2 . 4 9 3 6 4 5		XHI(15)	2 2 2 0	
1 2 . 4 9 3 6 4 5		XLO(16)		
13 3 . 0 5 2 4 4 5		XHI(16)		
25 3 . 0 5 2 4 4 5		XLO(17)		
37 3 . 0 9 0 5 4 5		XHI(17)		
49 3 . 0 9 0 5 4 5	73	XLO(18)	80	
61 3 . 7 2 5 5 4 5		XHI(18)	2 2 3 0	
1 3 . 7 2 5 5 4 5		XLO(19)		
13 3 . 7 5 6 0 2 5		XHI(19)		
25 3 . 7 5 6 0 2 5		XLO(20)		
37 4 . 3 3 0 0 6 5		XHI(20)		
49 4 . 3 3 0 0 6 5	73	XLO(21)	80	
61 4 . 3 9 8 6 4 5		XHI(21)	2 2 4 0	
1 4 . 3 9 8 6 4 5		XLO(22)		
13 4 . 9 5 7 4 4 5		XHI(22)		
25 4 . 9 5 7 4 4 5		XLO(23)		
37 4 . 9 9 5 5 4 5		XHI(23)		
49 4 . 9 9 5 5 4 5	73	XLO(24)	80	
61 5 . 3 1 3 0 4 5		XHI(24)	2 2 5 0	

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DECK NO.	PROGRAMMER	DATE	PAGE 36 of 53	JOB NO.
NUMBER	IDENTIFICATION	DESCRIPTION	DO NOT KEY PUNCH	
1 . 2 3 3 0 4 5		XLO(25)		
13 5 . 3 1 3 0 4 5		XHI(25)		
25 . 2 3 3 0 4 5		XLO(26)		
37 5 . 3 1 3 0 4 5		XHI(26)		
49 0 . 0	73	XLO(27)	80	
61 . 2 3 3 0 4 5		XHI(27)	2 2 6 0	
1 5 . 3 1 3 0 4 5		XLO(28)		
13 5 . 5 4 6 0 9		XHI(28)		
25 0 . 0		XLO(29)		
37 5 . 5 4 6 0 9		XHI(29)		
49 0 . 0	73	XLO(30)	80	
61 5 . 5 4 6 0 9		XHI(30)	2 2 7 0	
1 . 2 3 3 0 4 5		XLO(31)		
13 5 . 3 1 3 0 4 5		XHI(31)		
25				
37				
49	73		80	
61			2 2 8 0	
1 . 2 2 2 8 8 5		YLO(1)		
13 5 . 3 0 2 8 5		YHI(1)		
25 . 2 2 2 8 8 5		YLO(2)		
37 5 . 3 0 2 8 5		YHI(2)		
49 5 . 3 0 2 8 5	73	YLO(3)	80	
61 5 . 5 2 5 7 7		YHI(3)	2 2 9 0	

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DECK NO.		PROGRAMMER		DATE		PAGE 37 of 53	JOB NO.	
NUMBER		IDENTIFICATION		DESCRIPTION		DO NOT KEY PUNCH		
1	0 . 0			YLO(4)				
13	. 2 2 2 8 8 5			YHI(4)				
25	. 2 2 2 8 8 5			YLO(5)				
37	5 . 3 0 2 8 5			YHI(5)				
49	. 2 2 2 8 8 5	73	80	YLO(6)				
61	5 . 3 0 2 8 5	2 3 0 0		YHI(6)				
1	. 2 2 2 8 8 5			YLO(7)				
13	5 . 3 0 2 8 5			YHI(7)				
25	. 2 2 2 8 8 5			YLO(8)				
37	5 . 3 0 2 8 5			YHI(8)				
49	. 2 2 2 8 8 5	73	80	YLO(9)				
61	5 . 3 0 2 8 5	2 3 1 0		YHI(9)				
1	. 2 2 2 8 8 5			YLO(10)				
13	5 . 3 0 2 8 5			YHI(10)				
25	. 2 2 2 8 8 5			YLO(11)				
37	5 . 3 0 2 8 5			YHI(11)				
49	. 2 2 2 8 8 5	73	80	YLO(12)				
61	5 . 3 0 2 8 5	2 3 2 0		YHI(12)				
1	. 2 2 2 8 8 5			YLO(13)				
13	5 . 3 0 2 8 5			YHI(13)				
25	. 2 2 2 8 8 5			YLO(14)				
37	5 . 3 0 2 8 5			YHI(14)				
49	. 2 2 2 8 8 5	73	80	YLO(15)				
61	5 . 3 0 2 8 5	2 3 3 0		YHI(15)				

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FORTRAN FIXED 10 DIGIT DECIMAL DATA

DECK NO.		PROGRAMMER		DATE	PAGE 38 of 53	JOB NO.
NUMBER		IDENTIFICATION	DESCRIPTION	DO NOT KEY PUNCH		
1	. 2 2 2 8 8 5		YLO(16)			
13	5 . 3 0 2 8 5		YHI(16)			
25	. 2 2 2 8 8 5		YLO(17)			
37	5 . 3 0 2 8 5		YHI(17)			
49	. 2 2 2 8 8 5		YLO(18)			
61	5 . 3 0 2 8 5	2 3 4 0	YHI(18)			
1	. 2 2 2 8 8 5		YLO(19)			
13	5 . 3 0 2 8 5		YHI(19)			
25	. 2 2 2 8 8 5		YLO(20)			
37	5 . 3 0 2 8 5		YHI(20)			
49	. 2 2 2 8 8 5		YLO(21)			
61	5 . 3 0 2 8 5	2 3 5 0	YHI(21)			
1	. 2 2 2 8 8 5		YLO(22)			
13	5 . 3 0 2 8 5		YHI(22)			
25	. 2 2 2 8 8 5		YLO(23)			
37	5 . 3 0 2 8 5		YHI(23)			
49	. 2 2 2 8 8 5		YLO(24)			
61	5 . 3 0 2 8 5	2 3 6 0	YHI(24)			
1	. 2 2 2 8 8 5		YLO(25)			
13	5 . 3 0 2 8 5		YHI(25)			
25	. 2 2 2 8 8 5		YLO(26)			
37	5 . 3 0 2 8 5		YHI(26)			
49	. 2 2 2 8 8 5		YLO(27)			
61	5 . 3 0 2 8 5	2 3 7 0	YHI(27)			

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FORTRAN FIXED 10 DIGIT DECIMAL DATA

DECK NO.		PROGRAMMER	DATE	PAGE 39 of 53	JOB NO.
NUMBER		IDENTIFICATION	DESCRIPTION DO NOT KEY PUNCH		
1	. 2 2 2 8 8 5	73	YLO(28)		
13	5 . 3 0 2 8 5		YHI(28)		
25	5 . 3 0 2 8 5		YLO(29)		
37	5 . 5 2 5 7 7		YHI(29)		
49	0 . 0		YLO(30)		
61	. 2 2 2 8 8 5	2 3 8 0		YHI(30)	
1	. 2 2 2 8 8 5	73	YLO(31)		
13	5 . 3 0 2 8 5		YHI(31)		
25					
37					
49					
61		2 3 9 0			
1	0 . 0	73	ZLO(1)		
13	1 3 7 . 3 1 2 4		ZHI(1)		
25	0 . 0		ZLO(2)		
37	1 3 7 . 3 1 2 4		ZHI(2)		
49	0 . 0		ZLO(3)		
61	1 3 7 . 3 1 2 4	2 4 0 0		ZHI(3)	
1	0 . 0	73	ZLO(4)		
13	1 3 7 . 3 1 2 4		ZHI(4)		
25	3 0 . 4 8		ZLO(5)		
37	1 0 6 . 8 3 2 4		ZHI(5)		
49	3 0 . 4 8		ZLO(6)		
61	1 0 6 . 8 3 2 4	2 4 1 0		ZHI(6)	

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FORTRAN FIXED 10 DIGIT DECIMAL DATA

DECK NO.		PROGRAMMER	DATE	PAGE 40 of 53	JOB NO.
NUMBER		IDENTIFICATION	DESCRIPTION DO NOT KEY PUNCH		
1	3 0 . 4 8		ZLO(7)		
13	1 0 6 . 8 3 2 4		ZHI(7)		
25	3 0 . 4 8		ZLO(8)		
37	1 0 6 . 8 3 2 4		ZHI(8)		
49	3 0 . 4 8	73 . 80	ZLO(9)		
61	1 0 6 . 8 3 2 4	2 4 2 0		ZHI(9)	
1	3 0 . 4 8		ZLO(10)		
13	1 0 6 . 8 3 2 4		ZHI(10)		
25	3 0 . 4 8		ZLO(11)		
37	1 0 6 . 8 3 2 4		ZHI(11)		
49	3 0 . 4 8	73 . 80	ZLO(12)		
61	1 0 6 . 8 3 2 4	2 4 3 0		ZHI(12)	
1	3 0 . 4 8		ZLO(13)		
13	1 0 6 . 8 3 2 4		ZHI(13)		
25	3 0 . 4 8		ZLO(14)		
37	1 0 6 . 8 3 2 4		ZHI(14)		
49	3 0 . 4 8	73 . 80	ZLO(15)		
61	1 0 6 . 8 3 2 4	2 4 4 0		ZHI(15)	
1	3 0 . 4 8		ZLO(16)		
13	1 0 6 . 8 3 2 4		ZHI(16)		
25	3 0 . 4 8		ZLO(17)		
37	1 0 6 . 8 3 2 4		ZHI(17)		
49	3 0 . 4 8	73 . 80	ZLO(18)		
61	1 0 6 . 8 3 2 4	2 4 5 0		ZHI(18)	

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FORTRAN FIXED 10 DIGIT DECIMAL DATA

DECK NO.		PROGRAMMER	DATE	PAGE 41 of 53	JOB NO.
NUMBER		IDENTIFICATION	DESCRIPTION	DO NOT KEY PUNCH	
1	3 0 . 4 8		Z LO(19)		
13	1 0 6 . 8 3 2 4		Z HI(19)		
25	3 0 . 4 8		Z LO(20)		
37	1 0 6 . 8 3 2 4		Z HI(20)		
49	3 0 . 4 8		Z LO(21)		
61	1 0 6 . 8 3 2 4	73 2 4 6 0 80	Z HI(21)		
1	3 0 . 4 8		Z LO(22)		
13	1 0 6 . 8 3 2 4		Z HI(22)		
25	3 0 . 4 8		Z LO(23)		
37	1 0 6 . 8 3 2 4		Z HI(23)		
49	3 0 . 4 8		Z LO(24)		
61	1 0 6 . 8 3 2 4	73 2 4 7 0 80	Z HI(24)		
1	1 0 6 . 8 3 2 4		Z LO(25)		
13	1 3 7 . 3 1 2 4		Z HI(25)		
25	0 . 0		Z LO(26)		
37	3 0 . 4 8		Z HI(26)		
49	0 . 0		Z LO(27)		
61	1 3 7 . 3 1 2 4	73 2 4 8 0 80	Z HI(27)		
1	0 . 0		Z LO(28)		
13	1 3 7 . 3 1 2 4		Z HI(28)		
25	0 . 0		Z LO(29)		
37	1 3 7 . 3 1 2 4		Z HI(29)		
49	0 . 0		Z LO(30)		
61	1 3 7 . 3 1 2 4	73 2 4 9 0 80	Z HI(30)		

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FORTRAN FIXED 10 DIGIT DECIMAL DATA

DECK NO. _____		PROGRAMMER _____	DATE _____	PAGE 42 of 53	JOB NO. _____
NUMBER		IDENTIFICATION	DESCRIPTION	DO NOT KEY PUNCH	
1	0 . 0		ZLO(31)		
13	1 3 7 . 3 1 2 4		BIB(31)		
25					
37					
49					
61		75	80		
		2 5 0 0			
1
13					
25					
37					
49					
61		75	80		
1
13					
25					
37					
49					
61		75	80		
1
13					
25					
37					
49					
61		75	80		

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FORTRAN FIXED 10 DIGIT DECIMAL DATA

DECK NO.		PROGRAMMER		DATE		PAGE 43 of 53		JOB NO.	
NUMBER		IDENTIFICATION		DESCRIPTION		DO NOT KEY PUNCH			
1	. 0 3 4 7 0 9 6			DZONE		IZONE = 1			
13	. 0 0 9 3 1 9 6								
25	. 0 0 4 6 2 3 3								
37									
49		73	80						
61		2 5 1 0							
1	. 0 3 4 7 0 9 6					2			
13	. 0 0 9 3 1 9 6								
25	. 0 0 4 6 2 3 3								
37									
49		73	80						
61		2 5 2 0							
1	. 0 3 4 7 0 9 6					3			
13	. 0 0 9 3 1 9 6								
25	. 0 0 4 6 2 3 3								
37									
49		73	80						
61		2 5 3 0							
1	. 0 3 4 7 0 9 6					4			
13	. 0 0 9 3 1 9 6								
25	. 0 0 4 6 2 3 3								
37									
49		73	80						
61		2 5 4 0							

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FORTRAN FIXED 10 DIGIT DECIMAL DATA

DECK NO.		PROGRAMMER		DATE	PAGE 44 of 53	JOB NO.	
NUMBER		IDENTIFICATION	DESCRIPTION DO NOT KEY PUNCH				
1	. 0 7 8 7 2 6		DZONE IZONE = 5				
13							
25							
37							
49		73	80				
61		2 5 5 0					
1	. 0 7 7 0 8 7		6				
13	. 0 2 0 6 9 8						
25	. 0 1 0 2 6 8						
37							
49		73	80				
61		2 5 6 0					
1	. 0 2 2 3 6 8 5		7				
13							
25							
37							
49		73	80				
61		2 5 7 0					
1	. 0 7 7 0 8 7		8				
13	. 0 2 0 6 9 8						
25	. 0 1 0 2 6 8						
37							
49		73	80				
61		2 5 8 0					

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FORTRAN FIXED 10 DIGIT DECIMAL DATA

DECK NO.	PROGRAMMER	DATE	PAGE 45 of 53	JOB NO.
NUMBER	IDENTIFICATION	DESCRIPTION	DO NOT KEY PUNCH	
1 . 0 4 5 8 2 2 7 3		DZONE	IZONE = 9	
13 . 9 6 2 5 1 - 0 4				
25				
37				
49				
61	73 80	2 5 9 0		
1 . 0 7 7 0 8 7			10	
13 . 0 2 0 6 9 8				
25 . 0 1 0 2 6 8				
37				
49				
61	73 80	2 6 0 0		
1 . 0 2 5 0 8 5			11	
13 . 0 0 1 2 2 8 9				
25 . 0 0 0 1 6 7 7				
37 . 0 0 3 3 5 5 4				
49				
61	73 80	2 6 1 0		
1 . 0 7 7 0 8 7			12	
13 . 0 2 0 6 9 8				
25 . 0 1 0 2 6 8				
37				
49				
61	73 80	2 6 2 0		

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FORTRAN FIXED 10 DIGIT DECIMAL DATA

DECK NO.	PROGRAMMER	DATE	PAGE 46 of 53	JOB NO.
NUMBER	IDENTIFICATION	DESCRIPTION	DO NOT KEY PUNCH	
1 . 0 4 5 8 2 2 7 3		DZONE	IZONE = 13	
13 . 9 6 2 5 1 - 0 4				
25				
37				
49				
61	73 80	2 6 3 0		
1 . 0 7 8 7 2 6			14	
13				
25				
37				
49				
61	73 80	2 6 4 0		
1 . 0 7 7 0 8 7			15	
13 . 0 2 0 6 9 8				
25 . 0 1 0 2 6 8				
37				
49				
61	73 80	2 6 5 0		
1 . 0 2 2 3 6 8 5			16	
13				
25				
37				
49				
61	73 80	2 6 6 0		

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FORTRAN FIXED 10 DIGIT DECIMAL DATA

DECK NO.		PROGRAMMER		DATE	PAGE 47 of 53	JOB NO.
NUMBER		IDENTIFICATION	DESCRIPTION DO NOT KEY PUNCH			
1	. 0 7 7 0 8 7		DZONE IZONE = 17			
13	. 0 2 0 6 9 8					
25	. 0 1 0 2 6 8					
37						
49		73	80			
61		2 6 7 0				
1	. 0 7 8 7 2 6		18			
13						
25						
37						
49		73	80			
61		2 6 8 0				
1	. 0 7 7 0 8 7		19			
13	. 0 2 0 6 9 8					
25	. 0 1 0 2 6 8					
37						
49		73	80			
61		2 6 9 0				
1	. 0 2 7 1 7 4		20			
13	. 5 7 0 8 0 - 0 4					
25	. 6 0 3 5 2 4 - 0 2					
37	. 5 6 2 0 4 - 0 3					
49	. 4 0 4 - 0 4	73	80			
61	. 2 8 3 4 0 - 0 2	2 7 0 0				

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FORTRAN FIXED 10 DIGIT DECIMAL DATA

DECK NO.		PROGRAMMER		DATE	PAGE 48 of 53	JOB NO.
NUMBER		IDENTIFICATION	DESCRIPTION DO NOT KEY PUNCH			
1	. 0 7 7 0 8 7	73 80	DZONE IZONE = 21			
13	. 0 2 0 6 9 8					
25	. 0 1 0 2 6 8					
37						
49		73 80				
61	2 7 1 0					
1	. 0 2 2 3 6 8 5		22			
13						
25		73 80				
37						
49						
61	2 7 2 0					
1	. 0 7 7 0 8 7	73 80	23			
13	. 0 2 0 6 9 8					
25	. 0 1 0 2 6 8					
37						
49		73 80				
61	2 7 3 0					
1	. 0 7 8 7 2 6		24			
13						
25		73 80				
37						
49						
61	2 7 4 0					

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FORTAN FIXED 10 DIGIT DECIMAL DATA

DECK NO.		PROGRAMMER		DATE		PAGE 49 of 53		JOB NO.	
NUMBER		IDENTIFICATION		DESCRIPTION		DO NOT KEY PUNCH			
1	. 0 4 5 4 6 4	73	80	DZONE		IZONE = 25			
13	. 9 7 1 4 2 - 0 4								
25									
37				Axial blanket					
49									
61	2 7 5 0								
1	. 0 4 5 4 6 4	73	80			26			
13	. 9 7 1 4 2 - 0 4								
25									
37				Axial blanket					
49									
61	2 7 6 0								
1	. 0 2 8 0 7 2 5	73	80			27			
13	. 7 5 3 6 1 2 - 0 2								
25	. 3 7 0 8 0 8 - 0 2								
37									
49									
61	2 7 7 0								
1	. 0 2 8 0 7 2 5	73	80			28			
13	. 7 5 3 6 1 2 - 0 2								
25	. 3 7 0 8 0 8 - 0 2								
37									
49									
61	2 7 8 0								

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FORTAN FIXED 10 DIGIT DECIMAL DATA

DECK NO.		PROGRAMMER		DATE		PAGE 50 of 53		JOB NO.	
NUMBER		IDENTIFICATION		DESCRIPTION		DO NOT KEY PUNCH			
1	. 0 2 8 0 7 2 5	73	80	DZONE		IZONE = 29			
13	. 7 5 3 6 1 2 - 0 2								
25	. 3 7 0 8 0 8 - 0 2								
37									
49									
61				2 7 9 0					
1	. 0 2 8 0 7 2 5	73	80			30			
13	. 7 5 3 6 1 2 - 0 2								
25	. 3 7 0 8 0 8 - 0 2								
37									
49									
61				2 8 0 0					
1	. 0 4 7 1 4 7 3	73	80	DZONE		IZONE = 31			
13	. 9 8 3 2 6 7 - 0 4								
25									
37				Radial blanket					
49									
61				2 8 1 0					
1		73	80						
13									
25									
37									
49									
61									

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FORTRAN FIXED 10 DIGIT DECIMAL DATA

DECK NO.	PROGRAMMER	DATE	PAGE 51 of 53	JOB NO.
NUMBER	IDENTIFICATION	DESCRIPTION	DO NOT KEY PUNCH	
1 6 . 0 6 5 3 E 0 6		EGROUP(I), I = 1, NGROUP		
13 3 . 6 7 8 8 E 0 6				
25 2 . 2 3 1 3 E 0 6				
37 1 . 3 5 3 4 D 0 6				
49 8 2 0 . 8 5 E 0 3	73 80			
61 4 9 7 . 8 7 E 0 3				
1 3 0 1 9 7 0 .		EGROUP(7)		
13 1 8 3 1 6 0 .				
25 1 1 1 0 9 0 .				
37 6 7 3 7 9 .				
49 4 0 8 6 8 .	73 80			
61 2 4 7 8 8 .				
1 1 5 0 3 4 .		EGROUP(13)		
13 9 1 1 8 . 8				
25 5 5 3 0 . 8				
37 3 3 5 4 . 6				
49 2 0 3 4 . 7	73 80			
61 1 2 3 4 . 1				
1 7 4 8 . 5 2		EGROUP(19)		
13 4 5 4 .				
25 2 7 5 . 3 6				
37 1 6 7 . 0 2				
49 1 0 1 . 3	73 80			
61 6 1 . 4 4 2				

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FORTRAN FIXED 10 DIGIT DECIMAL DATA

DECK NO.	PROGRAMMER	DATE	PAGE 52 of 53	JOB NO.
NUMBER	IDENTIFICATION	DESCRIPTION	DO NOT KEY PUNCH	
1 3 7 . 2 6 7		EGROUP(25)		
13 2 2 . 6 0 3				
25 1 .				
37				
49	73 80			
61				
1 1 0		NEF		
13				
25				
37				
49	73 80			
61				
1 6 . 2 5 3 1		EFISS(I), I = 1, NEF		
13 4 . 6 4 2 9				
25 3 . 6 6 6 5				
37 2 . 9 4 7 5				
49 2 . 3 6 6 8	73 80			
61 1 . 8 6 9 4				
1 1 . 4 3 1 2		EFISS(7)		
13 1 . 0 5 1 7				
25 . 5 8 4 1				
37 0 .				
49	73 80			
61				

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FORTRAN FIXED 10 DIGIT DECIMAL DATA

DECK NO. _____ PROGRAMMER _____ DATE _____ PAGE 53 of 53 JOB NO. _____

NUMBER	IDENTIFICATION	DESCRIPTION DO NOT KEY PUNCH
1	3	NRAT
13	1	NURAT(I), I = 1, NRAT
25	3	NURAT(2)
37	2	NURAT(3)
49	73	80
61		
1	0	NTMTOT
13		
25		
37		
49	73	80
61		
1		
13		
25		
37		
49	73	80
61		
1		
13		
25		
37		
49	73	80
61		

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D. INPUT DESCRIPTION FOR VIM-1 (Spherical Geometry Version)

Simplified versions of VIM-1 for bare and reflected spheres are available. The simplified input required for the spherical version is presented here, along with the load sheets for a sample case based on JEZEBEL.

The first three cards are to have a 6I12 format:

1st Card	{	NTHIST	total number of histories to be run
		NPHIST	number of histories between printouts
		NTYPE	number of types (must equal 1 for spherical geometry)
		NROW	does not apply, leave blank
		NCOL	does not apply, leave blank
		NM	number of materials in problem ($NM \leq 13$)
2nd Card	{	NPUNCH	not used, leave blank
		NSTART	not used, leave blank
		ISTYPE	not used, leave blank
		NZTYPE	not used, leave blank
		ISPECT	if > 0: number of entries in fission spectrum table if = 0: input CK array
		NOMB	= 0: set all OMB = 0 (pure absorption weighting) = 1: set all OMB = 1 (analog) = 2: read in OMB array (see Section III-D)
3rd Card	{	NSIZE	must equal NPHIST
		NWRITE	= 0: do <u>not</u> = 1: do } print data read in from cross-section tape
		NCK	the number of Maxwellian fission temperatures to be input, (must equal the number of fissile or fertile isotopes in this problem, if ISPECT = 0)

The following arrays are entered in a 6I12 format:

NZONE	= number of zones (must equal either 1 or 2, for spherical version)
(MAT(I), I=1, NM)	ID numbers of materials used in this problem, including those needed for monitoring purposes only (e.g., central fission ratios)

(NMZONE(I),I=1,NZONE) number of materials in Zone I
 ((IDZONE(I,J),I=1,NMZONE(J)),J=1,NZONE) ID numbers of the materials in Zone J

Format 36X,2E12.8:

DELTA,BMASS,ECUT

DELTA = small distance used by the code to ensure the particle's entrance into the adjacent region (see Section III-B)

BMASS = mass number above which scattering is isotropic in lab system

ECUT = energy below which neutron history ends (≥ 10 ev)

((DZONE(I,J),I=1,NMZONE(J)),J=1,NZONE) DZONE(I,J) is the number density (in atoms/cm³) $\times 10^{-24}$ of the Ith material in the Jth zone

If ISPECT = 0, skip to Section A; otherwise input:

(SE(I),I=1,ISPECT) fission spectrum energy grid } see Section
 (Q(I),I=1,ISPECT) fission spectrum table } III-A-1

Skip to Section B

Section A (CK(I),I=1,NCK) Maxwellian fission spectrum temperatures (in ev) (see Section III-A-1)

Section B If NOMB = 2, input the following (otherwise, skip to Section C):

((OMB(I,J),I=1,4),J=1,NM) OMB(I,J) is the value of the absorption weighting parameter, $1 - \beta$, for Energy Range I of Isotope J (see Section III-D)

Section C

RCORE,RMAX,WCUT,RMON RCORE = radius of core (cm)
 RMAX = radius of blanket (cm); if NZONE = 1 (bare sphere), set RMAX = 0
 WCUT = value of the weight cutoff for absorption weighting (see Section III-D)
 RMON = radius of central monitoring region for calculation of central fission ratios

Format I12: NGROUP = number of groups for the monitoring of integrated group fluxes

Format 6E12.8: (EGROUP(I),I = 1,NGROUP) lower energy group boundaries for integrated flux monitoring (enter high energy to low energy, in ev)

Format 112: NEF = the number of energy bands for the stratified sampling of neutron source energies

Format 6E12.8: (EFISS(I), I = 1, NEF) the lower group boundaries of the energy bands for stratified sampling of neutron source energies (high energy to low energy, in Mev)

Format 6I12: NRAT, (NURAT(I), I = 1, NRAT) where NRAT-1 = the number of central fission ratios to be computed, and NURAT(I) is the material number for the Ith central fission ratio:

$$\frac{\sigma_f(\text{NURAT}(I))}{\sigma_f(\text{NURAT}(\text{NRAT}))}$$

Note that NURAT(NRAT) is the ID number of the base material, against which the NURAT(I), I = 1, ..., NRAT-1 are being compared.

If the user wishes to override the cross sections on the tape for the unresolved resonance region, provision has been made for input of smooth self-shielded cross sections for the unresolved resonance region: (Format 2I12) NTMTOT, NSET where NTMTOT = the number of isotopes with at least one unresolved set and NSET = the total number of unresolved sets.

If NTMTOT = 0, the rest of the input is to be skipped.

(Format 6I12) NTMAT(I), I = 1, NTMTOT: identification numbers of the isotopes with unresolved sets

For each of the isotopes with unresolved sets, input the following three card sets (i.e., for I = 1, NTMTOT):

(Format 2E12.8) EUPPER(I), ELOWER(I): The upper and lower energy boundaries for the unresolved range for material number NTMAT(I)

(Format 3I12) MATSET(I, J), J = 1, 3 zone number of the zone containing material NTMAT(I), using set number MSET(I, J)

(Format 3I12) MSET(I, J), J = 1, 3 data set numbers for isotope NTMAT(I).

For each of the unresolved sets, input the following card sets (i.e., for I = 1, NSET):

(Format 1I2) NTM(I) the number of points in the Ith unresolved set

For K = 1 to NTM(I), input:

(Format 4E12.8) EC(I, K), AT(I, K), AS(I, K), AF(I, K) the energy, total cross section, scattering cross section, and fission cross section respectively for the Kth point of the Ith set.

E. LOAD SHEETS FOR JEZEBEL SAMPLE CASE

FORTRAN FIXED 10 DIGIT DECIMAL DATA

DECK NO. _____		PROGRAMMER _____		DATE _____		PAGE 1 of 6		JOB NO. _____	
NUMBER		IDENTIFICATION		DESCRIPTION		DO NOT KEY PUNCH			
1	5 0 0 0 0			NTHIST					
13	1 0 0 0			NPHIST					
25	1			NTYPE					
37				leave blank					
49				leave blank					
61	3			NM					
1				NPUNCH		leave blank			
13				NSTART		leave blank			
25	1			ISTYPE					
37	2			NZTYPE					
49	0			ISPECT					
61	1			NOMB					
1	1 0 0 0			NSIZE					
13	0			NWRITE					
25									
37									
49									
61									
1	1			NZONE					
13									
25									
37									
49									
61									

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FORTRAN FIXED 10 DIGIT DECIMAL DATA

DECK NO. _____		PROGRAMMER _____		DATE _____		PAGE 2 of 6		JOB NO. _____	
NUMBER		IDENTIFICATION		DESCRIPTION		DO NOT KEY PUNCH			
1		3		MAT(1)					
13		4		MAT(2)					
25		5		MAT(3)					
37									
49		73	80						
61									
1		3		NMZONE(1)					
13									
25									
37									
49		73	80						
61									
1		3		IDZONE(1)					
13		4		IDZONE(2)					
25		5		IDZONE(3)					
37									
49		73	80						
61									
1				leave blank					
13				leave blank					
25				leave blank					
37	1 . 0		- 0 6	DELTA					
49	5 0 0 .	73	80	BMASS					
61	1 0 .			ECUT					

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FORTRAN FIXED 10 DIGIT DECIMAL DATA

DECK NO.	PROGRAMMER	DATE	PAGE 3 of 6	JOB NO.
NUMBER	IDENTIFICATION	DESCRIPTION	DO NOT KEY PUNCH	
1 . 0 3 7 0 5		DZONE(1)		
13 . 0 0 1 7 5 1		DZONE(2)		
25 . 0 0 0 1 1 7		DZONE(3)		
37				
49				
61				
1 1 . 4 1 + 0 6		CK		
13				
25				
37				
49				
61				
1 6 . 3 8 4 9		RCORE		
13 6 . 0		RMAX		
25 0 . 0		WCUT		
37 2 . 5		RMON		
49				
61				
1				
13				
25				
37				
49				
61				

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FORTRAN FIXED 10 DIGIT DECIMAL DATA

DECK NO.	PROGRAMMER	DATE	PAGE 4 of 6	JOB NO.
NUMBER	IDENTIFICATION	DESCRIPTION	DO NOT KEY PUNCH	
1 2 7		NGROUP		
13				
25				
37				
49				
61				
1 6 . 0 6 5 3 E 0 6		EGROUP(1)		
13 3 . 6 7 8 8 E 0 6				
25 2 . 2 3 1 3 E 0 6				
37 1 . 3 5 3 4 E 0 6				
49 . 8 2 0 8 5 E 0 6				
61 . 4 9 7 8 7 E 0 6				
1 3 0 1 9 7 0 .		EGROUP(7)		
13 1 8 3 1 6 0 .				
25 1 1 1 0 9 0 .				
37 6 7 3 7 9 .				
49 4 0 8 6 8 .				
61 2 4 7 8 8 .				
1 1 5 0 3 4 .		EGROUP(13)		
13 9 1 1 8 . 8				
25 5 5 3 0 . 8				
37 3 3 5 4 . 6				
49 2 0 3 4 . 7				
61 1 2 3 4 . 1				

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FORTRAN FIXED 10 DIGIT DECIMAL DATA

DECK NO.	PROGRAMMER	DATE	PAGE 5 of 6	JOB NO.
NUMBER	IDENTIFICATION	DESCRIPTION	DO NOT KEY PUNCH	
1 7 4 8 . 5 2		EGROUP(19)		
13 4 5 4				
25 2 7 5 . 3 6				
37 1 6 7 . 0 2				
49 1 0 1 . 3	73	80		
61 6 1 . 4 4 2				
1 3 7 . 2 6 7		EGROUP(25)		
13 2 2 . 6 0 3				
25 1 . 0				
37				
49	73	80		
61				
1 1 0		NEF		
13				
25				
37				
49	73	80		
61				
1 6 . 2 5 1 4		EFISS(1)		
13 4 . 6 4 2 9				
25 3 . 6 6 6 5				
37 2 . 9 4 7 5				
49 2 . 3 6 6 0	73	80		
61 1 . 8 6 9 4				

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FORTRAN FIXED 10 DIGIT DECIMAL DATA

DECK NO.	PROGRAMMER	DATE	PAGE 6 of 6	JOB NO.
NUMBER	IDENTIFICATION	DESCRIPTION	DO NOT KEY PUNCH	
1 1 . 4 3 1 2		EFISS(7)		
13 1 . 0 1 8				
25 . 5 8 4 4				
37 0				
49	73	80		
61				
1 3		NRAT		
13 1		NURAT(1) U238		
25 3		NURAT(2) Pu239		
37 2		NURAT(3) U235		
49	73	80		
61				
1 0		NTMTOT		
13 0		NSET		
25				
37				
49	73	80		
61				
1				
13				
25				
37				
49	73	80		
61				

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V. SAMPLE CASE OUTPUT

The output of the heterogeneous ZPR-3-48 sample case of Section IV-C is presented on the following pages. 10,000 histories were run on the CDC 6600 in 1014 sec, calculating a value of k_{eff} of 0.998 ± 0.009 .

The output of the JEZEBEL sample case of Section IV-C follows that of ZPR-3-48. The JEZEBEL case was run for 50,000 histories on the CDC 6600 in 190 sec.

\$\$\$LISTING OF DATA CARD INPUT \$\$\$

NTHIST = 10000 NPHIST = 400 NTYPE = 2 NROW = 27 NCOL = 27 NM = 12

NPUNCH = 0 NSTART = 0 ISTYPE = 1 NZTYPE = 2 ISPECT = 88 NOMB = 1

NSIZE = 400 NWRITE = 0

NZONE(I), I=1,NTYPE

26 5

NTZONE = 31

NADJ(I), I=1,NTZONE

5	5	6	6	6	6	6	6	6	6	6	6	6
6	6	6	6	6	6	6	6	6	6	6	6	6
6	6	3	3	3	3	4	6	6	6	6	6	6

IADJ(I,J), J=1,6, I=1,NTZONE

5	25	26	3	4	-0
24	25	26	3	4	-0
18	20	7	15	22	14
18	20	7	16	22	14
1	6	3	4	25	26
5	7	3	4	25	26
6	8	3	4	25	26
7	9	3	4	25	26
8	10	3	4	25	26
9	11	3	4	25	26
10	12	3	4	25	26
11	13	3	4	25	26
12	14	3	4	25	26
13	15	3	4	25	26
14	16	3	4	25	26
15	17	3	4	25	26
16	18	3	4	25	26
17	19	3	4	25	26
18	20	3	4	25	26
19	21	3	4	25	26
20	22	3	4	25	26
21	23	3	4	25	26
22	24	3	4	25	26
2	23	3	4	25	26
1	2	3	4	18	20
1	2	3	4	18	20
31	29	30	-0	-0	-0
31	29	30	-0	-0	-0
31	27	28	-0	-0	-0
31	27	28	-0	-0	-0
27	28	29	30	-0	-0

MAT(I), I=1,NM

1	2	3	4	5	11	12	13	14	15	16	17
---	---	---	---	---	----	----	----	----	----	----	----

NMZONE(I), I=1,NTZONE

3	3	3	3	1	3	1	3	2	3	4	3
2	1	3	1	3	1	3	6	3	1	3	1
2	2	3	3	3	3	2					

IZTYPE(I), I=1,NTZONE

1	1	1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	1	1	1
1	1	2	2	2	2	2					

INOUTZ(I,J), J=1,6, I=1,NTYPE

1	2	3	4	25	26	27	28	29	30	31	31
---	---	---	---	----	----	----	----	----	----	----	----

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INZONE(I,J), J=INTZONE, I=INRZONE(J)									
J=1	1	3	13	14	15				
J=2	1	3	13	14	15				
J=3	1	3	13	14	15				
J=4	1	3	13	14	15				
J=5	1	3	13	14	15				
J=6	1	3	13	14	15				
J=7	1	3	13	14	15				
J=8	1	3	13	14	15				
J=9	1	2	1	2					
J=10	1	3	13	14	15				
J=11	1	4	3	4	5	17			
J=12	1	3	13	14	15				
J=13	1	2	1	2					
J=14	1	3	13	14	15				
J=15	1	3	13	14	15				
J=16	1	3	13	14	15				
J=17	1	3	13	14	15				
J=18	1	3	13	14	15				
J=19	1	3	13	14	15				
J=20	1	3	13	14	15				
J=21	1	3	13	14	15				
J=22	1	3	13	14	15				
J=23	1	3	13	14	15				
J=24	1	3	13	14	15				
J=25	1	2	1	2					
J=26	1	2	1	2					
J=27	1	3	13	14	15				
J=28	1	3	13	14	15				
J=29	1	3	13	14	15				
J=30	1	3	13	14	15				
J=31	1	2	1	2					

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XMAX = 5.54609E+00 YMAX = 5.52577E+00 ZMAX = 1.37312E+02 DELTA = 1.00000E-06 BMASS = 5.00000E+02

XLO(I), I=1,NTZONE

0.	5.31304E+00	0.	0.	2.33045E-01	5.50545E-01
5.88645E-01	1.14744E+00	1.18554E+00	1.50305E+00	1.53352E+00	1.79006E+00
1.82055E+00	2.13805E+00	2.45555E+00	2.49365E+00	3.05245E+00	3.09055E+00
3.72554E+00	3.75602E+00	4.33006E+00	4.39864E+00	4.95745E+00	4.99554E+00
2.33045E-01	2.33045E-01	0.	5.31304E+00	0.	0.
2.33045E-01					

XHI(I), I=1,NTZONE

2.33045E-01	5.54609E+00	5.54609E+00	5.54609E+00	5.50545E-01	5.88645E-01
1.14744E+00	1.18554E+00	1.50305E+00	1.53352E+00	1.79006E+00	1.82055E+00
2.13805E+00	2.45555E+00	2.49365E+00	3.05245E+00	3.09055E+00	3.72554E+00
3.75602E+00	4.33006E+00	4.39864E+00	4.95745E+00	4.99554E+00	5.31304E+00
5.31304E+00	5.31304E+00	2.33045E-01	5.54609E+00	5.54609E+00	5.54609E+00
5.31304E+00					

YLO(I), I=1,NTZONE

2.22885E-01	2.22885E-01	5.30285E+00	0.	2.22885E-01	2.22885E-01
2.22885E-01	2.22885E-01	2.22885E-01	2.22885E-01	2.22885E-01	2.22885E-01
2.22885E-01	2.22885E-01	2.22885E-01	2.22885E-01	2.22885E-01	2.22885E-01
2.22885E-01	2.22885E-01	2.22885E-01	2.22885E-01	2.22885E-01	2.22885E-01
2.22885E-01	2.22885E-01	2.22885E-01	2.22885E-01	5.30285E+00	0.
2.22885E-01					

YHI(I), I=1,NTZONE

5.30285E+00	5.30285E+00	5.52577E+00	2.22885E-01	5.30285E+00	5.30285E+00
5.30285E+00	5.30285E+00	5.30285E+00	5.30285E+00	5.30285E+00	5.30285E+00
5.30285E+00	5.30285E+00	5.30285E+00	5.30285E+00	5.30285E+00	5.30285E+00
5.30285E+00	5.30285E+00	5.30285E+00	5.30285E+00	5.30285E+00	5.30285E+00
5.30285E+00	5.30285E+00	5.30285E+00	5.30285E+00	5.52577E+00	2.22885E-01
5.30285E+00					

ZLO(I), I=1,NTZONE

0.	0.	0.	0.	3.04800E+01	3.04800E+01
3.04800E+01	3.04800E+01	3.04800E+01	3.04800E+01	3.04800E+01	3.04800E+01
3.04800E+01	3.04800E+01	3.04800E+01	3.04800E+01	3.04800E+01	3.04800E+01
3.04800E+01	3.04800E+01	3.04800E+01	3.04800E+01	3.04800E+01	3.04800E+01
1.06832E+02	0.	0.	0.	0.	0.
0.					

ZHI(I), I=1,NTZONE

1.37312E+02	1.37312E+02	1.37312E+02	1.37312E+02	1.06832E+02	1.06832E+02
1.06832E+02	1.06832E+02	1.06832E+02	1.06832E+02	1.06832E+02	1.06832E+02
1.06832E+02	1.06832E+02	1.06832E+02	1.06832E+02	1.06832E+02	1.06832E+02
1.06832E+02	1.06832E+02	1.06832E+02	1.06832E+02	1.06832E+02	1.06832E+02
1.37312E+02	3.04800E+01	1.37312E+02	1.37312E+02	1.37312E+02	1.37312E+02
1.37312E+02					

OZONE(I,J), J=1,NTZONE, I=NMZONE(J)

J = 1	I = 3	3.47096E-02	9.31960E-03	4.62330E-03				
J = 2	I = 3	3.47096E-02	9.31960E-03	4.62330E-03				
J = 3	I = 3	3.47096E-02	9.31960E-03	4.62330E-03				
J = 4	I = 3	3.47096E-02	9.31960E-03	4.62330E-03				
J = 5	I = 1	7.87260E-02						
J = 6	I = 3	7.70870E-02	2.06980E-02	1.02680E-02				
J = 7	I = 1	2.23685E-02						
J = 8	I = 3	7.70870E-02	2.06980E-02	1.02680E-02				
J = 9	I = 2	4.58227E-02	9.62510E-05					
J = 10	I = 3	7.70870E-02	2.06980E-02	1.02680E-02				
J = 11	I = 4	2.50850E-02	1.22890E-03	1.67700E-04	3.35540E-03			
J = 12	I = 3	7.70870E-02	2.06980E-02	1.02680E-02				
J = 13	I = 2	4.58227E-02	9.62510E-05					
J = 14	I = 1	7.87260E-02						
J = 15	I = 3	7.70870E-02	2.06980E-02	1.02680E-02				
J = 16	I = 1	2.23685E-02						
J = 17	I = 3	7.70870E-02	2.06980E-02	1.02680E-02				
J = 18	I = 1	7.87260E-02						
J = 19	I = 3	7.70870E-02	2.06980E-02	1.02680E-02				
J = 20	I = 6	2.71740E-02	5.70800E-05	6.03524E-03	5.62040E-04	4.04000E-05	2.83400E-03	
J = 21	I = 3	7.70870E-02	2.06980E-02	1.02680E-02				
J = 22	I = 1	2.23685E-02						
J = 23	I = 3	7.70870E-02	2.06980E-02	1.02680E-02				
J = 24	I = 1	7.87260E-02						
J = 25	I = 2	4.54640E-02	9.71420E-05					
J = 26	I = 2	4.54640E-02	9.71420E-05					
J = 27	I = 3	2.80725E-02	7.53612E-03	3.70808E-03				
J = 28	I = 3	2.80725E-02	7.53612E-03	3.70808E-03				
J = 29	I = 3	2.80725E-02	7.53612E-03	3.70808E-03				
J = 30	I = 3	2.80725E-02	7.53612E-03	3.70808E-03				
J = 31	I = 2	4.71473E-02	9.83267E-05					

SE(I), I=1, ISPECT						
1.03050E+07	9.96150E+06	9.61800E+06	9.27450E+06	8.93100E+06	8.58750E+06	
8.24400E+06	7.90350E+06	7.55700E+06	7.21350E+06	6.87300E+06	6.73260E+06	
6.59520E+06	6.45780E+06	6.32040E+06	6.18300E+06	6.04560E+06	5.90820E+06	
5.77000E+06	5.63340E+06	5.49600E+06	5.35860E+06	5.22120E+06	5.08380E+06	
4.94640E+06	4.80900E+06	4.67160E+06	4.53420E+06	4.39680E+06	4.25940E+06	
4.12200E+06	3.98460E+06	3.84720E+06	3.70980E+06	3.57240E+06	3.43500E+06	
3.29760E+06	3.16020E+06	3.02280E+06	2.88540E+06	2.74800E+06	2.61060E+06	
2.47320E+06	2.33580E+06	2.19840E+06	2.06100E+06	1.92360E+06	1.78620E+06	
1.64880E+06	1.51140E+06	1.37400E+06	1.30530E+06	1.23660E+06	1.16790E+06	
1.09920E+06	1.03050E+06	9.61800E+05	8.93100E+05	8.24400E+05	7.55700E+05	
6.87000E+05	6.18300E+05	5.49600E+05	4.80900E+05	4.12200E+05	3.43500E+05	
2.74800E+05	2.06100E+05	1.37400E+05	6.87000E+04	6.18300E+04	5.49600E+04	
4.80900E+04	4.12200E+04	3.43500E+04	2.74800E+04	2.06100E+04	1.37400E+04	
6.87000E+03	6.18300E+03	5.49600E+03	4.80900E+03	4.12200E+03	3.43500E+03	
2.74800E+03	2.06100E+03	1.37400E+03	6.87000E+02			
Q(I), I=1, ISPECT						
9.98180E-01	9.97700E-01	9.97090E-01	9.96330E-01	9.95360E-01	9.94150E-01	
9.92620E-01	9.90690E-01	9.88260E-01	9.85240E-01	9.81430E-01	9.79660E-01	
9.77710E-01	9.75580E-01	9.73250E-01	9.70710E-01	9.67930E-01	9.64890E-01	
9.61570E-01	9.57950E-01	9.53990E-01	9.49670E-01	9.44960E-01	9.39820E-01	
9.34210E-01	9.28100E-01	9.21450E-01	9.14200E-01	9.06310E-01	8.97720E-01	
8.88390E-01	8.78240E-01	8.67220E-01	8.55260E-01	8.42280E-01	8.28200E-01	
8.12960E-01	7.98460E-01	7.78610E-01	7.59340E-01	7.38540E-01	7.16110E-01	
6.91980E-01	6.66030E-01	6.38190E-01	6.08370E-01	5.76500E-01	5.42510E-01	
5.06370E-01	4.68050E-01	4.27590E-01	4.06580E-01	3.85070E-01	3.63070E-01	
3.40610E-01	3.17730E-01	2.94470E-01	2.70870E-01	2.47000E-01	2.22930E-01	
1.98750E-01	1.74570E-01	1.50530E-01	1.26800E-01	1.03570E-01	8.11100E-02	
5.97600E-02	3.99700E-02	2.24100E-02	8.16000E-03	6.99000E-03	5.88000E-03	
4.82000E-03	3.84000E-03	2.93000E-03	2.10000E-03	1.37000E-03	7.50000E-04	
2.70000E-04	2.30000E-04	1.90000E-04	1.60000E-04	1.20000E-04	9.00000E-05	
7.00000E-05	4.00000E-05	2.00000E-05	1.00000E-05			
OMB(I, J), I=1,4, J=1,NM						
1.00000E+00	1.00000E+00	1.00000E+00	1.00000E+00	1.00000E+00	1.00000E+00	
1.00000E+00	1.00000E+00	1.00000E+00	1.00000E+00	1.00000E+00	1.00000E+00	
1.00000E+00	1.00000E+00	1.00000E+00	1.00000E+00	1.00000E+00	1.00000E+00	
1.00000E+00	1.00000E+00	1.00000E+00	1.00000E+00	1.00000E+00	1.00000E+00	
1.00000E+00	1.00000E+00	1.00000E+00	1.00000E+00	1.00000E+00	1.00000E+00	
1.00000E+00	1.00000E+00	1.00000E+00	1.00000E+00	1.00000E+00	1.00000E+00	
1.00000E+00	1.00000E+00	1.00000E+00	1.00000E+00	1.00000E+00	1.00000E+00	
1.00000E+00	1.00000E+00	1.00000E+00	1.00000E+00	1.00000E+00	1.00000E+00	
1.00000E+00	1.00000E+00	1.00000E+00	1.00000E+00	1.00000E+00	1.00000E+00	
1.00000E+00	1.00000E+00	1.00000E+00	1.00000E+00	1.00000E+00	1.00000E+00	

NUMBER OF HISTORIES = 10000

K-EFFECTIVE = 9.98430011E-01 LEAKAGE = 3.40000000E-02 ABSORPTION = 9.68700000E-01

NUMBER OF COLLISIONS = 400444

ABSORPTION BY ISOTOPE

U238
6.24900000E-01

U235
8.10000000E-03

PU239
3.03300000E-01

PU240
8.80000000E-03

PU241
2.80000000E-03

NA23
6.00000000E-04

C12
0.

FE
9.50000000E-03

CR
3.70000000E-03

NI
2.80000000E-03

MO
4.20000000E-03

AL
0.

AVERAGE SOURCE ENERGY = 2.03138151E+06

BLANKET PRODUCTION = 1.22995942E-01 , CORE PRODUCTION = 8.75434069E-01

BLANKET ABSORPTION = 4.22000000E-01 , CORE ABSORPTION = 5.46700000E-01

AVERAGE FISSION ENERGY = 1.03481539E+06, AVERAGE FISSION CROSS SECTION = 1.96413364E+00

PRODUCTION PER ISOTOPE

U238
2.30486620E-01

U235
1.55187369E-02

PU239
7.31544793E-01

PU240
1.34861559E-02

PU241
7.39370493E-03

FISSION PER ISOTOPE

U238
8.18982550E-02

U235
6.32410206E-03

PU239
2.46955513E-01

PU240
4.41108568E-03

PU241
2.44886877E-03

[illegible]

```

$$$LISTING OF DATA CARD INPUT $$$

NTHIST = 50000  NPHIST = 1000  NTYPE = 1  NM = 5
NPUNCH = 0  NSTART = 0  ISTATE = 1  NZTYPE = 2  ISPECT = 0  NOMB = 1
NSIZE = 1000  NWRITE = 0
NZONE(I), I=1,NTYPE
1
NTZONE = 1
MAT(I), I=1,NM
1 2 3 4 5
NMZONE(I), I=1,NTZONE
3
INZONE(I,J), J=1,NTZONE, I=1,NMZONE(J)
J = 1 I = 3 3 4 5
DELTA = .10000E-05  BMASS = .50000E+03
OZONE(I,J), J=1,NTZONE, I=NMZONE(J)
J = 1 I = 3 .37050E-01 .17510E-02 .11700E-03
CK = .14100000E+07
OMB(I,J), I=1,4, J=1,NM
.10000E+01 .10000E+01 .10000E+01 .10000E+01 .10000E+01 .10000E+01
.10000E+01 .10000E+01 .10000E+01 .10000E+01 .10000E+01 .10000E+01
.10000E+01 .10000E+01 .10000E+01 .10000E+01 .10000E+01 .10000E+01
.10000E+01 .10000E+01 .10000E+01 .10000E+01 .10000E+01 .10000E+01
.10000E+01 .10000E+01 .10000E+01 .10000E+01 .10000E+01 .10000E+01
.10000E+01 .10000E+01 .10000E+01 .10000E+01 .10000E+01 .10000E+01
.10000E+01 .10000E+01 .10000E+01 .10000E+01 .10000E+01 .10000E+01
RCORE = .63449E+01  RMAX = .60000E+01  WCUT = 0.  RMON = .25000000E+01
NRAT = 3
NURAT(I), I=1,NRAT
1 3 2

```

NUMBER OF HISTORIES = 50000

K-EFFECTIVE = .10082240E+01, LEAKAGE = .66836000E+00, ABSORPTION = .33202000E+00

NUMBER OF COLLISIONS = 72700

ABSORPTION PER ISOTOPE

PU239
.32012000E+00

PU240
.11080000E-01

PU241
.82000000E-03

AVERAGE SOURCE ENERGY = .21038345E+07

BLANKET PRODUCTION = 0.

CORE PRODUCTION = .10082240E+01

BLANKET ABSORPTION = 0.

CORE ABSORPTION = .33202000E+00

AVERAGE FISSION ENERGY = .19473870E+07, AVERAGE FISSION CROSS SECTION = .18053274E+01

PRODUCTION PER ISOTOPE

PU239
.97349436E+00

PU240
.321737783E-01

PU241
.25558941E-02

FISSION PER ISOTOPE

PU239
.31022659E+00

PU240
.10143423E-01

PU241
.78407664E-03

CENTRAL FISSION RATIOS

U238/U235

PU239/U235

TRACK LENGTH ESTIMATION .20986E+00

.13924E+01

ABSORPTION ESTIMATION .20849E+00

.13926E+01

INDIVIDUAL BATCH RESULTS

HISTS	K EFFECTIVE
1000	.88836910E+00
2000	.10051967E+01
3000	.10139862E+01
4000	.10246101E+01
5000	.96140490E+00
6000	.10229162E+01
7000	.10377013E+01
8000	.10206153E+01
9000	.95156526E+00
10000	.96938116E+00
11000	.98357709E+00
12000	.10213947E+01
13000	.10321200E+01
14000	.94377015E+00
15000	.10623676E+01
16000	.10724850E+01
17000	.91195258E+00
18000	.10167913E+01
19000	.10328901E+01
20000	.10625515E+01
21000	.99446925E+00
22000	.10724330E+01
23000	.94655825E+00
24000	.90020595E+00
25000	.10244999E+01
26000	.10540929E+01
27000	.10247182E+01
28000	.10267761E+01
29000	.98202949E+00
30000	.10200285E+01
31000	.10523253E+01
32000	.10503380E+01
33000	.10441250E+01
34000	.97588619E+00
35000	.99973082E+00
36000	.11214458E+01
37000	.95775668E+00
38000	.99178531E+00
39000	.98305798E+00
40000	.99831879E+00
41000	.10752134E+01
42000	.10227695E+01
43000	.96859557E+00
44000	.99383821E+00
45000	.92430315E+00
46000	.96481613E+00
47000	.10705060E+01
48000	.95714698E+00
49000	.11521919E+01
50000	.10255935E+01

STANDARD DEVIATION = .52402320E-01

CALCULATIONS NEGLECTING FIRST N HISTORIES

N	K EFFECTIVE
1000	.10106701E+01
2000	.10107841E+01
3000	.10107160E+01
4000	.10104139E+01
5000	.10115030E+01
6000	.10112436E+01
7000	.10106283E+01
8000	.10103905E+01
9000	.10118253E+01
10000	.10128864E+01
11000	.10136379E+01
12000	.10134338E+01
13000	.10129287E+01
14000	.10148498E+01
15000	.10134922E+01
16000	.10117571E+01
17000	.10147815E+01
18000	.10147187E+01
19000	.10141325E+01
20000	.10125185E+01
21000	.10131409E+01
22000	.10110233E+01
23000	.10134109E+01
24000	.10177650E+01
25000	.10174956E+01
26000	.10159707E+01
27000	.10155904E+01
28000	.10150819E+01
29000	.10166558E+01
30000	.10164872E+01
31000	.10146010E+01
32000	.10126156E+01
33000	.10107621E+01
34000	.10129418E+01
35000	.10138226E+01
36000	.10061352E+01
37000	.10098566E+01
38000	.10113626E+01
39000	.10139357E+01
40000	.10154974E+01
41000	.10088623E+01
42000	.10071239E+01
43000	.10126280E+01
44000	.10157596E+01
45000	.10340509E+01
46000	.10513596E+01
47000	.10449774E+01
48000	.10888927E+01
49000	.10255935E+01

LOWER GROUP BOUNDARY	GROUP NO.	CORE FLUX	BLANKET FLUX	LEAKAGE
.60653000E+07	1	.12283988E+00	0.	.18820000E-01
.36788000E+07	2	.47504087E+00	0.	.73600000E-01
.22313000E+07	3	.84780293E+00	0.	.12808000E+00
.13534000E+07	4	.94817742E+00	0.	.13810000E+00
.82035000E+06	5	.84407055E+00	0.	.12248000E+00
.49787000E+06	6	.60025104E+00	0.	.84940000E-01
.30197000E+06	7	.38199963E+00	0.	.50240000E-01
.18316000E+06	8	.22718637E+00	0.	.28120000E-01
.11109000E+06	9	.12053221E+00	0.	.13340000E-01
.67379000E+05	10	.54531386E-01	0.	.55600000E-02
.40868000E+05	11	.27721359E-01	0.	.29800000E-02
.24783000E+05	12	.98842853E-02	0.	.96000000E-03
.15034000E+05	13	.77321544E-02	0.	.68000000E-03
.91188000E+04	14	.25730548E-02	0.	.30000000E-03
.55308000E+04	15	.40599901E-03	0.	.10000000E-03
.33546000E+04	16	.38589798E-03	0.	.60000000E-04
.20347000E+04	17	.14725383E-03	0.	0.
.12341000E+04	18	.20676563E-04	0.	0.
.74852000E+03	19	.33176827E-04	0.	0.
.45400000E+03	20	0.	0.	0.
.27536000E+03	21	0.	0.	0.
.16702000E+03	22	.91476280E-05	0.	0.
.10130000E+03	23	0.	0.	0.
.61442000E+02	24	0.	0.	0.
.37267000E+02	25	0.	0.	0.
.22603000E+02	26	0.	0.	0.
.10000000E+01	27	0.	0.	0.
TOTAL		.46713953E+01	0.	.66836000E+00

VI. CROSS-SECTION LIBRARY

The VIM-1 Code handles the voluminous point cross-section data in a highly efficient manner. Cross sections for each isotope included in the critical assembly composition are read into core, and packed linear arrays for each cross-section type (total, elastic, fission, etc.) are formed at execution time, with the cross sections of the $n + 1^{\text{st}}$ isotope immediately following those for the n^{th} isotope in the linear array. The energy grid points are also read into a linear array at execution time and appropriate location indices are formed so that a given cross section at a given energy for a given isotope can be determined in the Monte Carlo portion of the code rapidly, requiring, in general, only one fixed point subtraction of location indices.

There are 12 isotopes on the cross-section tape which was generated for use with the ZPR-3-48 test case. The smooth point cross sections at higher energies were read from ENDF/B library tapes (Reference 2), using the VIMB Code (Reference 3).

The Doppler-broadened (293°K) point cross sections for the resolved resonance regions of U^{238} , Pu^{239} , and Pu^{240} were obtained, using the UNIDOP Code, a combined version of the UNICORN Code (Reference 4) and the DOPCROS Code (Reference 5). The BNL code, RESREG (Reference 6), was used to generate smooth point cross sections for the unresolved resonance regions of U^{238} , Pu^{239} , and Pu^{240} .

RESREG results were used for the Doppler-broadened (293°K) resolved resonance regions of U^{235} and Mo.

The following list summarizes the sources of the cross-section data for the 12 isotopes on the cross-section tape.

- 1) Tape Identification Number 1: U^{238} (ENDF/B MAT 1047)
 - a) UNIDOP Doppler-broadened (to 293°K) point cross sections for the resolved resonance region from 10 ev to 3820 ev
 - b) RESREG smooth cross sections for the unresolved resonance region from 3820 ev to 50 kev
 - c) ENDF/B smooth cross sections from 50 kev to 10 Mev

- 2) Tape Identification Number 2: U^{235} (ENDF/B MAT 1044)
 - a) RESREG Doppler-broadened (to 293°K) point cross sections for the resolved resonance region from 10 ev to 64 ev
 - b) ENDF/B smooth cross sections from 64 ev to 10 Mev
- 3) Tape Identification Number 3: Pu^{239} (ENDF/B MAT 1051)
 - a) UNIDOP Doppler-broadened (to 293°K) point cross sections for the resolved resonance region from 10 ev to 300 ev
 - b) RESREG smooth cross sections for the unresolved resonance region from 300 ev to 100 kev
 - c) ENDF/B smooth cross sections from 100 kev to 10 Mev
- 4) Tape Identification Number 4: Pu^{240} (ENDF/B MAT 1053)
 - a) UNIDOP Doppler-broadened (to 293°K) point cross sections for the resolved resonance region from 10 ev to 685 ev
 - b) RESREG smooth cross sections for the unresolved resonance region from 685 ev to 40 kev
 - c) ENDF/B smooth cross sections from 40 kev to 10 Mev
- 5) Tape Identification Number 5: Pu^{241} (ENDF/B MAT 1054)
- 6) Tape Identification Number 11: Na^{23} (ENDF/B MAT 1059)
- 7) Tape Identification Number 12: C^{12} (ENDF/B MAT 1010)
- 8) Tape Identification Number 13: Fe (ENDF/B MAT 1020)
- 9) Tape Identification Number 14: Cr (ENDF/B MAT 1018)
- 10) Tape Identification Number 15: Ni (ENDF/B MAT 1021)

The cross sections for the preceding 6 isotopes (Pu^{241} , Na^{23} , C^{12} , Fe, Cr, and Ni) were obtained from ENDF/B for the entire energy range from 10 ev to 10 Mev.

- 11) Tape Identification Number 16: Mo (ENDF/B MAT 1025)
 - a) RESREG Doppler-broadened (to 293°K) point cross sections for the resolved resonance region from 10 ev to 1000 ev

b) ENDF/B smooth cross sections from 1000 ev to 10 Mev

12) Tape Identification Number 17: Al (ENDF/B MAT 1015)

ENDF/B smooth cross sections from 10 ev to 10 Mev.

This library, while a reasonable representation of the nuclear data, was used primarily for purposes of checking out the code on representative critical assemblies, and is not intended to be the final library for the code. The reasons for this are: (1) the imminent availability of new (Version II) re-evaluated ENDF/B data, not available during the development of the code, and (2) a new procedure for handling unresolved resonance region data, without resorting either to pseudo-resolved resonances or self-shielded data, is presently being developed for use in the VIM series of codes. It would not have been in the best interests of the development of the VIM series of codes to delay the completion of VIM-1 until this new method could be implemented. Temporary provision for the use of self-shielded smooth cross sections in the unresolved resonance region is provided for in the present version of VIM-1. A description of the input required is in Section IV-B.

INPUT DESCRIPTION FOR VIM-1 CROSS-SECTION TAPE MAKER

Two individual energy grids are used for each isotope. The first energy grid, the EGRID array, is used for the tabulation of the total cross sections (SIGT array), the elastic scattering cross sections (SIGS array), the inelastic scattering cross section (SIGIN array), and the n,2n reaction cross section (SN2N array). The second energy grid, the EANG array, is used for the tabulation of the cumulative elastic angular distributions (ANGDIS array), as described in Section III-E-1.

For any given isotope, data may be treated differently for specified energy ranges. The number of such energy ranges is designated by NRANGE. The lower energy bound of the N^{th} energy range is designated ERANGE (N). An index defining the specific treatment to be given the data in this energy range, is designated IRANGE (N). The values of IRANGE have the following meaning:

IRANGE = 1: interpolation rule assumes that table of energy versus cross section is linear in energy, logarithmic in cross section

IRANGE = 2: logarithmic in energy, logarithmic in cross section

IRANGE = 4: linear in energy, linear in cross section

IRANGE = 6: logarithmic in energy, linear in cross section

IRANGE = 3: cross section at energy grid point closest to neutron energy is used.

If the need arises for other treatments (e.g., a new treatment of the unresolved resonance region), new indices may be added, with corresponding coding modifications to implement the new procedure.

Data for the generation of the cross-section tape should be input in the following manner.

For First File

(Format 112) NM = number of materials to be written on cross-section tape

(Format 6112) (MAT(N), N=1,NM) material ID numbers for each of the NM materials.

For Each Isotope

One file for each isotope will be written, using the following card sets, which should be input for each isotope in the same order as the MAT array of File 1.

(Format 6112)

one card	{	MATT = material ID number (must equal one of the material ID numbers of the MAT array of the first file)
		NPTS = number of points in the total cross-section energy grid
		NLEV = number of inelastic levels
		LFI = number of non-zero fission cross sections (energy index of last non-zero fission cross section)
		IN2N = 1: n,2n cross sections are to be entered for this isotope (= 0: no n,2n cross sections)
		LNU = 0: $\nu = \text{CONU}(1) + \text{CONU}(2) \cdot E + \dots + \text{CONU}(\text{NCO}) \cdot E^{\text{NCO}-1}$ = 1: ν is entered as a table of ν versus energy, which is to be linearly interpolated.

(Format E12.8)

AMASS = mass of nucleus/neutron mass

(Format 112)

NRANGE = total number of energy ranges over which this isotope's cross-section data may be treated differently

(Format 6E12.8)

(ERANGE(N), N=1, NRANGE) lower energy bound of the N^{th} range

(Format 6112)

IRANGE(N), N=1, NRANGE IRANGE(N) is the index which defines the specific treatment to be given the cross-section data in the N^{th} energy range.

(Format 4E12.8) (One set per card)

one card	{	EGRID(I)	energy grid for the total, elastic, inelastic, n,2n, and fission cross section (<u>high</u> energy to <u>low</u>)
		SIGT(I)	total cross section at Energy EGRID(I)
		SIGS(I)	elastic scattering cross section at Energy EGRID(I)
		SIGIN(I)	inelastic scattering cross section <u>plus</u> n,2n cross section at Energy EGRID(I)

If the isotope is non-fissile, non-fertile, skip to Section B; otherwise, input the fission cross sections in the following format:

(Format 6E12.8)

(SIGF(I), I=1, LFI) fission cross sections from EGRID(I) to EGRID(LFI)
(high energy to low energy)

If LNU = 1, skip to Section A; otherwise, input the following:

(Format 112)

NTAB = number of entries in table of ν versus energy, $NTAB \leq 6$ (linear interpolation rule is used)

(Format 6E12.8)

(ENU(I), I=1, NTAB) energy values in table of ν versus energy

(Format 6E12.8)

(ANU(I), I=1, NTAB) value of ν at Energy ENU(I).

Skip to Section B.

Section A

(Format 112)

NCO = number of coefficients in the polynomial representation of ν :

$$\nu = \sum_{i=1}^{NCO} CONU(i) E^{i-1}$$

(Format 6E12.8)

(CONU(I), I=1, NCO) coefficients in polynomial representation of ν

Section B

The following two card sets must be input for each inelastic level, starting with Level 1:

(Format 2I12, E12.8)

MIN, MAX, ESUBC where MIN, MAX are the minimum and maximum indices respectively for the SIGINL array, and ESUBC = the neutron energy in the laboratory frame below which the reaction cannot take place.

(Format 6E12.8)

(SIGINL(J), J=1, NINP) inelastic level cross sections for energies EGRID(MIN) to EGRID(MAX) (NINP = MAX - MIN + 1) (energies run from high energy to low energy)

If there are no (n,2n) cross sections (IN2N = 0), skip to Section C; otherwise, input the (n,2n) cross sections in the following manner:

(Format 2I12)

MIN, MAX minimum and maximum indices for the SN2N array

(Format 6E12.8)

SN2N(I), I=1, NINP: (n,2n) cross sections for Energies EGRID(MIN) to EGRID(MAX) (NINP = MAX - MIN + 1) (energies run from high to low)

Section C

The elastic scattering angular distributions are input, in the form of cumulative distribution functions of center-of-mass scattering angle at energies EANG(I), I = 1, NANG, where NANG = total number of angular distributions input for this isotope.

(Format E12.8, I12)

ESTART,NANG where ESTART is the energy below which elastic scattering is treated as isotropic in the center-of-mass

For each of the NANG angular distributions, one must input:

(Format 6E12.8)

EANG,(ANGDIS(J),J=1,19) where EANG is the lower energy bound of the energy range to which the cumulative distribution function (ANGDIS(J), J = 1,19) applies (see Section III-E-1).

The EANG values should be entered in decreasing order of magnitude.

REFERENCES

1. Handbook of Mathematical Functions, AMS 55, National Bureau of Standards
2. ENDF/B Library Tape, Version I, Data 10-26-67, Corrected 7-1-68 (Tape Numbers 114, 115, 116, and 117)
3. R. Hubner, VIMB, "A Code for Reading ENDF/B Cross-Section Tapes (unpublished)"
4. J. M. Otter, "UNICORN, A Program to Calculate Point Cross Sections From Resonance Parameters," NAA-SR-11980, Vol VI (June 30, 1966)
5. C. L. Dunford and E. L. Bramblett, "DOPCRS, A Code to Doppler Broaden Resonance Data for Monte Carlo Calculations," AI-CE-MEMO-21 (June 20, 1966)
6. BNL Program RESREG, designed to compute resonance cross sections directly from ENDF/B data tapes (unpublished)