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Validation of KENO V.a for Highly-Enriched Uranium Systems with Hydrogen and/or Carbon Moderation

A Thesis

Presented for the

Master of Science

Degree

The University of Tennessee, Knoxville

Ernest P. Elliott

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Abstract

This report describes the validation of KENO V.a using the 27-group ENDF/B-IV cross section library for systems containing highly-enriched uranium, carbon, and hydrogen and for systems containing highly-enriched uranium and carbon with high carbon to uranium (C/U) atomic ratios. The validation is in accordance with ANSI/ANS-8.1-1983(R1988) and has been performed for two separate computational platforms: an IBM 3090 mainframe and an HP 9000 Model 730 workstation, both using the Nuclear Criticality Safety Software (NCSS) code package.

Critical experiments performed at the Oak Ridge Critical Experiments Facility, in support of the Rover reactor program, and at the Pajarito site of Los Alamos National Laboratory were identified as having the constituents desired for this valiation as well as sufficient experimental detail to allow accurate construction of KENO V.a calculational models.

Calculated values of k_{eff} for the Rover critical experiments, which contain uranium, hydrogen, and carbon, are between 1.0012 +/- 0.0026 and 1.0245 +/- 0.0023. Calculation of the Los Alamos experiments, which contain uranium and carbon at high C/U ratios, yields k_{eff} values between 0.9746 +/- 0.0028 and 0.9983 +/- 0.0027. Safety criteria can be established for both types of systems using these data.

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Chapter I

Introduction

I.1 Background

KENO V.a is a multigroup Monte Carlo computer code which is used to determine effective neutron multiplication (k_{eff}) of multidimensional systems and is used as the primary calculational tool in many criticality safety evaluations. KENO V.a is part of the Standardized Computer Analysis for Licensing Evaluation (SCALE)[1] system and is maintained under strict configuration control through the use of various "frozen" versions, such as the NCSS (Nuclear Criticality Safety Software)[2] version used in this validation. Also included in the SCALE system are several cross section libraries and cross section processing modules which are user-specified through use of certain calculational sequences which invoke the desired modules as well as KENO V.a.

Two types of neutronic systems are representative of recycle and waste materials that are commonly encountered in plants that process fissile materials, especially highly-enriched uranium. These neutronic systems can be assigned to two broad categories: highly-enriched uranium systems with hydrogen and carbon moderation and highly-enriched uranium systems with carbon moderation at high C/U ratios. Some examples of these materials are given below:

- Contaminated hydrocarbons from uranium processing areas such as machine oils

- Contaminated cellulose-based materials such as paper wipes and plastic-based materials such as plastic bagging used to contain highly-enriched uranium-contaminated materials

- Combinations of the above, such as wipes that have been used to wipe up either contaminated machine oil spills or highly-enriched uranium solution spills

- Graphite casting molds used in the production of highly-enriched uranium metal parts and as a result retain highly-enriched uranium as a surface coating

- Furnace ash produced through incineration of the combustibles listed above.

These wastes may be placed in strorage configurations or may be processed further using appropriate equipment. As for any activity involving fissile material, an evaluation of the proposed storage or processing configurations must be performed to demonstrate criticality safety. The evaluation considers whether enough fissile material could be assembled, along with reactivity additions from moderation and/or reflection effects, to accidentally achieve criticality under double contigency criteria in accordance with Section 4.2.2 of Reference 3.

The current version of KENO V.a could be used to perform evaluations for the examples just cited by modeling the fissile and other materials as more reactive substances for which KENO V.a has already been validated.[4,5,6,7] This approach is unnecessarily conservative and leads to underutilization of storage containers and process equipment. For systems with high C/U ratios such that moderation is at optimal, credit could be taken for hydrogen being added to the system as water (which is a typical postulated scenario in criticality analyses) behaving as a neutron poison instead of a moderator. A further benefit of validating KENO V.a for the two neutronic systems listed above is that the results would be applicable for other low atomic weight elements commonly found in some of waste streams that are reasonable moderators but may be conservatively modeled as carbon for criticality safety analyses. Examples include oxygen, sodium, potassium, fluorine, calcium, iron, and alumnium. In conclusion, validation of KENO V.a for the two neutronic systems mentioned would help to eliminate superfluous conservatism in criticality analyses allowing more fissile material to be present in a given operation and thus reduce costs by more fully utilizing storage and process equipment.

I.2 Scope and Organization

This thesis documents validation of KENO V.a (actually the CSAS25 calculational sequence which includes KENO V.a and the BONAMI-S and NITAWL-S modules)[1] using the 27-group ENDF/B-IV cross section library in accordance with Reference 3 for

the two systems mentioned above: highly-enriched uranium with hydrogen and carbon moderation and highly-enriched uranium with carbon moderation at high C/U ratios.

Reference 3 promulgates the necessary elements for proper validation of a calculational method. Once calculations are performed, the systematic disagreement between the calculated results and the experimental data (bias) can be determined along with any significant trends in the results. From this information, safety criteria, including k_{eff} upper limit values for calculations, can be established. This procedure fulfills the requirements of Reference 3 and is sufficient to demonstrate validation. However, for this work to be truly and ultimately useful to others who may wish to validate KENO V.a on their own computational platforms, many other things that are inherent in the validation process must also be reported and in great detail. These necessary elements are covered by this thesis as indicated below.

Chapter II discusses the calculational method (codes, modules, and/or sequences) that was validated as well as the cross section library used in the validation. Also, a short discussion about cross section processing is presented.

Chapter III describes the critical experiments used for the validation including information on materials present in the critical assembly and exact geometric detail if available. If information was lacking or incomplete, assumptions made to reconcile the shortcomings are given.

Calculational model (KENO V.a model) development to represent the critical assembly configurations is discussed in Chapter IV. Also included are important assumptions that were necessary in model construction and information on cross section processing, especially where the geometries are different from standard SCALE fuel-moderator unit cell arrangements.

Chapter V reports the results of the calculations including results and significance of sensitivity studies performed to investigate the importance of certain parameters.

Chapter VI recapitulates important conclusions and observations derived from this effort. Recommendations for work that would benefit future efforts in this area are also listed.

Much of the detailed information about the critical assemblies is provided in the Appendix along with examples of KENO V.a input and output. In addition, microfiche of the input and output for all of the cases run for this thesis are available from the author.

Chapter II

Description of Calculational Method

II.1 Modules and Cross Section Library

The computer modules used in the validation effort are part of the SCALE system which is used as a calculational tool in many criticality safety analyses.[1] One of the control sequences utilized in such analyses is the CSAS25 control sequence which is part of the CSAS4 control sequence.[8] The CSAS25 sequence activates the BONAMI-S,[9] NITAWL-S,[10] and KENO V.a[11] functional modules. A different control sequence, CSASN, activates only the BONAMI-S and NITAWL-S modules, after which KENO V.a can be called by the user and will use the cross section library just generated by CSASN. This procedure is equivalent to specifying CSAS25 since the same modules are utilized, but more flexibility is afforded the analyst for geometries that cannot be directly represented by standard SCALE fuel-moderator unit cell configurations. For this validation, the CSASN control sequence was utilized followed by execution of KENO V.a since the experiments used had peculiarities that rendered them unamenable to strict use of the CSAS25 control sequence. The control sequence and functional modules will be described below. The 27-group ENDF/B-IV cross section library is the library chosen to be validated in this effort.

The CSASN control sequence reads input data including fuel-moderator unit cell geometry, size, and temperature for treatment of resonances, the desired cross section library, mixture and nuclide specifications, and other data depending on the arrangment of the unit cell geometry. Physical and neutronics information required by the functional modules such as theoretical densities, average resonance region background cross sections, and molecular weights are supplied by the Standard Composition Library[12] or calculated by the Materials Information Processor.[13] The user may also choose not to rely completely on the code to calculate number densities for the various materials and may enter them directly instead. Each nuclide in the Standard Composition Library is assigned a unique identification number. These data are used by BONAMI-S and NITAWL-S in developing a working cross section library for use by KENO V.a.

BONAMI-S performs resonance shielding through application of the Bondarenko shielding factor method to all nuclides that have Bondarenko data.[9] It reads the master format library and applies the Bondarenko correction factors to all nuclides that have Bondarenko data. The kinematics of neutron scattering with the resonance nuclide are explicitly treated.[4] Input data to BONAMI-S includes composition of the materials, size, geometry, and temperature of the unit cell configuration being analyzed. BONAMI-S produces a master format library which is read by NITAWL-S.

NITAWL-S applies the Nordheim Integral Treatment to perform neutron cross section processing for nuclides that have ENDF/B-IV resonance parameter data.[10] Input

data for NITAWL-S includes information similar to that required for BONAMI-S which relates the physical and neutronic characteristics of the unit-cell configuration being analyzed. NITAWL-S uses these data to complete processing of the working library from BONAMI-S. This library is then used by KENO V.a in the calculation of k_{eff}.

The 27-group ENDF/B-IV master cross section library in SCALE is invoked by specifying 27GROUPNDF4 for the cross section library name. The 27-group library was collapsed from the 218-group Criticality Safety Reference Library, which was developed for the Nuclear Regulatory Commission to utilize all of the general-purpose files in the ENDF/B-IV data compilation.[8] Explicit ENDF/B-IV resonance parameters are carried for resonance nuclides in both the 27-group and 218-group master libraries. These resonance parameters are used by NITAWL-S in the CSASN and CSAS25 control sequences for calculating problem-dependent, group-averaged cross sections in resonance regions. The 27-group library does not contain any Bondarenko factors, only resonance data used by NITAWL-S.

KENO V.a is a multigroup Monte Carlo computer code used to determine k_{eff} for multidimensional systems containing fissionable material.[11] The geometrical bodies allowed in KENO V.a for defining calculational regions include cuboids, spheres, and cylinders. Other, slightly more complicated shapes can be represented through other means. KENO V.a has an enhanced geometry package that allows arrays to be defined and positioned throughout the model. It also includes a P_N scattering treatment,

generates printer plots for checking input models, allows supergrouping of energy-dependent data, and has problem restart capability.

XSDRNPM-S[14] is a one-dimensional discrete ordinates transport code for performing neutron and/or gamma calculations.[4] XSDRNPM-S can be used to weight cross section libraries according the spatial neutron flux variation in a number of different ways. These include cell-weighting, zone-weighting, and vein-weighting.[15] In each of these cases, the reaction rates in the homogeneous mixture created by XSDRNPM-S are conserved. Executed within the context of CSAS2X control sequence XSDRNPM-S performs cell weighting based on the materials present and the dimensions of the fuel-moderator unit cell. The average cross section obtained using the equation listed below conserves reaction rates of the different materials in the cell. The defining equation for cell-weighting with input group g and output group G is[15]

$$\overline{N}\,\overline{\sigma}_G\,\overline{\Phi}_G\,V = \sum_j N_j V_j \sum_{g \in G} \sigma_g\,\overline{\Phi}_{g,j}$$

$$\overline{N} = \sum_j \frac{N_j\,V_j}{V} \qquad V = \sum_j V_j$$

where

$\overline{\phi}_{g,j}$ is the average group g flux in zone j;

$\overline{\phi}_G$ is the group G average flux;

σ_g is the group g cross section of the nuclide;

$\overline{\sigma}_G$ is the group G average cross section;

N_j is the zone j nuclide number density

V_j is the zone j volume

V is the total cell volume

$\overline{N}$ is the cell-averaged number density.

II.2 SCALE Cross Section Processing Primer

Cross section processing using modules as described above is required for multigroup codes and must be performed accurately if the physics of the problem are to be adequately reflected. SCALE contains three main options for cross section processing, one of which is must be specified for a given problem: infinite homogeneous medium, lattice cell, or multiregion.[13] The purpose of these manipulations is to obtain problem-dependent group-averaged cross sections for nuclides that have resonance data.

The infinite homogeneous medium approximation (specified as INFHOMMEDIUM) processes cross sections for a given material or isotope assuming a spatially uniform flux is present throughout the material which is treated as dimensionally infinite. The potential scattering cross section for a given resonance nuclide under these assumptions is defined by[16]

$$\sigma_{pD}=\sum_{i=1}^{M}\frac{\sigma_{scatt_i}N_i}{N_D}$$

where

σ_{pD} is the resonance correction for nuclide D

$\sigma_{scatt\ i}$ is the scattering cross section in the resonance range for the i^{th} nuclide

N_i is the number density of the i^{th} component of the mixture

M is the number of components in the mixture

N_D is the number density of the isotope for which σ_p is being calculated

For a lattice of discrete pieces of material containing a resonance nuclide (specified as LATTICECELL), cross section processing again assumes a uniform spatial flux distribution across an infinite, one-dimensional array of fuel-moderator unit cells. In this case, the σ_p for the resonance nuclide is calculated according to the following equation[16]

$$\sigma_{pD} = \frac{\left(\sum_{i=1}^{M} \sigma_{scatt_i} N_i\right) + \Sigma_H}{N_D}$$

$$\Sigma_H = \frac{(1-c)\,a}{\bar{l}\,(1+(a-1)\,c)}$$

where

$\bar{l}$ is a geometric factor approximated by 4V/S (S=surface area; V=volume)

c is the Dancoff[17] factor

a is a parameter to treat the curvature of the piece

This last equation adjusts the cross sections to account for neutron leakage from one piece of material containing the resonance nuclide and interaction with another piece of material containing the same nuclide. The MULTIREGION specification is similar to that of LATTICECELL with a=1 and c=0, which implies no interaction between pieces, such that the correction factor becomes $1/\bar{l}$. It is clear, however, that the working libraries produced using these three methods will not be the same. The differences between them are dependent on the degree of heterogeneity and the effect of the resonance treatment on the problem. It is also clear that any weighting of the cross

sections, such as by XSDRNPM-S, is an additional modification of the working cross section library.

The choice and use of a method is problem dependent and each problem should be evaluated on the basis of geometry and resonance nuclides present. Failure to process the cross sections correctly may lead to a poor estimate of neutron absorption in the resonance region. Subsequent calculation of k_{eff} in KENO V.a using the working library produced by BONAMI-S and NITAWL-S may then be in error (either high or low) depending on the magnitude of the error in the working library and/or the amount and type of resonance nuclide present in the problem.

Chapter III

Critical Experiments

III.1 Rover Experiments

III.1.a Introduction

The Rover program, as it came to be called, was started during the late 1950s to provide a means of propulsion for space missions. Out of this program came a design for a spacecraft engine called the Nuclear Engine for Rocket Vehicle Application (NERVA). Many variations of the NERVA fuel element were conceived, fabricated, and tested although the number of each design actually produced fluctuated based on the adequacy of the design. Regardless of the design, all proposed elements were made from graphite imbedded with uranium beads, enriched to 93.5 percent U^{235}, and containing holes that ran throughout their length. During the proposed space mission, liquid hydrogen, carried in a tank on the spacecraft, would be passed through the fuel element. As it traveled down the holes within the element, the fuel elements were moderated and criticality achieved, providing thermal energy to the liquid hydrogen and converting it into gas. The gaseous hydrogen, thus generated, would be under high pressure and would exit the end of the fuel element at tremendous velocity, providing propulsion for

the spacecraft.

Of the different fuel elements designed and fabricated, the 19-hole, hexagonally shaped fuel element appeared to be the most promising and thus was subjected to the greatest number of tests. At least two factories in the United States eventually built these elements: the Oak Ridge Y-12 Plant and the Westinghouse Astronuclear Laboratory. The Westinghouse fuel elements were apparently divided into two species designated NRX-A3 and NRX-A4.[18] The differences between them were small and will be discussed later. In order to ship and to store the fuel elements safely, critical experiments were performed to determine the number of elements that could safely reside together and the proper spacing required. These experiments were performed at the Y-12 Plant in the Critical Experiments Facility (Building 9213) during late 1965 and were found to be of high enough quality for this validation effort.

III.1.b Materials

As stated before, the Rover fuel elements were constructed of graphite which contained uranium dicarbide beads. This combination of materials was extruded to create 19 holes passing through the length of the element. Impurities in the graphite were obtained from a sample of a non-uranium loaded element and are given in Table 1. Other pertinent information about the two types of fuel elements is given in Table 2, with some of the distinctions elaborated on below. The uranium dicarbide beads were 0.0126

Table 1 Graphite Impurities for Rover Elements

Element	microgram/gram (ppm)
Beryllium	0.02
Vanadium	38.0
Aluminum	0.20
Cesium	1.0
Manganese	1.0
Bromine	0.30
Copper	6.0
Molybdenum	8.0
Iron	53.0
Calcium	130.0
Lead	0.80
Silicon	11.0
Boron	0.08
Zinc*	17.0
Cadmium	0.80
Gallium*	2.0
Potassium	86.0
Zirconium	1.0
Barium	14.0
Nickel	18.0
Total	388.20

* These elements are not in the 27-group cross section library and are treated as copper

Table 2 Characteristics of Rover Fuel Elements

	NRX-A3	NRX-A4
Average Uranium Conc. (gm U^{235}/cm^3)	0.418	0.449
Element Fuel Loading (gm U^{235})	118.336	123.051
Net Element Volume (cm^3)	303.918	294.210
Hole Diameter (cm)	0.244	0.251
Average Length (cm)	132.786	131.785
Overall C/U^{235}	90.0	87.0
Average Graphite Content (gm)	544.237	547.061
Average Graphite Density (gm/cm^3)	1.791	1.859

cm in diameter and were randomly distributed throughout the graphite matrix.[19] The beads were comprised of a tiny diameter uranium sphere (.0076 cm) surrounded by a very thin pyrolytic carbon coating (.0025 cm). Information of the coating was not available but was assumed to be roughly the same in composition as the graphite matrix. The average fuel loading density given was 0.418 g/cm^3 for the NRX-A3 and 0.449 g/cm^3 for the NRX-A4 which computed to an average uranium loading of 118.36 grams and 123.051 grams of U^{235}, respectively.[18] These values compared well with information with other sources including values for the fuel content of each element reported in the lab notebook.[19,20] The NRX-A3 and NRX-A4 elements were both hexagonal in shape and were very similar except for the hole sizes and overall length. The approximate dimensions of the NRX-A fuel element are shown in Figure 1. The number 10 hole, in the center of the each element, was slightly enlarged at both the top and bottom of the element as indicated on the drawing. The elements used in the critical experiments were not completely finished. Niobium plating was added to the elements to retard corrosion of the graphite by the hydrogen gas, but was not present on the elements used in these experiments. The length was also slightly different than the specified 132.08 cm (52.00 inches) shown in Figure 1. The NRX-A3 elements averaged 132.786 cm in length, while the NRX-A4 elements averaged 131.785 cm in length.[20] For three of the experiments, select fuel elements were cut into nominally 7.62 cm segments and were stacked into 38.1 cm pseudo-elements.[18]

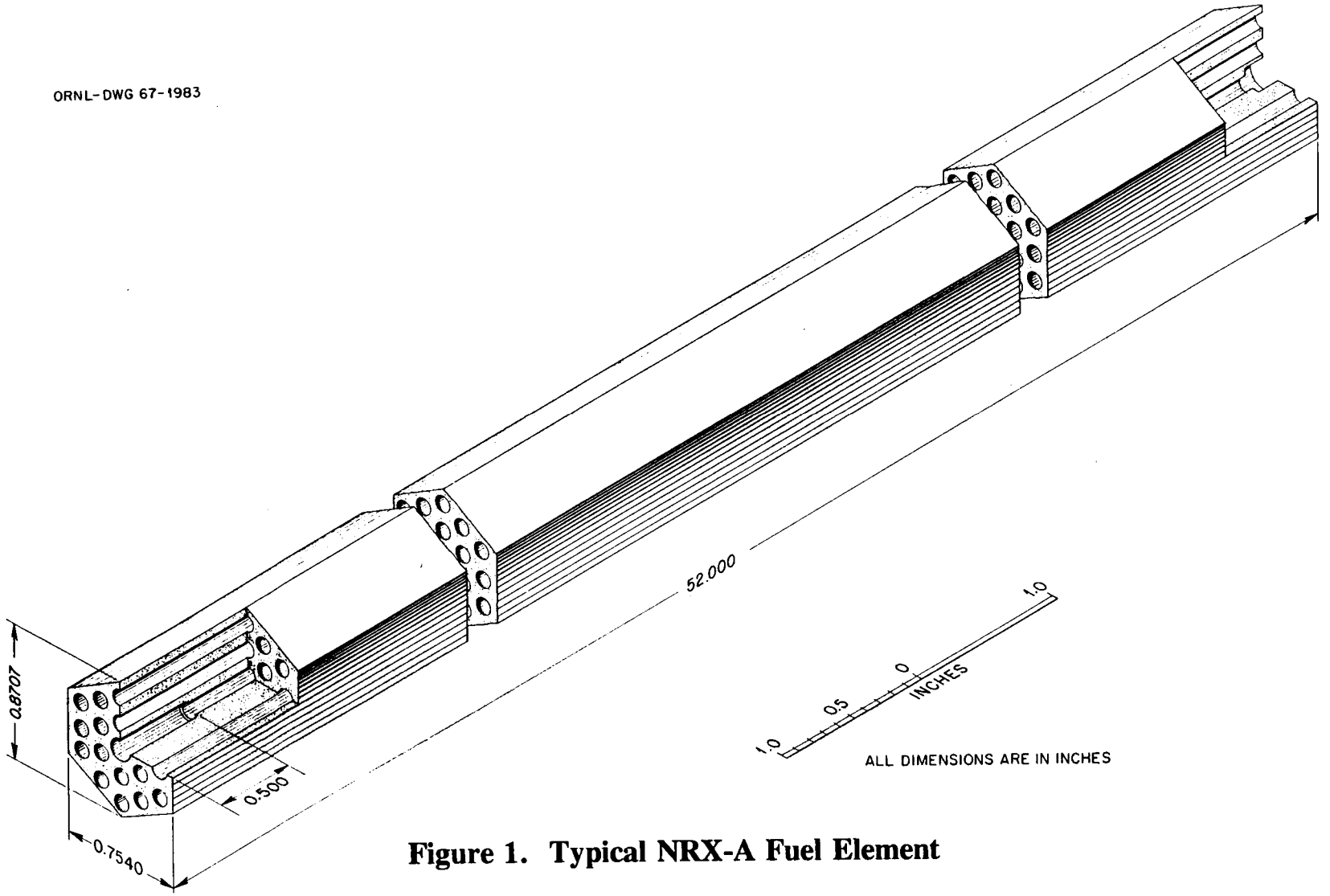


Figure 1. Typical NRX-A Fuel Element

For all of the square pitch and a few of the triangular pitch arrays, the fuel elements were placed in aluminum tubes and sealed with rubber stoppers assumed to be butyl in composition. The aluminum tubes had an outer diameter of 2.54 cm with a wall thickness of 0.0889 cm. The tubes were 135.89 cm in length and were assumed to have an aluminum end cap of 0.3175 cm thickness. The rubber stopper is reported to have extended about 1.27 cm into the tube, but was modeled as 1.09 cm.[18]

Plexiglas was used for strips and templates which maintained the desired element spacing and also for the table on which the elements rested during the experiment. The reason for choosing Plexiglas for these kinds of applications is that it is neutronically very similar to water. The chemical formula and subsequent number density information for Plexiglas was taken to be identical to that of methyl methacrylate which is the chemical name for this material.

Water was used to flood the large tank housing the constructed assembly and provided moderation and reflection for the critical assemblies. A laboratory analysis performed in late 1965 revealed that the water contained no significant impurities (less than 1 ppm total). A large, probably carbon steel, tank was used for these experiments. The composition is unimportant since greater than 30 cm of water was present between the outer edges of the critical assembly and the tank, neutronically isolating the assembly from the tank.[21]

III.1.c Configurations

A total of 25 critical assemblies were constructed during this experimental series. The configurations of the assemblies fall into four categories:

- Square pitch lattices, elements in tubes
- Triangular pitch lattices, elements in tubes
- Triangular pitch lattices, bare elements
- Triangular pitch lattices, 38.1 cm long bare elements

Photographs showing a configuration from each of the four major categories are reproduced as Figures 2 - 5. Fuel elements were used both in and out of the aluminum tubes, the latter arrangement allowing water to flood the holes of the element. The exact arrangment of the fuel elements for each of the 25 critical assemblies is presented in the Appendix.

The procedure followed in determining the number of fuel elements needed to achieve critical for a given lattice spacing was as follows. Elements were placed within the lattice, the number present usually being greater than needed for criticality under fully flooded and reflected conditions. The tank was then flooded and the assembly became critical at some water level less than the fully flooded level.

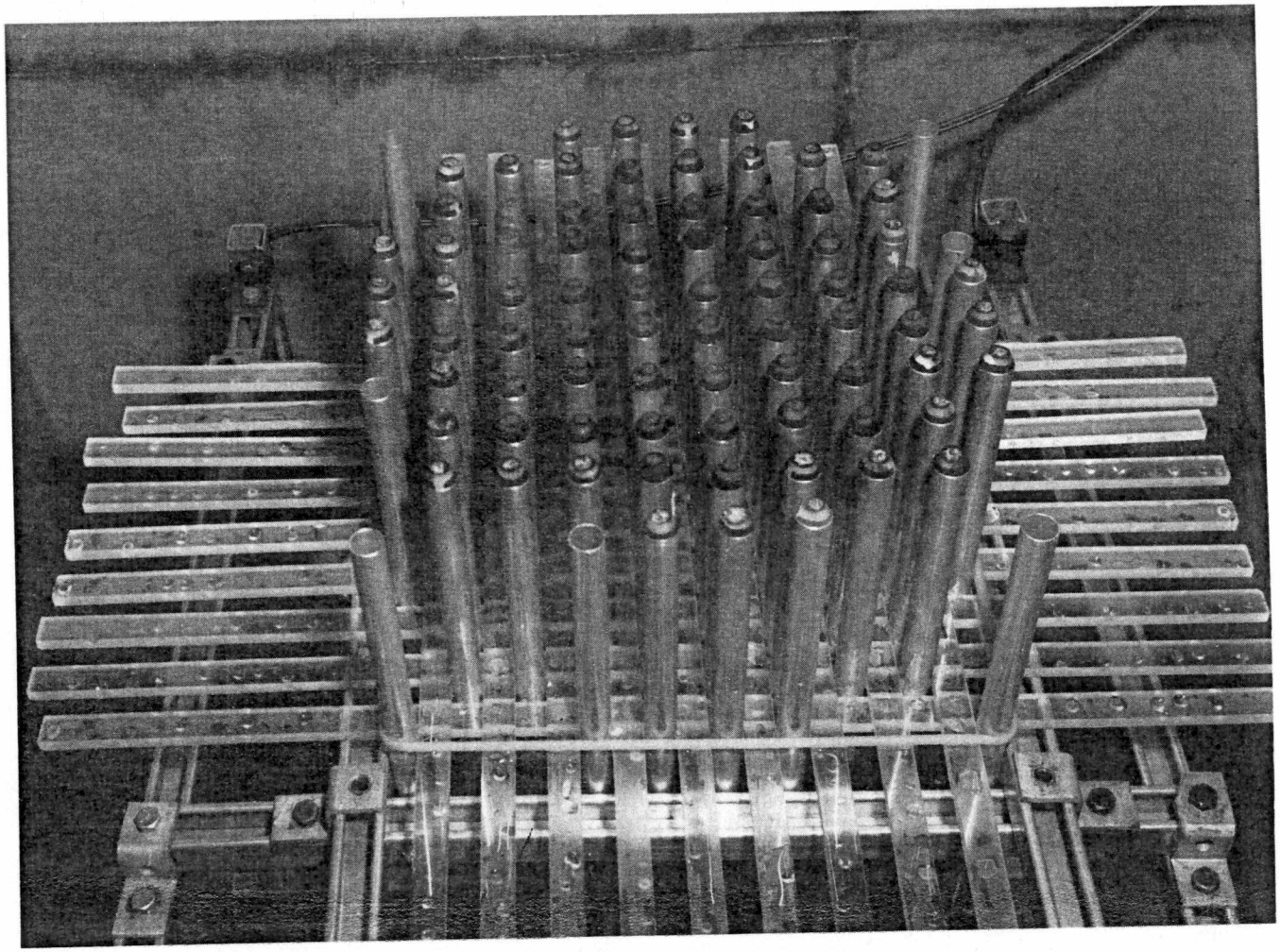


Figure 2. Photograph of Square-Pitch Experiment

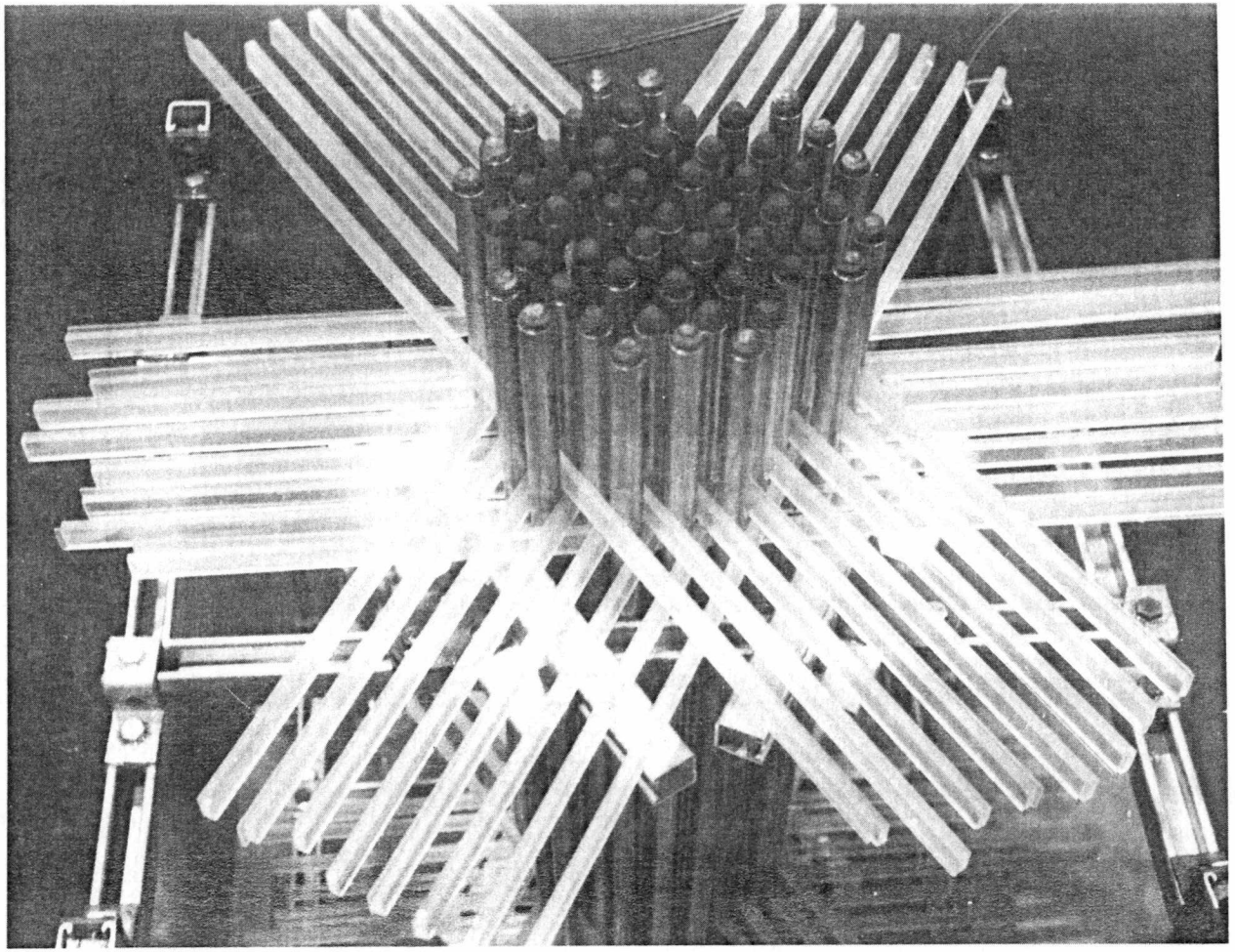


Figure 3. Photograph of Triangular-Pitch Experiment

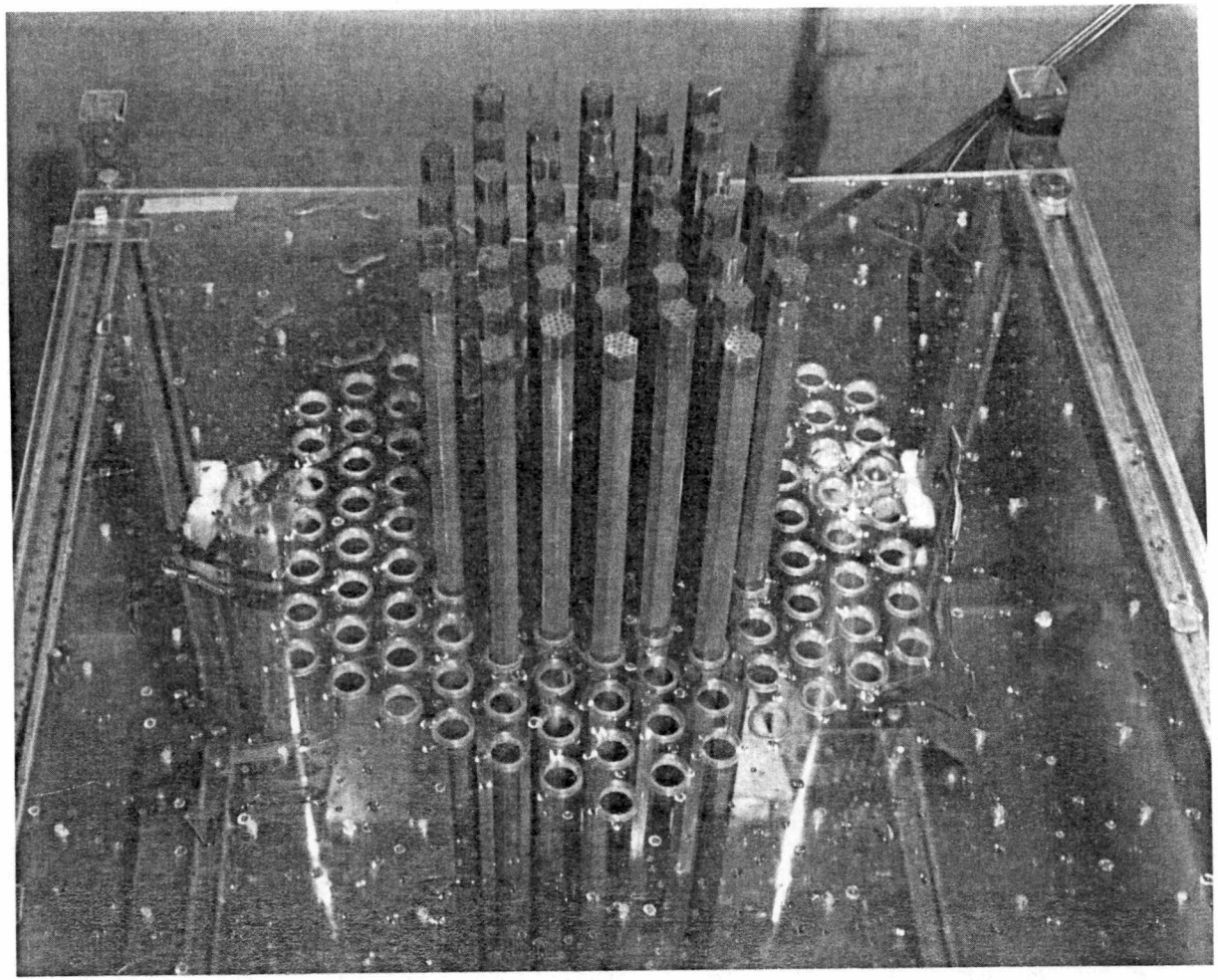


Figure 4. Photograph of Triangular-Pitch Experiments (Bare Elements)

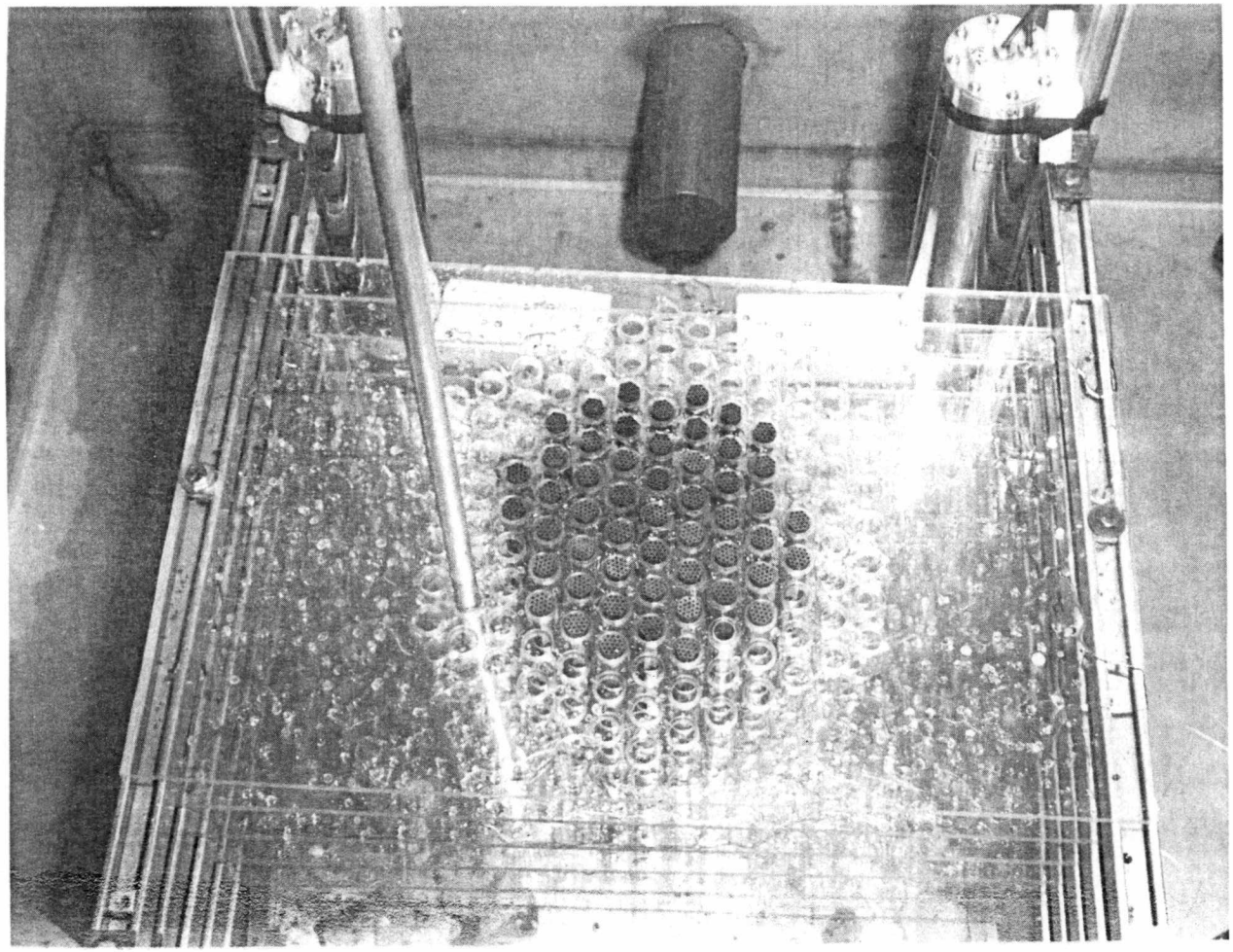


Figure 5. Photograph of 38.1 cm Element Experiment

The positive period was measured, indicative of the excess reactivity present, the water was drained, and one element removed. The assembly was then reflooded and usually was not completely critical once fully flooded, but the negative period could be ascertained. Based on the the magnitude of the two periods and the position of the element removed, an estimate could be made of the size of a "partial" element needed at that locale to make the assembly critical under fully moderated and reflected conditions. Location of the partial elements had to be assumed in a few cases and such assumptions are indicated in the Appendix.

In the square pitch lattice series, surface spacing varied from a minimum of 0.25 cm to a maximum of 2.54 cm. Figure 6 shows how the equipment was arranged for these experiments with some of the dimensions necessarily assumed. Plexiglas strips of appropriate thickness were placed between the encased elements at angles of 0 and 90 degrees in separate layers at two different heights along the element to provide stability. As can be seen in Figure 2 and as shown in Figure 6, aluminum channel pieces were placed against the outside of the assembly to hold the elements snugly. Although not clearly visible in Figure 2, the elements stood on a Plexiglas table. The top of the 3.80 cm thick table was approximately 32.3 cm above the bottom of the tank.[20]

The second configuration category, triangular pitch with elements in tubes, utilized Plexiglas spacers as well, but here they were placed at 0, 30, and 60 degree

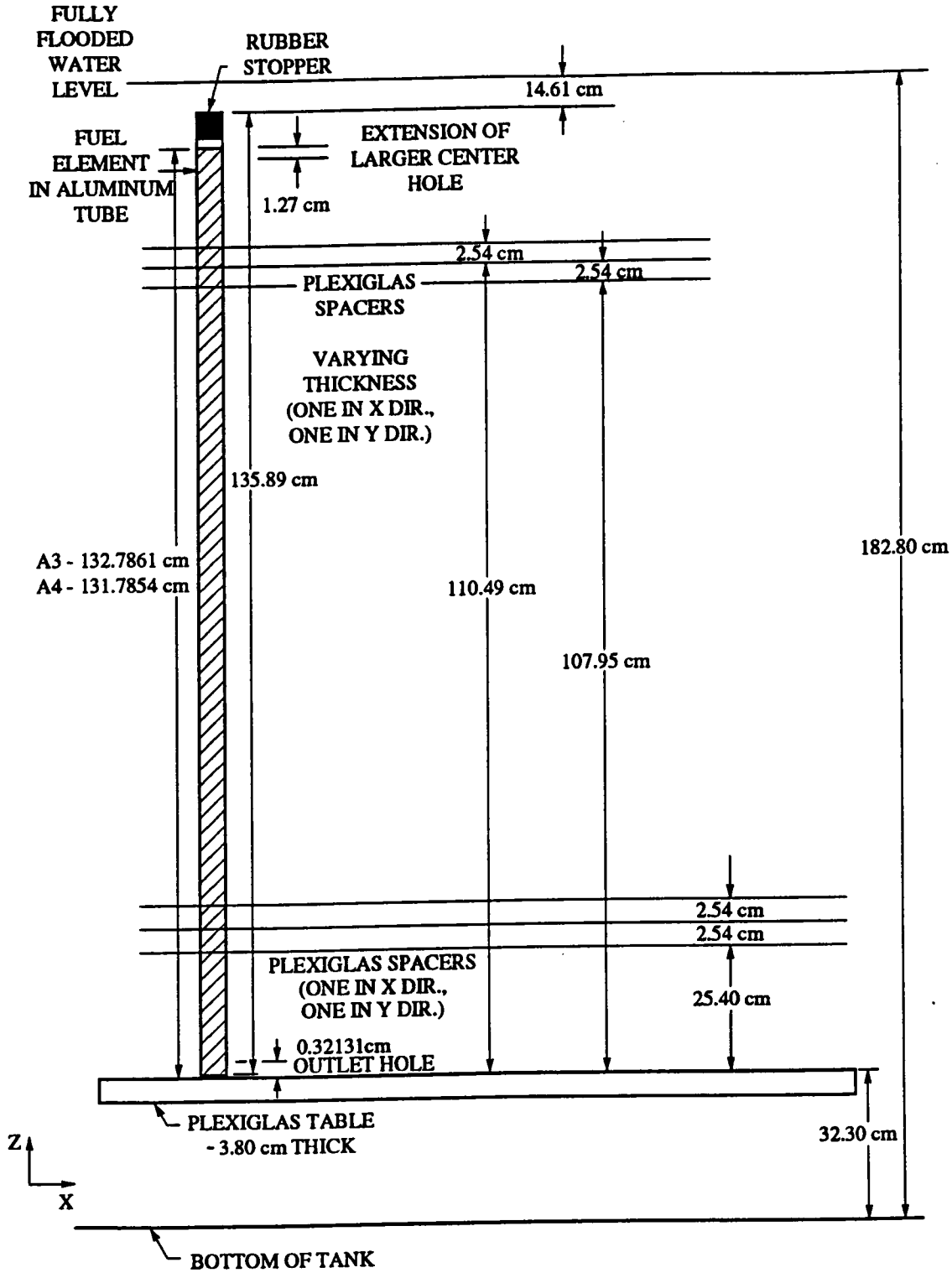


Figure 6. Axial View of Square-Pitch Experiments

angles as is evident in Figure 3. Surface spacing varied between 0.686 cm and 3.033 cm for the seven different configurations. The placement of various materials and their dimensions, both relative and absolute, is shown in Figure 7. The aluminum channel pieces were also placed at the three mentioned angles to provide support.

The triangular pitch lattice configurations using bare elements are somewhat different than the assemblies just described in that they used 1.27 cm thick Plexiglas templates to achieve the desired fuel element spacing. The materials are arranged as shown in Figure 8. Surface spacing between the elements ranged between 0.508 cm and 2.769 cm.

Plexiglas templates were used at five different elevations for the 38.1 cm long pseudo-element configurations. The fuel elements cut into the 7.62 cm sections and used for this series were apparently more heavily loaded than those used for the other experiments. The top of the Plexiglas table was somewhat different than previous experiments. Again, 1.27 cm thick Plexiglas templates, one every 7.62 cm (total of five), were used to achieve element spacing and to hold the small fuel element sections in place. Figure 9 shows how the various materials were arranged for this particular set of experiments.

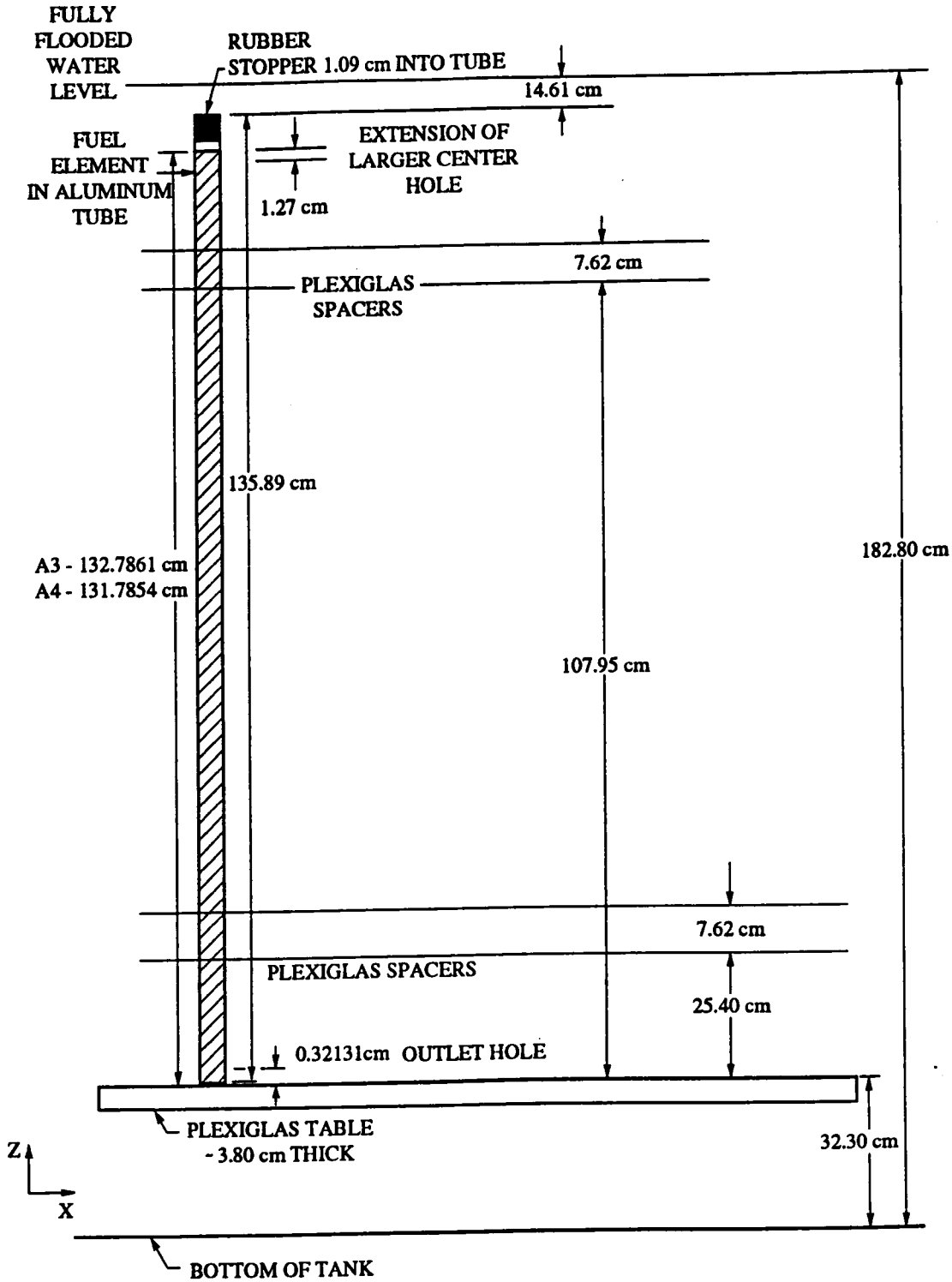


Figure 7. Axial View of Triangular-Pitch Experiments

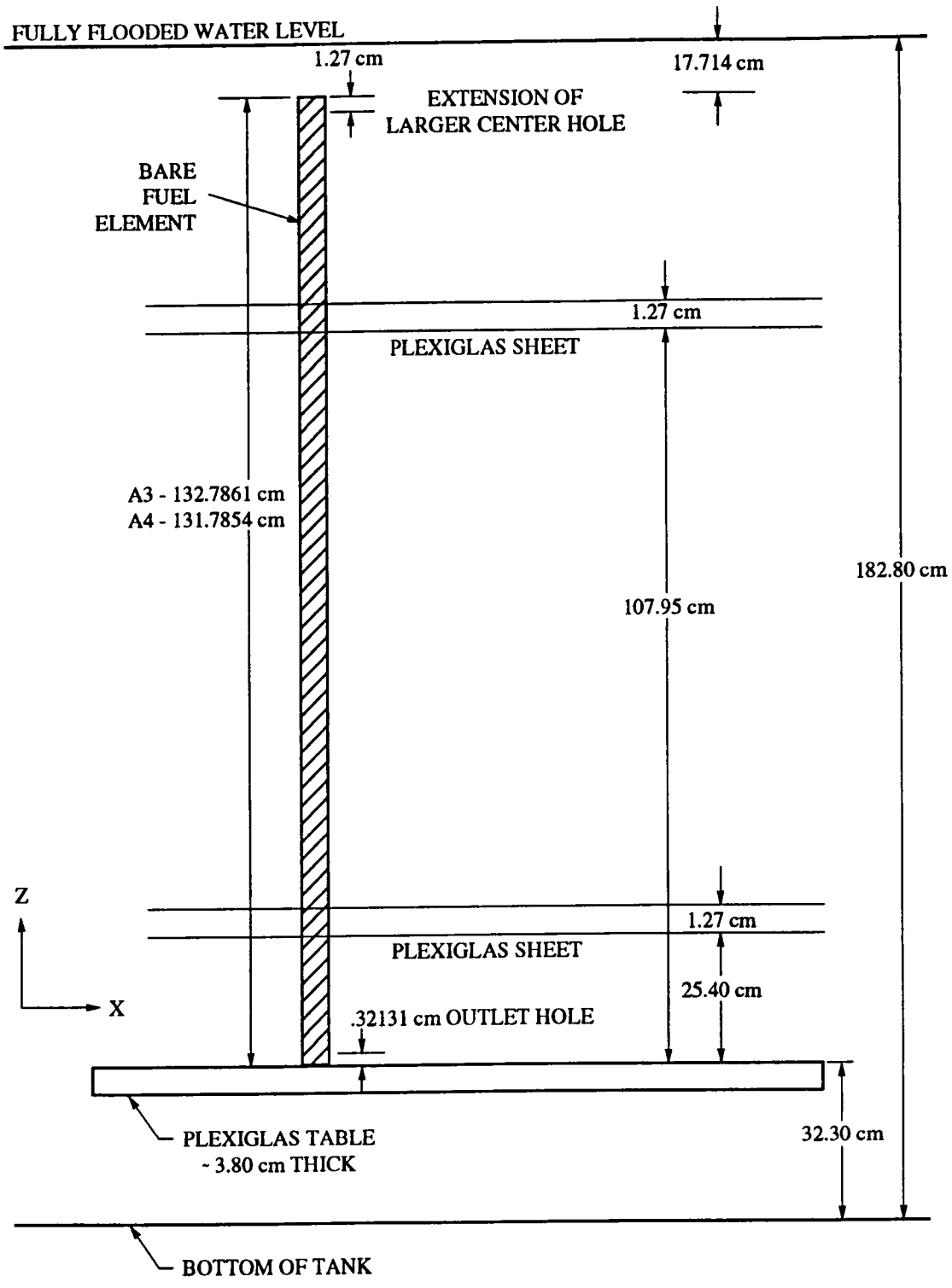


Figure 8. Axial View of Bare Triangular-Pitch Experiments

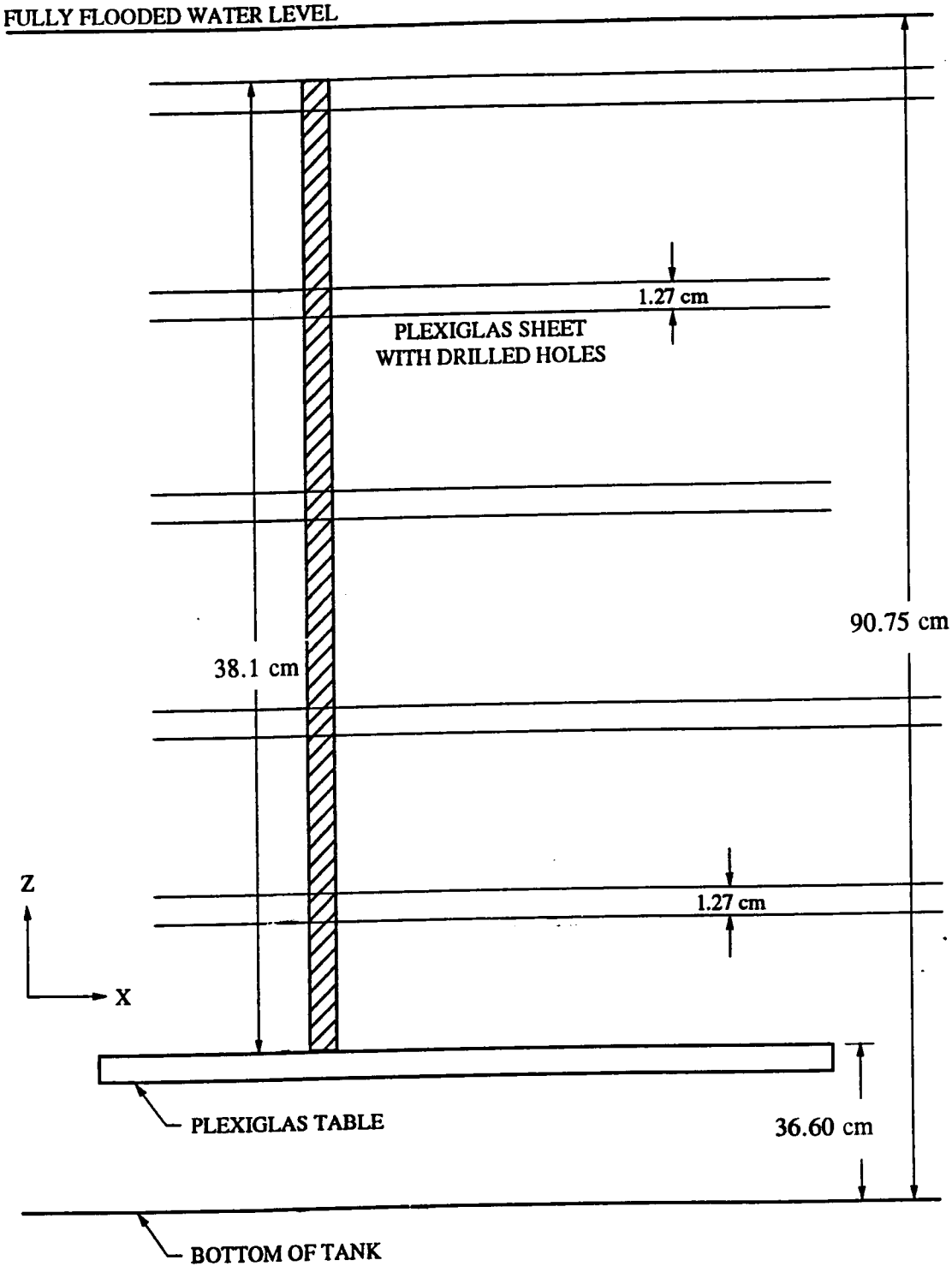


Figure 9. Axial View of 38.1 cm Element Experiments

III.2 Honeycomb Experiments

III.2.a Introduction

The Honeycomb experiments were performed at the Pajarito site of Los Alamos National Laboratory during late 1957. The apparent purpose for constructing this set of critical assemblies seems to have been to establish minimum critical masses for graphite moderated and reflected systems at numerous high C/U ratios. Also, based on the relatively small amount of uranium present in the assemblies and the large core volumes, the experiments may have been aimed toward low uranium density studies. The true purpose behind these experiments may have been lost over the 35 years that have passed since they were performed, but the information available from them remains unduplicated.

III.2.b Materials

The apparatus used to construct the critical assembly was the Honeycomb split-table machine. The Honeycomb machine consists of a 24 x 24 array of 7.62 cm square (outer dimensions) aluminum tubes that are divided at the center, each half approximately 91.44 cm in length. The wall thickness of the aluminum tubes is 0.1194 cm. A picture of the machine is shown in Figure 10. Materials are inserted into the two faces of the machine, except for the "control rods"; actually, fuel rods that are slowly inserted

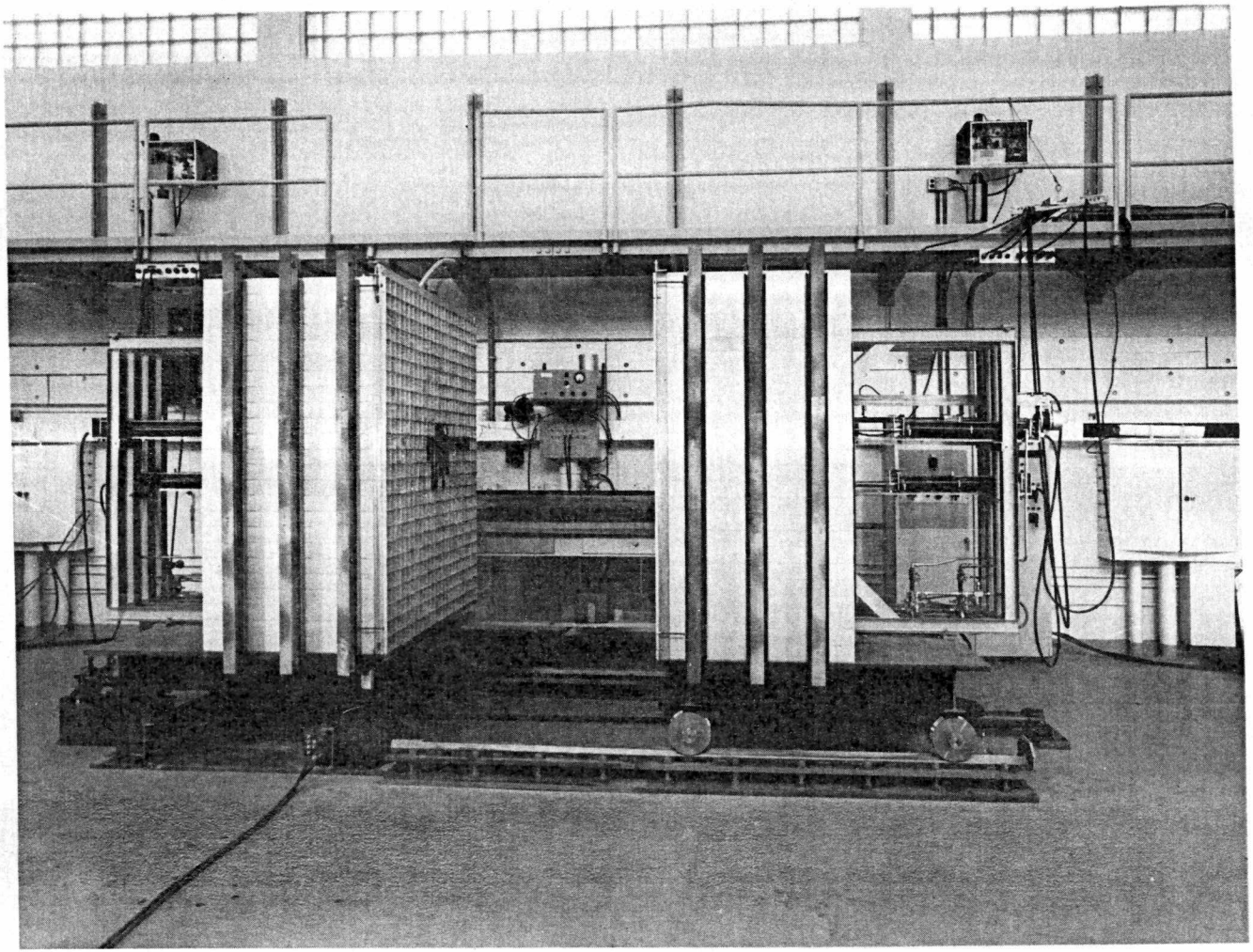


Figure 10. Honeycomb Split-Table Machine

to attain criticality, which enter from the back of the machine. Once all of the materials are inserted, the movable half of Honeycomb is rolled toward and eventually meets the other, fixed half. Reactivity is then added through insertion of the control rods until a small, positive period is obtained.

Uranium foils were interleaved with graphite blocks to form fuel tubes. Moderator tubes, comprised of a single graphite block (7.303 cm square), were stacked around the fuel tubes to form a checkboard pattern which is evident in Figure 11. Each of the uranium foils weigh 7.43 grams, of which .35 grams is Teflon coating added to retard oxidation. The foils are .00254 cm in thickness, 7.303 cm in width, and 19.05 cm in length. Visual inspection of the foils at the Pajarito site confirmed the width which had been previously reported as 7.112 cm.[22] The foils are enriched to 93.2 percent in U^{235} (6.8 weight percent U^{238}). The chemical formula for Teflon was taken to be C_2F_4, with an assumed density of 2.2 g/cm^3.

The graphite used in these experiments is identified as grade CS-312 graphite, a material commonly used during that period in neutronic applications and typically referred to as reactor grade graphite. It was not possible to conduct lab tests on this graphite, partly because one could not be sure that a sample selected from the storeroom for tests was the correct material used in these experiments. Another problem is that impurities found by such lab tests might be due to materials the graphite had come in

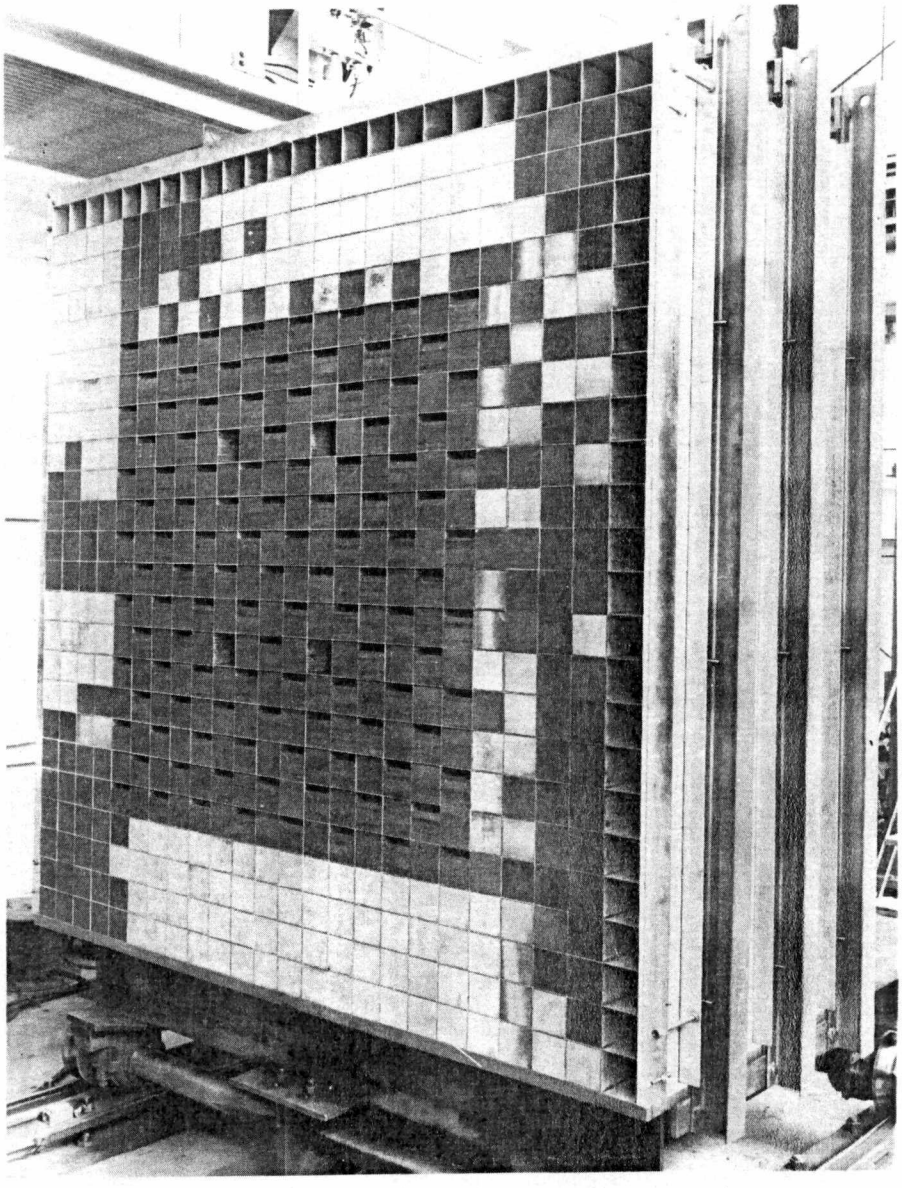


Figure 11. Example of Honeycomb Loading for Experiment

contact with over its long and probably varied history. However, accurate impurity information and other pertinent data concerning the graphite was located and is presented in Table 3.[22,23] The graphite blocks used in the fuel tubes varied in thickness as required to obtain an overall height of 7.303 cm (less for some experiments) and was also 7.303 cm in width, but measured 20.32 cm in length, slightly longer than the uranium foils. Graphite blocks used in moderator and reflector tubes were 7.303 cm square and 20.32 cm in length, except for those tubes which reflected the faces of the assembly which were 30.48 cm in length. Each critical assembly had 30.48 cm of graphite as a reflector on each of the six faces.[24]

No information is available for the aluminum tubes of which the Honeycomb machine was constructed. Therefore, pure aluminum at standard density is assumed.

III.2.c Configurations

A total of six experiments were performed in this series, two of which have not been previously reported in detail. The other four have been previously reported,[22] but the information published generally did not reflect the configurations recorded in the experiment logbook.[25] Each of the six configurations are presented in the Appendix.

The actual C/U ratios of the critical assemblies ranged from 2840 to 6680. The number of uranium foils in a fuel tube varied between one and four and all configurations

Table 3 Honeycomb Graphite Information

Graphite Density	1.67 g/cm^3
Graphite Grade	CS-312
Graphite Impurities[1]	ppm
Iron	320
Vanadium	49
Calcium	116
Titanium	60
Aluminum	350
Boron (natural)	1.3
Total	**896.3**

[1] Values taken from Reference 23

contained at least two different type of fuel tubes. The fuel tubes in two of the critical assemblies had an additional gap at the top and were tagged as "low density" experiments. As mentioned before, diagrams of the critical configurations are presented in the Appendix along with necessary information for KENO V.a model construction.

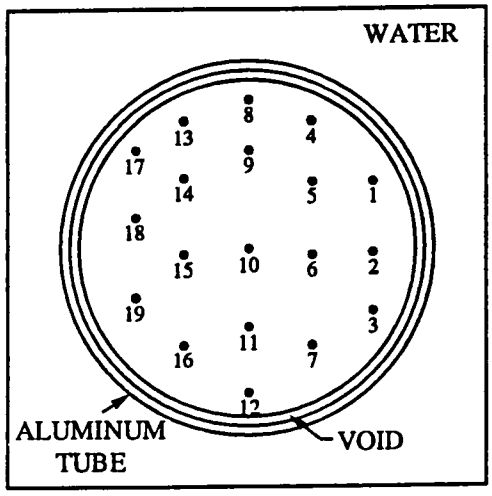
Chapter IV

Calculational Models

IV.1 Rover Models

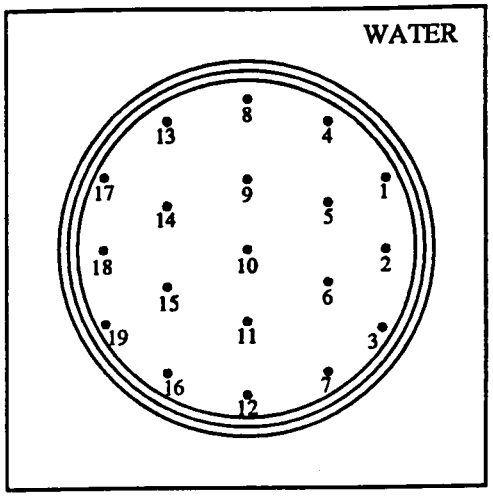
IV.1.a KENO Model Description

The KENO V.a models developed for the Rover critical assemblies directly reflect the actual configuration in almost every aspect. This is only possible because of the great detail in which the experimental data was recorded in the experimenter's logbook. The KENO V.a models of the critical assemblies are constructed as arrays of individually modeled fuel elements. The basic procedure is to construct a fuel-moderator cell sized according to pitch for each type of element (A3, A4, and partial) in the critical assembly starting with the very bottom of the element where the number 10 hole is enlarged and progressing in numerous axial levels up the element as shown in Figure 12. Each axial level is constructed as a cuboid and, to form the entire fuel element, the different levels are stacked in proper order. By using appropriate axial resolution, every significant detail of the fuel element, as well as other details such as Plexiglas spacers, the aluminum tube end cap and rubber stopper, and proper air gaps (for fuel elements which were in tubes) could be modeled. After the fuel elements are properly modeled, the elements can then be placed in another array according to the configuration presented in



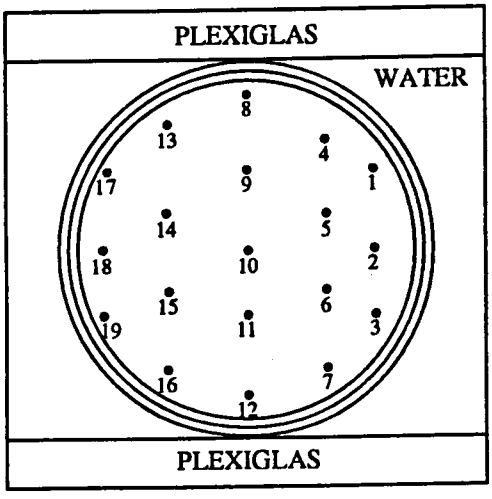
All holes .2438 or .2515 cm in diameter except #10, which is .5004 cm

Element Profile Between z = 0.00 cm (top of Plexiglas table) and z = .3213 cm



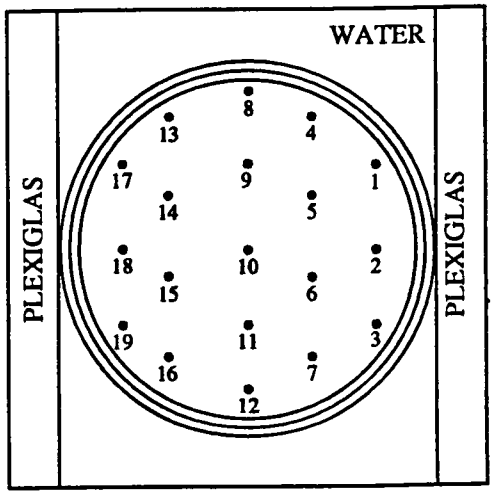
All holes .2438 or .2515 cm in diameter

Element Profile Between z = .32132 cm and 25.40 cm



All holes .2438 or .2515 cm in diameter

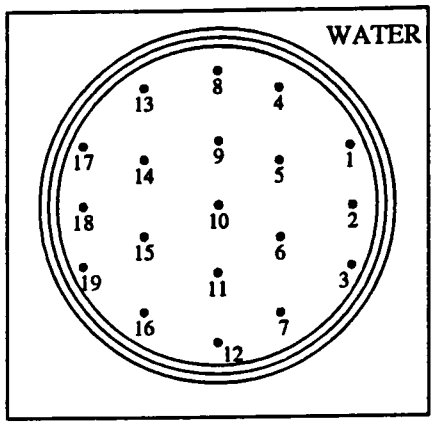
Element Profile Between z = 25.40 cm and z = 27.94 cm



All holes .2438 or .2515 cm in diameter

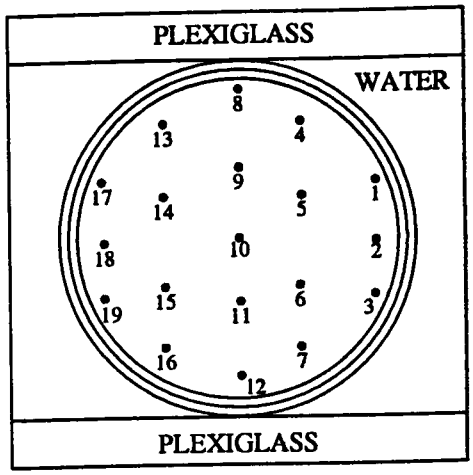
Element Profile Between z = 27.94 cm and z = 30.48 cm

Figure 12. Axial Model of Rover Element



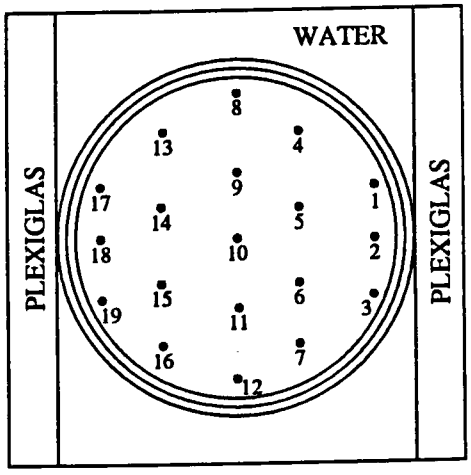
All holes .2438 or .2515 cm in diameter

Element Profile Between z = 30.84 cm and z = 107.95 cm



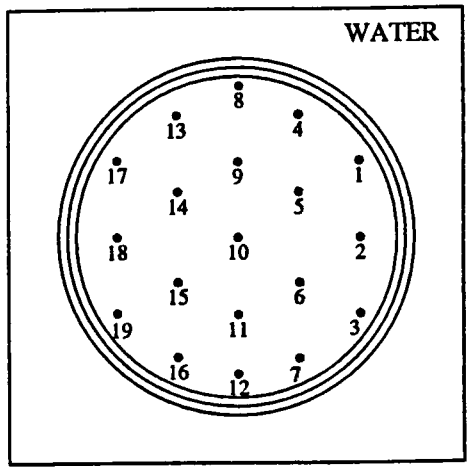
All holes .2438 or .2515 cm in diameter

Element Profile Between z = 107.95 cm and 110.49 cm



All holes .2438 or .2515 cm in diameter

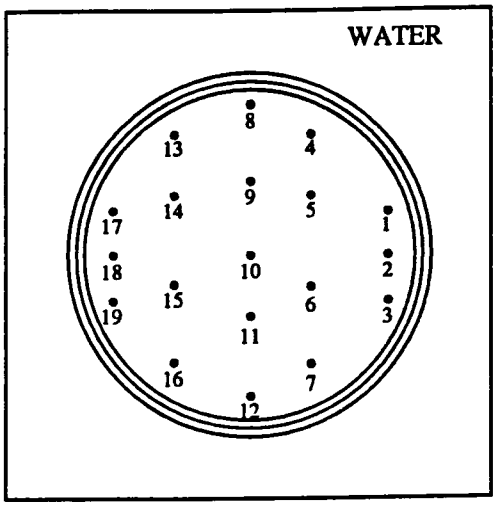
Element Profile Between z = 110.49 cm and z = 113.03 cm



All holes .2438 or .2515 cm in diameter

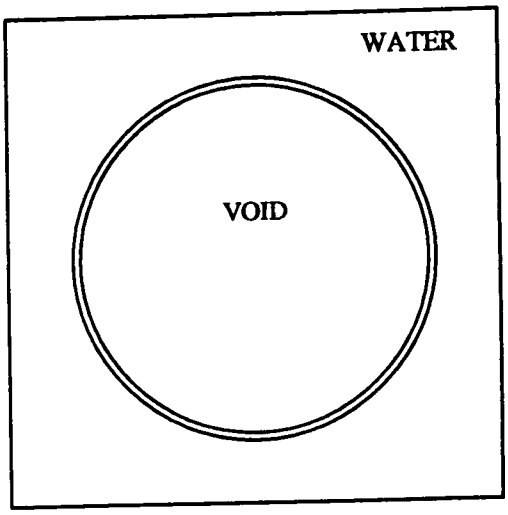
Element Profile Between z = 113.03 cm and 130.515 cm (A4) or 131.516 (A3)

Figure 12. (cont'd)



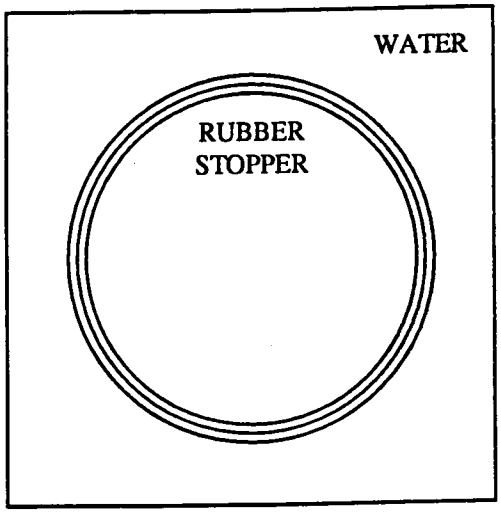
All holes .2438 or .2515 cm in diameter except #10, which is .254 cm diameter

Element Profile Between z = 130.515 cm (A4) or 131.516 (A3) and z = 131.785 cm (A4) or 132.786 (A3)



Fuel element not present at this level

Element Profile Between z = 131.785 cm (A4) or 132.781 (A3) and z = 134.80 cm



Element Profile Between z = 134.80 cm and z = 135.89 cm

Figure 12. (cont'd)

the logbook. Lastly, the Plexiglas table and water are modeled as cuboids that support the array and surround the critical assembly model, respectively. The tank is not modeled due to the thickness of the water reflector which effectively isolated the assembly. Since in each of the critical assemblies the elements do not overlap, model construction is possible using simple bodies such as cylinders and cuboids without using the HOLE option in KENO to place the individual elements, although the HOLE option is used to place the holes within each element. The KENO V.a input presented in the Appendix is not overkill but rather a testimony to the completeness of the records kept on the Rover critical experiments.

IV.1.b Assumptions and Approximations

Code limitations led to the necessity of a few assumptions while practical considerations and the limited knowledge about some aspects of the experiments or fuel elements led to others. Since hexagonal geometries cannot be modeled in KENO, the fuel element is approximated as an equivalent volume cylinder. The error thus introduced is small, resulting in a maximum dimensional discrepancy (the point where the the difference between the edge of the hexagon and that of the cylinder is greatest) of about .127 cm. The original coordinates for each of the 19 holes are maintained for the cylindrical approximation.

Another approximation was to assume the uranium within the element is homogeneously distributed throughout the graphite matrix and that each of the fuel elements belonging to one of the two categories used in this set of experiments contained equal amounts of uranium. The first assumption was necessary since, obviously, the exact location of the uranium dicarbide beads within an element could not be known due to the random nature of the fabrication procedure. However, since each element contained around 20 - 30 million such beads, the approximation is technically justified. The second assumption resulted from lack of information about the uranium loading of each individual fuel element. The elements were already segregated into two categories based partially on uranium loading, so one would expect fluctuations in that parameter to be relatively minor due to strict manufacturing tolerances. This was in fact the case, since the fuel elements used in these experiments (both NRX-A3 and NRX-A4) contained a minimum of 114 grams and a maximum of 129 grams of U^{235}. The partial elements were modeled as simple cylinders containing the amount of U^{235} required to match the reported critical mass while maintaining the correct C/U^{235} ratio.

The Plexiglas spacers, located at 30 and 60 degree angles with respect to the critical assembly in the triangular pitch lattices with the elements in tubes, could not be explicitly modeled in KENO V.a. The spacers were thus volume averaged with water in regions where Plexiglas was present as an approximation to the actual configuration. Also, the aluminum channel pieces placed at 30 and 60 degree angles were homogenized with water and placed against rows of elements at appropriate axial locations. In other

places where the aluminum channel pieces were placed at 0 or 90 degree angles, they were approximated using a 0.3175 cm thick aluminum plate of the same height. Under this approximation, also used in the square pitch lattice models, the other side and bottom of the channel were discarded. These methods are the only reasonable avenues to deal with the aluminum channel pieces short of completely ignoring them, but due to the small dimensions involved, the error introduced is assumed to be negligible.

IV.1.c Cross Section Processing

Because the arrangement of fuel elements in these critical experiments were either square or triangular pitch lattices, choice of a cross section processing method was relatively straight-forward. For each critical assembly calculation, the LATTICECELL specification, discussed in Section II.2, was used. Cross sections thus processed include a geometric correction for neutrons escaping the fuel element and interacting with neighboring elements. Additional information indicated whether the lattice being calculated was square or triangular pitch, the spacing of the elements, and whether an aluminum tube was present.

Since the fuel element contained holes, direct use of the CSAS25 control sequence for cross section processing was not considered strictly correct since the number densities of the nuclides present in the fuel element were effectively reduced. To address this situation, the holes were smeared into the fuel element to create a homogeneous

cylindrical element with appropriately reduced number densities. Cross section processing was then accomplished using the CSASN sequence. Correct number densities for the materials were then entered separately for the KENO V.a calculation which called for the cross section library written by the CSASN sequence.

The Plexiglas regions were modeled as water for cross section processing since they comprised only a small axial portion (7.7 percent of the total height) of the unit cell region and because Plexiglas is neutronically similar to water.

IV.1.d Additional Modeling Studies

The initial impression upon reviewing this set of experiments is that they could be represented neutronically as homogeneous systems, i.e., the assemblies do not display appreciable spatial variation in the neutron flux. To determine if this indeed was the case, three critical assemblies, both square and triangular pitch, were homogenized. The homogenization maintained the same C/U^{235}, H/U^{235}, and other atomic ratios found in the actual critical experiments. The cross sections were then processed in three separate ways and k_{eff} of the homogenized assemblies calculated using KENO V.a:

- **Case 1:** This method produces cross sections that do not have geometric or cell-weighting corrections. CSAS25 was executed using the INFHOMMEDIUM specification and homogenized number densities. The cross sections were

processed without cell weighting by XSDRNPM-S or geometric corrections typical of lattice cell problems.

- **Case 2:** This procedure incorporated lattice cell geometric corrections in the cross section processing, but did not use cell weighting of the cross sections. CSASN was executed using the LATTICECELL specification. Number densities used were based on an average uranium content of the fuel elements and maintained specific material regions as used in calculation of the actual critical assembly (Section IV.1.c). Homogenized number densities were then used by KENO V.a in calculation of k_{eff}.

- **Case 3:** Use of this method not only cell weights the cross sections, but also incorporates the geometric correction of the lattice problems. CSAS2X, which uses XSDRNPM-S to cell weight the cross sections according to the fuel-moderator unit cell configuration, was chosen and LATTICECELL was specified for cross section processing. Number densities used here are the same as Method 2. However, for the KENO V.a calculation, the number densities are homogenized by SCALE to form what is designated as mixture 500.

As an additional exercise, the heterogeneous critical assembly models for the three cases used above were rerun using the INFHOMMEDIUM specfication. Results of these cases would show the effect of the geometric correction incurred by using

LATTICECELL. Results of all these additional cases are presented in Chapter V.

IV.2 Honeycomb Models

IV.2.a KENO Model Description

The KENO models for this set of experiments are very detailed and represent the exact configuration recorded in the experimental logbook. All of the geometric bodies are cuboids (graphite blocks, uranium foils, aluminum tubes) and are easily modeled in KENO V.a. The fuel and moderator tubes are comprised of 20.32 cm long sections. These sections are built starting with one of the foils, adding graphite blocks and more foils (if present) until the fuel tube is accurately represented, and then adding the void space and aluminum tube. The uranium foils are assumed to be centered over the graphite blocks. Next, the 20.32 cm sections are stacked end-to-end (inward from the face of the machine) until a complete tube is modeled, including the graphite reflector. The different tubes are placed in arrays modeling vertical rows of tubes which are then stacked horizontally to form the complete critical configuration. Both moderator and reflector graphite tubes are modeled in the same way but lacked the diversity of regions in the fuel tubes. Details necessary for the construction of KENO V.a models are shown in the Appendix.

IV.2.b Assumptions and Approximations

Very few approximations were necessary since geometric information was available. Some of the dimensions, however, are either inconsistent or missing entirely. In these cases, values were assumed based on trends seen in the other cases. Each of the uranium foils were coated with a thin layer of teflon. This coating was uniformly smeared into the foil, since explicit modeling was not practical due to its thinness.

IV.2.c Cross Section Processing

None of the critical assemblies had standard SCALE fuel-moderator unit cell configurations. Therefore, different representations were used in cross section processing and the resultant effect on k_{eff} calculated by KENO V.a was evaluated by comparing results of the different cases. One critical assembly was chosen for this study and the results assumed to apply to each of the six since they are all very similar.

One method of cross section processing is to treat the unit cell as a slab geometry with moderator regions surrounding it. Both the minimum and maximum distances between foils, based on dimensions from the critical assembly, were used in the CSASN sequence to obtain minimum and maximum Dancoff factors, respectively, which were input to separate KENO V.a problems in the MORE DATA field. The cross section libraries written by the CSASN sequence are used in the KENO V.a calcuations along

with the Dancoff factor information.

Another approximation for cross section processing involves homogenizing a set of fuel and moderator tubes in a manner that maintains the overall C/U ratio in the core of the critical assembly and using the INFHOMMEDIUM specification. No geometric corrections were applied to the cross sections in this method, but a good indication of the neutron flux is obtained since the uranium and graphite are smeared together into a solution type mixture. Correct number densities for each of the materials are then entered into KENO V.a for calculation of k_{eff}.

Finally, the INFHOMMEDIUM specification was used in the CSAS25 sequence with correct number densities for each of the materials used in BONAMI-S, NITAWL-S, and KENO V.a. The materials retain their discreteness in this method and no geometric corrections for heterogeneity are applied.

IV.2.d Additional Modeling Studies

The additional modeling studies performed for the Honeycomb experiments were homogenization of the critical assemblies. For these cases, k_{eff} values had been reported based on self-shielding corrections. The core was smeared into a homogeneous mixture which was treated as an infinite homogeneous medium for the cross section processing. The graphite reflector regions maintained their heterogeneity for these problems.

Chapter V

Results

V.1 Rover Results

The results of the twenty-five calculations of the Rover critical experiments using the heterogeneous models and LATTICECELL specification are listed in Tables 4 and 5 for the IBM 3090 and HP Workstation platforms, respectively. The values of k_{eff} are generally high, ranging from 1.0012 +/- .0026 to 1.0245 +/- .0023. Most of the higher calculated k_{eff} values are obtained for the triangular-pitched lattice experiments with the elements in the aluminum tubes. There is no explanation for this, since the same procedure in setting up the problems is used for all assemblies. There does seem to be a small, positive bias in the k_{eff} results that would need to be accounted for in setting of safety criteria. The IBM 3090 and HP Workstation results are in good agreement on most of the cases, although there are a few where the differences are slightly greater than two standard deviations. The Average Energy Group (AEG) Causing Fission indicates the critical assemblies are neutronically thermal, depending on low-energy neutrons for the bulk of fissions. A graphical representation of the results is given in Figures 13 and 14 which plot k_{eff} as a function of AEG. The data seems to trend upward with increasing AEG, but the difference in the endpoints of the least-squares fit line is only about 0.006, or roughly two standard deviations of a typical calculation. This is not statistically

Table 4 Summary of Rover Results* (IBM 3090)

Lattice	Pitch (cm)	H/U^{235}	C/U^{235}	k_{eff}	AEG**	Histories
Square, in Tubes	2.79	79	88.8	1.0083 +/- .00303	22.83	78000
	3.05	121	88.3	1.0108 +/- .00338	23.35	84500
	3.30	164	88.0	1.0111 +/- .00310	23.67	90500
	3.56	215	87.8	1.0124 +/- .00287	23.87	93500
	3.81	267	87.5	1.0117 +/- .00273	24.01	95000
	4.06	324	87.5	1.0150 +/- .00247	24.11	97000
	4.32	384	87.6	1.0160 +/- .00252	24.20	99000
	4.57	450	87.7	1.0150 +/- .00214	24.26	100000
	4.83	520	88.1	1.0166 +/- .00246	24.31	100000
	5.08	594	88.3	1.0058 +/- .00251	24.36	100000
Triang., in Tubes	3.23	112	88.4	1.0112 +/- .00274	23.29	82500
	3.81	215	88.0	1.0125 +/- .00290	23.86	91500
	4.11	271	87.9	1.0202 +/- .00292	24.04	95000
	4.39	332	87.8	1.0155 +/- .00274	24.14	96500
	4.70	399	87.9	1.0136 +/- .00240	24.21	97500
	5.28	544	88.1	1.0162 +/- .00260	24.34	100000
	5.56	627	88.5	1.0155 +/- .00233	24.38	100000
Triang., Bare	2.51	93	88.0	1.0136 +/- .00347	23.05	85000
	3.12	176	87.1	1.0051 +/- .00307	23.75	93500
	3.73	277	87.0	1.0072 +/- .00297	24.05	98500
	4.14	354	87.0	1.0104 +/- .00268	24.18	100000
	4.78	497	87.6	1.0080 +/- .00233	24.31	100000
Triang., Bare (38 cm)	3.12	166	87.0	1.0037 +/- .00346	23.66	90500
	3.73	262	87.0	1.0070 +/- .00308	24.01	95000
	4.14	336	87.0	1.0089 +/- .00275	24.13	96500

* Heterogeneous Models, LATTICECELL Specification; **Average Energy Group of Neutrons Causing Fission

Table 5 Summary of Rover Results* (HP 9000)

Lattice	Pitch (cm)	H/U^{235}	C/U^{235}	k_{eff}	AEG**	Histories
Square, in Tubes	2.79	79	88.8	1.0088 +/- .00321	22.81	83500
	3.05	121	88.3	1.0072 +/- .00294	23.36	89000
	3.30	164	88.0	1.0090 +/- .00289	23.66	90000
	3.56	215	87.8	1.0062 +/- .00276	23.87	96000
	3.81	267	87.5	1.0086 +/- .00273	24.00	98000
	4.06	324	87.5	1.0160 +/- .00258	24.12	100000
	4.32	384	87.6	1.0129 +/- .00251	24.20	100000
	4.57	450	87.7	1.0112 +/- .00250	24.26	100000
	4.83	520	88.1	1.0124 +/- .00234	24.32	100000
	5.08	594	88.3	1.0099 +/- .00239	24.36	100000
Triang., in Tubes	3.23	112	88.4	1.0089 +/- .00338	23.30	83000
	3.81	215	88.0	1.0093 +/- .00282	23.88	90500
	4.11	271	87.9	1.0172 +/- .00275	24.03	97500
	4.39	332	87.8	1.0188 +/- .00259	24.13	99000
	4.70	399	87.9	1.0168 +/- .00263	24.21	100000
	5.28	544	88.1	1.0178 +/- .00245	24.34	100000
	5.56	627	88.5	1.0245 +/- .00227	24.39	100000
Triang., Bare	2.51	93	88.0	1.0125 +/- .00321	23.04	88000
	3.12	176	87.1	1.0042 +/- .00302	23.76	94000
	3.73	277	87.0	1.0012 +/- .00255	24.05	98500
	4.14	354	87.0	1.0071 +/- .00262	24.19	100000
	4.78	497	87.6	1.0054 +/- .00251	24.32	100000
Triang., Bare (38 cm)	3.12	166	87.0	1.0082 +/- .00291	23.66	92500
	3.73	262	87.0	1.0073 +/- .00291	23.99	96500
	4.14	336	87.0	1.0122 +/- .00273	24.13	98500

* Heterogeneous Models, LATTICECELL Specification; **Average Energy Group of Neutrons Causing Fission

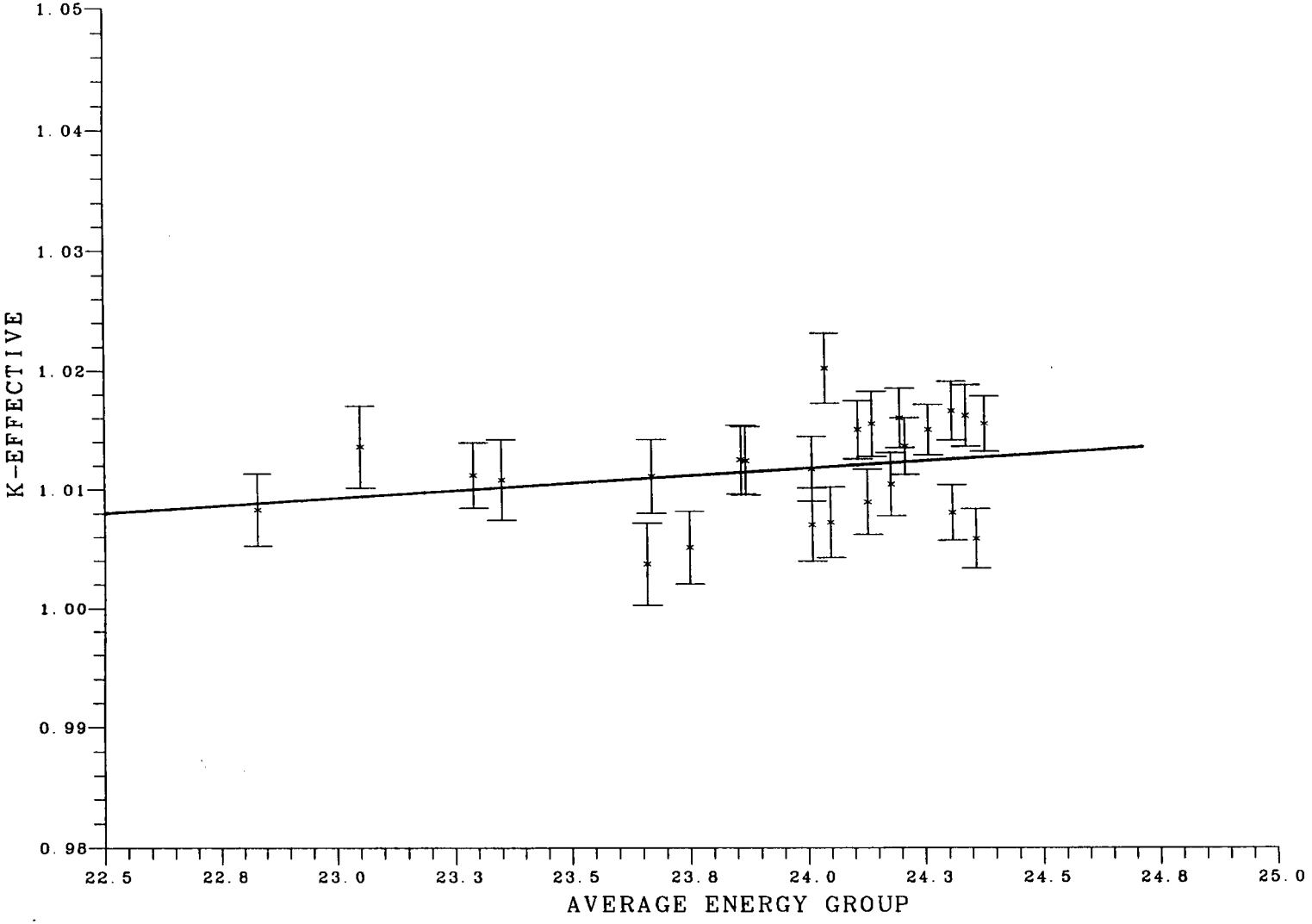


Figure 13. k_{eff} vs. AEG for Rover Experiments (IBM 3090)

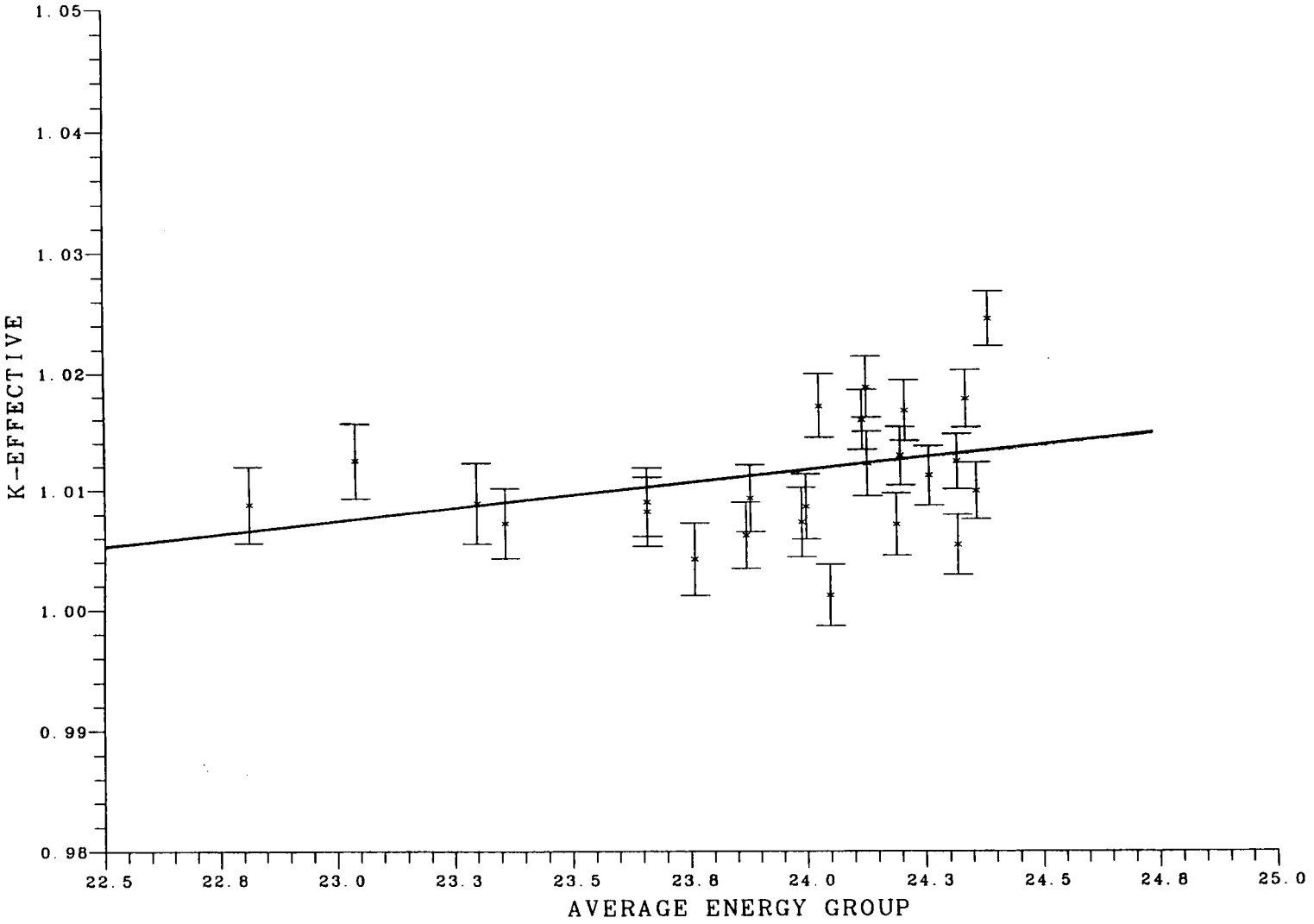


Figure 14. k_{eff} vs. AEG for Rover Experiments (HP 9000)

significant and does not conclusively indicate a trend in k_{eff} as a function of AEG.

The additional modeling studies performed to determine if the Rover critical assemblies could be treated as homogeneous yielded some rather interesting results. The three cases picked for homogenization were

- square pitch, elements in tubes, pitch = 2.794 cm
- triangular pitch, elements in tubes, pitch = 5.563 cm
- triangular pitch, bare elements, pitch = 4.140 cm

The resulting k_{eff} values for these cases, using the various methods described in Section IV.1.d, are shown in Table 6. An explanation of the effects of the various treatments is given below.

Several things are evident from examining Table 6. The first is that cross sections processed using the LATTICECELL specification and thus adjusted using a geometric correction yield results basically identical to cases using the INFHOMMEDIUM specification in cross section processing. This is true for Methods 1 and 2 using a homogenized mixture as well as for the two explicit cases listed at the bottom of Table 6. The resonance cross sections are indeed different for these cases, but the amount of resonance material in the core, U^{238} primarily, is simply not large enough to affect the calculation of k_{eff}.

Table 6 Summary of Additional Rover Studies

Cross-Section Treatment*	Case		
	Square Pitch (2.794 cm)	Triangular Pitch (5.563 cm)	Triangular Pitch (4.140 cm)
Case 1	1.0522 +/- .0030	1.2902 +/- .0021	1.1749 +/- .0029
Case 2	1.0494 +/- .0032	1.2827 +/- .0022	1.1701 +/- .0027
Case 3	1.0288 +/- .0040	1.0190 +/- .0024	1.0182 +/- .0033
Heterogeneous models, infinite homogeneous approximation	1.0120 +/- .0035	1.0180 +/- .0024	1.0047 +/- .0026
Heterogeneous models, lattice cell (from Tables 4 and 5)	1.0083 +/- .0030 1.0088 +/- .0032	1.0155 +/- .0023 1.0245 +/- .0023	1.0104 +/- .0023 1.0071 +/- .0026

*Used with Homogeneous KENO V.a Models

On the other hand, the differences in k_{eff} using either Method 1 or 2 versus the results calculated using Method 3, where the cross sections are cell weighted by XSDRNPM-S, shows that spatial variation in the neutron flux, present in the actual critical assembly, is the primary factor of importance for these cases. Regardless of the cross section processing treatment chosen, unless the reaction rates of the materials are conserved during homogenization of the critical assembly, the calculated k_{eff} obtained from KENO V.a is incorrect when compared to the actual experiment. These results show that spatial variation in neutron flux due to the fuel-moderator unit cell arrangement is present in the Rover critical assemblies and that they cannot be considered homogeneous from a neutronic point of view.

V.2 Honeycomb Results

Results of calculations for the Honeycomb critical experiments are shown in Table 7 and graphed as a function of AEG in Figures 15 and 16. The k_{eff} values from both computational platforms range between 0.9746 +/- .0028 and 0.9983 +/- .0027.

As can be seen, all of the results are slightly below 1.00, indicative of a small, negative bias. The actual k_{eff} for each critical assembly, based on excess reactivity figures given in the logbook, is also given in Table 7. The least squares fit of the data, shown in Figures 15 and 16, shows an apparent upward trend in k_{eff} with increasing AEG and, since the difference in the end points of the line are 0.10 (approximately 4 standard

Table 7 Summary of Honeycomb Results

Case	C/U		k_{eff}			AEG*		Histories
	Reported	Calculated	Actual**	IBM	HP	IBM	HP	
				Heterogeneous Models				
LA1	6650	6810	1.00038	0.9895 +/- .00284	0.9901 +/- .00279	23.46	23.44	100000
LA2	4937	4992	1.00028	0.9812 +/- .00283	0.9888 +/- .00267	23.10	23.09	100000
LA3	3140	3198	1.00035	0.9746 +/- .00277	0.9760 +/- .00281	22.43	22.40	100000
LA4	2365	2420	1.00155	0.9816 +/- .00275	0.9779 +/- .00265	21.93	21.92	100000
LA5	4366	4506	1.00069	0.9930 +/- .00290	0.9983 +/- .00267	23.00	23.00	100000
LA6	2770	2885	1.00079	0.9915 +/- .00283	0.9918 +/- .00267	22.23	22.26	100000
				Homogeneous Models				
LA1	-	6810	1.0666	1.0303 +/- .00282	--	23.54	-	75000
LA2	-	4992	1.0465	1.0156 +/- .00301	--	23.16	-	75000
LA3	-	3198	-	1.0084 +/- .00289	--	22.48	-	75000
LA4	-	2420	-	1.0082 +/- .00323	--	21.97	-	75000
LA5	-	4506	1.0480	1.0164 +/- .00314	--	23.01	-	75000
LA6	-	2885	-	1.0214 +/- .00355	--	22.29	-	75000

*Average Energy Group of Neutrons Causing Fission

**Values of k_{eff} Were Calculated Based on Figures for Excess Reactivity From Logbooks

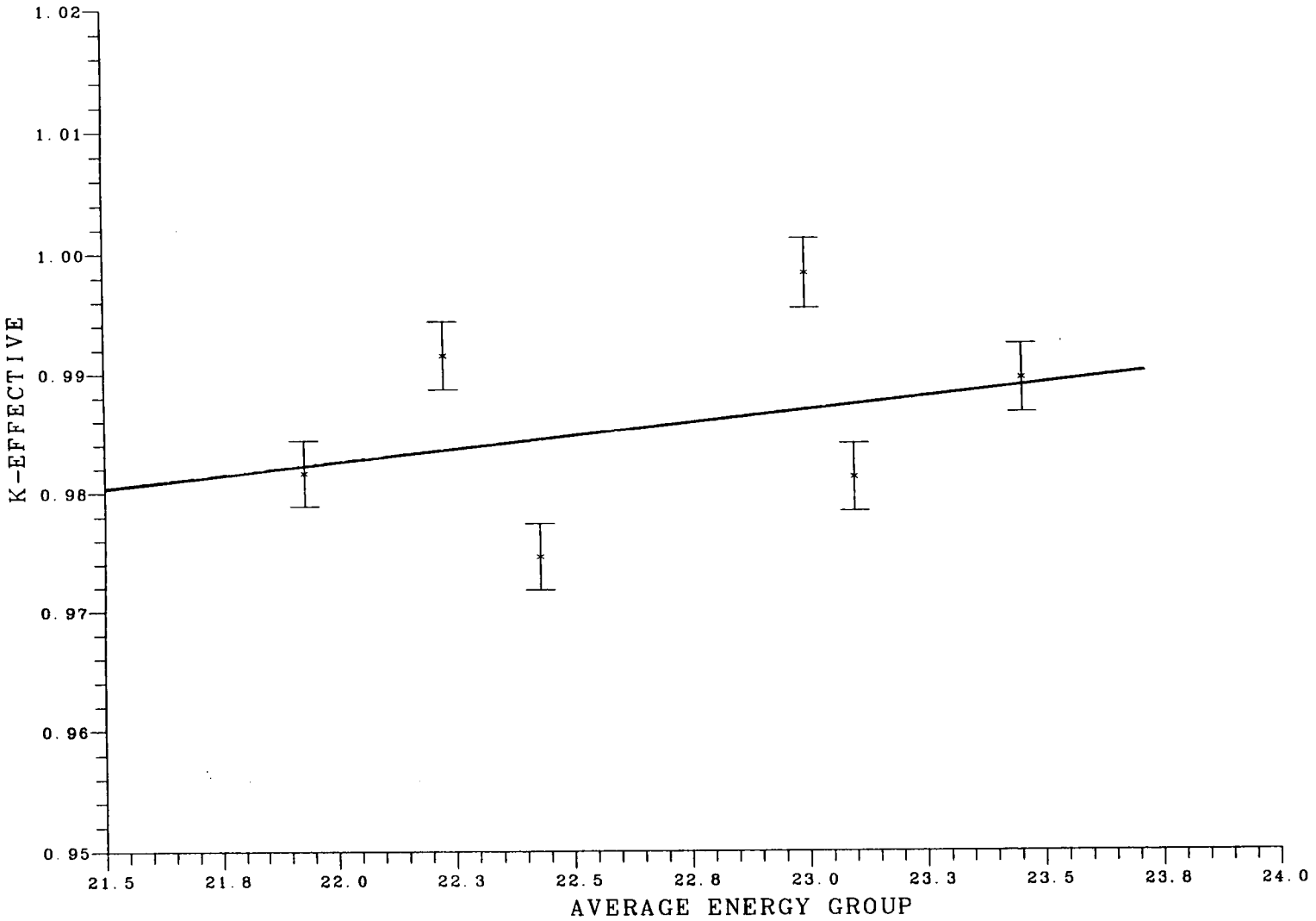


Figure 15. k_{eff} vs. AEG for Honeycomb Experiments (IBM 3090)

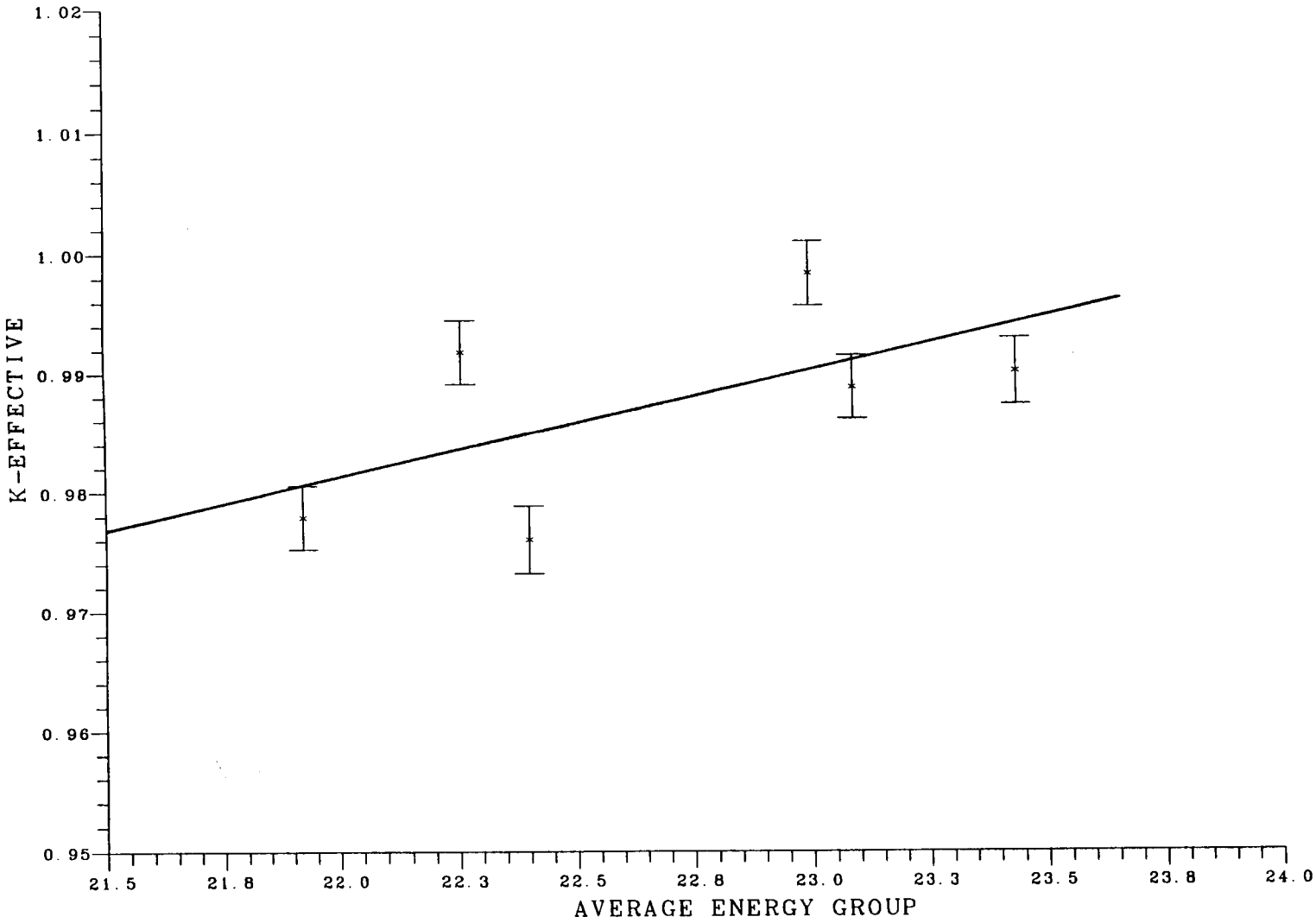


Figure 16. k_{eff} vs. AEG for Honeycomb Experiments (HP 9000)

deviations of a typical calculation), the data can be concluded to trend upward with increasing AEG.

Several cross section processing options were used for these experiments since none of the fuel-moderator unit cell arrangements are standard SCALE configurations. Depending on the method used, the absorption cross section for U^{238}, the only resonance absorber present in any quantity, varied from 8 barns to 267 barns. The large difference in these two values demonstrates that the various methods of cross section processing yield quite dissimilar results for the working library. However, regardless of the method used, the calculated k_{eff} values showed no statistically significant differences. It is felt that homogenization of fuel and moderator tubes at the same C/U ratio as the overall core is the best model to use for cross section processing since the neutron energies present during the resonance treatment would be similar to those near the uranium foils. Another advantage is the consistency such an approach achieves.

All six of the Honeycomb critical assemblies were homogenized and the k_{eff} of the resultant mixture determined using KENO V.a. The calculated values of k_{eff} are fairly close to those of the experiment, as shown in Table 7, indicating that the critical assembly could be treated as a neutronically homogeneous system.

Chapter VI

Summary

VI.1 Conclusions

The objective of this work is to validate KENO V.a using the 27-group ENDF/B-IV cross section library for two categories of systems: those containing highly-enriched uranium, carbon, and hydrogen, and those containing highly-enriched uranium and carbon at high C/U ratios. This validation has been performed for two computational platforms, an IBM 3090 mainframe computer and an HP 9000 model 730 workstation. The Nuclear Criticality Safety Software $(NCSS)^2$ code package is installed on both machines and is the code package used in this validation study. Another important aspect of this work is to document the critical experiments performed in support of the Rover program and the experiments performed on the Honeycomb machine. These two sets of experiments form the basis for this validation effort.

All available information from both sets of critical experiments has been reported in a manner that will enable others to model these critical assemblies and use them for their own validation exercises. Material information, accurate placings of fuel elements and uranium foils, and other vital data have been presented.

Results from calculations of the Rover criticals indicate good agreement with the experiments using the heterogeneous models. There is a small positive bias in the results that ranges up to 2.5 percent in k_{eff}. Spatial variation in neutron flux between fuel elements is evident from additional modeling studies based on homogenizing the entire assembly since the results from this exercise do not agree with those from the heterogeneous cases. The critical assembly configurations are either square or triangular pitch lattices, which are standard SCALE unit cell arrangements, so that cross section processing was straight-forward. Every attempt was made in this endeavor to model the actual experimental configuration and materials as accurately as possible and in most instances this meant constructing KENO models of excrutiating detail. However, it was deemed necessary to do this in order to eliminate modeling bias as a source of error and inconsistency in the calculations. Therefore, these results represent a best estimate of the critical assembly.

Results from calculations of the Honeycomb experiments show a negative bias up to around 3 percent in k_{eff}. The neutron flux across these critical assemblies is more uniform since homogenization changes k_{eff} only slightly. Several cross section processing options were used in these calculations since none of the assemblies allowed the use of standard SCALE unit cell arrangement options. MULTIREGION representation was not used because it was clearly not applicable. Regardless of the method of processing, the answers are statistically equivalent.

Specifying safety criteria using this information is not attempted in this thesis. The procedures used to derive such information as subcritical limits, k_{eff} bounds for calculations, and other parameters are facility specific, with no one method having distinct advantages over others. However, the heterogeneous models developed in this validation study have been shown to compare favorably with the actual critical experiments and, therefore, establishment of safety criteria should be based on results of the heterogeneous cases.

VI.2 Recommendations

As a result of this effort, several recommendations for future work can be made. First, with regard to the Rover experiments, critical experiments are needed involving highly-enriched uranium, carbon, and hydrogen which behave as neutronically homogeneous systems. It is obvious from this validation effort that the Rover experiments do not fit into this category. The current interpretation of "Range of Applicability"[3] would not permit the Rover experiments to be extended to homogeneous systems. This recommendation will be rather hard to accomplish since all but one critical experiments facility (Pajarito site at Los Alamos) are shut down. However, a recent Defense Nuclear Safety Board Recommendation (93-2) emphasizes that more critical experiments are needed to support criticality safety activities and analyses, especially since the thrust of such analyses is tending more toward decontamination and decommissioning work. The climate resulting from the DNFSB recommendation is

favorable for conducting additional critical experiments and, hopefully, mixtures containing the three constituents indicated above will be high on the priority list. Another piece of work that could be done with existing Rover experiment data would be to investigate the effect of different cross section sets on the calculated k_{eff} values. It is possible that the new 44-group or the 123-group cross section libraries may yield answers closer to a k_{eff} of 1.0. Along similar lines, the Rover experiments could also be modeled in MCNP or MONK, two other popular criticality analysis codes, which can represent the hexagonal fuel elements exactly without incurring the minor geometry approximations necessary in KENO V.a. Both MCNP and MONK use continuous energy cross section libraries which allows the analyst to avoid some of the cross section processing approximations necessary when using multi-group codes such as KENO V.a.

Future work involving Honeycomb experiment data should focus initially around using different cross section libraries in calculation of k_{eff}. It is not clear whether certain cross section libraries have better carbon scattering kernel models than others, but since the CS-312 graphite is relatively pure, a small improvement in the scattering treatment for carbon may yield answers much closer to k_{eff} of 1.0. Another area for consideration is performance of additional critical experiments at high C/U ratios. These six experiments are apparently the only ones ever performed for this range of C/U ratios. Alternatively, a more complete search of critical experiment data, including primarily classified experiments, may yield some more data that would augment the Honeycomb information.

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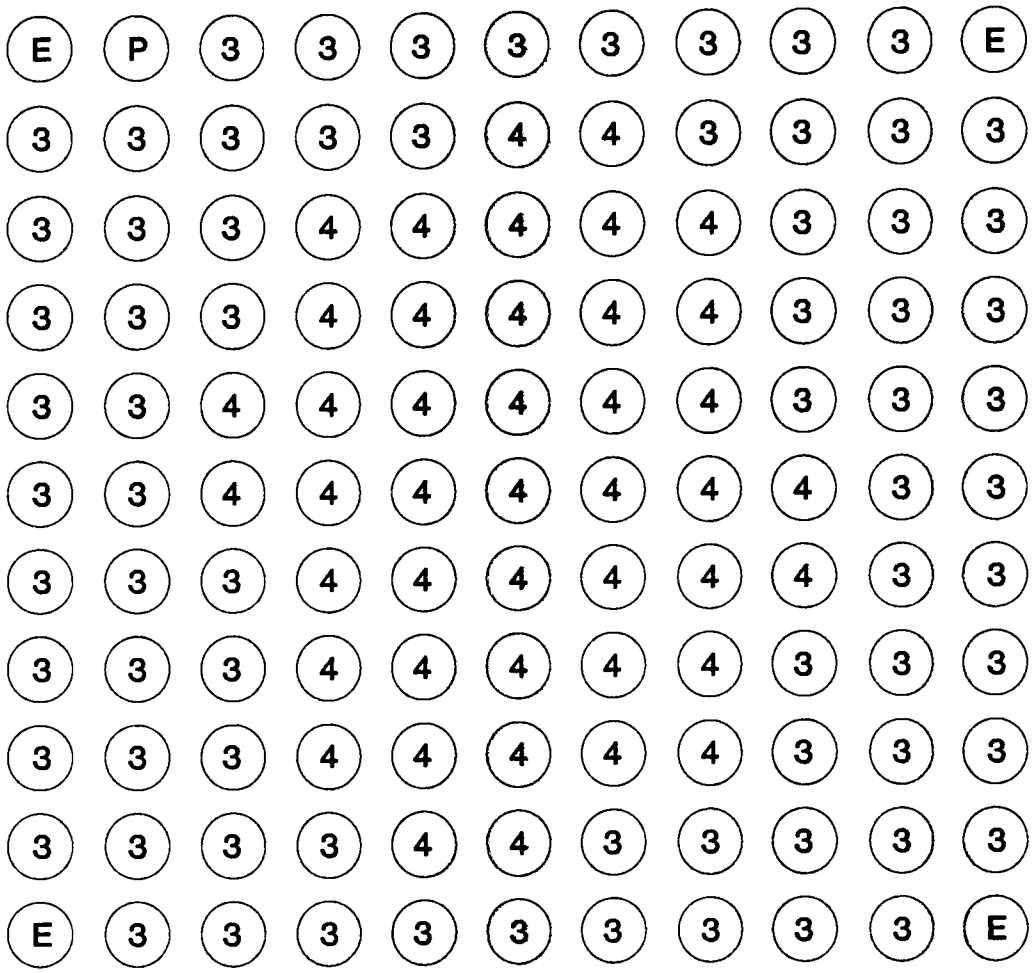
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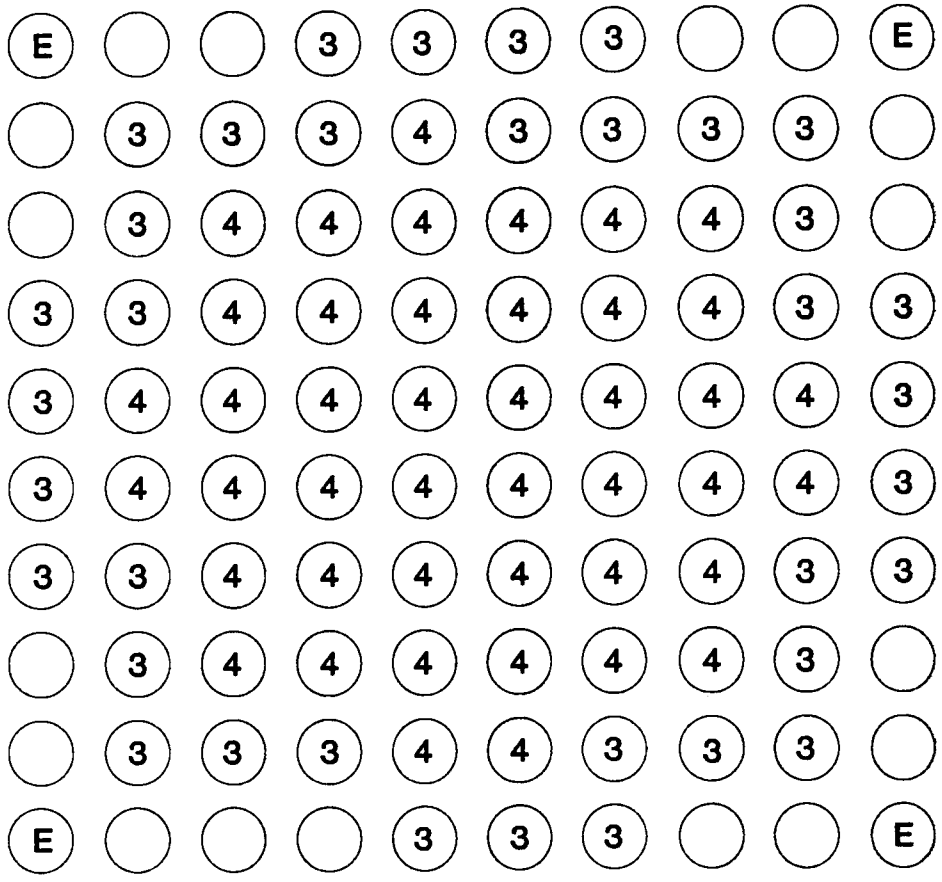
Appendix



3 - NRX-A3 Element
4 - NRX-A4 Element
P - Partial Element
E - Empty Aluminum Tube (used for support)

Lattice Type: Square-Pitch
Array Pitch (cm): 2.79
Critical Mass (kg U^{235}): 13.93
Mass of Partial Element (g U^{235}): 0.29

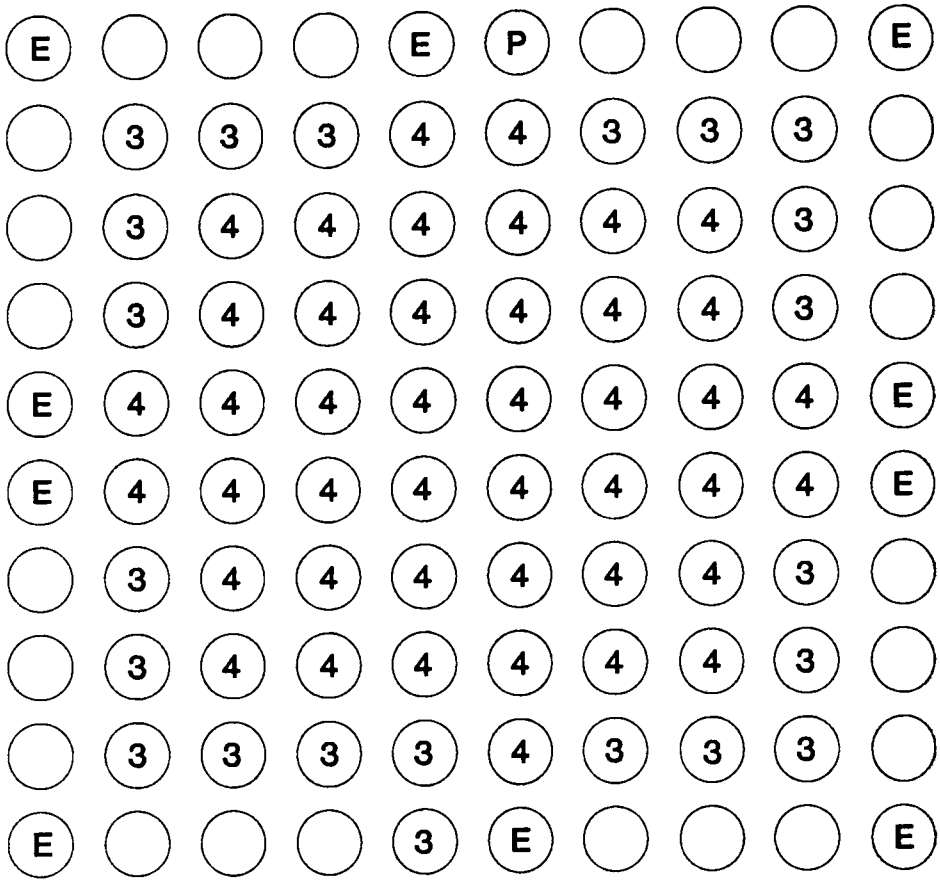
Figure A1 Rover Critical Configuration



3 - NRX-A3 Element
4 - NRX-A4 Element
P - Partial Element
E - Empty Aluminum Tube (used for support)

Lattice Type: Square-Pitch
Array Pitch (cm): 3.05
Critical Mass (kg U^{235}): 9.55
Mass of Partial Element (g U^{235}): 0.0

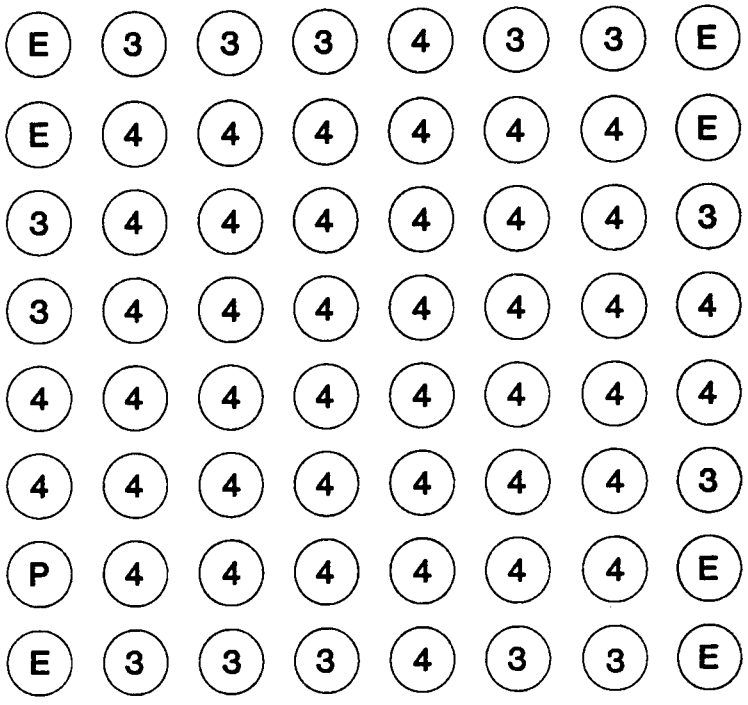
Figure A2 Rover Critical Configuration



3 - NRX-A3 Element
4 - NRX-A4 Element
P - Partial Element
E - Empty Aluminum Tube (used for support)

Lattice Type: Square-Pitch
Array Pitch (cm): 3.30
Critical Mass (kg U^{235}): 7.90
Mass of Partial Element (g U^{235}): 5.40

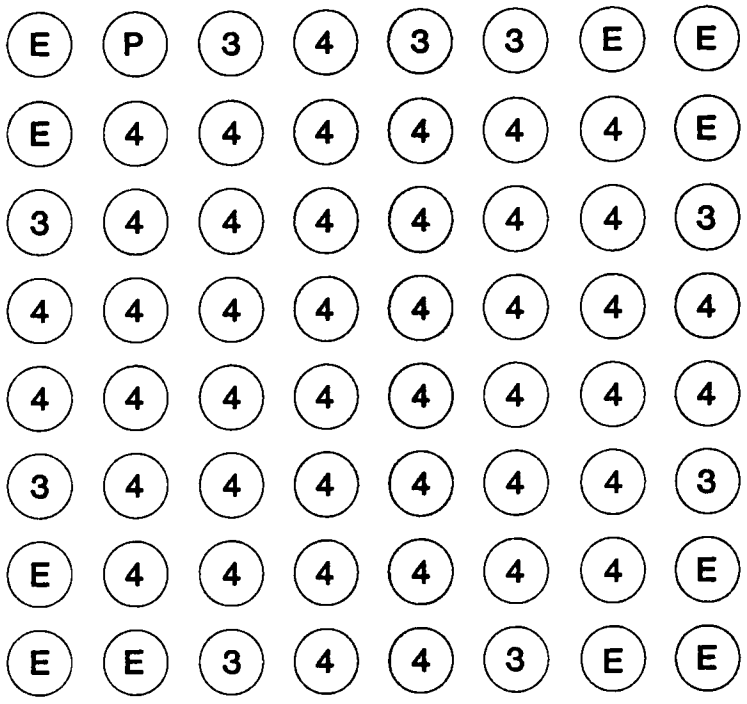
Figure A3 Rover Critical Configuration



3 - NRX-A3 Element
4 - NRX-A4 Element
P - Partial Element
E - Empty Aluminum Tube (used for support)

Lattice Type: Square-Pitch
Array Pitch (cm): 3.56
Critical Mass (kg U^{235}): 6.84
Mass of Partial Element (g U^{235}): 15.15

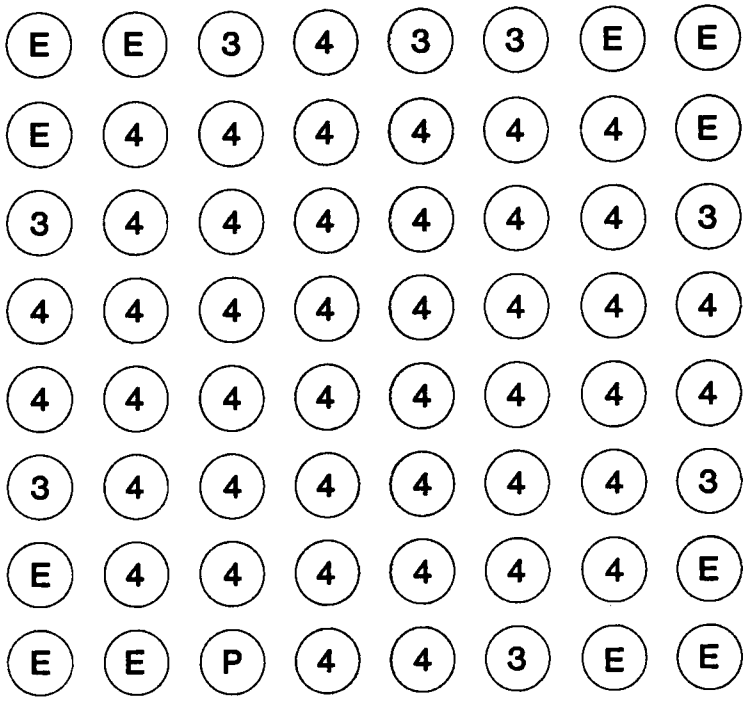
Figure A4 Rover Critical Configuration



3 - NRX-A3 Element
4 - NRX-A4 Element
P - Partial Element
E - Empty Aluminum Tube (used for support)

Lattice Type: Square-Pitch
Array Pitch (cm): 3.81
Critical Mass (kg U^{235}): 6.39
Mass of Partial Element (g U^{235}): 33.77

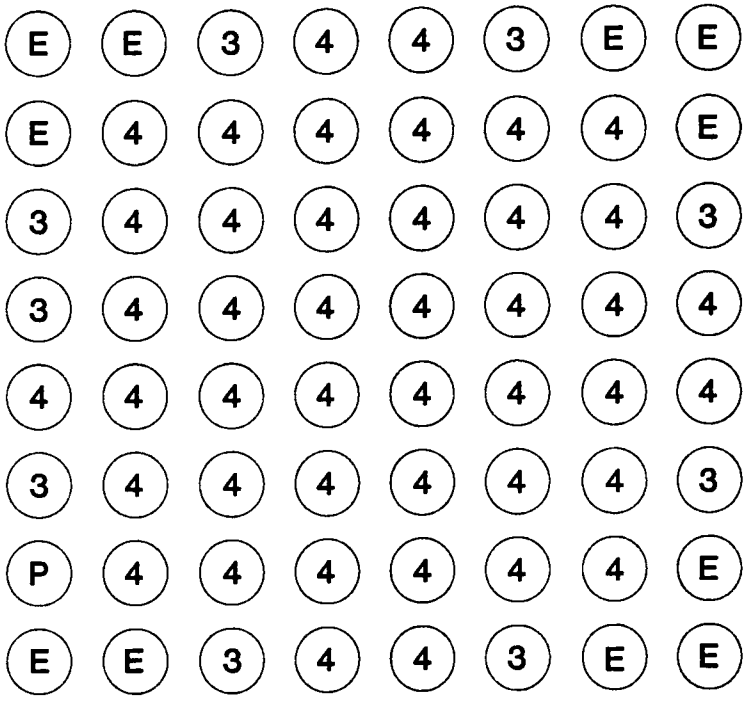
Figure A5 Rover Critical Configuration



3 - NRX-A3 Element
4 - NRX-A4 Element
P - Partial Element
E - Empty Aluminum Tube (used for support)

Lattice Type: Square-Pitch
Array Pitch (cm): 4.06
Critical Mass (kg U^{235}): 6.27
Mass of Partial Element (g U^{235}): 32.11

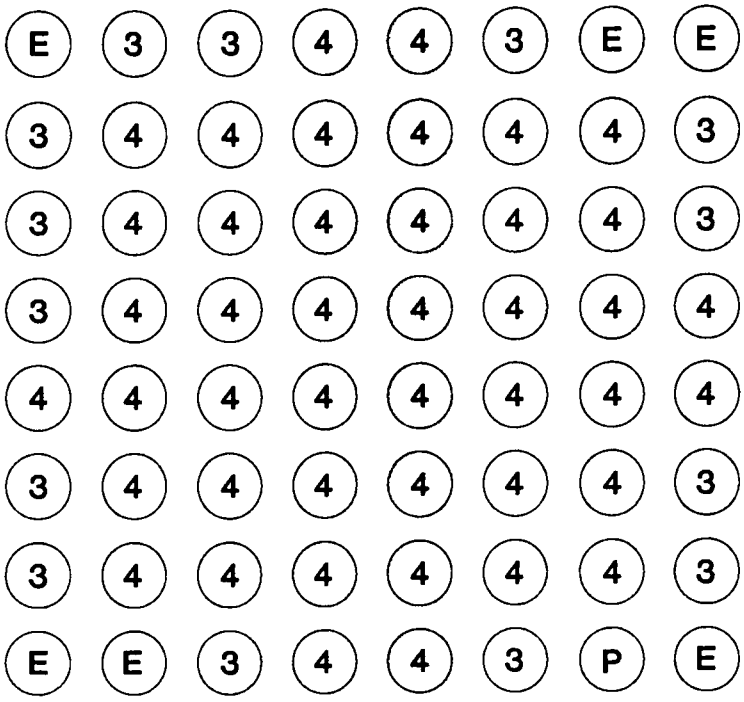
Figure A6 Rover Critical Configuration



3 - NRX-A3 Element
4 - NRX-A4 Element
P - Partial Element
E - Empty Aluminum Tube (used for support)

Lattice Type: Square-Pitch
Array Pitch (cm): 4.32
Critical Mass (kg U^{235}): 6.45
Mass of Partial Element (g U^{235}): 93.77

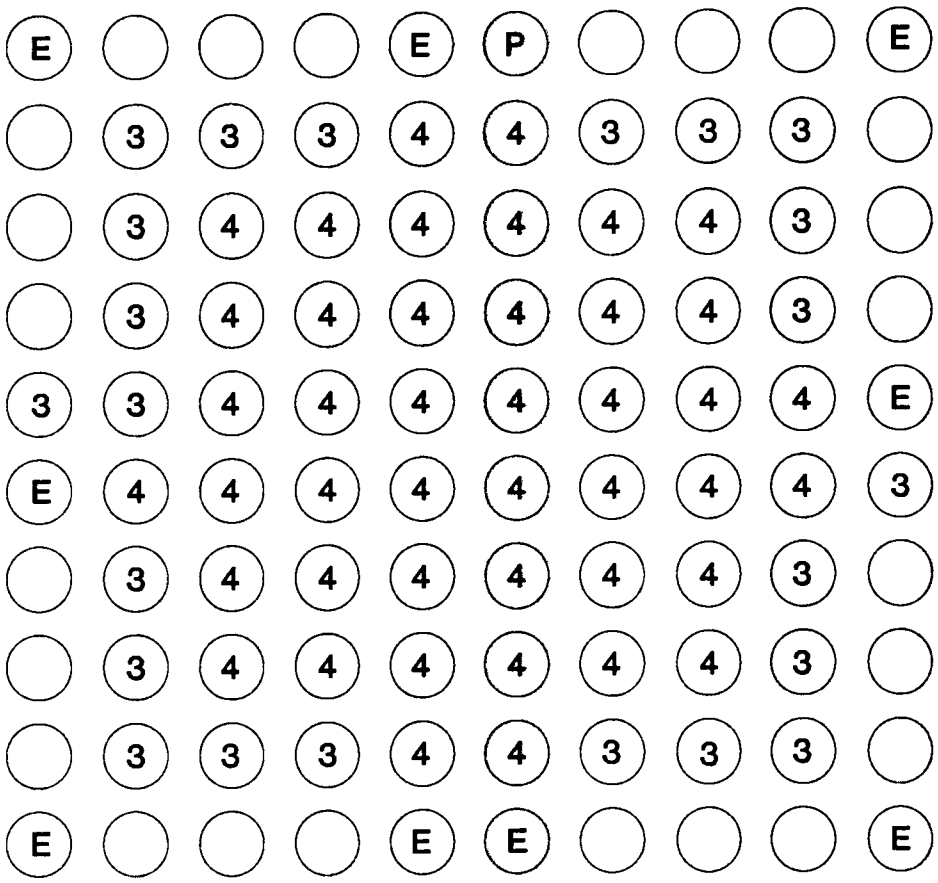
Figure A7 Rover Critical Configuration



3 - NRX-A3 Element
4 - NRX-A4 Element
P - Partial Element
E - Empty Aluminum Tube (used for support)

Lattice Type: Square-Pitch
Array Pitch (cm): 4.57
Critical Mass (kg U^{235}): 6.96
Mass of Partial Element (g U^{235}): 12.09

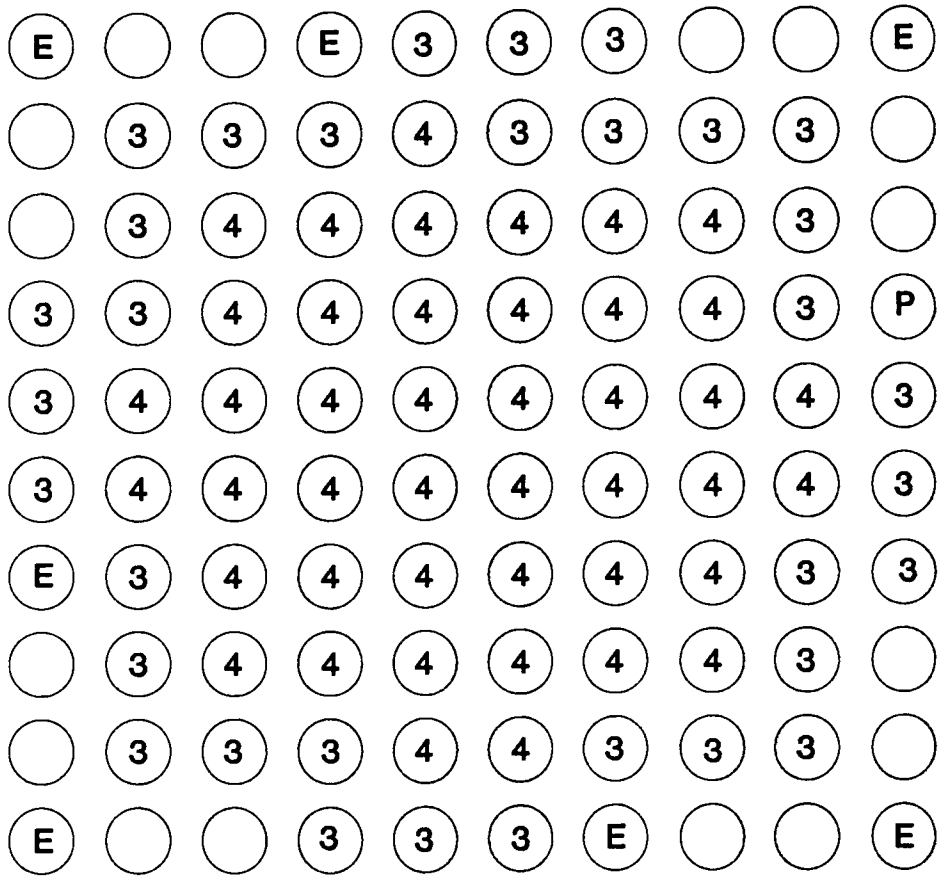
Figure A8 Rover Critical Configuration



3 - NRX-A3 Element
4 - NRX-A4 Element
P - Partial Element
E - Empty Aluminum Tube (used for support)

Lattice Type: Square-Pitch
Array Pitch (cm): 4.83
Critical Mass (kg U^{235}): 8.04
Mass of Partial Element (g U^{235}): 27.07

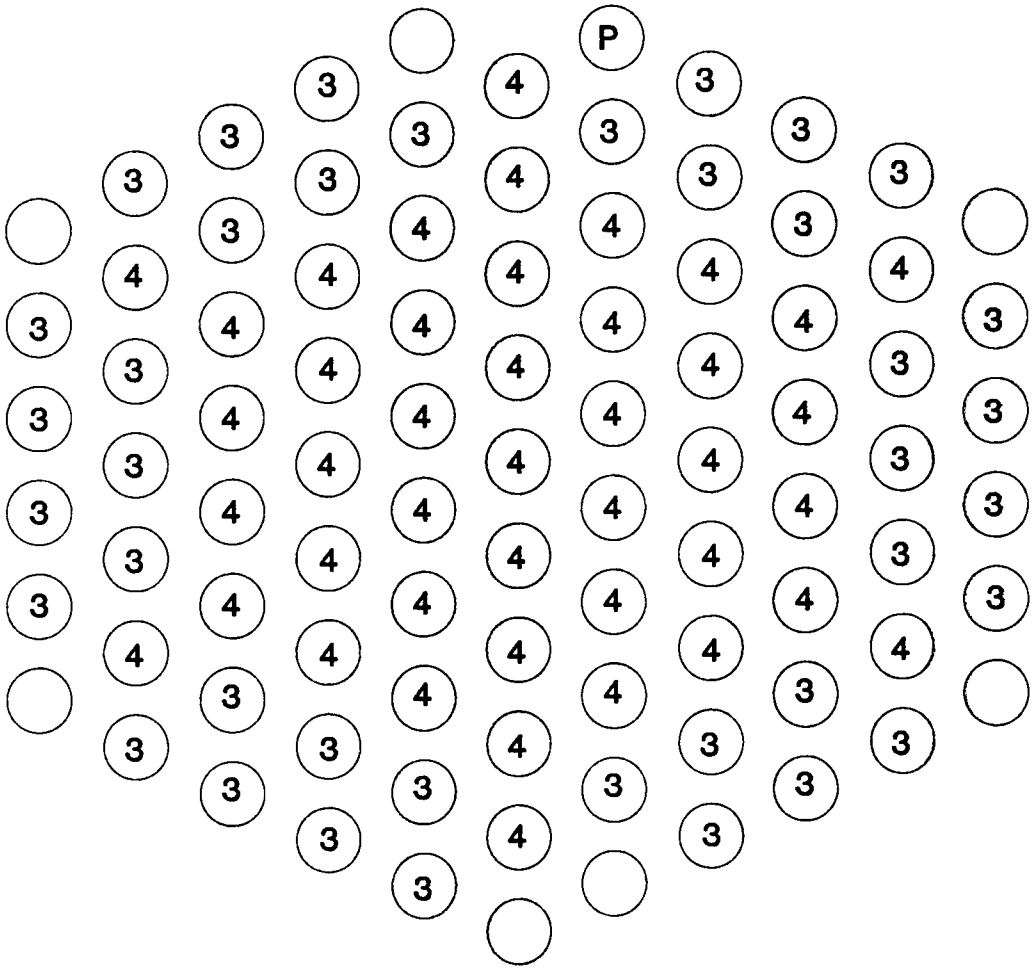
Figure A9 Rover Critical Configuration



3 - NRX-A3 Element
4 - NRX-A4 Element
P - Partial Element
E - Empty Aluminum Tube (used for support)

Lattice Type: Square-Pitch
Array Pitch (cm): 5.08
Critical Mass (kg U^{235}): 9.24
Mass of Partial Element (g U^{235}): 43.72

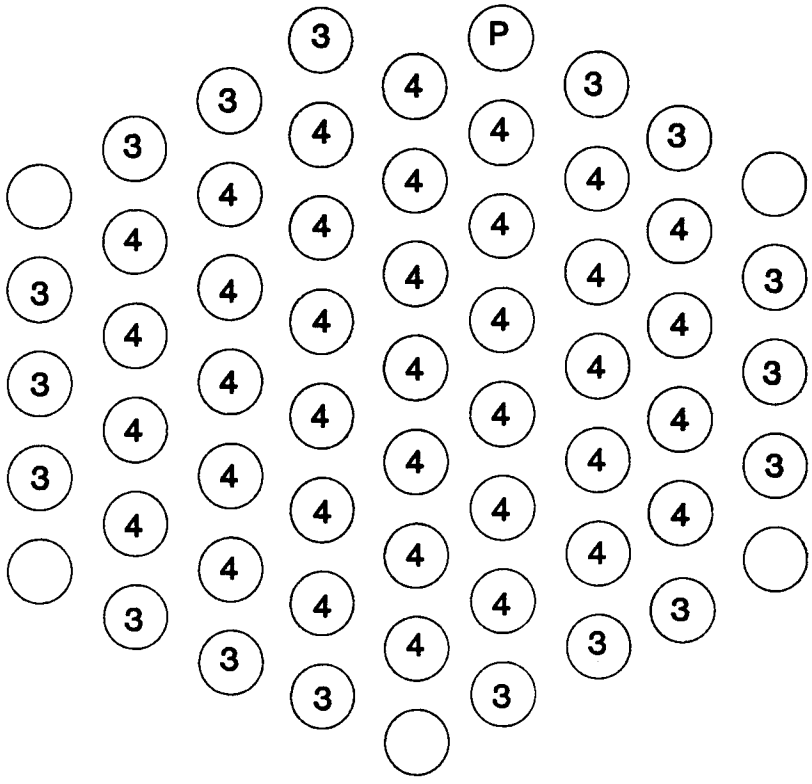
Figure A10 Rover Critical Configuration



3 - NRX-A3 Element
4 - NRX-A4 Element
P - Partial Element (Location Assumed)

Lattice Type: Triangular-Pitch (elements in tubes)
Array Pitch (cm): 3.23
Critical Mass (kg U^{235}): 9.93
Mass of Partial Element (g U^{235}): 42.56

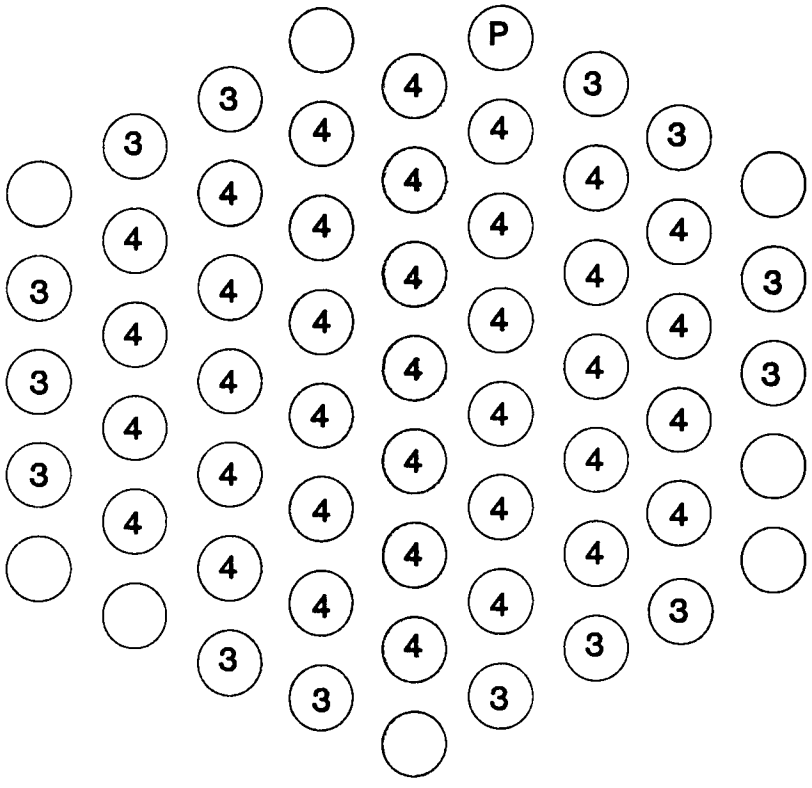
Figure A11 Rover Critical Configuration



3 - NRX-A3 Element
4 - NRX-A4 Element
P - Partial Element (Location Assumed)

Lattice Type: Triangular-Pitch (elements in tubes)
Array Pitch (cm): 3.81
Critical Mass (kg U^{235}): 6.66
Mass of Partial Element (g U^{235}): 95.40

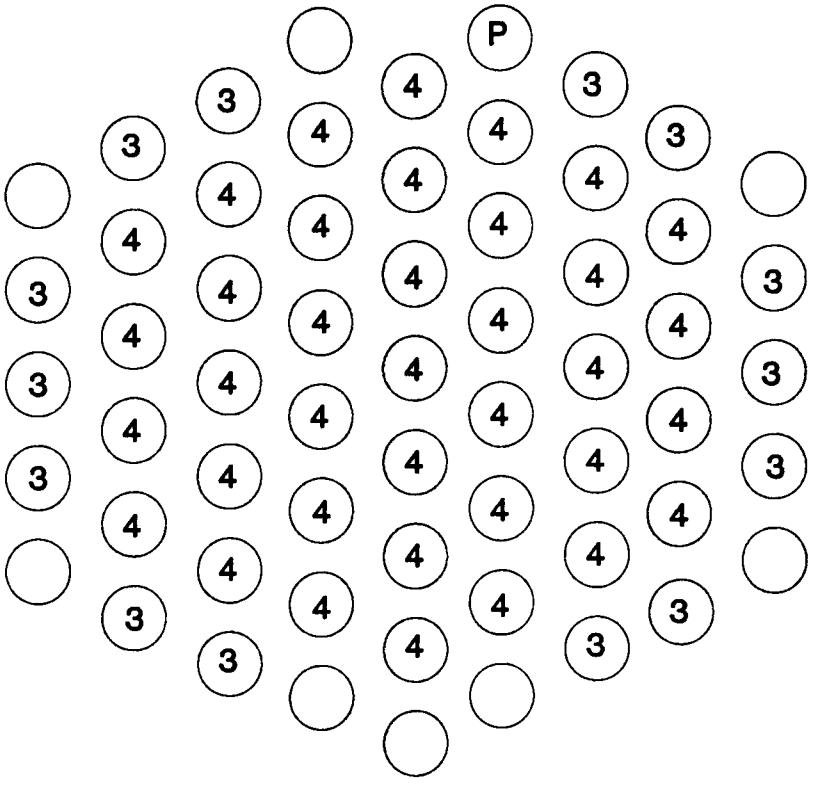
Figure A12 Rover Critical Configuration



3 - NRX-A3 Element
4 - NRX-A4 Element
P - Partial Element (Location Assumed)

Lattice Type: Triangular-Pitch (elements in tubes)
Array Pitch (cm): 4.11
Critical Mass (kg U^{235}): 6.30
Mass of Partial Element (g U^{235}): 90.40

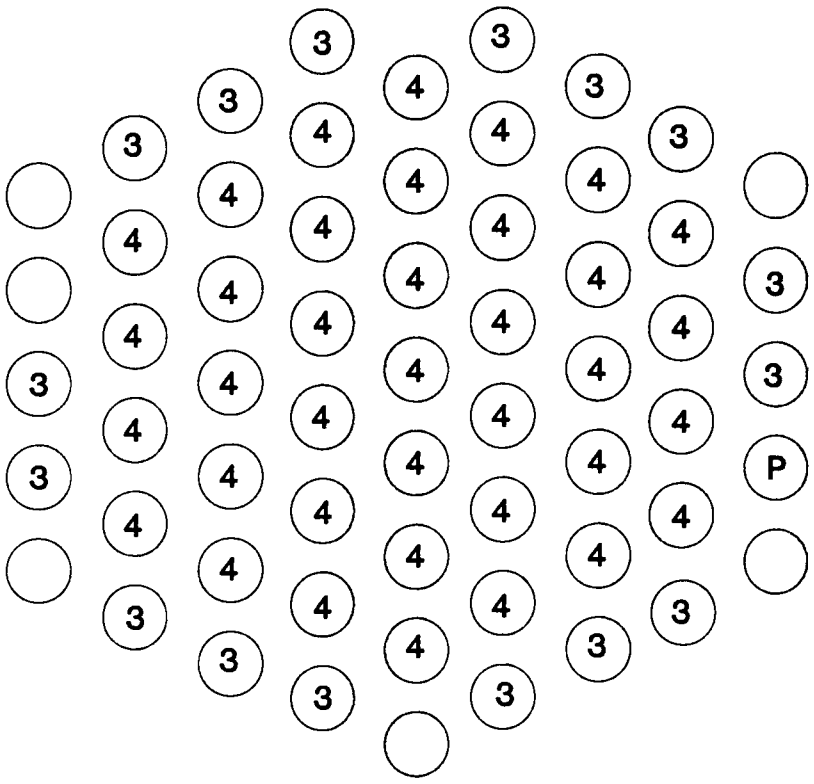
Figure A13 Rover Critical Configuration



3 - NRX-A3 Element
4 - NRX-A4 Element
P - Partial Element

Lattice Type: Triangular-Pitch (elements in tubes)
Array Pitch (cm): 4.39
Critical Mass (kg U^{235}): 6.24
Mass of Partial Element (g U^{235}): 30.40

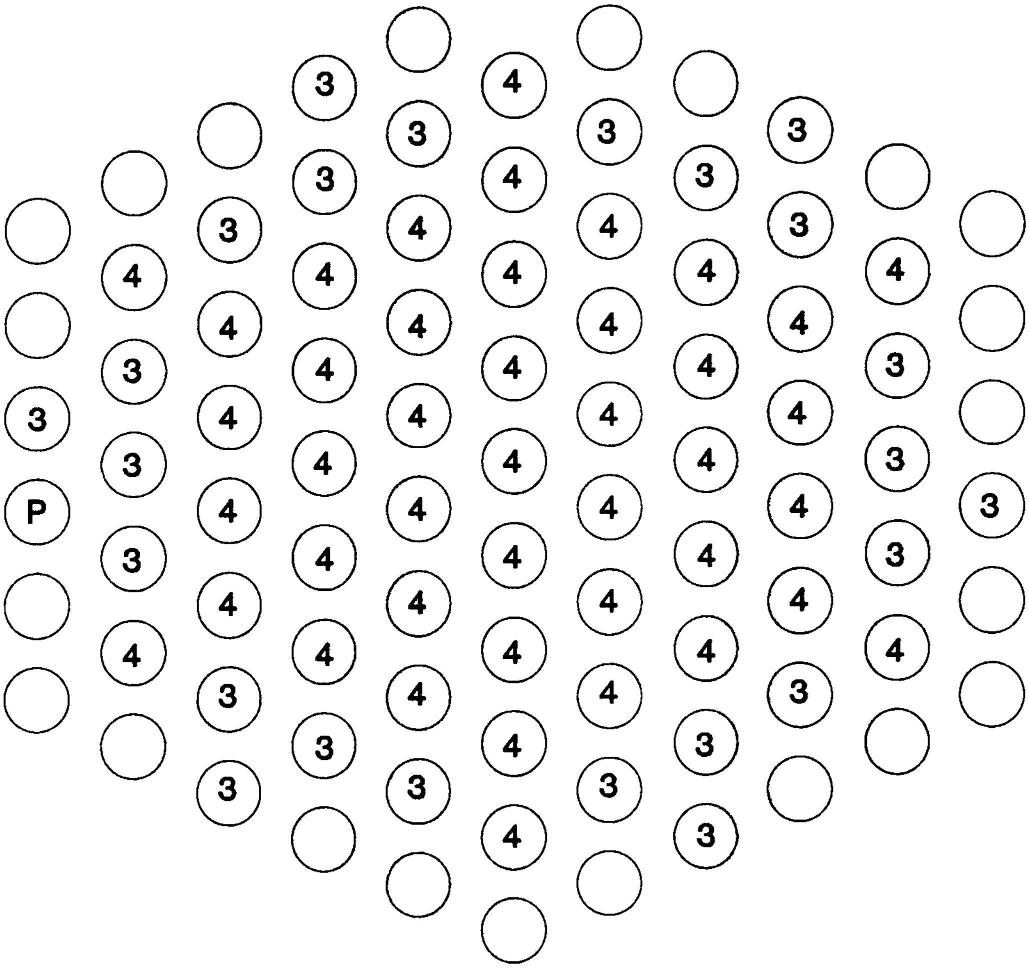
Figure A14 Rover Critical Configuration



3 - NRX-A3 Element
4 - NRX-A4 Element
P - Partial Element

Lattice Type: Triangular-Pitch (elements in tubes)
Array Pitch (cm): 4.70
Critical Mass (kg U^{235}): 6.45
Mass of Partial Element (g U^{235}): 3.73

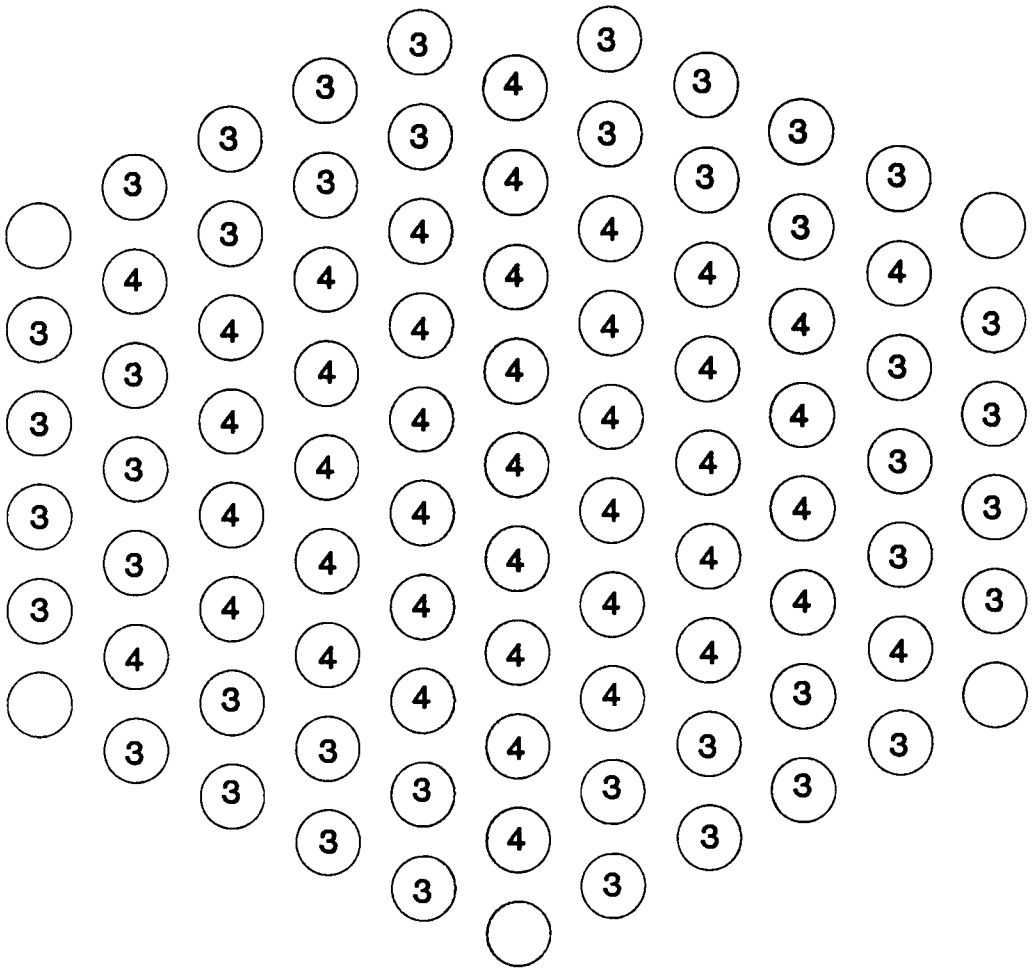
Figure A15 Rover Critical Configuration



3 - NRX-A3 Element
4 - NRX-A4 Element
P - Partial Element

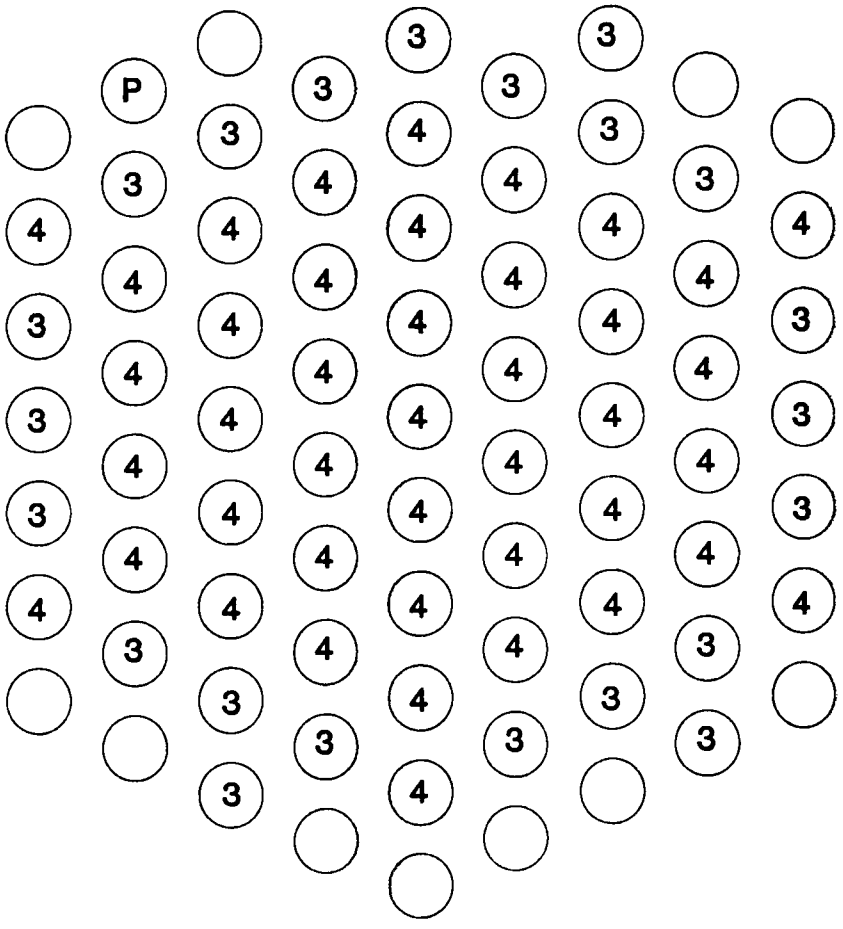
Lattice Type: Triangular-Pitch (elements in tubes)
Array Pitch (cm): 5.28
Critical Mass (kg U^{235}): 8.16
Mass of Partial Element (g U^{235}): 28.74

Figure A16 Rover Critical Configuration



Lattice Type: Triangular-Pitch (elements in tubes)
Array Pitch (cm): 5.56
Critical Mass (kg U^{235}): 10.26
Mass of Partial Element (g U^{235}): 0.0

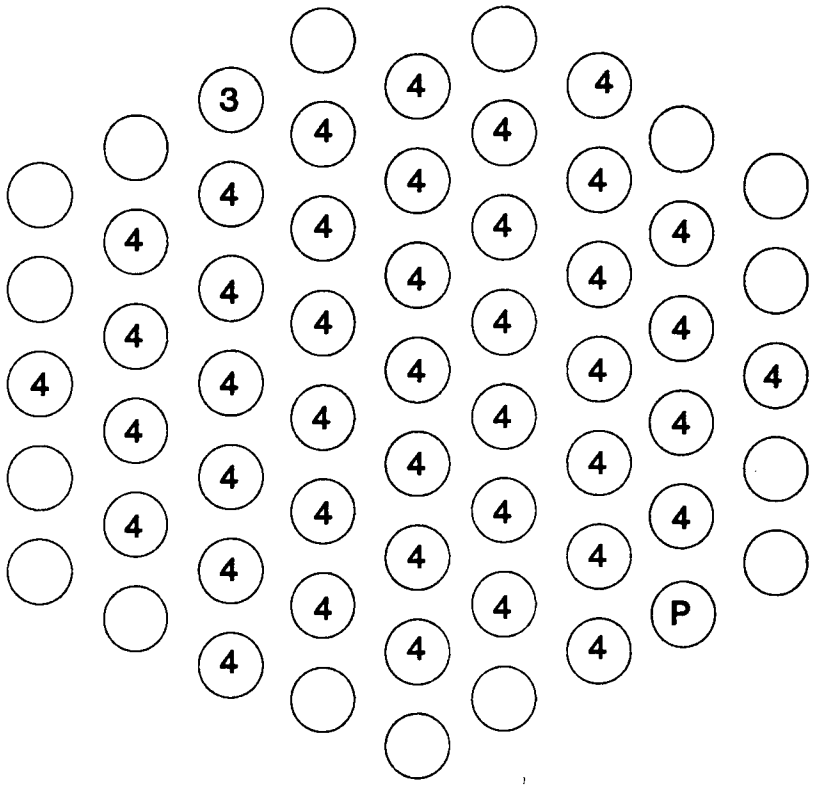
Figure A17 Rover Critical Configuration



3 - NRX-A3 Element
4 - NRX-A4 Element
P - Partial Element (Location Assumed)

Lattice Type: Triangular-Pitch (bare elements)
Array Pitch (cm): 2.51
Critical Mass (kg U^{235}): 7.80
Mass of Partial Element (g U^{235}): 28.46

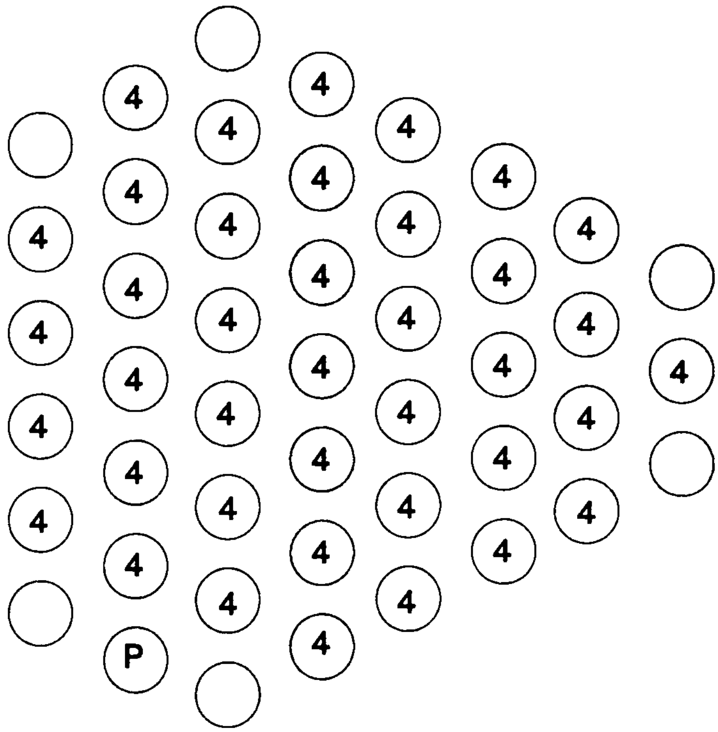
Figure A18 Rover Critical Configuration



3 - NRX-A3 Element
4 - NRX-A4 Element
P - Partial Element

Lattice Type: Triangular-Pitch (bare elements)
Array Pitch (cm): 3.12
Critical Mass (kg U^{235}): 5.30
Mass of Partial Element (g U^{235}): 13.51

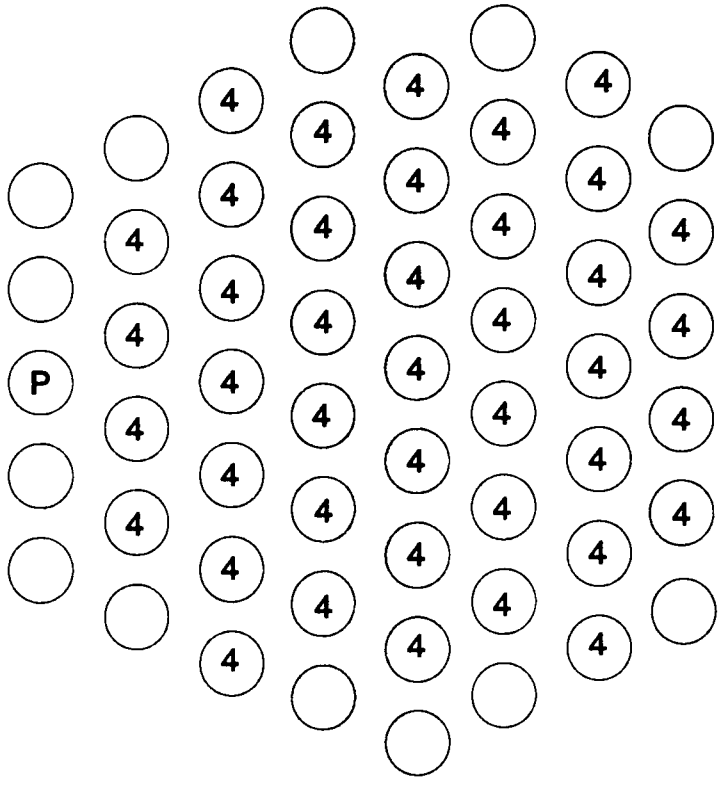
Figure A19 Rover Critical Configuration



3 - NRX-A3 Element
4 - NRX-A4 Element
P - Partial Element

Lattice Type: Triangular-Pitch (bare elements)
Array Pitch (cm): 3.73
Critical Mass (kg U^{235}): 4.84
Mass of Partial Element (g U^{235}): 41.0

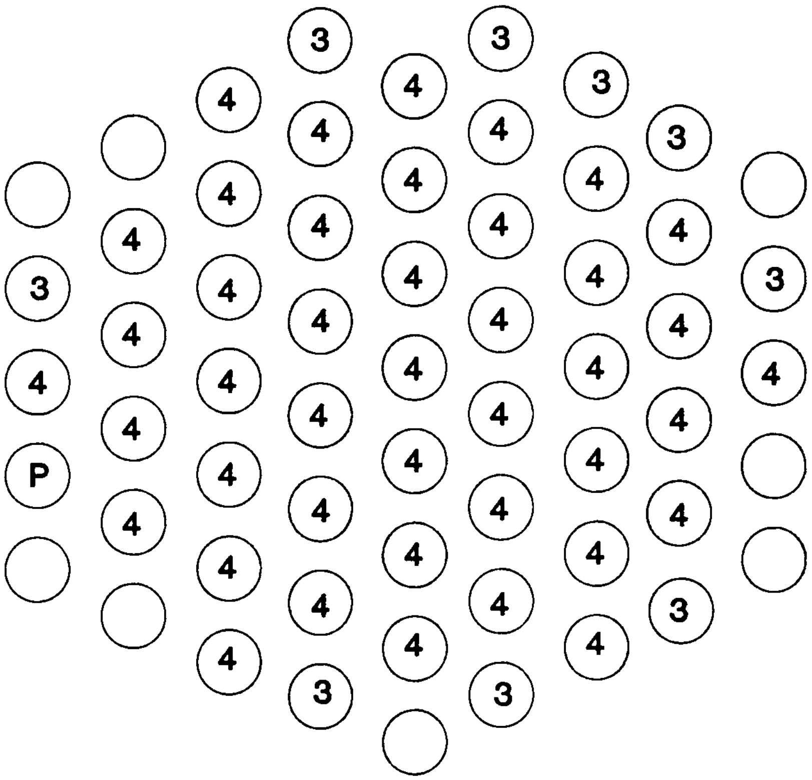
Figure A20 Rover Critical Configuration



3 - NRX-A3 Element
4 - NRX-A4 Element
P - Partial Element

Lattice Type: Triangular-Pitch (bare elements)
Array Pitch (cm): 4.14
Critical Mass (kg U^{235}): 5.06
Mass of Partial Element (g U^{235}): 14.90

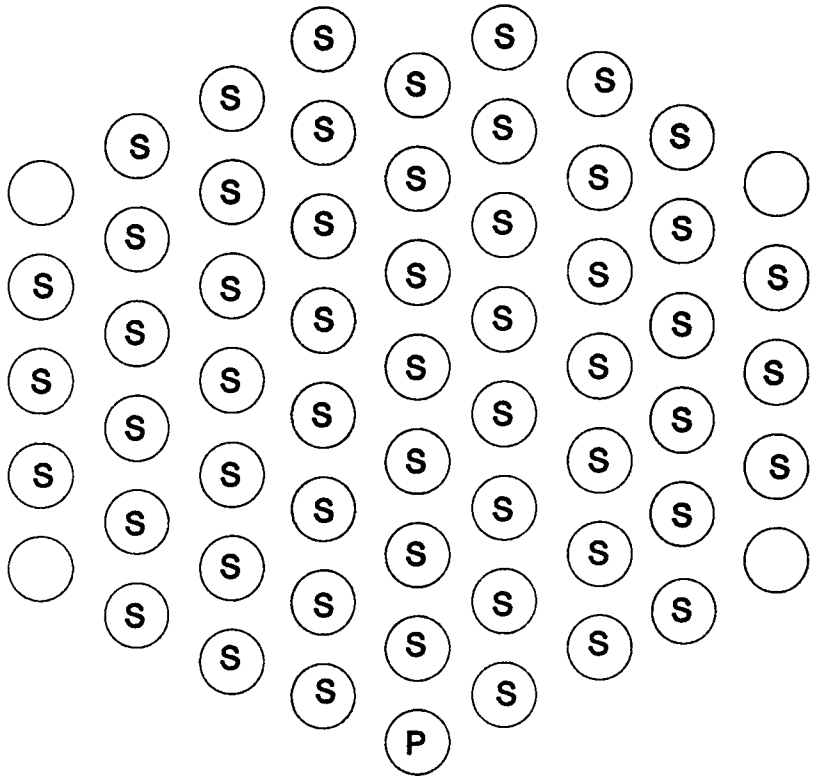
Figure A21 Rover Critical Configuration



3 - NRX-A3 Element
4 - NRX-A4 Element
P - Partial Element (Location Assumed)

Lattice Type: Triangular-Pitch (bare elements)
Array Pitch (cm): 4.78
Critical Mass (kg U^{235}): 6.29
Mass of Partial Element (g U^{235}): 56.82

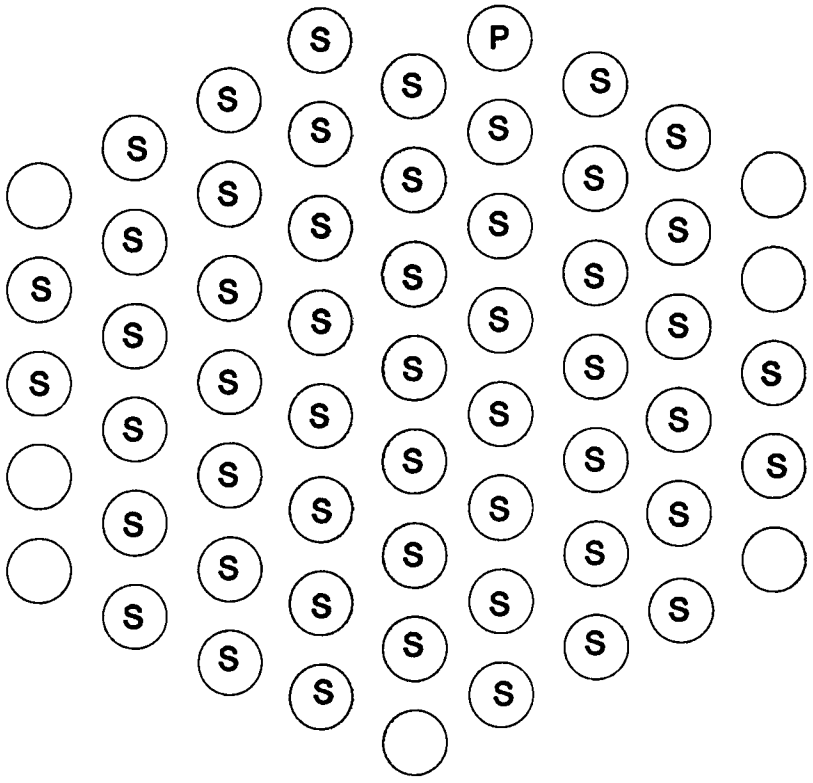
Figure A22 Rover Critical Configuration



S - 38.1 cm Pseudo-Element
P - Partial Element

Lattice Type: Triangular-Pitch (38.1 cm elements)
Array Pitch (cm): 3.12
Critical Mass (kg U^{235}): 2.16
Mass of Partial Element (g U^{235}): 20.80

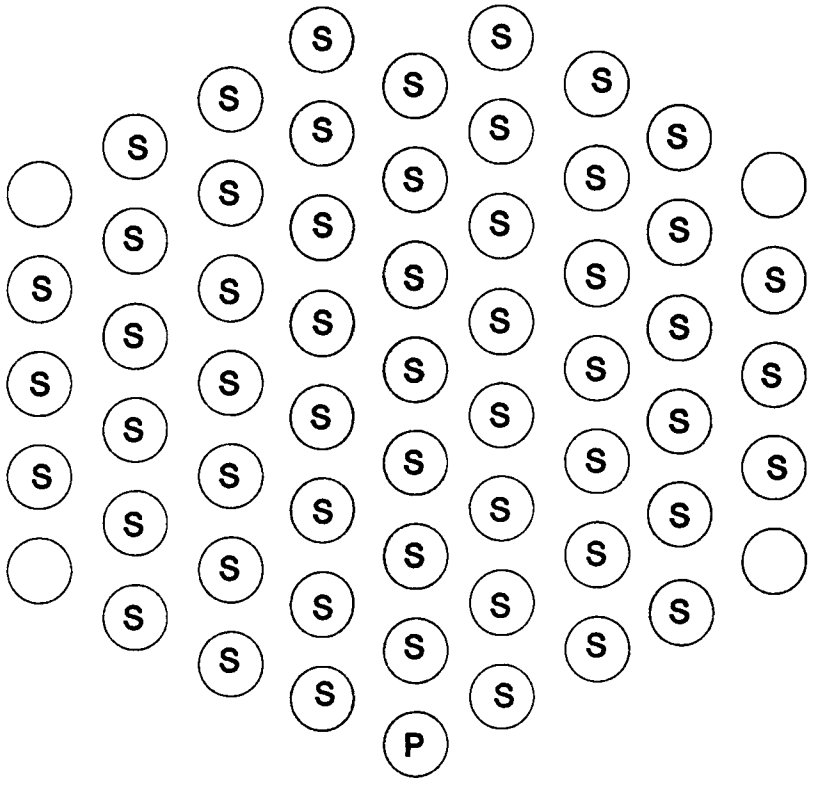
Figure A23 Rover Critical Configuration



S - 38.1 cm Pseudo-Element
P - Partial Element

Lattice Type: Triangular-Pitch (38.1 cm elements)
Array Pitch (cm): 3.73
Critical Mass (kg U^{235}): 2.00
Mass of Partial Element (g U^{235}): 13.6

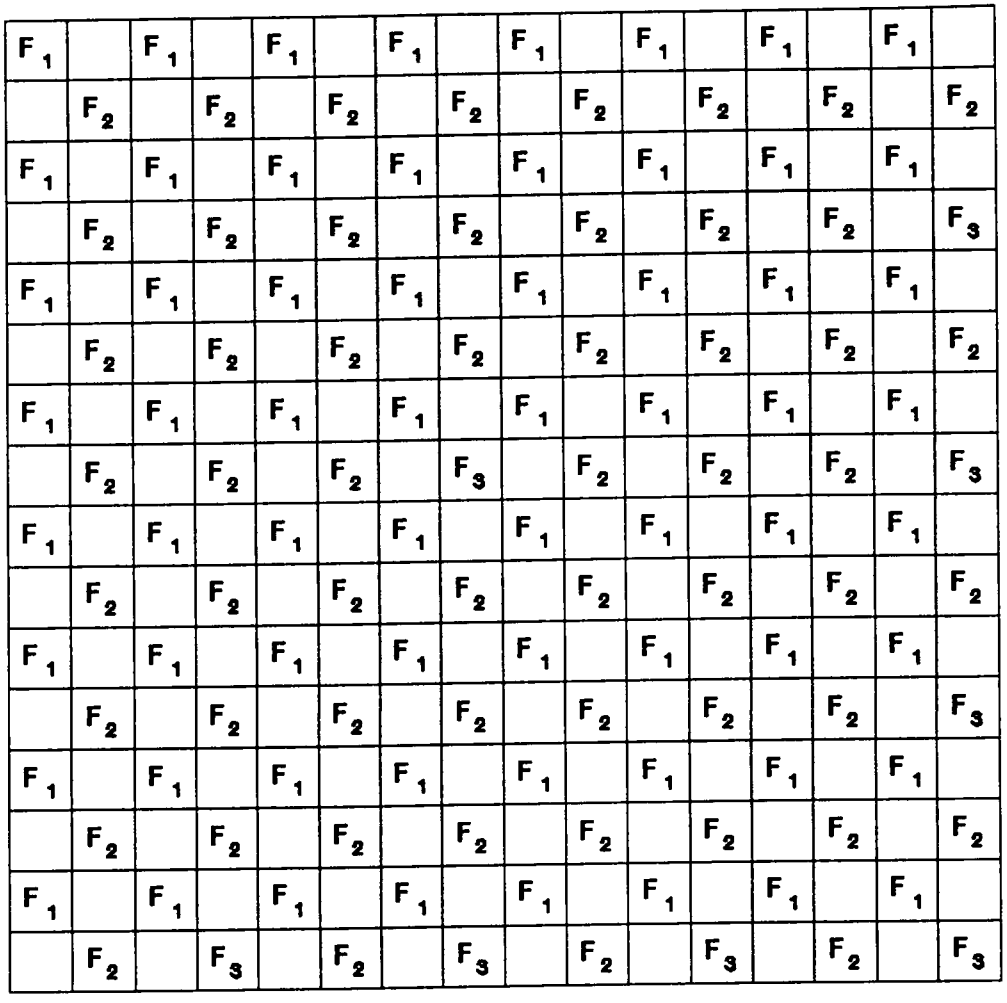
Figure A24 Rover Critical Configuration



S - 38.1 cm Pseudo-Element
P - Partial Element

Lattice Type: Triangular-Pitch (38.1 cm elements)
Array Pitch (cm): 4.14
Critical Mass (kg U^{235}): 2.12
Mass of Partial Element (g U^{235}): 19.0

Figure A25 Rover Critical Configuration



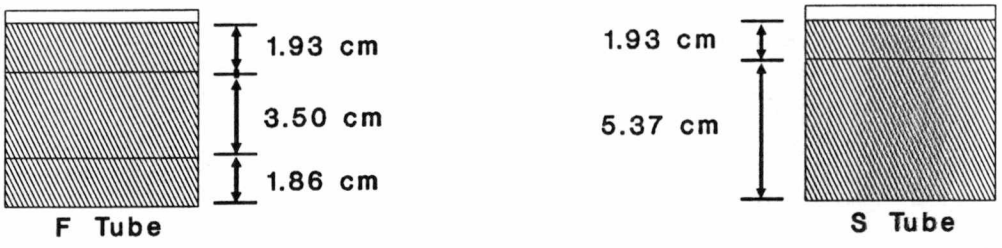
Assembly Designator: LA1
Core Dimensions (cm): 121.92 x 121.92 x 121.92
Critical Mass (kg U): 7.98
Reflector: 30.48 cm graphite, all sides
Uranium Foil Thickness (cm): 0.00254
Total Number of Foils: 1128

Figure A26 Honeycomb Critical Configuration

	F		F		F		F		F		F		F
F		F		F		F		F		F		F	
	F		F		F		F	S*	F		F		F
F		F		F		F		F		F		F	
	F		F		F		F		F		F		F
F		F		F		F		F		F		F	
	F		F		F		F		F		F		F
F		F		F		F		B		F		F	
	F		F	S**	F		F		F		F		F
F		F		F		F		F		F		F	
	F		F		F		F		F		F		F
F		F		F		F		F		F		F	
	F		F		F		F		F		F		F

East Face

S* - One 20.32 cm section in back of East half
S** - One 20.32 cm section in back of East and West half
B - Empty tube (CR3 withdrawn)



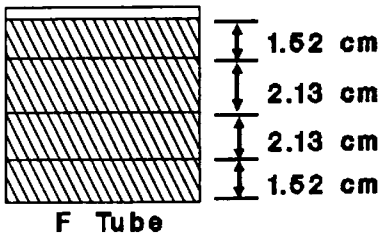
Assembly Designator: LA2
Core Dimensions (cm): 99.06 x 106.88 x 121.92
Critical Mass (kg U): 7.71
Reflector: 30.48 cm graphite, all sides
Uranium Foil Thickness (cm): 0.00254
Total Number of Foils: 1089

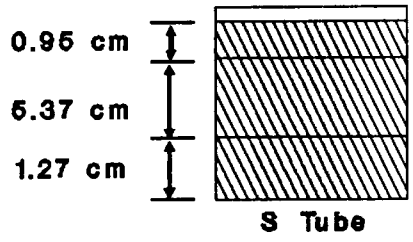
Figure A27 Honeycomb Critical Configuration

F		F		F		F		F*		F	
S	F		F		F		F		F		F
F		F		F		F		F		F	
	F	S	F		F		F		F	S	F
F		F		F		F		F		F	
	F		F	S	F		F	S	F		F
F		F		F		F		F		F	
	F		F		F	S	F		F		F
F		F		F		F		F		F	
	F		F	S	F		F	S	F		F
F		F		F		F		F		F	
	F	S	F		F		F		F	S	F

East Face

* - CR4 in East face withdrawn



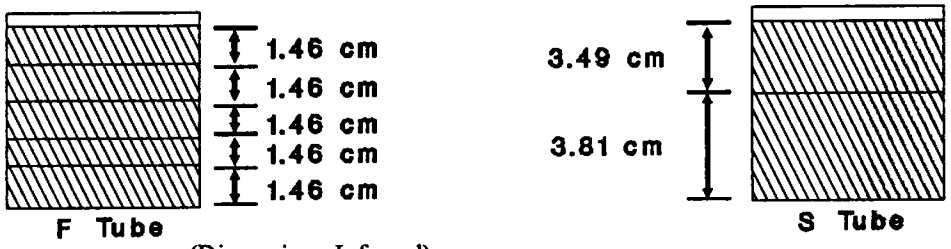


Assembly Designator: LA3
Core Dimensions (cm): 91.44 x 91.44 x 101.60
Critical Mass (kg U): 7.94
Reflector: 30.48 cm graphite, all sides
Uranium Foil Thickness (cm): 0.00254
Total Number of Foils: 1121

Figure A28 Honeycomb Critical Configuration

F	S	F		F		F		F		F
	F		F		F		F		F	
F		F	S	F		F		F		F
	F		F		F		F		F	
F		F		F	S	F		F		F
	F		F		F		F		F	
F		F		F		F	S	F		F
	F		F		F		F		F	
F		F		F		F		F	S	F
	F		F		F		F		F	S
F		F		F		F		F		F

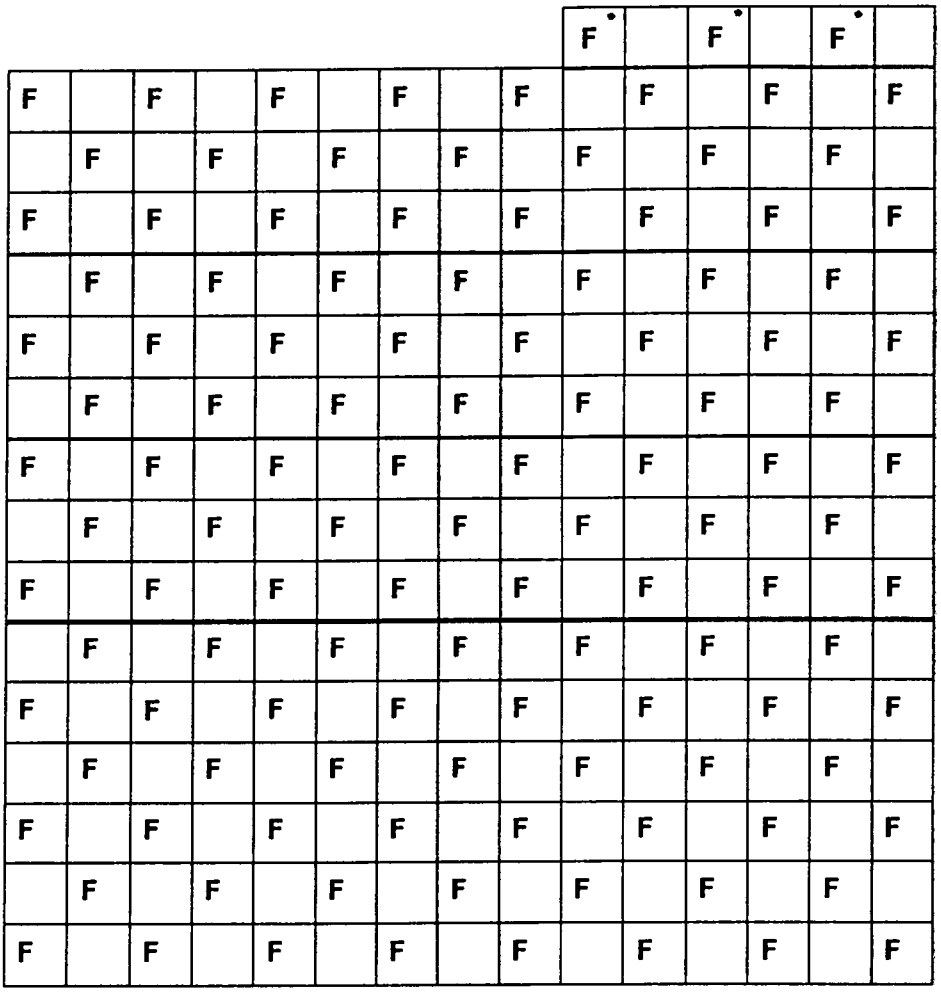
West Face



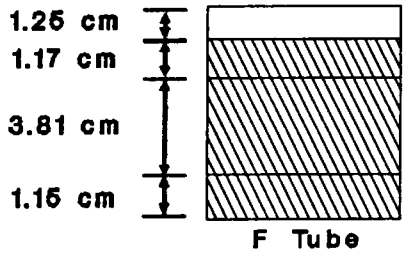
(Dimensions Inferred)

Assembly Designator: LA4
Core Dimensions (cm): 83.82 x 83.82 x 101.60
Critical Mass (kg U): 8.85
Reflector: 30.48 cm graphite, all sides
Uranium Foil Thickness (cm): 0.00254
Total Number of Foils: 1250

Figure A29 Honeycomb Critical Configuration



West Face



F* - These fuel tubes in in West half only

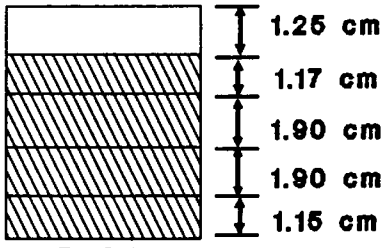
Assembly Designator: LA5
Core Dimensions (cm): 115.82 x 114.30 x 121.92
Critical Mass (kg U): 9.73
Reflector: 30.48 cm graphite, all sides
Uranium Foil Thickness (cm): 0.00254
Total Number of Foils: 1374

Figure A30 Honeycomb Critical Configuration

	F_1		F_1		F_1		F_1		F_1		F_1		F_1
F_1	F_2	F_1		F_1		F_1		F_1		F_1	F_3	F_1	
	F_1		F_1		F_1		F_1		F_1		F_1		F_1
F_1		F_1	F_2	F_1		F_1		F_1	F_3	F_1		F_1	
	F_1		F_1		F_1		F_1		F_1		F_1		F_1
F_1		F_1		F_1	F_2	F_1	F_3	F_1		F_1		F_1	
	F_1		F_1		F_1		F_1		F_1		F_1		F_1
F_1		F_1		F_1	F_3	B	F_2	F_1		F_1		F_1	
	F_1		F_1		F_1		F_1		F_1		F_1		F_1
F_1		F_1	F_3	F_1		F_1		F_1	F_2	F_1		F_1	
	F_1		F_1		F_1		F_1		F_1		F_1		F_1
F_1	F_3	F_1		F_1		F_1		F_1		F_1	F_2	F_1	
	F_1		F_1		F_1		F_1		F_1		F_1		F_1

West Face

B - CR3 out (F_1 tube in East half)



F_1 Tube (Dimensions Inferred)

F_2 same as F_2 for LA1
F_3 same as F_1 for LA1

Assembly Designator: LA6
Core Dimensions (cm): 99.06 x 106.68 x 101.60
Critical Mass (kg U): 10.24
Reflector: 30.48 cm graphite, all sides
Uranium Foil Thickness (cm): 0.00254
Total Number of Foils: 1446

Figure A31 Honeycomb Critical Configuration

Example Input for Rover Calculational Model

```
#csasn
homogenized materials in tube
27groupndf4          latticecell
u-235     1  0  7.37072e-4  296 end
u-238     1  0  5.35176e-5  296 end
c         1  0  6.52053e-2  296 end
be        1  0  1.73873e-9  296 end
v-51      1  0  5.84444e-7  296 end
al        1  0  5.80757e-9  296 end
cs-133    1  0  5.89507e-9  296 end
mn        1  0  1.42613e-8  296 end
br-79     1  0  1.50972e-9  296 end
br-81     1  0  1.43236e-9  296 end
cu        1  0  3.08236e-7  296 end
ca        1  0  2.54125e-6  296 end
fe        1  0  7.43545e-7  296 end
mo        1  0  6.53313e-8  296 end
pb        1  0  3.02504e-9  296 end
si        1  0  3.06861e-7  296 end
b-10      1  0  1.24570e-9  296 end
b-11      1  0  4.56030e-9  296 end
cd        1  0  5.57592e-9  296 end
k         1  0  1.72334e-6  296 end
zr        1  0  8.58897e-9  296 end
ba-138    1  0  7.95387e-8  296 end
ni        1  0  2.40251e-7  296 end
al        2  1.0  296 end
h2o       3  1.0  296 end
end comp
squarepitch 2.7940 2.011062 1 3 2.54 2 2.36220 0  end
end
#kenova
rover critical square  0.100      in. spacing
read parm plt=yes gen=203 npg=500 lib=4 nub=yes end parm
read mixt
mix=1 92235 9.976098e-4 92238 7.243490e-5 6012 8.974985e-2
23051 8.044412e-7 13027 7.99366e-9 55133 8.114089e-9 25055 1.962952e-8
35079 2.078012e-9 35081 1.971527e-9 29000 4.242620e-7 42000 8.992339e-8
82000 4.163731e-9 14000 4.223699e-7 5010 1.714605e-9
48000 7.674807e-9 19000 2.372045e-6 40000 1.182204e-8
28000 3.306868e-7 4009 2.39322e-9 20000 3.497824e-5 5011 6.276897e-9
26000 1.023431e-6 56138 1.094787e-7
mix=2 13027 6.02380-2
mix=3 1001 6.673583e-2  8016 3.336792e-2
```

Example Input for Rover Calculational Model (cont'd)

```
mix=4 1001 5.678253e-2  8016 1.419563e-2  6012 3.548908e-2
mix=5 1001 7.89969e-2  6012 3.94984e-2
mix=6 92235 1.071595e-3 92238 7.780686e-5 6012 9.319244e-2
23051 8.352973e-7 13027 8.30027e-9 55133 8.425323e-9 25055 2.038245e-8
35079 2.157719e-9 35081 2.047149e-9 29000 4.405356e-7 42000 9.337260e-8
82000 4.323440e-9 14000 4.385708e-7 5010 1.780372e-9
48000 7.969191e-9 19000 2.463030e-6 40000 1.227550e-8
28000 3.433710e-7 4009 2.485017e-9 20000 3.631992e-5 5011 6.517661e-9
26000 1.062687e-6 56138 1.136780e-7
end mixt
read start nst=1 xsm=-10.0 xsp=10.0 ysm=-10.0 ysp=10.0
zsm=0.0 zsp=135.89
end start
read geom
unit 1
cylinder 0 1 0.2502 0.32131 0.0
unit 2
cylinder 0 1 0.12192 0.32131 0.0
unit 3
cylinder 1 1 1.005531 0.32131 0.0
hole 1  0.0 0.0 0.0
hole 2  0.75794 0.43764 0.0
hole 2 0.75794 0.0 0.0
hole 2 0.75794 -0.43764 0.0
hole 2 0.368808 0.656336 0.0
hole 2 0.382778 0.220980 0.0
hole 2 0.382778 -0.220980 0.0
hole 2 0.368808 -0.656336 0.0
hole 2 0.0 0.875030 0.0
hole 2 0.0 0.441960 0.0
hole 2 0.0 -0.441960 0.0
hole 2 0.0 -0.875030 0.0
hole 2 -0.368808 0.656336 0.0
hole 2 -0.382778 0.220980 0.0
hole 2 -.382778 -0.229080 0.0
hole 2 -0.368808 -0.656336 0.0
hole 2 -0.75794 0.43764 0.0
hole 2 -0.75794 0.0 0.0
hole 2 -0.75794 -0.43764 0.0
cylinder 0 1 1.1811 0.32131 0.0
cylinder 2 1 1.2700 0.32131 -.3175
cuboid  3 1  1.3970 -1.3970 1.3970 -1.3970 0.32131 -.3175
unit 4
cylinder 0 1 0.12192 25.07869 0.0
unit 5
```

Example Input for Rover Calculational Model (cont'd)

```
cylinder 1 1 1.005531 25.07869 0.0
hole 4  0.0 0.0 0.0
hole 4  0.75794 0.43764 0.0
hole 4 0.75794 0.0 0.0
hole 4 0.75794 -0.43764 0.0
hole 4 0.368808 0.656336 0.0
hole 4 0.382778 0.220980 0.0
hole 4 0.382778 -0.220980 0.0
hole 4 0.368808 -0.656336 0.0
hole 4 0.0 0.875030 0.0
hole 4 0.0 0.441960 0.0
hole 4 0.0 -0.441960 0.0
hole 4 0.0 -0.875030 0.0
hole 4 -0.368808 0.656336 0.0
hole 4 -0.382778 0.220980 0.0
hole 4 -.382778 -0.229080 0.0
hole 4 -0.368808 -0.656336 0.0
hole 4 -0.75794 0.43764 0.0
hole 4 -0.75794 0.0 0.0
hole 4 -0.75794 -0.43764 0.0
cylinder 0 1 1.1811 25.07869 0.0
cylinder 2 1 1.2700 25.07869 0.0
cuboid 3 1 1.3970 -1.3970 1.3970 -1.3970 25.07869 0.0
unit 6
cylinder 0 1 0.12192 2.5400 0.0
unit 7
cylinder 1 1 1.005531 2.540 0.0
hole 6  0.0 0.0 0.0
hole 6  0.75794 0.43764 0.0
hole 6 0.75794 0.0 0.0
hole 6 0.75794 -0.43764 0.0
hole 6 0.368808 0.656336 0.0
hole 6 0.382778 0.220980 0.0
hole 6 0.382778 -0.220980 0.0
hole 6 0.368808 -0.656336 0.0
hole 6 0.0 0.875030 0.0
hole 6 0.0 0.441960 0.0
hole 6 0.0 -0.441960 0.0
hole 6 0.0 -0.875030 0.0
hole 6 -0.368808 0.656336 0.0
hole 6 -0.382778 0.220980 0.0
hole 6 -.382778 -0.229080 0.0
hole 6 -0.368808 -0.656336 0.0
hole 6 -0.75794 0.43764 0.0
hole 6 -0.75794 0.0 0.0
```

Example Input for Rover Calculational Model (cont'd)

```
hole 6 -0.75794 -0.43764 0.0
cylinder 0 1 1.1811 2.5400  0.0
cylinder 2 1 1.2700 2.5400  0.0
cuboid 3 1 1.3970 -1.3970 1.270 -1.270 2.5400 0.0
cuboid 4 1 1.3970 -1.3970 1.3970 -1.3970 2.5400 0.0
unit 8
cylinder 1 1 1.005531 2.540 0.0
hole 6  0.0 0.0 0.0
hole 6  0.75794 0.43764 0.0
hole 6 0.75794 0.0 0.0
hole 6 0.75794 -0.43764 0.0
hole 6 0.368808 0.656336 0.0
hole 6 0.382778 0.220980 0.0
hole 6 0.382778 -0.220980 0.0
hole 6 0.368808 -0.656336 0.0
hole 6 0.0 0.875030 0.0
hole 6 0.0 0.441960 0.0
hole 6 0.0 -0.441960 0.0
hole 6 0.0 -0.875030 0.0
hole 6 -0.368808 0.656336 0.0
hole 6 -0.382778 0.220980 0.0
hole 6 -.382778 -0.229080 0.0
hole 6 -0.368808 -0.656336 0.0
hole 6 -0.75794 0.43764 0.0
hole 6 -0.75794 0.0 0.0
hole 6 -0.75794 -0.43764 0.0
cylinder 0 1 1.1811 2.5400  0.0
cylinder 2 1 1.2700 2.5400  0.0
cuboid 3 1 1.270 -1.270 1.3970 -1.3970 2.540 0.0
cuboid 4 1 1.3970 -1.3970  1.3970 -1.3970 2.540 0.0
unit 9
cylinder 0 1 0.12192 77.47018 0.0
unit 10
cylinder 1 1 1.005531 77.47018 0.0
hole 9  0.0 0.0 0.0
hole 9  0.75794 0.43764 0.0
hole 9 0.75794 0.0 0.0
hole 9 0.75794 -0.43764 0.0
hole 9 0.368808 0.656336 0.0
hole 9 0.382778 0.220980 0.0
hole 9 0.382778 -0.220980 0.0
hole 9 0.368808 -0.656336 0.0
hole 9 0.0 0.875030 0.0
hole 9 0.0 0.441960 0.0
hole 9 0.0 -0.441960 0.0
```

```
hole 9 0.0 -0.875030 0.0
hole 9 -0.368808 0.656336 0.0
hole 9 -0.382778 0.220980 0.0
hole 9 -.382778 -0.229080 0.0
hole 9 -0.368808 -0.656336 0.0
hole 9 -0.75794 0.43764 0.0
hole 9 -0.75794 0.0 0.0
hole 9 -0.75794 -0.43764 0.0
cylinder 0 1 1.1811 77.47018 0.0
cylinder 2 1 1.2700 77.47018 0.0
cuboid 3 1 1.3970 -1.3970 1.3970 -1.3970 77.47018 0.0
unit 11
cylinder 0 1 0.12192 18.4861 0.0
unit 12
cylinder 1 1 1.005531 18.4861 0.0
hole 11 0.0 0.0 0.0
hole 11 0.75794 0.43764 0.0
hole 11 0.75794 0.0 0.0
hole 11 0.75794 -0.43764 0.0
hole 11 0.368808 0.656336 0.0
hole 11 0.382778 0.220980 0.0
hole 11 0.382778 -0.220980 0.0
hole 11 0.368808 -0.656336 0.0
hole 11 0.0 0.875030 0.0
hole 11 0.0 0.441960 0.0
hole 11 0.0 -0.441960 0.0
hole 11 0.0 -0.875030 0.0
hole 11 -0.368808 0.656336 0.0
hole 11 -0.382778 0.220980 0.0
hole 11 -.382778 -0.229080 0.0
hole 11 -0.368808 -0.656336 0.0
hole 11 -0.75794 0.43764 0.0
hole 11 -0.75794 0.0 0.0
hole 11 -0.75794 -0.43764 0.0
cylinder 0 1 1.1811 18.4861 0.0
cylinder 2 1 1.2700 18.4861 0.0
cuboid 3 1 1.3970 -1.3970 1.3970 -1.3970 18.4861 0.0
unit 13
cylinder 0 1 0.12192 1.270 0.0
unit 14
cylinder 0 1 0.12700 1.270 0.0
unit 15
cylinder 1 1 1.005531 1.270 0.0
hole 14 0.0 0.0 0.0
hole 13 0.75794 0.43764 0.0
```

```
hole 13 0.75794 0.0 0.0
hole 13 0.75794 -0.43764 0.0
hole 13 0.368808 0.656336 0.0
hole 13 0.382778 0.220980 0.0
hole 13 0.382778 -0.220980 0.0
hole 13 0.368808 -0.656336 0.0
hole 13 0.0 0.875030 0.0
hole 13 0.0 0.441960 0.0
hole 13 0.0 -0.441960 0.0
hole 13 0.0 -0.875030 0.0
hole 13 -0.368808 0.656336 0.0
hole 13 -0.382778 0.220980 0.0
hole 13 -.382778 -0.229080 0.0
hole 13 -0.368808 -0.656336 0.0
hole 13 -0.75794 0.43764 0.0
hole 13 -0.75794 0.0 0.0
hole 13 -0.75794 -0.43764 0.0
cylinder 0 1 1.1811 1.270 0.0
cylinder 2 1 1.270 1.270 0.0
cuboid  3  1 1.3970 -1.3970 1.3970 -1.3970 1.270 0.0
unit 16
cylinder 0 1 1.1811 1.6964 0.0
cylinder 2 1 1.2700 1.6964 0.0
cuboid 3  1 1.3970 -1.3970 1.3970 -1.3970 1.6964 0.0
unit 17
cylinder 5 1 1.1811 1.0900 0.0
cylinder 2 1 1.2700 1.0900 0.0
cuboid  3  1 1.3970 -1.3970  1.3970 -1.3970 1.0900 0.0
unit 18
cylinder 0 1 0.2502 0.32131 0.0
unit 19
cylinder 0 1 0.12573 0.32131 0.0
unit 20
cylinder 6 1 1.005531 0.32131 0.0
hole 18 0.0 0.0 0.0
hole 19 0.75794 0.43764 0.0
hole 19 0.75794 0.0 0.0
hole 19 0.75794 -0.43764 0.0
hole 19 0.368808 0.656336 0.0
hole 19 0.382778 0.220980 0.0
hole 19 0.382778 -0.220980 0.0
hole 19 0.368808 -0.656336 0.0
hole 19 0.0 0.875030 0.0
hole 19 0.0 0.441960 0.0
hole 19 0.0 -0.441960 0.0
```

```
hole 19 0.0 -0.875030 0.0
hole 19 -0.368808 0.656336 0.0
hole 19 -0.382778 0.220980 0.0
hole 19 -.382778 -0.229080 0.0
hole 19 -0.368808 -0.656336 0.0
hole 19 -0.75794 0.43764 0.0
hole 19 -0.75794 0.0 0.0
hole 19 -0.75794 -0.43764 0.0
cylinder 0 1 1.1811 0.32131 0.0
cylinder 2 1 1.270 0.32131 -.3175
cuboid  3  1 1.3970 -1.3970 1.3970 -1.3970 0.32131 -.3175
unit 21
cylinder 0 1 0.12573 25.07869 0.0
unit 22
cylinder 6 1  1.005531 25.07869 0.0
hole 21 0.0 0.0 0.0
hole 21 0.75794 0.43764 0.0
hole 21 0.75794 0.0 0.0
hole 21 0.75794 -0.43764 0.0
hole 21 0.368808 0.656336 0.0
hole 21 0.382778 0.220980 0.0
hole 21 0.382778 -0.220980 0.0
hole 21 0.368808 -0.656336 0.0
hole 21 0.0 0.875030 0.0
hole 21 0.0 0.441960 0.0
hole 21 0.0 -0.441960 0.0
hole 21 0.0 -0.875030 0.0
hole 21 -0.368808 0.656336 0.0
hole 21 -0.382778 0.220980 0.0
hole 21 -.382778 -0.229080 0.0
hole 21 -0.368808 -0.656336 0.0
hole 21 -0.75794 0.43764 0.0
hole 21 -0.75794 0.0 0.0
hole 21 -0.75794 -0.43764 0.0
cylinder 0 1 1.1811 25.07869 0.0
cylinder 2 1 1.2700 25.07869 0.0
cuboid 3 1 1.3970 -1.3970  1.3970 -1.3970 25.07869 0.0
unit 23
cylinder 0 1 0.12573 2.540 0.0
unit 24
cylinder 6 1 1.005531 2.540 0.0
hole 23 0.0 0.0 0.0
hole 23 0.75794 0.43764 0.0
hole 23 0.75794 0.0 0.0
hole 23 0.75794 -0.43764 0.0
```

```
hole 23 0.368808 0.656336 0.0
hole 23 0.382778 0.220980 0.0
hole 23 0.382778 -0.220980 0.0
hole 23 0.368808 -0.656336 0.0
hole 23 0.0 0.875030 0.0
hole 23 0.0 0.441960 0.0
hole 23 0.0 -0.441960 0.0
hole 23 0.0 -0.875030 0.0
hole 23 -0.368808 0.656336 0.0
hole 23 -0.382778 0.220980 0.0
hole 23 -.382778 -0.229080 0.0
hole 23 -0.368808 -0.656336 0.0
hole 23 -0.75794 0.43764 0.0
hole 23 -0.75794 0.0 0.0
hole 23 -0.75794 -0.43764 0.0
cylinder 0 1 1.1811 2.540 0.0
cylinder 2 1 1.2700 2.540 0.0
cuboid   3 1 1.3970 -1.3970 1.2700 -1.2700 2.540 0.0
cuboid   4 1 1.3970 -1.3970  1.3970 -1.3970 2.540 0.0
unit 25
cylinder 6 1 1.005531 2.540 0.0
hole 23 0.0 0.0 0.0
hole 23 0.75794 0.43764 0.0
hole 23 0.75794 0.0 0.0
hole 23 0.75794 -0.43764 0.0
hole 23 0.368808 0.656336 0.0
hole 23 0.382778 0.220980 0.0
hole 23 0.382778 -0.220980 0.0
hole 23 0.368808 -0.656336 0.0
hole 23 0.0 0.875030 0.0
hole 23 0.0 0.441960 0.0
hole 23 0.0 -0.441960 0.0
hole 23 0.0 -0.875030 0.0
hole 23 -0.368808 0.656336 0.0
hole 23 -0.382778 0.220980 0.0
hole 23 -.382778 -0.229080 0.0
hole 23 -0.368808 -0.656336 0.0
hole 23 -0.75794 0.43764 0.0
hole 23 -0.75794 0.0 0.0
hole 23 -0.75794 -0.43764 0.0
cylinder 0 1 1.1811 2.540 0.0
cylinder 2 1 1.2700 2.540 0.0
cuboid 3 1 1.2700 -1.2700 1.3970 -1.3970 2.540 0.0
cuboid 4 1 1.3970 -1.3970 1.3970 -1.3970 2.540 0.0
unit 26
```

```
cylinder 0 1 0.12573 77.47018 0.0
unit 27
cylinder 6 1 1.005531 77.47018 0.0
hole 26 0.0 0.0 0.0
hole 26 0.75794 0.43764 0.0
hole 26 0.75794 0.0 0.0
hole 26 0.75794 -0.43764 0.0
hole 26 0.368808 0.656336 0.0
hole 26 0.382778 0.220980 0.0
hole 26 0.382778 -0.220980 0.0
hole 26 0.368808 -0.656336 0.0
hole 26 0.0 0.875030 0.0
hole 26 0.0 0.441960 0.0
hole 26 0.0 -0.441960 0.0
hole 26 0.0 -0.875030 0.0
hole 26 -0.368808 0.656336 0.0
hole 26 -0.382778 0.220980 0.0
hole 26 -.382778 -0.229080 0.0
hole 26 -0.368808 -0.656336 0.0
hole 26 -0.75794 0.43764 0.0
hole 26 -0.75794 0.0 0.0
hole 26 -0.75794 -0.43764 0.0
cylinder 0 1 1.1811 77.47018 0.0
cylinder 2 1 1.2700 77.47018 0.0
cuboid  3 1 1.3970 -1.3970  1.3970 -1.3970 77.47018 0.0
unit 28
cylinder 0 1 0.12573 17.4854 0.0
unit 29
cylinder 6 1 1.005531 17.4854 0.0
hole 28 0.0 0.0 0.0
hole 28 0.75794 0.43764 0.0
hole 28 0.75794 0.0 0.0
hole 28 0.75794 -0.43764 0.0
hole 28 0.368808 0.656336 0.0
hole 28 0.382778 0.220980 0.0
hole 28 0.382778 -0.220980 0.0
hole 28 0.368808 -0.656336 0.0
hole 28 0.0 0.875030 0.0
hole 28 0.0 0.441960 0.0
hole 28 0.0 -0.441960 0.0
hole 28 0.0 -0.875030 0.0
hole 28 -0.368808 0.656336 0.0
hole 28 -0.382778 0.220980 0.0
hole 28 -.382778 -0.229080 0.0
hole 28 -0.368808 -0.656336 0.0
```

```
hole 28 -0.75794 0.43764 0.0
hole 28 -0.75794 0.0 0.0
hole 28 -0.75794 -0.43764 0.0
cylinder 0 1 1.1811 17.4854 0.0
cylinder 2 1 1.2700 17.4854 0.0
cuboid 3 1 1.3970 -1.3970  1.3970 -1.3970 17.4854 0.0
unit 30
cylinder 0 1 0.12573 1.270 0.0
unit 31
cylinder 0 1  0.12700 1.270 0.0
unit 32
cylinder 6 1 1.005531 1.270 0.0
hole 31 0.0 0.0 0.0
hole 30 0.75794 0.43764 0.0
hole 30 0.75794 0.0 0.0
hole 30 0.75794 -0.43764 0.0
hole 30 0.368808 0.656336 0.0
hole 30 0.382778 0.220980 0.0
hole 30 0.382778 -0.220980 0.0
hole 30 0.368808 -0.656336 0.0
hole 30 0.0 0.875030 0.0
hole 30 0.0 0.441960 0.0
hole 30 0.0 -0.441960 0.0
hole 30 0.0 -0.875030 0.0
hole 30 -0.368808 0.656336 0.0
hole 30 -0.382778 0.220980 0.0
hole 30 -.382778 -0.229080 0.0
hole 30 -0.368808 -0.656336 0.0
hole 30 -0.75794 0.43764 0.0
hole 30 -0.75794 0.0 0.0
hole 30 -0.75794 -0.43764 0.0
cylinder 0 1 1.1811 1.270 0.0
cylinder 2 1 1.2700 1.2700 0.0
cuboid  3 1 1.3970 -1.3970  1.3970 -1.3970 1.2700 0.0
unit 33
cylinder 0 1 1.1811 2.69710 0.0
cylinder 2 1 1.2700 2.69710 0.0
cuboid  3  1  1.3970 -1.3970  1.3970 -1.3970 2.69710 0.0
unit 34
cylinder 1 1 0.0421373  0.32131 0.0
cylinder 0 1 1.1811 0.32131 0.0
cylinder 2 1 1.270 0.32131 -.3175
cuboid  3  1 1.3970 -1.3970  1.3970 -1.3970 0.32131 -.3175
unit 35
cylinder 1 1  0.0421373 25.07869 0.0
```

Example Input for Rover Calculational Model (cont'd)

```
cylinder 0 1 1.1811 25.07869 0.0
cylinder 2 1 1.2700 25.07869 0.0
cuboid 3 1 1.3970 -1.3970 1.3970 -1.3970 25.07869 0.0
unit 36
cylinder 1 1 0.0421373  2.540 0.0
cylinder 0 1 1.1811 2.540 0.0
cylinder 2 1 1.2700 2.540 0.0
cuboid   3 1 1.3970 -1.3970 1.2700 -1.2700 2.540 0.0
cuboid   4 1 1.3970 -1.3970 1.2700 -1.3970 2.540 0.0
unit 37
cylinder 1 1 0.0421373 2.540 0.0
cylinder 0 1 1.1811 2.540 0.0
cylinder 2 1 1.2700 2.540 0.0
cuboid 3 1 1.270  -1.270  1.3970 -1.3970 2.540 0.0
cuboid 4 1 1.3970 -1.3970 1.3970 -1.3970 2.540 0.0
unit 38
cylinder 1 1 0.0421373 77.47018 0.0
cylinder 0 1 1.1811 77.47018 0.0
cylinder 2 1 1.2700 77.47018 0.0
cuboid  3 1 1.3970 -1.3970 1.3970 -1.3970 77.47018 0.0
unit 39
cylinder 1 1 0.0421373 19.7561 0.0
cylinder 0 1 1.1811 19.7561 0.0
cylinder 2 1 1.2700 19.7561 0.0
cuboid 3 1 1.3970 -1.3970 1.3970 -1.3970 19.7561 0.0
unit 40
cylinder 0 1 1.1811 1.69640 0.0
cylinder 2 1 1.2700 1.69640 0.0
cuboid  3  1  1.3970 -1.3970 1.3970 -1.3970 1.69640 0.0
unit 41
cylinder 3 1 1.1811 0.32131 0.0
cylinder 2 1 1.2700 0.32131 -.3175
cuboid  3  1 1.3970 -1.3970 1.3970 -1.3970 0.32131 -.3175
unit 42
cylinder 3 1 1.1811 25.07869 0.0
cylinder 2 1 1.2700 25.07869 0.0
cuboid 3 1 1.3970 -1.3970 1.3970 -1.3970 25.07869 0.0
unit 43
cylinder 3 1 1.1811 2.540 0.0
cylinder 2 1 1.2700 2.540 0.0
cuboid   3 1 1.3970 -1.3970 1.2700 -1.2700 2.540 0.0
cuboid   4 1 1.3970 -1.3970 1.3970 -1.3970 2.540 0.0
unit 44
cylinder 3 1 1.1811 2.540 0.0
cylinder 2 1 1.2700 2.540 0.0
```

```
cuboid 3 1 1.2700 -1.2700 1.3970 -1.3970 2.540 0.0
cuboid 4 1 1.3970 -1.3970 1.3970 -1.3970 2.540 0.0
unit 45
cylinder 3 1 1.1811 77.47018 0.0
cylinder 2 1 1.2700 77.47018 0.0
cuboid  3 1 1.3970 -1.3970 1.3970 -1.3970 77.47018 0.0
unit 46
cylinder 3 1 1.1811 18.75540 0.0
cylinder 2 1 1.2700 18.7554  0.0
cuboid 3 1 1.3970 -1.3970 1.3970 -1.3970 18.7554 0.0
unit 47
cylinder 3 1  1.1811 3.78710 0.0
cylinder 2 1 1.2700 3.78710 0.0
cuboid  3  1  1.3970 -1.3970 1.3970 -1.3970 3.78710 0.0
unit 48
cylinder 1 1 1.005531 2.540 0.0
hole 6  0.0 0.0 0.0
hole 6  0.75794 0.43764 0.0
hole 6 0.75794 0.0 0.0
hole 6 0.75794 -0.43764 0.0
hole 6 0.368808 0.656336 0.0
hole 6 0.382778 0.220980 0.0
hole 6 0.382778 -0.220980 0.0
hole 6 0.368808 -0.656336 0.0
hole 6 0.0 0.875030 0.0
hole 6 0.0 0.441960 0.0
hole 6 0.0 -0.441960 0.0
hole 6 0.0 -0.875030 0.0
hole 6 -0.368808 0.656336 0.0
hole 6 -0.382778 0.220980 0.0
hole 6 -.382778 -0.229080 0.0
hole 6 -0.368808 -0.656336 0.0
hole 6 -0.75794 0.43764 0.0
hole 6 -0.75794 0.0 0.0
hole 6 -0.75794 -0.43764 0.0
cylinder 0 1 1.1811 2.5400  0.0
cylinder 2 1 1.2700 2.5400  0.0
cuboid 3 1 1.3970 -1.3970 1.270 -1.270 2.5400 0.0
cuboid 4 1 1.3970 -1.3970 1.270 -1.3970 2.5400 0.0
unit 49
cylinder 1 1 1.005531 2.540 0.0
hole 6  0.0 0.0 0.0
hole 6  0.75794 0.43764 0.0
hole 6 0.75794 0.0 0.0
hole 6 0.75794 -0.43764 0.0
```

```
hole 6 0.368808 0.656336 0.0
hole 6 0.382778 0.220980 0.0
hole 6 0.382778 -0.220980 0.0
hole 6 0.368808 -0.656336 0.0
hole 6 0.0 0.875030 0.0
hole 6 0.0 0.441960 0.0
hole 6 0.0 -0.441960 0.0
hole 6 0.0 -0.875030 0.0
hole 6 -0.368808 0.656336 0.0
hole 6 -0.382778 0.220980 0.0
hole 6 -.382778 -0.229080 0.0
hole 6 -0.368808 -0.656336 0.0
hole 6 -0.75794 0.43764 0.0
hole 6 -0.75794 0.0 0.0
hole 6 -0.75794 -0.43764 0.0
cylinder 0 1 1.1811 2.5400  0.0
cylinder 2 1 1.2700 2.5400  0.0
cuboid 3 1 1.3970 -1.3970 1.270 -1.270 2.5400 0.0
cuboid 4 1 1.3970 -1.3970 1.3970 -1.270 2.5400 0.0
unit 50
cylinder 1 1 1.005531 2.540 0.0
hole 6  0.0 0.0 0.0
hole 6  0.75794 0.43764 0.0
hole 6 0.75794 0.0 0.0
hole 6 0.75794 -0.43764 0.0
hole 6 0.368808 0.656336 0.0
hole 6 0.382778 0.220980 0.0
hole 6 0.382778 -0.220980 0.0
hole 6 0.368808 -0.656336 0.0
hole 6 0.0 0.875030 0.0
hole 6 0.0 0.441960 0.0
hole 6 0.0 -0.441960 0.0
hole 6 0.0 -0.875030 0.0
hole 6 -0.368808 0.656336 0.0
hole 6 -0.382778 0.220980 0.0
hole 6 -.382778 -0.229080 0.0
hole 6 -0.368808 -0.656336 0.0
hole 6 -0.75794 0.43764 0.0
hole 6 -0.75794 0.0 0.0
hole 6 -0.75794 -0.43764 0.0
cylinder 0 1 1.1811 2.5400  0.0
cylinder 2 1 1.2700 2.5400  0.0
cuboid 3 1  1.270 -1.270 1.3970 -1.3970 2.5400 0.0
cuboid 4 1 1.3970 -1.270 1.3970 -1.3970 2.5400 0.0
unit 51
```

```
cylinder 1 1 1.005531 2.540 0.0
hole 6  0.0 0.0 0.0
hole 6  0.75794 0.43764 0.0
hole 6 0.75794 0.0 0.0
hole 6 0.75794 -0.43764 0.0
hole 6 0.368808 0.656336 0.0
hole 6 0.382778 0.220980 0.0
hole 6 0.382778 -0.220980 0.0
hole 6 0.368808 -0.656336 0.0
hole 6 0.0 0.875030 0.0
hole 6 0.0 0.441960 0.0
hole 6 0.0 -0.441960 0.0
hole 6 0.0 -0.875030 0.0
hole 6 -0.368808 0.656336 0.0
hole 6 -0.382778 0.220980 0.0
hole 6 -.382778 -0.229080 0.0
hole 6 -0.368808 -0.656336 0.0
hole 6 -0.75794 0.43764 0.0
hole 6 -0.75794 0.0 0.0
hole 6 -0.75794 -0.43764 0.0
cylinder 0 1 1.1811 2.5400  0.0
cylinder 2 1 1.2700 2.5400  0.0
cuboid 3 1  1.270 -1.270 1.3970 -1.3970 2.5400 0.0
cuboid 4 1  1.270 -1.3970 1.3970 -1.3970 2.5400 0.0
unit 52
cylinder 6 1 1.005531 2.540 0.0
hole 23 0.0 0.0 0.0
hole 23 0.75794 0.43764 0.0
hole 23 0.75794 0.0 0.0
hole 23 0.75794 -0.43764 0.0
hole 23 0.368808 0.656336 0.0
hole 23 0.382778 0.220980 0.0
hole 23 0.382778 -0.220980 0.0
hole 23 0.368808 -0.656336 0.0
hole 23 0.0 0.875030 0.0
hole 23 0.0 0.441960 0.0
hole 23 0.0 -0.441960 0.0
hole 23 0.0 -0.875030 0.0
hole 23 -0.368808 0.656336 0.0
hole 23 -0.382778 0.220980 0.0
hole 23 -.382778 -0.229080 0.0
hole 23 -0.368808 -0.656336 0.0
hole 23 -0.75794 0.43764 0.0
hole 23 -0.75794 0.0 0.0
hole 23 -0.75794 -0.43764 0.0
```

```
cylinder 0 1 1.1811 2.540 0.0
cylinder 2 1 1.2700 2.540 0.0
cuboid   3 1 1.3970 -1.3970 1.270 -1.2700 2.540 0.0
cuboid   4 1 1.3970 -1.3970 1.270 -1.3970 2.540 0.0
unit 53
cylinder 6 1 1.005531 2.540 0.0
hole 23 0.0 0.0 0.0
hole 23 0.75794 0.43764 0.0
hole 23 0.75794 0.0 0.0
hole 23 0.75794 -0.43764 0.0
hole 23 0.368808 0.656336 0.0
hole 23 0.382778 0.220980 0.0
hole 23 0.382778 -0.220980 0.0
hole 23 0.368808 -0.656336 0.0
hole 23 0.0 0.875030 0.0
hole 23 0.0 0.441960 0.0
hole 23 0.0 -0.441960 0.0
hole 23 0.0 -0.875030 0.0
hole 23 -0.368808 0.656336 0.0
hole 23 -0.382778 0.220980 0.0
hole 23 -.382778 -0.229080 0.0
hole 23 -0.368808 -0.656336 0.0
hole 23 -0.75794 0.43764 0.0
hole 23 -0.75794 0.0 0.0
hole 23 -0.75794 -0.43764 0.0
cylinder 0 1 1.1811 2.540 0.0
cylinder 2 1 1.2700 2.540 0.0
cuboid 3 1 1.3970  -1.3970  1.270 -1.270 2.540 0.0
cuboid 4 1 1.3970 -1.3970 1.3970 -1.270 2.540 0.0
unit 54
cylinder 6 1 1.005531 2.540 0.0
hole 23 0.0 0.0 0.0
hole 23 0.75794 0.43764 0.0
hole 23 0.75794 0.0 0.0
hole 23 0.75794 -0.43764 0.0
hole 23 0.368808 0.656336 0.0
hole 23 0.382778 0.220980 0.0
hole 23 0.382778 -0.220980 0.0
hole 23 0.368808 -0.656336 0.0
hole 23 0.0 0.875030 0.0
hole 23 0.0 0.441960 0.0
hole 23 0.0 -0.441960 0.0
hole 23 0.0 -0.875030 0.0
hole 23 -0.368808 0.656336 0.0
hole 23 -0.382778 0.220980 0.0
```

```
hole 23 -.382778 -0.229080 0.0
hole 23 -0.368808 -0.656336 0.0
hole 23 -0.75794 0.43764 0.0
hole 23 -0.75794 0.0 0.0
hole 23 -0.75794 -0.43764 0.0
cylinder 0 1 1.1811 2.540 0.0
cylinder 2 1 1.2700 2.540 0.0
cuboid  3 1  1.270 -1.270 1.3970  -1.3970  2.540 0.0
cuboid  4 1 1.3970 -1.270 1.3970 -1.3970 2.540 0.0
unit 55
cylinder 6 1 1.005531 2.540 0.0
hole 23 0.0 0.0 0.0
hole 23 0.75794 0.43764 0.0
hole 23 0.75794 0.0 0.0
hole 23 0.75794 -0.43764 0.0
hole 23 0.368808 0.656336 0.0
hole 23 0.382778 0.220980 0.0
hole 23 0.382778 -0.220980 0.0
hole 23 0.368808 -0.656336 0.0
hole 23 0.0 0.875030 0.0
hole 23 0.0 0.441960 0.0
hole 23 0.0 -0.441960 0.0
hole 23 0.0 -0.875030 0.0
hole 23 -0.368808 0.656336 0.0
hole 23 -0.382778 0.220980 0.0
hole 23 -.382778 -0.229080 0.0
hole 23 -0.368808 -0.656336 0.0
hole 23 -0.75794 0.43764 0.0
hole 23 -0.75794 0.0 0.0
hole 23 -0.75794 -0.43764 0.0
cylinder 0 1 1.1811 2.540 0.0
cylinder 2 1 1.2700 2.540 0.0
cuboid 3 1  1.270 -1.270 1.3970 -1.3970 2.540 0.0
cuboid 4 1  1.270 -1.3970 1.3970 -1.3970 2.540 0.0
unit 56
array 1 3r0.0
unit 57
array 2 3r0.0
unit 58
array 3 3r0.0
unit 59
array 4 3r0.0
unit 60
array 5 3r0.0
unit 61
```

Example Input for Rover Calculational Model (cont'd)

```
array 6 3r0.0
unit 62
array 7 3r0.0
unit 63
array 8 3r0.0
unit 64
array 9 3r0.0
unit 65
array 10 -15.367 -15.367 0.0
cuboid 3 1 15.575 -15.575 15.575 -15.575 0.63881 0.0
unit 66
array 11 3r0.0
unit 67
array 12 3r0.0
unit 68
array 13 3r0.0
unit 69
array 14 3r0.0
unit 70
array 15 3r0.0
unit 71
array 16 3r0.0
unit 72
array 17 3r0.0
unit 73
array 18 3r0.0
unit 74
array 19 3r0.0
unit 75
array 20 -15.367 -15.367 0.0
cuboid 3 1 15.575 -15.575 15.575 -15.575 25.07869 0.0
unit 76
array 21 3r0.0
unit 77
array 22 3r0.0
unit 78
array 23 3r0.0
unit 79
array 24 3r0.0
unit 80
array 25 3r0.0
unit 81
array 26 3r0.0
unit 82
array 27 3r0.0
```

Example Input for Rover Calculational Model (cont'd)

```
unit 83
array 28 3r0.0
unit 84
array 29 3r0.0
unit 85
array 30 -15.367 -15.240 0.0
cuboid 2 1 15.367 -15.367 15.575 -15.575 2.540 0.0
cuboid 3 1 15.575 -15.575 15.575 -15.575 2.540 0.0
unit 86
array 31 3r0.0
unit 87
array 32 3r0.0
unit 88
array 33 3r0.0
unit 89
array 34 3r0.0
unit 90
array 35 3r0.0
unit 91
array 36 3r0.0
unit 92
array 37 3r0.0
unit 93
array 38 3r0.0
unit 94
array 39 3r0.0
unit 95
array 40 3r0.0
unit 96
array 41 -15.240 -15.367 0.0
cuboid 2 1 15.575 -15.575 15.367  -15.367 2.540 0.0
cuboid 3 1 15.575 -15.575 15.575 -15.575 2.540 0.0
unit 97
array 42 3r0.0
unit 98
array 43 3r0.0
unit 99
array 44  3r0.0
unit 100
array 45 3r0.0
unit 101
array 46 3r0.0
unit 102
array 47 3r0.0
unit 103
```

```
array 48 3r0.0
unit 104
array 49 3r0.0
unit 105
array 50 3r0.0
unit 106
array 51 -15.367 -15.367 0.0
cuboid 3 1 15.575 -15.575 15.575 -15.575 77.47018 0.0
unit 107
array 52 3r0.0
unit 108
array 53 3r0.0
unit 109
array 54 3r0.0
unit 110
array 55 3r0.0
unit 111
array 56  3r0.0
unit 112
array 57  3r0.0
unit 113
array 58 3r0.0
unit 114
array 59 3r0.0
unit 115
array 60 3r0.0
unit 116
array 61 3r0.0
unit 117
array 62 3r0.0
unit 118
array 63 3r0.0
unit 119
array 64 3r0.0
unit 120
array 65 -15.367 -15.367 0.0
cuboid 3 1 15.575 -15.575 15.575 -15.575 22.5425 0.0
global unit 121
array 66 -15.575 -15.575 0.0
cuboid 3 1 39.370 -39.370 43.4975 -43.4975 150.89 0.0
cuboid 4 1 39.370 -39.370 43.4975 -43.4975 150.89 -3.800
cuboid 3 1 75.000 -75.000 75.000 -75.000 150.89 -32.30
unit 122
cylinder 3 1 1.1811 2.540 0.0
cylinder 2 1 1.2700 2.540 0.0
```

Example Input for Rover Calculational Model (cont'd)

```
cuboid   3 1 1.3970 -1.3970 1.270 -1.270  2.540 0.0
cuboid   4 1 1.3970 -1.3970 1.270 -1.3970 2.540 0.0
unit 123
cylinder 3 1 1.1811 2.540 0.0
cylinder 2 1 1.2700 2.540 0.0
cuboid 3 1 1.3970 -1.3970 1.270 -1.270 2.540 0.0
cuboid 4 1 1.3970 -1.3970 1.3970 -1.270 2.540 0.0
unit 124
cylinder 3 1 1.1811 2.540 0.0
cylinder 2 1 1.2700 2.540 0.0
cuboid   3 1  1.270 -1.270 1.3970 -1.3970 2.540 0.0
cuboid   4 1 1.3970 -1.270 1.3970 -1.3970 2.540 0.0
unit 125
cylinder 3 1 1.1811 2.540 0.0
cylinder 2 1 1.2700 2.540 0.0
cuboid 3 1  1.270 -1.270 1.3970 -1.3970 2.540 0.0
cuboid 4 1  1.270 -1.3970 1.3970 -1.3970 2.540 0.0
end geom
read array
ara=1 nux=1 nuy=11 nuz=1 fill 41 9r3 41 end fill
ara=2 nux=1 nuy=11 nuz=1 fill 10r3 34 end fill
ara=3 nux=1 nuy=11 nuz=1 fill 5r3 2r20 4r3 end fill
ara=4 nux=1 nuy=11 nuz=1 fill 2r3 7r20 2r3  end fill
ara=5 nux=1 nuy=11 nuz=1 fill 3 8r20 2r3 end fill
ara=6 nux=1 nuy=11 nuz=1 fill 3 9r20 3 end fill
ara=7 nux=1 nuy=11 nuz=1 fill 2r3 8r20 3 end fill
ara=8 nux=1 nuy=11 nuz=1 fill 4r3 2r20 5r3 end fill
ara=9 nux=1 nuy=11 nuz=1 fill 11r3 end fill
ara=10 nux=11 nuy=1 nuz=1 fill 56 57 58 59 60 61 62 59 63 64 56 end fill
ara=11 nux=1 nuy=11 nuz=1 fill 42 9r5 42 end fill
ara=12 nux=1 nuy=11 nuz=1 fill 10r5 35 end fill
ara=13 nux=1 nuy=11 nuz=1 fill 5r5 2r22 4r5 end fill
ara=14 nux=1 nuy=11 nuz=1 fill 2r5 7r22 2r5 end fill
ara=15 nux=1 nuy=11 nuz=1 fill 5 8r22 2r5 end fill
ara=16 nux=1 nuy=11 nuz=1 fill 5 9r22 5 end fill
ara=17 nux=1 nuy=11 nuz=1 fill 2r5 8r22 5 end fill
ara=18 nux=1 nuy=11 nuz=1 fill 4r5 2r22 5r5 end fill
ara=19 nux=1 nuy=11 nuz=1 fill 11r5 end fill
ara=20 nux=11 nuy=1 nuz=1 fill 66 67 68 69 70 71 72 69 73 74 66 end fill
ara=21 nux=1 nuy=11 nuz=1 fill 123 9r7 122 end fill
ara=22 nux=1 nuy=11 nuz=1 fill 49 9r7 36  end fill
ara=23 nux=1 nuy=11 nuz=1 fill 49 4r7 2r24 3r7 48 end fill
ara=24 nux=1 nuy=11 nuz=1 fill 49 7 7r24 7 48 end fill
ara=25 nux=1 nuy=11 nuz=1 fill 49 8r24 7 48 end fill
ara=26 nux=1 nuy=11 nuz=1 fill 49 9r24 48 end fill
```

Example Input for Rover Calculational Model (cont'd)

```
ara=27 nux=1 nuy=11 nuz=1 fill 49 7 8r24 48 end fill
ara=28 nux=1 nuy=11 nuz=1 fill 49 3r7 2r24 4r7 48 end fill
ara=29 nux=1 nuy=11 nuz=1 fill 49 9r7 48 end fill
ara=30 nux=11 nuy=1 nuz=1 fill 76 77 78 79 80 81 82 79 83 84 76 end fill
ara=31 nux=1 nuy=11 nuz=1 fill 124 9r50 124 end fill
ara=32 nux=1 nuy=11 nuz=1 fill 10r8 37  end fill
ara=33 nux=1 nuy=11 nuz=1 fill 5r8 2r25 4r8 end fill
ara=34 nux=1 nuy=11 nuz=1 fill 2r8 7r25 2r8 end fill
ara=35 nux=1 nuy=11 nuz=1 fill 8 8r25 2r8 end fill
ara=36 nux=1 nuy=11 nuz=1 fill 8 9r25 8 end fill
ara=37 nux=1 nuy=11 nuz=1 fill 2r8 8r25 8 end fill
ara=38 nux=1 nuy=11 nuz=1 fill 4r8 2r25 5r8 end fill
ara=39 nux=1 nuy=11 nuz=1 fill 11r8 end fill
ara=40 nux=1 nuy=11 nuz=1 fill 125 9r51 125 end fill
ara=41 nux=11 nuy=1 nuz=1 fill 86 87 88 89 90 91 92 89 93 94
95 end fill
ara=42 nux=1 nuy=11 nuz=1 fill 45 9r10 45 end fill
ara=43 nux=1 nuy=11 nuz=1 fill 10r10 38 end fill
ara=44 nux=1 nuy=11 nuz=1 fill 5r10 2r27 4r10 end fill
ara=45 nux=1 nuy=11 nuz=1 fill 2r10 7r27 2r10 end fill
ara=46 nux=1 nuy=11 nuz=1 fill 10 8r27 2r10 end fill
ara=47 nux=1 nuy=11 nuz=1 fill 10 9r27 10 end fill
ara=48 nux=1 nuy=11 nuz=1 fill 2r10 8r27 10 end fill
ara=49 nux=1 nuy=11 nuz=1 fill 4r10 2r27 5r10 end fill
ara=50 nux=1 nuy=11 nuz=1 fill 11r10 end fill
ara=51 nux=11 nuy=1 nuz=1 fill 97 98 99 100 101 102 103 100 104
105 97 end fill
ara=52 nux=1 nuy=1 nuz=4 fill 12 15 16 17 end fill
ara=53 nux=1 nuy=1 nuz=4 fill 29 32 33 17 end fill
ara=54 nux=1 nuy=1 nuz=3 fill 39 40 17 end fill
ara=55 nux=1 nuy=1 nuz=2 fill 46 47 end fill
ara=56 nux=1 nuy=11 nuz=1 fill 110 9r107 110  end fill
ara=57 nux=1 nuy=11 nuz=1 fill 10r107 109 end fill
ara=58 nux=1 nuy=11 nuz=1 fill 5r107 2r108 4r107 end fill
ara=59 nux=1 nuy=11 nuz=1 fill 2r107 7r108 2r107 end fill
ara=60 nux=1 nuy=11 nuz=1 fill 107 8r108 2r107 end fill
ara=61 nux=1 nuy=11 nuz=1 fill 107 9r108 107 end fill
ara=62 nux=1 nuy=11 nuz=1 fill 2r107 8r108 107 end fill
ara=63 nux=1 nuy=11 nuz=1 fill 4r107 2r108 5r107 end fill
ara=64 nux=1 nuy=11 nuz=1 fill 11r107 end fill
ara=65 nux=11 nuy=1 nuz=1 fill 111 112 113 114 115 116 117 114 118
119 111 end fill
ara=66 nux=1 nuy=1 nuz=8 fill 65 75 85 96 106 85 96 120 end fill
end array
read plot ttl='x-y slice of element ' xul=-2.5 yul=2.5  zul=100.0
```

Example Input for Rover Calculational Model (cont'd)

```
xlr=2.5  ylr= -2.5 zlr=100.0 uax=1.0 vdn=-1.0 nax=260   endplt1
ttl='x-y slice of core ' xul=-20.0 yul=20.0 zul=100.0 xlr=20.0
ylr=-20.0 zlr=100.0 uax=1.0 vdn=-1.0 nax=260  endplt2
end plot
end data
end
```

Example Output for Rover Calculations

Example Output for Rover Calculations (cont'd)


```
NN   NN  CCCCCCCCCC   SSSSSSSSSS   SSSSSSSSSS
NNN  NN CCCCCCCCCCCC SSSSSSSSSSSS SSSSSSSSSSSS
NNNN NN CC      CC   SS       SS  SS       SS
NN NN NN CC          SS           SS
NN  NN NN CC          SSSSSSSSSS   SSSSSSSSSS
NN   NNNN CC                 SSSS         SSSS
NN    NNN CC      CC SS       SS  SS       SS
NN     NN CCCCCCCCCCCC SSSSSSSSSSSS SSSSSSSSSSSS
NN      N  CCCCCCCCCC   SSSSSSSSSS   SSSSSSSSSS
```

```
**********************************************************************
**********************************************************************
*****                                                            *****
*****          PROGRAM VERIFICATION INFORMATION                  *****
*****                                                            *****
*****          CODE SYSTEM:   NCSS   VERSION:  1                 *****
*****                                                            *****
**********************************************************************
**********************************************************************
*****                                                            *****
*****          PROGRAM:  CSASM                                   *****
*****                                                            *****
*****     CREATION DATE:  92.014                                 *****
*****                                                            *****
*****          LIBRARY:  NCSS.ZAZ39461.CSAS25.V1R000.S000.LOAD   *****
*****                                                            *****
*****  PRODUCTION CODE:  CSAS25                                  *****
*****                                                            *****
*****         REVISION:  000                                     *****
*****                                                            *****
*****          JOBNAME:  E36ST1                                  *****
*****                                                            *****
*****  DATE OF EXECUTION:  01/23/93                              *****
*****                                                            *****
*****  TIME OF EXECUTION:  0.00.41                               *****
*****                                                            *****
**********************************************************************
**********************************************************************
```

Example Output for Rover Calculations (cont'd)

```
HOMOGENIZED MATERIALS IN TUBE

**** PROBLEM PARAMETERS ****

LIB 27GROUPNDF4  LIBRARY
MXX          3 MIXTURES
MSC         25 COMPOSITION SPECIFICATIONS
IZM          4 MATERIAL ZONES
GE   LATTICECELL  GEOMETRY
MORE         0 0/1 DO NOT READ/READ OPTIONAL PARAMETER DATA
MSLN         0 FUEL SOLUTIONS

**** PROBLEM COMPOSITION DESCRIPTION ****

SC  U-235        STANDARD COMPOSITION
MX           1 MIXTURE NO.
DEN   7.3707E-04 ATOMIC DENSITY
ROTH      1.0000 THEORETICAL DENSITY
TEMP       296.0 DEG KELVIN
END

SC  U-238        STANDARD COMPOSITION
MX           1 MIXTURE NO.
DEN   5.3518E-05 ATOMIC DENSITY
ROTH      1.0000 THEORETICAL DENSITY
TEMP       296.0 DEG KELVIN
END

SC  C            STANDARD COMPOSITION
MX           1 MIXTURE NO.
DEN   6.5205E-02 ATOMIC DENSITY
ROTH      2.3000 THEORETICAL DENSITY
TEMP       296.0 DEG KELVIN
END

SC  BE           STANDARD COMPOSITION
MX           1 MIXTURE NO.
DEN   1.7387E-09 ATOMIC DENSITY
ROTH      1.8480 THEORETICAL DENSITY
TEMP       296.0 DEG KELVIN
END

SC  V-51         STANDARD COMPOSITION
MX           1 MIXTURE NO.
DEN   5.8444E-07 ATOMIC DENSITY
ROTH      6.1100 THEORETICAL DENSITY
TEMP       296.0 DEG KELVIN
END

SC  AL           STANDARD COMPOSITION
MX           1 MIXTURE NO.
DEN   5.8076E-09 ATOMIC DENSITY
ROTH      2.6989 THEORETICAL DENSITY
TEMP       296.0 DEG KELVIN
END

SC  CS-133       STANDARD COMPOSITION
MX           1 MIXTURE NO.
DEN   5.8951E-09 ATOMIC DENSITY
ROTH      1.8730 THEORETICAL DENSITY
TEMP       296.0 DEG KELVIN
END

SC  MN           STANDARD COMPOSITION
MX           1 MIXTURE NO.
DEN   1.4261E-08 ATOMIC DENSITY
ROTH      7.4400 THEORETICAL DENSITY
TEMP       296.0 DEG KELVIN
END

SC  BR-79        STANDARD COMPOSITION
MX           1 MIXTURE NO.
```

```
DEN    1.5097E-09 ATOMIC DENSITY
ROTH       1.0000 THEORETICAL DENSITY
TEMP        296.0 DEG KELVIN
END

SC  BR-81          STANDARD COMPOSITION
MX              1 MIXTURE NO.
DEN    1.4324E-09 ATOMIC DENSITY
ROTH       1.0000 THEORETICAL DENSITY
TEMP        296.0 DEG KELVIN
END

SC  CU             STANDARD COMPOSITION
MX              1 MIXTURE NO.
DEN    3.0824E-07 ATOMIC DENSITY
ROTH       8.9600 THEORETICAL DENSITY
TEMP        296.0 DEG KELVIN
END

SC  CA             STANDARD COMPOSITION
MX              1 MIXTURE NO.
DEN    2.5412E-06 ATOMIC DENSITY
ROTH       1.5450 THEORETICAL DENSITY
TEMP        296.0 DEG KELVIN
END

SC  FE             STANDARD COMPOSITION
MX              1 MIXTURE NO.
DEN    7.4354E-07 ATOMIC DENSITY
ROTH       7.8740 THEORETICAL DENSITY
TEMP        296.0 DEG KELVIN
END

SC  MO             STANDARD COMPOSITION
MX              1 MIXTURE NO.
DEN    6.5331E-08 ATOMIC DENSITY
ROTH      10.2200 THEORETICAL DENSITY
TEMP        296.0 DEG KELVIN
END

SC  PB             STANDARD COMPOSITION
MX              1 MIXTURE NO.
DEN    3.0250E-09 ATOMIC DENSITY
ROTH      11.3500 THEORETICAL DENSITY
TEMP        296.0 DEG KELVIN
END

SC  SI             STANDARD COMPOSITION
MX              1 MIXTURE NO.
DEN    3.0686E-07 ATOMIC DENSITY
ROTH       2.3230 THEORETICAL DENSITY
TEMP        296.0 DEG KELVIN
END

SC  B-10           STANDARD COMPOSITION
MX              1 MIXTURE NO.
DEN    1.2457E-09 ATOMIC DENSITY
ROTH       2.1950 THEORETICAL DENSITY
TEMP        296.0 DEG KELVIN
END

SC  B-11           STANDARD COMPOSITION
MX              1 MIXTURE NO.
DEN    4.5603E-09 ATOMIC DENSITY
ROTH       2.4130 THEORETICAL DENSITY
TEMP        296.0 DEG KELVIN
END

SC  C              STANDARD COMPOSITION
MX              1 MIXTURE NO.
DEN    5.5759E-09 ATOMIC DENSITY
ROTH       8.6500 THEORETICAL DENSITY
TEMP        296.0 DEG KELVIN
END
```

```
SC  K          STANDARD COMPOSITION
MX                1 MIXTURE NO.
DEN    1.7233E-06 ATOMIC DENSITY
ROTH       0.8595 THEORETICAL DENSITY
TEMP        296.0 DEG KELVIN
END

SC  ZR         STANDARD COMPOSITION
MX                1 MIXTURE NO.
DEN    8.5890E-09 ATOMIC DENSITY
ROTH       6.4400 THEORETICAL DENSITY
TEMP        296.0 DEG KELVIN
END

SC  BA-138     STANDARD COMPOSITION
MX                1 MIXTURE NO.
DEN    7.9539E-08 ATOMIC DENSITY
ROTH       1.0000 THEORETICAL DENSITY
TEMP        296.0 DEG KELVIN
END

SC  NI         STANDARD COMPOSITION
MX                1 MIXTURE NO.
DEN    2.4025E-07 ATOMIC DENSITY
ROTH       8.9020 THEORETICAL DENSITY
TEMP        296.0 DEG KELVIN
END

SC  AL         STANDARD COMPOSITION
MX                2 MIXTURE NO.
VF         1.0000 VOLUME FRACTION
ROTH       2.6989 THEORETICAL DENSITY
TEMP        296.0 DEG KELVIN
END

SC  H2O        STANDARD COMPOSITION
MX                3 MIXTURE NO.
VF         1.0000 VOLUME FRACTION
ROTH       0.9982 THEORETICAL DENSITY
TEMP        296.0 DEG KELVIN
END

**** PROBLEM GEOMETRY ****

CTP SQUAREPITCH  CELL TYPE
PITCH      2.7940 CM CENTER TO CENTER SPACING
FUELOD     2.0111 CM FUEL DIAMETER OR SLAB THICKNESS
MFUEL            1 MIXTURE NO. OF FUEL
MMOD             3 MIXTURE NO. OF MODERATOR
CLADOD     2.5400 CM CLAD OUTER DIAMETER
MCLAD            2 MIXTURE NO. OF CLAD
GAPOD      2.3622 CM GAP OUTER DIAMETER
MGAP             0 MIXTURE NO. OF GAP

ZONE SPECIFICATIONS FOR LATTICECELL GEOMETRY

                  ZONE  1 IS FUEL
                  ZONE  2 IS GAP
                  ZONE  3 IS CLAD
                  ZONE  4 IS MOD
```

Example Output for Rover Calculations (cont'd)

```
LOGICAL ASSIGNMENTS

MASTER LIBRARY   11
WORKING LIBRARY   0
SCRATCH FILE     18
NEW LIBRARY       1

P R O B L E M   D E S C R I P T I O N

IGR--GEOMETRY (0/1/2/3--INF MED/SLAB/CYL/SPHERE                2
IZM--NUMBER OF ZONES OR MATERIAL REGIONS                       4
MS--MIXING TABLE LENGTH                                       27
IBL--SHIELDED CROSS SECTION EDIT OPTION (0/1--NO/YES)          0
IBR--BONDARENKO FACTOR EDIT OPTION (0/1--NO/YES)               0
ISSOFT--DANCOFF FACTOR OPTION                                  0
CONVERGENCE CRITERION   1.00000E-03
GEOMETRY CORRECTION FACTOR FOR HIGHER RATIONAL APPROXIMATION   1.350E+00

      3Q ARRAY HAS    27 ENTRIES.
      4Q ARRAY HAS    27 ENTRIES.
      5Q ARRAY HAS    27 ENTRIES.
      6Q ARRAY HAS     4 ENTRIES.
      7Q ARRAY HAS     4 ENTRIES.
      8Q ARRAY HAS     4 ENTRIES.
      9Q ARRAY HAS     4 ENTRIES.
     10Q ARRAY HAS    27 ENTRIES.
     11Q ARRAY HAS     4 ENTRIES.

M I X I N G   T A B L E

ENTRY  MIXTURE  ISOTOPE  NUMBER DENSITY  MEM IDENTIFIER
    1       1   92235   7.37072E-04   92235
    2       1   92238   5.35176E-05   92238
    3       1    6012   6.62065E-02    6012
    4       1    4009   6.75873E-09    4009
    5       1   23051   1.72873E-07   23051
    6       1   13027   5.84444E-07   13027
    7       2   13027   5.80757E-09   13027
    8       1   55133   6.01374E-02   55133
    9       1   25055   5.89507E-09   25055
   10       1   35079   1.42613E-08   35079
   11       1   35081   1.60972E-09   35081
   12       1   29000   1.43236E-09   29000
   13       1   20000   3.08236E-07   20000
   14       1   26000   2.64125E-06   26000
   15       1   42000   7.43545E-07   42000
   16       1   82000   6.83313E-08   82000
   17       1   14000   3.02504E-09   14000
   18       1    5010   3.06861E-07    5010
   19       1    5011   1.24570E-09    5011
   20       1   48000   4.64030E-09   48000
   21       1   19000   5.57592E-09   19000
   22       1   40000   1.72334E-06   40000
   23       1   56138   8.58897E-09   56138
   24       1   28000   7.95387E-08   28000
   25       3    1001   2.40251E-07    1001
   26       3    8016   6.67514E-02    8016
   27       4    8016   3.33757E-02    8016
                        1.00000E-20      27

GEOMETRY AND MATERIAL DESCRIPTION
```

```
ZONE   MIXTURE   OUTER DIMENSION   TEMPERATURE       EXTRA XS   TYPE (0/1--FUEL/MOD)
   1       1          1.00553E+00    2.96000E+02    4.97789E-01              0
   2       4          1.18110E+00    2.93000E+02    0.00000E+00              0
   3       2          1.27000E+00    2.96000E+02    0.00000E+00              0
   4       3          1.57634E+00    2.96000E+02    0.00000E+00              0
    4332 LOCATIONS OF   100000 AVAILABLE ARE REQUIRED TO MAKE A NEW MASTER CONTAINING THE SELF-SHIELDED VALUES

NO NUCLIDES IN YOUR PROBLEM HAVE BONDARENKO FACTOR DATA**BONAMI WILL COPY FROM LOGICAL 11 TO LOGICAL  1

COPY      1001   HYDROGEN          FROM LOG 11 TO LOG  1    BONDARENKO TRIGGER 0
COPY      4009   BERYLLIUM-9       FROM LOG 11 TO LOG  1    BONDARENKO TRIGGER 0
COPY      5010  B-10 1273 218NGP   FROM LOG 11 TO LOG  1    BONDARENKO TRIGGER 0
COPY      5011   BORON-11          FROM LOG 11 TO LOG  1    BONDARENKO TRIGGER 0
COPY      6012   CARBON-12         FROM LOG 11 TO LOG  1    BONDARENKO TRIGGER 0
COPY      8016   OXYGEN-16         FROM LOG 11 TO LOG 18    BONDARENKO TRIGGER 0
COPY      8016   OXYGEN-16         FROM LOG 18 TO LOG  1    BONDARENKO TRIGGER 0
COPY      8016   OXYGEN-16         FROM LOG 18 TO LOG  1    BONDARENKO TRIGGER 0
COPY     13027  AL-27 1193 218 G   FROM LOG 11 TO LOG 18    BONDARENKO TRIGGER 0
COPY     13027  AL-27 1193 218 G   FROM LOG 18 TO LOG  1    BONDARENKO TRIGGER 0
COPY     13027  AL-27 1193 218 G   FROM LOG 18 TO LOG  1    BONDARENKO TRIGGER 0
COPY     14000   SILICON           FROM LOG 11 TO LOG  1    BONDARENKO TRIGGER 0
COPY     19000   POTASSIUM         FROM LOG 11 TO LOG  1    BONDARENKO TRIGGER 0
COPY     20000  CALCIUM ENDF/B-I   FROM LOG 11 TO LOG  1    BONDARENKO TRIGGER 0
COPY     23051  V 1196 218 GP 1/   FROM LOG 11 TO LOG  1    BONDARENKO TRIGGER 0
COPY     25055   MANGANESE-55      FROM LOG 11 TO LOG  1    BONDARENKO TRIGGER 0
COPY     26000   IRON              FROM LOG 11 TO LOG  1    BONDARENKO TRIGGER 0
COPY     28000  NI 1190 218NGP M   FROM LOG 11 TO LOG  1    BONDARENKO TRIGGER 0
COPY     29000   COPPER            FROM LOG 11 TO LOG  1    BONDARENKO TRIGGER 0
COPY     35079   BROMINE-79        FROM LOG 11 TO LOG  1    BONDARENKO TRIGGER 0
COPY     35081   BROMINE-81        FROM LOG 11 TO LOG  1    BONDARENKO TRIGGER 0
COPY     40000   ZIRCONIUM         FROM LOG 11 TO LOG  1    BONDARENKO TRIGGER 0
COPY     42000  MO (1287) SIGP=5   FROM LOG 11 TO LOG  1    BONDARENKO TRIGGER 0
COPY     48000  CD 1281 WT 1/EST   FROM LOG 11 TO LOG  1    BONDARENKO TRIGGER 0
COPY     55133   CESIUM-133        FROM LOG 11 TO LOG  1    BONDARENKO TRIGGER 0
COPY     56138  BA-138 7040 218N   FROM LOG 11 TO LOG  1    BONDARENKO TRIGGER 0
COPY     82000  PB   1288 218NGP   FROM LOG 11 TO LOG  1    BONDARENKO TRIGGER 0
COPY     92235   URANIUM-235       FROM LOG 11 TO LOG  1    BONDARENKO TRIGGER 0
COPY     92238   URANIUM-238       FROM LOG 11 TO LOG  1    BONDARENKO TRIGGER 0
```

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NUCLEAR CRITICALITY SAFETY SOFTWARE VERSION 1 CROSS SECTION LIBRARY
27 NEUTRON GROUPS   REVISION 000     AUGUST 14, 1991
VERSION 1 REVISION 000 DATA TAKEN FROM SCALE 4.1

   TAPE ID                          27          NUMBER OF NUCLIDES              27
   NUMBER OF NEUTRON GROUPS         27          NUMBER OF GAMMA GROUPS           0
   FIRST THERMAL GROUP              15          LOGICAL UNIT                     1
                              TABLE OF CONTENTS
  HYDROGEN        ENDF/B-IV MAT 1269/THRM1002     UPDATED 10/12/89          ID      1001
  BERYLLIUM-9     ENDF/B-IV MAT 1289/THRM1064     UPDATED 10/12/89          ID      4009
 B-10 1273 218NGP 042375 P-3 293K                                           ID      5010
  BORON-11        ENDF/B-IV MAT 1160              UPDATED 10/12/89          ID      5011
  CARBON-12       ENDF/B-IV MAT 1274/THRM1065     UPDATED 10/12/89          ID      6012
  OXYGEN-16       ENDF/B-IV MAT 1276              UPDATED 10/12/89          ID      8016
  OXYGEN-16       ENDF/B-IV MAT 1276              UPDATED 10/12/89          ID        27
 AL-27 1193 218 GP 040375(5)                                                ID     13027
 AL-27 1193 218 GP 040375(5)                                                ID    213027
  SILICON         ENDF/B-IV MAT 1194              UPDATED 10/12/89          ID     14000
  POTASSIUM       ENDF/B-IV MAT 1150              UPDATED 10/12/89          ID     19000
 CALCIUM ENDF/B-IV MAT 1195                       UPDATED 9/07/89           ID     20000
 V 1196 218 GP 1/E=SIGT 040375(5)                                           ID     23051
  MANGANESE-55    ENDF/B-IV MAT 1197              UPDATED 10/12/89          ID     25055
  IRON            ENDF/B-IV MAT 1192              UPDATED 10/12/89          ID     26000
 NI 1190 218NGP WT 1/E P-3 293K SIGP=5+4 RE(042375)                         ID     28000
  COPPER          ENDF/B-IV MAT 1295              UPDATED 10/12/89          ID     29000
  BROMINE-79      ENDF/B-IV MAT 108               UPDATED 10/12/89          ID     35079
  BROMINE-81      ENDF/B-IV MAT 112               UPDATED 10/12/89          ID     35081
  ZIRCONIUM       ENDF/B-IV MAT 7141              UPDATED 10/12/89          ID     40000
 MO (1287) SIGP=5+4 NEWXLACS 218NGP F-1/E-M P-3 293K                        ID     42000
 CD 1281 WT 1/EST 218NGP P-3 293K RE(042375)                                ID     48000
  CESIUM-133      ENDF/B-IV MAT 1141              UPDATED 10/12/89          ID     55133
 BA-138 7040 218NGP WT 1/EST 042375 P3 293K                                 ID     56138
 PB    1288 218NGP 042375 P-3 293K                                          ID     82000
  URANIUM-235     ENDF/B-IV MAT 1261              UPDATED 10/12/89          ID     92235
  URANIUM-238     ENDF/B-IV MAT 1262              UPDATED 10/12/89          ID     92238

   TAPE COPY USED      0 I/O'S, AND TOOK     1.78 SECONDS
```

Example Output for Rover Calculations (cont'd)

```
      -1Q ARRAY HAS      1 ENTRIES.

       0Q ARRAY HAS      9 ENTRIES.

       1Q ARRAY HAS     12 ENTRIES.

SELECT 26 NUCLIDES FROM THE MASTER  LIBRARY ON LOGICAL  1
        0 NUCLIDES FROM THE WORKING LIBRARY ON LOGICAL  2
        0 NUCLIDES FROM THE WORKING LIBRARY ON LOGICAL  3
          TO CREATE THE NEW WORKING LIBRARY ON LOGICAL  4

      10 RESONANCE CALCULATIONS HAVE BEEN REQUESTED
      -1 OUTPUT OPTION FOR AMPX FORMATTED CROSS SECTION DATA

THE STORAGE ALLOCATED FOR THIS CASE IS 100000 WORDS

       2Q ARRAY HAS     26 ENTRIES.

       3Q ARRAY HAS    150 ENTRIES.

       4Q ARRAY HAS     26 ENTRIES.

 GENERAL INFORMATION CONCERNING CROSS SECTION LIBRARY
   TAPE IDENTIFICATION NUMBER                  27
   NUMBER OF NUCLIDES ON TAPE                  27
   NUMBER OF NEUTRON ENERGY GROUPS             27
   FIRST THERMAL NEUTRON ENERGY GROUP          15
   NUMBER OF GAMMA ENERGY GROUPS                0

   DIRECT ACCESS UNIT NUMBER  9 REQUIRES 118 BLOCKS OF LENGTH  1568 WORDS


 XSDRN TAPE     27
                     NUCLEAR CRITICALITY SAFETY SOFTWARE VERSION 1 CROSS SECTION LIBRARY
                     27 NEUTRON GROUPS   REVISION 000     AUGUST 14, 1991
                     VERSION 1 REVISION 000 DATA TAKEN FROM SCALE 4.1


 NUCLIDES FROM XSDRN TAPE
    1     HYDROGEN       ENDF/B-IV MAT 1269/THRM1002    UPDATED 10/12/89              1001
    2     BERYLLIUM-9    ENDF/B-IV MAT 1289/THRM1064    UPDATED 10/12/89              4009
    3    B-10 1273 218NGP 042375 P-3 293K                                             5010
    4     BORON-11       ENDF/B-IV MAT 1160             UPDATED 10/12/89              5011
    5     CARBON-12      ENDF/B-IV MAT 1274/THRM1065    UPDATED 10/12/89              6012
    6     OXYGEN-16      ENDF/B-IV MAT 1276             UPDATED 10/12/89              8016
    7    AL-27 1193 218 GP 040375(5)                                                  13027
    8    AL-27 1193 218 GP 040375(5)                                                 213027
    9     SILICON        ENDF/B-IV MAT 1194             UPDATED 10/12/89             14000
   10     POTASSIUM      ENDF/B-IV MAT 1150             UPDATED 10/12/89             19000
   11    CALCIUM ENDF/B-IV MAT 1195                     UPDATED 9/07/89              20000
   12    V 1196 218 GP 1/E*SIGT 040375(5)                                            23051
   13     MANGANESE-55   ENDF/B-IV MAT 1197             UPDATED 10/12/89             25055
   14     IRON           ENDF/B-IV MAT 1192             UPDATED 10/12/89             26000
   15    NI 1190 218NGP WT 1/E P-3 293K SIGP=5+4 RE(042375)                          28000
   16     COPPER         ENDF/B-IV MAT 1295             UPDATED 10/12/89             29000
   17     BROMINE-79     ENDF/B-IV MAT 108              UPDATED 10/12/89             35079
   18     BROMINE-81     ENDF/B-IV MAT 112              UPDATED 10/12/89             35081
   19     ZIRCONIUM      ENDF/B-IV MAT 7141             UPDATED 10/12/89             40000
   20    MO (1287) SIGP=5+4 NEWXLACS 218NGP F-1/E-M P-3 293K                         42000
   21    CD 1281 WT 1/EST 218NGP P-3 293K RE(042375)                                 48000
   22     CESIUM-133     ENDF/B-IV MAT 1141             UPDATED 10/12/89             55133
   23    BA-138 7040 218NGP WT 1/EST 042375 P3 293K                                  56138
   24    PB   1288 218NGP 042375 P-3 293K                                            82000
   25     URANIUM-235    ENDF/B-IV MAT 1261             UPDATED 10/12/89             92235
   26     URANIUM-238    ENDF/B-IV MAT 1262             UPDATED 10/12/89             92238

 HYDROGEN       ENDF/B-IV MAT 1269/THRM1002    UPDATED 10/12/89              1001    TEMPERATURE=   296.00
                          THERMAL SCATTERING MATRIX NUMBER   1 AT A TEMPERATURE OF   293.00 WAS SELECTED.

 BERYLLIUM-9    ENDF/B-IV MAT 1289/THRM1064    UPDATED 10/12/89              4009    TEMPERATURE=   296.00
                          THERMAL SCATTERING MATRIX NUMBER   1 AT A TEMPERATURE OF   296.01 WAS SELECTED.
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B-10 1273 218NGP 042375 P-3 293K                                    5010     TEMPERATURE=   296.00
                        THERMAL SCATTERING MATRIX NUMBER   1 AT A TEMPERATURE OF   293.00 WAS SELECTED.

 BORON-11       ENDF/B-IV MAT 1160          UPDATED 10/12/89         5011     TEMPERATURE=   296.00
                        THERMAL SCATTERING MATRIX NUMBER   1 AT A TEMPERATURE OF   293.00 WAS SELECTED.

 CARBON-12      ENDF/B-IV MAT 1274/THRM1065 UPDATED 10/12/89         6012     TEMPERATURE=   296.00
                        THERMAL SCATTERING MATRIX NUMBER   1 AT A TEMPERATURE OF   293.00 WAS SELECTED.

 OXYGEN-16      ENDF/B-IV MAT 1276          UPDATED 10/12/89         8016     TEMPERATURE=   296.00
AL-27 1193 218 GP 040375(5)                                         13027     TEMPERATURE=   296.00
AL-27 1193 218 GP 040375(5)                                        213027     TEMPERATURE=   296.00
 SILICON        ENDF/B-IV MAT 1194          UPDATED 10/12/89        14000     TEMPERATURE=   296.00
 POTASSIUM      ENDF/B-IV MAT 1150          UPDATED 10/12/89        19000     TEMPERATURE=   296.00
CALCIUM ENDF/B-IV MAT 1195                  UPDATED 9/07/89         20000     TEMPERATURE=   296.00
V 1196 218 GP 1/E*SIGT 040375(5)                                    23051     TEMPERATURE=   296.00
 MANGANESE-55   ENDF/B-IV MAT 1197          UPDATED 10/12/89        25055     TEMPERATURE=   296.00
RESONANCE DATA FOR THIS NUCLIDE
MASS NUMBER (A)          =    54.466          TEMPERATURE(KELVIN)       =   296.000
POTENTIAL SCATTER SIGMA  =     2.590          LUMPED NUCLEAR DENSITY    = 1.4261300E-08
SPIN FACTOR (G)          =    14.448          LUMP DIMENSION (A-BAR)    = 1.0055304E+00
INNER RADIUS             = 0.0000000E+00     DANCOFF CORRECTION (C)    = 2.5032175E-01
THE ABSORBER WILL BE TREATED BY THE NORDHEIM INTEGRAL METHOD.
MASS OF MODERATOR-1    =    12.000          SIGMA(PER ABSORBER ATOM)= 2.1489248E+07
MODERATOR-1 WILL BE TREATED BY THE NORDHEIM INTEGRAL METHOD.
MASS OF MODERATOR-2    =   231.958          SIGMA(PER ABSORBER ATOM)= 5.7597937E+05
MODERATOR-2 WILL BE TREATED BY THE NORDHEIM INTEGRAL METHOD.
THIS RESONANCE MATERIAL WILL BE TREATED AS A 2-DIMENSIONAL OBJECT.
VOLUME FRACTION OF LUMP IN CELL USED TO ACCOUNT FOR SPATIAL SELF-SHIELDING=1.00000

GROUP       RES ABS        RES FISS       RES SCAT
  8     -8.478668E-09   0.000000E+00   -4.270351E-06
  9      9.494221E-08   0.000000E+00    6.791882E-05
 10     -2.056533E-05   0.000000E+00    9.118740E-03
 11      1.719536E-04   0.000000E+00    1.076728E-02

 EXCESS RESONANCE INTEGRALS
                  RESOLVED

 ABSORPTION      8.73453E+00
 FISSION         0.00000E+00

   ELAPSED TIME   0.09 MIN.

  IRON          ENDF/B-IV MAT 1192          UPDATED 10/12/89         26000     TEMPERATURE=   296.00
 RESONANCE DATA FOR THIS NUCLIDE
 MASS NUMBER (A)          =    55.365          TEMPERATURE(KELVIN)       =   296.000
 POTENTIAL SCATTER SIGMA  =     2.659          LUMPED NUCLEAR DENSITY    = 7.4354494E-07
 SPIN FACTOR (G)          =     0.748          LUMP DIMENSION (A-BAR)    = 1.0055304E+00
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INNER RADIUS              = 0.0000000E+00          DANCOFF CORRECTION (C)    = 2.5032175E-01
THE ABSORBER WILL BE TREATED BY THE NORDHEIM INTEGRAL METHOD.
MASS OF MODERATOR-1    =    12.000               SIGMA(PER ABSORBER ATOM)= 4.1216700E+05
MODERATOR-1 WILL BE TREATED BY THE NORDHEIM INTEGRAL METHOD.
MASS OF MODERATOR-2    =   232.703               SIGMA(PER ABSORBER ATOM)= 1.1036066E+04
MODERATOR-2 WILL BE TREATED BY THE NORDHEIM INTEGRAL METHOD.
THIS RESONANCE MATERIAL WILL BE TREATED AS A 2-DIMENSIONAL OBJECT.
VOLUME FRACTION OF LUMP IN CELL USED TO ACCOUNT FOR SPATIAL SELF-SHIELDING=1.00000

GROUP        RES ABS         RES FISS        RES SCAT
  8      -1.606592E-08    0.000000E+00    -4.207624E-05
  9      -1.230393E-07    0.000000E+00    -5.184248E-05

EXCESS RESONANCE INTEGRALS

                  RESOLVED

ABSORPTION        1.54292E-02
FISSION           0.00000E+00

  ELAPSED TIME   0.11 MIN.

NI 1190 218NGP WT I/E P-3 293K SIGP=5+4 RE(042375)                    28000    TEMPERATURE=   296.00
 COPPER          ENDF/B-IV MAT 1295          UPDATED 10/12/89         29000    TEMPERATURE=   296.00
RESONANCE DATA FOR THIS NUCLIDE
MASS NUMBER (A)           =    62.994          TEMPERATURE(KELVIN)       =   296.000
POTENTIAL SCATTER SIGMA   =     6.700          LUMPED NUCLEAR DENSITY    = 3.0823600E-07
SPIN FACTOR (G)           =    19.778          LUMP DIMENSION (A-BAR)    = 1.0055304E+00
INNER RADIUS              = 0.0000000E+00      DANCOFF CORRECTION (C)    = 2.5032175E-01
THE ABSORBER WILL BE TREATED BY THE NORDHEIM INTEGRAL METHOD.
MASS OF MODERATOR-1    =    12.000               SIGMA(PER ABSORBER ATOM)= 9.9425350E+05
MODERATOR-1 WILL BE TREATED BY THE NORDHEIM INTEGRAL METHOD.
MASS OF MODERATOR-2    =   232.142               SIGMA(PER ABSORBER ATOM)= 2.6640961E+04
MODERATOR-2 WILL BE TREATED BY THE NORDHEIM INTEGRAL METHOD.
THIS RESONANCE MATERIAL WILL BE TREATED AS A 2-DIMENSIONAL OBJECT.
VOLUME FRACTION OF LUMP IN CELL USED TO ACCOUNT FOR SPATIAL SELF-SHIELDING=1.00000

GROUP        RES ABS         RES FISS        RES SCAT
  8      -7.668535E-08    0.000000E+00    -2.701236E-05
  9      -5.338205E-06    0.000000E+00    -4.954950E-04
 10      -2.952958E-04    0.000000E+00    -3.375586E-04
 11      -4.433961E-06    0.000000E+00    -1.888524E-06

EXCESS RESONANCE INTEGRALS

                  RESOLVED

ABSORPTION        2.58768E+00
FISSION           0.00000E+00

  ELAPSED TIME   0.17 MIN.

 BROMINE-79      ENDF/B-IV MAT 108           UPDATED 10/12/89         35079    TEMPERATURE=   296.00
```

RESONANCE DATA FOR THIS NUCLIDE

MASS NUMBER (A) = 78.240 TEMPERATURE(KELVIN) = 296.000

POTENTIAL SCATTER SIGMA = 3.366 LUMPED NUCLEAR DENSITY = 1.5097199E-09

SPIN FACTOR (G) = 3101.680 LUMP DIMENSION (A-BAR) = 1.0055304E+00

INNER RADIUS = 0.0000000E+00 DANCOFF CORRECTION (C) = 2.5032175E-01

THE ABSORBER WILL BE TREATED BY THE NORDHEIM INTEGRAL METHOD.

MASS OF MODERATOR-1 = 12.000 SIGMA(PER ABSORBER ATOM)= 2.0299442E+08

MODERATOR-1 WILL BE TREATED BY THE NORDHEIM INTEGRAL METHOD.

MASS OF MODERATOR-2 = 231.963 SIGMA(PER ABSORBER ATOM)= 5.4408230E+06

MODERATOR-2 WILL BE TREATED BY THE NORDHEIM INTEGRAL METHOD.

THIS RESONANCE MATERIAL WILL BE TREATED AS A 2-DIMENSIONAL OBJECT.

VOLUME FRACTION OF LUMP IN CELL USED TO ACCOUNT FOR SPATIAL SELF-SHIELDING=1.00000

GROUP	RES ABS	RES FISS	RES SCAT
11	9.348523E-05	0.000000E+00	4.066296E-04
12	-7.111841E-02	0.000000E+00	-8.953188E-03
13	1.839548E-05	0.000000E+00	-1.065247E-05

EXCESS RESONANCE INTEGRALS

	RESOLVED
ABSORPTION	1.14789E+02
FISSION	0.00000E+00

ELAPSED TIME 0.19 MIN.

BROMINE-81 ENDF/B-IV MAT 112 UPDATED 10/12/89 35081 TEMPERATURE= 296.00

RESONANCE DATA FOR THIS NUCLIDE

MASS NUMBER (A) = 80.221 TEMPERATURE(KELVIN) = 296.000

POTENTIAL SCATTER SIGMA = 3.422 LUMPED NUCLEAR DENSITY = 1.4323598E-09

SPIN FACTOR (G) = 7461.156 LUMP DIMENSION (A-BAR) = 1.0055304E+00

INNER RADIUS = 0.0000000E+00 DANCOFF CORRECTION (C) = 2.5032175E-01

THE ABSORBER WILL BE TREATED BY THE NORDHEIM INTEGRAL METHOD.

MASS OF MODERATOR-1 = 12.000 SIGMA(PER ABSORBER ATOM)= 2.1395792E+08

MODERATOR-1 WILL BE TREATED BY THE NORDHEIM INTEGRAL METHOD.

MASS OF MODERATOR-2 = 231.958 SIGMA(PER ABSORBER ATOM)= 5.7347340E+06

MODERATOR-2 WILL BE TREATED BY THE NORDHEIM INTEGRAL METHOD.

THIS RESONANCE MATERIAL WILL BE TREATED AS A 2-DIMENSIONAL OBJECT.

VOLUME FRACTION OF LUMP IN CELL USED TO ACCOUNT FOR SPATIAL SELF-SHIELDING=1.00000

GROUP	RES ABS	RES FISS	RES SCAT
11	-1.262860E-02	0.000000E+00	-1.154722E-02
12	-1.515010E-03	0.000000E+00	-8.635465E-04

EXCESS RESONANCE INTEGRALS

	RESOLVED
ABSORPTION	4.03808E+01
FISSION	0.00000E+00

```
 ELAPSED TIME   0.21 MIN.
 ZIRCONIUM      ENDF/B-IV MAT 7141            UPDATED 10/12/89            40000    TEMPERATURE=   296.00
MO (1287) SIGP=5+4 NEWXLACS 218NGP F-1/E-M P-3 293K                      42000    TEMPERATURE=   296.00
RESONANCE DATA FOR THIS NUCLIDE
MASS NUMBER (A)          =    95.116          TEMPERATURE(KELVIN)      =   296.000
POTENTIAL SCATTER SIGMA  =     4.934          LUMPED NUCLEAR DENSITY   = 6.5331278E-08
SPIN FACTOR (G)          =   383.781          LUMP DIMENSION (A-BAR)   = 1.0055304E+00
INNER RADIUS             = 0.0000000E+00      DANCOFF CORRECTION (C)   = 2.5032175E-01
THE ABSORBER WILL BE TREATED BY THE NORDHEIM INTEGRAL METHOD.
MASS OF MODERATOR-1    =    12.000           SIGMA(PER ABSORBER ATOM)= 4.6909340E+06
MODERATOR-1 WILL BE TREATED BY THE NORDHEIM INTEGRAL METHOD.
MASS OF MODERATOR-2    =   231.971           SIGMA(PER ABSORBER ATOM)= 1.2572644E+05
MODERATOR-2 WILL BE TREATED BY THE NORDHEIM INTEGRAL METHOD.
THIS RESONANCE MATERIAL WILL BE TREATED AS A 2-DIMENSIONAL OBJECT.
VOLUME FRACTION OF LUMP IN CELL USED TO ACCOUNT FOR SPATIAL SELF-SHIELDING=1.00000

GROUP       RES ABS        RES FISS       RES SCAT
 10     -9.680480E-06   0.000000E+00   -2.906926E-05
 11     -1.832208E-03   0.000000E+00   -2.272092E-03
 12     -1.498763E-02   0.000000E+00   -1.479635E-02
 13      2.563384E-07   0.000000E+00   -7.311806E-07

EXCESS RESONANCE INTEGRALS
                  RESOLVED

ABSORPTION       2.48599E+01
FISSION          0.00000E+00

  ELAPSED TIME   0.25 MIN.
CD 1281 WT 1/EST 218NGP P-3 293K RE(042375)                              48000    TEMPERATURE=   296.00
 CESIUM-133     ENDF/B-IV MAT 1141            UPDATED 10/12/89            55133    TEMPERATURE=   296.00
RESONANCE DATA FOR THIS NUCLIDE
MASS NUMBER (A)          =   131.764          TEMPERATURE(KELVIN)      =   296.000
POTENTIAL SCATTER SIGMA  =     7.100          LUMPED NUCLEAR DENSITY   = 5.8950675E-09
SPIN FACTOR (G)          =   374.437          LUMP DIMENSION (A-BAR)   = 1.0055304E+00
INNER RADIUS             = 0.0000000E+00      DANCOFF CORRECTION (C)   = 2.5032175E-01
THE ABSORBER WILL BE TREATED BY THE NORDHEIM INTEGRAL METHOD.
MASS OF MODERATOR-1    =    12.000           SIGMA(PER ABSORBER ATOM)= 5.1986624E+07
MODERATOR-1 WILL BE TREATED BY THE NORDHEIM INTEGRAL METHOD.
MASS OF MODERATOR-2    =   231.957           SIGMA(PER ABSORBER ATOM)= 1.3934010E+06
MODERATOR-2 WILL BE TREATED BY THE NORDHEIM INTEGRAL METHOD.
THIS RESONANCE MATERIAL WILL BE TREATED AS A 2-DIMENSIONAL OBJECT.
VOLUME FRACTION OF LUMP IN CELL USED TO ACCOUNT FOR SPATIAL SELF-SHIELDING=1.00000
GROUP       RES ABS        RES FISS       RES SCAT
```

```
 9       5.738146E-08    0.000000E+00   -3.245655E-07
10      -1.682005E-06    0.000000E+00   -4.947995E-06
11      -3.479924E-04    0.000000E+00   -2.565626E-04
12      -1.350112E-03    0.000000E+00   -9.205897E-05
13       1.728407E-03    0.000000E+00    2.383812E-04
14      -8.180594E-02    0.000000E+00   -2.307924E-03
15      -3.216079E-05    0.000000E+00    2.200325E-06
16      -8.006553E-06    0.000000E+00    6.761437E-07

EXCESS RESONANCE INTEGRALS

                  RESOLVED

ABSORPTION        3.63458E+02
FISSION           0.00000E+00

  ELAPSED TIME   0.38 MIN.

BA-138 7040 218NGP MT 1/EST 042375 P3 293K                              56138    TEMPERATURE=   296.00

PB   1288 218NGP 042375 P-3 293K                                        82000    TEMPERATURE=   296.00

 URANIUM-235    ENDF/B-IV MAT 1261          UPDATED 10/12/89            92235    TEMPERATURE=   296.00

RESONANCE DATA FOR THIS NUCLIDE

MASS NUMBER (A)          =   233.025          TEMPERATURE(KELVIN)      =   296.000

POTENTIAL SCATTER SIGMA  =    11.500          LUMPED NUCLEAR DENSITY   = 7.3707197E-04

SPIN FACTOR (G)          = 15171.098          LUMP DIMENSION (A-BAR)   = 1.0055304E+00

INNER RADIUS             = 0.0000000E+00      DANCOFF CORRECTION (C)   = 2.5032175E-01

THE ABSORBER WILL BE TREATED BY THE NORDHEIM INTEGRAL METHOD.

MASS OF MODERATOR-1    =    12.000            SIGMA(PER ABSORBER ATOM)= 4.1578662E+02

MODERATOR-1 WILL BE TREATED BY THE NORDHEIM INTEGRAL METHOD.

MASS OF MODERATOR-2    =   191.036            SIGMA(PER ABSORBER ATOM)= 6.4442056E-01

MODERATOR-2 WILL BE TREATED BY THE NORDHEIM INTEGRAL METHOD.

THIS RESONANCE MATERIAL WILL BE TREATED AS A 2-DIMENSIONAL OBJECT.

VOLUME FRACTION OF LUMP IN CELL USED TO ACCOUNT FOR SPATIAL SELF-SHIELDING=1.00000

GROUP        RES ABS         RES FISS        RES SCAT
 12      -5.634716E+00   -3.462540E+00   -1.430526E-01
 13      -1.612897E+01   -7.838006E+00   -3.813148E-01
 14      -1.185187E+01   -6.949266E+00   -7.857656E-02

EXCESS RESONANCE INTEGRALS

                  RESOLVED

ABSORPTION        1.87606E+02
FISSION           1.13022E+02

  ELAPSED TIME   0.49 MIN.

 URANIUM-238    ENDF/B-IV MAT 1262          UPDATED 10/12/89            92238    TEMPERATURE=   296.00

RESONANCE DATA FOR THIS NUCLIDE

MASS NUMBER (A)          =   236.006          TEMPERATURE(KELVIN)      =   296.000

POTENTIAL SCATTER SIGMA  =    10.599          LUMPED NUCLEAR DENSITY   = 5.3517593E-05

SPIN FACTOR (G)          =   656.527          LUMP DIMENSION (A-BAR)   = 1.0055304E+00

INNER RADIUS             = 0.0000000E+00      DANCOFF CORRECTION (C)   = 2.5032175E-01
```

```
THE ABSORBER WILL BE TREATED BY THE NORDHEIM INTEGRAL METHOD.
MASS OF MODERATOR-1    =    12.000              SIGMA(PER ABSORBER ATOM)= 5.7264258E+03
MODERATOR-1 WILL BE TREATED BY THE NORDHEIM INTEGRAL METHOD.
MASS OF MODERATOR-2    =   231.617              SIGMA(PER ABSORBER ATOM)= 1.4518668E+02
MODERATOR-2 WILL BE TREATED BY THE NORDHEIM INTEGRAL METHOD.
THIS RESONANCE MATERIAL WILL BE TREATED AS A 2-DIMENSIONAL OBJECT.
VOLUME FRACTION OF LUMP IN CELL USED TO ACCOUNT FOR SPATIAL SELF-SHIELDING=1.00000

GROUP        RES ABS          RES FISS         RES SCAT
  9      -4.602366E-04     0.000000E+00    -5.176228E-03
 10      -2.518489E-02    -1.360157E-07    -1.840974E-01
 11      -1.262961E+00     0.000000E+00    -4.031716E+00
 12      -1.154916E+01     0.000000E+00    -1.378216E+01
 13      -1.329348E+01     0.000000E+00    -4.393057E+00
 14      -2.445375E+01     0.000000E+00    -1.424618E+00

EXCESS RESONANCE INTEGRALS

                  RESOLVED

ABSORPTION        2.11627E+02
FISSION           5.33416E-04

   ELAPSED TIME   0.65 MIN.

   ELAPSED TIME   0.66 MIN.
```

```
THIS XSDRN WORKING TAPE WAS CREATED 01/23/93 AT  0.02.33
THE TITLE OF THE PARENT CASE IS AS FOLLOWS
NUCLEAR CRITICALITY SAFETY SOFTWARE VERSION 1 CROSS SECTION LIBRARY
27 NEUTRON GROUPS   REVISION 000     AUGUST 14, 1991
VERSION 1 REVISION 000 DATA TAKEN FROM SCALE 4.1
    TAPE ID                          27          NUMBER OF NUCLIDES              26
    NUMBER OF NEUTRON GROUPS         27          NUMBER OF GAMMA GROUPS           0
    FIRST THERMAL GROUP              15          LOGICAL UNIT                     4
                                TABLE OF CONTENTS
  HYDROGEN       ENDF/B-IV MAT 1269/THRM1002    UPDATED 10/12/89          ID      1001
  BERYLLIUM-9    ENDF/B-IV MAT 1289/THRM1064    UPDATED 10/12/89          ID      4009
 B-10 1273 218NGP 042375 P-3 293K                                          ID      5010
  BORON-11       ENDF/B-IV MAT 1160             UPDATED 10/12/89          ID      5011
  CARBON-12      ENDF/B-IV MAT 1274/THRM1065    UPDATED 10/12/89          ID      6012
  OXYGEN-16      ENDF/B-IV MAT 1276             UPDATED 10/12/89          ID      8016
 AL-27 1193 218 GP 040375(5)                                               ID     13027
 AL-27 1193 218 GP 040375(5)                                               ID    213027
  SILICON        ENDF/B-IV MAT 1194             UPDATED 10/12/89          ID     14000
  POTASSIUM      ENDF/B-IV MAT 1150             UPDATED 10/12/89          ID     19000
 CALCIUM ENDF/B-IV MAT 1195                     UPDATED 9/07/89           ID     20000
 V 1196 218 GP 1/E*SIGT 040375(5)                                          ID     23051
  MANGANESE-55   ENDF/B-IV MAT 1197             UPDATED 10/12/89          ID     25055
  IRON           ENDF/B-IV MAT 1192             UPDATED 10/12/89          ID     26000
 NI 1190 218NGP MT 1/E P-3 293K SIGP=5+4 RE(042375)                        ID     28000
  COPPER         ENDF/B-IV MAT 1295             UPDATED 10/12/89          ID     29000
  BROMINE-79     ENDF/B-IV MAT 108              UPDATED 10/12/89          ID     35079
  BROMINE-81     ENDF/B-IV MAT 112              UPDATED 10/12/89          ID     35081
  ZIRCONIUM      ENDF/B-IV MAT 7141             UPDATED 10/12/89          ID     40000
 MO (1287) SIGP=5+4 NEWXLACS 218NGP F-1/E-M P-3 293K                       ID     42000
 CD 1281 MT 1/EST 218NGP P-3 293K RE(042375)                               ID     48000
  CESIUM-133     ENDF/B-IV MAT 1141             UPDATED 10/12/89          ID     55133
 BA-138 7040 218NGP MT 1/EST 042375 P3 293K                                ID     56138
 PB   1288 218NGP 042375 P-3 293K                                          ID     82000
  URANIUM-235    ENDF/B-IV MAT 1261             UPDATED 10/12/89          ID     92235
  URANIUM-238    ENDF/B-IV MAT 1262             UPDATED 10/12/89          ID     92238

   TAPE COPY USED      0 I/O'S, AND TOOK     0.93 SECONDS
```

Example Output for Rover Calculations (cont'd)

```
X-Y SLICE OF CORE

                    MIXTURE MAP

MIXTURE  0 1 2 3 4 5 6
 SYMBOL    1 2 3 4 5 6

          UPPER  LEFT          LOWER RIGHT
          COORDINATES          COORDINATES

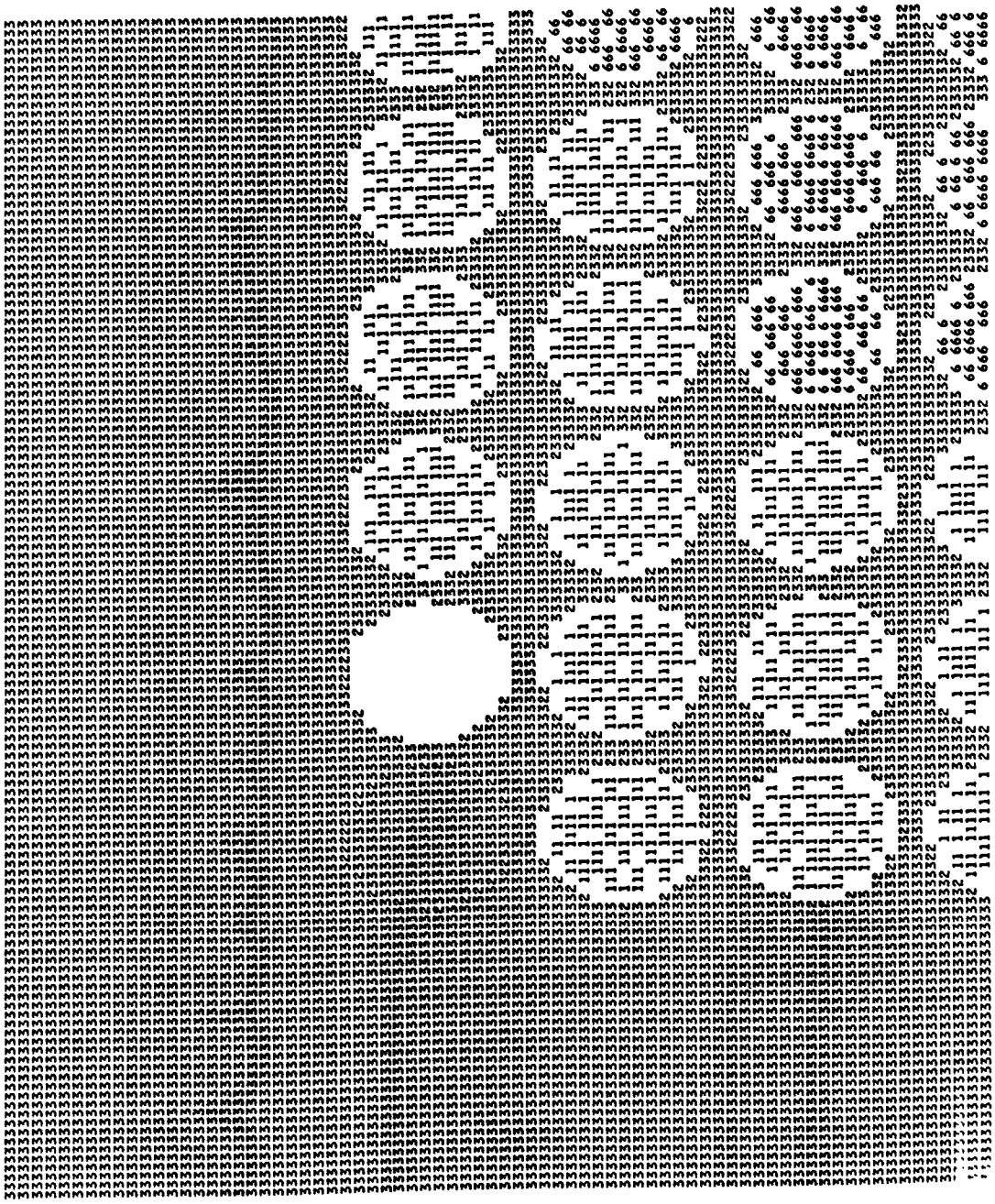
X    -2.0000E+01                2.0000E+01
Y     2.0000E+01               -2.0000E+01
Z     1.0000E+02                1.0000E+02

                    U AXIS      V AXIS
                    (DOWN)      (ACROSS)

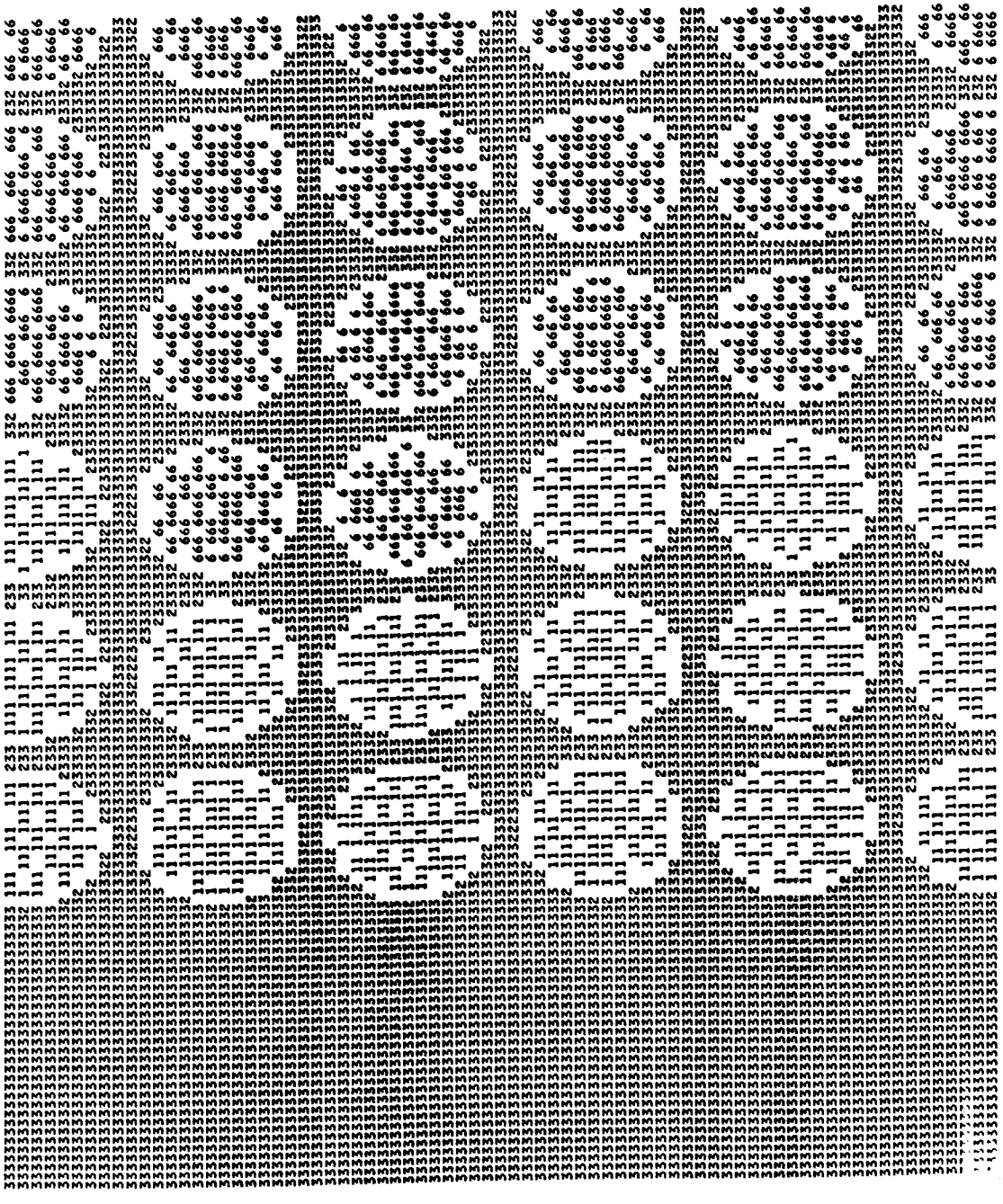
X                   0.00000     1.00000
Y                  -1.00000     0.00000
Z                   0.00000     0.00000

NU=  208   NV=  260    DELU= 1.9231E-01    DELV= 1.5385E-01
```

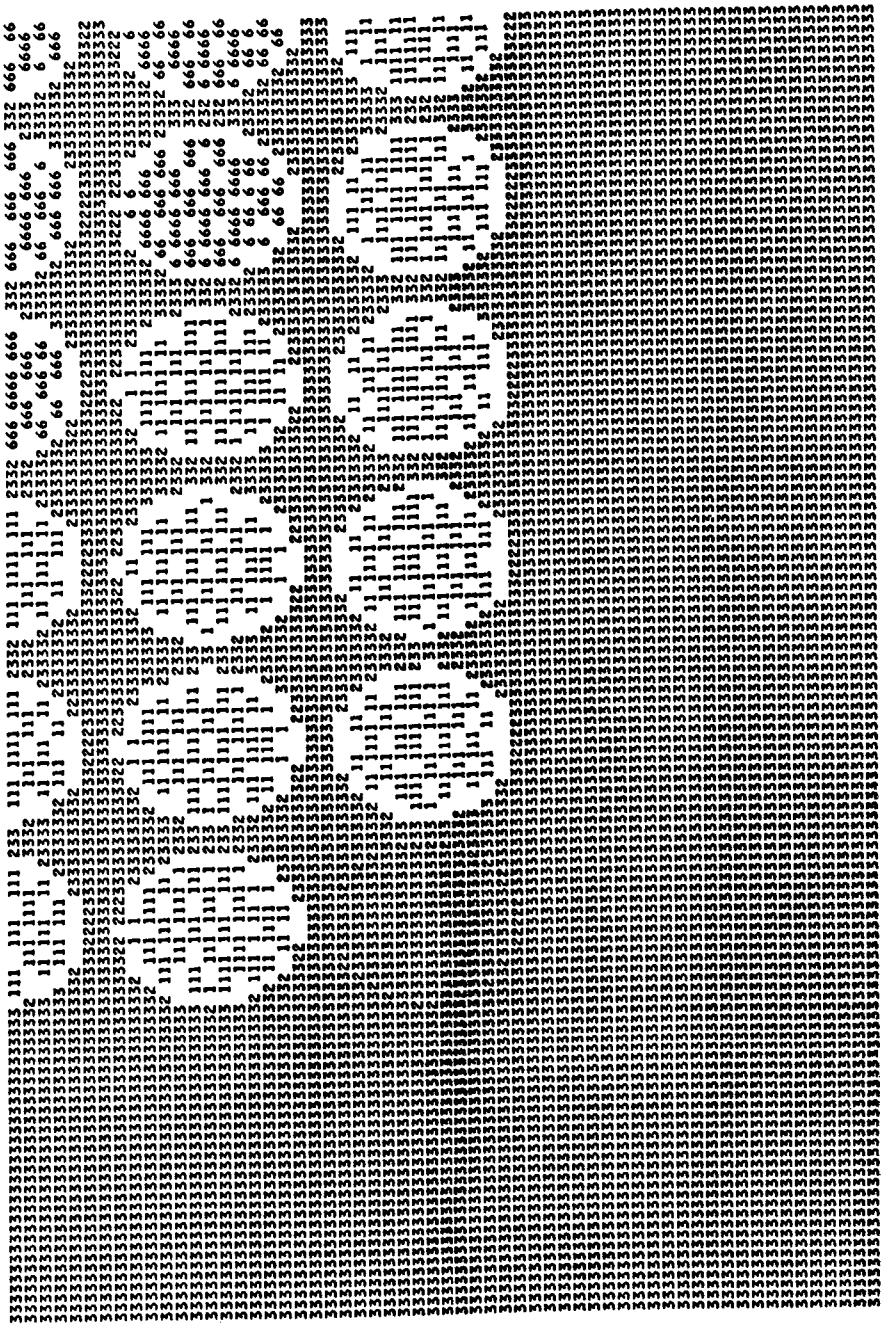
Example Output for Rover Calculations (cont'd)



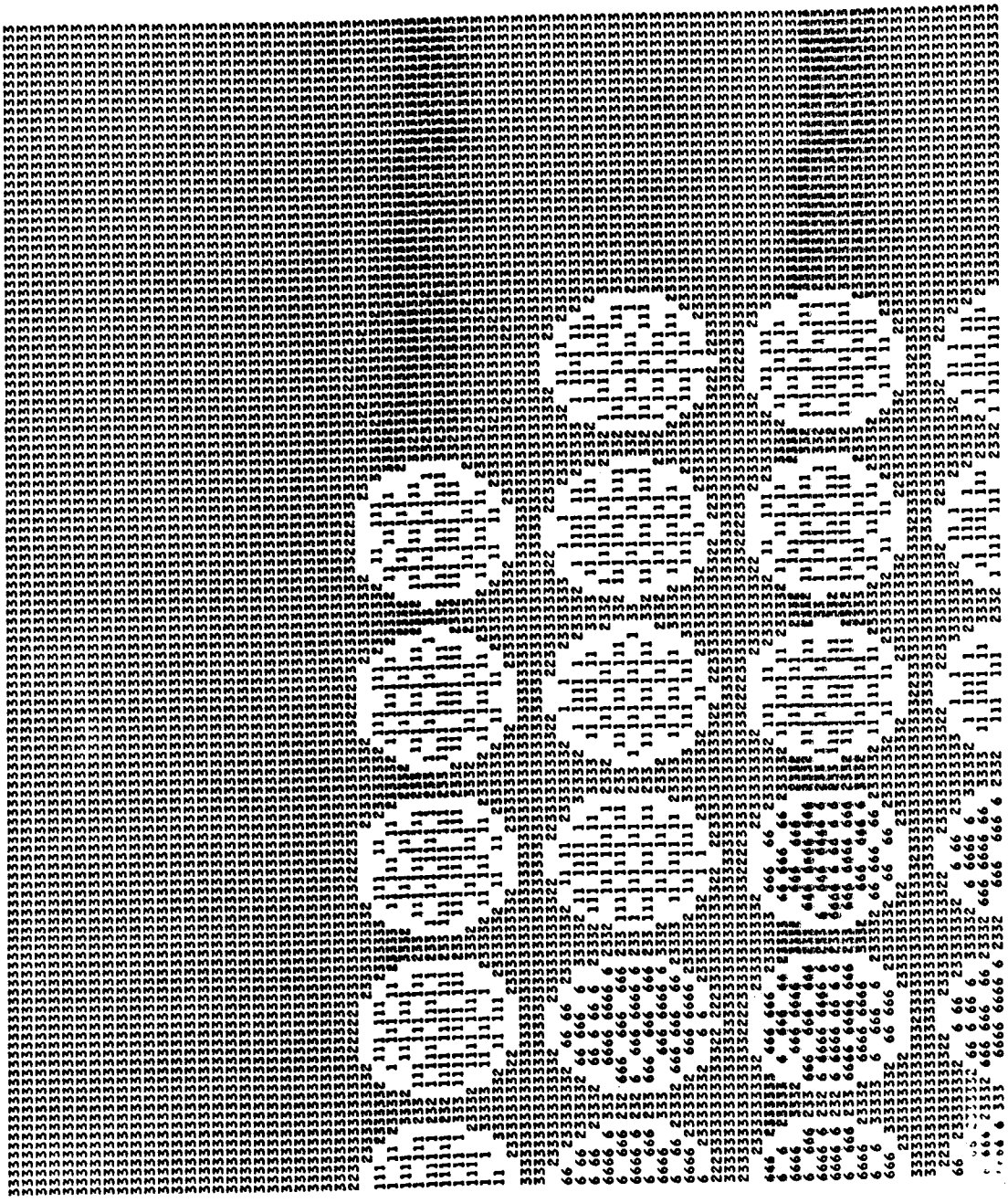
Example Output for Rover Calculations (cont'd)



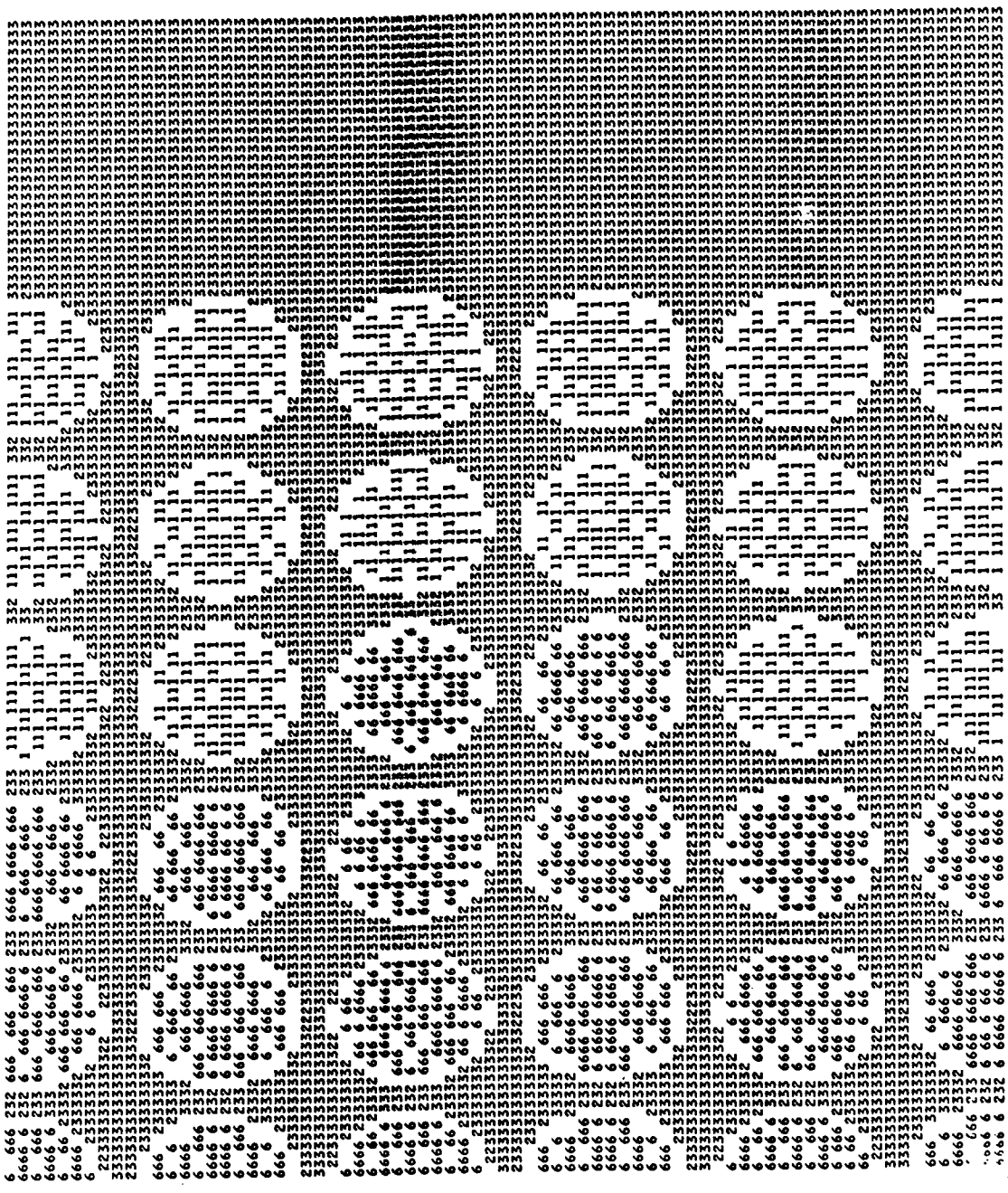
Example Output for Rover Calculations (cont'd)



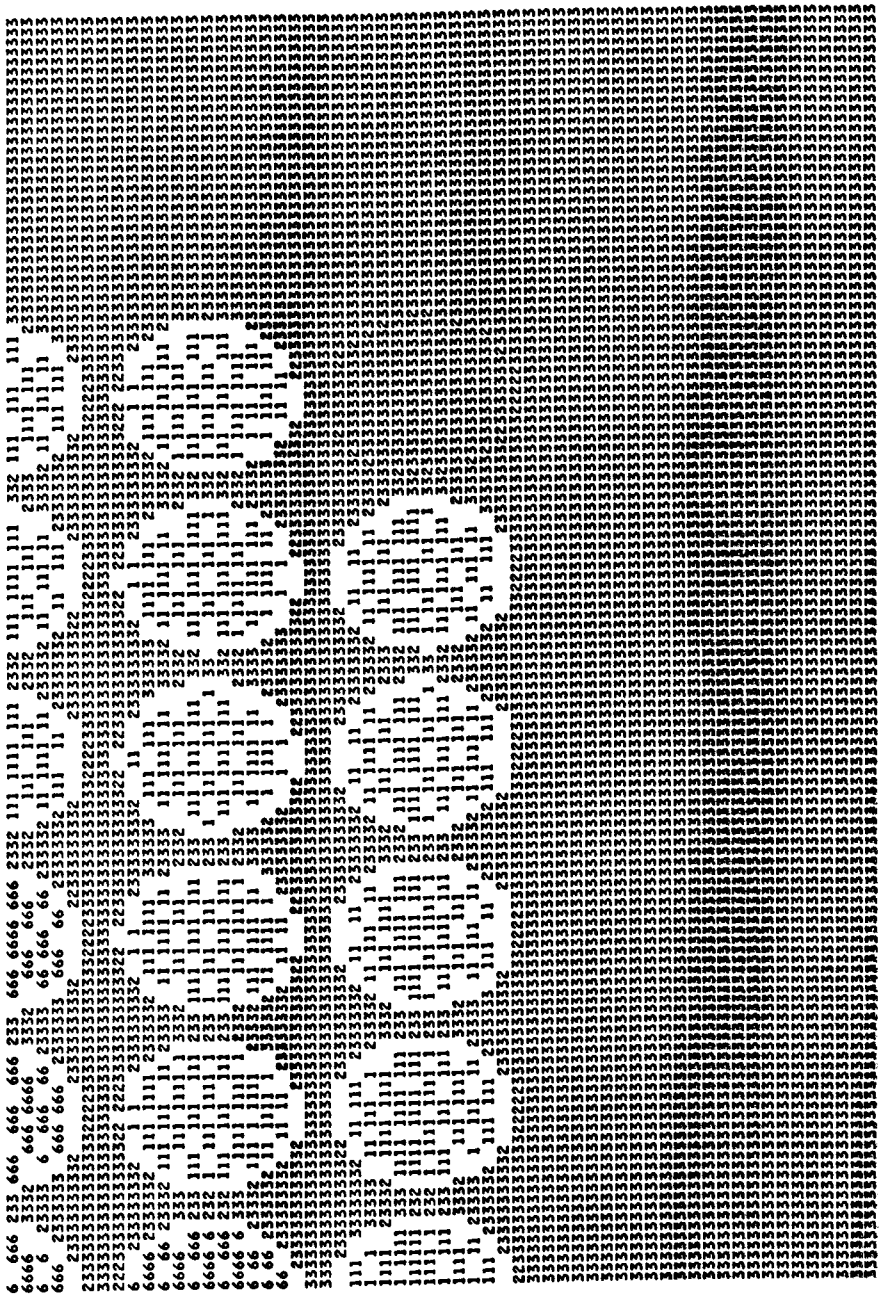
Example Output for Rover Calculations (cont'd)



Example Output for Rover Calculations (cont'd)



Example Output for Rover Calculations (cont'd)



ROVER CRITICAL SQUARE 0.100 IN. SPACING

LIFETIME = 2.08156E-04 + OR - 9.53959E-07
NU BAR = 2.42151E+00 + OR - 2.47491E-05

GENERATION TIME = 6.99496E-05 + OR - 4.71349E-07
AVERAGE FISSION GROUP = 2.28249E+01 + OR - 9.87549E-03

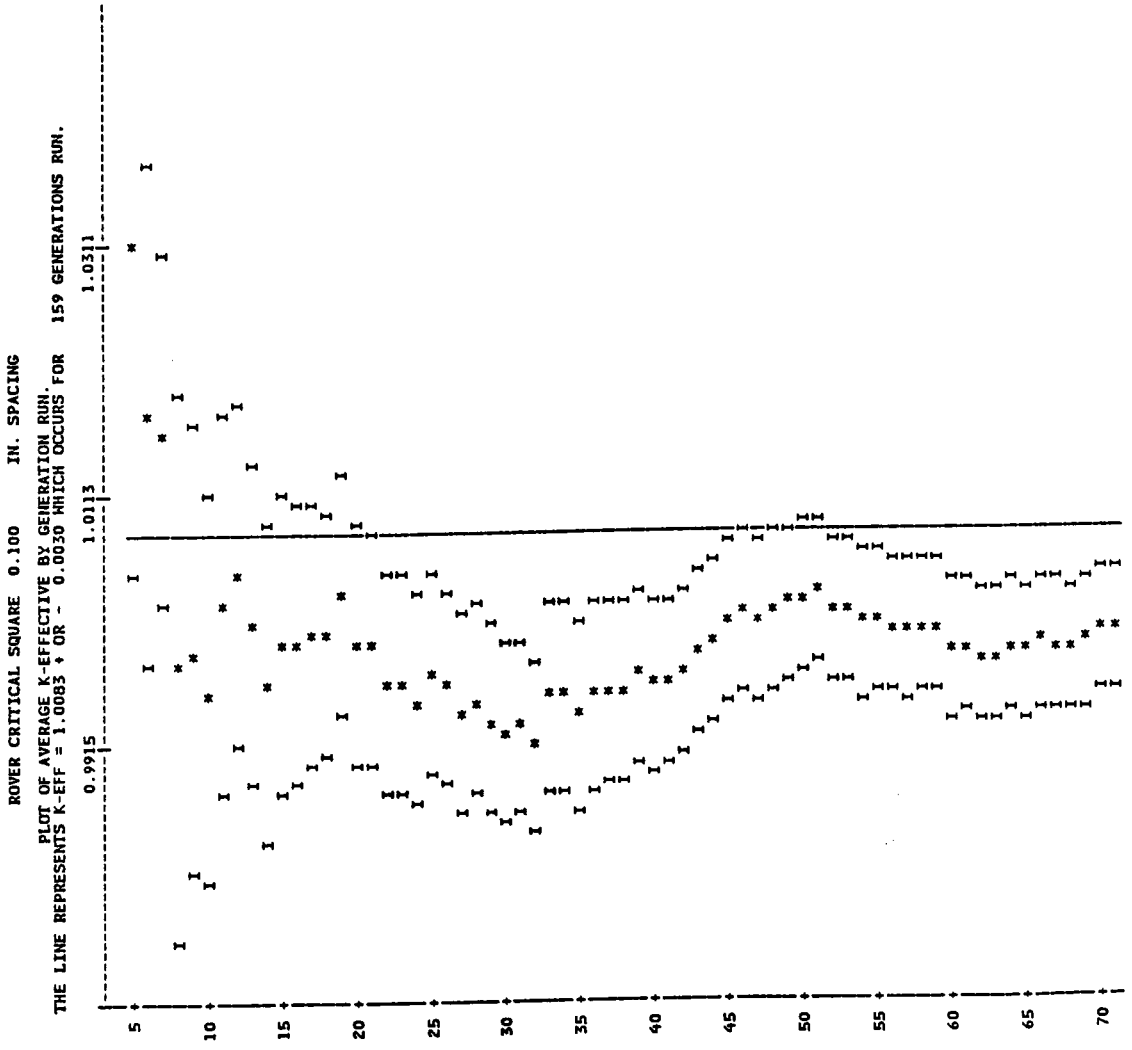
NO. OF INITIAL GENERATIONS SKIPPED	AVERAGE K-EFFECTIVE	DEVIATION	67 PER CENT CONFIDENCE INTERVAL	95 PER CENT CONFIDENCE INTERVAL	99 PER CENT CONFIDENCE INTERVAL	NUMBER OF HISTORIES
3	1.00833	+ OR - 0.00303	1.00529 TO 1.01136	1.00226 TO 1.01439	0.99923 TO 1.01742	78000
4	1.00835	+ OR - 0.00305	1.00530 TO 1.01140	1.00225 TO 1.01445	0.99920 TO 1.01750	77500
5	1.00803	+ OR - 0.00305	1.00498 TO 1.01108	1.00192 TO 1.01414	0.99887 TO 1.01719	77000
6	1.00813	+ OR - 0.00307	1.00506 TO 1.01120	1.00199 TO 1.01427	0.99892 TO 1.01734	76500
7	1.00810	+ OR - 0.00309	1.00501 TO 1.01119	1.00192 TO 1.01429	0.99883 TO 1.01738	76000
8	1.00867	+ OR - 0.00306	1.00561 TO 1.01173	1.00256 TO 1.01479	0.99950 TO 1.01785	75500
9	1.00868	+ OR - 0.00308	1.00560 TO 1.01176	1.00253 TO 1.01484	0.99945 TO 1.01792	75000
10	1.00890	+ OR - 0.00309	1.00581 TO 1.01200	1.00272 TO 1.01509	0.99963 TO 1.01818	74500
11	1.00862	+ OR - 0.00310	1.00552 TO 1.01172	1.00242 TO 1.01482	0.99932 TO 1.01792	74000
12	1.00851	+ OR - 0.00312	1.00539 TO 1.01163	1.00227 TO 1.01475	0.99915 TO 1.01787	73500
17	1.00909	+ OR - 0.00318	1.00591 TO 1.01227	1.00274 TO 1.01545	0.99956 TO 1.01863	71000
22	1.00994	+ OR - 0.00321	1.00673 TO 1.01315	1.00352 TO 1.01636	1.00031 TO 1.01956	68500
27	1.01090	+ OR - 0.00326	1.00764 TO 1.01416	1.00438 TO 1.01742	1.00112 TO 1.02068	66000
32	1.01218	+ OR - 0.00329	1.00889 TO 1.01547	1.00559 TO 1.01876	1.00230 TO 1.02206	63500
37	1.01182	+ OR - 0.00327	1.00854 TO 1.01509	1.00527 TO 1.01837	1.00200 TO 1.02164	61000
42	1.01188	+ OR - 0.00338	1.00850 TO 1.01526	1.00513 TO 1.01863	1.00175 TO 1.02201	58500
47	1.01107	+ OR - 0.00344	1.00763 TO 1.01450	1.00419 TO 1.01794	1.00076 TO 1.02137	56000
52	1.01113	+ OR - 0.00349	1.00763 TO 1.01462	1.00414 TO 1.01811	1.00065 TO 1.02161	53500
57	1.01254	+ OR - 0.00358	1.00895 TO 1.01612	1.00537 TO 1.01971	1.00179 TO 1.02329	51000
62	1.01430	+ OR - 0.00353	1.01077 TO 1.01782	1.00724 TO 1.02135	1.00372 TO 1.02487	48500
67	1.01473	+ OR - 0.00363	1.01110 TO 1.01836	1.00746 TO 1.02199	1.00383 TO 1.02562	46000
72	1.01344	+ OR - 0.00369	1.00975 TO 1.01713	1.00606 TO 1.02083	1.00237 TO 1.02452	43500
77	1.01183	+ OR - 0.00356	1.00826 TO 1.01539	1.00470 TO 1.01895	1.00114 TO 1.02252	41000
82	1.01142	+ OR - 0.00375	1.00767 TO 1.01517	1.00392 TO 1.01892	1.00017 TO 1.02267	38500
87	1.01159	+ OR - 0.00394	1.00765 TO 1.01552	1.00371 TO 1.01946	0.99977 TO 1.02340	36000
92	1.01231	+ OR - 0.00407	1.00824 TO 1.01638	1.00417 TO 1.02046	1.00010 TO 1.02453	33500

Example Output for Rover Calculations (cont'd)

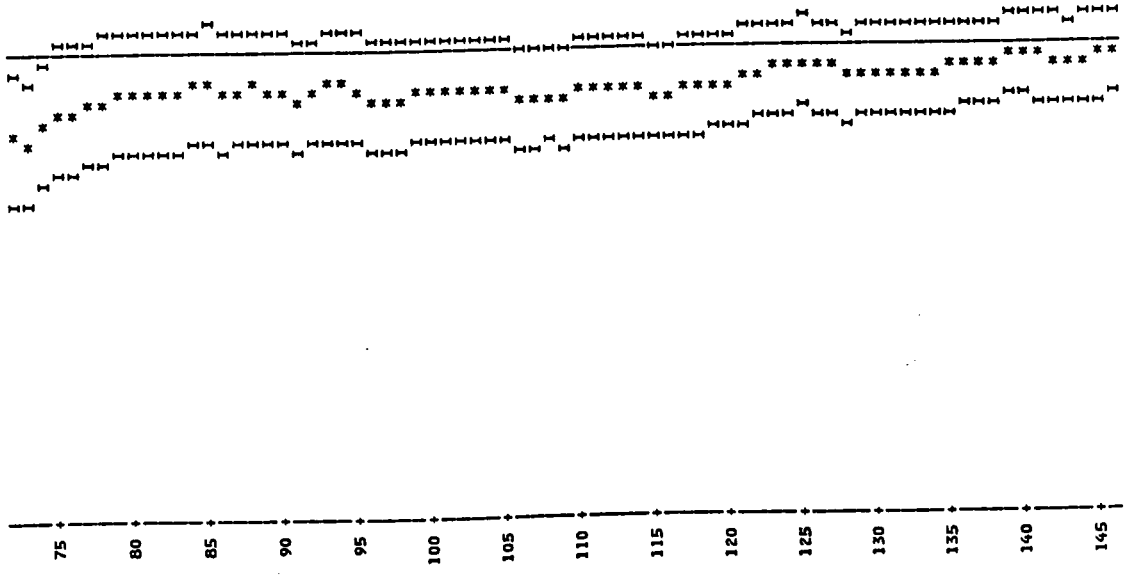
ROVER CRITICAL SQUARE 0.100 IN. SPACING

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	1.01359	+ OR - 0.00410	1.00949 TO 1.01769	1.00539 TO 1.02178	1.00130 TO 1.02588	31000
102	1.01392	+ OR - 0.00441	1.00950 TO 1.01833	1.00509 TO 1.02275	1.00067 TO 1.02716	28500
107	1.01557	+ OR - 0.00459	1.01098 TO 1.02017	1.00639 TO 1.02476	1.00180 TO 1.02935	26000
112	1.01580	+ OR - 0.00474	1.01106 TO 1.02054	1.00632 TO 1.02527	1.00158 TO 1.03001	23500
117	1.01610	+ OR - 0.00470	1.01140 TO 1.02080	1.00669 TO 1.02550	1.00199 TO 1.03021	21000
122	1.01417	+ OR - 0.00483	1.00933 TO 1.01900	1.00450 TO 1.02384	0.99966 TO 1.02867	18500
127	1.01431	+ OR - 0.00547	1.00884 TO 1.01978	1.00337 TO 1.02525	0.99790 TO 1.03072	16000
132	1.01736	+ OR - 0.00543	1.01193 TO 1.02279	1.00649 TO 1.02823	1.00106 TO 1.03366	13500
137	1.01762	+ OR - 0.00659	1.01103 TO 1.02421	1.00444 TO 1.03080	0.99785 TO 1.03739	11000
142	1.01755	+ OR - 0.00673	1.01083 TO 1.02428	1.00410 TO 1.03101	0.99737 TO 1.03773	8500
147	1.01465	+ OR - 0.00672	1.00793 TO 1.02137	1.00121 TO 1.02809	0.99449 TO 1.03481	6000
152	1.00815	+ OR - 0.00849	0.99966 TO 1.01663	0.99117 TO 1.02512	0.98268 TO 1.03361	3500
157	0.99994	+ OR - 0.01383	0.98611 TO 1.01376	0.97228 TO 1.02759	0.95845 TO 1.04142	1000

Example Output for Rover Calculations (cont'd)



Example Output for Rover Calculations (cont'd)



Example Output for Rover Calculations (cont'd)

```
ROVER CRITICAL SQUARE  0.100     IN. SPACING

                          FREQUENCY FOR GENERATIONS     4 TO  159

0.8837 TO 0.9015          *
0.9015 TO 0.9194          ****
0.9194 TO 0.9373          **********
0.9373 TO 0.9552          **********
0.9552 TO 0.9731          **********
0.9731 TO 0.9910          ********************
0.9910 TO 1.0089          ********************
1.0089 TO 1.0268          ********************
1.0268 TO 1.0447          ********************
1.0447 TO 1.0625          **********
1.0625 TO 1.0804          *****
1.0804 TO 1.0983          ***
1.0983 TO 1.1162          **

                          FREQUENCY FOR GENERATIONS    43 TO  159

0.8837 TO 0.9015          *
0.9015 TO 0.9194          ***
0.9194 TO 0.9373          ****
0.9373 TO 0.9552          ******
0.9552 TO 0.9731          ********
0.9731 TO 0.9910          ********************
0.9910 TO 1.0089          ********************
1.0089 TO 1.0268          ********************
1.0268 TO 1.0447          ********************
1.0447 TO 1.0625          **********
1.0625 TO 1.0804          *****
1.0804 TO 1.0983          ***
1.0983 TO 1.1162          *

                          FREQUENCY FOR GENERATIONS    82 TO  159

0.8837 TO 0.9015
0.9015 TO 0.9194          **
0.9194 TO 0.9373          ***
0.9373 TO 0.9552          ***
0.9552 TO 0.9731          ***
0.9731 TO 0.9910          **********
0.9910 TO 1.0089          **********
1.0089 TO 1.0268          **********
1.0268 TO 1.0447          **********
1.0447 TO 1.0625          *****
1.0625 TO 1.0804          *****
1.0804 TO 1.0983          *
1.0983 TO 1.1162

                          FREQUENCY FOR GENERATIONS   121 TO  159

0.8837 TO 0.9015
0.9015 TO 0.9194          *
0.9194 TO 0.9373
0.9373 TO 0.9552          **
0.9552 TO 0.9731          ****
0.9731 TO 0.9910          *****
0.9910 TO 1.0089          *********
1.0089 TO 1.0268          *********
1.0268 TO 1.0447          ****
1.0447 TO 1.0625          ***
1.0625 TO 1.0804
1.0804 TO 1.0983
1.0983 TO 1.1162

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

     CONGRATULATIONS! YOU HAVE SUCCESSFULLY TRAVERSED THE PERILOUS PATH THROUGH KENO V IN  30.09499 MINUTES

**********************************************************************************************************************************************************************
```

Example Input for Honeycomb Calculational Model

```
#csasn
treat critical configuration 1
27groupndf4                infhommedium
u-235          1  0 1.074459e-5 293 end
u-238          1  0 7.740383e-7 293 end
c             1  0 2.690244e-6 293 end
f             1  0 5.380488e-6 293 end
c             1  0.0 7.681011e-2 293 end
b-10           1  0.0 2.209824e-8 293 end
b-11           1  0.0 8.894820e-8 293 end
ca            1  0.0 2.672497e-6 293 end
al            1  0.0 1.197879e-5 293 end
fe            1  0.0 5.290708e-5 293 end
ti            1  0.0 1.156652e-6 293 end
v-51           1  0.0 8.881575e-7 293 end
al            1  0.0 9.289343e-4 293 end
end comp
end
#kenova
treat critical configuration 1
read parm run=yes lib=4 plt=yes gen=203 npg=500 tme=70 nub=yes
end parm
read start nst=1 xsm=76.20 xsp=121.92 ysm=76.20 ysp=121.92
zsm=76.20 zsp=121.92 end start
read mixt
mix=1 92235 4.783682e-2 92238 3.446153e-3 6012 1.19774e-2
9019 2.39548e-2
mix=2 13027 6.023740e-2
mix=3 6012 8.365627e-2 5010 2.406788e-8 5011 9.687624e-8
20000 2.910699e-6 13027 1.304647e-5 26000 5.762274e-5
22000 1.259746e-6 23051 9.673199e-7
end mixt
read geom
unit  1
cuboid    1  1 9.525 -9.525 3.65125 -3.65125 0.0 -.00254
cuboid    0  1 10.160 -10.160 3.65125 -3.65125 0.0 -.00254
cuboid    3  1 10.160 -10.160 3.65125 -3.65125 0.0 -1.27127
unit 2
cuboid    1  1 9.525 -9.525 3.65125 -3.65125 0.0 -.00254
cuboid    0  1 10.160 -10.160 3.65125 -3.65125 0.0 -.00254
cuboid    3  1 10.160 -10.160 3.65125 -3.65125 0.0 -5.0800
unit 3
cuboid    3  1 10.160 -10.160 3.65125 -3.65125 0.0 -0.95123
unit 4
array 1   0.0 -3.65125 -3.65125
```

Example Input for Honeycomb Calculational Model (cont'd)

```
cuboid    0  1 20.320 0.0 3.69062 -3.69062 3.72999 -3.65125
cuboid    2  1 20.320 0.0 3.810 -3.810 3.84937 -3.77063
unit 5
cuboid    1  1 9.525 -9.525 3.65125 -3.65125 0.0 -.00254
cuboid    0  1 10.160 -10.160 3.65125 -3.65125 0.0 -.00254
cuboid    3  1 10.160 -10.160 3.65125 -3.65125 0.0 -3.81127
unit 6
cuboid    3  1 10.160 -10.160 3.65125 -3.65125 0.0 -3.49123
unit 7
array 2   0.0 -3.65125 -3.65125
cuboid    0  1 20.320 0.0 3.69062 -3.69062 3.72999 -3.65125
cuboid    2  1 20.320 0.0 3.810 -3.810 3.84937 -3.77063
unit 8
cuboid    3  1 30.480 0.0 3.65125 -3.65125 3.65125  -3.65125
cuboid    0  1 30.480 0.0 3.69062 -3.69062 3.72999 -3.65125
cuboid    2  1 30.480 0.0 3.810 -3.810 3.84937 -3.77063
unit 9
cuboid    3  1 20.320 0.0 3.65125 -3.65125 3.65125 -3.65125
cuboid    0  1 20.320 0.0 3.69062 -3.69062 3.72999 -3.65125
cuboid    2  1 20.320 0.0 3.810 -3.810 3.84937 -3.77063
unit 10
array 3 3r0.0
unit 11
array 4 3r0.0
unit 12
array 5 3r0.0
unit 13
array 6 3r0.0
unit 14
array 7 3r0.0
unit 15
array 8 3r0.0
unit 16
array 9  3r0.0
unit 17
array 10 3r0.0
unit 18
array 11 3r0.0
unit 19
array 12 3r0.0
global unit 20
array 13 3r0.0
end geom
read array
ara=1 nux=1 nuy=1 nuz=3 fill 1 2 3 end fill
```

Example Input for Honeycomb Calculational Model (cont'd)

```
ara=2 nux=1 nuy=1 nuz=2 fill 5 6 end fill
ara=3 nux=8 nuy=1 nuz=1 fill 8  6r4  8 end fill
ara=4 nux=8 nuy=1 nuz=1 fill 8  6r7 8  end fill
ara=5 nux=8 nuy=1 nuz=1 fill 8  6r9 8 end fill
ara=6 nux=8 nuy=1 nuz=1 fill 8 3r7 3r4 8 end fill
ara=7 nux=1 nuy=1 nuz=24 fill 5r12 11 12 11 12 11 12 11 12
11 12 11 12 11 12 11 4r12 end fill
ara=8 nux=1 nuy=1 nuz=24 fill 4r12 10 12 10 12 10 12 10 12
10 12 10 12 10 12 10 5r12 end fill
ara=9 nux=1 nuy=1 nuz=24 fill 4r12 13 12 10 12 10 12 10 12
10 12 10 12 10 12 10 5r12 end fill
ara=10 nux=1 nuy=1 nuz=24 fill 4r12 13 12 10 12 13 12 10 12
13 12 10 12 13 12 10 5r12 end fill
ara=11 nux=1 nuy=1 nuz=24 fill 24r12 end fill
ara=12 nux=1 nuy=1 nuz=24 fill 4r12 13 12 10 12 10 12 10 12 13 12 10
12 10 12 10 5r12 end fill
ara=13 nux=1 nuy=24 nuz=1 fill 4r18 14 15 14 16 14 15 14
19 14 15 14 16 14 15 14 17 4r18 end fill
end array
end data
end
```

Example Output for Honeycomb Calculations

Example Output for Honeycomb Calculations (cont'd)


```
0 mm      mm  ccccccccccc   ssssssssss   ssssssssss   hh      hh  pppppppppp
  mmm     mm  ccccccccccc   ssssssssss   ssssssssss   hh      hh  pppppppppp
  mmmm    mm  cc      cc   ss           ss           hh      hh  pp      pp
  mm mm   mm  cc           ss           ss           hh      hh  pp      pp
  mm  mm  mm  cc           ssssssssss   ssssssssss   hhhhhhhhhhh  pppppppppp
  mm   mm mm  cc           ssssssssss   ssssssssss   hhhhhhhhhhh  pppppppppp
  mm    mmmm  cc                   ss           ss   hh      hh  pp
  mm     mm   cc                   ss           ss   hh      hh  pp
  mm          cc      cc   ss      ss           ss   hh      hh  pp
  mm          ccccccccccc  ssssssssss   ssssssssss   hh      hh  pp
  mm          ccccccccc    ssssssssss   ssssssssss   hh      hh  pp
```

```
*****
*****          program verification information          *****
*****                                                    *****
*****          code system: ncsshp  version: 1.0         *****
*****                                                    *****
**********************************************************
**********************************************************
*****                                                    *****
*****                                                    *****
*****          library:  /disk2/ncsshp.v1.0.0/load.v1.0.0/ *****
*****                                                    *****
*****          program:  csas                            *****
*****                                                    *****
*****     creation date:  07/22/92                       *****
*****                                                    *****
*****     production code:  csas25                       *****
*****                                                    *****
*****          revision:  1.0                            *****
*****                                                    *****
*****          jobname:  ee6                             *****
*****                                                    *****
*****  date of execution:  02/24/93                      *****
*****                                                    *****
*****  time of execution:  12:29:23                      *****
*****                                                    *****
**********************************************************
**********************************************************
**********************************************************
```

Example Output for Honeycomb Calculations (cont'd)

```
treat critical configuration 1

0  **** problem parameters ****

   lib 27groupndf4  library
   mxx          1 mixtures
   msc         13 composition specifications
   izm          1 material zones
   ge  infhommedium geometry
   more         0 0/1 do not read/read optional parameter data
   msln         0 fuel solutions

0  **** problem composition description ****

   sc  u-235        standard composition
   mx           1 mixture no.
   den   1.0745E-05 atomic density
   roth         1.0000 theoretical density
   temp       293.0 deg kelvin
   end

   sc  u-238        standard composition
   mx           1 mixture no.
   den   7.7404E-07 atomic density
   roth         1.0000 theoretical density
   temp       293.0 deg kelvin
   end

   sc  c            standard composition
   mx           1 mixture no.
   den   2.6902E-06 atomic density
   roth         2.3000 theoretical density
   temp       293.0 deg kelvin
   end

   sc  f            standard composition
   mx           1 mixture no.
   den   5.3805E-06 atomic density
   roth         1.0000 theoretical density
   temp       293.0 deg kelvin
   end

   sc  c            standard composition
   mx           1 mixture no.
   den   7.6810E-02 atomic density
   roth         2.3000 theoretical density
   temp       293.0 deg kelvin
   end

   sc  b-10         standard composition
   mx           1 mixture no.
   den   2.2098E-08 atomic density
   roth         2.1950 theoretical density
   temp       293.0 deg kelvin
   end
```

Example Output for Honeycomb Calculations (cont'd)

```
sc  b-11          standard composition
mx          1 mixture no.
den   8.8948E-08 atomic density
roth      2.4130 theoretical density
temp       293.0 deg kelvin
end

sc  ca            standard composition
mx          1 mixture no.
den   2.6725E-06 atomic density
roth      1.5450 theoretical density
temp       293.0 deg kelvin
end

sc  al            standard composition
mx          1 mixture no.
den   1.1979E-05 atomic density
roth      2.6989 theoretical density
temp       293.0 deg kelvin
end

sc  fe            standard composition
mx          1 mixture no.
den   5.2907E-05 atomic density
roth      7.8740 theoretical density
temp       293.0 deg kelvin
end

sc  ti            standard composition
mx          1 mixture no.
den   1.1567E-06 atomic density
roth      4.5400 theoretical density
temp       293.0 deg kelvin
end

sc  v-51          standard composition
mx          1 mixture no.
den   8.8816E-07 atomic density
roth      6.1100 theoretical density
temp       293.0 deg kelvin
end

sc  al            standard composition
mx          1 mixture no.
den   9.2893E-04 atomic density
roth      2.6989 theoretical density
temp       293.0 deg kelvin
end

0   **** problem geometry ****

0   **** infinite homogeneous medium ****
mfuel          1 mixture no. of the infinite homogeneous medium
```

Example Output for Honeycomb Calculations (cont'd)

Example Output for Honeycomb Calculations (cont'd)


```
program verification information
code system:  ncsshp  version:  1.0
program:  o0o008
creation date:  07/22/92
library:  /disk2/ncsshp.v1.0.0/load.v1.0.0/
production code:  bonaml
revision:  1.0
jobname:  ee6
date of execution:  02/24/93
time of execution:  12:29:26
```

Example Output for Honeycomb Calculations (cont'd)

```
0     -1q array has     1 entries.
0      0q array has     4 entries.
0      1q array has     6 entries.
0      2q array has     2 entries.
1logical assignments
0master library   11
 working library   0
 scratch file      18
 new library       1
0p r o b l e m   d e s c r i p t i o n
0igr--geometry (0/1/2/3--inf bad/slab/cyl/sphere          1
0izm--number of zones or material regions                 1
0ms--mixing table length                                 11
0ibl--shielded cross section edit option (0/1--no/yes)    0
0ibr--bondarenko factor edit option (0/1--no/yes)         0
0issopt--dancoff factor option                            0
0convergence criterion   1.00000E-03
0geometry correction factor for wigner rational approximation  1.000E+00
0          3q array has        11 entries.
0          4q array has        11 entries.
0          5q array has        11 entries.
0          6q array has         1 entries.
0          7q array has         1 entries.
0          8q array has         1 entries.
0          9q array has         1 entries.
0         10q array has        11 entries.
0         11q array has         1 entries.
0m i x i n g   t a b l e
0entry  mixture   isotope   number density   new identifier
      1         1     92235      1.07446E-05           92235
      2         1     92238      7.74038E-07           92238
      3         1      6012      7.68128E-02            6012
      4         1      9019      5.38049E-06            9019
      5         1      5010      2.20982E-08            5010
      6         1      5011      8.89482E-08            5011
      7         1     20000      2.67250E-06           20000
      8         1     13027      9.40913E-04           13027
      9         1     26000      5.29071E-05           26000
     10         1     22000      1.15665E-06           22000
     11         1     23051      8.88158E-07           23051
```

Example Output for Honeycomb Calculations (cont'd)

```
0geometry and material description
0zone   mixture   outer dimension   temperature      extra xs    type (0/1--fuel/mod)
    1         1        1.00000E+00    2.93000E+02   0.00000E+00              0
      2809 locations of  100000 available are required to make a new master containing the self-shielded values
 0no nuclides in your problem have bondarenko factor data**bonami will copy from logical 11 to logical  1
 0copy      5010  b-10 1273 218ngp from log 11 to log  1    bondarenko trigger 0
 0copy      5011  boron-11         from log 11 to log  1    bondarenko trigger 0
 0copy      6012  carbon-12        from log 11 to log  1    bondarenko trigger 0
 0copy      9019  fluorine         from log 11 to log  1    bondarenko trigger 0
 0copy     13027  al-27 1193 218 g from log 11 to log  1    bondarenko trigger 0
 0copy     20000  calcium endf/b-i from log 11 to log  1    bondarenko trigger 0
 0copy     22000  titanium         from log 11 to log  1    bondarenko trigger 0
 0copy     23051  v 1196 218 gp 1/ from log 11 to log  1    bondarenko trigger 0
 0copy     26000  iron             from log 11 to log  1    bondarenko trigger 0
 0copy     92235  uranium-235      from log 11 to log  1    bondarenko trigger 0
 0copy     92238  uranium-238      from log 11 to log  1    bondarenko trigger 0
```

Example Output for Honeycomb Calculations (cont'd)

Example Output for Honeycomb Calculations (cont'd)

```
0      -1q array has      1 entries.
0       0q array has      9 entries.
0       1q array has     12 entries.
0select 11 nuclides from the master  library on logical  1
         0 nuclides from the working library on logical  2
         0 nuclides from the working library on logical  3
           to create the new working library on logical  4

         3 resonance calculations have been requested
        -1 output option for ampx formatted cross section data
0the storage allocated for this case is 100000 words
0       2q array has     11 entries.
0       3q array has     45 entries.
0       4q array has     11 entries.
0 general information concerning cross section library
    tape identification number                  27
    number of nuclides on tape                  11
    number of neutron energy groups             27
    first thermal neutron energy group          15
    number of gamma energy groups                0
0  direct access unit number  9 requires 118 blocks of length  1568 words
- xsdrn tape    27
                        nuclear criticality safety software version 1 cross section library
                                27 neutron groups   revision 000    august 14, 1991
                                version 1 revision 000 data taken from scale 4.1


 0 nuclides from xsdrn tape
      1   b-10 1273 218gp 04237S p-3 293k                                    5010
      2   boron-11          endf/b-iv mat 1160    updated 10/12/89          5011
      3   carbon-12         endf/b-iv mat 1274/thrm1065  updated 10/12/89    6012
      4   fluorine          endf/b-iv mat 1277    updated 10/12/89          9019
      5   al-27 1193 218 gp 04037S(5)                                       13027
      6   calcium endf/b-iv mat 1195            updated 9/07/89             20000
      7   titanium          endf/b-iv mat 1286  updated 10/12/89            22000
      8   v 1196 218 gp 1/e*sigt 04037S(5)                                  23051
      9   iron              endf/b-iv mat 1192  updated 10/12/89            26000
     10   uranium-235       endf/b-iv mat 1261  updated 10/12/89            92235
     11   uranium-238       endf/b-iv mat 1262  updated 10/12/89            92238
```

Example Output for Honeycomb Calculations (cont'd)

```
0b-10 1273 218ngp 042375 p-3 293k                                    5010    temperature=  293.00
                thermal scattering matrix number   1 at a temperature of   293.00 was selected.
0 boron-11      endf/b-iv mat 1160                 updated 10/12/89    5011    temperature=  293.00
                thermal scattering matrix number   1 at a temperature of   293.00 was selected.
0 carbon-12     endf/b-iv mat 1274/thrm1065        updated 10/12/89    6012    temperature=  293.00
                thermal scattering matrix number   1 at a temperature of   293.00 was selected.
0 fluorine      endf/b-iv mat 1277                 updated 10/12/89    9019    temperature=  293.00
0al-27 1193 218 gp 042375(5)                                        13027    temperature=  293.00
0calcium endf/b-iv mat 1195                        updated 9/07/89  20000    temperature=  293.00
0 titanium      endf/b-iv mat 1286                 updated 10/12/89 22000    temperature=  293.00
0v 1196 218 gp 1/e*sigt 042375(5)                                   23051    temperature=  293.00
0 iron          endf/b-iv mat 1192                 updated 10/12/89 26000    temperature=  293.00
0geometry has been set to homogeneous as tbar is  0.0000E+00
0resonance data for this nuclide
0mass number (a)          =   55.365          temperature(kelvin)     =   293.000
0potential scatter sigma  =    2.659          lumped nuclear density  = 5.290707BE-05
0spin factor (g)          =     .748          lump dimension (a-bar)  = 0.0000000E+00
0inner radius             = 0.0000000E+00     dancoff correction (c)  = 0.0000000E+00
0the absorber will be treated by the nordheim integral method.
                                              sigma(par absorber atom)= 6.8236641E+03
0mass of moderator-1      =   12.000
0moderator-1 will be treated by the nordheim integral method.
0mass of moderator-2      =   29.066          sigma(par absorber atom)= 2.7906229E+01
0moderator-2 will be treated by the nordheim integral method.
0this resonance material will be treated as a 0-dimensional object.
0volume fraction of lump in cell used to account for spatial self-shielding=1.00000
0group      res abs       res fiss      res scat
     8   -2.236335E-06  0.000000E+00  -6.307345E-03
     9   -2.803153E-05  0.000000E+00  -1.151659E-02
0excess resonance integrals
0           resolved
0absorption      1.52575E-02
  fission        0.00000E+00
 . elapsed time   .02 min.
```

Example Output for Honeycomb Calculations (cont'd)

```
0 uranium-235    endf/b-iv mat 1261        updated 10/12/89          92235    temperature=   293.00
0geometry has been set to homogeneous as lbar is  0.0000E+00
0resonance data for this nuclide
0mass number (a)          =   233.025          temperature(kelvin)       =   293.000
0potential scatter sigma  =    11.500          lumped nuclear density    = 1.0744590E-05
0spin factor (g)          = 15171.100          lump dimension (a-bar)    = 0.0000000E+00
0inner radius             = 0.0000000E+00      dancoff correction (c)    = 0.0000000E+00
0the absorber will be treated by the nordheim integral method.
0mass of moderator-1      =    12.000          sigma(per absorber atom)= 3.3600176E+04
0moderator-1 will be treated by the nordheim integral method.
0mass of moderator-2      =    32.168          sigma(per absorber atom)= 1.8270181E+02
0moderator-2 will be treated by the nordheim integral method.
0this resonance material will be treated as a 0-dimensional object.
0volume fraction of lump in cell used to account for spatial self-shielding=1.00000
0group      res abs        res fiss       res scat
   12     -2.346138E-01   -1.447781E-01   -5.802286E-03
   13     -8.219845E-01   -3.968134E-01   -1.555598E-02
   14     -2.815282E-01   -1.442862E-01    4.575240E-04
0excess resonance integrals
0          resolved
0absorption      2.24808E+02
 fission         1.33287E+02
 . elapsed time      .08 min.
0 uranium-238    endf/b-iv mat 1262        updated 10/12/89          92238    temperature=   293.00
0geometry has been set to homogeneous as lbar is  0.0000E+00
0resonance data for this nuclide
0mass number (a)          =   236.006          temperature(kelvin)       =   293.000
0potential scatter sigma  =    10.599          lumped nuclear density    = 7.7403831E-07
0spin factor (g)          =   656.527          lump dimension (a-bar)    = 0.0000000E+00
0inner radius             = 0.0000000E+00      dancoff correction (c)    = 0.0000000E+00
0the absorber will be treated by the nordheim integral method.
0mass of moderator-1      =    12.000          sigma(per absorber atom)= 4.6641119E+05
0moderator-1 will be treated by the nordheim integral method.
0mass of moderator-2      =    33.688          sigma(per absorber atom)= 2.6735754E+03
0moderator-2 will be treated by the nordheim integral method.
0this resonance material will be treated as a 0-dimensional object.
0volume fraction of lump in cell used to account for spatial self-shielding=1.00000
0group      res abs        res fiss       res scat
   9      -1.244094E-05    0.000000E+00   -1.631894E-04
   10     -8.443999E-04   -5.309158E-09   -4.176339E-03
   11     -5.251247E-02    0.000000E+00   -1.683700E-01
   12     -6.150901E-01    0.000000E+00   -7.311488E-01
   13     -4.679463E-01    0.000000E+00   -1.314558E-01
   14     -3.938370E-01    0.000000E+00   -1.029539E-02
```

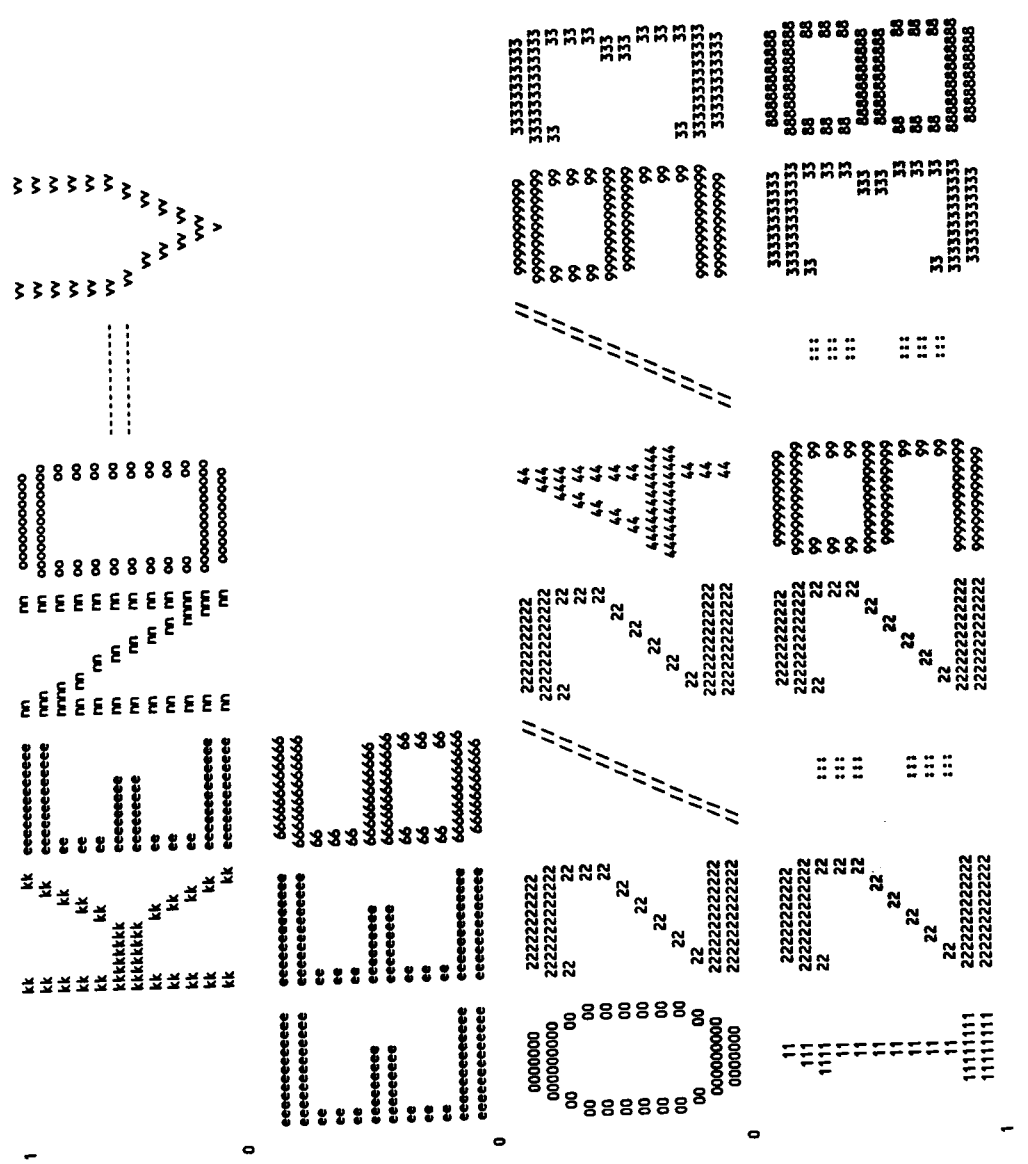
Example Output for Honeycomb Calculations (cont'd)

```
0excess resonance integrals
0          resolved
0absorption      2.67811E+02
 fission         5.33631E-04
 - elapsed time    .16 min.
 - elapsed time    .17 min.
1    this xsdrn working tape was created 02/24/93 at 12:29:28
     the title of the parent case is as follows
     nuclear criticality safety software version 1 cross section library
     27 neutron groups   revision 000   august 14, 1991
     version 1 revision 000 data taken from scale 4.1
          tape id                    27          number of nuclides          11
          number of neutron groups   27          number of gamma groups       0
          first thermal group        15          logical unit                 4

                         table of contents

     b-10 1273 218gp 04237S p-3 293k                          id      5010
      boron-11          endf/b-iv mat 1160      updated 10/12/89 id      5011
      carbon-12         endf/b-iv mat 1274/thrm1065 updated 10/12/89 id  6012
      fluorine          endf/b-iv mat 1277      updated 10/12/89 id      9019
     al-27 1193 218 gp 04037S(5)                               id      13027
     calcium endf/b-iv mat 1195               updated 9/07/89  id      20000
      titanium          endf/b-iv mat 1286     updated 10/12/89 id      22000
     v 1196 218 gp 1/e*sigt 04037S(5)                          id      23051
      iron              endf/b-iv mat 1192     updated 10/12/89 id      26000
      uranium-235       endf/b-iv mat 1261     updated 10/12/89 id      92235
      uranium-238       endf/b-iv mat 1262     updated 10/12/89 id      92238
0         tape copy used      0 i/o's, end took      .03 seconds
0
```

Example Output for Honeycomb Calculations (cont'd)



```
1
Olifetime =  8.68668E-04 + or -  3.67766E-06
nu bar    =  2.41907E+00 + or -  2.87332E-05
Ono. of initial
   generations      average
       skipped   k-effective          deviation
              3     .99140  + or -    .00298
              4     .99153  + or -    .00299
              5     .99152  + or -    .00301
              6     .99152  + or -    .00302
              7     .99171  + or -    .00303
              8     .99210  + or -    .00302
              9     .99224  + or -    .00304
             10     .99210  + or -    .00305
             11     .99193  + or -    .00306
             12     .99190  + or -    .00308
             17     .99271  + or -    .00309
             22     .99266  + or -    .00315
             27     .99289  + or -    .00319
             32     .99331  + or -    .00323
             37     .99408  + or -    .00329
             42     .99244  + or -    .00322
             47     .99262  + or -    .00330
             52     .99290  + or -    .00338
             57     .99268  + or -    .00346
             62     .99356  + or -    .00354
             67     .99372  + or -    .00366
             72     .99427  + or -    .00372
             77     .99497  + or -    .00379
             82     .99638  + or -    .00380
             87     .99596  + or -    .00392
             92     .99508  + or -    .00405
              1

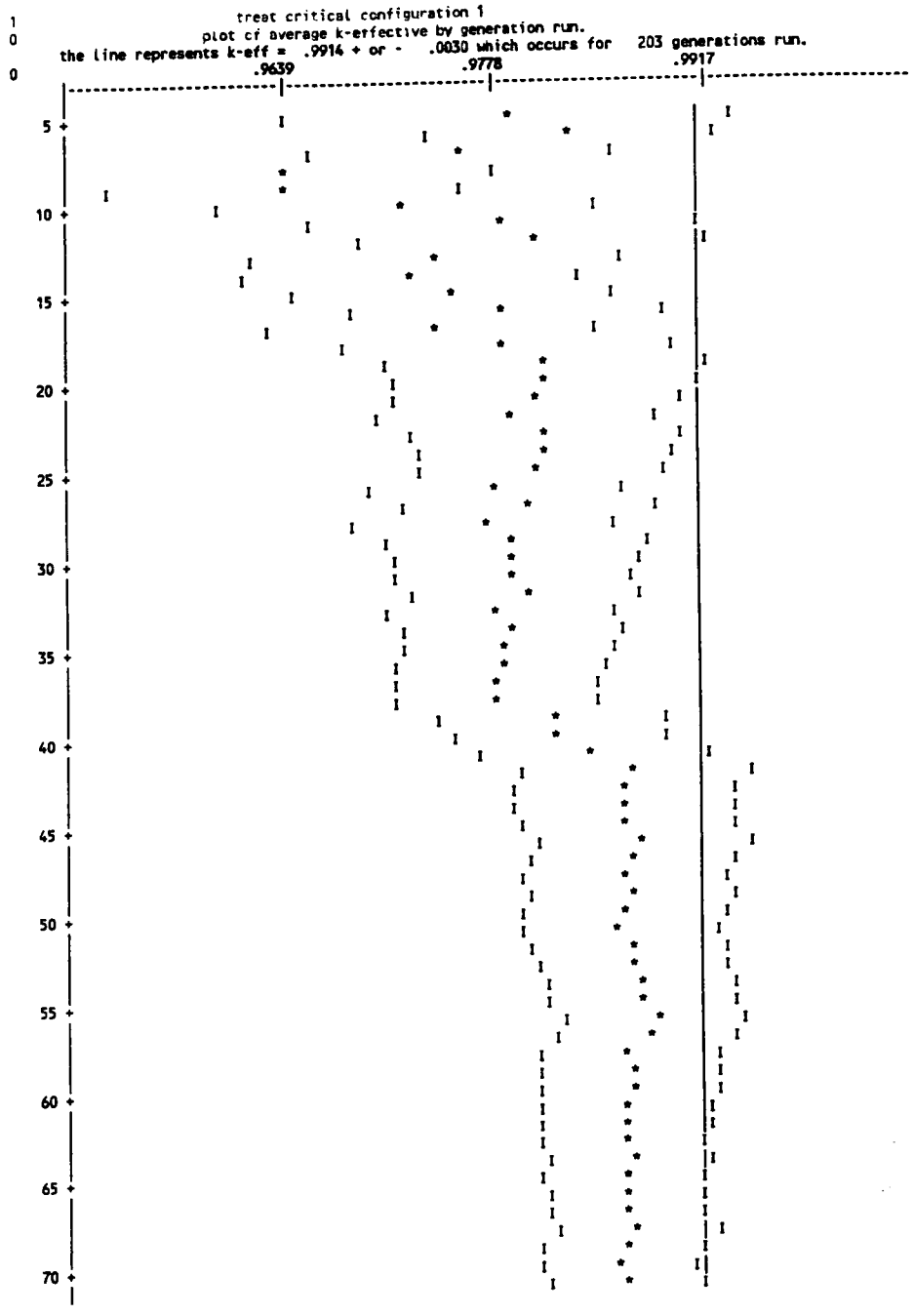
treat critical configuration 1
        generation time =  8.11417E-04 + or -  3.90394E-06
        average fission group =  2.34387E+01 + or -  1.23053E-02

                67 per cent                 95 per cent                 99 per cent                 number of
             confidence interval         confidence interval         confidence interval           histories
              .98842 to .99438            .98543 to .99736            .98245 to 1.00034            100000
              .98854 to .99453            .98555 to .99752            .98256 to 1.00051             99500
              .98851 to .99453            .98551 to .99754            .98250 to 1.00055             99000
              .98850 to .99455            .98548 to .99757            .98245 to 1.00059             98500
              .98868 to .99475            .98565 to .99778            .98262 to 1.00081             98000
              .98908 to .99513            .98606 to .99815            .98303 to 1.00117             97500
              .98921 to .99528            .98617 to .99831            .98313 to 1.00135             97000
              .98905 to .99515            .98600 to .99819            .98295 to 1.00124             96500
              .98887 to .99499            .98581 to .99805            .98275 to 1.00111             96000
              .98882 to .99497            .98575 to .99805            .98267 to 1.00112             95500
              .98962 to .99580            .98653 to .99889            .98344 to 1.00198             93000
              .98951 to .99580            .98637 to .99895            .98322 to 1.00209             90500
              .98971 to .99608            .98652 to .99927            .98333 to 1.00245             88000
              .99009 to .99654            .98686 to .99976            .98364 to 1.00299             85500
              .99079 to .99737            .98750 to 1.00065           .98421 to 1.00394             83000
              .98922 to .99566            .98600 to .99888            .98278 to 1.00210             80500
              .98932 to .99592            .98602 to .99922            .98272 to 1.00232             78000
              .98952 to .99629            .98614 to .99967            .98275 to 1.00306             75500
              .98922 to .99615            .98576 to .99961            .98229 to 1.00308             73000
              .99002 to .99710            .98649 to 1.00064           .98295 to 1.00418             70500
              .99007 to .99738            .98641 to 1.00104           .98275 to 1.00469             68000
              .99056 to .99799            .98684 to 1.00171           .98312 to 1.00542             65500
              .99118 to .99876            .98738 to 1.00256           .98359 to 1.00635             63000
              .99258 to 1.00018           .98878 to 1.00398           .98498 to 1.00778             60500
              .99204 to .99988            .98812 to 1.00380           .98419 to 1.00772             58000
              .99103 to .99913            .98698 to 1.00318           .98293 to 1.00723             55500
                    treat critical configuration 1
```

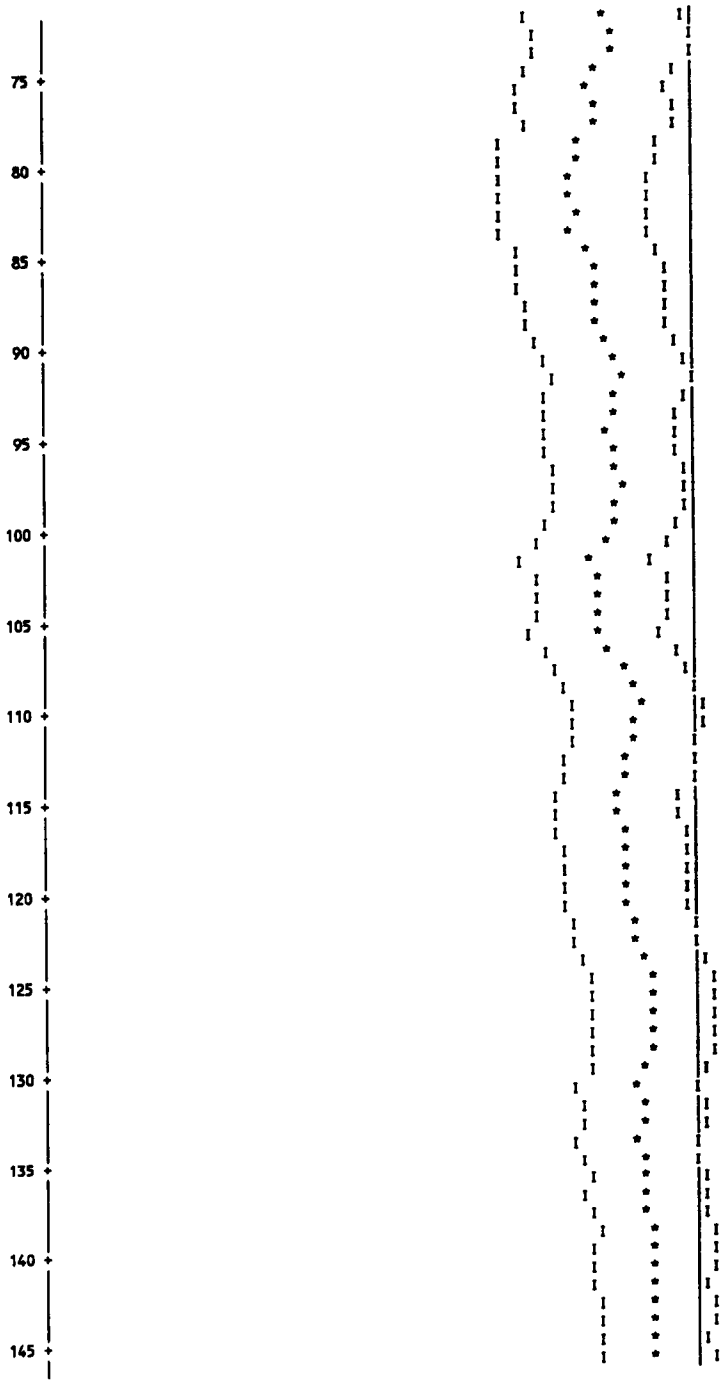
Example Output for Honeycomb Calculations (cont'd)

Ono. 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
0 97	.99556	+ or -	.00419	.99136 to .99975	.98717 to 1.00395	.98297 to 1.00814	53000
0 102	.99811	+ or -	.00414	.99396 to 1.00225	.98982 to 1.00639	.98568 to 1.01053	50500
0 107	.99728	+ or -	.00421	.99307 to 1.00149	.98885 to 1.00571	.98464 to 1.00992	48000
0 112	.99595	+ or -	.00429	.99166 to 1.00023	.98737 to 1.00452	.98309 to 1.00880	45500
0 117	.99755	+ or -	.00434	.99321 to 1.00190	.98887 to 1.00624	.98452 to 1.01058	43000
0 122	.99718	+ or -	.00459	.99259 to 1.00177	.98800 to 1.00636	.98342 to 1.01095	40500
0 127	.99595	+ or -	.00469	.99126 to 1.00064	.98656 to 1.00534	.98187 to 1.01003	38000
0 132	.99764	+ or -	.00472	.99292 to 1.00236	.98820 to 1.00708	.98348 to 1.01180	35500
0 137	.99801	+ or -	.00485	.99315 to 1.00286	.98830 to 1.00771	.98345 to 1.01257	33000
0 142	.99782	+ or -	.00517	.99265 to 1.00299	.98748 to 1.00816	.98232 to 1.01332	30500
0 147	.99759	+ or -	.00559	.99199 to 1.00318	.98640 to 1.00877	.98081 to 1.01437	28000
0 152	.99604	+ or -	.00606	.98998 to 1.00210	.98391 to 1.00817	.97785 to 1.01423	25500
0 157	.99644	+ or -	.00653	.98992 to 1.00297	.98339 to 1.00950	.97686 to 1.01602	23000
0 162	.99523	+ or -	.00696	.98827 to 1.00219	.98131 to 1.00915	.97435 to 1.01611	20500
0 167	1.00174	+ or -	.00625	.99549 to 1.00800	.98924 to 1.01425	.98299 to 1.02050	18000
0 172	1.00136	+ or -	.00717	.99419 to 1.00852	.98702 to 1.01569	.97986 to 1.02286	15500
0 177	.99940	+ or -	.00794	.99144 to 1.00734	.98352 to 1.01527	.97559 to 1.02321	13000
0 182	.99331	+ or -	.00873	.98458 to 1.00204	.97584 to 1.01077	.96713 to 1.01950	10500
0 187	.99093	+ or -	.01040	.98034 to 1.00153	.96974 to 1.01212	.95915 to 1.02272	8000
0 192	.99269	+ or -	.01345	.97924 to 1.00615	.96579 to 1.01960	.95233 to 1.03305	5500
0 197	.98774	+ or -	.02154	.96619 to 1.00928	.94465 to 1.03083	.92311 to 1.05237	3000

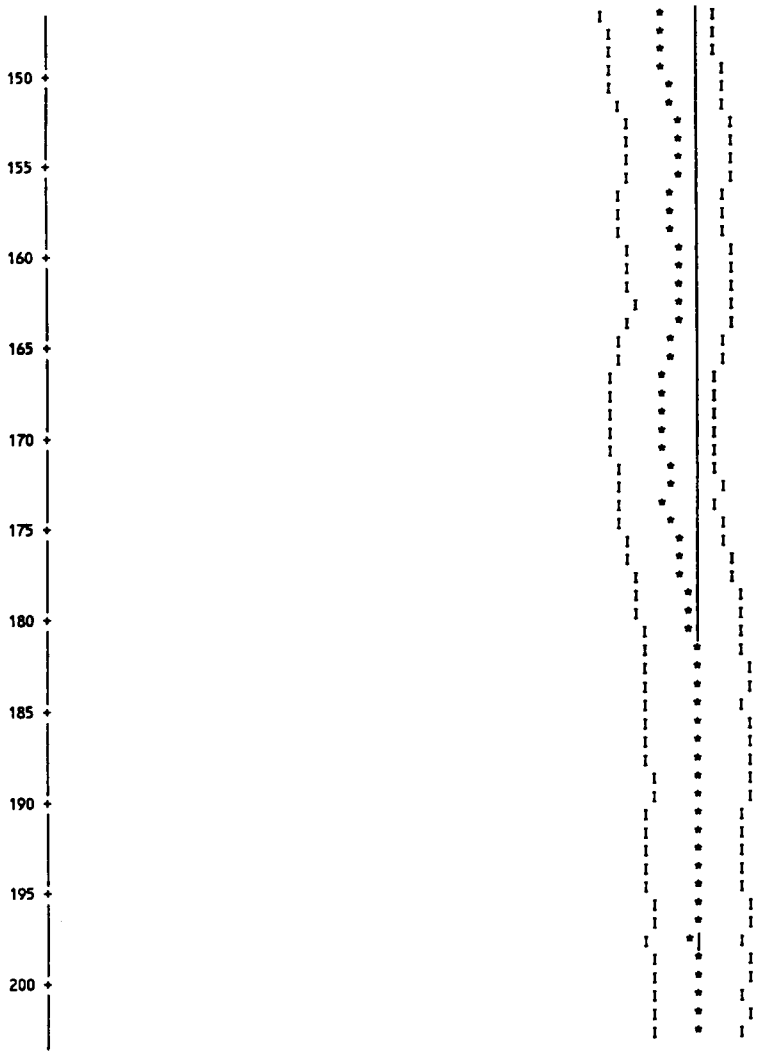
Example Output for Honeycomb Calculations (cont'd)



Example Output for Honeycomb Calculations (cont'd)



Example Output for Honeycomb Calculations (cont'd)



Example Output for Honeycomb Calculations (cont'd)

```
1treat critical configuration 1
0                              frequency for generations    4 to  203
  .8401 to  .8580     *
  .8580 to  .8759     *
  .8759 to  .8937     *
  .8937 to  .9116     ******
  .9116 to  .9295     *********
  .9295 to  .9474     **
  .9474 to  .9653     ****************************
  .9653 to  .9832     ******************************************
  .9832 to 1.0011     ***********************************
 1.0011 to 1.0190     *********************************
 1.0190 to 1.0369     ****************************
 1.0369 to 1.0547     ***********
 1.0547 to 1.0726     *********
 1.0726 to 1.0905     ****
 1.0905 to 1.1084
 1.1084 to 1.1263     *
0                              frequency for generations   54 to  203
  .8401 to  .8580     *
  .8580 to  .8759     *
  .8759 to  .8937     *
  .8937 to  .9116     ***
  .9116 to  .9295     ******
  .9295 to  .9474     **
  .9474 to  .9653     ******************
  .9653 to  .9832     *******************************
  .9832 to 1.0011     ***************************
 1.0011 to 1.0190     ***************************
 1.0190 to 1.0369     ******************
 1.0369 to 1.0547     **********
 1.0547 to 1.0726     ********
 1.0726 to 1.0905     ***
 1.0905 to 1.1084
 1.1084 to 1.1263
0                              frequency for generations  104 to  203
  .8401 to  .8580     *
  .8580 to  .8759
  .8759 to  .8937
  .8937 to  .9116     ***
  .9116 to  .9295     **
  .9295 to  .9474     **
  .9474 to  .9653     *********
  .9653 to  .9832     ******************
  .9832 to 1.0011     ******************
 1.0011 to 1.0190     ******************
 1.0190 to 1.0369     ************
 1.0369 to 1.0547     ********
 1.0547 to 1.0726     *******
 1.0726 to 1.0905     **
 1.0905 to 1.1084
 1.1084 to 1.1263
1treat critical configuration 1
0                              frequency for generations  154 to  203
  .8401 to  .8580     *
  .8580 to  .8759
  .8759 to  .8937
  .8937 to  .9116     *
  .9116 to  .9295     **
  .9295 to  .9474
  .9474 to  .9653     ******
  .9653 to  .9832     ********
  .9832 to 1.0011     **********
 1.0011 to 1.0190     *********
 1.0190 to 1.0369     *****
 1.0369 to 1.0547     **
 1.0547 to 1.0726     *****
 1.0726 to 1.0905     *
 1.0905 to 1.1084
 1.1084 to 1.1263
```

Vita

Ernest Paul Elliott was born in Lexington, Kentucky on February 24, 1961. He moved to Johnson City, Tennessee in late 1961 and was graduated from Science Hill High School in June, 1979. In September, 1979, he entered The University of Tennessee in Knoxville, Tennessee where he received Bachelor of Science degrees in Nuclear Engineering (June, 1984) and Mechanical Engineering (March, 1986).

After graduation, Mr. Elliott worked for both Duke Power Company in Charlotte, North Carolina and for EG&G Rocky Flats in Golden, Colorado. In June, 1991, he accepted a position at the Martin Marietta Energy Systems, Inc., Oak Ridge Y-12 Plant.

In August of 1991, Mr. Elliott enrolled in The University of Tennessee and began study toward a Master of Science degree in Nuclear Engineering. This degree was awarded in December of 1993.

Mr. Elliott is a member of the American Nuclear Society and is currently employed with Martin Marietta Energy Systems as a Nuclear Criticality Safety Engineer at the Oak Ridge Y-12 Plant.