AEA

AEA RS 5520-NP-A

TOPICAL REPORT ON THE USE OF MONK6A FOR THE ANALYSIS OF CRITICALITY PROBLEMS ASSOCIATED WITH THE STORAGE AND TRANSPORTATION OF LOW-ENRICHED UO2 FUEL

Prepared by N R Smith & A K Ziver
AEA Technology
May 1993

9405270111 940520
PDR TOPRP EEC*****
B PDR

AEA

AEA RS 5520

TOPICAL REPORT ON THE USE OF MONK6B FOR THE ANALYSIS OF CRITICALITY PROBLEMS ASSOCIATED WITH THE STORAGE AND TRANSPORTATION OF LOW-ENRICHED UO2 FUEL

Prepared by N R Smith & A K Ziver
AEA Technology
May 1993

Summary

This document contains a collection of material to support the use of the MONK6B Monte Carlo criticality computer code for the purposes of analysing the safety of storage and transportation operations involving low-enriched UO_2 fuel. The document comprises: a general introduction to MONK6B; a description of the MONK6B validation database with particular reference to the intended application; a guide to the application of MONK6B to a typical problem; a comparison of MONK6B with the KENOVa Monte Carlo code for a range of problems; an overview of the MONK6B nuclear data library; a description of the QA Programme for MONK6B; and a description of the main user manuals that accompany this document.

	NAME	SIGNATURE	POSITION	DATE
Lead Author	Mr N R Smith	N R Smith	Project Manager	28/6/93
Checked	Dr A K Ziver	A K Ziver	Safety Analyst	28/6/93
Approved	Dr C A Cooper	C A Cooper	Department Manager	30/6/93

UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001

January 8, 1994

Mr. Neil M. Irvine, Executive Vice President
Business Development
AEA O'Donnell, Inc.
241 Curry Hollow Road
Pittsburgh, Pennsylvania 15236-4696

Dear Mr. Irvine:

SUBJECT: ACCEPTANCE OF REFERENCING OF THE AEA O'DONNELL TOPICAL REPORT AEA RS 5520, "TOPICAL REPORT ON THE USE OF MONK6B FOR THE ANALYSIS OF CRITICALITY PROBLEMS ASSOCIATED WITH THE STORAGE AND TRANSPORTATION OF LOW-ENRICHED UO_2 FUEL"

The staff has completed its review of the subject topical report submitted by AEA O'Donnell, Inc. in a letter of September 3, 1993. This report provides the analysis to qualify the AEA O'Donnell MONK6B criticality code for use in criticality studies.

The topical report is acceptable for referencing in criticality study submittals to the extent specified in, and under the limitations delineated in, the report and the associated NRC technical evaluation. The evaluation defines the basis for accepting the report.

The staff will not repeat its review of the matters described in the report, except to ensure that future submittals referencing the report adhere to the restrictions described in the technical evaluation and that the topical report is applicable to the referencing analysis. Staff acceptance applies only to the matters discussed in the topical report.

In accordance with procedures established in NUREG-0390, it is requested that AEA O'Donnell publish accepted versions of this report, proprietary and non-proprietary, within three months of receipt of this letter. The accepted versions shall incorporate this letter and the enclosed evaluation between the title page and the abstract. The accepted versions shall include an -A (designating accepted) following the report identification symbol.

Should NRC criteria or regulations change so that the conclusion concerning the acceptability of the report is invalidated, AEA O'Donnell and/or the individuals referencing the topical report will be expected to revise and resubmit their respective documentation, or submit justification for the continued effective applicability of the topical report without revision of their respective documentation.

Sincerely,

Ashok C. Thadani, Director
Division of Systems and Safety Analysis
Office of Nuclear Reactor Regulation

Enclosure:
Safety Evaluation

UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001

ENCLOSURE

SAFETY EVALUATION BY THE OFFICE OF NUCLEAR REACTOR REGULATION RELATING TO THE AEA O'DONNELL TOPICAL REPORT AEA RS 5520, "TOPICAL REPORT ON THE USE OF MONK6B FOR THE ANALYSIS OF CRITICALITY PROBLEMS ASSOCIATED WITH THE STORAGE AND TRANSPORTATION OF LOW-ENRICHED UO_2 FUEL"

1. INTRODUCTION

In a letter of September 3, 1993, from N. Irvine (AEA O'Donnell, Inc.) to R. Jones (NRC), AEA O'Donnell Inc. submitted Topical Report AEA RS 5520 for NRC review. This report provides information about the qualification of the MONK6B computer code for use in criticality studies. Included in the submittal was a copy of the MONK6B User's Manual which discusses code models, provides bench-marking data, and outlines the input and output structure.

The comparative studies in the topical report outline the use of MONK6B to model (1) the 12 standard criticality problems established for use in the U.S., (2) a fuel storage cask, and (3) a spent fuel storage facility. The results from the models for the standard problems and the fuel storage cask are compared to data from critical experiments, and the results of the spent fuel storage facility model was compared to a SCALE 3.1 (KENOVa) solution. These data, a detailed review of the supplied user's guide, and a limited review of available literature sources (Refs. 1 and 2) form the basis for the conclusions in this Safety Evaluation Report (SER), and they will be discussed in detail below.

2. MONK6B DESCRIPTION

MONK6B uses point energy Monte Carlo for criticality calculations on a wide variety of systems. MONK6B uses the UKNDL library, which includes data on many nuclides, including those usually associated with criticality studies. MONK6B consists of several major models. The two most important are the geometry and point energy models; these are discussed in the next two sections.

2.1 GEOMETRY MODELING

A MONK6B model is constructed by combining basic geometric shapes into the desired configuration. These individual volumes may comprise combinations of different materials that must be specified by the user. Each individual volume has its own coordinate system associated with it; MONK6B, therefore, must transform the coordinate system once a neutron crosses a boundary. The geometry package is very complex and, with the exception of the next paragraph, will not be discussed further except to say that the staff finds it acceptable.

One aspect of the geometry package which was new to the staff is what are referred to as hole geometries. A hole region contains regions of the model

which are "hidden" because a method called Woodcock tracking has been used (Ref. 3). Woodcock tracking involves artificially equating all of the total cross-sections in the region to the largest total cross-sections in the region, which reduces the number of boundaries that must be traced and has a favorable effect on code speed. As MONK6B tracks a particle through a hole region, it counts a number of pseudo-collisions, which are those collisions that occur because of the modifications to the total cross sections. MONK6B has the capability of determining whether or not the collision is real and it does not count artificial events by allowing the particles to continue along their original trajectory undisturbed. Because the MONK6B hole routines can delineate between real and artificial events, the use of hole geometries has no effect on the answer and the staff considers their use acceptable.

2.2 POINT ENERGY MODELING

MONK6B uses a point energy algorithm that uses the ultra-fine group UKNDL library consisting of 8220 data points per nuclide. All of the energy models discussed in the topical report have been reviewed and are considered acceptable. MONK6B specifically examines neutron thermalization, resonance reactions, and fission reactions by random number sampling from many different distributions representing these effects. MONK6B tracks all of the resulting neutrons from their initial distribution to their end-state, keeping track of any secondary neutrons along the way. This series of events is called a history. MONK6B combines these histories into what are termed super-histories in an attempt to improve the estimation of the variance and the bias. Furthermore, MONK6B has several different starting source and settling options (Ref. 3). The staff has reviewed this approach and finds it acceptable.

MONK6B uses four different k_{eff} estimators. Two are calculated directly from scored parameters and two are calculated by linear combinations of scored parameters. MONK6B also calculates a variance and a bias for each value of k_{eff}. The MONK6B bias is slightly negative and it accounts for small errors in the calculation of neutron importance (Ref. 3). The staff has reviewed the MONK6B approach to k_{eff}, variance, and bias calculation and finds it acceptable.

3.0 BENCHMARKING

This discussion focuses on two of the three data sets used to validate MONK6B for criticality studies. The first set consists of the results from the comparison of MONK6B to the standard problems used for criticality code validation in the US and the second consists of data from a MONK6B simulation of a spent fuel storage bay (Ref. 4). Both of these cases are compared to KENOVa results. To allow for a better understanding of the KENOVa methodology, the SCALE 3.1 documentation was reviewed (Ref. 5).

3.1 COMPARISON TO STANDARD CRITICALITY PROBLEMS

MONK6B was used to model all 12 of the standard criticality problems established for code validation. The MONK6B models were created to simulate the geometry as accurately as possible. Comparison of MONK6B results to KENOVa results show that both methods are, for the most part, equally accurate with results that are comparable to the tolerances of 1.0% and 2.0% for Uranium and Plutonium systems, respectively, established in the validation

database. The error on uranium systems is small and can be attributed to modeling differences between the two methods and evidence from the MONK6B validation database. The error on the plutonium systems, however, is rather large; but the staff concurs with the author's assertion that it is within the uncertainty associated in the basic nuclear data of both methods.

3.2 COMPARISON BETWEEN KENOVA AND MONK6B MODELING OF A SPENT FUEL BAY

A discussion of the modeling of a 4x2 high-density, poisoned storage rack used to store standard 17x17 fuel elements using both MONK6B and KENOVa follows. One MONK6B run was made and two KENOVa runs using the 16 and 27 group libraries were performed. Both KENOVa and MONK6B can precisely model this arrangement. The results of these runs show that the MONK6B and KENOVa results are in good agreement, with MONK6B being more conservative than either KENOVa run. Because the MONK6B database suggests a slight over-prediction of k_{eff} for these systems, and because nuclear data libraries have some error associated with them, the staff finds that these results demonstrate reasonable assurance that the MONK6B method is acceptable.

4.0 CONCLUSIONS

The staff reviewed the topical report covering the use of MONK6B as a tool for criticality studies, examining the solution methodology, the validation studies, and documentation on similar methods. The MONK6B solution approach, although different in many ways from the KENOVa method, uses many of the same ideas. This, coupled with the fact that in its review of the documents supplied to it, the staff discovered no major model discrepancies; provides the staff reasonable assurance that the solution technique employed in MONK6B is accurate. In order to determine that MONK6B predictions are acceptable, the staff examined the provided validation studies. On the basis of the acceptability of these studies and previous findings regarding the solution technique, MONK6B is acceptable for use in criticality studies.

5. REFERENCES

(1) J. Duderstadt and L. Hamilton, "Nuclear Reactor Analysis," John Wiley and Sons, 1976.

(2) R. V. Rubinstein, "Simulation and the Monte Carlo Method," John Wiley and Sons, 1981.

(3) "MONK6: A Monte Carlo Code for Criticality Calculations User Guide," UKAEA.

(4) N. R. Smith and A. K. Ziver, "Topical Report on the use of MONK6B for the Analysis of Criticality Problems Associated with the Storage and Transportation of Low-Enriched UO_2 Fuel," AEA, May 1993. (Proprietary)

(5) J. A. Bucholz, "SCALE: A Modular System for Performing Standardized Computer Analyses for Licensing Evaluation, NUREG/CR-0200," U.S. Nuclear Regulatory Commission, 1982.

CONTENTS

SECTION A

AN INTRODUCTION TO MONK6B

Summary

An introduction to the MONK6B code is presented comprising: Overview, The Monte Carlo Method, Nuclear Data Library and Collision Processing, Geometry Modelling, Starting Source Options, Control Parameters, Validation, Geometry Visualisation, Quality Assured Code Management and Code Distribution and User Support.

1 OVERVIEW

MONK is a Monte Carlo neutronics computer code written to assist in the study of criticality safety problems. MONK originated from a code called GEM, which came out of the post-war nuclear weapons programme in the United Kingdom. The most recent period of development was stimulated by the needs of the UK reprocessing industry and resulted in the production of MONK6 in the late 1980's. The most recent version of the code is MONK6B and this is used throughout the UK nuclear industry wherever criticality problems arise. MONK6B is distributed and actively supported in use by AEA Technology and the code is subject to an on-going maintenance and development programme.

For neutronics modelling, the Monte Carlo method enables considerable geometric complexity to be represented and physically-realistic accounts of the neutron interactions to be modelled. No significant modelling approximation is required on theoretical grounds, although some might be introduced to enhance the efficiency of the calculation. The accuracy of the basic nuclear data is the only real limit on the ultimate accuracy achievable, although computer storage and running times might impose further limitations. MONK6B takes full advantage of the possibilities provided by the Monte Carlo method in its modelling repertoire.

The primary aim of MONK6B is to calculate the neutron multiplication factor (k-effective) of systems by the computer simulation of the birth, migration and ultimate fate of a finite sample of typical neutrons. The actual number of neutrons followed or tracked determines the statistical precision associated with the calculated value of k-effective. In fact the variance on any scored parameter (MONK6B also calculates other quantities including neutron fluxes, reaction rates and boundary crossings) varies inversely with the number of neutrons sampled.

A model of the system to be assessed is assembled from simpler sub-systems using the MONK6B geometry package. The basic component of this package is a set of simple bodies, including the sphere, box, rod, prism, cone and torus. These bodies can have general orientation and can overlap each other if necessary. They are used as basic building blocks to form simple parts of the geometry, each part being defined quite independently of the rest of the system using local co-ordinates. These simple parts are then used to make more complex parts in the same way and so on, until the whole system is assembled. Hole geometries (making use of a technique called Woodcock tracking) are used extensively in MONK6B to provide a lot of the more complicated fine geometric details, and to short-cut the specification of some of the commonly-occurring array items.

Neutron interactions are considered in the MONK6B collision processing package called DICE. The standard MONK6B nuclear data library is an 8220 group library based on UKNDL and JEF evaluations. This library, together with the point-energy collision processing algorithms, provides a very detailed modelling of the physics, so that the ultimate accuracy of the MONK6B code largely depends only on the numerical accuracy of the basic nuclear data. It is this continuous energy package that has been the subject of extensive validation studies and is therefore the recommended method for criticality assessments. However for cross-checking purposes MONK6B can also accept multigroup data from the well-established SCALE and WIMS libraries.

MONK6B calculates the k-effective for the system modelled using a staged calculation with each stage consisting of a fixed number of superhistories. A neutron superhistory is the set of tracks followed by a neutron and its fission progeny from birth to absorption or leakage, through a fixed number of fission generations (normally 10). Superhistory powering produces a stable calculation of the scored parameters and their variances which are essentially unbiased and results in a calculation that concentrates on the most reactive parts of a system, thereby enabling MONK6B to be used with confidence even for highly-decoupled systems.

MONK6B has been successfully used in support of the design and operation of a wide range of nuclear facilities covering the complete fuel cycle including:

- fuel fabrication for thermal, fast and experimental reactors
- uranium enrichment covering diffusion and centrifuge plant
- new and spent fuel transportation both within the UK and overseas
- spent fuel handling and pool storage
- fuel consolidation and dry cell handling
- fuel dissolution and chemical separation involving mixer-settlers and pulsed-columns
- product finishing and storage
- waste treatment, handling and storage including evaporation, vitrification, encapsulation and consolidation
- plutonium metal production and handling

2 THE MONTE CARLO METHOD

The Monte Carlo method is distinguished from other numerical techniques by its use of random sampling to obtain solutions to mathematical problems. In many ways the Monte Carlo method can be regarded as a numerical experiment, with statistical techniques being employed to estimate the required quantities by sampling from appropriate probability distributions. For example the probability of throwing double six with two unbiased die can be readily estimated by Monte Carlo means, by repeated random sampling of pairs of numbers between one and six. In this case where the result can be obtained exactly by the laws of the combinations of probabilities, the use of the Monte Carlo method is pointless. However in the wide range of problems where no such simple solution exists, as in the case of general three-dimensional particle transport, the Monte Carlo method is often the only feasible method of solution.

With deterministic methods computing errors are systematic arising from: measurement uncertainties in the nuclear data; discretisation of space/angle/energy; simplifications to 1 or 2 dimensions; and geometric modelling approximations. In contrast Monte Carlo methods can: represent space/angle/energy continuously; deal with complex geometric configurations; and deal with neutron collisions with great physical realism.

The Monte Carlo method therefore has an ultimate accuracy dependent on only the following:

- measurement uncertainties in the nuclear data
- measurement uncertainties in the geometry and composition (these are often negligible)

In addition a Monte Carlo calculation will always provide answers with some stochastic uncertainty; this can be reduced to any desired level by increasing the running time.

The Monte Carlo method is used to estimate numerical quantities by sampling from a stochastic model of a physical system. An estimate for a particular quantity is normally

obtained by performing a number of experimental trials or samples and calculating the sample mean:

$$Xn = \frac{1}{n}\sum_{i=1}^{n} xi$$

where x1,x2,.....xn are individual sample values of the random variable X that is being estimated.

In addition, when applying the Monte Carlo method to practical problems some confidence is required in the precision of this estimate due to the limited sample size that has been employed. Clearly the greater the value of n, the more precise the estimate of X is expected to be. A measure of this precision involves obtaining an estimate of the statistical uncertainty of X.

Concerning the mean value, the so-called 'law of large numbers' from probability theory states that the sample mean (Xn) approximates the population or true mean (μ) with a probability that tends to 1 as n increases:

$$P\{\lim_{n\to\infty} Xn = \mu\} = 1$$

Thus the mean of n sample values converges to its expected value as n increases.

An estimate of the range of values that the mean may take and the rate of convergence to the expected value is given by the central limit theorem. This states that if a series of sample means is obtained from a population (of arbitrary distribution) with mean μ and standard deviation σ, then the sample means will form a distribution which tends to a normal distribution. Moreover this distribution of sample means will also have a mean of μ, but will have a smaller standard deviation (often called the standard error) equal to:

$$\sigma/\sqrt{N}$$

where N is the number of sample means. The number of sample means required to approximate a normal distribution varies depending on the shape of the parent distribution, and can be very large (e.g. several thousand) for a highly-skewed distribution.

In a practical calculation it should be born in mind that the true mean μ is unknown and the standard deviation must be estimated in order to apply the central limit theorem. However provided the sample mean is fairly estimated and a large number of individual sample means are considered, the underlying normal distribution can be used to predict the probability of the estimated mean deviating from the true mean in units of σ. Thus the estimated mean is within ±one standard error of the true mean 68.3% of the time, within ±two standard errors 95.4% of the time and within ±three standard errors 99.7% of the time.

In addition the central limit theorem states that the standard error reduces with the inverse of the square root of the increasing number of sample means; this gives rise to the well-known requirement that to half the standard error on the result of a Monte Carlo calculation, four times the number of samples are required.

It is rare in criticality experience for the normal distribution condition of the central limit theorem to be breached, but for unusual situations the normality condition should be carefully checked; remember that the smaller the statistical uncertainty the bigger the population sample, and hence the better the central limit hypothesis.

In summary, the 'numerical experiment' performed by MONK6B consists of:

- tracking neutron samples through the geometry
- processing collisions as they occur
- scoring appropriate quantities in an efficient manner.

Each scored quantity will have associated with it a stochastic uncertainty characterised by its standard deviation.

3 NUCLEAR DATA LIBRARY AND COLLISION PROCESSING

A neutron being tracked through matter undergoes repeated collisions with the nuclei of the atoms. These interactions are handled by means of primary microscopic reaction cross-sections which represent the relative probabilities of occurrence of the reactions. The outcome of an interaction may be that the neutron is captured or it may be merely deflected in its path with altered energy. In this latter case further information is required detailing the probability of scattering through various angles with the corresponding change in energy. Another possibility is that the neutron on being absorbed produces a whole set of new neutrons, in which case once again angles and energies of the secondaries are required. These processes are all handled with good physical realism by the collision processing package and associated nuclear data library of MONK6B.

The standard MONK6B nuclear data library is a continuous energy library based on United Kingdom Nuclear Data Library (UKNDL) and Joint Evaluated File (JEF) evaluations. A highly detailed continuous energy representation is recommended for criticality calculations because:

- a realistic representation of the physics is desirable
- absolute answers are required for k-effective, rather than comparative ones
- a large range of materials in complex geometries must be covered

The continuous energy treatment provides the best physical model of the neutron-nuclei collision process and the ultimate accuracy of the MONK6B code effectively only depends on the numerical accuracy of the basic nuclear data. The UKNDL and JEF nuclear data have been extensively evaluated but still contain some systematic errors (as do all other nuclear data libraries).

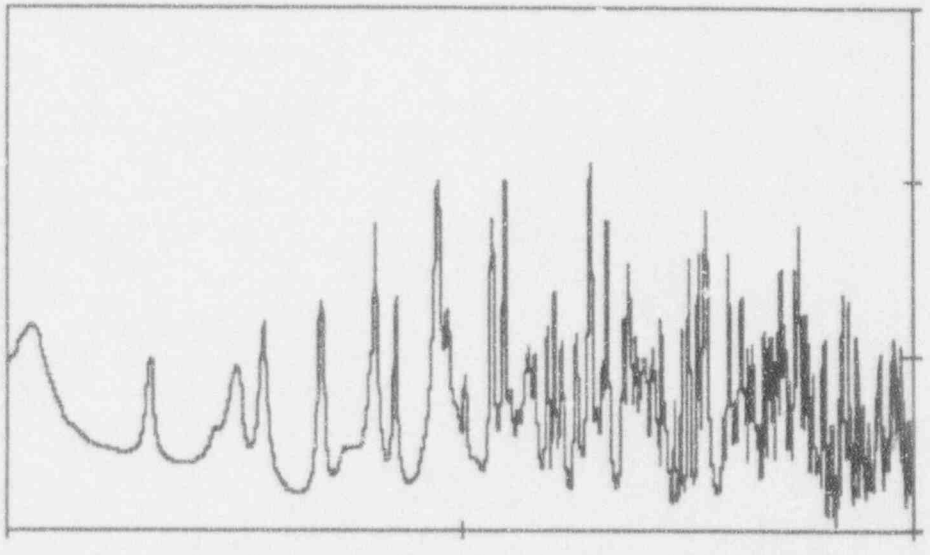
The MONK6B continuous energy library therefore contains additional adjustments made using good-quality critical experiments. These adjustments all lie within the differential experimental uncertainties ascribed to the evaluated data and are not tunings made to compensate for modelling inaccuracies. The sole exception is the thermal η-value for Pu239 which is still the subject of controversy in criticality work; the adjustment made here will ensure, however, that MONK6B produces a conservative estimate of k-effective.

The MONK6B continuous energy library uses 8220 energy groups as defined below. A simple group averaging process is employed which means that the ultra-fine resolved resonance cross-section structure can be averaged out without noticeable loss of accuracy. At higher energies a subgroup treatment is used to achieve the same end. This means that the nuclear data library is effectively system-independent and can be used directly by MONK6B without the need for resonance pre-processing treatments with their inherent limitations. The criticality analyst simply has to select the nuclides in their appropriate proportions for the materials of the problem.

Group Nos.		Energy Range		Energy Mesh
from	to	from	to	
1	1536	0.0eV	3.0eV	0.001953125eV
1537	4096	3.0eV	33.0eV	0.01171875eV
4097	6653	33.0eV	72.9531eV	0.015625eV
6654	6654	72.9531eV	72.9643eV	irregular joining group
6655	8218	72.9643eV	14.7737MeV	equal lethargy (1/128)
8219	8219	14.7737MeV	14.8950MeV	irregular end group
8220	8220	14.8950MeV	15.0MeV	irregular end group

The large number of groups at low energy reflects the importance of thermalisation in criticality work, and particularly the important role of hydrogen in many situations has resulted in the development of a special thermalisation treatment for hydrogen in water.

The resonance energy region also has a special treatment and the UKNDL nuclear data for the principal fissile and fissionable isotopes have been supplemented by very detailed additional data incorporating a subgroup treatment. This effectively increases the number of groups in this region to give a well-defined resonance structure. An example of the detail that is present in the MONK6B continuous energy library is shown below (for U235 total cross-section over the energy range 1 to 100 eV).



4 GEOMETRY MODELLING

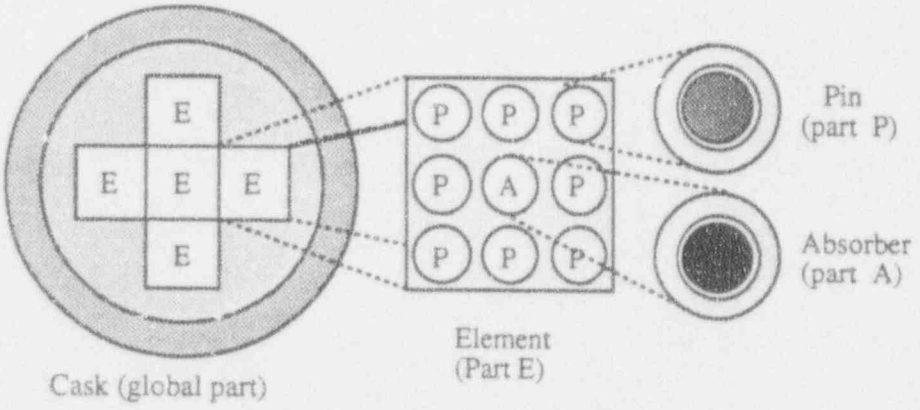
4.1 Simple Body Geometry

It is a key property of Monte Carlo codes that versatile and accurate geometry modelling is possible. The MONK6B geometry package makes efficient use of this power, enabling models of considerable complexity to be created, both accurately and with reasonable ease. The package consists of two distinct but intimately-related sections: simple body and hole geometries. The majority of criticality calculations will employ a mixture of the two to model any given system.

A MONK6B calculation consists of simulating the movement of neutrons within a system and recording what happens to them; in Monte Carlo terminology this is called neutron tracking. For tracking a neutron within a simple body geometry (explicit tracking) the code needs to determine the distance from the current position of the neutron to the boundaries of the neighbouring simple bodies, and select the nearest distance as the body to be entered next. This distance is then compared with the distance to the next neutron interaction with the medium being tracked through, which is obtained by sampling from the transmission probability distribution. The code then determines whether the geometry boundary crossing or the collision is the next event to occur.

Explicit tracking takes place over a range of simple body types including the sphere, box, rod, trapezoidal prism, truncated cone and torus. These are assembled into parts which can be included in other parts and so on until the whole geometry is included in a global part with suitable external boundary conditions.

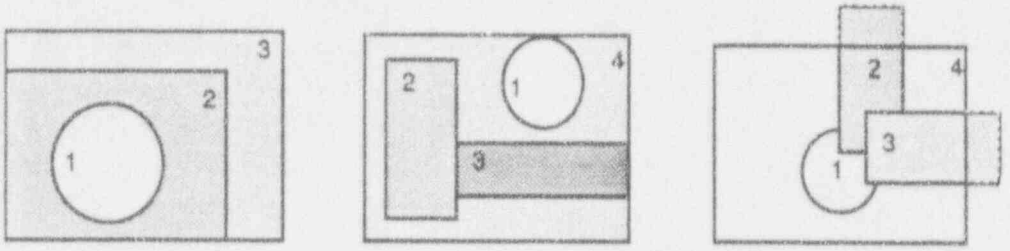
Each part is a self-contained sub-system with its own local co-ordinates. The outer surface of a part is referred to as the part container body. Any body, in any part, may contain a subsidiary part provided that the container of the subsidiary part matches the shape and size of the parent body. This system is specifically tailored to the repeated structures common in criticality applications. Consider the example of a simplified cask model (see below). A fuel pin (with cladding, fuel pellets and end caps) may be defined as a part. A fuel element is a part which includes the fuel pins and an absorber pin as subsidiary parts.



In this simple example, each part (E, P and A) is defined just once but included in parent parts as often as required. Common requirements are met by simple structured parts which serves to simplify the user image.

Each simple body has its own intrinsic co-ordinate system which defines where that body is within a part. Each body may be freely oriented within the part by employing translation and/or rotation transformations.

Each part is constructed from any number of simple bodies and there are two ways of assembling the bodies: the nest and the cluster. For a nest, the bodies are concentric with one inside another and all inside the outermost body or container. For a cluster the simplest arrangement is for each body to be completely inside the container and distinct from all other bodies. More complex use of the cluster can be made where internal bodies may overlap each other to form clumps and/or bodies may be cut back by the container.



Nest Simple cluster Overlap cluster

The co-ordinate system of the container body is used as the local co-ordinate system for the part; all the other bodies in the part are located with respect to it. Each body of the part is first located at the part origin with its axes lined up with the part axes. Then its origin may be moved to the point $\mathbf{b}$ and its axes may be rotated by the orthogonal matrix A, i.e. a point $\mathbf{x}$ becomes $\mathbf{x}^* = A\mathbf{x} + \mathbf{b}$.

The effect of creating parts is to containerise the geometry so that the explicit tracking can be performed on a subset of the whole system at any one time. Until the neutron leaves the container the boundaries of the bodies in other parts can be ignored and hence the efficiency of the tracking process is improved. Even in the absence of extensive repetition there are advantages to be gained from dividing the total geometry into sub-sets. It is not uncommon for a major geometry model to include hundreds of bodies. It is a severe test of the user's memory to grasp the entirety of such a model. Communicating the model to another user or attempting modifications after the passage of time are difficult and error prone operations. The use of small, self-contained parts alleviates such problems.

This modelling structure is analogous to the engineering drawing practice of detailing components and then combining them in drawings of larger assemblies. Advantages include the simplification of exercises involving a series of related calculations (such as the evaluation of a shipping cask with different loadings) and the ability to create and use libraries of standard parts. The use of local co-ordinate systems and component numbering means that there are few problems associated with the assembly of a complex model from a kit of relatively simple parts.

The structure imposed by the nest has its own additional efficiency factor. At any point in the nest there are only the boundaries of two bodies (or for the very centre body only one) that can be encountered next. This greatly simplifies the explicit tracking computation. For a cluster, when a neutron leaves a body the code has to consider all other bodies within the cluster to determine which one will be encountered next; the use of overlapping bodies within the cluster increases the complexity further. Thus the nest should be used if possible in preference to a cluster. However as the use of a cluster is often unavoidable, the number of bodies within a cluster should be minimised by further containerisation if possible for optimum tracking efficiency.

Each simple body within a part has some portion of its inside delineated to hold its contents. The exact portion depends on whether the part is a nest (where except for the innermost body the contents occupy the annulus between the body and the next one in) or a cluster. The contents of a simple body may be a real material (a homogeneous mixture of nuclides), a hole geometry (a heterogeneous mixture of nuclides having further geometric detail) or in certain circumstances a subsidiary part (the container and interior simple bodies of some other part which must fit exactly into the delineated space).

MONK6B has a further kind of part called an array which is a large box cut by parallel planes in each of the three directions. Each cuboidal compartment created contains a subsidiary part, which again must fit exactly into the space reserved for it. The array structure also has efficiency advantages over a cluster as the code knows which compartments are next

to each other, and so the array should be used wherever practicable in preference to a cluster, or to break-up a cluster in some circumstances.

The explicit tracking algorithm is designed to answer the following question: 'A neutron is at position **x** travelling in the direction Ω within some part. What is the distance to the nearest simple body boundary?'.

If the equations of the boundaries of the bodies in the part are:

$$Bi(\mathbf{x}) = 0 \quad ; \qquad i = 1,2,3....$$

then all the equations of the form:

$$Bi(\mathbf{x} + si\,\Omega) = 0 \quad ; \qquad i = 1,2,3....$$

have in principle to be solved to obtain the shortest distance s along the direction Ω from the point **x**. This is why only simple bodies are possible if the Monte Carlo tracking is to proceed with acceptable efficiency.

4.2 Hole Geometry

Explicit tracking has certain important limitations:

- Only simple bodies can be employed due to the difficulties involved in solving equations for more complex bodies
- Attempts to model realistic situations can result in a large number of boundary distances to be computed and compared
- Preparing and checking the data for such a case would be a formidable task and the resulting code execution speed could be slow
- Making large geometric modelling approximations is a source of systematic error of unknown size which is unjustified in a point-energy Monte Carlo calculation.

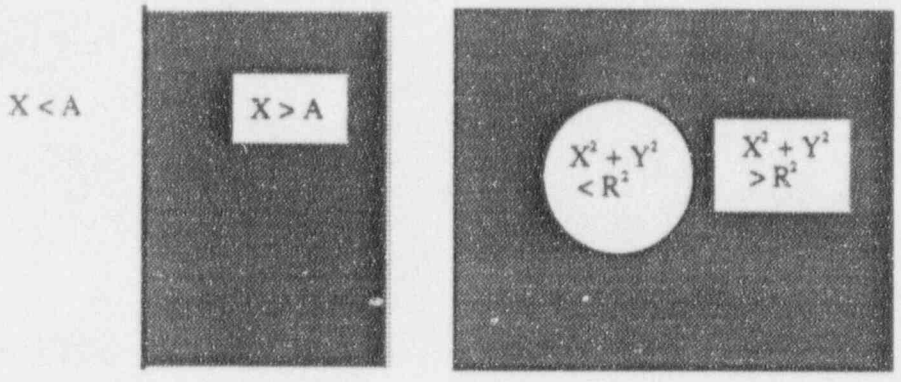
An alternative strategy is available in MONK6B called Woodcock tracking and this enables the code to deal with complex geometry details. Woodcock tracking occurs inside hole geometries and these may be used inside a simple body instead of a real material or subsidiary part.

A hole geometry has:

- its own co-ordinate system which is located with respect to the body or part co-ordinates of the body it is in
- a hidden geometry of some generic type which is made specific by user-supplied parameter values
- zones of its hidden geometry filled with either real materials or hole materials (and these may contain further hole materials and so on to any depth).

The only reason for computing distances to boundaries with explicit tracking is that the mean free path varies from material to material. The basic idea of Woodcock tracking is to artificially give the complex geometry a constant mean free path equal to the shortest mean free path of those materials in the hole. Now tracking can be performed using this value, and calculations of boundary distances are not needed. Instead the code has the much easier task

of checking inequalities as a means of determining the material present at a collision point, e.g.:

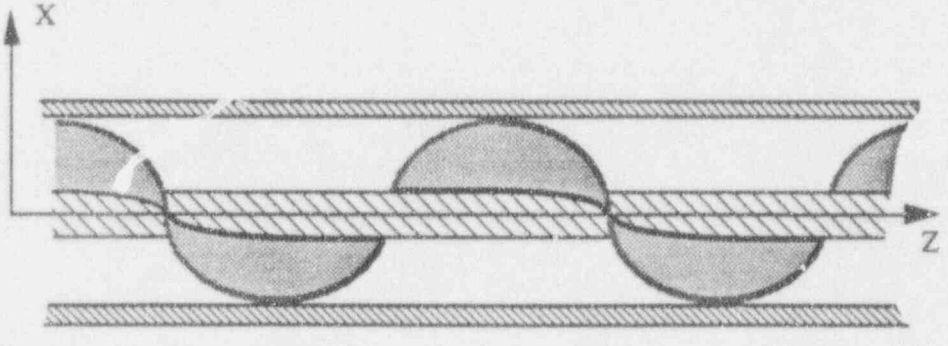


The mean free path is the average distance between collisions so that using a value that is shorter than it should be introduces extra collisions called pseudo collisions, which have to be treated as non-events (i.e. the neutron proceeds in the same direction and at the same speed as before the pseudo collision). Non-events are obviously easy to process, but even so some care must be taken to prevent the introduction of too many of them.

This can happen when one of the real materials in the hole geometry has a much larger total cross-section than all the others. Then the pseudo collision probability would be relatively large resulting in a very large number of pseudo collisions, seriously downgrading the performance of the code. Therefore very heavy absorbers present in relatively small proportions (for example) are best kept out of Woodcock tracking geometries if possible, as are sections of geometry containing a large proportion of void space, but in the majority of other cases Woodcock tracking is faster than complex explicit tracking. Note that there is no harm in using Woodcock tracking in a section of geometry containing a heavy absorber provided it occupies a relatively large proportion of the volume of that section.

There are many different types of hole geometry available in MONK6B and all are infinite in extent. They are only cut to size when they are included in a simple body and any of the geometry outside the simple body or within internal other bodies is discarded. This cutting-to-fit rule provides a solution in many situations to the problem mentioned above of materials with relatively large total cross-sections.

With Woodcock tracking it is possible to model such structures as a screw feeder (see below) or spiral reactivity control blades. It is also very efficient when modelling fine detail such as large arrays of fuel pins.



In many systems the use of hole geometry modelling will dominate with simple bodies being employed to provide only the containers and isolated components. For many applications the use of hole geometries makes the input specification much easier and therefore reduces the possibility of input error considerably, but it is the combination of the two types of geometry that gives the MONK6B package its real power and flexibility, coupled with a straightforward user-image.

Hole geometries provide an enormous range of possibilities for modelling complex geometries and in many cases there exists a choice between different modelling strategies. At first sight the job of optimising code performance looks daunting, but it turns out that the largest savings come from decisions that are easy to make, namely the question of handling heavy absorbers and dealing with complex clusters. However code efficiency is not the only consideration and in a safety-related area it is not necessarily the most important one. Some comments have been made about how to improve the code efficiency, but except in extreme cases this is now less important due to the vast reduction in the cost of performing a calculation. The cost of preparing and checking a case is now dominant and so clarity of specification at the expense of code performance pays dividends, because it simplifies the job of someone independently checking assessments; an important consideration in a safety situation.

4.3 Boundary Conditions

The boundary conditions available in MONK6B include the specular or periodic reflection conditions to provide infinite arrays in one or more direction, or to enable only part of a system to be modelled. There are also albedo co-efficients which are designed to be used in conjunction with thin reflectors in place of thick reflectors thus saving computer time. It has been found however that to avoid biasing the calculation of k-effective, the thin reflector actually needs to be fairly thick, and the result is that little or even no time is saved over modelling the reflector explicitly. Therefore for criticality assessment calculations it is strongly recommended that reflectors are modelled explicitly and that albedo co-efficients are used only for design or survey calculations.

5 STARTING SOURCE OPTIONS

MONK6B contains a wide range of source options which are used as the first guess of the neutron distribution. The code then performs a staged calculation with the source for the next stage being derived from the collisions that occurred during the current stage. Hence the starting source is only used to get the calculation off to a reasonable start.

Superhistory powering enables MONK6B to concentrate on the most reactive parts of a system provided that the initial source guess is not unreasonable; that is provided it allows neutron tracks to reach all parts of the system during settling. In the majority of cases a starting source to meet this criterion can be easily identified. It is normally adequate to have starting source neutrons in all regions of fissile material and this can be done by selecting a source by material and/or volume.

The default starting energy distribution is that the neutrons have an energy sampled from a U235 fission spectrum; the default angular distribution is that the neutrons are sampled isotropically (equally in all directions). Both of these defaults are adequate for normal criticality calculations.

6 CONTROL PARAMETERS

Having selected the source distribution some initial tracking stages (typically two) are performed by MONK6B, the results of which are not included in the scoring statistics. This preliminary process is called settling and it allows time for the neutron distribution to move from the guessed distribution and approach the true neutron distribution.

The computed standard error arising from the Monte Carlo calculation (σ) is usually employed to provide an upper confidence limits on the calculated value of k-effective. Considerable mathematical analysis has been performed analysing the mean and variance computed by MONK6B, and this work led directly to the encoding of the superhistory powering algorithm employed by the code. Superhistory powering provides accurate values of k-effective and its standard error in all practical circumstances providing the following conditions are met:

- The size of the neutron population per stage must be sufficiently large. It is recommended that at least 600 superhistories per stage be employed and the assessor should check all aspects of the output for adequate sampling.

- The calculation must run sufficient samples to provide a normal distribution for the calculated value of k-effective, otherwise three standard errors cannot be claimed to represent a 99.7% confidence limit; indeed it may err below this confidence value by a large margin. It is recommended that a target standard error of 0.003 be aimed for in all calculations and the assessor should check all aspects of the output for convergence.

- The initial source distribution should not be unreasonable (i.e. preclude the tracking process from proceeding to all parts of the system in principle) in order to minimise the transmission of settling effects into the calculation proper. However note that even if the settling is inadequate, it has been demonstrated that the settling effects tend to zero much faster than the standard error, so for small standard errors ($\sigma<0.003$) the settling effects are always effectively absent.

Having run a MONK6B calculation for a certain number of stages a more precise answer may be required. Rather than extending the initial calculation, a far better approach is to re-run the calculation to get additional independent results. These calculations can then be combined as follows:

$$k = \frac{k_1/\sigma_1^2 + k_2/\sigma_2^2 + k_3/\sigma_3^2 + ...}{1/\sigma_1^2 + 1/\sigma_2^2 + 1/\sigma_3^2 + ...}$$

$$\sigma = \frac{1}{\sqrt{1/\sigma_1^2 + 1/\sigma_2^2 + 1/\sigma_3^2 + ...}}$$

Independent calculations using different sources adds considerably to the confidence of the user regarding the settling issue.

7 VALIDATION

Validation can be defined as the process of ensuring that the data, method of solution, code or calculational route is adequate for the solution of a particular problem. This may be achieved by comparison with experimental data and standard analytical solutions, or by comparison against another computer program. With particular reference to MONK6B this can be interpreted as:

Validation is the process of demonstrating that MONK6B can accurately reproduce experimental data over a specified range of applications - i.e. do we get the right answer?

For a criticality analyst to have confidence in the results of MONK6B calculations for a particular type of system, and also to be able to judge how accurate these results might be, the code package (comprising the code itself and its nuclear data library) must be validated by comparison with suitable measured data provided by critical experiments. As far as practicable, the experimental configuration should have neutron leakage and energy distribution similar to that of the system being studied as well as similarities in the materials and geometrical configuration. In addition, the experiment selected for the validation system should have quantified errors on the measured results that can be compared with the calculated uncertainty.

The MONK6B validation database comprises data from a wide range of experimental systems from a number of international laboratories. The validation database covers many of the materials and geometries that are encountered in the nuclear industry, particularly in the areas of reprocessing, transportation and storage, and is subject to on-going review and enhancement. Criticality analysts would normally consult the validation database and identify relevant supporting experiments for each system that is to be studied.

Due to the physically-realistic continuous energy collision modelling employed by MONK6B, interpolation and extrapolation of the validation database are much easier to justify than with multigroup treatments. This is because the ultimate accuracy of the code depends more directly on the uncertainties of the nuclear data library.

In order to assist the criticality analyst in locating relevant supporting validation calculations, a categorisation facility has been included in MONK6B. It may sound surprising that the analyst needs assistance in this, since he is already aware of the system's composition and geometry. However when neutrons move around the system they see the composition and geometry very considerably distorted by the cross-sections. The MONK6B categorisation facility provides an objective view of the system as seen by the neutrons and it is intended to be employed in conjunction with the criticality engineer's knowledge of the system.

The aim of the categorisation process is to select properties which can be used to adequately cover the key neutronic behaviour variations between systems. Obviously all such differences cannot be covered in any manageable scheme but, by concentrating on those that most significantly effect the calculation of k-effective, a usable scheme can be created. The scheme adopted for MONK6B comprises the following seven properties: principal fissile nuclide, non-fuel absorption, leakage, resonance absorption, fast fission, spectrum and geometry type.

Each categorisation property is scored during a MONK6B calculation to produce a real number which is a quantitative measure of the property. The possible range of real numbers for each property is divided into a number of partitions and so for each property the appropriate partition can be located. Thus we end up with each system lying in some partitioned compartment (called a category) of the 7-dimensional property space. The seven properties used by MONK6B, and their sub-divisions, have been selected to provide adequate distinction between systems in the areas that most significantly affect the accuracy of the calculation.

If a validation case lies in the same compartment as a system being studied it may be used as supporting evidence for the accuracy of the MONK6B calculation as it displays comparable neutronic behaviour. In addition supporting validation cases can come from neighbouring partitions if they are carefully reviewed, using a sensitivity analysis if necessary. It should be noted however that unusual nuclides are not covered by the categorisation analysis and need to be separately considered.

8 GEOMETRY VISUALISATION

Companion codes to MONK6B exist called SCAN2D and VISAGE1B which are used to produce two-dimensional pictures of the geometry model. These are either with low-resolution on paper (SCAN) or interactively on a high-resolution computer monitor (VISAGE1B).

VISAGE1B is a high-resolution mouse/menu driven graphics tool for the generation, display and manipulation of two-dimensional slices through the geometry specification. VISAGE1B has been implemented in C and uses the X-Windows and OSF/Motif tool-kits and hence is as portable as possible. SCAN2D and VISAGE1B images are produced using the geometry tracking routines of MONK6B and so are a genuine indication of the geometry seen by the modelling codes themselves.

The value of these codes (especially the high-resolution graphics package) should not be underestimated and a comprehensive verification stage should precede all MONK6B calculations.

9 QUALITY ASSURED CODE MANAGEMENT

Quality Assurance (QA) is a widespread requirement in the areas of design, manufacture and operation of nuclear facilities. Computer software used to analyse these facilities is clearly no exception, especially in the area of criticality safety assessment. QA principles embrace all aspects of a software package including development, maintenance and in-service use within the industry. In the United Kingdom, these requirements have led to the establishment of the ANSWERS Service to act as a centrally controlled repository and distribution centre for all the major computer codes and data libraries used in the areas of criticality, shielding and reactor physics. In addition ANSWERS provides a code user support and training service.

The ANSWERS Service has produced a comprehensive set of software management QA procedures covering the entire software life-cycle including specification, design, coding, testing and in-use support and maintenance. These standards are employed in the development and validation of MONK6B and of course by ANSWERS themselves in its commissioning and user support roles. The Quality Management System provided by these procedures has been certified against the International Standard ISO 9001.

When the development of a version of MONK has been completed the source code is then passed to ANSWERS for testing, commissioning and finally distribution as a recognised updated version of the MONK code. The version of MONK is formally identified (e.g. MONK6B) and the changes made since the previous version and the documentation that supports those changes are recorded and archived. ANSWERS then commissions the version of MONK6B onto a range of industry standard computer platforms and distributes the code to the user community in the form of uniquely identified load modules.

The load module for each computer type is fully tested at the completion of the commissioning phase and again on installation at the user site. Note that this latter installation phase is simply a process of copying an executable program - no source code implementation is required by the user and the code can be up and running within a couple of hours.

Each issue of a version of MONK6B is distributed in ready-to-run form for maximum user confidence and convenience, with each step in the development and distribution sequence being performed under an effective Quality Management System. The route from source

code to in-use load module is maintained in a fully traceable form by ANSWERS for current and archived versions of the code. The adoption of these QA procedures have added to the confidence in the use of MONK6B for criticality safety assessment and are aimed at meeting the requirements of all code users both today and in the years to come.

10 CODE DISTRIBUTION AND USER SUPPORT

The current version of MONK is MONK6B and is available through the ANSWERS Service of AEA Technology. MONK6B has been commissioned on a wide range of computer hardware including mainframes, workstations and personal computers (PCs). A version is also available for running on a parallel processing supercomputer.

The standard package issued by ANSWERS comprises:

- Executable code modules for MONK, SCAN and VISAGE
- Standard nuclear data library (87 20 groups)
- Sample problem inputs and outputs for implementation testing
- Hardware-specific installation guide
- User Guide and Reference Manual
- Validation reports

The ANSWERS Service offers a comprehensive user support package which includes maintenance, trouble-shooting and expert advice, as well as providing access to new code versions as they become available. In addition regular seminars and training courses are held, including well-established hands-on workshops for those new to the code.

SECTION B

VALIDATION OF MONK6B

Summary

An overview of the MONK6B validation database is presented. Detailed experimental analyses pertaining to the storage and transportation of low-enriched UO2 fuel are also available for MONK code users.

SECTION C

APPLICATION OF MONK6B TO A TYPICAL PROBLEM

Summary

A guide to applying MONK6B to a typical problem is presented, namely the criticality safety assessment of an LWR fuel shipping cask. The guide follows through a complete MONK6B calculation describing each section of the modelling process in some detail. In addition a detailed discussion of the various output tables is given.

CONTENTS

1. INTRODUCTION

The need to be able to ensure the subcriticality of irradiated reactor fuel during transportation is of fundamental importance to the nuclear industry. The fuel is removed from a reactor and stored in a water pond at the reactor site to allow for some cooling and decay of short-lived radioactive isotopes. The fuel is then removed from the pond and transported in massive metal containers called flasks to another site for further storage and reprocessing. With the increasing number of fuel movements that are becoming necessary, there is a very strong incentive for the operator to maximise the amount of fuel transported within each flask, and thus reduce the overall costs.

A number of features in addition to criticality safety influence the design of flasks, and hence the amount of fuel that can be transported in one shipment. These include the overall size and weight of the flask, the heat dissipated by the fuel, the structural integrity of the flask and contents, and the radiation exposure to both the operating personnel and the general population. However the need to achieve criticality safety during the transportation process under normal and accident conditions is vital to the whole operation, and is a major design consideration.

This document is intended as a guide to applying the MONK6 Monte Carlo criticality code to the problem of determining the reactivity of an LWR transport flask. It will be of benefit to the knowledgeable but inexperienced user of the code, but is not a substitute for the MONK6 training course as far as the complete beginner is concerned. The guide will follow through a complete MONK6 calculation describing each section of the modelling process in some detail, including the arguments for and against particular options on the occasions when the user is presented with a choice of strategies. In addition a detailed discussion of the various output tables will be given, enabling the user to interpret the MONK6 output.

Section two of the document gives a very brief overview of the transport flask criticality safety problem and section three discusses the process of applying MONK6 to the problem. This will include an overview of the code and data, validation and the calculational uncertainties. Section four contains a description of the general modelling capabilities of MONK6 as a prelude to section five, which describes the construction of a model of a typical flask. Section four contains some information that is available in other MONK6 documents but has been included here for completeness to allow the various options to be meaningfully discussed. Section six analyses the output from a typical MONK6 calculation and section seven puts the calculation in the context of a criticality assessment. Although some of the comments made on modelling using MONK6 will be specific to the transport flask problem, many of the recommendations will be appropriate to other criticality problems.

2. BRIEF DESCRIPTION OF THE PROBLEM

Irradiated light water reactor (LWR) fuel is transported from reactor sites to locations for storage or reprocessing in fuel transport flasks. The movement of such flasks is governed by International Atomic Energy Agency (IAEA) regulations, which state that all fissile material shall be transported in such a manner that sub-criticality is maintained under all foreseeable circumstances; this covers both normal variations in operations (e.g. differing fuel enrichments) and accident scenarios.

LWR fuel elements for transport are often held within a compartmentalised container called a multi-element bottle, with the compartment walls constructed from a material aimed at reducing the reactivity of the bottle by parasitic neutron absorption. The multi-element bottle itself is partially flooded with water and it is transported within a water-filled flask, the main body of which is typically a massive iron cylinder with cooling fins around most of its outer surface. Upon removal from the flask the multi-element bottle is normally stored intact under water in a pond, whilst awaiting reprocessing. Certain other types of flask have no internal multi-element bottle, and the fuel elements are located within open racks; in addition some of the flask types employed in France are transported dry. However the type of flask considered for this document is a wet flask containing a multi-element bottle, although many of the comments will also apply to the other types.

It is at present not possible to determine by measurement the reactivity of a particular flask loaded with fuel, and so fundamental to the safe transport of fuel is the criticality safety assessment. The result of the assessment must provide the operator with a suitable safety margin which is preserved under all foreseeable circumstances. Due to the lack of directly-applicable experimental data, the criticality assessment will be based on performing extensive computer calculations, and reasonable allowance should be made for all uncertainties in these calculations. It is therefore required that the assessor performs a demonstrably-safe calculation of the expected state of the flask under normal conditions and under a range of potential accident conditions, and to thereby prove that the sub-criticality safety limits needed by the regulatory bodies are maintained.There are strong economic incentives to maximise flask payloads and hence reduce overall transport costs, and these can only be met by a high standard of criticality safety assessment. Of paramount importance are the potential accident conditions and for this reason a criticality assessment must always aim for identifying the worst-case scenarios.

A large amount of effort has been extended over the years in performing experiments representative of the types of problem encountered in the transport of reactor fuel. The complex computer codes employed in criticality assessments have been extensively validated against such experiments, and are capable of physically-realistic modelling. This may suggest that tools are available to enable precise calculations to be performed, but the users of such tools must avoid complacency and consider each assessment on its own merits. Adequate physical realism is a necessary but not sufficient condition for achieving an accurate criticality assessment. Data uncertainties and biases, code limitations, operational uncertainties and possible mis-reporting, input data errors, and the postulated accident scenarios all require careful consideration during the course of an assessment. It is essential that the assessor is skilled in the application of these complex tools and aware of their many limitations, because of their unique status in criticality work. This status arises from the fact that reactivity cannot be measured in situ and the codes therefore are effectively being used in place of measuring instruments.

The following sections describe the commissioning of an LWR flask calculation and the description is aimed at the novice user of criticality codes based on the Monte Carlo method of calculation, which is the most widely-used method for criticality assessment. Further consideration of how this calculation fits into a full criticality assessment will be reserved for section 7.

3. APPLICATION OF MONK6

a) Basic Statistical Ideas

The Monte Carlo method is distinguished from other numerical techniques by its use of random sampling to obtain solutions to mathematical problems. In many ways the Monte Carlo method can be regarded as a numerical experiment, with statistical techniques being employed to estimate the required quantities by sampling from appropriate probability distributions. For example the probability of throwing double six with two unbiased die can be readily estimated by Monte Carlo means, by repeated random sampling of pairs of numbers between one and six. In this case where the result can be obtained exactly by the laws of the combinations of probabilities, the use of the Monte Carlo method is pointless. However in the wide range of problems where no such simple solution exists, as in the case of general three-dimensional particle transport, the Monte Carlo method is often the only feasible method of solution.

The Monte Carlo method can be used to estimate some numerical quantity by sampling from a stochastic model of a physical system. The estimate is normally obtained by performing a number of experimental trials or samples and calculating the sample mean:

$$X_n = 1/n \sum_{i=1}^{n} x_i$$

where $x_1, x_2, \ldots, x_n$ are sample values of the random variable X that is being estimated.

In addition when applying the Monte Carlo method to practical problems some confidence is required in the accuracy of this estimate, and this normally involves obtaining an estimate of the statistical uncertainty in the value.

Concerning the mean value the so-called 'law of large numbers' from probability theory states that the sample mean (X_n) approximates the population or true mean (μ) with a probability that tends to 1 as n increases:

$$P\{ \lim_{n \to \infty} X_n = \mu \} = 1$$

Thus the mean of n sample values converges to its expected value as n increases. An estimate of the range of values that the mean may take and the rate of convergence to the expected value is given by the central limit theorem. This states that if a series of sample means is obtained from a population (of arbitrary distribution) with mean μ and standard deviation σ, then the sample means will form a distribution which tends to a normal distribution. Moreover this distribution of sample means will also have a mean of μ, but will have a smaller standard deviation (often called the standard error) equal to $\sigma/N^{\frac{1}{2}}$, where N is the number of sample means. The number of sample means required to approximate a normal distribution varies depending on the shape of the parent distribution, and can be very large (e.g. several thousand) for a highly-skewed distribution.

In a practical calculation it should be born in mind that the true mean μ is unknown and the standard

deviation must be estimated in order to apply the central limit theorem. However provided the sample mean is fairly estimated and a large number of individual sample means are considered, the underlying normal distribution can be used to predict the probability of the estimated mean deviating from the true mean in units of σ. Thus the observed mean is within one standard error of the true mean 68.3% of the time, within two standard errors 95.4% of the time and within three standard errors 99.7% of the time. In addition the theorem states that the standard error reduces with the inverse of the square root of the increasing number of sample means; this gives rise to the well-known result that to half the standard error of a Monte Carlo calculation four times the number of samples are required. It is rare in criticality experience for this normal distribution condition to be breached, and very unlikely for standard transport flask calculations. However for non-standard situations the normality condition should be carefully checked; remember that the smaller the statistical uncertainty the bigger the population sample, and hence the better the central limit hypothesis.

b) An Introduction to MONK6

MONK6 is a Monte Carlo neutronics computer code written to assist in the study of criticality safety problems [1]. It is a property of the Monte Carlo method that considerable geometric complexity can be represented and a physically-realistic account of the neutron interactions can be modelled. No significant approximation is required on theoretical grounds, although some might be introduced to enhance the efficiency of the calculation. The accuracy of the basic nuclear data is the only real limit on the ultimate accuracy achievable. Although computer storage and running times might impose further limitations it is a false economy at a time when good computing facilities are cheaply and easily available; no safety assessor should be forced to work without such facilities.

The primary aim of MONK6 is to calculate the reactivity of systems by the computer simulation of the birth, migration and ultimate fate of a finite sample of neutrons. The actual number of neutrons followed or tracked determines the statistical accuracy of the final scored parameters. In fact the variance on any scored parameter varies inversely with the number of neutrons sampled as indicated above.

A system under study is assembled from simpler sub-systems using the MONK6 geometry package. The basic component of this package is a set of simple bodies, namely the sphere, box, rod, prism, cone and torus. These bodies can have general orientation and can overlap each other if necessary. They are used as building blocks to form simple parts of the geometry, each part being defined quite independently of the rest of the system using local co-ordinates. These simple parts are then used to make more complex parts in the same way and so on, until the whole system is assembled. Hole geometries (making use of a technique called Woodcock tracking) are used extensively in MONK6 to provide a lot of the more complicated fine geometric details, and to short-cut the specification of some of the commonly-occurring items.

Neutron interactions are considered in the MONK6 collision processing package called DICE. The basic MONK6 nuclear data library is an 8220 group library based on UKNDL and JEF evaluations. This library together with the point-energy collision processing provides a very detailed modelling of the physics, and the ultimate accuracy of the MONK6 code using this option depends only on the numerical accuracy of the basic nuclear data. It is this DICE package that has been the subject of extensive validation and is therefore the recommended method for criticality assessments. However for cross-checking purposes MONK6 can also accept data from a number of established multigroup

libraries, namely the Hansen and Roach 16-group library, the US SCALE libraries and the WIMS UK reactor physics libraries.

MONK6 calculates the multiplication constant k-effective using a staged calculation with each stage consisting of a fixed number of superhistories. A neutron superhistory is the set of tracks followed by a neutron and its fission progeny from birth to absorption or leakage through a fixed number of fission generations (normally 10). Superhistory tracking produces a stable calculation of the scored parameters and their variances which are essentially unbiased. A superhistory calculation concentrates on the most reactive parts of a system and thereby extends the use of MONK6 to highly-decoupled systems. In addition to k-effective the MONK6 output includes estimates of fluxes, reaction rates and boundary crossings.

c) Validation

For the user to have confidence in the results of MONK6 calculations for any type of system, and also to be able to judge how accurate these results may be, the code and its nuclear data library must be validated against suitable experiments. As far as practicable, the experimental configuration should have neutron leakage and energy distribution similar to that of the system being studied as well as similarities in the materials and geometrical configuration. In addition the experiment selected for the validation should have measurement errors smaller than any calculational uncertainty. MONK6 has been validated against a number of systems covering a range of materials and geometries that are encountered in the nuclear industry, particularly in the areas of reprocessing, transportation and storage [2-4].

For fuel transport flask conditions there exists a relatively large set of relevant experimental data, arising from extensive programmes of work in the USA and France. A summary of the experimental data up to 1983 is available [5] which also points to some remaining gaps in the database, and work has continued in the USA [6] to fill one of the more important omissions. The summary document also highlights areas where particular moderation, geometric and enrichment conditions are not covered by any experimental data. In addition the computerised CESAR database, accessible through the Nuclear Criticality Information System (NCIS) [7], gives information on a wide range of critical experiments. The use of NCIS also enables UK criticality practitioners to access a flow of useful information from other workers internationally, via electronic mail and assorted databases.

The MONK6 validation database includes a number of experiments applicable to fuel transport systems, covering a range of problems encountered in practice; these should be studied before employing the code for criticality assessment of a particular system. For these systems, MONK6 performs well, predicting k-effective to an accuracy of about 1% for low-enriched uranium fuel pins with water moderator. However care should be taken to ensure that the validation database includes suitable systems for a particular assessment.

d) Calculational Uncertainties

A sub-critical margin is normally employed (typically several percent in k-effective) for criticality

assessments, and this margin is an upper bound on calculated results plus all uncertainties. This margin does not depend only on the accuracy of the code and data, but is chosen with some judgement regarding the sensitivity of the reactivity to changes under operational or accidental reconfigurations.

By testing MONK6 against a large number of well-reported experiments some confidence in the use of the code for certain fuel transport calculations can be obtained. As a heavy responsibility is often thrown onto the MONK6 code, particularly in the study of accident conditions where validation is less well-defined, certain pessimistic assumptions are normally made when performing such calculations. These include the assumptions: all fuel is unirradiated and at the maximum enrichment; the fuel is arranged in its most reactive configuration; and the moderation and reflection conditions are optimum (i.e. the most pessimistic). The geometric flexibility of MONK6 enables accurate or conservative models to be created for all realistic situations, and this should be exploited.

The k-effective calculated by MONK6 is related to the true k-effective by an equation of the form:

$$k_{TRUE} = k_{MONK} + B + E + R + S$$

where B is the systematic bias of the MONK6 code and data library and may be positive or negative if sufficient justification can be made; $E \geq 0$ is the total random error made up from random errors in the preparation and execution of the MONK6 calculation; $R \geq 0$ is the bias to allow for operational or accidental changes causing increases in reactivity; $S \geq 0$ is the statistical error of the Monte Carlo method.

The sub-critical margin requires that:

$$k_{TRUE} \leq L$$

where L is some pre-defined limit, typically 0.95 for transport flask assessments. By examining the validation of MONK6, the only evidence of any bias for fuel transport systems is a slight tendency to over-predict k-effective. Thus the systematic bias (B) is negative, provided that the system being assessed is covered by those cases in the validation database, but for added conservatism is normally taken as zero. Note that only under extreme necessity, requiring detailed supporting arguments, is use made of a negative value for B.

The random error (E) in the preparation and execution of the MONK6 calculation cannot be completely eliminated, but by a combination of standard QA practices and operational procedures it can be made vanishingly small. These procedures include: rigorous and independent checking of input data and calculations; re-use of standard specifications wherever possible; extensive use of the geometry display code SCAN6; cross-checks with hand calculations, other codes and similar systems; ensuring that the information upon which the model is based is accurate and representative of the operational situation; and modelling the system as accurately as necessary.

The MONK6 code contains a lot of internal checks on input data suitability and consistency but these can never be exhaustive. MONK6 has been carefully developed and tested over many years and has been employed for thousands of criticality calculations, but still the possibility of encountering a code error cannot be entirely discounted. However the possibility of a code error allowing the code to e-

cute successfully and produce a believable k-effective value lower than the true value with no warning symptoms in the output can be ignored, provided the output is carefully checked. More probable sources of error are the computer hardware, operating system and FORTRAN compiler being employed. These problems can be solved by employing quality-assured ANSWERS versions of MONK6 on licensed computer installations, and by performing regular checks.

The term R, arising from the possibility of accidental changes causing an increase in reactivity can often be set to zero by the use of worst-case scenarios for the Monte Carlo modelling. Such an assumption needs to be considered for each type of system independently and verified by reference to published data or supporting calculations.

The statistical error arising from the Monte Carlo calculation (S) is usually included as some multiple (normally three) of the computed standard error. Considerable mathematical analysis has been performed analysing the mean and variance computed by MONK6 [8], and this work lead directly to the encoding of the superhistory tracking concept now employed by the code. Superhistory tracking provides accurate values of k-effective and its standard error in all practical circumstances providing the following conditions are met:

1) The size of the neutron population per stage must be sufficiently large. There are many symptoms of an insufficient population being used and these are discussed in section 6. It is recommended that for most systems at least 600 neutrons per stage be employed.

2) The calculation must run sufficient samples to provide a normal distribution for the k-effective estimators, otherwise three standard errors cannot be claimed to represent a 99.7% confidence limit; indeed it may err below this confidence value by a large margin. It is recommended that a target standard error of 0.003 be aimed for in all calculations and the assessor should check all aspects of the output for convergence, as described in section 6.

3) The initial source distribution should not be unreasonable (i.e. preclude the tracking process from proceeding to all parts of the system in principle). The superhistory tracking algorithm allows the code user to be less concerned about specifying a very accurate spatial source distribution, and a sensible simple approximation to the true distribution (as shown in section 4d) should be employed to minimise the transmission of settling effects into the calculation proper. However even if this should occur it has been demonstrated [8] that the settling effects tend to zero much faster than the standard error, so for small standard errors ($\sigma \approx 0.003$) the settling effects are always effectively absent.

If all these practices are rigorously adopted the sub-critical margin inequality for a well-validated fuel transport calculation can reduce to:

$$k_{MONK} + 3\sigma \leq L$$

subject to correct use being made of the MONK6 code. However justification for the elimination of the other terms needs to be made for each case in turn. Note that the standard error arising from the Monte Carlo process determines the precision of the calculation and this can be chosen by the user by running an appropriate-length calculation. The accuracy of the calculation however is determined

principally by the accuracy of the nuclear data being employed, provided the geometry has been acceptably modelled. Thus the accuracy of the calculation is outside the control of the user for any given nuclear dataset and the inaccuracies therein (in the form of biases) must be accepted as a real error in the calculation.

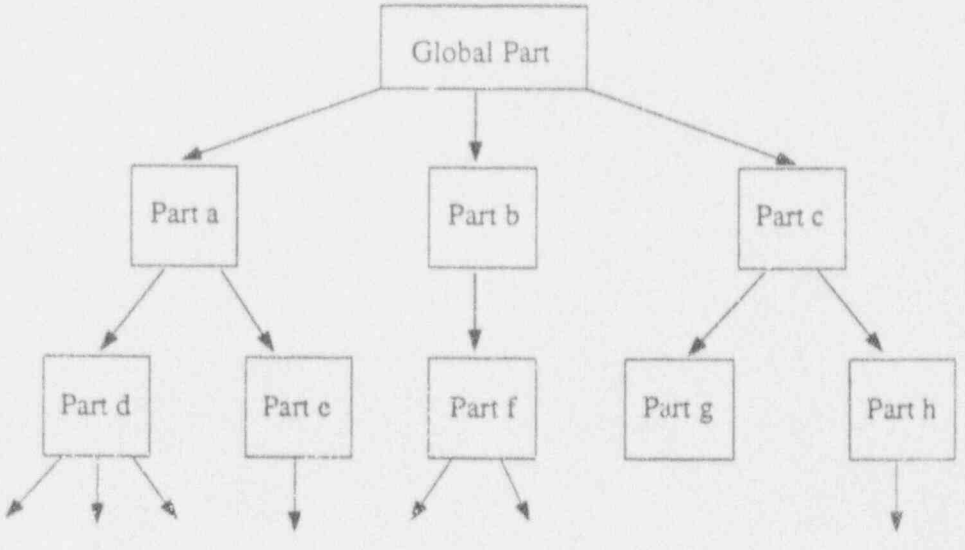
4. GENERAL MONK6 MODELLING

a) Simple Body Geometry

It is a key property of Monte Carlo codes that versatile and accurate geometry modelling is possible. The MONK6 geometry package (described in some detail in Chapter 2 of the User Guide [9]) makes efficient use of this power, enabling models of considerable complexity to be created, both accurately and with reasonable ease. The package consists of two distinct but intimately-related sections: simple body and hole geometries. The majority of criticality calculations will employ a mixture of the two to model any given system.

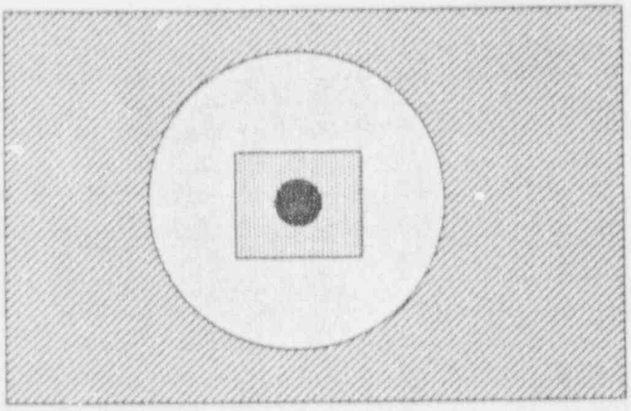
A MONK6 calculation involves simulating the movement of neutrons within a system and recording what happens to them; in Monte Carlo terminology this is called neutron tracking. For tracking a neutron within a simple body geometry (explicit tracking) the code needs to determine the distance from the current position of the neutron to the boundaries of the simple bodies, and select the nearest distance. This distance is then compared with the distance to the next neutron interaction with the medium being tracked through, which is obtained by sampling from the transmission probability distribution, to determine whether a boundary crossing or collision is the next event to occur.

Explicit tracking takes place over six simple body types: sphere, box, rod, trapezoidal prism, truncated cone and torus. These are assembled into parts which can be included in other parts and so on until the whole geometry is included in a global part with suitable external boundary conditions, e.g. :

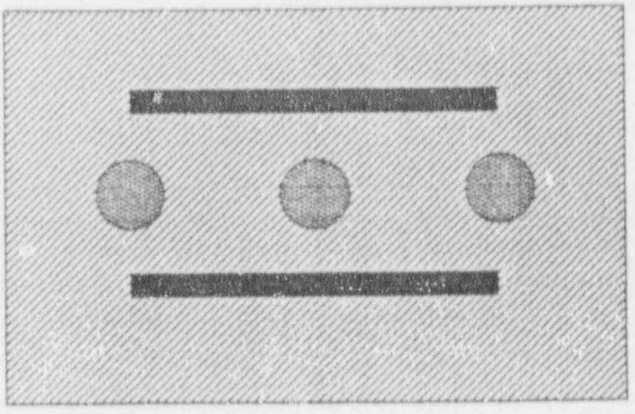


Each simple body has its own intrinsic co-ordinate system which defines where that body is within a part. Each body may be freely orientated within the part by employing translation and/or rotation transformations.

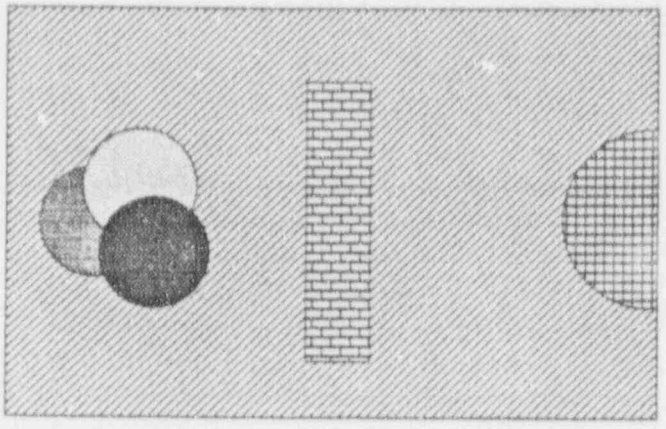
Each part is constructed from any number of simple bodies and there are two ways of assembling the bodies: the nest or the cluster. For a nest the bodies are concentric with one inside another and all inside the outermost body or container:



For a cluster the simplest arrangement is for each body to be completely inside the container and distinct from all other bodies:



More complex use of the cluster can be made where internal bodies may overlap each other to form clumps and/or bodies may be cut back by the container:



The co-ordinate system of the container body is used as the local co-ordinate system for the part; all the other bodies in the part are located with respect to it (note this assumes that the container is neither translated or rotated, as will be recommended in section 4c). Each body of the part is first located at the part origin with its axes lined up with the part axes. Then its origin may be moved to the point **b** and its axes may be rotated by the orthogonal matrix A, i.e. a point **x** becomes $\mathbf{x}^* = A\mathbf{x} + \mathbf{b}$.

The effect of creating parts is to containerise the geometry so that the explicit tracking can be performed on a subset of the whole system at any one time. Until the neutron leaves the container the boundaries of the bodies in other parts can be ignored.

The structure imposed by the nest has its own additional efficiency factor. At any point in the nest there are only the boundaries of two bodies (or for the very centre body only one) that can be encountered next. This greatly simplifies the explicit tracking computation. For a cluster, when a neutron leaves a body the code has to consider all other bodies within the cluster to determine which one will be encountered next; the use of overlapping bodies within the cluster increases the complexity further. Thus the nest should be used if possible in preference to a cluster. However as the use of a cluster is often unavoidable, the number of bodies within a cluster should be minimised by further containerisation if possible for optimum tracking efficiency.

Each simple body within a part has some portion of its inside delineated to hold its contents. The exact portion depends on whether the part is a nest (where except for the innermost body the contents occupy the annulus between the body and the next one in) or a cluster. For overlapping bodies within a cluster additional rules apply based on the dominance number assigned to the relevant bodies. The portion of the body inside that holds the contents is termed a scoring region, and if the part is employed on more than one occasion in the model the scores for the scoring regions of the part are summed over all the occurrences. The contents of a simple body may be a real material (a homogeneous mixture of nu-

clides), a hole geometry (a heterogeneous mixture of nuclides having further geometric detail) in certain circumstances a subsidiary part (the container and interior simple bodies of some other part which must fit exactly into the space of the simple body).

MONK6 has a further kind of part called an array which is a large box cut by parallel planes in each of the three directions. Each cuboidal compartment created contains a subsidiary part, which again must fit exactly into the space reserved for it. The array structure also has efficiency advantages over a cluster as the code knows which compartments are next to each other, and so the array should be used wherever practicable in preference to a cluster, or to break-up a cluster in some circumstances.

The explicit tracking algorithm is designed to answer the following question: 'A neutron is at position $\mathbf{x}$ travelling in the direction Ω within some part. What is the distance to the nearest simple body boundary?'.

If the equations of the boundaries of the bodies in the part are:

$$B_i(\mathbf{x}) = 0 \quad ; \quad i = 1,2,3....$$

then all the equations of the form:

$$B_i(\mathbf{x} + s_i \Omega) = 0 \quad ; \quad i = 1,2,3....$$

have in principle to be solved to obtain the shortest distance s along the direction Ω from the point $\mathbf{x}$. This is why only simple bodies are possible if the Monte Carlo tracking is to proceed at acceptable speed. The input data for the simple body geometry is given in Chapter 3 Unit 2 of the User Guide [9].

b) Hole Geometry

Explicit tracking has certain important limitations:

1) Only simple bodies can be employed due to the difficulties involved in solving equations for more complex bodies

2) Attempts to model realistic situations can result in a large number of boundary distances to be computed and compared

3) Preparing and checking the data for such a case would be a formidable task and the resulting code execution speed could be slow

4) Making large geometric modelling approximations is a source of systematic error of unknown size which is unjustified in a point-energy Monte Carlo calculation.

An alternative strategy is available in MONK6 called Woodcock tracking and this enables the code to

deal with complex geometry details. Woodcock tracking occurs inside hole geometries and these may be used inside a simple body instead of a real material or subsidiary part.

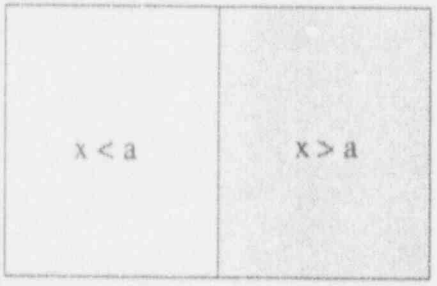
A hole geometry has:

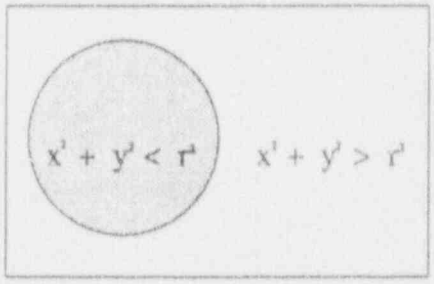
1) its own co-ordinate system which is located with respect to the body or part co-ordinates of the body it is in

2) a hidden geometry of some generic type which is made specific by user-supplied parameter values

3) zones of its hidden geometry filled with either real materials or hole materials (and these may contain further hole materials and so on to any depth).

The only reason for computing distances to boundaries with explicit tracking is that the mean free path varies from material to material. The basic idea of Woodcock tracking is to artificially give the complex geometry a constant mean free path equal to the shortest mean free path of those materials in the hole. Now tracking can be performed using this value, and calculations of boundary distances are not needed. Instead the code has the much easier task of checking inequalities as a means of determining the material present at a collision point, e.g.:



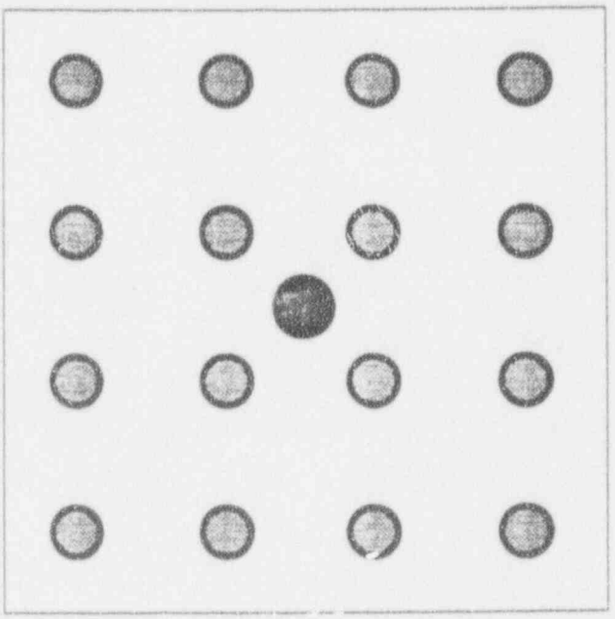


The mean free path is the average distance between collisions so that using a value that is shorter than it should be introduces extra collisions called pseudo collisions, which have to be treated as non-events (i.e. the neutron proceeds in the same direction and at the same speed as before the pseudo collision). Non-events are obviously easy to process, but even so some care must be taken to prevent the introduction of too many of them.

This can happen when one of the real materials in the hole geometry has a much larger total cross-section than all the others. Then the pseudo collision probability would be relatively large resulting in a very large number of pseudo collisions, seriously downgrading the performance of the code. Therefore very heavy absorbers present in relatively small proportions (for example) are best kept out of Woodcock tracking geometries if possible, as are sections of geometry containing a large proportion

of void space, but in the majority of other cases Woodcock tracking is faster than complex explicit tracking. Note that there is no harm in using Woodcock tracking in a section of geometry containing a heavy absorber provided it occupies a relatively large proportion of the volume of that section.

There are many different types of hole geometry available in MONK6 and all are infinite in extent. They are only cut to size when they are included in a simple body and any of the geometry outside the simple body or within internal other bodies is discarded. This cutting-to-fit rule provides a solution in many situations to the problem mentioned above of materials with relatively large total cross-sections. Consider an array of fuel pins with an absorber control pin present in the centre:



This could be specified as a single body nest containing a square hole (an array of pins on a square pitch) containing a further square hole as a subsidiary hole in the interstitial medium to provide the control pin. Thus the total cross-section of the absorber pin will be used for the tracking throughout the whole array even though it occupies only a relatively small volume.
Typical input data could be:

* material 1 ... UO2 fuel
* material 2 ... water
* material 3 ... boron
* material 4 ... zirconium

NEST 1
BOX BH1 14 14 100
ALBEDO 1 1 1 1 1 1

```
SQUARE 4  1 2 3 4    HTRANS 7 7 0
          3.4 1.7 1.7    0.55 0.65
          1 4 -2
SQUARE 2  2 3
          10 0 0  0.8 0.8
          3 3 2
```

An alternative more efficient specification would consist of a two body nest with the inner body defining the absorber pin. The square hole defining the array would be placed in the container but would not overlay the inner simple body, so now the smallest mean free path of the other materials will be used for tracking in the majority of the system, and the very small mean free path of the absorber will only be used when the control pin is actually entered. Typical input data could be:

* material 1 ... UO2 fuel
* material 2 ... water
* material 3 ... boron
* material 4 ... zirconium

```
NEST 2
ZROD  ORIGIN 7 7 0     3    0.8 100
BOX                  BH1    14 14 100
ALBEDO 1 1 1 1 1 1

SQUARE 3  1 2 4    HTRANS 7 7 0
          3.4 1.7 1.7  0.55 0.65
          1 4 2
```

If the above two cases are run for the same number of samples the first one with the boron in the hole geometry takes six times longer than the second case with the boron in the separate simple body. Thus there are potentially large gains to be made when materials such as boron, cadmium and gadolinium are employed. If a large series of calculations is planned it is ofter worthwhile determining by trial calculations whether the efficiency of the calculations can be improved in this way. This technique clearly extends to more complicated systems than the one considered here.

If the absorber pin was more compicated geometrically, this detail could be included as a separate hole geometry within the first body of the nest (in the second example) without significant penalty. This is because the absorber cross-section would only apply over that simple body space (as for the uniform material example), and the tracking in the bulk of the system would be unaffected. Therefore materials with relatively large cross-sections can be sensibly employed in hole geometries on many occasions and precautions like those employed above can alleviate most problems.

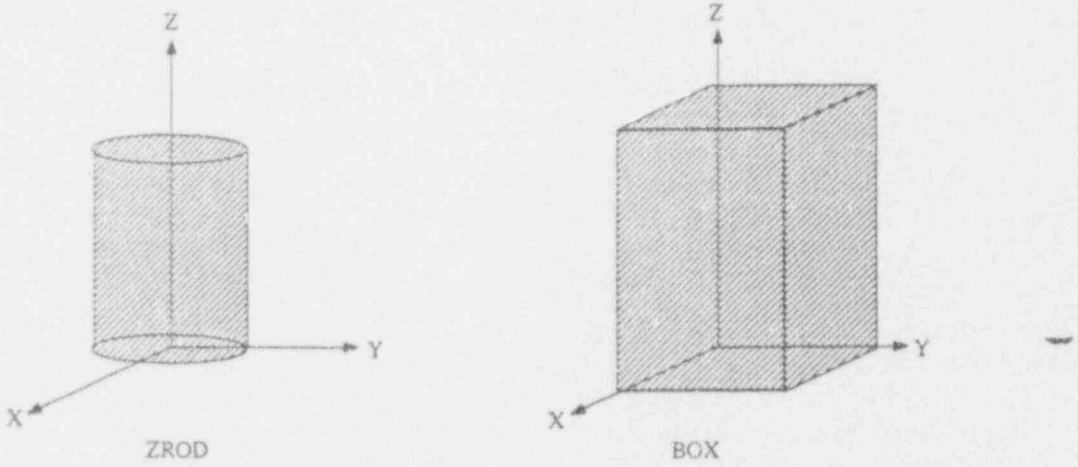
In many systems the use of hole geometries dominates with simple bodies being employed to provide only the containers and isolated components. For many applications the use of hole geometries make the input specification much easier and therefore reduces the possibility of input error considerably, but it is the combination of the two that gives the MONK6 package its real power and flexibility.

coupled with a straightforward user-image.

Hole geometries provide an enormous range of possibilities for modelling complex geometries and in many cases there exists a choice between different modelling strategies. At first sight the job of optimising code performance looks daunting, but it turns out that the largest savings come from decisions that are easy to make, namely the question of handling heavy absorbers and dealing with complex clusters. However code efficiency is not the only consideration and in a safety-related area it is not necessarily the most important one. Some comments have been made about how to improve the code efficiency, but except in extreme cases (such as the hole geometry example shown above) this is becoming less important due to the vast reduction in the cost of performing a calculation on modern high-speed micro-computers. The cost of preparing and checking a case now dominates the cost of performing an assessment and so clarity of specification at the expense of code performance pays dividends, because it simplifies the job of someone independently checking assessments; an important consideration in a safety situation. Using the hole geometries effectively requires Chapter 2 of the User Guide [9] to be read in conjunction with the input specification in Chapter 3 Unit 3.

c) Co-ordinate Systems

Every simple body is given its own intrinsic co-ordinate system, e.g.:



MONK6 allows a general part co-ordinate system against which every body of the part may be located and orientated. However this is an unnessary generalisation and it is strongly recommended that each part takes on the intrinsic co-ordinate system of its container body as the part co-ordinate frame. This is because when a part is assigned as a subsidiary part to a body it takes on the co-ordinate system of that body which becomes its effective container, and all bodies within the subsidiary part are orientated accordingly. Thus there is no need to transform the co-ordinates of the container of any part as the required transformation is performed by the simple body containing that part. The use of local co-ordinates for each part means that the user does not have to individually place every body correctly in the global part, but merely in the correct relative place in the parent part of the body. These parent parts then become additional building blocks which can form further parts and so on, each time the building blocks being positioned relative to the current part being defined. The local co-ordinate s-

tem approach to geometry modelling is most suitable for the kind of geometries normally encountered in criticality calculations and enables frequently reccurring geometries to be re-used in other models.

The hidden geometry of a hole forms the contents of a scoring region associated with a simple body and the hole tracking algorithm is either passed the position co-ordinates of the neutron in the part frame or the co-ordinates in the simple body intrinsic frame. The two options are distinguished by the specification of the keywords HOLE or BHOLE (H or BH) respectively.

In most cases the use of the intrinsic co-ordinates of the simple body (BHOLE) is the more appropriate because it is generally more sensible for the hole co-ordinate system to be defined with respect to something fixed, such as the simple body co-ordinate system, rather than the part co-ordinates, which can be rather arbitrary. The user who always employs BHOLE will never be disadvantaged in speed of execution and the simplification of the geometry contruction is a real benefit. The use of HOLE should be reserved for special effects, for example when the part co-ordinates are in fact global co-ordindates being read from an engineering drawing.

However the facilities of the two methods of specification overlap completely and it recommended that BHOLE be employed whenever possible. The following simple example shows how a square lattice of pins within a wrapper can be specified using the two options:

```
NEST 1
BOX  ORIGIN -7 -7 0   H1   14 14 100

SQUARE 3  1 2 3
          3.4 1.7 1.7  0.55 0.65
          WRAP 4 4  6 7 6 7
          1 2 3
```

is equivalent to:

```
NEST 1
BOX   BH1   14 14 100

SQUARE 3  1 2 3   HTRANS 7 7 0
          3.4 1.7 1.7  0.55 0.65
          WRAP 4 4  6 7 6 7
          1 2 3
```

When a hole geometry contains a subsidiary hole the possibility of a further co-ordinate system exists and here the co-ordinates that are passed from parent hole to subsidiary hole are entirely at the discretion of the designer of the parent hole geometry. These rules are chosen for their likely convenience and in general are consistent between the various hole geometries, e.g. the lattice-type holes pass on co-ordinates relative to the local pin for subsidiary holes within the pin or clad, but pass on those it received itself for subsidiary holes in the interstitial space. However the rules need to be

known for each hole type as the use of holes within holes is frequently used and can provide an elegant solution to the specification of many complex geometries.

d) Source Options

MONK6 contains a wide range of source options which are used as the first guess to the neutron spatial distribution. These were developed during a period when the code lacked a mathematical foundation and many of the options are largely superfluous with the introduction of superhistory tracking. Superhistory tracking enables MONK6 to concentrate on the most reactive parts of a system provided that the initial source guess is not unreasonable; that is provided it allows neutron tracks to reach all parts of the system during settling.

The nature of criticality situations is that there are usually a great many structural materials around the fissile material to parasitically absorb neutrons, so that they settle reasonably quickly into the fundamental mode that is needed to compute k-effective correctly (provided there are sufficient neutrons per stage to allow this to happen). Superhistory tracking forces the input source to pass through ten fission generations without interference, which effectively removes those neutrons not in the fundamental mode (i.e. those in the harmonic modes), leaving only the most reactive component of the population; this has a powerful stabilising influence on the calculation.

The most generally useful of the source options is the MULTIFISS description, as that distributes the starting neutrons over a selection of simple bodies with only points within fissile material being employed. The most useful of the other options are the POINT, VOLUME and FISSILE descriptions. The following section gives a brief description of how each of these source options work.

The POINT option is clearly the simplest; all of the initial source superhistories start from the same point in space. For homogeneous systems it is usually sufficient to specify a point source at the centre of the fissile material; this gives the added confidence of the code converging from a high value of k-effective as the central point source will normally over-estimate k-effective.

The VOLUME source option is almost as simple; the user defines a source volume and random points are chosen from within the volume at which the superhistories are started. Again for homogeneous systems this can be quite suitable, but for heterogeneous systems, as there is no control over which materials the random points will placed in, some of the points will inevitably be in non-fissile materials. However by suitable choice of source volume this problem can be minimised in many cases.

The FISSILE option will perform a search over the whole system and select source points from within simple bodies that contain fissile material. If a simple body selected contains a real material then obviously the source point will actually lie in a fissile material. However if the body contains a hole geometry there is no guarantee that the point actually chosen will be in a fissile material. For many cases though this may not be a major problem, and this source option has a wide range of application.

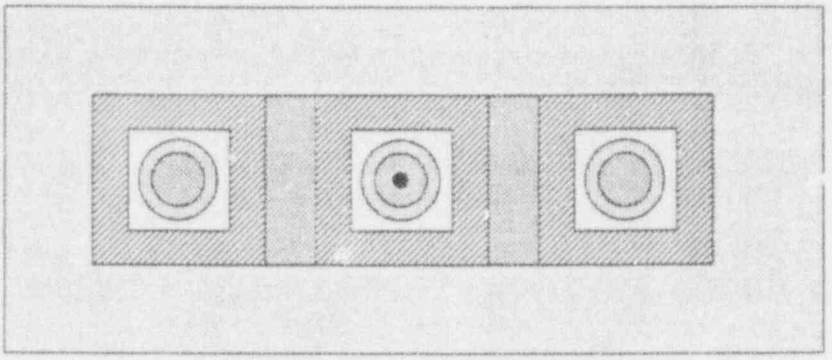
The MULTIFISS option selects points at random from within specified simple bodies but only accepts the points if they lie within fissile material. Thus all source points will start in a suitable material which makes this option generally applicable to all systems. There may be some small inefficiency he

amount of fissile material is small within a given simple body but suitable partitioning of the body using the non-default MULTIFISS source options can usually overcome this.

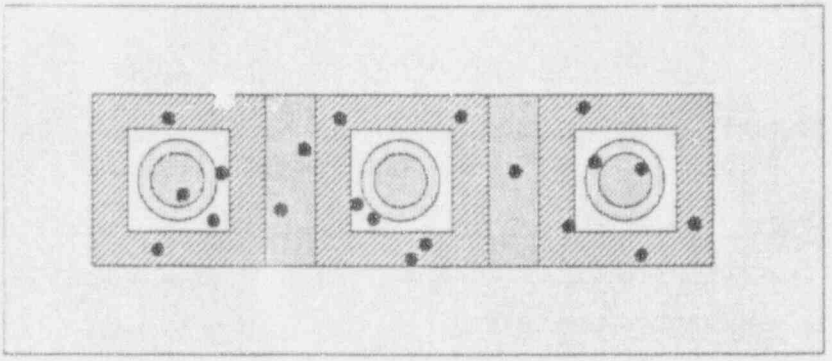
The following input data describes an collection of fuel bodies within compartments separated by absorbing plates. The location of the source points obtained by employing each of the options considered above will then be indicated:

```
* material 1 ... UO2 fuel
* material 2 ... water
* material 3 ... zirconium
* material 4 ... steel
* material 5 ... boron

* single compartment

NEST 2
BOX  ORIGIN 2 2 0     BH1  6 6 10
BOX                        4  10 10 10

* single absorber

NEST 1
BOX  5  3 10 10

* form compartment/absorber array

ARRAY 5 1 1
1 2 1 2 1

* surround array with water

NEST 2
BOX  ORIGIN 5 5 5  P3   36 10 10
BOX                  2   46 20 20

SQUARE 3  1 2 3   HTRANS 3 3 0
          10 0 0 1.5 2.5
          1 3 2
```

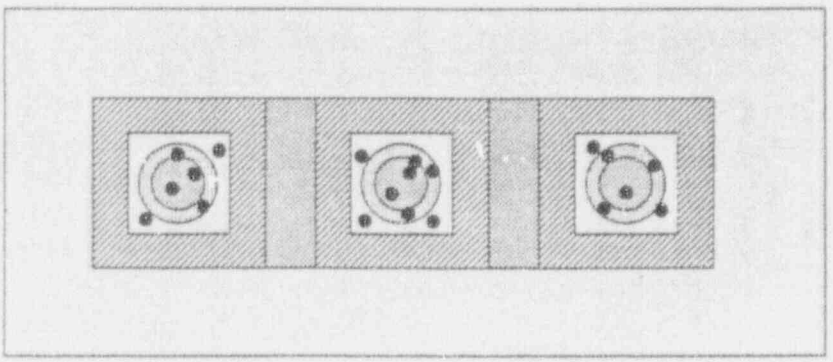
A POINT source specified as POINT 23 10 10 would result in the following initial source distribution (with source points denoted as solid black circles):



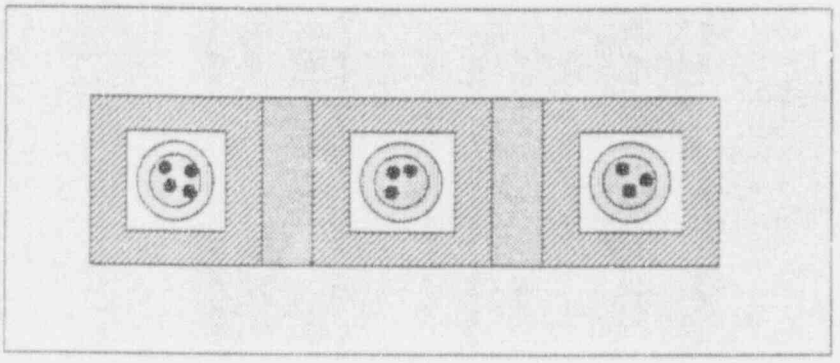
A VOLUME source specified as VOLUME REGION 1 PART 4 / would result in the following initial source distribution:



A FISSILE source specified as FISSILE REGION 1 PART 4 / would result in the following initial source distribution:



A MULTIFISS source specified as MULTIFISS STD REGION 1 PART 4 / would result in the following initial source distribution:



e) Control Parameters

Having selected the source distribution some initial tracking stages are performed by MONK6, the results of which are not included in the scoring statistics. This preliminary process is called settling and it allows time for the neutron distribution to move from the guessed distribution and approach the fundemental mode. The amount of settling that is performed is chosed by the user but provided a reasonable source guess is employed some fairly safe guidelines can be given.

Settling depends on two things:

1) Primarily having enough neutrons per stage - the more diverse the geometry the more neutrons per stage are required to prevent the Monte Carlo statistical error continually disrupting the settling process.

2) Having enough settling stages - this number is governed by the dominance of the fundamental mode over the harmonic distributions which will always be present to some extent. It is not necessary (or even possible) to get rid of these harmonics before starting to score, and so settling is never really complete; however the bias on k-effective due to the harmonics dies away much faster than the Monte Carlo statistical error, so provided a lot of superhistories are scored this effect is negligible.

There is no maximum number of neutrons per stage in MONK6 but a value of 600 has been found to be suitable for a wide range of criticality problems. Indeed there is no reason not to use at least this value for all but very simple geometries where 200-300 may be more suitable to reduce the amount of settling performed. Experience has also shown that two settling stages is sufficient over a similar range of calculations, and again as for the number of neutrons per stage, should be regarded as a minimum

value except for very simple geometries.

Having run a MONK6 calculation for a certain number of stages a more precise answer may be required. Rather than extending the initial calculation, a far better approach is to re-run the calculation to get additional independent results. These calculations can then be combined as follows:

$$\bar{k} = \frac{k_1/\sigma_1^2 + k_2/\sigma_2^2 + k_3/\sigma_3^2 + ...}{1/\sigma_1^2 + 1/\sigma_2^2 + 1/\sigma_3^2 + ...}$$

$$\bar{\sigma} = [\ 1/(\ 1/\sigma_1^2 + 1/\sigma_2^2 + 1/\sigma_3^2 + ...\ )\ ]^{1/2}$$

Independent calculations using different sources adds considerably to the confidence of the user regarding the settling issue.

f) Miscellaneous Items

For criticality assessments the nuclear data employed will generally be the MONK6 point-energy library. This has been extensively validated over a wide range of systems and is controlled and administered as part of the MONK6 code package. To select nuclides from this library for a particular calculation the recommended method is to use the NUCNAMES option. This is because mistakes are less likely when specifying familiar nuclide names than when using the original MONK6 format of employing rather obscure data file numbers; in addition the NUCNAMES format is more readable. If the nuclear data are computed by some auxiliary computer code then efforts should be made to transfer the output from this code directly into the MONK6 input file and thus avoid re-typing the data. Mistakes made in specifying nuclear concentrations or ratios (however they arise) can be very difficult to locate on occasions, so the chance of making a mistake should be minimised as far as possible. Note that the materials are numbered in the order of specification in the input data.

The boundary conditions available in MONK6 include the specular or periodic reflection conditions to provide infinite arrays in one or more direction, or to enable only part of a system to be modelled. There are also albedo co-efficients which are designed to be used in conjunction with thin reflectors in place of thick reflectors thus saving computer time. It has been found however that to avoid biasing the calculation of k-effective, the thin reflector actually needs to be fairly thick, and the result is that little or even no time is saved over modelling the reflector explicitly. Therefore for criticality assessment calculations it is strongly recommended that reflectors are modelled explicitly and that albedo co-efficients are used only for design or survey calculations.

A companion code to MONK6 exists called SCAN6 which is used to produce two-dimensional cross-section pictures of the geometry either on paper or preferably on a high-resolution colour monitor. The use of SCAN6 should not be underestimated. The vast majority of the FORTRAN coding of SCAN6 comes directly from MONK6, so a comprehensive check on the data can be performed by SCAN6. More importantly the pictures produced by SCAN6 are calculated by tracking through the geor ry

using the MONK6 tracking routines; thus the geometry depicted by SCAN6 is exactly that seen by the neutrons during the MONK6 calculation. No other method of depicting the MONK6 geometry can provide this. SCAN6 can depict the geometry specification at any level of resolution chosen by the user. In all but the simplest geometries this will involve producing several pictures (at least) with varying resolution, although the use of a colour monitor can reduce this number due to the extra detail that is visible in a single picture.

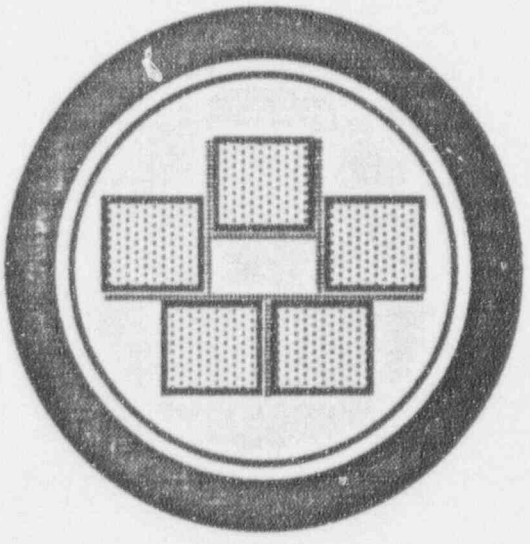
5. MODELLING A FUEL TRANSPORT FLASK

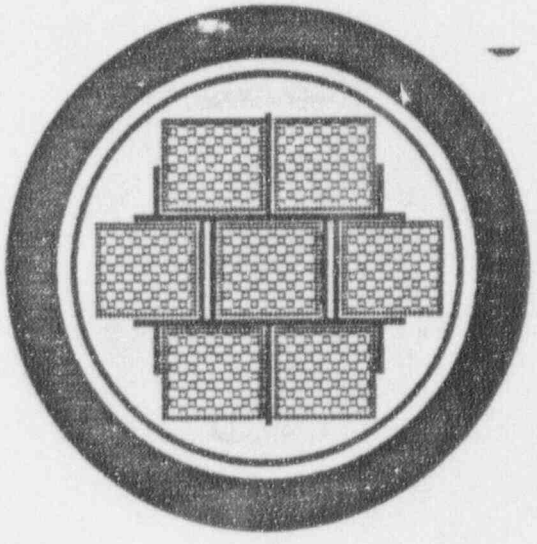
a) Introduction

The geometry of an LWR fuel transport flask is usually fairly straightforward, although as with most configurations there are a number of different ways of modelling the problem using the MONK6 geometry package. The geometric dimensions of the flask are generally well-established and accurate and efficient MONK6 models can be constructed which make use of most of the basic features described in the last section, including the three basic part types and some of the simpler hole geometries. The fuel within the flask is normally assumed to be unirradiated and so the material data are also well-known.

Many of the LWR transport flasks in use in the world have very similar geometries. The main flask structure and inner container (multi-element bottle) are cylindrical in shape, and the interior of the multi-element bottle is compartmentalised in some way to accept a certain number of fuel elements. The number of fuel elements depends on the type of bottle and the type of fuel being transported and so each case requires assessment on its own merits.

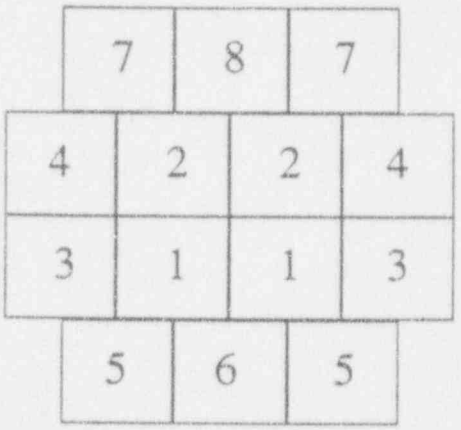
For a criticality calculation the heat-dissipating fins of the flask, the shock absorbing end sections and the assorted securing bolts and handling structure on the exterior of the flask can be ignored as they will have a negligible effect on the reactivity of the whole structure. Details within the fuel elements such as grid plates, spacers and control pins are also ignored which makes for a much simpler model. In addition certain minor localised features within the flask itself can also be omitted from a model such as water draining pipes for cleaning and filling and miscellaneous bolts and locating devices. These are in any case conservative approximations due to the primarily neutron absorbing properties of the omitted materials. The main components can then be modelled as specified with considerable accuracy. Two typical flask radial cross-sections are shown below:





An alternative approach is to make thirteen copies of part one to use as parts two to fourteen and create the cluster of elements from these; this would give detailed scoring information for each element individually. However if the first approach provides too little information, the second approach, although much better, could be considered to provide too much information, which may well suffer from lack of precision and could be misleading if not thoroughly understood.

The best approach is to note the bi-lateral symmetry of the flask geometry (the flask is symmetric about a central vertical plane) and create the following model:



Hence only seven copies of part one are required which are deployed as shown above. To copy a pre-defined part the MONK6 option SAME is employed. Therefore specifying SAME 1 seven times defines parts 2 to 8; the numbering order shown in the diagram is completely arbitrary. Note that there is nothing wrong with specifying fourteen different elements and the efficiency of the code is on no way affected, but making use of the symmetry of the system in this way produces all the information necessary for examining the adequacy of the Monte Carlo sampling.

It may be considered that the calculation would be improved if created by employing a central vertical specular reflective boundary and just modelling one half of the geometry, and indeed there is nothing wrong with that approach. However no improvement in efficiency of execution would be obtained, and the model would be more difficult to contruct, as half-fuel elements and half-cylinders would be required. The recommended approach exploits the symmetry of the flask but in such a way that the geometry model is easy to construct.

The fuel elements could now be assembled into a cluster part to give the main components of the multi-element bottle. However most of the tracking will be performed in this cluster and some efficiency improvement is possible by reducing the number of simple bodies in the cluster by further containerisation using the array part type. This results in three arrays: one for the top row, one for the central two rows, and one for the bottom row.

The next three parts of the geometry are therefore array parts. The top and bottom rows each have three boxes in the x-direction and one elsewhere, and the central section has four in the x-direction, two in the y-direction and one in the z-direction. The input data for each array are the dimensions of the array

and the part numbers of the appropriate fuel element/compartment constructions, so the MONK geometry data becomes:

```
* bottom row

ARRAY 3 1 1      5 6 5

* central two rows

ARRAY 4 2 1      3 1 1 3
                 4 2 2 4

* top row

ARRAY 3 1 1      7 8 7
```

These three arrays are now included in the cluster part that defines the multi-element bottle (note that the main cluster now only has four simple bodies rather than the fifteen that would result from the original strategy). To give an idea of the gain in performance arising from this further containerisation both cases have been run for the reference flask. The results show that the case employing the arrays tracks the same number of superhistories about 30% faster than the large cluster model.

The specification of a cluster requires the user to define any number of internal components and then a container which has some associated material that fills all the interstitial space around the internal components. This material is called the interstitial material and it can be a real material or a hole material, but not a subsidiary part.

If a hole geometry is chosen then like all uses of a hole geometry it is cut to fit the available interstitial space. This effect can produce complex and unusual geometries, with hole geometries intimately mixed around simple bodies which may contain real materials, further hole geometries or subsidiary parts. A further complexity can be that the internal component parts may overlap one another and the container. This enables the majority of plant items to accurately modelled as well as providing many possibilities for overcoming the hole geometry inefficiency reqarding materials with very small mean free paths.

A common use of the cluster interstitial material is to produce a plane boundary within the components to give an effective level of solution. This can be done by employing the plate hole geometry as the interstitial material. The plate hole geometry produces a series of infinite parallel plane boundaries, and the spaces between the planes can be filled with real materials or subsidiary hole geometries. The plane boundaries are then cut to fit the simple body container as usual. A description of the plate hole geometry can be found in Chapter 2 Section 2.10.3 of the User Guide [9].

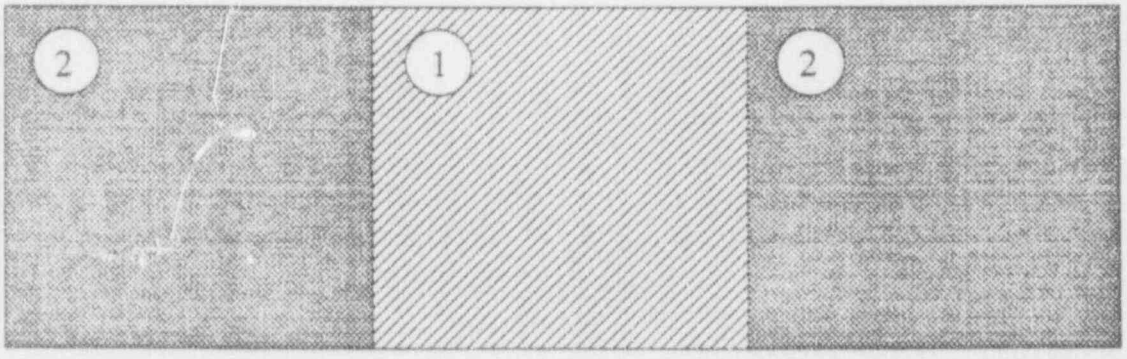
Thus a simple plate hole implementation could provide a water level for a pair of bodies within a cluster:

The boron steel compartment could be incorporated as a subsidiary hole outside the wrapper; the efficiency of the hole tracking would not be greatly downgraded as the boron content is relatively small, meaning that the cross-section of the compartment would not result in too many pseudo collisions. However as the compartment extends beyond both ends of the element it is probably simpler and possibly slightly more efficient, because distance to plane surfaces are easily computed, to include the compartment as another body within a nest.

This nest part needs to include the water that is inside the compartment at either end of the fuel element. This can be readily included by specifying coincident body boundaries to create the effect of a stack or row of bodies. For example the following specification:

```
NEST 2
BOX  ORIGIN 10 0 0  1  10 10 10
BOX                 2  30 10 10
```

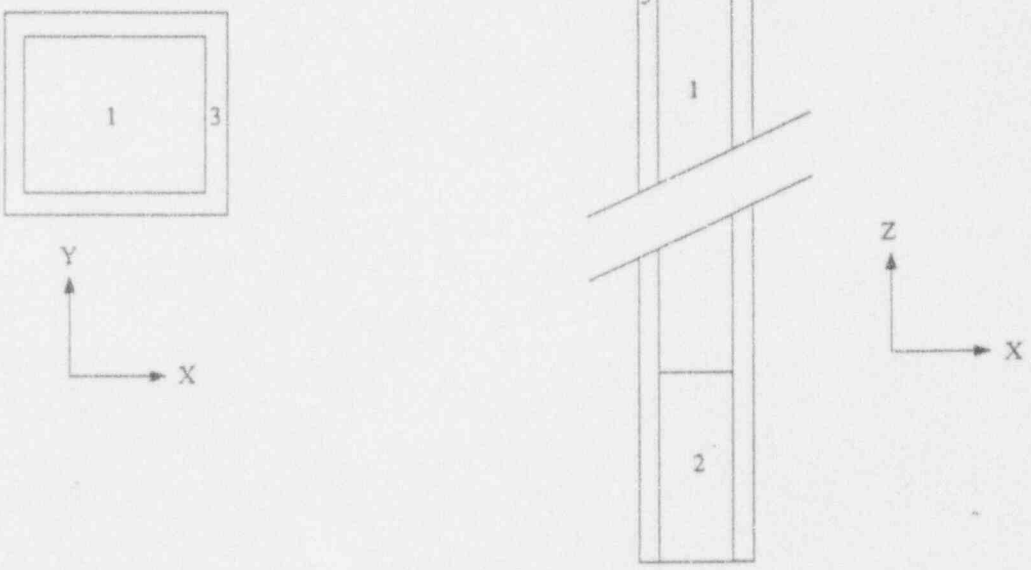
results in the geometry:



Therefore to model the fuel element/compartment construction a nest consisting of three bodies can be used:

1. fuel element and sleeve (square hole geometry)
2. water above and below element
3. compartment wall.

The internal dimensions of the compartment is 14.20 x 14.20cm and the walls are 0.50cm thick per compartment. Axially the fuel element is of length 409.50cm and is positioned symmetrically within the compartment which is of length 449.50cm; the compartment is fully flooded with water. Thus the single element/compartment construction looks as follows (not to scale):



This becomes the following MONK6 specification:

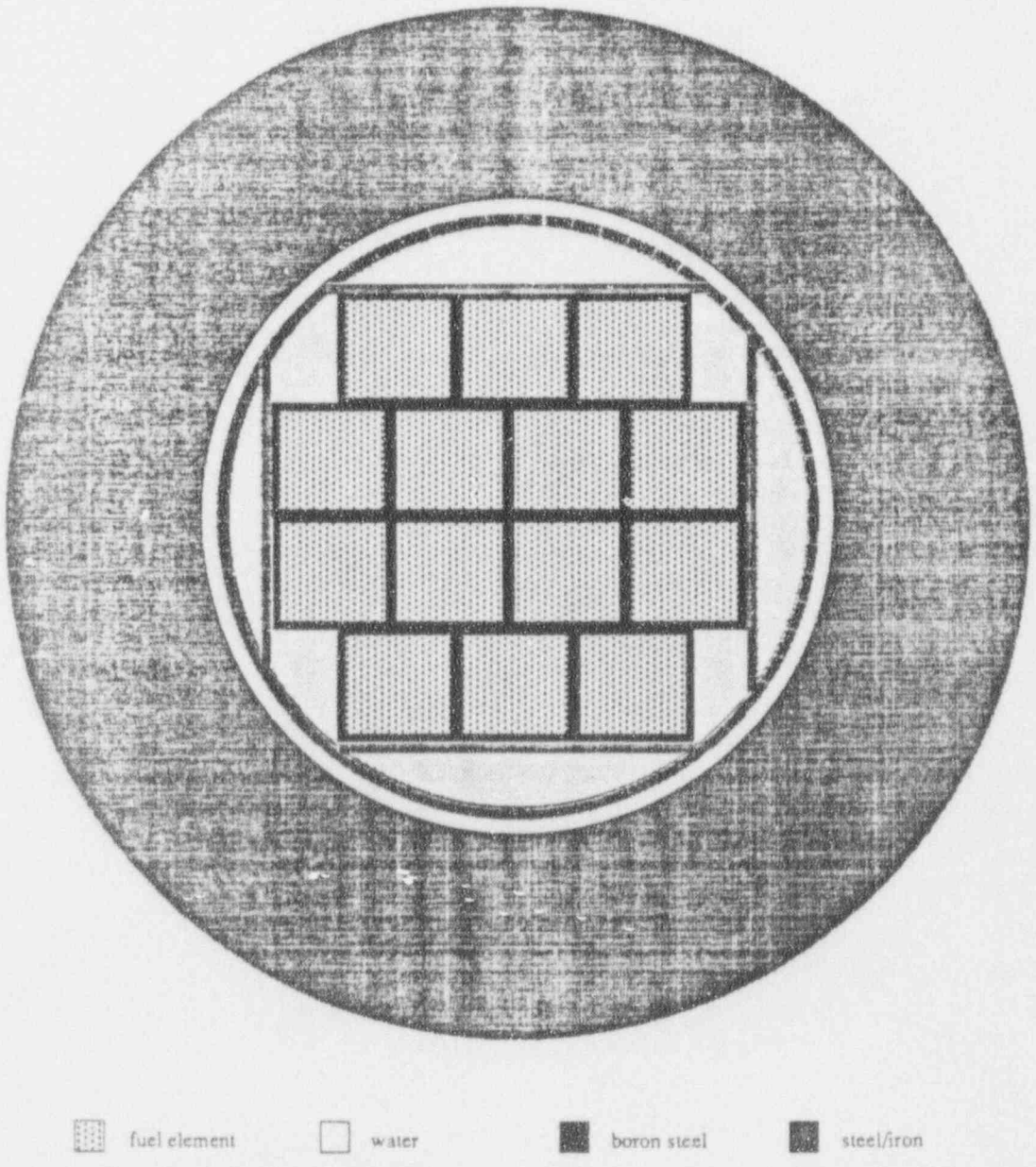
```
NEST 3
BOX  ORIGIN 0.5 0.5 20.0  BH1   14.2 14.2 409.5
BOX  ORIGIN 0.5 0.5 0.0     2   14.2 14.2 449.5
BOX                         3   15.2 15.2 449.5
```

This becomes part one of the reference flask model.

It would probably seem reasonable to employ part one repeatedly within the flask to produce the required cluster of fourteen fuel elements. However if that were done some detailed scoring information would be lost. This is because reaction rates, boundary crossings and flux scores for part one would be the sum over all occurrences of the part, as described in section 4a. Information relating to the neutron activity distribution within the flask, which provides a useful check on the adequacy of the Monte Carlo sampling, would therefore be lost.

Apart from obvious dimensional differences the principle variations are in the materials used to form the compartment walls and flux traps that separate the fuel elements. However most of these variations can be incorporated into a basic template for creating a MONK6 model of the generic flask that will be considered in the following sections. The reference flask will be one of the simpler designs, but having followed the basic principles in setting up such a model extra details can be readily included without deviating too far from the basic approach.

b) The Reference Flask



The reference flask contains fourteen LWR fuel elements as shown above. Each element consists of an eight by eight lattice of 3.5% enriched UO_2 zirconium clad fuel pins. The pins have a radius of 0.55cm and the clad is 0.10cm thick; the pins are positioned on a 1.70cm pitch. The pins are contained within a zirconium sleeve of thickness 0.20cm, the inner boundary of which is located symmetrically 6.80cm from the centre of the element. Although the data are not taken from any particular fuel element specification they are typical of those for a BWR element. The left/right reflective symmetry of the flask is apparent from the drawing and this will be exploited in the modelling.

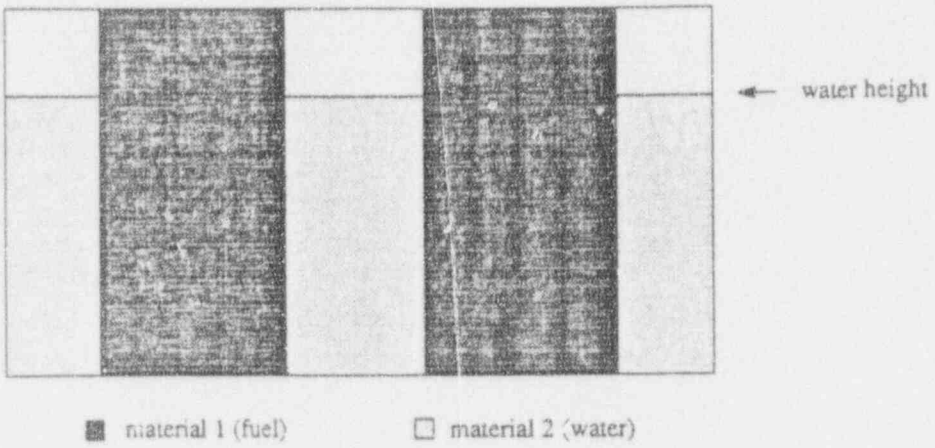
The fuel elements are of length 409.50cm and are contained symmetrically within a boron steel walled compartment of length 449.50cm. The inner wall of the compartment is 0.10cm away from the sleeve of the fuel element and the walls are 0.50cm thick per fuel element; thus where fuel elements are adjacent the wall thickness between them will be 1.00cm. In addition there are steel supports surrounding the outer compartments as shown, and these extend the full length of the multi-element bottle. The bottle contains water to the height shown when the flask is horizontal and it sits inside the main flask body separated from the flask inner wall by a 1.00cm water gap. The multi-element bottle wall is 1.00cm thick and the flask has walls of thickness 33.80cm.

c) The Reference Flask Simple Body Geometry

The recommended way to model any system using the MONK6 geometry package is to take advantage of the local co-ordinate structure and use a building block approach. This means starting from the basic components (the simple bodies and hole geometries) and create the next largest entities (the simple first-level parts), and then use these to construct larger parts and so on until the whole system has been built. For the reference flask described above this translates into creating a model of a single fuel element, copy this to create the required number of elements, arrange the elements within the multi-element bottle and then place the bottle into the flask. Working this way, the use of local co-ordinates is optimised and there should rarely be any need to transform part containers, as the absolute position of any part need not be considered until it is employed in some later part.

As each fuel element has associated with it some thickness of compartment wall, it is convenient to consider the compartment wall as in integral part of the fundamental building block of the geometry. This is a simple technique that is useful on many occasions where the MONK6 building blocks do not necessarily equate exactly to what might be considered engineering components, but include some fraction of the immediate surrounding structure.

The most straightforward way to model the fuel element is to employ the square hole geometry. This generic geometry models a lattice of clad pins on a square pitch and is described in Chapter 2 Section 2.10.4 of the User Guide [9]. The lattice of pins is either infinite in extent (and hence cut back by the containing simple body) or finite and bounded by a plane-sided wrapper medium. This latter option maps directly onto the fuel element as the lattice is finite (eight by eight pins) and resides in a zirconium sleeve (wrapper).



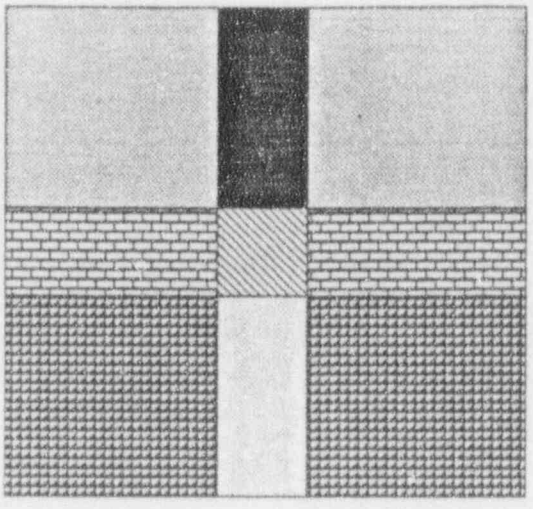
which could be modelled as:

```
CLUSTER 3
ZROD  ORIGIN 10 10 0     1  5 20
ZROD  ORIGIN 30 10 0     1  5 20
BOX                   BH1  40 20 20

PLATE 1 2
        0.0 0.0 1.0
        1  15.0  0 2
```

A more complex but similar use of the plate hole geometry could be to produce a grid by specifying hole geometries with mutually perpendicular plane boundaries:

```
PLATE 6  1 2 3 4 5 6
        1.0 0.0 0.0
        2  10.0 -2  5.0 -3  -2
PLATE 3  1 2 3
        0.0 1.0 0.0
        2  10.0 1  5.0 2  3
PLATE 3  4 5 6
        0.0 1.0 0.0
        1  10.0 4  5.0 5  6
```

which would produce:



1 2 3 4 5 6

This type of geometry can be applied to the flask model as there are plane boundaries in two perpendicular directions to be modelled (i.e. the steel supports). Therefore if the interstitial material of the cluster is assigned to hole geometry number 2 for this purpose then the definition of the inside of the multi-element bottle becomes:

```
CLUSTER 4
BOX   ORIGIN -22.8  15.2 5.0   P11   45.6 15.2 449.5
BOX   ORIGIN -30.4 -15.2 5.0   P10   60.8 30.4 449.5
BOX   ORIGIN -22.8 -30.4 5.0   P9    45.6 15.2 449.5
ZROD                           BH2   39.2 459.5
```

The multi-element bottle components can now be placed within the container, and the container positioned within the main flask body. As explained above the flask body can be safely modelled as a uniform cylinder due to the large quantities of iron. This becomes a simple nest structure as follows:

```
NEST 5
ZROD   ORIGIN 0.0 0.0 41.0    P12    39.2 459.5
ZROD   ORIGIN 0.0 0.0 38.0      4    40.2 465.5
ZROD   ORIGIN 0.0 0.0 32.0      2    41.2 477.5
ZROD                            5    75.0 541.5
BOX    ORIGIN -76.0 -76.0 -1.0  0    152.0 152.0 543.5
```

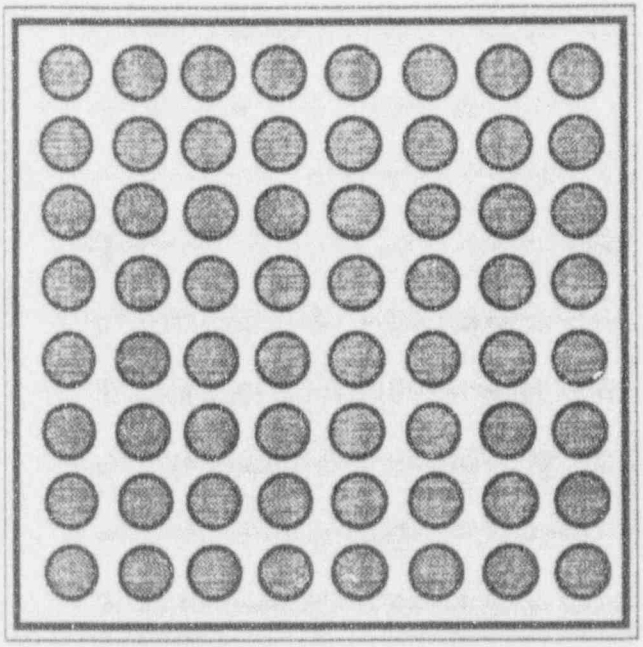
Note that an additional voided box has been included around the flask to enable SCAN6 pictures to be drawn that include the whole flask; a limitation of SCAN6 is that the picture frame co-ordinates must be inside the geometry outer boundary.

This completes the definition of the simple body geometry and boundary conditions can now be specified for the voided box. In this case, having modelled the geometry sufficiently accurately, and with

the expected isolation of the flask, a free boundary condition is sufficient. However it is good criticality practice to include full specular reflection on an outer boundary to accommodate situations when the flask is not isolated (e.g. during storage). This boundary condition constitutes a worst-case scenario as any real arrangement of similar flasks will be less reactive than the infinite array produced by the full specular reflection. If the flask is positioned adjacent to a more reactive flask, the fact that this latter flask has been cleared by consideration of an infinite array means that the situation is implicitly safe.

d) The Reference Flask Hole Geometry

Hole geometry number 1 defines the fuel element as employed by parts 1-8. This is a square hole and models the fuel pins, zirconium sleeve and interstitial water, but not the compartment walls:



The preliminary data (see Chapter 3 Unit 3.1 of the User Guide [9]) starts with a list of all the real materials used by the hole and any subsidiary holes. If a material is accidently included here which is not actually used, time is wasted in considering it, but more importantly if this material happens to have a very small mean free path, then the hole geometry tracking will be slowed down as described in section 4b.

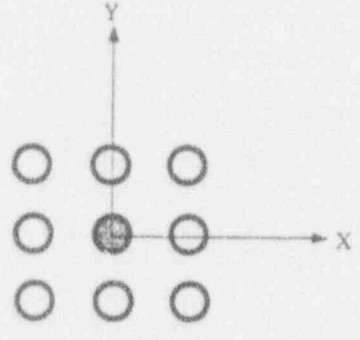
To model the fuel element no subsidiary holes are required and so the material list consists of just the real materials employed in this hole, namely UO_2, zirconium and water. The remaining preliminary hole data consists of hole geometry transformation data for a translation and/or a rotation of the com-

plete hole geometry. The square hole has the centre of a pin of the lattice as the hole origin if the lattice of pins in infinite (i.e. not wrapped). When a wrapper is used the hole origin is at the geometric centre of the rectangular outer boundary of the wrapper, with XY axes parallel to the wrapper sides. For the reference flask the sleeve of the fuel element is being modelled as the hole wrapper, so the hole origin needs to be moved to the centre of the container box. Thus the preliminary data reads:

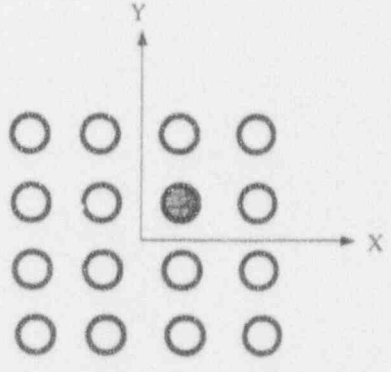
SQUARE 3 1 2 6 HTRANS 7.1 7.1 0.0

Note that there is no need to transform the z co-ordinate as the square hole pins are infinite in length and will be cut to length by the container.

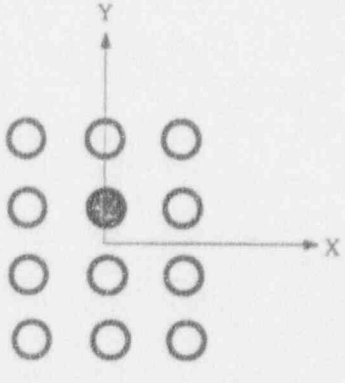
The first item of square hole data (see Chapter 3 Unit 3.5 of the User Guide [9]) is the lattice pitch which is 1.70cm. The next item arises because the pins are not automatically positioned symmetrically inside the wrapper, and so (DX,DY) is required, which is the location of a pin centre from the hole origin. For an odd number of pins by odd number of pins the pin chosen for this purpose is the centre pin of the lattice, and for the other combinations the pin to the right and up is chosen as necessary:



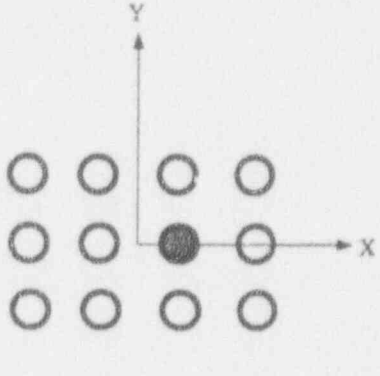
odd by odd



even by even



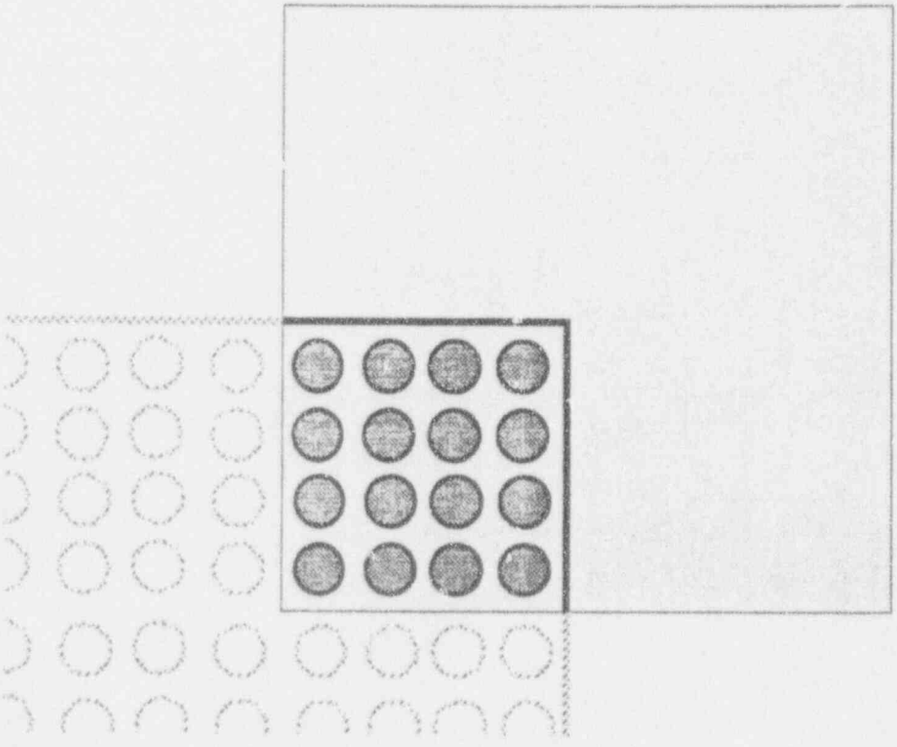
odd by even



even by odd

Thus for the reference flask the data DX = DY = -0.85 are required, giving the lattice of pins a symmetric position within the wrapper (note the negative sign on these values; this is a confusing square hole convention).The next two items are the radius of the pin and the radius of the pin plus cladding (0.55cm and 0.65cm respectively). The remaining items of data apart from the allocation of materials are optional. However it has been decided that the zirconium sleeve will be modelled using a square hole wrapper so the WRAP key word plus associated data is required. First comes the number of pins (8 in each direction), then the perpendicular distances to the inner and outer boundaries of the wrapper in the x- and y-directions; these are measured from the centre of the hole geometry (i.e. the point (7.1,7.1)). The sleeve starts 6.8cm from the centre of the element and is 0.2cm thick, therefore the values 6.8 7.0 are required for each direction. A full 8x8 lattice is required so no OMIT data are required. The remaining hole data allocates the materials to the five zones defined: inside the pin, the clad, interstitial material inside the wrapper, the wrapper itself and outside the wrapper. Note that the container will cut back as much of this definition as required, so although the wrapper has been described in the hole geometry it will only appear in the model if the container is suitably-sized.

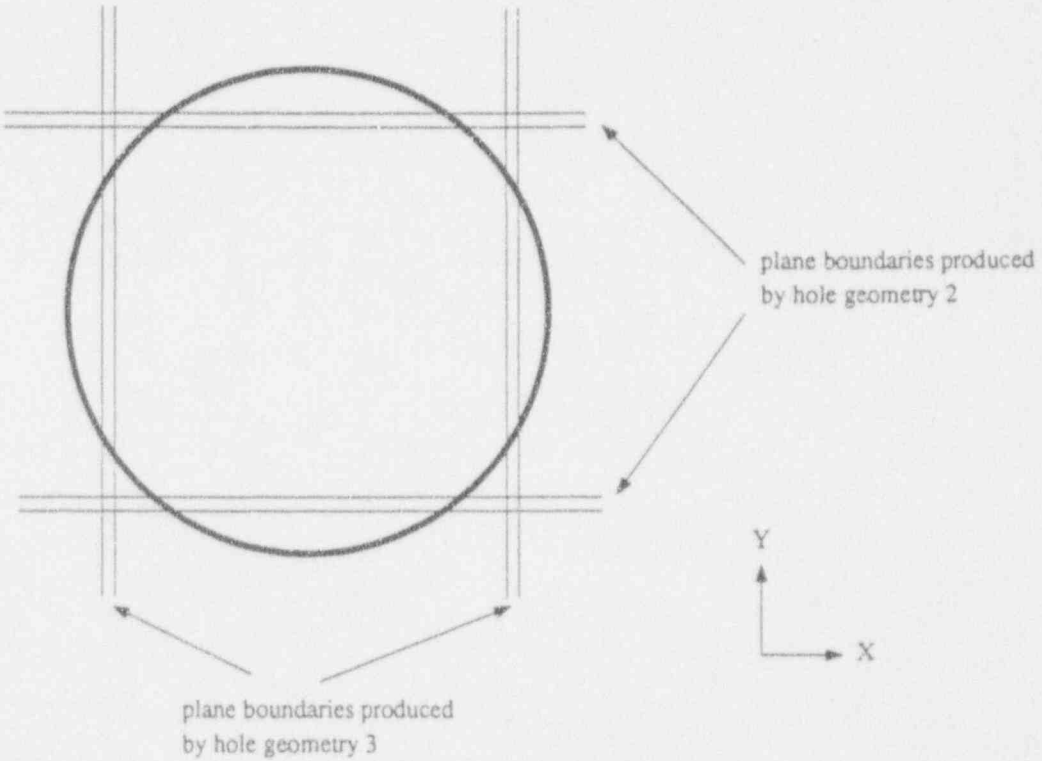
Having used BHOLE for the simple body, had the HTRANS option not been employed the centre of the square hole would have been at (0,0) and the following geometry would have been obtained:



The complete square hole specification for the fuel element is:

```
SQUARE 3 1 2 6  HTRANS 7.1 7.1 0.0
       1 7 0 0.85 0.85  0.55 0.65
       WRAP 8 8  6.8 7.0 6.8 7.0
       1 6 2 6 2
```

Hole geometry number 2 will be a plate hole defining the interstitial space within the multi-element bottle; it will provide the steel supports and the water. As there are perpendicular planes required to produce the steel supports a subsidiary hole (hole 3) will be required and this will also be a plate hole. The following diagram shows the planes produced by the two plate holes:



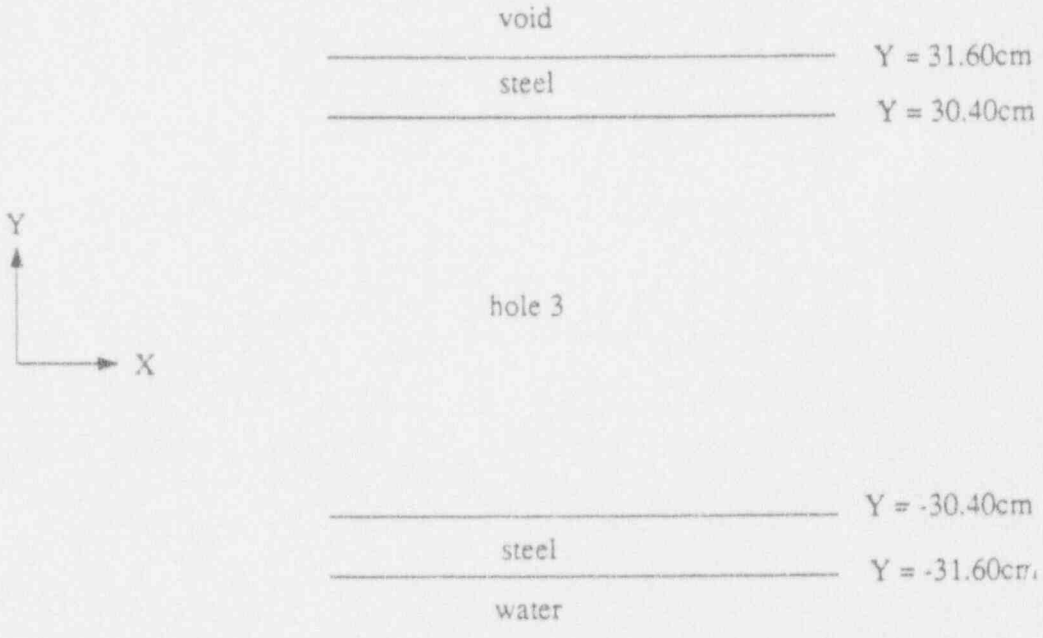
The preliminary data for the first plate hole (hole 2) starts with the material list for this hole and any subsidiary holes (in this case hole 3). However both holes employ the same two materials (water and steel) so the list contains just these. Note that material 0 (void) is not a real material. Transformation data is almost never required for the plate hole as the orientation and location of the planes is given explicitly as plate hole data. As hole 2 is contained within the untransformed cylindrical container of a cluster the use of HOLE and BHOLE are the same for this plate hole.

The first item of plate hole specific data (see Chapter 3 Unit 3.2 of the User Guide [9]) defines the orientation of the parallel planes. The requirement is a vector (normalised or unnormalised) defining the normal to the planes. The next item of data gives the number of internal plane boundaries (note that there may be other plane boundaries provided by the container, but there is no need to specify them here as the hole geometry outside the container is discarded). A repeated CELL structure is not appropriate here so this item can be omitted.

Hole 2 is to provide planes in the xz plane so the normal vector is (0.0,1.0,0.0). Four plane boundaries are required to produce the steel supports shown above. The boundary of the side of each support nearest the centre of the flask coincides with that for the outer edge of the fuel element compartments and the support is 1.2cm thick. The plane boundaries and associated materials (i.e. the material on the

'far' side of the boundary in the direction of the normal vector) are now given, followed by the material on the near side of the final boundary. The boundaries are given in descending order, so the first boundary is at a distance 31.60cm from the origin of the hole with the void space on the far side (i.e. material 0), and the second boundary is at 30.40cm with steel on the far side of it. The third boundary is at -30.40cm and the material on the far side of this is the subsidiary plate hole geometry (hole 3 , denoted by -3 in the input); hole 3 will provide the steel supports in the perpendicular direction. The final boundary is at -31.60cm with steel again on its far side and the final material on the near side is water.

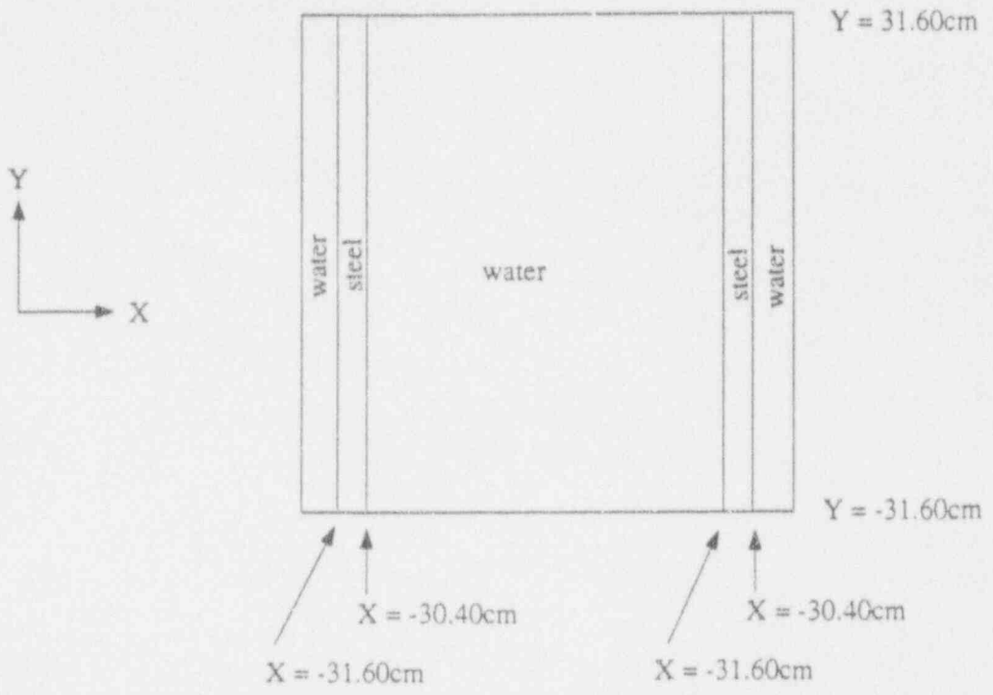
Therefore the following hole has been defined:



and the materials will be cut by the inner boundary of the cylindrical container of the multi-element bottle. The complete data specification for hole 2 is:

```
PLATE 2 2 4
      0.0 1.0 0.0
      4  31.6 0  30.4 4  -30.4 -3  -31.6 4  2
```

The second plate hole (hole 3) only appears between the boundaries y=30.4 and y=-30.4cm. The preliminary hole data are as for hole 2. The normal vector is now in the x-direction (1.0,0.0,0.0), but the plane boundaries are the same as for hole 2, except that materials are now water or steel only. This gives the following geometry:



and again the materials will be cut by the multi-element bottle container. The complete data specification for hole 3 is:

```
PLATE 2 2 4
      1.0 0.0 0.0
      4  31.6 2  30.4 4  -30.4 2  -31.6 4  2
```

This completes the geometry specification for the reference flask; a complete input listing is given in Appendix A.

e) Other Data

The standard point-energy library is being employed for the calculation and the material data are specified exactly as supplied. Note that the method of specification can vary between materials, thus in the reference input data material numbers one and four have been defined by nuclide concentration (atom/barn.cm), and the others by atom ratios. The third option (weight ratios) has not been employed here. The material density is not required for the nuclide concentration option as its value is implicit in the concentration values, and note that the atom and weight ratios do not need to be normalised. The NUCNAMES option has been employed to make this part of the input more readable. Note that there are some examples on how to compute atom ratios etc. for simple materials in Chapter 5 Unit 1 of the User Guide [9], and for more chemically complex materials handbook formulae or auxiliary cor ıter

codes are often employed.

As described in section 4d the MULTIFISS starting source is the most generally useful of the many MONK6 options, especially for heterogeneous systems, and this has been employed for the reference flask. The starting neutrons will be placed randomly within the fuel pins of the flask, which is a good approximation to the true distribution. It is difficult to conceive of a situation where some form of the MULTIFISS source will not be appropriate; here the default option is sufficient.

The remaining data define the frames for a number of SCAN6 pictures. The CODE option has been used to select non-default symbols for paper display output, so that better contrast between adjacent materials will be obtained than with the default numerals. For colour output this is of no concern. The first picture draws a radial cross-section through the centre of the flask, and whereas this shows a good level of detail on a high-resolution monitor, on the line printer the picture is of limited value (see Appendix B Picture 1). The main flask structure is clearly visible but the fuel elements are poorly defined. The following four picture frames zoom in on the flask to produce quarter sections of the model and this enable the internal features to be more clearly seen; an example is shown in Appendix B Picture 2. Further close-ups are still required though to show a fuel element, the steel support/container intersections and an even closer look at a compartment intersection (Appendix B Pictures 3-5). The SCAN6 pictures are completed by axial views of the top and bottom of the flask (the top is shown in Appendix B Picture 6).

Finally the use of comment lines in the reference input data (Appendix A) should be noted. These take very little time to include with the input data and should be used liberally throughout. They help both as a reminder when browsing the input data and are a great help for cases that need to be independently checked. Where appropriate it is also sensible to include references to drawings, documents, validation reports, approximations etc. so that the MONK6 input data becomes a readable part of the documentation of the whole assessment.

f) Variations on a Theme

The difference between the reference flask and other LWR transport flasks can be considered principally as geometric variations as far as standard, non-accident calculations are concerned. Any material variations such as fuel enrichment, structural steel composition etc. are readily incorporated into the material data section of the input.

The main geometric variations are likely to be the type and number of fuel elements and the nature of the internal structures of the flask. For LWR fuel the square hole will almost certainly be used with the dimensions of the components supplied as hole geometry data. Indeed fuel element models could be saved once set up as hole geometries are normally readily employable in other models. The square hole is one of the easiest of the MONK6 hole geometries to use and provided careful use is made of SCAN6 the fuel element variations can be easily modelled.

Where further complexity is likely to be found is in the compartment construction and additional isolating geometric structure. The reference flask has deliberately considered a simple internal structure - a symmetric arrangement of close-packed uniform compartments. Non-uniform shapes, plates

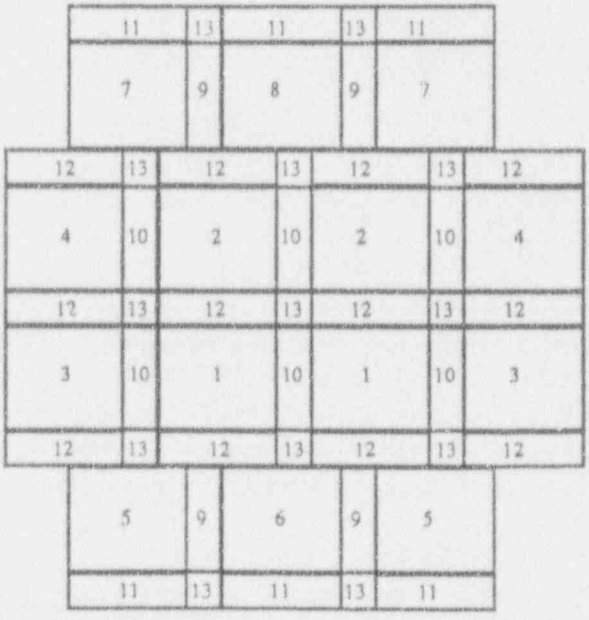
separated by water and water circulating holes are just three examples of geometric variations within the fuel element compartment structure. However these complexities can be readily included in a model by following the outline used for the reference flask.

The main guidelines are to start simple and build up the more complex parts, and to use nests and array part types as much as possible (within reason). However the relative inefficiency of using large clusters should not be overstated and is often quite small anyway when compared with the potential for loss of efficiency present in poorly specified hole geometries. The cluster is often the simplest way of specifying some systems and there is a great QA benefit in using this inherent simplicity and accepting the possible small computing overhead.

The use of the array in the reference flask was restricted to collecting together identical objects; for some of the more complex internal layouts the array might consist of some parts defining fuel elements and other parts defining compartments and other structures. This should pose few problems as the array is a very straightforward construction which can be used to model quite diverse geometries.

For small hole geometries containing heavy absorbers with very small mean free paths or where such an absorber occupies a relatively large volume of a hole geometry, the tracking inefficiency will be considerably reduced and probably tolerable. With experience it will become apparent when special precautions are required to exclude such materials from the hole geometry, and sometimes there will be no alternative but to accept the time penalty.

Thus most basic LWR flask models can be constructed using the tools employed for the reference flask - the box and rod bodies; nest,array and cluster part types; square and plate hole geometries. For example consider a flask similar to the reference flask but with a more complex compartment construction. Let parts 1-8 again define the fuel elements, part 9 define a vertical separating wall for the top and bottom row of elements, part 10 a vertical separating wall for the central two rows. Further let part 10 define a horizontal wall at the top and bottom of the flask, part 12 a horizontal wall between the elements and part 13 a corner section, e.g.:



This could be accommodated within a four body cluster as for the reference flask by forming the following three arrays:

```
ARRAY 5 2 1   11 13 11 13 11
               5  9  6  9  5

ARRAY 7 5 1   12 13 12 13 12 13 12
               3 10  1 10  1 10  3
              12 13 12 13 12 13 12
               4 10  2 10  2 10  4
              12 13 12 13 12 13 12

ARRAY 5 2 1    7  9  8  9  7
              11 13 11 13 11
```

This would lead to a similar geometry layout to that for the reference flask, so although the reference flask model was quite simple it can be used as a template for more complex systems.

6. OUTPUT EXAMINATION

a) Introduction

The input data file for the reference flask as listed in Appendix A was submitted for execution by MONK6. This section will follow through the output from this calculation, selected pages from which are included in Appendix C. The process of input data checking and processing will be considered and each table of computed quantities will be examined; where appropriate optional variations to the standard output will be described.

b) Input Data Verification and Processing

MONK6 contains a large number of built-in input data verification checks which as far as pc ble ensure that the data supplied is acceptable. This means the code checks the data supplied agains the rules of construction as laid down in the User Guide [9], as well as performing a large number of trivial checks to try to locate mis-typed or missing information. What is not checked, and indeed what would be impossible to check, is that the data makes good criticality sense; that is for the user to ensure. During execution certain extreme calculations will cause the code to terminate prematurely, and although the real physical cause for the termination may not emerge from the code's diagnostic messages, what is printed will normally be a good guide to enable the user to locate a data error.

It is the intention of the code authors that all the input data verification error messages should be self-explanatory. That happy state of affairs may not have been quite reached yet, but any user problems that do occur normally result in improved or additional diagnostic messages. Thus a list of error messages, apart from being too voluminous, should be unnecessary. However although the reference calculation runs to normal completion, the cause of potential user errors will be considered when appropriate in this section.

It should also be noted that although the code can check much of the data for consistency, if ite of data are omitted by the user or if additional illegal data are supplied the code termination message may be quite confusing. This is because within any section of input data the code can only examine what it has read against what it expected to read. If the two are of different type (e.g. one a keyword and one a number) then the code's interpretation of the error may only point in the direction of the real error rather than locate it precisely.

The first pages of output contain various headings and general information regarding the ANSWERS service, the status of the code and details of the version being employed. A message box updated by the local system administrator is also included which should contain information concerning any current problems and errors.

The output listing proper starts with a listing of the input data supplied to the code. As well as being a useful summary of the data (plus comments), it can be helpful in locating input errors as in some parts of the code errors are flagged before a full interpreted listing of the data is printed.

The code continues by rewinding this input file and reading each section of data in turn, with any comment lines being printed as they are read. Note that the code employs a free-format data reading package (called DECIN) and the input is largely keyword driven. Thus as the code often looks ahead to see whether an optional keyword has been specified, comment lines sometimes appear in the output at odd locations. The initial comment lines (and there must be at least one) are now mirrored in the output file. The next page contains a banner detailing the type of calculation (normally FISSION tracking for a k-effective calculation), and the time and date, followed by a statement giving the number of single length storage locations available.

Most of the MONK6 input data and output scores are stored in a single large FORTRAN array within the code. On most installations the size of this large array is fixed at some dimension which will be suitable for the vast majority of criticality calculations. The size of this array can also have an effect on the computer usage efficiency of the code, especially on workstations, and so it has been chosen so that an average workstation can accommodate a MONK6 calculation without a serious degradation in performance. For particularly large calculations a version of the code with a much larger array may be required, provided that the host computer has sufficient memory resources.

The single large array contains a mixture of FORTRAN integers (normally 4 bytes each), single precision reals (normally 4 bytes) and double precision reals (8 bytes). The majority of the space required by a MONK6 calculation (e.g. > 95%) is taken by the point-energy nuclear data. Due to its large volume (there are 8220 energy groups employed) and because the raw source data is only available in limited precision, the real nuclear data are stored as single precision numbers. All of the remaining real data are stored as double precision numbers, and all of the code processing is performed using double precision arithmetic. This is done to reduce the probability of encountering rounding problems close to geometric boundaries and to make it extremely unlikely that any scored quantity will become saturated in normal calculations. Saturation here means that a very large number is having a very small number added to it, and the difference in magnitudes is outside the precision of the arithmetic; in this case the very small number will effectively be set to zero which can lead to biased scores.

The first message concerning the storage therefore gives the number of single length locations (normally 4 bytes) as the nuclear data are to be read and processed first. This is followed by an interpreted summary of the material data specified in the input data headed by a list of all the nuclides available in the point energy library. This gives for each nuclide a data file number (DFN) and nuclide name; if NUCNAMES is being employed the DFN is redundant. A list of the nuclides available in alphabetical order together with their atomic weights is given in the Chapter 1 Appendix A of the User Guide [9].

Two tables are then given in the material data interpretation, the first of which reproduces the material data supplied by the user with the method of specification for each material (i.e. CONC,ATOM or WGT) and the density (for the ATOM and WGT options) on the left. The second table is similar except that it just gives nuclide concentrations (in atoms/barn.cm) for each material, the ratios for the ATOM and WGT options having been converted. Note that the temperature appears in the first table; this is always 293K and cannot be changed by the user at present. This section ends by specifying the units of the geometry dimensions (centimetres or inches).

At this point the code has read all the problem-specific nuclear data but has not accessed the point-energy library (except to produce the nuclide index). The next step is to read the data required for each nuclide employed from the library and create and store the probability sampling distributions and

score contribution tables employed during the Monte Carlo tracking; a description of the data stored is given in Chapter 1 of the User Guide [9]. The library contains cross-sections for each reaction of each nuclide; each nuclide may of course have a different number of reactions tabulated although all will have at least an elastic scatter and a parasitic absorption reaction. In addition the library has general nuclide data and secondary particle information, including their distribution by energy and angle. All of this needs to be read and combined to create tables suitable for rapid access during the calculation proper. Some of the data tables created will be material specific (e.g. mean free paths, expected number of fission secondaries (used to score k-effective)), whilst other tables will be nuclide specific (e.g reaction probabilities) and reaction specific (e.g. secondary emission data). The amount of data involved for an average calculation is quite large (~4Mbytes), and processing it requires a large number of operations to be performed.

When the processing is complete a summary of the data is produced by DICE (the point-energy collision processing package). This lists the built-in adjustments to the basic nuclear data that have been employed by the code (see Chapter 2 and 3 of the MONK6 Supporting Document [2]); a standard set of adjustments are built into MONK6 to create a library suitable for a large range of criticality calculations. The actual number of single length locations employed and the time taken to process the nuclear data are given. For the reference transport flask the nuclear data occupies over 800,000 locations, and this is after considerable optimisation and compression within DICE.

A summary of the material data now appears which supplements the user-supplied input with information taken from the library. The proportion by atom (normalised) appears for each nuclide of each material, as does the density of each material, even where these items were not supplied by the user. This can be a useful check that any concentrations supplied in the input data were sensible. This section of the code concludes by printing the number of location remaining in the main FORTRAN array for the other data and the scoring space; note that for the reasons described above this has now been converted into double length storage locations.

Due to the amount of space occupied by the nuclear data there is always the possibility for big cases that the main FORTRAN array will not be large enough for the materials and nuclides specified. This will normally be reported by a terminating error that starts:

NOT ENOUGH SPACE IN THE MAIN ARRAY FOR NUCLEAR DATA

and finishes with:

INCREASE SIZE OF MAIN ARRAY AND RESUBMIT.

Some computers have a storage allocation facility called dynamic allocation. In these cases the actual size of the single large array can be supplied as control or input data by the user, and in these cases the user can simply increase this value and resubmit the calculation. For most of the micro-computer implementations of MONK6 this is not the case and a new version of the code is needed with a main array fixed at some larger value. In both cases there is obviously a real physical limit on the maximum size that the main array can take, imposed by the virtual or real memory size of the host computer.

An alternative to using a version of the code with a larger array is obviously to reduce the amount of

nuclear data that the case actually needs. The amount of space required by a nuclide varies greatly as different nuclides have different numbers of reactions tabulated, and different quantities of secondary particle data. In addition there is a certain amount of material data, the size of which depends on the number of nuclides in the material. An approximate formula that can be used to estimate the likely space required is:

SPACE (in single length locations) = (3*Number of materials + 6*Number of nuclides +
Total number of nuclide occurrences) * 8220

where in the reference flask calculation the number of materials is 6, the number of nuclides is 11 and the total number of nuclide occurrences is 15 (material 1 has 3 nuclides, material 2 has 2, material 3 has 5, material 4 has 3, material 5 and 6 each have 1).

Note that the error on the space predicted by this formula is estimated at about 20%, so it is not very useful for accurate predictions, but it can be used to choose the optimum way of reducing the amount of nuclear data by removing materials, nuclides or a mixture of the two from the model. If any nuclide other than one present in a trace quantity is to be removed from the model then some knowledge of the nuclear interaction properties of that nuclide is required, so that the approximation is acceptable from a criticality viewpoint.

The next section of the output is an interpreted summary of the simple body geometry. This summary is not produced until all the simple body geometry has been read, and so any errors in the input data that cause the job to terminate will appear before the geometry data is printed. The summary of the data is self-explanatory with the properties of each part being listed in turn. The volume of each scoring region is computed wherever possible. For bodies that overlap within a cluster it is not possible to calculate volumes analytically and so the appropriate space in the table contains the ordinal clump number and the dominance integer, except for the container which just has the title OVERLAPPED as it does not explicitly belong to any one clump and always has the highest dominance integer. If any bodies are rotated the transformation data are printed in a sub-table after the appropriate part table; otherwise the title NO ROTATIONS appears. Array part types are printed with the direction with the largest dimension appearing across the page. The simple body geometry summary is completed by the details of the boundary conditions, even when the default free-boundary conditions apply. At this point in the code some further simple geometry checks are made, for example checking that the array part types fit together properly and that any overlap data are consistent.

The simple body geometry summary is followed by an interpreted summary of the hole geometry data which is printed for each hole geometry as its data are read. Therefore any error messages that may appear will refer to the current hole geometry. This table is again self-explanatory and follows the order of presentation in the input data, although some of the terminology used for certain of the older hole geometries may not exactly match that used in the more recent User Guide [9]. Some consistency checks are made for each hole, for example checking that pins within the lattice-type holes do not overlap, and the hole preliminary data material lists are checked for consistency with the materials used by the hole and any subsidiary holes.

At this point in the calculation the main simple body geometry checking is performed. This consists of comparing each pair of bodies within each nest and cluster and determining using a numerical minimisation algorithm, whether the bodies overlap or not [10]. The result is compared with that ex-

pected according to the rules of construction for the part type (taking account of any overlap d. for a cluster) and if the data is invalid an error message is printed. If an error is discovered the calculation is not terminated immediately, and the remaining parts are checked first. Passing successfully through this section only means that the geometry obeys the rules for the creation of nest and clusters; the geometry could still be engineering nonsense and this aspect must be checked by using SCAL 6.

The edit data section normally consists of entirely default options. The code prints how the action counts (reaction rates) are to be scored in energy partitions; the default number of partitions is three corresponding to a fast, intermediate and thermal zone. The values can be changed by employing the edit data PARTITION keyword. This can be used to split up the default nine-group scheme (see Chapter 3 Unit 1 note 3 of the User Guide [9]) into any number of partitions. For example to score the reaction rates in just one partition (i.e. the whole energy range from 0 to 15MeV) the data required are:

EDIT PARTITION 1 9

where the keyword EDIT introduces the edit data section (i.e. it has been assumed that it does yet exist), the number 1 means just 1 partition and the number 9 means that the partition runs from energy group 1 through to 9. For two partitions the data could be:

EDIT PARTITION 2 8 9

giving a thermal and epi-thermal partition. For a energy split of one partition per energy group:

EDIT PARTITION GROUPS

could be specified.

If some other inherent group structure is required this needs to have been specified in Unit 1 Item 8 of the input data; the edit partitions are then based in these groups rather than the default scheme.

The default energy group structure for the neutron fluxes is the reaction rate energy partitions a[redacted] any change made there using the PARTITION keyword will also apply to the fluxes. If it required to score the neutron fluxes in the default energy group scheme (nine groups) or some other group scheme defined as above then the OPTIONS keyword is required to change the sixth trigger from 2 to -2 so the data would be:

EDIT OPTIONS * * * * * -2

The most useful of the other EDIT data options is the CATEGORY keyword which requests that the calculation be categorised according to certain characteristics of the system; this information can be used to investigate possible biases in the nuclear data and to identify systems outside the current validation range of the code.

The control data section merely summarises the supplied and default calculation control parameters. The default mode of tracking for k-effective calculations is superhistory tracking with a maximum of

ten generations per stage; there will rarely if ever be any need to change this number. The value of ten has been chosen as a best compromise between efficiency and the need to produce a stable and unbiased calculation. The other superhistory parameter is the υ-value multiplier (the number of neutrons produced per fission collision) which should be equal to 1/k-effective to ensure that neutrons survive the required number of generations. The code can soon determine its own value for this and all that is required is a starting approximate value. The default starting guess of 1.0 is suitable for the majority of normal criticality calculations, but for certain survey calculations a better estimate of 1/k-effective may improve the efficiency of the settling stages. For example for as case where it is expected that the k-effective is very low, say≈0.3, then the following data would improve the settling efficiency:

SUPERHIST 10 3.0

However provided that a sensible initial source distribution is supplied there will be no need to amend the default value for the majority of systems.

The phrase:

NO STATISTICS WILL COUNTED UNTIL STAGE 1

in the control data printout means that the stages before stage 1 (e.g. stages -1 and 0) will be used only to settle the initial source guess, and will not be used to calculate any of the scored quantities. The phrase:

SOURCE USED TO START FIRST STAGE ONLY

means that under normal circumstances the initial source guess will just be employed as the source for the first settling stage (e.g. stage -1), after which the neutrons that pass through ten generations will form the source for the next stage. In extreme cases a poor source selection and an inappropriate value for the υ-value multiplier may mean that no neutrons actually pass through ten generations; in this case the source that was used to start the previous stage will be re-employed.

The final part of the input summary contains details of the initial source guess. Normally the user supplies a spatial distribution (e.g. MULTIFISS, FISSILE, VOLUME or POINT) and accepts the default energy and directional distribution. This default is that the energy is selected from a typical U235 fission spectrum and the direction is distributed isotropically. It is possible to change both of these items although it will rarely be necessary to do so for the majority of criticality calculations.

The final statement gives the number of locations used by the non-nuclear data. This includes all of the data and the space allocations that will be used to accumulate the scored quantities and their standard errors. For the reference flask this amounts to 7336 double length locations (equivalent to 14672 single length locations), compared with the 807129 single length locations required for the nuclear data. Thus over 98% of the storage used is taken by the nuclear data, which is fairly typical for a point-energy MONK6 calculation.

During the course of the non-nuclear data reading it is of course possible that the large FORTRAN

array will become full; this will be flagged by an error message of the form:

INSUFFICIENT SPACE IN MAIN ARRAY - INCREASE SIZE AND RESUBMIT

Similar comments apply to those for the similar failure during the nuclear data reading section, as any reduction in the total size of the model will almost certainly mean some reduction in the nuclear data, unless a particularly large geometry model has been created. If this latter situation applies it is worth noting that scoring space needs to be assigned for the various quantities, some of which depend of the number of scoring regions, the number of energy partitions or both. In addition for each scored quantity (e.g. the flux in scoring region 1 group 1 or the boundary crossings into scoring region 1) four double length locations are required. These hold the current superhistory score, the cumulative total score, the cumulative sum of squares and the cumulative sum of cross products of score with sample weight (see later in this section when the scoring of k-effective is described). Thus is some cases the balance of storage may be such that some small economy in the scoring space (e.g. reduce the number of energy partitions) may be enough to fit the model into the available space.

This concludes the input data listing, and this is marked by the large MONK OUTPUT banner occupying a page to itself. The remainder of the printout contains all the quantities that have been scored during the course of the Monte Carlo tracking; copies of certain tables from the reference flask calculation are included in Appendix C. The first page of scored results lists the collision counts for the settling stages. Normally this is of little value but can give some indication on the suitability of the initial source guess.

The first table giving results for the scoring stages (stage 1 onwards) lists the total collision counts for each stage, both individually on the left and cumulatively on the right (Appendix C Table 1). The STAGE column is exactly what it says and the SAMPLE column gives the total number of neutron fission-to-fission histories. A default superhistory consists of about 10 such histories as the υ-value multiplier is employed to approximately simulate a critical system. Each fission-to-fission history consists of a single generation neutron emerging from a fission and finishing when escaping, being captured or causing further fission.The SCAT/SCATTER column gives the total number of single neutron emission scattering events (elastic and inelastic), the CAP/CAPTURE column gives the number of parasitic capture events (normally (n,γ)), and the FISS/FISSION column gives the number of fission events.

The next two columns (CHILD/CHILDREN and SCORE) are used to form two estimates of k-effective. The CHILDREN are simply the total expected number of neutrons emerging from all the real fission events (with the superhistory υ-value multiplier removed), and this total is used to form the simplest estimator of k-effective, which is the ratio of the number of neutrons in one generation to the number in the preceding:

$$k_{COLL} = \frac{\text{total number of neutrons emerging from fission}}{\text{total number of neutrons}} = \frac{\text{CHILDREN}}{\text{SAMPLE}}$$

The numerator in k_{COLL} can be obtained another way by scoring the expected number of fission neutrons to emerge from a collision at every collision, rather than the actual number emerging from just the fission collisions. This leads to a quantity in the table headed SCORE and another estimate of

k-effective:

$$k_{SCORE} = \frac{SCORE}{SAMPLE}$$

k_{COLL} and k_{SCORE} are both unbiased estimators of k-effective (i.e. they both have an expected value equal to the true k-effective), and on average are equally efficient (i.e. they will normally have very similar standard errors). The printing of the values of the k-effective estimators is reserved for the next table. The remaining items in the first table give the event count for escaping neutrons (leakage), and multiple-emission scatter events ((n,2n) and (n,3n)).

The outcome of all neutrons tracked is accounted for in this first table. Each of the SAMPLE neutrons is eventually captured, causes a fission or escapes from the system. The definition of SAMPLE is that is is a count of the single generation neutrons, thus neutrons emerging from multiple emission scattering events are of the same fission generation as the neutron that caused the event, and therefore part of the same SAMPLE. Therefore a simple neutron balance applies to this first table:

SAMPLE = CAPTURE + FISSION + TOTESC - TOTN2N - 2*TOTN3N

Although this table contains no actual k-effective estimators explicitly it is a useful global summary of the calculation and the fate of the neutron samples.

The second of the main stage-by-stage tables (Appendix C Table 2) gives the main k-effective estimators and their standard errors. The following is a formal definition of all the k-effective estimators produced by MONK6.

During the course of each superhistory four basic quantities are scored in order to calculate k-effective. The are:

(i) H_m - the total weight of the m^{th} superhistory, which is the sum of the weights of all the histories in the superhistory; this is the quantity head SAMPLE in the first output table

(ii) - the total expected real fission production in the m^{th} superhistory, which is the weight multiplied by υ for all real fission events (FISSION)

(iii) F_m - the sum over all collisions of the expected fission yield at each collision for the m^{th} superhistory; this is the value $\upsilon\Sigma_f/\Sigma_t$ at the collision point multiplied by the neutron weight (SCORE)

(iv) L_m - the sum over all collisions of the expected nett absorption at each collision for the m^{th} superhistory; this is the value $(\Sigma_t - \Sigma_{n,2n} - 2\Sigma_{n,3n} ....)/\Sigma_t$ at the collision point plus the real leakage (if any) at the end of the superhistory multiplied by the neutron weight.

Note that F_m and L_m are scored (appropriately weighted) at hole pseudo collisions, so that these artificial collisions are not entirely wasted.

At the end of each superhistory the four cumulative totals are updated, in order to estimate the mean values:

$$\Sigma H_n, \Sigma R_n, \Sigma F_n, \Sigma L_n$$

the four sum of squares totals are updated, in order to estimate the variances:

$$\Sigma H_n^2, \Sigma R_n^2, \Sigma F_n^2, \Sigma L_n^2$$

and the six cross-product totals are updated, in order to estimate the covariances:

$$\Sigma H_n R_n, \Sigma H_n F_n, \Sigma H_n L_n, \Sigma R_n F_n, \Sigma R_n L_n, \Sigma F_n L_n$$

The end of each stage is used to produce a monitor point showing the progress of the calculation. The means, variances and covariances are calculated at these point as follows (with X and Y taken to mean any of H, R, F or L and N is the number of superhistories):

$$\bar{X} = \Sigma X_n / N$$

$$S_x^2 = \{ N\Sigma X_n^2 - (\Sigma X_n)^2 \} / N(N-1)$$

$$S_{xy} = \{ N\Sigma X_n Y_n - \Sigma X_n \Sigma Y_n \} / N(N-1)$$

which gives the best estimates of $\langle X \rangle$, σ_x and σ_{xy} respectively.

These are combined in various ways to produce the k-effective estimators and their variances.

The two basic k-effective estimators described above can now be defined as:

$$k_{COLL} = \Sigma R_n / \Sigma H_n$$

$$k_{SCORE} = \Sigma F_n / \Sigma H_n$$

The estimator k_{BASIS} makes use of the fact that F_n and L_n are highly correlated in many systems, leading to an unbiased estimator with smaller variance than either k_{COLL} or k_{SCORE}. k_{BASIS} is defined as:

$$k_{BASIS} = \{ \Sigma F_n + \lambda \Sigma (H_n - L_n) \} / \Sigma H_n$$

where λ is a constant. In the MONK6 output a quantity A (the nett absorption per sample) is printed which is defined as:

$$A = \Sigma L_n / \Sigma H_n$$

and as A accounts for all the possible fates of the sample it has an expected value of 1.

If R_m is also included into a further estimator to take advantage of its smaller correlation with L_m and F_m, the recommended estimator k_{THREE} is obtained:

$$k_{THREE} = \{ \alpha\Sigma R_m + (1-\alpha)\Sigma F_m + \beta\Sigma(H_m - L_m) \} / \Sigma H_m$$

where α,β are constants.

The above estimators are termed individual sample estimator because the sum of squares and cross-products are accumulated at the end of each independent sample (i.e. superhistory). This assumption that the superhistories are independent has a small enough error to be neglected for practical purposes when ten generations per superhistory are performed. For fewer generations, and especially for single generation ordinary tracking, there may be some biasing of the mean and variance introduced by this assumption.

The second stage-by-stage table contains all the k-effective estimators and the constants used in their calculation. Thus the columns headed by the k-effective estimators are as defined above; λ,α andβ are the constants used to form k_{BIAS} and k_{THREE}, and R(S,A), R(C,A) and R(C,S) are the correlation coefficients between the estimators k_{SCORE} and A, k_{COLL} and A and k_{COLL} and k_{SCORE} respectively.

In many cases, due to the limited correlation between k_{COLL} and A, k_{THREE} is only slightly more efficient than k_{BIAS}; however it is never less efficient and so k_{THREE} is regarded as the standard MONK6 k-effective estimator. The variance reduction achieved by k_{THREE} over k_{COLL} or k_{SCORE} is often a factor of between 2 and 5 on the running time to achieve a given standard error. This is achieved simply by extracting the maximum information from the scored quantities.

This second table can be employed to check on the adequacy of the settling and Monte Carlo sampling of the problem. Problems can be caused by lack of settling and most importantly employing insufficient neutrons per stage (see section 4e). The advice already given should alleviate the majority of problems, but the code cannot be treated as a black box. If insufficient settling was performed the initial stages of the calculation will be overly contaminated with neutron distributions other than the fundamental one; this can be detected by large fluctuations in the values of the k-effective estimators. Some variations will always be visible due to the random fluctuations of the Monte Carlo sampling and because the other distributions cannot be entirley eliminated, but it should always be believable when the statistics are taken into account.

Although the k_{THREE} estimator is recommended for k-effective calculations the other estimators are all unbiased estimators and their values should be consistent within the statistical uncertainties. Further the expected value of A is 1 as it accounts for the ultimate fate of all the neutrons in the problem, and this can be checked within the statistical uncertainty. If problems are observed here then it is likely that insufficient neutrons per stage have been employed to represent the neutron distribution and the calculation may well be biased; it cannot be stressed too much that a large number of neutrons per stage will help eliminate settling/sampling problems for most calculations.

In addition to the k-effective and A estimators the constants and correlation coefficients should also appear fairly well settled as the calculation progresses. However the main checks are applied to the four k-effective estimators (which all have the same expected value) and the value of A, together with their standard errors and the question that needs to be asked is 'are the values statistically sensible?'.

Upon examining the reference output, the k-effective estimators are all consistent, as the differences between their final values are well within the statistical uncertainty (e.g. the difference between k_{COLL} and k_{SCORE} is 0.0039 and the standard error on the difference is the square root of the sum of the variances which is 0.0055). The value of A is within one standard error of its expected value (which should be the case 68.3% of the time); remember A should only fall outside two standard errors of unity about one time in twenty if sufficient neutrons per stage have been employed. In addition the values of λ,α and β are reasonably well settled (this is difficult to quantify) and there are no wild swings in k_{TRACK}. Thus on the evidence of this table the run would appear to be acceptable although there are a number of other things to check later.

The following two tables contain further information which can be of use when examining the output for adequacy of sampling and settling. However with the introduction of superhistory tracking and provided the guidelines concerning the size of the neutron population are adhered to they are now of more limited use.

The first of these tables (Appendix C Table 3) gives estimates of k-effective and A from the scores for each stage independently. Provided sufficient settling has been performed and enough neutrons per stage have been utilised the values should be acceptable estimates of k-effective and A based on typically several hundred superhistories, and no large variations should be observed; such variations can easily be effectively hidden within the cumulative table. For the reference calculation the stage values differ very little, with those for the first stage statistically indistinguishable from those for the last, and with little observable variation during the calculation. This gives further confidence in the sampling of the problem.

The second of these tables and the final stage-by-stage table gives the variation of the main estimators with the number of settling stages (Appendix C Table 4). Here the user is presented with a picture of what would have happened if more (and less) settling stages had been performed. The main use of this table is to examine the variation of k-effective with the number of settling stages. The line corresponding to 2 settling stages is obviously the actual result given in the first k-effective table, and for the reference case increasing or decreasing this number has little effect on the values, suggesting again that the settling is satisfactory. It will be seen that the minimum variance estimates are obtained for 0 settling stages. Unless the starting source is exceptionally poor this will almost always be the case due to the heavy dependence of the variance on the number of superhistories. However this does not mean that this value should be used as the best estimate of k-effective, because unless the starting source was extremely good, an unacceptable bias will almost certainly be present at that stage.

The final page of the k-effective print contains a banner giving the final value of k_{TRACK} for easy reference, and gives the time taken, last stage number and last random number. These last two values have also been saved in the restart file if that is produced. A restart file (which enables the calculation to be continued from where it left off) can be requested by supplying the keyword PUNCH in Unit 4.2 Item 9 of the input data. This means that a file (possibly quite large) containing the current neutron distri-

bution and all the scored quantities to date will be saved, and this file may be used to obtain a more precise calculation by restarting the run. This is the only reason for performing a restart run. If a case has visibly not settled it should be re-run from scratch with more neutrons per stage and/or more settling. A better approach than extending a calculation is to perform independent calculations and combine the results as described in section 4e. More than one consistent independent calculation not only adds greatly to the confidence in the result, but also gives a further chance for any unexpected sampling problems to be revealed. Note that the restart file will be produced automatically whether it was requested or not if the time allowed for the job expires before the requested number of stage can be completed, or when the job satisfies a requested standard error limit inside the requested number of stages (using the STDV option in the control data). The production of a restart file will be noted on the k-effective banner page, before the final random number is printed.

In order that the results from a calculation can be employed to give confidence limits for safety margins (i.e. $k + 3\sigma$), a reasonable size calculation is required; otherwise the 99.7% confidence limit arising from the central limit theorem may be invalid. It is recommended that a precision of at least 0.005 should be aimed for as adequate for criticality assessments, with a precision of 0.003 being achieved whenever possible. With the advent of much cheaper computing (e.g. a workstation is estimated to give computing over fifty times cheaper than a mainframe operated by a bureau), some of these savings should be put back into doing better calculations. It is recommended that this means using superhistory tracking with ten generations, more neutrons per stage (≥600 for all but the most trivial geometries), more settling stages (at least 2) and longer calculations (to a precision on k_{mean} of 0.003). The final criterion could also be reached by a combination of two independent runs, each individual run calculated to a precision on k_{mean} of 0.0045. For today's top performance workstations this can be comfortable achieved for most problems in well under an hour of computer time.

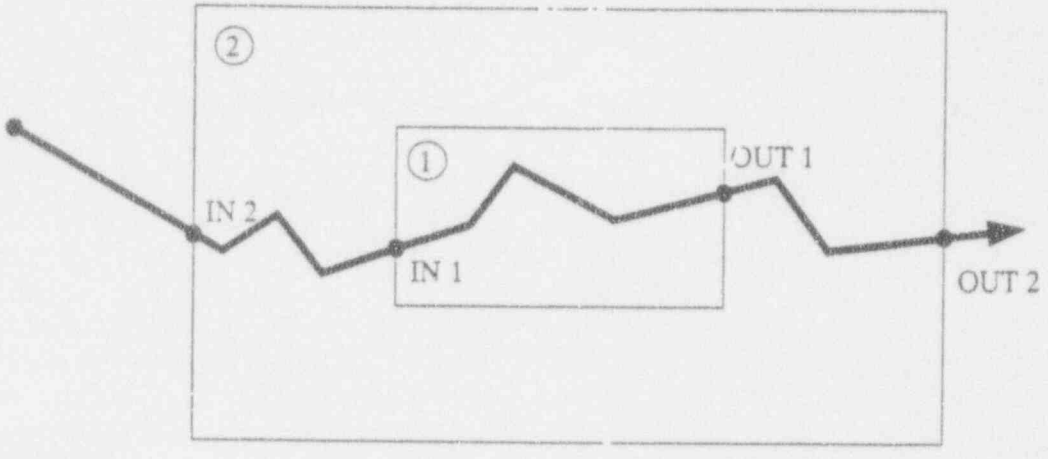
The first of the MONK6 detailed scoring tables gives the spatial distribution of the initial source by scoring region. These region numbers are defined in the geometry summary and refer to the space within the simple body boundary that holds the contents of that body (e.g. for a nest the scoring region is the annular space between the simple body boundary and the next one in). For the reference case this table is given in Appendix C Table 5 and shows the distribution of the 600 source points within the flask. Obviously the level of information contained here is determined by how the geometry is constructed, so having employed the SAME keyword some sub-division of the spatial distribution is available; however some parts have been employed twice so the score for those parts is a combination of the score from the two locations; therefore this table (and the other based on scoring regions) required careful interpretation. The MULTIFISS source spread over the flask should result in about 600/14≈43 source points per element (note that this is less than one per pin on average). Examination of the table for the reference calculation shows that scoring regions 1,4,7,10,13 and 19 (containing the fissile material zones within parts 1,2,3,4,5 and 7) do each have about 86 source points (2 occurrences each) and scoring regions 16 and 22 (parts 6 and 8) have about 43. Provided that the source was correctly specified any variations from the expected values are only random fluctuations; however this table is a good check as to whether the source was correctly specified.

In common with the other scoring region-based tables (except the neutron flux) the scores are effectively carried up the hierarchic geometry part tree (see the diagram in section 4a). Region 25 corresponds to part 9, which is the array forming the bottom row of elements consisting of parts 5,6 and 5 again. Thus the score for region 25 is the sum of the scores for parts 5 and 6, namely 140−98+42. Similarly region 26 corresponds to the central array and region 27 the top row. Region 28 corresponds to the simple body in the cluster holding the array of region 27 and so the scores are the same; similarly

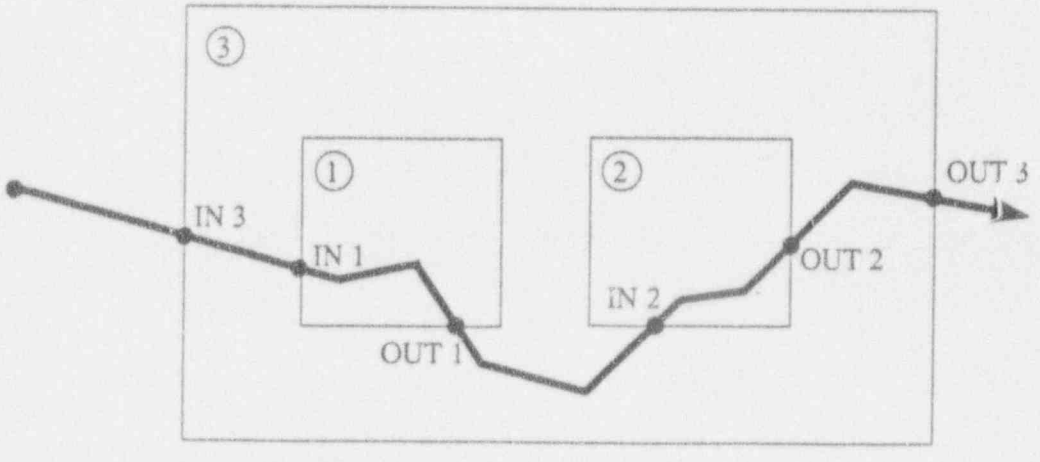
for regions 29 and 30. Finally region 32 is the inner body of the nest that holds the fuel elements and so its score is 600. The standard deviation in each case is simply that arising from the Poisson distribution ($\sqrt{n}$).

The second of the auxiliary tables gives the boundary crossings for the simple bodies. It should be noted that this table and those that follow are by default normalised to 10,000 neutron samples. This is done to give some scale to the scores and enable calculation of varying sizes to be readily compared. The boundary crossing table can be used to assess the degree of isolation of various components of a system, for example to examine the separation effectiveness of a thickness of water or an absorbing plate. For the reference calculation this table is given in Appendix C Table 6. This clearly demonstrates, due to the large numbers of IN and OUT boundary crossing for the various elements within the multi-element bottle that there is a large interaction between the elements (as expected).

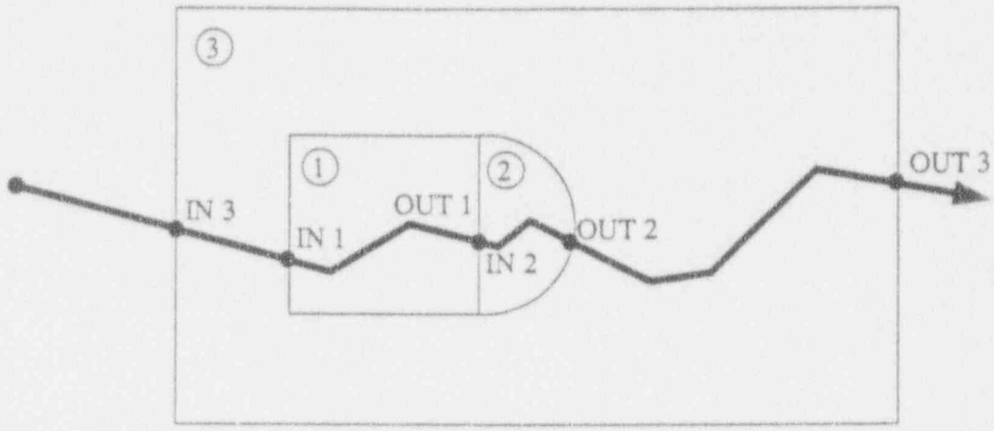
In order to make effective use of this table the definition of IN and OUT needs to be fully appreciated. For a nest and a simple cluster (i.e. no overlaps) the boundary crossings are easily defined, as they refer to neutrons crossing simple body boundaries; note that they do not refer to neutrons entering scoring regions as the following drawings show. For a nest the scores are accumulated as follows:

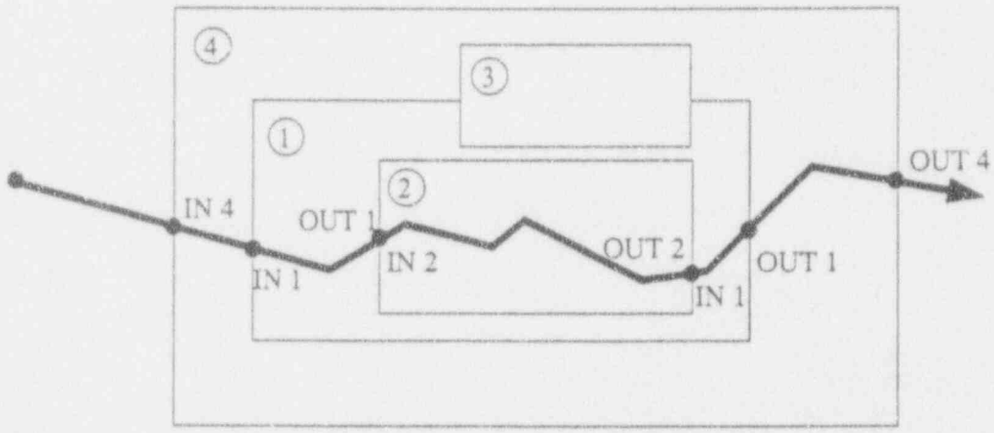


and for a simple cluster as follows:



However for general clusters the scores need more careful interpretation as they are accumulated by scoring region for bodies forming clumps, as the following two diagrams show:





This apparent anomaly occurs because the cluster geometry tracking algorithm has no knowledge of the relative positions of the overlapping bodies. On exit from a scoring region within a clump (which does not necessarily correspond to crossing a simple body boundary) the algorithm will search for the next body to enter in exactly the same way as if the bodies were distinct. The boundary crossings therefore reflect this.

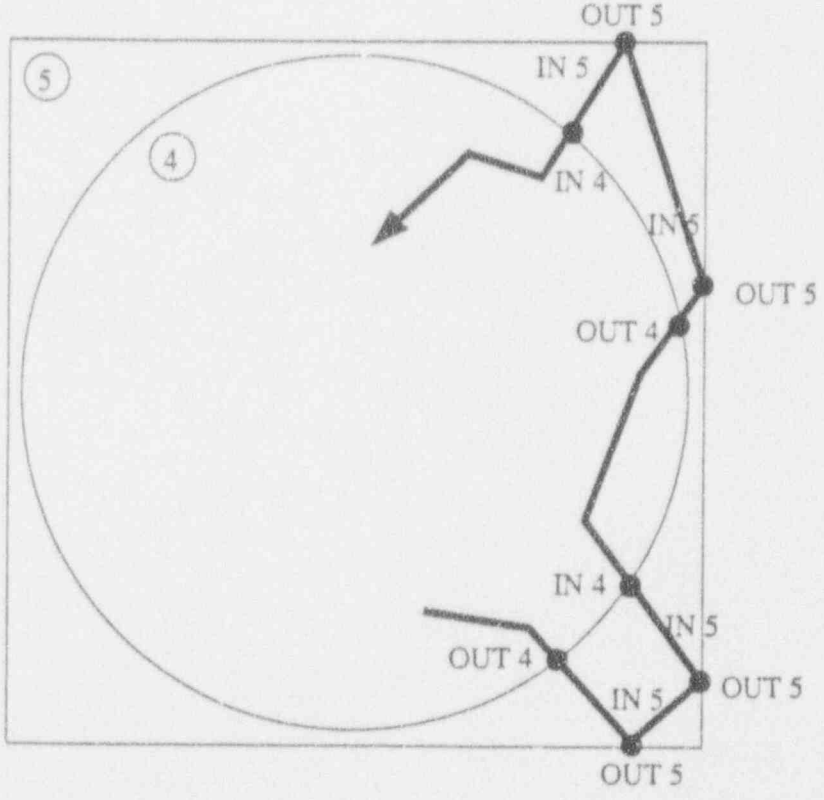
The boundary crossings can also be employed to examine the sampling within the system to a limited extent, by ensuring that bodies expected to see a lot of neutron activity actually do so. In the reference case this is indeed the case with the central elements (parts 1 and 2) seeing more neutron activity in terms of boundary crossings than the other parts, due to their more reactive locations (i.e. completely surrounded by other elements).

Having decided to impose full specular reflection on the outer boundary of the system (for a pessi-

mistic criticality calculation) some information on the number of neutrons reaching the outer boundary of the system has been lost. Results from a similar calculation with a free boundary condition were as follows for part 13:

REGION	IN	OUT
1	956	1584
2	939	1359
3	838	1238
4	0	135
5	0	135

This shows that of the 1238 neutrons (per 10,000 samples) that enter the main flask wall only 135 (≈10%) reach the outside. Thus it is clear that the flask wall thickness is sufficient to isolate the fuel elements from the outside as far as criticality interaction is concerned. This information is missing from the reference calculation as the IN and OUT scores will mainly consist of neutrons continually entering and leaving the flask and others just bouncing around the reflective boundary:



The final part of the boundary crossings table gives the energy distribution by partition of the neutrons reaching the outer boundary of the system, but it excludes those being reflected back by a full re-

flective boundary. Thus for the reference flask the scores are zero. For the calculation mentioned above with a free boundary, of the 135 neutrons leaving the system 93 were in the fast partition (>0.1MeV) and 42 in the intermediate partition (between 0.1MeV and 0.4 eV).

In some calculations this final part of the table can be used to examine the validity of employing a particular thickness of reflector or of employing non-unit albedo coefficients to simulate additional reflector. The albedo coefficients approximately represent the return probability for an incident thermal neutron, otherwise biases of unknown size may be introduced. To avoid these problems it is recommended that sufficient real material reflector thickness be included in the model for assessment calculations, thus completely avoiding the use of the non-unit albedo coefficients, although for survey and design work their use may be more appropriate. In the reference model the full body thickness of the flask has been included and an infinite array of such flasks has been modelled in the calculation.

The next table presents the material action counts or reaction rates for all the materials in the problem. This information is presented for each nuclide in each energy partition for each material. All of the possible reactions tabulated in the DICE library are put into one of six generic types: capture, fission, elastic scatter, inelastic scatter, (n,2n) and (n,3n). An example table for material 1 (the fuel) from the reference calculation is contained in Appendix C Table 7.

This table can be employed to distinguish between different parts of the same material by the simple technique of duplicating materials. If the U235 fission rate was required separately for the central four fuel elements then an additional material (material 7) could have been specified which was an exact copy of material 1. Then for parts 3 to 8 the contents of the inner body of the nest could have been a new hole (hole 4) which had material 7 in its pin material. Note that part 3 would now need to be LIKE part 1 rather than the SAME as part 1, and parts 4 to 8 would now be the same as part 3. The revised input data for parts 3 to 8 could be:

```
LIKE  1   BH4  2  3
SAME 3
SAME 3
SAME 3
SAME 3
SAME 3
```

and the fuel material action counts would now be split between material 1 and 7 according to the location of the fuel element.

As far as checking is concerned the material action count table should be used to ensure that all materials behave as expected, e.g. if gadolinium is present in some quantity and the material data have been correctly specified then gadolinium should score a large number of capture reactions. If it does not then there could be an error in the material or geometry specification.

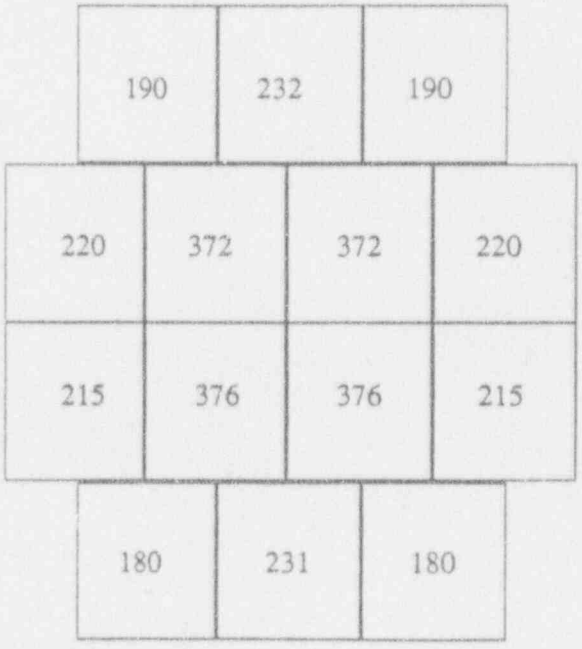
The neutron gain value printed for each energy partition is the neutron balance for the reactions within that energy partition. It is computed as:

GAIN = FISSION CHILDREN + (N,2N) + 2*(N,3N) - CAPTURE - FISSION

Note that although the FISSION CHILDREN is printed as an integer it is scored as a real number (υ, the expected number of fission children). Only an integral number of neutrons can be tracked (randomly sampled from the real value), but less variance is introduced by actually scoring the real expected value. As the neutron gain is also printed as an integer, due to the rounding of the individual fission children scores that make up the gain, the gain sum may not appear to tally exactly. It is the printed gain that is the better estimate than that computed from the printed integral values.

The region action count table presents similar information concerning reaction rates but now by scoring region (Appendix C Table 8). The number of reaction types has been reduced by combining the various types of scattering reaction into a single quantity for clarity. In a similar way to the use of the previous table for material sampling, this table can be employed to check for geometry sampling. As for the boundary crossing table, what is obtained here is dependent on how the geometry was constructed, so if specific information is required (e.g. reaction rate by fuel element) this must be considered at the geometry modelling stage. Note that this table also has the information carried up the hierarchic geometry part tree.

This table can be employed to see whether that various sections of geometry have been adequately sampled. If the sampling appears to be not as expected, it must be determined whether it actually matters as far as criticality safety is concerned. As stated in the geometry modelling description, for symmetric geometries lack of sampling uniformity about the plane of symmetry is unimportant, and this has been eliminated from the reference calculation by the duplication of parts. Superhistory tracking will normally seek out the most reactive part of the system [11,12] provided sufficient neutrons per stage are employed and sufficient settling has been performed. The region action count table can be used to check whether that has actually happened. If the distribution of fissions by scoring region is examined for the reference calculation, the following picture emerges (in fissions per 10,000 neutrons):



Note that where parts are employed twice the score has been halved. This shows that as expected the central elements are the most reactive as they are completely surrounded by other elements. Of the other elements the central positions in the top and bottom row are most reactive (slightly more so than the central side locations) as they are surrounded on three out of four sides by other elements. Within the statistical uncertainties there appears to be symmetry about the horizontal centre of the fuel element cluster, indicating that the fact that water is not present above the top row is unimportant. This is because most of the moderation is taking place within the fuel elements.

The next table lists the neutron fluxes by energy partition and scoring region (Appendix C Table 9 contains the printout from the first page of the reference flask calculation). The flux is a track length estimator meaning that the actual distance travelled within a scoring region (the track length) is used as the measure of the flux. For this table the scores are not carried up the hierarchic geometry part tree and so bodies containing subsidiary parts appear to have zero flux (and are therefore not listed in the table). The reason for this is that the flux is accumulated at every boundary crossing as well as at every collision (i.e. at the end of every track length), and so there would be a significant scoring overhead for complex geometries if the full table was scored. This treatment for the neutron flux is considered acceptable due to the limited use made of this table for most criticality applications. It is of more use for comparisons with other codes and methods and for validation purposes.

The neutrons parameters table that follows gives a summary by material of the collision information presented earlier. It also presents a quantity headed 'Mean Energy of Neutrons Causing Events' which is exactly what is says it is and is of little if any value. Remember that a mean value based on neutron energies which may vary by several orders of magnitude can be heavily biased by one large contribution, and except for reactions with energy thresholds it is difficult to put these values to any sensible use. The table is mainly preserved for historical reasons.

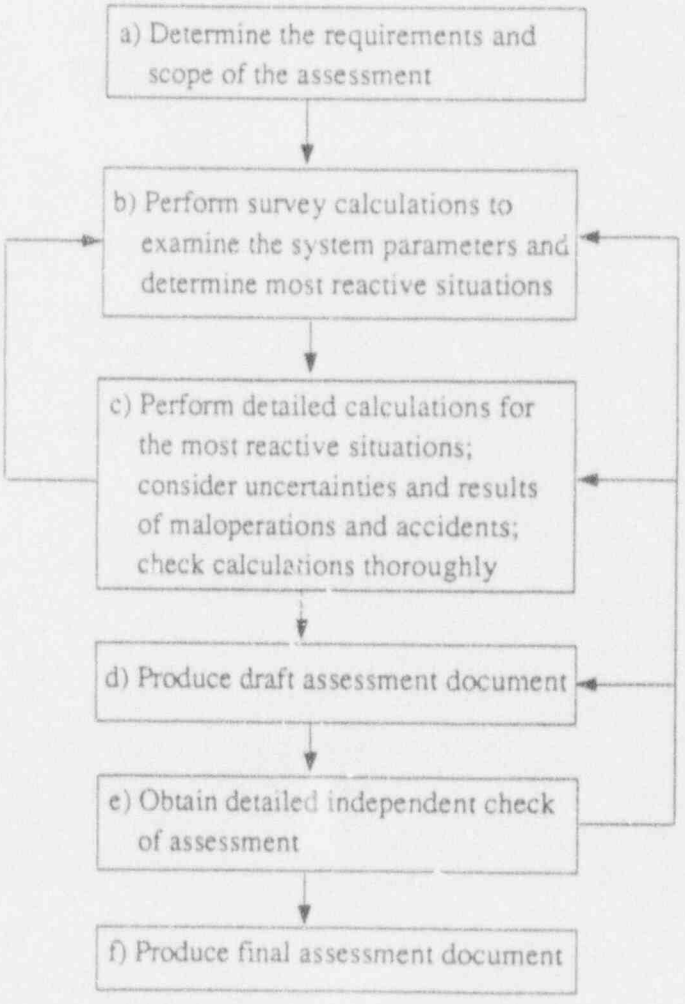
This is followed by the k-effective plot by stage number which can be used to spot fluctuations and sampling problems in a similar way to the use of the main stage-by-stage tables. The plot for the reference calculation is given in Appendix C Table 10.

For the reference calculation the final piece of information is the categorisation output (note that this is optional); the table for the reference calculation is given in Appendix C Table 11. The main aim of the case categorisation is to enable comparisons with code validation systems to be easily made. MONK6 will categorise a calculation by considering a number of criteria which go to make up a description of the system. Seven different criteria are scored by considering the output from the calculation and the individual scores are combined to give a category number. Obviously cases which differ only slightly in one of the category criteria may still be suitable validation for the system under study, but the category number can alert the user to the fact that the calculation is outside the current range of validation. Details of the categorisation criteria are available [13] together with the category numbers for the standard MONK6 validation cases. The reference flask calculation falls into category number 565 which as expected is an area well covered by the MONK6 validation. This concludes the MONK6 output listing.

7. CRITICALITY ASSESSMENTS

Sections 4 to 6 considered the setting up and running of a single MONK6 calculation for a LWR fuel transport flask. Normally such a calculation would form part of a criticality assessment of a particular flask, and as such would be only a relatively small part of the whole exercise. Although expertise in the use of the MONK6 code is essential in criticality assessments, the assessment process consists of much more, including the knowledge and use of other calculational methods and data sources, and the application of detailed criticality analysis to the problem.

Procedures for performing criticality assessments vary between organisations and although the basic structures are similar (and indeed the basic goal the same) the detailed practices can unfortunately be quite different. This document is clearly not the place to advocate any particular working practice, but this section will consider the important features of a criticality assessment. A simplified flowchart of the assessment process is given below:



the range of fuel that may be loaded into the flask; this then automatically covers all the less reactive configurations.

The control by geometry is accomplished by the compartmentalisation of the fuel into fixed positions within the multi-element bottle, and for the bottle itself to be securely fixed within the flask. This limits the interaction effect between the elements to some extent and hence controls the leakage contribution to the neutron balance; it also forms part of the engineered approach to criticality safety as under normal operating conditions the separation of the fuel is ensured.

The control by absorption also forms part of the engineered approach to safety as under normal conditions the neutron absorbers are fixed engineering features of the flask (e.g. boron steel walls, boral sheets). One of the most effective absorption control devices is boral sheet separated by water and here it must be ensured that water is always present; otherwise it needs removing from the criticality assessment and considered as an additional secondary safety feature. Due to the inability to guarantee their presence allowance cannot be taken for dissolved absorbers in the flask.

b) Survey Calculations

Survey calculations for transport flasks consist of considering: various types of fuel element; differing levels of fuel enrichment;sensitivity to the loss or addition of moderating material; separation changes; and temperature effects. These would involve a mixture of handbook usage, simple calculations (such as buckling/shape conversion, density analogue), deterministic computer codes (e.g. WIMS [16], SCALE [17]) and MONK6 and KENO [17] calculations. The requirement at this stage is to perform comparative or scoping calculations to investigate the properties of the system and the sensitivites to various changes. Therefore definitive Monte Carlo calculations are not essential for all such considerations and where simpler, quicker methods are applicable, or where published data aready exist, these should be employed.

At this stage it is also possible to examine any bias in the various calculational methods that might influence the more detailed calculations that will be performed later. It is worth comparing some of the simpler calculations with MONK6 and examining the causes of any differences. It should also be considered whether the system is suitably covered by the MONK6 validation database, as this clearly has a great bearing on the nature of the assessment; if no such validation is available the user is responsible for performing his own, either by locating details of a suitable experiment or if necessary commissioning a new experiment. In addition the survey calculations can be used to establish conservative modelling strategies by examining the sensitivity of the reactivity to various modelling assumptions, for example simplifying the fuel element geometry by the omission of spacer grids or control pins; this again will aid the detailed calculations.This stage of the assessment can also be used to consider some of the simpler contingencies such as corrosion and distortion of the fuel elements and compartments.

The normal assumption for criticality assessments is that all of the fuel in the flask is unirradiated. This is a conservative assumption in practice if the burnable poison complication can be ignored; if it cannot there is the possibility that the reactivity of such fuel may be higher at low burnup than when unirradiated, and so this needs to be taken into account [18]. However in the majority of cases the assumption of zero burnup is conservative and also allows maximum operator flexibility as knowledge

a) Requirements and Scope

The safety requirements for the transport of radioactive materials are by some considerable margin stricter than those for other toxic materials, and to meet these requirements careful attention to detail is needed in addition to sound engineering practices. It is the careful attention to detail that is the business of the criticality assessor. The international regulations concerning the transport of fissile materials in all packages (including flasks) are given in the International Atomic Energy Agency Safety Series No.6 [14], which state that 'fissile material shall be packaged and shipped in such a manner that subcriticality is maintained under conditions likely to be encountered during normal conditions of transport and in accidents'. The regulations go on to say that 'the following contingencies shall be considered:

a) water leaking into or out of packages

b) the loss of efficiency of built-in neutron absorbers or moderators

c) possible rearrangement of the radioactive contents either within the package or as a result of loss from the package

d) reduction of spaces between packages or radioactive contents

e) packages becoming immersed in water or buried in snow

f) possible effects of temperature changes'.

Advisory material on the interpretation of the international regulations relating to criticality assessment is given in Appendix X of the International Atomic Energy Agency Safety Series No.37 [15]. Due to the inability to measure the degree of subcriticality, the criticality assessment assumes a most important position, and as good a study as possible is required of the likely state of the flask under both normal and postulated accident conditions. In addition to the international regulations additional local or national rules may apply, and these may depend on the nature of the assessment package and the mode and route of transportation.

Fundamental to the job of criticality assessment is the task of considering the neutron balance within the system, i.e. determining the fate of neutrons arising from fission events. This fate can be considered as three parts: fission, where neutrons give rise to further neutrons; capture, where the neutrons are removed from the system by parasitic absorption; and leakage, where neutrons escape from the modelled system and may interact with various postulated adjacent materials. The balance that occurs between these three activities dictates the reactivity of the system.

Criticality control is normally accomplished by the combined use of enrichment control, geometry and parasitic absorption. The control of the maximum fuel enrichment permitted for a given flask limits the reactivity of the fuel element by control of the fission process. Note that this cannot be considered as a primary control mechanism as it depends on fully-reliable administrative practices to ensure that the flask is loaded only with fuel up to the permitted maximum enrichment. Therefore the normal practice is for the criticality assessment to consider that all of the fuel is of the most reactive type from

of the fuel element history is not required to ensure criticality safety is maintained (subject to any maximum initial enrichment limits). It is also conservatively assumed that all fuel within the flask is uniformly at the maximum enrichment.

However this conservativism in the criticality safety assessment can amount to a relatively large effect on the operating sub-critical limits and could be perceived as undue pessimism for the majority of fuel shipments. Significant economic benefits can be realised if credit can be taken in the safety margins for the burnup effects, i.e. the depletion of fissile material and the buildup of fission products and higher actinides. The result of burnup for most fuel is a lowering in the reactivity and this could allow each shipment of fuel to consist of more elements, meaning fewer total shipments and reduced overheads. Moreover the risk of accidents is reduced and the radiation exposure to both the operations staff and general population can be cut.

Although the concept of taking credit for fuel burnup appears attractive, some problems exist that need to be resolved [19-23]. These include ensuring that the irradiation history of each element is available before shipment; being able to calculate the isotopic composition of the irradiated fuel; the availability of nuclear data for the fission products and higher actinides present in irradiated fuel; and most importantly the need for stringent administrative controls to ensure that flask misloading cannot occur.

However with the likely increase in the use of higher fuel enrichments which could fail to meet existing safety margins under the fresh fuel assumption, and with higher fuel burnup where the in-built pessimism of the fresh fuel loading will be greater, taking credit for burnup is not an option that will be discarded and so it will soon form part of the surveying process.

As a conclusion to this stage of the assessment it is recommended that the results and conclusions obtained so far be checked by an independent assessor.

(c) Detailed Calculations

Having performed the survey calculations and gained the necessary insight into the system the conservative approach to safety demands that the most reactive configurations are adopted for fuller investigation, normally by performing extensive MONK6 calculations to establish definitive results for the extreme cases, e.g. maximum reactivity fuel elements in the most reactive configuration with optimum moderation. The various contingencies defined in the regulations also need to be considered together with the effects of reflection and interaction, and suitable supporting calculations need to be made where necessary. If a scenario can be eliminated by careful argument, reference to published data or with reference to the survey calculations then this can reduce the number of detailed calculations required.

For fuel flask transport the assessment requires analysis of the transport, storage and loading/unloading phases and the associated accidents that may occur during handling. These include dropping a fuel element, the multi-element bottle or even the whole flask, and flask impacts during transportation, which each require criticality analysis as they can lead to: compartment collapse; distortion of the fuel; the accumulation of fuel debris; loss or addition of moderation; and fire damage. These type of accidents may require detailed calculation using the MONK6 code due to the geometry

modelling complexity, although some further parametric-style calculations may be required to determine the sensitivity of the reactivity to particular reconfigurations.

It is essential to consider the worst-case scenario in each case. For those involving the accumulation of fuel debris, this means determining its most reactive configuration. Studies have shown [24] that it is only fuel elements that have developed cladding material cracks that are likely to fracture during an impact, and it is conservatively assumed that this would apply to 4% of the fuel in a given flask shipment. In many of the accident circumstances the use of probabilistic risk assessment is becoming widespread as supporting evidence in the criticality assessment [25,26]. Manufacturing tolerances and changes due to maintenance (i.e. the differences between the operational flask and the designed one) also need to be considered as the data obtained from engineering drawings may not correspond to the operating flask.

Consideration must be given to the sources of uncertainty in the detailed calculations as described in section 2d, namely the systematic bias (B), the random error in the preparation and execution of the calculations (E), the bias arising from operational or accidental changes causing increases in reactivity (R), and the statistical Monte Carlo error (S). These must be allowed for or eliminated in demonstrating that the sub-critical margin is maintained. If any doubts exist concerning the calculations then independent checking is essential by employing alternative methods, data or codes, and as a conclusion to this stage of the assessment it is recommended that the detailed calculations be checked by an independent assessor.

d) Draft Assessment Document

The assessor is now confident that sufficient calculations have been performed to prove that the flask will remain below the sub-critical margin under normal and postulated accident scenarios. A draft assessment document is therefore produced that describes the criticality analysis and supporting calculations that have lead to this conclusion. It is important that the arguments employed be unambiguously developed and that the worst-case scenarios be adequately described. Detailed descriptions are also required of the calculations performed, and the document should address the applicability and validation of the calculational methods employed. The calculational uncertainties need to be specified and it is essential to remember that the accuracy of the assessment lies unambiguously with the assessor; if there is any doubt concerning the calculations then further checking is essential. The contingencies that either general or local regulations demand must be considered, even if they can be eliminated by a simple statement. Any operating limitations that need applying to the flask and all assumptions made during the assessment must be clearly stated.

e) Independent Checking

The assessment document and supporting calculations should now be passed to an independent assessor who will re-consider the safety argument. Whilst it is normally not necessary for a full independent assessment to be performed, in difficult cases this may be unaviodable. For well-validated fuel transport flasks the independent check would consist of examining the selection of worst-case scenarios, the application of the various calculational methods and the arguments that are used to demonstrate the sub-criticality. The advantages of an independent assessment in difficult cases

are that it may result in highlighting problems that the original assessor has neglected or not considered adequately, as well as producing general comments on how the document may be improved. Note that simple mistakes in setting-up calculations should have been eliminated at an earlier stage. The comments of the independent assessor may lead to the original assessor performing additional survey or detailed calculations, as well as amending the text of the document before the independent assessment stage is complete.

f) Final Document

Once the two assessors (or the assessor and the checker) are satisfied with the assessment the final document is produced and issued to the appropriate bodies. As this is the main published record of the assessment the document should be as far as possible self-contained. However it is clearly unreasonable to include full calculational results or copies of published references, but the availability of these items must be ensured, for as long as the assessment remains valid. This forms part of the assessor's QA registry, and forms a vital supplement to the assessment document.

8. CONCLUSION

This document is intended as a guide to applying the MONK6 criticality code to a particular problem. Simple examples exist on the use of the code [9], but are not as detailed as the problem considered here. In addition some attempts have been made to answer some of the questions often encountered by new users of the code, particularly those relating to the choice between two apparently equivalent options. In this respect the guide is of some relevance to other criticality problems, as the main choices presented to the user are not specific to transport flask problems. The same can be said for the output examination section which describes how the information presented in each output table is accumulated. However this guide is in no way intended to replace the two existing main volumes of MONK6 documentation [2,9], which should be regarded as essential reading for a prospective code user, but can be regarded as a supplement where a 'real' problem is tackled from beginning to end.

The sample calculation set up for this guide has been constructed by trying to accommodate the twin goals of simple modelling and calculational efficiency. For the transport flask situation it has been possible to succeed reasonably well on both counts, but for many cases a more severe compromise in one or both directions may be required. It is the author's view that, due to the safety-related nature of the code and the low cost of computing compared with a full assessment cost, the user should not stray too far from the simple approach, apart from avoiding the well-documented gross inefficiencies. This will then enable calculations to be set-up and independently checked much more readily than would be the case where unnecessarily complex geometric construction is employed. In this respect it is hoped that this guide will provide useful information for the novice and experienced user alike, and that the modelling strategies used for the reference calculation will have relevance to a much wider range of criticality problems.

REFERENCES

1. MONK6 - A Monte Carlo Code for Criticality Calculations - available from the ANSWERS Service, Winfrith Technology Centre

2. MONK6 Supporting Documentation - ANSWERS/MONK6)2

3. A Prescott - MONK6 Validation for Criticality Assessment of Transport Flasks Carrying LWR Fuel - WPC/P133/1

4. G Walker - Further Validation of MONK6 - Presented at the ANSWERS Criticality Seminar, October 1989

5. S R Bierman - Existing Experimental Criticality Data Applicable to Nuclear Fuel Transportation Systems - PNL 4118

6. S R Bierman - Criticality Experiments to Provide Benchmark Date on Neutron Flux Traps - PNL 6205

7. The Nuclear Criticality Information System (NCIS) - Lawrence Livermore National Laboratory

8. R J Brissenden & A R Garlick - Biases in the Estimation of k-effective and its Error by Monte Carlo Methods - Annals of Nuclear Energy Volume 13 No.2

9. MONK6 User Guide - ANSWERS(MONK6)1

10. N R Smith - The MONK6 Prism Shape - MMC/P90

11. A Prescott - Criticality Interaction Problems Associated with Monte Carlo Computer Codes - Proceeding of a Topical Meeting on Criticality Safety in the Storage of Fissile Material, Jackson, September 1985

12. R J Brissenden & N R Smith - Further Studies of the Prescott Interaction Problem Using Superstage Powering in MONK6 - Proceeding of a Topical Meeting on Criticality Safety in the Storage of Fissile Material, Jackson, September 1985

13. N R Smith - Categorisation of MONK6 Calculations - ANSWERS/MONK/MEMO/5

14. International Atomic Energy Agency - Regulations for the Safe Transport of Radioactive Materials - Safety Series No.6, 1985 edition

15. International Atomic Energy Agency - Advisory Material for the IAEA Regulations for the Safe Transport of Radioactive Materials - Safety Series No.37, 1985 edition

16. WIMS - The Winfrith Reactor Physics Code Suite - available from the ANSWERS Service, Winfrith Technology Centre

17. SCALE - A Modular Code Scheme for Performing Standardized Computer Analyses for Licensing Evaluation - NUREG/CR-0200

18. L D Gerrald & O C Brown - Taking Credit for Burnable Absorber in BWR Fuel Criticality Safety Analyses - Proceeding of a Topical Meeting on Criticality Safety in the Storage of Fissile Material, Jackson, September 1985

19. Alan H Wells - Burnup Credit in Nuclear Criticality Safety Analysis: Application to Spent Fuel Storage/Transport Casks - Proceeding of an International Seminar on Nuclear Criticality Safety, Tokyo, October 1987

20. H Toffer & A H Wells - Spent Fuel Critical Masses and Supportive Measurements - Proceeding of an International Seminar on Nuclear Criticality Safety, Tokyo, October 1987

21. Amercian Nuclear Society - A Tutorial on Burnup Credit Issues in Spent Fuel Transportation - ANS Winter Meting, Washington, November 1988

22. A M Evans - Taking Credit for Burnup in Criticality Safety Assessments - A Review - WPC/P160

23. Thomas L Sanders & R Michael Westfall - Feasibility and Incentives for Burnup Credit in Spent Fuel Transport Casks - Nuclear Science and Engineering, Volume 104, 66-77

24. P D Clemson & M H Watmough - Potential Fuel Damage Within a Shipping Cask Following a Postulated Impact Accident - Proceedings of PATRAM89, Washington, June 1989

25. S J Walls - Applications of Probabilistic Risk Assessment at BNFL Sellafield - Proceedings of an International Topical Meeting on Safety Margins in Criticality Safety, San Francisco, November 1989

26. P E Broad & M H Watmough - Applications of PRA to Underwater Handling of Spent Oxide Fuel at Sellafield - Proceedings of an International Topical Meeting on Safety Margins in Criticality Safety, San Francisco, November 1989

APPENDIX A - REFERENCE FLASK INPUT DATA

```
* Reference transport flask containing 14 LWR fuel elements
* ----------------------------------------------------------------

* 3.5% enriched UO2 fuel
* pin radius = 0.55cm, zirconium can thickness = 1.0cm
* pin pitch = 1.70cm,  element wrapper thickness = 0.2cm
* element length = 409.5cm
* flask flooded to the top of the fuel

FISSION
6 10 NUCNAMES

* material 1 ... UO2 fuel
* material 2 ... water
* material 3 ... boron steel
* material 4 ... steel
* material 5 ... iron
* material 6 ... zirconium

CONC      U238 2.238E-2  U235 8.2213E-4  O 4.6054E-2
ATOM 0.998 O 1.0         HINH2O 2.0
ATOM 7.7  FE 1.2311      CR 0.3847       NI 0.1807     B10 1.109E-2
          B11 4.436E-2
CONC      FE 6.2669E-2   CR 1.6343E-2    NI 6.4342E-3
ATOM 7.85 FE 1.0
ATOM 5.66 ZR 1.0

CM

* Part 1 - single fuel element with boron steel compartment walls

NEST 3
BOX  ORIGIN 0.500 0.500 20.0   BH1   14.200 14.200 409.5
BOX  ORIGIN 0.500 0.500 0.0      2   14.200 14.200 449.5
BOX                              3   15.200 15.200 449.5
```

* Parts 2-8 - exact copies of part 1 to produce sampling information

```
SAME 1
SAME 1
SAME 1
SAME 1
SAME 1
SAME 1
SAME 1
```

* Part 9 - bottom row of three fuel elments
* Part 10 - middle two rows of four elements each (lower row first)
* Part 11 - top row of three fuel elments

```
ARRAY 3 1 1     5 6 5
ARRAY 4 2 1     3 1 1 3
                4 2 2 4
ARRAY 3 1 1     7 8 7
```

* Part 12 - assemble all elements and add steel walls and interstitial
* water

```
CLUSTER 4
BOX  ORIGIN -22.8  15.2 5.0   P11    45.6 15.2 449.5
BOX  ORIGIN -30.4 -15.2 5.0   P10    60.8 30.4 449.5
BOX  ORIGIN -22.8 -30.4 5.0   P9     45.6 15.2 449.5
ZROD                          BH2    39.2 459.5
```

* Part 13 - place elements in multi-element bottle container and
* position in flask (note flask fins ignored)

```
NEST 5
ZROD  ORIGIN 0.0 0.0 41.0     P12    39.2 459.5
ZROD  ORIGIN 0.0 0.0 38.0       4    40.2 465.5
ZROD  ORIGIN 0.0 0.0 32.0       2    41.2 477.5
ZROD                            5    75.0 541.5
BOX   ORIGIN -76.0 -76.0 -1.0   0    152.0 152.0 543.5
```

* full specular reflection to simulate infinite array of flasks

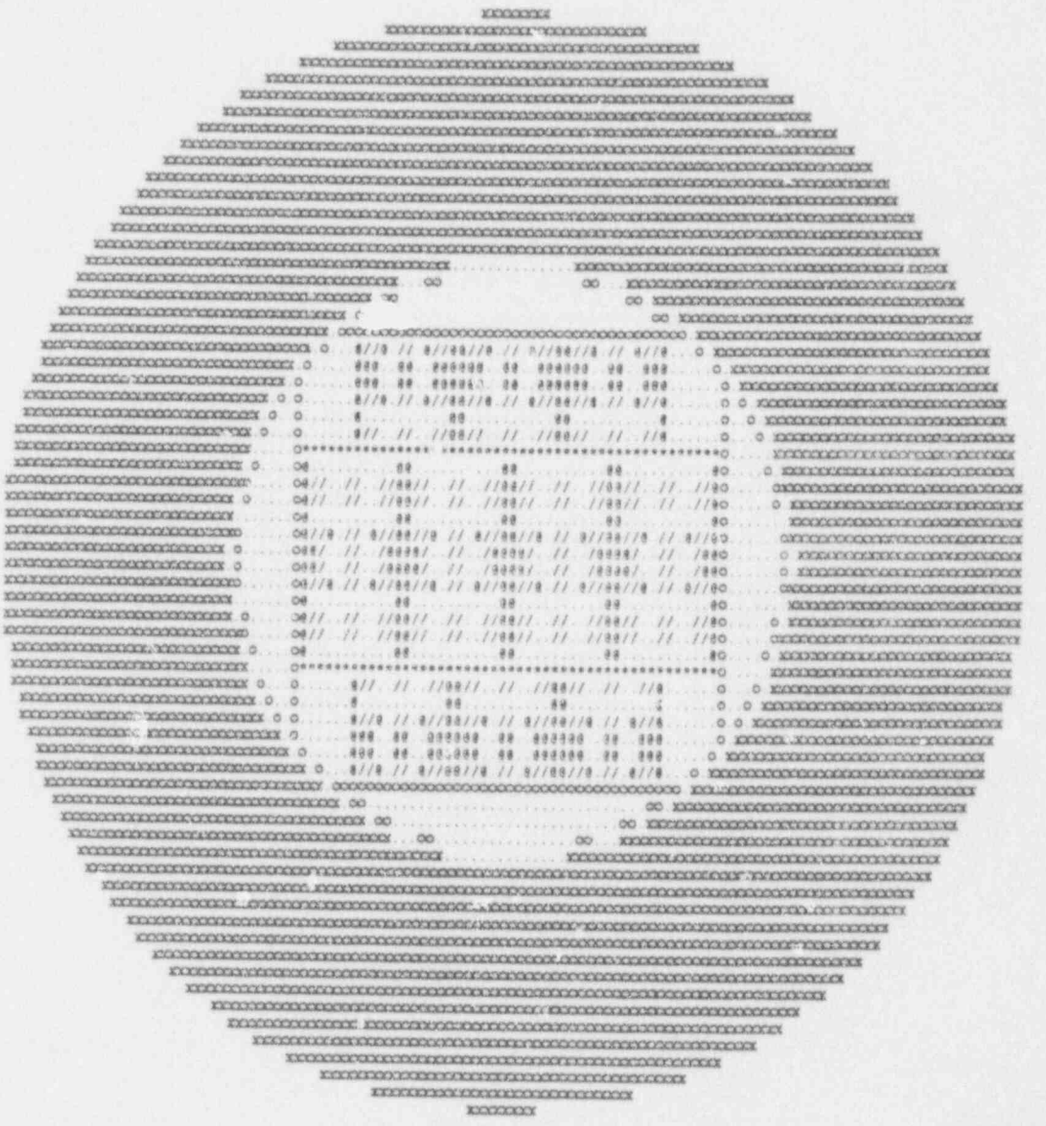
```
ALBEDO 1 1 1 1 1 1
```

```
* Hole 1 - LWR fuel element positioned in centre of compartment

SQUARE 3 1 2 6   HTRANS 7.1 7.1 0.0
          1.70 -0.85 -0.85 0.55 0.65
          WRAP 8 8  6.8 7.0 6.8 7.0
          1 6 2 6 2

* Hole 2 - Horizontal steel walls and interstitial water

PLATE 2 2 4
          0.0 1.0 0.0
          4  31.6 0 30.4 4 -30.4 -3 -31.6 4  2

* Hole 3 - Vertical steel walls and interstitial water

PLATE 2 2 4
          1.0 0.0 0.0
          4  31.6 2 30.4 4 -30.4 2 -31.6 4  2

EDIT CATEGORY
-1 20 600 0 STDV 0.0030 -1

* Position source randomly over all fuel elements

MULTIFISS STD
REGION 1 PART 13 /
END

* SCAN data

CODE 6
/.*OX@

* Picture 1 - complete flask section
* Pictures 2-5 - flask quarter radial sections
* Pictures 6-8 - radial close-ups
* Pictures 9-10 - top and bottom of flask axially

-76 76 250 76 76 250 -76 -76 250
-50 50 250 0 50 250 -50 0 250
0 50 250 50 50 250 0 0 250
-50 0 250 0 0 250 -50 -50 250
0 0 250 50 0 250 0 -50 250
```

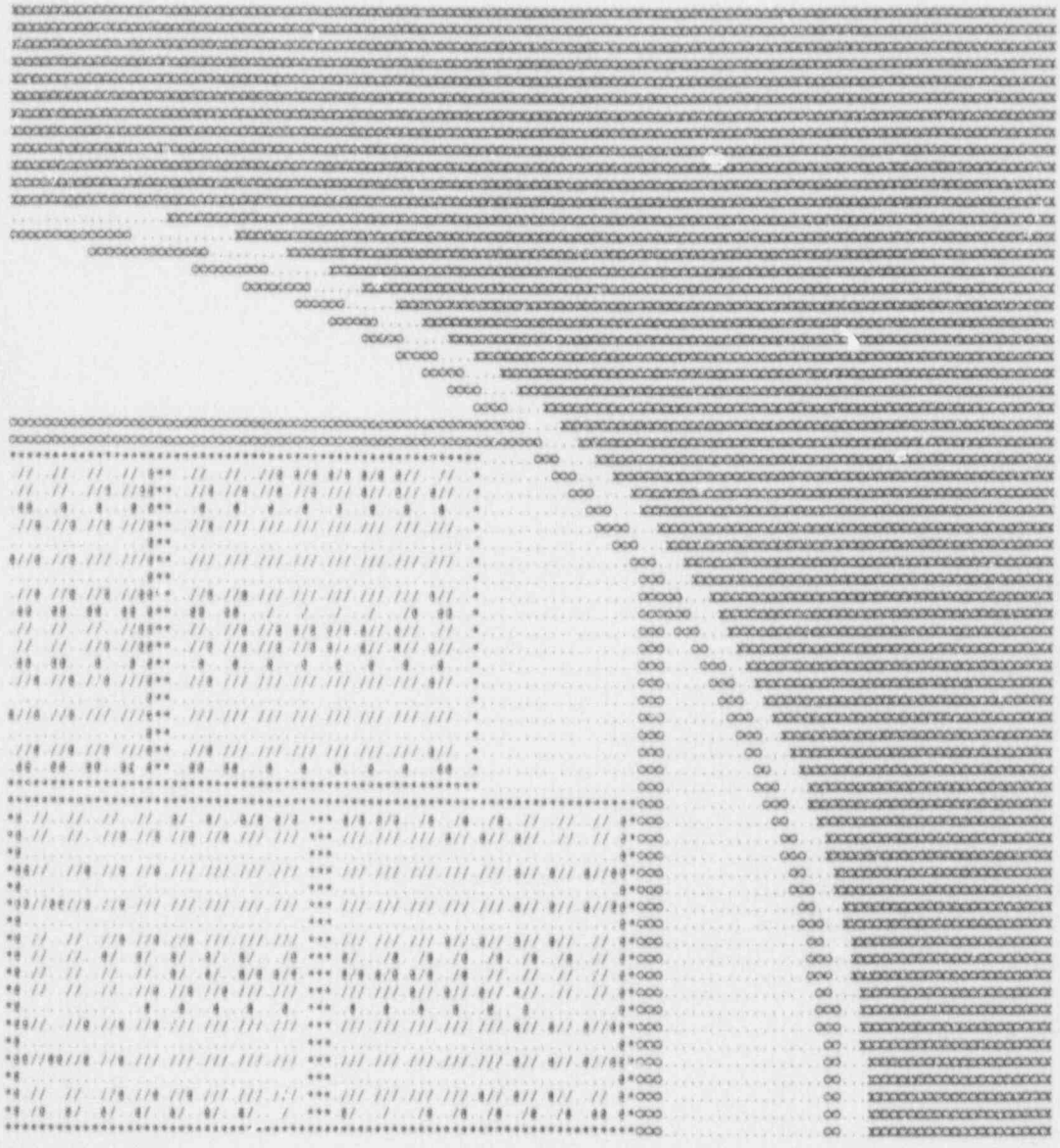
-5 20 250 20 20 250 -5 -5 250
20 35 250 45 35 250 20 10 250
-5 5 250 5 5 250 -5 -5 250
25 7.95 511 42 7.95 511 25 7.95 471
25 7.95 70 42 7.95 70 25 7.95 30
END

APPENDIX B - SCAN6 PICTURES OF THE REFERENCE FLASK

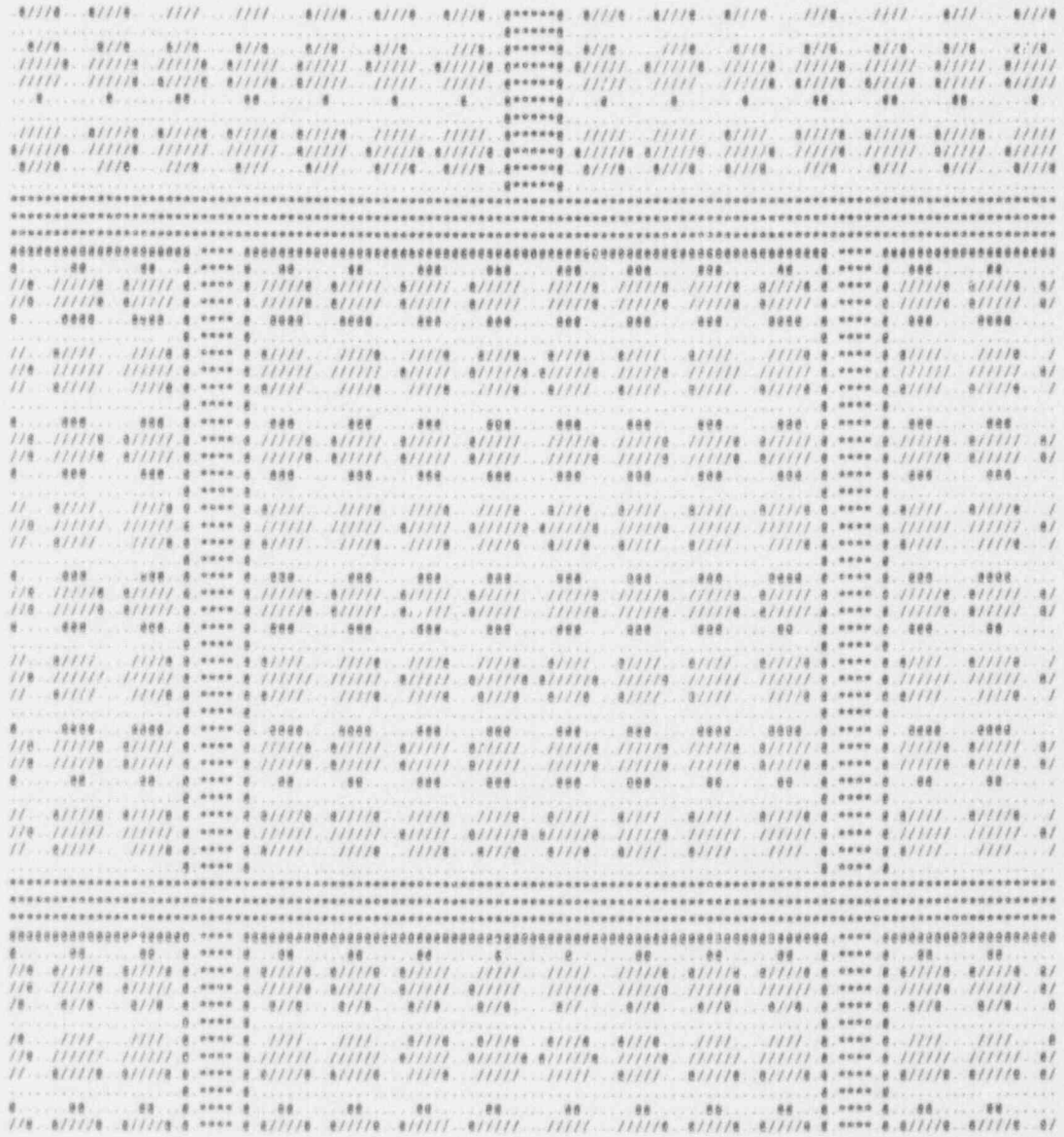
PICTURE 1



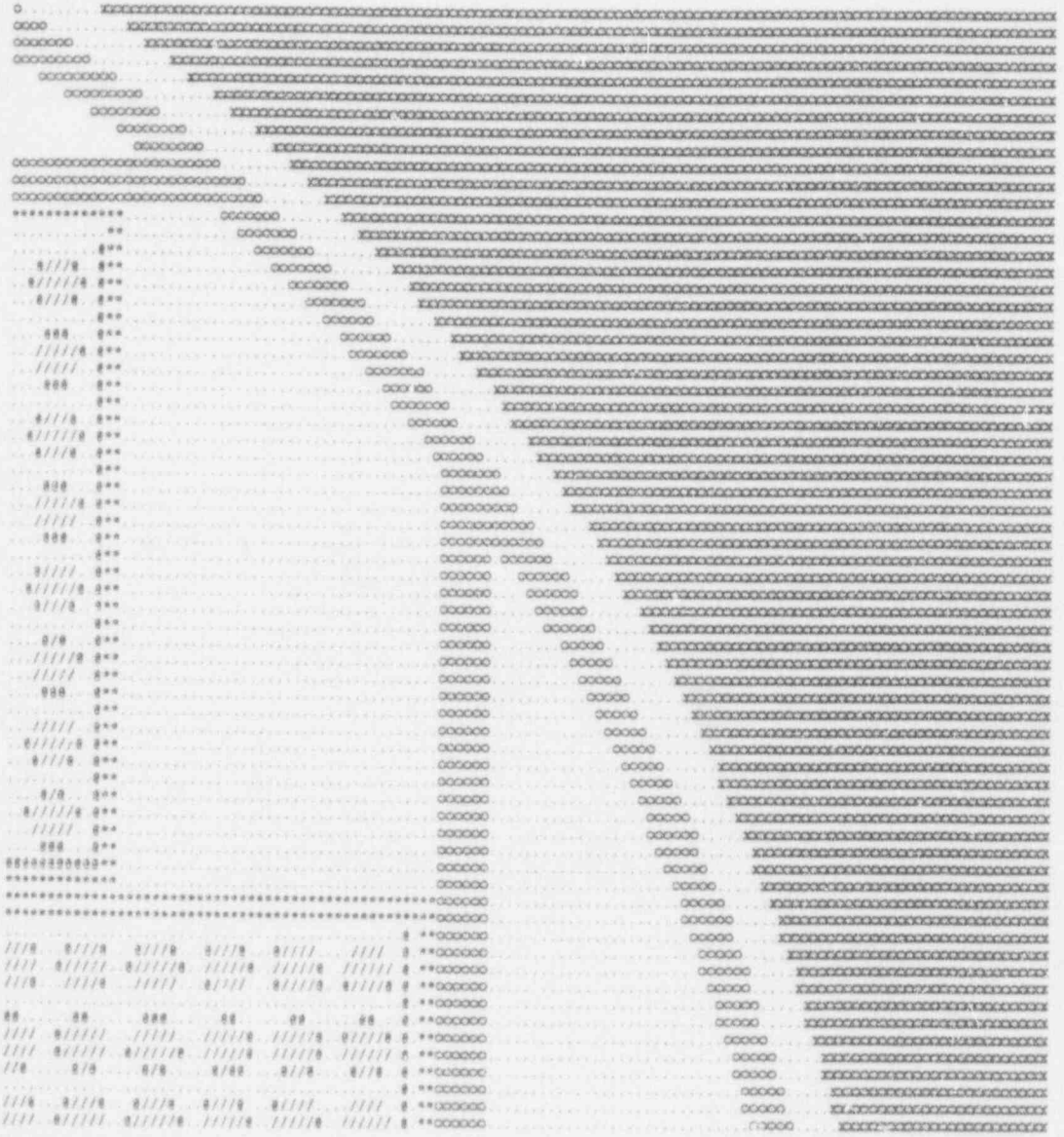
PICTURE 2



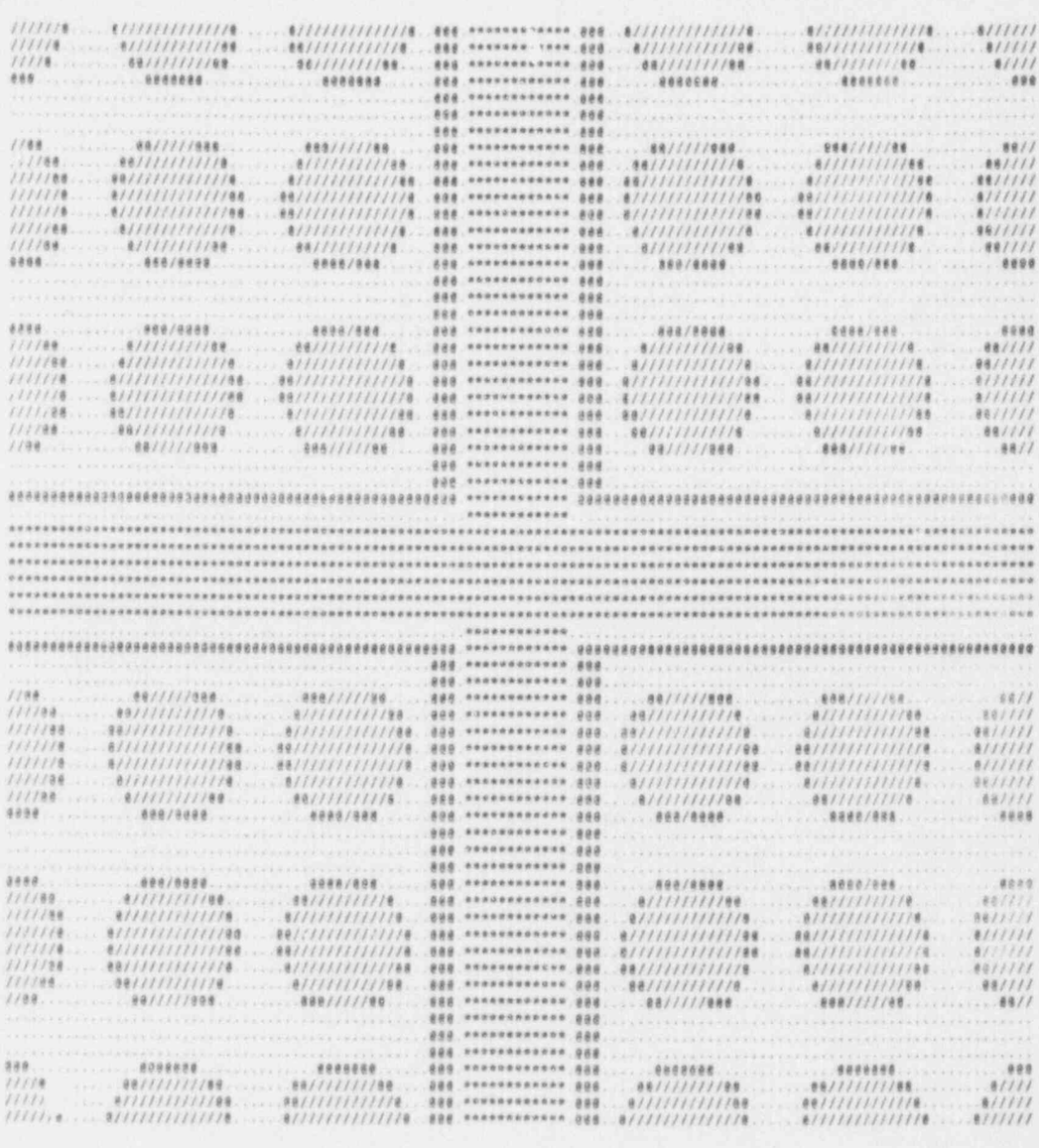
PICTURE 3



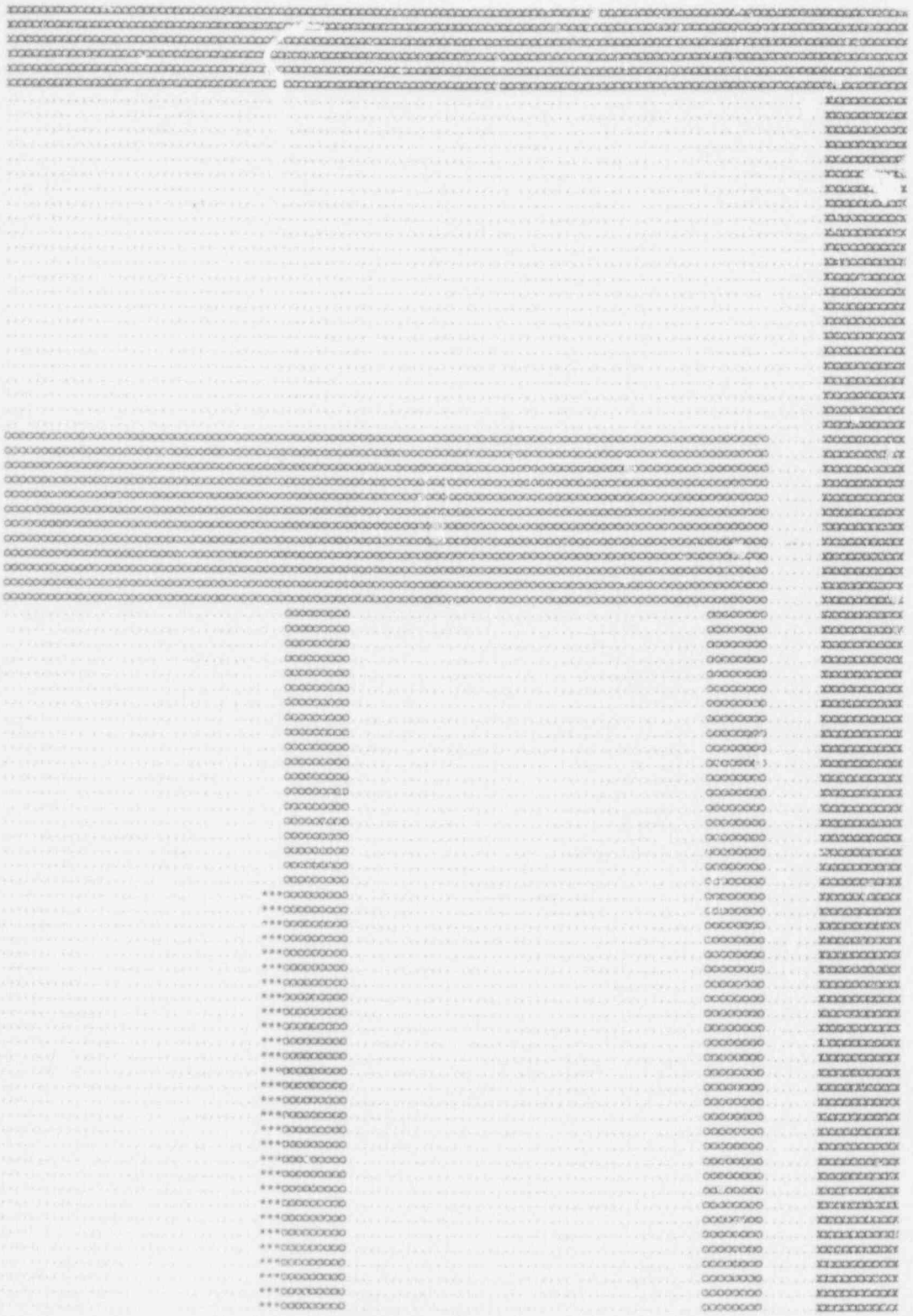
PICTURE 4

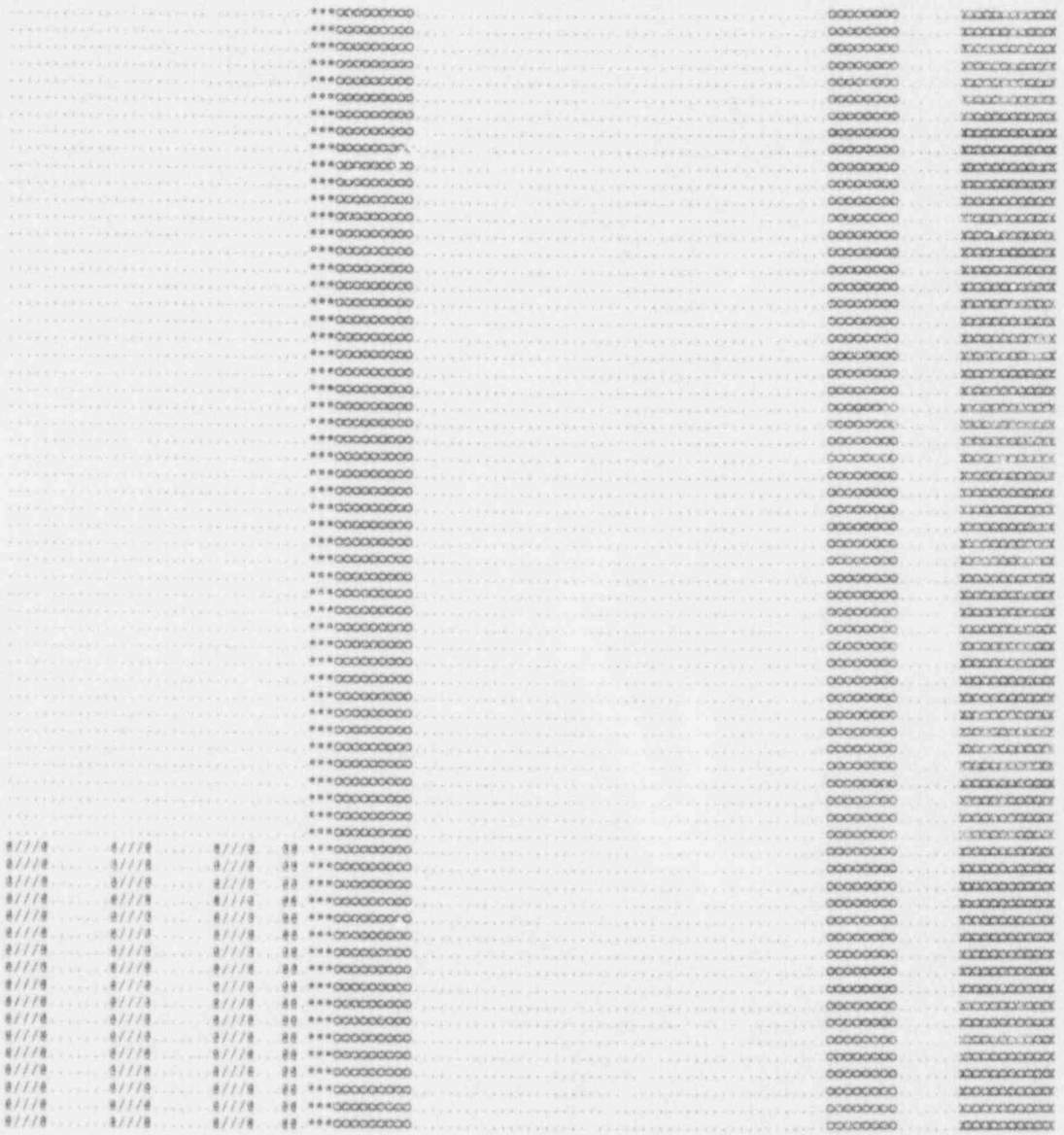


PICTURE 5



PICTURE 6





APPENDIX C - SELECTED MONK6 OUTPUT TABLES

TABLE 1

	INDIVIDUAL STAGE COUNTS									CUMULATIVE COUNTS								
STAGE	SAMPLE	SCAT	CAP	FISS	CHILD	SCORE	ESC	N2N	N3N	SAMPLE	SCATTER	CAPTURE	FISSION	CHILDREN	SCORE	TOTESC	TOTN2N	TOTN3N
1	6115	234965	3939	2188	5377	5274	0	12	0	6115	234965	3939	2188	5377	5274	0	12	0
2	6455	252769	4114	2346	5759	5670	0	7	0	12570	487734	8085	4534	11136	10944	0	19	0
3	6696	251647	4273	2424	5944	5991	0	1	0	19266	739181	12328	6958	17080	16935	0	20	0
4	6039	224224	3890	2159	5308	5313	0	10	0	25305	963405	16218	9117	22389	22247	0	30	0
5	5843	222626	3753	2098	5150	5194	0	8	0	31148	1186031	19971	11215	27538	27442	0	38	0
6	5550	206748	3552	2002	4910	4879	0	4	0	36698	1392799	23523	13217	32448	32320	0	42	0
7	5245	201489	3404	1845	4532	4595	0	4	0	41943	1594288	26927	15062	36980	36915	0	46	0
8	4783	177619	3143	1642	4023	4221	0	4	0	46726	1771907	30072	16704	41003	41136	0	50	0
9	6125	228073	3906	2226	5469	5511	0	7	0	52851	1999980	33978	18930	46472	46647	0	57	0
10	5368	205319	3502	1871	4595	4721	0	5	0	58219	2205299	37480	20801	51067	51368	0	62	0
11	5674	212476	3676	2007	4916	4787	0	9	0	63893	2417775	41156	22808	55983	56155	0	71	0
12	5893	228964	3761	2119	5201	5288	0	7	0	69786	2646739	44937	24927	61184	61443	0	78	0
13	6690	251608	4259	2435	5976	6076	0	4	0	76476	2898147	49196	27362	67160	67519	0	82	0
14	5432	210761	3553	1904	4673	4813	0	5	0	81908	3108908	52729	29266	71833	72332	0	87	0
15	5711	217222	3718	1996	4902	5014	0	3	0	87619	3326130	56447	31262	76735	77346	0	90	0
16	5743	222225	3709	2042	5008	4782	0	8	0	93362	3548355	60156	33304	81743	82129	0	98	0
17	5793	218847	3695	2104	5171	5109	0	6	0	99155	3767202	63851	35408	86913	87237	0	104	0
18	5168	199256	3378	1795	4415	4491	0	5	0	104323	3966458	67229	37203	91329	91728	0	109	0

TABLE 2

	CUMULATIVE						INDIVIDUAL		SAMPLE ESTIMATORS							
STAGE	K(COLL)	STD	K(SCORE)	STD	K(BRIER)	STD	A	STD	LAMBDA	R(S,A)	R(C,A)	R(C,S)	ALPHA	BETA	K(THREE)	STD
1	0.8793	0.0131	0.8424	0.0172	0.8836	0.0125	0.9787	0.0111	1.0427	0.9945	0.9928	0.9846	0.1220	0.8990	0.8928	0.0124
2	0.8859	0.0104	0.8706	0.0122	0.8906	0.0081	0.9913	0.0079	1.1473	0.9936	0.9920	0.9855	0.1609	0.9780	0.8816	0.0080
3	0.8866	0.0085	0.8790	0.0097	0.8853	0.0066	0.9943	0.0064	1.1073	0.9937	0.9913	0.9862	0.1865	0.9161	0.8856	0.0065
4	0.8847	0.0074	0.8792	0.0085	0.8860	0.0058	0.9838	0.0057	1.0869	0.9938	0.9910	0.9860	0.1814	0.9058	0.8858	0.0057
5	0.8841	0.0068	0.8810	0.0075	0.8857	0.0052	0.9956	0.0050	1.0742	0.9936	0.9909	0.9862	0.2147	0.8641	0.8855	0.0051
6	0.8842	0.0063	0.8807	0.0069	0.8861	0.0049	0.9950	0.0046	1.0769	0.9933	0.9908	0.9856	0.2168	0.8619	0.8857	0.0047
7	0.8817	0.0059	0.8801	0.0065	0.8832	0.0046	0.9970	0.0043	1.0671	0.9930	0.9903	0.9850	0.2341	0.8335	0.8830	0.0044
8	0.8775	0.0056	0.8804	0.0062	0.8812	0.0044	0.9992	0.0041	1.0435	0.9925	0.9901	0.9847	0.2623	0.8089	0.8802	0.0042
9	0.8793	0.0053	0.8826	0.0059	0.8841	0.0042	0.9886	0.0039	1.0683	0.9926	0.9901	0.9846	0.2689	0.7993	0.8829	0.0040
10	0.8772	0.0050	0.8823	0.0055	0.8833	0.0040	0.9990	0.0037	1.0609	0.9923	0.9901	0.9848	0.2822	0.7838	0.8816	0.0038
11	0.8742	0.0048	0.8789	0.0053	0.8821	0.0038	0.9969	0.0035	1.0294	0.9922	0.9899	0.9846	0.2773	0.7550	0.8805	0.0036
12	0.8767	0.0046	0.8805	0.0050	0.8831	0.0036	0.9974	0.0033	1.0417	0.9922	0.9901	0.9847	0.2841	0.7644	0.8814	0.0035
13	0.8782	0.0043	0.8829	0.0048	0.8842	0.0034	0.9988	0.0032	1.0317	0.9923	0.9899	0.9847	0.2912	0.7495	0.8824	0.0032
14	0.8770	0.0042	0.8831	0.0046	0.8835	0.0033	1.0005	0.0031	1.0463	0.9922	0.9900	0.9847	0.2942	0.7634	0.8809	0.0031
15	0.8758	0.0040	0.8828	0.0045	0.8820	0.0032	1.0007	0.0030	1.0440	0.9922	0.9899	0.9845	0.3043	0.7509	0.8801	0.0030
16	0.8755	0.0039	0.8797	0.0043	0.8808	0.0031	0.9989	0.0029	1.0354	0.9920	0.9897	0.9842	0.3015	0.7406	0.8792	0.0030
17	0.8765	0.0038	0.8796	0.0042	0.8811	0.0030	0.9997	0.0028	1.0220	0.9920	0.9894	0.9842	0.2893	0.7362	0.8798	0.0029
18	0.8754	0.0037	0.8793	0.0041	0.8808	0.0030	0.9988	0.0028	1.0149	0.9920	0.9893	0.9842	0.2915	0.7292	0.8793	0.0028

TABLE 3

INDIVIDUAL SAMPLE ESTIMATORS FOR EACH STAGE

STAGE	K(COLL)	STD	K(SCORE)	STD	K(BRIER)	STD	A	STD	K(THREE)	STD
1	0.8793	0.0151	0.8624	0.0172	0.8836	0.0125	0.9797	0.0111	0.8828	0.0124
2	0.8922	0.0144	0.8784	0.0172	0.8756	0.0107	1.0023	0.0109	0.8790	0.0103
3	0.8878	0.0148	0.8947	0.0156	0.8946	0.0112	1.0001	0.0107	0.8931	0.0109
4	0.8790	0.0170	0.8798	0.0175	0.8881	0.0121	0.9920	0.0124	0.8867	0.0118
5	0.8813	0.0142	0.8890	0.0156	0.8854	0.0118	1.0036	0.0101	0.8837	0.0110
6	0.8847	0.0172	0.8790	0.0184	0.8880	0.0132	0.9918	0.0117	0.8873	0.0127
7	0.8641	0.0166	0.8761	0.0182	0.8652	0.0131	1.0106	0.0127	0.8649	0.0119
8	0.8610	0.0175	0.8825	0.0205	0.8632	0.0153	1.0186	0.0130	0.8670	0.0130
9	0.8929	0.0163	0.8997	0.0188	0.9070	0.0137	0.9935	0.0114	0.9022	0.0131
10	0.8561	0.0144	0.8795	0.0163	0.8759	0.0120	1.0037	0.0113	0.8662	0.0105
11	0.8663	0.0150	0.8837	0.0154	0.8801	0.0133	0.9745	0.0117	0.8788	0.0127
12	0.8825	0.0155	0.8974	0.0170	0.8932	0.0118	1.0036	0.0106	0.8887	0.0105
13	0.8933	0.0132	0.9082	0.0148	0.8964	0.0102	1.0126	0.0115	0.8952	0.0090
14	0.8602	0.0183	0.8860	0.0197	0.8533	0.0132	1.0255	0.0110	0.8521	0.0121
15	0.8583	0.0134	0.8780	0.0162	0.8747	0.0111	1.0033	0.0116	0.8672	0.0092
16	0.8720	0.0149	0.8327	0.0183	0.8563	0.0149	0.9713	0.0123	0.8580	0.0144
17	0.8926	0.0169	0.8819	0.0158	0.8855	0.0124	0.9955	0.0119	0.8863	0.0122
18	0.8544	0.0161	0.8690	0.0171	0.8744	0.0132	0.9938	0.0124	0.8675	0.0124

TABLE 4

NO. OF SETTLING STAGES	SAMPLE	CUMULATIVE K(COLL)	STD	INDIVIDUAL K(SCORE)	STD	SAMPLE K(SKIRT)	STD	ESTIMATORS A	STD	VARYING LAMBDA	R(S,A)	R(C,A)	R(C,S)	NO. OF SETTLING STAGES ALPHA	BETA	K(THREE)	STD
19	8168	0.8544	0.0161	0.8690	0.0171	0.8744	0.0132	0.9838	0.0124	0.8834	0.9921	0.9875	0.9851	0.3820	0.5950	0.8675	0.0124
18	16961	0.8746	0.0119	0.8758	0.0116	0.8802	0.0090	0.9947	0.0086	0.8497	0.9922	0.9856	0.9843	0.2052	0.6389	0.8789	0.0088
17	16704	0.8737	0.0093	0.8610	0.0100	0.8726	0.0078	0.9867	0.0071	0.9568	0.9910	0.9862	0.9828	0.2347	0.6078	0.8721	0.0076
16	22415	0.8692	0.0078	0.8653	0.0085	0.8735	0.0065	0.9909	0.0061	0.8972	0.9911	0.9864	0.9820	0.2908	0.5940	0.8720	0.0061
15	27847	0.8679	0.0072	0.8694	0.0079	0.8716	0.0059	0.9977	0.0054	0.9609	0.9911	0.9876	0.9824	0.2927	0.6746	0.8705	0.0056
14	34537	0.8728	0.0063	0.8749	0.0070	0.8763	0.0051	1.0006	0.0048	0.9645	0.9915	0.9877	0.9831	0.3061	0.6623	0.8753	0.0048
13	40430	0.8742	0.0058	0.8799	0.0065	0.8789	0.0047	1.0010	0.0045	0.9915	0.9917	0.9884	0.9835	0.3128	0.6904	0.8774	0.0044
12	46104	0.8733	0.0055	0.8754	0.0060	0.8776	0.0044	0.9977	0.0042	0.9589	0.9917	0.9882	0.9833	0.3027	0.6630	0.8763	0.0042
11	51672	0.8715	0.0051	0.8758	0.0056	0.8774	0.0042	0.9984	0.0039	0.9609	0.9917	0.9885	0.9837	0.3144	0.6596	0.8755	0.0039
10	57597	0.8736	0.0048	0.8784	0.0054	0.8805	0.0040	0.9978	0.0037	0.9759	0.9915	0.9886	0.9838	0.3166	0.6631	0.8783	0.0038
9	62380	0.8713	0.0048	0.8787	0.0052	0.8792	0.0039	0.9994	0.0036	0.9808	0.9912	0.9884	0.9836	0.3323	0.6590	0.8766	0.0036
8	67425	0.8707	0.0046	0.8785	0.0050	0.8782	0.0037	1.0003	0.0034	0.9828	0.9912	0.9884	0.9833	0.3336	0.6580	0.8757	0.0035
7	73175	0.8718	0.0044	0.8785	0.0049	0.8788	0.0036	0.9997	0.0033	0.9905	0.9912	0.9885	0.9832	0.3237	0.6731	0.8766	0.0034
6	78018	0.8725	0.0042	0.8793	0.0047	0.8793	0.0034	1.0000	0.0032	0.9912	0.9913	0.9887	0.9835	0.3269	0.6728	0.8771	0.0032
5	85057	0.8729	0.0041	0.8793	0.0045	0.8798	0.0033	0.9994	0.0031	0.9945	0.9915	0.9888	0.9837	0.3137	0.6902	0.8777	0.0031
4	91753	0.8740	0.0040	0.8805	0.0043	0.8810	0.0032	0.9995	0.0029	0.9961	0.9918	0.9889	0.9840	0.3083	0.6971	0.8788	0.0030
3	98208	0.8752	0.0038	0.8803	0.0042	0.8807	0.0031	0.9996	0.0028	1.0108	0.9918	0.9890	0.9840	0.3007	0.7194	0.8790	0.0029
2	104323	0.8756	0.0037	0.8793	0.0041	0.8808	0.0030	0.9985	0.0028	1.0149	0.9920	0.9893	0.9842	0.2915	0.7[illegible]2	0.8793	0.0029
1	109544	0.8739	0.0036	0.8792	0.0040	0.8802	0.0029	0.9990	0.0027	1.0131	0.9921	0.9892	0.9840	0.2914	0.7[illegible]1	0.8784	0.0027
0	112817	0.8735	0.0036	0.8785	0.0039	0.8791	0.0028	0.9993	0.0027	1.0115	0.9920	0.9891	0.9838	0.2905	0.7300	0.8775	0.0027

TABLE 5

SOURCE DISTRIBUTION AS SAMPLED BY REGION

REGION	FIXED SOURCE	ST DEV.
1	82	9
2	0	0
3	0	0
4	88	9
5	0	0
6	0	0
7	82	9
8	0	0
9	0	0
10	77	9
11	0	0
12	0	0
13	98	10
14	0	0
15	0	0
16	42	6
17	0	0
18	0	0
19	82	9
20	0	0
21	0	0
22	49	7
23	0	0
24	0	0
25	140	12
26	329	18
27	131	11
28	131	11
29	329	18
30	140	12
31	0	0
32	600	24
33	0	0
34	0	0
35	0	0
36	0	0

TABLE 6

BOUNDARY CROSSINGS FOR STAGES 1 TO 18 NORMALISED TO 10,000 SOURCE NEUTRONS

PART 1	REGION (ABS)	IN	ST.DEV.	OUT	ST.DEV.	OUT/IN
(WEST)	1 (1)	3406	43	4173	58	1.2253
	2 (2)	3406	43	4171	58	1.2248
	3 (3)	3453	45	3972	54	1.0875
PART 2	REGION (ABS)	IN	ST.DEV.	OUT	ST.DEV.	OUT/IN
(WEST)	1 (4)	3386	44	4128	58	1.2193
	2 (5)	3389	44	4129	58	1.2183
	3 (6)	3469	45	3972	55	1.0827
PART 3	REGION (ABS)	IN	ST.DEV.	OUT	ST.DEV.	OUT/IN
(WEST)	1 (7)	1920	27	2354	38	1.2263
	2 (8)	1921	27	2353	38	1.2252
	3 (9)	2122	28	2250	35	1.0601
PART 4	REGION (ABS)	IN	ST.DEV.	OUT	ST.DEV.	OUT/IN
(WEST)	1 (10)	1914	26	2366	37	1.2362
	2 (11)	1916	26	2367	37	1.2352
	3 (12)	2123	27	2263	34	1.0662
PART 5	REGION (ABS)	IN	ST.DEV.	OUT	ST.DEV.	OUT/IN
(WEST)	1 (13)	1579	32	1961	43	1.2422
	2 (14)	1579	32	1960	43	1.2412
	3 (15)	1780	35	1874	40	1.0527
PART 6	REGION (ABS)	IN	ST.DEV.	OUT	ST.DEV.	OUT/IN
(WEST)	1 (16)	1065	26	1292	34	1.2130
	2 (17)	1067	26	1293	34	1.2122
	3 (18)	1172	27	1240	32	1.0582
PART 7	REGION (ABS)	IN	ST.DEV.	OUT	ST.DEV.	OUT/IN
(WEST)	1 (19)	1685	34	2078	46	1.2329
	2 (20)	1689	34	2080	46	1.2316
	3 (21)	1903	37	1990	44	1.0458
PART 8	REGION (ABS)	IN	ST.DEV.	OUT	ST.DEV.	OUT/IN
(WEST)	1 (22)	1137	27	1362	35	1.1977
	2 (23)	1138	27	1363	35	1.1973
	3 (24)	1234	28	1301	32	1.0542
PART 9	REGION (ABS)	IN	ST.DEV.	OUT	ST.DEV.	OUT/IN
(ARRAY)	1 (25)	1735	31	1697	30	1.0934
PART 10	REGION (ABS)	IN	ST.DEV.	OUT	ST.DEV.	OUT/IN
(ARRAY)	1 (26)	2667	21	3558	24	1.3341
PART 11	REGION (ABS)	IN	ST.DEV.	OUT	ST.DEV.	OUT/IN
(ARRAY)	1 (27)	1877	33	2031	43	1.0821
PART 12	REGION (ABS)	IN	ST.DEV.	OUT	ST.DEV.	OUT/IN
(CLUSTER)	1 (28)	1877	33	2031	43	1.0821
	2 (29)	2667	21	3558	24	1.3341
	3 (30)	1735	31	1897	30	1.0934
	4 (31)	1016	18	1605	24	1.5798
PART 13	REGION (ABS)	IN	ST.DEV	OUT	ST.DEV.	OUT/IN
(WEST)	1 (32)	1016	18	1605	24	1.5798
	2 (33)	1016	18	1366	22	1.3642
	3 (34)	908	17	1257	22	1.3841
	4 (35)	690	26	690	26	1.0000
	5 (36)	894	34	894	34	1.0000

TABLE 7

MATERIAL ACTION COUNTS FOR STAGES 1 TO 18 NORMALISED TO 10.000 SOURCE NEUTRONS

****
* MATERIAL 1 *
****

NUCLIDE	CAPTURE	FISSION	FISSION CHILDREN	ELASTIC	(N,N*)	(N,2N)	(N,3N)
PARTITION 1 ..... FROM 100.0000 KEV TO 15.0000 MEV							
U238	103	220	614	6332	2038	10	0
..... ST DEV	3	4	13	29	14	1	0
U235	5	51	133	204	41	0	0
..... ST DEV	1	2	6	4	2	0	0
O	12	--	--	6741	4	--	--
..... ST DEV	1	--	--	31	1	--	--
NEUTRON GAIN = 367							
PARTITION 2 ..... FROM 0.4000 EV TO 100.0000 KEV							
U238	1172	0	0	9850	11	0	0
..... ST DEV	10	0	0	43	1	0	0
U235	254	586	1423	300	0	0	0
..... ST DEV	5	7	17	5	0	0	0
O	0	--	--	6290	0	--	--
..... ST DEV	0	--	--	31	0	--	--
NEUTRON GAIN = -585							
PARTITION 3 ..... FROM 0.0000 EV TO 0.4000 EV							
U238	377	0	0	1648	0	0	0
..... ST DEV	6	0	0	16	0	0	0
U235	465	2710	6585	121	0	0	0
..... ST DEV	6	14	34	3	0	0	0
O	0	--	--	1638	0	--	--
..... ST DEV	0	--	--	14	0	--	--
NEUTRON GAIN = 3033							

TABLE 8

REGION ACTION COUNTS FOR STAGES 1 TO 18 NORMALISED TO 10,000 SOURCE NEUTRONS

REGION NO.	CAPTURE	ST.DEV.	FISSION	ST.DEV.	CHILDREN	ST.DEV.	SCATTER	ST.DEV.
1	589	10	752	16	1844	39	48661	770
2	2	1	0	0	0	0	498	106
3	446	7	0	0	0	0	3736	55
4	598	10	743	16	1822	38	48494	781
5	3	1	0	0	0	0	472	105
6	437	8	0	0	0	0	3732	57
7	337	7	430	11	1057	28	27381	529
8	2	0	0	0	0	0	364	93
9	305	6	0	0	0	0	2117	36
10	346	7	440	11	1081	28	27591	526
11	1	0	0	0	0	0	231	55
12	310	6	0	0	0	0	2122	36
13	274	7	359	12	883	28	22497	571
14	1	0	0	0	0	0	250	59
15	287	7	0	0	0	0	1795	40
16	191	6	231	9	566	22	15194	465
17	1	0	0	0	0	0	106	35
18	158	5	0	0	0	0	1161	32
19	293	7	379	12	930	30	24099	601
20	1	0	0	0	0	0	376	96
21	304	7	0	0	0	0	1891	43
22	194	6	232	9	571	22	15261	444
23	0	0	0	0	0	0	97	27
24	158	5	0	0	0	0	1225	32
25	912	18	590	18	1449	43	41193	983
26	3375	21	2365	23	5805	57	165401	1172
27	950	19	611	18	1501	44	42970	1004
28	950	19	611	18	1501	44	42970	1004
29	3375	21	2365	23	5805	57	165401	1172
30	912	18	590	18	1449	43	41193	983
31	618	9	0	0	0	0	86575	1196
32	5855	15	3566	15	8754	37	336139	1091
33	219	5	0	0	0	0	3003	53
34	21	1	0	0	0	0	6983	138
35	349	7	0	0	0	0	34084	839
36	0	0	0	0	0	0	0	0

TABLE 9

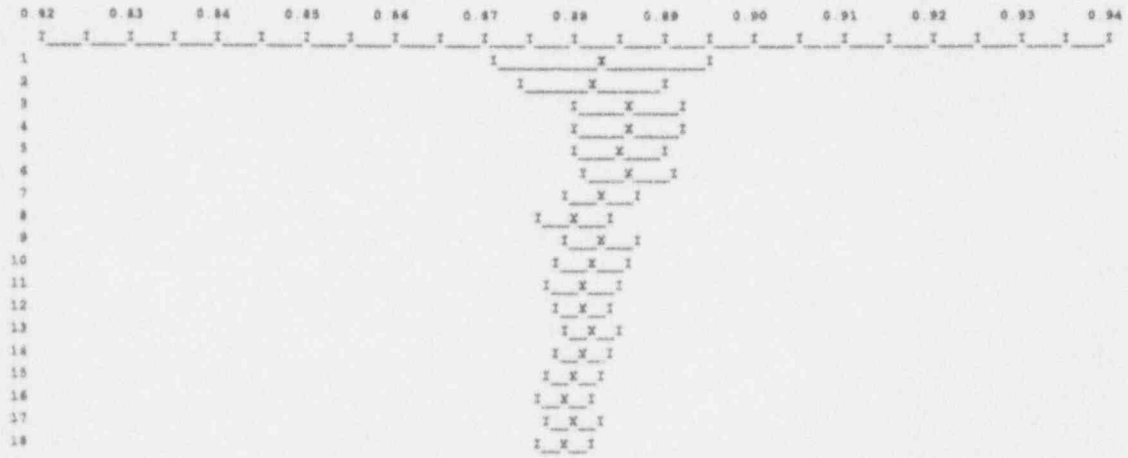
NEUTRON FLUXES FOR STAGES 1 TO 18 NORMALISED TO 10,000 SOURCE NEUTRONS

N.B. FOR REGIONS WHICH OVERLAP THE FLUX PRINTED BELOW IS THE TOTAL FLUX AND NOT THE FLUX PER UNIT VOLUME
REGIONS CONTAINING SUBSIDIARY PARTS OR WITH ZERO FLUXES ARE NOT PRINTED

GROUP NO	ENERGY RANGE	REGION 1	REGION 2	REGION 3	REGION 4	REGION 5	REGION 6	REGION 7	REGION 8
1	100.000KEV - 15.000MEV	3.718E-01	6.795E-03	2.872E-01	3.642E-01	6.281E-03	2.885E-01	2.068E-01	2.594E-03
	..... ST DEV	5.784E-03	1.518E-03	4.195E-03	5.810E-03	1.189E-03	4.292E-03	4.007E-03	5.989E-04
2	0.400 EV -100.000KEV	3.202E-01	6.913E-03	2.556E-01	3.214E-01	6.828E-03	2.523E-01	1.788E-01	3.444E-03
	..... ST DEV	4.973E-03	1.267E-03	3.871E-03	4.980E-03	1.091E-03	3.861E-03	3.343E-03	7.533E-04
3	0.000 EV - 0.400 EV	9.567E-02	1.543E-02	1.676E-02	9.480E-02	1.470E-02	1.626E-02	4.937E-02	1.253E-02
	..... ST DEV	1.624E-03	3.517E-03	4.082E-04	1.680E-03	3.625E-03	4.09?E-04	1.164E-03	3.399E-03
	**** TOTALS ****	7.777E-01	2.914E-02	5.596E-01	7.744E-01	2.780E-02	5.570E-01	4.369E-01	1.857E-02
	**** ****								
	**** ST DEV ****	1.184E-02	5.674E-03	7.475E-03	1.196E-02	5.184E-03	7.616E-03	5.111E-03	4.237E-03

TABLE 10

PLOT OF CUMULATIVE MEAN K(THERM) AGAINST STAGE NUMBER



FINAL VALUE OF K(THERM) = 0.8793 (ST.DEV =0.0028)

TABLE 11

CASE CATEGORISATION

THERE ARE 2592 CATEGORIES SPLIT AS FOLLOWS

A=0 URANIUM SYSTEMS ..... 1 - 864
A=1 PLUTONIUM SYSTEMS ... 865 - 1728
A=2 MIXED SYSTEMS ..... 1729 - 2592

WITHIN EACH 864 NUMBER SEGMENT :

B=0 LOW NON-FUEL ABSORPTION .... 1 - 432
B=1 HIGH NON-FUEL ABSORPTION ... 433 - 864

WITHIN EACH 432 NUMBER SEGMENT :

C=0 EXPONENTIAL ASSEMBLIES ... 1 - 108
C=1 LOW LEAKAGE SYSTEMS ..... 109 - 216
C=2 MEDIUM LEAKAGE SYSTEMS ... 217 - 324
C=3 HIGH LEAKAGE SYSTEMS ..... 325 - 432

WITHIN EACH 108 NUMBER SEGMENT :

D=0 LOW RESONANCE ABSORPTION ..... 1 - 36
D=1 MEDIUM RESONANCE ABSORPTION ... 37 - 72
D=2 HIGH RESONANCE ABSORPTION ..... 73 - 108

WITHIN EACH 36 NUMBER SEGMENT :

E=0 NO FAST FISSION ..... 1 - 9
E=1 LOW FAST FISSION ..... 10 - 18
E=2 MEDIUM FAST FISSION ... 19 - 27
E=3 HIGH FAST FISSION ..... 28 - 36

WITHIN EACH 9 NUMBER SEGMENT :

F=0 FAST SPECTRUM ..... 1 - 3
F=1 INTERMEDIATE SPECTRUM ... 4 - 6
F=2 THERMAL SPECTRUM ..... 7 - 9

WITHIN EACH 3 NUMBER SEGMENT :

G=0 HETEROGENEOUS 1
G=1 HETEROGENEOUS/HOMOGENEOUS ... 2
G=2 HOMOGENEOUS 3

TYPE OF SYSTEM ..... A = 0 FRACTION OF FISSIONS IN URANIUM = 1.0000

NON-FUEL CAPTURE .... B = 1 FRACTION OF TOTAL CAPTURES IN FUEL = 0.5935

LEAKAGE ..... C = 1 FRACTION OF NEUTRONS LEAKING = 0.0000

RESONANCE CAPTURE .... D = 0 MEASURE OF RESONANCE CAPTURE = 0.8259

FAST FISSION ..... E = 3 MEASURE OF FAST FISSION = 1.0307

SPECTRUM TYPE ..... F = 2 FRACTION OF CAPTURES IN EACH PARTITION = 0.0450 0.3214 0.6336

GEOMETRY TYPE..... G = 0 MEASURE OF HETEROGENEITY = 0.1007

```
*******************************************
* THIS CASE FALLS INTO CATEGORY NUMBER  565 *
*******************************************
```

THE CATEGORY NUMBER IS NOT A GUARANTEED INDICATOR OF THE BIAS TO BE EXPECTED ON THE FINAL VALUE OF KEFF
IT SHOULD BE USED WITH GREAT CAUTION SINCE MANY OTHER FACTORS ARE INVOLVED (E.G. UNUSUAL/EXOTIC MATERIALS AND NUCLIDES)

```
FINAL VALUE OF K3 = 0.8793    ( ST.DEV = 0.0020 )
************************************************
```

SECTION D

COMPARISON OF MONK6B AND KENOVa

Summary

A comparison of MONK6B is presented in two parts: firstly, a wide-ranging overview comparison for a set of standard criticality test cases employed in the USA; and secondly, a detailed comparison for a hypothetical simplified fuel storage test case.

Additional comparisons between MONK6B and other international criticality codes is regularly undertaken by a OECD/NEA working group. Reports of their activites can be obtained from: The Organisation for Economic Cooperation and Development - Nuclear Energy Agency, Paris, France.

COMPARISON OF MONK6B AND SCALE3.1 FOR A SET OF STANDARD CRITICALITY BENCHMARK PROBLEMS

A K Ziver

AEA TECHNOLOGY

Summary

This report presents the results obtained from criticality calculations for a standard set of US code benchmark problems. The problems were modelled using MONK6B and SCALE3.1 systems. The MONK6B calculations were performed using the point energy UKNDL nuclear data library. The SCALE3.1 analysis using KENOVa and XSDRN were performed with the 16 group and the 27 group standard libraries.

CONTENTS

LIST OF TABLES

LIST OF FIGURES

1 INTRODUCTION

A set of 12 benchmark problems have been employed in the United States for the comparison of criticality safety codes. The problems cover a wide range of conditions, including bare and reflected single units containing uranium or plutonium in metal or liquid form, and arrays of similar units. Each problem is presented clearly giving simplified geometrical data and material compositions. This enables equivalent computer models to be constructed for a range of criticality safety codes including both Monte Carlo and deterministic methods.

In this work the point energy Monte Carlo criticality code MONK6B (1) has been used to calculate the system multiplication of the test problems. Calculations were also carried out using the SCALE3.1 (2) package by activating its CSAS control sequences for criticality analysis which employ XSDRN (1D S_n Code) and KENOVa (3D Monte Carlo Code) with multi-group nuclear data.

This report gives a detailed description of the 12 benchmark problems and presents their corresponding computer models as implemented in the MONK6B and SCALE3.1 codes. The system multiplication factors (k-effectives) obtained using MONK6B are presented and compared against SCALE3.1 (XSDRN and KENOVa) results.

2 THE CRITICALITY CODE SYSTEMS

2.1 MONK6B

The current standard version MONK6B has been employed to perform the calculations with its standard point energy nuclear data library.

2.2 SCALE3.1

The version 3.1 of the SCALE3.1 (2) package was used which was released by the Oak Ridge National Laboratory in October 1986. The following Criticality Safety Analysis System (CSAS) modules of the package were used in the present work.

NITAWL: Employs the Nordheim Integral Technique to perform resonance shielding calculations and processes the multi-group nuclear data.

BONAMI: Performs resonance shielding using the Bondarenko shielding factor method and prepares the nuclear data files for use in KENOVa and XSDRN calculations.

XSDRN: The one-dimensional S_n transport code for performing criticality calculations. XSDRN can also be used to perform lattice cell calculations to obtain cell-averaged cross sections for use in KENOVa.

KENO Va: The standard 3D Monte Carlo code used in the US for criticality analysis. It calculates the system multiplication factor (k-effective) using multi-group nuclear data which are derived from ENDFB compilations and pre-processed using the modules in the SCALE3.1 system.

3 DESCRIPTION OF BENCHMARK PROBLEMS

A summary of the test problems is given in Table 1, which was taken from the original specification. The problems are geometrically fairly simple and well-defined, enabling analysis to be performed with a range of computer methods. The first seven of the 12 benchmark problems represent spherical systems comprising either bare or water-reflected plutonium or uranium materials. Problems 8 and 9 represent a water- reflected cylindrical tank containing plutonium-uranium and plutonium-uranium-gadolinium nitrate solutions respectively. In problem 10 a triangular lattice of PuO_2-UO_2 rods are modelled in plutonium-uranium-gadolinium nitrate solution. An array of 4 x 4 x 4 bare plutonium metal units are presented in problem 11. Problem 12 describes 6 tanks containing plutonium nitrate solution positioned as 3 x 2 array in a cell with concrete walls. Table 2 presents the material specifications for each test problem. The geometrical arrangement for the benchmark problems are shown in Figures 1 to 6.

3.1 The MONK6B Models of Benchmark Problems

The nuclides used from UKNDL point energy nuclear data file are given in Table 2. The input data listing for each case is presented in Appendix A.

3.2 The SCALE3.1 Models

The SCALE3.1 models of the test problems are presented in Appendix B. The CSAS1X and CSAS25 sequences were employed to perform a 1D and 3D criticality calculation using both the 16-group and 27-group libraries.

The CSAS1X sequence comprises the codes BONAMI and NITAWL for cross-section processing including resonance shielding. Then the code XSDRN is used to calculate k-effective for one-dimensional systems. Problems 1 to 7 were modelled using CSAS1X as they can be represented in one-dimensional spherical geometry. The test problems 8 to 12 are three-dimensional and therefore were not modelled using the CSAS1X sequence.

The CSAS25 sequence is designed to calculate system multiplication factors using the KENOVa multi-group Monte Carlo code. It comprises the functional modules BONAMI, NITAWL and KENO Va. The 12 test problems were modelled using the CSAS25 sequence.

4 RESULTS

The results of the criticality calculations using the point energy UKNDL data with MONK6B and multi-group data with the SCALE3.1 package (KENOVa and XSDRN) are presented in Tables 3 to 6.

In Tables 3 and 4 the values of k-effective obtained from MONK6B (UKNDL) are compared against the KENOVa (16-Group Hansen-Roach) and KENOVa (27-Group 27GROUPNDF4) results respectively.

Table 5 compares the values of k-effective obtained from KENOVa code using the CSAS25 analytical sequence of the SCALE3.1 package with the two different libraries.

Table 6 gives the results from CSAS1X analytical sequence which gives the one-dimensional solutions based on deterministic solution of the Boltzmann transport equation. Problems 1 to 7 represent spherical systems for which one-dimensional solutions were carried out.

5 CONCLUSIONS

A series of benchmark problems covering a wide range of criticality applications have been analysed with MONK6B and KENOVa and XSDRN. In the light of the results presented in Tables 3 to 6, the following observations can be made:

- The results obtained for problems which do not involve plutonium solutions showed reasonable agreement. The maximum difference in k-effective obtained for these cases was of the order of 0.6%±0.2%.

- The results obtained for the plutonium solution cases showed much worse agreement with significant differences between MONK6B and SCALE3.1 of up to 3%. These larger differences can be attributed to a combination of effects. Firstly, the larger uncertainties that still exist in the basic thermal data for plutonium. Secondly, the limited energy resolution of the small multi-group libraries make it difficult to accurately predict k-effective for a wide range of systems. This is supported by significant inconsistencies between the 16-group and 27-group KENOVa results for plutonium systems, and the generally reasonable agreement between MONK6B and experiments for such systems.

- As expected, XSDRN results agree well with the corresponding KENOVa results.

REFERENCES

[1] The ANSWERS Service
MONK6 - A Monte Carlo Code for Criticality Calculations.
ANSWERS(MONK6) 1 (1991).

[2] SCALE
A Modular System for Performing Standardised Computer Analysis for Licensing Evaluation. NUREG/CR-0200 (ORNL/NUREG/CSD-2). Version 3.1. (1986).

TABLE 1. A SUMMARY OF US BENCHMARK TEST PROBLEMS

Problem	Description
1	Water-reflected plutonium metal sphere. Plutonium density 19.74 g/cc. Plutonium composition 5.2 w/o Pu240, 0.3 w/o Pu 241, 0.2 w/o Pu242
2	Water-reflected plutonium solution sphere. Solution Composition: gPu/l=140, gNO3/l=284, gH2O/l=880.8 Plutonium Composition 4.57 w/o Pu240.
3	Bare plutonium solution sphere. Solution Composition: gPu/l=9.457 Acid Molarity=1.105 Specific Gravity=1.503. Plutonium composition: 2.521 w/o Pu240, 0.075 w/o Pu241, 0.014 w/o Pu242
4	Bare Uranium (U233) Solution Sphere Solution composition gU/l=17.14
5	Bare Uranium (U235) Metal Sphere Uranium Density = 18.75 g/cc.
6	Bare Uranium (U235) Solution Sphere Solution Composition: gU/l=20.12
7	Water-reflected Low-enriched, Unmoderated Mixed Oxide Sphere Composition: 8 w/o PuO2 in U(nat.)O2.
8	Water-reflected Pu-U Nitrate Solution in Cylindrical Tank. No Reflector above Solution within Solution Tank. Solution Composition: gPu/l=12.4 gU/=29.9 Acid Molarity=1.3 Specific Gravity=1.1030
9	Water-reflected Pu-U-Gd Nitrate Solution in Cylindrical Tank. No Reflector above solution within Solution Tank. Solution Composition gPu/l=77.3 gU/l=176.8, gGd/l=1.06. Acid molarity=3.25 Specific Gravity=1.462
10	Lattice of PuO2-UO2 Rods in Pu-U-Gd nitrate solution in water reflected cylindrical tank. No reflector above rods inside the tank. Solution Composition gPu/l=77.63, gU/l=180.0, gGd/l=1.338. Acid Molarity=3.4 Specific Gravity=1.463
11	Bare Cylindrical array of Plutonium Metal Units (4x4x4) Plutonium density 19.53 g/cc, Plutonium weight = 3 kg.
12	An Array (3x2x1) of Cylindrical Tanks Containing Plutonium Solution in a Cell which has 30 cm Thick Concrete Walls. Solution Composition: gPu/l=115.1, Acid Molarity=2.01 Specific Gravity=1.260. Plutonium Composition 4.23 w/o Pu240, 0.29 w/o Pu241, 0.016 w/o Pu242

TABLE 2 MATERIAL SPECIFICATIONS

Benchmark Problem	Materials	Nuclide Identifiers		Atom Densities (atoms/barn cm)
		UKNDL	SCALE3.1	
1	Plutonium Metal	PU239	PU-239	4.6980E-02
		PU240	PU-240	2.5750E-03
		PU241	PU-241	1.4900E-04
		PU242	PU-242	9.9000E-06
	Water	HINH2O	H	6.6063E-02
		O	O	3.3032E-03
2	Plutonium Solution	PU239	PU-239	3.3662E-04
		PU240	PU-240	1.6163E-05
		HINH2O	H	6.0260E-02
		O	O	3.7734E-02
		N	N	2.7595E-03
	St. Steel	FE	FE	5.8886E-02
		NI	NI	8.2374E-04
		CR	CR	1.7672E-02
	Water	HINH2O	H	6.6063E-02
		O	O	3.3032E-02
3	Plutonium Solution	PU239	PU-239	2.3201E-05
		PU240	PU-240	6.0140E-07
		PU241	PU-241	1.7720E-08
		HINH2O	H	6.4836E-02
		O	O	3.4367E-02
		N	N	7.6043E-04
	Aluminium	AL27	AL	6.0260E-02
4	Uranium Solution	U233	U-233	4.3280E-05
		U234	U-234	7.1600E-07
		U235	U-235	1.8000E-08
		U238	U-238	2.8100E-07
		HINH2O	H	6.6636E-02
		O	O	3.3607E-02
		N	N	1.1780E-04
	Aluminium	AL27	AL	6.0260E-02
5	Uranium Metal	U235	U-235	4.5447E-02
		U238	U-238	2.5600E-03
6	Uranium Solution	U234	U-234	5.3800E-07
		U235	U-235	4.8066E-05
		U236	U-236	1.3800E-07
		U238	U-238	2.8070E-06
		HINH2O	H	6.6228E-02
		O	O	3.3736E-02
		N	N	1.8690E-04
	Aluminium	AL27	AL	6.0260E-02

Table 2 Continued

7	Mixed Oxide	PU239	PU-239	1.9591E-03
		U235	U-235	1.6460E-04
		U238	U-238	2.2450E-02
		O	O	4.9148E-02
	Water	HINH2O	H	6.6680E-02
		O	O	3.3343E-02
8	Plutonium Uranium Nitrate Solution	PU238	PU-238	8.3767E-09
		PU239	PU-239	2.9365E-05
		PU240	PU-240	1.7386E-06
		PU241	PU-241	1.0752E-07
		PU242	PU-242	2.1964E-08
		U235	U-235	5.0609E-07
		U236	U-236	1.4077E-08
		U238	U-238	7.5163E-05
		HINH2O	H	6.3896E-02
		O	O	3.4957E-02
		N	N	1.0883E-03
	St. Steel	FE	FE	6.3310E-02
		CR	CR	1.6540E-02
		NI	NI	6.5100E-03
	Water	HINH2O	H	6.6680E-02
		O	O	3.3343E-02
9	Plutonium Uranium Gadolinium Nitrate Solution	PU238	PU-238	2.3500E-06
		PU239	PU-239	1.8260E-04
		PU240	PU-240	1.1180E-05
		PU241	PU-241	7.1600E-07
		PU242	PU-242	1.1900E-07
		U234	U-234	2.7000E-08
		U235	U-235	3.0130E-06
		U236	U-236	5.4000E-08
		U238	U-238	4 .442E-04
		HINH2O	H	5.5178E-02
		O	O	3.8688E-02
		N	N	3.7278E-03
		GD	GD	4.0600E-06
	St. Steel	FE	FE	6.3310E-02
		CR	CR	1.6540E-02
		NI	NI	6.5100E-03
	Water	HINH2O	H	6.6680E-02
		O	O	3.3343E-02
10	Fuel PuO2-UO2 Rods	PU239	PU-239	4.9900E-03
		PU240	PU-240	6.9190E-04
		PU241	PU-241	1.0020E-04
		U235	U-235	1.2430E-04
		U238	U-238	1.7170E-02
		O	O	4.6120E-02

Table 2 Continued

10	Plutonium Uranium Gadolinium Nitrate Solution	PU239	PU-239	1.8354E-04
		PU240	PU-240	1.1180E-05
		PU241	PU-241	7.1180E-07
		U235	U-235	3.0670E-06
		U238	U-238	4.5340E-04
		HINH2O	H	5.4974E-02
		O	O	3.8564E-02
		N	N	3.7298E-03
		FE	FE	8.6273E-06
		GD	GD	5.1244E-06
	St.Steel (304L)	FE	FE	5.8886E-02
		NI	CR	8.2374E-03
		CR	NI	1.7672E-02
	St.Steel (316L)	FE	FE	4.8381E-02
		NI	CR	7.9078E-03
		CR	NI	1.2649E-02
	Water	HINH2O	H	6.6884E-02
		O	O	3.3442E-02
11	Plutonium Metal Units	PU239	PU-239	4.6053E-02
		PU240	PU-240	2.9263E-03
		PU241	PU-241	2.2454E-04
		PU242	PU-242	4.8612E-06
12	Plutonium Solution	PU239	PU-239	2.7682E-04
		PU240	PU-240	1.2214E-05
		PU241	PU-241	8.3390E-07
		PU242	PU-242	4.5800E-08
		HINH2O	H	6.0070E-02
		O	O	3.6540E-02
		N	N	2.3699E-03
	St.Steel (Z3CN18/10)	FE	FE	6.3310E-02
		CR	CR	1.6540E-02
		NI	NI	6.5100E-03
	Concrete	HINH2O	H	9.5470E-03
		O	O	4.5374E-02
		FE	FE	1.3431E-03
		SI	SI	1.2899E-02
		AL27	AL	3.3567E-03
		CA	CA	2.6128E-03

TABLE 3 COMPARISON OF MONK6B AND KENO Va (16-GROUP)

No	Benchmark Problem Description	MONK6B UKNDL	SCALE 3.1 KENO Va 16-Group	Difference in (*) k-effective
1	Water-reflected Plutonium Metal Sphere	1.0037±0.0013	0.9935±0.0015	+0.0102±0.0020
2	Water-reflected Plutonium Solution Sphere	1.0046±0.0012	1.0057±0.0014	-0.0011±0.0018
3	Bare Plutonium Solution Sphere	1.0038±0.0010	1.0354±0.0010	-0.0316±0.0014
4	Bare Uranium (U233) Solution Sphere	0.9960±0.0011	1.0007±0.0012	-0.0047±0.0016
5	Bare Uranium (U235) Metal Sphere	1.0064±0.0012	0.9999±0.0017	+0.0065±0.0021
6	Bare Uranium (U235) Solution Sphere	1.0015±0.0012	1.0054±0.0012	-0.0039±0.0017
7	Water-reflected Low-enriched Unmoderated Mixed-oxide Sphere	0.7541±0.0013	0.7647±0.0010	-0.0106±0.0016
8	Water-reflected Pu-U Nitrate Solution in Cylindrical Tank	0.9992±0.0011	1.0300±0.0012	-0.0308±0.0016
9	Water-reflected Pu-U-Gd Nitrate Solution in Cylindrical Tank	0.9893±0.0011	1.0025±0.0010	-0.0132±0.0014
10	Lattice of PuO2-UO2 Rods in Pu-U-Gd Nitrate Solution	0.9725±0.0012	0.9934±0.0013	-0.0209±0.0018
11	Bare Cylindrical array of plutonium metal units	0.9614±0.0012	0.9609±0.0013	+0.0005±0.0018
12	An Array of cylindrical tanks containing plutonium solutions	0.9883±0.0011	0.9824±0.0019	+0.0059±0.0022

Note: The errors quoted are one standard deviation (Monte Carlo statistics)
(*) k(MONK6B)-k(KENOVa)

TABLE 4 COMPARISON OF MONK6B AND KENO Va (27-GROUP)

No	Benchmark Problem Description	MONK6B UKNDL	SCALE 3.1 KENO Va 27GROUPNDF4	Difference in (*) k-effective
1	Water-reflected (+) Plutonium Metal Sphere	1.0037±0.0013	1.0056±0.0014	-0.0019±0.0019
2	Water-reflected Plutonium Solution Sphere	1.0046±0.0012	1.0204±0.0013	-0.0158±0.0018
3	Bare Plutonium Solution Sphere	1.0038±0.0010	1.0306±0.0009	-0.0268±0.0014
4	Bare Uranium (U233) Solution Sphere	0.9960±0.0011	1.0006±0.0012	-0.0046±0.0016
5	Bare Uranium (U235) Metal Sphere	1.0064±0.0012	1.0030±0.0015	+0.0034±0.0019
6	Bare Uranium (U235) Solution Sphere	1.0015±0.001[illegible]	0.9980±0.0012	+0.0035±0.0017
7	Water-reflected Low-enriched Unmoderated Mixed-oxide Sphere	0.7541±0.001[illegible]	0.7604±0.0015	-0.0063±0.0020
8	Water-reflected Pu-U Nitrate Solution in Cylindrical Tank	0.9992±0.0011	1.0226±0.0010	-0.0234±0.0014
9	Water-reflected Pu-U-Gd Nitrate Solution in Cylindrical Tank	0.9893±0.0011	0.9985±0.0010	-0.0092±0.0014
10	Lattice of PuO2-UO2 Rods in Pu-U-Gd Nitrate Solution	0.9725±0.0[illegible]	0.9642±0.0013	+0.0083±0.0018
11	Bare Cylindrical array of plutonium metal units	0.9614±0.0012	0.9601±0.0013	+0.0013±0.0018
12	An Array of cylindrical tanks containing plutonium solutions	0.9883±0.0011	1.0013±0.0019	-0.0130±0.0022

Note: The errors quoted are one standard deviation (Monte Carlo statistics)
(*) k(MONK6B)-k(KENOVa)
(+) The KENOVa k-effective given for this problem was obtained using the 123-Group Gam-Thermos Library. The 27-Group case failed during NITAWL precessing.

TABLE 5 COMPARISON OF KENO Va 16 GROUP AND 27 GROUP RESULTS

No	Benchmark Problem Description	SCALE 3.1 KENO Va 16-Group	SCALE 3.1 KENO Va 27GROUPNDF4	Difference in (*) k-effective
1	Water-reflected (+) Plutonium Metal Sphere	0.9935±0.0015	1.0056±0.0014	-0.0121±0.0021
2	Water-reflected Plutonium Solution Sphere	1.0057±0.0014	1.0204±0.0013	-0.0147±0.0019
3	Bare Plutonium Solution Sphere	1.0354±0.0010	1.0306±0.0009	+0.0048±0.0014
4	Bare Uranium (U233) Solution Sphere	1.0007±0.0012	1.0006±0.0012	+0.0001±0.0017
5	Bare Uranium (U235) Metal Sphere	0.9999±0.0017	1.0030±0.0015	-0.0031±0.0023
6	Bare Uranium (U235) Solution Sphere	1.0054±0.0012	0.9980±0.0012	+0.0074±0.0017
7	Water-reflected Low-enriched Unmoderated Mixed-oxide Sphere	0.7647±0.0010	0.7604±0.0015	+0.0043±0.0018
8	Water-reflected Pu-U Nitrate Solution in Cylindrical Tank	1.0300±0.0012	1.0226±0.0010	+0.0074±0.0015
9	Water-reflected Pu-U-Gd Nitrate Solution in Cylindrical Tank	1.0025±0.0010	0.9985±0.0010	+0.0040±0.0014
10	Lattice of PuO2-UO2 Rods in Pu-U-Gd Nitrate Solution	0.9934±0.0013	0.9642±0.0013	+0.0292±0.0018
11	Bare Cylindrical array of plutonium metal units	0.9609±0.0013	0.9601±0.0013	+0.0008±0.0018
12	An Array of cylindrical tanks containing plutonium solutions	0.9824±0.0019	1.0013±0.0019	-0.0189±0.0027

Note: The errors quoted are one standard deviation (Monte Carlo statistics)
(*) k(KENOVa 16 GROUP)-k(KENOVa 27 GROUP)
(+) The KENOVa k-effective given for this problem was obtained using the 123-Group Gam-Thermos Library.

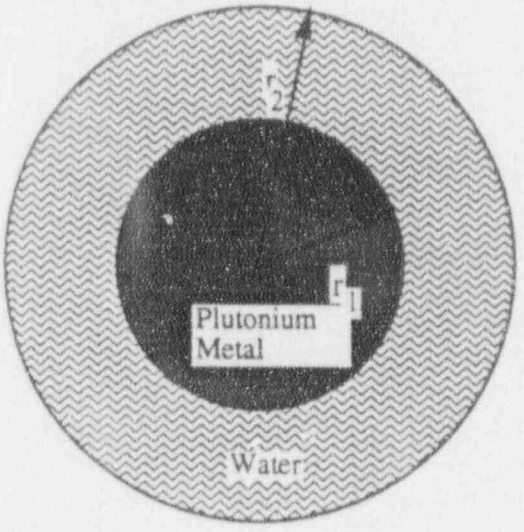
TABLE 6 COMPARISON XSDRN 16-GROUP AND 27-GROUP RESULTS

No	Benchmark Problem Description	SCALE 3.1 XSDRN 16- GROUP	SCALE 3.1 XSDRN 27 GROUP	Difference in k-effective (*)
1	Water-reflected Plutonium Metal Sphere	0.9966	1.0039	-0.0073
2	Water-reflected Plutonium Solution Sphere	1.0055	1.0208	-0.0153
3	Bare Plutonium Solution Sphere	1.0366	1.0290	+0.0076
4	Bare Uranium (U233) Solution Sphere	1.0031	1.0012	+0.0019
5	Bare Uranium (U235) Metal Sphere	0.9999	1.0060	-0.0061
6	Bare Uranium (U235) Solution Sphere	1.0071	0.9991	+0.0080
7	Water-reflected Low-enriched Unmoderated Mixed-oxide Sphere	0.7634	0.7592	+0.0042

(*) k(XSDRN 16 GROUP)-k(XSDRN 27 GROUP)

$r_1 = 4.11$

$r_2 = 24.11$

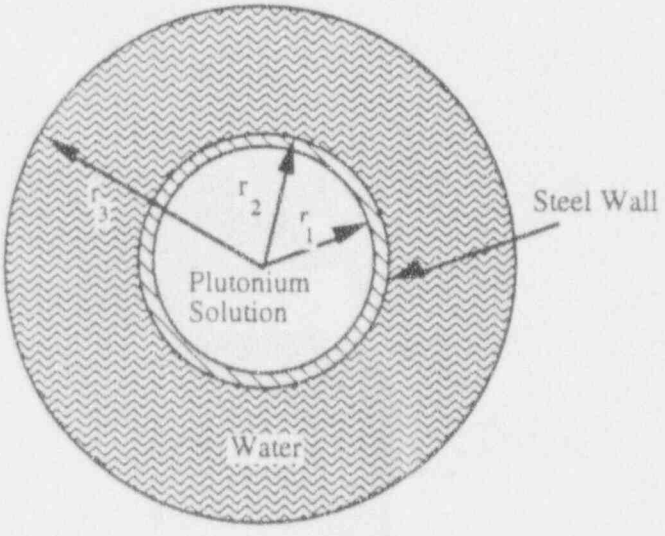


Problem 1 Water-Reflected Plutonium Metal Sphere

$r_1 = 14.568$

$r_2 = 14.692$

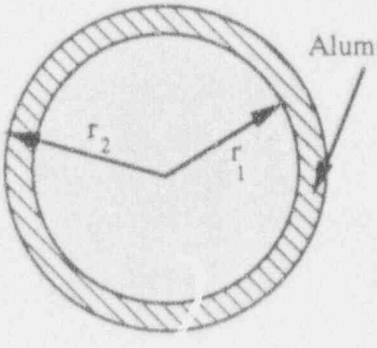
$r_3 = 39.6922$



Problem 2 Water-Reflected Plutonium Solution Sphere

$r_1 = 61.01$

$r_2 = 61.79$



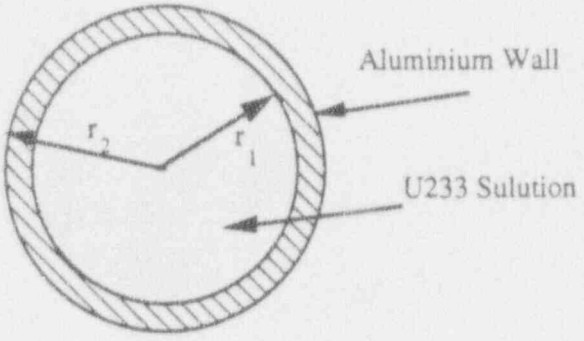
Notes: Dimensions in cm
Drawing not to scale

Problem 3 Bare Plutonium Solution Sphere

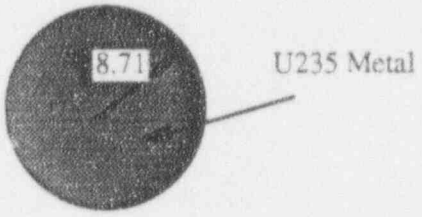
Fig. 1 MONK Models of Problems 1,2 and 3

$r_1 = 34.595$

$r_2 = 34.925$



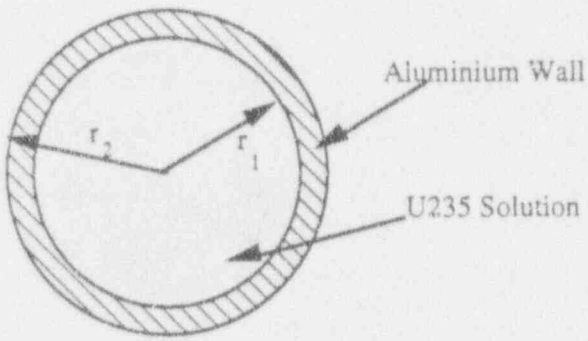
Problem 4 Bare U233 Solution Sphere



Problem 5 Bare U235 Metal Sphere

$r_1 = 34.595$

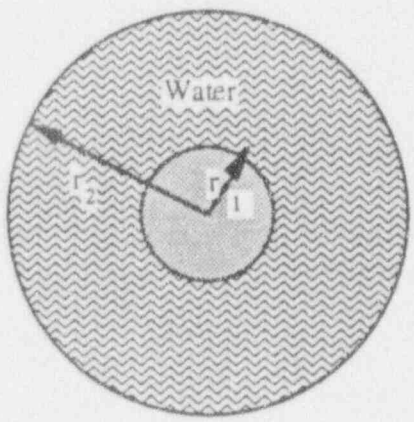
$r_2 = 34.925$



Problem 6 Bare U235 Solution Sphere

$r_1 = 19.4$

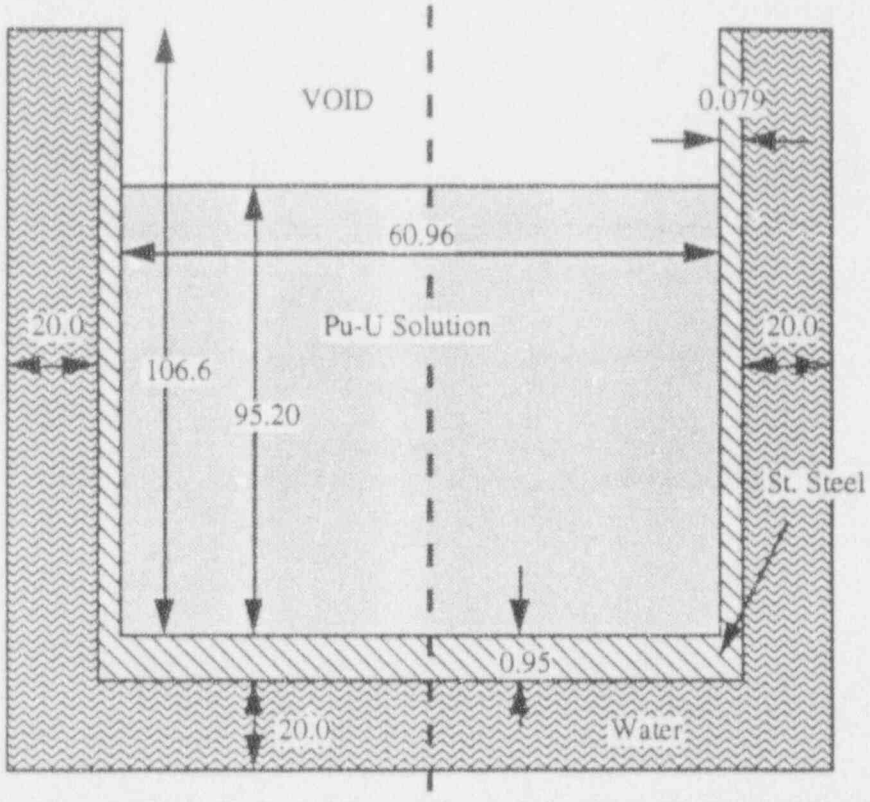
$r_2 = 39.4$



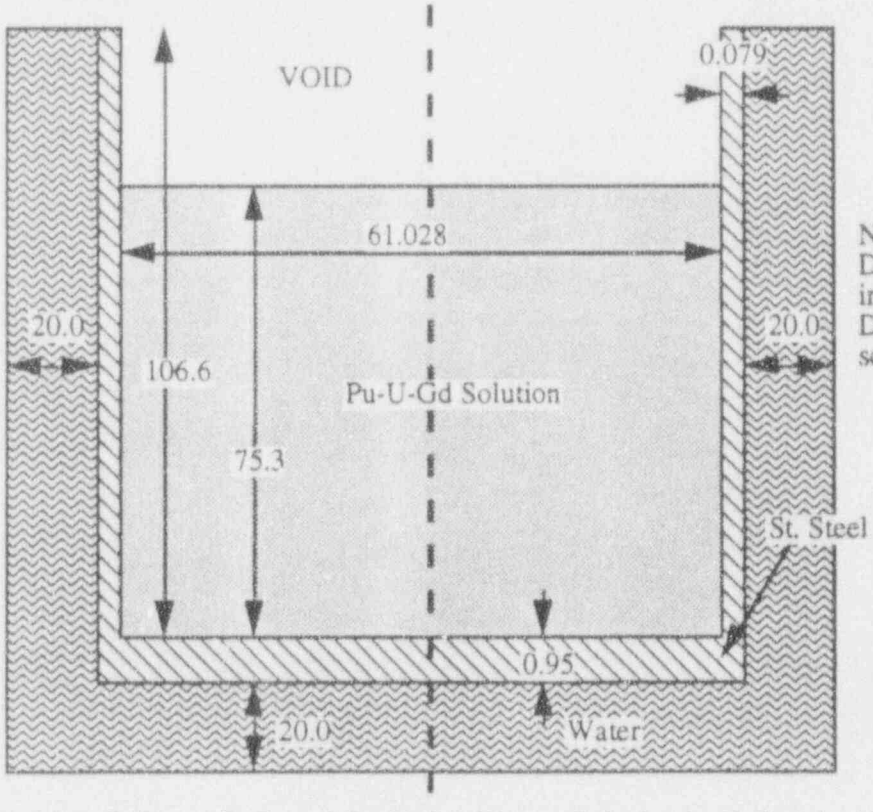
Notes: Dimensions in cm
Drawing not to scale

Problem 7 Water-reflected, Low-enriched,Unmoderated Mixed Oxide Sphere

Fig. 2 MONK Models of Problems 4,5,6 and 7



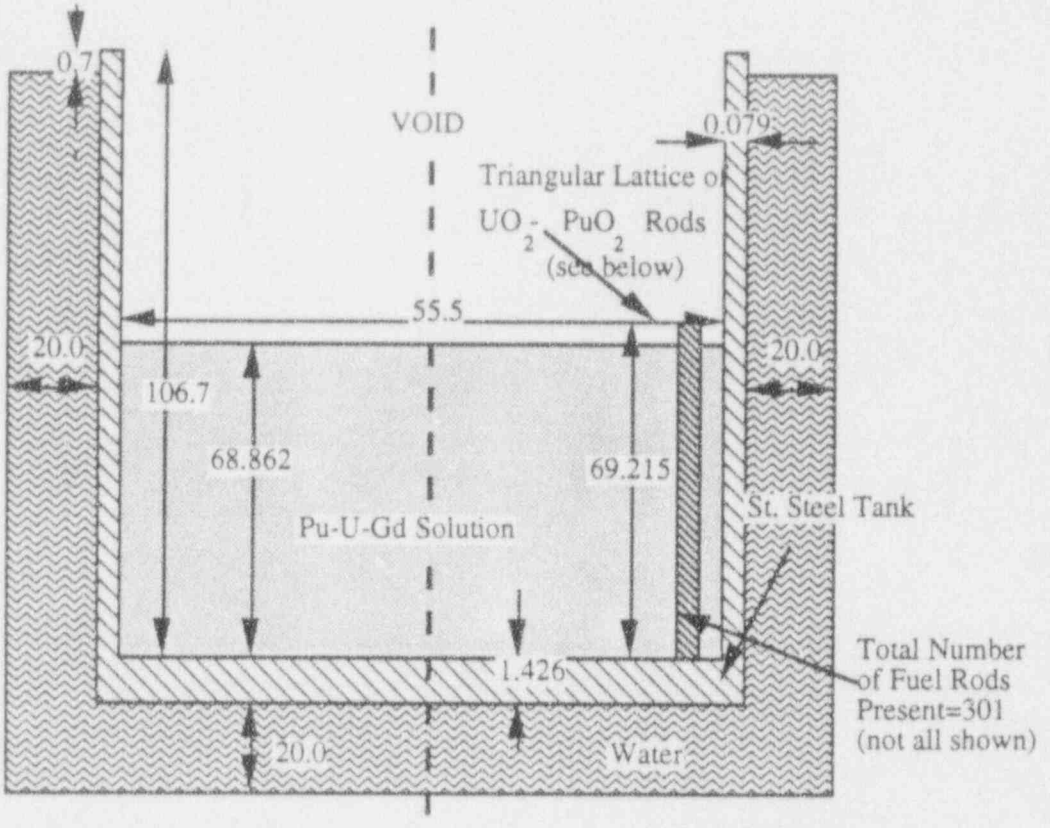
Problem 8 Water Reflected Pu-U Nitrate Solution in Cylindrical Tank



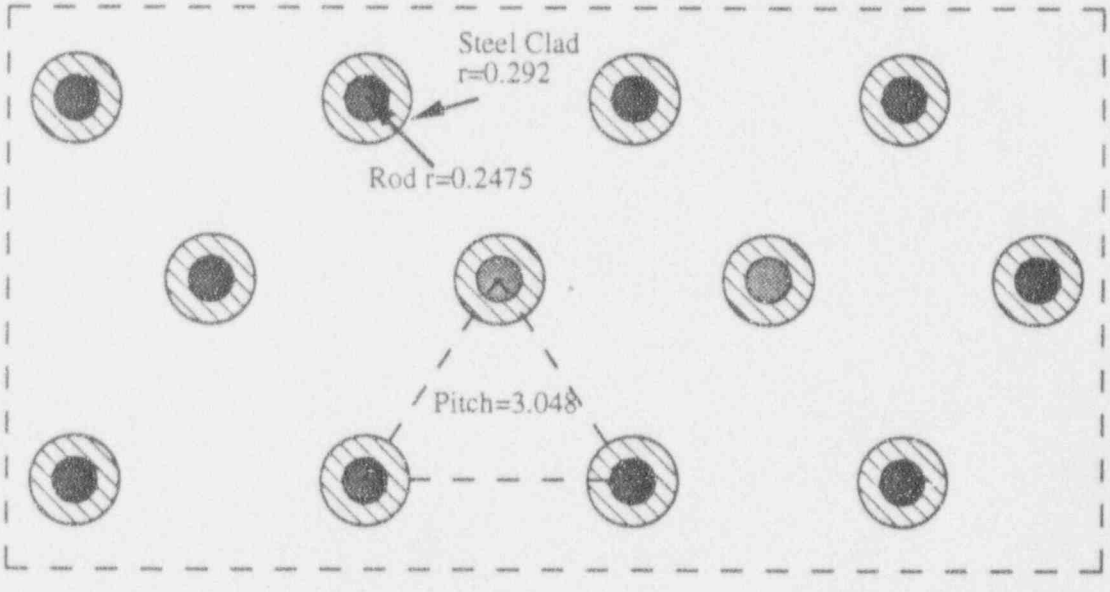
Notes:
Dimensions are in cm
Drawing not to scale

Problem 9 Water Reflected Pu-U-Gd Nitrate Solution in Cylindrical Tank

Fig 3. MONK Models of Problem 8 and 9



A PLAN VIEW OF THE PART OF THE LATTICE



Notes:
Dimensions are in cm
Drawing not to scale

Fig 4. MONK Model of Problem 10

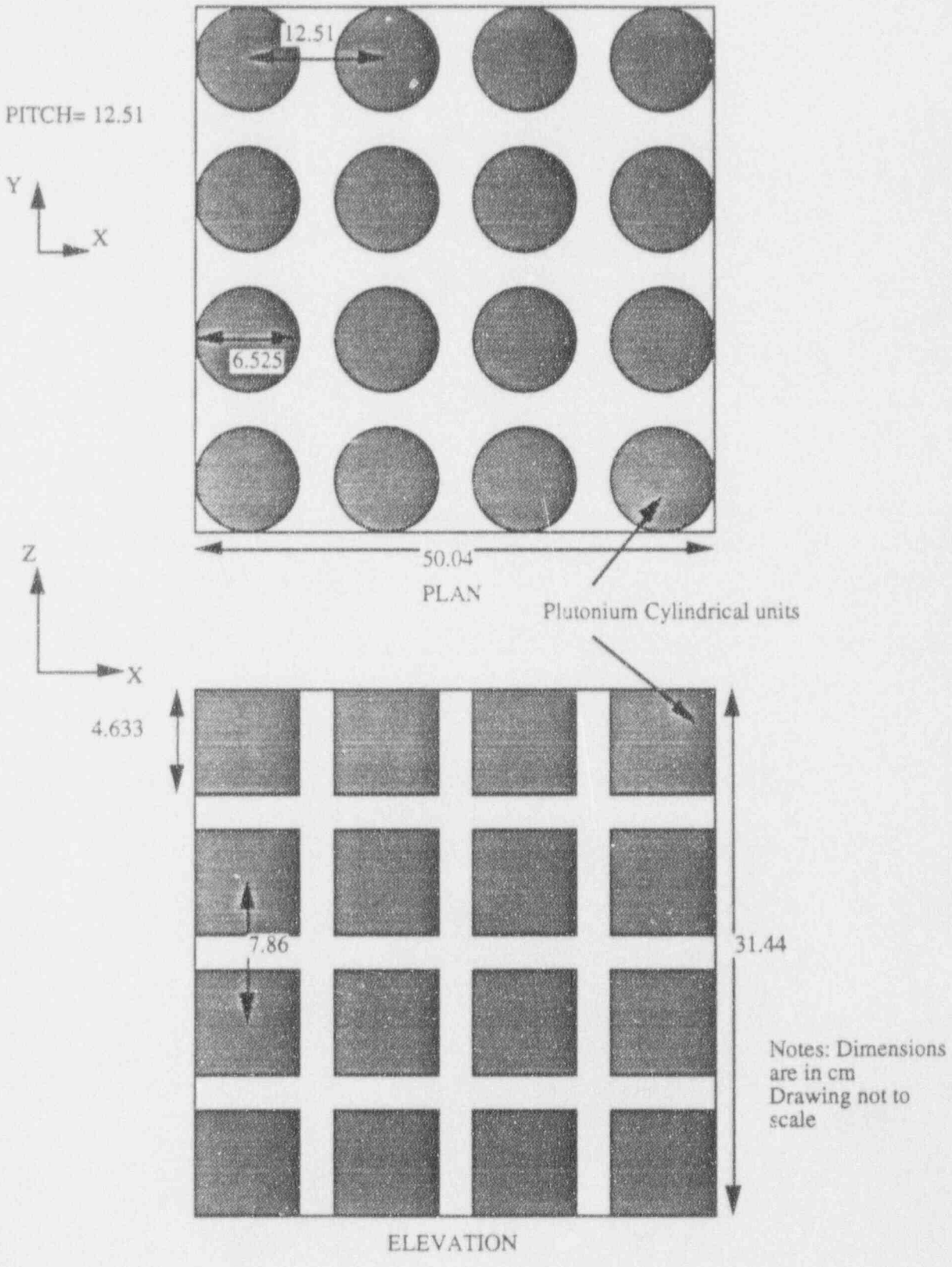
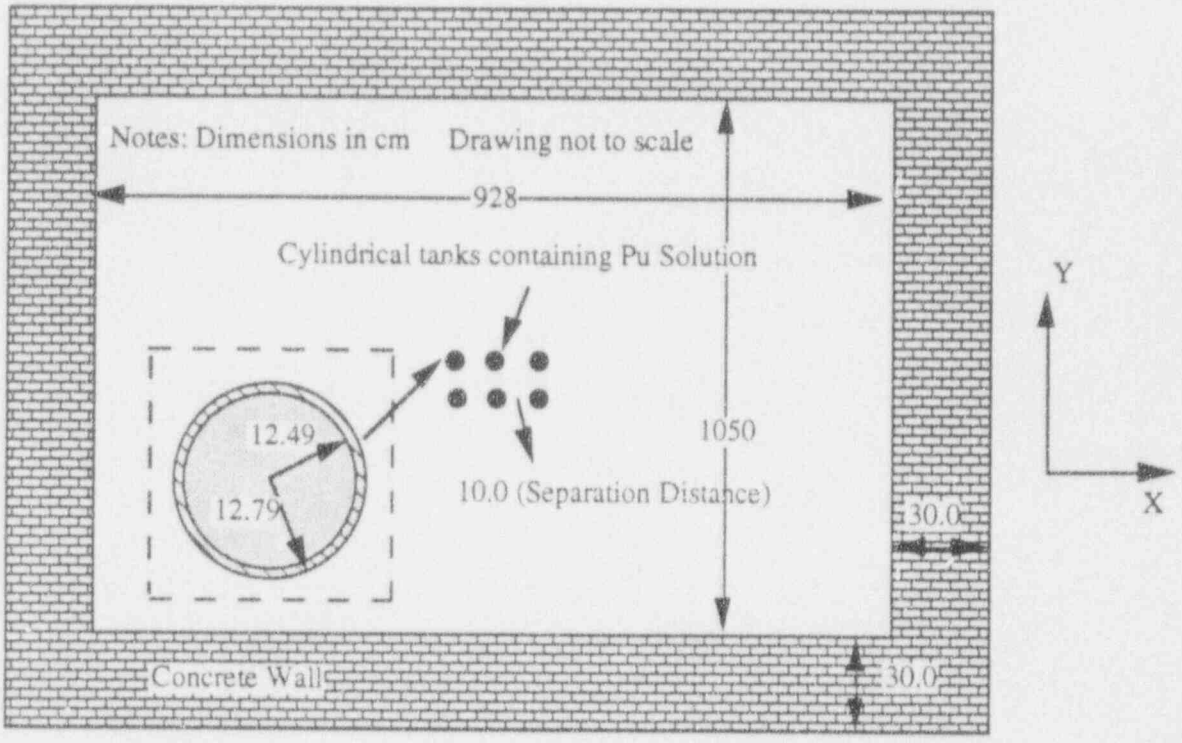
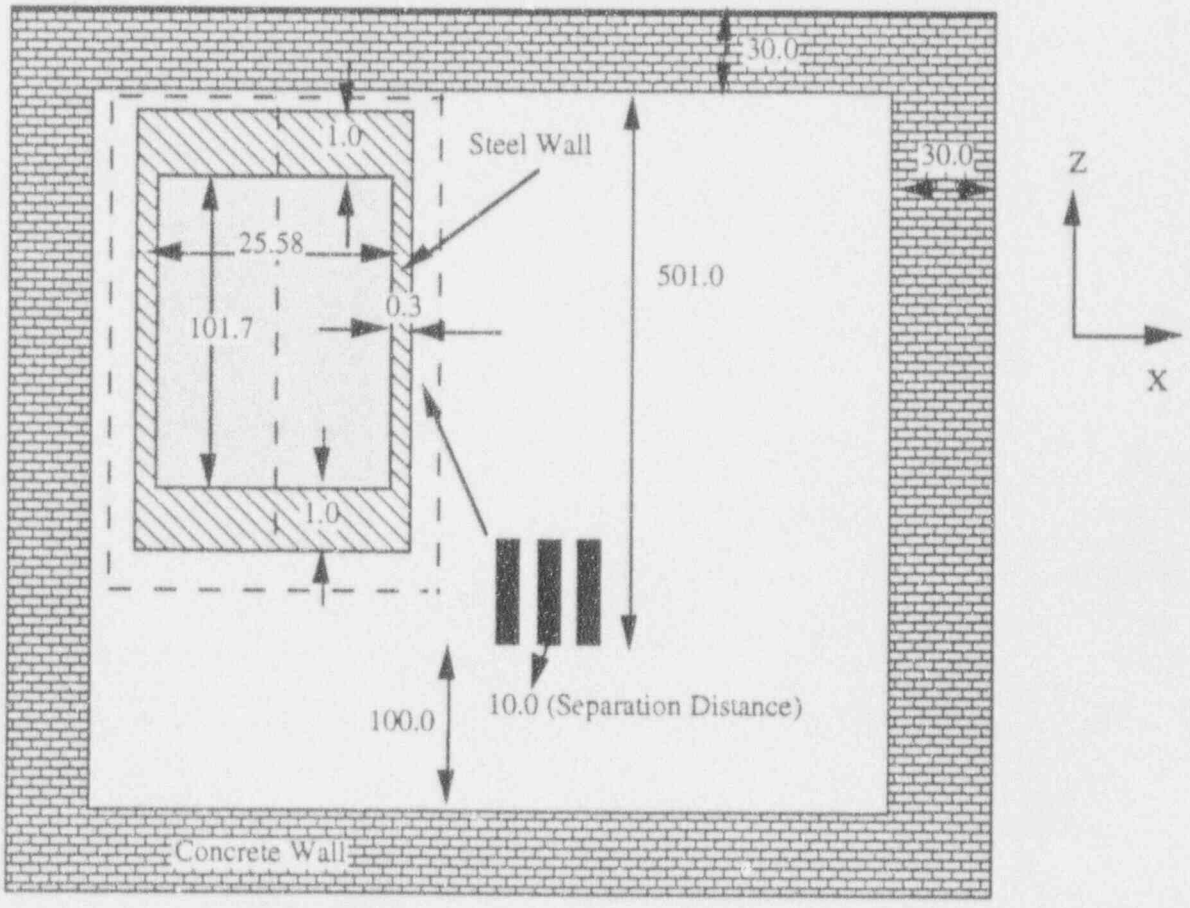


Fig. 5 MONK Model of Benchmark Problem 10

PLAN



ELEVATION



APPENDIX A THE DESCRIPTION OF MONK MODELS

Problem 1.

The benchmark problem 1 was modelled using two nested spheres representing the plutonium metal in the middle and the reflector (water) outside with radii 4.11 and 24.11 cm.

Problem 2.

The MONK model of problem 2 consists of 3 concentric spheres of radii 14.568, 14.692 and 39.6922 cm which are modelled as a NEST. The inner sphere contains the plutonium solution inside a steel container. The outer sphere contains the reflector region (water).

Problem 3.

A bare plutonium solution was represented as a sphere of radius 61.01 cm. The aluminium shell outside was also represented as a sphere of 61.79 cm radius. In MONK the spheres were defined as a NEST.

Problem 4.

The MONK model of problem 4 is composed of two concentric spheres representing the uranium solution inside and the aluminium shell outside. The radii of spheres were modelled as 34.595 and 34.925 cm respectively using the NEST option of the code.

Problem 5.

A bare uranium metal was represented using a sphere of radius 8.71 cm.

Problem 6.

The geometry of this problem was represented using two nested spheres of radii 34.595 and 34.925 cm. The inner sphere contains the U235 solution. The outer sphere represents the aluminium shell.

Problem 7.

The problem 7 represents a bare plutonium solution sphere in an aluminium shell. The MONK model of this problem consists of two concentric spheres of radii 19.4 and 39.4 cm respectively.

Figures 1 and 2 show the MONK models of the benchmark problems 1 to 7. Each problem was modelled using free boundary conditions at the external boundaries. The VOLUME source option was used as the starting source in unit 4 of the MONK input data.

Problem 8.

The problem 8 represents a water-reflected plutonium-uranium nitrate solution in a cylindrical tank. The MONK model of problem 8 contains four nested cylinders as shown in Figure 3. The first and second cylinders represent the plutonium-uranium solution and the voided region above the solution respectively. The third cylinder represents the stainless steel tank. The fourth (outer) cylinder represents the reflector (water) region which covers the full height of the tank. The dimensions of the regions are given in Figure 3.

Problem 9.

The geometrical arrangement of problem 9 is similar to problem 8. The fissile system contains plutonium-uranium-gadolinium nitrate solution in a water-reflected tank. The geometry of this problem was represented by four nested cylinders described as (ZROD) in the MONK code. The first and second cylinders represent the fissile solution and the voided region above the solution respectively The third cylinder was modelled to represent the stainless steel tank. The reflector outside was represented as the fourth cylinder. The dimensions of each region are shown in Figure 3.

Problem 10.

The benchmark problem 10 represents a triangular lattice of PuO_2-UO_2 rods in plutonium-uranium-gadolinium nitrate solution in a stainless steel cylindrical tank. The tank is water-reflected with no reflector above the rods. The detailed description of the tank showing the key dimensions is presented in Figure 10. The MONK model of this problem consists of two parts. The first part describes the water-reflected steel tank in four nested cylinders (ZROD). The first cylinder describes the triangular lattice inside the Pu-U-Gd solution as the HOLE data. The second cylinder gives the voided region above the rods. The third cylinder describes the stainless steel tank. The reflector (water) outside the tank and the voided region above the reflector are represented as the outer most cylinder. The contents of the fourth cylinder was defined as a PLATE HOLE data.

The second part of the geometry describes the HOLE data. First the triangular lattice is described using the TRIANGLE hole facility of the code. The finite number of rods were presented in the tank using the WRAP option in the HOLE data defining number of rods (11) along one side of the hexagon. The 30 fuel rods of the total (331) were defined using a subsidiary PLATE HOLE, the rest (301) rods were represented as a subsidiary GLOBE HOLE using the MATS option. In the PLATE HOLE data the fuel rods were replaced with the nitrate solution. The GLOBE HOLE was used to define the rod and the clad regions of the fuel lattice. The final HOLE (PLATE HOLE) data was used to define the reflector and the voided regions outside the tank. Figure 10 shows the geometric arrangement of the MONK model. A plan view of the part of the triangular lattice is also shown in this figure.

Problem 11.

The problem 11 represents an array of (4 x 4 x 4) bare plutonium metal units as shown in Figure 5. The MONK model of this problem is described in three parts. The first part represents a metal unit of the array as a cylinder (ZROD) inside a box. The second part describes the 4x4x4 array which is constructed from part 1, using individual units. The part 3 gives the array inside the box which is defined to include the whole array given in part 2.

Problem 12.

The problem 12 represents 6 tanks containing plutonium solution in two lines (3x2) with 10 cm edge to edge spacing (see also reference 4). The cylindrical tanks are positioned at the centre of a cell which has 30 cm thick concrete walls. The MONK model of this problem was constructed in three parts. The first part describes one member of the array as NESTED cylinders containing the solution, the tank wall and the part of the voided region outside. The array (two lines) 3x2x1 was described in part 2 using the ARRAY facility of the code which was based on the unit given in part 1. The part 3 of the model represents the the whole array inside the cell with 30 cm thick concrete walls represented as nested BOXes. The geometry and the dimensions of this problem are shown in Figure 6.

APPENDIX A MONK6B Input Data Listings UKNDL Library

```
* Problem 1
* ------------------------------------------------
* Water-reflected plutonium metal sphere
* Sphere diameter: 8.220 cm
* Plutonium density: 19.74 g/cc , 5.20 w/o Pu-240
*                    0.30 w/o Pu-241, 0.20 w/o Pu-242
* ------------------------------------------------
* MONK DATA:
*
* UNIT 1  MATERIAL COMPOSITIONS
* --------------------------------

  FISSION
  2     6   NUCNAMES

*  MAT  1  Plutonium
*  MAT  2  Water
*
* MAT 1
 CONC    PU239  0.04698  PU240  0.002575  PU241 0.000149
         PU242  0.0000099

* MAT 2
 CONC      HINH2O  0.066063      O  0.033032
*************************************************************
 CM
*************************************************************

***************UNIT 2 - SPECIFICATION OF PROBLEM GEOMETRY
******************
*
* PART 1
*
  NEST 2
1 SPHERE      1  4.110
2 SPHERE      2  24.110

ALBEDO  0.0
*************************************************************
* END OF GEOMETRY MODEL (UNIT 2)
*************************************************************
* UNIT 4
*
 EDIT  CATEGORY
  -1  20  1000 0  STDV  0.003  -1
 VOLUME
 REGION 1  PART 1 /
 END
*
* END OF MONK DATA
*
*------------------------------------------------
```

```
* Problem 2
* ------------------------------------------------
* Water-reflected plutonium solution sphere
* Sphere diameter: 11.5 inches
* Wall thickness:  0.049 inches 304L St. Steel
* Solution composition: gPu/l = 140, gNO3/l = 284.0
*                       gH2O/l = 880.8
* Plutonium Composition: 4.57 w.o  Pu240
* ------------------------------------------------
* MONK DATA:
*
* UNIT 1  MATERIAL COMPOSITIONS
* --------------------------------

  FISSION
  3     8   NUCNAMES

*  MAT  1  Plutonium Solution
*  MAT  2  St. Steel
*  Mat  3  Water
*
* MAT 1
 CONC   PU239  3.3662E-04  PU240  1.6163E-05 HINH2O 6.0260E-02
        O 3.7734E-02  N  2.7595E-03

* MAT 2
 CONC   FE 5.8886E-02  NI 8.2374E-03 CR 1.7672E-02
* MAT 3
 CONC     HINH2O  0.066063     O  0.033032
************************************************************
 CM
************************************************************
***************UNIT 2 - SPECIFICATION OF PROBLEM GEOMETRY
******************
*
* PART 1
*
  NEST 3
1 SPHERE      1  14.568
2 SPHERE      2  14.692
3 SPHERE      3  39.6922

ALBEDO  0.0
*****************************************************************
* END OF GEOMETRY MODEL (UNIT 2)
*****************************************************************
* UNIT 4
 EDIT  CATEGORY
  -1  20  1000 0  STDV  0.003  -1
 VOLUME
 REGION 1  PART 1 /
 END
* END OF MONK DATA
*-------------------------------------------------
```

```
* Problem 3
* ------------------------------------------------
* Bare plutonium solution sphere
* Sphere diameter: 48.0 inches
* Wall thickness:  0.303 inches aluminium
* Solution composition: gPu/l = 9.457, Acid Molarity = 1.105
*                       Specific Gravity = 1.503
* Plutonium Composition: 2.521 w/o Pu240, 0.075 w/o Pu241,
*                         0.014 w/o Pu242
* ------------------------------------------------
* MONK DATA:
*
* UNIT 1  MATERIAL COMPOSITIONS
* --------------------------------

  FISSION
  2     7   NUCNAMES

*  MAT  1  Plutonium Solution
*  MAT  2  Aluminium Wall
*
* MAT 1
 CONC    PU239 2.3201E-05 PU240 6.0140E-07 PU241 1.7720E-08
         HINH2O  6.4836E-02  O  3.4367E-02 N 7.6043E-04

* MAT 2
 CONC    AL27 6.0260E-02
************************************************************
 CM
************************************************************
***************UNIT 2 - SPECIFICATION OF PROBLEM GEOMETRY
******************
* PART 1
*
  NEST 2

1 SPHERE      1  61.01
2 SPHERE      2  61.79

ALBEDO  0.0

*****************************************************************
* END OF GEOMETRY MODEL (UNIT 2)
*****************************************************************
* UNIT 4
 EDIT  CATEGORY
  -1  20  1000 0  STDV  0.003  -1
 VOLUME
 REGION 1  PART 1 /
 END
*
* END OF MONK DATA
*------------------------------------------------
```

```
* Problem 4
* ------------------------------------------------
* Bare U233 Solution Sphere
* Sphere diameter: 27.24 inches
* Wall thickness:  0.13 inch aluminium
* Solution composition: gU/l = 17.14
* ------------------------------------------------
* MONK DATA:
*
* UNIT 1  MATERIAL COMPOSITIONS
* --------------------------------

  FISSION
  2     8   NUCNAMES

*  MAT  1  U233 Solution
*  MAT  2  Aluminium Wall
*
* MAT 1
 CONC    U233 4.3280E-05 U234 7.1600E-07 U235 1.8000E-08
         U238 2.8100E-07  HINH2O 6.6636E-02  O 3.3607E-02
         N    1.1780E-04
* MAT 2
 CONC    AL27 6.0260E-02
************************************************************
 CM
************************************************************

***************UNIT 2 - SPECIFICATION OF PROBLEM GEOMETRY
******************
*
* PART 1
*
  NEST 2

1 SPHERE      1  34.595
2 SPHERE      2  34.925

ALBEDO  0.0


*****************************************************************
* END OF GEOMETRY MODEL (UNIT 2)
*****************************************************************
* UNIT 4
 EDIT  CATEGORY
  -1  20  1000 0  STDV  0.003  -1
 VOLUME
 REGION 1  PART 1 /
 END
* END OF MONK DATA
*-------------------------------------------------
```

```
* Problem 5
* ------------------------------------------------
* Bare U235 Metal sphere
* Sphere diameter: 17.42 cm
* Uranium density: 18.75 g/cc
* ------------------------------------------------
* MONK DATA:
*
* UNIT 1  MATERIAL COMPOSITIONS
* --------------------------------

  FISSION
  1     2    NUCNAMES

*  MAT  1  U235 Metal
*
* MAT 1
 CONC   U235  4.5447E-02  U238 2.5600E-03
*************************************************************
 CM
*************************************************************

***************UNIT 2 - SPECIFICATION OF PROBLEM GEOMETRY
******************
*
* PART 1
*
  NEST 1
1 SPHERE      1  8.71

ALBEDO  0.0


*****************************************************************
* END OF GEOMETRY MODEL (UNIT 2)
*****************************************************************

*
* UNIT 4
*
 EDIT  CATEGORY
  -1  20  1000 0  STDV  0.003  -1
 VOLUME
 REGION 1  PART 1 /
 END
*
* END OF MONK DATA
*
*-----------------------------------------------
```

```
* Problem 6
* ------------------------------------------------
* Bare U235 Solution sphere
* Sphere diameter: 27.24 inches
* Wall thickness: 0.13 inch aluminium
* Solution Composition: gU/l = 20.12
*
* ------------------------------------------------
* MONK DATA:
*
* UNIT 1  MATERIAL COMPOSITIONS
* --------------------------------

  FISSION
  2     8   NUCNAMES

*  MAT  1  U235 Solution Sphere
*  MAT  2  Aluminium Wall
*
* MAT 1
 CONC    U234 5.3800E-07 U235 4.8066E-05 U236 1.3800E-07
         U238 2.8070E-06  HINH2O 6.6228E-02 O 3.3736E-02
         N    1.8690E-04

* MAT 2
 CONC    AL27  6.0260E-02
************************************************************
 CM
************************************************************

***************UNIT 2 - SPECIFICATION OF PROBLEM GEOMETRY
******************
*
* PART 1
*
  NEST 2
1 SPHERE      1  34.595
2 SPHERE      2  34.925

ALBEDO  0.0
************************************************************
* END OF GEOMETRY MODEL (UNIT 2)
************************************************************
* UNIT 4
*
 EDIT  CATEGORY
  -1  20  1000 0  STDV  0.003  -1
 VOLUME
 REGION 1  PART 1 /
 END
* END OF MONK DATA
*
*------------------------------------------------
```

```
* Problem 7
* ------------------------------------------------
* Water Reflected, low enriched, unmoderated mixed oxide
* sphere, 8 w/o 239PuO2 in U(natural)O2
*
* Sphere diameter: 38.8 cm
* Oxide density:   11.0170 g/cc
*
* ------------------------------------------------
* MONK DATA:
*
* UNIT 1  MATERIAL COMPOSITIONS
* --------------------------------

  FISSION
  2     5   NUCNAMES

*  MAT  1  Mixed Oxide Sphere
*  MAT  2  Water
*
* MAT 1
 CONC   PU239 0.0019591 U235 0.0001646 U238 0.022450
        O 0.049148

* MAT 2
 CONC   HINH2O  6.6680E-02  O 3.3343E-02
************************************************************
 CM
************************************************************

***************UNIT 2 - SPECIFICATION OF PROBLEM GEOMETRY
******************
*
* PART 1
*
  NEST 2
1 SPHERE      1  19.4
2 SPHERE      2  39.4

ALBEDO  0.0
*****************************************************************
* END OF GEOMETRY MODEL (UNIT 2)
*****************************************************************
* UNIT 4
*
 EDIT  CATEGORY
  -1  20  1000 0  STDV  0.003  -1
 VOLUME
 REGION 1  PART 1 /
 END
* END OF MONK DATA
*
*-------------------------------------------------
```

```
* Problem 8
* ------------------------------------------------
* Water Reflected, Pu-U nitrate solution in cylindrical
* Tank (no reflector above solution within solution tank)
*
* Cylinder solution diameter:  60.96 cm
*
* Wall thickness:  0.079 cm, 304L St.Steel
* Bottom thickness: 0.95 cm, 304L St.Steel
* Reflector thickness:  20 cm  (walls and bottom)
* Solution height: 95.20 cm
* Reflector height: 106.6 cm (from bottom of solution)
* Solution composition: gPu/l = 12.4  gU/l=29.9
*                       Excess acid molarity = 1.3
*                        Specific Gravity = 1.1030
* ------------------------------------------------
* MONK DATA:
*
* UNIT 1  MATERIAL COMPOSITIONS
* -------------------------------

  FISSION
  3     14   NUCNAMES

*  MAT  1  Pu-U Solution
*  MAT  2  St. Steel
*  MAT  3  Water
*
* MAT 1
 CONC PU238 8.3767E-09 PU239 2.9365E-05 PU240 1.7386E-06
      PU241 1.0752E-07 PU242 2.1964E-08 U235  5.0609E-07
      U236 1.4077E-08  U238 7.5163E-05
      HINH2O 6.3896E-02 O 3.4957E-02 N 1.0883E-03
* MAT 2
  CONC  FE 6.331E-02  CR 1.654E-02  NI 6.510E-03
* MAT 3
 CONC   HINH2O  6.6680E-02  O 3.3343E-02
************************************************************
 CM
************************************************************

***************UNIT 2 - SPECIFICATION OF PROBLEM GEOMETRY
******************
*
* PART 1
*
  NEST 4
1 ZROD  ORIGIN  0.0  0.0  20.95   1  30.48  95.20
2 ZROD  ORIGIN  0.0  0.0  20.95   0  30.48  106.6
3 ZROD  ORIGIN  0.0  0.0  20.0    2  30.559 107.55
4 ZROD                            3  50.559 127.55



*****************************************************************
* END OF GEOMETRY MODEL (UNIT 2)
*****************************************************************

*
* UNIT 4
*
 EDIT  CATEGORY
  -1  20  1000 0  STDV  0.003  -1
```

```
 VOLUME
 REGION 1  PART 1 /
 END
*
* END OF MONK DATA
*
*-----------------------------------------------------
*
* END OF MONK DATA
*
* END OF MONK DATA
* SCAN DATA
CODE 6
123456
VISAGE
  1000
# PLAN VIEW 1
 0.0    35.0   18.0     35.0   35.0   18.0
 0.0    0.0   18.0
VISAGE  1000
# ELEVATION 1
 0.0    0.0   127.0     35.0   0.0   127.0
 0.0    0.0   0.0
 END
```

```
* Problem 9
* ------------------------------------------------
* Water Reflected, Pu-U-Gd nitrate solution in cylindrical
* Tank (no reflector above solution within solution tank)
*
* Cylinder solution diameter:  61.028 cm
*
* Wall thickness:   0.079 cm, 304L St.Steel
* Bottom thickness: 0.95 cm,  304L St.Steel
* Reflector thickness:  20 cm  (walls and bottom)
* Solution height: 75.3 cm
* Reflector height: 106.6 cm (from bottom of solution)
* Solution composition: gPu/l = 77.3  gU/l=176.8
*                        Excess acid molarity = 3.25
*                        Specific. Gravity = 1.462
* ------------------------------------------------
* MONK DATA:
*
* UNIT 1  MATERIAL COMPOSITIONS
* --------------------------------

  FISSION
  3     16   NUCNAMES

*  MAT  1  Pu-U-Gd Solution
*  MAT  2  St. Steel
*  MAT  3  Water
*
* MAT 1
 CONC PU238 2.35E-06   PU239 1.826E-04  PU240 1.118E-05
      PU241 7.160E-07  PU242 1.190E-07  U234  2.700E-08
       U235 3.013E-06  U236 5.400E-08  U238 4.442E-04
       HINH2O 5.5178E-02 O 3.8688E-02 N 3.7278E-03
       GD     4.060E-06
* MAT 2
  CONC  FE 6.331E-02  CR 1.654E-02  NI 6.510E-03
* MAT 3
 CONC   HINH2O  6.6680E-02  O 3.3343E-02
*************************************************************
 CM
*************************************************************

***************UNIT 2 - SPECIFICATION OF PROBLEM GEOMETRY
******************
*
* PART 1
*
  NEST 4
1 ZROD ORIGIN  0.0  0.0  20.95   1  30.514  75.3
2 ZROD ORIGIN  0.0  0.0  20.95   0  30.514  106.6
3 ZROD ORIGIN  0.0  0.0  20.0    2  30.593  107.55
4 ZROD                           3  50.593  127.55

*****************************************************************
* END OF GEOMETRY MODEL (UNIT 2)
*****************************************************************

*
* UNIT 4
*
 EDIT  CATEGORY
  -1  20  1000 0  STDV  0.003  -1
 VOLUME
```

```
 REGION 1  PART 1 /
 END
*
* END OF MONK DATA
*
*-------------------------------------------------------
*
* END OF MONK DATA
```

```
* Problem 10
* ------------------------------------------------
* Lattice of PuO2-UO2 rods in Pu-U-Gd nitrate solution in
* water-reflected cylindrical tank. (no reflector above rods
* inside tank)
* Tank Geometry:
*
* Inside diameter:  55.5 cm
* Wall thickness: 0.79 cm (304L St. Steel)
* Inside Height:  106.7 cm
* Reflector thickness:  20 cm (walls and bottom)
* Base thickness: 1.426 cm (304L St. Steel)
* Reflector Height: 106 cm (from bottom of solution)
* Solution composition: gPu/l = 77.63, gU/l = 180.0  gGd/l = 1.338
* Excess acid molarity = 3.4, Specific gravity = 1.463
*
*
* Fuel Pins
* ---------
* Fuel pin lattice pitch: 3.048 cm (triangular)
* Number of fuel pins: 301
* Cladding: 316 St. Steel
* Fuel Column Length: 69.215
* Fuel O.D.:  0.495 cm
* Cladding O.D:  0.584 cm
*
* Solution
* --------
* Critical Height:   68.862
*
* ------------------------------------------------
* MONK DATA:
*
* UNIT 1  MATERIAL COMPOSITIONS
* ---------------------------------

  FISSION
  5     12   NUCNAMES

*  MAT  1  Fuel
*  MAT  2  Pu-U-Gd Solution
*  MAT  3  304L St. Steel
*  MAT  4  316L St. Steel
*  MAT  5  Water

* MAT 1
 CONC   PU239 0.004990 PU240 0.0006919 PU241 0.0001002
         U235 0.0001243 U238 0.01717    O  0.04612
* MAT 2
  CONC   PU239 0.00018354  PU240 0.00001118 PU241 0.0000007118
          U235 0.000003067  U238 0.0004534 HINH2O 0.054974
          O    0.038564     N  0.0037298   FE 0.0000086273
          GD   0.0000051244
* MAT 3
  CONC   FE  0.058886  NI 0.0082374 Ck 0.017672
* MAT 4
  CONC   FE  0.048381  NI 0.0079078 CR 0.012649
* MAT 5
  CONC   HINH2O  0.066884   O  0.033442
************************************************************
 CM
************************************************************
```

```
***************UNIT 2 - SPECIFICATION OF PROBLEM GEOMETRY
******************
*
* PART 1
*
  NEST 4
1 ZROD   ORIGIN 0.0  0.0  21.426     BH1 27.75  69.215
2 ZROD   ORIGIN 0.0  0.0  21.426      0  27.75  106.7
3 ZROD   ORIGIN 0.0  0.0  20.0        3  28.54  108.126
4 ZROD                               BH4 48.54  128.126

* HOLE DATA

TRIANGLE  3  1 2 4
    3.048   0.292  0.292  WRAP  11  100 100
    MATS 11
 (-3)*3 (-2)*5 (-3)*3
  -3 (-2)*10 -3
 -3 (-2)*11 -3
      (-2)*80
 -3 (-2)*17 -3
 -3 (-2)*18 -3
 -3 (-2)*19 -3
 -3 (-2)*18 -3
 -3 (-2)*17 -3
      (-2)*80
 -3 (-2)*11 -3
 -3 (-2)*10 -3
 (-3)*3 (-2)*5 (-3)*3
 1  4   -3  0 0

GLOBE  2  1  4
       1  0.2475  1  4

PLATE  1 2
       0  0  1   1  68.862  0  2

PLATE  1  5
       0  0  1   1   127.426  0  5

*****************************************************************
* END OF GEOMETRY MODEL (UNIT 2)
*****************************************************************

*
* UNIT 4
*
 EDIT  CATEGORY
  -1  20  1000 0  STDV  0.003  -1
 MULTIFISS STD
 REGION 1  PART 1 /
 END
*
* END OF MONK DATA
*
*-------------------------------------------------------
*
* END OF MONK DATA
* SCAN DATA
CODE 6
123456
VISAGE
  1000
```

```
# PLAN VIEW 1
 -30  30  30   30  30  30   -30  -30 30
VISAGE
  1000
# ELEVATION
 -48   0 128  48  0  128   -48  0 0
 END
```

```
* Problem 11
* ----------------------------------------------
* 3 kg plutonium cylindrical metal units in a 4 x 4 x 4
* bare square array
* Plutonium diameter: 6.525 cm
* Plutonium height:   4.633 cm
* Centre-centre spacing
*                vertical: 7.86 cm
*              horizontal: 12.51 cm
*
* Plutonium density:   19.53  g/cc
*
* ----------------------------------------------
* MONK DATA:
*
* UNIT 1  MATERIAL COMPOSITIONS
* --------------------------------

  FISSION
  1     4   NUCNAMES

*  MAT  1  Plutonium cylindrical units
*
* MAT 1
 CONC   PU239 4.6053E-02 PU240 2.9263E-03 PU241 2.2454E-04
        PU242 4.8612E-06
*************************************************************
 CM
*************************************************************

***************UNIT 2 - SPECIFICATION OF PROBLEM GEOMETRY
******************
*
* PART 1
*
  NEST 2
1 ZROD   ORIGIN 6.255 6.255 1.6135  1  3.2625   4.633
2 BOX                               0 12.51 12.51  7.86

*
* PART 2
*
ARRAY  4 4 4
(1)*64

*
* PART 3
*

NEST 2
1 BOX                       P2  50.04 50.04  31.44
2 BOX                        0  50.04 50.04  31.44


*****************************************************************
* END OF GEOMETRY MODEL (UNIT 2)
*****************************************************************

*
* UNIT 4
*
 EDIT  CATEGORY
  -1  20  1000 0  STDV  0.003  -1
```

```
 MULTIFISS STD
 REGION 1  PART 3 /
 END
*
* END OF MONK DATA
*
*-------------------------------------------------------
*
* END OF MONK DATA
```

```
* Problem 12
* ------------------------------------------------
* REFERENCE: PNL-TR-452 (CEA-R-3946), J. BOULY, ET. AL.,
* "Neutron Interaction in Air of Cylindrical Containers
*  Holding Either Uranium and Plutonium Solutions"
*  March, 1970
*
* GEOMETRY: 6 tanks in two lines 3 (x = 3 y = 2), 10 cm
*           edge-to-edge spacing
*
*  Tank i.d.  = 24.98 cm
*  Tank inside height = 101.7 cm
*  Tank Wall Thickness (radial):  0.3 cm (Z3CN18/10 St. Steel)
*  Tank Wall Thickness (top and bottom)= 1.0 cm
*  ARRAY is centred in room with (estimated)
*  Distance, centre to X direction Walls: 464.0 cm
*  Distance, centre to Y direction Walls: 525.0 cm
*  Distance, tank bottom to floor: 100.0 cm
*  Distance, tank bottom to ceiling: 501.0 cm
*  Wall, floor, ceiling concrete thickness= 30.0 cm
*

*  Solution composition: gPu/l = 115.1, Acid Molarity = 2.01
*                        Specific Gravity = 1.260
*
* Pu composition: 4.23 w/o Pu240, 0.29 w/o Pu240,
*                 0.016 w/o Pu242
* ------------------------------------------------
* MODEL DATA:
*
* UNIT 1  MATERIAL COMPOSITIONS
* --------------------------------

  FISSION
  3     13   NUCNAMES

*  MAT  1  Plutonium Solution
*  MAT  2  St. Steel
*  MAT  3  Concrete
*
* MAT 1
 CONC    PU239 2.7682E-04 PU240 1.2214E-05 PU241 8.339E-07
         PU242 4.58E-08 HINH2O 6.0070E-02 O 3.6540E-02
         N  2.3699E-03

* MAT 2
   CONC    FE  6.331E-02  CR 1.654E-02  NI 6.510E-03

* MAT 3
   CONC    HINH2O  9.5470E-03 O 4.5374E-02 FE 1.3431E-03
           SI  1.2899E-02  AL27 3.3567E-03  CA  2.6128E-03

*  Critical Height  39.24 cm
************************************************************
 CM
************************************************************

***************UNIT 2 - SPECIFICATION OF PROBLEM GEOMETRY
*******************
*
* PART 1
*
  NEST 3
```

```
1 ZROD   ORIGIN  17.79 17.79  1.0  BH1  12.49  101.7
2 ZROD   ORIGIN  17.79 17.79  0.0  2  12.79  103.7
3 BOX                             0  35.58  35.58  103.7

*
* PART 2
*
ARRAY  3 2 1
(1)*6

*
* PART 3
*

NEST 3
1 BOX ORIGIN 410.63  489.42 100.0 P2 106.74  71.16   103.7
2 BOX ORIGIN 30.0 30.0 30.0         0 928.0  1050.0   601.0
3 BOX                               3 988.0  1110.0   661.0

* HOLE DATA

PLATE  1  1
 0 0 1  1  39.24  0  1
*****************************************************************
* END OF GEOMETRY MODEL (UNIT 2)
*****************************************************************

*
* UNIT 4
*
 EDIT  CATEGORY
  -1  20  1000 0  STDV  0.003  -1
 MULTIFISS STD
 REGION 1  PART 3 /
 END
*
* END OF MONK DATA
*-----------------------------------------------------
```

APPENDIX B SCALE3.1 INPUT DATA LISTINGS FOR KENOVa CASES

```
=CSAS 25
PROBLEM 1 WATER-REFLECTED PLUTONIUM METAL SPHERE
HANSEN-ROACH  INFHOMMEDIUM
PU-239  1 0.0  0.04698  END
PU-240  1 0.0  0.002575 END
PU-241  1 0.0  0.000149 END
PU-242  1 0.0  0.0000099 END
H       2 0.0  0.066067  END
O       2 0.0  0.033032  END

END COMP
PROB 1 KENO 5 WATER-REFLECTED PLUTONIUM METAL SPHERE
READ PARAM  RND=6  TME=400  GEN=103  NPG=300  MKU=YES
            CKU=YES   END PARAM
READ GEOM
SPHERE  1   1  4.11
SPHERE  2   1  24.11
CUBOID  0   1  25.0  -25.0 25.0  -25.0  25.0  -25.0
END GEOM
READ BOUNDS
ALL=VAC
END BOUNDS
READ ARRAY
NUX=1  NUY=1  NUZ=1
END ARRAY
END DATA
END
```

```
=CSAS 25
PROBLEM 2 WATER-REFLECTED PLUTONIUM SOLUTION SPHERE
HANSEN-ROACH  INFHOMMEDIUM
PU-239  1 0.0  3.3662E-4 END
PU-240  1 0.0  1.6163E-5 END
H       1 0.0  6.0260E-2 END
O       1 0.0  3.7734E-2 END
N       1 0.0  2.7595E-3 END
FE      2 0.0  5.8886E-2 END
NI      2 0.0  8.2374E-3 END
CR      2 0.0  1.7672E-2 END
H       3 0.0  0.066067  END
O       3 0.0  0.033032  END

END COMP
PROB2 KENO5 WATER-REFLECTED PLUTONIUM SOLUTION SPHERE
READ PARAM  RND=6  TME=400  GEN=103  END PARAM
READ GEOM
SPHERE  1   1  14.568
SPHERE  2   1  14.692
SPHERE  3   1  39.6922
CUBOID  0   1  55.0  -55.0 55.0  -55.0  55.0  -55.0
END GEOM
READ BOUNDS
ALL=VAC
END BOUNDS
READ ARRAY
NUX=1  NUY=1  NUZ=1
END ARRAY
END DATA
END
```

```
=CSAS 25
PROBLEM 3 BARE PLUTONIUM SOLUTION SPHERE
218GROUPNDF4  INFHOMMEDIUM
PU-239  1 0.0  2.3201E-5 END
PU-240  1 0.0  6.0140E-7 END
PU-241  1 0.0  1.7720E-8 END
H       1 0.0  6.4836E-2 END
O       1 0.0  3.4367E-2 END
N       1 0.0  7.6043E-4 END
AL      2 0.0  6.0260E-2 END
END COMP
PROB 3 KENO 5 BARE PLUTONIUM SOLUTION SPHERE
READ PARAM  RND=6  TME=400  GEN=103  END PARAM
READ GEOM
SPHERE  1   1  61.01
SPHERE  2   1  61.75
CUBOID  0   1  75.0  -75.0 75.0  -75.0 75.0  -75.0
END GEOM
READ BOUNDS
ALL=VAC
END BOUNDS
READ ARRAY
NUX=1  NUY=1  NUZ=1
END ARRAY
END DATA
END
```

```
=CSAS 25
PROBLEM 4 BARE U233 SOLUTION SPHERE
218GROUPNDF4  INFHOMMEDIUM
U-233    1 0.0  4.3280E-5 END
U-234    1 0.0  7.1600E-7 END
U-235    1 0.0  1.8000E-8 END
U-238    1 0.0  2.8100E-7 END
H        1 0.0  6.6636E-2 END
O        1 0.0  3.3607E-2 END
N        1 0.0  1.1780E-4 END
AL       2 0.0  6.0260E-2 END
END COMP
PROB 4 KENO BARE U233 SOLUTION SPHERE
READ PARAM  RND=6  TME=400  GEN=103  END PARAM
READ GEOM
SPHERE  1   1  34.595
SPHERE  2   1  34.925
CUBOID  0   1  75.0  -75.0 75.0  -75.0  75.0  -75.0
END GEOM
READ BOUNDS
ALL=VAC
END BOUNDS
READ ARRAY
NUX=1  NUY=1  NUZ=1
END ARRAY
END DATA
END
```

```
=CSAS 25
PROBLEM 5 BARE U235 METAL SPHERE
HANSEN-ROACH  INFHOMMEDIUM
U-235 1 0.0  4.5447E-2 END
U-238 1 0.0  2.560E-3  END
H     2 0.0   0.066  END

END COMP
PROB 5 KENO 5 BARE U235 METAL SPHERE
READ PARAM  RND=6  TME=400  GEN=103  END PARAM
READ GEOM
SPHERE  1   1  8.71
CUBOID  0   1  25.0  -25.0 25.0  -25.0  25.0  -25.0
END GEOM
READ BOUNDS
ALL=VAC
END BOUNDS
READ ARRAY
NUX=1  NUY=1  NUZ=1
END ARRAY
END DATA
END
```

```
=CSAS 25
PROBLEM 6 BARE U235 SOLUTION SPHERE
HANSEN-ROACH  INFHOMMEDIUM
U-234    1 0.0  5.3800E-7 END
U-235    1 0.0  4.8066E-5 END
U-236    1 0.0  1.3800E-7 END
U-238    1 0.0  2.8070E-6 END
H        1 0.0  6.6228E-2 END
O        1 0.0  3.3736E-2 END
N        1 0.0  1.8690E-4 END
AL       2 0.0  6.0260E-2 END
END COMP
PROB 6 KENO 5  BARE U235 SOLUTION SPHERE
READ PARAM  RND=6  TME=400  GEN=103  END PARAM
READ GEOM
SPHERE  1   1  34.595
SPHERE  2   1  34.925
CUBOID  0   1  55.0  -55.0 55.0  -55.0  55.0  -55.0
END GEOM
READ BOUNDS
ALL=VAC
END BOUNDS
READ ARRAY
NUX=1  NUY=1  NUZ=1
END ARRAY
END DATA
END
```

```
=CSAS 25
PROBLEM 7 WATER REFLECTED,LOW ENRICHED,UNMODERATED MIXED OXIDE SPHERE
HANSEN-ROACH  INFHOMMEDIUM
PU-239  1 0.0  1.9591E-3 END
U-235   1 0.0  1.6460E-4 END
U-238   1 0.0  2.2450E-2 END
O       1 0.0  4.9148E-2 END
H2O  2  1.0   END
END COMP
PROB 7 KENO 5 WATER REFLECTED,LOW ENRICHED,UNMODERATED MIXED OXIDE SPHERE
READ PARAM  RND=6  TME=400  GEN=103  END PARAM
READ GEOM
SPHERE  1   1  19.4
SPHERE  2   1  39.4
CUBOID  0   1  55.0  -55.0 55.0  -55.0  55.0  -55.0
END GEOM
READ BOUNDS
ALL=VAC
END BOUNDS
READ ARRAY
NUX=1  NUY=1  NUZ=1
END ARRAY
END DATA
END
```

```
=CSAS 25
PROBLEM 8 WATER-REFLECTED PU-U NITRATE SOLUTION IN CYLINDRICAL TANK
HANSEN-ROACH  INFHOMMEDIUM
PU-238  1 0.0  8.3767E-9  END
PU-239  1 0.0  2.9365E-5  END
PU-240  1 0.0  1.7386E-6  END
PU-241  1 0.0  1.0752E-7  END
PU-242  1 0.0  2.1964E-8  END
U-235   1 0.0  5.0609E-7  END
U-236   1 0.0  1.4077E-8  END
U-238   1 0.0  7.5163E-5  END
H       1 0.0  6.3896E-2  END
O       1 0.0  3.4957E-2  END
N       1 0.0  1.0883E-3  END
FE      2 0.0  6.331E-2   END
CR      2 0.0  1.654E-2   END
NI      2 0.0  6.510E-3   END
H       3 0.0  6.6680E-2  END
O       3 0.0  3.3343E-2  END
END COMP
PROB 8 KENO5 PLUTONIUM SPHERE IN WATER
READ PARAM  RND=6  TME=500  GEN=103  END PARAM
READ GEOM
CYLINDER  1  1  30.48  95.2    0.0
CYLINDER  0  1  30.48  106.6   0.0
CYLINDER  2  1  30.559 106.6  -0.95
CYLINDER  3  1  50.559 106.6  -20.95
CUBOID    0  1  200.0  -200.0  200.0 -200.0  200.0  -200.0
END GEOM
READ BOUNDS
ALL=VAC
END BOUNDS
READ ARRAY
NUX=1  NUY=1  NUZ=1
END ARRAY
END DATA
END
```

```
=CSAS 25
PROBLEM 9 WATER-REFLECTED PU-U-GD NITRATE SOLUTION IN CYLINDRICAL TANK
HANSEN-ROACH  INFHOMMEDIUM
PU-238  1 0.0  2.3500E-6  END
PU-239  1 0.0  1.8260E-4  END
PU-240  1 0.0  1.1180E-5  END
PU-241  1 0.0  7.1600E-7  END
PU-242  1 0.0  1.1900E-7  END
U-234   1 0.0  2.7000E-8  END
U-235   1 0.0  3.0130E-6  END
U-236   1 0.0  5.4000E-8  END
U-238   1 0.0  4.4420E-4  END
H       1 0.0  5.5178E-2  END
O       1 0.0  3.8688E-2  END
N       1 0.0  3.7278E-3  END
GD      1 0.0  4.0600E-6  END
FE      2 0.0  6.331E-2   END
CR      2 0.0  1.654E-2   END
NI      2 0.0  6.510E-3   END
H       3 0.0  6.6680E-2  END
O       3 0.0  3.3343E-2  END
END COMP
PROB 9 CENOS PU-U-GD NITRATE SOLUTION IN CYL. TANK
READ PARAM  RND=6  TME=200  GEN=40  END PARAM
READ GEOM
CYLINDER  1  1  30.514  75.3   0.0
CYLINDER  0  1  30.514  106.6   0.0
CYLINDER  2  1  30.593  106.6  -0.95
CYLINDER  3  1  50.593  106.6  -20.95
CUBOID    0  1  200.0  -200.0  200.0 -200.0  200.0  -200.0
END GEOM
READ BOUNDS
ALL=VAC
END BOUNDS
READ ARRAY
NUX=1  NUY=1  NUZ=1
END ARRAY
END DATA
END
```

```
=CSAS 25
PROBLEM 10 LATTICE OF PUO2-UO2 RODS IN PU-U-GD SOLUTION
HANSEN-ROACH  LATTICECELL
PU-239   1 0.0   4.9900E-3   END
PU-240   1 0.0   6.9190E-4   END
PU-241   1 0.0   1.0020E-4   END
U-235    1 0.0   1.2430E-4   END
U-238    1 0.0   1.7170E-2   END
O        1 0.0   4.6120E-2   END
PU-239   2 0.0   1.8354E-4   END
PU-240   2 0.0   1.1180E-5   END
PU-241   2 0.0   7.1180E-7   END
U-235    2 0.0   3.0670E-6   END
U-238    2 0.0   4.5340E-4   END
H        2 0.0   5.4974E-2   END
O        2 0.0   3.8564E-2   END
N        2 0.0   3.7298E-3   END
FE       2 0.0   8.6273E-6   END
GD       2 0.0   5.1244E-6   END
FE       3 0.0   5.8886E-2   END
NI       3 0.0   8.2374E-3   END
CR       3 0.0   1.7672E-2   END
FE       4 0.0   4.8381E-2   END
NI       4 0.0   7.9078E-3   END
CR       4 0.0   1.2649E-2   END
H        5 0.0   6.6884E-2   END
O        5 0.0   3.3442E-2   END
END COMP
TRIANGPITCH  3.048  0.495  1  5  0.584  4  END
PROB 10 LATTICE OF PUO2-UO2 RODS IN PU-U-GD SOLUTION IN CYL TANK
READ PARAM  RND=6  TME=600  GEN=103  END PARAM
READ GEOM
UNIT 1
CYLINDER  1   1   0.2475  68.862   0.0
CYLINDER  4   1   0.292   68.862   0.0
CUBOID    2   1  0.65991  -0.65991  0.762  -0.762  68.862  0.0
UNIT 2
CUBOID    2   1  0.65991  -0.65991  0.762  -0.762  68.862  0.0
UNIT 3
CYLINDER  1   1   0.2475  68.862   0.0
CYLINDER  4   1   0.292   68.862   0.0
UNIT 4
CYLINDER  1   1   0.2475  0.353  0.0
CYLINDER  4   1   0.292   0.353  0.0
CUBOID    0   1  0.65991  -0.65991  0.762  -0.762  0.353 0.0
UNIT 5
CUBOID    0   1  0.65991  -0.65991  0.762  -0.762  0.353 0.0
UNIT 6
CYLINDER  1   1   0.2475  0.353    0.0
CYLINDER  4   1   0.292   0.353    0.0
UNIT 7
ARRAY 4  -1.979735  -11.43  0.0
UNIT 8
ARRAY 3   -8.57885  -22.098  0.0

UNIT 9
ARRAY 2  -1.979735  -11.43  0.0
CORE  1  1  -8.57885  -22.098  0.0
CYLINDER  2  1  27.75   68.862  0.0
HOLE 9  -10.55858  0.0  0.0
```

```
HOLE 9   10.55858  0.0  0.0

HOLE 3  13.1983  0.0  0.0
HOLE 3 -13.1983  0.0  0.0
HOLE 3  13.1983  3.048  0.0
HOLE 3 -13.1983  3.048  0.0
HOLE 3  13.1983  6.096  0.0
HOLE 3 -13.1983  6.096  0.0
HOLE 3  13.1983  -3.048  0.0
HOLE 3 -13.1983  -3.048  0.0
HOLE 3  13.1983  -6.096  0.0
HOLE 3 -13.1983  -6.096  0.0

HOLE 3  1.31983  22.86  0.0
HOLE 3  3.95949  22.86  0.0
HOLE 3  6.59915  22.86  0.0
HOLE 3  -1.31983  22.86  0.0
HOLE 3  -3.95949  22.86  0.0
HOLE 3  -6.59915  22.86  0.0
HOLE 3  1.31983  -22.86  0.0
HOLE 3  3.95949  -22.86  0.0
HOLE 3  6.59915  -22.86  0.0
HOLE 3  -1.31983 -22.86  0.0
HOLE 3  -3.95949  -22.86  0.0
HOLE 3  -6.59915  -22.86  0.0

HOLE 3  0.0       24.384  0.0
HOLE 3  2.63966  24.384  0.0
HOLE 3  5.27932  24.384  0.0
HOLE 3  0.0       -24.384  0.0
HOLE 3  2.63966  -24.384  0.0
HOLE 3  5.27932  -24.384  0.0
HOLE 3  -2.63966  24.384  0.0
HOLE 3  -5.27932  24.384  0.0
HOLE 3  -2.63966  -24.384  0.0
HOLE 3  -5.27932  -24.384  0.0

HOLE 3  1.31983  23.908  0.0
HOLE 3  3.95949  23.908  0.0
HOLE 3  -1.31983  23.908  0.0
HOLE 3  -3.95949  23.908  0.0
HOLE 3  1.31983  -23.908  0.0
HOLE 3  3.95949  -23.908  0.0
HOLE 3  -1.31983  -23.908  0.0
HOLE 3  -3.95949  -23.908  0.0
HOLE 3   0.0       25.432  0.0
HOLE 3   0.0      -25.432  0.0
HOLE 3   10.55864  12.192  0.0
HOLE 3   -10.55864  12.192  0.0
HOLE 3   9.23881  13.716  0.0
HOLE 3   11.87847 13.717  0.0
HOLE 3   -9.23881  13.716  0.0
HOLE 3   -11.87847 13.717  0.0
HOLE 3   10.55864  15.241  0.0
HOLE 3   -10.55864  15.241  0.0
HOLE 3   9.23881    16.765  0.0
HOLE 3   -9.23881    16.765  0.0
HOLE 3   9.23881    19.813  0.0
HOLE 3   -9.23881    19.813  0.0
HOLE 3   10.55864  -12.192  0.0
HOLE 3   -10.55864 -12.192  0.0
HOLE 3   9.23881  -13.716  0.0
HOLE 3   11.87847 -13.717  0.0
```

```
HOLE 3   -9.23881 -13.716  0.0
HOLE 3   -11.87847 -13.717  0.0
HOLE 3   10.55864  -15.241  0.0
HOLE 3   -10.55864  -15.241  0.0
HOLE 3   9.23881    -16.765  0.0
HOLE 3   -9.23881    -16.765  0.0
HOLE 3   9.23881    -19.813  0.0
HOLE 3   -9.23881    -19.813  0.0

CYLINDER  0  1  27.75   106.0   0.0

HOLE 7  -10.55858  0.0  68.862
HOLE 7   10.55858  0.0  68.862
HOLE 8   0.0  0.0  68.862
HOLE 6  13.1983  0.0  68.862
HOLE 6 -13.1983  0.0  68.862
HOLE 6  13.1983  3.048  68.862
HOLE 6 -13.1983  3.048  68.862
HOLE 6  13.1983  6.096  68.862
HOLE 6 -13.1983  6.096  68.862
HOLE 6  13.1983  -3.048  68.862
HOLE 6 -13.1983  -3.048  68.862
HOLE 6  13.1983  -6.096  68.862
HOLE 6 -13.1983  -6.096  68.862

HOLE 6  1.31983  22.86  68.862
HOLE 6  3.95949  22.86  68.862
HOLE 6  6.59915  22.86  68.862
HOLE 6  -1.31983  22.86  68.862
HOLE 6  -3.95949  22.86  68.862
HOLE 6  -6.59915  22.86  68.862
HOLE 6  1.31983  -22.86  68.862
HOLE 6  3.95949  -22.86  68.862
HOLE 6  6.59915  -22.86  68.862
HOLE 6  -1.31983 -22.86  68.862
HOLE 6  -3.95949  -22.86 68.862
HOLE 6  -6.59915  -22.86  68.862

HOLE 6  0.0       24.384  68.862
HOLE 6  2.63966  24.384  68.862
HOLE 6  5.27932  24.384  68.862
HOLE 6  0.0       -24.384  68.862
HOLE 6  2.63966  -24.384  68.862
HOLE 6  5.27932  -24.384  68.862
HOLE 6  -2.63966  24.384  68.862
HOLE 6  -5.27932  24.384  68.862
HOLE 6  -2.63966  -24.384 68.862
HOLE 6  -5.27932  -24.384  68.862

HOLE 6  1.31983  23.908  68.862
HOLE 6  3.95949  23.908  68.862
HOLE 6  -1.31983  23.908 68.862
HOLE 6  -3.95949  23.908  68.862
HOLE 6  1.31983  -23.908  68.862
HOLE 6  3.95949  -23.908  68.862
HOLE 6  -1.31983  -23.908  68.862
HOLE 6  -3.95949  -23.908  68.862
HOLE 6   0.0       25.432  68.862
HOLE 6   0.0      -25.432  68.862


HOLE 6   10.55864  12.192  68.862
HOLE 6   -10.55864  12.192  68.862
```

```
HOLE 6   9.23881  13.716  68.862
HOLE 6   11.87847 13.717  68.862
HOLE 6   -9.23881  13.716  68.862
HOLE 6   -11.87847 13.717  68.862
HOLE 6   10.55864  15.241  68.862
HOLE 6   -10.55864  15.241  68.862
HOLE 6   9.23881    16.765  68.862
HOLE 6   -9.23881    16.765 68.862
HOLE 6   9.23881    19.813  68.862
HOLE 6   -9.23881    19.813  68.862

HOLE 6   10.55864  -12.192  68.862
HOLE 6   -10.55864 -12.192  68.862
HOLE 6   9.23881  -13.716  68.862
HOLE 6   11.87847 -13.717  68.862
HOLE 6   -9.23881 -13.716  68.862
HOLE 6   -11.87847 -13.717  68.862
HOLE 6   10.55864  -15.241  68.862
HOLE 6   -10.55864  -15.241  68.862
HOLE 6   9.23881    -16.765  68.862
HOLE 6   -9.23881    -16.765  68.862
HOLE 6   9.23881    -19.813  68.862
HOLE 6   -9.23881    -19.813  68.862


CYLINDER  3  1  27.829  106.0  -1.426
CYLINDER  5  1  47.829  106.0  -21.426
CUBOID    0  1  50  -50  50  -50  110  -30
END GEOM
READ ARRAY
ARA=1
NUX=13  NUY=29  NUZ=1
FILL
    1  2  1  2  1  2  1  2  1  2  1  2  1
    2  1  2  1  2  1  2  1  2  1  2  1  2
    1  2  1  2  1  2  1  2  1  2  1  2  1
    2  1  2  1  2  1  2  1  2  1  2  1  2
    1  2  1  2  1  2  1  2  1  2  1  2  1
    2  1  2  1  2  1  2  1  2  1  2  1  2
    1  2  1  2  1  2  1  2  1  2  1  2  1
    2  1  2  1  2  1  2  1  2  1  2  1  2
    1  2  1  2  1  2  1  2  1  2  1  2  1
    2  1  2  1  2  1  2  1  2  1  2  1  2
    1  2  1  2  1  2  1  2  1  2  1  2  1
    2  1  2  1  2  1  2  1  2  1  2  1  2
    1  2  1  2  1  2  1  2  1  2  1  2  1
    2  1  2  1  2  1  2  1  2  1  2  1  2
    1  2  1  2  1  2  1  2  1  2  1  2  1
    2  1  2  1  2  1  2  1  2  1  2  1  2
    1  2  1  2  1  2  1  2  1  2  1  2  1
    2  1  2  1  2  1  2  1  2  1  2  1  2
    1  2  1  2  1  2  1  2  1  2  1  2  1
    2  1  2  1  2  1  2  1  2  1  2  1  2
    1  2  1  2  1  2  1  2  1  2  1  2  1
    2  1  2  1  2  1  2  1  2  1  2  1  2
    1  2  1  2  1  2  1  2  1  2  1  2  1
    2  1  2  1  2  1  2  1  2  1  2  1  2
    1  2  1  2  1  2  1  2  1  2  1  2  1
    2  1  2  1  2  1  2  1  2  1  2  1  2
    1  2  1  2  1  2  1  2  1  2  1  2  1
    2  1  2  1  2  1  2  1  2  1  2  1  2
    1  2  1  2  1  2  1  2  1  2  1  2  1
END FILL
```

```
ARA=2
NUX=3  NUY=17  NUZ=1
FILL
     1  2  1
     2  1  2
     1  2  1
     2  1  2
     1  2  1
     2  1  2
     1  2  1
     2  1  2
     1  2  1
     2  1  2
     1  2  1
     2  1  2
     1  2  1
     2  1  2
     1  2  1
END FILL
ARA=3
NUX=13  NUY=29  NUZ=1
FILL
     4  5  4  5  4  5  4  5  4  5  4  5  4
     5  4  5  4  5  4  5  4  5  4  5  4  5
     4  5  4  5  4  5  4  5  4  5  4  5  4
     5  4  5  4  5  4  5  4  5  4  5  4  5
     4  5  4  5  4  5  4  5  4  5  4  5  4
     5  4  5  4  5  4  5  4  5  4  5  4  5
     4  5  4  5  4  5  4  5  4  5  4  5  4
     5  4  5  4  5  4  5  4  5  4  5  4  5
     4  5  4  5  4  5  4  5  4  5  4  5  4
     5  4  5  4  5  4  5  4  5  4  5  4  5
     4  5  4  5  4  5  4  5  4  5  4  5  4
     5  4  5  4  5  4  5  4  5  4  5  4  5
     4  5  4  5  4  5  4  5  4  5  4  5  4
     5  4  5  4  5  4  5  4  5  4  5  4  5
     4  5  4  5  4  5  4  5  4  5  4  5  4
     5  4  5  4  5  4  5  4  5  4  5  4  5
     4  5  4  5  4  5  4  5  4  5  4  5  4
     5  4  5  4  5  4  5  4  5  4  5  4  5
     4  5  4  5  4  5  4  5  4  5  4  5  4
     5  4  5  4  5  4  5  4  5  4  5  4  5
     4  5  4  5  4  5  4  5  4  5  4  5  4
     5  4  5  4  5  4  5  4  5  4  5  4  5
     4  5  4  5  4  5  4  5  4  5  4  5  4
     5  4  5  4  5  4  5  4  5  4  5  4  5
     4  5  4  5  4  5  4  5  4  5  4  5  4
     5  4  5  4  5  4  5  4  5  4  5  4  5
     4  5  4  5  4  5  4  5  4  5  4  5  4
     5  4  5  4  5  4  5  4  5  4  5  4  5
     4  5  4  5  4  5  4  5  4  5  4  5  4
END FILL
ARA=4
NUX=3  NUY=15  NUZ=1
FILL
     4  5  4
     5  4  5
     4  5  4
     5  4  5
     4  5  4
     5  4  5
     4  5  4
     5  4  5
```

```
    4  5  4
    5  4  5
    4  5  4
    5  4  5
    4  5  4
    5  4  5
    4  5  4
END FILL
END ARRAY
READ PLOT

XUL=-48        YUL=48             ZUL=50
XLR=48         YLR=-48            ZLR=50
UAX=1.0   VDN=-1.0   NAX=120   END

XUL=-18        YUL=18             ZUL=50
XLR=18         YLR=-18            ZLR=50
UAX=1.0   VDN=-1.0   NAX=120   END

XUL=-18        YUL=18             ZUL=69.1
XLR=18         YLR=-18            ZLR=69.1
UAX=1.0   VDN=-1.0   NAX=120   END

XUL=-48         YUL=0      ZUL=107
XLR=48          YLR=0      ZLR=-20
UAX=1.0   WDN=-1.0   NAX=120   END

XUL=-28         YUL=0      ZUL=70
XLR=28          YLR=0      ZLR=40
UAX=1.0   WDN=-1.0   NAX=120   END
 END
END PLOT
END DATA
END
```

```
=CSAS 25
PROBLEM 11 PLUTONIUM CYLINDRICAL METAL UNITS
HANSEN-ROACH  INFHOMMEDIUM
PU-239  1 0.0  4.6053E-2  END
PU-240  1 0.0  2.9263E-3  END
PU-241  1 0.0  2.2454E-4  END
PU-242  1 0.0  4.8612E-6  END
END COMP
PROB 11 KENO5  PLUTONIUM CYLINDRICAL METAL UNITS
READ PARAM  RND=6  TME=600  GEN=103  NPG=330  MKU=YES
          CKU=YES   END PARAM
READ GEOM
UNIT 1
CYLINDER  1   1   3.2625  4.633  0.0
CUBOID    0   1  6.255  -6.255  6.255  -6.255  6.2465  -1.6135
END GEOM
READ BOUNDS
ALL=VAC
END BOUNDS
READ ARRAY
ARA=1
NUX=4  NUY=4  NUZ=4
FILL   64R1   END FILL
END ARRAY
READ PLOT
RUN=YES

XUL=0.0     YUL=50.04  ZUL=4.0
XLR=50.04   YLR=0.0    ZLR=4.0
UAX=1.0   VDN=-1.0   NAX=120   END

XUL=0.0     YUL=5      ZUL=49.972
XLR=50.04   YLR=5      ZLR=0.0
UAX=1.0   WDN=-1.0   NAX=120   END
 END
END PLOT
END DATA
END
```

```
=CSAS 25
PROBLEM 12 AN ARRAY OF A CYLINDRICAL TANKS CONTAINING PU SOLUTION
HANSEN-ROACH LATTICECELL
PU-239  1 0.0  2.7682E-4  END
PU-240  1 0.0  1.2214E-5  END
PU-241  1 0.0  8.3390E-7  END
PU-242  1 0.0  4.5800E-8  END
H       1 0.0  6.0070E-2  END
O       1 0.0  3.654E-02  END
N       1 0.0  2.3699E-03 END
FE      2 0.0  6.3310E-2  END
CR      2 0.0  1.6540E-2  END
NI      2 0.0  6.5100E-3  END
H       3 0.0  9.547E-03  END
O       3 0.0  4.5374E-2  END
FE      3 0.0  1.3431E-03 END
SI      3 0.0  1.2899E-02 END
AL      3 0.0  3.3567E-03 END
CA      3 0.0  2.6128E-03 END
END COMP
SQUAREPITCH  35.58  24.98  1  1  25.58  2  END
PROB 12 KENO5 AN ARRAY OF CYLINDRICAL TANKS CONTAINING PU SOLUTION
READ PARAM  RND=6  TME=400  GEN=103  NPG=300  MKU=YES
            CKU=YES   END PARAM
READ GEOM
UNIT 1
CYLINDER  1   1   12.49  39.24  0.0
CYLINDER  0   1   12.49  101.7  0.0
CYLINDER  2   1   12.79  102.7  -1.0
CUBOID    0   1  18.09  -18.09  18.09  -18.09  102.7 -1.0
ARRAY 1  -54.27  -36.18  -1.0
CUBOID    0   1  464  -464  525   -525   501    -100
CUBOID    3   1  494  -494  555   -555   531    -130
END GEOM
READ ARRAY
ARA=1
NUX=3  NUY=2  NUZ=1
FILL   6R1   END FILL
END ARRAY
READ PLOT

XUL=-494              YUL=555                ZUL=50
XLR=494               YLR=-555               ZLR=50
UAX=1.0   VDN=-1.0    NAX=120   END

XUL=-494         YUL=18.09      ZUL=500
XLR=494          YLR=18.09      ZLR=-130
UAX=1.0   WDN=-1.0   NAX=120    END
 END
END PLOT
END DATA
END
```

APPENDIX C SCALE3.1 ONE-DIMENSIONAL CALCULATIONS (XSDRN CASES)

```
=CSAS 1X
PROBLEM 1 WATER-REFLECTED PLUTONIUM METAL SPHERE
HANSEN-ROACH  MULTIREGION
PU-239  1 0.0  0.04698  END
PU-240  1 0.0  0.002575 END
PU-241  1 0.0  0.000149 END
PU-242  1 0.0  0.0000099 END
H       2 0.0  0.066067  END
O       2 0.0  0.033032  END
END COMP
SPHERICAL  END
1  4.11  ONEEXTERMOD
2  24.11   NOEXTERMOD
END ZONE
END

=CSAS 1X
PROBLEM 2 WATER-REFLECTED PLUTONIUM SOLUTION SPHERE
HANSEN-ROACH  MULTIREGION
PU-239  1 0.0  3.3662E-4 END
PU-240  1 0.0  1.6163E-5 END
H       1 0.0  6.0260E-2 END
O       1 0.0  3.7734E-2 END
N       1 0.0  2.7595E-3 END
FE      2 0.0  5.8886E-2 END
NI      2 0.0  8.2374E-3 END
CR      2 0.0  1.7672E-2 END
H       3 0.0  0.066067  END
O       3 0.0  0.033032  END
END COMP
SPHERICAL  END
1  14.568  TWOEXTERMOD
2  14.692  ONEEXTERMOD
3  39.6922 NOEXTERMOD
END ZONE
END

=CSAS 1X
PROBLEM 3 BARE PLUTONIUM SOLUTION SPHERE
HANSEN-ROACH  MULTIREGION
PU-239  1 0.0  2.3201E-5 END
PU-240  1 0.0  6.0140E-7 END
PU-241  1 0.0  1.7720E-8 END
H       1 0.0  6.4836E-2 END
O       1 0.0  3.4367E-2 END
N       1 0.0  7.6043E-4 END
AL      2 0.0  6.0260E-2 END
END COMP
SPHERICAL  END
1  61.01   ONEEXTERMOD
2  61.79   NOEXTERMOD
END ZONE
END

=CSAS 1X
PROBLEM 4 BARE U233 SOLUTION SPHERE
HANSEN-ROACH  MULTIREGION
U-233   1 0.0  4.3280E-5 END
U-234   1 0.0  7.1600E-7 END
U-235   1 0.0  1.8000E-8 END
U-238   1 0.0  2.8100E-7 END
```

```
H        1 0.0  6.6636E-2 END
O        1 0.0  3.3607E-2 END
N        1 0.0  1.1780E-4 END
AL       2 0.0  6.0260E-2 END
END COMP
SPHERICAL  END
1  34.595  ONEEXTERMOD
2  34.925   NOEXTERMOD
END ZONE
END
```

```
=CSAS 1X
PROBLEM 5 BARE U235 METAL SPHERE
HANSEN-ROACH  MULTIREGION
U-235 1 0.0  4.5447E-2 END
U-238 1 0.0  2.560E-3  END
H     2 0.0  0.066  END
END COMP
SPHERICAL  END
1  8.71    NOEXTERMOD
END ZONE
END
```

```
=CSAS 1X
PROBLEM 6 BARE U235 SOLUTION SPHERE
HANSEN-ROACH  MULTIREGION
U-234    1 0.0  5.3800E-7 END
U-235    1 0.0  4.8066E-5 END
U-236    1 0.0  1.3800E-7 END
U-238    1 0.0  2.8070E-6 END
H        1 0.0  6.6228E-2 END
O        1 0.0  3.3736E-2 END
N        1 0.0  1.8690E-4 END
AL       2 0.0  6.0260E-2 END
END COMP
SPHERICAL  END
1  34.595  ONEEXTERMOD
2  34.925   NOEXTERMOD
END ZONE
END
```

```
=CSAS 1X
PROBLEM 7 WATER REFLECTED,LOW ENRICHED,UNMODERATED MIXED OXIDE SPHERE
HANSEN-ROACH  MULTIREGION
PU-239  1 0.0  1.9591E-3 END
U-235   1 0.0  1.6460E-4 END
U-238   1 0.0  2.2450E-2 END
O       1 0.0  4.9148E-2 END
H2O  2  1.0   END
END COMP
SPHERICAL  END
1  19.4    ONEEXTERMOD
2  39.4    NOEXTERMOD
END ZONE
END
```

MONK6B/KENOVa COMPARISON FOR A NOTIONAL FUEL STORE

A K Ziver and N R Smith

AEA TECHNOLOGY

Summary

MONK6B and KENOVa criticality safety codes are used to model part of a notional fuel store containing PWR fuel assemblies. The results obtained from both codes are presented together with the input/output listings.

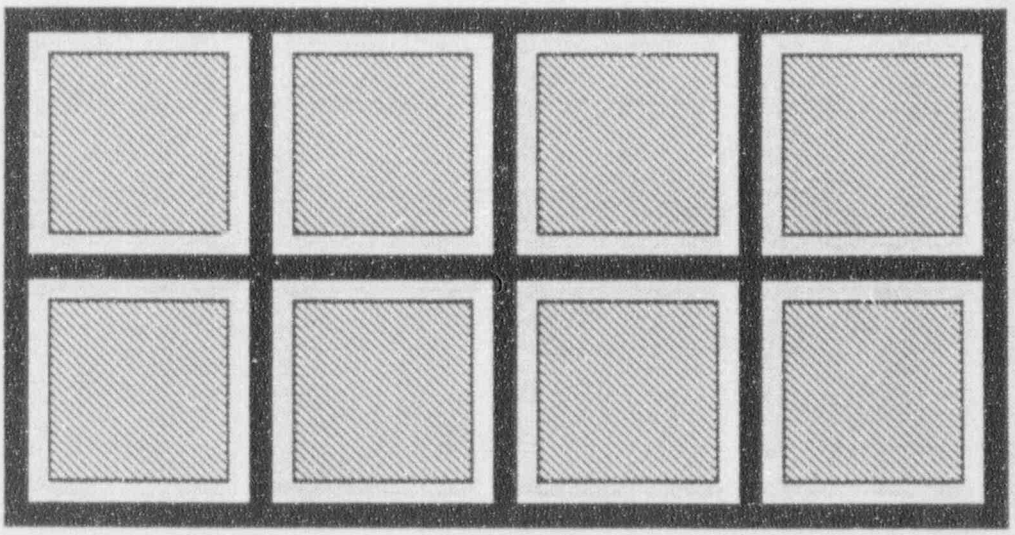
CONTENTS

1 DESCRIPTION OF THE PROBLEM

The problem represents 4x2 array of 3.0% enriched PWR fuel elements located between boronated stainless steel storage compartments. The fuel elements comprise 17x17 array of pins located on a 1.27 cm pitch and are 400.0 cm long including 2.0 cm end-caps. The pins have an outer diameter of 1.08 cm which includes a 0.06 cm zircalloy cladding.

The internal dimensions of the storage compartments are 24x24 cm in cross-section and 420 cm in length. The compartment wall thickness is 1.0 cm and there is a 2.0 cm thick base. The compartment has no lid. The fuel elements are surrounded by 30.0 cm water in all directions.

A plan view of the geometrical model is shown below:



 Fuel-elements 17 x 17  Water  Boronated Steel

Both MONK6B and KENOVa can model this geometry exactly using basic options.

Two KENOVa calculations were performed:

(i) Using the 16-Group Hansen-Roach Library

(ii) Using the 27-Group library (a standard criticality library)

2 MONK6B INPUT DATA LISTING

```
* MONK6B Model of PWR Fuel Elements in Water
* ------------------------------------------------------
* Using the UKNDL Point Nuclear Data

FISSION 4 10 NUCNAMES

* material 1 - UO2
* material 2 - zircalloy
* material 3 - boronated stainless steel
* material 4 - water

ATOM 10.65    U235 0.0304      U238 0.9696      O 2.0
WGT  6.5      ZR 1.0
CONC          FE 5.81377E-2    CR 1.57421E-2    NI 7.74679E-3
              B10 4.99157E-4   B11 2.02430E-3
ATOM 0.998    HINH2O 2.0       O 1.0

CM

*************************************************************************

* part 1 - single fuel element plus half-thickness compartment
*          (fuel; water at end; compartment)

NEST 3
BOX   ORIGIN 0.5 0.5 2.0   BH1   24.0 24.0 400.0
BOX   ORIGIN 0.5 0.5 2.0     4   24.0 24.0 420.0
BOX                          3   25.0 25.0 422.0

* part 2 - assemble 4x2 array of elements in compartments

ARRAY 4 2 1    (1)*8

* part 3 - add remaining half-thickness of compartment and w[illegible] r

NEST 3
BOX   ORIGIN 30.5 30.5 30.0   P2   100.0 50.0 422.0
BOX   ORIGIN 30.0 30.0 30.0    3   101.0 51.0 422.0
BOX                            4   161.0 111.0 482.0


*************************************************************************[illegible]*

* hole 1 - PWR fuel element

SQUARE 3 1 2 4   HTRANS 12.0 12.0 0.0
  1.27 0 0   0.48 0.54
  WRAP 17 17 10.795 10.795 10.795 10.795
  -2 2 4 4 4

* hole 2 - provide axial partitions in fuel region

PLATE 2 1 2
  0 0 1   2   398.0 2 2.0 1  2

*************************************************************************

* 1000 superhistories per stage
* terminating when standard deviation < 0.0015
```

```
-1 5 100 0 STDV 0.0015 -1

* starting source distributed within the column

MULTIFISS STD
REGION 1 PART 3 /
END

*******************************************************************************

* picture 1 - horizontal section array
* picture 2 - close-up of picture 1
* picture 3 - vertical section at top of array
* picture 4 - vertical section at base of array

*CODE 4
*/*.O
*VISAGE 1000
*0 111 200        161 111 200        0 0 200
*30 56 200        56 56 200          30 30 200
*42 0 482         42 111 482         42 0 420
*42 0 40          42 111 40          42 0 0
*END
```

3 SCALE3.1 (KENOVa) INPUT LISTING

```
=CSAS 25
 PWRARRAY  KENOVa  CASE  COMPARISON WITH  MONK6B
27GROUPNDF4  LATTICECELL
U-235    1   0.0    7.22222E-4   END
U-238    1   0.0    2.30351E-2   END
O        1   0.0    4.75146E-2   END
ZR       2   0.0    4.29091E-2   END
FE       3   0.0    5.81377E-2   END
CR       3   0.0    1.57421E-2   END
NI       3   0.0    7.74679E-3   END
B-10     3   0.0    4.99157E-4   END
B-11     3   0.0    2.02430E-3   END
H        4   0.0    6.67221E-2   END
O        4   0.0    3.3361E-02   END
END COMP
SQUAREPITCH  1.27  0.96  1  4  1.08  2  END
 PWRARRAY  KENO  CASE  COMPARISON WITH  MONK6B
READ PARAM  RND=6  TME=360  GEN=40  END PARAM
READ GEOM
UNIT 1
CYLINDER  1  1   0.48  398.0  2.0
CYLINDER  2  1   0.54  400.0  0.0
CUBOID    4  1   0.635  -0.635  0.635  -0.635  400.0  0.0
UNIT 2
ARRAY  1   -10.795  -10.795  0.0
CUBOID 4  1  12    -12    12    -12    420.0  0.0
CUBOID 3  1  12.5  -12.5  12.5  -12.5 420.0  -2.0
ARRAY 2   -50  -25   -2
CUBOID 3  1  50.5  -50.5  25.5  -25.5  420.0  -2.0
CUBOID 4  1  80.5  -80.5  55.5  -55.5  450.0  -32.0
END GEOM
READ BOUNDS
ALL=VAC
END BOUNDS
READ ARRAY
ARA=1
NUX=17   NUY=17  NUZ=1
FILL
  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  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  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  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  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  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  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  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  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  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  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  1  1  1
END FILL
```

```
ARA=2
NUX=4   NUY=2  NUZ=1
FILL
     2   2   2   2
     2   2   2   2
END FILL
END ARRAY
END DATA
END
```

4 A VIEW OF MONK6B GEOMETRY MODEL USING VISAGE1B

In this section four figures are presented to show the geometrical model using high resolution graphics package VISAGE1B.

Figure 1 shows a plan view of the fuel assemblies arranged as 4 x 2 array.

Figure 2 shows a cross-sectional view of the a fuel assembly.

Figures 3 and 4 show elevation views of the ends of the model.

visage1b

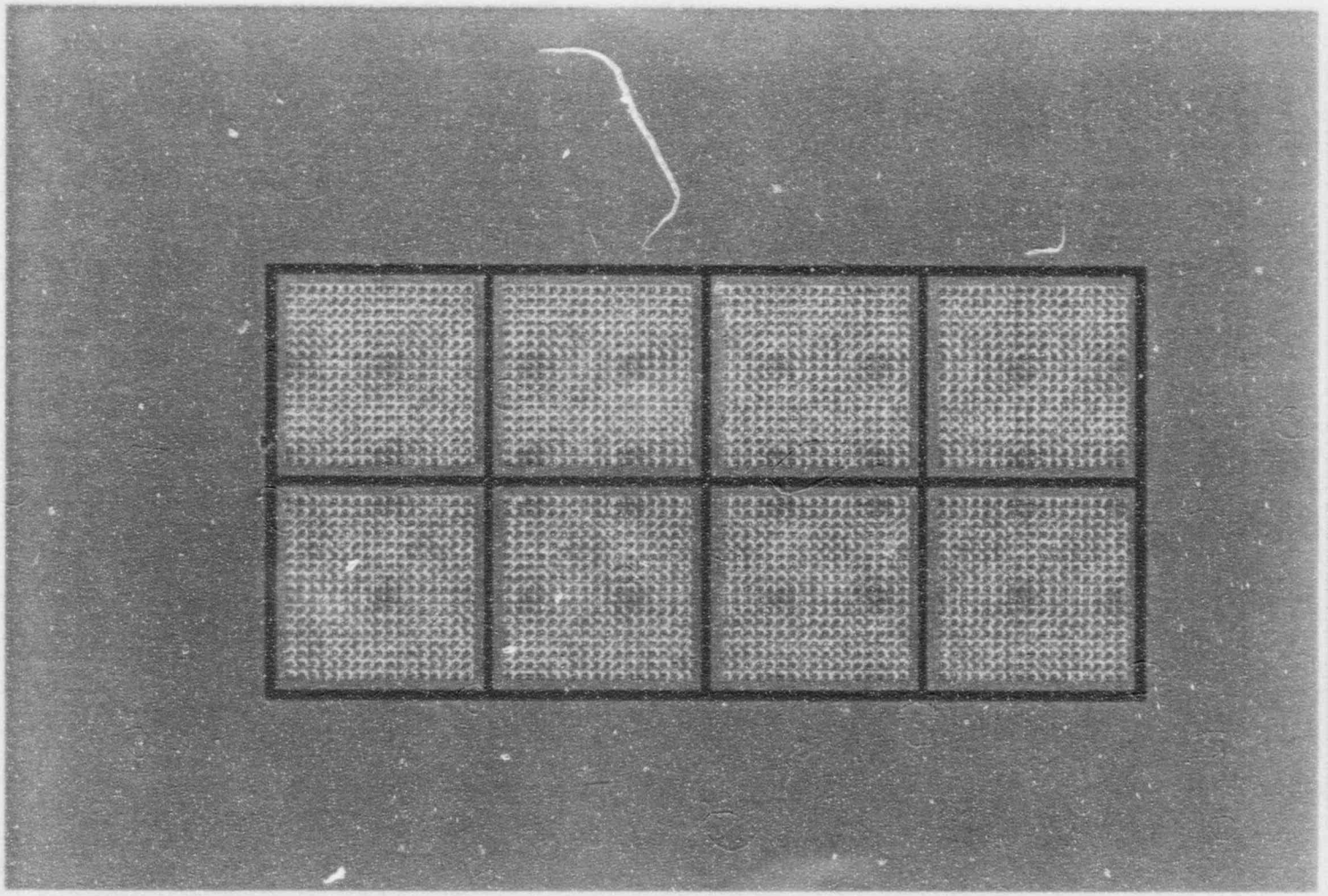
File Picture View Help

Current file : pwr.vis

Current picture : PICT 1

Material -> Colour Key

0 1 2 3 4



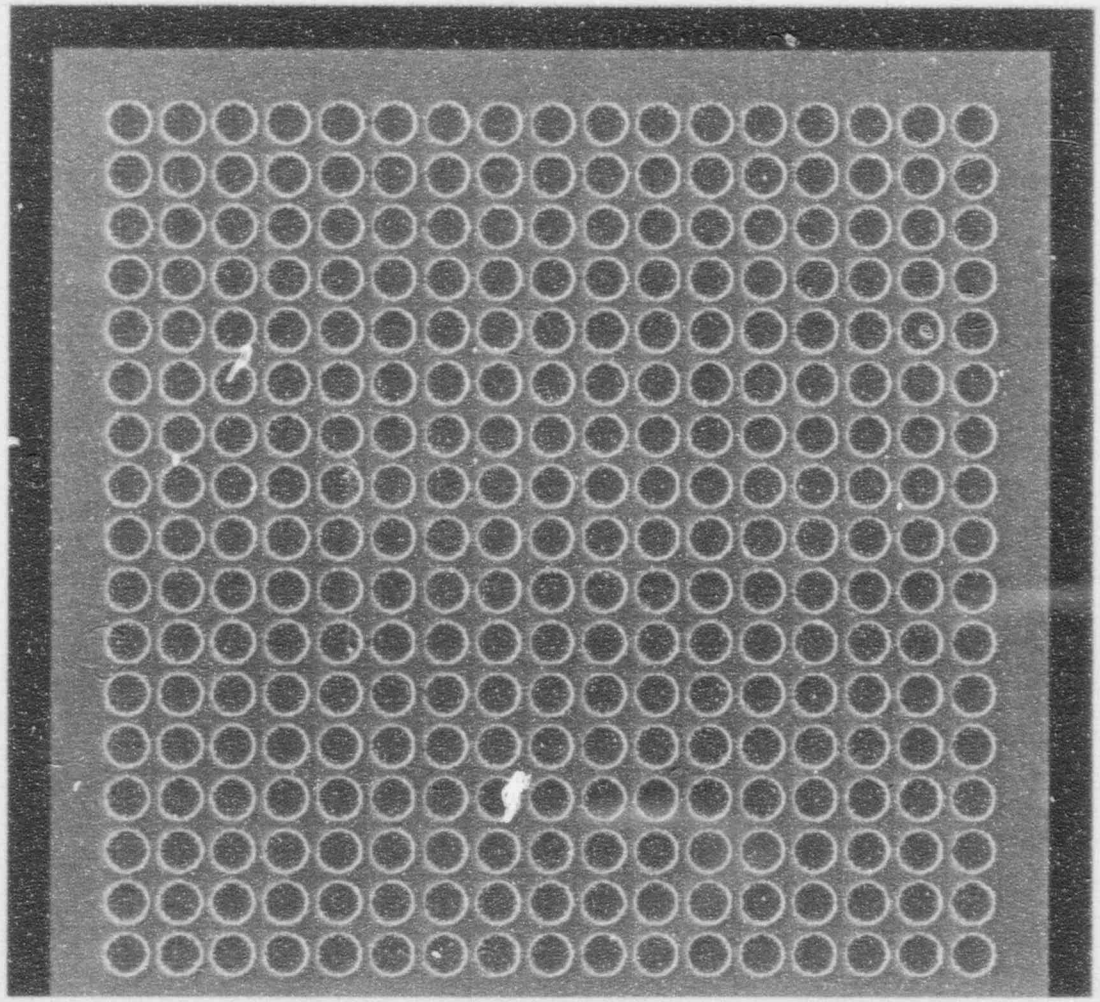
visage1b

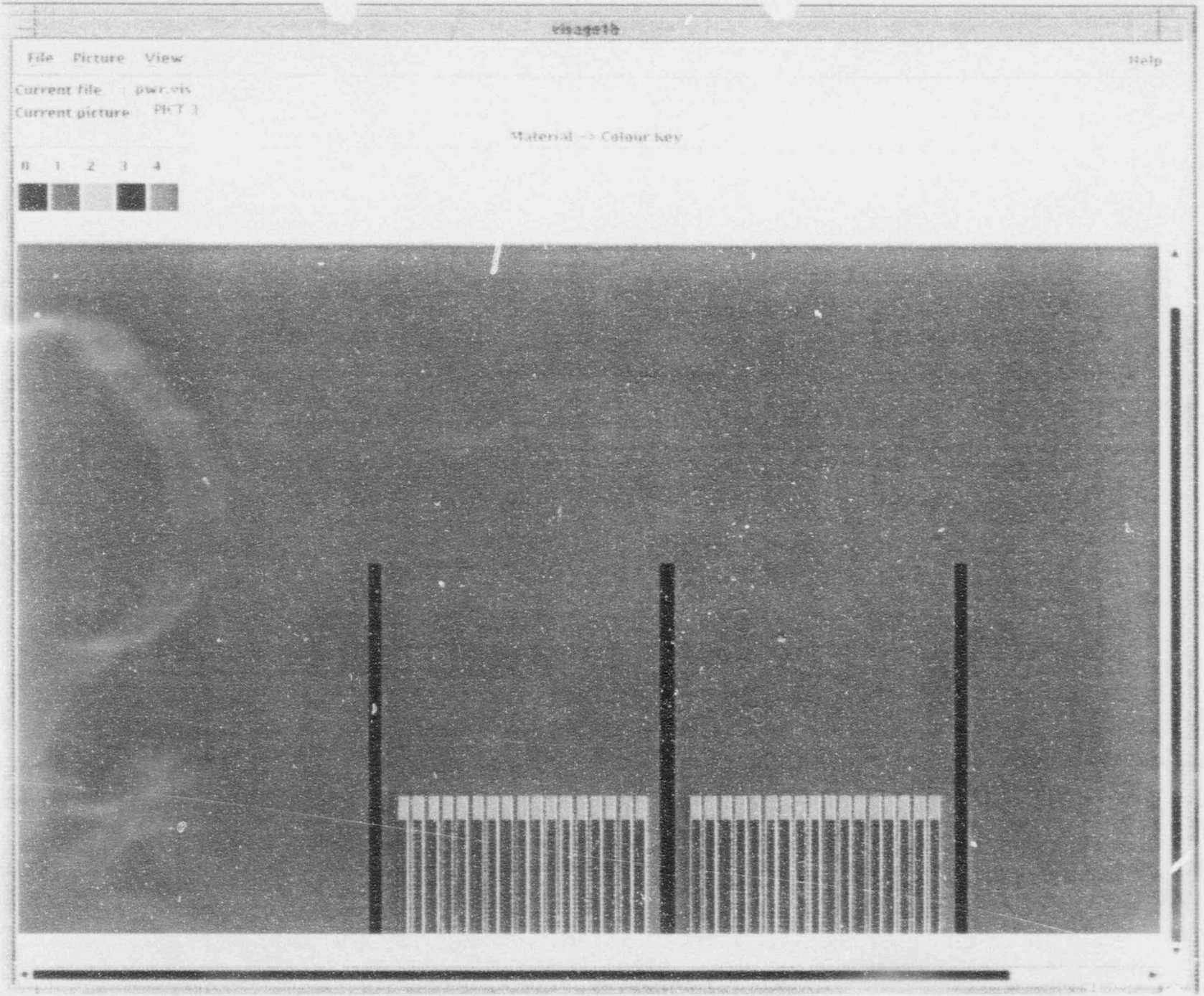
File Picture View Help

Current file : pwr.vis
Current picture : PICT 2

Material -> Colour Key

0 1 2 3 4




visageth
File Picture View
Help
Current file : pwr.vis
Current picture : PICT 1
Material -> Colour key
0 1 2 3 4


visagetk
File
Picture
View
Help
Curren Last Picture
Ctrl L
Curren
Select Picture...
Ctrl S
Material -> Colour Key
0 1 2 3 4

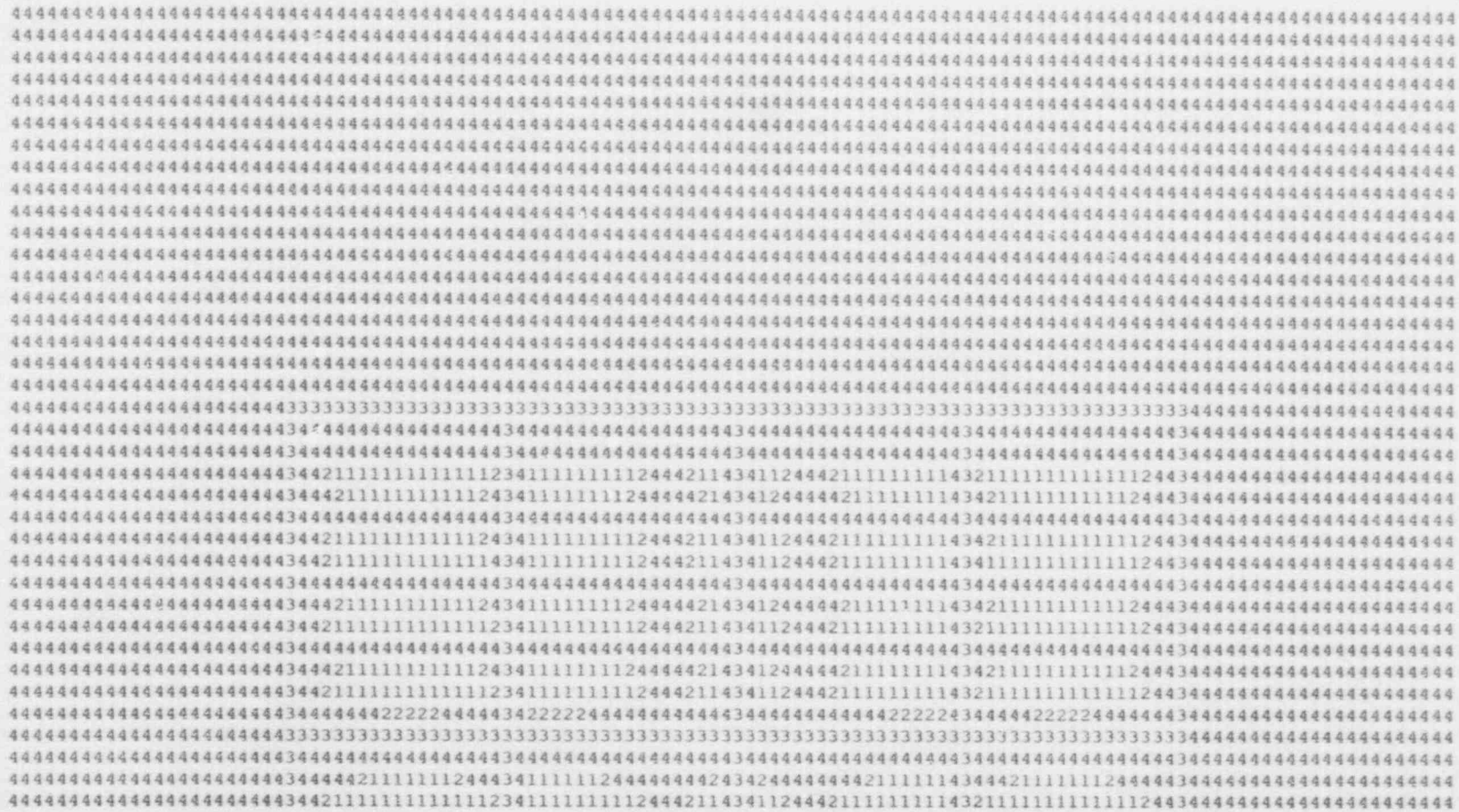
5 A VIEW OF THE KENOVa GEOMETRY

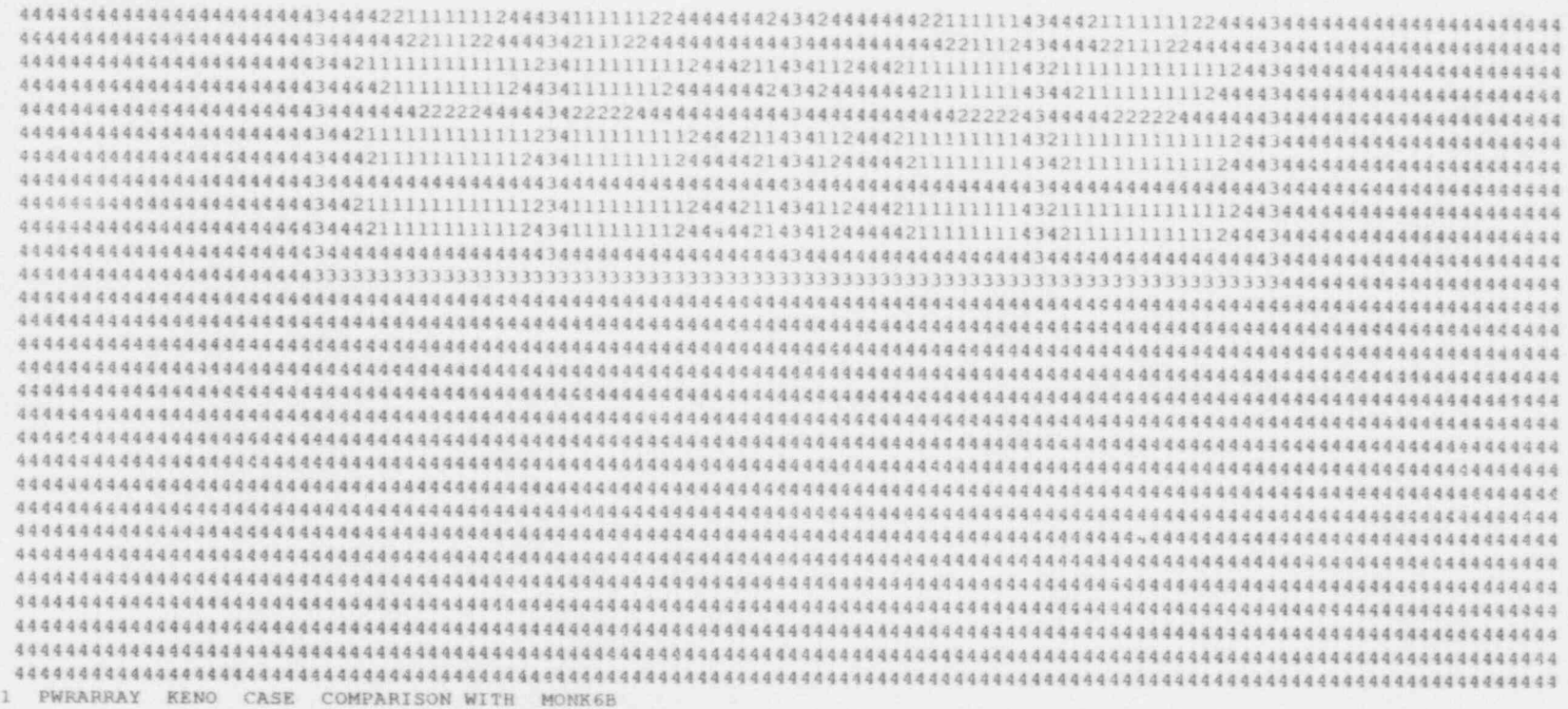
In this section three figures are presented to show the geometrical model obtained using the graphical option in KENOVa.

Figure 1 shows a plan view of the fuel assemblies arranged as 4 x 2 array.

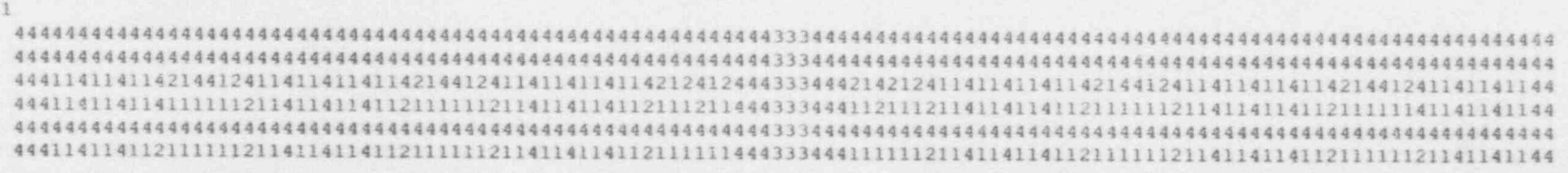
Figures 2 and 3 show an enlarged cross-sectional view of a fuel assembly and the boronated steel plates positioned between the fuel assemblies.

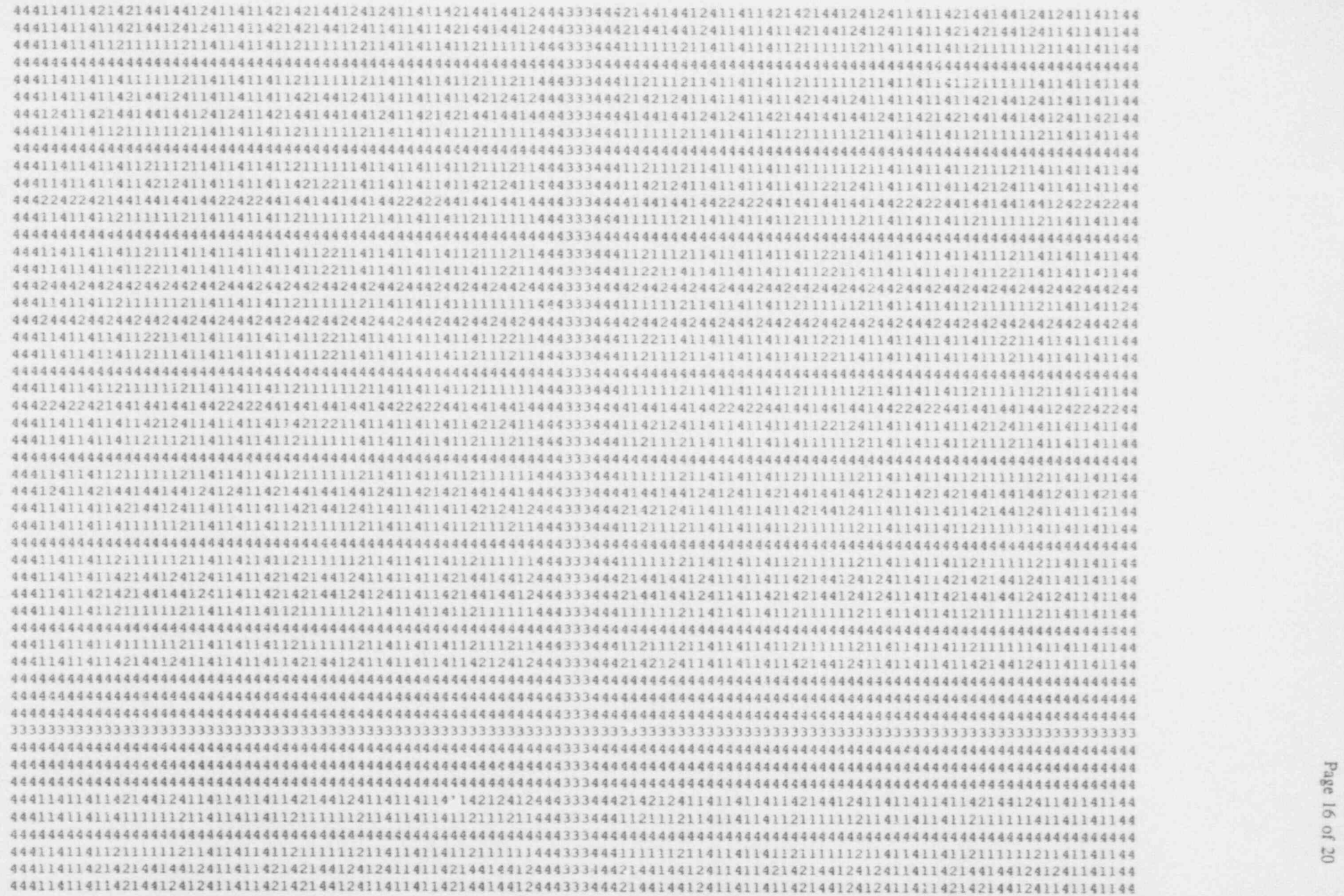
```
0MIXTURE     0   1   2   3   4
  SYMBOL         1   2   3   4
0       UPPER  LEFT           LOWER RIGHT
        COORDINATES           COORDINATES
0X      -8.0500E+01            8.0500E+01
 Y       5.5500E+01           -5.5500E+01
 Z       5.0000E+01            5.0000E+01
0           U AXIS       V AXIS
           (DOWN)       (ACROSS)
0X          0.00000       1.00000
 Y         -1.00000       0.00000
 Z          0.00000       0.00000
0NU=    66   NV=  120     DELU= 1.6771E+00     DELV= 1.3417E+00
1
```

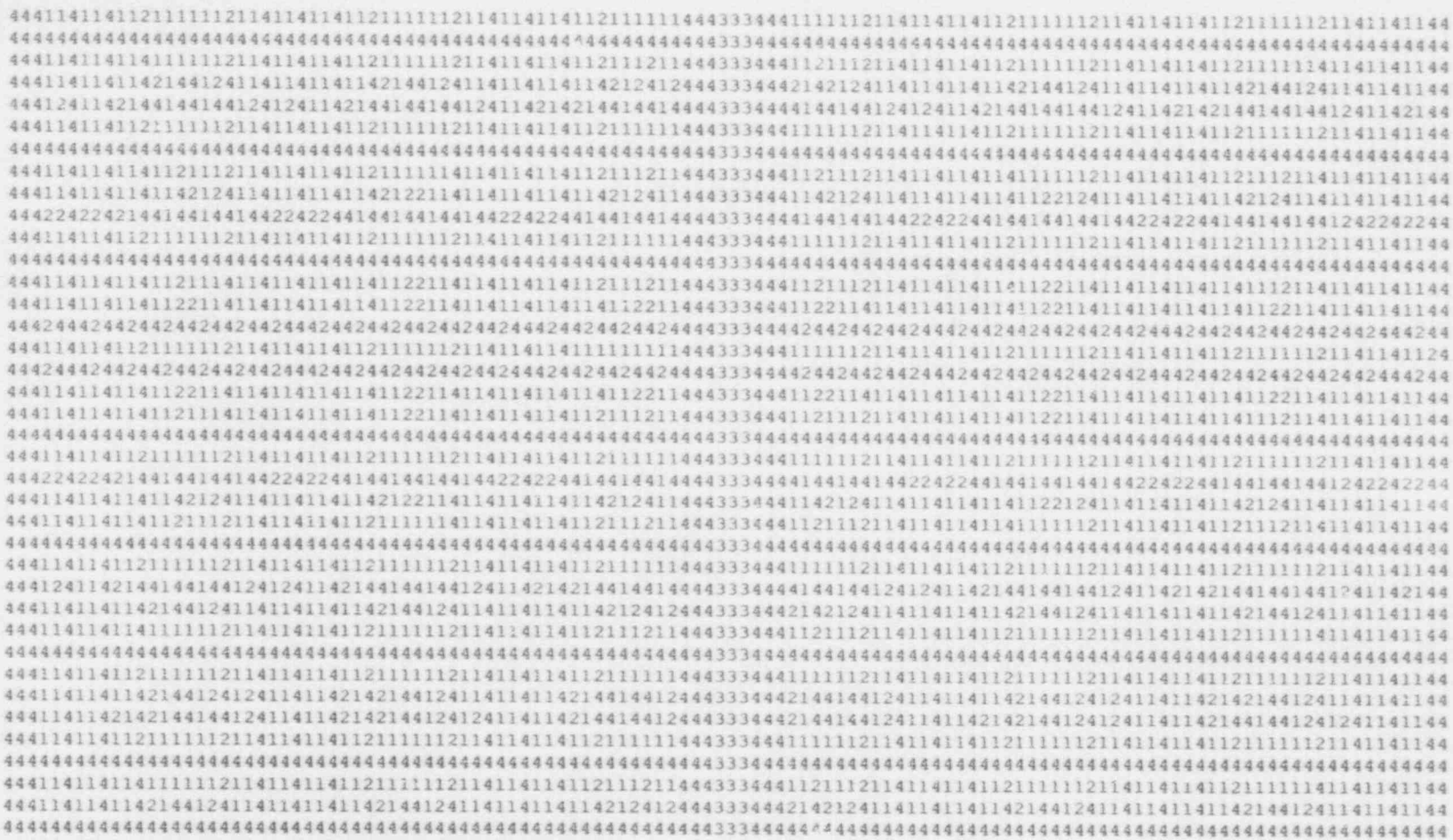




```
1  PWRARRAY  KENO  CASE  COMPARISON WITH  MONK6B
0                                MIXTURE MAP

0MIXTURE    0   1   2   3   4
  SYMBOL        1   2   3   4
0       UPPER  LEFT           LOWER RIGHT
        COORDINATES           COORDINATES
0X     -2.4000E+01            2.4000E+01
 Y      2.4000E+01           -2.4000E+01
 Z      5.0000E+01            5.0000E+01
0          U AXIS       V AXIS
           (DOWN)       (ACROSS)
0X         0.00000       1.00000
 Y        -1.00000       0.00000
 Z         0.00000       0.00000
0NU=   96   NV=  120     DELU= 5.0000E-01     DELV= 4.0000E-01
1
```



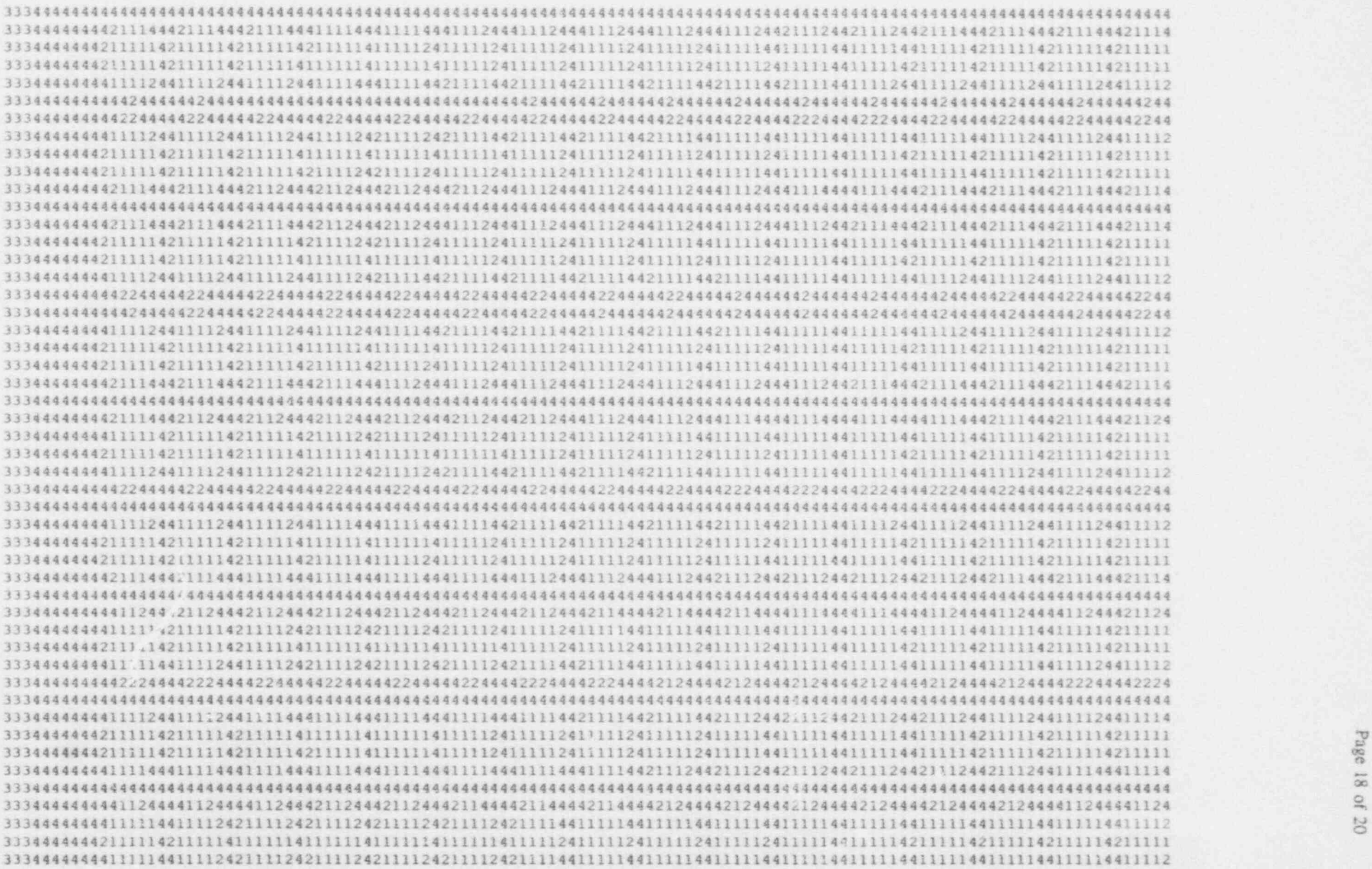


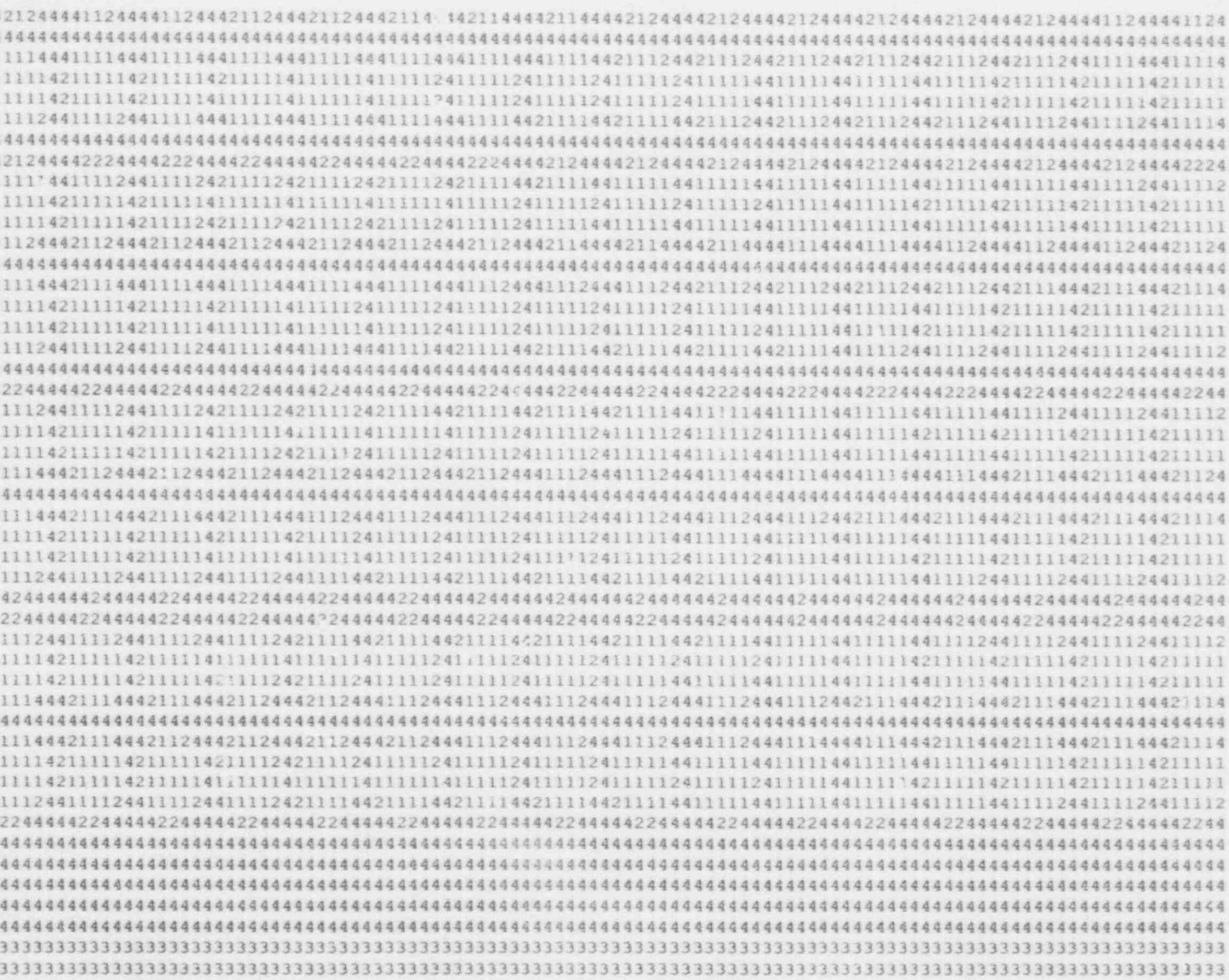


1 PWRARRAY KENO CASE COMPARISON WITH MONK6B
0 MIXTURE MAP

0MIXTURE 0 1 2 3 4
SYMBOL 1 2 3 4
0 UPPER LEFT LOWER RIGHT
COORDINATES COORDINATES
0X 0.0000E+00 2.2000E+01
Y 2.2000E+01 0.0000E+00
Z 5.0000E+01 5.0000E+01
0 U AXIS V AXIS
(DOWN) (ACROSS)
0X 0.00000 1.00000
Y -1.00000 0.00000

```
 Z          0.00000       0.00000
GNU=    96   NV=  120      DELU= 2.2917E-01      DELV= 1.8333E-01
1
```





1 PWRARRAY KENO CASE COMPARISON WITH MONK6B
0 MIXTURE MAP

0MIXTURE 0 1 2 3 4
SYMBOL 1 2 3 4

6 COMPARISON OF MONK6B AND KENOVa RESULTS

MONK6B	SCALE 3.1 KENO Va	Difference in (*) k-effective
0.9369±0.0015	0.9221±0.0013	+0.0148±0.0020
0.9369±0.0015	0.9123±0.0014	+0.0246±0.0020

The errors quoted are one standard deviation (Monte Carlo Statistics)
(*) k(MONK6B)-k(KENOVa)

From the results given above, it is possible to make the following observations:

1. Differences in k-effectives are significant at the 3 standard deviation level for both libraries (between 1.5% and 2.5%) with MONK6B producing more conservative results.

2. MONK6B validation database shows MONK6B over-predicts critical experiments for low-enriched UO2 systems by between 0.5% to 1.0%. This suggests that there is some evidence of under-prediction by KENOVa for the 16-group library and strong evidence of under-prediction for the 27-group library.

```
SSSSSSSSSSA
SSSSSSSSSSAA
SS       SS AA
SS       SS AA
SS       SS  AA
 SS     SS   AA
 SS     SSAAAAAAA
  SS   SSAAAAAAAA
  SS  SS        AA
   SSSS         AA
```

```
M      M   OOOOOO   N      NN  KK     KK        0000       66   BBBBBB
MM    MM  OOOOOOOO  NN     NN  KK    KK        000000      66    BBBBBBB
MMM  MMM  OO    OO  NNN    NN  KK   KK        00    00    66      BB   BB
MMMMMMMM  OO    OO  NNNN   NN  KK KK          00    00   66       BB   BB
MM MM MM  OO    OO  NN NN NN   KKKK           00    00  666666    BBBBBB
MM    MM  OO    OO  NN NN NN   KKKK           00    00 66666666   BBBBBBB
MM    MM  OO    OO  NN  NNNN   KK KK          00    00 66     66  BB    BB
MM    MM  OO    OO  NN   NNN   KK  KK         00    00 66     66  BB    BB
MM    MM  OOOOOOOO  NN     NN  KK    KK        000000   66666666  BBBBBBBB
MM    MM   OOOOOO   NN      N  KK     KK        0000     666666   BBBBBBB
```

```
**************************************************************
*                                                            *
*              P R O G R A M   M O N K   0 6 B               *
*              ---------------------------------             *
*                                                            *
*      This is the ANSWERS QA Set SUN Version of MONK6.      *
*  This version has executed the designated set of test      *
*  cases on the HPD ANSWERS SUN Installation.                *
*                                                            *
*  10 August 1989                                            *
**************************************************************
```

1

1
1

```
     *** NO MESSAGE BOX HAS BEEN CONNECTED TO CHANNEL -  20 ***

     *** PLEASE CONNECT THE MESSAGE BOX IN FUTURE ***

1

          VERSION 03A OF <RCARD> PACKAGE IS USED HERE (2/87)
          --------------------------------------------------

1

          ****************************************
          ***  HARDWARE AUTHORISATION PROCEDURE ***
          ****************************************

 "SYSID" keyword read , for integer code - 1003993     23      9

 "SYSID" keyword read , for integer code - 1004019      6     19

 *** SUCCESSFUL AUTHORISATION ACHIEVED FOR THE PROGRAM ON YOUR HARDWARE ***

 *** The SYSTEM Identification Number is - 1392574372 ***

1

          ****************************************
          *** SOFTWARE AUTHORISATION PROCEDURE ***
          ****************************************

 "PASSWORD" syntax read for specified password - NHYFPZX9

 *** Password read & verified -- this password expires at the end of DEC  1993  ***

          ************************************************************
          *                                                          *
          *                 WARNING  TO  USERS                       *
          *                 *****************                        *
          *                                                          *
          *   THIS PROGRAM IS AVAILABLE FOR -- Local Use             *
          *   USE ONLY AND ACCESS SHOULD NOT BE GIVEN TO ANY THIRD   *
          *   PARTY WITHOUT WRITTEN PERMISSION FROM AEE WINFRITH.    *
          *                                                          *
          ************************************************************
          *                                                          *
          *                   ISSUE DETAILS                          *
          *                  ****************                        *
          *                                                          *
```

```
*   THIS IS A COPY OF THE SUN V `SION OF THE PROGRAM AND    *
*   IS REGISTERED AS COPY - S1                              *
*                                                           *
*   DATE -  As Release Date for Program                     *
*                                                           *
*************************************************************

1
1               INPUT DATA
                ----------


                INPUT READ FROM :
                /dylan/akziver/monkval/pwratr.dat

                OUTPUT WRITTEN TO :
                /dylan/akziver/monkval/pwratr.out


                SYSID   1003993  23  9
                SYSID   1004019   6  19
                PASSWORD NHYFPZX9

                * An Introduction to the MONK Monte Carlo Criticality Code
                * --------------------------------------------------------

                * University of New Mexico - June 1992

                * Practical III - An array of PWR fuel elements
                * ---------------------------------------------

                * 4x2 array of 3.0% enriched PWR fuel elements located within
                * boronated stainless steel storage compartments.
                * The fuel elements comprise 17x17 array of pins on a 1.27cm
                * pitch and are 4.0m long including 2cm end caps.
                * The pins have an outer diameter of 0.96cm, which includes a
                * 0.06cm zircalloy cladding.
                * The internal dimensions of the storage compartments are
                * 24.0x24.0cm in cross-section and 4.2m in length.  The compartment
                * wall thickness is 1.0cm and there is a 2.0cm thick base.

                ********************************************************************************

                FISSION 4 10 NUCNAMES

                * material 1 - UO2
                * material 2 - zircalloy
                * material 3 - boronated stainless steel
                * material 4 - water

                ATOM 10.65    U235 0.0304      U238 0.9696      O 2.0
                WGT  6.5      ZR 1.0
                CONC          FE 5.81377E-2    CR 1.57421E-2    NI 7.74679E-3
                              B10 4.99157E-4   B11 2.02430E-3
                ATOM 0.998    HINK2O 2.0       O 1.0

                CM

                ********************************************************************************
```

```
        * part 1 - single fuel element plus half-thickness compartment
*           (fuel; water at e    compartment)

NEST 3
BOX    ORIGIN 0.5 0.5 2.0    BH1    24.0 24.0 400.0
BOX    ORIGIN 0.5 0.5 2.0      4    24.0 24.0 420.0
BOX                            3    25.0 25.0 422.0

* part 2 - assemble 4x2 array of elements in compartments

ARRAY 4 2 1     (1)*8

* part 3 - add remaining half-thickness of compartment and water

NEST 3
BOX    ORIGIN 30.5 30.5 30.0    P2    100.0 50.0 422.0
BOX    ORIGIN 30.0 30.0 30.0     3    101.0 51.0 422.0
BOX                              4    161.0 111.0 482.0


*******************************************************************************

* hole 1 - PWR fuel element

SQUARE 3 1 2 4    HTRANS 12.0 12.0 0.0
  1.27 0 0    0.48 0.54
  WRAP 17 17 10.795 10.795 10.795 10.795
  -2 2 4 4 4

* hole 2 - provide axial partitions in fuel region

PLATE 2 1 2
  0 0 1    2    398.0 2 2.0 1  2

*******************************************************************************

* 1000 superhistories per stage
* terminating when standard deviation < 0.0015

-1 100 1000 0 STDV 0.0015 -1

* starting source distributed within the column

MULTIFISS STD
REGION 1 PART 3 /
END

*******************************************************************************

* picture 1 - horizontal section array
* picture 2 - close-up of picture 1
* picture 3 - vertical section at top of array
* picture 4 - vertical section at base of array

*CODE 4
*/*.0
*VISAGE 1000
*0 111 200       161 111 200        0 0 200
*30 56 200       56 56 200          30 30 200
*42 0 482        42 111 482         42 0 420
```

```
          *42 0 40          42 1' 40          42 0 0
     *END

     ****************************** ******************************************
* An Introduction to the MONK Monte Carlo Criticality Code
* An Introduction to the MONK Monte Carlo Criticality Code
* ------------------------------------------------------

* University of New Mexico - June 1992
* Practical III - An array of PWR fuel elements
* ------------------------------------------
* 4x2 array of 3.0% enriched PWR fuel elements located within
* boronated stainless steel storage compartments.
* The fuel elements comprise 17x17 array of pins on a 1.27cm
* pitch and are 4.0m long including 2cm end caps.
* The pins have an outer diameter of 0.96cm, which includes a
* 0.06cm zircalloy cladding.
* The internal dimensions of the storage compartments are
* 24.0x24.0cm in cross-section and 4.2m in length.  The compartment
* wall thickness is 1.0cm and there is a 2.0cm thick base.
**********************************************************************
1

                     ******************************************************************
                     ******************************************************************
                     **                                                              **
                     **  FISSION TRACKING CALCULATION STARTED AT 13.28. 0 ON 24/ 3/93 **
                     **                                                              **
                     ******************************************************************
                     ******************************************************************


          THERE ARE A MAXIMUM OF   1994997 SINGLE LENGTH STORAGE LOCATIONS AVAILABLE FOR THE NUCLEAR DATA

1NUCLEAR DATA
 ------------


 ******************************************************************************************************************

                          LIST OF AVAILABLE DATA FILE NUMBERS
                          -----------------------------------

   159  (    U235)    160  (   U238 )    161  (   PU239)   9159  (    U235)    25E (      SI)   9160  (     U238)
   923A (  HINH2O)    935A (    AL27)    902B (       C)    908A (      FE)   259A (       N)   138E (       CA)
   446C (      CR)    907A (      NI)     82B (      ZR)     26C (      PB)    90B (     B10)   835B (       CU)
   949B (      GD)     60A (   PU241)    975A (   PU242)     49B (     B11)    70A (      CD)    23E (      F19)
   141E (      CL)    934B (    CO59)    182E (    NA23)    213B (       W)   274A (   PU238)   190B (       TI)
    84B (       K)    105B (      GA)     81C (      MO)     88A (      MN)    87B (    U233)   953A (     U234)
   954A (    U236)    167A (    U237)    276B (    U239)    277B (    U240)   211  (       H)    55A (ONEOVERV)
   933C (       O)   9161  (   PU239)    402C (   PU240)    930A (   TH232)   960A ;   NP237)  1009C (    AM241)
  1010A (   AM243)    976B (   CM244)    984A (   CM245)     71B (   CD113)   921B (   EU151)   922B (    EU153)
```

```
      1201B (   HF174)    1202B (   HF176)    1203B (   HF177)    1204B (   HF178)    1205B (   HF179)    1206B (   HF180)
    967A (      BE9)     905A (  DIND2O)      25  (         T)      47  (      HE)      44  (      HE3)     221D (      HE4)
      91 (      LI6)     215E (      LI7)     681B       CU63)     682B (    CU65)     79C (     IB93)     973A (    AG107)
    974. (    AG109)     328B (       TA)     986  .       MG)     987  (     S32)     988  (      SN)    4963B (    CM243)
   4953B (  AM242M)    7821B (      P31)    4495B (    IN115)    4493B (    IN113)    9160A (    U238)    4937D (JEFNP237)
   4954B (JEFAM243)    4965B (JEFCM245)    4964B (JEFCM244)    4951D (JEFAM241)
```

****

```
 * material 1 - UO2
 * material 2 - zircalloy
 * material 3 - boronated stainless steel
 * material 4 - water
0NUCLIDE NAMES              U235        U238           O          ZR          FE          CR          NI         S10
                            B11       HINH2O
0ATOMIC WEIGHTS        235.04390   238.05080    15.99938    91.22375    55.84532    51.99763    58.70483    10.01294
                        11.00930     1.00783
```

```
 NUCLIDE RATIOS (EITHER BY WEIGHT(WGT) OR BY ATOM(ATOM)), OR ACTUAL CONCENTRATIONS(CONC) :-

  MAT       DENSITY                                                                                                  TEMP(K)

    1 ATOM 10.65000                                                                                                  293.00
+                   3.04000E-02 9.69600E-01 2.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00
                    0.00000E+00 0.00000E+00

    2 WGT   6.50000                                                                                                  293.00
+                   0.00000E+00 0.00000E+00 0.00000E+00 1.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00
                    0.00000E+00 0.00000E+00

    3 CONC                                                                                                           293.00
+                   0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 5.81377E-02 1.57421E-02 7.74679E-03 4.99157E-04
                    2.02430E-03 0.00000E+00

    4 ATOM  0.99800                                                                                                  293.00
+                   0.00000E+00 0.00000E+00 1.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00
                    0.00000E+00 2.00000E+00


 CONCENTRATIONS :-

  MATERIAL

       1            7.22222E-04 2.30351E-02 4.75146E-02 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00
                    0.00000E+00 0.00000E+00

       2            0.00000E+00 0.00000E+00 0.00000E+00 4.29091E-02 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00
                    0.00000E+00 0.00000E+00

       3            0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 5.81377E-02 1.57421E-02 7.74679E-03 4.99157E-04
                    2.02430E-03 0.00000E+00

       4            0.00000E+00 0.00000E+00 3.33610E-02 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00
```

```
                0.00000E+00 6.67221E

 DIMENSIONS ARE SPECIFIED IN
+                          CENTIMETRES
                           ***********
 ************************************************************************
 * part 1 - single fuel element plus half-thickness compartment
 *          (fuel; water at end; compartment)
1                                        DICE MK. VI(SYS) , ABSYND VERSION  3
                                         -----------------------------------
 NUCLEAR DATA IS PROVIDED FOR  4 MATERIAL(S).

 THERE ARE  8220 CROSS-SECTION  ENERGY GROUPS FROM 1.50000E+01 MEV TO 0.00000E+00 MEV


 POINT DATA ADJUSTMENT ... CROSS SECTIONS FOR DFN 9159
 POINT DATA ADJUSTMENT ... CROSS SECTIONS FOR DFN  923
 POINT DATA ADJUSTMENT ... CROSS SECTIONS FOR DFN  908
 POINT DATA ADJUSTMENT ... CROSS SECTIONS FOR DFN 9160
 POINT DATA ADJUSTMENT ... NU VALUES FOR DFN 9159

          THE NUCLEAR DATA OCCUPIES  741245 LOCATIONS AND TOOK   37.3 SECS OF CPU TO PROCESS
          ---------------------------------------------------------------------------------


                                SUMMARY OF MATERIAL DATA
                                ========================


                                        MATERIAL
                                        --------

                DENSITY 1.06500E+01 GRMS/CC     NUMBER OF NUCLIDES  3     TEMPERATURE 293.0 DEGREES KELVIN

 NUCLIDE NO.      NAME       ATOMIC NO.      ATOMIC WT    PROP BY NUCLIDE       DFN       TAPE REF NO.
 -----------      ----       ----------      ----------   ---------------       ---       ------------

       1          U235           92            235.04       1.0133E-02        9159             4

       2          U238           92            238.05       3.2320E-01        9160A            83

       3            O             8             16.00       6.6667E-01        933C             43


                                        MATERIAL  2
                                        --------

                DENSITY 6.50000E+00 GRMS/CC     NUMBER OF NUCLIDES  1     TEMPERATURE 293.0 DEGREES KELVIN

 NUCLIDE NO.      NAME       ATOMIC NO.      ATOMIC WT    PROP BY NUCLIDE       DFN       TAPE REF NO.
```

1	ZR	[illegible].0	91.22	1.0000E+00	8	15

MATERIAL 3

DENSITY 7.55114E+00 GRMS/CC NUMBER OF NUCLIDES 5 TEMPERATURE 293.0 DEGREES KELVIN

NUCLIDE NO.	NAME	ATOMIC NO.	ATOMIC WT	PROP BY NUCLIDE	DFN	TAPE REF NO.
1	FE	26	55.85	6.9088E-01	908A	10
2	CR	24	52.00	1.8707E-01	446C	13
3	NI	28	58.70	9.2059E-02	907A	14
4	B10	5	10.01	5.9317E-03	90B	17
5	B11	5	11.01	2.4056E-02	49B	22

MATERIAL 4

DENSITY 9.98000E-01 GRMS/CC NUMBER OF NUCLIDES 2 TEMPERATURE 293.0 DEGREES KELVIN

NUCLIDE NO.	NAME	ATOMIC NO.	ATOMIC WT	PROP BY NUCLIDE	DFN	TAPE REF NO.
1	O	8	16.00	3.3333E-01	933C	43
2	HINH2O	1	1.01	6.6667E-01	923A	7

++++++++++

THERE ARE THE EQUIVALENT OF 623809 DOUBLE LENGTH STORAGE LOCATIONS LEFT FOR THE REST OF THE DATA

* part 2 - assemble 4x2 array of elements in compartments
* part 3 - add remaining half-thickness of compartment and water
****
* hole 1 - PWR fuel element
1SUMMARY OF GEOMETRY DATA

LEGEND FOR PART PRINT

SHAPE	PARAM1	PARAM2	PARAM3	PARAM4	PARAM5
SPHERE	RADIUS				
ROD OR CYLINDER	RADIUS	HEIGHT			
TORUS	RADIUS1	RADIUS2			
BOX OR CUBOID	LENGTH	BREADTH	DEPTH		
TRUNCATED CONE	B-RADIUS	T-RADIUS	HEIGHT		
TRAPEZOIDAL PRISM	T-BASE	T-HEIGHT	P-HEIGHT	I-ANGLE1	I-ANGLE2

PART 1 (3 BODY NEST)

BODY NO.	REG NO.	SHAPE NAME	MATERIAL CONTENT	SHAPE PARAMETERS PARAM1	PARAM2	PARAM3	PARAM4	PARAM5	VOLUME OR CLUMP&DOMNO	LOCATION OF ORIGIN X-COORD	Y-COORD	Z-COORD	BODY IS ROTATED
1	1	BOX	BHOLE 1	24.0000	24.0000	400.0000			2.30400E+05	0.5000	0.5000	2.0000	NO
2	2	BOX	4	24.0000	24.0000	420.0000			1.15200E+04	0.5000	0.5000	2.0000	NO
3	3	BOX	3	25.0000	25.0000	422.0000			2.18300E+04	0.0000	0.0000	0.0000	NO

NO ROTATIONS

PART 2 (4 BY 2 BY 1 ARRAY)

Y	Z	X: 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	1	1	1	1	1																
2	1	1	1	1	1																

PART 3 (3 BODY NEST)

BODY NO.	REG NO.	SHAPE NAME	MATERIAL CONTENT	SHAPE PARAMETERS PARAM1	PARAM2	PARAM3	PARAM4	PARAM5	VOLUME OR CLUMP&DOMNO	LOCATION OF ORIGIN X-COORD	Y-COORD	Z-COORD	BODY IS ROTATED
1	5	BOX	PART 2	100.0000	50.0000	422.0000			2.11000E+06	30.5000	30.5000	30.0000	NO
2	6	BOX	3	101.0000	51.0000	422.0000			6.37220E+04	30.0000	30.0000	30.0000	NO
3	7	BOX	4	161.0000	111.0000	482.0000			6.44010E+06	0.0000	0.0000	0.0000	NO

NO ROTATIONS

THE OUTERMOST REGION OF THE PROBLEM IS REGION NO. 7 WHICH HAS A FREE BOUNDARY

1HOLE DATA

HOLE 1 SQUARE NO. OF MATERIALS IN HOLE GEOMETRY - 3
LIST OF MATERIALS - 1 2 4
HOLE ORIGIN - 12.0000 12.0000 0.0000
0 PITCH - 1.2700 DISPLACEMENTS 0.0000 0.0000 RADII 0.4800 0.5400
0 WRAP 17 AND 17 PINS/SIDE FLATS 10.7950 10.7950 10.7950 10.7950
0 MATERIALS -2 2 OR 4
0 WRAPPER MATERIALS 4 4
* hole 2 - provide axial partitions in fuel region

HOLE 2 PLATE NO. OF MATERIALS IN HOLE GEOMETRY - 2
LIST OF MATERIALS - 1 2
0 A - 0.0000 B - 0.0000 C - 1.0000 NP - 2

W M

2
398.0000
1
2.0000
0 2

* 1000 superhistories per stage
* terminating when standard deviation < 0.0015

1EDIT DATA

THE ACTION COUNTS WILL BE ACCUMULATED IN THE FOLLOWING 3 PARTITIONS

PARTITION NUMBER	GROUP NUMBERS	ENERGY RANGE (MEV)
1	1 TO 2	ABOVE 1.00E-01
2	3 TO 8	4.00E-07 TO 1.00E-01
3	9 TO 9	BELOW 4.00E-07

THE CASE CATEGORISATION WILL BE BASED ON THE ABOVE PARTITIONS

INDIVIDUAL STAGE ESTIMATORS WILL BE SCORED

A TABLE SHOWING K VARYING AS A FUNCTION OF THE NUMBER OF SETTLING STAGES WILL BE PRODUCED

NEUTRON FLUXES WILL BE SCORED IN THE ACTION COUNT PARTITIONS SHOWN ABOVE

THE BOUNDARY CROSSINGS,ACTION COUNTS,NEUTRON FLUXES ETC. WILL BE NORMALISED TO 10,000 SOURCE NEUTRONS

1CONTROL DATA

SUPERHISTORY TYPE TRACKING WILL BE PERFORMED WITH NEUTRONS TRACKED FOR A MAXIMUM OF 10 GENERATIONS PER STAGE (NUFACT = 1.00)

THE STARTING RANDOM NUMBER IS 48511648

0FIRST STAGE IS -1 LAST STAGE IS 100

\+ NUMBER OF NEUTRONS/STAGE IS ***

NO STATISTICS WILL BE COUNTED UNTIL STAGE 1

THIS RUN WILL STOP IF THE STANDARD DEVIATION ON K(THREE) FALLS BELOW 0.0015 FOR THREE CONSECUTIVE STAGES

0SOURCE USED TO START FIRST STAGE ONLY

0

1SOURCE DATA
----

* starting source distributed within the column

'MULTIPLE FISSILE' SOURCE.

STANDARD OPTIONS REQUESTED WITH NEUTRONS STARTING IN THE FISSILE MATERIAL CONTAINED IN THE FOLLOWING REGIONS:-

5

THE SOURCE IS A FISSION SOURCE
0

THE EQUIVALENT OF 6739 DOUBLE LENGTH STORAGE LOCATIONS ARE OCCUPIED BY THE NON-NUCLEAR DATA
1

1 SUMMARY OF COLLISION COUNTS FOR SETTLING STAGES

STAGE	SAMPLE	SCAT	CAP	FISS	CHILD	SCORE	ESC	N2N	N3N
-1	7002	294317	4421	2578	6351	6341	10	7	0
0	12183	507497	7508	4678	11506	11275	13	16	0

1 <:::::::::::::::: INDIVIDUAL STAGE COUNTS ::::::::::::::::> <:::::::::::::::::::::: CUMULATIVE COUNTS ::::::::::::::::::::::>

STAGE	SAMPLE	SCAT	CAP	FISS	CHILD	SCORE	ESC	N2N	N3N	SAMPLE	SCATTER	CAPTURE	FISSION	CHILDREN	SCORE	TOTESC	TOTN2N	TOTN3N
STAGE NO. = 1 K-EFFECTIVE = 0.9259 (0.0095)																		
1	9150	371657	5722	3438	8465	8497	6	16	0	9150	371657	5722	3438	8465	8497	6	16	0
STAGE NO. = 2 K-EFFECTIVE = 0.9317 (0.0065)																		
2	12102	488856	7399	4710	11601	11135	12	19	0	21252	860513	13121	8148	20067	19632	18	35	0
STAGE NO. = 3 K-EFFECTIVE = 0.9352 (0.0054)																		
3	9873	386835	6102	3773	9271	9268	8	10	0	31125	1247348	19223	11921	29338	28900	26	45	0
STAGE NO. = 4 K-EFFECTIVE = 0.9366 (0.0047)																		
4	9162	360450	5672	3497	8589	8592	8	15	0	40287	1607798	24895	15418	37927	37492	34	60	0
STAGE NO. = 5 K-EFFECTIVE = 0.9391 (0.0041)																		
5	10084	398104	6230	3861	9502	9751	8	15	0	50371	2005902	31125	19279	47429	47244	42	75	0
STAGE NO. = 6 K-EFFECTIVE = 0.9386 (0.0038)																		
6	10041	399055	6178	3874	9528	9228	8	19	0	60412	2404957	37303	23153	56958	56472	50	94	0
STAGE NO. = 7 K-EFFECTIVE = 0.9388 (0.0035)																		
7	9539	375068	5968	3579	8790	8967	7	15	0	69951	2780025	43271	26732	65748	65439	57	109	0
STAGE NO. = 8 K-EFFECTIVE = 0.9378 (0.0033)																		
8	8911	359313	5606	3310	8143	8403	9	14	0	78862	3139338	48877	30042	73891	73841	66	123	0

```
      STAGE NO. =    9  K-EFFECTIVE = 0.9381 (0.0031)
   9    11517 459027 7037 4484  11026  10708   13   17    0   90379 3598365   55914   3[illegible]5   84918   84549     79  140    0
STAGE N[illegible]  10  K-EFFECTIVE = 0.9375 (0.00[illegible]
  10    [illegible]510 421224 6484 4036   9945   9549   10   20    0  100889 4019589   62398   38562   [illegible]4863   94098     89  160    0
STAGE NO. =   11  K-EFFECTIVE = 0.9370 (0.0028)
  11     9654 380932 6004 3654   8992   8858    7   11    0  110543 4400521   68402   42216  103855  102956     96  171    0
STAGE NO. =   12  K-EFFECTIVE = 0.9364 (0.0027)
  12     9278 371771 5783 3497   8603   8662    8   10    0  119821 4772294   74185   45713  112458  111618    104  181    0
STAGE NO. =   13  K-EFFECTIVE = 0.9358 (0.0026)
  13    10102 409125 6283 3830   9428   9368    6   17    0  129923 5181419   80468   49543  121886  120986    110  198    0
STAGE NO. =   14  K-EFFECTIVE = 0.9355 (0.0025)
  14    10699 440246 6591 4117  10115  10015   10   19    0  140622 5621665   87059   53660  132001  131000    120  217    0
STAGE NO. =   15  K-EFFECTIVE = 0.9354 (0.0024)
  15     9648 381770 6001 3650   8973   9012   12   15    0  150270 6003435   93069   57310  140974  140013    132  232    0
STAGE NO. =   16  K-EFFECTIVE = 0.9351 (0.0023)
  16    10453 428788 6492 3969   9759   9748   11   19    0  160723 6432223   99552   61279  150733  149760    143  251    0
STAGE NO. =   17  K-EFFECTIVE = 0.9351 (0.0023)
  17     9948 395334 6151 3804   9357   9360   11   18    0  170671 6827557  105703   65083  160090  159121    154  269    0
STAGE NO. =   18  K-EFFECTIVE = 0.9350 (0.0022)
  18    10066 398330 6270 3810   9362   9369    8   22    0  180737 7225887  111973   68893  169452  168490    162  291    0
STAGE NO. =   19  K-EFFECTIVE = 0.9356 (0.0021)
  19    10000 393934 6168 3844   9456   9468   10   22    0  190737 7619821  118141   72737  178908  177958    172  313    0
STAGE NO. =   20  K-EFFECTIVE = 0.9360 (0.0021)
  20    10138 407229 6266 3874   9522   9506   14   16    0  200875 8027050  124407   76611  188430  187464    186  329    0
STAGE NO. =   21  K-EFFECTIVE = 0.9359 (0.0020)
  21     8723 343175 5486 3248   7980   8233    5   16    0  209598 8370225  129893   79859  196409  195696    191  345    0
STAGE NO. =   22  K-EFFECTIVE = 0.9355 (0.0020)
  22     9565 381725 5960 3609   8873   8885   15   19    0  219163 8751950  135853   83468  205283  204582    206  364    0
STAGE NO. =   23  K-EFFECTIVE = 0.9364 (0.0019)
  23    10960 430600 6759 4210  10366  10336    7   14    1  230123 9182550  142612   87678  215648  214918    213  378    1
STAGE NO. =   24  K-EFFECTIVE = 0.9361 (0.0019)
  24     9420 379944 5883 3532   8686   8711   14    9    0  239543 9562494  148495   91210  224334  223629    227  387    1
STAGE NO. =   25  K-EFFECTIVE = 0.9361 (0.0019)
  25     9361 371436 5852 3520   8660   8719    4   15    0  248904 9933930  154347   94730  232994  232347    231  402    1
STAGE NO. =   26  K-EFFECTIVE = 0.9367 (0.0018)
  26    10500 422617 6455 4060   9982  10035    5   20    0 259404 10356547  160802   98790  242976  242382    236  422    1
STAGE NO. =   27  K-EFFECTIVE = 0.9370 (0.0018)
  27    10626 415383 6568 4064  10001   9854   13   17    1 270030 10771930  167370  102854  252977  252236    249  439    2
STAGE NO. =   28  K-EFFECTIVE = 0.9377 (0.0018)
  28    10621 422445 6523 4108  10094  10073    6   16    0 280651 11194375  173893  106962  263071  262309    255  455    2
STAGE NO. =   29  K-EFFECTIVE = 0.9377 (0.0017)
  29    11178 452189 6831 4353  10681  10576    9   15    0 291829 11646564  180724  111315  273754  272885    264  470    2
STAGE NO. =   30  K-EFFECTIVE = 0.9373 (0.0017)
  30     9180 379467 5745 3430   8438   8488   13    8    0 301009 12026031  186469  114745  282192  281373    277  478    2
STAGE NO. =   31  K-EFFECTIVE = 0.9369 (0.0017)
  31     9110 364090 5732 3382   8324   8520    8   12    0 310119 12390121  192201  118127  290516  289893    285  490    2
STAGE NO. =   32  K-EFFECTIVE = 0.9367 (0.0016)
  32    10090 406259 6246 3848   9474   9382   12   16    0 320209 12796380  198447  121975  299989  299275    297  506    2
STAGE NO. =   33  K-EFFECTIVE = 0.9366 (0.0016)
  33     9175 361977 5760 3421   8419   8622    5   11    0 329384 13158357  204207  125396  308408  307897    302  517    2
STAGE NO. =   34  K-EFFECTIVE = 0.9367 (0.0016)
  34    10790 434458 6652 4147  10199  10170    7   16    0 340174 13592815  210859  129543  318607  318067    309  533    2
STAGE NO. =   35  K-EFFECTIVE = 0.9367 (0.0016)
  35     9797 398174 6066 3739   9192   9149    7   13    1 349971 13990989  216925  133282  327799  327217    316  546    3
STAGE NO. =   36  K-EFFECTIVE = 0.9367 (0.0015)
  36    10104 412544 6210 3899   9576   9451   11   16    0 360075 14403533  223135  137181  337375  336668    327  562    3
STAGE NO. =   37  K-EFFECTIVE = 0.9368 (0.0015)
  37     9913 387125 6153 3766   9273   9182   13   19    0 369988 14790658  229288  140947  346649  345851    340  581    3
STAGE NO. =   38  K-EFFECTIVE = 0.9371 (0.0015)
  38     9601 377738 5928 3683   9055   9035    9   19    0 379589 15168396  235216  144630  355703  354886    349  600    3
```

STAGE NO. - 39 K-EFFECTIVE = 0.9371 (0.0015)

39	10/82	428755	6631	4152	10224	9927	16	17	0	390171155971S1	241847	148	?	365927	364812	365	617	3

STAGE NO. 40 K EFFECTIVE = 0.9370 (0.00[illegible]

40	9/29	377969	5940	3691	9077	8968	9	1	0	400000815975120	247787	152473	[illegible]	3004	373780	374	628	3

INDIVIDUAL STAGE COUNTS									CUMULATIVE COUNTS							
STAGE	SAMPLE	SCAT	CAP	FISS	CHILD	SCORE	ESC	N2N	N3N	SAMPLE	SCATTER	CAPTURE	FISSION	CHILDREN	SCORE	TOTESC	TOTN2N	TOTN3N

STAGE NO. - 41 K EFFECTIVE = 0.9369 (0.0015)

41	9/29	381746	6043	3688	9078	9033	7	9	0	409729163568S6	253830	156161	384083	382813	381	637	3	

CUMULATIVE INDIVIDUAL SAMPLE ESTIMATORS

STAGE	K(COLL)	STD	K(SCORE)	STD	K(BRISS)	STD	A	STD	LAMBDA	R(S,A)	R(C,A)	R(C,S)	ALPHA	BETA	K(THREE)	STD
1	0.9252	0.0136	0.9286	0.0136	0.9261	0.0097	1.0023	0.0085	1.1231	0.9921	0.9871	0.9820	0.1909	0.9087	0.9259	0.0095
2	0.9442	0.0086	0.9238	0.0095	0.9292	0.0067	0.9951	0.0061	1.1026	0.9923	0.9874	0.9819	0.1661	0.9212	0.9317	0.0065
3	0.9426	0.0070	0.9285	0.0080	0.9335	0.0055	0.9957	0.0050	1.1471	0.9925	0.9884	0.9828	0.1859	0.9496	0.9352	0.0054
4	0.9414	0.0063	0.9306	0.0069	0.9354	0.0049	0.9958	0.0044	1.1217	0.9924	0.9881	0.9826	0.1944	0.9148	0.9366	0.0047
5	0.9416	0.0056	0.9379	0.0061	0.9384	0.0042	0.9995	0.0039	1.1343	0.9928	0.9884	0.9830	0.2165	0.9105	0.9391	0.0041
6	0.9428	0.0051	0.9348	0.0056	0.9374	0.0039	0.9977	0.0036	1.1079	0.9925	0.9880	0.9827	0.2099	0.8917	0.9386	0.0038
7	0.9399	0.0047	0.9355	0.0051	0.9385	0.0037	0.9973	0.0033	1.0964	0.9924	0.9881	0.9829	0.2327	0.8563	0.9388	0.0035
8	0.9370	0.0044	0.9363	0.0049	0.9381	0.0034	0.9984	0.0032	1.1005	0.9921	0.9876	0.9821	0.2588	0.8342	0.9378	0.0033
9	0.9396	0.0041	0.9355	0.0045	0.9376	0.0032	0.9980	0.0029	1.0862	0.9923	0.9877	0.9827	0.2474	0.8328	0.9381	0.0031
10	0.9403	0.0038	0.9327	0.0043	0.9366	0.0030	0.9965	0.0028	1.1031	0.9923	0.9881	0.9828	0.2334	0.8620	0.9375	0.0029
11	0.9395	0.0037	0.9314	0.0041	0.9362	0.0029	0.9956	0.0027	1.0985	0.9922	0.9881	0.9828	0.2341	0.8559	0.9370	0.0028
12	0.9385	0.0035	0.9315	0.0040	0.9357	0.0028	0.9963	0.0026	1.0988	0.9922	0.9883	0.9830	0.2470	0.8463	0.9364	0.0027
13	0.9381	0.0034	0.9312	0.0039	0.9350	0.0027	0.9966	0.0025	1.1095	0.9922	0.9884	0.9830	0.2487	0.8562	0.9358	0.0026
14	0.9387	0.0033	0.9316	0.0037	0.9343	0.0026	0.9975	0.0024	1.1068	0.9923	0.9885	0.9833	0.2446	0.8585	0.9355	0.0025
15	0.9381	0.0032	0.9317	0.0036	0.9345	0.0025	0.9975	0.0023	1.1040	0.9923	0.9885	0.9834	0.2448	0.8553	0.9354	0.0024
16	0.9378	0.0030	0.9318	0.0034	0.9342	0.0024	0.9979	0.0022	1.0984	0.9923	0.9884	0.9833	0.2518	0.8415	0.9351	0.0023
17	0.9380	0.0030	0.9323	0.0033	0.9342	0.0024	0.9983	0.0021	1.0995	0.9923	0.9884	0.9833	0.2499	0.8440	0.9351	0.0023
18	0.9376	0.0029	0.9322	0.0032	0.9341	0.0023	0.9983	0.0021	1.0967	0.9922	0.9885	0.9833	0.2579	0.8335	0.9350	0.0022
19	0.9380	0.0028	0.9330	0.0031	0.9348	0.0022	0.9984	0.0020	1.0963	0.9923	0.9885	0.9834	0.2526	0.8409	0.9356	0.0021
20	0.9388	0.0027	0.9332	0.0031	0.9353	0.0022	0.9981	0.0019	1.0945	0.9923	0.9885	0.9835	0.2519	0.8385	0.9360	0.0021
21	0.9371	0.0027	0.9337	0.0030	0.9355	0.0021	0.9983	0.0019	1.0975	0.9924	0.9884	0.9834	0.2596	0.8330	0.9359	0.0020
22	0.9367	0.0026	0.9335	0.0029	0.9351	0.0021	0.9985	0.0019	1.0984	0.9923	0.9885	0.9834	0.2565	0.8360	0.9355	0.0020
23	0.9371	0.0026	0.9339	0.0029	0.9361	0.0020	0.9981	0.0018	1.0977	0.9923	0.9883	0.9834	0.2540	0.8379	0.9364	0.0019
24	0.9365	0.0025	0.9336	0.0028	0.9359	0.0020	0.9979	0.0018	1.0968	0.9923	0.9883	0.9833	0.2571	0.8341	0.9361	0.0019
25	0.9361	0.0025	0.9335	0.0027	0.9361	0.0020	0.9976	0.0018	1.1003	0.9921	0.9884	0.9834	0.2581	0.8358	0.9361	0.0019
26	0.9367	0.0024	0.9344	0.0027	0.9367	0.0019	0.9979	0.0017	1.1040	0.9924	0.9885	0.9835	0.2582	0.8412	0.9367	0.0018
27	0.9368	0.0024	0.9341	0.0026	0.9370	0.0019	0.9974	0.0017	1.1046	0.9924	0.9886	0.9836	0.2566	0.8425	0.9370	0.0018
28	0.9374	0.0023	0.9346	0.0026	0.9377	0.0018	0.9973	0.0016	1.1082	0.9925	0.9886	0.9836	0.2561	0.8457	0.9377	0.0018
29	0.9381	0.0023	0.9351	0.0025	0.9375	0.0018	0.9978	0.0016	1.1057	0.9925	0.9885	0.9837	0.2517	0.8488	0.9377	0.0017
30	0.9375	0.0022	0.9348	0.0025	0.9372	0.0018	0.9978	0.0016	1.1022	0.9925	0.9884	0.9836	0.2510	0.8457	0.9373	0.0017
31	0.9368	0.0022	0.9348	0.0025	0.9369	0.0017	0.9980	0.0016	1.1036	0.9925	0.9884	0.9835	0.2540	0.8438	0.9369	0.0017
32	0.9369	0.0022	0.9346	0.0024	0.9367	0.0017	0.9982	0.0016	1.0981	0.9925	0.9884	0.9836	0.2557	0.8371	0.9367	0.0016
33	0.9363	0.0021	0.9348	0.0024	0.9366	0.0017	0.9983	0.0015	1.0994	0.9925	0.9884	0.9836	0.2573	0.8364	0.9366	0.0016
34	0.9366	0.0021	0.9350	0.0023	0.9367	0.0017	0.9984	0.0015	1.1056	0.9925	0.9885	0.9837	0.2584	0.8422	0.9367	0.0016
35	0.9366	0.0021	0.9350	0.0023	0.9367	0.0016	0.9985	0.0015	1.1061	0.9925	0.9885	0.9836	0.2573	0.8431	0.9367	0.0016
36	0.9370	0.0020	0.9350	0.0023	0.9366	0.0016	0.9986	0.0015	1.1056	0.9925	0.9885	0.9836	0.2543	0.8456	0.9367	0.0015
37	0.9369	0.0020	0.9348	0.0022	0.9367	0.0016	0.9982	0.0014	1.1024	0.9925	0.9884	0.9836	0.2519	0.8450	0.9368	0.0015
38	0.9371	0.0020	0.9349	0.0022	0.9370	0.0016	0.9981	0.0014	1.0993	0.9925	0.9885	0.9837	0.2524	0.8416	0.9371	0.0015
39	0.9374	0.0020	0.9345	0.0022	0.9369	0.0016	0.9978	0.0014	1.0984	0.9925	0.9884	0.9837	0.2472	0.8441	0.9371	0.0015
40	0.9375	0.0019	0.9344	0.0022	0.9368	0.0015	0.9979	0.0014	1.0960	0.9925	0.9884	0.9836	0.2454	0.8442	0.9370	0.0015
41	0.9374	0.0019	0.9343	0.0021	0.9367	0.0015	0.9978	0.0014	1.0975	0.9925	0.9883	0.9835	0.2451	0.8454	0.9369	0.0015

INDIVIDUAL SAMPLE ESTIMATORS FOR EACH STAGE

STAGE	K(COLL)	STD	K(SCORE)	STD	K(BRISS)	STD	A	STD	K(THREE)	STD

1	0.9252	0.0136	0.9286	0.0[illegible]	0.9261	0.0097	1.0023	0.00[illegible]	0.9259	0.0095	
2	0.9586	0.0109	0.9201	0.0[illegible]	0.9314	0.0092	0.9897	0.00[illegible]	0.9355	0.0090	
3	0.9191	0.0123	0.9387	0.0148	0.9425	0.0097	0.9969	0.0090	0.9419	0.0094	
4	0.9174	0.0140	0.9378	0.0139	0.9419	0.0101	0.9961	0.0090	0.9408	0.0100	
5	0.9423	0.0125	0.9670	0.0130	0.9507	0.0082	1.0146	0.0088	0.9469	0.0073	
6	0.9489	0.0127	0.9190	0.0135	0.9304	0.0105	0.9882	0.0088	0.9336	0.0103	
7	0.9215	0.0118	0.9400	0.0132	0.9452	0.0101	0.9949	0.0083	0.9350	0.0092	
8	0.9138	0.0118	0.9430	0.0154	0.9347	0.0101	1.0074	0.0103	0.9241	0.0085	
9	0.9574	0.0106	0.9297	0.0117	0.9343	0.0089	0.9953	0.0078	0.9379	0.0088	
10	0.9462	0.0114	0.9085	0.0142	0.9291	0.0096	0.9832	0.0086	0.9307	0.0095	
11	0.9315	0.0125	0.9176	0.0141	0.9314	0.0106	0.9867	0.0090	0.9313	0.0102	
12	0.9273	0.0133	0.9336	0.0155	0.9296	0.0117	1.0037	0.0091	0.9283	0.0107	
13	0.9133	0.0122	0.9273	0.0149	0.9264	0.0098	1.0008	0.0091	0.9282	0.0093	
14	0.9454	0.0121	0.9360	0.0130	0.9271	0.0093	1.0083	0.0085	0.9306	0.0090	
15	0.9301	0.0129	0.9341	0.0131	0.9362	0.0100	0.9980	0.0080	0.9347	0.0097	
16	0.9336	0.0105	0.9325	0.0123	0.9300	0.0089	1.0025	0.0084	0.9314	0.0081	
17	0.9406	0.0131	0.9409	0.0135	0.9340	0.0099	1.0062	0.0082	0.9354	0.0096	
18	0.9301	0.0110	0.9308	0.0133	0.9325	0.0099	0.9984	0.0084	0.9315	0.0089	
19	0.9456	0.0133	0.9468	0.0130	0.9475	0.0090	0.9993	0.0087	0.9472	0.0088	
20	0.9393	0.0125	0.9377	0.0138	0.9452	0.0104	0.9929	0.0086	0.9437	0.0101	
21	0.9148	0.0124	0.9438	0.0149	0.9395	0.0102	1.0037	0.0094	0.9282	0.0089	
22	0.9277	0.0125	0.9289	0.0135	0.9260	0.0089	1.0026	0.0092	0.9263	0.0086	
23	0.9458	0.0122	0.9431	0.0135	0.9557	0.0095	0.9884	0.0088	0.9539	0.009[illegible]	
24	0.9221	0.0117	0.9247	0.0138	0.9308	0.0098	0.9944	0.0090	0.9279	0.0091	
25	0.9251	0.0127	0.9314	0.014[illegible]	[illegible]9428	0.0103	0.9904	0.0089	0.9380	0.0099	
26	0.9507	0.0117	0.9557	0.0136	[illegible].9510	0.0089	1.0041	0.0088	0.9506	0.0084	
27	0.9412	0.0115	0.9273	0.0131	0.9437	0.0097	0.9853	0.0079	0.9432	0.0095	
28	0.9504	0.0126	0.9484	0.0140	0.9559	0.0098	0.9937	0.0085	0.9547	0.0094	
29	0.9557	0.0121	0.9461	0.0125	0.9330	0.0085	1.0126	0.0087	0.9367	0.0083	
30	0.9192	0.0127	0.9247	0.0141	0.9280	0.0097	0.9967	0.0101	0.9259	0.0093	
31	0.9137	0.0118	0.9352	0.0139	0.9287	0.0092	1.0056	0.0090	0.9229	0.0084	
32	0.9389	0.0113	0.9298	0.0127	0.9284	0.0098	1.0016	0.0087	0.9316	0.0093	
33	0.9176	0.0123	0.9397	0.0137	0.9347	0.0089	1.0044	0.0091	0.9291	0.0082	
34	0.9452	0.0117	0.9425	0.0142	0.9399	0.0094	1.0021	0.0081	0.9413	0.0089	
35	0.9383	0.0130	0.9339	0.0147	0.9352	0.0097	0.9988	0.0099	0.9359	0.0093	
36	0.9478	0.0121	0.9354	0.0125	0.9318	0.0087	1.0033	0.0083	0.9342	0.0085	
37	0.9355	0.0126	0.9263	0.0128	0.9412	0.0095	0.9848	0.0087	0.9402	0.0093	
38	0.9431	0.0132	0.9411	0.0140	0.9471	0.0112	0.9937	0.0086	0.9461	0.0108	
39	0.9482	0.0122	0.9207	0.0124	0.9338	0.0090	0.9873	0.0081	0.9348	0.0090	
40	0.9427	0.0142	0.9313	0.0137	0.9312	0.0103	1.0001	0.0090	0.9334	0.0100	
41	0.9431	0.0121	0.9285	0.0153	0.9344	0.0095	0.9949	0.0105	0.9341	0.0092	

NO. OF SETTLING SCORING STAGES	SAMPLE	CUMULATIVE K(COLL)	STD	INDIVIDUAL K(SCORE)	STD	SAMPLE K(BRISS)	STD	ESTIMATORS A	STD	VARYING LAMBDA	NO. OF R(S,A)	SETTLING R(C,A)	STAGES R(C,S)	ALPHA	BETA	K(THREE)	STD
42	9729	0.9331	0.0121	0.9285	0.0153	0.9344	0.0095	0.9949	0.0105	1.1397	0.9921	0.9857	0.9790	0.2301	0.8850	0.9341	0.009
41	19358	0.9379	0.0094	0.9299	0.0103	0.9326	0.0070	0.9975	0.0069	1.0833	0.9921	0.9860	0.9806	0.2070	0.8689	0.9338	0.006
40	30140	0.9416	0.0074	0.9266	0.0080	0.9332	0.0056	0.9938	0.0053	1.0729	0.9923	0.9863	0.9811	0.1648	0.8883	0.9345	0.005
39	39741	0.9420	0.0065	0.9301	0.0069	0.9366	0.0050	0.9938	0.0045	1.0520	0.9920	0.9874	0.9826	0.1892	0.8462	0.9376	0.004
38	49654	0.9407	0.0058	0.9293	0.0061	0.9376	0.0045	0.9920	0.0040	1.0383	0.9923	0.9876	0.9830	0.1846	0.8402	0.9381	0.004
37	59758	0.9419	0.0052	0.9304	0.0055	0.9367	0.0040	0.9939	0.0036	1.0458	0.9923	0.9877	0.9832	0.1794	0.8541	0.9376	0.003
36	69555	0.9414	0.0048	0.9309	0.0052	0.9365	0.0037	0.9946	0.0034	1.0582	0.9923	0.9876	0.9829	0.1868	0.8579	0.9374	0.003
35	80345	0.9419	0.0045	0.9324	0.0049	0.9372	0.0034	0.9956	0.0032	1.0891	0.9923	0.9882	0.9833	0.1990	0.8792	0.9382	0.003
34	89520	0.9394	0.0042	0.9332	0.0046	0.9370	0.0032	0.9965	0.0030	1.0950	0.9924	0.9881	0.9832	0.2095	0.8736	0.9375	0.003
33	99610	0.9393	0.0039	0.9328	0.0043	0.9360	0.0031	0.9970	0.0028	1.0785	0.9924	0.9882	0.9835	0.2184	0.8498	0.9368	0.003
32	108720	0.9372	0.0038	0.9330	0.0041	0.9355	0.0029	0.9978	0.0027	1.0843	0.9924	0.9881	0.9831	0.2290	0.8445	0.9359	0.002
31	117900	0.9358	0.0036	0.9324	0.0040	0.9349	0.0028	0.9977	0.0026	1.0776	0.9924	0.9879	0.9831	0.2289	0.8377	0.9351	0.002

30	129078	0.9375	0.0035	0.9336	0.0038	0.9347	0.0026	0.9990	0.0025	1.0753	0.9925	0.9878	0.9833	0.2219	0.8452	0.935
29	139699	0.9385	0.0033	0.9347	0.0036	[illegible] 363	0.0026	0.9986	0.0024	1.0843	0.9925	0 79	0 9833	0.2243	0.8506	0.9368 0.002
28	325	0.9387	0.0032	0.9342	0.0035	[illegible]	0025	0.9976	0.0023	1.0865	0.9926	0. 81	835	0.2235	0.8526	0.9372 0.002
27	150825	0.9395	0.0031	0.9356	0.0034	0.9377	0.0024	0.9981	0.0022	1.0933	0.9927	0.9883	0.9837	0.2259	0.8595	0.9381 0.002
26	170186	0.9387	0.0030	0.9354	0.0033	0.9380	0.0023	0.9976	0.0022	1.0984	0.9926	0.9883	0.9837	0.2286	0.8610	0.9382 0.002
25	179606	0.9378	0.0029	0.9348	0.0032	0.9376	0.0023	0.9975	0.0021	1.0972	0.9926	0.9883	0.9837	0.2337	0.8550	0.9377 0.002
24	190566	0.9383	0.0028	0.9353	0.0031	0.9386	0.0022	0.9969	0.0020	1.0965	0.9926	0.9882	0.9837	0.2318	0.8564	0.9386 0.002
23	200131	0.9378	0.0028	0.9350	0.0031	0.9380	0.0021	0.9972	0.0020	1.0975	0.9927	0.9882	0.9836	0.2297	0.8588	0.9380 0.002
22	208854	0.9368	0.0027	0.9353	0.0030	0.9381	0.0021	0.9975	0.0019	1.1002	0.9926	0.9881	0.9835	0.2384	0.8522	0.9378 0.002
21	218992	0.9369	0.0026	0.9354	0.0029	0.9384	0.0021	0.9973	0.0019	1.0985	0.9926	0.9882	0.9836	0.2382	0.8499	0.9381 0.002
20	228992	0.9373	0.0026	0.9359	0.0029	0.9388	0.0020	0.9974	0.0019	1.0981	0.9927	0.9882	0.9836	0.2347	0.8551	0.9385 0.001
19	239058	0.9370	0.0025	0.9357	0.0028	0.9386	0.0020	0.9974	0.0018	1.0960	0.9926	0.9883	0.9837	0.2415	0.8465	0.9382 0.001
18	249006	0.9371	0.0025	0.9359	0.0027	0.9384	0.0019	0.9978	0.0018	1.0968	0.9926	0.9883	0.9837	0.2406	0.8480	0.9381 0.001
17	259459	0.9370	0.0024	0.9358	0.0027	0.9380	0.0019	0.9979	0.0017	1.0937	0.9926	0.9882	0.9836	0.2453	0.8396	0.9378 0.001
16	269107	0.9367	0.0024	0.9357	0.0026	0.9380	0.0019	0.9980	0.0017	1.0926	0.9926	0.9882	0.9836	0.2453	0.8385	0.9377 0.001
15	279806	0.9371	0.0023	0.9357	0.0026	0.9375	0.0018	0.9983	0.0017	1.0918	0.9926	0.9883	0.9837	0.2434	0.8402	0.9375 0.001
14	289908	0.9369	0.0023	0.9355	0.0025	0.9372	0.0018	0.9984	0.0016	1.0968	0.9926	0.9883	0.9837	0.2443	0.8448	0.9371 0.001
13	299186	0.9366	0.0023	0.9354	0.0025	0.9369	0.0018	0.9986	0.0016	1.0968	0.9926	0.9884	0.9838	0.2493	0 3411	0.9369 0.001
12	308840	0.9365	0.0022	0.9348	0.0025	0.9368	0.0017	0.9982	0.0016	1.0955	0.9925	0.9884	0.9837	0.2490	0.8397	0.9367 0.001
11	319350	0.9368	0.0022	0.9340	0.0024	0.9365	0.0017	0.9977	0.0016	1.1007	0.9925	0.9885	0.9837	0.2443	0.8490	0.9366 0.001
10	330867	0.9375	0.0021	0.9338	0.0024	0.9364	0.0017	0.9976	0.0015	1.0968	0.9925	0.9885	0.9838	0.2415	0.8483	0.9367 0.001
9	339778	0.9369	0.0021	0.9341	0.0023	0.9364	0.0017	0.9979	0.0015	1.0978	0.9925	0.9884	0.9836	0.2478	0.8430	0.9365 0.001
8	349317	0.9365	0.0021	0.9342	0.0023	0.9366	0.0016	0.9978	0.0015	1.0957	0.9925	0.9884	0.9836	0.2520	0.8365	0.9366 0.001
7	359358	0.9368	0.0020	0.9338	0.0023	0.9365	0.0016	0.9976	0.0015	1.0922	0.9924	0.9883	0.9836	0.2496	0.8356	0.9366 0.001
6	369442	0.9370	0.0020	0.9347	0.0022	0.9369	0.0016	0.9980	0.0014	1.0944	0.9925	0.9884	0.9836	0.2509	0.8376	0.9369 0.001
5	378604	0.9370	0.0020	0.9348	0.0022	0.9370	0.0016	0.9980	0.0014	1.0931	0.9925	0.9883	0.9836	0 2500	0.8366	0.9370 0.001
4	388477	0.9370	0.0020	0.9349	0.0022	0.9371	0.0016	0.9979	0.0014	1.0969	0.9925	0.9884	0.9836	0.2 97	0.8409	0.9372 0.001
3	400579	0.9377	0.0019	0.9344	0.0022	0.9370	0.0015	0.9977	0.0014	1.0970	0.9925	0.9884	0.9835	0.2463	0.8440	0.9372 0.001
2	409729	0.9374	0.0019	0.9343	0.0021	0.9367	0.0015	0.9978	0.0014	1.0975	0.9925	0.9883	0.9835	0.2451	0.8454	0.9369 0.001
1	421912	0.9376	0.0019	0.9341	0.0021	0.9364	0.0015	0.9979	0.0014	1.1014	0.9925	0.9884	0.9835	0.2470	0.8473	0.9367 0.001
0	428914	0.9371	0.0019	0.9336	0.0021	0.9360	0.0015	0.9978	0.0013	1.1013	0.9925	0.9884	0.9835	0.2465	0.8476	0.9363 0.001

1

```
**********************************************************************************
**********************************************************************************
**..............................................................................**
**.......                                                              .......**
**.......     FINAL VALUE OF K(THREE)  =  0.9369    ( ST.DEV.  = 0.0015 )     .......**
**.......                                                              .......**
**..............................................................................**
**********************************************************************************
**********************************************************************************
```

AFTER 41 STAGES THE STANDARD DEVIATION ON [redacted] HREF HAS FALLEN BELOW THE REQUESTED VALU OF 0.0015 FOR THREE CONSECUTIVE STAGES
THIS WAS ACHIEVED IN 460.24 MINUTES

A DUMP FILE FOR USE IN A RESTART RUN WILL BE WRITTEN TO THE DATA SET ALLOCATED TO UNIT 7

THE FINAL RANDOM NUMBER IS 1981236573

1SOURCE DISTRIBUTION AS SAMPLED BY REGION
****

REGION	FIXED SOURCE	ST.DEV.
1	1000	32
2	0	0
3	0	0
4	1000	32
5	1000	32
6	0	0
7	0	0

TOTAL WT. OF NEUTRONS STARTED FROM FIXED SOURCE = 1000 TOTAL SOURCE WT. = 409729

N.B. FIXED SOURCE MEANS THE IMPOSED SOURCE FOR A FIXSOURCE RUN
AND THE USER SUPPLIED STARTING SOURCE FOR A FISSION TRACKING RUN.

THE FOLLOWING TABLES ARE BY DEFAULT NORMALISED TO 10,000 SOURCE NEUTRONS.
FOR A FIXSOURCE RUN THESE SOURCE NEUTRONS ARE NEUTRONS STARTED FROM THE FIXED SOURCE,
AND FOR A FISSION TRACKING RUN IT IS THE TOTAL WT. OF NEUTRONS TRACKED IN THE SCORING STAGES.

1BOUNDARY CROSSINGS FOR STAGES 1 TO 41 NORMALISED TO 10,000 SOURCE NEUTRONS
****

			IN	ST.DEV.	OUT	ST.DEV.	OUT/IN
PART 1	REGION (ABS)	1 (1)	7910	23	10873	24	1.3746
+ (NEST)							
		2 (2)	7937	23	10868	24	1.3745
		3 (3)	8316	26	9525	25	1.1453
PART 2	REGION (ABS)		IN	ST.DEV.	OUT	ST.DEV.	OUT/IN
		1 (4)	782	6	1991	11	2.5455
+ (ARRAY)							
PART 3	REGION (ABS)		IN	ST.DEV.	OUT	ST.DEV.	OUT/IN
		1 (5)	782	6	1991	11	2.5455
+ (NEST)							
		2 (6)	984	7	1791	10	1.8203
		3 (7)	0	0	9	0	0.0000

DISTRIBUTION OF NEUTRONS REACHING THE OUTER BOUNDARY OF THE SYSTEM

PARTITION	NO.	ST.DEV.
[redacted]	5	0
	1	0
3	3	0

MATERIAL ACTION COUNTS FOR STAGES 1 TO 41 NORMALISED TO 10,000 SOURCE NEUTRONS

* MATERIAL 1 *

NUCLIDE	CAPTURE	FISSION	FISSION CHILDREN	ELASTIC	(N,N*)	(N,2N)	(N,3N)
PARTITION 1 ..... FROM 100.0000 KEV TO 15.0000 MEV							
U235	6	54	139	231	46	0	0
.....ST.DEV.	0	1	3	2	1	0	0
U238	147	289	806	8586	2687	15	0
.....ST.DEV.	2	3	7	19	8	1	0
O	12	--	--	8911	6	--	--
.....ST.DEV.	1	--	--	20	0	--	--

NEUTRON GAIN = 453

PARTITION 2 ..... FROM 0.4000 EV TO 100.0000 KEV							
U235	287	651	1583	340	0	0	0
.....ST.DEV.	3	4	9	3	0	0	0
U238	1452	0	0	13058	18	0	0
.....ST.DEV.	6	0	0	27	1	0	0
O	0	--	--	8399	0	--	--
.....ST.DEV.	0	--	--	19	0	--	--

NEUTRON GAIN = -807

PARTITION 3 ..... FROM 0.6000 EV TO 0.4000 EV							
U235	487	2818	6846	121	0	0	0
.....ST.DEV.	3	7	17	2	0	0	0
U238	435	0	0	2245	0	0	0
.....ST.DEV.	3	0	0	10	0	0	0
O	0	--	--	2010	0	--	--
.....ST.DEV.	0	--	--	9	0	--	--

EUTRON GAIN = 3107

****
* MATERIAL 2 *
****

NUCLIDE	CAPTURE	FISSION	FISSION CHILDREN	ELASTIC	(N,N*)	(N,2N)	(N,3N)
PARTITION 1 ..... FROM 100.0000 KEV TO 15.0000 MEV							
ZR	4	--	--	4405	245	0	--
.....ST.DEV.	0	--	--	12	2	0	--

NEUTRON GAIN = -4

PARTITION 2 ..... FROM 0.4000 EV TO 100.0000 KEV							
ZR	25	--	--	4231	0	0	--
.....ST.DEV.	1	--	--	12	0	0	--

NEUTRON GAIN = -25

PARTITION 3 ..... FROM 0.0000 EV TO 0.4000 EV							
ZR	15	--	--	868	0	0	--
.....ST.DEV.	1	--	--	5	0	0	--

NEUTRON GAIN = -15

****
* MATERIAL 3 *
****

NUCLIDE	CAPTURE	FISSION	FISSION CHILDREN	ELASTIC	(N,N*)	(N,2N)	(N,3N)
PARTITION 1 ..... FROM 100.0000 KEV TO 15.0000 MEV							
FE	4	--	--	1355	179	0	--
.....ST.DEV.	0	--	--	8	2	0	--

CR	0	-	--	447	[illegible]	0	--
.....ST.DEV.	0		--	4		0	--
NI	4	--	--	265	20	0	--
.....ST.DEV.	0	--	--	3	1	0	--
B10	3	--	--	12	0	--	--
.....ST.DEV.	0	--	--	1	0	--	--
B11	0	--	--	52	0	--	--
.....ST.DEV.	0	--	--	1	0	--	--

NEUTRON GAIN = -11

PARTITION 2 ..... FROM 0.4000 EV TO 100.0000 KEV

FE	43	--	--	4891	0	0	--
.....ST.DEV.	1	--	--	21	0	0	--
CR	15	--	--	861	0	0	--
.....ST.DEV.	1	--	--	5	0	0	--
NI	11	--	--	1237	0	0	--
.....ST.DEV.	1	--	--	7	0	0	--
B10	523	--	--	11	0	--	--
.....ST.DEV.	3	--	--	1	0	--	--
B11	0	--	--	92	0	--	--
.....ST.DEV.	0	--	--	2	0	--	--

NEUTRON GAIN = -592

PARTITION 3 ..... FROM 0.0000 EV TO 0.4000 EV

FE	109	--	--	803	0	0	--
.....ST.DEV.	2	--	--	6	0	0	--
CR	36	--	--	81	0	0	--
.....ST.DEV.	1	--	--	1	0	0	--
NI	26	--	--	164	0	0	--
.....ST.DEV.	1	--	--	2	0	0	--
B10	1381	--	--	2	0	--	--
.....ST.DEV.	5	--	--	0	0	--	--
B11	0	--	--	12	0	--	--
.....ST.DEV.	0	--	--	1	0	--	--

NEUTRON GAIN = -1551

****
* MATERIAL 4 *
****

NUCLIDE	CAPTURE	FISSION	FISSION CHILDREN	ELASTIC	(N,N*)	(N,2N)	(N,3N)
PARTITION 1 ..... FROM 100.0000 KEV TO 15.0000 MEV							
O	12	--	--	8410	6	--	--
.....ST.DEV.	1	--	--	17	0	--	--
HINH2O	0	--	--	28404	--	--	--
.....ST.DEV.	0	--	--	26	--	--	--
NEUTRON GAIN = -13							
PARTITION 2 ..... FROM 0.4000 EV TO 100.0000 KEV							
O	0	--	--	9659	0	--	--
.....ST.DEV.	0	--	--	17	0	--	--
HINH2O	56	--	--	102251	--	--	--
.....ST.DEV.	1	--	--	74	--	--	--
NEUTRON GAIN = -56							
PARTITION 3 ..... FROM 0.0000 EV TO 0.4000 EV							
O	0	--	--	8078	0	--	--
.....ST.DEV.	0	--	--	43	0	--	--
HINH2O	1100	--	--	175512	--	--	--
.....ST.DEV.	6	--	--	929	--	--	--

NEUTRON GAIN = -1101

1REGION ACTION COUNTS FOR STAGES 1 TO 41 NORMALISED TO 10,000 SOURCE NEUTRONS

REGION NO.	CAPTURE	ST.DEV.	FISSION	ST.DEV.	CHILDREN	ST.DEV.	SCATTER	ST.DEV.
1	3241	7	3811	8	9374	19	241477	271
2	2	0	0	0	0	0	454	77
3	1753	6	0	0	0	0	9109	32
4	4996	8	3811	8	9374	19	251040	289
5	4996	8	3811	8	9374	19	251040	289
6	402	3	0	0	0	0	1361	11
7	798	5	0	0	0	0	146810	1067

1NEUTRON FLUXES FOR STAGES 1 TO 41 NORMALISED TO 10,000 SOURCE NEUTRONS

N.B. FOR REGIONS WHICH OVERLAP THE FLUX PRINTED BELOW IS THE TOTAL FLUX AND NOT THE FLUX PER UNIT VOLUME.
REGIONS CONTAINING SUBSIDIARY PARTS OR WITH ZERO FLUXES ARE NOT PRINTED.

GROUP	ENERGY RANGE	REGION 1	REGION 2	REGION 3	REGION 6	REGION 7
1	100.000KEV - 15.000MEV	6.479E-01	2.196E-03	3.707E-01	1.795E-02	1.363E-03
	.....ST.DEV.....	8.050E-04	4.068E-04	1.447E-03	1.474E-04	1.063E-05
2	0.400 EV -100.000KEV	5.585E-01	2.947E-03	3.755E-01	1.797E-02	1.646E-03
	.....ST.DEV.....	6.627E-04	4.381E-04	1.409E-03	1.525E-04	9.758E-06
3	0.000 EV - 0.400 EV	1.493E-01	1.102E-02	4.495E-02	3.691E-03	6.380E-03
	.....ST.DEV.....	3.706E-04	1.962E-03	2.622E-04	3.928E-05	4.885E-05
	**** TOTALS ****	1.356E+00	1.616E-02	7.911E-01	1.961E-02	9.388E-03
	**** ****					
	**** ST.DEV ****	1.261E-03	2.664E-03	2.360E-03	2.643E-04	6.279E-05

1NEUTRON PARAMETERS FOR STAGES 1 TO 41 NORMALISED TO 10,000 SOURCE NEUTRONS

MATERIAL 1

HOLE 1
HOLE 2

	ELASTIC	CAPTURE	FISSION	(N,N*)	(N,2N)	(N,3N)	TOTAL
TOTAL NO. OF EVENTS	43901	2826	3811	2756	15	0	53309
MEAN ENERGY OF NEUTRONS CAUSING EVENTS (MEV)	4.36474E-01	6.80858E-02	2.51368E-01	1.70771E+00	8.24131E+00	1.33975E+01	4.71688E-01

MATERIAL 2

HOLE 1
HOLE 2

	ELASTIC	CAPTURE	FISSION	(N,N*)	(N,2N)	(N,3N)	TOTAL
TOTAL NO. OF EVENTS	9504	45	0	245	0	0	9794
MEAN ENERGY OF NEUTRONS CAUSING EVENTS (MEV)	4.33737E-01	1.75978E-01	0.00000E+00	1.39578E+00	1.19093E+01	0.00000E+00	5.06887E-01

MATERIAL 3

REGION 3
REGION 6

	ELASTIC	CAPTURE	FISSION	(N,N*)	(N,2N)	(N,3N)	TOTAL
TOTAL NO. OF EVENTS	10224	2154	0	246	0	0	12625
MEAN ENERGY OF NEUTRONS CAUSING EVENTS (MEV)	2.59054E-01	1.46862E-02	0.00000E+00	3.03160E+00	1.03724E+01	0.00000E+00	2.71474E-01

MATERIAL 4

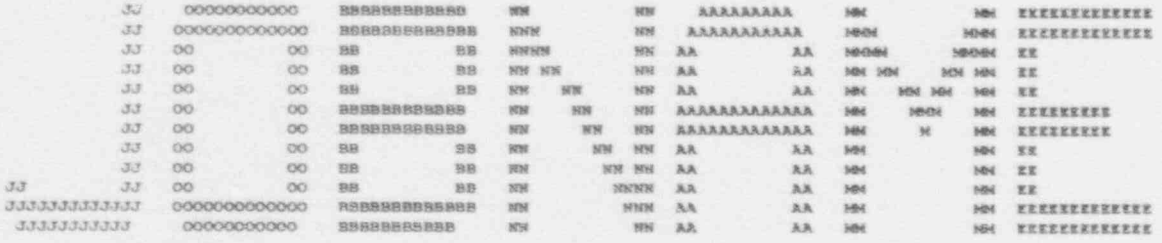
REGION 2
REGION 7
HOLE 1

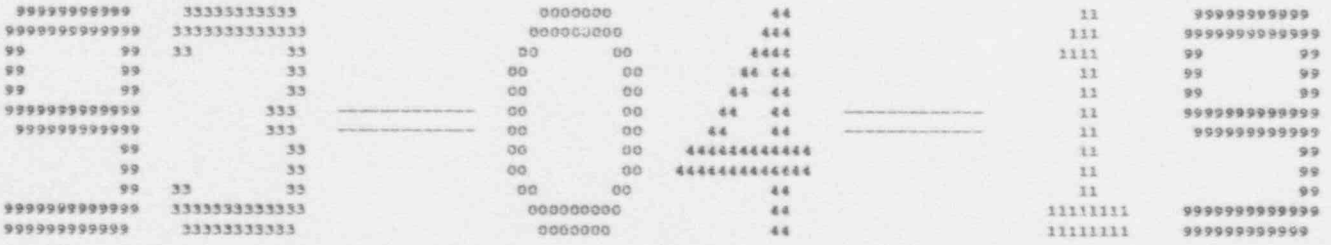
	ELASTIC	CAPTURE	FISSION	(N,N*)	(N,2N)	(N,3N)	TOTAL
TOTAL NO. OF EVENTS	332315	1170	0	6	0	0	333491
MEAN ENERGY OF NEUTRONS CAUSING EVENTS (MEV)	1.00253E-01	5.93815E-02	0.00000E+00	8.95752E+00	0.00000E+00	0.00000E+00	1.00271E-01

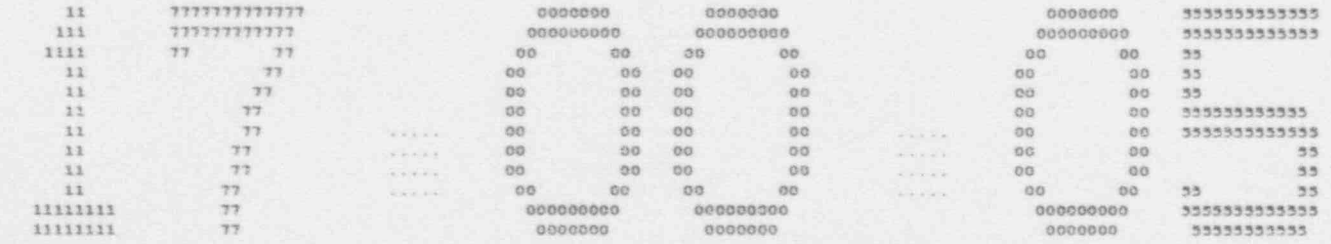
1PLOT OF CUMULATIVE MEAN K(THREE) AGAINST STAGE NUMBER

```
     30                                    I-X-I
 31                                  I-X-I                                      I
 32                                  I-X-I                                      I
 33                                  I-X-I                                      I
 34                                  I-X-I                                      I
 35                                  I-X-I                                      I
 36                                  I-X-I                                      I
 37                                  I-X-I                                      I
 38                                  I-X-I                                      I
 39                                   IXI                                       I
 40                                   IXI                                       I
 41                                   IXI                                       I

               FINAL VALUE OF K(THREE)  = 0.9369   ( ST.DEV.  =0.0015 )

*** WARNING *** ERROR WHILE OPENING FILE - /usr1/qeset/codes/sunOs4/monitor/MONITOR.FILES    ON UNIT -  82

THE I/O STATUS CODE WAS RETURNED WITH THE VALUE -        118
```


XX XX XXXXXXXXXXXXX NN NN OOOOOOOOOOO VV VV AAAAAAAAA MM MM
XX XX XXXXXXXXXXXXX NNN NN OOOOOOOOOOOOO VV VV AAAAAAAAAAA MM MM
XX XX XX NNNN NN OO OO VV VV AA AA MM MM
XX XX XX NN NN NN OO OO VV VV AA AA MM MM
XX XX XX NN NN NN OO OO VV VV AA AA MM MM
XXXXXXXX XXXXXXXXX NN NN NN OO OO VV VV AAAAAAAAAAAAA MM M MM
XXXXXXXX XXXXXXXXX NN NN NN OO OO VV VV AAAAAAAAAAAAA MM MMM MM
XX XX XX NN NN NN OO OO VV VV AA AA MM MM MM MM
XX XX XX NN NN NN OO OO VV VV AA AA MM MM MM MM
XX XX XX NN NNNN OO OO VV VV AA AA MMMM MMMM
XX XX XXXXXX XXXXXX NN NNN OOOOOOOOOOOO VVV AA AA MMM MMM
XX XX XXXXXXXXXXXXX NN NN OOOOOOOOOO V AA AA MM MM


JJ OOOOOOOOOO BBBBBBBBBBB NN NN AAAAAAAAA MM MM EEEEEEEEEEEEE
JJ OOOOOOOOOOO BBBBBBBBBBBB NNN NN AAAAAAAAAAA MMM MMM EEEEEEEEEEEEE
JJ OO OO BB BB NNN NN AA AA MMMM MMMM EE
JJ OO OO BB BB NN NN NN AA AA MM MM MM MM EE
JJ OO OO BB BB NN NN NN AA AA MM MM MM MM EE
JJ OO OO BBBBBBBBBB NN NN NN AAAAAAAAAAA MM MM EEEEEEEE
JJ OO OO BBBBBBBBBB NN NN NN AAAAAAAAAAA MM M MM EEEEEEEE
JJ OO OO BB BB NN NN NN AA AA MM MM EE
JJ OO OO BB BB NN NN NN AA AA MM MM EE
JJ JJ OO OO BB BB NN NNN AA AA MM MM EE
JJJJJJJJJJJJ OOOOOOOOOOO BBBBBBBBBBB NN NNN AA AA MM MM EEEEEEEEEEEEE
JJJJJJJJJJ OOOOOOOOOO BBBBBBBBBB NN NN AA AA MM MM EEEEEEEEEEEEE


999999999999 333333333333 OOOOOOO 44 11 999999999999
99999999999999 33333333333333 OOOOOOOOO 444 111 99999999999999
99 99 33 33 OO OO 4444 1111 99 99
99 99 33 OO OO 44 44 11 99 99
99 99 33 OO OO 44 44 11 99 99
99999999999999 333 OO OO 44 44 11 99999999999999
99999999999999 333 OO OO 44 44 11 999999999999
99 33 OO OO 4444444444444 11 99
99 33 OO OO 4444444444444 11 99
99 33 33 OO OO 44 11 99
99999999999999 33333333333333 OOOOOOOOO 44 11111111 99999999999999
999999999999 333333333333 OOOOOOO 44 11111111 999999999999


11 77777777777777 OOOOOOO OOOOOOO OOOOOOO 555555555555
111 77777777777 OOOOOOOOO OOOOOOOOO OOOOOOOOO 555555555555
1111 77 77 OO OO OO OO OO OO 55
11 77 OO OO OO OO OO OO 55
11 77 OO OO OO OO OO OO 55
11 77 OO OO OO OO OO OO 555555555555
11 77 OO OO OO OO OO OO 555555555555
11 77 OO OO OO OO OO OO 55
11 77 OO OO OO OO OO OO 55
11 77 OO OO OO OO OO OO 55 55
11111111 77 OOOOOOOOO OOOOOOOOO OOOOOOOOO 555555555555
11111111 77 OOOOOOO OOOOOOO OOOOOOO 55555555555

PROGRAM	VER	LOAD DATE	USERNAME	ACCOUNT	NODE	RUN ID NUMBER
KENOVA-W	1.3W	88-09-07	AKZIVER	AKZIVER	RPSCV1	93-04-19 17.00.05

PROGRAM VERIFICATION INFORMATION

PROGRAM: KENOVA-W

CREATION DATE: 88-09-07

LIBRARY: AECL$SAB1:[SAB_CODES.SCALECODE]KENOVA.EXE

JOBNAME: JOBNAME

DATE OF EXECUTION: 93-04-19

TIME OF EXECUTION: 17.00.05

PWRARRAY KENO CASE COMPARISON WITH MONK6B

****** NUMERIC PARAMETERS ******

TME	MAXIMUM PROBLEM TIME (MIN)	900.00	
TBA	TIME PER GENERATION (MIN)	0.50	
GEN	NUMBER OF GENERATIONS	803	
NPG	NUMBER PER GENERATION	300	
NSK	NUMBER OF GENERATIONS TO BE SKIPPED	3	
BEG	BEGINNING GENERATION NUMBER	1	
RES	GENERATIONS BETWEEN CHECKPOINTS	0	
X1D	NUMBER OF EXTRA 1-D CROSS SECTIONS	0	
NBK	NEUTRON BANK SIZE	325	
XNB	EXTRA POSITIONS IN NEUTRON BANK	0	
NFB	FISSION BANK SIZE	300	
XFB	EXTRA POSITIONS IN FISSION BANK	0	
WTA	DEFAULT VALUE OF WEIGHT AVERAGE	0.5000	
WTH	WEIGHT HIGH FOR SPLITTING	3.0000	
WTL	WEIGHT LOW FOR RUSSIAN ROULETTE	0.3333	
RND	STARTING RANDOM NUMBER	4038	
NB8	NUMBER OF D.A. BLOCKS ON UNIT 8	200	
NL8	LENGTH OF D.A. BLOCKS ON UNIT 8	512	
ADJ	MODE OF CALCULATION	FORWARD	
	INPUT DATA WRITTEN ON RESTART UNIT	NO	
	BINARY DATA INTERFACE	YES	

PWRARRAY KENO CASE COMPARISON WITH MONK6B

****** LOGICAL PARAMETERS ******

RUN	EXECUTE PROBLEM AFTER CHECKING DATA	YES	PLT	PLOT PICTURE MAP(S)	YES	
FLX	COMPUTE FLUX	NO	FDN	COMPUTE FISSION DENSITIES	NO	
SNU	COMPUTE AVG UNIT SELF-MULTIPLICATION	NO	NUB	COMPUTE NU-BAR & AVG FISSION GROUP	NO	
MKU	COMPUTE MATRIX K-EFF BY UNIT NUMBER	NO	MKP	COMPUTE MATRIX K-EFF BY UNIT LOCATION	NO	
CKU	COMPUTE COFACTOR K-EFF BY UNIT NUMBER	NO	CKP	COMPUTE COFACTOR K-EFF BY UNIT LOCATION	NO	
FMU	PRINT FISS PROD MATRIX BY UNIT NUMBER	NO	FMP	PRINT FISS PROD MATRIX BY UNIT LOCATION	NO	
MKH	COMPUTE MATRIX K-EFF BY HOLE NUMBER	NO	MKA	COMPUTE MATRIX K-EFF BY ARRAY NUMBER	NO	
CKH	COMPUTE COFACTOR K-EFF BY HOLE NUMBER	NO	CKA	COMPUTE COFACTOR K-EFF BY ARRAY NUMBER	NO	
FMH	PRINT FISS PROD MATRIX BY HOLE NUMBER	NO	FMA	PRINT FISS PROD MATRIX BY ARRAY NUMBER	NO	
HHL	COLLECT MATRIX BY HIGHEST HOLE LEVEL	NO	HAL	COLLECT MATRIX BY HIGHEST ARRAY LEVEL	NO	
AMX	PRINT ALL MIXED CROSS SECTIONS	NO	FAP	PRINT FIS. AND ABS. BY REGION	NO	
XS1	PRINT 1-D MIXTURE X-SECTIONS	NO	PAX	PRINT X-SEC-ALBEDO CORRELATION TABLES	NO	
XS2	PRINT 2-D MIXTURE X-SECTIONS	NO	PWT	PRINT WEIGHT AVERAGE ARRAY	NO	
XAP	PRINT MIXTURE ANGLES & PROBABILITIES	NO	PGM	PRINT INPUT GEOMETRY	NO	
PKI	PRINT FISSION SPECTRUM	NO	BUG	PRINT DEBUG INFORMATION	NO	
P1D	PRINT EXTRA 1-D CROSS SECTIONS	NO	TRK	PRINT TRACKING INFORMATION	NO	

PARAMETER INPUT COMPLETED

..... 0 IO'S WERE USED READING THE PARAMETER DATA .....

********** DATA READING COMPLETED **********

DATA LIBRARY VERIFICATION INFORMATION

DEFAULT DIRECTORY : USER1:[AKEIVER]

	UNIT NUMBER	DATA SET NAME	UNIT FUNCTION
XSC	14	(UNDEFINED)	MIXED CROSS SECTIONS
ALB	79	USER1:[SCALE.LIBX]ALBEDO.BIN	INPUT ALBEDOS
WTS	80	USER1:[SCALE.LIBX]WEIGHT.BIN	INPUT WEIGHTS
SKT	16	USER1:[AKEIVER]ZZZ16	WRITE SCRATCH DATA
BIN	95	(UNDEFINED)	BINARY INPUT DATA
RST	95	(UNDEFINED)	READ RESTART DATA
LIB	4	USER1:[AKEIVER]ZZZ04	INPUT AMPX WORKING LIBRARY
	8	(UNDEFINED)	INPUT DATA DIRECT ACCESS
	9	USER1:[AKEIVER]ZZZ09	SUPER GROUPED DIRECT ACCESS
	10	(UNDEFINED)	XSEC MIXING DIRECT ACCESS

..... 0 IO'S WERE USED PREPARING INPUT DATA .....

THIS XSDRN WORKING TAPE WAS CREATED 93-04-19 AT 17.00.05
THE TITLE OF THE PARENT CASE IS AS FOLLOWS
27 NEUTRON GROUP LIBRARY
BASED ON ENDF/B VERSION 4 DATA
COMPILED FOR NRC

FWRARRAY KENO CASE COMPARISON WITH MONK6B

MIXING TABLE

NUMBER OF SCATTERING ANGLES = 2
CROSS SECTION MESSAGE THRESHOLD =3.0E-05

ENTRY	MIXTURE	NUCLIDE	DENSITY
1	1	92235	7.22222E-04
2	1	92238	2.30351E-02
3	1	8016	4.75146E-02
4	4	408016	3.33610E-02
5	2	40000	4.29091E-02
6	3	26000	5.81377E-02
7	3	24000	1.57421E-02
8	3	28000	7.74679E-05
9	3	5010	4.99157E-04
10	3	5011	2.02430E-03
11	4	1001	6.67221E-02

CROSS SECTIONS READ FROM THE AMPX WORKING LIBRARY ON UNIT 4

1001 H 1269 F, 1002 T 218 GP 032475(2)
5010 B-10 1273 218NGP 042375 P-3 293K
5011 B-11 1160 WT 1/EST 218NGP P-3 293K RE(042375)
8016 O-16 1276 218 GP 030476(7)
408016 O-16 1276 218 GP 030476(7)
24000 CR 1191 218NGP WT 1/E P-3 293K SIGP=5+4 RE(042375)
26000 FE 218GP RE 5-17-78(1)
28000 NI 1190 218NGP WT 1/E P-3 293K SIGP=5+4 RE(042375)
40000 ER(NAT) 7141 21 NGP WT FIS(0.1TO20)-1/E-MAX P-3
92235 U-235 1261 SIGP=5+4 NEWXLACS 218NGP P-3 293K(3)
92238 U-238 218GP RE 5-17-78(1)

K5-60 THE ANGULAR SCATTERING DISTRIBUTION FOR MIXTURE 4 HAS BAD MOMENTS FOR THE TRANSFER FROM GROUP 5 TO GROUP 12
1 MOMENTS WERE ACCEPTED
THE LEGENDRE EXPANSION OF THE CROSS SECTION (P0-PN) IS
4.246326E-05 3.222786E-07 -2.122832E-05 -4.833539E-07
THE MOMENTS CORRESPONDING TO THIS DISTRIBUTION ARE
7.589587E-03 5.200385E-05 6.031954E-07
THE MOMENTS CORRESPONDING TO THE GENERATED DISTRIBUTION ARE
7.589587E-03 2.500576E-01 3.320854E-03
THE LEGENDRE EXPANSION CORRESPONDING TO THESE MOMENTS IS
4.246326E-05 3.222786E-07 -5.304239E-06 -1.308822E-07

..... 0 IO'S WERE USED MIXING CROSS-SECTIONS .....

..... 0 IO'S WERE USED PREPARING THE CROSS SECTIONS .....

PWRARRAY KENO CASE COMPARISON WITH MONK6B

****** ADDITIONAL INFORMATION ******

NUMBER OF ENERGY GROUPS	27	USE LATTICE GEOMETRY	YES
NO. OF FISSION SPECTRUM SOURCE GROUP	1	GLOBAL ARRAY NUMBER	2
NO. OF SCATTERING ANGLES IN XSECS	2	NUMBER OF UNITS IN THE GLOBAL X DIR.	4
ENTRIES/NEUTRON IN THE NEUTRON BANK	21	NUMBER OF UNITS IN THE GLOBAL Y DIR.	2
ENTRIES/NEUTRON IN THE FISSION BANK	14	NUMBER OF UNITS IN THE GLOBAL Z DIR.	1
NUMBER OF MIXTURES USED	4	USE A GLOBAL REFLECTOR	YES
NUMBER OF BIAS ID'S USED	1	USE NESTED HOLES	NO
NUMBER OF DIFFERENTIAL ALBEDOS USED	0	NUMBER OF HOLES	0
TOTAL INPUT GEOMETRY REGIONS	9	MAXIMUM HOLE NESTING LEVEL	0
NUMBER OF GEOMETRY REGIONS USED	9	USE NESTED ARRAYS	YES
NUMBER OF GEOMETRY UNITS	3	NUMBER OF ARRAYS USED	2
LARGEST ARRAY NUMBER	2	MAXIMUM ARRAY NESTING LEVEL	2
+X BOUNDARY CONDITION	VAC	-X BOUNDARY CONDITION	VAC
+Y BOUNDARY CONDITION	VAC	-Y BOUNDARY CONDITION	VAC
+Z BOUNDARY CONDITION	VAC	-Z BOUNDARY CONDITION	VAC

PWRARRAY KENO CASE COMPARISON WITH MONK5B

****** SPACE AND SUPERGROUP INFORMATION ******

1000000 WORDS IS THE TOTAL SPACE AVAILABLE.

12969 WORDS WERE USED FOR NON-SUPERGROUP STORAGE.

987031 WORDS OF STORAGE ARE AVAILABLE FOR SUPERGROUPED DATA.

999854 WORDS OF STORAGE ARE AVAILABLE FOR CONSTRUCTING THE SUPERGROUPS.

986971 WORDS OF STORAGE ARE AVAILABLE TO EACH SUPERGROUP.

516 WORDS ARE NEEDED FOR THE LARGEST GROUP.

13701 WORDS OF STORAGE IS SUFFICIENT TO RUN THIS PROBLEM.

18709 WORDS OF STORAGE WILL ALLOW THE PROBLEM TO RUN WITH ONE SUPERGROUP.

19008 WORDS OF STORAGE WILL BE USED TO RUN THIS PROBLEM.

SUPERGROUP	STARTING GROUP	ENDING GROUP	XSEC LENGTH	ALBEDO LENGTH	TOTAL LENGTH
1	1	27	1069	0	5680

..... 0 IO'S WERE USED IN SUPERGROUPING .....

ARRAY NUMBER	UNITS IN X DIR.	UNITS IN Y DIR.	UNITS IN Z DIR.	NESTING LEVEL
1	17	17	1	2
2 GLOBAL	4	2	1	1

..... 0 IO'S WERE USED LOADING THE DATA .....

PWRARRAY KENO CASE COMPARISON WITH MONK6B

GEOMETRY DESCRIPTION FOR THOSE UNITS UTILIZED IN THIS PROBLEM

REGION	MEDIA NUM	BIAS ID											
----- UNIT 1 -----													
1 CYLINDER	1	1	RADIUS = 0.48000		+Z = 398.00		-Z = 2.0000	CENTERLINE IS AT	X = 0.00000E+00	Y = 0.00000E+00			
2 CYLINDER	2	1	RADIUS = 0.54000		+Z = 400.00		-Z = 0.00000E+00	CENTERLINE IS AT	X = 0.00000E+00	Y = 0.00000E+00			
3 CUBOID	4	1	+X = 0.63500	-X = -0.63500		+Y = 0.63500	-Y = -0.63500		+Z = 400.00	-Z = 0.00000E+00			
----- UNIT 2 EXTERNAL TO LATTICE 1 -----													
1 ARRAY NUMBER	1		+X = 10.795	-X = -10.795		+Y = 10.795	-Y = -10.795		+Z = 400.00	-Z = 0.00000E+00			
2 CUBOID	5	1	+X = 12.000	-X = -12.000		+Y = 12.000	-Y = -12.000		+Z = 420.00	-Z = 0.00000E+00			
3 CUBOID	3	1	+X = 12.500	-X = -12.500		+Y = 12.500	-Y = -12.500		+Z = 420.00	-Z = -2.0000			
********** GLOBAL **********													
----- UNIT 3 EXTERNAL TO LATTICE 2 -----													
1 ARRAY NUMBER	2		+X = 50.000	-X = -50.000		+Y = 25.000	-Y = -25.000		+Z = 420.00	-Z = -2.0000			
2 CUBOID	3	1	+X = 50.500	-X = -50.500		+Y = 25.500	-Y = -25.500		+Z = 420.00	-Z = -2.0000			
3 CUBOID	4	1	+X = 80.500	-X = -80.500		+Y = 55.500	-Y = -55.500		+Z = 450.00	-Z = -32.000			

```
                    PWRARRAY  KENO  CASE  COMPARISON WITH  MONK6B

              -------  UNIT ORIENTATION DESCRIPTION FOR ARRAY   1          -------

Z LAYER   1, X COLUMN   1 TO  17 LEFT TO RIGHT   Y ROW   1 TO  17  BOTTOM TO TOP

 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 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 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 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 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 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 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 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 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 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 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 1 1 1

              -------  UNIT ORIENTATION DESCRIPTION FOR ARRAY   2          -------

Z LAYER   1, X COLUMN   1 TO   4 LEFT TO RIGHT   Y ROW   1 TO   2  BOTTOM TO TOP

 2 2 2 2
 2 2 2 2
```

PWRARRAY KENO CASE COMPARISON WITH MONK6B
VOLUMES FOR THOSE UNITS UTILIZED IN THIS PROBLEM

UNIT	REGION	GEOMETRY REGION	VOLUME	CUMULATIVE VOLUME
1	1	1	2.86634E+02 CM**3	2.86634E+02 CM**3
	2	2	7.98015E+01 CM**3	3.66435E+02 CM**3
	3	3	2.78725E+02 CM**3	6.45160E+02 CM**3
SURROUNDING GEOMETRY VOLUMES -		GEOMETRY REGION	4 IS AN ARRAY PLACEMENT BOUNDARY REGION	
2	1	4	1.86451E+05 CM**3	1.86451E+05 CM**3
	2	5	5.54688E+04 CM**3	2.41920E+05 CM**3
	3	6	2.18300E+04 CM**3	2.63750E+05 CM**3
SURROUNDING GEOMETRY VOLUMES -		GEOMETRY REGION	7 IS AN ARRAY PLACEMENT BOUNDARY REGION	
3	1	7	2.11000E+06 CM**3	2.11000E+06 CM**3
	2	8	6.37220E+04 CM**3	2.17372E+06 CM**3
	3	9	6.44010E+06 CM**3	8.61382E+06 CM**3

UNIT	USES	REGION	MIXTURE	TOTAL VOLUME
1	2312	1	1	6.62698E+05 CM**3
		2	2	1.86501E+05 CM**3
		3	4	6.44411E+05 CM**3
2	8	1		1.49161E+06 CM**3
		2	4	4.43750E+05 CM**3
		3	3	1.74640E+05 CM**3
3	1	1		2.11000E+06 CM**3
		2	3	6.37220E+04 CM**3
		3	4	6.44010E+06 CM**3

TOTAL MIXTURE VOLUMES

MIXTURE	TOTAL VOLUME
1	6.62698E+05 CM**3
2	1.86501E+05 CM**3
3	2.38362E+05 CM**3
4	7.52826E+06 CM**3

****

***

*** BIASING INFORMATION ***

***

*** A DEFAULT WEIGHT OF 0.500 WILL BE USED FOR ALL BIAS ID'S. ***

***

****

..... 0 IO'S WERE USED IN KENO-V BEFORE TRACKING .....

..... 0.09817MINUTES WERE USED PROCESSING DATA. .....

VOLUME FRACTION OF FISSILE MATERIAL IN THE CORE= 0.31407E+00

START TYPE 0 WAS USED.

THE NEUTRONS WERE STARTED WITH A FLAT DISTRIBUTION IN A CUBOID DEFINED BY:

+X= 5.00000E+01 -X=-5.00000E+01 +Y= 2.50000E+01 -Y=-2.50000E+01 +Z= 4.20000E+02 -Z=-2.00000E+00

0.01217 MINUTES WERE REQUIRED FOR STARTING. TOTAL ELAPSED TIME IS 0.11033 MINUTES.

PWRARRAY KENO CASE COMPARISON WITH MONK6B

GENERATION	GENERATION K-EFFECTIVE	ELAPSED TIME MINUTES	AVERAGE K-EFFECTIVE	AVG K-EFF DEVIATION	MATRIX K-EFFECTIVE	MATRIX K-EFF DEVIATION
1	8.93873E-01	2.77667E-01	1.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
2	8.79455E-01	4.33000E-01	1.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
3	8.97690E-01	5.90167E-01	8.97690E-01	0.00000E+00	0.00000E+00	0.00000E+00
4	8.88033E-01	7.53000E-01	8.82861E-01	1.48304E-02	0.00000E+00	0.00000E+00
5	9.42253E-01	9.17833E-01	9.02659E-01	2.15695E-02	0.00000E+00	0.00000E+00
6	8.99714E-01	1.08083E+00	9.01922E-01	1.52700E-02	0.00000E+00	0.00000E+00
7	9.09771E-01	1.24600E+00	9.03492E-01	1.19330E-02	0.00000E+00	0.00000E+00
8	8.98619E-01	1.40750E+00	9.02680E-01	9.77722E-03	0.00000E+00	0.00000E+00
9	8.99137E-01	1.56000E+00	9.02174E-01	8.27801E-03	0.00000E+00	0.00000E+00
10	9.90830E-01	1.71433E+00	9.13256E-01	1.31984E-02	0.00000E+00	0.00000E+00
11	8.87133E-01	1.85617E+00	9.10353E-01	1.19939E-02	0.00000E+00	0.00000E+00
12	8.62306E-01	2.01517E+00	9.03552E-01	1.17554E-02	0.00000E+00	0.00000E+00
13	8.90501E-01	2.18333E+00	9.04183E-01	1.07205E-02	0.00000E+00	0.00000E+00
14	8.88657E-01	2.35200E+00	9.02690E-01	9.87158E-03	0.00000E+00	0.00000E+00
15	8.90122E-01	2.50733E+00	9.01908E-01	9.13300E-03	0.00000E+00	0.00000E+00
16	8.88604E-01	2.66883E+00	9.00957E-01	8.50890E-03	0.00000E+00	0.00000E+00
17	8.73173E-01	2.82300E+00	8.99105E-01	8.13474E-03	0.00000E+00	0.00000E+00
18	8.93122E-01	2.99033E+00	8.98731E-01	7.61860E-03	0.00000E+00	0.00000E+00
19	9.67042E-01	3.13850E+00	9.02749E-01	8.20690E-03	0.00000E+00	0.00000E+00
20	9.08126E-01	3.29017E+00	9.03048E-01	7.74376E-03	0.00000E+00	0.00000E+00
21	9.17846E-01	3.45300E+00	9.03827E-01	7.36637E-03	0.00000E+00	0.00000E+00
22	8.92690E-01	3.60900E+00	9.03270E-01	7.00994E-03	0.00000E+00	0.00000E+00
23	8.96224E-01	3.76133E+00	9.02934E-01	6.67648E-03	0.00000E+00	0.00000E+00
24	9.41932E-01	3.92050E+00	9.04707E-01	6.60835E-03	0.00000E+00	0.00000E+00
25	9.49455E-01	4.09417E+00	9.06652E-01	6.60740E-03	0.00000E+00	0.00000E+00
26	9.09505E-01	4.26117E+00	9.06771E-01	6.32762E-03	0.00000E+00	0.00000E+00
27	8.71152E-01	4.40917E+00	9.05347E-01	6.23396E-03	0.00000E+00	0.00000E+00
28	9.24972E-01	4.56917E+00	9.06101E-01	6.03694E-03	0.00000E+00	0.00000E+00
29	8.80369E-01	4.73333E+00	9.05148E-01	5.88631E-03	0.00000E+00	0.00000E+00
30	9.18736E-01	4.87650E+00	9.05634E-01	5.69313E-03	0.00000E+00	0.00000E+00
31	9.61348E-01	5.04517E+00	9.07555E-01	5.81982E-03	0.00000E+00	0.00000E+00
32	9.67577E-01	5.19550E+00	9.09555E-01	5.96781E-03	0.00000E+00	0.00000E+00
33	9.65053E-01	5.35050E+00	9.11346E-01	6.04299E-03	0.00000E+00	0.00000E+00
34	9.03625E-01	5.50417E+00	9.11105E-01	5.85626E-03	0.00000E+00	0.00000E+00
35	9.10462E-01	5.65900E+00	9.11085E-01	5.67594E-03	0.00000E+00	0.00000E+00
36	8.90931E-01	5.82067E+00	9.10492E-01	5.53799E-03	0.00000E+00	0.00000E+00
37	8.78156E-01	5.99483E+00	9.09568E-01	5.45642E-03	0.00000E+00	0.00000E+00
38	9.05496E-01	6.15117E+00	9.09455E-01	5.30425E-03	0.00000E+00	0.00000E+00
39	9.62054E-01	6.30550E+00	9.10877E-01	5.35117E-03	0.00000E+00	0.00000E+00
40	8.94[illegible]E-01	6.47400E+00	9.10451E-01	5.22576E-03	0.00000E+00	0.00000E+00
41	8.95332E-01	6.63750E+00	9.10043E-01	5.10657E-03	0.00000E+00	0.00000E+00
42	9.57954E-01	6.78950E+00	9.11241E-01	5.11950E-03	0.00000E+00	0.00000E+00
43	8.99512E-01	6.95083E+00	9.10955E-01	5.00086E-03	0.00000E+00	0.00000E+00
44	8.24935E-01	7.10767E+00	9.08907E-01	5.29257E-03	0.00000E+00	0.00000E+00
45	9.07223E-01	7.26400E+00	9.08868E-01	5.16817E-03	0.00000E+00	0.00000E+00
46	8.85350E-01	7.42050E+00	9.08333E-01	5.07778E-03	0.00000E+00	0.00000E+00
47	9.19397E-01	7.57733E+00	9.08579E-01	4.96971E-03	0.00000E+00	0.00000E+00
48	9.22717E-01	7.74000E+00	9.08886E-01	4.87018E-03	0.00000E+00	0.00000E+00
49	9.28905E-01	7.89983E+00	9.09312E-01	4.78443E-03	0.00000E+00	0.00000E+00
50	8.73183E-01	8.05133E+00	9.08560E-01	4.74343E-03	0.00000E+00	0.00000E+00
51	8.83633E-01	8.20033E+00	9.08031E-01	4.67348E-03	0.00000E+00	0.00000E+00
52	9.18735E-01	8.35883E+00	9.08265E-01	4.58407E-03	0.00000E+00	0.00000E+00
53	9.34612E-01	8.52383E+00	9.08781E-01	4.52300E-03	0.00000E+00	0.00000E+00
54	9.29775E-01	8.68017E+00	9.09185E-01	4.45344E-03	0.00000E+00	0.00000E+00
55	9.12656E-01	8.83667E+00	9.09250E-01	4.36916E-03	0.00000E+00	0.00000E+00
56	8.95214E-01	8.98467E+00	9.08991E-01	4.29527E-03	0.00000E+00	0.00000E+00
57	8.92907E-01	9.14650E+00	9.08698E-01	4.22668E-03	0.00000E+00	0.00000E+00
58	9.21677E-01	9.30133E+00	9.08930E-01	4.15704E-03	0.00000E+00	0.00000E+00
59	9.12337E-01	9.45817E+00	9.08990E-01	4.08382E-03	0.00000E+00	0.00000E+00
60	9.11125E-01	9.61800E+00	9.09027E-01	4.01281E-03	0.00000E+00	0.00000E+00
61	9.03946E-01	9.77467E+00	9.08940E-01	3.94525E-03	0.00000E+00	0.00000E+00

62	9.16402E-01	9.92567E+00	9.09065E-01	3.88108E-03	0.00000E+00	0.00000E+00
63	8.55937E-01	1.00787E+01	9.08194E-01	3.91476E-03	0.00000E+00	0.00000E+00
64	9.23040E-01	1.02363E+01	9.08433E-01	3.83856E-03	0.00000E+00	0.00000E+00
65	9.04026E-01	1.03918E+01	9.08363E-01	3.79768E-03	0.00000E+00	0.00000E+00
66	9.37906E-01	1.05503E+01	9.08825E-01	3.76629E-03	0.00000E+00	0.00000E+00
67	8.71819E-01	1.06953E+01	9.08256E-01	3.75143E-03	0.00000E+00	0.00000E+00
68	9.09835E-01	1.08432E+01	9.08279E-01	3.69415E-03	0.00000E+00	0.00000E+00
69	9.20348E-01	1.10102E+01	9.08460E-01	3.64307E-03	0.00000E+00	0.00000E+00
70	9.66709E-01	1.11592E+01	9.09316E-01	3.68970E-03	0.00000E+00	0.00000E+00
71	9.19560E-01	1.13165E+01	9.09465E-01	3.63906E-03	0.00000E+00	0.00000E+00
72	8.82861E-01	1.14798E+01	9.09085E-01	3.60685E-03	0.00000E+00	0.00000E+00
73	8.99473E-01	1.16412E+01	9.08949E-01	3.55797E-03	0.00000E+00	0.00000E+00
74	8.75723E-01	1.18057E+01	9.08488E-01	3.53841E-03	0.00000E+00	0.00000E+00
75	8.96107E-01	1.19693E+01	9.08318E-01	3.49355E-03	0.00000E+00	0.00000E+00
76	8.54998E-01	1.21278E+01	9.07598E-01	3.52070E-03	0.00000E+00	0.00000E+00
77	8.80277E-01	1.22780E+01	9.07340E-01	3.48298E-03	0.00000E+00	0.00000E+00
78	9.29014E-01	1.24368E+01	9.07625E-01	3.44864E-03	0.00000E+00	0.00000E+00
79	9.42083E-01	1.25963E+01	9.08073E-01	3.43274E-03	0.00000E+00	0.00000E+00
80	8.77217E-01	1.27390E+01	9.07677E-01	3.41139E-03	0.00000E+00	0.00000E+00
81	9.87428E-01	1.28938E+01	9.07421E-01	3.37760E-03	0.00000E+00	0.00000E+00
82	8.43875E-01	1.30412E+01	9.08652E-01	3.42271E-03	0.00000E+00	0.00000E+00
83	9.32992E-01	1.32008E+01	9.06977E-01	3.39577E-03	0.00000E+00	0.00000E+00
84	8.08379E-01	1.33563E+01	9.05774E-01	3.56312E-03	0.00000E+00	0.00000E+00
85	8.56558E-01	1.35218E+01	9.05182E-01	3.56943E-03	0.00000E+00	0.00000E+00
86	9.53658E-01	1.36705E+01	9.05759E-01	3.57358E-03	0.00000E+00	0.00000E+00
87	8.79221E-01	1.38297E+01	9.05446E-01	3.54515E-03	0.00000E+00	0.00000E+00
88	8.49916E-01	1.39857E+01	9.04801E-01	3.56292E-03	0.00000E+00	0.00000E+00
89	9.37251E-01	1.41348E+01	9.05174E-01	3.54136E-03	0.00000E+00	0.00000E+00
90	9.97291E-01	1.42918E+01	9.06220E-01	3.63387E-03	0.00000E+00	0.00000E+00
91	9.39791E-01	1.44395E+01	9.06822E-01	3.66248E-03	0.00000E+00	0.00000E+00
92	8.58000E-01	1.46027E+01	9.06591E-01	3.62886E-03	0.00000E+00	0.00000E+00
93	1.00039E+00	1.47557E+01	9.07622E-01	3.73375E-03	0.00000E+00	0.00000E+00
94	9.33775E-01	1.49172E+01	9.07906E-01	3.70373E-03	0.00000E+00	0.00000E+00
95	9.43797E-01	1.50772E+01	9.08292E-01	3.68416E-03	0.00000E+00	0.00000E+00
96	9.25739E-01	1.52293E+01	9.08677E-01	3.64949E-03	0.00000E+00	0.00000E+00
97	9.55703E-01	1.53838E+01	9.08975E-01	3.64493E-03	0.00000E+00	0.00000E+00
98	9.27444E-01	1.55348E+01	9.09167E-01	3.61182E-03	0.00000E+00	0.00000E+00
99	8.81507E-01	1.56847E+01	9.08892E-01	3.58578E-03	0.00000E+00	0.00000E+00
100	9.74740E-01	1.58432E+01	9.09554E-01	3.61219E-03	0.00000E+00	0.00000E+00
101	9.82275E-01	1.59947E+01	9.10288E-01	3.65022E-03	0.00000E+00	0.00000E+00
102	9.63677E-01	1.61418E+01	9.10822E-01	3.65273E-03	0.00000E+00	0.00000E+00
103	9.01600E-01	1.62893E+01	9.10731E-01	3.61740E-03	0.00000E+00	0.00000E+00
104	9.08418E-01	1.64493E+01	9.10708E-01	3.59195E-03	0.00000E+00	0.00000E+00
105	8.83305E-01	1.66077E+01	9.10444E-01	3.55663E-03	0.00000E+00	0.00000E+00
106	9.12904E-01	1.67642E+01	9.10469E-01	3.52244E-03	0.00000E+00	0.00000E+00
107	9.36785E-01	1.69170E+01	9.10719E-01	3.49769E-03	0.00000E+00	0.00000E+00
108	9.63511E-01	1.70853E+01	9.11216E-01	3.50019E-03	0.00000E+00	0.00000E+00
109	8.76900E-01	1.72537E+01	9.10896E-01	3.48202E-03	0.00000E+00	0.00000E+00
110	9.60864E-01	1.74180E+01	9.11358E-01	3.48071E-03	0.00000E+00	0.00000E+00
111	9.24458E-01	1.75802E+01	9.11479E-01	3.45051E-03	0.00000E+00	0.00000E+00
112	8.72902E-01	1.77393E+01	9.11128E-01	3.43688E-03	0.00000E+00	0.00000E+00
113	9.48891E-01	1.79047E+01	9.11468E-01	3.42272E-03	0.00000E+00	0.00000E+00
114	8.30410E-01	1.80657E+01	9.10744E-01	3.46830E-03	0.00000E+00	0.00000E+00
115	8.39388E-01	1.82103E+01	9.10113E-01	3.49518E-03	0.00000E+00	0.00000E+00
116	9.13486E-01	1.83662E+01	9.10142E-01	3.46457E-03	0.00000E+00	0.00000E+00
117	9.28392E-01	1.85327E+01	9.10301E-01	3.43810E-03	0.00000E+00	0.00000E+00
118	9.01326E-01	1.86910E+01	9.10224E-01	3.40924E-03	0.00000E+00	0.00000E+00
119	8.76762E-01	1.88495E+01	9.09938E-01	3.39194E-03	0.00000E+00	0.00000E+00
120	9.37605E-01	1.90042E+01	9.10172E-01	3.37115E-03	0.00000E+00	0.00000E+00
121	8.86384E-01	1.91512E+01	9.09972E-01	3.34869E-03	0.00000E+00	0.00000E+00
122	9.04873E-01	1.93148E+01	9.09930E-01	3.32082E-03	0.00000E+00	0.00000E+00
123	8.99467E-01	1.94682E+01	9.09843E-01	3.29447E-03	0.00000E+00	0.00000E+00
124	8.86763E-01	1.96248E+01	9.09654E-01	3.27278E-03	0.00000E+00	0.00000E+00
125	8.73458E-01	1.97857E+01	9.09360E-01	3.25942E-03	0.00000E+00	0.00000E+00
126	9.25935E-01	1.99510E+01	9.09494E-01	3.23567E-03	0.00000E+00	0.00000E+00

127	9.63689E-01	2.01102E+01	9.09927E-01	3.23889E-03	0.00000E+00	0.00000E+00
128	9.18869E-01	2.02532E+01	9.09998E-01	3.21377E-03	0.00000E+00	0.00000E+00
129	8.94014E-01	2.04095E+01	9.09872E-01	3.19092E-03	0.00000E+00	0.00000E+00
130	9.01228E-01	2.05625E+01	9.09805E-01	3.16657E-03	0.00000E+00	0.00000E+00
131	9.50255E-01	2.07208E+01	9.10118E-01	3.15757E-03	0.00000E+00	0.00000E+00
132	9.20745E-01	2.08817E+01	9.10200E-01	3.13427E-03	0.00000E+00	0.00000E+00
133	9.60854E-01	2.10297E+01	9.10587E-01	3.13414E-03	0.00000E+00	0.00000E+00
134	8.75132E-01	2.11992E+01	9.10318E-01	3.12194E-03	0.00000E+00	0.00000E+00
135	8.55406E-01	2.13700E+01	9.09905E-01	3.12573E-03	0.00000E+00	0.00000E+00
136	9.11458E-01	2.15203E+01	9.09917E-01	3.10235E-03	0.00000E+00	0.00000E+00
137	9.15009E-01	2.16872E+01	9.09955E-01	3.07951E-03	0.00000E+00	0.00000E+00
138	9.58467E-01	2.18503E+01	9.09576E-01	3.08016E-03	0.00000E+00	0.00000E+00
139	8.32551E-01	2.20210E+01	9.09014E-01	3.10874E-03	0.00000E+00	0.00000E+00
140	8.80002E-01	2.22013E+01	9.06804E-01	3.09337E-03	0.00000E+00	0.00000E+00
141	9.23461E-01	2.23455E+01	9.08909E-01	3.07281E-03	0.00000E+00	0.00000E+00
142	8.43400E-01	2.25090E+01	9.08441E-01	3.08643E-03	0.00000E+00	0.00000E+00
143	9.23326E-01	2.26652E+01	9.08547E-01	3.06630E-03	0.00000E+00	0.00000E+00
144	8.84651E-01	2.28223E+01	9.08378E-01	3.04932E-03	0.00000E+00	0.00000E+00
145	8.64439E-01	2.29917E+01	9.08071E-01	3.04339E-03	0.00000E+00	0.00000E+00
146	8.82379E-01	2.31507E+01	9.07893E-01	3.02730E-03	0.00000E+00	0.00000E+00
147	9.38779E-01	2.32968E+01	9.08106E-01	3.01382E-03	0.00000E+00	0.00000E+00
148	9.23977E-01	2.34458E+01	9.08215E-01	2.99511E-03	0.00000E+00	0.00000E+00
149	9.06306E-01	2.35963E+01	9.08202E-01	2.97463E-03	0.00000E+00	0.00000E+00
150	8.87525E-01	2.37538E+01	9.08062E-01	2.95772E-03	0.00000E+00	0.00000E+00
151	8.70458E-01	2.39017E+01	9.07810E-01	2.94873E-03	0.00000E+00	0.00000E+00
152	8.59306E-01	2.40570E+01	9.07688E-01	2.94650E-03	0.00000E+00	0.00000E+00
153	9.28869E-01	2.42053E+01	9.07629E-01	2.93043E-03	0.00000E+00	0.00000E+00
154	9.42051E-01	2.43650E+01	9.07856E-01	2.91997E-03	0.00000E+00	0.00000E+00
155	9.13484E-01	2.45273E+01	9.07892E-01	2.90104E-03	0.00000E+00	0.00000E+00
156	9.15673E-01	2.46965E+01	9.07943E-01	2.88237E-03	0.00000E+00	0.00000E+00
157	8.83013E-01	2.48527E+01	9.07782E-01	2.86834E-03	0.00000E+00	0.00000E+00
158	9.28187E-01	2.50140E+01	9.07913E-01	2.85281E-03	0.00000E+00	0.00000E+00
159	1.00951E+00	2.51693E+01	9.08560E-01	2.90750E-03	0.00000E+00	0.00000E+00
160	9.06978E-01	2.53443E+01	9.08550E-01	2.88891E-03	0.00000E+00	0.00000E+00
161	9.46225E-01	2.54998E+01	9.08787E-01	2.88034E-03	0.00000E+00	0.00000E+00
162	9.18948E-01	2.56493E+01	9.08850E-01	2.86310E-03	0.00000E+00	0.00000E+00
163	9.79635E-01	2.58102E+01	9.09290E-01	2.87915E-03	0.00000E+00	0.00000E+00
164	9.13046E-01	2.59625E+01	9.09313E-01	2.86141E-03	0.00000E+00	0.00000E+00
165	8.86913E-01	2.61125E+01	9.09176E-01	2.84702E-03	0.00000E+00	0.00000E+00
166	9.12778E-01	2.62647E+01	9.09198E-01	2.82975E-03	0.00000E+00	0.00000E+00
167	9.32803E-01	2.64250E+01	9.09361E-01	2.81621E-03	0.00000E+00	0.00000E+00
168	9.26398E-01	2.65777E+01	9.09444E-01	2.80110E-03	0.00000E+00	0.00000E+00
169	9.98418E-01	2.67382E+01	9.09976E-01	2.83482E-03	0.00000E+00	0.00000E+00
170	9.25507E-01	2.68835E+01	9.10069E-01	2.81943E-03	0.00000E+00	0.00000E+00
171	9.23603E-01	2.70333E+01	9.10149E-01	2.80395E-03	0.00000E+00	0.00000E+00
172	8.81537E-01	2.71877E+01	9.09980E-01	2.79261E-03	0.00000E+00	0.00000E+00
173	9.78469E-01	2.73382E+01	9.10381E-01	2.80490E-03	0.00000E+00	0.00000E+00
174	9.20345E-01	2.74977E+01	9.10439E-01	2.78914E-03	0.00000E+00	0.00000E+00
175	9.95702E-01	2.76505E+01	9.10932E-01	2.81637E-03	0.00000E+00	0.00000E+00
176	8.53090E-01	2.78230E+01	9.10599E-01	2.81997E-03	0.00000E+00	0.00000E+00
177	9.57966E-01	2.79803E+01	9.10870E-01	2.81684E-03	0.00000E+00	0.00000E+00
178	9.25611E-01	2.81462E+01	9.10954E-01	2.80199E-03	0.00000E+00	0.00000E+00
179	8.27746E-01	2.82955E+01	9.11048E-01	2.78770E-03	0.00000E+00	0.00000E+00
180	9.22370E-01	2.84455E+01	9.11112E-01	2.77278E-03	0.00000E+00	0.00000E+00
181	9.05446E-01	2.85858E+01	9.11080E-01	2.75753E-03	0.00000E+00	0.00000E+00
182	8.97677E-01	2.87453E+01	9.11006E-01	2.74308E-03	0.00000E+00	0.00000E+00
183	9.26289E-01	2.89013E+01	9.11090E-01	2.72927E-03	0.00000E+00	0.00000E+00
184	8.51858E-01	2.90525E+01	9.10765E-01	2.73373E-03	0.00000E+00	0.00000E+00
185	9.47332E-01	2.92110E+01	9.10965E-01	2.72615E-03	0.00000E+00	0.00000E+00
186	9.21303E-01	2.93628E+01	9.11021E-01	2.71174E-03	0.00000E+00	0.00000E+00
187	9.65897E-01	2.95180E+01	9.11317E-01	2.71333E-03	0.00000E+00	0.00000E+00
188	9.38200E-01	2.96643E+01	9.11462E-01	2.70253E-03	0.00000E+00	0.00000E+00
189	8.84250E-01	2.98157E+01	9.11317E-01	2.69192E-03	0.00000E+00	0.00000E+00
190	9.19001E-01	2.99733E+01	9.11357E-01	2.67782E-03	0.00000E+00	0.00000E+00
191	8.90157E-01	3.01313E+01	9.11245E-01	2.66606E-03	0.00000E+00	0.00000E+00

192	8.60021E-01	3.02858E+01	9.11502E-01	2.66427E-03	0.00000E+00	0.00000E+00
193	8.71162E-01	3.04457E+01	9.11291E-01	2.65890E-03	0.00000E+00	0.00000E+00
194	8.89035E-01	3.06035E+01	9.11175E-01	2.64751E-03	0.00000E+00	0.00000E+00
195	8.87914E-01	3.07563E+01	9.11054E-01	2.63655E-03	0.00000E+00	0.00000E+00
196	8.76314E-01	3.09025E+01	9.10875E-01	2.62912E-03	0.00000E+00	0.00000E+00
197	9.79588E-01	3.10598E+01	9.11228E-01	2.63916E-03	0.00000E+00	0.00000E+00
198	9.27491E-01	3.12080E+01	9.11310E-01	2.62703E-03	0.00000E+00	0.00000E+00
199	9.50439E-01	3.13612E+01	9.11509E-01	2.62125E-03	0.00000E+00	0.00000E+00
200	9.59325E-01	3.15177E+01	9.11731E-01	2.61921E-03	0.00000E+00	0.00000E+00
201	9.10663E-01	3.16722E+01	9.11745E-01	2.60507E-03	0.00000E+00	0.00000E+00
202	9.81548E-01	3.18282E+01	9.12094E-01	2.61634E-03	0.00000E+00	0.00000E+00
203	9.33943E-01	3.19835E+01	9.12203E-01	2.60551E-03	0.00000E+00	0.00000E+00
204	9.92131E-01	3.21360E+01	9.12598E-01	2.62270E-03	0.00000E+00	0.00000E+00
205	8.19692E-01	3.22900E+01	9.12141E-01	2.64965E-03	0.00000E+00	0.00000E+00
206	9.19191E-01	3.24405E+01	9.12175E-01	2.63683E-03	0.00000E+00	0.00000E+00
207	9.28567E-01	3.25970E+01	9.12255E-01	2.62514E-03	0.00000E+00	0.00000E+00
208	9.17109E-01	3.27518E+01	9.12279E-01	2.61243E-03	0.00000E+00	0.00000E+00
209	9.40813E-01	3.29017E+01	9.12417E-01	2.60349E-03	0.00000E+00	0.00000E+00
210	8.05688E-01	3.30595E+01	9.11904E-01	2.64122E-03	0.00000E+00	0.00000E+00
211	9.15814E-01	3.32242E+01	9.11922E-01	2.62860E-03	0.00000E+00	0.00000E+00
212	8.43119E-01	3.33797E+01	9.11593E-01	2.63641E-03	0.00000E+00	0.00000E+00
213	9.22227E-01	3.35337E+01	9.11645E-01	2.62440E-03	0.00000E+00	0.00000E+00
214	9.16328E-01	3.36942E+01	9.11667E-01	2.61218E-03	0.00000E+00	0.00000E+00
215	8.81090E-01	3.38605E+01	9.11524E-01	2.60390E-03	0.00000E+00	0.00000E+00
216	8.52997E-01	3.40202E+01	9.11230E-01	2.60606E-03	0.00000E+00	0.00000E+00
217	9.20379E-01	3.41820E+01	9.11293E-01	2.59428E-03	0.00000E+00	0.00000E+00
218	8.21319E-01	3.43490E+01	9.10876E-01	2.61552E-03	0.00000E+00	0.00000E+00
219	1.01565E+00	3.45028E+01	9.11359E-01	2.64770E-03	0.00000E+00	0.00000E+00
220	9.08698E-01	3.46530E+01	9.11347E-01	2.63563E-03	0.00000E+00	0.00000E+00
221	8.74844E-01	3.48038E+01	9.11180E-01	2.62885E-03	0.00000E+00	0.00000E+00
222	9.64820E-01	3.49598E+01	9.11424E-01	2.62823E-03	0.00000E+00	0.00000E+00
223	9.18376E-01	3.51142E+01	9.11455E-01	2.61651E-03	0.00000E+00	0.00000E+00
224	9.12174E-01	3.52743E+01	9.11459E-01	2.60474E-03	0.00000E+00	0.00000E+00
225	8.96294E-01	3.54268E+01	9.11391E-01	2.59391E-03	0.00000E+00	0.00000E+00
226	9.64571E-01	3.55813E+01	9.11628E-01	2.59319E-03	0.00000E+00	0.00000E+00
227	8.99948E-01	3.57377E+01	9.11576E-01	2.58209E-03	0.00000E+00	0.00000E+00
228	9.35647E-01	3.58955E+01	9.11683E-01	2.57275E-03	0.00000E+00	0.00000E+00
229	9.09228E-01	3.60480E+01	9.11672E-01	2.56150E-03	0.00000E+00	0.00000E+00
230	9.32389E-01	3.62145E+01	9.11850E-01	2.55636E-03	0.00000E+00	0.00000E+00
231	8.96189E-01	3.63745E+01	9.11782E-01	2.54613E-03	0.00000E+00	0.00000E+00
232	8.88368E-01	3.65365E+01	9.11680E-01	2.53703E-03	0.00000E+00	0.00000E+00
233	9.05397E-01	3.66885E+01	9.11653E-01	2.52633E-03	0.00000E+00	0.00000E+00
234	9.02133E-01	3.68408E+01	9.11612E-01	2.51569E-03	0.00000E+00	0.00000E+00
235	9.09995E-01	3.69947E+01	9.11605E-01	2.50478E-03	0.00000E+00	0.00000E+00
236	8.68686E-01	3.71532E+01	9.11422E-01	2.50093E-03	0.00000E+00	0.00000E+00
237	9.16438E-01	3.73045E+01	9.11443E-01	2.49027E-03	0.00000E+00	0.00000E+00
238	9.15798E-01	3.74663E+01	9.11461E-01	2.47970E-03	0.00000E+00	0.00000E+00
239	9.00370E-01	3.76183E+01	9.11415E-01	2.46969E-03	0.00000E+00	0.00000E+00
240	8.82785E-01	3.77817E+01	9.11210E-01	2.46764E-03	0.00000E+00	0.00000E+00
241	8.86606E-01	3.79350E+01	9.11107E-01	2.45945E-03	0.00000E+00	0.00000E+00
242	8.78642E-01	3.80867E+01	9.10972E-01	2.45292E-03	0.00000E+00	0.00000E+00
243	8.98854E-01	3.82403E+01	9.10922E-01	2.44324E-03	0.00000E+00	0.00000E+00
244	8.82120E-01	3.83985E+01	9.10803E-01	2.43608E-03	0.00000E+00	0.00000E+00
245	8.56030E-01	3.85530E+01	9.10578E-01	2.43641E-03	0.00000E+00	0.00000E+00
246	8.51788E-01	3.87008E+01	9.10337E-01	2.43829E-03	0.00000E+00	0.00000E+00
247	8.58656E-01	3.88665E+01	9.10126E-01	2.43750E-03	0.00000E+00	0.00000E+00
248	1.03577E+00	3.90140E+01	9.10636E-01	2.48075E-03	0.00000E+00	0.00000E+00
249	9.61299E-01	3.91678E+01	9.10842E-01	2.47917E-03	0.00000E+00	0.00000E+00
250	9.04815E-01	3.93152E+01	9.10817E-01	2.46922E-03	0.00000E+00	0.00000E+00
251	9.54665E-01	3.94650E+01	9.10993E-01	2.46565E-03	0.00000E+00	0.00000E+00
252	9.14071E-01	3.96150E+01	9.11006E-01	2.45578E-03	0.00000E+00	0.00000E+00
253	8.55371E-01	3.97712E+01	9.10784E-01	2.45591E-03	0.00000E+00	0.00000E+00
254	9.41200E-01	3.99287E+01	9.10905E-01	2.44922E-03	0.00000E+00	0.00000E+00
255	9.01831E-01	4.00872E+01	9.10869E-01	2.43981E-03	0.00000E+00	0.00000E+00
256	8.47745E-01	4.02433E+01	9.10620E-01	2.44281E-03	0.00000E+00	0.00000E+00

257	9.19790E-01	4.03890E+01	9.10652E-01	2.43342E-03	0.00000E+00	0.00000E+00
258	9.81393E-01	4.05510E+01	9.10929E-01	2.43959E-03	0.00000E+00	0.00000E+00
259	8.99719E-01	4.07002E+01	9.10885E-01	2.43046E-03	0.00000E+00	0.00000E+00
260	9.13652E-01	4.08643E+01	9.10896E-01	2.42104E-03	0.00000E+00	0.00000E+00
261	9.63198E-01	4.10255E+01	9.11105E-01	2.42083E-03	0.00000E+00	0.00000E+00
262	9.11314E-01	4.11822E+01	9.11106E-01	2.41148E-03	0.00000E+00	0.00000E+00
263	9.30269E-01	4.13312E+01	9.11180E-01	2.40331E-03	0.00000E+00	0.00000E+00
264	8.98241E-01	4.14792E+01	9.11130E-01	2.39470E-03	0.00000E+00	0.00000E+00
265	8.60240E-01	4.16378E+01	9.10937E-01	2.39336E-03	0.00000E+00	0.00000E+00
266	9.37168E-01	4.17902E+01	9.11036E-01	2.38639E-03	0.00000E+00	0.00000E+00
267	9.61807E-01	4.19418E+01	9.11228E-01	2.38509E-03	0.00000E+00	0.00000E+00
268	9.05793E-01	4.20935E+01	9.11207E-01	2.37623E-03	0.00000E+00	0.00000E+00
269	9.35148E-01	4.22478E+01	9.11297E-01	2.36892E-03	0.00000E+00	0.00000E+00
270	9.56143E-01	4.24042E+01	9.11464E-01	2.36609E-03	0.00000E+00	0.00000E+00
271	9.29758E-01	4.25633E+01	9.11532E-01	2.35814E-03	0.00000E+00	0.00000E+00
272	9.78549E-01	4.27219E+01	9.11410E-01	2.35282E-03	0.00000E+00	0.00000E+00
273	9.16186E-01	4.28770E+01	9.11428E-01	2.34398E-03	0.00000E+00	0.00000E+00
274	9.49889E-01	4.30345E+01	9.11569E-01	2.33960E-03	0.00000E+00	0.00000E+00
275	9.34008E-01	4.31897E+01	9.11725E-01	2.33609E-03	0.00000E+00	0.00000E+00
276	8.95101E-01	4.33305E+01	9.11664E-01	2.32648E-03	0.00000E+00	0.00000E+00
277	9.73261E-01	4.34810E+01	9.11524E-01	2.32423E-03	0.00000E+00	0.00000E+00
278	9.07059E-01	4.36315E+01	9.11508E-01	2.31579E-03	0.00000E+00	0.00000E+00
279	9.30322E-01	4.37860E+01	9.11576E-01	2.30837E-03	0.00000E+00	0.00000E+00
280	9.31864E-01	4.39412E+01	9.11649E-01	2.30116E-03	0.00000E+00	0.00000E+00
281	9.60835E-01	4.40967E+01	9.11825E-01	2.29972E-03	0.00000E+00	0.00000E+00
282	8.37581E-01	4.42513E+01	9.11560E-01	2.30674E-03	0.00000E+00	0.00000E+00
283	1.05217E+00	4.44022E+01	9.12061E-01	2.35228E-03	0.00000E+00	0.00000E+00
284	9.35487E-01	4.45540E+01	9.12215E-01	2.34895E-03	0.00000E+00	0.00000E+00
285	8.90670E-01	4.47168E+01	9.12138E-01	2.34203E-03	0.00000E+00	0.00000E+00
286	9.11932E-01	4.48698E+01	9.12138E-01	2.33379E-03	0.00000E+00	0.00000E+00
287	9.21257E-01	4.50210E+01	9.12170E-01	2.32575E-03	0.00000E+00	0.00000E+00
288	9.05555E-01	4.51847E+01	9.12147E-01	2.31770E-03	0.00000E+00	0.00000E+00
289	8.95314E-01	4.53515E+01	9.12088E-01	2.31036E-03	0.00000E+00	0.00000E+00
290	9.25377E-01	4.55067E+01	9.12134E-01	2.30272E-03	0.00000E+00	0.00000E+00
291	9.36272E-01	4.56568E+01	9.12218E-01	2.29615E-03	0.00000E+00	0.00000E+00
292	8.56589E-01	4.58177E+01	9.12026E-01	2.29627E-03	0.00000E+00	0.00000E+00
293	8.78243E-01	4.59743E+01	9.11910E-01	2.29136E-03	0.00000E+00	0.00000E+00
294	8.35698E-01	4.61410E+01	9.11649E-01	2.29832E-03	0.00000E+00	0.00000E+00
295	8.46697E-01	4.62928E+01	9.11427E-01	2.30113E-03	0.00000E+00	0.00000E+00
296	8.88469E-01	4.64483E+01	9.11349E-01	2.29463E-03	0.00000E+00	0.00000E+00
297	9.47003E-01	4.66030E+01	9.11470E-01	2.29011E-03	0.00000E+00	0.00000E+00
298	8.85854E-01	4.67648E+01	9.11383E-01	2.28601E-03	0.00000E+00	0.00000E+00
299	9.35132E-01	4.69200E+01	9.11430E-01	2.27679E-03	0.00000E+00	0.00000E+00
300	8.84096E-01	4.70748E+01	9.11338E-01	2.27097E-03	0.00000E+00	0.00000E+00
301	9.73811E-01	4.72333E+01	9.11547E-01	2.27293E-03	0.00000E+00	0.00000E+00
302	8.69475E-01	4.74002E+01	9.11407E-01	2.26970E-03	0.00000E+00	0.00000E+00
303	9.70267E-01	4.75495E+01	9.11602E-01	2.27046E-03	0.00000E+00	0.00000E+00
304	8.82851E-01	4.77073E+01	9.11507E-01	2.26503E-03	0.00000E+00	0.00000E+00
305	9.09201E-01	4.78480E+01	9.11499E-01	2.25752E-03	0.00000E+00	0.00000E+00
306	9.15114E-01	4.80105E+01	9.11511E-01	2.25021E-03	0.00000E+00	0.00000E+00
307	9.75879E-01	4.81550E+01	9.11722E-01	2.25265E-03	0.00000E+00	0.00000E+00
308	8.96783E-01	4.83158E+01	9.11674E-01	2.24582E-03	0.00000E+00	0.00000E+00
309	9.17450E-01	4.84817E+01	9.11692E-01	2.23834E-03	0.00000E+00	0.00000E+00
310	9.04830E-01	4.86427E+01	9.11670E-01	2.23146E-03	0.00000E+00	0.00000E+00
311	8.93677E-01	4.88117E+01	9.11612E-01	2.22497E-03	0.00000E+00	0.00000E+00
312	9.19379E-01	4.89722E+01	9.11638E-01	2.21784E-03	0.00000E+00	0.00000E+00
313	8.78876E-01	4.91302E+01	9.11532E-01	2.21326E-03	0.00000E+00	0.00000E+00
314	9.33210E-01	4.92832E+01	9.11602E-01	2.20732E-03	0.00000E+00	0.00000E+00
315	8.93714E-01	4.94482E+01	9.11544E-01	2.20104E-03	0.00000E+00	0.00000E+00
316	8.90180E-01	4.96042E+01	9.11476E-01	2.19510E-03	0.00000E+00	0.00000E+00
317	8.99181E-01	4.97652E+01	9.11437E-01	2.18848E-03	0.00000E+00	0.00000E+00
318	8.77008E-01	4.99302E+01	9.11328E-01	2.18427E-03	0.00000E+00	0.00000E+00
319	9.12137E-01	5.00953E+01	9.11331E-01	2.17735E-03	0.00000E+00	0.00000E+00
320	8.92609E-01	5.02587E+01	9.11272E-01	2.17131E-03	0.00000E+00	0.00000E+00
321	8.81860E-01	5.04180E+01	9.11180E-01	2.16638E-03	0.00000E+00	0.00000E+00

322	9.44749E-01	5.05823E+01	9.11285E-01	2.15216E-03	0.00000E+00	0.00000E+00
323	8.94851E-01	5.07388E+01	9.11234E-01	2.15602E-03	0.00000E+00	0.00000E+00
324	9.98639E-01	5.08932E+01	9.11505E-01	2.16646E-03	0.00000E+00	0.00000E+00
325	9.03892E-01	5.10598E+01	9.11481E-01	2.15988E-03	0.00000E+00	0.00000E+00
326	9.43353E-01	5.12207E+01	9.11580E-01	2.15538E-03	0.00000E+00	0.00000E+00
327	9.57208E-01	5.13713E+01	9.11720E-01	2.15329E-03	0.00000E+00	0.00000E+00
328	8.24231E-01	5.15320E+01	9.11452E-01	2.16341E-03	0.00000E+00	0.00000E+00
329	9.91848E-01	5.16867E+01	9.11667E-01	2.16757E-03	0.00000E+00	0.00000E+00
330	9.14389E-01	5.18435E+01	9.11676E-01	2.16092E-03	0.00000E+00	0.00000E+00
331	9.22197E-01	5.20108E+01	9.11708E-01	2.15451E-03	0.00000E+00	0.00000E+00
332	9.43707E-01	5.21645E+01	9.11804E-01	2.15018E-03	0.00000E+00	0.00000E+00
333	9.17284E-01	5.23252E+01	9.11821E-01	2.14367E-03	0.00000E+00	0.00000E+00
334	9.48315E-01	5.24753E+01	9.11931E-01	2.14001E-03	0.00000E+00	0.00000E+00
335	9.70907E-01	5.26332E+01	9.12108E-01	2.14094E-03	0.00000E+00	0.00000E+00
336	9.61474E-01	5.27842E+01	9.12256E-01	2.13957E-03	0.00000E+00	0.00000E+00
337	9.14201E-01	5.29422E+01	9.12262E-01	2.13310E-03	0.00000E+00	0.00000E+00
338	9.15591E-01	5.31032E+01	9.12272E-01	2.12882E-03	0.00000E+00	0.00000E+00
339	9.40755E-01	5.32548E+01	9.12356E-01	2.12211E-03	0.00000E+00	0.00000E+00
340	9.13256E-01	5.34063E+01	9.12359E-01	2.11578E-03	0.00000E+00	0.00000E+00
341	8.66998E-01	5.35637E+01	9.12225E-01	2.11378E-03	0.00000E+00	0.00000E+00
342	9.25600E-01	5.37092E+01	9.12264E-01	2.10795E-03	0.00000E+00	0.00000E+00
343	9.76270E-01	5.38613E+01	9.12452E-01	2.11013E-03	0.00000E+00	0.00000E+00
344	9.22682E-01	5.40160E+01	9.12482E-01	2.10425E-03	0.00000E+00	0.00000E+00
345	8.79600E-01	5.41653E+01	9.12396E-01	2.10022E-03	0.00000E+00	0.00000E+00
346	9.02866E-01	5.43185E+01	9.12358E-01	2.09434E-03	0.00000E+00	0.00000E+00
347	9.22122E-01	5.44727E+01	9.12387E-01	2.08843E-03	0.00000E+00	0.00000E+00
348	9.42993E-01	5.46250E+01	9.12475E-01	2.08428E-03	0.00000E+00	0.00000E+00
349	9.58864E-01	5.47870E+01	9.12609E-01	2.08259E-03	0.00000E+00	0.00000E+00
350	9.57453E-01	5.49357E+01	9.12738E-01	2.08058E-03	0.00000E+00	0.00000E+00
351	8.86185E-01	5.50950E+01	9.12662E-01	2.07594E-03	0.00000E+00	0.00000E+00
352	8.90880E-01	5.52467E+01	9.12600E-01	2.07090E-03	0.00000E+00	0.00000E+00
353	9.31775E-01	5.54067E+01	9.12654E-01	2.06576E-03	0.00000E+00	0.00000E+00
354	8.49514E-01	5.55643E+01	9.12475E-01	2.06775E-03	0.00000E+00	0.00000E+00
355	9.37593E-01	5.57137E+01	9.12546E-01	2.06308E-03	0.00000E+00	0.00000E+00
356	8.46868E-01	5.58760E+01	9.12360E-01	2.06564E-03	0.00000E+00	0.00000E+00
357	9.31221E-01	5.60312E+01	9.12413E-01	2.06056E-03	0.00000E+00	0.00000E+00
358	8.55444E-01	5.61860E+01	9.12253E-01	2.06100E-03	0.00000E+00	0.00000E+00
359	9.38691E-01	5.63433E+01	9.12327E-01	2.05647E-03	0.00000E+00	0.00000E+00
360	8.93946E-01	5.65030E+01	9.12276E-01	2.05140E-03	0.00000E+00	0.00000E+00
361	8.74873E-01	5.66605E+01	9.12172E-01	2.04832E-03	0.00000E+00	0.00000E+00
362	8.77906E-01	5.68198E+01	9.12077E-01	2.04490E-03	0.00000E+00	0.00000E+00
363	8.48249E-01	5.69832E+01	9.11900E-01	2.04688E-03	0.00000E+00	0.00000E+00
364	8.36516E-01	5.71368E+01	9.11692E-01	2.05179E-03	0.00000E+00	0.00000E+00
365	8.93256E-01	5.72837E+01	9.11641E-01	2.04685E-03	0.00000E+00	0.00000E+00
366	9.03010E-01	5.74362E+01	9.11617E-01	2.04130E-03	0.00000E+00	0.00000E+00
367	9.35819E-01	5.76005E+01	9.11683E-01	2.03685E-03	0.00000E+00	0.00000E+00
368	1.00191E+00	5.77493E+01	9.11930E-01	2.04606E-03	0.00000E+00	0.00000E+00
369	9.04656E-01	5.79060E+01	9.11910E-01	2.04051E-03	0.00000E+00	0.00000E+00
370	9.22062E-01	5.80615E+01	9.11938E-01	2.03518E-03	0.00000E+00	0.00000E+00
371	8.98739E-01	5.82250E+01	9.11902E-01	2.02998E-03	0.00000E+00	0.00000E+00
372	8.86958E-01	5.83663E+01	9.11835E-01	2.02555E-03	0.00000E+00	0.00000E+00
373	8.76034E-01	5.85187E+01	9.11738E-01	2.02234E-03	0.00000E+00	0.00000E+00
374	9.89771E-01	5.86787E+01	9.11948E-01	2.02775E-03	0.00000E+00	0.00000E+00
375	8.53915E-01	5.88328E+01	9.11792E-01	2.02926E-03	0.00000E+00	0.00000E+00
376	9.43604E-01	5.89942E+01	9.11877E-01	2.02463E-03	0.00000E+00	0.00000E+00
377	9.41421E-01	5.91413E+01	9.11936E-01	2.02078E-03	0.00000E+00	0.00000E+00
378	9.70221E-01	5.92952E+01	9.12111E-01	2.02131E-03	0.00000E+00	0.00000E+00
379	8.89507E-01	5.94482E+01	9.12051E-01	2.01693E-03	0.00000E+00	0.00000E+00
380	9.08893E-01	5.96045E+01	9.12043E-01	2.01151E-03	0.00000E+00	0.00000E+00
381	8.19677E-01	5.97680E+01	9.11799E-01	2.02094E-03	0.00000E+00	0.00000E+00
382	9.31868E-01	5.99225E+01	9.11852E-01	2.01640E-03	0.00000E+00	0.00000E+00
383	9.15098E-01	6.00797E+01	9.11860E-01	2.01113E-03	0.00000E+00	0.00000E+00
384	9.23447E-01	6.02235E+01	9.11891E-01	2.00596E-03	0.00000E+00	0.00000E+00
385	9.91374E-01	6.03748E+01	9.12098E-01	2.01153E-03	0.00000E+00	0.00000E+00
386	7.99611E-01	6.05318E+01	9.11805E-01	2.02752E-03	0.00000E+00	0.00000E+00

387	9.21668E-01	6.06843E+01	9.11831E-01	2.02233E-03	0.00000E+00	0.00000E+00
388	9.07398E-01	6.08448E+01	9.11819E-01	2.01711E-03	0.00000E+00	0.00000E+00
389	8.91918E-01	6.09947E+01	9.11768E-01	2.01258E-03	0.00000E+00	0.00000E+00
390	9.298.1E-01	6.11573E+01	9.11815E-01	2.00787E-03	0.00000E+00	0.00000E+00
391	8.59654E-01	6.13183E+01	9.11681E-01	2.00724E-03	0.00000E+00	0.00000E+00
392	9.23813E-01	6.14743E+01	9.11712E-01	2.00240E-03	0.00000E+00	0.00000E+00
393	8.87650E-01	6.16323E+01	9.11630E-01	1.99819E-03	0.00000E+00	0.00000E+00
394	8.62811E-01	6.17837E+01	9.11526E-01	1.99700E-03	0.00000E+00	0.00000E+00
395	9.59163E-01	6.19415E+01	9.11647E-01	1.99552E-03	0.00000E+00	0.00000E+00
396	9.23694E-01	6.21003E+01	9.11677E-01	1.99062E-03	0.00000E+00	0.00000E+00
397	8.57631E-01	6.22723E+01	9.11541E-01	1.99034E-03	0.00000E+00	0.00000E+00
398	9.34899E-01	6.24197E+01	9.11600E-01	1.98611E-03	0.00000E+00	0.00000E+00
399	9.41602E-01	6.25675E+01	9.11675E-01	1.98257E-03	0.00000E+00	0.00000E+00
400	9.24386E-01	6.27377E+01	9.11707E-01	1.97787E-03	0.00000E+00	0.00000E+00
401	9.01551E-01	6.28968E+01	9.11682E-01	1.97304E-03	0.00000E+00	0.00000E+00
402	9.06473E-01	6.30638E+01	9.11669E-01	1.96821E-03	0.00000E+00	0.00000E+00
403	8.93757E-01	6.32280E+01	9.11624E-01	1.96374E-03	0.00000E+00	0.00000E+00
404	8.26629E-01	6.33902E+01	9.11412E-01	1.97025E-03	0.00000E+00	0.00000E+00
405	9.69289E-01	6.35552E+01	9.11556E-01	1.97051E-03	0.00000E+00	0.00000E+00
406	9.23352E-01	6.37037E+01	9.11586E-01	1.96584E-03	0.00000E+00	0.00000E+00
407	8.88878E-01	6.38605E+01	9.11530E-01	1.96176E-03	0.00000E+00	0.00000E+00
408	9.25725E-01	6.40233E+01	9.11565E-01	1.95726E-03	0.00000E+00	0.00000E+00
409	9.55595E-01	6.41810E+01	9.11673E-01	1.95342E-03	0.00000E+00	0.00000E+00
410	9.55693E-01	6.43380E+01	9.11781E-01	1.95361E-03	0.00000E+00	0.00000E+00
411	9.08833E-01	6.45018E+01	9.11774E-01	1.94882E-03	0.00000E+00	0.00000E+00
412	9.95504E-01	6.46567E+01	9.11978E-01	1.95477E-03	0.00000E+00	0.00000E+00
413	8.85422E-01	6.48137E+01	9.11913E-01	1.95100E-03	0.00000E+00	0.00000E+00
414	8.74212E-01	6.49735E+01	9.11822E-01	1.94837E-03	0.00000E+00	0.00000E+00
415	9.03087E-01	6.51323E+01	9.11801E-01	1.94384E-03	0.00000E+00	0.00000E+00
416	8.53291E-01	6.52883E+01	9.11659E-01	1.94424E-03	0.00000E+00	0.00000E+00
417	9.21972E-01	6.54493E+01	9.11684E-01	1.93977E-03	0.00000E+00	0.00000E+00
418	9.25977E-01	6.55987E+01	9.11718E-01	1.93540E-03	0.00000E+00	0.00000E+00
419	8.80633E-01	6.57572E+01	9.11664E-01	1.93218E-03	0.00000E+00	0.00000E+00
420	9.72680E-01	6.59065E+01	9.11790E-01	1.93304E-03	0.00000E+00	0.00000E+00
421	9.46564E-01	6.60598E+01	9.11873E-01	1.93017E-03	0.00000E+00	0.00000E+00
422	9.42778E-01	6.62148E+01	9.11947E-01	1.92702E-03	0.00000E+00	0.00000E+00
423	9.32166E-01	6.63708E+01	9.11995E-01	1.92299E-03	0.00000E+00	0.00000E+00
424	8.73374E-01	6.65268E+01	9.11913E-01	1.92023E-03	0.00000E+00	0.00000E+00
425	8.71753E-01	6.66783E+01	9.11818E-01	1.91795E-03	0.00000E+00	0.00000E+00
426	8.92328E-01	6.68350E+01	9.11772E-01	1.91399E-03	0.00000E+00	0.00000E+00
427	9.33107E-01	6.70055E+01	9.11822E-01	1.91015E-03	0.00000E+00	0.00000E+00
428	8.98103E-01	6.71668E+01	9.11790E-01	1.90388E-03	0.00000E+00	0.00000E+00
429	8.86757E-01	6.73307E+01	9.11731E-01	1.90232E-03	0.00000E+00	0.00000E+00
430	8.89729E-01	6.74982E+01	9.11680E-01	1.89858E-03	0.00000E+00	0.00000E+00
431	9.11727E-01	6.76705E+01	9.11680E-01	1.89416E-03	0.00000E+00	0.00000E+00
432	8.65756E-01	6.78432E+01	9.11573E-01	1.89272E-03	0.00000E+00	0.00000E+00
433	8.86469E-01	6.79973E+01	9.11515E-01	1.88920E-03	0.00000E+00	0.00000E+00
434	9.56900E-01	6.81525E+01	9.11620E-01	1.88781E-03	0.00000E+00	0.00000E+00
435	8.91253E-01	6.83113E+01	9.11573E-01	1.88398E-03	0.00000E+00	0.00000E+00
436	8.96603E-01	6.84642E+01	9.11538E-01	1.87994E-03	0.00000E+00	0.00000E+00
437	8.99492E-01	6.86175E+01	9.11511E-01	1.87376E-03	0.00000E+00	0.00000E+00
438	8.99043E-01	6.87850E+01	9.11482E-01	1.87162E-03	0.00000E+00	0.00000E+00
439	9.15274E-01	6.89460E+01	9.11491E-01	1.86735E-03	0.00000E+00	0.00000E+00
440	8.81702E-01	6.91017E+01	9.11423E-01	1.86434E-03	0.00000E+00	0.00000E+00
441	9.08723E-01	6.92595E+01	9.11417E-01	1.86009E-03	0.00000E+00	0.00000E+00
442	8.36115E-01	6.94052E+01	9.11291E-01	1.86016E-03	0.00000E+00	0.00000E+00
443	8.77882E-01	6.95578E+01	9.11215E-01	1.85753E-03	0.00000E+00	0.00000E+00
444	8.20916E-01	6.97213E+01	9.11011E-01	1.86451E-03	0.00000E+00	0.00000E+00
445	8.95492E-01	6.98785E+01	9.10976E-01	1.86066E-03	0.00000E+00	0.00000E+00
446	9.29536E-01	7.00402E+01	9.11018E-01	1.85697E-03	0.00000E+00	0.00000E+00
447	8.12478E-01	7.01973E+01	9.10796E-01	1.86599E-03	0.00000E+00	0.00000E+00
448	8.86601E-01	7.03525E+01	9.10742E-01	1.86263E-03	0.00000E+00	0.00000E+00
449	9.24699E-01	7.05123E+01	9.10773E-01	1.85867E-03	0.00000E+00	0.00000E+00
450	8.93266E-01	7.06738E+01	9.10734E-01	1.85487E-03	0.00000E+00	0.00000E+00
451	8.75525E-01	7.08232E+01	9.10656E-01	1.85240E-03	0.00000E+00	0.00000E+00

452	9.26373E-01	7.09670E+01	9.10691E-01	1.84869E-03	0.00000E+00	0.00000E+00
453	9.20973E-01	7.11182E+01	9.10714E-01	1.84677E-03	0.00000E+00	0.00000E+00
454	9.61259E-01	7.12732E+01	9.10826E-01	1.84401E-03	0.00000E+00	0.00000E+00
455	8.89173E-01	7.14260E+01	9.10734E-01	1.84225E-03	0.00000E+00	0.00000E+00
456	8.86782E-01	7.15859E+01	9.10681E-01	1.83893E-03	0.00000E+00	0.00000E+00
457	8.71030E-01	7.17382E+01	9.10596E-01	1.83698E-03	0.00000E+00	0.00000E+00
458	9.31032E-01	7.18898E+01	9.10639E-01	1.83346E-03	0.00000E+00	0.00000E+00
459	8.19123E-01	7.20573E+01	9.10438E-01	1.84042E-03	0.00000E+00	0.00000E+00
460	9.65842E-01	7.22127E+01	9.10539E-01	1.84032E-03	0.00000E+00	0.00000E+00
461	9.97917E-01	7.23743E+01	9.10750E-01	1.84611E-03	0.00000E+00	0.00000E+00
462	8.62433E-01	7.25383E+01	9.10645E-01	1.84516E-03	0.00000E+00	0.00000E+00
463	9.52296E-01	7.26898E+01	9.10735E-01	1.84336E-03	0.00000E+00	0.00000E+00
464	8.30662E-01	7.28608E+01	9.10562E-01	1.84750E-03	0.00000E+00	0.00000E+00
465	9.12193E-01	7.29960E+01	9.10565E-01	1.84367E-03	0.00000E+00	0.00000E+00
466	9.59965E-01	7.31443E+01	9.10672E-01	1.84259E-03	0.00000E+00	0.00000E+00
467	8.64271E-01	7.33078E+01	9.10572E-01	1.84141E-03	0.00000E+00	0.00000E+00
468	8.67507E-01	7.34552E+01	9.10479E-01	1.83978E-03	0.00000E+00	0.00000E+00
469	9.56531E-01	7.36063E+01	9.10578E-01	1.83843E-03	0.00000E+00	0.00000E+00
470	9.06921E-01	7.37738E+01	9.10570E-01	1.83455E-03	0.00000E+00	0.00000E+00
471	9.14353E-01	7.39315E+01	9.10578E-01	1.83057E-03	0.00000E+00	0.00000E+00
472	9.08854E-01	7.40845E+01	9.10575E-01	1.82670E-03	0.00000E+00	0.00000E+00
473	9.01950E-01	7.42445E+01	9.10556E-01	1.82295E-03	0.00000E+00	0.00000E+00
474	9.39036E-01	7.43953E+01	9.10617E-01	1.82011E-03	0.00000E+00	0.00000E+00
475	9.13424E-01	7.45533E+01	9.10623E-01	1.81624E-03	0.00000E+00	0.00000E+00
476	9.54802E-01	7.47115E+01	9.10716E-01	1.81477E-03	0.00000E+00	0.00000E+00
477	9.16488E-01	7.48665E+01	9.10728E-01	1.81105E-03	0.00000E+00	0.00000E+00
478	9.81822E-01	7.50323E+01	9.10877E-01	1.81347E-03	0.00000E+00	0.00000E+00
479	9.23279E-01	7.51938E+01	9.10903E-01	1.80973E-03	0.00000E+00	0.00000E+00
480	8.95301E-01	7.53503E+01	9.10870E-01	1.80631E-03	0.00000E+00	0.00000E+00
481	8.42400E-01	7.55055E+01	9.10728E-01	1.80815E-03	0.00000E+00	0.00000E+00
482	9.06963E-01	7.56802E+01	9.10720E-01	1.80440E-03	0.00000E+00	0.00000E+00
483	9.67753E-01	7.58240E+01	9.10838E-01	1.80458E-03	0.00000E+00	0.00000E+00
484	9.37842E-01	7.59730E+01	9.10936E-01	1.80346E-03	0.00000E+00	0.00000E+00
485	8.86842E-01	7.61295E+01	9.10886E-01	1.80046E-03	0.00000E+00	0.00000E+00
486	9.45343E-01	7.62907E+01	9.10957E-01	1.79811E-03	0.00000E+00	0.00000E+00
487	8.46158E-01	7.64365E+01	9.10823E-01	1.79937E-03	0.00000E+00	0.00000E+00
488	9.31916E-01	7.66188E+01	9.10867E-01	1.79522E-03	0.00000E+00	0.00000E+00
489	8.94650E-01	7.67748E+01	9.10834E-01	1.79274E-03	0.00000E+00	0.00000E+00
490	9.78525E-01	7.69338E+01	9.10972E-01	1.79447E-03	0.00000E+00	0.00000E+00
491	9.07158E-01	7.70912E+01	9.10964E-01	1.79082E-03	0.00000E+00	0.00000E+00
492	8.68203E-01	7.72620E+01	9.10877E-01	1.78930E-03	0.00000E+00	0.00000E+00
493	9.35996E-01	7.74163E+01	9.10928E-01	1.78642E-03	0.00000E+00	0.00000E+00
494	9.63087E-01	7.75715E+01	9.11034E-01	1.78596E-03	0.00000E+00	0.00000E+00
495	9.70309E-01	7.77238E+01	9.11155E-01	1.78635E-03	0.00000E+00	0.00000E+00
496	9.64684E-01	7.78820E+01	9.11263E-01	1.78602E-03	0.00000E+00	0.00000E+00
497	9.52008E-01	7.80332E+01	9.11345E-01	1.78435E-03	0.00000E+00	0.00000E+00
498	9.25630E-01	7.81862E+01	9.11374E-01	1.78096E-03	0.00000E+00	0.00000E+00
499	9.25692E-01	7.83562E+01	9.11403E-01	1.77757E-03	0.00000E+00	0.00000E+00
500	8.89510E-01	7.85105E+01	9.11359E-01	1.77457E-03	0.00000E+00	0.00000E+00
501	9.23669E-01	7.86690E+01	9.11384E-01	1.77116E-03	0.00000E+00	0.00000E+00
502	8.77179E-01	7.88253E+01	9.11315E-01	1.76895E-03	0.00000E+00	0.00000E+00
503	8.80305E-01	7.89778E+01	9.11253E-01	1.76654E-03	0.00000E+00	0.00000E+00
504	9.07956E-01	7.91317E+01	9.11247E-01	1.76299E-03	0.00000E+00	0.00000E+00
505	9.42571E-01	7.92910E+01	9.11309E-01	1.76059E-03	0.00000E+00	0.00000E+00
506	8.94250E-01	7.94565E+01	9.11275E-01	1.75739E-03	0.00000E+00	0.00000E+00
507	9.53821E-01	7.96085E+01	9.11359E-01	1.75593E-03	0.00000E+00	0.00000E+00
508	9.31607E-01	7.97698E+01	9.11399E-01	1.75293E-03	0.00000E+00	0.00000E+00
509	8.89794E-01	7.99292E+01	9.11356E-01	1.74999E-03	0.00000E+00	0.00000E+00
510	9.49686E-01	8.00912E+01	9.11430E-01	1.74802E-03	0.00000E+00	0.00000E+00
511	8.95937E-01	8.02592E+01	9.11401E-01	1.74489E-03	0.00000E+00	0.00000E+00
512	8.93599E-01	8.04032E+01	9.11366E-01	1.74183E-03	0.00000E+00	0.00000E+00
513	9.15303E-01	8.05543E+01	9.11375E-01	1.73841E-03	0.00000E+00	0.00000E+00
514	9.05322E-01	8.07072E+01	9.11363E-01	1.73503E-03	0.00000E+00	0.00000E+00
515	8.87117E-01	8.08669E+01	9.11316E-01	1.73229E-03	0.00000E+00	0.00000E+00
516	8.63613E-01	8.10352E+01	9.11227E-01	1.73121E-03	0.00000E+00	0.00000E+00

317	9.34631E-01	9.11940E+01	9.11272E-01	1.72848E-03	0.00000E+00	0.00000E+00
318	8.69588E-01	8.13483E+01	9.11191E-01	1.72701E-03	0.00000E+00	0.00000E+00
319	9.40809E-01	8.15028E+01	9.11249E-01	1.72463E-03	0.00000E+00	0.00000E+00
320	9.16726E-01	8.16605E+01	9.11259E-01	1.72135E-03	0.00000E+00	0.00000E+00
321	9.85840E-01	8.18122E+01	9.11364E-01	1.72123E-03	0.00000E+00	0.00000E+00
322	9.35393E-01	8.19703E+01	9.11411E-01	1.71857E-03	0.00000E+00	0.00000E+00
323	9.72351E-01	8.21233E+01	9.11528E-01	1.71922E-03	0.00000E+00	0.00000E+00
324	9.37391E-01	8.22813E+01	9.11577E-01	1.71670E-03	0.00000E+00	0.00000E+00
325	9.66647E-01	8.24365E+01	9.11682E-01	1.71662E-03	0.00000E+00	0.00000E+00
326	9.29363E-01	8.25882E+01	9.11716E-01	1.71368E-03	0.00000E+00	0.00000E+00
327	8.86606E-01	8.27497E+01	9.11668E-01	1.71115E-03	0.00000E+00	0.00000E+00
328	9.24338E-01	8.28995E+01	9.11692E-01	1.70805E-03	0.00000E+00	0.00000E+00
329	9.61366E-01	8.30420E+01	9.11787E-01	1.70739E-03	0.00000E+00	0.00000E+00
330	9.11402E-01	8.31958E+01	9.11786E-01	1.70419E-03	0.00000E+00	0.00000E+00
331	9.10498E-01	8.33512E+01	9.11784E-01	1.70094E-03	0.00000E+00	0.00000E+00
332	9.64949E-01	8.35033E+01	9.11884E-01	1.70069E-03	0.00000E+00	0.00000E+00
333	8.72396E-01	8.36635E+01	9.11810E-01	1.69912E-03	0.00000E+00	0.00000E+00
334	8.48253E-01	8.38272E+01	9.11691E-01	1.70009E-03	0.00000E+00	0.00000E+00
335	9.01529E-01	8.39778E+01	9.11672E-01	1.69701E-03	0.00000E+00	0.00000E+00
336	9.15292E-01	8.41270E+01	9.11678E-01	1.69387E-03	0.00000E+00	0.00000E+00
337	9.58793E-01	8.42692E+01	9.11766E-01	1.69294E-03	0.00000E+00	0.00000E+00
338	9.62697E-01	8.44185E+01	9.11675E-01	1.69221E-03	0.00000E+00	0.00000E+00
339	9.36394E-01	8.45677E+01	9.11758E-01	1.69116E-03	0.00000E+00	0.00000E+00
340	9.08090E-01	8.47178E+01	9.11751E-01	1.68807E-03	0.00000E+00	0.00000E+00
341	9.11603E-01	8.48752E+01	9.11751E-01	1.68496E-03	0.00000E+00	0.00000E+00
342	8.88663E-01	8.50328E+01	9.11708E-01	1.68234E-03	0.00000E+00	0.00000E+00
343	9.90188E-01	8.51812E+01	9.11853E-01	1.68554E-03	0.00000E+00	0.00000E+00
344	8.96606E-01	8.53340E+01	9.11825E-01	1.68264E-03	0.00000E+00	0.00000E+00
345	8.70976E-01	8.54885E+01	9.11750E-01	1.68125E-03	0.00000E+00	0.00000E+00
346	9.00160E-01	8.56290E+01	9.11729E-01	1.67833E-03	0.00000E+00	0.00000E+00
347	9.23458E-01	8.57845E+01	9.11750E-01	1.67538E-03	0.00000E+00	0.00000E+00
348	9.39022E-01	8.59447E+01	9.11800E-01	1.67302E-03	0.00000E+00	0.00000E+00
349	9.02336E-01	8.61057E+01	9.11783E-01	1.67002E-03	0.00000E+00	0.00000E+00
350	9.10025E-01	8.62782E+01	9.11780E-01	1.66702E-03	0.00000E+00	0.00000E+00
351	8.69618E-01	8.64522E+01	9.11703E-01	1.66570E-03	0.00000E+00	0.00000E+00
352	8.61135E-01	8.66147E+01	9.11611E-01	1.66519E-03	0.00000E+00	0.00000E+00
353	9.54250E-01	8.67647E+01	9.11688E-01	1.66397E-03	0.00000E+00	0.00000E+00
354	9.30907E-01	8.69247E+01	9.11723E-01	1.66129E-03	0.00000E+00	0.00000E+00
355	9.71223E-01	8.70762E+01	9.11831E-01	1.66160E-03	0.00000E+00	0.00000E+00
356	9.65331E-01	8.72307E+01	9.11927E-01	1.66153E-03	0.00000E+00	0.00000E+00
357	9.26601E-01	8.73813E+01	9.11954E-01	1.65876E-03	0.00000E+00	0.00000E+00
358	9.55757E-01	8.75370E+01	9.12032E-01	1.65766E-03	0.00000E+00	0.00000E+00
359	9.01879E-01	8.76900E+01	9.12014E-01	1.65477E-03	0.00000E+00	0.00000E+00
360	9.23230E-01	8.78537E+01	9.12034E-01	1.65196E-03	0.00000E+00	0.00000E+00
361	8.97609E-01	8.80063E+01	9.12009E-01	1.64918E-03	0.00000E+00	0.00000E+00
362	9.13636E-01	8.81510E+01	9.12011E-01	1.64622E-03	0.00000E+00	0.00000E+00
363	9.11126E-01	8.83055E+01	9.12010E-01	1.64323E-03	0.00000E+00	0.00000E+00
364	9.23487E-01	8.84578E+01	9.12030E-01	1.64044E-03	0.00000E+00	0.00000E+00
365	8.74247E-01	8.86130E+01	9.11963E-01	1.63891E-03	0.00000E+00	0.00000E+00
366	9.67010E-01	8.87572E+01	9.12061E-01	1.63894E-03	0.00000E+00	0.00000E+00
367	9.88759E-01	8.89152E+01	9.12197E-01	1.64138E-03	0.00000E+00	0.00000E+00
368	9.28808E-01	8.90832E+01	9.12226E-01	1.63894E-03	0.00000E+00	0.00000E+00
369	9.39496E-01	8.92360E+01	9.12274E-01	1.63672E-03	0.00000E+00	0.00000E+00
370	8.91658E-01	8.93888E+01	9.12238E-01	1.63421E-03	0.00000E+00	0.00000E+00
371	9.12013E-01	8.95527E+01	9.12237E-01	1.63136E-03	0.00000E+00	0.00000E+00
372	8.33122E-01	8.96910E+01	9.12099E-01	1.63438E-03	0.00000E+00	0.00000E+00
373	9.00254E-01	8.98548E+01	9.12078E-01	1.63164E-03	0.00000E+00	0.00000E+00
374	9.17782E-01	9.00130E+01	9.12088E-01	1.62880E-03	0.00000E+00	0.00000E+00
375	8.60863E-01	9.01722E+01	9.11998E-01	1.62843E-03	0.00000E+00	0.00000E+00
376	8.77944E-01	9.03355E+01	9.11939E-01	1.62672E-03	0.00000E+00	0.00000E+00
377	9.26965E-01	9.04898E+01	9.11985E-01	1.62412E-03	0.00000E+00	0.00000E+00
378	9.56768E-01	9.06398E+01	9.12043E-01	1.62315E-03	0.00000E+00	0.00000E+00
379	9.75514E-01	9.07958E+01	9.12153E-01	1.62404E-03	0.00000E+00	0.00000E+00
380	9.31358E-01	9.09557E+01	9.12186E-01	1.62158E-03	0.00000E+00	0.00000E+00
381	9.17453E-01	9.11118E+01	9.12195E-01	1.61878E-03	0.00000E+00	0.00000E+00

582	9.13961E-01	9.12813E+01	9.12198E-01	1.61601E-03	0.00000E+00	0.00000E+00
583	8.37340E-01	9.14258E+01	9.12070E-01	1.61833E-03	0.00000E+00	0.00000E+00
584	9.04180E-01	9.15837E+01	9.12056E-01	1.61564E-03	0.00000E+00	0.00000E+00
585	8.56547E-01	9.17432E+01	9.11951E-01	1.61563E-03	0.00000E+00	0.00000E+00
586	9.01762E-01	9.19082E+01	9.11563E-01	1.61303E-03	0.00000E+00	0.00000E+00
587	8.71158E-01	9.20682E+01	9.11876E-01	1.61174E-03	0.00000E+00	0.00000E+00
588	8.80598E-01	9.22240E+01	9.11820E-01	1.60985E-03	0.00000E+00	0.00000E+00
589	8.99829E-01	9.23790E+01	9.11800E-01	1.60725E-03	0.00000E+00	0.00000E+00
590	8.35945E-01	9.25578E+01	9.11671E-01	1.60967E-03	0.00000E+00	0.00000E+00
591	8.64735E-01	9.27287E+01	9.11591E-01	1.60693E-03	0.00000E+00	0.00000E+00
592	8.66407E-01	9.28915E+01	9.11515E-01	1.60800E-03	0.00000E+00	0.00000E+00
593	9.01313E-01	9.30500E+01	9.11497E-01	1.60541E-03	0.00000E+00	0.00000E+00
594	9.05755E-01	9.32200E+01	9.11488E-01	1.60276E-03	0.00000E+00	0.00000E+00
595	8.90639E-01	9.33860E+01	9.11453E-01	1.60047E-03	0.00000E+00	0.00000E+00
596	9.35320E-01	9.35340E+01	9.11493E-01	1.59827E-03	0.00000E+00	0.00000E+00
597	8.80345E-01	9.36813E+01	9.11440E-01	1.59642E-03	0.00000E+00	0.00000E+00
598	8.69139E-01	9.38360E+01	9.11370E-01	1.59526E-03	0.00000E+00	0.00000E+00
599	9.32832E-01	9.39842E+01	9.11406E-01	1.59295E-03	0.00000E+00	0.00000E+00
600	9.30088E-01	9.41513E+01	9.11437E-01	1.59058E-03	0.00000E+00	0.00000E+00
601	9.21349E-01	9.43028E+01	9.11454E-01	1.58797E-03	0.00000E+00	0.00000E+00
602	8.36855E-01	9.44682E+01	9.11329E-01	1.59018E-03	0.00000E+00	0.00000E+00
603	9.37578E-01	9.46245E+01	9.11373E-01	1.58810E-03	0.00000E+00	0.00000E+00
604	9.38473E-01	9.47778E+01	9.11418E-01	1.58616E-03	0.00000E+00	0.00000E+00
605	8.70978E-01	9.49397E+01	9.11351E-01	1.58493E-03	0.00000E+00	0.00000E+00
606	9.39261E-01	9.50987E+01	9.11397E-01	1.58299E-03	0.00000E+00	0.00000E+00
607	8.51935E-01	9.52502E+01	9.11299E-01	1.58343E-03	0.00000E+00	0.00000E+00
608	9.24644E-01	9.54103E+01	9.11321E-01	1.58100E-03	0.00000E+00	0.00000E+00
609	8.82428E-01	9.55635E+01	9.11273E-01	1.57910E-03	0.00000E+00	0.00000E+00
610	8.73258E-01	9.57143E+01	9.11211E-01	1.57777E-03	0.00000E+00	0.00000E+00
611	9.40752E-01	9.58650E+01	9.11259E-01	1.57597E-03	0.00000E+00	0.00000E+00
612	1.01581E+00	9.60173E+01	9.11431E-01	1.58268E-03	0.00000E+00	0.00000E+00
613	8.82995E-01	9.61808E+01	9.11384E-01	1.58079E-03	0.00000E+00	0.00000E+00
614	8.63332E-01	9.63413E+01	9.11306E-01	1.58015E-03	0.00000E+00	0.00000E+00
615	7.95175E-01	9.65082E+01	9.11116E-01	1.58891E-03	0.00000E+00	0.00000E+00
616	9.31067E-01	9.66660E+01	9.11149E-01	1.58660E-03	0.00000E+00	0.00000E+00
617	9.37780E-01	9.68295E+01	9.11192E-01	1.58457E-03	0.00000E+00	0.00000E+00
618	8.93880E-01	9.69813E+01	9.11164E-01	1.58230E-03	0.00000E+00	0.00000E+00
619	8.73576E-01	9.71350E+01	9.11103E-01	1.58087E-03	0.00000E+00	0.00000E+00
620	8.94590E-01	9.72893E+01	9.11076E-01	1.57848E-03	0.00000E+00	0.00000E+00
621	9.14494E-01	9.74372E+01	9.11082E-01	1.57598E-03	0.00000E+00	0.00000E+00
622	9.10433E-01	9.76163E+01	9.11081E-01	1.57336E-03	0.00000E+00	0.00000E+00
623	9.40496E-01	9.77708E+01	9.11128E-01	1.57157E-03	0.00000E+00	0.00000E+00
624	9.48617E-01	9.79313E+01	9.11189E-01	1.57025E-03	0.00000E+00	0.00000E+00
625	1.00231E+00	9.80777E+01	9.11335E-01	1.57453E-03	0.00000E+00	0.00000E+00
626	9.33458E-01	9.82337E+01	9.11370E-01	1.57239E-03	0.00000E+00	0.00000E+00
627	8.75702E-01	9.83970E+01	9.11313E-01	1.57085E-03	0.00000E+00	0.00000E+00
628	8.99903E-01	9.85472E+01	9.11295E-01	1.56841E-03	0.00000E+00	0.00000E+00
629	9.32387E-01	9.87005E+01	9.11329E-01	1.56627E-03	0.00000E+00	0.00000E+00
630	8.91278E-01	9.88480E+01	9.11297E-01	1.56405E-03	0.00000E+00	0.00000E+00
631	8.45737E-01	9.90050E+01	9.11193E-01	1.56502E-03	0.00000E+00	0.00000E+00
632	8.43090E-01	9.91670E+01	9.11084E-01	1.56632E-03	0.00000E+00	0.00000E+00
633	8.89629E-01	9.93208E+01	9.11050E-01	1.56414E-03	0.00000E+00	0.00000E+00
634	9.74650E-01	9.94787E+01	9.11151E-01	1.56489E-03	0.00000E+00	0.00000E+00
635	9.32750E-01	9.96392E+01	9.11185E-01	1.56278E-03	0.00000E+00	0.00000E+00
636	8.83465E-01	9.97918E+01	9.11142E-01	1.56091E-03	0.00000E+00	0.00000E+00
637	8.88327E-01	9.99462E+01	9.11106E-01	1.55890E-03	0.00000E+00	0.00000E+00
638	8.95839E-01	1.00108E+02	9.11082E-01	1.55658E-03	0.00000E+00	0.00000E+00
639	8.63140E-01	1.00265E+02	9.11006E-01	1.55597E-03	0.00000E+00	0.00000E+00
640	9.06582E-01	1.00419E+02	9.10999E-01	1.55354E-03	0.00000E+00	0.00000E+00
641	9.17683E-01	1.00575E+02	9.11010E-01	1.55117E-03	0.00000E+00	0.00000E+00
642	8.85160E-01	1.00721E+02	9.10969E-01	1.54936E-03	0.00000E+00	0.00000E+00
643	8.67960E-01	1.00867E+02	9.10902E-01	1.54833E-03	0.00000E+00	0.00000E+00
644	8.88603E-01	1.01017E+02	9.10868E-01	1.54620E-03	0.00000E+00	0.00000E+00
645	8.89108E-01	1.01184E+02	9.10834E-01	1.54429E-03	0.00000E+00	0.00000E+00
646	9.11614E-01	1.01340E+02	9.10835E-01	1.54192E-03	0.00000E+00	0.00000E+00

647	9.21245E-01	1.01499E+02	9.10851E-01	1.53961E-03	0.00000E+00	0.00000E+00
648	9.01735E-01	1.01659E+02	9.10837E-01	1.53721E-03	0.00000E+00	0.00000E+00
649	9.90137E-01	1.01812E+02	9.10960E-01	1.53977E-03	0.00000E+00	0.00000E+00
650	9.43291E-01	1.01970E+02	9.11009E-01	1.53819E-03	0.00000E+00	0.00000E+00
651	9.05654E-01	1.02130E+02	9.11001E-01	1.53581E-03	0.00000E+00	0.00000E+00
652	8.13601E-01	1.02282E+02	9.11005E-01	1.53349E-03	0.00000E+00	0.00000E+00
653	8.79119E-01	1.02428E+02	9.10956E-01	1.53192E-03	0.00000E+00	0.00000E+00
654	8.87040E-01	1.02584E+02	9.10919E-01	1.53005E-03	0.00000E+00	0.00000E+00
655	9.10298E-01	1.02741E+02	9.10918E-01	1.52774E-03	0.00000E+00	0.00000E+00
656	8.35975E-01	1.02892E+02	9.10804E-01	1.52968E-03	0.00000E+00	0.00000E+00
657	8.58339E-01	1.03055E+02	9.10724E-01	1.52940E-03	0.00000E+00	0.00000E+00
658	9.31375E-01	1.03210E+02	9.10756E-01	1.52734E-03	0.00000E+00	0.00000E+00
659	8.83620E-01	1.03361E+02	9.10714E-01	1.52555E-03	0.00000E+00	0.00000E+00
660	9.17060E-01	1.03514E+02	9.10724E-01	1.52332E-03	0.00000E+00	0.00000E+00
661	9.79530E-01	1.03662E+02	9.10828E-01	1.52437E-03	0.00000E+00	0.00000E+00
662	9.31042E-01	1.03809E+02	9.10859E-01	1.52252E-03	0.00000E+00	0.00000E+00
663	8.92987E-01	1.03963E+02	9.10832E-01	1.52042E-03	0.00000E+00	0.00000E+00
664	9.22963E-01	1.04119E+02	9.10850E-01	1.51823E-03	0.00000E+00	0.00000E+00
665	9.73617E-01	1.04272E+02	9.10945E-01	1.51889E-03	0.00000E+00	0.00000E+00
666	8.66506E-01	1.04436E+02	9.10878E-01	1.51804E-03	0.00000E+00	0.00000E+00
667	9.86626E-01	1.04586E+02	9.10992E-01	1.52009E-03	0.00000E+00	0.00000E+00
668	9.07103E-01	1.04764E+02	9.10986E-01	1.51776E-03	0.00000E+00	0.00000E+00
669	8.96538E-01	1.04890E+02	9.10965E-01	1.51565E-03	0.00000E+00	0.00000E+00
670	9.43858E-01	1.05037E+02	9.11017E-01	1.51431E-03	0.00000E+00	0.00000E+00
671	9.28850E-01	1.05186E+02	9.11043E-01	1.51223E-03	0.00000E+00	0.00000E+00
672	8.13284E-01	1.05347E+02	9.10897E-01	1.51695E-03	0.00000E+00	0.00000E+00
673	8.87349E-01	1.05504E+02	9.10862E-01	1.51518E-03	0.00000E+00	0.00000E+00
674	9.16033E-01	1.05661E+02	9.10873E-01	1.51293E-03	0.00000E+00	0.00000E+00
675	9.36402E-01	1.05810E+02	9.10911E-01	1.51113E-03	0.00000E+00	0.00000E+00
676	8.98261E-01	1.05970E+02	9.10892E-01	1.50901E-03	0.00000E+00	0.00000E+00
677	8.53267E-01	1.06132E+02	9.10807E-01	1.50912E-03	0.00000E+00	0.00000E+00
678	9.49111E-01	1.06287E+02	9.10863E-01	1.50860E-03	0.00000E+00	0.00000E+00
679	9.44071E-01	1.06447E+03	9.10912E-01	1.50662E-03	0.00000E+00	0.00000E+00
680	8.60165E-01	1.06610E+02	9.10837E-01	1.50618E-03	0.00000E+00	0.00000E+00
681	9.23091E-01	1.06758E+02	9.10856E-01	1.50408E-03	0.00000E+00	0.00000E+00
682	9.97627E-01	1.06901E+02	9.10983E-01	1.50729E-03	0.00000E+00	0.00000E+00
683	9.42814E-01	1.07069E+02	9.11030E-01	1.50583E-03	0.00000E+00	0.00000E+00
684	9.31408E-01	1.07225E+03	9.11089E-01	1.50475E-03	0.00000E+00	0.00000E+00
685	9.18944E-01	1.07370E+03	9.11101E-01	1.50260E-03	0.00000E+00	0.00000E+00
686	9.29241E-01	1.07535E+02	9.11127E-01	1.50060E-03	0.00000E+00	0.00000E+00
687	9.78837E-01	1.07690E+02	9.11223E-01	1.50151E-03	0.00000E+00	0.00000E+00
688	9.16631E-01	1.07845E+02	9.11231E-01	1.49934E-03	0.00000E+00	0.00000E+00
689	9.14792E-01	1.08013E+03	9.11236E-01	1.49720E-03	0.00000E+00	0.00000E+00
690	9.28855E-01	1.08181E+02	9.11262E-01	1.49527E-03	0.00000E+00	0.00000E+00
691	8.97583E-01	1.08333E+02	9.11227E-01	1.49348E-03	0.00000E+00	0.00000E+00
692	9.04364E-01	1.08487E+02	9.11217E-01	1.49139E-03	0.00000E+00	0.00000E+00
693	8.78944E-01	1.08645E+02	9.11171E-01	1.48990E-03	0.00000E+00	0.00000E+00
694	9.03614E-01	1.08808E+02	9.11160E-01	1.48778E-03	0.00000E+00	0.00000E+00
695	9.05684E-01	1.08962E+02	9.11152E-01	1.48563E-03	0.00000E+00	0.00000E+00
696	9.51864E-01	1.09110E+02	9.11210E-01	1.48464E-03	0.00000E+00	0.00000E+00
697	9.84788E-01	1.09275E+02	9.11316E-01	1.48629E-03	0.00000E+00	0.00000E+00
698	9.24949E-01	1.09421E+02	9.11336E-01	1.48433E-03	0.00000E+00	0.00000E+00
699	9.52468E-01	1.09564E+02	9.11395E-01	1.48332E-03	0.00000E+00	0.00000E+00
700	9.05842E-01	1 09749E+02	9.11392E-01	1.48116E-03	0.00000E+00	0.00000E+00
701	9.75089E-01	1 09905E+02	9.11484E-01	1.48185E-03	0.00000E+00	0.00000E+00
702	8.88311E-01	1.10062E+02	9.11448E-01	1.48019E-03	0.00000E+00	0.00000E+00
703	9.20433E-01	1.10214E+02	9.11460E-01	1.47815E-03	0.00000E+00	0.00000E+00
704	9.82268E-01	1.10384E+02	9.11561E-01	1.47949E-03	0.00000E+00	0.00000E+00
705	9.09989E-01	1.10540E+02	9.11559E-01	1.47743E-03	0.00000E+00	0.00000E+00
706	9.39994E-01	1.10684E+02	9.11599E-01	1.47583E-03	0.00000E+00	0.00000E+00
707	9.35321E-01	1.10830E+02	9.11633E-01	1.47415E-03	0.00000E+00	0.00000E+00
708	9.27456E-01	1.10976E+02	9.11655E-01	1.47227E-03	0.00000E+00	0.00000E+00
709	8.95073E-01	1.11143E+02	9.11632E-01	1.47037E-03	0.00000E+00	0.00000E+00
710	9.28888E-01	1.11304E+02	9.11656E-01	1.46849E-03	0.00000E+00	0.00000E+00
711	9.15619E-01	1.11452E+02	9.11662E-01	1.46639E-03	0.00000E+00	0.00000E+00

712	9.11073E-01	1.11613E+02	9.11661E-01	1.46436E-03	0.00000E+00	0.00000E+00
713	8.91880E-01	1.11769E+02	9.11633E-01	1.46252E-03	0.00000E+00	0.00000E+00
714	8.67057E-01	1.11925E+02	9.11571E-01	1.46181E-03	0.00000E+00	0.00000E+00
715	8.97919E-01	1.12089E+02	9.11552E-01	1.45986E-03	0.00000E+00	0.00000E+00
716	8.85590E-01	1.12243E+02	9.11515E-01	1.45824E-03	0.00000E+00	0.00000E+00
717	9.03913E-01	1.12389E+02	9.11505E-01	1.45618E-03	0.00000E+00	0.00000E+00
718	9.63311E-01	1.12552E+02	9.11577E-01	1.45594E-03	0.00000E+00	0.00000E+00
719	8.93433E-01	1.12715E+02	9.11552E-01	1.45415E-03	0.00000E+00	0.00000E+00
720	9.14375E-01	1.12873E+02	9.11556E-01	1.45210E-03	0.00000E+00	0.00000E+00
721	9.57154E-01	1.13022E+02	9.11619E-01	1.45146E-03	0.00000E+00	0.00000E+00
722	9.68629E-01	1.13184E+02	9.11698E-01	1.45163E-03	0.00000E+00	0.00000E+00
723	9.79781E-01	1.13352E+02	9.11793E-01	1.45261E-03	0.00000E+00	0.00000E+00
724	9.27270E-01	1.13499E+02	9.11814E-01	1.45081E-03	0.00000E+00	0.00000E+00
725	8.54591E-01	1.13656E+02	9.11735E-01	1.45094E-03	0.00000E+00	0.00000E+00
726	9.08251E-01	1.13802E+02	9.11730E-01	1.44891E-03	0.00000E+00	0.00000E+00
727	9.11344E-01	1.13958E+02	9.11730E-01	1.44695E-03	0.00000E+00	0.00000E+00
728	9.27572E-01	1.14119E+02	9.11751E-01	1.44518E-03	0.00000E+00	0.00000E+00
729	9.85366E-01	1.14267E+02	9.11833E-01	1.44671E-03	0.00000E+00	0.00000E+00
730	9.02892E-01	1.14425E+02	9.11841E-01	1.44472E-03	0.00000E+00	0.00000E+00
731	8.98114E-01	1.14584E+02	9.11822E-01	1.44285E-03	0.00000E+00	0.00000E+00
732	8.78623E-01	1.14740E+02	9.11776E-01	1.44158E-03	0.00000E+00	0.00000E+00
733	9.56578E-01	1.14896E+02	9.11838E-01	1.44090E-03	0.00000E+00	0.00000E+00
734	9.36474E-01	1.15050E+02	9.11871E-01	1.43932E-03	0.00000E+00	0.00000E+00
735	8.65716E-01	1.15204E+02	9.11808E-01	1.43871E-03	0.00000E+00	0.00000E+00
736	8.98927E-01	1.15357E+02	9.11791E-01	1.43688E-03	0.00000E+00	0.00000E+00
737	8.81603E-01	1.15518E+02	9.11750E-01	1.43547E-03	0.00000E+00	0.00000E+00
738	8.89614E-01	1.15674E+02	9.11720E-01	1.43387E-03	0.00000E+00	0.00000E+00
739	9.13979E-01	1.15824E+02	9.11723E-01	1.43188E-03	0.00000E+00	0.00000E+00
740	9.17096E-01	1.15973E+02	9.11730E-01	1.42998E-03	0.00000E+00	0.00000E+00
741	9.01620E-01	1.16131E+02	9.11716E-01	1.42808E-03	0.00000E+00	0.00000E+00
742	9.03719E-01	1.16275E+02	9.11706E-01	1.42618E-03	0.00000E+00	0.00000E+00
743	8.85941E-01	1.16428E+02	9.11671E-01	1.42473E-03	0.00000E+00	0.00000E+00
744	9.56344E-01	1.16589E+02	9.11731E-01	1.42405E-03	0.00000E+00	0.00000E+00
745	9.86416E-01	1.16748E+02	9.11831E-01	1.42569E-03	0.00000E+00	0.00000E+00
746	8.52895E-01	1.16910E+02	9.11752E-01	1.42599E-03	0.00000E+00	0.00000E+00
747	9.45228E-01	1.17071E+02	9.11797E-01	1.42475E-03	0.00000E+00	0.00000E+00
748	9.21900E-01	1.17229E+02	9.11911E-01	1.42293E-03	0.00000E+00	0.00000E+00
749	9.67849E-01	1.17373E+02	9.11886E-01	1.42301E-03	0.00000E+00	0.00000E+00
750	8.70053E-01	1.17526E+02	9.11830E-01	1.42223E-03	0.00000E+00	0.00000E+00
751	8.94088E-01	1.17677E+02	9.11806E-01	1.42049E-03	0.00000E+00	0.00000E+00
752	9.22394E-01	1.17851E+02	9.11820E-01	1.41867E-03	0.00000E+00	0.00000E+00
753	7.60672E-01	1.17999E+02	9.11619E-01	1.43095E-03	0.00000E+00	0.00000E+00
754	9.61354E-01	1.18150E+02	9.11685E-01	1.43058E-03	0.00000E+00	0.00000E+00
755	9.38618E-01	1.18303E+02	9.11721E-01	1.42913E-03	0.00000E+00	0.00000E+00
756	9.31170E-01	1.18437E+02	9.11747E-01	1.42751E-03	0.00000E+00	0.00000E+00
757	8.82011E-01	1.18618E+02	9.11708E-01	1.42612E-03	0.00000E+00	0.00000E+00
758	9.51542E-01	1.18774E+02	9.11760E-01	1.42521E-03	0.00000E+00	0.00000E+00
759	9.66478E-01	1.18925E+02	9.11833E-01	1.42515E-03	0.00000E+00	0.00000E+00
760	8.51242E-01	1.19078E+02	9.11753E-01	1.42553E-03	0.00000E+00	0.00000E+00
761	9.30916E-01	1.19226E+02	9.11778E-01	1.42388E-03	0.00000E+00	0.00000E+00
762	9.72038E-01	1.19371E+02	9.11857E-01	1.42418E-03	0.00000E+00	0.00000E+00
763	9.17258E-01	1.19524E+02	9.11864E-01	1.42233E-03	0.00000E+00	0.00000E+00
764	9.32746E-01	1.19673E+02	9.11892E-01	1.42076E-03	0.00000E+00	0.00000E+00
765	8.56700E-01	1.19835E+02	9.11819E-01	1.42077E-03	0.00000E+00	0.00000E+00
766	9.07428E-01	1.19988E+02	9.11813E-01	1.41896E-03	0.00000E+00	0.00000E+00
767	9.00637E-01	1.20149E+02	9.11799E-01	1.41717E-03	0.00000E+00	0.00000E+00
768	9.68113E-01	1.20307E+02	9.11742E-01	1.41647E-03	0.00000E+00	0.00000E+00
769	9.04803E-01	1.20468E+02	9.11733E-01	1.41466E-03	0.00000E+00	0.00000E+00
770	9.05387E-01	1.20622E+02	9.11725E-01	1.41280E-03	0.00000E+00	0.00000E+00
771	8.95179E-01	1.20773E+02	9.11703E-01	1.41106E-03	0.00000E+00	0.00000E+00
772	8.65398E-01	1.20936E+02	9.11643E-01	1.41050E-03	0.00000E+00	0.00000E+00
773	1.00190E+00	1.21093E+02	9.11760E-01	1.41353E-03	0.00000E+00	0.00000E+00
774	9.36966E-01	1.21241E+02	9.11793E-01	1.41209E-03	0.00000E+00	0.00000E+00
775	9.68339E-01	1.21388E+02	9.11866E-01	1.41216E-03	0.00000E+00	0.00000E+00
776	8.99371E-01	1.21541E+02	9.11850E-01	1.41046E-03	0.00000E+00	0.00000E+00

777	9.66056E-01	1.21688E+02	9.11920E-01	1.41037E-03	0.00000E+00	0.00000E+00
778	9.43908E-01	1.21843E+02	9.11963E-01	1.40921E-03	0.00000E+00	0.00000E+00
779	9.56314E-01	1.22004E+02	9.12021E-01	1.40860E-03	0.00000E+00	0.00000E+00
780	9.58372E-01	1.22165E+02	9.12078E-01	1.40791E-03	0.00000E+00	0.00000E+00
781	9.21156E-01	1.22326E+02	9.12089E-01	1.40816E-03	0.00000E+00	0.00000E+00
782	9.44885E-01	1.22480E+02	9.12131E-01	1.40502E-03	0.00000E+00	0.00000E+00
783	9.52899E-01	1.22633E+02	9.12183E-01	1.40417E-03	0.00000E+00	0.00000E+00
784	8.97420E-01	1.22798E+02	9.12164E-01	1.40256E-03	0.00000E+00	0.00000E+00
785	8.57187E-01	1.22964E+02	9.12094E-01	1.40251E-03	0.00000E+00	0.00000E+00
786	9.28032E-01	1.23128E+02	9.12115E-01	1.40085E-03	0.00000E+00	0.00000E+00
787	9.03623E-01	1.23284E+02	9.12104E-01	1.39912E-03	0.00000E+00	0.00000E+00
788	8.91846E-01	1.23453E+02	9.12078E-01	1.39760E-03	0.00000E+00	0.00000E+00
789	9.55185E-01	1.23614E+02	9.12133E-01	1.39685E-03	0.00000E+00	0.00000E+00
790	9.18384E-01	1.23773E+02	9.12138E-01	1.39514E-03	0.00000E+00	0.00000E+00
791	9.45339E-01	1.23922E+02	9.12180E-01	1.39402E-03	0.00000E+00	0.00000E+00
792	8.64544E-01	1.24077E+02	9.12120E-01	1.39359E-03	0.00000E+00	0.00000E+00
793	9.91510E-01	1.24235E+02	9.12220E-01	1.39544E-03	0.00000E+00	0.00000E+00
794	9.80397E-01	1.24383E+02	9.12306E-01	1.39632E-03	0.00000E+00	0.00000E+00
795	8.91619E-01	1.24542E+02	9.12280E-01	1.39481E-03	0.00000E+00	0.00000E+00
796	9.61456E-01	1.24697E+02	9.12342E-01	1.39447E-03	0.00000E+00	0.00000E+00
797	8.80217E-01	1.24846E+02	9.12301E-01	1.39330E-03	0.00000E+00	0.00000E+00
798	9.80091E-01	1.25000E+02	9.12387E-01	1.39412E-03	0.00000E+00	0.00000E+00
799	9.06683E-01	1.25166E+02	9.12380E-01	1.39235E-03	0.00000E+00	0.00000E+00
800	8.50326E-01	1.25321E+02	9.12339E-01	1.39124E-03	0.00000E+00	0.00000E+00
801	8.36392E-01	1.25479E+02	9.12244E-01	1.39275E-03	0.00000E+00	0.00000E+00
802	9.01753E-01	1.25632E+02	9.12231E-01	1.39108E-03	0.00000E+00	0.00000E+00
803	9.08875E-01	1.25792E+02	9.12227E-01	1.38938E-03	0.00000E+00	0.00000E+00

KENO MESSAGE NUMBER K5-123 EXECUTION TERMINATED DUE TO COMPLETION OF THE SPECIFIED NUMBER OF GENERATIONS.

FMBARRAY KENO CASE COMPARISON WITH MONK5B

LIFETIME = 5.19904E-05 + OR - 2.76423E-07 GENERATION TIME = 2.29799E-05 + OR - 6.72287E-08

NO. OF INITIAL GENERATIONS SKIPPED	AVERAGE K-EFFECTIVE	DEVIATION	67 PER CENT CONFIDENCE INTERVAL	95 PER CENT CONFIDENCE INTERVAL	99 PER CENT CONFIDENCE INTERVAL	NUMBER OF HISTORIES
3	0.91225	+ OR - 0.00139	0.91085 TO 0.91364	0.90946 TO 0.91503	0.90807 TO 0.91642	240000
4	0.91230	+ OR - 0.00139	0.91091 TO 0.91369	0.90952 TO 0.91508	0.90812 TO 0.91648	239700
5	0.91226	+ OR - 0.00139	0.91087 TO 0.91366	0.90948 TO 0.91505	0.90808 TO 0.91644	239400
6	0.91228	+ OR - 0.00140	0.91088 TO 0.91367	0.90949 TO 0.91507	0.90809 TO 0.91646	239100
7	0.91228	+ OR - 0.00140	0.91088 TO 0.91368	0.90949 TO 0.91508	0.90809 TO 0.91647	238800
8	0.91230	+ OR - 0.00140	0.91090 TO 0.91370	0.90950 TO 0.91510	0.90810 TO 0.91649	238500
9	0.91232	+ OR - 0.00140	0.91092 TO 0.91372	0.90952 TO 0.91512	0.90811 TO 0.91652	238200
10	0.91222	+ OR - 0.00140	0.91082 TO 0.91361	0.90942 TO 0.91501	0.90802 TO 0.91641	237900
11	0.91225	+ OR - 0.00140	0.91085 TO 0.91365	0.90943 TO 0.91505	0.90805 TO 0.91645	237600
12	0.91231	+ OR - 0.00140	0.91091 TO 0.91371	0.90951 TO 0.91511	0.90811 TO 0.91651	237300
17	0.91248	+ OR - 0.00141	0.91107 TO 0.91388	0.90966 TO 0.91529	0.90826 TO 0.91670	235800
22	0.91246	+ OR - 0.00141	0.91104 TO 0.91387	0.90963 TO 0.91528	0.90821 TO 0.91670	234300
27	0.91245	+ OR - 0.00142	0.91103 TO 0.91387	0.90961 TO 0.91529	0.90819 TO 0.91671	232800
32	0.91233	+ OR - 0.00143	0.91091 TO 0.91376	0.90548 TO 0.91518	0.90805 TO 0.91661	231300
37	0.91235	+ OR - 0.00143	0.91092 TO 0.91378	0.90949 TO 0.91521	0.90805 TO 0.91665	229800
42	0.91228	+ OR - 0.00144	0.91084 TO 0.91372	0.90940 TO 0.91516	0.90796 TO 0.91659	228300
47	0.91244	+ OR - 0.00144	0.91100 TO 0.91389	0.90956 TO 0.91533	0.90812 TO 0.91677	226800
52	0.91249	+ OR - 0.00145	0.91104 TO 0.91394	0.90959 TO 0.91539	0.90816 TO 0.91684	225300
57	0.91249	+ OR - 0.00146	0.91103 TO 0.91395	0.90957 TO 0.91541	0.90811 TO 0.91687	223800
62	0.91248	+ OR - 0.00147	0.91101 TO 0.91395	0.90954 TO 0.91542	0.90807 TO 0.91689	222300
67	0.91258	+ OR - 0.00148	0.91110 TO 0.91405	0.90963 TO 0.91553	0.90815 TO 0.91701	220800
72	0.91253	+ OR - 0.00148	0.91104 TO 0.91401	0.90956 TO 0.91549	0.90808 TO 0.91698	219300
77	0.91273	+ OR - 0.00149	0.91124 TO 0.91422	0.90975 TO 0.91571	0.90826 TO 0.91720	217800
82	0.91285	+ OR - 0.00150	0.91135 TO 0.91434	0.90985 TO 0.91584	0.90836 TO 0.91733	216300
87	0.91303	+ OR - 0.00149	0.91154 TO 0.91453	0.91004 TO 0.91602	0.90855 TO 0.91752	214800
92	0.91294	+ OR - 0.00150	0.91144 TO 0.91444	0.90995 TO 0.91593	0.90845 TO 0.91743	213300

PWRARRAY KENO CASE COMPARISON WITH MONK6B

NO. OF INITIAL GENERATIONS SKIPPED	AVERAGE K-EFFECTIVE	DEVIATION	67 PER CENT CONFIDENCE INTERVAL	95 PER CENT CONFIDENCE INTERVAL	99 PER CENT CONFIDENCE INTERVAL	NUMBER OF HISTORIES
97	0.91268	+ OR - 0.00150	0.91117 TO 0.91416	0.90967 TO 0.91566	0.90817 TO 0.91716	211800
102	0.91243	+ OR - 0.00150	0.91093 TO 0.91393	0.90942 TO 0.91543	0.90792 TO 0.91693	210300
107	0.91245	+ OR - 0.00151	0.91094 TO 0.91396	0.90943 TO 0.91548	0.90792 TO 0.91699	208800
112	0.91240	+ OR - 0.00152	0.91089 TO 0.91392	0.90937 TO 0.91543	0.90785 TO 0.91695	207300
117	0.91255	+ OR - 0.00152	0.91103 TO 0.91407	0.90951 TO 0.91558	0.90800 TO 0.91710	205800
122	0.91263	+ OR - 0.00153	0.91110 TO 0.91416	0.90958 TO 0.91568	0.90805 TO 0.91721	204300
127	0.91265	+ OR - 0.00153	0.91112 TO 0.91419	0.90958 TO 0.91572	0.90805 TO 0.91726	202800
132	0.91262	+ OR - 0.00154	0.91107 TO 0.91416	0.90953 TO 0.91571	0.90799 TO 0.91725	201300
137	0.91269	+ OR - 0.00155	0.91114 TO 0.91424	0.90958 TO 0.91579	0.90803 TO 0.91734	199800
142	0.91303	+ OR - 0.00155	0.91148 TO 0.91458	0.90993 TO 0.91613	0.90837 TO 0.91768	198300
147	0.91314	+ OR - 0.00156	0.91158 TO 0.91470	0.91002 TO 0.91626	0.90846 TO 0.91782	196800
152	0.91332	+ OR - 0.00157	0.91175 TO 0.91489	0.91018 TO 0.91645	0.90862 TO 0.91802	195300
157	0.91329	+ OR - 0.00158	0.91171 TO 0.91487	0.91014 TO 0.91643	0.90856 TO 0.91803	193800
162	0.91307	+ OR - 0.00158	0.91149 TO 0.91465	0.90990 TO 0.91623	0.90832 TO 0.91782	192300
167	0.91297	+ OR - 0.00159	0.91138 TO 0.91457	0.90979 TO 0.91616	0.90820 TO 0.91775	190800
172	0.91283	+ OR - 0.00160	0.91124 TO 0.91443	0.90964 TO 0.91602	0.90804 TO 0.91762	189300
177	0.91261	+ OR - 0.00160	0.91101 TO 0.91420	0.90941 TO 0.91580	0.90782 TO 0.91739	187800
182	0.91258	+ OR - 0.00161	0.91097 TO 0.91419	0.90936 TO 0.91579	0.90776 TO 0.91740	186300
187	0.91250	+ OR - 0.00161	0.91088 TO 0.91411	0.90927 TO 0.91573	0.90766 TO 0.91734	184800
192	0.91245	+ OR - 0.00162	0.91083 TO 0.91408	0.90920 TO 0.91570	0.90758 TO 0.91732	183300
197	0.91255	+ OR - 0.00163	0.91092 TO 0.91418	0.90929 TO 0.91581	0.90766 TO 0.91744	181800
202	0.91227	+ OR - 0.00164	0.91063 TO 0.91391	0.90900 TO 0.91554	0.90736 TO 0.91719	180300
207	0.91222	+ OR - 0.00164	0.91058 TO 0.91385	0.90894 TO 0.91549	0.90731 TO 0.91713	178800
212	0.91245	+ OR - 0.00164	0.91081 TO 0.91409	0.90918 TO 0.91572	0.90754 TO 0.91736	177300
217	0.91257	+ OR - 0.00165	0.91092 TO 0.91421	0.90928 TO 0.91586	0.90763 TO 0.91750	175800
222	0.91253	+ OR - 0.00164	0.91089 TO 0.91417	0.90925 TO 0.91581	0.90761 TO 0.91745	174300
227	0.91248	+ OR - 0.00165	0.91083 TO 0.91413	0.90918 TO 0.91578	0.90753 TO 0.91743	172800

PWRARRAY KENO CASE COMPARISON WITH MONK6B

NO. OF INITIAL GENERATIONS SKIPPED	AVERAGE K-EFFECTIVE	DEVIATION	67 PER CENT CONFIDENCE INTERVAL	95 PER CENT CONFIDENCE INTERVAL	99 PER CENT CONFIDENCE INTERVAL	NUMBER OF HISTORIES
232	0.91245	+ OR - 0.00166	0.91078 TO 0.91411	0.90912 TO 0.91577	0.90746 TO 0.91743	171300
237	0.91255	+ OR - 0.00167	0.91088 TO 0.91423	0.90920 TO 0.91590	0.90753 TO 0.91756	169800
242	0.91276	+ OR - 0.00169	0.91108 TO 0.91445	0.90939 TO 0.91613	0.90771 TO 0.91782	168300
247	0.91315	+ OR - 0.00169	0.91146 TO 0.91484	0.90977 TO 0.91653	0.90808 TO 0.91822	166800
252	0.91278	+ OR - 0.00169	0.91109 TO 0.91447	0.90941 TO 0.91615	0.90772 TO 0.91784	165300
257	0.91296	+ OR - 0.00169	0.91127 TO 0.91466	0.90957 TO 0.91635	0.90788 TO 0.91804	163600
262	0.91277	+ OR - 0.00170	0.91106 TO 0.91447	0.90936 TO 0.91617	0.90766 TO 0.91787	162300
267	0.91272	+ OR - 0.00171	0.91101 TO 0.91443	0.90930 TO 0.91614	0.90759 TO 0.91785	160800
272	0.91264	+ OR - 0.00172	0.91092 TO 0.91437	0.90920 TO 0.91609	0.90747 TO 0.91781	159300
277	0.91259	+ OR - 0.00173	0.91086 TO 0.91433	0.90913 TO 0.91606	0.90739 TO 0.91780	157800
282	0.91259	+ OR - 0.00174	0.91084 TO 0.91433	0.90910 TO 0.91607	0.90736 TO 0.91781	156300
287	0.91226	+ OR - 0.00174	0.91052 TO 0.91399	0.90879 TO 0.91573	0.90705 TO 0.91746	154800
292	0.91234	+ OR - 0.00175	0.91059 TO 0.91409	0.90885 TO 0.91584	0.90710 TO 0.91758	153300
297	0.91267	+ OR - 0.00175	0.91092 TO 0.91442	0.90917 TO 0.91617	0.90742 TO 0.91792	151800
302	0.91272	+ OR - 0.00176	0.91096 TO 0.91448	0.90920 TO 0.91624	0.90744 TO 0.91800	150300
307	0.91254	+ OR - 0.00177	0.91077 TO 0.91430	0.90900 TO 0.91607	0.90723 TO 0.91784	148800
312	0.91260	+ OR - 0.00178	0.91081 TO 0.91438	0.90903 TO 0.91617	0.90724 TO 0.91795	147300
317	0.91274	+ OR - 0.00180	0.91094 TO 0.91454	0.90914 TO 0.91634	0.90734 TO 0.91814	145800
322	0.91285	+ OR - 0.00181	0.91104 TO 0.91467	0.90922 TO 0.91648	0.90741 TO 0.91830	144300
327	0.91257	+ OR - 0.00182	0.91075 TO 0.91439	0.90893 TO 0.91621	0.90711 TO 0.91803	142800
332	0.91252	+ OR - 0.00182	0.91070 TO 0.91435	0.90888 TO 0.91617	0.90705 TO 0.91799	141300
337	0.91220	+ OR - 0.00183	0.91037 TO 0.91404	0.90853 TO 0.91587	0.90670 TO 0.91770	139800
342	0.91220	+ OR - 0.00183	0.91035 TO 0.91405	0.90850 TO 0.91590	0.90665 TO 0.91775	138300
347	0.91211	+ OR - 0.00186	0.91024 TO 0.91397	0.90838 TO 0.91583	0.90652 TO 0.91769	136800
352	0.91194	+ OR - 0.00188	0.91006 TO 0.91381	0.90819 TO 0.91569	0.90631 TO 0.91756	135300
357	0.91208	+ OR - 0.00188	0.91019 TO 0.91396	0.90831 TO 0.91583	0.90643 TO 0.91773	133800
362	0.91235	+ OR - 0.00190	0.91045 TO 0.91425	0.90856 TO 0.91614	0.90666 TO 0.91804	132300

PWRARRAY KENO CASE COMPARISON WITH NOMX6B

NO. OF INITIAL GENERATIONS SKIPPED	AVERAGE K-EFFECTIVE	DEVIATION	67 PER CENT CONFIDENCE INTERVAL	95 PER CENT CONFIDENCE INTERVAL	99 PER CENT CONFIDENCE INTERVAL	NUMBER OF HISTORIES
367	0.91260	+ OR - 0.00190	0.91078 TO 0.91458	0.90888 TO 0.91649	0.90697 TO 0.91839	130800
372	0.91256	+ OR - 0.00191	0.91065 TO 0.91448	0.90874 TO 0.91639	0.90683 TO 0.91830	129300
377	0.91247	+ OR - 0.00192	0.91055 TO 0.91438	0.90863 TO 0.91630	0.90672 TO 0.91821	127800
382	0.91257	+ OR - 0.00192	0.91065 TO 0.91449	0.90872 TO 0.91641	0.90680 TO 0.91833	126300
387	0.91259	+ OR - 0.00191	0.91068 TO 0.91451	0.90876 TO 0.91642	0.90685 TO 0.91834	124800
392	0.91272	+ OR - 0.00193	0.91078 TO 0.91465	0.90885 TO 0.91658	0.90692 TO 0.91851	123300
397	0.91289	+ OR - 0.00194	0.91095 TO 0.91484	0.90901 TO 0.91678	0.90707 TO 0.91872	121800
402	0.91278	+ OR - 0.00196	0.91082 TO 0.91475	0.90885 TO 0.91671	0.90689 TO 0.91868	120300
407	0.91294	+ OR - 0.00197	0.91097 TO 0.91491	0.90900 TO 0.91688	0.90703 TO 0.91885	118800
412	0.91249	+ OR - 0.00198	0.91051 TO 0.91447	0.90853 TO 0.91645	0.90655 TO 0.91842	117300
417	0.91281	+ OR - 0.00199	0.91082 TO 0.91480	0.90882 TO 0.91680	0.90683 TO 0.91879	115800
422	0.91254	+ OR - 0.00201	0.91053 TO 0.91454	0.90852 TO 0.91655	0.90651 TO 0.91856	114300
427	0.91268	+ OR - 0.00203	0.91066 TO 0.91471	0.90863 TO 0.91674	0.90660 TO 0.91877	112800
432	0.91299	+ OR - 0.00205	0.91094 TO 0.91503	0.90889 TO 0.91708	0.90684 TO 0.91913	111300
437	0.91308	+ OR - 0.00207	0.91101 TO 0.91515	0.90894 TO 0.91722	0.90687 TO 0.91929	109800
442	0.91337	+ OR - 0.00209	0.91128 TO 0.91546	0.90919 TO 0.91755	0.90710 TO 0.91964	108300
447	0.91402	+ OR - 0.00208	0.91193 TO 0.91610	0.90985 TO 0.91818	0.90777 TO 0.92026	106800
452	0.91420	+ OR - 0.00211	0.91209 TO 0.91630	0.90999 TO 0.91841	0.90788 TO 0.92051	105300
457	0.91437	+ OR - 0.00212	0.91225 TO 0.91650	0.91013 TO 0.91862	0.90801 TO 0.92074	103800
462	0.91436	+ OR - 0.00211	0.91225 TO 0.91647	0.91014 TO 0.91858	0.90803 TO 0.92069	102300
467	0.91452	+ OR - 0.00211	0.91240 TO 0.91663	0.91029 TO 0.91875	0.90818 TO 0.92086	100800
472	0.91457	+ OR - 0.00214	0.91244 TO 0.91671	0.91030 TO 0.91885	0.90816 TO 0.92098	99300
477	0.91441	+ OR - 0.00216	0.91225 TO 0.91658	0.91008 TO 0.91874	0.90792 TO 0.92091	97800
482	0.91448	+ OR - 0.00218	0.91231 TO 0.91666	0.91013 TO 0.91883	0.90795 TO 0.92101	96300
487	0.91438	+ OR - 0.00218	0.91220 TO 0.91657	0.91001 TO 0.91875	0.90783 TO 0.92094	94800
492	0.91435	+ OR - 0.00220	0.91215 TO 0.91656	0.90995 TO 0.91876	0.90774 TO 0.92096	93300
497	0.91365	+ OR - 0.00222	0.91144 TO 0.91587	0.90922 TO 0.91808	0.90701 TO 0.92030	91800

PWRARRAY KENO CASE COMPARISON WITH MONK6B

NO. OF INITIAL GENERATIONS SKIPPED	AVERAGE K-EFFECTIVE	DEVIATION	67 PER CENT CONFIDENCE INTERVAL	95 PER CENT CONFIDENCE INTERVAL	99 PER CENT CONFIDENCE INTERVAL	NUMBER OF HISTORIES
302	0.91374	+ OR - 0.00225	0.91150 TO 0.91599	0.90925 TO 0.91823	0.90700 TO 0.92048	90300
307	0.91371	+ OR - 0.00227	0.91143 TO 0.91598	0.90916 TO 0.91826	0.90688 TO 0.92053	88800
312	0.91373	+ OR - 0.00231	0.91143 TO 0.91604	0.90912 TO 0.91835	0.90682 TO 0.92065	87300
317	0.91395	+ OR - 0.00234	0.91161 TO 0.91628	0.90927 TO 0.91862	0.90693 TO 0.92096	85800
322	0.91374	+ OR - 0.00236	0.91137 TO 0.91610	0.90901 TO 0.91846	0.90665 TO 0.92083	84300
327	0.91329	+ OR - 0.00238	0.91090 TO 0.91567	0.90852 TO 0.91806	0.90613 TO 0.92044	82800
332	0.91290	+ OR - 0.00241	0.91048 TO 0.91531	0.90807 TO 0.91773	0.90565 TO 0.92014	81300
337	0.91315	+ OR - 0.00244	0.91072 TO 0.91559	0.90828 TO 0.91803	0.90584 TO 0.92046	79800
342	0.91330	+ OR - 0.00247	0.91083 TO 0.91577	0.90836 TO 0.91824	0.90589 TO 0.92070	78300
347	0.91324	+ OR - 0.00249	0.91075 TO 0.91573	0.90826 TO 0.91822	0.90577 TO 0.92072	76800
352	0.91358	+ OR - 0.00252	0.91105 TO 0.91610	0.90853 TO 0.91862	0.90600 TO 0.92115	75300
357	0.91284	+ OR - 0.00255	0.91029 TO 0.91539	0.90775 TO 0.91794	0.90520 TO 0.92049	73800
362	0.91273	+ OR - 0.00259	0.91013 TO 0.91532	0.90754 TO 0.91792	0.90495 TO 0.92051	72300
367	0.91230	+ OR - 0.00261	0.90969 TO 0.91491	0.90707 TO 0.91753	0.90446 TO 0.92014	70800
372	0.91254	+ OR - 0.00264	0.90990 TO 0.91519	0.90726 TO 0.91783	0.90462 TO 0.92047	69300
377	0.91289	+ OR - 0.00269	0.91021 TO 0.91558	0.90752 TO 0.91826	0.90484 TO 0.92095	67800
382	0.91230	+ OR - 0.00272	0.90958 TO 0.91502	0.90686 TO 0.91775	0.90413 TO 0.92047	66300
387	0.91318	+ OR - 0.00274	0.91044 TO 0.91593	0.90769 TO 0.91867	0.90495 TO 0.92142	64800
392	0.91422	+ OR - 0.00276	0.91146 TO 0.91698	0.90870 TO 0.91974	0.90393 TO 0.92250	63300
397	0.91430	+ OR - 0.00282	0.91148 TO 0.91732	0.90886 TO 0.92013	0.90604 TO 0.92295	61800
402	0.91491	+ OR - 0.00285	0.91206 TO 0.91776	0.90921 TO 0.92061	0.90635 TO 0.92346	60300
407	0.91509	+ OR - 0.00289	0.91220 TO 0.91798	0.90931 TO 0.92087	0.90642 TO 0.92376	58800
412	0.91477	+ OR - 0.00290	0.91187 TO 0.91767	0.90897 TO 0.92057	0.90607 TO 0.92347	57300
417	0.91565	+ OR - 0.00289	0.91276 TO 0.91853	0.90988 TO 0.92142	0.90699 TO 0.92430	55800
422	0.91615	+ OR - 0.00295	0.91320 TO 0.91910	0.91025 TO 0.92205	0.90730 TO 0.92501	54300
427	0.91547	+ OR - 0.00298	0.91250 TO 0.91845	0.90952 TO 0.92142	0.90655 TO 0.92440	52800
432	0.91644	+ OR - 0.00300	0.91344 TO 0.91943	0.91044 TO 0.92243	0.90744 TO 0.92543	51300

PWRARRAY RENO CASE COMPARISON WITH MONK6B

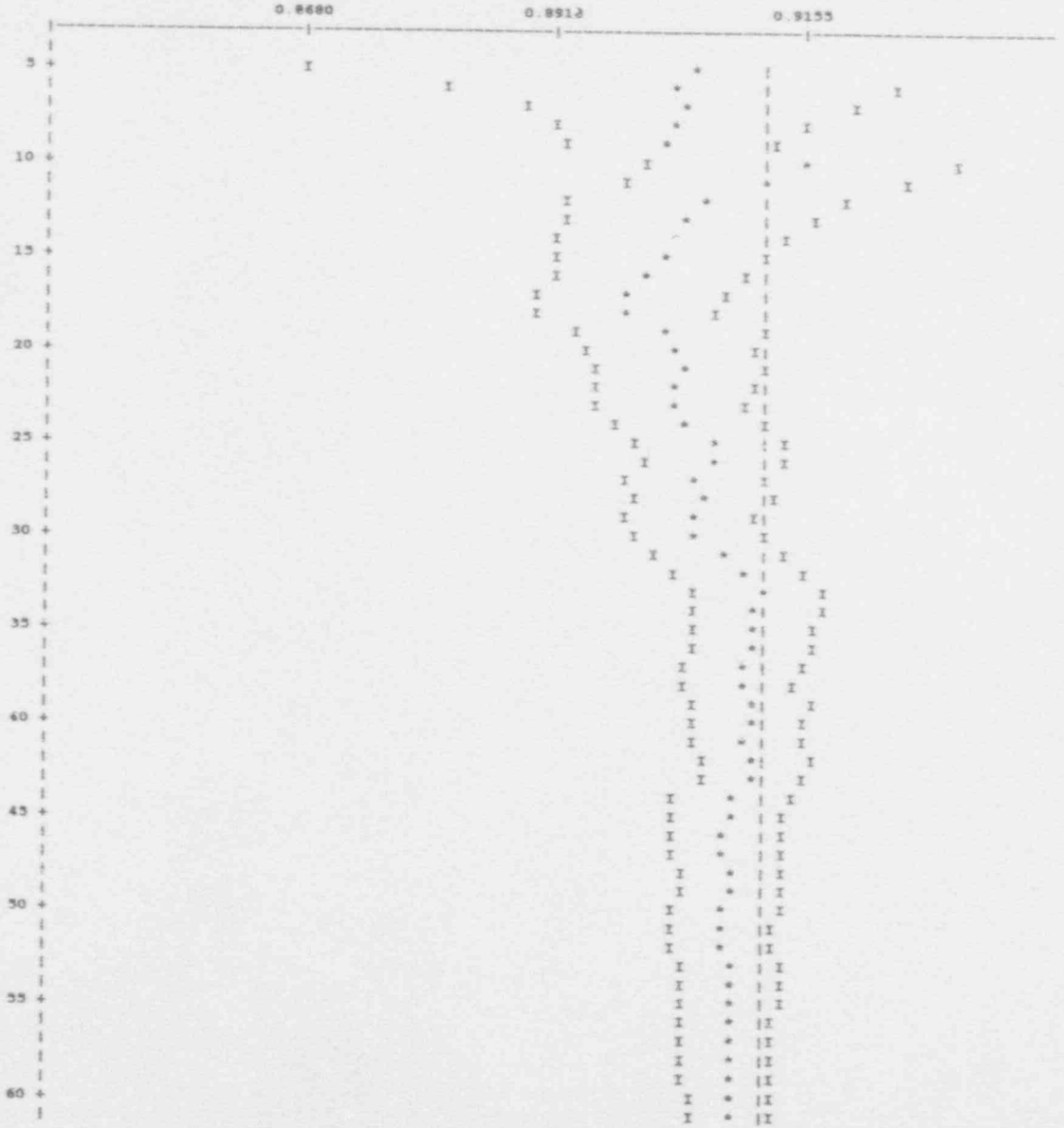
NO. OF INITIAL GENERATIONS SKIPPED	AVERAGE K-EFFECTIVE	DEVIATION	67 PER CENT CONFIDENCE INTERVAL	95 PER CENT CONFIDENCE INTERVAL	99 PER CENT CONFIDENCE INTERVAL	NUMBER OF HISTORIES
637	0.91652	+ OR - 0.00305	0.91347 TO 0.91957	0.91041 TO 0.92262	0.90736 TO 0.92567	49800
642	0.91723	+ OR - 0.00312	0.91411 TO 0.92034	0.91099 TO 0.92346	0.90787 TO 0.92658	46300
647	0.91792	+ OR - 0.00319	0.91472 TO 0.92111	0.91153 TO 0.92430	0.90834 TO 0.92749	46800
652	0.91769	+ OR - 0.00326	0.91423 TO 0.92074	0.91098 TO 0.92400	0.90772 TO 0.92725	45300
657	0.91897	+ OR - 0.00328	0.91569 TO 0.92224	0.91242 TO 0.92552	0.90914 TO 0.92880	43800
662	0.91863	+ OR - 0.00335	0.91528 TO 0.92198	0.91192 TO 0.92534	0.90857 TO 0.92869	42300
667	0.91827	+ OR - 0.00339	0.91488 TO 0.92165	0.91149 TO 0.92504	0.90810 TO 0.92843	40800
672	0.91903	+ OR - 0.00341	0.91562 TO 0.92244	0.91220 TO 0.92585	0.90879 TO 0.92927	39300
677	0.91984	+ OR - 0.00349	0.91634 TO 0.92333	0.91285 TO 0.92682	0.90936 TO 0.93032	37800
682	0.91922	+ OR - 0.00353	0.91569 TO 0.92275	0.91216 TO 0.92628	0.90862 TO 0.92981	36300
687	0.91816	+ OR - 0.00363	0.91452 TO 0.92179	0.91089 TO 0.92542	0.90726 TO 0.92905	34800
692	0.91850	+ OR - 0.00378	0.91472 TO 0.92229	0.91094 TO 0.92607	0.90716 TO 0.92985	33300
697	0.91920	+ OR - 0.00388	0.91432 TO 0.92207	0.91045 TO 0.92595	0.90657 TO 0.92982	31800
702	0.91763	+ OR - 0.00400	0.91363 TO 0.92163	0.90963 TO 0.92563	0.90563 TO 0.92963	30300
707	0.91659	+ OR - 0.00414	0.91245 TO 0.92073	0.90831 TO 0.92487	0.90416 TO 0.92901	28800
712	0.91664	+ OR - 0.00436	0.91228 TO 0.92100	0.90792 TO 0.92536	0.90356 TO 0.92972	27300
717	0.91823	+ OR - 0.00454	0.91369 TO 0.92279	0.90915 TO 0.92732	0.90460 TO 0.93186	25800
722	0.91693	+ OR - 0.00471	0.91221 TO 0.92164	0.90750 TO 0.92636	0.90278 TO 0.93107	24300
727	0.91697	+ OR - 0.00488	0.91209 TO 0.92186	0.90720 TO 0.92674	0.90232 TO 0.93163	22800
732	0.91686	+ OR - 0.00510	0.91176 TO 0.92196	0.90667 TO 0.92706	0.90157 TO 0.93215	21300
737	0.91734	+ OR - 0.00535	0.91219 TO 0.92290	0.90683 TO 0.92825	0.90148 TO 0.93361	19800
742	0.91855	+ OR - 0.00577	0.91279 TO 0.92432	0.90702 TO 0.93009	0.90126 TO 0.93585	18300
747	0.91795	+ OR - 0.00598	0.91198 TO 0.92391	0.90602 TO 0.92987	0.90006 TO 0.93584	16800
752	0.91821	+ OR - 0.00639	0.91182 TO 0.92460	0.90543 TO 0.93099	0.89904 TO 0.93738	15300
757	0.92076	+ OR - 0.00603	0.91473 TO 0.92679	0.90870 TO 0.93282	0.90267 TO 0.93885	13800
762	0.91909	+ OR - 0.00627	0.91281 TO 0.92536	0.90654 TO 0.93163	0.90027 TO 0.93791	12300
767	0.92139	+ OR - 0.00689	0.91444 TO 0.92822	0.90735 TO 0.93511	0.90066 TO 0.94200	10800

PWRARRAY KENO CASE COMPARISON WITH MONK6B

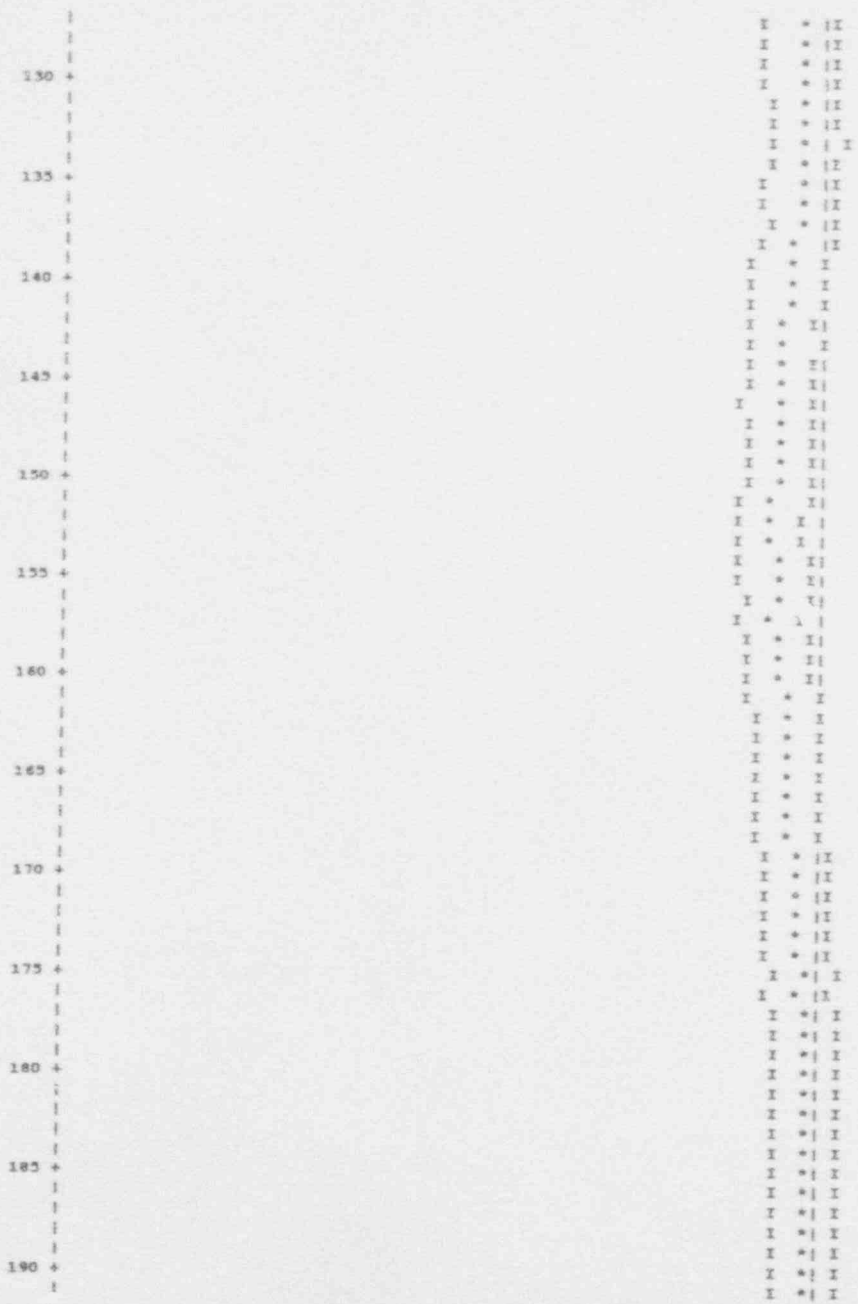
NO. OF INITIAL GENERATIONS SKIPPED	AVERAGE K-EFFECTIVE	DEVIATION	67 PER CENT CONFIDENCE INTERVAL	95 PER CENT CONFIDENCE INTERVAL	99 PER CENT CONFIDENCE INTERVAL	NUMBER OF HISTORIES
772	0.92674	+ OR - 0.00746	0.91928 TO 0.93420	0.91182 TO 0.94165	0.90436 TO 0.94911	9300
777	0.92139	+ OR - 0.00796	0.91343 TO 0.92935	0.90547 TO 0.93732	0.89750 TO 0.94528	7800
782	0.91579	+ OR - 0.00938	0.90641 TO 0.92517	0.89703 TO 0.93455	0.88765 TO 0.94393	6300
787	0.91827	+ OR - 0.01144	0.90683 TO 0.92972	0.89539 TO 0.94116	0.88395 TO 0.95260	4800
792	0.91794	+ OR - 0.01528	0.90466 TO 0.93521	0.88938 TO 0.95049	0.87410 TO 0.96577	3300
797	0.90235	+ OR - 0.01910	0.88325 TO 0.92145	0.86416 TO 0.94054	0.84506 TO 0.95964	1800

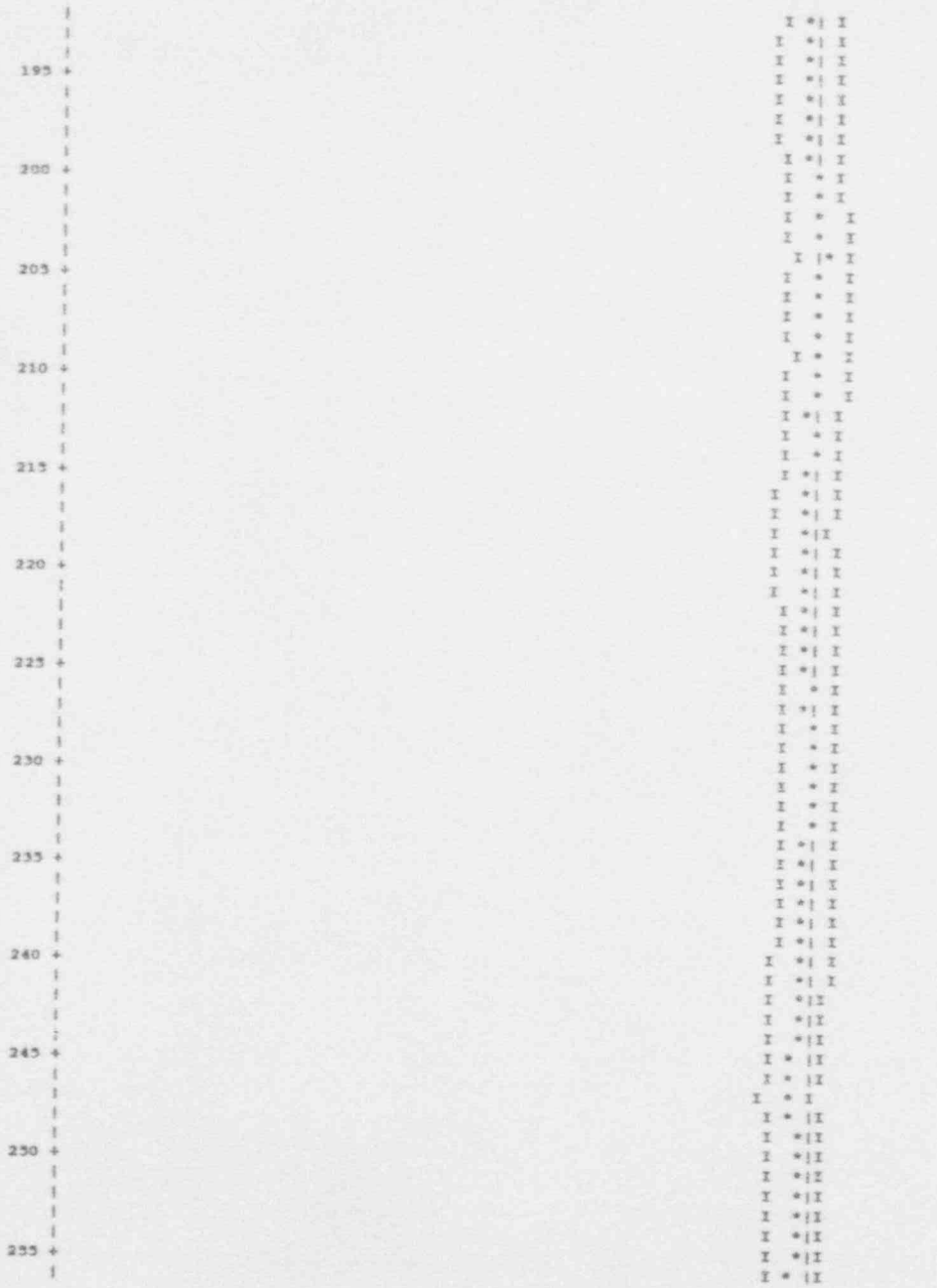
PWRARRAY KENO CASE COMPARISON WITH MONK6B

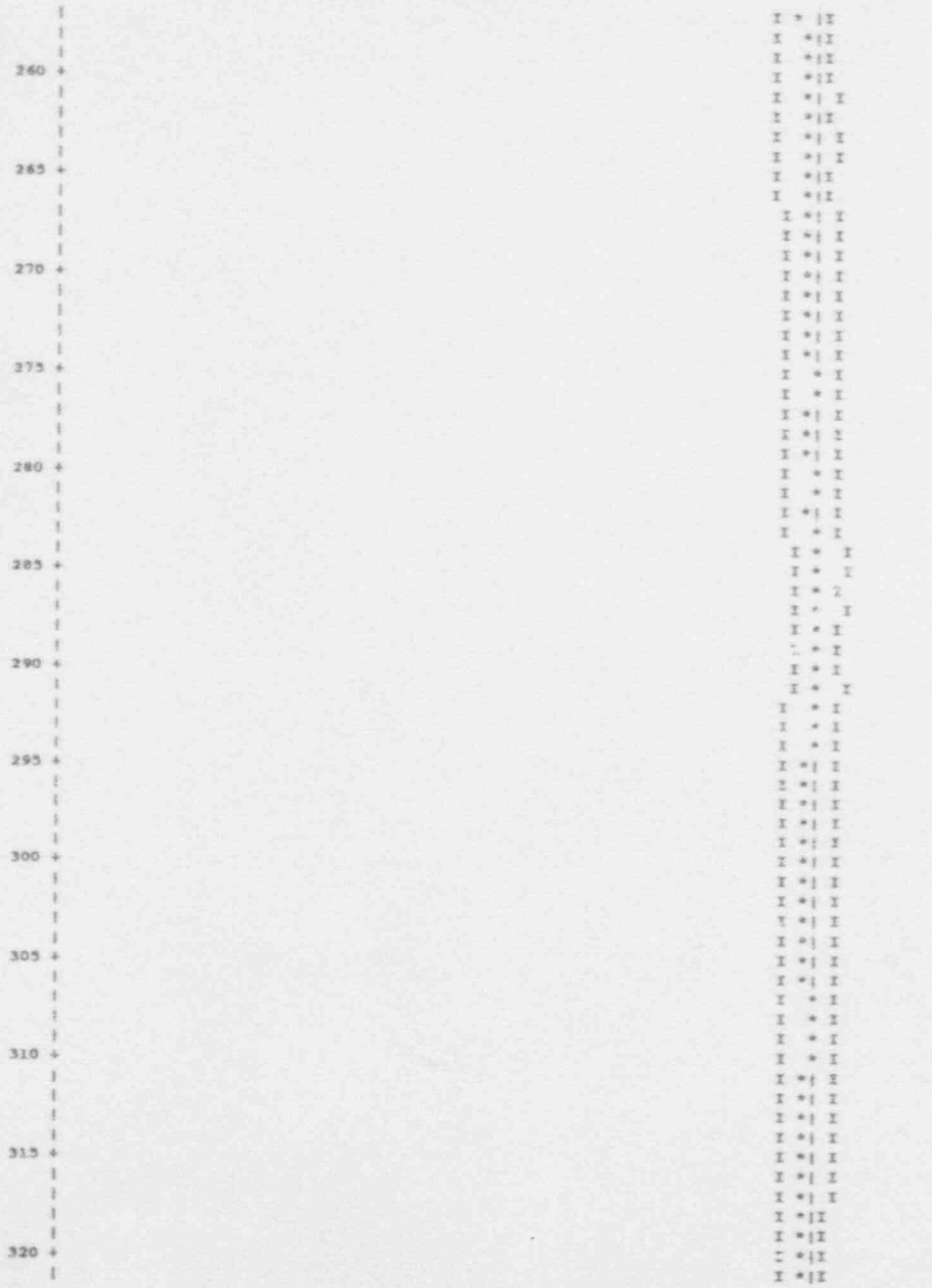
PLOT OF AVERAGE K-EFFECTIVE BY GENERATION ROW.
THE LINE REPRESENTS K-EFF = 0.9122 + OR - 0.0014 WHICH OCCURS FOR 803 GENERATIONS RUN.

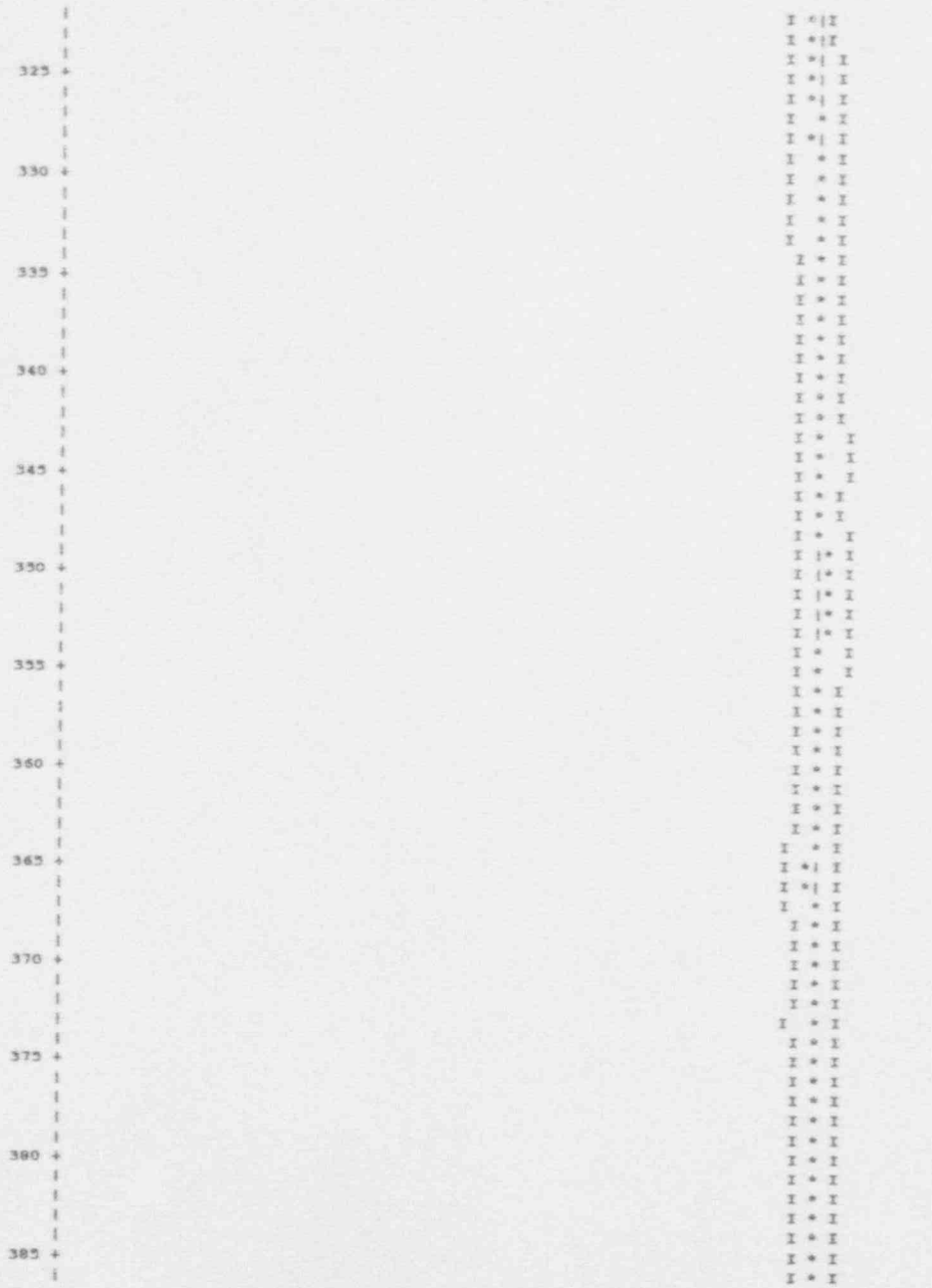


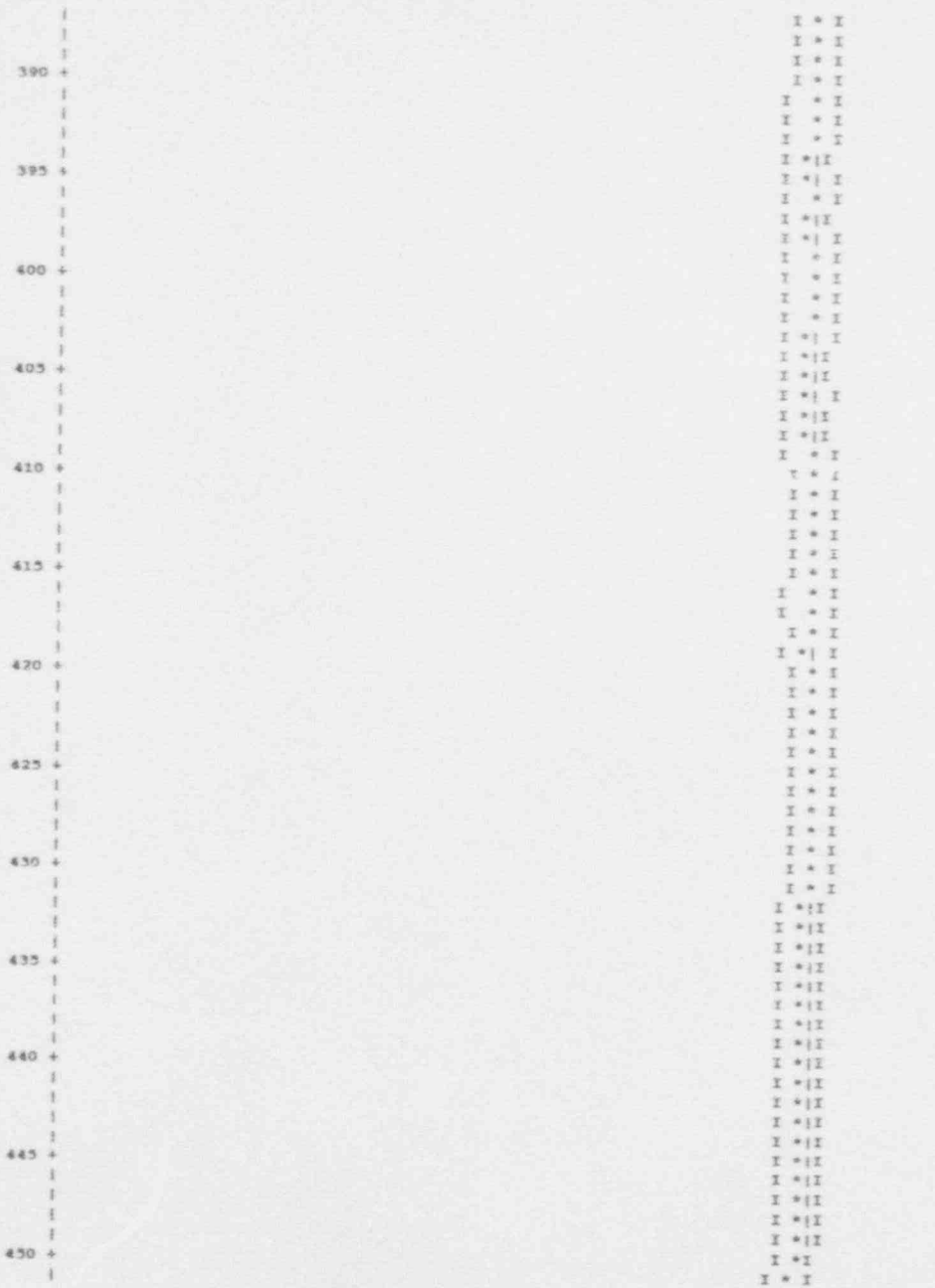

65
70
75
80
85
90
95
100
105
110
115
120
125

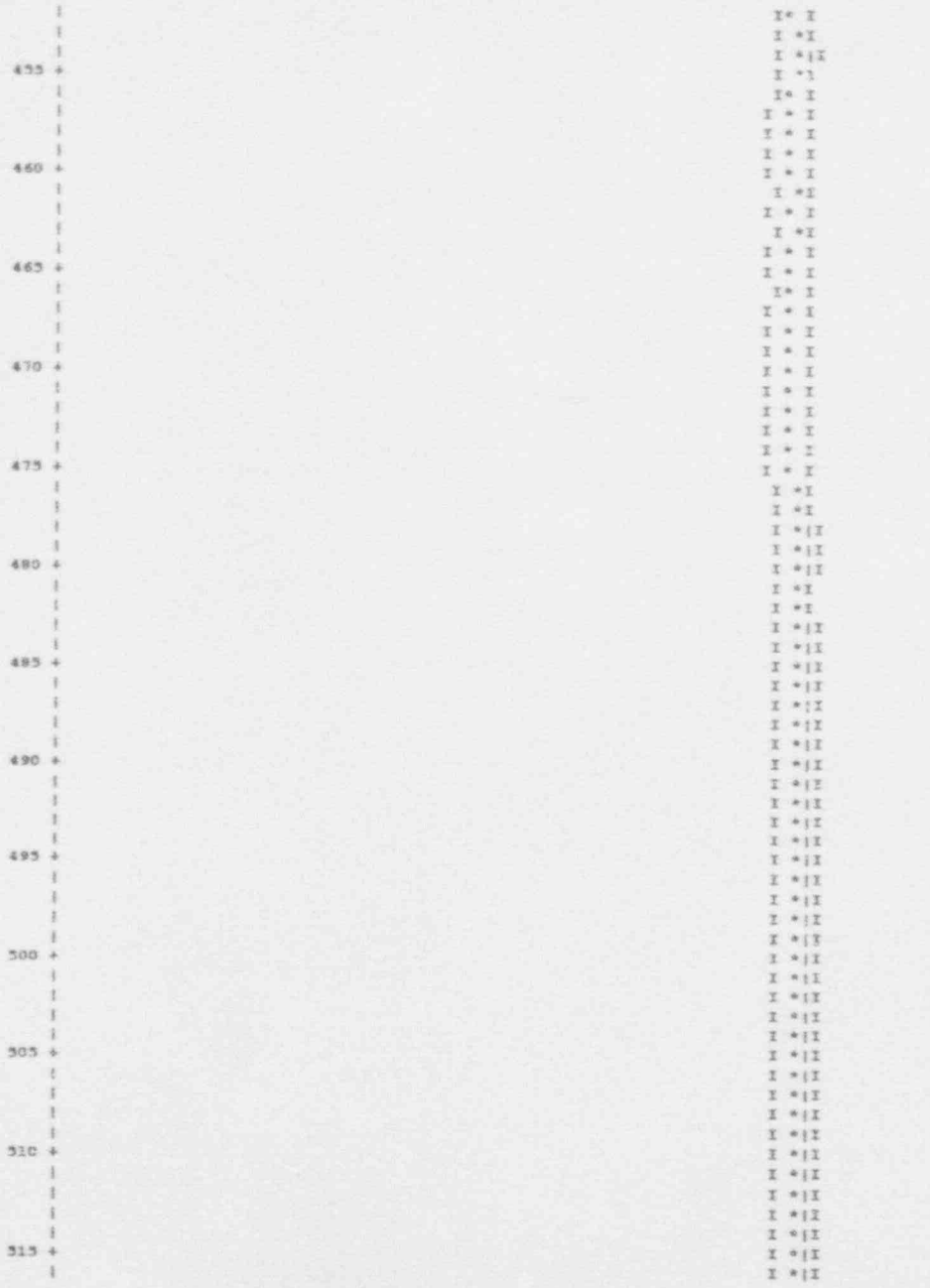

130
135
140
145
150
155
160
165
170
175
180
185
190

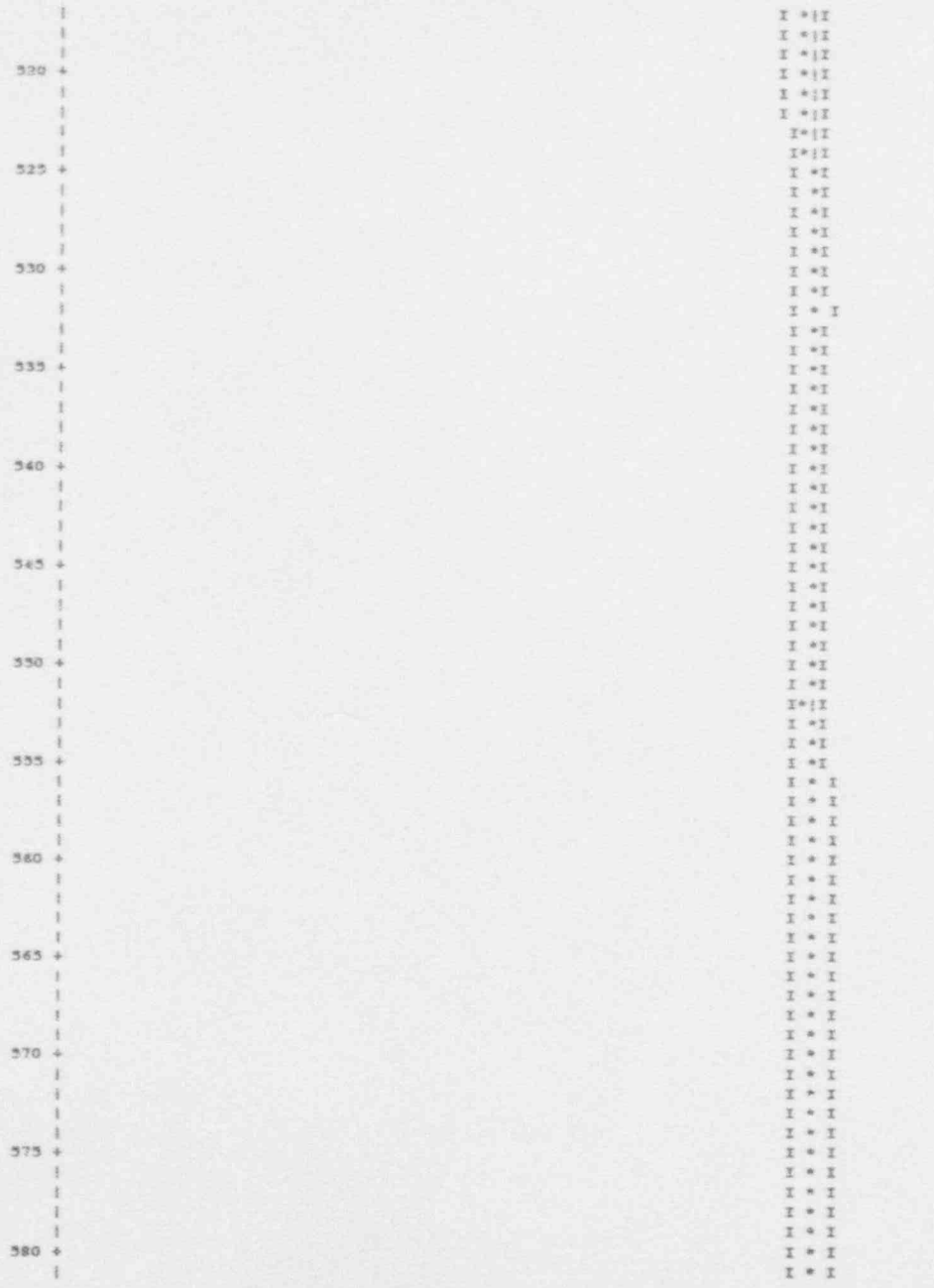

195
200
205
210
215
220
225
230
235
240
245
250
255

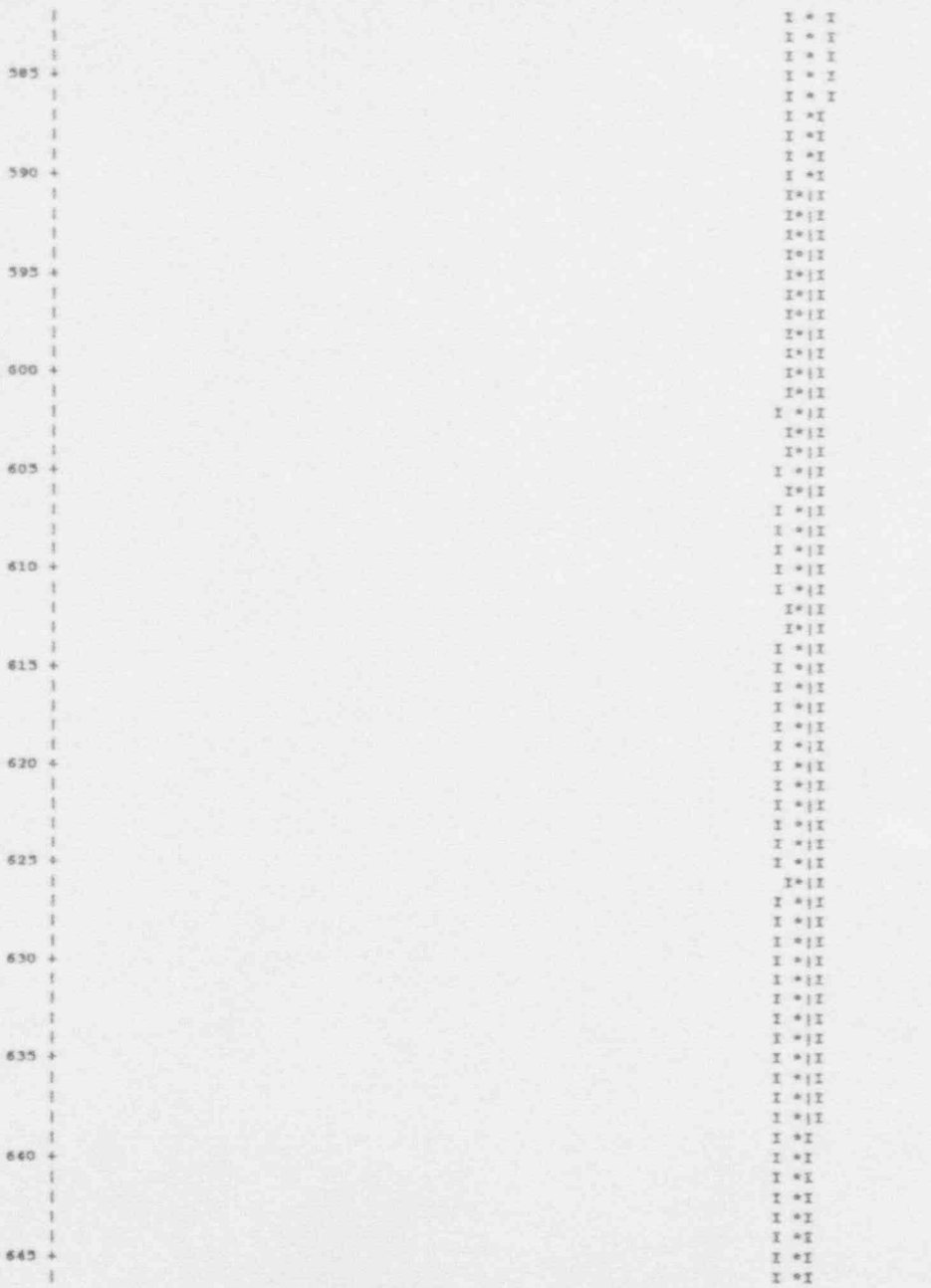

260
265
270
275
280
285
290
295
300
305
310
315
320

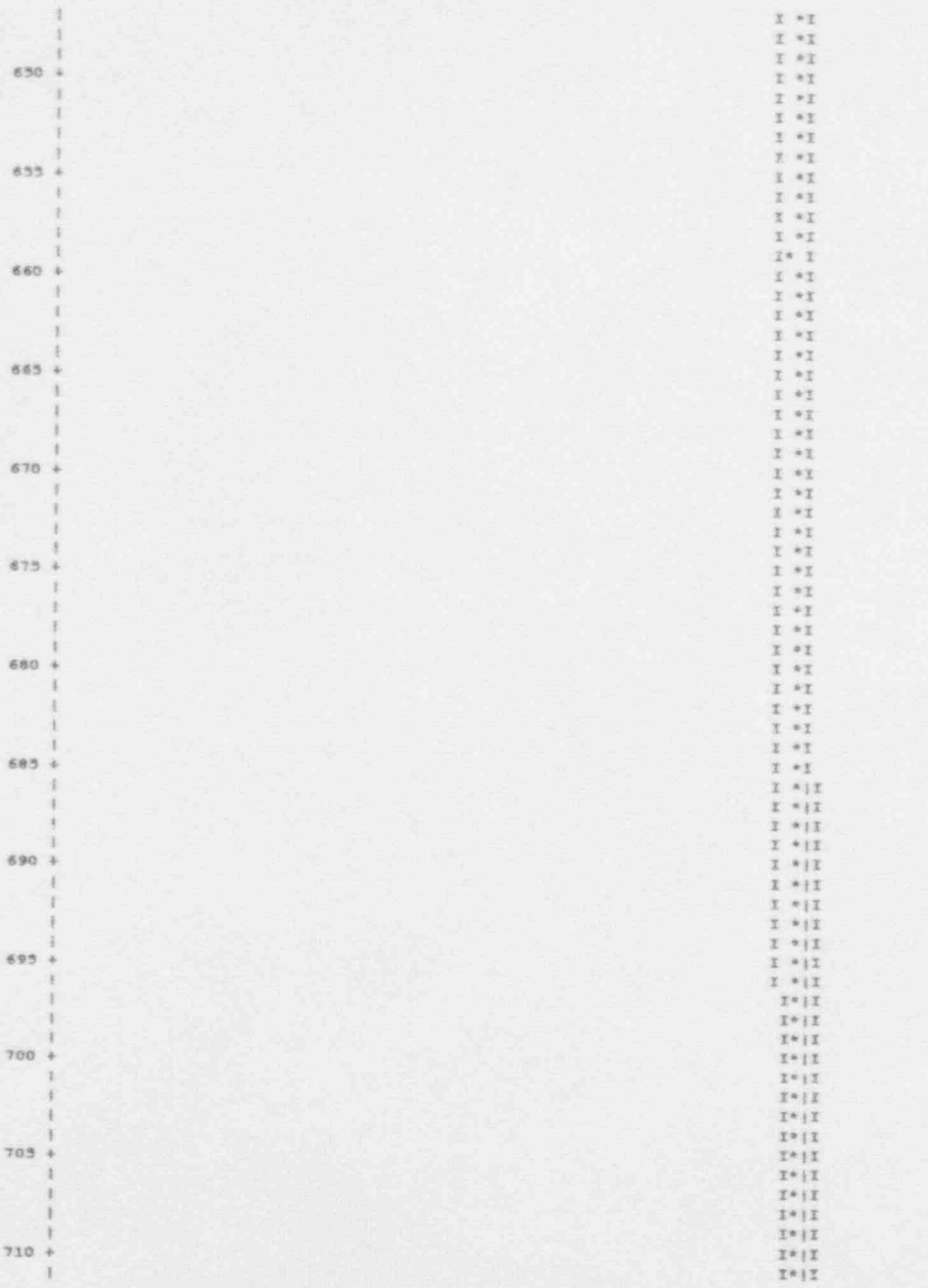

325
330
335
340
345
350
355
360
365
370
375
380
385


390
395
400
405
410
415
420
425
430
435
440
445
450


455
460
465
470
475
480
485
490
495
500
505
510
515


520
525
530
535
540
545
550
555
560
565
570
575
580


585
590
595
600
605
610
615
620
625
630
635
640
645

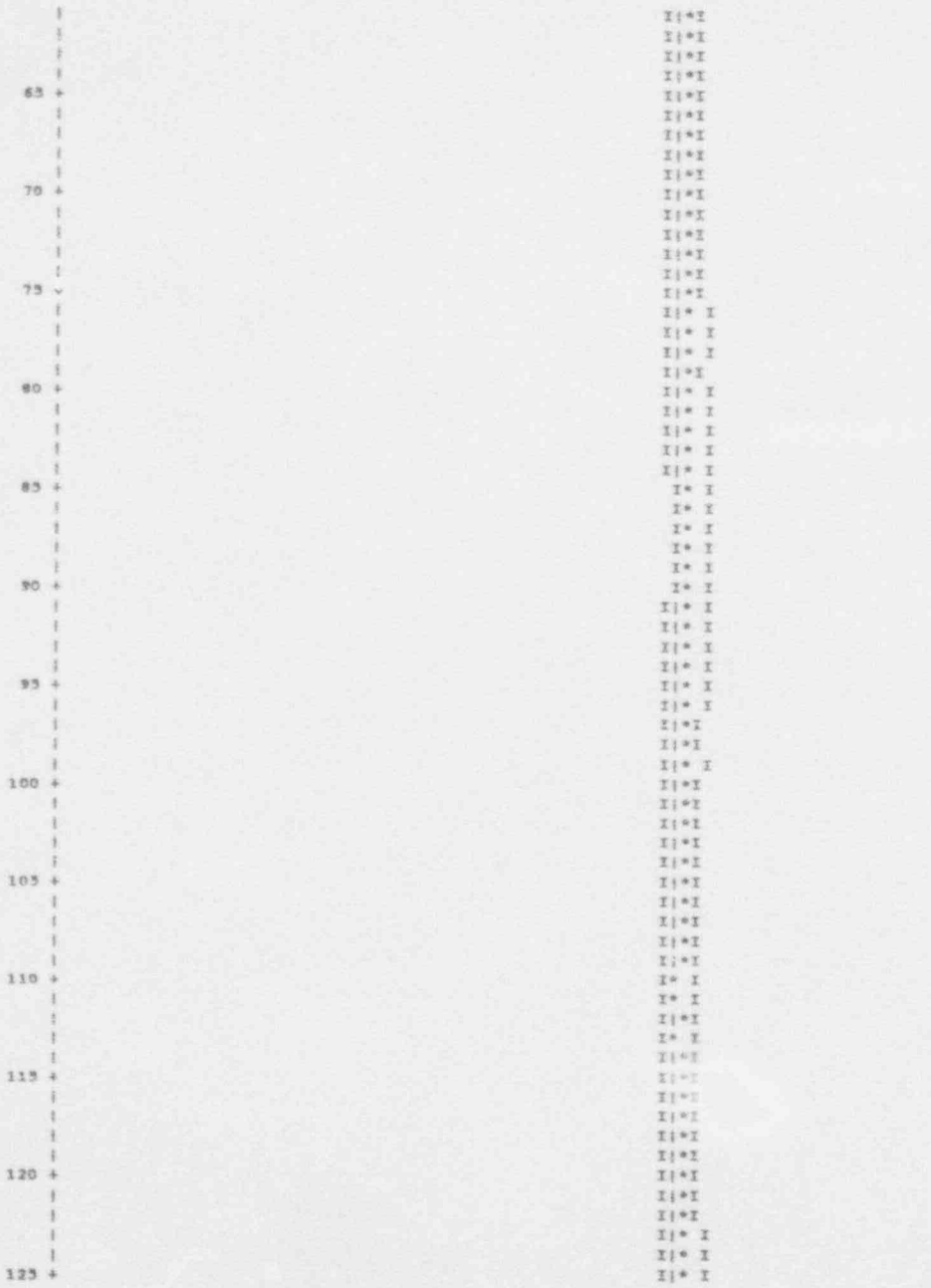

650
655
660
665
670
675
680
685
690
695
700
705
710

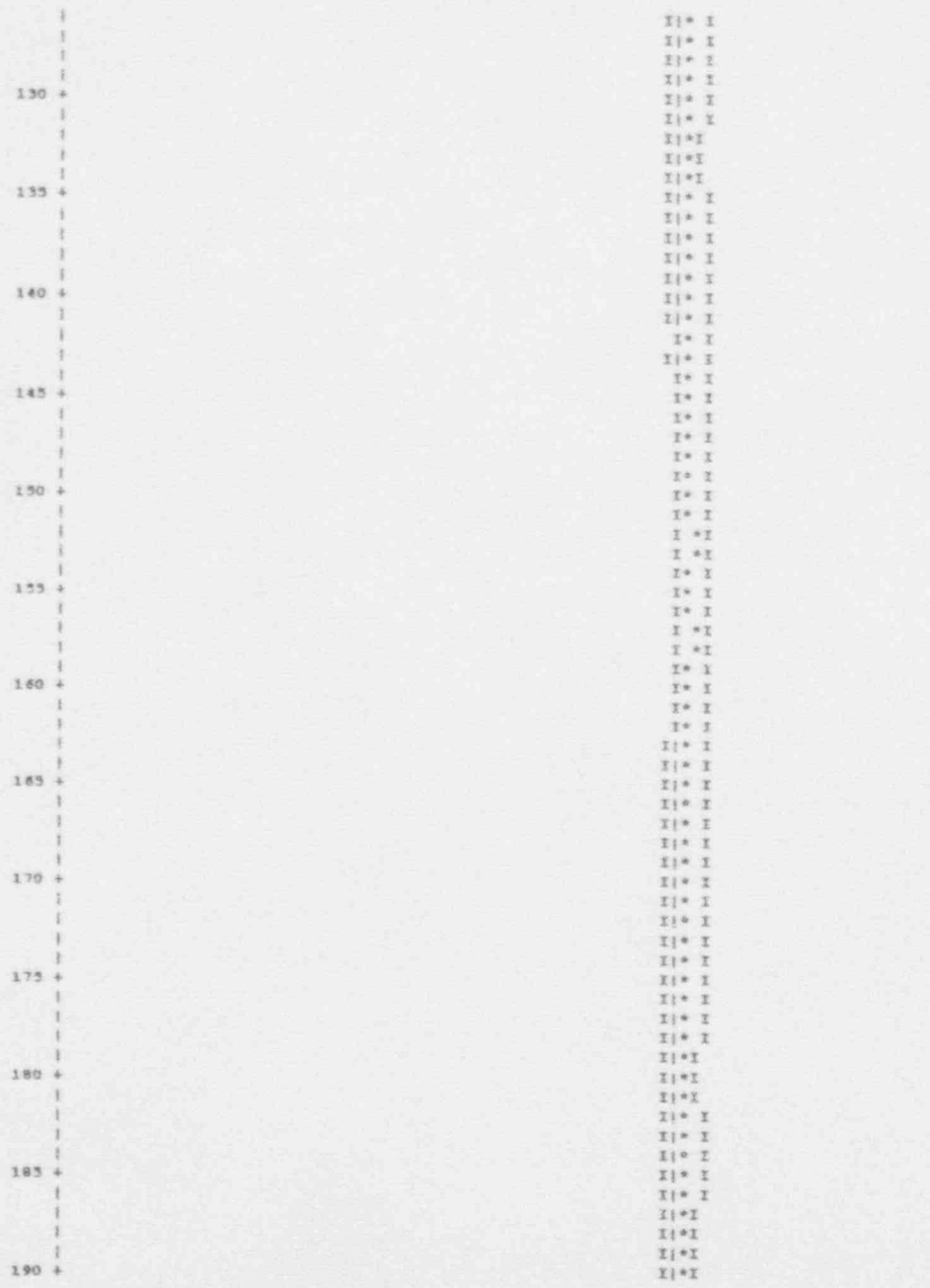

715
720
725
730
735
740
745
750
755
760
765
770
775

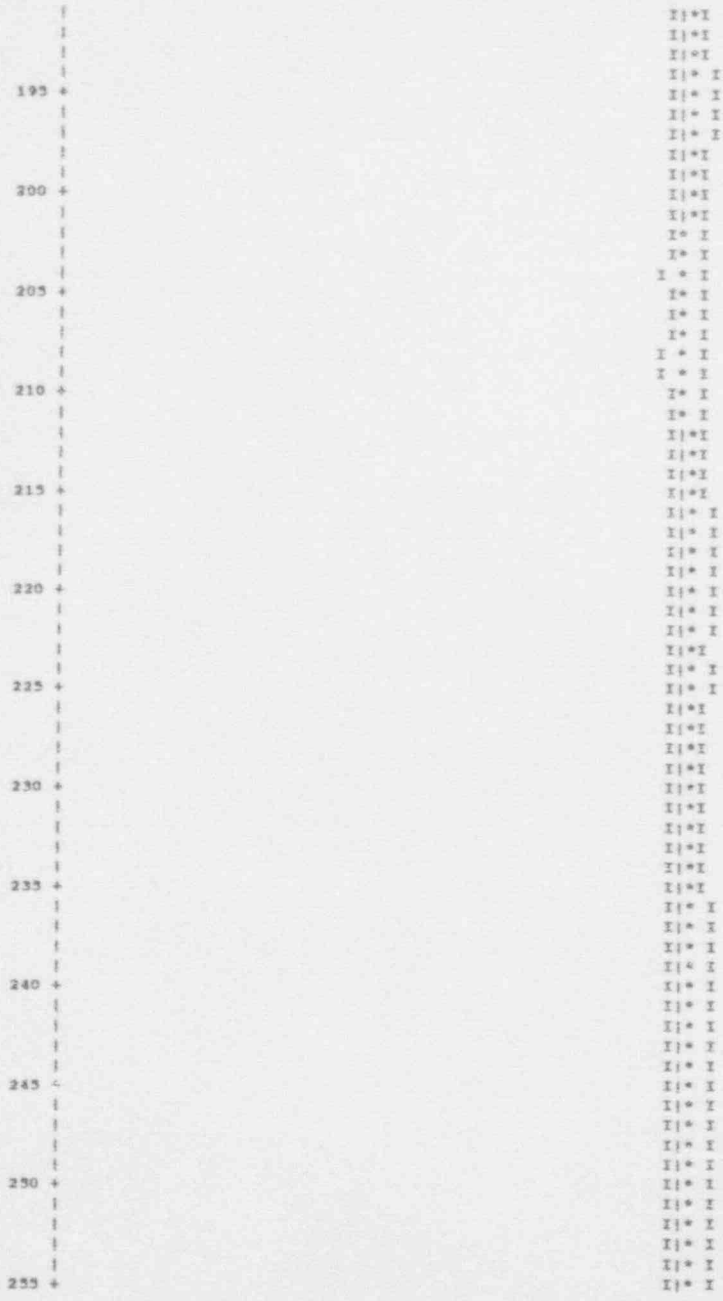

780
785
790
795
800

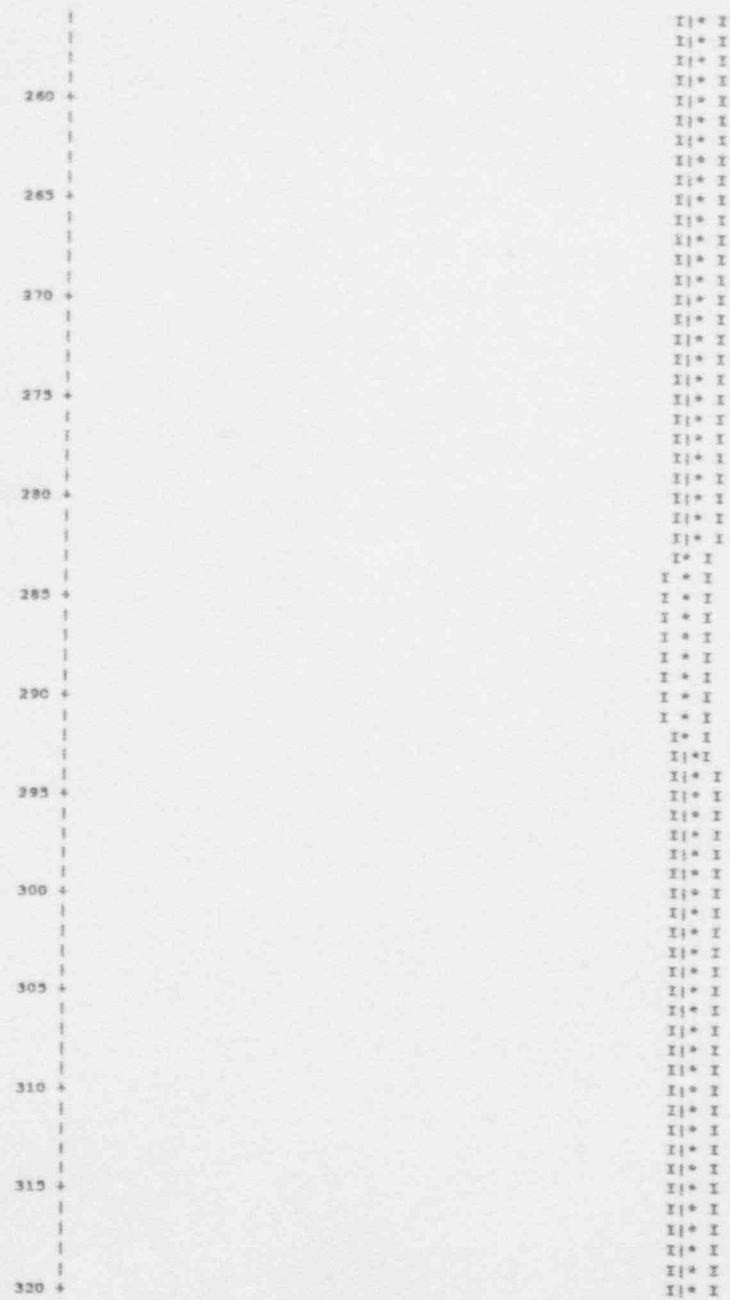
PWRARRAY KENO CASE COMPARISON WITH MONK6B

PLOT OF AVERAGE K-EFFECTIVE BY GENERATION SKIPPED.
THE LINE REPRESENTS K-EFF = 0.9122 + OR - 0.0014 WHICH OCCURS FOR 3 GENERATIONS SKIPPED.

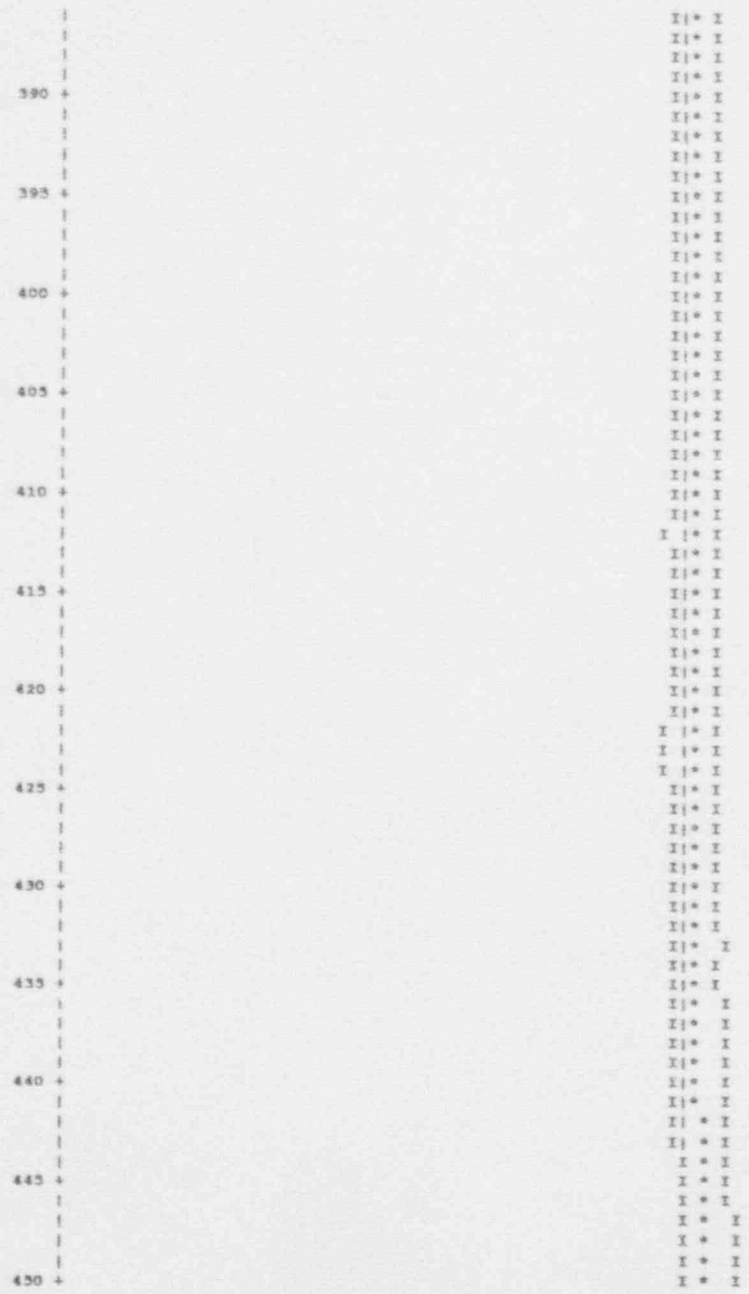

65
70
75
80
85
90
95
100
105
110
115
120
125

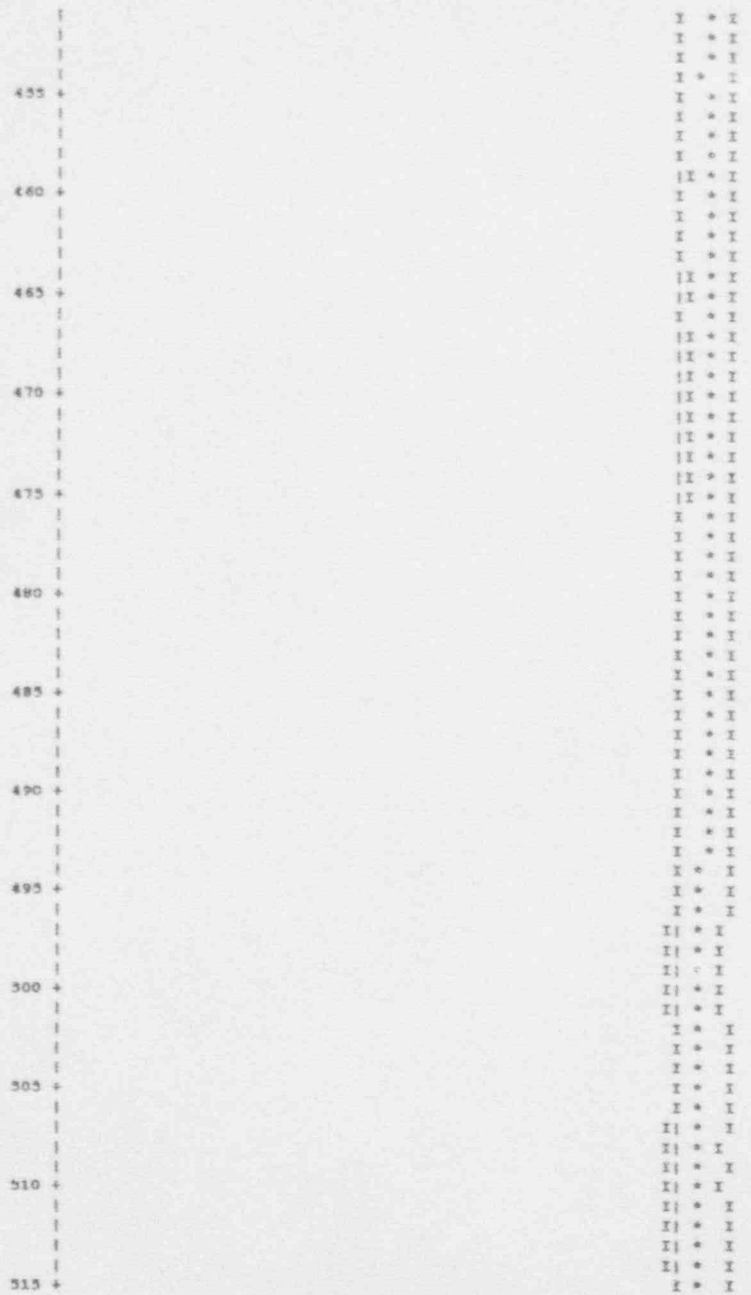

130
135
140
145
150
155
160
165
170
175
180
185
190

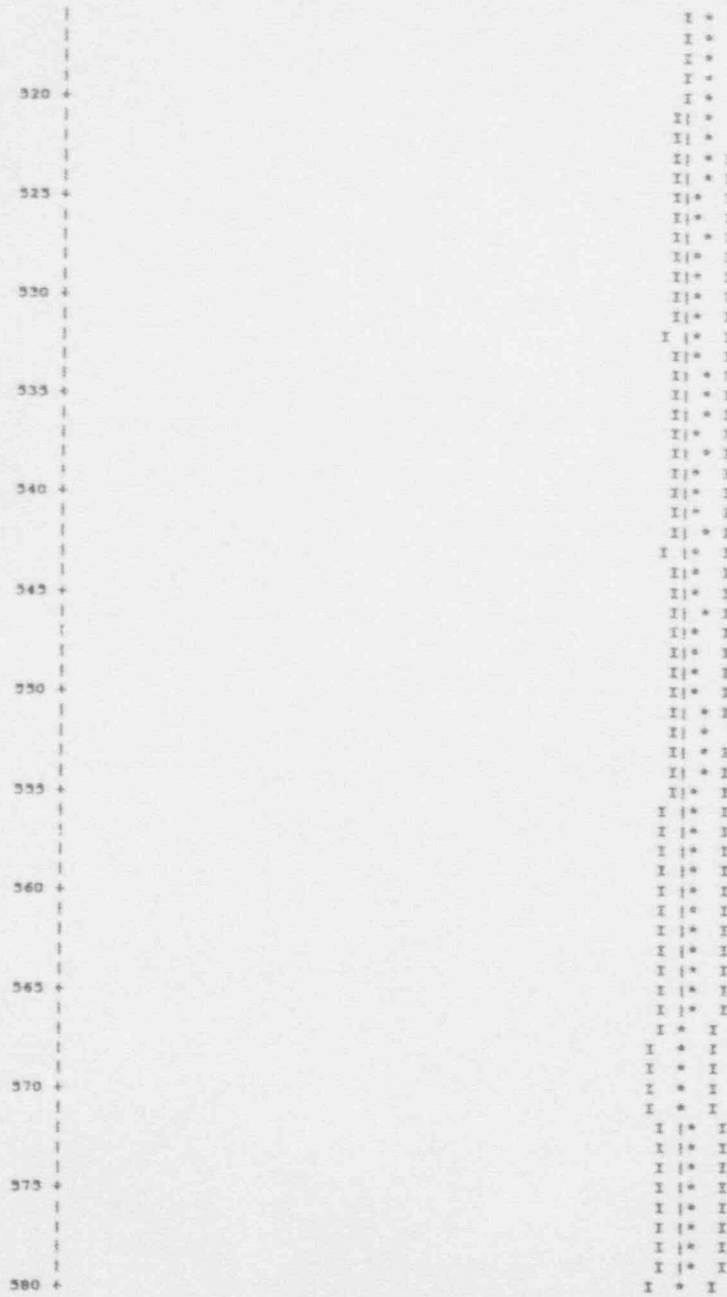

195
200
205
210
215
220
225
230
235
240
245
250
255

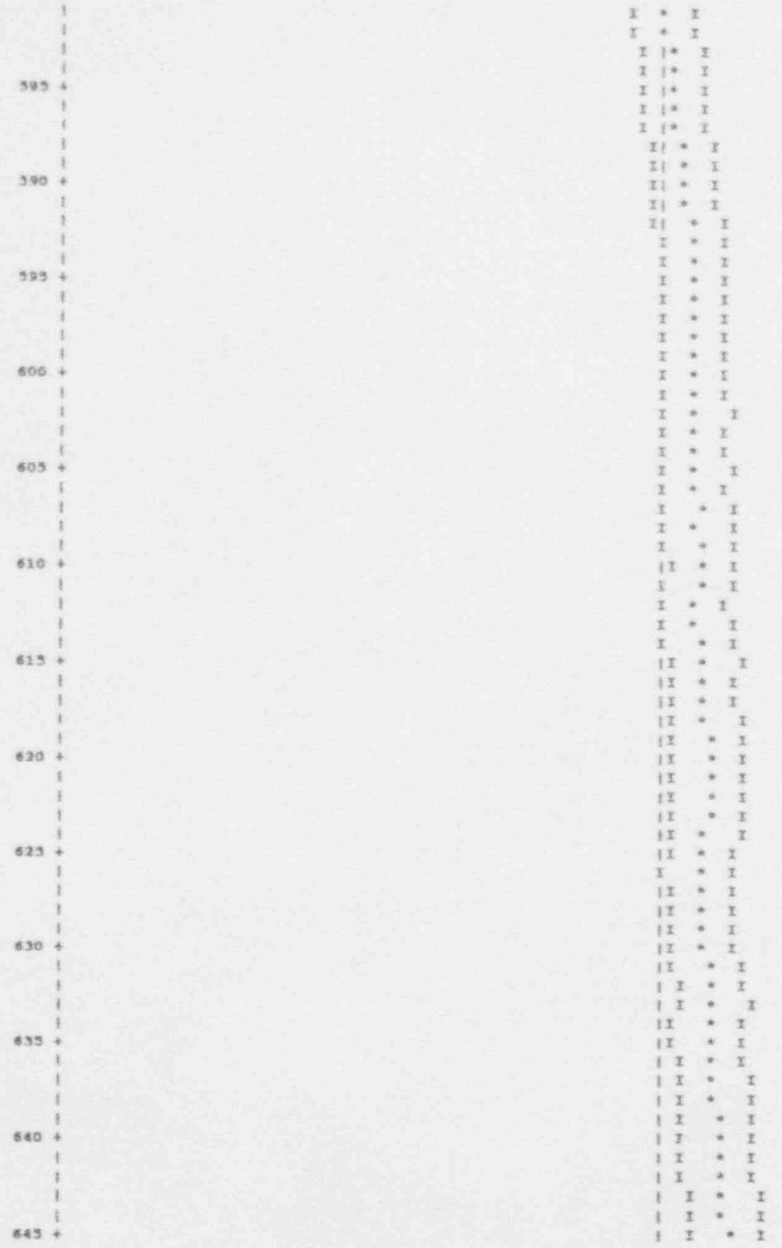

260
265
270
275
280
285
290
295
300
305
310
315
320

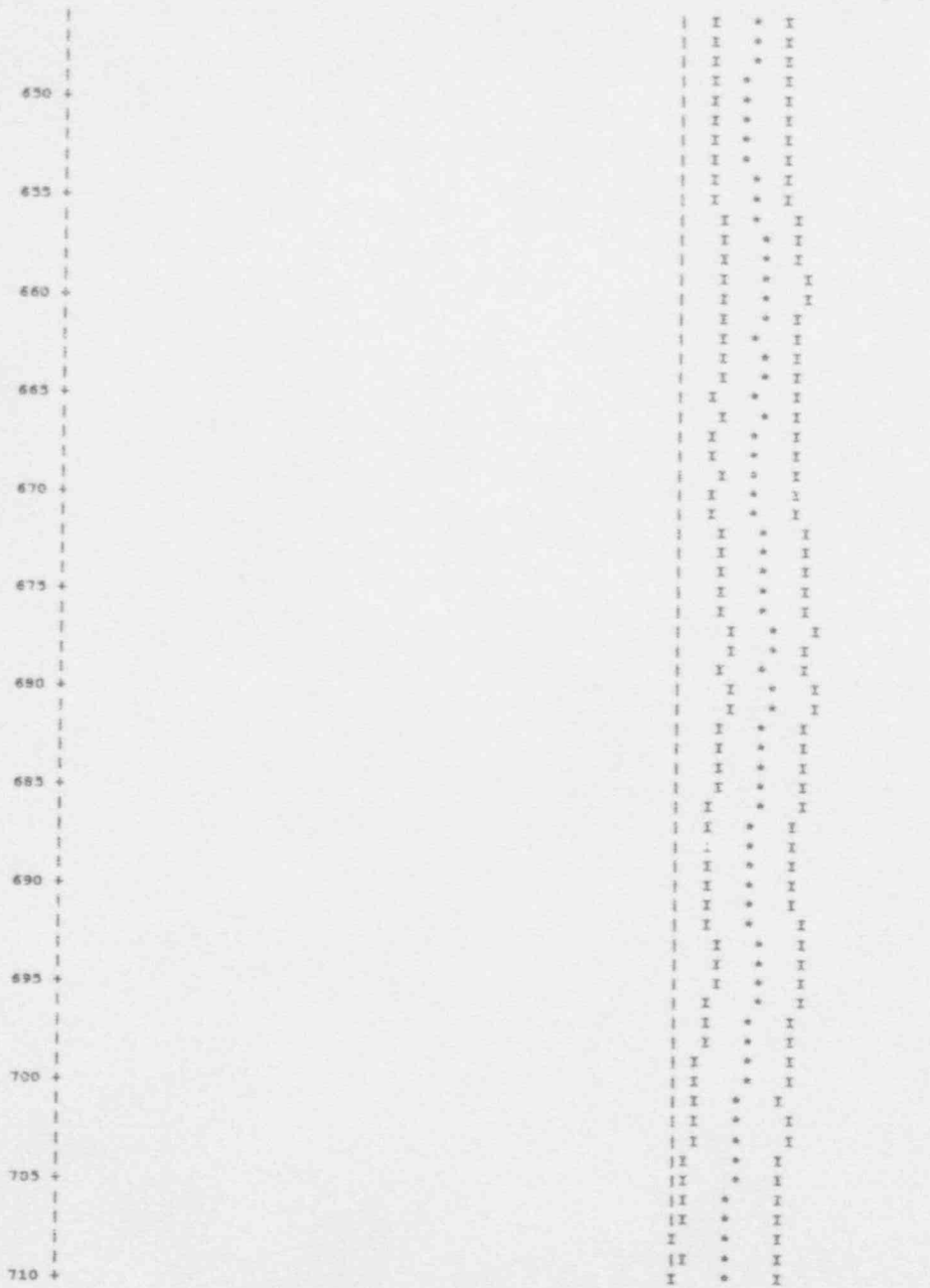

325
330
335
340
345
350
355
360
365
370
375
380
385


390
393
400
405
410
415
420
425
430
435
440
445
450


455
460
465
470
475
480
485
490
495
500
505
510
515


520
525
530
535
540
545
550
555
560
565
570
575
580


595
590
595
600
605
610
615
620
625
630
635
640
645


650
655
660
665
670
675
680
685
690
695
700
705
710


715
720
725
730
735
740
745
750
755
760
765
770
775


780
785
790
795
800

PMRARRAY KENO CASE COMPARISON WITH MONK5B

SKIPPING 3 GENERATIONS

GROUP	FISSION FRACTION	UNIT	REGION	FISSIONS	PERCENT DEVIATION	ABSORPTIONS	PERCENT DEVIATION	LEAKAGE	PERCENT DEVIATION
1	0.0075			6.84339E-03	2.1164	2.96519E-03	1.8543	9.27808E-05	20.1313
2	0.0313			2.83955E-02	0.6345	1.26411E-02	0.5887	7.70707E-05	22.1228
3	0.0356			3.25115E-02	0.5711	1.31510E-02	0.5651	1.04322E-04	18.9775
4	0.0147			1.34456E-02	0.6554	6.23990E-03	0.6505	5.39408E-05	26.5636
5	0.0043			3.93274E-03	0.5490	3.81515E-03	0.5381	3.51411E-05	33.2218
6	0.0038			3.46982E-03	0.4138	6.01944E-03	0.4080	6.26674E-05	24.8062
7	0.0038			3.45332E-03	0.4132	6.49852E-03	0.3989	3.11093E-05	35.2698
8	0.0038			3.49585E-03	0.4362	1.14296E-02	0.4195	3.90829E-06	100.0000
9	0.0052			4.71442E-03	0.4597	1.84544E-02	0.4332	1.59350E-05	49.9269
10	0.0110			1.00250E-02	0.4861	2.67627E-02	0.4412	3.85146E-06	100.0000
11	0.0225			2.04830E-02	0.4508	4.21184E-02	0.4078	1.21980E-05	57.6680
12	0.0274			2.49722E-02	0.5388	4.59188E-02	0.4928	1.17607E-05	57.7540
13	0.0250			2.28275E-02	0.5788	4.45674E-02	0.5212	7.97607E-06	70.6992
14	0.0185			1.69067E-02	0.5384	6.02973E-02	0.4803	1.52686E-05	49.9409
15	0.0043			3.91615E-03	0.8661	1.13861E-02	0.9272	3.13490E-06	100.0000
16	0.0029			2.62024E-03	1.1646	7.04960E-03	1.2385	0.00000E+00	0.0000
17	0.0045			4.07487E-03	1.4955	5.01621E-03	1.3584	3.90829E-06	100.0000
18	0.0059			5.42623E-03	1.5605	5.21270E-03	1.5713	0.00000E+00	0.0000
19	0.0071			6.50715E-03	1.2602	7.78485E-03	1.2210	0.00000E+00	0.0000
20	0.0300			2.73574E-02	0.7058	3.12133E-02	0.6626	3.77174E-06	100.0000
21	0.0162			1.47851E-02	1.1021	1.34694E-02	0.9607	0.00000E+00	0.0000
22	0.0368			3.35656E-02	0.8101	2.97218E-02	0.7018	4.76817E-06	83.9226
23	0.1140			1.03994E-01	0.4629	9.97190E-02	0.3782	3.65785E-05	25.6826
24	0.1897			1.73062E-01	0.3924	1.65961E-01	0.2822	9.19241E-05	16.4943
25	0.1503			1.37355E-01	0.4423	1.29752E-01	0.3109	6.32634E-05	17.6913
26	0.1695			1.54585E-01	0.4660	1.46013E-01	0.3345	3.87515E-05	22.7041
27	0.0541			4.93401E-02	0.8369	4.80475E-02	0.5627	4.48878E-06	71.1998
SYSTEM TOTAL =				9.12245E-01	0.1525	1.00122E+00	0.0491	7.79519E-04	6.6957

ELAPSED TIME 125.86100 MINUTES

RANDOM NUMBER= F3F111CC

PWRARRAY KENO CASE COMPARISON WITH MONK6B

FREQUENCY FOR GENERATIONS 4 TO 603

```
0.7550 TO 0.7641     *
0.7641 TO 0.7732
0.7732 TO 0.7823
0.7823 TO 0.7914
0.7914 TO 0.8005     **
0.8005 TO 0.8096     **
0.8096 TO 0.8188     **
0.8188 TO 0.8279     ********
0.8279 TO 0.8370     **********
0.8370 TO 0.8461     **********
0.8461 TO 0.8552     ***********************
0.8552 TO 0.8643     ******************************
0.8643 TO 0.8734     ****************************************
0.8734 TO 0.8825     **************************************************
0.8825 TO 0.8916     ***************************************************************************
0.8916 TO 0.9008     *****************************************************************************
0.9008 TO 0.9099     ********************************************************************************
0.9099 TO 0.9190     ***************************************************************************************************
0.9190 TO 0.9281     ********************************************************************************
0.9281 TO 0.9372     ****************************************************************
0.9372 TO 0.9463     ************************************************
0.9463 TO 0.9554     ****************************
0.9554 TO 0.9645     ************************************************
0.9645 TO 0.9737     ********************************
0.9737 TO 0.9828     ************************
0.9828 TO 0.9919     ***********
0.9919 TO 1.0010     *********
1.0010 TO 1.0101     ****
1.0101 TO 1.0192     **
1.0192 TO 1.0283
1.0283 TO 1.0374     *
1.0374 TO 1.0465
1.0465 TO 1.0557     *
```

PWRARRAY MEM3 CASE COMPARISON WITH MONK6B

FREQUENCY FOR GENERATIONS 204 TO 803

```
0.7550 TO 0.7641     *
0.7641 TO 0.7732
0.7732 TO 0.7823
0.7823 TO 0.7914
0.7914 TO 0.8005     **
0.8005 TO 0.8096     *
0.8096 TO 0.8188     **
0.8188 TO 0.8279     *******
0.8279 TO 0.8370     ********
0.8370 TO 0.8461     ******
0.8461 TO 0.8552     ****************
0.8552 TO 0.8643     ************************
0.8643 TO 0.8734     ******************************
0.8734 TO 0.8825     ************************************
0.8825 TO 0.8916     ********************************************
0.8916 TO 0.9008     ************************************************************
0.9008 TO 0.9099     ************************************************************
0.9099 TO 0.9190     ********************************************************************************
0.9190 TO 0.9281     ************************************************
0.9281 TO 0.9372     ******************************************************
0.9372 TO 0.9463     ************************************
0.9463 TO 0.9554     ********************
0.9554 TO 0.9645     **********************************
0.9645 TO 0.9737     ****************************
0.9737 TO 0.9828     ****************
0.9828 TO 0.9919     **********
0.9919 TO 1.0010     *****
1.0010 TO 1.0101     ***
1.0101 TO 1.0192     **
1.0192 TO 1.0283
1.0283 TO 1.0374     *
1.0374 TO 1.0465
1.0465 TO 1.0557     *
```

PWRARRAY KENO CASE COMPARISON WITH MONK6B

FREQUENCY FOR GENERATIONS 404 TO 803

```
0.7550 TO 0.7641     *
0.7641 TO 0.7732
0.7732 TO 0.7823
0.7823 TO 0.7914
0.7914 TO 0.8005     *
0.8005 TO 0.8096
0.8096 TO 0.8188     **
0.8188 TO 0.8279     ***
0.8279 TO 0.8370     ******
0.8370 TO 0.8461     ****
0.8461 TO 0.8552     *********
0.8552 TO 0.8643     *************
0.8643 TO 0.8734     ***************************
0.8734 TO 0.8825     ***********************
0.8825 TO 0.8916     ************************************
0.8916 TO 0.9008     ****************************************
0.9008 TO 0.9099     ****************************************
0.9099 TO 0.9190     ************************************************
0.9190 TO 0.9281     ***************************************
0.9281 TO 0.9372     ********************************************
0.9372 TO 0.9463     ***********************
0.9463 TO 0.9554     ****************
0.9554 TO 0.9645     ***********************
0.9645 TO 0.9737     ********************
0.9737 TO 0.9828     ***********
0.9828 TO 0.9919     *********
0.9919 TO 1.0010     ***
1.0010 TO 1.0101     **
1.0101 TO 1.0192     *
1.0192 TO 1.0283
1.0283 TO 1.0374
1.0374 TO 1.0465
1.0465 TO 1.0557
```

PWRARRAY KENO CASE COMPARISON WITH MONK6B

FREQUENCY FOR GENERATIONS 604 TO 803

```
0.7550 TO 0.7641     *
0.7641 TO 0.7732
0.7732 TO 0.7823
0.7823 TO 0.7914
0.7914 TO 0.8005     *
0.8005 TO 0.8096
0.8096 TO 0.8188     *
0.8188 TO 0.8279
0.8279 TO 0.8370     **
0.8370 TO 0.8461     **
0.8461 TO 0.8552     *****
0.8552 TO 0.8643     ******
0.8643 TO 0.8734     **********
0.8734 TO 0.8825     **********
0.8825 TO 0.8916     ******************
0.8916 TO 0.9008     ********************
0.9008 TO 0.9099     ********************
0.9099 TO 0.9190     ********************
0.9190 TO 0.9281     *************
0.9281 TO 0.9372     ******************
0.9372 TO 0.9463     ***************
0.9463 TO 0.9554     ********
0.9554 TO 0.9645     ********
0.9645 TO 0.9737     *******
0.9737 TO 0.9828     ********
0.9828 TO 0.9919     ******
0.9919 TO 1.0010     *
1.0010 TO 1.0101     **
1.0101 TO 1.0192     *
1.0192 TO 1.0283
1.0283 TO 1.0374
1.0374 TO 1.0465
1.0465 TO 1.0557
```

****

CONGRATULATIONS! YOU HAVE SUCCESSFULLY TRAVERSED THE PERILOUS PATH THROUGH KENO V IN 125.86300 MINUTES

****

SECTION E

NUCLEAR DATA LIBRARY

Summary

A summary is presented of the history, development and contents of the MONK6B nuclear data library.

1 SUMMARY AND BACKGROUND

The standard isotopic library available with MONK is based on the United Kingdom Nuclear Data Library (UKNDL) compilation. The history of UK Nuclear Data evaluation is long and diverse; for the purpose of this report the description starts around the mid 1960s. This era corresponds to the early years of the UK reactor development programme.

The first UKNDL nuclear data library was issued in 1964 [1]. At that time UKNDL probably contained the best consistent nuclear data available in the world. During 1964-73 many evaluations and revisions were carried out which were included in NDL Tapes [2]. In 1973 Pope [3] published a document summarising the contents of the NDL-1 tape which quotes the energy range of the cross section tabulations together with a list of tabulated reactions. This document referred to the sources of the origins of the data used in NDL-1.

In the period from 1973 to 1979 a number of inconsistencies, mostly minor, were identified in several of the files and a number of new evaluations (some for materials already in the 1973 edition) became available. During 1979 the Nuclear Data Group at UKAEA Winfrith began to revise and recompile the 1973 edition of the UKNDL and this was completed in early 1980. This revised library contained NDL-1, NDL-2 and NDL-3 files (tapes) and a tape mainly for dosimetry files.

In early 1980's the method development groups at UKAEA Harwell and Winfrith began a program of work making extensive use of 1980 edition of NDL files for the production of Monte Carlo cross-section data using the processing code MOULD. During the course of this work further improvements were made to some of the files and a new version of the UKNDL tapes was issued in 1981 [4].

Table 1 gives a summary of the historical evolution of the UKNDL library. More information can be obtained from references [1] to [4]. A recent review of the UKNDL data evaluation is given in reference [5]. For the purpose of criticality calculations a UKNDL library was created containing 77 nuclides including fissile isotopes and other important nuclides. Table 2 presents the reference sources used during the compilations for some of the important isotopes. A full list of the nuclides available in the UKNDL library with MONK6 is given in Table 3.

Results from benchmarking the MONK library based on the UKNDL led to adjustments to the nuclear data for U235, U238, Pu239, Pu240, Gd and Fe. These adjustments reduced the error on k-effective from ±3.5% to ±2%. All adjustments were made, to produce a systematically high k value; an important safety issue for a criticality code.

Since 1981 UKNDL libraries have been used as one source of evaluations for incorporation into the Joint Evaluated File (JEF). The JEF library is in ENDF6 format. It is a joint Japanese European library. The first version JEF1 was a collection of the best evaluations available in collaborating countries together with published ENDF files. A benchmarking exercise highlighted where further evaluation effort was needed and resulted in the JEF2.2 evaluation [6]; released internationally in 1993. JEF2.2 evaluations are considered to be of equal quality to those in ENDF/B-VI and both libraries are undergoing extensive benchmarking.

Currently, MONK libraries are based on adjusted UKNDL data. However MONK is being used with new JEF based test libraries for benchmarking the JEF2.2. This exercise should also result in a revised MONK library for users.

2 THE CONTENTS OF UKNDL NUCLEAR DATA FILES

NDL-1 : The 1981 edition of NDL-1 contains neutron cross section data for 82 materials. About 21 files in the library were either completely new evaluations or MISSIONARY conversions of American ENDF files (mainly ENDF III).

NDL-2 : The NDL-2 tape contains neutron cross section data for 192 fission product nuclides compiled by an Australian group at Lucas Heights [7]. All 192 files have common energy range 1.0263 meV to 15 MeV and they contain data only for capture, elastic,inelastic and transport cross sections.

NDL-3 : The 1981 edition of NDL-3 tape contains 63 files of neutron cross section data. The original notion of maintaining NDL3 as a library of files for activation detectors is widened to include other small files; nevertheless most of the files in NDL-3 are for activation detectors.

3 PROCESSING CODES

During the evaluation period of UKNDL data (1964-81) various processing codes were written to prepare data for application codes. Those relevant to MONK are listed below.

CHECK [8]

This code was written to check the internal structure of the data files as well as the cross-sections making sure that all components of the reactions added to the total cross section at every energy point.

GALAXY [9]

GALAXY was used as the main processing tool. It generated group average cross sections and scatter matrices at the temperature of the UKNDL evaluation. It was used for all nuclides in the library.

GENEX/SDR and RESP [10]

The program GENEX is used to calculate Doppler broadened cross sections from resonance parameters. The resolved and unresolved resonance calculations were made with this code. The resonance data for most important heavy nuclides, (U-238, U-235, PU-239 etc.) were generated using GENEX. The RESP code was developed to generate statistical resonance parameters which were used in GENEX calculations.

ERIC2 [11]

The programme was used to process resonance data for some important resonance absorbers.

MINIGAL [12]

Calculates thermal cross-sections, resonance integrals and fission spectrum averaged values from UKNDL. These can be compared with other evaluations.

MISSIONERY [13]

The UKNDL data contains nuclides obtained form American ENDF evaluations. These nuclear data for these nuclides were converted to UKNDL format using the MISSIONERY code.

DICE [14] - MOULD

DICE converts the nuclear data in the UKNDL library into a form which can be used in MONK. It is employed in MONK for accessing the nuclear data for a particular calculation. The main part of the DICE package is the MOULD module. MOULD accepts neutron cross section data in the UKNDL library format and converts them to the MONK library format.

References

[1] J S Story, W M M Kerr, K Parker, I C Pull and P Schofield. 3rd Geneva Conference on the Peaceful Uses of Atomic Energy. P/168 (1964).

[2] D S Norton. The UKAEA Nuclear Data Library.
AEEW-M 824 Feb. (1968).

[3] A L Pope. The Current Edition of the Main Tape NDL-I of the UK Nuclear Data Library.
AEEW-M1208 March (1973).

[4] J S Story , R W Smith. The 1981 Edition of the United Kingdom Nuclear Data Library. A Status Summary. Sept. 1981. Internal Paper DIDW9(81)/P246.

[5] R J Perry, C. Dean. WIMS Data Library, Chapter 2. AEA-RS-1254 (1993).

[6] N R Smith, D Hanlon and A K Ziver. Benchmarking JEF2.2 with MONK.
AEA-RS-1238 (1993).

[7] W K Bertram, E Clayton, J H Cook,W D Ferguson, A R Musgrove and E K Rose. A Fission Product Group Cross Section Library. AAEC/E214 June 1971.

[8] L W Blott and K Parker. CHECK AEEW - M 347 (1964).

[9] J A Price. A Guide to GALAXY 6 Part 1. AWRE 01/75.

[10] R J Brissenden and C Durston. A Users Guide to GENEX/SDR and Related Computer Codes. AEEW -R622 Aug (1968).

[11] H M Sumner. ERIC2 A Fortran Program to Calculate Resonance Integrals and from them Effective Capture and Fission Cross-Section. AEEW -R 323 April (1964).

[12] A L Pope and J S Story. MINIGAL Output from UK Nuclear Data Library - NDL1 (1973) Thermal Cross Sections, Resonance Integrals and Fission Spectrum Averages.
AEEW - M 1234 Dec (1973).

[13] J Cameron. MISSIONERY- A Computer Program to Convert Data in the ENDF Format to the UKNDL Library Format. AWRE 0 17/76 Oct. (1976).

[14] J B Parker (editor). Preparation of Nuclear Data into a form suitable for Monte Carlo Calculations using an Electronic Computer. AWRE 0-27/66 May 1966 DICE Mk V.

Table 1 The Historical Development of the UK Nuclear Data Library

Year	UK Evaluated Data	Format	Other Major Data Choice	Processing	Remarks
1964	UKNDL	UKNDL	None	GALAXY, GENEX/SDR	The UKNDL probably contained the best consistent nuclear data available at this time
1975	UKNDL	UKNDL	ENDFB III	GALAXY GENEX/SDR,ERIC2	Data of equal quality UKNDL has better QA than ENDFB III
1981	UKNDL	UKNDL	ENDFB IV	GALAXY	Fewer new evaluation in UKNDL (Am and Hf isotopes) than ENDFB IV. ENDFB IV QA improved

Table 2 The UKNDL Evaluations of Some Important Nuclides

Mat./ DFN	Energy Range,eV Min	Max	Reference (Source)	Lab. (+)	Comments, Data Type	Eval. Date
U-233 87B	1.0E-04	1.5E+07	Ainger (1969), NDFWP/P97,unpublished Hart(1969),AHSB(S)R-124 fission cross section	WIN RLY WIN	Total, Elastic, Inelastic, N,2N, N,3N, N,Fission, N,Gamma.	1969 1970 1973
U-234 953A	1.0E-05	1.5E+07	Drake & Nichols (1970) GA-8135 ENDF/B2, MAT-1043 Douglas (1972) NDFWP(72) P21, unpublished	GGA ALD	ENDFB/2 Mat 1043 Converted to UKNDL format, Total,Elasitic, Inelastic, N,2N, N,3N, N,Fission, N,Gamma.	1972 1973
U-235 159 B 9159 (*)	1.0E-04	1.5E+07	Douglas (1972) AWRE Nuclear Research Note NRN-4/72 Sowerby et al (1972) AERE-M2497 Mather et al (1972) AWRE-O 72/72 Pendlebury (1972) unpublished	ALD HAR ALD ALD	Revised to DFN-271 above 25KeV using older file DFN66A at lower energies. Nu-bar revised over whole energy range. Further revised to DFN 159 for N,2N cross-sections. Total Elastic,Nonelastic,Inelastic,N,2N, N,3N, N,Fission, N,Gamma.	1972
U-236 954A	1.0E-05	1.5E+07	Drake and Nichols (1970) GA-8135 ENDF/B2 MAT-1046 Douglas (1972) NDFWP(72) P21 unpublished	GGA ALD	ENDF/B2 MAT-1046 converted to UKNDL format. Total, Elastic, Inelastic, N,2N , N,3N, N,Fission, N,Gamma.	1972
U-238 160 A 9160A (*)	1.0E-04	1.5E+07	Douglas (1972) AWRE Nuclear Research Note NRN-4/72 Sowerby et al (1972) AERE-N2497 Mather & Bampten (1971) AWRE O-44/71 Pendlebury (1972) Unpublished	ALD HAR ALD ALD	Revised to DFN-272 above 25KeV, using at lower energies the French File DFN-401. Further revised as DFN-160 for N,2N cross sections. Total, Elastic, Nonelastic, Inelastic, N,Fission, N,Gamma.	1972
U-239 276 B	1.0E+03	1.5E+07	Pendlebury (1972) Unpublished	ALD	Total,Elastic,Inelastic, N,2N , N,3N , N,Fission, N,Gamma.	1972
U-240 277 B	1.0E+03	1.5E+07	Pendlebury (1972) Unpublished	ALD	Total,Elastic,Inelastic, N,2N , N,3N , N,Fission, N,Gamma.	1972
Pu-238 274 A	1.0E-04	1.5E+07	Pendlebury (1972) Unpublished	ALD	Total,Elastic,Inelastic, N,2N , N,3N , N,Fission, N,Gamma.	1972
Pu-239 161 A 9161 (*)	1.0E-04	1.5E+07	Douglas (1972) AWRE Nuclear Research Note NRN-4/72 Sowerby et al (1972) AERE-M2497 Mather et al (1970) AWRE O-86/70 Pendlebury unpublished	ALD HAR ALD ALD	Revised to DFN-269 above 25 KeV using older file DFN-65A at lower energies. Nu-bar revised over whole energy range. Further revised to DFN-161 for N,2N cross sections Total,Elastic,Inelastic, N,2N , N,3N , N,Fission, N,Gamma.	1972
Pu-240 402 C	2.5E-10	1.5E+07	L'Heriteau and Ribon (1970) CEA-N-1273	SAC	Total,Elastic,Inelastic, N,2N , N,3N , N,Fission, N,Gamma.	1970 1980

Table 2 Continued

Mat./ DFN	Energy Range,eV Min	Max	Reference (Source)	Lab. (+)	Comments, Data Type	Eval. Date
Pu-241 60A	1.0E-04	1.5E+07	Pope (1968) AEEW-M824 Appendix B Doherty (1966) AEEW-M714	WIN WIN	Extensive revisions by Pope above 50 eV to Doherty's DFN 40. Total,Elastic,Inelastic, N,2N , N,3N , N,Fission N,Gamma.	1967 1973
Pu-242 975A	1.0E-05	1.5E+07	Alter & Dunford (1967) NAA-SR-12271 and supplement ENDF/B3 MAT-1161	GGA AI ALD	ENDFB/3 Mat 1161 Converted to UKNDL format. Total,Elastic, Inelastic ,N,2N , N,3N, N,fission , N,Gamma.	1972 1973
HinH2O 923A	1.0E-04	2.0E+07	Butland (1970) WNDG/76 unpublished below 1KeV, Pope Story (1972) NNDEN/8 above 1KeV; angular distributions deduced from Stewart et al (1971) LA-4574	WIN	For H in Water Total, Elastic, N,gamma. Revised in 1980.	1972
O 933C	1.0E-04	1.5E+07	Slaggie & Reynolds (1965) KAPL-M6452 above 15KeV Butland, Pope & Story (1967-1971) below 15KeV ENDF/B2 MAT-1046	KAPL WIN	Revised below 1KeV. Mainly ENDF/B file MAT 1013. LASL revisions included. Total, Elastic,Nonelastic,Inelastic, N,Gamma , N,P, N,D , N,Alpha.	1971
B-10 90 E	1.0E-04	1.5E+07	Iijima (1970) unpublished	WIN JAERI	Total,Elastic,Nonelastic, Inelastic,Parasitic Absorption, N,P , N,T , N,Alpha, N,D.	1970
Fe 908A	1.0E-04	1.5E+07	Pope & Story (1972) unpublished	WIN	SIGAR is used to calculate resonance parameters up to 330 KeV. Above 330 KeV DFN 950 was used.	1972
Zr 82B	1.0E-04	1.5E+07	Pope and Story (1969) AEEW-M921	WIN	Total, Elastic, Nonelastic, Inelastic, N,2N, N,gamma, N,P.	1970
AL27 935A	1.0E-04	1.5E+07	King (1964) AEEW-M445	WIN	Total, Elastic, Nonelastic, N,alpha, Inelastic, N,2N, N,gamma, N,P.	1967

(+) See below for Laboratory Codes
WIN:AEA-Winfrith (UK)
RLY:AEA-Risley (UK)
GGA:Gulf General Atomic,San Diego, California (USA)
ALD:AWRE, Aldermaston (UK)
HAR:AEA-Harwell (UK)
SAC:CEN Sacley, France
AI:Atomics International, Canoga Park, Calif. (USA)
KAPL:Knolls Atomic Power Lab., Schenectady, New York (USA)
JAERI: Atomic Energy Research Inst., Tokyo, Japan

(*) For U235,U238 and Pu239 data in resonance region were generated using the GENEX code.

Table 3 - MONK6B Continuous Energy Nuclear Data Library

Nuclide	File No.	Nuclide	File No.
H	211	Ag107	973A
HinH$_2$O	923A	Ag109	974A
DinD$_2$O	905A	Cd	70A
T	252A	Cd113	71B
He	47	Sn	988
He3	44	Eu151	921B
He4	221D	Eu153	922B
Li6	914A	Gd	949B
Li7	215E	Hf174	1201B
Be9	967A	Hf176	1202B
B10	90E	Hf177	1203B
B11	49B	Hf178	1204B
C	902B	Hf179	1205B
N	259A	Hf180	1206B
O	933C	Ta	328B
F19	23E	W	213E
Na23	182E	Pb	26C
Mg	986	Th232	930A
Al27	935A	U233	87B
Si	25E	U234	953A
P31	7821B	U235	9159
S32	987	U236	954A
Cl	141E	U237	167A
K	84B	U238	9160A
Ca	138E	U239	276B
Ti	190B	U240	277B
Cr	446C	Np237	960A
Mn	88A	Pu238	274A
Fe	908A	Pu239	9161
Co59	934B	Pu240	402C
Ni	907A	Pu241	60A
Cu	835B	Pu242	975A
Cu63	681B	Am241	1009C
Cu65	682B	Am242m	4953B
Ga	105B	Am243	1010A
Zr	82B	Cm243	4963B
Nb93	79C	Cm244	976B
Mo	81C	Cm245	984A

SECTION F

QA PROGRAMME

Summary

A description of the Quality Assurance programme for MONK6B can be provided to MONK code users. This comprises two parts: firstly, a general programme for all codes provided by the ANSWERS Software Service (which includes MONK6B); and secondly, additional features specific to MONK6B in recognition of its criticality safety role.

SECTION G

MONK6B USER GUIDE & REFERENCE MANUAL

Summary

A summary of the contents of the MONK6B User Guide and Reference Manual is presented. The documents themselves are distributed as part of the MONK code package.

1 SUMMARY OF USER DOCUMENTATION

The documentation which supports the use of MONK6B comprises two volumes:

- User Guide
- Reference Manual

A summary of the contents of the two volumes is given below.

1.1 MONK6 - User Guide (ANSWERS/MONK6/1)

The MONK6B User Guide contains a description of the code input data, output data and the principal modelling facilities, including a number of example problems. The document is divided into six chapters as follows:

Chapter 1 Point Energy Modelling

Chapter 1 gives the details of the MONK6B nuclear data library and its use by the collision processing section of the code (the so-called DICE module). Included here is: an overview of the thermalisation and resonance treatments; a description of the material tracking algorithm; a summary of the collision mechanics; and a range of miscellaneous items, including a definition of the k-effective estimators used by MONK6B.

Chapter 2 Geometry Modelling

Chapter 2 describes the MONK6B geometry modelling package, covering both simple body and hole geometries. A description of the algorithms used in each case is provided. The use of generally-oriented simple bodies to form structured parts is presented, together with the inherent limitations of such a scheme. This leads on to the introduction of hole geometries, where each of the MONK6B options is described.

Chapter 3 Input Description

The input data for the MONK6B code are a free-format mixture of keywords and numeric items. The input description is given by a means of numbered items within sections (units), together with overview flow-charts; a introduction to the format is given at the start of the chapter. The description is presented as five units: the material specifications; simple body geometry; hole geometry; control and edit data; and geometry visualisation.

Chapter 4 Output Description

This chapter describes the MONK6B output, which includes an interpreted summary of the input data, followed by a number of output tables, some of which are optional.

Chapter 5 Multigroup Pre-processing Calculations

Multigroup nuclear data libraries can be employed in MONK6B in place of the standard continuous energy library. The code can access the SCALE and WIMS systems and this chapter describes the input data requirements for the various pre-processing codes that need to be used.