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6.0 CRITICALITY

The following analyses demonstrate that the Traveller complies fully with the requirements of 10CFR71[1] and TS-R-1[2]. The nuclear criticality safety requirements for Type A fissile packages are satisfied for single package and array configurations under normal conditions of transport and hypothetical accident conditions. A comprehensive description of the Traveller packaging is provided in Section 1. This section provides a description of the package (i.e., packaging and contents) that is sufficient for understanding the features of the Traveller that maintain criticality safety.

Specifically, this criticality evaluation presents the following information[3]:

1. Description of the contents and packaging, including maximum and minimum mass of materials, maximum ^{235}U enrichment, physical parameters, type, form, and composition.

2. Description of the calculational models, including sketches with dimensions and materials, pointing out the differences between the models and actual package design, with explanation of how the differences affect the calculations.

3. Justification for the credit assumed for the fixed neutron absorber content, including reference to the acceptance tests that are implemented which verify the presence and uniformity of the absorber.

4. Justification for assuming 90% credit for fixed moderating material.

5. Description of the most reactive content loading and the most reactive configuration of the contents, the packaging, and the package array in the criticality evaluation.

6. Description of the codes and cross-section data used, together with references that provide complete information.

7. Discussion of software capabilities and limitations of importance to the criticality safety evaluations.

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1. Title 10, Code of Federal Regulations, Part 71 (10CFR71), Packaging and Transportation of Radioactive Material, edition effective Oct 2004.
2. TS-R-1 1996 (Revised), Regulations for the Safe Transport of Radioactive Material.
3. NUREG/CR-5661, Recommendations for Preparing the Criticality Safety Evaluation of Transport Packages.

8. Description of validation procedures to justify the bias and uncertainties associated with the calculational method, including use of the administrative subcritical margin of 0.05 delta k to set an upper safety limit (USL) of 0.94.

9. Demonstration that the effective neutron multiplication factor (k_{eff}) calculated in the safety analysis is less than the USL after consideration of appropriate bias and uncertainties for the following.

   a. A single package with optimum moderation within the containment (i.e., confinement) system, close water reflection, and the most reactive packaging and content configuration consistent with the effects of either normal conditions of transport or hypothetical accident conditions, whichever is more reactive.

   b. An array of 5N undamaged packages (packages subject to normal conditions of transport) with nothing between the packages and close water reflection of the array.

   c. An array of 2N damaged packages (packages subject to hypothetical accident conditions) if each package were subjected to the tests specified in §71.73, with optimum interspersed moderation and close water reflection of the array.

10. Calculation of the Criticality Safety Index (CSI) based on the value of N determined in the array analyses.

11. Description of the Traveller's Confinement System.

6.1 DESCRIPTION OF CRITICALITY DESIGN

6.1.1 Design Features

This section describes the design features of the Traveller that are important for criticality. The Traveller shipping package carries either a single PWR fuel assembly, VVER fuel assembly, or a single rod container that hold either PWR or BWR rods. The Traveller is divided into two major systems, Outerpack and Clamshell. The Outerpack consists of a polyurethane foam material sandwiched between concentric stainless steel shells. The Outerpack is a split-shell design with the two halves hinged together. Neutron-moderating high-density polyethylene blocks are affixed to the upper and lower halves of the Outerpack.

The Clamshell is a rectangular aluminum box that completely encloses the contents. It is rotated 45° and mounted in the Outerpack with rubber shock mounts. Neutron absorber panels are slotted into the inner face of each Clamshell side. The Clamshell is designed such that it retains its original dimensions when subjected to the HAC tests. See Figure 6-1 for an exploded view of the Traveller.

The VVER design features including the hexagonal clamshell design are further described in Section 6.10.11.2.

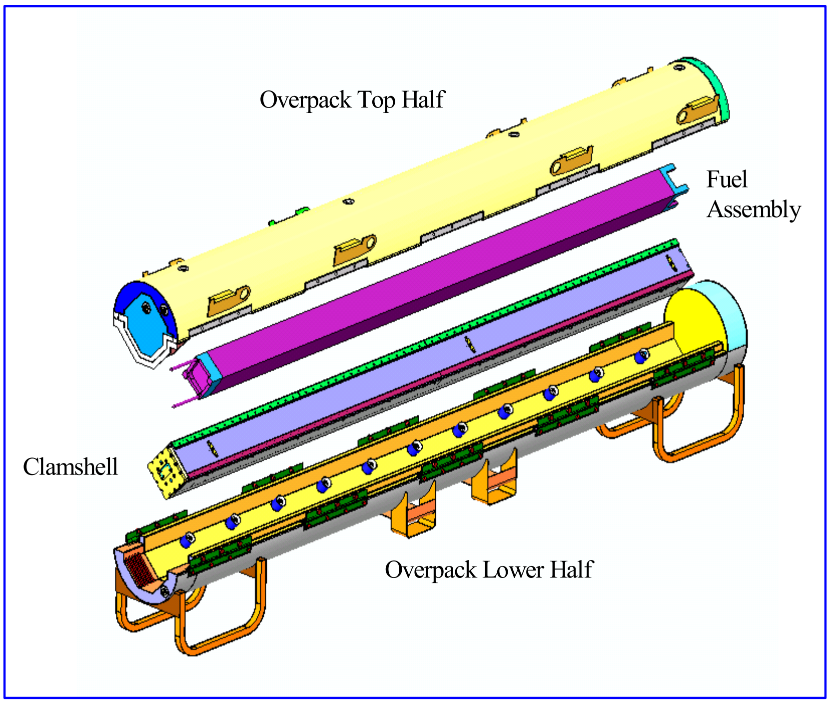

Figure 6-1 Traveller Exploded View

6.1.1.1 Containment System

The Containment System is described in both TSR-1 and 10CFR71 as, “the assembly of components of the packaging intended to retain the radioactive material during transport.” The Containment System for the Traveller consists of the fuel rods, regardless of whether the Traveller is carrying a fuel assembly or rods in a rod container.

6.1.1.2 Confinement System

The Confinement System is defined in TS-R-1 as “the assembly of fissile material and packaging components specified by the designer and agreed to by the competent authority as intended to preserve criticality safety.” Note that TS-G-1.1[1] further describes the confinement system as “that part of a package necessary to maintain the fissile material in the configuration that was assumed in the criticality safety assessment for an individual package.” NUREG 1609[2] recommends that the analysis include a discussion of the “structural components that maintain the fissile material or neutron poisons in a fixed position within the package or in a fixed position relative to each other.” These structural components are intended to maintain criticality safety of the package. These structural components of the packaging actually comprise part of the Confinement System.

The Confinement System for the Traveller consists of those assembly and packaging components that preserve criticality safety of a single package in isolation. Hence, it consists of the fuel rods, the fuel assembly (or rod container), and the Clamshell assembly, including the neutron absorber panels. The Confinement System is shown in Figure 6-2.

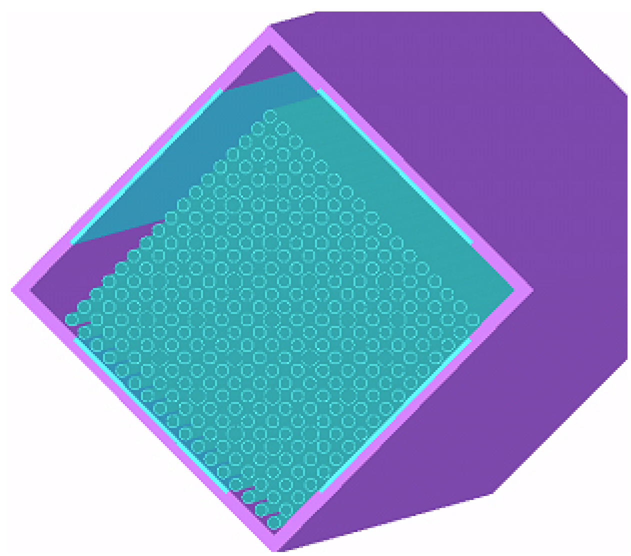

Figure 6-2 Traveller Confinement System

1. IAEA TS-G-1.1, Advisory Material for the IAEA Regulations for the Safe Transport of Radioactive Material.
2. NUREG 1609, Standard Review Plan for Transportation Packages for Radioactive Material

6.1.1.3 Flux Traps

The Traveller package features a unique flux trap system, which does not require an accident condition (i.e., flooding) in order to function. The system was designed to ensure an acceptable subcritical margin for the unlikely but most conservative flooding scenario, described later in this section. The flux trap system consists of neutron absorber panels in the Clamshell immediately adjacent to the contents, and high-density polyethylene (UHMW) blocks affixed to the inside of the Outerpack. Neutrons escaping from one fuel assembly would pass through two moderator blocks prior to passing through the absorber of the neighboring package.

Any flooding outside the Clamshell enhances the performance of the flux trap. The UHMW blocks ensure that there will be neutron moderation, and therefore, flux trap operation, in those array configurations where the contents are moderated inside the Clamshell but where there is no flooding in void spaces outside the Clamshell or between the packages. The flux trap components are further described below. Figure 6-3 shows the flux traps in a seven-package triangular-pitch array of Traveller packages.

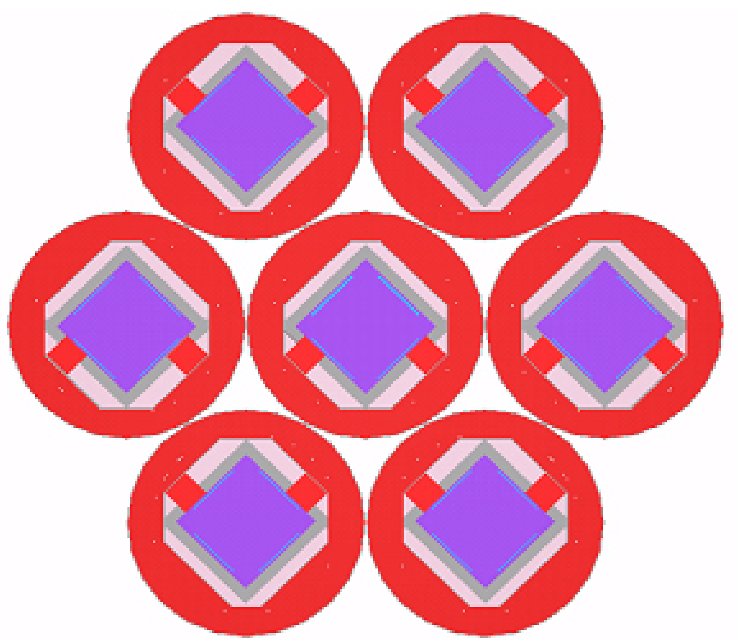

Figure 6-3 Seven Package Array Showing the Flux Trap System

6.1.1.4 Neutron-Absorbing Materials

Neutron absorbing materials are present in the Traveller in two forms: materials of construction and neutron poisons.

6.1.1.4.1 Materials of Construction

Materials of construction include those materials normally present, namely the stainless steel in the Outerpack, the fuel assembly skeleton, and the top nozzle. It also includes the burnable absorbers in the fuel. The evaluation takes credit for approximately 60% of the stainless steel in the inner and outer shells of the Outerpack. See Table 6-11. No credit is taken for the neutron absorbing properties of the fuel assembly skeleton or top nozzle, with the exception of the zirconium thimble tube material. In the criticality model the volumes occupied by skeleton and top nozzle are modeled as water. Water is assumed to increase reactivity more than steel by providing more neutron reflection or moderation than the steel. Finally, the evaluation does not consider the presence of any integral or burnable absorbers.

6.1.1.4.2 Neutron Poisons

Neutron poison has been added to the Traveller specifically to limit reactivity during hypothetical accident conditions. The neutron poison used in the Traveller is in the form of BORAL® panels in the Clamshell. These panels are permanently fixed.

6.1.1.4.3 Deleted

6.1.1.4.4 BORAL

BORAL is a thermal neutron poison material composed of boron carbide and 1100 alloy aluminum. Boron carbide is a compound having a high boron content in a physically stable and chemically inert form. The 1100 alloy aluminum is a light-weight metal with high tensile strength which is protected from corrosion by a highly resistant oxide form. The two materials, boron carbide and aluminum, are chemically compatible and ideally suited for long-term use. BORAL has been licensed by the NRC for use in numerous BWR and PWR spend fuel storage racks and has been used in international reactor installations. Manufacturing QA (i.e., neutronics or chemical testing) ensures that the minimum areal densities are achieved.

The BORAL sheets measure 0.125 inches (0.3175 cm) thick, including cladding and core. The nominal thickness of the cladding and core are as follows: Cladding (0.0179 inches/0.0455 cm), Core (0.0892 inches/ 0.2266 cm), Cladding (0.0179 inches/0.0455 cm). The maximum areal density loading for ^{10}B that corresponds to this thickness is 0.0240 g/cm^2, which equates to a B4C loading of 36.5%. This analysis assumes 75% credit for areal density, which equates to 0.0180 g/cm^2.

6.1.1.5 Neutron-Moderating Materials

Neutron-moderating materials in the Traveller include the polyurethane foam in the Outerpack, the shock mounts, and the high-density polyethylene (UHMW) blocks.

6.1.1.5.1 Polyurethane Foam

Results from the formal thermal test and the numerous scoping burn tests that were conducted indicate that an unpredictable amount of the polyurethane foam burns away. Therefore, no credit is taken for the foam under accident conditions. Rather, the foam is considered to be a floodable void space and will be modeled either as a void or filled with water, depending upon which is the most conservative.

6.1.1.5.2 Shock Mounts

Testing indicates that the shock mounts remain intact and hold the Clamshell in place. However, their contribution as a moderator is insignificant and therefore, they are modeled as full density water in the single package cases and as void spaces in the array cases.

The Traveller STD and Traveller XL have different shock mount configurations, which can be seen in the license drawings. Both configurations are symmetrical about the center of the outerpack. The Traveller STD configuration features four pair of shock mounts at either end of the outerpack, spaced 9.0 inches (22.9 cm) on center, with the end pair about 18 inches (45.7 cm) from the end. The Traveller XL configuration has three pair of shock mounts at either end plus a pair in the middle. The pair at the end is about 15 inches (37 cm) from the end. The second pair is 36 inches (91.4 cm) from the first pair, and the third pair is 18 inches (45.7 cm) from the second. The Traveller VVER outerpack is the same design as the Traveller XL, therefore the shock mounts are in the same design configuration.

6.1.1.5.3 High-density Polyethylene

High-density polyethylene (UHMW) “poly” is attached to the inside of the upper and lower sections of the Outerpack. The poly configuration is identical for both the Traveller STD and Traveller XL Outerpacks. The thickness is 1.25 in. [3.18 cm] in the upper section and 1.75 in [4.445 cm] in the lower section. The HPDE is a fixed moderator that together with the fixed neutron absorber installed in the Clamshell forms the flux trap system, which is discussed in Section 6.1.1.3. The UHMW density is 0.92 g/cc. The analysis assumes 90% density, or 0.828 g/cc. Section 6.7.7 discusses the effect of varying the HPDE density on system reactivity.

6.1.1.6 Floodable Void Spaces

The Traveller, including packaging and contents, contains six floodable regions. These regions have been modeled in various flooding combinations, including flooding with partial density water, in order to determine the most conservative accident configuration. The floodable regions are shown in Figure 6-4. (Note that region 1, the pin-gap, is shown in Figure 6-28). Flooding is addressed in Section 6.7.1. The region numbers below correspond to the numbers used in the criticality input decks.

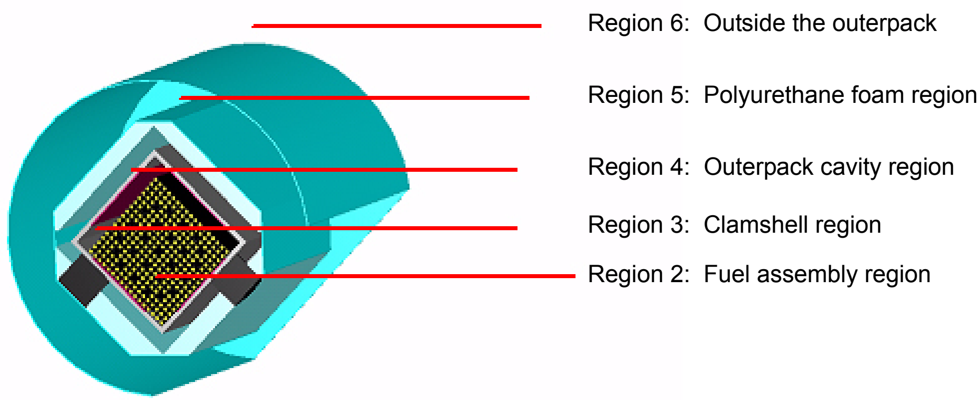

Figure 6-4 Floodable Void Spaces

6.1.1.6.1 Region 1 – Pellet-Cladding Gap (Pin Gap)

The pellet-cladding gap, or pin gap, is the floodable space inside the cladding. It was seen from the testing that some fuel rods may crack. Therefore, it is assumed that all rods have fully flooded pin gaps. The pin-gap is shown in Figure 6-28.

6.1.1.6.2 Region 2 – Fuel Assembly Region

The fuel assembly region is the floodable space in the fuel assembly envelope. It is modeled fully flooded in all configurations. Sensitivity studies were conducted with this area partially flooded to evaluate the effects of differential flooding.

6.1.1.6.3 Region 3 – Clamshell Region

The Clamshell region is the floodable space outside the fuel assembly region and inside the Clamshell. It is modeled both flooded and dry to determine which configuration is most conservative for single package or array. Sensitivity studies were conducted with the Clamshell partially full to evaluate the partial flooding scenario.

6.1.1.6.4 Region 4 – Outerpack Cavity Region

The Outerpack cavity region is the floodable space outside the Clamshell and inside the Outerpack. It was modeled both flooded and dry to determine which configuration is most conservative for single package or array configurations. Sensitivity studies were conducted with the Outerpack cavity region partially full to evaluate the partial flooding scenario.

6.1.1.6.5 Region 5 – Polyurethane Foam Region

The polyurethane foam region is the floodable space that is formed when the polyurethane foam burns away. As mentioned above, since it is difficult to predict how much foam will actually burn away, the entire foam region is modeled as water for the individual package cases and as a void for the array cases. These are the most conservative configurations.

6.1.1.6.6 Region 6 – Outside Outerpack Region

This is the volume outside the Outerpack. It has been modeled both flooded and dry to determine which configuration is most conservative for single package and array.

6.1.1.7 Array Spacing Significant Components

The single component that affects the physical separation of the fissile material contents in package arrays is the Outerpack. The Outerpack outer radius is 12.50 inches ± 1.0 inch (317.50 mm ±25.40 mm). It is a cylindrical annular shell split along the longitudinal axis to form two separate halves. The inner and outer shells are fabricated from 12-gauge [0.104 in. 0.264 cm)] stainless steel sheet, and the space between the shells is filled with polyurethane foam. The foam has a nominal 3.0 in. (7.62 cm) radial thickness and axial thickness of approximately 8.0 in. (20.32 cm). The foam material limits impact forces on the fuel assembly and insulates the fuel assembly from heat generated by a fire. Circumferential stiffeners mounted outside provide significant impact protection to the Outerpack diameter. The Outerpack diameter is not reduced at all following hypothetical accident tests. A sensitivity study was performed to evaluate k_{eff} as a function of Outerpack diameter. This evaluation is described in Section 6.7.11.

6.1.2 Summary Tables of Criticality Evaluation

Sensitivity studies were performed using the Traveller XL to determine the most conservative configurations for the normal and hypothetical accident conditions for an individual package and package arrays. These results, rounded to three decimal places, are shown in Table 6-1 for PWR and VVER. Calculations were also made to show that the Traveller STD is bounded by the Traveller XL. Results for the Traveller STD are given in Table 6-2. Finally, Table 6-3 shows the results for the Rod Pipe in the Traveller XL. Results for VVER fuel assembly contents evaluated within the Traveller XL are detailed in Section 6.10.11; results of Table 6-43 are repeated in Table 6-1, where it can be seen that the Traveller XL with PWR fuel assembly contents remains bounding.

Table 6-1 Summary Table for Traveller XL with PWR and VVER

Traveller XL	K_{eff}
Single Package - PWR	
Normal	0.201
HAC	0.885
Single Package - VVER	
Normal	0.848
HAC	0.891
Package Array - PWR	
Normal	0.272
HAC	0.939
Package Array - VVEW	
Normal	0.344
HAC	0.935

Table 6-2 Summary Table for Traveller STD with PWR Fuel Assembly

Traveller STD	K_{eff}
Single Package	
Normal	n/a
HAC	0.865
Package Array	
Normal	0.256
HAC	0.897

Table 6-3 Summary Table for Traveller XL with the Rod Pipe	
	K_{eff}
Single Package	
Rod Pipe	0.750
Package Array	
Rod Pipe	0.750

6.1.3 Criticality Safety Index (CSI)

6.1.3.1 PWR Fuel Transport Index

The Criticality Safety Index when transporting PWR fuel assemblies is calculated as follows:

2 * N = Array Size
Array Size = 150
N= 150/2 → 75
Therefore, CSI = 50/75 → 0.7

6.1.3.2 VVER Fuel Transport Index

The Criticality Safety Index when transporting VVER fuel assemblies is calculated as follows:

2 * N = Array Size
Array Size = 150
N= 150/2 → 75
Therefore, CSI = 50/75 → 0.7

Details of the VVER calculations are in Section 6.10.11.

6.1.3.3 Rod Pipe Transport Index

The Criticality Safety Index when transporting rods in either rod container is calculated as follows:

2 * N = Array Size
Array Size = infinite
N= infinity/2 → infinity
Therefore, CSI = 50/infinity → 0.0

6.2 FISSILE MATERIAL CONTENTS

The package will be used to carry heterogeneous uranium compounds in the form of fuel rods. These rods will be transported either as PWR fuel assemblies, VVER fuel assemblies, or as loose PWR or BWR fuel rods in a rod container. The uranium enrichment shall not be greater than 5.0 wt% ^{235}U. The uranium isotopic distribution considered in the models in this criticality safety analysis is shown in Table 6-4.

Table 6-4 Uranium Isotope Distribution

Isotope	Modeled Wt%
^{235}U	5.0
^{238}U	95.0

Reactor control cluster (RCC) assemblies, secondary source assemblies, and solid stainless steel rods that may be placed in the PWR fuel assembly are non-fissile material. VVER fuel assembly contents are detailed further in subsections of Section 6.10.11.3.

6.2.1 PWR Fuel Assemblies

The fuel assembly types to be transported in the Traveller belong to the 14x14, 15x15, 16x16, 17x17, and 18x18 families. Different fuel assembly products in each family may have names not included in this application, but the parameters important to criticality are described in Appendix 6.10.1. The Traveller XL will carry all fuel assembly types while the Traveller will carry the 12-ft. long assemblies.

Calculations were performed to determine which fuel assembly would be the most reactive. Appendix 6.10.2 provides more detail. The analysis compares k_{eff} versus fuel assembly envelope when expanding a 100 cm length of the assembly from nominal to 14 inches (35.56 cm). Figure 6-23 shows the results over the entire range. Figure 6-5 shows regression curve fits over the range of interest, that is, up to 9.6 inches/24.384 cm.

This analysis indicates that the 17x17OFA is the most reactive fuel assembly over the range of interest. However, the difference between the 17x17STD and the 17x17OFA is less significant at the top end of the range (9.6 inches/24.384 cm). The 17x17OFA is the most reactive contents and fuel assembly to use in all calculations. Reactor control cluster (RCC) assemblies, secondary source assemblies, and solid stainless steel that may be placed in the PWR fuel assembly are non-fissile material and lower the water-to-fuel ration in the fuel rod lattice. The fuel rod lattice is under moderated for both nominal and accident conditions; therefore, the displacement of water from the thimble tube locations by the RCC or secondary source assemblies caused k_{eff} to decrease. In addition to adding neutron absorption the solid stainless steel rod displaces a uranium rod from the fuel lattice which also causes k_{eff} to decrease.

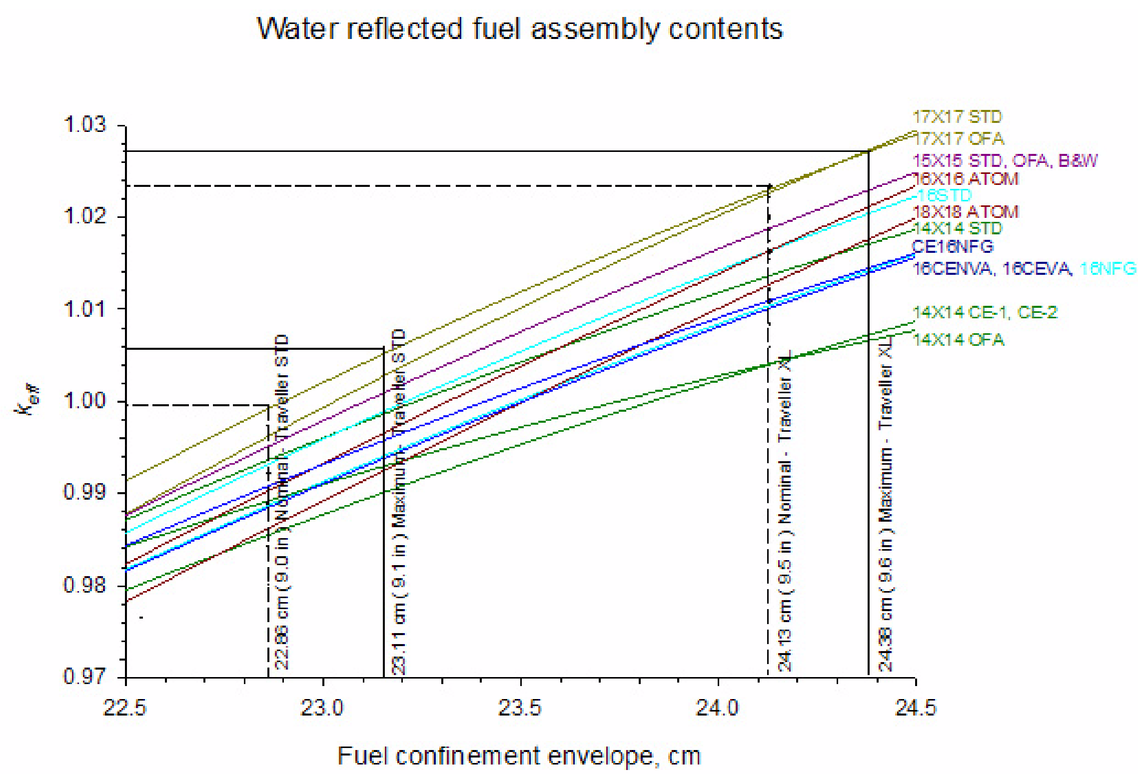

Figure 6-5 Regression Curves of k_{eff} Versus Fuel Assembly Envelope over Range of Interest

6.2.2 PWR and BWR Rods

The Traveller will carry loose rods in a rod pipe. Table 6-5 below gives the nominal parameter ranges for the fuel rods. Analysis for the rod pipe was based solely on pellet diameter and pellet pitch. Therefore, there are no restrictions on the non-fuel components of the rods. Fuel rods that satisfy the criteria of Table 6-5 may be transported. This applies to PWR and BWR fuel rods.

Table 6-5 Fuel Rod Parameters

Parameter	Limit
Maximum Enrichment	5.0 weight percent Uranium-235
Pellet diameter	0.508 – 1.524 cm (0.20 – 0.60 in.)
Maximum stack length	Up to rod container length
Cladding	Zirconium alloy
Integral absorber	Permitted (types include: Gadolinia, Erbia, Boron)
Wrapping or sleeving	Plastic or other material with moderating capability not greater than full density water, except for polyethylene sleeving used to protect fuel rods.
Maximum number of rods per container	Up to rod container capacity

6.3 GENERAL CONSIDERATIONS

The models developed for these calculations are not exact representations of the package, but they do explicitly include all of the physical features that are important to criticality safety. Modeling approximations will be shown to be either conservative or neutral with respect to the criticality safety case. This section describes the packaging and the contents models.

6.3.1 Model Configuration

Geometry input dimensions are taken directly from design drawings and are derived by stacking dimensions from design drawings or calculated using geometric relationships and dimensions shown on design drawings. Longitudinal dimensions in the model are oriented along the z-axis, and latitudinal dimensions are oriented in the x-y plane. The origin of the individual package unit is near the bottom of the package along the z-axis and at the center of the package in the x-y plane. The positive direction is from bottom to top of the package along the z-axis, the positive direction is from left to right along the x-axis when viewed from the top of the package and the positive direction is from lower to upper along the y-axis.

6.3.1.1 Contents Models

The contents models used in support of this analysis include the PWR fuel assembly model, the BWR fuel rod model, and the Rod Pipe.

6.3.1.1.1 PWR Fuel Assembly Model: 17OFA-XL

Section 6.2.1 established that the 17x17OFA would be the fuel assembly used in all calculations. In order to incorporate the maximum fuel assembly length, the 17x17STD-XL, an imaginary fuel assembly, the 17OFA-XL, was modeled in the calculations. The 17OFA-XL model is described in detail in Appendix 6.10.3. It basically consists of concentric cuboids to model the top nozzle assembly, skeleton, and fuel regions. The fuel assembly origin is at the bottom left hand corner of the fuel assembly lower nozzle. The fuel assembly is placed inside the fuel confinement with no translation of the origin. Table 6-6 shows the parameters of the 17OFA-XL and how they compare to the 17x17OFA and 17x17STD. In the following tables, units are defined by inches and millimeters in parentheses.

Table 6-6 17OFA-XL Parameters			
Fuel Assembly Type	**W-STD/XL**	**W-OFA**	**W-OFA/XL**
Nominal Pellet Diameter	0.3225 (8.192)	0.3088 (7.843)	0.3088 (7.843)
Annular Pellet Inner Diameter	0.155 (3.937)	0.155 (3.937)	0.155 (3.937)
Nominal Clad Thickness	0.0225 (0.572)	0.0225 (0.572)	0.0225 (0.572)
Clad Material	Zirconium alloy	Zirconium alloy	Zirconium alloy
Nominal Clad Outer Diameter	0.374 (9.499)	0.360 (9.144)	0.360 (9.144)
Maximum Stack Length	169 (4292.6)	145 (3683)	169 (4292.6)
Nominal Assembly Envelope	8.418 (213.817)	8.418 (213.817)	8.418 (213.817)
Kg's ^{235}U Assembly	28	22	28
Nominal Lattice Pitch	0.496 (12.598)	0.496 (12.598)	0.496 (12.598)
GT Diameter	0.482 (12.243)	0.474 (12.040)	0.474 (12.040)
GT Thickness	0.016 (0.406)	0.016 (0.406)	0.016 (0.406)
GT Material	ZIRC	ZIRC	ZIRC
IT Diameter	0.482 (12.243)	0.474 (12.040)	0.474 (12.040)
IT Thickness	0.016 (0.406)	0.016 (0.406)	0.016 (0.406)
IT Material	ZIRC	ZIRC	ZIRC

6.3.1.1.2 Fuel Rod Model

The fuel rods for the rod containers are conservatively modeled in order to bound all PWR and BWR fuel rods that will be transported. The rods are modeled as pellet stacks with no consideration given to cladding or other non-fuel characteristics or properties. The rod container analysis consists of evaluating arrays of pellet stacks inside each container type (Rod Box and Rod Pipe), varying the pellet diameter and pitch to determine the optimum configuration. Actual pellet diameters of fuel to be transported ranges from 0.20 inches to 0.60 inches [0.508 cm to 1.524 cm]. The evaluation modeled the pellets over the range from 0.05 inches to 1.0 inch [0.127 cm to 2.54 cm] at 0.05 inch increments. Pellet pitch in the model ranged from close-packed to 4.0 cm in order to find the optimum water-to-fuel ratios for each pellet diameter.

No credit is taken for integral burnable absorbers. 100% theoretical density is assumed. Parameters are given in Table 6-7. There are no restrictions with respect to the type of neutron absorbers that may be included in the fuel design.

Table 6-7 Fuel Rod Model Dimension Ranges

Element	(cm)	(inch)
Pellet Radius	0.0635 – 1.27	0.025 – 0.50
Pellet Diameter	0.127 – 2.54	0.050 – 1.0
Full Length Rod	448.3862	176.53

6.3.1.1.3 Rod Pipe Model

The Rod Pipe is described in Section 1. It is modeled as a simple cylinder with diameter 6.625 inches/ 16.8275 cm, which equates the nominal outside dimension of a 6.0 inch diameter stainless steel pipe. It is sealed at both ends. No internal padding or cushioning is modeled. Nor is it modeled with any flanges or fittings that enable it to seat inside the Clamshell. It's length is 177 inches/450 cm. The Rod Pipe is positioned at the bottom of the Clamshell.

6.3.1.2 Packaging Model

The following sections define the Traveller STD and Traveller XL models and criticality safety analyses performed for PWR fuel assemblies and fuel rod contents. Section 6.10.11 defines the Traveller VVER model and criticality safety analyses performed for VVER fuel assemblies.

6.3.1.2.1 Outerpack Model

The actual Traveller STD and Traveller XL outerpacks are identical with the exception that the XL is longer than the STD and the shock mount configurations are different. The shock mount configurations are shown in License Drawing 10001E58. The criticality evaluations will use the same outerpack model for both the STD and XL calculations with the exception of shock mount configuration. The outerpack model is described further in Appendix 6.10.5.

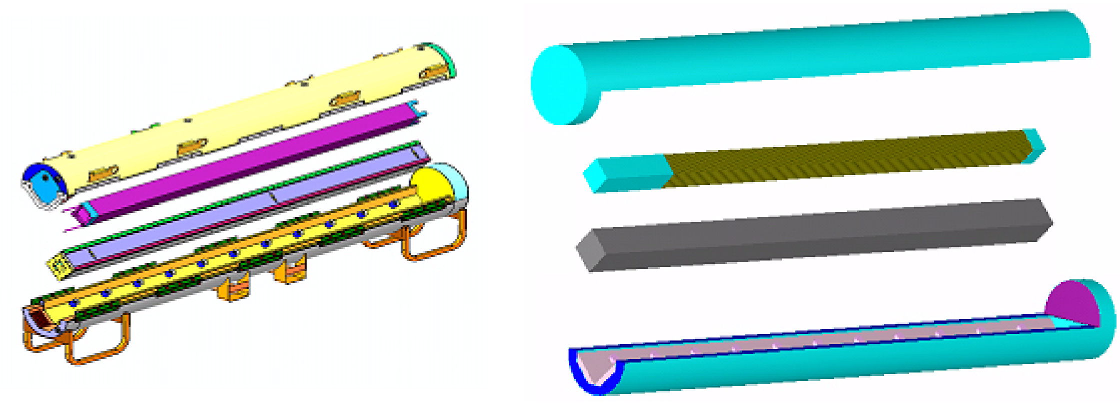

Figure 6-6 Solid Works Model and Keno3D Rendering of Traveller

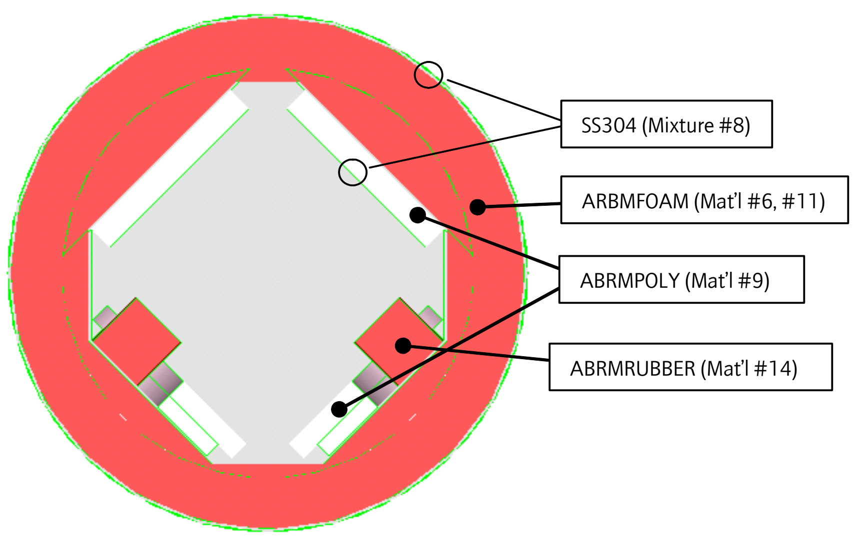

Figure 6-7 Outerpack Model Showing Material

6.3.1.2.2 Clamshell Model

The square Clamshell model is described in greater detail in Appendix 6.10.5. It consists of two concentric cuboids to model the outer wall and two intersecting cuboids to model the fixed neutron absorber panels, which are inset into the walls. The Clamshell origin is at the bottom left hand corner of the inside surface. The Clamshell is rotated 45 degrees in the positive direction and the origin is translated in the positive z direction to position the Clamshell inside the Outerpack. The Clamshell can be seen in Figure 6-2 and Figure 6-4.

6.3.2 Material Properties

The Standard Composition Library was used to specify material and mixtures. Those not found in the library are specified using the procedures for arbitrary mixtures described in the SCALE manual. Table 6-8 shows an excerpt from an input deck showing how the material properties are described. The technique used for modeling certain materials as a void (e.g. arbmfoam, arbmrubber) was to change the density by taking it to the 10^{-20} power).

Table 6-8 Sample Input Showing Material Properties

```
TRAVELLER XL,17WOFA,ENV=24.384      cm,L=100      cm,B10=0.018   g/cm2
44groupndf5  latticecell
 uo2 1 1 293 92235 5 92238 95 end
 h2o 2 1 293 end
 zirc4 3 1 293 end
 h2o 4 1 293 end
 h2o 5 1 293 end
 arbmfoam 0.1602e-20  4  0  0  0 6012 70 1001 10 8016 16 7014 4  6 1 293
 end
 al 7 1 293 end
 ss304 8 1 293 end
 polyethylene 9 DEN=0.828 1.0 293 end
 arbmfoam 0.1602e-20  4  0  0  0 6012 70 1001 10 8016 16 7014 4 11 1 293
 end
 b-10 12 0 0.0047781    end
 b-11 12 0 0.019398     end
 c   12 0 0.0060439    end
 al  12 0 0.043223     end
 arbmrubber 1.59e-20  7  0  0  0 8016 46.94 13000 19.92 14000 17.54 6012
 10.79 1001 4.73 11000 0.06 26000 0.02  14 1 293 end
 h2o 15 1 293 end
 uo2 16 1 293 92235 5 92238 95 end
 h2o 17 1 293 end
 zirc4 18 1 293 end
 h2o 19 1 293 end
end comp
squarepitch 1.4669       0.78435      16 19 0.9144       18 0.8001       17 end
more data
res=1  cylinder 0.39218      dan(1)=0.22632       end
```

To more fully document the composition of each compound and/or document the assumptions used in producing the associated cross-section data, a brief description of each material is given in Table 6-9 below:

Table 6-9 Material Descriptions

ZIRC4: Zircaloy - 6.56 g/cc • 98.23 wt % zirconium • 1.45 wt % tin • 0.1 wt % chromium • 0.210 wt % iron • 0.01 wt % hafnium	**SS304:** Stainless steel - 304 - 7.94 g/cc • 68.375 wt % iron • 19 wt % chromium • 9.5 wt % nickel • 2 wt % manganese • 1 wt % silicon • 0.08 wt % carbon • 0.045 wt % phosphorus
UO_2: Uranium dioxide: UO_2 - 10.96 g/cc	**POLYETHYLENE:** Polyethylene: $[C_2H_2]_n$, 0.92 g/cc
H2O: Water: cross sections developed using 1/E weighting everywhere, 0.9982 g/cc	**ARBMFOAM:** • C 50-70 wt % • O14-34 wt % • N 4-12 wt % • H 4-10 wt % • P 0-2 wt % • Si, <1 wt % • Cl <1800 ppm • Other <1 wt %
ARBMRUBBER: Rubber • O 49.94 wt% • Al 19.92 wt% • Si 17.54 wt% • H 4.73 wt% • Na 0.060 wt% • Fe 0.020 wt%	
ARBMBORAL: BORAL • B_4C • ^{10}B loading – 0.024 g/cm^2 • BORAL core thickness – 0.3175cm	

Multiple sets of iron, nickel, and chromium nuclides are available in the Standard Composition Library (FESS, NISS, CRSS). These sets correspond to different weighting functions used in generating the multigroup cross sections. For the 44- and 238-group libraries generated from ENDF/B-V data, there are two special weighting functions. One special weighting function corresponds to 1/E σ_t (E), where σ_t (E) is the total cross section of stainless steel 304. In the other special weighting, σ_t (E) is the cross section for the referenced nuclide.

Table 6-10 Material Compositions

Compound	Density (g/cm^3)	Elt.	Atomic density (atoms/b-cm)	Compound	Density (g/cm^3)	Elt.	Atomic density (atoms/b-cm)
Uranium dioxide	10.9600	U-235	1.23767E-03	BORAL	2.5891	B-10	0.0047781
		U-238	2.32186E-02			B-11	0.019398
		O	4.89126E-02			C	0.0060439
Water	0.9982	O	3.33846E-02			AL-27	0.043223
		H	6.67692E-02	Aluminum	2.7020	AL	6.03066E-02
Zirc 4	6.5600	ZR	4.25413E-02	Stainless steel	7.9400	C	3.18772E-04
		SN-112	4.68065E-06			SI	1.70252E-03
		SN-114	3.13652E-06			P	6.94680E-05
		SN-115	1.73715E-06			CRSS	1.74726E-02
		SN-116	7.01133E-05			MN	1.74071E-03
		SN-117	3.70592E-05			FESS	5.85446E-02
		SN-118	1.16872E-04			NISS	7.74020E-03
		SN-119	4.14021E-05	Polyethylene	0.9200	C	3.95300E-02
		SN-120	1.57260E-04			H	7.90600E-02
		SN-122	2.23417E-05	Silicone Rubber	1.5900	O	2.81077E-02
		SN-124	2.79391E-05			H	4.49402E-02
		FE	1.48557E-04			Fe	3.42922E-06
		CR	7.59779E-05			C	8.60970E-03
		HF	2.21333E-06			Al	7.06913E-03
Foam 11 PCF	0.1602	O	9.65313E-04			Si	5.97996E-03
		H	9.57279E-03			Na	2.49902E-05
		C	5.62769E-03				
		N	2.75581E-04				

6.3.2.1 Package to Model Comparison

A comparison of the mass of materials in the package model to the actual package provides an overall assessment of differences in geometry and material composition. The mass of the materials in the package model is calculated using the volume option in KENO-VI that calculates volumes of each material using the random method. The model volume is multiplied by the material density to obtain the model mass for each material. There are some materials in the actual package that are not included in the package model. Tables 6-11 through Table 6-13 compares the model mass quantities to the actual.

The actual mass of materials is obtained from design drawings for the package. A small quantity of plastic in the Outerpack vent plugs and steel in the shock mount bolts are not included. Also, some of the stainless steel structure in the Outerpack is not included in the model. Over 100 kg (220 lb.) of stainless steel in the components of the package were not included in the model. The cork rubber used as spacer material in the Clamshell, and the stainless steel in the Clamshell hinge pins are not included in the model.

Table 6-11 Material Compositions

Material No.	Material	Density	Model Mass	Approx. Mass
8	ASTM A240 type 304 SS	7.94 g/cm^3 [494.38 lb/ft^3]	408.7 kg [901 lb.]	488 kg [1866 lb.]
6, 11	Foam	0.10–0.32 g/cm^3 [6.20 lb/ft^3]	130.5 kg [287.7 lb.]	153 kg [339 lb.]
14	Rubber	1.59 g/cm^3 [68.7 lb/ft^3]	3.8 kg [8.3 lb.]	4.5 kg [14 lb.]
9	Polyethylene	0.92 g/cm^3 [57.43 lb/ft^3]	161.5 kg [356 lb.]	187 kg [340 lb.]

Table 6-12 Actual Mass Versus Modeled Mass – Clamshell

Material No.	Material	Density	Model mass	Actual mass
7	6061 Aluminum	2.64 g/cm^3 [164.98 lb/ft^3]	118 kg [260 lb.]	162 kg [357 lb.]
12	BORAL	2.71 g/cm^3 [169.16 lb/ft^3]	25 kg [55 lb.]	25 kg [55 lb.]
NA	Cork/natural rubber	[0.56 g/cm^3] [34.73 lb/ft^3]	0	4.5 kg [9.9 lb.]
NA	Stainless steel	7.94 g/cm^3 [495.68 lb/ft^3]	0	3.72 kg [7.6 lb.]

None of the stainless steel in the bottom and top nozzle is included in the fuel assembly. The uranium dioxide actual mass is less than the model mass because theoretical density is used in the model, but actual density is 96.5 percent the theoretical density. The zirconium mass is less in the model because the spacer grids are not included. Neither the model mass nor the actual mass for the contents includes the mass of the fuel rod bottom and top end plugs, plenum spring. Also, the skeleton stainless steel lock tube and top nozzle insert mass are not included in the comparison.

Table 6-13 Material Specifications for Contents

Material No.	Material	Density	Model mass	Actual mass
1	Uranium dioxide	10.96 g/cm^3 [494.38 lb/ft^3]	575 kg [1268 lb.]	560 kg [1234 lb.]
2, 4	Water	0.9982 g/cm^3 [62.31 lb/ft^3]	Variable	Variable
3	Zircaloy	6.56 g/cm^3 [409.48 lb/ft^3]	126 kg [278 lb.]	148 kg [326 lb.]
NA	Stainless steel	7.94 g/cm^3 [795.63 lb/ft^3]	0 kg [0 lb.]	17 kg [37 lb.]
NA	Inconel		0 kg [0 lb.]	2.60 kg [5.7 lb.]

6.3.3 Computer Codes and Cross-Section Libraries

The 44-group ENDF/B-V library has been developed for use in the analysis of fresh and spent fuel and radioactive waste systems. The library was initially released in version 4.3 of SCALE. Collapsed from the finegroup 238-group ENDF/B-V cross-section library, this broad-group library contains all nuclides (more than 300) from the ENDF/B-V data files. Broad-group boundaries were chosen as a subset of the parent 238-group ENDF/B-V boundaries, emphasizing the key spectral aspects of a typical LWR fuel package.

Specifically, the broad-group structure was designed to accommodate the following features: two windows (where the cross section drops significantly at a particular energy, allowing neutrons at that energy to pass through the material) in the oxygen cross-section spectrum; a window in the cross section of iron; the Maxwellian peak in the thermal range; and the 0.3-eV resonance in 239Pu (which, due to its low energy, cannot be properly modeled via the SCALE Nordheim Integral Treatment module NITAWL-II). The resulting boundaries represent 22 fast and 22 thermal energy groups; the full-group structure is compared with that of the 238-group library. The finegroup 238-group ENDF/B-V cross sections were collapsed into this broad-group structure using a fuel-cell spectrum calculated based on a 17 × 17 Westinghouse pressurized-water reactor (PWR) assembly. Thus, the 44-group library performs well for LWR lattices, but not as well for other types of systems. The 44-group ENDF/B-V library has been tested against its parent library, using a set of 33 benchmark problems in order to demonstrate that the collapsed set was an acceptable representation of 238-group ENDF/B-V, except for intermediate-energy systems.

6.3.4 Demonstration of Maximum Reactivity

This section demonstrates the most reactive configuration of each case presented in sections 6.4, 6.5, and 6.6. Assumptions and approximations are identified and justified. The optimum combinations of internal and interspersed moderation for the different cases are also explained.

6.3.4.1 Evaluation Strategy

It is important to understand the significant differences that exist between the routine transport configuration, the normal condition of transport case, the as-found configuration after hypothetical accident (HAC) testing, and the license-basis case. The Traveller CTU was tested in accordance with U.S. and IAEA regulatory requirements. Mechanical design calculations, finite element analysis calculations, actual drop test data, reasoned engineering analysis, and sound engineering judgment were used to determine worst-case orientations for the mechanical and thermal tests. This is explained in Section 2. The as-found condition of the package represents the most damaging configuration following actual testing. Therefore, it follows that the as-found package configuration combined with the worst-case flooding configuration, conservative material assumptions, and conservative fuel assembly assumptions should form the license-basis case for the safety analysis. (The worst-case flooding condition must be assumed because the Traveller was not actually subjected to an immersion test). The evaluation strategy used to arrive at the license-basis case is presented below. A flow chart showing the evaluation strategy is given in Figure 6-8.

Using the license-basis case as a frame of reference, a series of sensitivity studies were then performed to evaluate certain hypothetical conditions and scenarios. They are listed in Section 6.3.4.9 and discussed in Section 6.7.

6.3.4.2 Baseline Case for Packaging (Routine Condition of Transport)

The baseline case is the routine condition of transport. See Table 6-15. Note that the Routine case was not modeled. It is presented in order to show the conservative differences that exist between it, the normal condition of transport, the as-found condition after testing, and the license-basis case, which are modeled.

The lateral dimensions of the Outerpack for the Traveller STD and Traveller XL are identical and remain the same for all conditions of transport. The Outerpack outer diameter is 25.0 inches (63.5 cm). This diameter does not change throughout the testing. The circumferential stiffeners absorb the impact forces of the 9-meter drop, leaving the packaging diameter unchanged. The lower section polyethylene blocks measure 1.75 inches (4.445 cm). The upper section poly blocks measure 1.25 (3.175) inches. The conditions that vary in the Outerpack model are the condition of the floodable void spaces and the material densities. These items are discussed in the respective sections below.

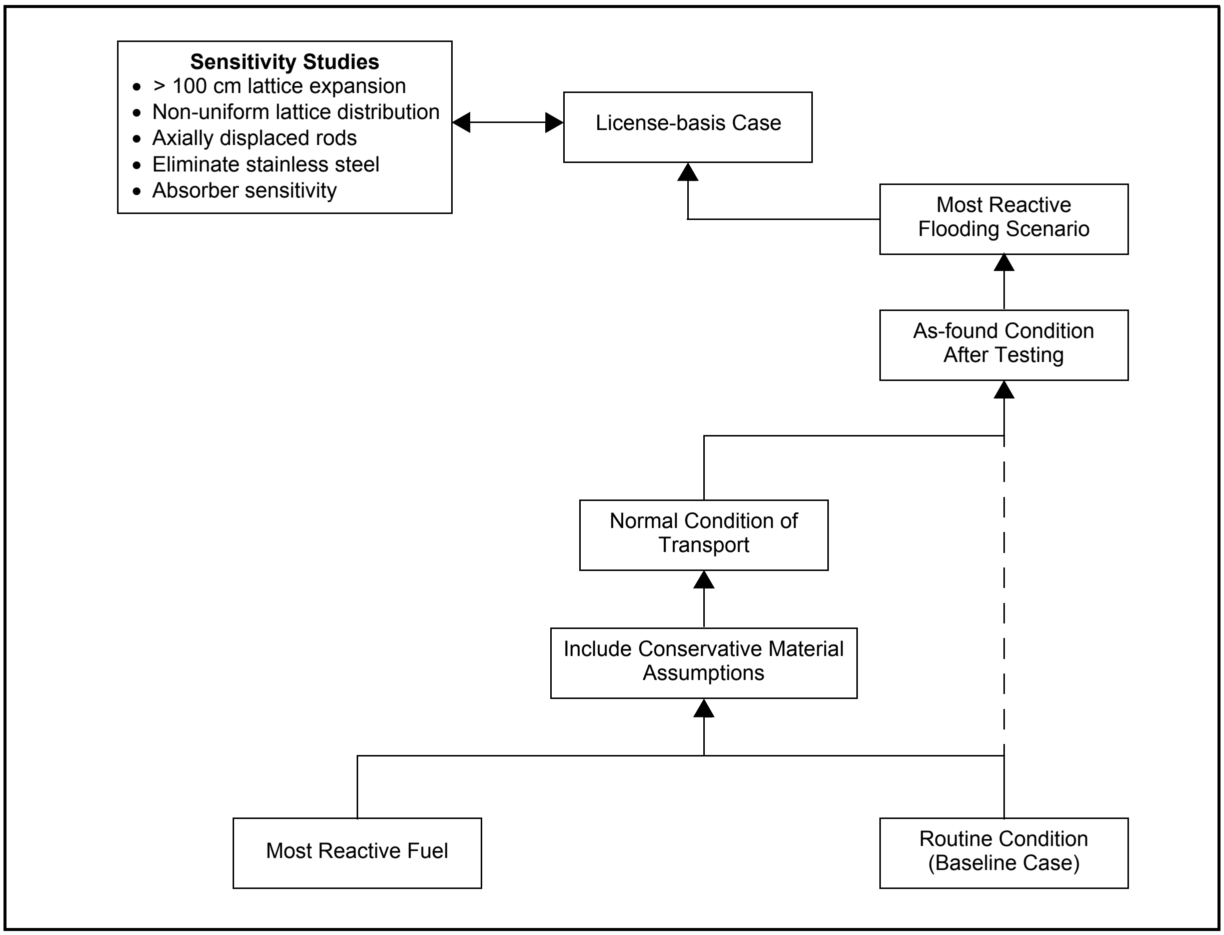

Figure 6-8 Criticality Evaluation Strategy

The internal dimension of the Traveller XL Clamshell measures 9.50±0.05 inches (24.13±0.127 cm), making the maximum dimension 9.55 inches (24.257 cm). The bottom faces of the clamshell are lined with 0.188 inch (0.476 cm) thick cork. The cork lining therefore reduces the effective clamshell dimension to 9.36 inches (23.78 cm).

The internal dimension of the Traveller STD clamshell is 9.00± 0.05 inches (22.86±0.127 cm). The effective volume of the clamshell with the cork lining in place is 8.86 inches (22.51 cm).

For the routine case the polyurethane foam, moderator blocks, and rubber shock mounts are in place.

The ^{10}B content of the neutron absorber plates has a minimum areal density of 0.024 g/cm^2 (BORAL).

All floodable void spaces of the Outerpack are dry for the routine configuration.

The fuel assembly is undamaged. That is, there is no expansion of the lattice pitch and the pin-gap is dry. Nominal cladding thickness is used.

6.3.4.3 Most Reactive Fuel Assembly Type (Contents)

Establishing the most reactive fuel assembly type involved performing a comparison of all PWR fuel assemblies to be transported in the Traveller. The analysis is described in section 6.2.1 and appendix 6.10.2. The following assumptions and conservatisms were included:

- Assumed 100% TD
- Assumed flooded pin-gap
- Ignored dishing, chamfering of pellets
- Ignored burnable poisons (Gd, Erbia, Boron)

6.3.4.4 Most Reactive Flooding Configurations (Flooding Case)

The flooding case takes the license basis case with the most reactive fuel assembly and analyzes for the most reactive flooding scenario for a single package a package array. This was done by modeling the floodable void spaces (see Section 6.1.1.6) in different combinations to determine which combination produces the highest k_{eff}. Included in the combinations were those that replicate total water immersion (full density water) or burial in snow (low density water). The flooding scenarios are discussed in section 6.7.1. The most reactive flooding configuration for a single package is described in section 6.4.1.2. The most reactive flooding configuration for a package array configuration is described in section 6.6.1. The most reactive flooding cases for the individual package and package array cases are summarized in Table 6-15.

Table 6-14 has been deleted.

6.3.4.5 Conservative Material Assumptions

The following conservative material assumptions are incorporated:

- The Traveller XL clamshell is conservatively modeled at 9.60-inches (23.384 cm), neglecting the presence of the cork liner and the manufacturing tolerance. This is a difference of 0.24 inches (0.61 cm).

- The Traveller STD clamshell is conservatively modeled at 9.1 inches (23.114 cm).

- Cork liner in clamshell not considered.

- The polyethylene moderator blocks are modeled 90% actual density, or 0.828g/cc.

- The ^{10}B content is modeled at 75% areal density for BORAL (0.0180 g/cm^2).

- The shock mounts are modeled as a void.

- Shock mount placement is important to criticality because the shock mounts penetrate the moderator through a 6 inch (15.24 cm) cutout. The shock mount configuration for the Traveller STD is modeled according to drawing, relative to either end of the outerpack. The Traveller XL is modeled conservatively in order to maximize the extent to which the 100-cm section of expanded lattice of the fuel assembly is placed over the shock mounts. Hence, the shock mounts are not placed at either end as shown in the license drawing and described in section 6.1.1.5. The first pair is locted 15 inches from the end. The second pair is 18 inches (45.7cm) from the first, and the third is 36 inches from the second. The gap between the first two pair of shock mounts is eliminated in order to maximize the interaction between the expanded sections of fuel.

6.3.4.6 Normal Condition of Transport

The Traveller model under normal condition of transport is described as follows:

- Outerpack dimensions are modeled as in section 6.3.4.2.
- Clamshell is modeled as in section 6.3.4.5.
- Fuel assembly is modeled as in section 6.3.4.2.
- The polyurethane foam and shock mounts are modeled at nominal density. Neither is altered under normal conditions of transport.
- The moderator blocks are modeled as in section 6.3.4.5.
- The neutron absorber is modeled as in section 6.3.4.5.
- All floodable void spaces of the Outerpack are modeled dry.
- The package is close reflected by 20 cm water.

As required by 10CFR71 and TS-R-1, the Traveller shipping package has been designed and constructed such that under the tests specified for normal conditions of transport, the following pertains:

- The contents are subcritical.
- The geometric forms of the package contents are not altered.
- There is no inleakage of water.

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- There was no reduction in effectiveness of the packaging. Section 2.12.4.2.3 describes the Certification Test Unit (CTU) following the hypothetical accident tests. From that inspection, the following can be concluded:

  — There was no reduction in the total effective volume of the packaging on which nuclear safety is assessed. Because there was no reduction in volume following the hypothetical accident condition testing, it follows that there is none during normal conditions of transport.

  — There was no reduction in the effective spacing between the fissile contents and the outer surface of the packaging. Test results report that the clamshell held the contents in place.

  — There were no breeches in the Outerpack. Hence, there is no occurrence of an aperture in the outer surface of the packaging large enough to allow the entry of a 10 cm (4 in) cube.

- The loss of efficiency of built-in neutron absorbers is addressed. The calculations assume less than 100% ^{10}B for the neutron absorber.

- The loss of efficiency of built-in moderators is addressed. The calculations assume 90% actual moderator density.

- The rearrangement of the contents within the package is addressed. There was no loss of contents from the package.

- There was no reduction of space within the package.

- There was no reduction of spacing between packages.

- The effect of temperature changes is addressed below.

6.3.4.7 Actual As-found Condition After HAC Testing

The actual condition of the Traveller XL package after HAC testing is described in Table 2-5 and section 2.12.4.2.3. It is important to note the actual as-found condition so comparisons can be made between it and the more conservative license-basis condition. The actual as-found condition was analyzed to determine the relative k_{eff} between it and the license-basis case. Results are found under section 6.7.

The Outerpack diameter was unchanged. A good portion, but not all, of the polyurethane foam had burned away. The moderator blocks were in place and not damaged. All shock mounts were in place, holding the clamshell in place. The cork liner was in place.

The bottom nozzle end drop is believed to be the worst-case drop orientation for the fuel assembly because it directly challenges the criticality safety of the package in ways that other drop angles do not. The bottom nozzle impact has been shown to produce the most severe localized damage to the bottom end of the fuel assembly. Further, it is the angle most likely to produce lattice expansion.

As can be seen from above, the as-found condition of the fuel assembly showed 20 cracked rods. Due to the nature of the end impact, the fuel rod array is tightly packed and forced into the bottom nozzle. As the bottom nozzle buckles, the rods located nearest the corners of the adapter plate experience a side loading due to the deforming movement of the plate. This momentum is sufficient to crack the weld but not to break off the bottom end plug because the rods are so tightly packed.

The average magnitude of the crack-widths was 0.03 inches (0.76 mm). The largest crack encompassed about ½ a rod diameter, meaning that none of the end plugs was completely broken off. This cracking is considered insignificant since a 17OFA fuel pellet diameter is 10 times larger than the visible crack widths. Furthermore, localized inward buckling of the rods at the end plug weld zone would tend to reduce the inner diameter of the fuel rod bottom end and preclude the pellet stack from axial movement.

As stated above, the end drop is most likely to produce fuel lattice expansion. In the several prototype and qualification tests conducted prior to the certification test unit testing, (see section 2), it was found that all drop angles other than the end drop compress the fuel assembly lattice. Only the end drop resulted in lattice expansion.

At no point did the lattice pitch expand to fill the clamshell. From the bottom nozzle to the first grid, a 4.0 inch (10.16 cm) span, the fuel envelope measured 9.0 inches (22.86 cm) on one side and 8.75 inches (22.1 cm) on the other. Between grids #1 and #2, about 20 inches (50 cm), the fuel envelope measured 8.32 inches (21.13 cm) on both sides. Between grids #2 and #3, also 20 inches (50 cm), the fuel envelope measured 8.5 inches (21.59 cm) and 8.0 inches (20.32 cm). Between grids #3 and #4 the envelope measured 8.5 inches (21.59 cm) and 8.44 inches (21.44 cm). For the rest of the assembly, the envelope measured no greater than 8.375 inches (21.27 cm). Close examination of the rod arrangement showed that throughout the assembly there was a combination of compressed, nominal, and slightly expanded rod pitches. Several rows of rods were actually touching, some were at nominal pitch, and one or two rods had larger pitch.

Therefore, confinement held because the fissile material remained in the fuel rods and the fuel rods remained inside the clamshell. Neutron absorber and neutron moderator material remained in place.

6.3.4.8 License-Basis Case

The License-Basis Case bounds the as-found condition of the Traveller XL by combining the most reactive flooding configuration of section 6.3.4.4, the conservative material assumptions of section 6.3.4.5, and the conservative assumptions for the fuel assembly which are described in this section. The License-Basis Case is shown in Table 6-15 and described below:

- Outerpack dimensions are modeled as in section 6.3.4.2.
- Clamshell is modeled as in section 6.3.4.5.
- Moderator is modeled as in section 6.3.4.5.
- Neutron absorber is modeled as in section 6.3.4.5.
- Shock mounts are modeled as a void.
- Shock mount placement is modeled as in section 6.3.4.5.
- Foam density, which differs for individual package and package array calculations, is modeled as in Table 6-15.
- Floodable void spaces are modeled as in Table 6-15.
- The fuel assembly is modeled so that it bounds the as-found condition. The model assumes lattice pitch expansion to 9.1 inches (23.114 cm) for the Traveller STD and 9.6 inches (23.384 cm) for the Traveller XL. The lattice expansion is uniformly distributed and extends 100 cm of fuel length.

6.3.4.9 Sensitivity Studies

Sensitivity studies were performed for the following conditions, starting from the license-basis case.

- Partial flooding
- Preferential flooding
- Lattice pitch expansion for full length of fuel assembly
- Non-uniform distribution in lattice expansion
- Axial rod displacement
- ^{10}B areal density
- Moderator density
- Outerpack shell thickness
- Array size
- Annular pellet
- Outerpack diameter
- Actual As-found condition after HAC testing

Table 6-15 Parameters for the Different Traveller Conditions

Parameter	Routine Condition (Not Modeled)	Conservative Material Assumptions (Not Modeled)	Normal Condition of Transport (Modeled)	HAC License-basis Case (Modeled)
SAR Section	6.3.4.2	6.3.4.5	6.3.4.6	6.3.4.8
Outerpack dimension	25.0 inches (63.5 cm)		25.0 inches (63.5 cm)	25.0 inches (63.5 cm)
Polyurethane foam density	Nominal Density		Nominal Density	Water/Void
Shock mount density	Nominal Density		Nominal Density	Void
Clamshell dimension: Traveller	9.0± 0.05 inches (22.86±0.127 cm)			
Clamshell dimension: Traveller XL	9.5±0.05 inches (24.13±0.127 cm)			
Cork liner in place on bottom faces	0.188 inches (0.476 cm)	Not in place	Not in place	Not in place
Effective Clamshell dimension: Traveller	8.86 inches (22.51 cm)	9.1 inches (23.114 cm)	9.1 inches (23.114 cm)	9.1 inches (23.114 cm)
Effective Clamshell dimension: Traveller XL	9.36 inches (23.78 cm)	9.6 inches (24.384 cm)	9.6 inches (24.384 cm)	9.6 inches (24.384 cm)
Neutron absorber density (B-Al/BORAL)	Nominal Density	75%	75%	75%
Moderator density	Nominal Density	90%	90%	90%
Flooding condition (single/array)				
Region 1 – Pin Gap	Dry/Dry		Dry/Dry	Flooded/Flooded
Region 2 – Fuel Assembly Envelope	Dry/Dry		Dry/Dry	Flooded/Flooded
Region 3 - Clamshell	Dry/Dry		Dry/Dry	Flooded/Dry
Region 4 - Outerpack	Dry/Dry		Dry/Dry	Flooded/Dry
Region 5 - Polyurethane Foam	Dry/Dry		Foam/Foam	H_2O/Void
Region 6 - Outside Outerpack	Dry/Dry		H_2O Reflected/Dry	H_2O Reflected/Dry
Fuel Assembly Lattice Pitch Expansion	None	None	None	100 cm

6.4 SINGLE PACKAGE EVALUATION

Calculations were performed to determine the most reactive configuration for a single package in isolation under normal and hypothetical accident conditions of transport. The configurations are described below. These descriptions hold for the Traveller STD and Traveller XL. Discussion for the rod containers is included in section 6.10.7.

6.4.1 Configuration for Fuel Assemblies

6.4.1.1 Configuration Under Normal Conditions of Transport

10CFR71 and TS-R-1 require that the contents be subcritical under normal conditions of transport. TS-R-1 indicates that when it can be demonstrated that the confinement system remains within the packaging following the prescribed tests, close reflection of the package by at least 20-cm water may be assumed. Since this is the case for the Traveller, the individual package evaluation includes the close-reflection around the Outerpack.

The parameters for the normal condition of transport are described in section 6.3.4.6 and shown in Table 6-15.

6.4.1.2 Configuration Under Hypothetical Accident Conditions

The hypothetical accident condition requires that the most reactive flooding configuration be considered. It is generally true that the most reactive configuration for an individual package would be that in which the neutrons are moderated as close to the fuel as possible and reflected back into the fuel assembly region. They should not be allowed to escape or to reach the neutron poison where they would be absorbed.

Calculations have shown that this is the case for the Traveller. Therefore, all floodable void spaces in the package are modeled as fully flooded, and the package is close reflected by 20-cm full density water.

The remaining parameters for the hypothetical accident condition (i.e., the license-basis case) for the Traveller are described in section 6.3.4.8 and shown in Table 6-15.

6.4.2 Results for Fuel Assemblies

The results for single package in isolation calculations are presented in Table 6-16. They include results for normal conditions of transport and hypothetical accident conditions. Included are results for both neutron absorber types.

Table 6-16 Most Reactive Configuration for a Single Package in Isolation

Configuration	Run No.	k_s	Uncert.	Calculated k_{eff}
Traveller STD – Fuel Assembly				
Normal	Bounded by XL			
HAC	STD-HAC-IND	0.8621	0.0012	0.8645
Traveller XL– Fuel Assembly				
Normal	XL-NOR-IND	0.2000	0.0006	0.2012
HAC	XL-HAC-IND	0.8833	0.0009	0.8851
Rod Container				
Normal	Bounded by HAC calculation			
HAC	P-IND-15-6	0.7462	0.0014	0.7490

Figure 6-9 has been deleted.

6.4.3 Configuration for Rod Containers

The discussion on the rod container is found in appendix 6.10.7.

6.5 EVALUATION OF PACKAGE ARRAYS UNDER NORMAL CONDITIONS OF TRANSPORT

6.5.1 Configuration for Fuel Assemblies

The package model for the normal condition of transport is described in section 6.3.4.6. In this analysis it was modeled in an infinite array.

6.5.2 Results for Fuel Assemblies

Table 6-17 Normal Conditions of Transport for Package Array

Configuration	Run No.	k_s	Uncert.	Calculated k_{eff}
Traveller STD – Fuel Assembly				
Package Array – Infinite Package Array				
Normal	STD-NOR-ARRAY-INF	0.2546	0.0005	0.2556
Traveller XL– Fuel Assembly				
Package Array – Infinite Package Array				
Normal	XL-NOR-ARRAY	0.2709	0.0006	0.2721

6.6 PACKAGE ARRAYS UNDER HYPOTHETICAL ACCIDENT CONDITIONS

6.6.1 Configuration for Fuel Assemblies

The most reactive configuration for a package array, in contrast to the individual case, is the one that allows maximum thermal neutron interaction between packages. Section 6.7.1 discusses this in detail. This model assumes a flooding configuration that maximizes neutron interaction. Region 1 (pin-gap) and region 2 (fuel assembly) are flooded to maximize reactivity inside the fuel assembly. Region 3 (Clamshell) is modeled as a void to increase the probability that neutrons escaping the fuel assembly envelope will pass through the neutron poison. The remaining floodable void spaces (region 4 – Outerpack cavity; region 5 – foam; region 6 – outside Outerpack) are modeled as a void to allow maximum interaction between packages in the array.

The configuration of the Outerpack, Clamshell, and contents for the hypothetical accident condition for the Traveller are described in section 6.3.4.8 and shown in Table 6-15. Table 6-18 gives results. Figure 6-10 shows curves for the Traveller XL in a fixed package array as a function of k_{eff} versus length of fuel assembly with lattice expansion.

6.6.2 Results for Fuel Assemblies

Table 6-18 Hypothetical Accident Condition Results for a Package Array

Configuration	Run No.	k_s	Uncert.	Calculated k_{eff}
Traveller STD				
HAC	STD-HAC-ARRAY-100	0.8954	0.0009	0.8972
Traveller XL				
HAC	XL-HAC-ARRAY-100	0.9377	0.0008	0.9393

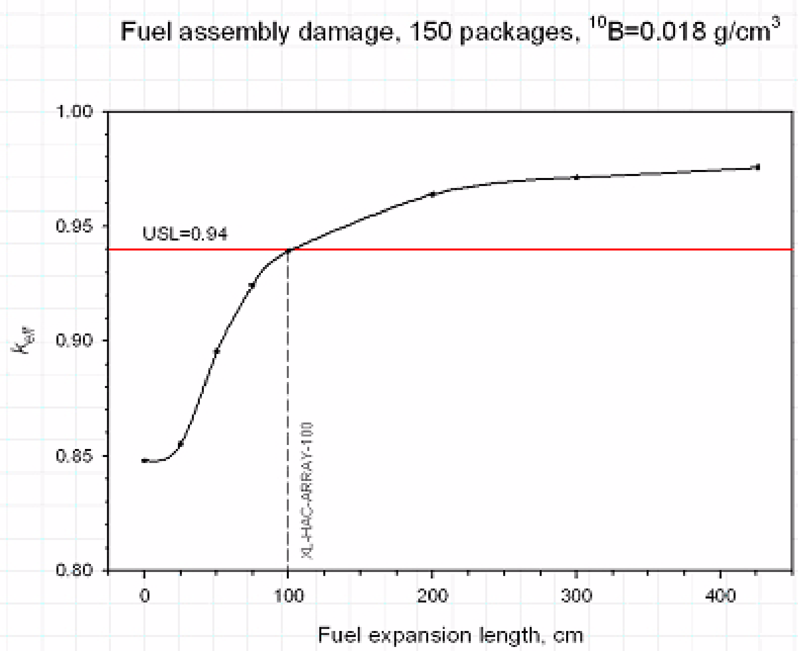

Figure 6-10 Package Array HAC Curve for Traveller XL

6.6.3 Results for Rod Containers

The discussion on the rod container results is found in appendix 6.10.7.

Table 6-19 Hypothetical Accident Condition Results for Rod Container – Package Array

Configuration	Run No.	k_s	Uncert.	Calculated k_{eff}
Rod Box	B-ARR-12-5	0.5367	0.0013	0.5393
Rod Pipe	P-ARR-15-6	0.6518	0.0016	0.6550

6.7 SENSITIVITY STUDIES

6.7.1 Flooding

During transport the package may be subjected to moderation provided by immersion of the package in naturally occurring sources of water (lakes, rivers, ocean, snow, rain) or fire extinguishing agents (water, foams, dry chemicals). Moderator ingress provides varying degrees of moderation inside and outside of the package. The analysis of variance for moderation that is provided by packaging components is evaluated assuming the fuel assembly is moderated with full density water. The greatest interaction between packages, that results in the highest k_{eff} for a package array, occurs when the transport condition causes moderation of the pin-cladding gap and the fuel region, and keeps all other void spaces inside and between the packages dry.

The criticality evaluation considered the Traveller under various flooding schemes to determine the most reactive flooding combination for both the individual package and the array. Note that because the Traveller was not subjected to the immersion test, it is necessary to consider all plausible flooding combinations.

6.7.1.1 Pin-Cladding Gap Flooding

Test results demonstrated that it is possible that rods will crack. Therefore, the evaluation assumes that the pin-gap is flooded for accident conditions. Therefore, the criticality evaluation modeled region 1 as full density water.

6.7.1.2 Most Reactive For Individual Package – Fully Flooded

It is generally true from a criticality perspective that the most reactive configuration for an individual package would be that in which the neutrons are moderated and reflected back into the fuel region before they escape or are absorbed by the neutron poison. Therefore, the most reactive flooding scenario for the individual package assumes that all floodable regions are fully flooded.

6.7.1.3 Most Reactive For Package Array – Preferential Flooding

Preferential flooding (also called differential or sequential flooding) is defined as that scenario in which one cavity of the package remains flooded while one or more of the other cavities drain completely. Referring to section 6.1.1.6 (Floodable Void Spaces) and Figure 6-4, the most reactive configuration for a package array is one in which the neutrons are fully moderated within the fuel region (regions #1 and #2) but where the remaining floodable spaces are modeled as a void to allow neutrons that escape one fuel assembly to have maximum interaction with surrounding packages. Modeling region #3 (Clamshell region) as a void maximizes the probability that neutrons escaping the fuel assembly region will pass out of the Clamshell through the neutron poison. Modeling regions #4 – #6 as voids gives the highest probability of neutron interaction among packages. The array is fully reflected by 20 cm full density water.

The preferential flooding scenario modeled here is unlikely but not impossible. It assumes that the Clamshell drains everywhere except inside the fuel envelope. This scenario does however bound the more likely scenario where the Clamshell drains leaving a water film on the fuel rods.

The preferential flooding scenario also presumes that the entire Outerpack drains leaving water only around the fuel region. The Clamshell is not watertight. Hinge knuckles will allow drainage. As the Outerpack drains, the Clamshell level would drop also.

6.7.1.4 Partial Flooding

Partial flooding differs from preferential flooding in that it is defined as changing water levels in the void spaces of the package. Calculations were performed to evaluate two partial flooding scenarios.

Both involve rotating the package 45° and then changing the water levels in regions #2, #3, and #4. Recall that region #2 is the fuel assembly envelope, region #3 is the area inside the clamshell around the non-expanded fuel assembly, and region #4 is the area inside the outerpack outside the clamshell.

The first scenario involves first keeping regions #2 and #3 flooded (i.e., the areas inside the clamshell) and varying the level in region #4. It can be seen that k_{eff} for the array case drops as region #4 fills because the packages are becoming more isolated. The bounding case here is the preferential flooding scenario described in the previous section. Figure 6-11 shows a rendering of this flooding scenario. Figure 6-12A shows the plot of k_{eff} versus water height in the outerpack. Results are shown in Table 6-37A and a sample input deck is found in Table 6-37C

The second scenario evaluates k_{eff} as a function of varying the water levels in regions #2, #3, and #4 together. That is, this scenario assumes that the water level inside the clamshell rises and falls with the water level in the outerpack. As expected, k_{eff} begins to drop as soon as the fuel is uncovered. Figure 6-12 shows a rendering of this flooding scenario. Figure 6-12B shows the plot of k_{eff} versus water height. Results are shown in Table 6-37B and a sample input deck is found in Table 6-37D.

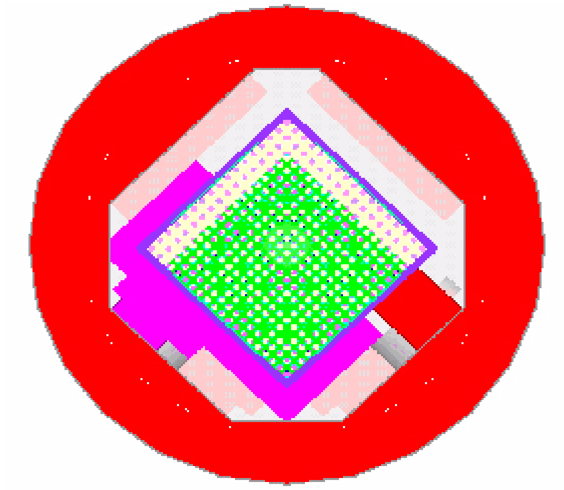

Figure 6-11 Partial Flooding Scenario #1

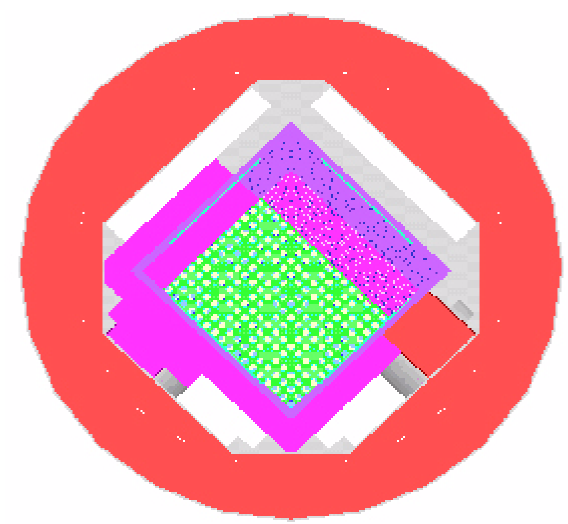

Figure 6-12 Partial Flooding Scenario #2

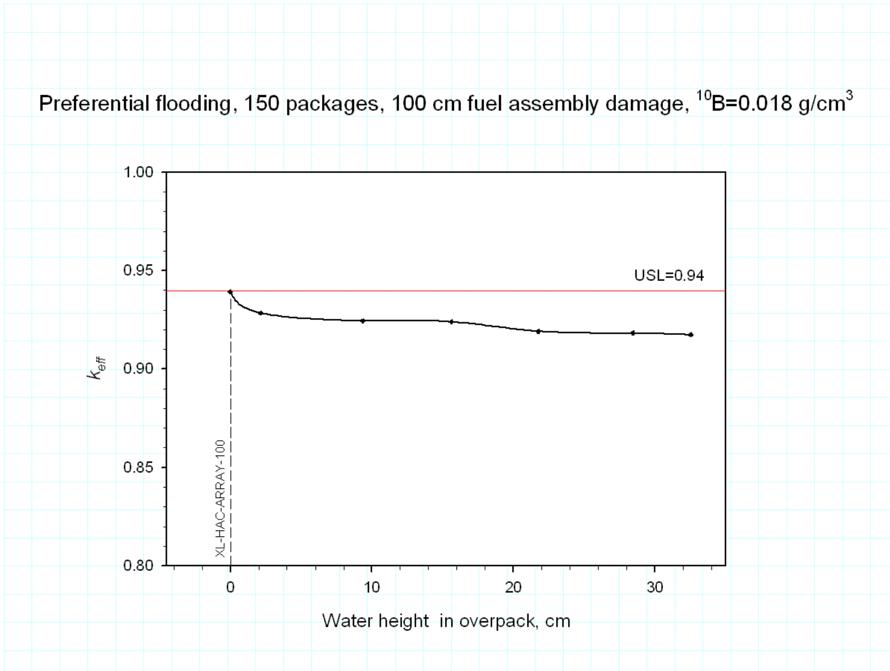

Figure 6-12A Partial Flooding Scenario #1

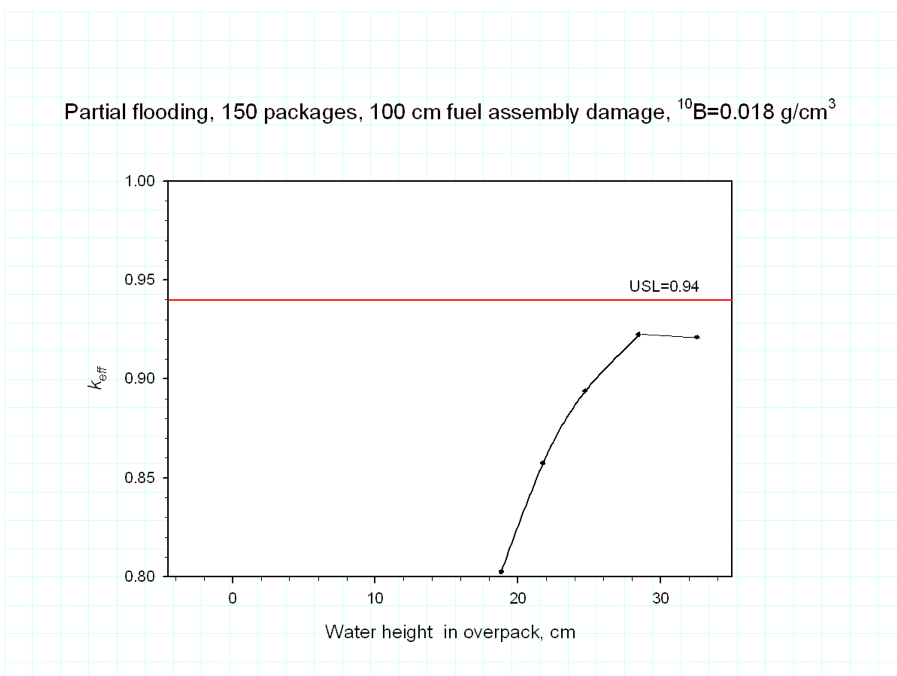

Figure 6-12B Partial Flooding Scenario #2

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6.7.1.5 Partial Density Interspersed Moderation

Spacing maintains void regions between the packages where environmental factors (snow, rain, ice, and immersion) may provide moderation. Also, materials of construction may scatter or moderate neutrons. The spacing is assumed to be no less than 25 inches provided by the nominal diameter of the Outerpack outer shell. Figure 6-13 shows that the package is overmoderated with respect to interspersed moderation for fuel lattice expansion along a partial length with 2 wt. % Boron where the number of packages in the array is 150.

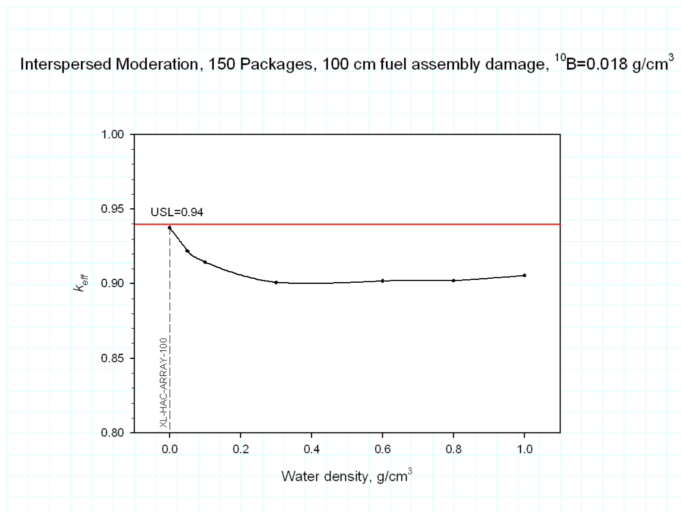

Figure 6-13 Interspersed Moderation Density Curve

6.7.2 Lattice Expansion

From calculations done in support of the Traveller package licensing effort, and from other literature available, it is clear that the factor that has the greatest effect on k_{eff} for a moderated system is lattice pitch expansion. Expanding the lattice pitch of undermoderated fuel assemblies increases the water-fuel ratio. K_{eff} will increase until the water-fuel ratio reaches optimum

This evaluation considered the effect of lattice expansion for all accident configurations. The fuel lattice was expanded to the Clamshell (9.6 inches in Traveller XL and 9.1 inches for Traveller STD) in incremental lengths of 25 cm, 50 cm, 75 cm, 100 cm, 150 cm, 200 cm, 300 cm, and full length (426 cm). It must be noted that analyzing these scenarios does not imply that full-length expansion becomes the license-basis case. Figure 6-10 shows k_{eff} versus length of expanded section for the Traveller XL. Results are given in Table 6-32.

It has been seen from numerous 9-meter drops at different drop angles that any horizontal or shallow angle drop will compress the fuel assembly envelope rather than expand it. Similarly, center-of-gravity drops on the end will cause local crumpling on the end but will not expand the lattice pitch.

Results from a bottom nozzle end drop shows fuel rod lattice pitch expansion at the bottom 20 inches (50 cm). The expansion was not uniformly distributed. There was a combination of rods touching or at compressed pitch, rods at nominal pitch, and rods with expanded pitch.

6.7.2.1 Non-uniform Lattice Expansion

Non-uniform lattice expansion is defined as a fuel envelope with rods at different pitches, such as was found in the tested fuel assemblies. There will be some rods touching, some compressed, some at nominal pitch, and some at expanded pitch. An analysis was performed to determine how non-uniform lattice expansion compared to uniform expansion.

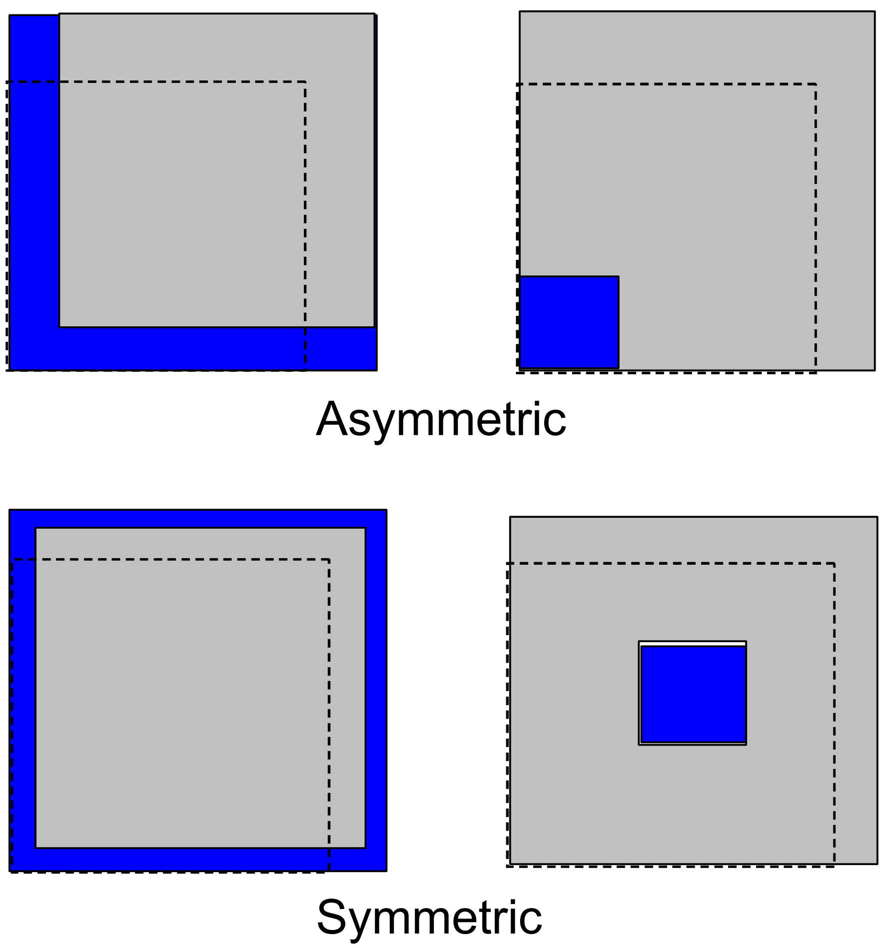

Figure 6-14 Symmetric and Asymmetric Non-uniform Distribution

The analysis assumed a fixed number of rods, namely 289 in a 17x17 array. It then looked at four types of expansion/compression combinations, which can be seen in Figure 6-14. The combinations included compressed rods around the edge of the assembly or in a cluster, in both a symmetric and asymmetric arrangement. The small grid in the figure represents the nominal or close packed rods, and the large grid

represents the remaining rods expanded to the space available for expansion within the confinement of the Clamshell 9.5 inch by 9.5 inch cross section. There are no thimble tubes. These configurations are confined to 100 cm of fuel length.

The graph in Figure 6-15 shows two curves: k_{eff} as a function of the number of rods in the expansion zone {x} and the remaining rods {289-x} either at (1) nominal pitch or (2) close packed. The area between the curves is expected to bound all the rod rearrangements possible within the confinement of the Clamshell. The results show that any compaction of the lattice suppresses the reactivity increase due to rod expansion up until the expansion includes about 100 rods (~1/3 of the assembly). The results also show the importance of the confinement dimension in limiting the possible rearrangements without rods leaving the confines of the Clamshell. These results support the assumption that the most reactive rearrangement is uniform expansion.

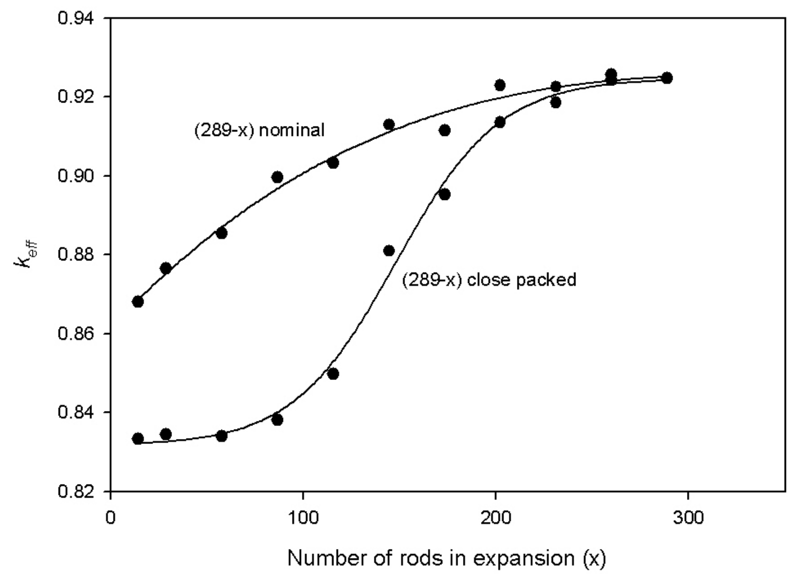

Figure 6-15 Non-uniform Expansion k_{eff} Plot

6.7.3 Annular Pellets

Analysis has determined that annular pellets in the fuel assembly do not increase k_{eff}. Therefore, the fuel assemblies and rods that are allowed to be carried in the Traveller may container annular pellets. Results are given in Table 6-37E. A sample input deck is provided in Table 6-37F. The study was conducted using an earlier version of the Traveller XL model. The most reactive k_{eff} for this model was 0.9332 including the uncertainty. The same model with the annular pellets yielded a result of 0.9290; hence, irrespective of the outerpack used, the study demonstrates that annular pellets are bounded by solid pellets.

6.7.4 Axially Displaced Rods

An axial rod displacement study was conducted using as the baseline model an earlier version of the HAC license-basis case model using a Traveller XL. A sample input deck is included in Table 6-37H. It can be seen that this model includes the appropriate positioning of the neutron absorber plates inside the clamshell such that it bounds the actual package. Likewise the moderator blocks are properly positioned inside the outerpack with the shock mount positions conservatively located. This model is acceptable for use in this analysis because it is looking at the relative importance of displacing rods. The analysis looked at the displacement of 0, 4, 8, 12, 20, 28, 56, 92, and 132 rods. The rods are displaced until they reach the top of the Clamshell. Results showed that k_{eff} remains constant for a few displaced rods (N12) and then drops as N increases. The reason is that the displaced rods effectively displace fissile material from high reactivity region (i.e., the region with the expanded lattice) and put them into a region of low reactivity (the region of the top, which is always overmoderated). Taking into account that the expanded lattice is already close to the optimum pitch value (which, for that assembly size, occurs at P≈1.54 cm or 12 displaced rods), not too much advantage is taken from the fact that "holes" appear in the bottom of the fuel lattice. Figure 6-16 shows the model with 92 axially displaced rods. Results are given in Table 6-37G. A sample input deck is provided in Table 6-37H.

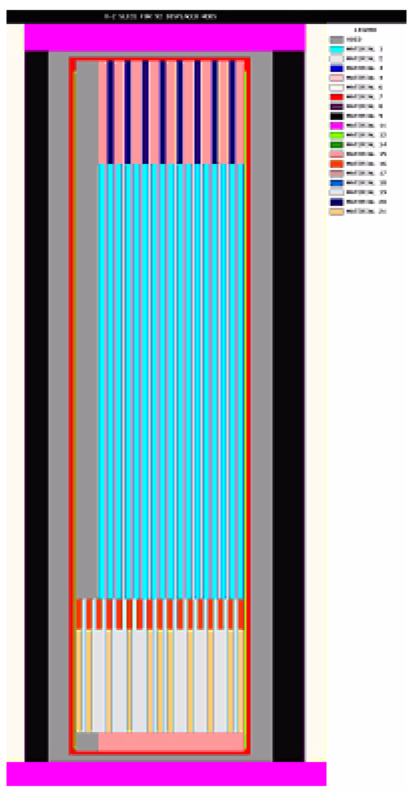

Figure 6-16 Axial Slice Showing 92 Displaced Rods

6.7.5 Polyurethane Foam Moderating Effect

Foam is used as both a thermal insulator and impact absorbing material in the Outerpack. The hydrogen content in the polyurethane foam moderates neutrons outside the confinement system boundary of the individual package. Change to the foam composition can significantly affect the interaction between packages in an array. The polyurethane foam starts to burn when the temperature exceeds 600°F (315°C) leaving a low-density char residual material.

Calculations were not specifically run to determine the effect of removing the foam from the package. However the sensitivity study that was done to evaluate interspersed moderation included modeling the foam region with varying water densities. This analysis bounds the effects of varying foam density.

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Calculations were run to determine the effect of removing the foam from the package. The configuration evaluated is an infinite array of packages with the fuel assembly moderated and the remainder of the package regions dry. This configuration results in the maximum interaction between individual packages in a package array and emphasizes the effect of eliminating the moderating effect of the foam. Removal of the foam to a lesser extent may be considered equivalent evaluation of interspersed moderation discussed in Section 6.7.1.5. Results showed that eliminating the foam for the configuration that results in maximum interaction results in an increase in k_{eff} of 0.025.

6.7.6 Deleted

6.7.7 Polyethylene Density

Moderator blocks are a packaging component that provide moderation control by maintaining a fixed amount of moderation between the contents in the individual packages. The polyethylene moderator blocks provide moderation that in combination with a neutron poison effectively reduces the interaction between packages. The fixed moderator and a neutron poison are arranged to function as a neutron flux trap.

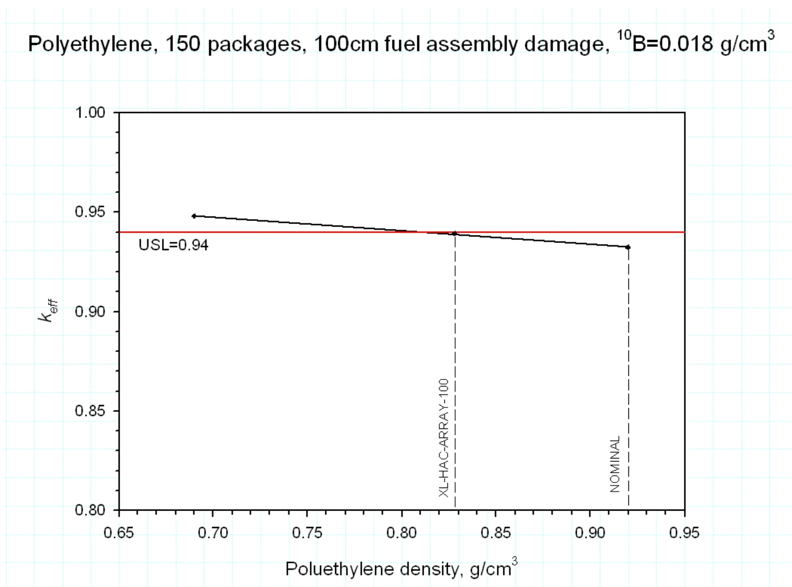

Figure 6-17 Effect of Varying Polyethylene Density

The HAC License-Basis case for the polyethylene was evaluated at densities equating to 100% (ρ = 0.92 gm/cc), 90% (ρ = 0.83 gm/cc), and 75% (ρ = 0.69 gm/cm^3) to determine effect. The configuration is an infinite array of packages with the fuel assembly moderated and the remainder of the package regions dry results in the maximum interaction between individual packages in a package array. The polyurethane foam in the outer pack shell is eliminated and replaced with void to maximize the interaction and emphasize the effect of changes in the polyethylene moderator. Figure 6-17 shows the effect of reducing the polyethylene density for a range of boron content from 2.0 wt% boron to 4.5 wt% boron in the poison plates. The average effect of reducing polyethylene density by 10% increased k_{eff} approximately 1%, and reducing

density to 75% increases k_{eff} approximately 2%. This effect of reducing the polyethylene density blocks is not strongly dependent on the neutron poison content within the range of parameters evaluated. Results are given in Table 6-39B. A sample input deck is provided in Table 6-38.

6.7.8 Reduction of Boron Content in Neutron Absorber

The analysis included a sensitivity study of boron content in the neutron absorber. The sensitivity to ^{10}B areal density is evaluated for a package array with 100 cm fuel lattice expansion. Figure 6-18 shows k_{eff} versus ^{10}B content for BORAL. The ^{10}B effectiveness does not diminish significantly until the areal density decreases to approximately 0.010 gm/cm^2. As can be seen in the curves,

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the boron content in the Traveller neutron absorbers is well beyond the "knee" on the curve. Results are given in Table 6-39. Number densities used in the boron content analysis are given in Table 6-39A.

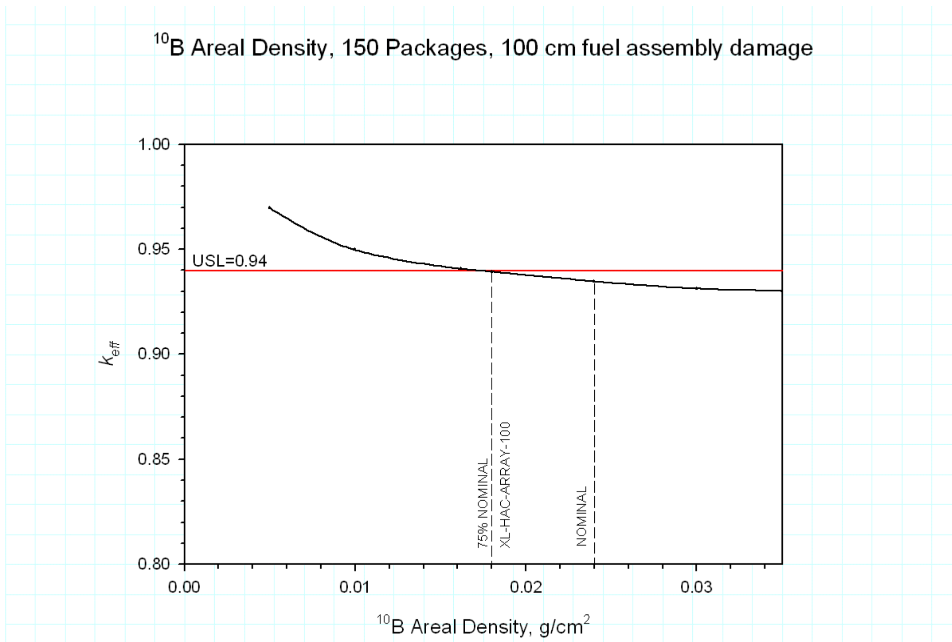

Figure 6-18 Sensitivity Study of Boron Content for Traveller XL Package Array

6.7.9 Elimination of Structural Stainless Steel

Neutron absorption occurs in the stainless steel of the package due to its chromium content. Note that the model takes credit for only about 60% of the stainless steel in the package. Calculations were performed to determine the effect on k_{eff} of variations in stainless steel thickness due to manufacturing tolerances. Figure 6-18A shows the effect. Results are given in Table 6-39C.

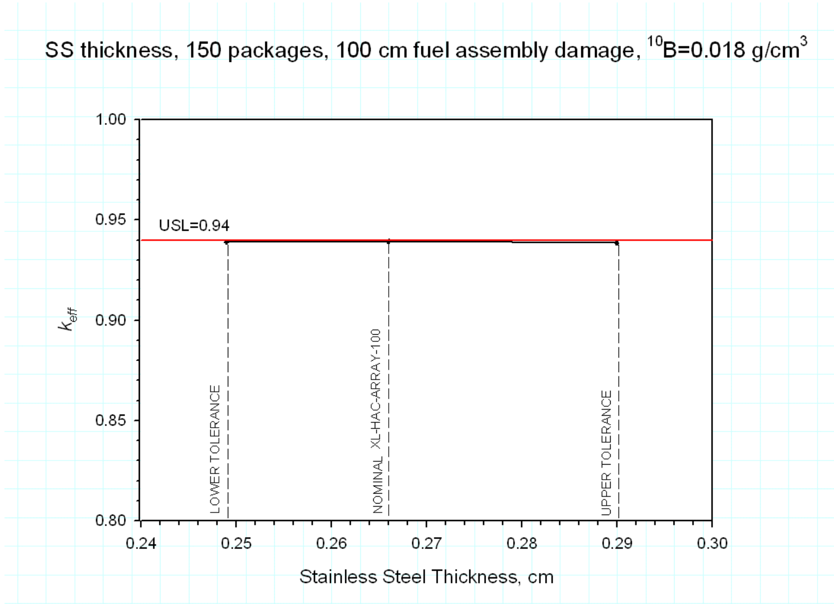

Figure 6-18A Sensitivity Study of Stainless Steel Thickness

6.7.10 Zirconium Reduction

In the accident configurations, the cladding and guide tubes were modeled with nominal dimensions. Cases were run with thinner tubes, dimensioned to reflect the manufacturing tolerance band. The effect of reducing the tube thickness of the zirconium fuel rod and guide thimble tubes by 5 percent is evaluated. The cladding material includes Zirconium-40 that is a resonance absorber within the fuel envelope. Results indicate that a small reduction in absorption in the Zirconium is offset by the increase in moderation when the zirconium is replaced with full density water in the model. There is a net change in k_{eff} that is less than 0.005 for a small reduction in cladding thickness.

6.7.11 Outerpack Diameter

An analysis was performed to evaluate the effect that varying the outerpack diameter has on k_{eff}. Cases were run to bound the manufacturing tolerance band. Results indicate that a change in package diameter equivalent to manufacturing tolerance has virtually no affect on system k_{eff}. Results are given in Table 6-39B. A sample input deck is provided in Table 6-39C.

6.7.12 Actual As-found Condition After HAC Testing

An analysis was performed to determine k_{eff} for the Traveller XL in the actual condition in which it was found following HAC testing. The fuel assembly was modeled in the same way as for the license-basis case, with lattice expansion to 100 cm and 100% theoretical density. The flooding configuration was also modeled the same as for the license-basis case. The packaging was modified in the following ways:

- Moderator blocks modeled at 100% nominal density.
- Neutron absorbers modeled at 100% B-10 content.
- Shock mounts modeled in place at nominal density.

Results from this analysis showed that keff was reduced by approximately 1%.

6.7.13 Package Array Size

An analysis was performed to evaluate the effect that varying the package array size for the Traveller XL under HAC license-basis-conditions. Results indicate that an array of 150 packages will satisfy the USL requirements. Results are given in Table 6-39D. The data are plotted in Figure 6-18B.

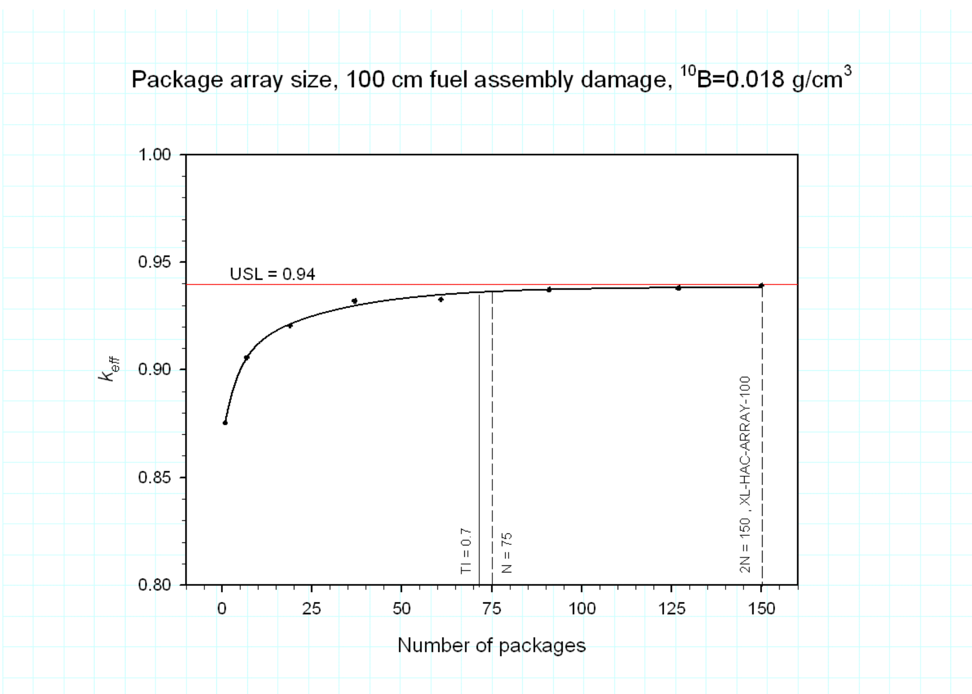

Figure 6-18B Sensitivity Study of Package Array

6.7.14 Clamshell Position Inside Outerpack

An analysis was performed to evaluate the effect of the clamshell coming loose from the shock mounts and coming to rest on the moderator blocks. The study assumes that all of the shock mounts burn away. The two calculations consider the license basis case (XL-HAC-ARRAY-100 model) with the clamshell resting on the moderator blocks either in the lower half of the outerpack (clamshell down model) or, assuming the packages were upside down, with the clamshell resting on the moderator blocks in the upper half of the outerpack. For the clamshell-up model, the clamshell is rotated 180 degrees so the fuel assembly makes contact with the clamshell at the outerpack edge.

The likelihood of this event occurring is very small for numerous reasons. First, even though the shock mounts are not safety related items, actual testing showed that all of the shock mounts survived the drop and fire tests, and remain connected to the clamshell. Second, engineering scoping analysis estimates that if only one pair of shock mounts at each end survives the drop and fire, they are sufficient to hold the clamshell suspended in the outerpack. If all the shock mounts at one end were to be destroyed, then the clamshell may come into contact with the outerpack at that end only.

Nevertheless, calculations were performed to show the effect on keff if all shock mounts were destroyed. The results show no change in keff for the clamshell down model, and a slight increase for the clamshell up and rotated model. Table 6-19A below gives the results. Figure 6-18C shows the clamshell up and rotated model. Table 6-39F gives the input deck for the clamshell up and rotated model.

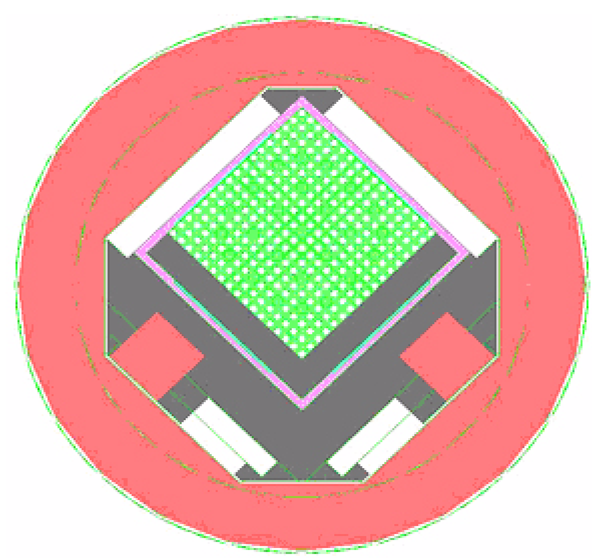

Figure 6-18C Clamshell Up and Rotated Model

Table 6-19A Clamshell Position Inside Outerpack			
Configuration	ks	Uncert.	Calculated keff
Clamshell Up-Rotated	0.9392	0.0009	0.9410
Clamshell Down	0.9377	0.0008	0.9393

6.8 FISSILE MATERIAL PACKAGES FOR AIR TRANSPORT

Application for air transport for the Traveller will be made at a later date.

6.9 BENCHMARK EVALUATIONS

The computer code used for these criticality calculations has been benchmarked against applicable criticality experiments.

6.9.1 Applicability of Benchmark Experiments

There are approximately 180 experiments that are applicable to transport.[1] Of these, 55 were selected based on their structural, material, poison, geometry, and spectral similarities to the Traveller. Table 6-40 in Appendix 6.10.10 gives a summary of available LWR critical experiments and indicates how many of each type were selected. The selected experiments were grouped into four classifications: Simple Lattice, Separator Plate, Flux Trap, and Water Hole experiments. Table 6-41 shows the breakdown of the experiments into the four classifications. In general, there were 15 Simple Lattice experiments, 26 Separator Plate experiments, 8 Flux Trap experiments, and 6 Water Hole experiments.

In determining which experiments were not applicable, criteria were established by which experiments would be rejected. These criteria include:

- No separator plates made of hafnium, copper, cadmium, zirconium, or depleted uranium (include only separator plates made of stainless steel, aluminum or boron),
- No thick wall lead, steel, or uranium reflector material,
- No hexagonal fuel rod lattices,
- No burnable poison rods (Ag-In-Cd rods, B_4C rods, UO_2-Gd_2O_3 rods)
- No soluble boron

The 55 experiments were analyzed for their applicability to the Traveller package. Table 6-42 shows a summary comparison of the benchmark critical experiment properties to the Traveller package. The range of properties for the critical experiment includes range of values for the Traveller package.

In addition, a qualitative evaluation of the neutron event probabilities is also done to compare the importance of the contents and packaging materials relative to neutron absorption. Comparing the absorption probabilities for the critical experiments and package indicates that the importance of neutron absorption is similar between the critical experiments and package model.

1. NUREG/CR-6361 (ORNL/TM-13211): Criticality Benchmark Guide for Light-Water-Reactor Fuel in Transportation and Storage Packages.

The input decks for the 55 experiments were run locally using Keno V.a. The results compared favorably to published results. The input decks were then converted to Keno-VI using the C5TOC6 utility program and run again. These results were used to determine the USL for the Traveller calculations.

The analysis concluded that no single group of critical benchmark experiments (simple lattice, separator plate, flux trap, or water hole) contains all the characteristics of the Traveller shipping package. However, the four groups each represent different aspects of the package model that are important to understanding the bias associated with the package modeling. The simple lattice and water hole experiments represent the fuel region modeling (i.e., fuel enrichment, lattice pitch, water-to-fuel ratio), and the separator plate and flux trap experiments represent additional characteristics of the package modeling (i.e., moderator, neutron absorbers).

6.9.2 Bias Determination

After comparison of critical experiments, USLSTATS was used to assist with the statistical analysis of the benchmark experiments. It provides two methods of determining a USL, and a comparison of these two methods is shown in Figure 6-19.

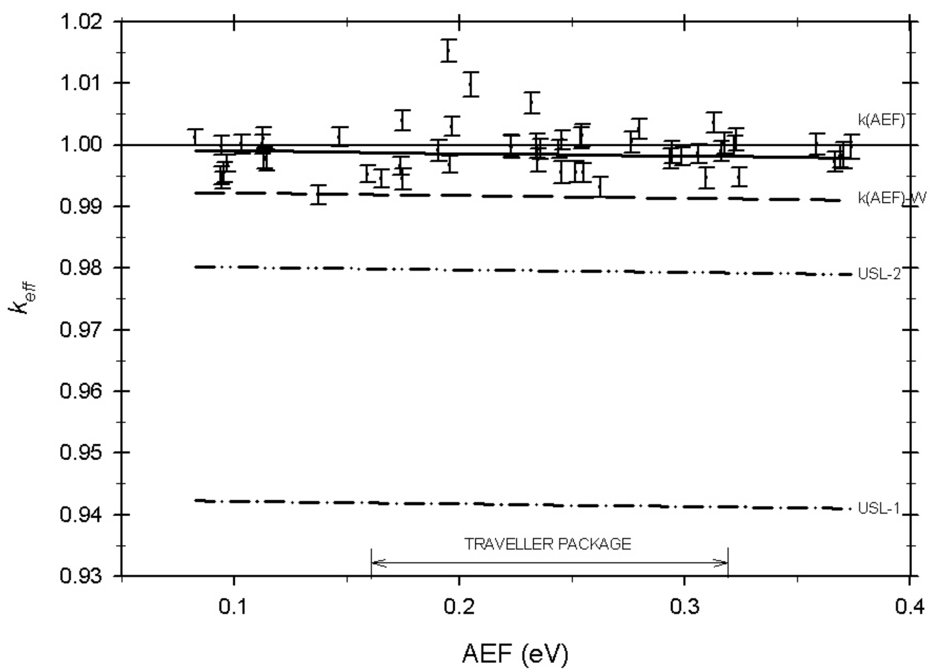

Figure 6-19 Upper Safety Limits (USLs) for 55 LWR Fuel Critical Experiments

The first (referred to as USL-1) uses a confidence band calculated using a linear regression fit based on the results from the selected benchmarks, and places an additional administrative margin on the lower band, which is then used as the USL.

The second method (referred to as USL-2) is a single-sided closed interval approach, using a uniform width. The purpose of this method is to determine a uniform tolerance band over a specified closed interval, based on a linear least squares model. This method uses a statistically calculated subcritical margin (with a confidence level of 0.95 in this case), and is used to determine whether the USL-1 method is sufficiently conservative.

The trending parameter chosen for the two methods was the AEF. The AEF range in the benchmark cases provides ample coverage for the calculated average energy of fission (AEF) values of the various Traveller configurations (individual vs. package array, normal transport vs. HAC, etc). Ample coverage means that no extrapolation is required in order to determine the USL. The end result of this is shown graphically in Figure 6-19.

The results shown in Figure 6-19 indicate that a USL of 0.94 is acceptable including an administrative margin, $\Delta k_m = 0.05$, and a bias of negative 0.01 ($\beta + \Delta\beta = -0.01$). The administrative margin is acceptable because for all grouping of experiments the minimum subcritical margin is positive, USL2-USL1≥ 0. The largest statistical bias (USL-2) is associated with the flux trap group. The application of the statistically based subcritical margin indicates the administrative margin is adequate by a margin of at least 0.015 (USL-2 minus USL-1) even for groups were there is a limited number of data points (i.e., flux trap, water hole). Therefore, the bias determination is made by including all 55 experiments in the USLSTAT calculation.

6.10 APPENDICES

The following appendices are included to provide additional information on material contained elsewhere in Section 6.

6.10.1: References

6.10.2: PWR Fuel Assembly Parameters

6.10.3: Fuel Assembly Comparison

6.10.4: 17OFA-XL Model

6.10.5: Traveller Packaging Model

6.10.6: Single Package Evaluation Calculations

6.10.7: Package Array Evaluation Calculations

6.10.8: Rod Container Calculations

6.10.9: Calculations for Sensitivity Studies

6.10.10: Benchmark Critical Experiments

6.10.1 References

None

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6.10.2 PWR Fuel Assembly Parameters

The following tables and figures provide the fuel assembly parameters important to criticality safety for the 14x14, 15x15, 16x16, 17x17, and 18x18 fuel types to be transported in the Traveller. Fuel assemblies with other product names, but which satisfy the parameters found in this section may be transported in the Traveller.

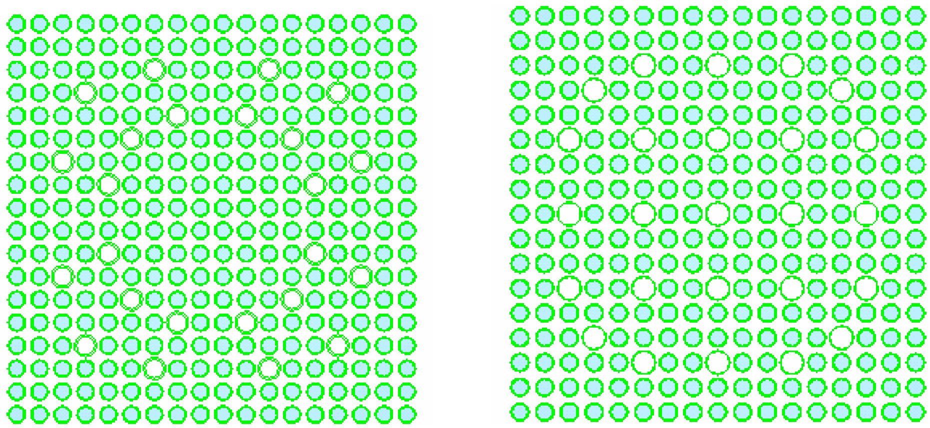

Figure 6-20 Cross Section for 18x18 and 17x17 Assemblies

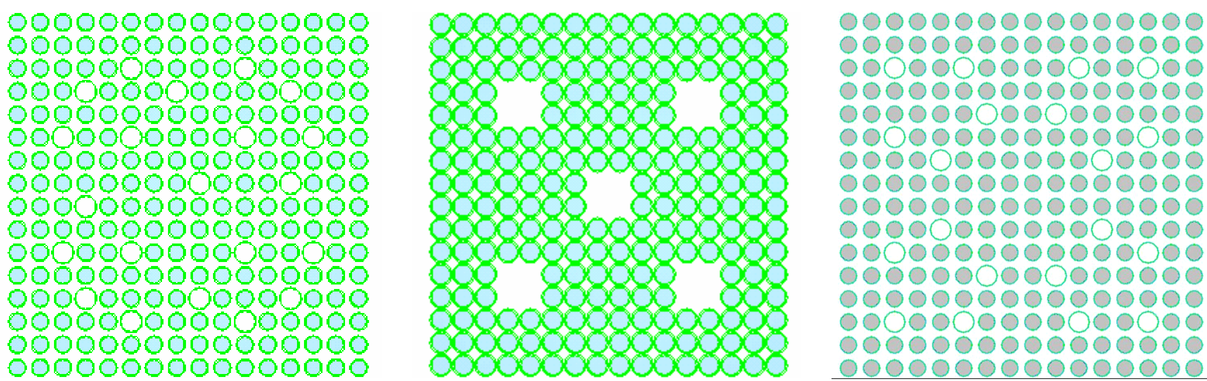

Figure 6-21 Cross Sections for 16x16 Assemblies

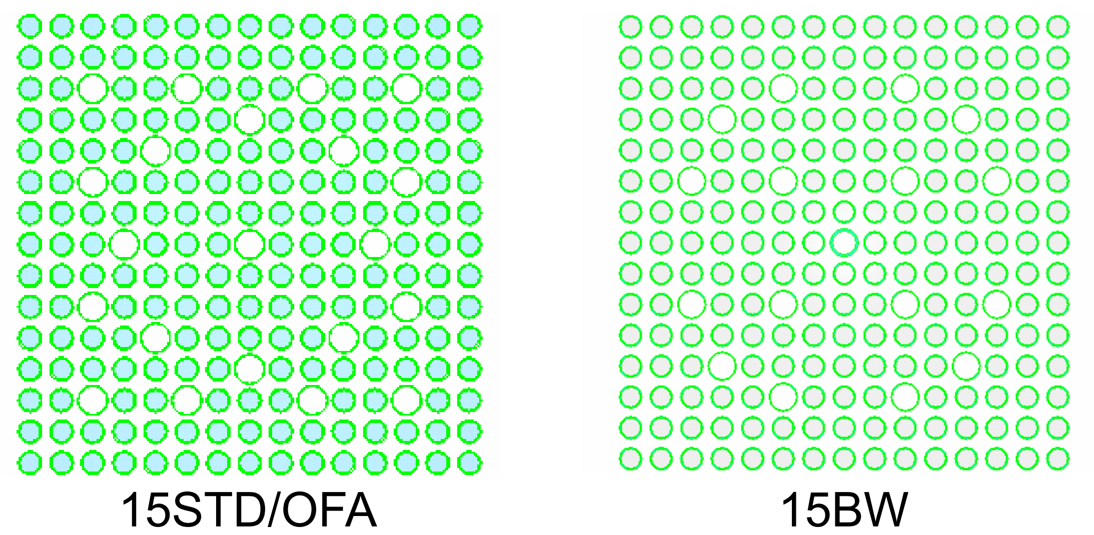

Figure 6-22 Cross Sections for 15x15 Assemblies

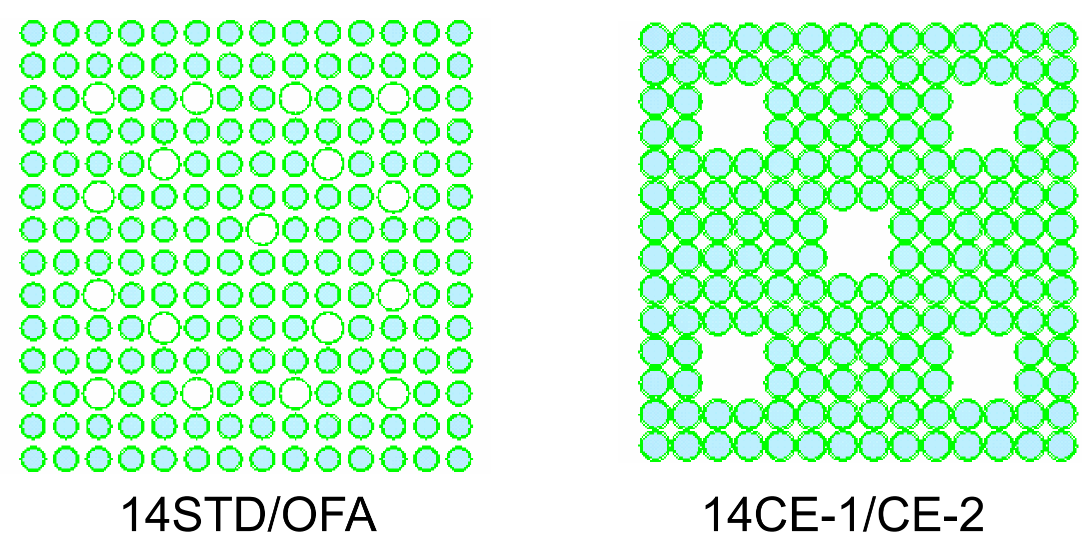

Figure 6-22A Cross Sections for 14x14 Assemblies

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Table 6-20 Parameters for 14x14 Fuel Assemblies			
Fuel Assembly Description	**14 X 14**	**14 X 14**	**14 X 14**
Fuel Assembly Type	W-STD	W-OFA	CE-1/CE-2
No. Fuel Rods per assembly	179	179	176
No. Non-Fuel Rods	17	17	20
Nominal Guide Tube Wall Thickness	0.043 cm (0.017 in.)	0.043 cm (0.017 in.)	0.097 cm (0.038 in.)
Nominal Guide Tube Outer Diameter	1.369 cm (0.539 in.)	1.336 cm (0.526 in.)	2.822 cm (1.111 in.)
Nominal Pellet Diameter	0.929 cm (0.366 in.)	0.875 cm (0.344 in.)	0.956/0.966 cm (0.376/0.381 in.)
Nominal Clad Outer Diameter	1.072 cm (0.422 in.)	1.016 cm (0.400 in.)	1.118 cm (0.440 in.)
Nominal Clad Thickness	0.062 cm (0.024 in.)	0.062 cm (0.024 in.)	0.071/0.066 cm (0.028/0.026 in.)
Clad Material	Zirconium alloy	Zirconium alloy	Zirconium alloy
Nominal Assembly Envelope	19.70 cm (7.76 in.)	19.70 cm (7.76 in.)	20.60 cm (8.11 in.)
Nominal Lattice Pitch	1.412 cm (0.556 in.)	1.412 cm (0.556 in.)	1.473 cm (0.580 in.)

Table 6-21 Parameters for 15x15 Fuel Assemblies		
Fuel Assembly Description	**15 X 15**	**15 X 15**
Fuel Assembly Type	STD/OFA	B&W
No. Fuel Rods per Assembly	204	208
No. Non-Fuel Rods	21	17
Nominal Guide Tube Wall Thickness	0.043/0.043 cm (0.017/0.017 in.)	0.043 cm (0.017 in.)
Nominal Guide Tube Outer Diameter	1.387/1.354 cm (0.546/0.533 in.)	1.354 cm (0.533 in.)
Nominal Pellet Diameter	0.929 cm (0.366 in.)	0.929 cm (0.366 in.)
Nominal Clad Outer Diameter	1.072 cm (0.422 in.)	1.072 cm (0.422 in.)
Nominal Clad Thickness	0.062 cm (0.024 in.)	0.062 cm (0.024 in.)
Clad Material	Zirconium alloy	Zirconium alloy
Nominal Assembly Envelope	21.39 cm (8.42 in.)	21.66 cm (8.53 in.)
Nominal Lattice Pitch	1.430 cm (0.563 in.)	1.443 cm (0.568 in.)

Table 6-22 Parameters for 16x16 Fuel Assemblies

Fuel Assembly Description	16 X 16	16 X 16	16 X 16	16 X 16
Fuel Assembly Type	16STD	16NGF	ATOM	
No. Fuel Rods per Assembly	235	235	236	
No. Non-Fuel Rods	21	21	20	
Nominal Guide Tube Wall Thickness	0.046 cm (0.018 in.)	0.041 cm (0.016 in.)	0.070 cm (0.028 in.)	
Nominal Guide Tube Outer Diameter	1.196 cm (0.471 in.)	1.204 cm (0.474 in.)	1.380 cm (0.543 in.)	
Nominal Pellet Diameter	0.819 cm (0.3225 in.)	0.784 cm (0.3088 in.)	0.911 cm (0.359 in.)	
Nominal Clad Outer Diameter	0.950 cm (0.3740 in.)	0.914 cm (0.3600 in.)	1.075 cm (0.423 in.)	
Nominal Clad Thickness	0.057 cm (0.0225 in.)	0.057 cm (0.0225 in.)	0.072 cm (0.029 in.)	
Clad Material	Zirconium alloy	Zirconium alloy	Zirconium alloy	
Nominal Assembly Envelope	19.72 cm (7.76 in.)	19.72 cm (7.76 in.)	22.95 cm (9.03 in.)	
Nominal Lattice Pitch	1.232 cm (0.485 in.)	1.232 cm (0.485 in.)	1.430 cm (0.563 in.)	

Table 6-22 Parameters for 16x16 Fuel Assemblies (cont)

Fuel Assembly Description	16 X 16	16 X 16	16 X 16	16 X 16
Fuel Assembly Type	CE16NVA	CE16VA	CE16NFG	
No. Fuel Rods per Assembly	236	236	236	
No. Non-Fuel Rods	20	20	20	
Nominal Guide Tube Wall Thickness	0.102 cm (0.040 in.)	0.102 cm (0.040 in.)	0.102 cm (0.040 in.)	
Nominal Guide Tube Outer Diameter	2.489 cm (0.980 in.)	2.489 cm (0.980 in.)	2.489 cm (0.980 in.)	
Nominal Pellet Diameter	0.8255 cm (0.3250 in.)	0.8268 cm (0.3255 in.)	0.8192 cm (0.3225 in.)	
Nominal Clad Outer Diameter	0.970 cm (0.382 in.)	0.970 cm (0.382 in.)	0.9500 cm (0.3740 in.)	
Nominal Clad Thickness	0.064 cm (0.025 in.)	0.064 cm (0.025 in.)	0.057 cm (0.0225 in.)	
Clad Material	Zirconium alloy	Zirconium alloy	Zirconium alloy	
Nominal Assembly Envelope	20.63 cm (8.12 in.)	20.63 cm (8.12 in.)	20.63 cm (8.12 in.)	
Nominal Lattice Pitch	1.285 cm (0.506 in.)	1.285 cm (0.506 in.)	1.285 cm (0.506 in.)	

Table 6-23 Parameters for 17x17 and 18x18 Fuel Assemblies

Fuel Assembly Description	17 X 17	17 X 17	18 X 18
Fuel Assembly Type	W-STD or XL	W-OFA	ATOM
No. Fuel Rods per Assembly	264	264	300
No. Non-Fuel Rods	25	25	24
Nominal Guide Tube Wall Thickness	0.041/0.051 cm (0.016/0.020 in.)	0.041 cm (0.016 in.)	0.065 cm (0.026 in.)
Nominal Guide Tube Outer Diameter	1.204/1.224/1.24 cm (0.474/0.482/0.488 in.)	1.204 cm (0.474 in.)	1.240 cm (0.488 in.)
Nominal Pellet Diameter	0.819 cm (0.323 in.)	0.784 cm (0.309 in.)	0.805 cm (0.317 in.)
Nominal Clad Outer Diameter	0.950 cm (0.374 in.)	0.914 cm (0.360 in.)	0.950 cm (0.374 in.)
Nominal Clad Thickness	0.057 cm (0.023 in.)	0.057 cm (0.023 in.)	0.064 cm (0.025 in.)
Clad Material	Zirconium alloy	Zirconium alloy	Zirconium alloy
Nominal Assembly Envelope	21.39 cm (8.42 in.)	21.39 cm (8.42 in.)	22.94 cm (9.03 in.)
Nominal Lattice Pitch	1.260 cm (0.496 in.)	1.260 cm (0.496 in.)	1.270 cm (0.500 in.)

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6.10.3 Fuel Assembly Comparison

Comparison of the fuel assembly k_{eff} values to determine the most reactive contents is done on basis of the fuel confinement envelope. A fuel rod pitch is calculated for each fuel assembly that corresponds to each fuel envelope dimension [nominal, 22.86 cm (9.0 inch), 24.13 cm (9.5 inch), 25.40 cm (10.0 inch), 27.94 cm (11.0 inch), 30.48 cm (12.0 inch), 33.02 cm (13.0 inch), 35.56 cm (14.0 inch)]. A range of fuel envelope dimensions were evaluated to evaluate the sensitivity of keff to the fuel envelope confinement system dimension. Table 6-24 summarizes the k_{eff} values calculated for each fuel assembly with the 100 cm section of expanded lattice where the pitch corresponds to each of the fuel envelope dimension. A summary ranking of fuel assemblies from most to least reactive is provided in Table 6-24A and shows that the ranking depends on the fuel envelope dimension. As such, no single fuel assembly can be shown to represent the contents with the maximum reactivity for a given fuel envelope confinement dimension. Figure 6-23 shows these k_{eff} values as a function of the fuel envelope confinement dimension, where the accident condition inset is also shown is Figure 6-5. The trendlines represent an equation that provides a reasonable best fit to each series of data points. The ranking of the trendlines does not necessarily match the ranking of the individual data points, but reflect the trends as influenced by the overall fit of the equation to the individual data points. The 17X17 OFA consistently ranks as one of more reactive of the fuel assemblies and the difference between the highest k_{eff} value and the value calculated for the 17X17 OFA is less than 0.005 Δk_{eff} within the range of dimensions for the clamshell confinement (22.86 cm (9.0 in) to 24.13 cm (9.5 in)). The 17X17 OFA is selected to represent the fuel assembly contents for the accident transport condition. Figure 6-24 is a sample input deck used to calculate the k_{eff} values for the individual fuel assembly.

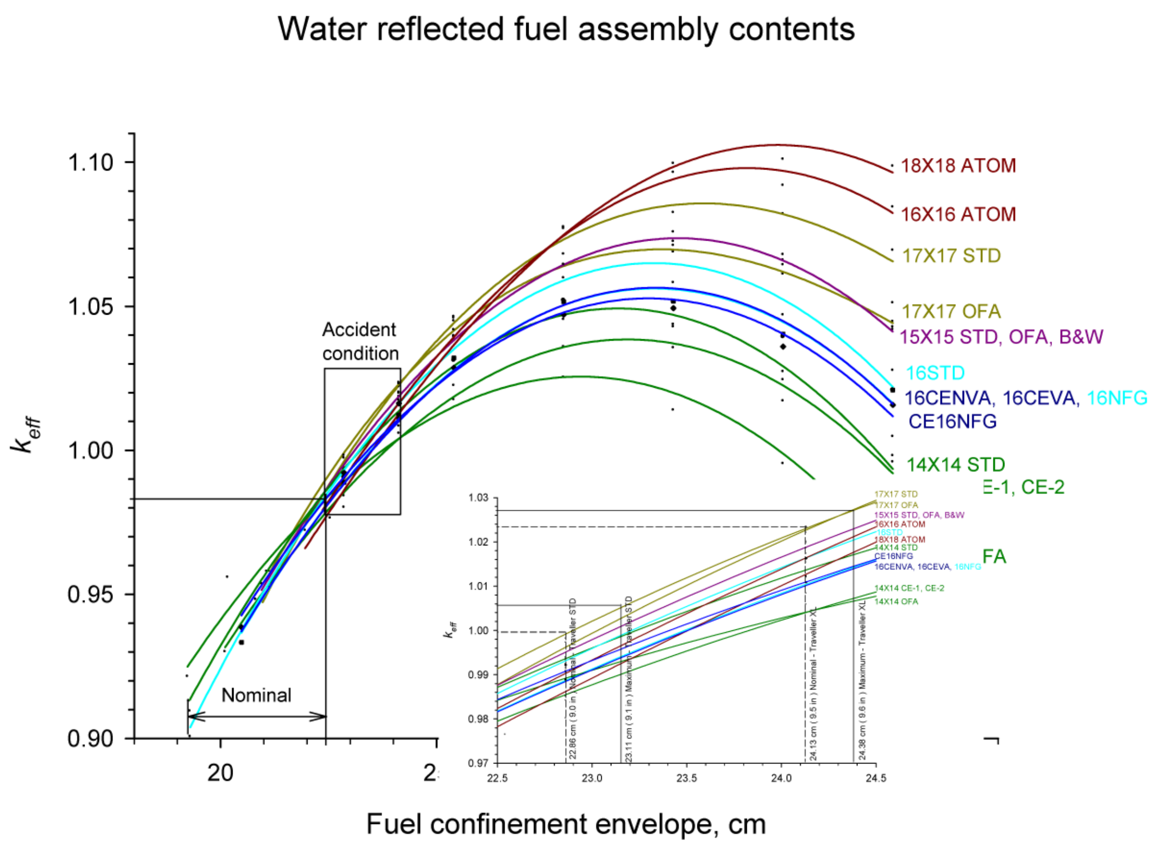

Figure 6-23 Comparison of Fuel Assemblies – Individual Fuel Assembly, 20 cm Water Reflection, 100 cm Lattice Expansion

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Table 6-24A Summary and Ranking Results in Table 6-24								
	Fuel envelope confinement dimension							
		Traveller STD	Traveller XL					
Fuel Assembly	Nominal	22.86 cm (9.0 in)	24.13 cm (9.5 in)	25.40 cm (10.0 in)	27.94 cm (11.0 in)	30.48 cm (12.0 in)	33.02 cm (13.0 in)	35.56 cm (14.0 in)
18X18 ATOM	2	16	12	8	1	8	8	1
	0.9765	0.9802	1.0120	1.0385	1.0775	1.0995	1.101	1.0986
17X17 STD	7	9	1	3	3	9	12	3
	0.9527	0.9915	1.0235	1.0449	1.0769	1.0825	1.082	1.0694
17X17 OFA	4	3	3	2	6	4	2	5
	0.9580	0.9940	1.0221	1.0459	1.0644	1.0688	1.0611	1.0447
16STD	16	4	5	6	8	5	10	8
	0.9006	0.9937	1.0201	1.0394	1.0598	1.0582	1.047	1.0277
16NFG	14	2	7	11	13	13	9	12
	0.9129	0.9973	1.0186	1.031	1.0454	1.0428	1.0273	1.0048
16ATOM	1	14	10	7	2	7	11	2
	0.9841	0.9851	1.0154	1.0387	1.0771	1.0964	1.0919	1.0844
CE16NVA	10	11	11	10	9	10	3	9
	0.9331	0.9906	1.0122	1.0312	1.0520	1.0515	1.0394	1.0209
CE16VA	9	12	14	9	10	6	1	10
	0.9334	0.9889	1.0109	1.0321	1.0516	1.0518	1.0404	1.0209
CE16NFG	8	8	9	13	11	11	7	11
	0.9386	0.9922	1.0163	1.0287	1.0471	1.0493	1.036	1.0158
15X15 STD	6	7	6	4	7	3	5	7
	0.9529	0.9925	1.0198	1.0418	1.064	1.0711	1.066	1.0419
15X15 OFA	5	5	4	5	5	2	6	6
	0.9537	0.9933	1.0209	1.0397	1.0645	1.0725	1.0644	1.0428
15X15 BW	3	6	2	1	4	1	4	4
	0.9581	0.9933	1.0231	1.0464	1.0681	1.0758	1.0679	1.0512
14X14 STD	15	1	8	12	12	12	13	14
	0.9095	0.9982	1.0174	1.0288	1.0465	1.0437	1.0245	0.9981
14X14 OFA	13	10	15	16	16	15	16	16
	0.9215	0.9909	1.0084	1.0176	1.0253	1.0139	0.9954	0.9666
14X14 CE-1	12	13	13	14	14	14	15	13
	0.9301	0.9842	1.0059	1.0225	1.0359	1.0356	1.0171	0.9959
14X14 CE-2	11	15	16	15	15	16	14	15
	0.9276	0.9861	1.0111	1.0264	1.0382	1.0384	1.0245	1.0022

Table 6-24 Individual Fuel Assembly, 20 cm water reflection, 100 cm fuel lattice expansion					
Fuel envelope	**Pitch (cm)**	**p/d ratio**	**k_s**	**σ_s**	**$k_s + 2\sigma_s$**
18x18 ATOM					
Nominal	1.2700	1.5778	0.9731	1.7000e-3	0.9765
22.86 cm (9.0 inch)	1.2888	1.6011	0.9774	1.4000e-3	0.9802
24.13 cm (9.5 inch)	1.3635	1.6939	1.0088	1.6000e-3	1.0120
25.40 cm (10.0 inch)	1.4382	1.7867	1.0353	1.6000e-3	1.0385
27.94 cm (11.0 inch)	1.5876	1.9723	1.0739	1.8000e-3	1.0775
30.48 cm (12.0 inch)	1.7371	2.1581	1.0963	1.6000e-3	1.0995
33.02 cm (13.0 inch)	1.8865	2.3437	1.0980	1.5000e-3	1.1010
35.56 cm (14.0 inch)	2.0359	2.5293	1.0958	1.4000e-3	1.0986
17x17 STD					
Nominal	1.2598	1.5379	0.9497	1.5000e-3	0.9527
22.86 cm (9.0 inch)	1.3694	1.6717	0.9885	1.5000e-3	0.9915
24.13 cm (9.5 inch)	1.4488	1.7687	1.0201	1.7000e-3	1.0235
25.40 cm (10.0 inch)	1.5281	1.8655	1.0419	1.5000e-3	1.0449
27.94 cm (11.0 inch)	1.6869	2.0593	1.0735	1.7000e-3	1.0769
30.48 cm (12.0 inch)	1.8456	2.2531	1.0793	1.6000e-3	1.0825
33.02 cm (13.0 inch)	2.0044	2.4469	1.0792	1.4000e-3	1.0820
35.56 cm (14.0 inch)	2.1613	2.6385	1.0666	1.4000e-3	1.0694
17x17 OFA					
Nominal	1.2598	1.6062	0.9550	1.5000e-3	0.9580
22.86 cm (9.0 inch)	1.3716	1.7487	0.9910	1.5000e-3	0.9940
24.13 cm (9.5 inch)	1.4510	1.8499	1.0191	1.5000e-3	1.0221
25.40 cm (10.0 inch)	1.5303	1.9510	1.0427	1.6000e-3	1.0459
27.94 cm (11.0 inch)	1.6891	2.1535	1.0616	1.4000e-3	1.0644
30.48 cm (12.0 inch)	1.8479	2.3560	1.0656	1.6000e-3	1.0688
33.02 cm (13.0 inch)	2.0066	2.5583	1.0579	1.6000e-3	1.0611
35.56 cm (14.0 inch)	2.1654	2.7608	1.0419	1.4000e-3	1.0447

Table 6-24 Individual Fuel Assembly, 20 cm water reflection, 100 cm fuel lattice expansion (cont.)					
Fuel envelope	**Pitch (cm)**	**p/d ratio**	k_s	σ_s	$k_s + 2\sigma_s$
16STD					
Nominal	1.2319	1.5039	0.8978	1.4000e-3	0.9006
22.86 cm (9.0 inch)	1.4607	1.7832	0.9909	1.4000e-3	0.9937
24.13 cm (9.5 inch)	1.5453	1.8865	1.0167	1.7000e-3	1.0201
25.40 cm (10.0 inch)	1.6300	1.9899	1.0364	1.5000e-3	1.0394
27.94 cm (11.0 inch)	1.7993	2.1965	1.0564	1.7000e-3	1.0598
30.48 cm (12.0 inch)	1.9687	2.4033	1.0556	1.3000e-3	1.0582
33.02 cm (13.0 inch)	2.1380	2.6100	1.0442	1.4000e-3	1.0470
35.56 cm (14.0 inch)	2.3073	2.8167	1.0245	1.6000e-3	1.0277
16NFG					
Nominal	1.2319	1.5706	0.9097	1.6000e-3	0.9129
22.86 cm (9.0 inch)	1.4630	1.8652	0.9943	1.5000e-3	0.9973
24.13 cm (9.5 inch)	1.5477	1.9732	1.0154	1.6000e-3	1.0186
25.40 cm (10.0 inch)	1.6324	2.0812	1.0278	1.6000e-3	1.0310
27.94 cm (11.0 inch)	1.8017	2.2971	1.0424	1.5000e-3	1.0454
30.48 cm (12.0 inch)	1.9710	2.5129	1.0394	1.7000e-3	1.0428
33.02 cm (13.0 inch)	2.1404	2.7289	1.0245	1.4000e-3	1.0273
35.56 cm (14.0 inch)	2.3097	2.9447	1.0016	1.6000e-3	1.0048
16ATOM					
Nominal	1.4300	1.5682	0.9811	1.5000e-3	0.9841
22.86 cm (9.0 inch)	1.4523	1.5927	0.9821	1.5000e-3	0.9851
24.13 cm (9.5 inch)	1.5370	1.6856	1.0120	1.7000e-3	1.0154
25.40 cm (10.0 inch)	1.6217	1.7785	1.0355	1.6000e-3	1.0387
27.94 cm (11.0 inch)	1.7910	1.9641	1.0739	1.6000e-3	1.0771
30.48 cm (12.0 inch)	1.9603	2.1498	1.0932	1.6000e-3	1.0964
33.02 cm (13.0 inch)	2.1297	2.3356	1.0889	1.5000e-3	1.0919
35.56 cm (14.0 inch)	2.2990	2.5212	1.0816	1.4000e-3	1.0844

Table 6-24 Individual Fuel Assembly, 20 cm water reflection, 100 cm fuel lattice expansion (cont.)

Fuel envelope	Pitch (cm)	p/d ratio	k_s	σ_s	$k_s + 2\sigma_s$
CE16NVA					
Nominal	1.3106	1.5876	0.9301	1.5000e-3	0.9331
22.86 cm (9.0 inch)	1.4593	1.7678	0.9876	1.5000e-3	0.9906
24.13 cm (9.5 inch)	1.5440	1.8704	1.0088	1.7000e-3	1.0122
25.40 cm (10.0 inch)	1.6286	1.9729	1.0276	1.8000e-3	1.0312
27.94 cm (11.0 inch)	1.7980	2.1781	1.0492	1.4000e-3	1.0520
30.48 cm (12.0 inch)	1.9673	2.3832	1.0483	1.6000e-3	1.0515
33.02 cm (13.0 inch)	2.1366	2.5882	1.0368	1.3000e-3	1.0394
35.56 cm (14.0 inch)	2.3060	2.7935	1.0179	1.5000e-3	1.0209
CE16VA					
Nominal	1.3106	1.5851	0.9302	1.6000e-3	0.9334
22.86 cm (9.0 inch)	1.4593	1.7650	0.9857	1.6000e-3	0.9889
24.13 cm (9.5 inch)	1.5440	1.8674	1.0079	1.5000e-3	1.0109
25.40 cm (10.0 inch)	1.6286	1.9698	1.0287	1.7000e-3	1.0321
27.94 cm (11.0 inch)	1.7980	2.1746	1.0486	1.5000e-3	1.0516
30.48 cm (12.0 inch)	1.9673	2.3794	1.0490	1.4000e-3	1.0518
33.02 cm (13.0 inch)	2.1366	2.5842	1.0376	1.4000e-3	1.0404
35.56 cm (14.0 inch)	2.3060	2.7891	1.0177	1.6000e-3	1.0209
CE16NFG					
Nominal	1.3120	1.6016	0.9354	1.6000e-3	0.9386
22.86 cm (9.0 inch)	1.4607	1.7831	0.9886	1.8000e-3	0.9922
24.13 cm (9.5 inch)	1.5453	1.8864	1.0133	1.5000e-3	1.0163
25.40 cm (10.0 inch)	1.6300	1.9897	1.0251	1.8000e-3	1.0287
27.94 cm (11.0 inch)	1.7993	2.1964	1.0437	1.7000e-3	1.0471
30.48 cm (12.0 inch)	1.9687	2.4032	1.0463	1.5000e-3	1.0493
33.02 cm (13.0 inch)	2.1380	2.6099	1.0334	1.3000e-3	1.0360
35.56 cm (14.0 inch)	2.3073	2.8165	1.0132	1.3000e-3	1.0158

Table 6-24 Individual Fuel Assembly, 20 cm water reflection, 100 cm fuel lattice expansion (cont.)					
Fuel envelope	**Pitch (cm)**	**p/d ratio**	**k_s**	**σ_s**	**$k_s + 2\sigma_s$**
15X15 STD					
Nominal	1.4300	1.5386	0.9501	1.4000e-3	0.9529
22.86 cm (9.0 inch)	1.5563	1.6745	0.9891	1.7000e-3	0.9925
24.13 cm (9.5 inch)	1.6470	1.7721	1.0168	1.5000e-3	1.0198
25.40 cm (10.0 inch)	1.7377	1.8697	1.0386	1.6000e-3	1.0418
27.94 cm (11.0 inch)	1.9192	2.0650	1.0608	1.6000e-3	1.0640
30.48 cm (12.0 inch)	2.1006	2.2602	1.0677	1.7000e-3	1.0711
33.02 cm (13.0 inch)	2.2820	2.4554	1.0626	1.7000e-3	1.0660
35.56 cm (14.0 inch)	2.4634	2.6506	1.0393	1.3000e-3	1.0419
15X15 OFA					
Nominal	1.4300	1.5386	0.9507	1.5000e-3	0.9537
22.86 cm (9.0 inch)	1.5563	1.6745	0.9903	1.5000e-3	0.9933
24.13 cm (9.5 inch	1.6470	1.7721	1.0177	1.6000e-3	1.0209
25.40 cm (10.0 inch)	1.7377	1.8697	1.0359	1.9000e-3	1.0397
27.94 cm (11.0 inch)	1.9192	2.0650	1.0617	1.4000e-3	1.0645
30.48 cm (12.0 inch)	2.1006	2.2602	1.0693	1.6000e-3	1.0725
33.02 cm (13.0 inch)	2.2820	2.4554	1.0616	1.4000e-3	1.0644
35.56 cm (14.0 inch)	2.4634	2.6506	1.0400	1.4000e-3	1.0428
15X15 BW					
Nominal	1.4427	1.5523	0.9551	1.5000e-3	0.9581
22.86 cm (9.0 inch)	1.5563	1.6745	0.9899	1.7000e-3	0.9933
24.13 cm (9.5 inch)	1.6470	1.7721	1.0201	1.5000e-3	1.0231
25.40 cm (10.0 inch)	1.7377	1.8697	1.0430	1.7000e-3	1.0464
27.94 cm (11.0 inch)	1.9192	2.0650	1.0649	1.6000e-3	1.0681
30.48 cm (12.0 inch)	2.1006	2.2602	1.0730	1.4000e-3	1.0758
33.02 cm (13.0 inch)	2.2820	2.4554	1.0643	1.8000e-3	1.0679
35.56 cm (14.0 inch)	2.4634	2.6506	1.0482	1.5000e-3	1.0512

Table 6-24 Individual Fuel Assembly, 20 cm water reflection, 100 cm fuel lattice expansion (cont.)					
Fuel envelope	**Pitch (cm)**	**p/d ratio**	k_s	σ_s	$k_s + 2\sigma_s$
14X14 STD					
Nominal	1.4122	1.5195	0.9067	1.4000e-3	0.9095
22.86 cm (9.0 inch)	1.6760	1.8033	0.9950	1.6000e-3	0.9982
24.13 cm (9.5 inch)	1.7737	1.9085	1.0146	1.4000e-3	1.0174
25.40 cm (10.0 inch)	1.8714	2.0136	1.0258	1.5000e-3	1.0288
27.94 cm (11.0 inch)	2.0668	2.2238	1.0429	1.8000e-3	1.0465
30.48 cm (12.0 inch)	2.2622	2.4341	1.0405	1.6000e-3	1.0437
33.02 cm (13.0 inch)	2.4575	2.6442	1.0219	1.3000e-3	1.0245
35.56 cm (14.0 inch)	2.6529	2.8545	0.9955	1.3000e-3	0.9981
14X14 OFA					
Nominal	1.4122	1.6143	0.9183	1.6000e-3	0.9215
22.86 cm (9.0 inch)	1.6803	1.9208	0.9879	1.5000e-3	0.9909
24.13 cm (9.5 inch)	1.7780	2.0325	1.0054	1.5000e-3	1.0084
25.40 cm (10.0 inch)	1.8757	2.1442	1.0144	1.6000e-3	1.0176
27.94 cm (11.0 inch)	2.0711	2.3676	1.0223	1.5000e-3	1.0253
30.48 cm (12.0 inch)	2.2665	2.5909	1.0111	1.4000e-3	1.0139
33.02 cm (13.0 inch)	2.4618	2.8142	0.9924	1.5000e-3	0.9954
35.56 cm (14.0 inch)	2.6572	3.0376	0.9634	1.6000e-3	0.9666
14X14 BW					
Nominal	1.4732	1.5405	0.9271	1.5000e-3	0.9301
22.86 cm (9.0 inch)	1.6725	1.7489	0.9812	1.5000e-3	0.9842
24.13 cm (9.5 inch)	1.7702	1.8511	1.0029	1.5000e-3	1.0059
25.40 cm (10.0 inch)	1.8679	1.9532	1.0189	1.8000e-3	1.0225
27.94 cm (11.0 inch)	2.0633	2.1576	1.0331	1.4000e-3	1.0359
30.48 cm (12.0 inch)	2.2586	2.3618	1.0326	1.5000e-3	1.0356
33.02 cm (13.0 inch)	2.4540	2.5661	1.0143	1.4000e-3	1.0171
35.56 cm (14.0 inch)	2.6494	2.7704	0.9931	1.4000e-3	0.9959

Table 6-24 Individual Fuel Assembly, 20 cm water reflection, 100 cm fuel lattice expansion (cont.)					
Fuel envelope	**Pitch (cm)**	**p/d ratio**	**k_s**	**σ_s**	**$k_s + 2\sigma_s$**
14X14 CE-2					
Nominal	1.4732	1.5243	0.9246	1.5000e-3	0.9276
22.86 cm (9.0 inch)	1.6725	1.7305	0.9829	1.6000e-3	0.9861
24.13 cm (9.5 inch)	1.7702	1.8316	1.0081	1.5000e-3	1.0111
25.40 cm (10.0 inch)	1.8679	1.9327	1.0232	1.6000e-3	1.0264
27.94 cm (11.0 inch)	2.0633	2.1349	1.0350	1.6000e-3	1.0382
30.48 cm (12.0 inch)	2.2586	2.3370	1.0352	1.6000e-3	1.0384
33.02 cm (13.0 inch)	2.4540	2.5391	1.0217	1.4000e-3	1.0245
35.56 cm (14.0 inch)	2.6494	2.7413	0.9990	1.6000e-3	1.0022

```
17x17w-ofa_4_1.451_24.13_in

=csas26     parm=size=300000
17X17W-OFA Fuel envelope=24.13 cm,  HAC length=100
cm
44groupndf5  latticecell
 uo2 1 1 293 92235 5 92238 95 end
 h2o 2 1 293 end
 zirc4 3 1 293 end
 h2o 4 1 293 end
 h2o  5 1 293 end
 h2o 15 1 293 end
 uo2 16 1 293 92235 5 92238 95 end
 h2o 17 1 293 end
 zirc4 18 1 293 end
 h2o 19 1 293 end
end comp
squarepitch 1.451   0.78435  16 19 0.9144   18 0.8001   17 end
more data
res=1  cylinder 0.39218      dan(1)=0.22842       end
read parameter
gen=303
wrs=1
end parameter
read geometry

global
unit 20
com='fuel assembly'
cuboid 1 24.13        0 24.13        0 368.3       0
cuboid 2 44.13       -20          44.13       -20          368.3       -20
hole 31 origin  x=0    y=0       z=0       rotate  a1=0  a2=0 a3=0
hole 21 origin  x=0    y=0       z=100    rotate  a1=0  a2=0 a3=0
media   0 1  1
media  15 1 -1   2
boundary 2

unit 21
com='fuel rods - nominal pitch'
cuboid 1  21.072       0 21.072       0 268.3        0.0000
cuboid 2  21.382       0 21.382       0 268.3        0.0000
array 1 1 place 1 1 1 0.4572       0.4572       0
media 0 1  -1  2
boundary 2

unit 22
com='solid fuel rod - nominal pitch'
cylinder 1  0.39218       368.3           0
cylinder 2  0.40005      368.3           0
cylinder 3  0.4572       368.3           0
cuboid 4  4P0.62992       368.3           0
media 1 1  1
media 2 1  2 -1
media 3 1  3 -2 -1
media 4 1  4 -3 -2 -1
boundary 4

unit 23
com='thimble tube - nominal pitch'
cylinder 1  0.56134       368.3          0
cylinder 2  0.60198        368.3          0
cuboid 3    4P0.62992      368.3          0
media 4 1 1
media 3 1 2 -1
media 4 1 3 -2 -1
boundary 3
```

```
unit 31
com='fuel rods - expanded pitch'
cuboid 1  24.13       0 24.13       0 100         0
array 2 1 place 1 1 1 0.4572       0.4572       0
boundary 1

unit 32
com='solid fuel rod - expanded pitch'
cylinder 1  0.39218       368.3           0
cylinder 2  0.40005      368.3           0
cylinder 3  0.4572       368.3           0
cuboid 4  4P0.72549       368.3           0
media 16  1 1
media 17  1 2 -1
media 18  1 3 -2 -1
media 19  1 4 -3 -2 -1
boundary 4

unit 33
com='thimble tube - expanded pitch'
cylinder 1  0.56134      368.3           0
cylinder 2  0.60198      368.3           0
cuboid 3  4P0.72549       368.3           0
media 19 1 1
media 18 1 2 -1
media 19 1 3 -2 -1
boundary 3

end geometry

read array
ara=1 typ=square nux=17 nuy=17 nuz=1
fill 39*22 23 2*22 23 2*22 23 8*22 23 9*22 23 22*22 23
2*22 23 2*22 23
 2*22 23 2*22 23 38*22 23 2*22 23 2*22 23 2*22 23 2*22 23
38*22 23
 2*22 23 2*22 23 2*22 23 2*22 23 22*22 23 9*22 23 8*22 23
2*22 23 2*22
 23 39*22
end fill
ara=2 typ=square nux=17 nuy=17 nuz=1
fill 39*32 33 2*32 33 2*32 33 8*32 33 9*32 33 22*32 33
2*32 33 2*32 33
 2*32 33 2*32 33 38*32 33 2*32 33 2*32 33 2*32 33 2*32 33
38*32 33
 2*32 33 2*32 33 2*32 33 2*32 33 22*32 33 9*32 33 8*32 33
2*32 33 2*32
 33 39*32
end fill

end array

read bnds
+xb=vacuum
-xb=vacuum
+yb=vacuum
-yb=vacuum
+zb=mirror
-zb=vacuum
end bnds

end data
end
```

Figure 6-24 Input Deck for 17x17 OFA

6.10.4 17x17OFA-XL Model

6.10.4.1 Introduction

The same general fuel assembly input deck is used for the several Traveller and Traveller XL criticality calculations. The primary differences are the length and the extent to which the lattice pitch expands in the expanded section. The fuel is expanded to 9.1 inches in the Traveller and 9.6 inches in the Traveller XL.

6.10.4.2 Fuel Assembly Model

The fuel assembly is typically designated as unit 20 in the input decks. Figure 6-25 shows a sample of the unit 20 input lines for the Traveller. Fuel assembly input consists of concentric cuboids to model the top nozzle assembly, skeleton and fuel regions. The fuel assembly origin is at the bottom left hand corner of the fuel assembly lower nozzle. Units #21 (nominal pitch fuel rod array), #31 (expanded pitch fuel rod array), and #40 (top nozzle assembly) are dropped into unit #20 as hole #21 and hole #31. Figure 6-26 shows the different parts that make up unit #20.

```
unit 20
com='fuel assembly'
cuboid 1 21.4122 0 21.4122  0    0       -14.0208
cuboid 2 23.1140 0 23.1140  0  504.1392  -14.0208
hole 31 origin x=0 y=0 z= 0.      rotate  a1=0  a2=0 a3=0
hole 21 origin x=0 y=0 z=100.0000 rotate  a1=0  a2=0 a3=0
hole 40 origin x=0 y=0 z=426.7200 rotate  a1=0  a2=0 a3=0
media  15 1  1
media   0 1 -1 2
boundary 2
```

Figure 6-25 Sample Input Lines for Traveller Fuel Assembly

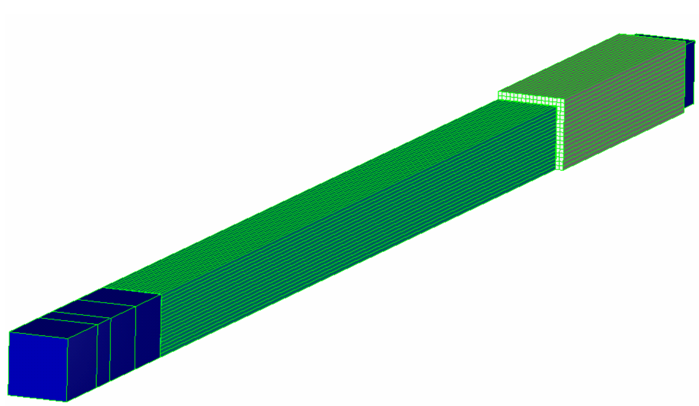

Figure 6-26 Keno 3D Image of Fuel Assembly

6.10.4.3 Fuel Rod Arrays

Units #21 and #31 are the fuel rod arrays. The arrays are identical except that cuboid #4 is sized according to the nominal pitch (unit #21) or expanded pitch (unit #31).

Unit #21 is made up of nominal pitch fuel rods (unit #22) and thimble tubes (unit #23). Unit #31 similarly is made up of expanded pitch fuel rods (unit #32) and thimble tubes (unit #33). Sample input deck lines for these units are found in Figure 6-27.

```
unit 21
com='fuel rods - nominal pitch'
cuboid 1  21.4166  0  21.4166  0  326.7200 0.0000
array 2 1 place 1 1 1 0.6299 0.6299 0
boundary 1

unit 22
com='solid fuel rod - nominal pitch'
cylinder 1  0.3922  448.3862     0
cylinder 2  0.4  448.3862     0
cylinder 3  0.4572  448.3862     0
cuboid 4 0.6299 -0.6299 0.6299 -0.6299 448.3862 0
media 1   1 1
media 2   1 2 -1
media 3   1 3 -2 -1
media 4   1 4 -3 -2 -1
boundary 4

unit 23
com='thimble tube - nominal pitch'
cylinder 1  0.5613  448.3862     0
cylinder 2  0.6020 448.3862     0
cuboid 3 0.6299 -0.6299 0.6299 -0.6299 448.3862 0
media 4 1 1
media 3 1 2 -1
media 4 1 3 -2 -1
boundary 3
```

```
unit 31
com='fuel rods - expanded pitch'
cuboid 1  23.1140   0  23.1140   0  100.0000 0
array 3 1 place 1 1 1 0.4572 0.4572 0
boundary 1

unit 32
com='solid fuel rod - expanded pitch'
cylinder 1  0.3922  448.3862     0
cylinder 2  0.4  448.3862     0
cylinder 3  0.4572  448.3862     0
cuboid 4  0.6937 -0.6937 0.6937 -0.6937 448.3862 0
media 16  1 1
media 17  1 2 -1
media 18  1 3 -2 -1
media 19  1 4 -3 -2 -1
boundary 4

unit 33
com='thimble tube - expanded pitch'
cylinder 1  0.5613  448.3862     0
cylinder 2  0.6020 448.3862     0
cuboid 3 0.6937 -0.6937 0.6937 -0.6937 448.3862 0
media 19 1 1
media 18 1 2 -1
media 19 1 3 -2 -1
boundary 3
```

Figure 6-27 Sample Input Lines for Fuel Rod Cells

6.10.4.4 Fuel Rod Cell

Fuel rod cells (units #22 and #32) are modeled as concentric cylinders for the pellet, gap, and cladding. The cells are bounded by a cuboid whose dimension is determined by lattice pitch. Thimble tubes (units #23 and 33) are similarly structured. Sample input lines for the rod cell units are shown in Figure 6-27. A fuel cell is shown in Figure 6-28.

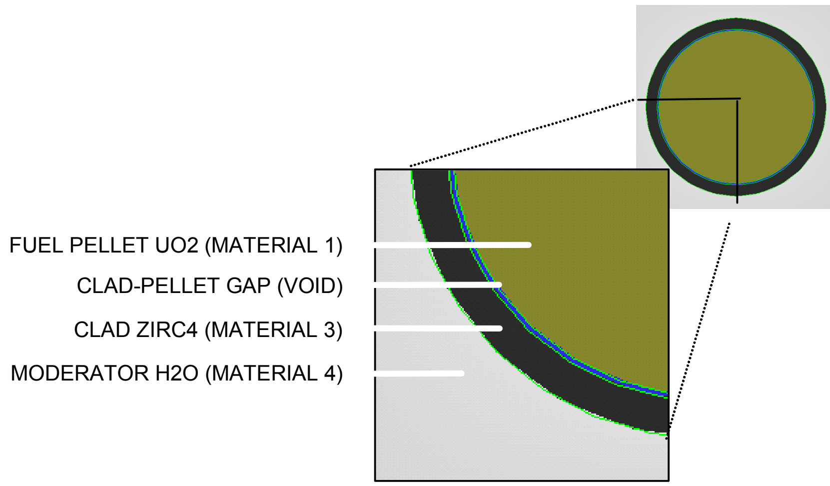

Figure 6-28 Fuel Rod Cell

6.10.5 Traveller Packaging Model

6.10.5.1 Introduction

The Traveller packaging model consists of the Outerpack (unit 10) and clamshell (unit 11). The same Outerpack input deck is used for the Traveller STD and Traveller XL calculations. The axial dimensions for the Traveller XL are used for the Traveller STD because axial differences do not affect results. The shock mount configuration used in the model is a conservative arrangement that bounds both the STD and XL configurations.

The primary difference between the STD and XL models is the lateral dimension of the clamshell where the face-to-face dimensions are different. The STD clamshell is modeled at 9.1 inches and the XL clamshell is modeled at 9.6 inches.

6.10.5.2 Outerpack Model

The Outerpack is defined in unit 10. Figure 6-29 gives a sample of the unit 10 input lines for the Traveller. Some features of the outerpack model are: the shock mounts and shock mount cutouts are defined using cylinders; and the six moderator blocks are defined with cuboids. Figure 6-30 through Figure 6-32 show various renderings of the outerpack. The shock mount configuration for the Traveller XL is a conservative arrangement of the actual configuration. As seen in figure 6-32, there are two pair of shock mounts at the end spaced 18 inches center-to-center. The second set was moved to be 18 inches from the first pair in order that the expanded section of fuel would “see” two pair of shock mounts.

```
unit 10
com='individual package'
cuboid 1    16.904      -15.634      16.904      -15.634      533.1330 0
rotate  a1=45 a2=0 a3=0 origin x=0  y=-1.460 z=0
cuboid 2    21.5900  -21.5900    1.5720   -1.0310   533.1330    0
cuboid 3    20.0790  -20.0790   20.0790  -20.0790   533.1330    0
rotate  a1=45 a2=0 a3=0 origin x=0  y=-1.460 z=0
cuboid 4    20.3450  -20.3450   20.3450  -20.3450   533.3990   -
0.2660
rotate  a1=45 a2=0 a3=0 origin x=0  y=-1.460 z=0
cuboid 5    21.5900  -21.590    23.1498  -23.1498   533.1330    0
cuboid 6    21.8560  -21.8560   23.4158  -23.4158   533.3990   -
0.2660
cuboid 7    20.3840  -20.3840   20.3840  -20.3840   553.8922   -
19.8448
rotate  a1=45 a2=0 a3=0 origin x=0  y=-1.460 z=0
cuboid 8    21.8950  -21.895    23.4548  -23.4548   553.8922   -
19.8448
cylinder  9    25.1050    533.4380    -0.2660
cylinder 10    25.1050    553.9312   -19.8448
cylinder 11    31.4840    533.4380    -0.2660
cylinder 12    31.4840    553.9312   -19.8448
cylinder 13    31.4840    533.4380   -19.8448
cylinder 14    31.7500    554.1972   -20.1100
plane 15  zpl=1  con= -10.0000
cylinder 16 7.62   0 -4.5
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270
z=494.4364
cylinder 17 3.962  0 -7.60
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270
z=494.4364
cylinder 18 7.62   0 -4.5
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270
z=494.4364
cylinder 19 3.962  0 -7.60
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270
z=494.4364
cylinder 20 7.62   0 -4.5
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270
z=448.7164
cylinder 21 3.962  0 -7.60
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270
z=448.7164
cylinder 22 7.62   0 -4.5
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270
z=448.7164
cylinder 23 3.962  0 -7.60
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270
z=448.7164
cylinder 24 7.62   0 -4.5
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270
z=402.9964
cylinder 25 3.962  0 -7.60
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270
z=402.9964
cylinder 26 7.62   0 -4.5
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270
z=402.9964
cylinder 27 3.962  0 -7.60
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270
z=402.9964
cylinder 28 7.62   0 -4.5
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270
z=357.2764
cylinder 29 3.962  0 -7.60
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270
z=357.2764
cylinder 30 7.62   0 -4.5
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270
z=357.2764
cylinder 31 3.962  0 -7.60
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270
z=357.2764
cylinder 54 7.62   0 -4.5
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270
z=265.8364
cylinder 55 3.962  0 -7.60
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270
z=265.8364
cylinder 56 7.62   0 -4.5
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270
z=265.8364
cylinder 57 3.962  0 -7.60
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270
z=265.8364
cylinder 32 7.62   0 -4.5
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270
z=174.3964
cylinder 33 3.962  0 -7.60
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270
z=174.3964
cylinder 34 7.62   0 -4.5
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270
z=174.3964
cylinder 35 3.962  0 -7.60
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270
z=174.3964
cylinder 36 7.62   0 -4.5
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270
z=128.6764
cylinder 37 3.962  0 -7.60
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270
z=128.6764
cylinder 38 7.62   0 -4.5
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270
z=128.6764
cylinder 39 3.962  0 -7.60
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270
z=128.6764
cylinder 40 7.62   0 -4.5
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=82.9564
cylinder 41 3.962  0 -7.60
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=82.9564
cylinder 42 7.62   0 -4.5
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270
z=82.9564
```

Figure 6-29 Sample Input Deck for Traveller Outerpack (Sheet 1 of 2)

```
cylinder 43 3.962  0 -7.60
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270
z=82.9564cylinder 44 7.62   0 -4.5
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270
z=37.2364
cylinder 45 3.962  0 -7.60
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270
 z=37.2364
cylinder 46 7.62   0 -4.5
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270
z=37.2364
cylinder 47 3.962  0 -7.60
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270
z=37.2364
hole 11 rotate  a1=45 a2=0 a3=0  origin  x=0 y=-17.700 z=5.240
cuboid 48    18.174    20.079    10.4238   -9.5152    533.3990    -
0.2660
rotate  a1=-45 a2=0 a3=0 origin x=0  y=-1.460 z=0
cuboid 49    13.6554  -10.4238  16.904    20.079    533.3990    -
0.2660
rotate  a1=45 a2=0 a3=0 origin x=0  y=-1.460 z=0
cuboid 50    16.904    20.079   13.6554  -10.4238   533.3990    -
0.2660
rotate  a1=45 a2=0 a3=0 origin x=0  y=-1.460 z=0
cuboid 51     9.5152  -10.4238 -18.174   -20.079    533.3990    -
0.2660
rotate  a1=-45 a2=0 a3=0 origin x=0  y=-1.460 z=0
cuboid 52    15.634    18.174   12.0238 -11.9197    533.3990    -
0.2660
rotate  a1=-45 a2=0 a3=0 origin x=0  y=-1.460 z=0
cuboid 53    11.9197  -12.0238 -15.634   -18.174    533.3990    -
0.2660
rotate  a1=-45 a2=0 a3=0 origin x=0  y=-1.460 z=0
media  0 1   1   3  5 -17 -19 -21 -23 -29 -31 -55 -57 -33 -35
-41 -43 -45 -47
media  0 1  -1   3  5 -48 -49 -50 -51 -52 -53
media  9 1   3  -16  -17 -20 -21 -28 -29 -54 -55 -32 -33
-40 -41 -44 -45 48
media  9 1   3  -18  -19 -22 -23 -30 -31 -56 -57 -34 -35
-42 -43 -46 -47 51
media  9 1   3  -18  -22  -30  -56  -34  -42  -46  53
media  9 1   3  -16  -20  -28  -54  -32  -40  -44  52
media  9 1   3  49
media  9 1   3  50
media  8 1  -3   4   6
media  8 1   3  -5   6
media  6 1  -4   9
media  6 1   4  -6   9
media  6 1  -9  11
media  6 1  -7  10 -13
media  6 1   7  -8  10 -13  12
media  6 1 -10 -13  12
media 11 1 -11  13
media 11 1   7   8 -13  12
media  8 1 -12  14
media  0 1 16  -17 3 48
media  0 1 18  -19 3 51
media  0 1 20  -21 3 48
media  0 1 22  -23 3 51
media  0 1 28  -29 3 48
media  0 1 30  -31 3 51
media  0 1 54  -55 3 48
media  0 1 56  -57 3 51
media  0 1 32  -33 3 48
media  0 1 34  -35 3 51
media  0 1 40  -41 3 48
media  0 1 42  -43 3 51
media  0 1 44  -45 3 48
media  0 1 46  -47 3 51
media  0 1 16  -17 3 52
media  0 1 18  -19 3 53
media  0 1 20  -21 3 52
media  0 1 22  -23 3 53
media  0 1 28  -29 3 52
media  0 1 30  -31 3 53
media  0 1 54  -55 3 52
media  0 1 56  -57 3 53
media  0 1 32  -33 3 52
media  0 1 34  -35 3 53
media  0 1 40  -41 3 52
media  0 1 42  -43 3 53
media  0 1 44  -45 3 52
media  0 1 46  -47 3 53
media 14 1 17  3
media 14 1 19  3
media 14 1 21  3
media 14 1 23  3
media 14 1 29  3
media 14 1 31  3
media 14 1 55  3
media 14 1 57  3
media 14 1 33  3
media 14 1 35  3
media 14 1 41  3
media 14 1 43  3
media 14 1 45  3
media 14 1 47  3
boundary 14
```

Figure 6-29 Sample Input Deck for Traveller Outerpack (Sheet 2 of 2)

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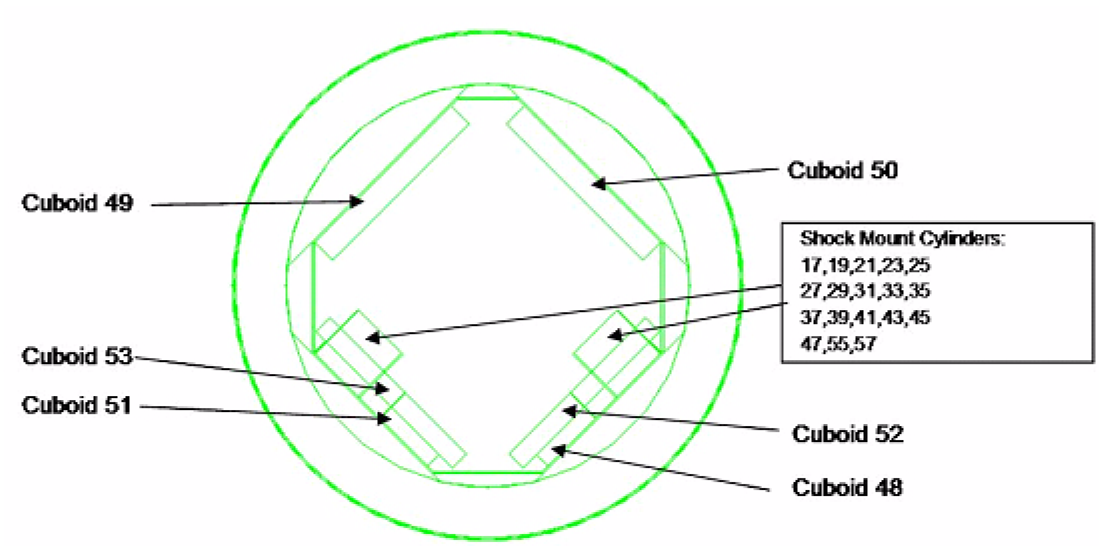

Figure 6-30 Keno 3D Line Schematic of Outerpack Cuboids

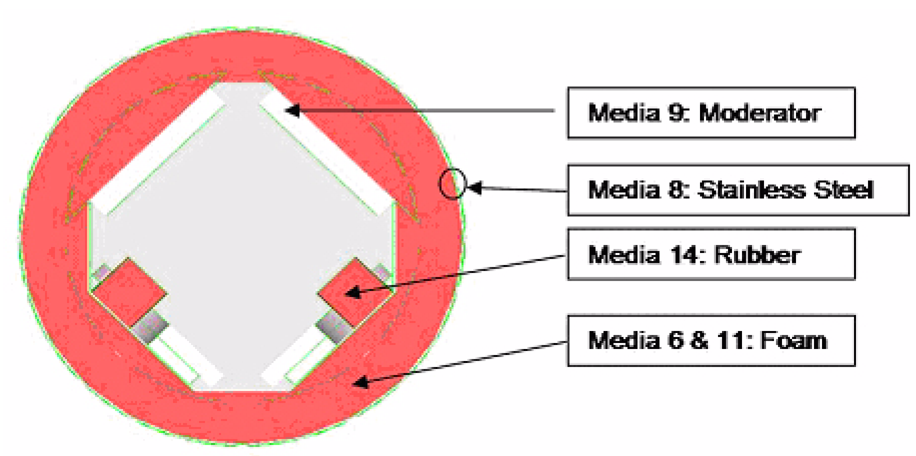

Figure 6-31 Keno 3D Rendering of Outerpack

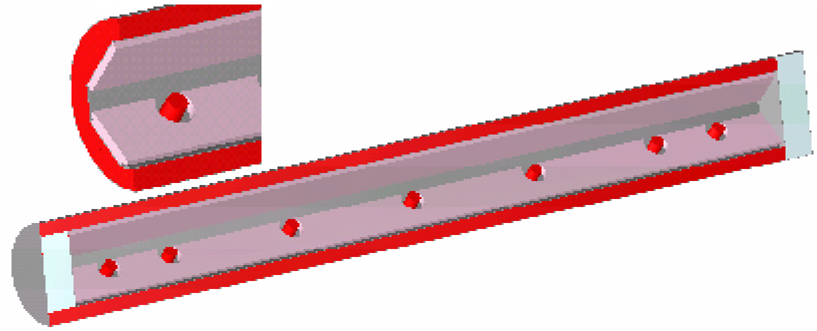

Figure 6-32 Keno 3D Rendering of XL Outerpack

6.10.5.3 Clamshell Model

The Clamshell is defined in unit 11. Figure 6-33 shows a sample of the unit 11 input lines for the Clamshell. Figure 6-34 is a schematic drawing of the Clamshell model.

```
unit 11
com='fuel assembly confinement system'
cuboid 1    24.384       0 24.384       0 520.7000 2.5400
cuboid 2    25.337       -0.9525 25.337        -0.9525
 523.2400  0.0000
cuboid 3    19.812       4.572        24.429       -0.04545
 513.0800  3.81
cuboid 4    19.812       4.572        24.656       -0.27205
 513.0800  3.81
cuboid 5    19.812       4.572        24.702       -0.3175
 513.0800  3.81
cuboid 6    24.429       -0.04545      19.812       4.572
 513.0800  3.81
cuboid 7    24.656       -0.27205      19.812       4.572
 513.0800  3.81
cuboid 8    24.702       -0.3175       19.812       4.572
 513.0800  3.81
hole 20  origin  x=0  y=0  z=16.56  rotate  a1=0 a2=0 a3=0
media  0 1   1
media  7 1  -1   2  -5  -8
media  7 1  -1   3
media 12 1  -3   4
media  7 1  -4   5
media  7 1  -1   6
media 12 1  -6   7
media  7 1  -7   8
boundary 2
```

Figure 6-33 Sample Input Lines for Clamshell

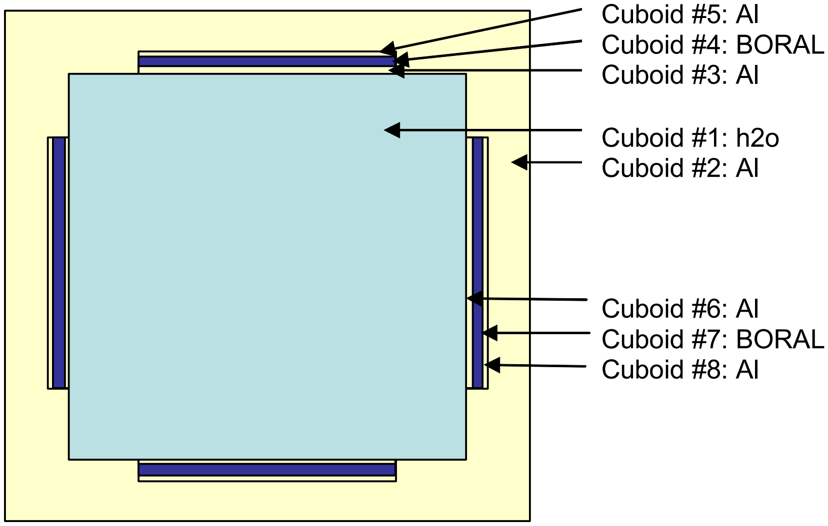

Figure 6-34 Clamshell

6.10.6 Single Package Evaluation Calculations

Results for the single package in isolation calculations are presented below. Table 6-25 shows the results for normal conditions analyzed for Traveller XL only. Table 6-26 presents results for hypothetical accident conditions for the Traveller STD. Table 6-27 gives similar results for the Traveller XL.

Table 6-25 Results for Traveller XL – Normal Conditions of Transport – Individual Package

Run #	ks	σks	ks+2×σks
XL-NOR-IND	0.2000	0.0006	0.2012

Table 6-26 Results for Traveller XL – Hypothetical Accident Conditions – Individual Package

Run #	ks	σks	ks+2×σks
STD-HAC-IND	0.8621	0.0012	0.8645

Table 6-27 Results for Traveller XL – Hypothetical Accident Conditions – Individual Package

Run #	ks	σks	ks+2×σks
XL-HAC-IND-100	0.8833	0.0009	0.8851

Table 6-28 has been deleted.

Pages 6-72 through 6-76 intentionally left blank.

Table 6-29 Sample Input Deck for Traveller XL Single Package – Normal Condition of Transport

```
=csas26     parm=size=300000
TRAVELLER XL,17WOFA,ENV=24.384      cm,L=100      cm,B10=0.018   g/cm2
44groupndf5  latticecell
 uo2 1 1 293 92235 5 92238 95 end
 h2o 2 1 293 end
 zirc4 3 1 293 end
 h2o 4 1 293 end
 h2o 5 1 293 end
 arbmfoam 0.1602  4  0  0  0 6012 70 1001 10 8016 16 7014 4  6 1 293
 end
 al 7 1 293 end
 ss304 8 1 293 end
 polyethylene 9 DEN=0.828 1.0 293 end
 arbmfoam 0.1602  4  0  0  0 6012 70 1001 10 8016 16 7014 4 11 1 293
 end
 b-10 12 0 0.0047781    end
 b-11 12 0 0.019398     end
 c   12 0 0.0060439    end
 al  12 0 0.043223     end
 arbmrubber 1.59  7  0  0  0 8016 46.94 13000 19.92 14000 17.54 6012
 10.79 1001 4.73 11000 0.06 26000 0.02  14 1 293 end
 h2o 15 1 293 end
 uo2 16 1 293 92235 5 92238 95 end
 h2o 17 1 293 end
 zirc4 18 1 293 end
 h2o 19 1 293 end
end comp
squarepitch 1.4669       0.78435      16 19 0.9144       18 0.8001       17 end
more data
res=1  cylinder 0.39218      dan(1)=0.22632       end

read parameter
gen=450
npg=2500
nsk=50
wrs=1
tme=240
end parameter
```

Table 6-29 Sample Input Deck for Traveller XL Single Package – Normal Condition of Transport (cont.)

```
read geometry
unit 10
com='individual package'
cuboid 1    16.904      -15.634      16.904      -15.634      533.1330 0
rotate  a1=45 a2=0 a3=0 origin x=0  y=-1.460 z=0
cuboid 2     21.5900   -21.5900     1.5720    -1.0310   533.1330     0
cuboid 3     20.0790   -20.0790    20.0790   -20.0790   533.1330     0
rotate  a1=45 a2=0 a3=0 origin x=0  y=-1.460 z=0
cuboid 4     20.3450   -20.3450    20.3450   -20.3450   533.3990    -0.2660
rotate  a1=45 a2=0 a3=0 origin x=0  y=-1.460 z=0
cuboid 5     21.5900   -21.590     23.1498   -23.1498   533.1330     0
cuboid 6     21.8560   -21.8560    23.4158   -23.4158   533.3990    -0.2660
cuboid 7     20.3840   -20.3840    20.3840   -20.3840   553.8922   -19.8448
rotate  a1=45 a2=0 a3=0 origin x=0  y=-1.460 z=0
cuboid 8     21.8950   -21.895     23.4548   -23.4548   553.8922   -19.8448
cylinder  9    25.1050    533.4380    -0.2660
cylinder 10    25.1050    553.9312   -19.8448
cylinder 11    31.4840    533.4380    -0.2660
cylinder 12    31.4840    553.9312   -19.8448
cylinder 13    31.4840    533.4380   -19.8448
cylinder 14    31.7500    554.1972   -20.1100
plane 15  zpl=1  con= -10.0000
cylinder 16 7.62   0 -4.5
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=494.4364
cylinder 17 3.962  0 -7.60
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=494.4364
cylinder 18 7.62   0 -4.5
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=494.4364
cylinder 19 3.962  0 -7.60
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=494.4364
cylinder 20 7.62   0 -4.5
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=448.7164
cylinder 21 3.962  0 -7.60
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=448.7164
cylinder 22 7.62   0 -4.5
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=448.7164
cylinder 23 3.962  0 -7.60
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=448.7164
cylinder 24 7.62   0 -4.5
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=402.9964
cylinder 25 3.962  0 -7.60
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=402.9964
cylinder 26 7.62   0 -4.5
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=402.9964
cylinder 27 3.962  0 -7.60
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=402.9964
cylinder 28 7.62   0 -4.5
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=357.2764
cylinder 29 3.962  0 -7.60
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=357.2764
```

Table 6-29 Sample Input Deck for Traveller XL Single Package – Normal Condition of Transport (cont.)

```
cylinder 30 7.62   0 -4.5
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=357.2764
cylinder 31 3.962  0 -7.60
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=357.2764
cylinder 54 7.62   0 -4.5
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=265.8364
cylinder 55 3.962  0 -7.60
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=265.8364
cylinder 56 7.62   0 -4.5
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=265.8364
cylinder 57 3.962  0 -7.60
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=265.8364
cylinder 32 7.62   0 -4.5
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=174.3964
cylinder 33 3.962  0 -7.60
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=174.3964
cylinder 34 7.62   0 -4.5
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=174.3964
cylinder 35 3.962  0 -7.60
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=174.3964
cylinder 36 7.62   0 -4.5
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=128.6764
cylinder 37 3.962  0 -7.60
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=128.6764
cylinder 38 7.62   0 -4.5
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=128.6764
cylinder 39 3.962  0 -7.60
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=128.6764
cylinder 40 7.62   0 -4.5
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=82.9564
cylinder 41 3.962  0 -7.60
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=82.9564
cylinder 42 7.62   0 -4.5
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=82.9564
cylinder 43 3.962  0 -7.60
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=82.9564
cylinder 44 7.62   0 -4.5
rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=37.2364
cylinder 45 3.962  0 -7.60
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=37.2364
cylinder 46 7.62   0 -4.5
  rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=37.2364
cylinder 47 3.962  0 -7.60
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=37.2364
hole 11 rotate  a1=45 a2=0 a3=0  origin  x=0 y=-17.700 z=5.240
cuboid 48    18.174    20.079   10.4238  -9.5152    533.3990    -0.2660
rotate  a1=-45 a2=0 a3=0 origin x=0  y=-1.460 z=0
cuboid 49    13.6554  -10.4238  16.904    20.079    533.3990    -0.2660
rotate  a1=45 a2=0 a3=0 origin x=0  y=-1.460 z=0
cuboid 50    16.904    20.079   13.6554  -10.4238   533.3990    -0.2660
rotate  a1=45 a2=0 a3=0 origin x=0  y=-1.460 z=0
```

Table 6-29 Sample Input Deck for Traveller XL Single Package – Normal Condition of Transport (cont.)

```
cuboid 51    9.5152  -10.4238 -18.174   -20.079    533.3990    -0.2660
rotate  a1=-45 a2=0 a3=0 origin x=0  y=-1.460 z=0
cuboid 52    15.634    18.174    12.0238 -11.9197    533.3990    -0.2660
rotate  a1=-45 a2=0 a3=0 origin x=0  y=-1.460 z=0
cuboid 53    11.9197  -12.0238 -15.634   -18.174    533.3990    -0.2660
rotate  a1=-45 a2=0 a3=0 origin x=0  y=-1.460 z=0
media  0 1   1   3  5 -17 -19 -21 -23 -29 -31 -55 -57 -33 -35
-41 -43 -45 -47
media  0 1  -1   3  5 -48 -49 -50 -51 -52 -53
media  9 1   3  -16  -17 -20 -21 -28 -29 -54 -55 -32 -33
-40 -41 -44 -45 48
media  9 1   3  -18  -19 -22 -23 -30 -31 -56 -57 -34 -35
-42 -43 -46 -47 51
media  9 1   3  -18  -22  -30  -56  -34  -42  -46  53
media  9 1   3  -16  -20  -28  -54  -32  -40  -44  52
media  9 1   3  49
media  9 1   3  50
media  8 1  -3   4   6
media  8 1   3  -5   6
media 15 1  -4   9
media 15 1   4  -6   9
media 15 1  -9  11
media 15 1  -7  10 -13
media 15 1   7  -8  10 -13  12
media 15 1 -10 -13  12
media 15 1 -11  13
media 15 1   7   8 -13  12
media  8 1 -12  14
media 15 1 16  -17 3 48
media 15 1 18  -19 3 51
media 15 1 20  -21 3 48
media 15 1 22  -23 3 51
media 15 1 28  -29 3 48
media 15 1 30  -31 3 51
media 15 1 54  -55 3 48
media 15 1 56  -57 3 51
media 15 1 32  -33 3 48
media 15 1 34  -35 3 51
media 15 1 40  -41 3 48
media 15 1 42  -43 3 51
media 15 1 44  -45 3 48
media 15 1 46  -47 3 51
media 15 1 16  -17 3 52
media 15 1 18  -19 3 53
media 15 1 20  -21 3 52
media 15 1 22  -23 3 53
media 15 1 28  -29 3 52
media 15 1 30  -31 3 53
media 15 1 54  -55 3 52
media 15 1 56  -57 3 53
media 15 1 32  -33 3 52
```

Table 6-29 Sample Input Deck for Traveller XL Single Package – Normal Condition of Transport (cont.)

```
media 15 1 34  -35 3 53
media 15 1 40  -41 3 52
media 15 1 42  -43 3 53
media 15 1 44  -45 3 52
media 15 1 46  -47 3 53
media 15 1 17  3
media 15 1 19  3
media 15 1 21  3
media 15 1 23  3
media 15 1 29  3
media 15 1 31  3
media 15 1 55  3
media 15 1 57  3
media 15 1 33  3
media 15 1 35  3
media 15 1 41  3
media 15 1 43  3
media 15 1 45  3
media 15 1 47  3
boundary 14

unit 11
com='fuel assembly confinement system'
cuboid 1    24.384      0 24.384      0 520.7000 2.5400
cuboid 2    25.337      -0.9525 25.337       -0.9525
 523.2400  0.0000
cuboid 3    19.812      4.572       24.429      -0.04545
 513.0800  3.81
cuboid 4    19.812      4.572       24.656      -0.27205
 513.0800  3.81
cuboid 5    19.812      4.572       24.702      -0.3175
 513.0800  3.81
cuboid 6    24.429      -0.04545      19.812      4.572
 513.0800  3.81
cuboid 7    24.656      -0.27205      19.812      4.572
 513.0800  3.81
cuboid 8    24.702      -0.3175      19.812      4.572
 513.0800  3.81
hole 20  origin  x=0  y=0  z=16.56  rotate  a1=0 a2=0 a3=0
media 15 1   1
media  7 1  -1   2  -5  -8
media  7 1  -1   3
media 12 1  -3   4
media  7 1  -4   5
media  7 1  -1   6
media 12 1  -6   7
media  7 1  -7   8
boundary 2

unit 20
```

Table 6-29 Sample Input Deck for Traveller XL Single Package – Normal Condition of Transport (cont.)

```
com='fuel assembly'
cuboid 1 21.072      0 21.072      0   0       -14.0208
cuboid 2 24.384      0 24.384      0 504.1392   -14.0208
hole 21 origin  x=0      y=0      z=0.0001   rotate  a1=0  a2=0 a3=0
hole 40 origin  x=0      y=0      z=426.7201 rotate  a1=0  a2=0 a3=0
media  15 1  1
media   0 1 -1   2
boundary 2

unit 21
com='fuel rods - nominal pitch'
cuboid 1  21.072      0 21.072      0 426.72      0.0000
array 2 1 place 1 1 1 0.4572      0.4572      0
boundary 1

unit 22
com='solid fuel rod - nominal pitch'
cylinder 1  0.39218      426.72          0
cylinder 2  0.40005      426.72          0
cylinder 3  0.4572       426.72          0
cuboid 4  4P0.62992      426.72          0
media 1 1  1
media 0 1  2 -1
media 3 1  3 -2 -1
media 0 1  4 -3 -2 -1
boundary 4

unit 23
com='thimble tube - nominal pitch'
cylinder 1  0.56134      426.72         0
cylinder 2  0.60198      426.72         0
cuboid 3    4P0.62992     426.72         0
media 0 1 1
media 3 1 2 -1
media 0 1 3 -2 -1
boundary 3

unit 31
com='fuel rods - expanded pitch'
cuboid 1  24.384      0 24.384      0 100        0
array 3 1 place 1 1 1 0.4572      0.4572      0
boundary 1
```

Table 6-29 Sample Input Deck for Traveller XL Single Package – Normal Condition of Transport (cont.)

```
unit 32
com='solid fuel rod - expanded pitch'
cylinder 1  0.39218      426.72         0
cylinder 2  0.40005      426.72         0
cylinder 3  0.4572       426.72         0
cuboid 4  4P0.73342      426.72         0
media 16  1 1
media 17  1 2 -1
media 18  1 3 -2 -1
media 19  1 4 -3 -2 -1
boundary 4

unit 33
com='thimble tube - expanded pitch'
cylinder 1  0.56134      426.72         0
cylinder 2  0.60198      426.72         0
cuboid 3  4P0.73342      426.72         0
media 19 1 1
media 18 1 2 -1
media 19 1 3 -2 -1
boundary 3

unit 40
com='top nozzle assembly'
cuboid 1     21.072      0 21.072      0      21.2090     0.0000
cuboid 2     21.072      0 21.072      0      41.8846     0.0000
cuboid 3     21.072      0 21.072      0      52.8193     0.0000
cuboid 4     21.072      0 21.072      0      77.4192     0.0000
cuboid 5     24.384      0 24.384      0      77.4192     0.0008
media  15 1   1
media  15 1  -1   2
media  15 1  -2   3
media  15 1  -3   4
media  15 1  -4   5
boundary 5

global
unit 66
com='individual package 0-deg rotation'
hexprism 1  31.75    554.1972  -20.1498
hole 10  origin  x=0 y=0  z=0  rotate  a1=0 a2=0 a3=0
cylinder 2  51.75    574.1972  -40.1498
cuboid 3  4P51.75   574.1972  -40.1498
media  15 1   1
media  15 1  -1   2
media   0 1  -2   3
boundary  3
```

Table 6-29 Sample Input Deck for Traveller XL Single Package – Normal Condition of Transport (cont.)

```
unit 77
com='individual package 180-deg rotation'
hexprism 1  31.75    554.1972  -20.1498
hole 10  origin  x=0 y=0  z=0  rotate  a1=0 a2=0 a3=180
media   0 1   1
boundary 1

unit 88
com='dummy cell'
hexprism 1  31.75    554.1972  -20.1498
media  15 1   1
boundary 1

unit 99
com='package array'
cylinder 1  31.75    554.1972  -20.1498
cylinder 2  51.75    574.1972  -40.1498
cuboid 3  4P51.75   574.1972  -40.1498
array 1 1  place 9 9 1 0 0 0
media  15 1  -1   2
media   0 1  -2   3
boundary 3

end geometry

read array
ara=1 typ=triangular nux=17 nuy=17 nuz=1 gbl=1
fill
88 88 88 88 88 88 88 88 88 88 88 88 88 88 88 88 88
 88 88 88 88 88 88 88 88 88 88 77 77 77 88 88 88 88
  88 88 88 88 88 88 88 88 66 66 66 66 66 66 66 88 88
   88 88 88 88 88 88 77 77 77 77 77 77 77 77 77 77 88
    88 88 88 88 88 66 66 66 66 66 66 66 66 66 66 66 88
     88 88 88 88 77 77 77 77 77 77 77 77 77 77 77 77 88
      88 88 88 66 66 66 66 66 66 66 66 66 66 66 66 66 88
       88 88 88 77 77 77 77 77 88 88 77 77 77 77 77 88 88
        88 88 66 66 66 66 66 88 66 88 66 66 66 66 66 88 88
         88 88 77 77 77 77 77 88 88 77 77 77 77 77 88 88 88
          88 66 66 66 66 66 66 66 66 66 66 66 66 66 88 88 88
           88 77 77 77 77 77 77 77 77 77 77 77 77 88 88 88 88
            88 66 66 66 66 66 88 88 66 66 66 66 88 88 88 88 88
             88 77 77 77 77 77 77 77 77 77 77 88 88 88 88 88 88
              88 88 66 66 66 66 66 66 66 88 88 88 88 88 88 88 88
               88 88 88 77 77 77 77 88 88 88 88 88 88 88 88 88 88
               88 88 88 88 88 88 88 88 88 88 88 88 88 88 88 88 88
end fill
```

Table 6-29 Sample Input Deck for Traveller XL Single Package – Normal Condition of Transport (cont.)

```
ara=2 typ=square nux=17 nuy=17 nuz=1
fill 39*22 23 2*22 23 2*22 23 8*22 23 9*22 23 22*22 23 2*22 23 2*22 23
 2*22 23 2*22 23 38*22 23 2*22 23 2*22 23 2*22 23 2*22 23 38*22 23
 2*22 23 2*22 23 2*22 23 2*22 23 22*22 23 9*22 23 8*22 23 2*22 23 2*22
 23 39*22
end fill
ara=3 typ=square nux=17 nuy=17 nuz=1
fill 39*32 33 2*32 33 2*32 33 8*32 33 9*32 33 22*32 33 2*32 33 2*32 33
 2*32 33 2*32 33 38*32 33 2*32 33 2*32 33 2*32 33 2*32 33 38*32 33
 2*32 33 2*32 33 2*32 33 2*32 33 22*32 33 9*32 33 8*32 33 2*32 33 2*32
 33 39*32
end fill

end array

read bnds
+xb=vacuum
-xb=vacuum
+yb=vacuum
-yb=vacuum
+zb=vacuum
-zb=vacuum
end bnds

end data
end
```

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6.10.7 Package Array Evaluation Calculations

Results for the package array calculations are presented below. Table 6-30 shows the results for normal conditions for the Traveller XL. Tables 6-31 and 6-32 show results for hypothetical accident conditions for the Traveller STD and Traveller XL, respectively. Table 6-34 shows a sample input deck for the Traveller XL calculations.

Table 6-30 Results for Traveller XL – Normal Conditions of Transport – Package Array

Run #	ks	σks	ks+2×σks
XL-NOR-ARRAY	0.2709	0.0006	0.2721

Table 6-31 Results for Traveller STD – Hypothetical Accident Conditions – Package Array

Run #	Length of Exp. (cm)	ks	σks	ks+2×σks
STD-HAC-ARRAY-100	100.0000	0.8954	0.0009	0.8972

Table 6-32 Package Array Calculations for Traveller XL – HAC				
Run #	**Length of Exp.(cm)**	**ks**	**σks**	**ks+2×σks**
XL-HAC-ARRAY-000	0	0.8466	0.0007	0.8480
XL-HAC-ARRAY-025	25	0.8537	0.0008	0.8553
XL-HAC-ARRAY-050	50	0.8939	0.0009	0.8957
XL-HAC-ARRAY-075	75	0.9223	0.0011	0.9245
XL-HAC-ARRAY-100	100	0.9377	0.0008	0.9393
XL-HAC-ARRAY-200	200	0.9623	0. 0009	0.9641
XL-HAC-ARRAY-300	300	0.9694	0. 0010	0.9714
XL-HAC-ARRAY-426	426	0.9742	8.0000e-4	0.9758

Table 6-33 has been deleted.

Pages 6-87 – 6-91 intentionally left blank.

Table 6-34 Input Deck for Traveller XL Package Array – HAC

```
PA_HAC_BORAL_5_5_100_0.19630.out
=csas26     parm=size=300000
TRAVELLER XL,17WOFA,ENV=24.384      cm,L=100      cm,B10=0.018   g/cm2
44groupndf5  latticecell
 uo2 1 1 293 92235 5 92238 95 end
 h2o 2 1 293 end
 zirc4 3 1 293 end
 h2o 4 1 293 end
 h2o 5 1 293 end
 arbmfoam 0.1602e-20  4  0  0  0 6012 70 1001 10 8016 16 7014 4  6 1 293
 end
 al 7 1 293 end
 ss304 8 1 293 end
 polyethylene 9 DEN=0.828 1.0 293 end
 arbmfoam 0.1602e-20  4  0  0  0 6012 70 1001 10 8016 16 7014 4 11 1 293
 end
 b-10 12 0 0.0047781    end
 b-11 12 0 0.019398     end
 c   12 0 0.0060439    end
 al  12 0 0.043223     end
 arbmrubber 1.59e-20  7  0  0  0 8016 46.94 13000 19.92 14000 17.54 6012
 10.79 1001 4.73 11000 0.06 26000 0.02  14 1 293 end
 h2o 15 1 293 end
 uo2 16 1 293 92235 5 92238 95 end
 h2o 17 1 293 end
 zirc4 18 1 293 end
 h2o 19 1 293 end
end comp
squarepitch 1.4669       0.78435      16 19 0.9144       18 0.8001       17 end
more data
res=1  cylinder 0.39218      dan(1)=0.22632       end

read parameter
gen=450
npg=2500
nsk=50
wrs=1
tme=240
end parameter

read geometry
unit 10
com='individual package'
cuboid 1    16.904      -15.634      16.904      -15.634      533.1330 0
rotate  a1=45 a2=0 a3=0 origin x=0  y=-1.460 z=0
cuboid 2     21.5900   -21.5900     1.5720    -1.0310   533.1330     0
cuboid 3     20.0790   -20.0790    20.0790   -20.0790   533.1330     0
rotate  a1=45 a2=0 a3=0 origin x=0  y=-1.460 z=0
cuboid 4     20.3450   -20.3450    20.3450   -20.3450   533.3990    -0.2660
rotate  a1=45 a2=0 a3=0 origin x=0  y=-1.460 z=0
cuboid 5     21.5900   -21.590     23.1498   -23.1498   533.1330     0
```

Table 6-34 Input Deck for Traveller XL Package Array – HAC (cont.)

```
PA_HAC_BORAL_5_5_100_0.19630.out
cuboid 6    21.8560  -21.8560   23.4158  -23.4158  533.3990   -0.2660
cuboid 7    20.3840  -20.3840   20.3840  -20.3840  553.8922  -19.8448
rotate  a1=45 a2=0 a3=0 origin x=0  y=-1.460 z=0
cuboid 8    21.8950  -21.895    23.4548  -23.4548  553.8922  -19.8448
cylinder  9   25.1050   533.4380   -0.2660
cylinder 10   25.1050   553.9312  -19.8448
cylinder 11   31.4840   533.4380   -0.2660
cylinder 12   31.4840   553.9312  -19.8448
cylinder 13   31.4840   533.4380  -19.8448
cylinder 14   31.7500   554.1972  -20.1100
plane 15  zpl=1  con= -10.0000
cylinder 16 7.62   0 -4.5
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=494.4364
cylinder 17 3.962  0 -7.60
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=494.4364
cylinder 18 7.62   0 -4.5
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=494.4364
cylinder 19 3.962  0 -7.60
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=494.4364
cylinder 20 7.62   0 -4.5
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=448.7164
cylinder 21 3.962  0 -7.60
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=448.7164
cylinder 22 7.62   0 -4.5
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=448.7164
cylinder 23 3.962  0 -7.60
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=448.7164
cylinder 24 7.62   0 -4.5
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=402.9964
cylinder 25 3.962  0 -7.60
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=402.9964
cylinder 26 7.62   0 -4.5
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=402.9964
cylinder 27 3.962  0 -7.60
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=402.9964
cylinder 28 7.62   0 -4.5
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=357.2764
cylinder 29 3.962  0 -7.60
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=357.2764
cylinder 30 7.62   0 -4.5
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=357.2764
cylinder 31 3.962  0 -7.60
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=357.2764
cylinder 54 7.62   0 -4.5
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=265.8364
cylinder 55 3.962  0 -7.60
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=265.8364
cylinder 56 7.62   0 -4.5
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=265.8364
cylinder 57 3.962  0 -7.60
```

Table 6-34 Input Deck for Traveller XL Package Array – HAC (cont.)

```
 PA_HAC_BORAL_5_5_100_0.19630.out
rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=265.8364
cylinder 32 7.62   0 -4.5
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=174.3964
cylinder 33 3.962  0 -7.60
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=174.3964
cylinder 34 7.62   0 -4.5
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=174.3964
cylinder 35 3.962  0 -7.60
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=174.3964
cylinder 36 7.62   0 -4.5
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=128.6764
cylinder 37 3.962  0 -7.60
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=128.6764
cylinder 38 7.62   0 -4.5
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=128.6764
cylinder 39 3.962  0 -7.60
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=128.6764
cylinder 40 7.62   0 -4.5
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=82.9564
cylinder 41 3.962  0 -7.60
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=82.9564
cylinder 42 7.62   0 -4.5
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=82.9564
cylinder 43 3.962  0 -7.60
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=82.9564
cylinder 44 7.62   0 -4.5
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=37.2364
cylinder 45 3.962  0 -7.60
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=37.2364
cylinder 46 7.62   0 -4.5
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=37.2364
cylinder 47 3.962  0 -7.60
rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=37.2364
hole 11 rotate  a1=45 a2=0 a3=0  origin  x=0 y=-17.700 z=5.240
cuboid 48    18.174    20.079   10.4238  -9.5152    533.3990    -0.2660
rotate  a1=-45 a2=0 a3=0 origin x=0  y=-1.460 z=0
cuboid 49    13.6554  -10.4238  16.904    20.079    533.3990    -0.2660
rotate  a1=45 a2=0 a3=0 origin x=0  y=-1.460 z=0
cuboid 50    16.904    20.079   13.6554  -10.4238   533.3990    -0.2660
rotate  a1=45 a2=0 a3=0 origin x=0  y=-1.460 z=0
cuboid 51     9.5152  -10.4238 -18.174   -20.079    533.3990    -0.2660
rotate  a1=-45 a2=0 a3=0 origin x=0  y=-1.460 z=0
cuboid 52    15.634    18.174   12.0238 -11.9197    533.3990    -0.2660
rotate  a1=-45 a2=0 a3=0 origin x=0  y=-1.460 z=0
cuboid 53    11.9197  -12.0238 -15.634   -18.174    533.3990    -0.2660
rotate  a1=-45 a2=0 a3=0 origin x=0  y=-1.460 z=0
media  0 1   1   3  5 -17 -19 -21 -23 -29 -31 -55 -57 -33 -35
-41 -43 -45 -47
media  0 1  -1   3  5 -48 -49 -50 -51 -52 -53
media  9 1   3  -16  -17 -20 -21 -28 -29 -54 -55 -32 -33
```

Table 6-34 Input Deck for Traveller XL Package Array – HAC (cont.)

```
PA_HAC_BORAL_5_5_100_0.19630.out
-40 -41 -44 -45 48
media  9 1   3  -18  -19 -22 -23 -30 -31 -56 -57 -34 -35
-42 -43 -46 -47 51
media  9 1   3  -18  -22  -30  -56  -34  -42  -46  53
media  9 1   3  -16  -20  -28  -54  -32  -40  -44  52
media  9 1   3  49
media  9 1   3  50
media  8 1  -3   4   6
media  8 1   3  -5   6
media  6 1  -4   9
media  6 1   4  -6   9
media  6 1  -9  11
media  6 1  -7  10 -13
media  6 1   7  -8  10 -13  12
media  6 1 -10 -13  12
media 11 1 -11  13
media 11 1   7   8 -13  12
media  8 1 -12  14
media  0 1 16  -17 3 48
media  0 1 18  -19 3 51
media  0 1 20  -21 3 48
media  0 1 22  -23 3 51
media  0 1 28  -29 3 48
media  0 1 30  -31 3 51
media  0 1 54  -55 3 48
media  0 1 56  -57 3 51
media  0 1 32  -33 3 48
media  0 1 34  -35 3 51
media  0 1 40  -41 3 48
media  0 1 42  -43 3 51
media  0 1 44  -45 3 48
media  0 1 46  -47 3 51
media  0 1 16  -17 3 52
media  0 1 18  -19 3 53
media  0 1 20  -21 3 52
media  0 1 22  -23 3 53
media  0 1 28  -29 3 52
media  0 1 30  -31 3 53
media  0 1 54  -55 3 52
media  0 1 56  -57 3 53
media  0 1 32  -33 3 52
media  0 1 34  -35 3 53
media  0 1 40  -41 3 52
media  0 1 42  -43 3 53
media  0 1 44  -45 3 52
media  0 1 46  -47 3 53
media 14 1 17  3
media 14 1 19  3
media 14 1 21  3
media 14 1 23  3
```

Table 6-34 Input Deck for Traveller XL Package Array – HAC (cont.)

```
 PA_HAC_BORAL_5_5_100_0.19630.out
media 14 1 29  3
media 14 1 31  3
media 14 1 55  3
media 14 1 57  3
media 14 1 33  3
media 14 1 35  3
media 14 1 41  3
media 14 1 43  3
media 14 1 45  3
media 14 1 47  3
boundary 14

unit 11
com='fuel assembly confinement system'
cuboid 1    24.384       0 24.384       0 520.7000 2.5400
cuboid 2    25.337       -0.9525 25.337        -0.9525
 523.2400  0.0000
cuboid 3    19.812       4.572        24.429       -0.04545
513.0800  3.81
cuboid 4    19.812       4.572        24.656       -0.27205
 513.0800  3.81
cuboid 5    19.812       4.572        24.702       -0.3175
 513.0800  3.81
cuboid 6    24.429       -0.04545      19.812       4.572
  513.0800  3.81
cuboid 7    24.656       -0.27205      19.812       4.572
 513.0800  3.81
cuboid 8    24.702       -0.3175       19.812       4.572
 513.0800  3.81
hole 20  origin  x=0  y=0  z=16.56  rotate  a1=0 a2=0 a3=0
media  0 1   1
media  7 1  -1   2  -5  -8
media  7 1  -1   3
media 12 1  -3   4
media  7 1  -4   5
media  7 1  -1   6
media 12 1  -6   7
media  7 1  -7   8
boundary 2

unit 20
com='fuel assembly'
cuboid 1 21.072       0 21.072       0   0       -14.0208
cuboid 2 24.384       0 24.384       0 504.1392   -14.0208
hole 31 origin  x=0       y=0       z=0.0001   rotate  a1=0  a2=0 a3=0
hole 21 origin  x=0       y=0       z=100.0001 rotate  a1=0  a2=0 a3=0
hole 40 origin  x=0       y=0       z=426.7201 rotate  a1=0  a2=0 a3=0
media  15 1  1
media   0 1 -1   2
boundary 2
```

Table 6-34 Input Deck for Traveller XL Package Array – HAC (cont.)

```
 PA_HAC_BORAL_5_5_100_0.19630.out
unit 21
com='fuel rods - nominal pitch'
cuboid 1  21.072       0 21.072       0 326.72       0.0000
array 2 1 place 1 1 1 0.4572       0.4572       0
boundary 1

unit 22
com='solid fuel rod - nominal pitch'
cylinder 1  0.39218       426.72          0
cylinder 2  0.40005      426.72          0
cylinder 3  0.4572       426.72          0
cuboid 4  4P0.62992       426.72          0
media 1 1  1
media 2 1  2 -1
media 3 1  3 -2 -1
media 4 1  4 -3 -2 -1
boundary 4

unit 23
com='thimble tube - nominal pitch'
cylinder 1  0.56134       426.72         0
cylinder 2  0.60198       426.72         0
cuboid 3    4P0.62992      426.72         0
media 4 1 1
media 3 1 2 -1
media 4 1 3 -2 -1
boundary 3

unit 31
com='fuel rods - expanded pitch'
cuboid 1  24.384       0 24.384       0 100         0
array 3 1 place 1 1 1 0.4572       0.4572       0
boundary 1

unit 32
com='solid fuel rod - expanded pitch'
cylinder 1  0.39218       426.72          0
cylinder 2  0.40005      426.72          0
cylinder 3  0.4572       426.72          0
cuboid 4  4P0.73342       426.72          0
media 16  1 1
media 17  1 2 -1
media 18  1 3 -2 -1
media 19  1 4 -3 -2 -1
boundary 4

unit 33
com='thimble tube - expanded pitch'
cylinder 1  0.56134      426.72          0
cylinder 2  0.60198      426.72          0
```

Table 6-34 Input Deck for Traveller XL Package Array – HAC (cont.)

```
 PA_HAC_BORAL_5_5_100_0.19630.out
cuboid 3  4P0.73342      426.72          0
media 19 1 1
media 18 1 2 -1
media 19 1 3 -2 -1
boundary 3

unit 40
com='top nozzle assembly'
cuboid 1     21.072      0 21.072      0       21.2090     0.0000
cuboid 2     21.072      0 21.072      0      41.8846     0.0000
cuboid 3     21.072      0 21.072      0       52.8193     0.0000
cuboid 4     21.072      0 21.072      0       77.4192     0.0000
cuboid 5     24.384      0 24.384      0       77.4192     0.0008
media  15 1   1
media  15 1  -1   2
media  15 1  -2   3
media  15 1  -3   4
media  15 1  -4   5
boundary 5

unit 66
com='individual package 0-deg rotation'
hexprism 1  31.75    554.1972  -20.1498
hole 10  origin  x=0 y=0  z=0  rotate  a1=0 a2=0 a3=0
media   0 1   1
boundary 1

unit 77
com='individual package 180-deg rotation'
hexprism 1  31.75    554.1972  -20.1498
hole 10  origin  x=0 y=0  z=0  rotate  a1=0 a2=0 a3=180
media   0 1   1
boundary 1

unit 88
com='dummy cell'
hexprism 1  31.75    554.1972  -20.1498
media  15 1   1
boundary 1

global
unit 99
com='package array'
cylinder 1  432.2355   554.1972  -20.1498
cylinder 2  452.2355   574.1972  -40.1498
cuboid 3  452.2355  -452.2355  452.2355  -452.2355   574.1972  -40.1498
array 1 1  place 9 9 1 0 0 0
media  15 1  -1   2
media   0 1  -2   3
boundary 3

end geometry
```

Table 6-34 Input Deck for Traveller XL Package Array – HAC (cont.)

```
 PA_HAC_BORAL_5_5_100_0.19630.out
read array
ara=1 typ=triangular nux=17 nuy=17 nuz=1 gbl=1
fill
88 88 88 88 88 88 88 88 88 88 88 88 88 88 88 88 88
 88 88 88 88 88 88 88 88 88 88 77 77 77 88 88 88 88
  88 88 88 88 88 88 88 88 66 66 66 66 66 66 66 88 88
   88 88 88 88 88 88 77 77 77 77 77 77 77 77 77 77 88
    88 88 88 88 88 66 66 66 66 66 66 66 66 66 66 66 88
     88 88 88 88 77 77 77 77 77 77 77 77 77 77 77 77 88
      88 88 88 66 66 66 66 66 66 66 66 66 66 66 66 66 88
       88 88 88 77 77 77 77 77 77 77 77 77 77 77 77 88 88
        88 88 66 66 66 66 66 66 66 66 66 66 66 66 66 88 88
         88 88 77 77 77 77 77 77 77 77 77 77 77 77 88 88 88
          88 66 66 66 66 66 66 66 66 66 66 66 66 66 88 88 88
           88 77 77 77 77 77 77 77 77 77 77 77 77 88 88 88 88
            88 66 66 66 66 66 66 66 66 66 66 66 88 88 88 88 88
             88 77 77 77 77 77 77 77 77 77 77 88 88 88 88 88 88
              88 88 66 66 66 66 66 66 66 88 88 88 88 88 88 88 88
               88 88 88 77 77 77 77 88 88 88 88 88 88 88 88 88 88
               88 88 88 88 88 88 88 88 88 88 88 88 88 88 88 88 88
end fill

ara=2 typ=square nux=17 nuy=17 nuz=1
fill 39*22 23 2*22 23 2*22 23 8*22 23 9*22 23 22*22 23 2*22 23 2*22 23
 2*22 23 2*22 23 38*22 23 2*22 23 2*22 23 2*22 23 2*22 23 38*22 23
 2*22 23 2*22 23 2*22 23 2*22 23 22*22 23 9*22 23 8*22 23 2*22 23 2*22
 23 39*22
end fill
ara=3 typ=square nux=17 nuy=17 nuz=1
fill 39*32 33 2*32 33 2*32 33 8*32 33 9*32 33 22*32 33 2*32 33 2*32 33
 2*32 33 2*32 33 38*32 33 2*32 33 2*32 33 2*32 33 2*32 33 38*32 33
 2*32 33 2*32 33 2*32 33 2*32 33 22*32 33 9*32 33 8*32 33 2*32 33 2*32
 33 39*32
end fill

end array
read bnds
+xb=vacuum
-xb=vacuum
+yb=vacuum
-yb=vacuum
+zb=vacuum
-zb=vacuum
end bnds

end data
end
```

Table 6-35 has been deleted.

Pages 6-99 – 6-103 intentionally left blank

6.10.8 Rod Container Calculations

6.10.8.1 Introduction

The calculations involved two separate analyses, one for the Rod Pipe, and another for the Rod Box. The approach used was the same for both. First, each container was modeled using the Traveller XL outerpack model for the hypothetical accident conditions for individual package and package array cases. Second, the analyses consisted of modeling pellet stacks inside the container and varying the pitch to determine the optimum pellet pitch-to-diameter ratio. The following pellet diameters were used with corresponding pitches in order to find the optimum values. Note that not all pitch/diameter runs were completed. However, sufficient data were obtained to define curves.

Pitch Value (cm)	Pellet Diameters (cm)
Close Packed (pitch = diameter)	0.25/ 0.30/0.35/0.40/0.45/0.50/0.60/0.80/0.90/1.00
1.2	0.05/0.10/0.15/0.20/0.25/0.30/0.35/0.40/0.45/0.50
1.5	0.05/0.10/0.15/0.20/0.25/0.30/0.35/0.40/0.45/0.50
1.8	0.05/0.10/0.15/0.20/0.25/0.30/0.35/0.40/0.45/0.50
2.0	0.05/0.10/0.15/0.20/0.25/0.30/0.35/0.40/0.45/0.50
2.5	0.25/ 0.30/0.35/0.40/0.45/0.50/0.60/0.80/0.90/1.00
3.0	0.25/ 0.30/0.35/0.40/0.45/0.50/0.60/0.80/0.90/1.00
4.0	0.25/ 0.30/0.35/0.40/0.45/0.50/0.60/0.80/0.90/1.00

After plotting curves to find approximate maximum k_{eff} values for the pitch/diameter combinations, two array cases were selected, one each for the rod box and rod pipe. These were analyzed to determine the effect on k_{eff} of varying the interspersed moderation water density. These results are shown in Figure 6-39.

6.10.8.2 Models

The fuel rod model is described in Section 6.3.1.1.2. The container models, which consist of a simple cylinder and cube, are described in Section 6.3.1.1.3 and Section 6.3.1.1.4. The box and pipe materials were not included in the models. The dimensions equate to the outside dimensions of the particular container. Figure 6-40 shows the rod box and rod pipe models inside the Traveller XL.

6.10.8.3 Individual Package Configuration

The analysis assumes the most conservative flooding configuration for the individual package, which is the fully flooded condition. This is discussed in Section 6.7.1.

6.10.8.4 Package Array Configuration

The analysis uses the same flooding configuration for the package array case under hypothetical accident conditions, namely the XL-HAC-ARRAY-100 model. This is discussed in Section 6.7.1.

6.10.8.5 Results

The results indicate that both rod container types are geometry limiting with respect to criticality. Calculated k_{eff} results were found to be less than 0.75 for all cases. The rod pipe appears to be the bounding container, and that the individual case results were higher than the infinite planar array cases that were modeled. Note that the infinite planar array cases assumed full water density inside the rod container and void in all interstitial spaces. That is, referring to Figure 6-4 (Floodable Void Spaces), regions 3 through 6 were modeled as a void. While this flooding configuration is most conservative for a fuel assembly, an interspersed moderation density sensitivity study demonstrated that full density water in all interstitial spaces results in the highest k_{eff}. The infinite planar array case with full density interstitial moderation is essentially equivalent to an individual package in isolation. Therefore, the highest k_{eff} for an package array for rod containers will be equal to the highest k_{eff} for an individual package in isolation.

Plots are provided that to show k_{eff} versus pellet diameter for the pitch values, for each of the four groups. These are presented as Figures 6-35 (Rod Pipe Individual Package), 6-36 (Rod Pipe Package Array), 6-37 (Rod Box Individual Package), and 6-38 (Rod Box Package Array).

Results are given in Tables 6-36 (Rod Pipe Individual Package), 6-36A (Rod Pipe Package Array), 6-36B (Rod Box Individual), and 6-36C (Rod Box Package Array). The highest k_{eff} values from the four tables are shown below.

Table	Run #	ks	sigma	Ks+2s	Pell. Diam. (inch)	Pell. Diam. (cm)	Rod Pitch (inch)	Rod Pitch (cm)	p/d
6-36	P-IP-15-6	0.7425	0.0015	0.7455	0.25	0.762	0.591	1.50	1.97
6-36A	P-ARR-15-6	0.6622	0.0016	0.6654	0.30	0.762	0.591	1.50	1.97
6-36B	B-IP-15-6	0.7008	0.0015	0.7038	0.30	0.762	0.591	1.50	1.97
6-36C	B-ARR-15-6	0.5512	0.0014	0.5540	0.30	0.762	0.591	1.50	1.97

The interspersed moderation density study was performed using the P-ARR-15-6 and B-ARR-15-6 array cases. Results are shown in Table 6-36D. It can be seen that there is good agreement between the zero density interspersed case (B-INTER-000, P-INTER-000) and the package array case (B-ARR-15-6, P-ARR-15-6), and between the full density interspersed case (B-INTER-100, P-INTER-100) and the individual package case (B-IP-15-6, P-IP-15-6). The data are plotted in Figure 6-39. This analysis demonstrates that the full density water interspersed case is the optimum infinite planar array case. A final calculation was made to show that the infinite 3-D array case compares will with the infinite planar array case. The 3D array case was modeled by replacing the water boundary condition on the +/- z axes with a mirror boundary condition. These results are also shown in Table 6-36D.

Sample input decks for Rod Box Individual Package, Rod Pipe Package Array, and Rod Pipe Interspersed Moderation are provided in Tables 6-36E, 6-36F, and 6-36G, respectively.

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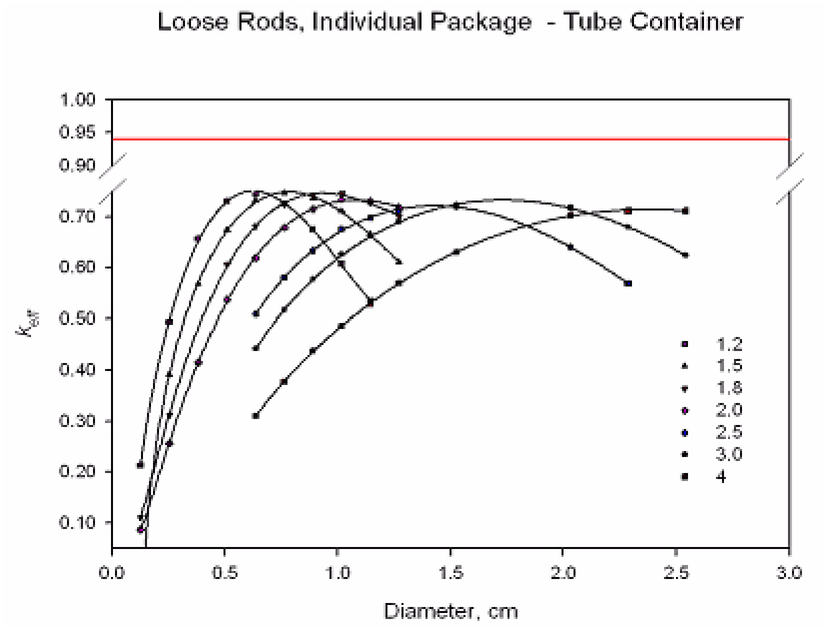

Figure 6-35 Rod Pipe – k_{eff} vs. Pellet Diameter for Individual Package

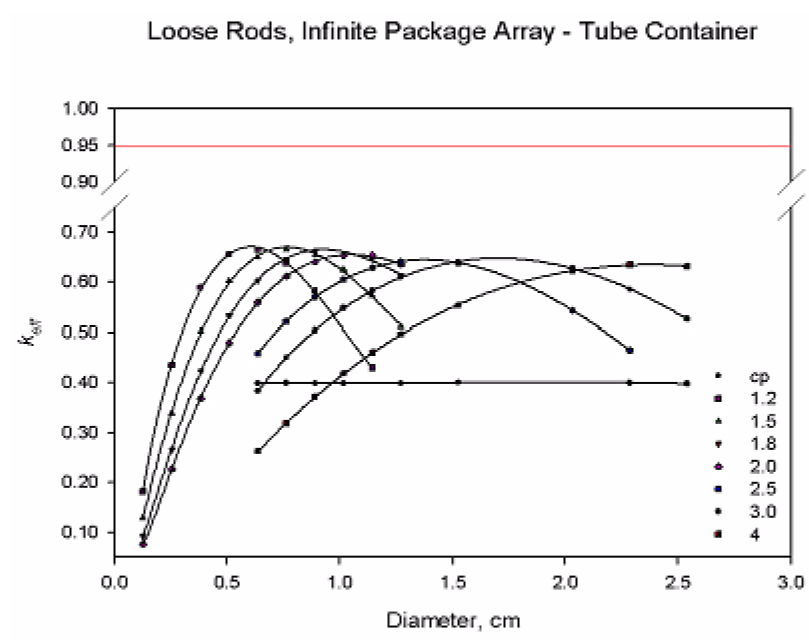

Figure 6-36 Rod Pipe – k_{eff} vs. Pellet Diameter for Infinite Array

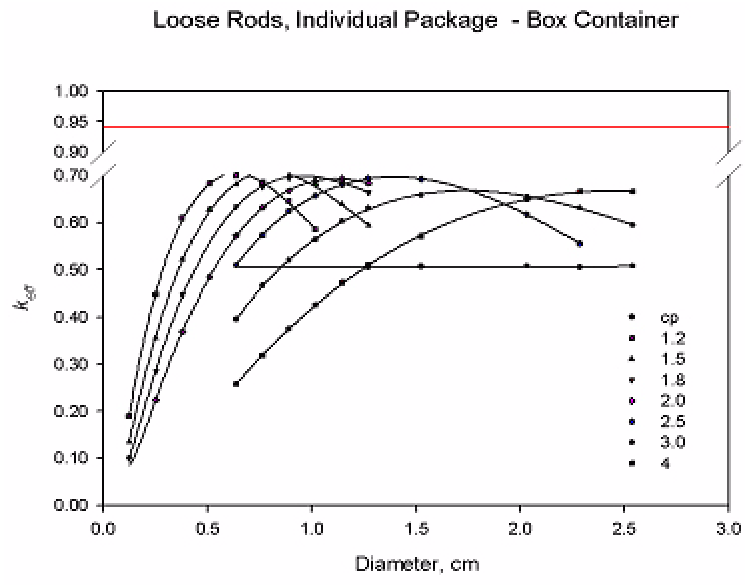

Figure 6-37 Rod Box – k_{eff} vs. Pellet Diameter for Individual Package

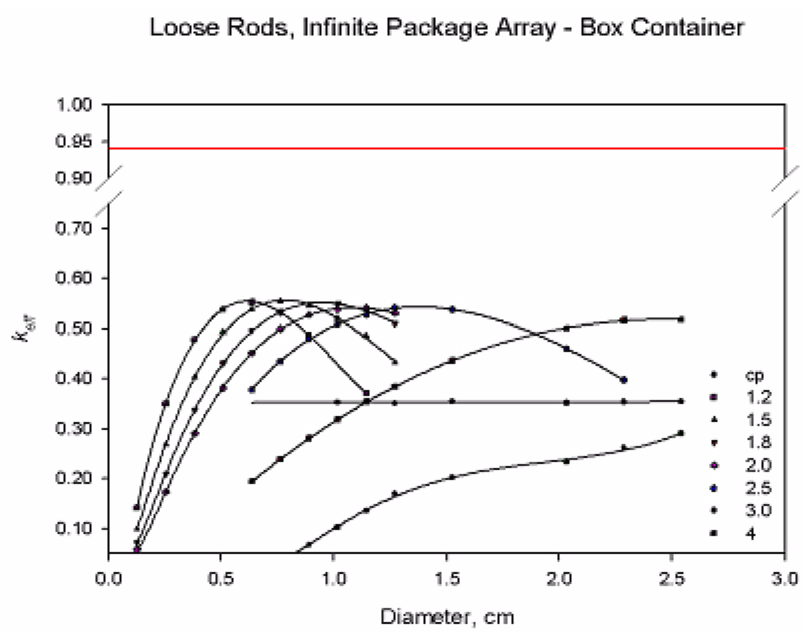

Figure 6-38 Rod Box – k_{eff} vs. Pellet Diameter for Package Array

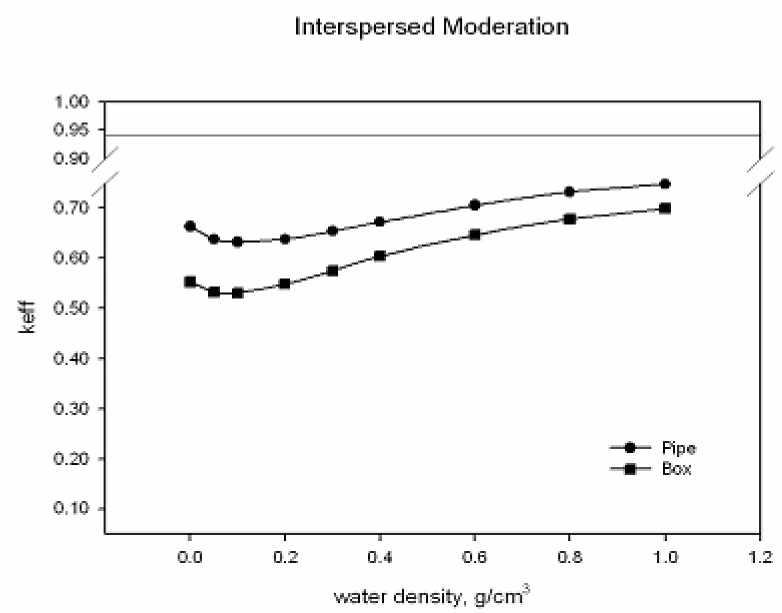

Figure 6-39 Interspersed Moderation Curves for Rod Box and Rod Pipe

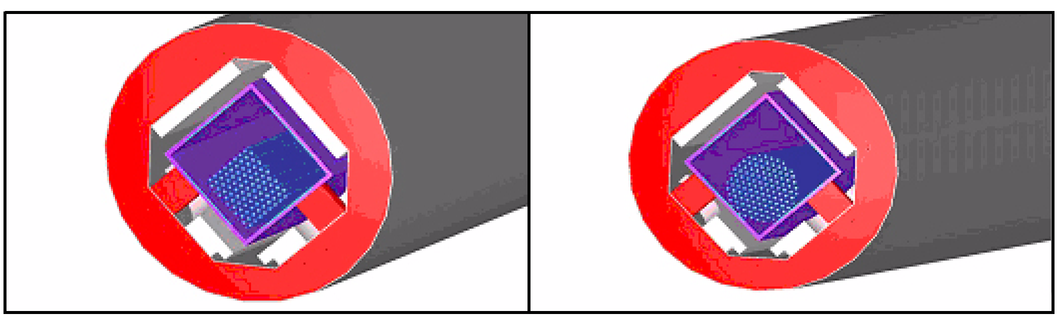

Figure 6-40 Rod Box and Rod Pipe in Traveller XL

Table 6-36 Results for Rod Pipe Individual Package HAC

Run #	ks	sigma	Ks+2s	No. Fuel Rods	Pell. Diam. (inch)	Pell. Diam. (cm)	Rod Pitch (inch)	Rod Pitch (cm)	p/d
1.2 cm Pitch									
P-IP-12-1	0.2118	0.0008	0.2134	187	0.05	0.127	0.472	1.20	9.45
P-IP-12-2	0.4917	0.0012	0.4941	187	0.10	0.254	0.472	1.20	4.72
P-IP-12-3	0.6545	0.0013	0.6571	187	0.15	0.381	0.472	1.20	3.15
P-IP-12-4	0.7281	0.0014	0.7309	187	0.20	0.508	0.472	1.20	2.36
P-IP-12-5	0.7416	0.0013	0.7442	187	0.25	0.635	0.472	1.20	1.89
P-IP-12-6	0.7233	0.0014	0.7261	187	0.30	0.762	0.472	1.20	1.57
P-IP-12-7	0.6731	0.0014	0.6759	187	0.35	0.889	0.472	1.20	1.35
P-IP-12-8	0.6049	0.0011	0.6071	187	0.40	1.016	0.472	1.20	1.18
P-IP-12-9	0.5329	0.0011	0.6071	187	0.45	1.143	0.472	1.20	1.05
P-IP-12-10				187	0.50	1.270	0.472	1.20	0.94
1.5 cm Pitch									
P-IP-15-2	0.3893	0.0011	0.3915	121	0.05	0.127	0.591	1.50	11.81
P-IP-15-3	0.5654	0.0013	0.5680	121	0.10	0.254	0.591	1.50	5.91
P-IP-15-4	0.6706	0.0015	0.6736	121	0.15	0.381	0.591	1.50	3.94
P-IP-15-5	0.7285	0.0015	0.7315	121	0.20	0.508	0.591	1.50	2.95
P-IP-15-6	0.7425	0.0015	0.7455	121	0.25	0.635	0.591	1.50	2.36
P-IP-15-7	0.7339	0.0014	0.7367	121	0.30	0.762	0.591	1.50	1.97
P-IP-15-8	0.7073	0.0015	0.7103	121	0.35	0.889	0.591	1.50	1.69
P-IP-15-9	0.6639	0.0013	0.6665	121	0.40	1.016	0.591	1.50	1.48
P-IP-15-10	0.6081	0.0014	0.6109	121	0.45	1.143	0.591	1.50	1.31
1.8 cm Pitch									
P-IP-18-1	0.1097	0.0005	0.1107	85	0.05	0.127	0.709	1.80	14.17
P-IP-18-2	0.3104	0.0009	0.3122	85	0.10	0.254	0.709	1.80	7.09
P-IP-18-3				85	0.15	0.381	0.709	1.80	4.72
P-IP-18-4	0.6039	0.0015	0.6069	85	0.20	0.508	0.709	1.80	3.54
P-IP-18-5	0.6776	0.0016	0.6808	85	0.25	0.635	0.709	1.80	2.83
P-IP-18-6	0.7225	0.0013	0.7251	85	0.30	0.762	0.709	1.80	2.36
P-IP-18-7	0.7384	0.0015	0.7414	85	0.35	0.889	0.709	1.80	2.02
P-IP-18-8	0.7425	0.0015	0.7455	85	0.40	1.016	0.709	1.80	1.77
P-IP-18-9	0.7246	0.0015	0.7276	85	0.45	1.143	0.709	1.80	1.57
P-IP-18-10	0.6977	0.0013	0.7003	85	0.50	1.270	0.709	1.80	1.42

Table 6-36 Results for Rod Pipe Individual Package HAC (cont.)									
Run #	**ks**	**sigma**	**Ks+2s**	**No. Fuel Rods**	**Pell. Diam. (inch)**	**Pell. Diam. (cm)**	**Rod Pitch (inch)**	**Rod Pitch (cm)**	**p/d**
2.0 cm Pitch									
P-IP-20-1	0.0858	0.0005	0.0868	61	0.05	0.127	0.787	2.00	15.75
P-IP-20-2	0.2548	0.0008	0.2564	61	0.10	0.254	0.787	2.00	7.87
P-IP-20-3	0.4130	0.0010	0.4150	61	0.15	0.381	0.787	2.00	5.25
P-IP-20-4	0.5349	0.0012	0.5373	61	0.20	0.508	0.787	2.00	3.94
P-IP-20-5	0.6165	0.0013	0.6191	61	0.25	0.635	0.787	2.00	3.15
P-IP-20-6	0.6754	0.0015	0.6784	61	0.30	0.762	0.787	2.00	2.62
P-IP-20-7	0.7118	0.0014	0.7146	61	0.35	0.889	0.787	2.00	2.25
P-IP-20-8	0.7310	0.0014	0.7338	61	0.40	1.016	0.787	2.00	1.97
P-IP-20-9	0.7274	0.0015	0.7304	61	0.45	1.143	0.787	2.00	1.75
P-IP-20-10	0.7159	0.0014	0.7187	61	0.50	1.270	0.787	2.00	1.57
2.5 cm Pitch									
P-IP-25-1	0.5069	0.0014	0.5097	37	0.25	0.635	0.984	2.50	3.94
P-IP-25-2	0.5780	0.0013	0.5806	37	0.30	0.762	0.984	2.50	3.28
P-IP-25-3	0.6304	0.0015	0.6334	37	0.35	0.889	0.984	2.50	2.81
P-IP-25-4	0.6730	0.0015	0.6760	37	0.40	1.016	0.984	2.50	2.46
P-IP-25-5	0.6953	0.0014	0.6981	37	0.45	1.143	0.984	2.50	2.19
P-IP-25-6	0.7094	0.0015	0.7124	37	0.50	1.270	0.984	2.50	1.97
P-IP-25-7	0.7169	0.0015	0.7199	37	0.60	1.524	0.984	2.50	1.64
P-IP-25-8	0.6371	0.0014	0.6399	37	0.80	2.032	0.984	2.50	1.23
P-IP-25-9				37	0.90	2.286	0.984	2.50	1.09
P-IP-25-10				37	1.00	2.540	0.984	2.50	0.98
3.0 cm Pitch									
P-IP-30-1				31	0.25	0.635	1.181	3.00	4.72
P-IP-30-2				31	0.30	0.762	1.181	3.00	3.94
P-IP-30-3	0.5740	0.0014	0.5768	31	0.35	0.889	1.181	3.00	3.37
P-IP-30-4	0.6234	0.0013	0.6260	31	0.40	1.016	1.181	3.00	2.95
P-IP-30-5	0.6578	0.0015	0.6608	31	0.45	1.143	1.181	3.00	2.62
P-IP-30-6	0.6873	0.0014	0.6901	31	0.50	1.270	1.181	3.00	2.36
P-IP-30-7	0.7198	0.0014	0.7226	31	0.60	1.524	1.181	3.00	1.97
P-IP-30-8	0.7132	0.0018	0.7168	31	0.80	2.032	1.181	3.00	1.48
P-IP-30-9	0.6765	0.0016	0.6797	31	0.90	2.286	1.181	3.00	1.31
P-IP-30-10	0.6212	0.0013	0.6238	31	1.00	2.540	1.181	3.00	1.18

Table 6-36 Results for Rod Pipe Individual Package HAC (cont.)									
Run #	ks	sigma	Ks+2s	No. Fuel Rods	Pell. Diam. (inch)	Pell. Diam. (cm)	Rod Pitch (inch)	Rod Pitch (cm)	p/d
4.0 cm Pitch									
P-IP-40-1	0.3085	0.0010	0.3105	19	0.25	0.635	1.575	4.00	6.30
P-IP-40-2	0.3754	0.0011	0.3776	19	0.30	0.762	1.575	4.00	5.25
P-IP-40-3	0.4356	0.0012	0.4380	19	0.35	0.889	1.575	4.00	4.50
P-IP-40-4	0.4837	0.0013	0.4863	19	0.40	1.016	1.575	4.00	3.94
P-IP-40-5	0.5266	0.0013	0.5292	19	0.45	1.143	1.575	4.00	3.50
P-IP-40-6	0.5676	0.0013	0.5702	19	0.50	1.270	1.575	4.00	3.15
P-IP-40-7	0.6280	0.0013	0.6306	19	0.60	1.524	1.575	4.00	2.62
P-IP-40-8	0.6999	0.0014	0.7027	19	0.80	2.032	1.575	4.00	1.97
P-IP-40-9				19	0.90	2.286	1.575	4.00	1.75
P-IP-40-10	0.7081	0.0015	0.7111	19	1.00	2.540	1.575	4.00	1.57

Table 6-36A Results for Rod Pipe Package Array HAC

Run #	ks	sigma	Ks+2s	No. Fuel Rods	Pell. Diam. (inch)	Pell. Diam. (cm)	Rod Pitch (inch)	Rod Pitch (cm)	p/d
Close Packed									
P-ARR-CP-1	0.3961	0.0009	0.3979		0.25	0.635	0.25	0.64	1.0
P-ARR-CP-2	0.3972	0.0009	0.3990		0.30	0.762	0.30	0.76	1.0
P-ARR-CP-3	0.3962	0.0009	0.3980		0.35	0.889	0.35	0.89	1.0
P-ARR-CP-4	0.3967	0.0008	0.3983	253	0.40	1.016	0.40	1.02	1.0
P-ARR-CP-5				200	0.45	1.143	0.45	1.14	1.0
P-ARR-CP-6	0.3967	0.0009	0.3985	163	0.50	1.270	0.50	1.27	1.0
P-ARR-CP-7	0.3981	0.0008	0.3997	109	0.60	1.524	0.60	1.52	1.0
P-ARR-CP-8				64	0.80	2.032	0.80	2.03	1.0
P-ARR-CP-9	0.3975	0.0008	0.3991	54	0.90	2.286	0.90	2.29	1.0
P-ARR-CP-10	0.3950	0.0009	0.3968	41	1.00	2.540	1.00	2.54	1.0
1.2 cm Pitch									
P-ARR-12-1	0.1800	0.0007	0.1814	187	0.05	0.127	0.472	1.20	9.45
P-ARR-12-2	0.4332	0.0012	0.4356	187	0.10	0.254	0.472	1.20	4.72
P-ARR-12-3	0.5860	0.0013	0.5886	187	0.15	0.381	0.472	1.20	3.15
P-ARR-12-4	0.6532	0.0014	0.6560	187	0.20	0.508	0.472	1.20	2.36
P-ARR-12-5	0.6604	0.0017	0.6638	187	0.25	0.635	0.472	1.20	1.89
P-ARR-12-6	0.6351	0.0014	0.6379	187	0.30	0.762	0.472	1.20	1.57
P-ARR-12-7	0.5792	0.0016	0.5824	187	0.35	0.889	0.472	1.20	1.35
P-ARR-12-8				187	0.40	1.016	0.472	1.20	1.18
P-ARR-12-9	0.4271	0.0010	0.4291		0.45	1.143	0.472	1.20	1.05
P-ARR-12-10					0.50	1.270	0.472	1.20	0.94
1.5 cm Pitch									
P-ARR-15-1	0.1271	0.0006	0.1283	121	0.05	0.127	0.591	1.50	11.81
P-ARR-15-2	0.3364	0.0011	0.3386	121	0.10	0.254	0.591	1.50	5.91
P-ARR-15-3	0.4993	0.0013	0.5019	121	0.15	0.381	0.591	1.50	3.94
P-ARR-15-4	0.5984	0.0014	0.6012	121	0.20	0.508	0.591	1.50	2.95
P-ARR-15-5	0.6463	0.0015	0.6493	121	0.25	0.635	0.591	1.50	2.36
P-ARR-15-6	0.6622	0.0016	0.6654	121	0.30	0.762	0.591	1.50	1.97
P-ARR-15-7	0.6511	0.0016	0.6543	121	0.35	0.889	0.591	1.50	1.69
P-ARR-15-8	0.6218	0.0014	0.6246	121	0.40	1.016	0.591	1.50	1.48
P-ARR-15-9	0.5706	0.0013	0.5732	121	0.45	1.143	0.591	1.50	1.31
P-ARR-15-10	0.5090	0.0011	0.5112	121	0.50	1.270	0.591	1.50	1.18

Table 6-36A Results for Rod Pipe Package Array HAC (cont.)

Run #	ks	sigma	Ks+2s	No. Fuel Rods	Pell. Diam. (inch)	Pell. Diam. (cm)	Rod Pitch (inch)	Rod Pitch (cm)	p/d
1.8 cm Pitch									
P-ARR-18-1	0.0919	0.0005	0.0929	85	0.05	0.127	0.709	1.80	14.17
P-ARR-18-2	0.2645	0.0009	0.2663	85	0.10	0.254	0.709	1.80	7.09
P-ARR-18-3	0.4208	0.0012	0.4232	85	0.15	0.381	0.709	1.80	4.72
P-ARR-18-4	0.5298	0.0013	0.5324	85	0.20	0.508	0.709	1.80	3.54
P-ARR-18-5	0.6002	0.0014	0.6030	85	0.25	0.635	0.709	1.80	2.83
P-ARR-18-6	0.6426	0.0014	0.6454	85	0.30	0.762	0.709	1.80	2.36
P-ARR-18-7	0.6598	0.0015	0.6628	85	0.35	0.889	0.709	1.80	2.02
P-ARR-18-8				85	0.40	1.016	0.709	1.80	1.77
P-ARR-18-9	0.6430	0.0014	0.6458	85	0.45	1.143	0.709	1.80	1.57
P-ARR-18-10	0.6098	0.0010	0.6118	85	0.50	1.270	0.709	1.80	1.42
2.0 cm Pitch									
P-ARR-20-1	0.0751	0.0004	0.0759	61	0.05	0.127	0.787	2.00	15.75
P-ARR-20-2	0.2248	0.0009	0.2266	61	0.10	0.254	0.787	2.00	7.87
P-ARR-20-3	0.3662	0.0010	0.3682	61	0.15	0.381	0.787	2.00	5.25
P-ARR-20-4	0.4765	0.0012	0.4789	61	0.20	0.508	0.787	2.00	3.94
P-ARR-20-5	0.5565	0.0014	0.5593	61	0.25	0.635	0.787	2.00	3.15
P-ARR-20-6	0.6077	0.0016	0.6109	61	0.30	0.762	0.787	2.00	2.62
P-ARR-20-7	0.6371	0.0014	0.6399	61	0.35	0.889	0.787	2.00	2.25
P-ARR-20-8	0.6505	0.0015	0.6535	61	0.40	1.016	0.787	2.00	1.97
P-ARR-20-9	0.6497	0.0017	0.6531	61	0.45	1.143	0.787	2.00	1.75
P-ARR-20-10	0.6317	0.0010	0.6337	61	0.50	1.270	0.787	2.00	1.57
2.5 cm Pitch									
P-ARR-25-1	0.4558	0.0013	0.4584	37	0.25	0.635	0.984	2.50	3.94
P-ARR-25-2	0.5188	0.0013	0.5214	37	0.30	0.762	0.984	2.50	3.28
P-ARR-25-3	0.5679	0.0013	0.5705	37	0.35	0.889	0.984	2.50	2.81
P-ARR-25-4	0.6022	0.0014	0.6050	37	0.40	1.016	0.984	2.50	2.46
P-ARR-25-5	0.6257	0.0013	0.6283	37	0.45	1.143	0.984	2.50	2.19
P-ARR-25-6	0.6373	0.0015	0.6403	37	0.50	1.270	0.984	2.50	1.97
P-ARR-25-7	0.6351	0.0014	0.6379	37	0.60	1.524	0.984	2.50	1.64
P-ARR-25-8	0.5410	0.0012	0.5434	37	0.80	2.032	0.984	2.50	1.23
P-ARR-25-9	0.4619	0.0011	0.4641	37	0.90	2.286	0.984	2.50	1.09
P-ARR-25-10					1.00	2.540	0.984	2.50	0.98

Table 6-36A Results for Rod Pipe Package Array HAC (cont.)

Run #	ks	sigma	Ks+2s	No. Fuel Rods	Pell. Diam. (inch)	Pell. Diam. (cm)	Rod Pitch (inch)	Rod Pitch (cm)	p/d
3.0 cm Pitch									
P-ARR-30-1	0.3806	0.0012	0.3830	31	0.25	0.635	1.181	3.00	4.72
P-ARR-30-2	0.4473	0.0012	0.4497	31	0.30	0.762	1.181	3.00	3.94
P-ARR-30-3	0.5012	0.0012	0.5036	31	0.35	0.889	1.181	3.00	3.37
P-ARR-30-4	0.5451	0.0015	0.5481	31	0.40	1.016	1.181	3.00	2.95
P-ARR-30-5	0.5806	0.0013	0.5832	31	0.45	1.143	1.181	3.00	2.62
P-ARR-30-6	0.6066	0.0013	0.6092	31	0.50	1.270	1.181	3.00	2.36
P-ARR-30-7	0.6367	0.0015	0.6397	31	0.60	1.524	1.181	3.00	1.97
P-ARR-30-8	0.6246	0.0015	0.6276	31	0.80	2.032	1.181	3.00	1.48
P-ARR-30-9	0.5822	0.0014	0.5850	31	0.90	2.286	1.181	3.00	1.31
P-ARR-30-10	0.5232	0.0013	0.5258	31	1.00	2.540	1.181	3.00	1.18
4.0 cm Pitch									
P-ARR-40-1	0.2606	0.0009	0.2624	19	0.25	0.635	1.575	4.00	6.30
P-ARR-40-2	0.3157	0.0011	0.3179	19	0.30	0.762	1.575	4.00	5.25
P-ARR-40-3	0.3690	0.0011	0.3712	19	0.35	0.889	1.575	4.00	4.50
P-ARR-40-4	0.4158	0.0011	0.4180	19	0.40	1.016	1.575	4.00	3.94
P-ARR-40-5	0.4577	0.0012	0.4601	19	0.45	1.143	1.575	4.00	3.50
P-ARR-40-6	0.4942	0.0013	0.4968	19	0.50	1.270	1.575	4.00	3.15
P-ARR-40-7	0.5506	0.0013	0.5532	19	0.60	1.524	1.575	4.00	2.62
P-ARR-40-8	0.6191	0.0014	0.6219	19	0.80	2.032	1.575	4.00	1.97
P-ARR-40-9	0.6309	0.0015	0.6339	19	0.90	2.286	1.575	4.00	1.75
P-ARR-40-10	0.6280	0.0014	0.6308	19	1.00	2.540	1.575	4.00	1.57

Table 6-36B Results for Rod Box Individual Package HAC

Run #	ks	sigma	Ks+2s	No. Fuel Rods	Pell. Diam. (inch)	Pell. Diam. (cm)	Rod Pitch (inch)	Rod Pitch (cm)	p/d
Close Packed									
B-IP-CP-1					0.25	0.635	0.25	0.64	1.0
B-IP-CP-2					0.30	0.762	0.30	0.76	1.0
B-IP-CP-3					0.35	0.889	0.35	0.89	1.0
B-IP-CP-4				196	0.40	1.016	0.40	1.02	1.0
B-IP-CP-5	0.5025	0.0011	0.5047	155	0.45	1.143	0.45	1.14	1.0
B-IP-CP-6	0.5044	0.0011	0.5066	120	0.50	1.270	0.50	1.27	1.0
B-IP-CP-7				85	0.60	1.524	0.60	1.52	1.0
B-IP-CP-8	0.5048	0.0011	0.5070	51	0.80	2.032	0.80	2.03	1.0
B-IP-CP-9	0.5028	0.0010	0.5048	42	0.90	2.286	0.90	2.29	1.0
B-IP-CP-10	0.5044	0.0012	0.5068	32	1.00	2.540	1.00	2.54	1.0
1.2 cm Pitch									
B-IP-12-1	0.188	0.0007	0.1894	143	0.05	0.127	0.472	1.20	9.45
B-IP-12-2	0.4459	0.0012	0.4483	143	0.10	0.254	0.472	1.20	4.72
B-IP-12-3	0.6061	0.0015	0.6091	143	0.15	0.381	0.472	1.20	3.15
B-IP-12-4	0.6798	0.0015	0.6828	143	0.20	0.508	0.472	1.20	2.36
B-IP-12-5	0.6967	0.0014	0.6995	143	0.25	0.635	0.472	1.20	1.89
B-IP-12-6	0.6819	0.0014	0.6847	143	0.30	0.762	0.472	1.20	1.57
B-IP-12-7	0.6430	0.0013	0.6456	143	0.35	0.889	0.472	1.20	1.35
B-IP-12-8	0.5829	0.0012	0.5853		0.40	1.016	0.472	1.20	1.18
B-IP-12-9					0.45	1.143	0.472	1.20	1.05
B-IP-12-10				143	0.50	1.270	0.472	1.20	0.94
1.5 cm Pitch									
B-IP-15-1	0.1333	0.0006	0.1345	93	0.05	0.127	0.591	1.50	11.81
B-IP-15-2	0.3543	0.0010	0.3563	93	0.10	0.254	0.591	1.50	5.91
B-IP-15-3	0.5198	0.0012	0.5222	93	0.15	0.381	0.591	1.50	3.94
B-IP-15-4	0.6254	0.0013	0.6280	93	0.20	0.508	0.591	1.50	2.95
B-IP-15-5	0.6774	0.0015	0.6804	93	0.25	0.635	0.591	1.50	2.36
B-IP-15-6	0.7008	0.0015	0.7038	93	0.30	0.762	0.591	1.50	1.97
B-IP-15-7	0.6964	0.0016	0.6996	93	0.35	0.889	0.591	1.50	1.69
B-IP-15-8	0.6780	0.0014	0.6808	93	0.40	1.016	0.591	1.50	1.48
B-IP-15-9	0.6363	0.0014	0.6391	93	0.45	1.143	0.591	1.50	1.31
B-IP-15-10	0.5906	0.0014	0.5934	93	0.50	1.270	0.591	1.50	1.18

Table 6-36B Results for Rod Box Individual Package HAC (cont.)									
Run #	ks	sigma	Ks+2s	No. Fuel Rods	Pell. Diam. (inch)	Pell. Diam. (cm)	Rod Pitch (inch)	Rod Pitch (cm)	p/d
1.8 cm Pitch									
B-IP-18-1	0.0994	0.0005	0.1004	67	0.05	0.127	0.709	1.80	14.17
B-IP-18-2	0.2836	0.0009	0.2854	67	0.10	0.254	0.709	1.80	7.09
B-IP-18-3	0.4446	0.0012	0.4470	67	0.15	0.381	0.709	1.80	4.72
B-IP-18-4				67	0.20	0.508	0.709	1.80	3.54
B-IP-18-5	0.6307	0.0013	0.6333	67	0.25	0.635	0.709	1.80	2.83
B-IP-18-6	0.6733	0.0014	0.6761	67	0.30	0.762	0.709	1.80	2.36
B-IP-18-7	0.6912	0.0016	0.6944	67	0.35	0.889	0.709	1.80	2.02
B-IP-18-8	0.6972	0.0015	0.7002	67	0.40	1.016	0.709	1.80	1.77
B-IP-18-9	0.6822	0.0015	0.6852	67	0.45	1.143	0.709	1.80	1.57
B-IP-18-10	0.6606	0.0014	0.6634	67	0.50	1.270	0.709	1.80	1.42
2.0 cm Pitch									
B-IP-20-1				45	0.05	0.127	0.787	2.00	15.75
B-IP-20-2	0.2234	0.0008	0.2250	45	0.10	0.254	0.787	2.00	7.87
B-IP-20-3	0.3674	0.0010	0.3694	45	0.15	0.381	0.787	2.00	5.25
B-IP-20-4	0.4817	0.0013	0.4843	45	0.20	0.508	0.787	2.00	3.94
B-IP-20-5	0.5695	0.0013	0.5721	45	0.25	0.635	0.787	2.00	3.15
B-IP-20-6	0.6295	0.0013	0.6321	45	0.30	0.762	0.787	2.00	2.62
B-IP-20-7	0.6645	0.0014	0.6673	45	0.35	0.889	0.787	2.00	2.25
B-IP-20-8	0.6854	0.0017	0.6888	45	0.40	1.016	0.787	2.00	1.97
B-IP-20-9	0.6895	0.0017	0.6929	45	0.45	1.143	0.787	2.00	1.75
B-IP-20-10	0.6807	0.0016	0.6839	45	0.50	1.270	0.787	2.00	1.57
2.5 cm Pitch									
B-IP-25-1	0.5067	0.0013	0.5093	39	0.25	0.635	0.984	2.50	3.94
B-IP-25-2	0.5712	0.0012	0.5736	39	0.30	0.762	0.984	2.50	3.28
B-IP-25-3	0.6216	0.0014	0.6244	39	0.35	0.889	0.984	2.50	2.81
B-IP-25-4	0.6539	0.0014	0.6567	39	0.40	1.016	0.984	2.50	2.46
B-IP-25-5	0.6775	0.0014	0.6803	39	0.45	1.143	0.984	2.50	2.19
B-IP-25-6	0.6910	0.0015	0.6940	39	0.50	1.270	0.984	2.50	1.97
B-IP-25-7	0.6890	0.0014	0.6918	39	0.60	1.524	0.984	2.50	1.64
B-IP-25-8	0.6143	0.0014	0.6171	39	0.80	2.032	0.984	2.50	1.23
B-IP-25-9	0.5528	0.0012	0.5552	39	0.90	2.286	0.984	2.50	1.09
B-IP-25-10				39	1.00	2.540	0.984	2.50	0.98

Table 6-36B Results for Rod Box Individual Package HAC (cont.)

Run #	ks	sigma	Ks+2s	No. Fuel Rods	Pell. Diam. (inch)	Pell. Diam. (cm)	Rod Pitch (inch)	Rod Pitch (cm)	p/d
3.0 cm Pitch									
B-IP-30-1	0.3935	0.0011	0.3957	23	0.25	0.635	1.181	3.00	4.72
B-IP-30-2	0.4641	0.0011	0.4663	23	0.30	0.762	1.181	3.00	3.94
B-IP-30-3	0.5174	0.0013	0.5200	23	0.35	0.889	1.181	3.00	3.37
B-IP-30-4	0.5609	0.0013	0.5635	23	0.40	1.016	1.181	3.00	2.95
B-IP-30-5	0.5996	0.0014	0.6024	23	0.45	1.143	1.181	3.00	2.62
B-IP-30-6	0.6279	0.0013	0.6305	23	0.50	1.270	1.181	3.00	2.36
B-IP-30-7	0.6551	0.0014	0.6579	23	0.60	1.524	1.181	3.00	1.97
B-IP-30-8	0.6522	0.0014	0.6550	23	0.80	2.032	1.181	3.00	1.48
B-IP-30-9	0.6275	0.0016	0.6307	23	0.90	2.286	1.181	3.00	1.31
B-IP-30-10	0.5917	0.0014	0.5945	23	1.00	2.540	1.181	3.00	1.18
4.0 cm Pitch									
B-IP-40-1	0.2573	0.0009	0.2591	14	0.25	0.635	1.575	4.00	6.30
B-IP-40-2	0.3168	0.0009	0.3186	14	0.30	0.762	1.575	4.00	5.25
B-IP-40-3	0.3734	0.0011	0.3756	14	0.35	0.889	1.575	4.00	4.50
B-IP-40-4	0.4227	0.0014	0.4255	14	0.40	1.016	1.575	4.00	3.94
B-IP-40-5	0.4695	0.0012	0.4719	14	0.45	1.143	1.575	4.00	3.50
B-IP-40-6	0.5075	0.0014	0.5103	14	0.50	1.270	1.575	4.00	3.15
B-IP-40-7	0.5683	0.0012	0.5707	14	0.60	1.524	1.575	4.00	2.62
B-IP-40-8	0.6459	0.0015	0.6489	14	0.80	2.032	1.575	4.00	1.97
B-IP-40-9	0.6631	0.0014	0.6659	14	0.90	2.286	1.575	4.00	1.75
B-IP-40-10	0.6620	0.0010	0.6640	14	1.00	2.540	1.575	4.00	1.57

Table 6-36C Results for Rod Box Package Array HAC

Run #	ks	sigma	Ks+2s	No. Fuel Rods	Pell. Diam. (inch)	Pell. Diam. (cm)	Rod Pitch (inch)	Rod Pitch (cm)	p/d
Close Packed									
B-ARR-CP-1					0.25	0.635	0.25	0.64	1.0
B-ARR-CP-2					0.30	0.762	0.30	0.76	1.0
B-ARR-CP-3					0.35	0.889	0.35	0.89	1.0
B-ARR-CP-4	0.3506	0.0009	0.3524	196	0.40	1.016	0.40	1.02	1.0
B-ARR-CP-5	0.3502	0.0008	0.3518	155	0.45	1.143	0.45	1.14	1.0
B-ARR-CP-6	0.3493	0.0008	0.3509	120	0.50	1.270	0.50	1.27	1.0
B-ARR-CP-7	0.3523	0.0008	0.3539	85	0.60	1.524	0.60	1.52	1.0
B-ARR-CP-8	0.3496	0.0009	0.3514	51	0.80	2.032	0.80	2.03	1.0
B-ARR-CP-9	0.3513	0.0008	0.3529	42	0.90	2.286	0.90	2.29	1.0
B-ARR-CP-10	0.3526	0.0008	0.3542	32	1.00	2.540	1.00	2.54	1.0
1.2 cm Pitch									
B-ARR-12-1	0.1397	0.0007	0.1411	143	0.05	0.127	0.472	1.20	9.45
B-ARR-12-2	0.3478	0.0011	0.3500	143	0.10	0.254	0.472	1.20	4.72
B-ARR-12-3	0.4753	0.0014	0.4781	143	0.15	0.381	0.472	1.20	3.15
B-ARR-12-4	0.5352	0.0013	0.5378	143	0.20	0.508	0.472	1.20	2.36
B-ARR-12-5	0.5492	0.0014	0.5520	143	0.25	0.635	0.472	1.20	1.89
B-ARR-12-6	0.5301	0.0014	0.5329	143	0.30	0.762	0.472	1.20	1.57
B-ARR-12-7	0.4843	0.0012	0.4867	143	0.35	0.889	0.472	1.20	1.35
B-ARR-12-8				143	0.40	1.016	0.472	1.20	1.18
B-ARR-12-9	0.3689	0.0009	0.3707	143	0.45	1.143	0.472	1.20	1.05
B-ARR-12-10				143	0.50	1.270	0.472	1.20	0.94
1.5 cm Pitch									
B-ARR-15-1	0.0977	0.0006	0.0989	93	0.05	0.127	0.591	1.50	11.81
B-ARR-15-2	0.2661	0.0008	0.2677	93	0.10	0.254	0.591	1.50	5.91
B-ARR-15-3	0.4009	0.0011	0.4031	93	0.15	0.381	0.591	1.50	3.94
B-ARR-15-4	0.4894	0.0014	0.4922	93	0.20	0.508	0.591	1.50	2.95
B-ARR-15-5	0.5343	0.0017	0.5377	93	0.25	0.635	0.591	1.50	2.36
B-ARR-15-6	0.5512	0.0014	0.5540	93	0.30	0.762	0.591	1.50	1.97
B-ARR-15-7	0.5427	0.0014	0.5455	93	0.35	0.889	0.591	1.50	1.69
B-ARR-15-8	0.5175	0.0013	0.5201	93	0.40	1.016	0.591	1.50	1.48
B-ARR-15-9	0.4835	0.0012	0.4859	93	0.45	1.143	0.591	1.50	1.31
B-ARR-15-10	0.4301	0.0010	0.4321	93	0.50	1.270	0.591	1.50	1.18

Table 6-36C Results for Rod Box Package Array HAC (cont.)

Run #	ks	sigma	Ks+2s	No. Fuel Rods	Pell. Diam. (inch)	Pell. Diam. (cm)	Rod Pitch (inch)	Rod Pitch (cm)	p/d
1.8 cm Pitch									
B-ARR-18-1	0.0714	0.0005	0.0724	67	0.05	0.127	0.709	1.80	14.17
B-ARR-18-2	0.2078	0.0008	0.2094	67	0.10	0.254	0.709	1.80	7.09
B-ARR-18-3	0.3349	0.0011	0.3371	67	0.15	0.381	0.709	1.80	4.72
B-ARR-18-4	0.4284	0.0013	0.4310	67	0.20	0.508	0.709	1.80	3.54
B-ARR-18-5	0.4928	0.0014	0.4956	67	0.25	0.635	0.709	1.80	2.83
B-ARR-18-6	0.5290	0.0014	0.5318	67	0.30	0.762	0.709	1.80	2.36
B-ARR-18-7	0.5450	0.0014	0.5478	67	0.35	0.889	0.709	1.80	2.02
B-ARR-18-8	0.5458	0.0015	0.5488	67	0.40	1.016	0.709	1.80	1.77
B-ARR-18-9	0.5351	0.0012	0.5375	67	0.45	1.143	0.709	1.80	1.57
B-ARR-18-10	0.5075	0.0012	0.5099	67	0.50	1.270	0.709	1.80	1.42
2.0 cm Pitch									
B-ARR-20-1	0.0573	0.0004	0.0581	45	0.05	0.127	0.787	2.00	15.75
B-ARR-20-2	0.1719	0.0008	0.1735	45	0.10	0.254	0.787	2.00	7.87
B-ARR-20-3	0.2884	0.0010	0.2904	45	0.15	0.381	0.787	2.00	5.25
B-ARR-20-4	0.3791	0.0013	0.3817	45	0.20	0.508	0.787	2.00	3.94
B-ARR-20-5	0.4485	0.0012	0.4509	45	0.25	0.635	0.787	2.00	3.15
B-ARR-20-6	0.4957	0.0016	0.4989	45	0.30	0.762	0.787	2.00	2.62
B-ARR-20-7	0.5245	0.0014	0.5273	45	0.35	0.889	0.787	2.00	2.25
B-ARR-20-8	0.5354	0.0014	0.5382	45	0.40	1.016	0.787	2.00	1.97
B-ARR-20-9	0.5369	0.0015	0.5399	45	0.45	1.143	0.787	2.00	1.75
B-ARR-20-10	0.5281	0.0013	0.5307	45	0.50	1.270	0.787	2.00	1.57
2.5 cm Pitch									
B-ARR-25-1	0.3757	0.0011	0.3779	39	0.25	0.635	0.984	2.50	3.94
B-ARR-25-2	0.4322	0.0012	0.4346	39	0.30	0.762	0.984	2.50	3.28
B-ARR-25-3	0.4771	0.0013	0.4797	39	0.35	0.889	0.984	2.50	2.81
B-ARR-25-4	0.5060	0.0013	0.5086	39	0.40	1.016	0.984	2.50	2.46
B-ARR-25-5	0.5241	0.0015	0.5271	39	0.45	1.143	0.984	2.50	2.19
B-ARR-25-6	0.5388	0.0013	0.5414	39	0.50	1.270	0.984	2.50	1.97
B-ARR-25-7	0.5344	0.0015	0.5374	39	0.60	1.524	0.984	2.50	1.64
B-ARR-25-8	0.4577	0.0012	0.4601	39	0.80	2.032	0.984	2.50	1.23
B-ARR-25-9	0.3956	0.0009	0.3974	39	0.90	2.286	0.984	2.50	1.09
B-ARR-25-10				39	1.00	2.540	0.984	2.50	0.98

Table 6-36C Results for Rod Box Package Array HAC (cont.)									
Run #	ks	sigma	Ks+2s	No. Fuel Rods	Pell. Diam. (inch)	Pell. Diam. (cm)	Rod Pitch (inch)	Rod Pitch (cm)	p/d
3.0 cm Pitch									
B-ARR-30-1	0.3011	0.0010	0.3031	23	0.25	0.635	1.181	3.00	4.72
B-ARR-30-2	0.3604	0.0011	0.3626	23	0.30	0.762	1.181	3.00	3.94
B-ARR-30-3	0.4042	0.0012	0.4066	23	0.35	0.889	1.181	3.00	3.37
B-ARR-30-4	0.4404	0.0012	0.4428	23	0.40	1.016	1.181	3.00	2.95
B-ARR-30-5	0.4714	0.0013	0.4740	23	0.45	1.143	1.181	3.00	2.62
B-ARR-30-6	0.4946	0.0013	0.4972	23	0.50	1.270	1.181	3.00	2.36
B-ARR-30-7	0.5184	0.0013	0.5210	23	0.60	1.524	1.181	3.00	1.97
B-ARR-30-8	0.5063	0.0012	0.5087	23	0.80	2.032	1.181	3.00	1.48
B-ARR-30-9	0.4758	0.0012	0.4782	23	0.90	2.286	1.181	3.00	1.31
B-ARR-30-10	0.4345	0.0011	0.4367	23	1.00	2.540	1.181	3.00	1.18
4.0 cm Pitch									
B-ARR-40-1	0.1926	0.0008	0.1942	14	0.25	0.635	1.575	4.00	6.30
B-ARR-40-2	0.2364	0.0009	0.2382	14	0.30	0.762	1.575	4.00	5.25
B-ARR-40-3	0.2784	0.0010	0.2804	14	0.35	0.889	1.575	4.00	4.50
B-ARR-40-4	0.3159	0.0013	0.3185	14	0.40	1.016	1.575	4.00	3.94
B-ARR-40-5	0.3522	0.0011	0.3544	14	0.45	1.143	1.575	4.00	3.50
B-ARR-40-6	0.3814	0.0011	0.3836	14	0.50	1.270	1.575	4.00	3.15
B-ARR-40-7	0.4332	0.0014	0.4360	14	0.60	1.524	1.575	4.00	2.62
B-ARR-40-8	0.4976	0.0013	0.5002	14	0.80	2.032	1.575	4.00	1.97
B-ARR-40-9	0.5137	0.0014	0.5165	14	0.90	2.286	1.575	4.00	1.75
B-ARR-40-10	0.5140	0.0014	0.5168	14	1.00	2.540	1.575	4.00	1.57

Table 6-36D Rod Box and Rod Pipe Interspersed Moderation Results			
Run #	**ks**	**sigma**	**Ks+2s**
Rod Box Interspersed Moderation Cases			
B-INTER-000	0.5501	0.0013	0.5527
B-INTER-005	0.5296	0.0014	0.5324
B-INTER-010	0.5284	0.0014	0.5312
B-INTER-020	0.5457	0.0014	0.5485
B-INTER-030	0.5731	0.0013	0.5757
B-INTER-040	0.6013	0.0015	0.6043
B-INTER-060	0.6443	0.0014	0.6471
B-INTER-080	0.6755	0.0015	0.6785
B-INTER-100	0.6962	0.0016	0.6994
Corresponding Rod Box Individual Package and Infinite Planar Array Cases			
B-ARR-15-6	0.5512	0.0014	0.5540
B-IP-15-6	0.7008	0.0015	0.7038
Rod Box Infinite Three Dimensional Array Cases			
B-ARR-15-6-3D	0.6962	0.0016	0.6994
Rod Pipe Interspersed Moderation Cases			
P-INTER-000	0.6611	0.0015	0.6641
P-INTER-005	0.6347	0.0016	0.6379
P-INTER-010	0.6299	0.0014	0.6327
P-INTER-020	0.6350	0.0015	0.6380
P-INTER-030	0.6514	0.0015	0.6544
P-INTER-040	0.6696	0.0014	0.6724
P-INTER-060	0.7028	0.0015	0.7058
P-INTER-080	0.7296	0.0016	0.7328
P-INTER-100	0.7455	0.0013	0.7481
Corresponding Rod Pipe Individual Package and Infinite Planar Array Cases			
P-ARR-15-6	0.6622	0.0016	0.6654
P-IP-15-6	0.7425	0.0015	0.7455
Rod Pipe Infinite Three Dimensional Array Cases			
P-ARR-15-6-3D	0.7455	0.0013	0.7481

Table 6-36E Input Deck for Rod Box Individual Package – 1.5 cm Pitch; 0.35 inch Diameter

```
PA_HAC_BORAL_6_3_1.5_7_0.889_in
=csas26     parm=size=300000
TRAVELLER XL,ROD TUBE,PA,NPD=0.889       ,PITCH=1.5
44groupndf5  latticecell
 uo2 1 1 293 92235 5 92238 95 end
 h2o 2 1 293 end
 zirc4 3 1 293 end
 h2o 4 1 293 end
 h2o 5 1 293 end
 arbmfoam 0.1602e-20  4  0  0  0 6012 70 1001 10 8016 16 7014 4  6 1 293
 end
 al 7 1 293 end
 ss304 8 1 293 end
 polyethylene 9 DEN=0.828 1.0 293 end
 arbmfoam 0.1602e-20  4  0  0  0 6012 70 1001 10 8016 16 7014 4 11 1 293
 end
 b-10 12 0 0.0047781    end
 b-11 12 0 0.019398     end
 c   12 0 0.0060439    end
 al  12 0 0.043223     end
 arbmrubber 1.59  7  0  0  0 8016 46.94 13000 19.92 14000 17.54 6012
 10.79 1001 4.73 11000 0.06 26000 0.02  14 1 293 end
 h2o 15 1 293 end
 uo2 16 1 293 92235 5 92238 95 end
 h2o 17 1 293 end
 zirc4 18 1 293 end
 h2o 19 1 293 end
end comp
triangpitch 1.5          0.889      16 19 end
more data
res=1  cylinder 0.39218      dan(1)=0.22632       end

read parameter
gen=303
wrs=1
end parameter
read geometry
unit 10
com='individual package'
cuboid 1    16.904       -15.634       16.904       -15.634       533.1330 0
rotate  a1=45 a2=0 a3=0 origin x=0  y=-1.460 z=0
cuboid 2     21.5900   -21.5900     1.5720    -1.0310   533.1330     0
cuboid 3     20.0790   -20.0790    20.0790   -20.0790   533.1330     0
rotate  a1=45 a2=0 a3=0 origin x=0  y=-1.460 z=0
cuboid 4     20.3450   -20.3450    20.3450   -20.3450   533.3990    -0.2660
rotate  a1=45 a2=0 a3=0 origin x=0  y=-1.460 z=0
cuboid 5     21.5900   -21.590     23.1498   -23.1498   533.1330     0
cuboid 6     21.8560   -21.8560    23.4158   -23.4158   533.3990    -0.2660
cuboid 7     20.3840   -20.3840    20.3840   -20.3840   553.8922   -19.8448
rotate  a1=45 a2=0 a3=0 origin x=0  y=-1.460 z=0
cuboid 8     21.8950   -21.895     23.4548   -23.4548   553.8922   -19.8448
```

Table 6-36E Input Deck for Rod Box Individual Package – 1.5 cm Pitch; 0.35 inch Diameter (cont.)

```
PA_HAC_BORAL_6_3_1.5_7_0.889_in
cylinder  9    25.1050    533.4380    -0.2660
cylinder 10    25.1050    553.9312   -19.8448
cylinder 11    31.4840    533.4380    -0.2660
cylinder 12    31.4840    553.9312   -19.8448
cylinder 13    31.4840    533.4380   -19.8448
cylinder 14    31.7500    554.1972   -20.1100

plane 15  zpl=1  con= -10.0000
cylinder 16 7.62   0 -4.5
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=494.4364
cylinder 17 3.962  0 -7.60
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=494.4364
cylinder 18 7.62   0 -4.5
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=494.4364
cylinder 19 3.962  0 -7.60
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=494.4364
cylinder 20 7.62   0 -4.5
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=448.7164
cylinder 21 3.962  0 -7.60
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=448.7164
cylinder 22 7.62   0 -4.5
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=448.7164
cylinder 23 3.962  0 -7.60
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=448.7164
cylinder 24 7.62   0 -4.5
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=402.9964
cylinder 25 3.962  0 -7.60
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=402.9964
cylinder 26 7.62   0 -4.5
rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=402.9964
cylinder 27 3.962  0 -7.60
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=402.9964
cylinder 28 7.62   0 -4.5
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=357.2764
cylinder 29 3.962  0 -7.60
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=357.2764
cylinder 30 7.62   0 -4.5
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=357.2764
cylinder 31 3.962  0 -7.60
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=357.2764
cylinder 54 7.62   0 -4.5
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=265.8364
cylinder 55 3.962  0 -7.60
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=265.8364
cylinder 56 7.62   0 -4.5
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=265.8364
cylinder 57 3.962  0 -7.60
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=265.8364
```

Table 6-36E Input Deck for Rod Box Individual Package – 1.5 cm Pitch; 0.35 inch Diameter (cont.)

```
PA_HAC_BORAL_6_3_1.5_7_0.889_in
cylinder 32 7.62   0 -4.5
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=174.3964
cylinder 33 3.962  0 -7.60
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=174.3964
cylinder 34 7.62   0 -4.5
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=174.3964
cylinder 35 3.962  0 -7.60
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=174.3964
cylinder 36 7.62   0 -4.5
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=128.6764
cylinder 37 3.962  0 -7.60
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=128.6764
cylinder 38 7.62   0 -4.5
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=128.6764
cylinder 39 3.962  0 -7.60
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=128.6764
cylinder 40 7.62   0 -4.5
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=82.9564
cylinder 41 3.962  0 -7.60
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=82.9564
cylinder 42 7.62   0 -4.5
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=82.9564
cylinder 43 3.962  0 -7.60
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=82.9564
cylinder 44 7.62   0 -4.5
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=37.2364
cylinder 45 3.962  0 -7.60
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=37.2364
cylinder 46 7.62   0 -4.5
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=37.2364
cylinder 47 3.962  0 -7.60
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=37.2364
hole 11 rotate  a1=45 a2=0 a3=0  origin  x=0 y=-17.700 z=5.240
cuboid 48    18.174    20.079   10.4238  -9.5152    533.3990    -0.2660
rotate  a1=-45 a2=0 a3=0 origin x=0  y=-1.460 z=0
cuboid 49    13.6554  -10.4238  16.904    20.079    533.3990    -0.2660
rotate  a1=45 a2=0 a3=0 origin x=0  y=-1.460 z=0
cuboid 50    16.904    20.079   13.6554  -10.4238   533.3990    -0.2660
rotate  a1=45 a2=0 a3=0 origin x=0  y=-1.460 z=0
cuboid 51     9.5152  -10.4238 -18.174   -20.079    533.3990    -0.2660
rotate  a1=-45 a2=0 a3=0 origin x=0  y=-1.460 z=0
cuboid 52    15.634    18.174   12.0238 -11.9197    533.3990    -0.2660
rotate  a1=-45 a2=0 a3=0 origin x=0  y=-1.460 z=0
cuboid 53    11.9197  -12.0238 -15.634   -18.174    533.3990    -0.2660
rotate  a1=-45 a2=0 a3=0 origin x=0  y=-1.460 z=0
media 15 1   1   3  5 -17 -19 -21 -23 -29 -31 -55 -57 -33 -35
-41 -43 -45 -47
media 15 1  -1   3  5 -48 -49 -50 -51 -52 -53
```

Table 6-36E Input Deck for Rod Box Individual Package – 1.5 cm Pitch; 0.35 inch Diameter (cont.)
PA_HAC_BORAL_6_3_1.5_7_0.889_in media 9 1 3 -16 -17 -20 -21 -28 -29 -54 -55 -32 -33 -40 -41 -44 -45 48 media 9 1 3 -18 -19 -22 -23 -30 -31 -56 -57 -34 -35 -42 -43 -46 -47 51 media 9 1 3 -18 -22 -30 -56 -34 -42 -46 53 media 9 1 3 -16 -20 -28 -54 -32 -40 -44 52 media 9 1 3 49 media 9 1 3 50 media 8 1 -3 4 6 media 8 1 3 -5 6 media 15 1 -4 9 media 15 1 4 -6 9 media 15 1 -9 11 media 15 1 -7 10 -13 media 15 1 7 -8 10 -13 12 media 15 1 -10 -13 12 media 15 1 -11 13 media 15 1 7 8 -13 12 media 8 1 -12 14 media 15 1 16 -17 3 48 media 15 1 18 -19 3 51 media 15 1 20 -21 3 48 media 15 1 22 -23 3 51 media 15 1 28 -29 3 48 media 15 1 30 -31 3 51 media 15 1 54 -55 3 48 media 15 1 56 -57 3 51 media 15 1 32 -33 3 48 media 15 1 34 -35 3 51 media 15 1 40 -41 3 48 media 15 1 42 -43 3 51 media 15 1 44 -45 3 48 media 15 1 46 -47 3 51 media 15 1 16 -17 3 52 media 15 1 18 -19 3 53 media 15 1 20 -21 3 52 media 15 1 22 -23 3 53 media 15 1 28 -29 3 52 media 15 1 30 -31 3 53 media 15 1 54 -55 3 52 media 15 1 56 -57 3 53 media 15 1 32 -33 3 52 media 15 1 34 -35 3 53 media 15 1 40 -41 3 52 media 15 1 42 -43 3 53 media 15 1 44 -45 3 52 media 15 1 46 -47 3 53 media 14 1 17 3 media 14 1 19 3

Table 6-36E Input Deck for Rod Box Individual Package – 1.5 cm Pitch; 0.35 inch Diameter (cont.)

```
PA_HAC_BORAL_6_3_1.5_7_0.889_in
media 14 1 21  3
media 14 1 23  3
media 14 1 29  3
media 14 1 31  3
media 14 1 55  3
media 14 1 57  3
media 14 1 33  3
media 14 1 35  3
media 14 1 41  3
media 14 1 43  3
media 14 1 45  3
media 14 1 47  3
boundary 14

unit 11
com='fuel assembly confinement system'
cuboid 1    24.384       0 24.384       0 520.7000 2.5400
cuboid 2    25.337       -0.9525 25.337        -0.9525
 523.2400  0.0000
cuboid 3    19.812       4.572        24.429       -0.04545
 513.0800  3.81
cuboid 4    19.812       4.572        24.656       -0.27205
 513.0800  3.81
cuboid 5    19.812       4.572        24.702       -0.3175
 513.0800  3.81
cuboid 6    24.429       -0.04545      19.812       4.572
 513.0800  3.81
cuboid 7    24.656       -0.27205      19.812       4.572
 513.0800  3.81
cuboid 8    24.702       -0.3175       19.812       4.572
 513.0800  3.81
hole 13  origin  x=8.4138       y=8.4138       z=16.5600  rotate  a1=0 a2=0 a3=0
media 15 1   1
media  7 1  -1   2  -5  -8
media  7 1  -1   3
media 12 1  -3   4
media  7 1  -4   5
media  7 1  -1   6
media 12 1  -6   7
media  7 1  -7   8
boundary 2

unit 13
com='rod box with tri pitch rod array'
cuboid  1   2P6.5         2P6.75         450.0  -0.0
array 10          1  place 12 12 1 0 0 0
boundary 1
```

Table 6-36E Input Deck for Rod Box Individual Package – 1.5 cm Pitch; 0.35 inch Diameter (cont.)

```
PA_HAC_BORAL_6_3_1.5_7_0.889_in
unit 67
com='solid fuel rod'
cylinder 1 0.4445       448.3862     0
hexprism 2 0.75             450.0       -0.0
media 16  1 1
media 19  2 2 -1
boundary 2
global
unit 55
com='single package unit'
cylinder 1    51.75    574.1972 -40.1498
hole 10  origin  x=0 y=0  z=0  rotate  a1=0 a2=0 a3=0
cuboid   2 4p51.75 574.1972 -40.1498
media  15 1    1
media   0 1  -1 2
boundary 2

unit 66
com='individual package 0-deg rotation'
hexprism 1  31.75    554.1972  -20.1498
hole 10  origin  x=0 y=0  z=0  rotate  a1=0 a2=0 a3=0
media   0 1    1
boundary 1
unit 68
com='individual rod dummy cell'
hexprism 1  0.75         450.0  -0.0
media   19 1    1
boundary 1
unit 77
com='individual package 180-deg rotation'
hexprism 1  31.75    554.1972  -20.1498
hole 10  origin  x=0 y=0  z=0  rotate  a1=0 a2=0 a3=180
media   0 1    1
boundary 1
unit 88
com='dummy cell'
hexprism 1  31.75    554.1972  -20.1498
media  0 1    1
boundary 1

unit 99
com='package array'
cylinder 1  372.0761   554.1972  -20.1498
cylinder 2  392.0761   574.1972  -40.1498
cuboid 3  392.0761  -392.0761  392.0761  -392.0761   574.1972  -40.1498
array 1 1  place 8 8 1 0 0 0
media   0 1  -1   2
media   0 1  -2   3
boundary 3
```

Table 6-36E Input Deck for Rod Box Individual Package – 1.5 cm Pitch; 0.35 inch Diameter (cont.)

```
PA_HAC_BORAL_6_3_1.5_7_0.889_in
end geometry
read array
ara=1 typ=triangular nux=15 nuy=15 nuz=1 gbl=1
fill
88 88 88 88 88 88 88 88 88 88 88 88 88 88 88
  88 88 88 88 88 88 88 88 88 66 66 66 88 88 88
    88 88 88 88 88 88 88 77 77 77 77 77 77 88 88
     88 88 88 88 88 88 66 66 66 66 66 66 66 88 88
       88 88 88 88 88 77 77 77 77 77 77 77 77 88 88
         88 88 88 88 66 66 66 66 66 66 66 66 66 88 88
           88 88 88 77 77 77 77 77 77 77 77 77 77 88 88
             88 88 66 66 66 66 66 66 66 66 66 66 66 88 88
               88 88 77 77 77 77 77 77 77 77 77 77 88 88 88
                 88 88 66 66 66 66 66 66 66 66 66 88 88 88 88
                   88 77 77 77 77 77 77 77 77 77 77 88 88 88 88
                     88 66 66 66 66 66 66 66 66 66 88 88 88 88 88
                       88 88 77 77 77 77 77 77 88 88 88 88 88 88 88
                         88 88 88 88 88 88 88 88 88 88 88 88 88 88 88
                           88 88 88 88 88 88 88 88 88 88 88 88 88 88 88
end fill
ara=10 typ=triangular nux=30 nuy=30 nuz=1
com='rodbox filled'
fill 900*67 end fill
end array
read bnds
+xb=vacuum
-xb=vacuum
+yb=vacuum
-yb=vacuum
+zb=vacuum
-zb=vacuum
end bnds
end data
end
```

Table 6-36F Input Deck for Rod Pipe Package Array – 1.5 cm Pitch; 0.30 inch Diameter

```
PA_HAC_BORAL_6_3_1.5_7_0.889_in
=csas26     parm=size=300000
TRAVELLER XL,ROD TUBE,PA,NPD=0.762       ,PITCH=1.5
44groupndf5  latticecell
 uo2 1 1 293 92235 5 92238 95 end
 h2o 2 1 293 end
 zirc4 3 1 293 end
 h2o 4 1 293 end
 h2o 5 1 293 end
 arbmfoam 0.1602e-20  4  0  0  0 6012 70 1001 10 8016 16 7014 4  6 1 293
 end
 al 7 1 293 end
 ss304 8 1 293 end
 polyethylene 9 DEN=0.828 1.0 293 end
 arbmfoam 0.1602e-20  4  0  0  0 6012 70 1001 10 8016 16 7014 4 11 1 293
 end
 b-10 12 0 0.0047781    end
 b-11 12 0 0.019398     end
 c   12 0 0.0060439    end
 al  12 0 0.043223     end
 arbmrubber 1.59e-20  7  0  0  0 8016 46.94 13000 19.92 14000 17.54 6012
 10.79 1001 4.73 11000 0.06 26000 0.02  14 1 293 end
 h2o 15 1 293 end
 uo2 16 1 293 92235 5 92238 95 end
 h2o 17 1 293 end
 zirc4 18 1 293 end
 h2o 19 1 293 end
end comp
triangpitch 1.5          0.762      16 19 end
more data
res=1  cylinder 0.39218      dan(1)=0.22632       end

read parameter
gen=303
wrs=1
end parameter

read geometry
unit 10
com='individual package'
cuboid 1    16.904       -15.634       16.904       -15.634       533.1330 0
rotate  a1=45 a2=0 a3=0 origin x=0  y=-1.460 z=0
cuboid 2     21.5900   -21.5900     1.5720    -1.0310   533.1330     0
cuboid 3     20.0790   -20.0790    20.0790   -20.0790   533.1330     0
rotate  a1=45 a2=0 a3=0 origin x=0  y=-1.460 z=0
cuboid 4     20.3450   -20.3450    20.3450   -20.3450   533.3990    -0.2660
rotate  a1=45 a2=0 a3=0 origin x=0  y=-1.460 z=0
cuboid 5     21.5900   -21.590     23.1498   -23.1498   533.1330     0
cuboid 6     21.8560   -21.8560    23.4158   -23.4158   533.3990    -0.2660
cuboid 7     20.3840   -20.3840    20.3840   -20.3840   553.8922   -19.8448
rotate  a1=45 a2=0 a3=0 origin x=0  y=-1.460 z=0
```

Table 6-36F Input Deck for Rod Pipe Package Array – 1.5 cm Pitch; 0.30 inch Diameter (cont.)

```
PA_HAC_BORAL_6_3_1.5_7_0.889_in
cuboid 8    21.8950  -21.895    23.4548  -23.4548  553.8922  -19.8448
cylinder  9   25.1050   533.4380   -0.2660
cylinder 10   25.1050   553.9312  -19.8448
cylinder 11   31.4840   533.4380   -0.2660
cylinder 12   31.4840   553.9312  -19.8448
cylinder 13   31.4840   533.4380  -19.8448
cylinder 14   31.7500   554.1972  -20.1100

plane 15  zpl=1  con= -10.0000
cylinder 16 7.62   0 -4.5
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=494.4364
cylinder 17 3.962  0 -7.60
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=494.4364
cylinder 18 7.62   0 -4.5
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=494.4364
cylinder 19 3.962  0 -7.60
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=494.4364
cylinder 20 7.62   0 -4.5
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=448.7164
cylinder 21 3.962  0 -7.60
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=448.7164
cylinder 22 7.62   0 -4.5
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=448.7164
cylinder 23 3.962  0 -7.60
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=448.7164
cylinder 24 7.62   0 -4.5
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=402.9964
cylinder 25 3.962  0 -7.60
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=402.9964
cylinder 26 7.62   0 -4.5
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=402.9964
cylinder 27 3.962  0 -7.60
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=402.9964
cylinder 28 7.62   0 -4.5
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=357.2764
cylinder 29 3.962  0 -7.60
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=357.2764
cylinder 30 7.62   0 -4.5
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=357.2764
cylinder 31 3.962  0 -7.60
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=357.2764
cylinder 54 7.62   0 -4.5
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=265.8364
cylinder 55 3.962  0 -7.60
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=265.8364
cylinder 56 7.62   0 -4.5
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=265.8364
cylinder 57 3.962  0 -7.60
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=265.8364
```

Table 6-36F Input Deck for Rod Pipe Package Array – 1.5 cm Pitch; 0.30 inch Diameter (cont.)

```
PA_HAC_BORAL_6_3_1.5_7_0.889_in
cylinder 32 7.62   0 -4.5
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=174.3964
cylinder 33 3.962  0 -7.60
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=174.3964
cylinder 34 7.62   0 -4.5
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=174.3964
cylinder 35 3.962  0 -7.60
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=174.3964
cylinder 36 7.62   0 -4.5
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=128.6764
cylinder 37 3.962  0 -7.60
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=128.6764
cylinder 38 7.62   0 -4.5
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=128.6764
cylinder 39 3.962  0 -7.60
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=128.6764
cylinder 40 7.62   0 -4.5
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=82.9564
cylinder 41 3.962  0 -7.60
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=82.9564
cylinder 42 7.62   0 -4.5
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=82.9564
cylinder 43 3.962  0 -7.60
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=82.9564
cylinder 44 7.62   0 -4.5
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=37.2364
cylinder 45 3.962  0 -7.60
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=37.2364
cylinder 46 7.62   0 -4.5
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=37.2364
cylinder 47 3.962  0 -7.60
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=37.2364
hole 11 rotate  a1=45 a2=0 a3=0  origin  x=0 y=-17.700 z=5.240
cuboid 48    18.174    20.079   10.4238  -9.5152    533.3990    -0.2660
rotate  a1=-45 a2=0 a3=0 origin x=0  y=-1.460 z=0
cuboid 49    13.6554  -10.4238  16.904    20.079    533.3990    -0.2660
rotate  a1=45 a2=0 a3=0 origin x=0  y=-1.460 z=0
cuboid 50    16.904    20.079   13.6554  -10.4238   533.3990    -0.2660
rotate  a1=45 a2=0 a3=0 origin x=0  y=-1.460 z=0
cuboid 51     9.5152  -10.4238 -18.174   -20.079    533.3990    -0.2660
rotate  a1=-45 a2=0 a3=0 origin x=0  y=-1.460 z=0
cuboid 52    15.634    18.174   12.0238 -11.9197    533.3990    -0.2660
rotate  a1=-45 a2=0 a3=0 origin x=0  y=-1.460 z=0
cuboid 53    11.9197  -12.0238 -15.634   -18.174    533.3990    -0.2660
rotate  a1=-45 a2=0 a3=0 origin x=0  y=-1.460 z=0
media  0 1   1   3  5 -17 -19 -21 -23 -29 -31 -55 -57 -33 -35
-41 -43 -45 -47
media  0 1  -1   3  5 -48 -49 -50 -51 -52 -53
```

Table 6-36F Input Deck for Rod Pipe Package Array – 1.5 cm Pitch; 0.30 inch Diameter (cont.)

```
PA_HAC_BORAL_6_3_1.5_7_0.889_in
media  9 1   3  -16  -17 -20 -21 -28 -29 -54 -55 -32 -33
-40 -41 -44 -45 48
media  9 1   3  -18  -19 -22 -23 -30 -31 -56 -57 -34 -35
-42 -43 -46 -47 51
media  9 1   3  -18  -22  -30  -56  -34  -42  -46  53
media  9 1   3  -16  -20  -28  -54  -32  -40  -44  52
media  9 1   3  49
media  9 1   3  50
media  8 1  -3   4   6
media  8 1   3  -5   6
media  6 1  -4   9
media  6 1   4  -6   9
media  6 1  -9  11
media  6 1  -7  10 -13
media  6 1   7  -8  10 -13  12
media  6 1 -10 -13  12
media 11 1 -11  13
media 11 1   7   8 -13  12
media  8 1 -12  14
media  0 1 16  -17 3 48
media  0 1 18  -19 3 51
media  0 1 20  -21 3 48
media  0 1 22  -23 3 51
media  0 1 28  -29 3 48
media  0 1 30  -31 3 51
media  0 1 54  -55 3 48
media  0 1 56  -57 3 51
media  0 1 32  -33 3 48
media  0 1 34  -35 3 51
media  0 1 40  -41 3 48
media  0 1 42  -43 3 51
media  0 1 44  -45 3 48
media  0 1 46  -47 3 51
media  0 1 16  -17 3 52
media  0 1 18  -19 3 53
media  0 1 20  -21 3 52
media  0 1 22  -23 3 53
media  0 1 28  -29 3 52
media  0 1 30  -31 3 53
media  0 1 54  -55 3 52
media  0 1 56  -57 3 53
media  0 1 32  -33 3 52
media  0 1 34  -35 3 53
media  0 1 40  -41 3 52
media  0 1 42  -43 3 53
media  0 1 44  -45 3 52
media  0 1 46  -47 3 53
media 14 1 17  3
```

Table 6-36F Input Deck for Rod Pipe Package Array – 1.5 cm Pitch; 0.30 inch Diameter (cont.)

```
PA_HAC_BORAL_6_3_1.5_7_0.889_in
media 14 1 19  3
media 14 1 21  3
media 14 1 23  3
media 14 1 29  3
media 14 1 31  3
media 14 1 55  3
media 14 1 57  3
media 14 1 33  3
media 14 1 35  3
media 14 1 41  3
media 14 1 43  3
media 14 1 45  3
media 14 1 47  3
boundary 14

unit 11
com='fuel assembly confinement system'
cuboid 1    24.384      0 24.384      0 520.7000 2.5400
cuboid 2    25.337      -0.9525 25.337       -0.9525
 523.2400  0.0000
cuboid 3    19.812      4.572       24.429      -0.04545
 513.0800  3.81
cuboid 4    19.812      4.572       24.656      -0.27205
 513.0800  3.81
cuboid 5    19.812      4.572       24.702      -0.3175
 513.0800  3.81
cuboid 6    24.429      -0.04545      19.812      4.572
 513.0800  3.81
cuboid 7    24.656      -0.27205      19.812      4.572
 513.0800  3.81
cuboid 8    24.702      -0.3175       19.812      4.572
 513.0800  3.81
hole 13  origin  x=8.4138      y=8.4138      z=16.5600  rotate  a1=0 a2=0 a3=0
media  0 1   1
media  7 1  -1   2  -5  -8
media  7 1  -1   3
media 12 1  -3   4
media  7 1  -4   5
media  7 1  -1   6
media 12 1  -6   7
media  7 1  -7   8
boundary 2

unit 13
com='rod box with tri pitch rod array'
cylinder 1  8.4138         450.0  -0.0
cuboid  2  4p8.4138        450.0  -0.0
array 10          1  place 15 15 1 0 0 0
```

Table 6-36F Input Deck for Rod Pipe Package Array – 1.5 cm Pitch; 0.30 inch Diameter (cont.)

```
PA_HAC_BORAL_6_3_1.5_7_0.889_in
media   0 1  -1  2
boundary 2

unit 67
com='solid fuel rod'
cylinder 1 0.381        448.3862     0
hexprism 2 0.75              450.0       -0.0
media 16  1 1
media 19  2 2 -1
boundary 2
global
unit 55
com='single package unit'
cylinder 1    31.7500    554.1972   -20.1498
hole 10  origin  x=0 y=0  z=0  rotate  a1=0 a2=0 a3=0
cuboid   2 4p31.75 554.1972 -20.1498
media   0 1   1
media   0 1  -1 2
boundary 2

unit 66
com='individual package 0-deg rotation'
hexprism 1  31.75    554.1972  -20.1498
hole 10  origin  x=0 y=0  z=0  rotate  a1=0 a2=0 a3=0
media   0 1   1
boundary 1

unit 68
com='individual rod dummy cell'
hexprism 1  0.75         450.0  -0.0
media   19 1   1
boundary 1

unit 77
com='individual package 180-deg rotation'
hexprism 1  31.75    554.1972  -20.1498
hole 10  origin  x=0 y=0  z=0  rotate  a1=0 a2=0 a3=180
media   0 1   1
boundary 1

unit 88
com='dummy cell'
hexprism 1  31.75    554.1972  -20.1498
media  0 1   1
boundary 1

unit 99
com='package array'
cylinder 1  372.0761   554.1972  -20.1498
```

Table 6-36F Input Deck for Rod Pipe Package Array – 1.5 cm Pitch; 0.30 inch Diameter (cont.)

```
PA_HAC_BORAL_6_3_1.5_7_0.889_in
cylinder 2  392.0761   574.1972  -40.1498
cuboid 3  392.0761  -392.0761  392.0761  -392.0761   574.1972  -40.1498
array 1 1  place 8 8 1 0 0 0
media   0 1  -1   2
media   0 1  -2   3
boundary 3

end geometry

read array
ara=1 typ=triangular nux=15 nuy=15 nuz=1 gbl=1
fill
88 88 88 88 88 88 88 88 88 88 88 88 88 88 88
 88 88 88 88 88 88 88 88 88 66 66 66 88 88 88
  88 88 88 88 88 88 88 77 77 77 77 77 77 88 88
   88 88 88 88 88 88 66 66 66 66 66 66 66 88 88
    88 88 88 88 88 77 77 77 77 77 77 77 77 88 88
     88 88 88 88 66 66 66 66 66 66 66 66 66 88 88
      88 88 88 77 77 77 77 77 77 77 77 77 77 88 88
       88 88 66 66 66 66 66 66 66 66 66 66 66 88 88
        88 88 77 77 77 77 77 77 77 77 77 77 88 88 88
         88 88 66 66 66 66 66 66 66 66 66 88 88 88 88
          88 77 77 77 77 77 77 77 77 77 77 88 88 88 88
           88 66 66 66 66 66 66 66 66 66 88 88 88 88 88
            88 88 77 77 77 77 77 77 88 88 88 88 88 88 88
             88 88 88 88 88 88 88 88 88 88 88 88 88 88 88
              88 88 88 88 88 88 88 88 88 88 88 88 88 88 88
end fill
ara=10 typ=triangular nux=30 nuy=30 nuz=1
com='rodbox filled'
fill 900*67 end fill
end array
read bnds
+xb=mirror
-xb=mirror
+yb=mirror
-yb=mirror
+zb=h2o
-zb=h2o
end bnds
end data
end
```

Table 6-36G Input Deck for Rod Pipe Interspersed Moderation – 60% H2O Density

```
PA_HAC_BORAL_6_3_INTER060_in
=csas26     parm=size=300000
TRAVELLER XL,ROD TUBE,PA,NPD=0.762       ,PITCH=1.5
44groupndf5  latticecell
 uo2 1 1 293 92235 5 92238 95 end
 h2o 2 1 293 end
 zirc4 3 1 293 end
 h2o 4 1 293 end
 h2o 5 1 293 end
 arbmfoam 0.1602e-20  4  0  0  0 6012 70 1001 10 8016 16 7014 4  6 1 293
 end
 al 7 1 293 end
 ss304 8 1 293 end
 polyethylene 9 DEN=0.828 1.0 293 end
 arbmfoam 0.1602e-20  4  0  0  0 6012 70 1001 10 8016 16 7014 4 11 1 293
 end
 b-10 12 0 0.0047781    end
 b-11 12 0 0.019398     end
 c   12 0 0.0060439    end
 al  12 0 0.043223     end
 arbmrubber 1.59  7  0  0  0 8016 46.94 13000 19.92 14000 17.54 6012
 10.79 1001 4.73 11000 0.06 26000 0.02  14 1 293 end
 h2o 15 DEN=0.60 1.0 293 end
 uo2 16 1 293 92235 5 92238 95 end
 h2o 17 1 293 end
 zirc4 18 1 293 end
 h2o 19 1 293 end
end comp
triangpitch 1.5          0.762      16 19 end
more data
res=1  cylinder 0.39218      dan(1)=0.22632       end

read parameter
gen=303
wrs=1
end parameter

read geometry
unit 10
com='individual package'
cuboid 1    16.904       -15.634       16.904       -15.634       533.1330 0
rotate  a1=45 a2=0 a3=0 origin x=0  y=-1.460 z=0
cuboid 2     21.5900   -21.5900     1.5720    -1.0310   533.1330     0
cuboid 3     20.0790   -20.0790    20.0790   -20.0790   533.1330     0
rotate  a1=45 a2=0 a3=0 origin x=0  y=-1.460 z=0
cuboid 4     20.3450   -20.3450    20.3450   -20.3450   533.3990    -0.2660
rotate  a1=45 a2=0 a3=0 origin x=0  y=-1.460 z=0
cuboid 5     21.5900   -21.590     23.1498   -23.1498   533.1330     0
cuboid 6     21.8560   -21.8560    23.4158   -23.4158   533.3990    -0.2660
cuboid 7     20.3840   -20.3840    20.3840   -20.3840   553.8922   -19.8448
rotate  a1=45 a2=0 a3=0 origin x=0  y=-1.460 z=0
```

Table 6-36G Input Deck for Rod Pipe Interspersed Moderation – 60% H2O Density (cont.)
PA_HAC_BORAL_6_3_INTER060_in cuboid 8 21.8950 -21.895 23.4548 -23.4548 553.8922 -19.8448 cylinder 9 25.1050 533.4380 -0.2660 cylinder 10 25.1050 553.9312 -19.8448 cylinder 11 31.4840 533.4380 -0.2660 cylinder 12 31.4840 553.9312 -19.8448 cylinder 13 31.4840 533.4380 -19.8448 cylinder 14 31.7500 554.1972 -20.1100 plane 15 zpl=1 con= -10.0000 cylinder 16 7.62 0 -4.5 rotate a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=494.4364 cylinder 17 3.962 0 -7.60 rotate a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=494.4364 cylinder 18 7.62 0 -4.5 rotate a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=494.4364 cylinder 19 3.962 0 -7.60 rotate a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=494.4364 cylinder 20 7.62 0 -4.5 rotate a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=448.7164 cylinder 21 3.962 0 -7.60 rotate a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=448.7164 cylinder 22 7.62 0 -4.5 rotate a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=448.7164 cylinder 23 3.962 0 -7.60 rotate a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=448.7164 cylinder 24 7.62 0 -4.5 rotate a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=402.9964 cylinder 25 3.962 0 -7.60 rotate a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=402.9964 cylinder 26 7.62 0 -4.5 rotate a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=402.9964 cylinder 27 3.962 0 -7.60 rotate a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=402.9964 cylinder 28 7.62 0 -4.5 rotate a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=357.2764 cylinder 29 3.962 0 -7.60 rotate a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=357.2764 cylinder 30 7.62 0 -4.5 rotate a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=357.2764 cylinder 31 3.962 0 -7.60 rotate a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=357.2764 cylinder 54 7.62 0 -4.5 rotate a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=265.8364 cylinder 55 3.962 0 -7.60 rotate a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=265.8364 cylinder 56 7.62 0 -4.5 rotate a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=265.8364 cylinder 57 3.962 0 -7.60 rotate a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=265.8364

Table 6-36G Input Deck for Rod Pipe Interspersed Moderation – 60% H2O Density (cont.)

```
PA_HAC_BORAL_6_3_INTER060_in
cylinder 32 7.62   0 -4.5
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=174.3964
cylinder 33 3.962  0 -7.60
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=174.3964
cylinder 34 7.62   0 -4.5
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=174.3964
cylinder 35 3.962  0 -7.60
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=174.3964
cylinder 36 7.62   0 -4.5
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=128.6764
cylinder 37 3.962  0 -7.60
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=128.6764
cylinder 38 7.62   0 -4.5
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=128.6764
cylinder 39 3.962  0 -7.60
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=128.6764
cylinder 40 7.62   0 -4.5
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=82.9564
cylinder 41 3.962  0 -7.60
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=82.9564
cylinder 42 7.62   0 -4.5
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=82.9564
cylinder 43 3.962  0 -7.60
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=82.9564
cylinder 44 7.62   0 -4.5
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=37.2364
cylinder 45 3.962  0 -7.60
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=37.2364
cylinder 46 7.62   0 -4.5
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=37.2364
cylinder 47 3.962  0 -7.60
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=37.2364
hole 11 rotate  a1=45 a2=0 a3=0  origin  x=0 y=-17.700 z=5.240
cuboid 48    18.174    20.079   10.4238  -9.5152    533.3990    -0.2660
rotate  a1=-45 a2=0 a3=0 origin x=0  y=-1.460 z=0
cuboid 49    13.6554  -10.4238  16.904    20.079    533.3990    -0.2660
rotate  a1=45 a2=0 a3=0 origin x=0  y=-1.460 z=0
cuboid 50    16.904    20.079   13.6554  -10.4238   533.3990    -0.2660
rotate  a1=45 a2=0 a3=0 origin x=0  y=-1.460 z=0
cuboid 51     9.5152  -10.4238 -18.174   -20.079    533.3990    -0.2660
rotate  a1=-45 a2=0 a3=0 origin x=0  y=-1.460 z=0
cuboid 52    15.634    18.174   12.0238 -11.9197    533.3990    -0.2660
rotate  a1=-45 a2=0 a3=0 origin x=0  y=-1.460 z=0
cuboid 53    11.9197  -12.0238 -15.634   -18.174    533.3990    -0.2660
rotate  a1=-45 a2=0 a3=0 origin x=0  y=-1.460 z=0
media 15 1   1   3  5 -17 -19 -21 -23 -29 -31 -55 -57 -33 -35
-41 -43 -45 -47
media 15 1  -1   3  5 -48 -49 -50 -51 -52 -53
```

Table 6-36G Input Deck for Rod Pipe Interspersed Moderation – 60% H2O Density (cont.)

```
PA_HAC_BORAL_6_3_INTER060_in
media  9 1   3  -16  -17 -20 -21 -28 -29 -54 -55 -32 -33
-40 -41 -44 -45 48
media  9 1   3  -18  -19 -22 -23 -30 -31 -56 -57 -34 -35
-42 -43 -46 -47 51
media  9 1   3  -18  -22  -30  -56  -34  -42  -46  53
media  9 1   3  -16  -20  -28  -54  -32  -40  -44  52
media  9 1   3  49
media  9 1   3  50
media  8 1  -3   4   6
media  8 1   3  -5   6
media 15 1  -4   9
media 15 1   4  -6   9
media 15 1  -9  11
media 15 1  -7  10 -13
media 15 1   7  -8  10 -13  12
media 15 1 -10 -13  12
media 15 1 -11  13
media 15 1   7   8 -13  12
media  8 1 -12  14
media 15 1 16  -17 3 48
media 15 1 18  -19 3 51
media 15 1 20  -21 3 48
media 15 1 22  -23 3 51
media 15 1 28  -29 3 48
media 15 1 30  -31 3 51
media 15 1 54  -55 3 48
media 15 1 56  -57 3 51
media 15 1 32  -33 3 48
media 15 1 34  -35 3 51
media 15 1 40  -41 3 48
media 15 1 42  -43 3 51
media 15 1 44  -45 3 48
media 15 1 46  -47 3 51
media 15 1 16  -17 3 52
media 15 1 18  -19 3 53
media 15 1 20  -21 3 52
media 15 1 22  -23 3 53
media 15 1 28  -29 3 52
media 15 1 30  -31 3 53
media 15 1 54  -55 3 52
media 15 1 56  -57 3 53
media 15 1 32  -33 3 52
media 15 1 34  -35 3 53
media 15 1 40  -41 3 52
media 15 1 42  -43 3 53
media 15 1 44  -45 3 52
media 15 1 46  -47 3 53
media 14 1 17  3
```

Table 6-36G Input Deck for Rod Pipe Interspersed Moderation – 60% H2O Density (cont.)

```
PA_HAC_BORAL_6_3_INTER060_in
media 14 1 19  3
media 14 1 21  3
media 14 1 23  3
media 14 1 29  3
media 14 1 31  3
media 14 1 55  3
media 14 1 57  3
media 14 1 33  3
media 14 1 35  3
media 14 1 41  3
media 14 1 43  3
media 14 1 45  3
media 14 1 47  3
boundary 14

unit 11
com='fuel assembly confinement system'
cuboid 1    24.384       0 24.384       0 520.7000 2.5400
cuboid 2    25.337       -0.9525 25.337        -0.9525
 523.2400  0.0000
cuboid 3    19.812       4.572        24.429       -0.04545
 513.0800  3.81
cuboid 4    19.812       4.572        24.656       -0.27205
 513.0800  3.81
cuboid 5    19.812       4.572        24.702       -0.3175
 513.0800  3.81
cuboid 6    24.429       -0.04545      19.812       4.572
 513.0800  3.81
cuboid 7    24.656       -0.27205      19.812       4.572
 513.0800  3.81
cuboid 8    24.702       -0.3175       19.812       4.572
 513.0800  3.81
hole 13  origin  x=8.4138       y=8.4138       z=16.5600  rotate  a1=0 a2=0 a3=0
media 15 1   1
media  7 1  -1   2  -5  -8
media  7 1  -1   3
media 12 1  -3   4
media  7 1  -4   5
media  7 1  -1   6
media 12 1  -6   7
media  7 1  -7   8
boundary 2
unit 13
com='rod box with tri pitch rod array'
cylinder 1  8.4138          450.0  -0.0
cuboid  2  4p8.4138         450.0  -0.0
array 10           1  place 15 15 1 0 0 0
media  15 1  -1  2
boundary 2
```

Table 6-36G Input Deck for Rod Pipe Interspersed Moderation – 60% H2O Density (cont.)

```
PA_HAC_BORAL_6_3_INTER060_in
unit 67
com='solid fuel rod'
cylinder 1 0.381        448.3862     0
hexprism 2 0.75              450.0       -0.0
media 16  1 1
media 19  2 2 -1
boundary 2
global
unit 55
com='single package unit'
cylinder 1    31.75    554.1972 -20.1498
hole 10  origin  x=0 y=0  z=0  rotate  a1=0 a2=0 a3=0
cuboid   2 4p31.75 554.1972 -20.1498
media  15 1    1
media  15 1  -1 2
boundary 2

unit 66
com='individual package 0-deg rotation'
hexprism 1  31.75    554.1972  -20.1498
hole 10  origin  x=0 y=0  z=0  rotate  a1=0 a2=0 a3=0
media   0 1    1
boundary 1

unit 68
com='individual rod dummy cell'
hexprism 1  0.75         450.0  -0.0
media   19 1    1
boundary 1

unit 77
com='individual package 180-deg rotation'
hexprism 1  31.75    554.1972  -20.1498
hole 10  origin  x=0 y=0  z=0  rotate  a1=0 a2=0 a3=180
media   0 1    1
boundary 1

unit 88
com='dummy cell'
hexprism 1  31.75    554.1972  -20.1498
media  0 1    1
boundary 1

unit 99
com='package array'
cylinder 1  372.0761   554.1972  -20.1498
cylinder 2  392.0761   574.1972  -40.1498
cuboid 3  392.0761  -392.0761  392.0761  -392.0761   574.1972  -40.1498
```

Table 6-36G Input Deck for Rod Pipe Interspersed Moderation – 60% H2O Density (cont.)

```
PA_HAC_BORAL_6_3_INTER060_in
array 1 1  place 8 8 1 0 0 0
media   0 1  -1   2
media   0 1  -2   3
boundary 3

end geometry

read array
ara=1 typ=triangular nux=15 nuy=15 nuz=1 gbl=1
fill

88 88 88 88 88 88 88 88 88 88 88 88 88 88 88
  88 88 88 88 88 88 88 88 88 66 66 66 88 88 88
    88 88 88 88 88 88 88 77 77 77 77 77 77 88 88
     88 88 88 88 88 88 66 66 66 66 66 66 66 88 88
       88 88 88 88 88 77 77 77 77 77 77 77 77 88 88
         88 88 88 88 66 66 66 66 66 66 66 66 66 88 88
           88 88 88 77 77 77 77 77 77 77 77 77 77 88 88
             88 88 66 66 66 66 66 66 66 66 66 66 66 88 88
               88 88 77 77 77 77 77 77 77 77 77 77 88 88 88
                 88 88 66 66 66 66 66 66 66 66 66 88 88 88 88
                   88 77 77 77 77 77 77 77 77 77 77 88 88 88 88
                     88 66 66 66 66 66 66 66 66 66 88 88 88 88 88
                       88 88 77 77 77 77 77 77 88 88 88 88 88 88 88
                         88 88 88 88 88 88 88 88 88 88 88 88 88 88 88
                           88 88 88 88 88 88 88 88 88 88 88 88 88 88 88

end fill


ara=10 typ=triangular nux=30 nuy=30 nuz=1
com='rodbox filled'
fill 900*67 end fill

end array

read bnds
+xb=mirror
-xb=mirror
+yb=mirror
-yb=mirror
+zb=h2o
-zb=h2o
end bnds

end data
end
```

6.10.9 Calculations for Sensitivity Studies

6.10.9.1 Partial Density Interspersed Moderation Data

The data below reports the results of one of the interspersed moderation studies. The Traveller STD package accident condition model was run with different moderation densities. Table 6-37 shows the results for the graph in section 6.7.1.5. Table 6-38 shows a sample input deck.

Table 6-37 Partial Density Interspersed Moderation Results for Traveller XL

Run No.	Interspersed Water Density (g/cc)	ks	σks	ks+2×σks
XL-HAC-ARRAY-100	0.0000	0.9377	0.0008	0.9393
INTER-005	0.0500	0.9203	0.0008	0.9219
INTER-010	0.1000	0.9127	0.0009	0.9145
INTER-030	0.3000	0.8991	0.0009	0.9009
INTER-060	0.6000	0.8998	0.0010	0.9018
INTER-080	0.8000	0.9003	0.0009	0.9021
INTER-100	1.0000	0.9035	0.0010	0.9055

6.10.9.2 Partial Flooding Data

Table 6-37A Results for Partial Flooding Scenario #1

Run #	Level	ks	σks	ks+2×σks
XL-HAC-ARRAY-100	0.0000	0.9377	0.0008	0.9393
PREF-LVL1	2.1657	0.9268	0.0008	0.9284
PREF-LVL2	9.3761	0.9229	0.0008	0.9245
PREF-LVL3	15.6340	0.9220	0.0010	0.9240
PREF-LVL4	21.7746	0.9176	0.0008	0.9192
PREF-LVL5	28.4553	0.9162	0.0010	0.9182
PREF-LVL6	32.5380	0.9158	0.0008	0.9174

Table 6-37B Results for Partial Flooding Scenario #2

Run #	Level	ks	σks	ks+2×σks
PART-LVL1	0.0000	0.3043	0.0006	0.3055
PART-LVL1	2.1657	0.2967	0.0007	0.2981
PART-LVL2	18.8297	0.8010	0.0008	0.8026
PART-LVL3	21.7634	0.8555	0.0010	0.8575
PART-LVL4	24.6971	0.8920	0.0009	0.8938
PART-LVL5	28.4553	0.9204	0.0010	0.9224
PART-LVL6	32.5380	0.9193	0.0009	0.9211

Table 6-37C Input Deck for Partial Flooding Scenario #1

```
=csas26     parm=size=300000
TRAVELLER XL,17WOFA,ENV=24.384      cm,L=100      cm,B10=0.018   g/cm2
44groupndf5  latticecell
 uo2 1 1 293 92235 5 92238 95 end
 h2o 2 1 293 end
 zirc4 3 1 293 end
 h2o 4 1 293 end
 h2o 5 1 293 end
 arbmfoam 0.1602e-20  4  0  0  0 6012 70 1001 10 8016 16 7014 4  6 1 293
 end
 al 7 1 293 end
 ss304 8 1 293 end
 polyethylene 9 DEN=0.828 1.0 293 end
 arbmfoam 0.1602e-20  4  0  0  0 6012 70 1001 10 8016 16 7014 4 11 1 293
 end
 b-10 12 0 0.0047781    end
 b-11 12 0 0.019398     end
 c   12 0 0.0060439    end
 al  12 0 0.043223     end
 arbmrubber 1.59e-20  7  0  0  0 8016 46.94 13000 19.92 14000 17.54 6012
 10.79 1001 4.73 11000 0.06 26000 0.02  14 1 293 end
 h2o 15 1 293 end
 uo2 16 1 293 92235 5 92238 95 end
 h2o 17 1 293 end
 zirc4 18 1 293 end
 h2o 19 1 293 end
end comp
squarepitch 1.4669       0.78435      16 19 0.9144       18 0.8001       17 end
more data
res=1  cylinder 0.39218      dan(1)=0.22632       end

read parameter
gen=450
npg=2500
nsk=50
wrs=1
tme=240
end parameter
```

Table 6-37C Input Deck for Partial Flooding Scenario #1 (cont.)

```
read geometry
unit 10
com='individual package'
cuboid 1    16.904     -15.634     16.904     -15.634     533.1330 0
rotate  a1=45 a2=0 a3=0 origin x=0  y=-1.460 z=0
cuboid 2     21.5900   -21.5900     1.5720    -1.0310   533.1330     0
cuboid 3     20.0790   -20.0790    20.0790   -20.0790   533.1330     0
rotate  a1=45 a2=0 a3=0 origin x=0  y=-1.460 z=0
cuboid 4     20.3450   -20.3450    20.3450   -20.3450   533.3990    -0.2660
rotate  a1=45 a2=0 a3=0 origin x=0  y=-1.460 z=0
cuboid 5     21.5900   -21.590     23.1498   -23.1498   533.1330     0
cuboid 6     21.8560   -21.8560    23.4158   -23.4158   533.3990    -0.2660
cuboid 7     20.3840   -20.3840    20.3840   -20.3840   553.8922   -19.8448
rotate  a1=45 a2=0 a3=0 origin x=0  y=-1.460 z=0
cuboid 8     21.8950   -21.895     23.4548   -23.4548   553.8922   -19.8448
cylinder  9    25.1050    533.4380    -0.2660
cylinder 10    25.1050    553.9312   -19.8448
cylinder 11    31.4840    533.4380    -0.2660
cylinder 12    31.4840    553.9312   -19.8448
cylinder 13    31.4840    533.4380   -19.8448
cylinder 14    31.7500    554.1972   -20.1100
plane 15  xpl=1 ypl=1  con= 0.0
cylinder 16 7.62   0 -4.5
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=494.4364
cylinder 17 3.962  0 -7.60
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=494.4364
cylinder 18 7.62   0 -4.5
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=494.4364
cylinder 19 3.962  0 -7.60
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=494.4364
cylinder 20 7.62   0 -4.5
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=448.7164
cylinder 21 3.962  0 -7.60
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=448.7164
cylinder 22 7.62   0 -4.5
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=448.7164
cylinder 23 3.962  0 -7.60
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=448.7164
cylinder 24 7.62   0 -4.5
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=402.9964
cylinder 25 3.962  0 -7.60
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=402.9964
cylinder 26 7.62   0 -4.5
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=402.9964
cylinder 27 3.962  0 -7.60
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=402.9964
cylinder 28 7.62   0 -4.5
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=357.2764
cylinder 29 3.962  0 -7.60
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=357.2764
cylinder 30 7.62   0 -4.5
```

Table 6-37C Input Deck for Partial Flooding Scenario #1 (cont.)

```
rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=357.2764
cylinder 31 3.962  0 -7.60
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=357.2764
cylinder 54 7.62   0 -4.5
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=265.8364
cylinder 55 3.962  0 -7.60
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=265.8364
cylinder 56 7.62   0 -4.5
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=265.8364
cylinder 57 3.962  0 -7.60
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=265.8364
cylinder 32 7.62   0 -4.5
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=174.3964
cylinder 33 3.962  0 -7.60
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=174.3964
cylinder 34 7.62   0 -4.5
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=174.3964
cylinder 35 3.962  0 -7.60
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=174.3964
cylinder 36 7.62   0 -4.5
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=128.6764
cylinder 37 3.962  0 -7.60
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=128.6764
cylinder 38 7.62   0 -4.5
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=128.6764
cylinder 39 3.962  0 -7.60
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=128.6764
cylinder 40 7.62   0 -4.5
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=82.9564
cylinder 41 3.962  0 -7.60
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=82.9564
cylinder 42 7.62   0 -4.5
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=82.9564
cylinder 43 3.962  0 -7.60
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=82.9564
cylinder 44 7.62   0 -4.5
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=37.2364
cylinder 45 3.962  0 -7.60
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=37.2364
cylinder 46 7.62   0 -4.5
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=37.2364
cylinder 47 3.962  0 -7.60
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=37.2364
hole 11 rotate  a1=45 a2=0 a3=0  origin  x=0 y=-17.700 z=5.240
cuboid 48    18.174    20.079   10.4238  -9.5152    533.3990    -0.2660
rotate  a1=-45 a2=0 a3=0 origin x=0  y=-1.460 z=0
cuboid 49    13.6554  -10.4238  16.904    20.079    533.3990    -0.2660
rotate  a1=45 a2=0 a3=0 origin x=0  y=-1.460 z=0
cuboid 50    16.904    20.079   13.6554  -10.4238   533.3990    -0.2660
rotate  a1=45 a2=0 a3=0 origin x=0  y=-1.460 z=0
cuboid 51     9.5152  -10.4238 -18.174   -20.079    533.3990    -0.2660
```

Table 6-37C Input Deck for Partial Flooding Scenario #1 (cont.)

```
rotate  a1=-45 a2=0 a3=0 origin x=0  y=-1.460 z=0
cuboid 52    15.634    18.174   12.0238 -11.9197    533.3990    -0.2660
rotate  a1=-45 a2=0 a3=0 origin x=0  y=-1.460 z=0
cuboid 53    11.9197  -12.0238 -15.634   -18.174    533.3990    -0.2660
rotate  a1=-45 a2=0 a3=0 origin x=0  y=-1.460 z=0
media  0 1   1  15  3  5 -17 -19 -21 -23 -29 -31 -55 -57 -33 -35
-41 -43 -45 -47
media 15 1   1 -15  3  5 -17 -19 -21 -23 -29 -31 -55 -57 -33 -35
-41 -43 -45 -47
media  0 1  -1   3  5 -48 -49 -50 -51 -52 -53
media  9 1   3  -16  -17 -20 -21 -28 -29 -54 -55 -32 -33
-40 -41 -44 -45 48
media  9 1   3  -18  -19 -22 -23 -30 -31 -56 -57 -34 -35
-42 -43 -46 -47 51
media  9 1   3  -18  -22  -30  -56  -34  -42  -46  53
media  9 1   3  -16  -20  -28  -54  -32  -40  -44  52
media  9 1   3  49
media  9 1   3  50
media  8 1  -3   4   6
media  8 1   3  -5   6
media  6 1  -4   9
media  6 1   4  -6   9
media  6 1  -9  11
media  6 1  -7  10 -13
media  6 1   7  -8  10 -13  12
media  6 1 -10 -13  12
media 11 1 -11  13
media 11 1   7   8 -13  12
media  8 1 -12  14
media  0 1 16  -17 3 48
media  0 1 18  -19 3 51
media  0 1 20  -21 3 48
media  0 1 22  -23 3 51
media  0 1 28  -29 3 48
media  0 1 30  -31 3 51
media  0 1 54  -55 3 48
media  0 1 56  -57 3 51
media  0 1 32  -33 3 48
media  0 1 34  -35 3 51
media  0 1 40  -41 3 48
media  0 1 42  -43 3 51
media  0 1 44  -45 3 48
media  0 1 46  -47 3 51
media  0 1 16  -17 3 52
media 15 1 18  -19 3 53
media  0 1 20  -21 3 52
media 15 1 22  -23 3 53
media  0 1 28  -29 3 52
media 15 1 30  -31 3 53
media  0 1 54  -55 3 52
media 15 1 56  -57 3 53
```

Table 6-37C Input Deck for Partial Flooding Scenario #1 (cont.)

```
media  0 1 32  -33 3 52
media 15 1 34  -35 3 53
media  0 1 40  -41 3 52
media 15 1 42  -43 3 53
media  0 1 44  -45 3 52
media 15 1 46  -47 3 53
media 14 1 17  3
media 15 1 19  3
media 14 1 21  3
media 15 1 23  3
media 14 1 29  3
media 15 1 31  3
media 14 1 55  3
media 15 1 57  3
media 14 1 33  3
media 15 1 35  3
media 14 1 41  3
media 15 1 43  3
media 14 1 45  3
media 15 1 47  3
boundary 14

unit 11
com='fuel assembly confinement system'
cuboid 1    24.384       0 24.384       0 520.7000 2.5400
cuboid 2    25.337       -0.9525 25.337        -0.9525
 523.2400  0.0000
cuboid 3    19.812       4.572        24.429       -0.04545
 513.0800  3.81
cuboid 4    19.812       4.572        24.656       -0.27205
 513.0800  3.81
cuboid 5    19.812       4.572        24.702       -0.3175
 513.0800  3.81
cuboid 6    24.429       -0.04545      19.812       4.572
 513.0800  3.81
cuboid 7    24.656       -0.27205      19.812       4.572
 513.0800  3.81
cuboid 8    24.702       -0.3175       19.812       4.572
 513.0800  3.81
hole 20  origin  x=0  y=0  z=16.56  rotate  a1=0 a2=0 a3=0
media  0 1   1
media  7 1  -1   2  -5  -8
media  7 1  -1   3
media 12 1  -3   4
media  7 1  -4   5
media  7 1  -1   6
media 12 1  -6   7
media  7 1  -7   8
boundary 2
```

Table 6-37C Input Deck for Partial Flooding Scenario #1 (cont.)

```
unit 20
com='fuel assembly'
cuboid 1 21.072       0 21.072       0   0       -14.0208
cuboid 2 24.384       0 24.384       0 504.1392   -14.0208
hole 31 origin  x=0       y=0       z=0.0001   rotate  a1=0  a2=0 a3=0
hole 21 origin  x=0       y=0       z=100.0001 rotate  a1=0  a2=0 a3=0
hole 40 origin  x=0       y=0       z=426.7201 rotate  a1=0  a2=0 a3=0
media  15 1  1
media   0 1 -1   2
boundary 2

unit 21
com='fuel rods - nominal pitch'
cuboid 1  21.072       0 21.072       0 326.72       0.0000
array 2 1 place 1 1 1 0.4572       0.4572       0
boundary 1

unit 22
com='solid fuel rod - nominal pitch'
cylinder 1  0.39218       426.72          0
cylinder 2  0.40005      426.72          0
cylinder 3  0.4572       426.72          0
cuboid 4  4P0.62992       426.72          0
media 1 1  1
media 2 1  2 -1
media 3 1  3 -2 -1
media 4 1  4 -3 -2 -1
boundary 4

unit 23
com='thimble tube - nominal pitch'
cylinder 1  0.56134       426.72         0
cylinder 2  0.60198       426.72         0
cuboid 3    4P0.62992      426.72         0
media 4 1 1
media 3 1 2 -1
media 4 1 3 -2 -1
boundary 3

unit 31
com='fuel rods - expanded pitch'
cuboid 1  24.384       0 24.384       0 100         0
array 3 1 place 1 1 1 0.4572       0.4572       0
boundary 1

unit 32
com='solid fuel rod - expanded pitch'
cylinder 1  0.39218       426.72          0
cylinder 2  0.40005      426.72          0
cylinder 3  0.4572       426.72          0
cuboid 4  4P0.73342       426.72          0
media 16  1 1
```

Table 6-37C Input Deck for Partial Flooding Scenario #1 (cont.)

```
media 17  1 2 -1
media 18  1 3 -2 -1
media 19  1 4 -3 -2 -1
boundary 4

unit 33
com='thimble tube - expanded pitch'
cylinder 1  0.56134      426.72         0
cylinder 2  0.60198      426.72         0
cuboid 3  4P0.73342       426.72          0
media 19 1 1
media 18 1 2 -1
media 19 1 3 -2 -1
boundary 3

unit 40
com='top nozzle assembly'
cuboid 1     21.072       0 21.072      0       21.2090     0.0000
cuboid 2     21.072       0 21.072      0      41.8846     0.0000
cuboid 3     21.072       0 21.072      0       52.8193     0.0000
cuboid 4     21.072       0 21.072      0       77.4192     0.0000
cuboid 5     24.384       0 24.384      0       77.4192     0.0008
media  15 1   1
media  15 1  -1   2
media  15 1  -2   3
media  15 1  -3   4
media  15 1  -4   5
boundary 5

unit 66
com='individual package 0-deg rotation'
hexprism 1  31.75    554.1972  -20.1498
hole 10  origin  x=0 y=0  z=0  rotate  a1=0 a2=0 a3=0
media   0 1   1
boundary 1

unit 77
com='individual package 180-deg rotation'
hexprism 1  31.75    554.1972  -20.1498
hole 10  origin  x=0 y=0  z=0  rotate  a1=0 a2=0 a3=180
media   0 1   1
boundary 1

unit 88
com='dummy cell'
hexprism 1  31.75    554.1972  -20.1498
media  15 1   1
boundary 1

global
unit 99
```

Table 6-37C Input Deck for Partial Flooding Scenario #1 (cont.)

```
com='package array'
cylinder 1  432.2355   554.1972  -20.1498
cylinder 2  452.2355   574.1972  -40.1498
cuboid 3  452.2355  -452.2355  452.2355  -452.2355   574.1972  -40.1498
array 1 1  place 9 9 1 0 0 0
media  15 1  -1   2
media   0 1  -2   3
boundary 3

end geometry

read array
ara=1 typ=triangular nux=17 nuy=17 nuz=1 gbl=1
fill
88 88 88 88 88 88 88 88 88 88 88 88 88 88 88 88 88
  88 88 88 88 88 88 88 88 88 88 77 77 77 88 88 88 88
    88 88 88 88 88 88 88 88 66 66 66 66 66 66 66 88 88
      88 88 88 88 88 88 77 77 77 77 77 77 77 77 77 77 88
        88 88 88 88 88 66 66 66 66 66 66 66 66 66 66 66 88
          88 88 88 88 77 77 77 77 77 77 77 77 77 77 77 77 88
            88 88 88 66 66 66 66 66 66 66 66 66 66 66 66 66 88
              88 88 88 77 77 77 77 77 77 77 77 77 77 77 77 88 88
                88 88 66 66 66 66 66 66 66 66 66 66 66 66 66 88 88
                  88 88 77 77 77 77 77 77 77 77 77 77 77 77 88 88 88
                    88 66 66 66 66 66 66 66 66 66 66 66 66 66 88 88 88
                      88 77 77 77 77 77 77 77 77 77 77 77 77 88 88 88 88
                        88 66 66 66 66 66 66 66 66 66 66 66 88 88 88 88 88
                          88 77 77 77 77 77 77 77 77 77 77 88 88 88 88 88 88
                            88 88 66 66 66 66 66 66 66 88 88 88 88 88 88 88 88
                             88 88 88 77 77 77 77 88 88 88 88 88 88 88 88 88 88
                             88 88 88 88 88 88 88 88 88 88 88 88 88 88 88 88 88
end fill

ara=2 typ=square nux=17 nuy=17 nuz=1
fill 39*22 23 2*22 23 2*22 23 8*22 23 9*22 23 22*22 23 2*22 23 2*22 23
 2*22 23 2*22 23 38*22 23 2*22 23 2*22 23 2*22 23 2*22 23 38*22 23
 2*22 23 2*22 23 2*22 23 2*22 23 22*22 23 9*22 23 8*22 23 2*22 23 2*22
 23 39*22
end fill
ara=3 typ=square nux=17 nuy=17 nuz=1
fill 39*32 33 2*32 33 2*32 33 8*32 33 9*32 33 22*32 33 2*32 33 2*32 33
 2*32 33 2*32 33 38*32 33 2*32 33 2*32 33 2*32 33 2*32 33 38*32 33
 2*32 33 2*32 33 2*32 33 2*32 33 22*32 33 9*32 33 8*32 33 2*32 33 2*32
 33 39*32
end fill

end array

read bnds
+xb=vacuum
-xb=vacuum
```

Table 6-37C Input Deck for Partial Flooding Scenario #1 (cont.)
+yb=vacuum -yb=vacuum +zb=vacuum -zb=vacuum end bnds end data end

Table 6-37D Input Deck for Partial Flooding Scenario #2

```
=csas26     parm=size=300000
TRAVELLER XL,17WOFA,ENV=24.384      cm,L=100      cm,B10=0.018   g/cm2
44groupndf5  latticecell
 uo2 1 1 293 92235 5 92238 95 end
 h2o 2 1 293 end
 zirc4 3 1 293 end
 h2o 4 1 293 end
 h2o 5 1 293 end
 arbmfoam 0.1602e-20  4  0  0  0 6012 70 1001 10 8016 16 7014 4  6 1 293
 end
 al 7 1 293 end
 ss304 8 1 293 end
 polyethylene 9 DEN=0.828 1.0 293 end
 arbmfoam 0.1602e-20  4  0  0  0 6012 70 1001 10 8016 16 7014 4 11 1 293
 end
 b-10 12 0 0.0047781    end
 b-11 12 0 0.019398     end
 c   12 0 0.0060439    end
 al  12 0 0.043223     end
 arbmrubber 1.59e-20  7  0  0  0 8016 46.94 13000 19.92 14000 17.54 6012
 10.79 1001 4.73 11000 0.06 26000 0.02  14 1 293 end
 h2o 15 1 293 end
 uo2 16 1 293 92235 5 92238 95 end
 h2o 17 1 293 end
 zirc4 18 1 293 end
 h2o 19 1 293 end
uo2 20 1 293 92235 5 92238 95 end
 zirc4 21 1 293 end
 uo2 22 1 293 92235 5 92238 95 end
 zirc4 23 1 293 end
end comp
squarepitch 1.4669       0.78435      16 19 0.9144       18 0.8001       17 end
more data
res=1  cylinder 0.39218      dan(1)=0.22632
res=20 cylinder 0.39218      dan(20)=9.6506941E-01
res=22 cylinder 0.39218      dan(22)=9.7027081E-01 end

read parameter
gen=450
npg=2500
nsk=50
wrs=1
tme=240
end parameter
```

Table 6-37D Input Deck for Partial Flooding Scenario #2 (cont.)

```
read geometry
unit 10
com='individual package'
cuboid 1    16.904      -15.634      16.904      -15.634      533.1330 0
rotate  a1=45 a2=0 a3=0 origin x=0  y=-1.460 z=0
cuboid 2     21.5900   -21.5900     1.5720    -1.0310   533.1330     0
cuboid 3     20.0790   -20.0790    20.0790   -20.0790   533.1330     0
rotate  a1=45 a2=0 a3=0 origin x=0  y=-1.460 z=0
cuboid 4     20.3450   -20.3450    20.3450   -20.3450   533.3990    -0.2660
rotate  a1=45 a2=0 a3=0 origin x=0  y=-1.460 z=0
cuboid 5     21.5900   -21.590     23.1498   -23.1498   533.1330     0
cuboid 6     21.8560   -21.8560    23.4158   -23.4158   533.3990    -0.2660
cuboid 7     20.3840   -20.3840    20.3840   -20.3840   553.8922   -19.8448
rotate  a1=45 a2=0 a3=0 origin x=0  y=-1.460 z=0
cuboid 8     21.8950   -21.895     23.4548   -23.4548   553.8922   -19.8448
cylinder  9    25.1050    533.4380    -0.2660
cylinder 10    25.1050    553.9312   -19.8448
cylinder 11    31.4840    533.4380    -0.2660
cylinder 12    31.4840    553.9312   -19.8448
cylinder 13    31.4840    533.4380   -19.8448
cylinder 14    31.7500    554.1972   -20.1100
plane 15  xpl=1 ypl=1  con=-13.02668
cylinder 16 7.62   0 -4.5
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=494.4364
cylinder 17 3.962  0 -7.60
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=494.4364
cylinder 18 7.62   0 -4.5
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=494.4364
cylinder 19 3.962  0 -7.60
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=494.4364
cylinder 20 7.62   0 -4.5
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=448.7164
cylinder 21 3.962  0 -7.60
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=448.7164
cylinder 22 7.62   0 -4.5
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=448.7164
cylinder 23 3.962  0 -7.60
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=448.7164
cylinder 24 7.62   0 -4.5
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=402.9964
cylinder 25 3.962  0 -7.60
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=402.9964
cylinder 26 7.62   0 -4.5
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=402.9964
cylinder 27 3.962  0 -7.60
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=402.9964
cylinder 28 7.62   0 -4.5
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=357.2764
cylinder 29 3.962  0 -7.60
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=357.2764
cylinder 30 7.62   0 -4.5
```

Table 6-37D Input Deck for Partial Flooding Scenario #2 (cont.)

```
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=357.2764
cylinder 31 3.962  0 -7.60
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=357.2764
cylinder 54 7.62   0 -4.5
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=265.8364
cylinder 55 3.962  0 -7.60
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=265.8364
cylinder 56 7.62   0 -4.5
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=265.8364
cylinder 57 3.962  0 -7.60
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=265.8364
cylinder 32 7.62   0 -4.5
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=174.3964
cylinder 33 3.962  0 -7.60
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=174.3964
cylinder 34 7.62   0 -4.5
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=174.3964
cylinder 35 3.962  0 -7.60
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=174.3964
cylinder 36 7.62   0 -4.5
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=128.6764
cylinder 37 3.962  0 -7.60
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=128.6764
cylinder 38 7.62   0 -4.5
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=128.6764
cylinder 39 3.962  0 -7.60
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=128.6764
cylinder 40 7.62   0 -4.5
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=82.9564
cylinder 41 3.962  0 -7.60
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=82.9564
cylinder 42 7.62   0 -4.5
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=82.9564
cylinder 43 3.962  0 -7.60
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=82.9564
cylinder 44 7.62   0 -4.5
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=37.2364
cylinder 45 3.962  0 -7.60
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=37.2364
cylinder 46 7.62   0 -4.5
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=37.2364
cylinder 47 3.962  0 -7.60
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=37.2364
hole 11 rotate  a1=45 a2=0 a3=0  origin  x=0 y=-17.700 z=5.240
cuboid 48    18.174    20.079   10.4238  -9.5152    533.3990    -0.2660
rotate  a1=-45 a2=0 a3=0 origin x=0  y=-1.460 z=0
cuboid 49    13.6554  -10.4238  16.904    20.079    533.3990    -0.2660
rotate  a1=45 a2=0 a3=0 origin x=0  y=-1.460 z=0
cuboid 50    16.904    20.079   13.6554  -10.4238   533.3990    -0.2660
rotate  a1=45 a2=0 a3=0 origin x=0  y=-1.460 z=0
cuboid 51     9.5152  -10.4238 -18.174   -20.079    533.3990    -0.2660
```

Table 6-37D Input Deck for Partial Flooding Scenario #2 (cont.)

```
rotate  a1=-45 a2=0 a3=0 origin x=0  y=-1.460 z=0
cuboid 52    15.634    18.174   12.0238 -11.9197    533.3990    -0.2660
rotate  a1=-45 a2=0 a3=0 origin x=0  y=-1.460 z=0
cuboid 53    11.9197  -12.0238 -15.634   -18.174    533.3990    -0.2660
rotate  a1=-45 a2=0 a3=0 origin x=0  y=-1.460 z=0
media  0 1   1  15  3  5 -17 -19 -21 -23 -29 -31 -55 -57 -33 -35
-41 -43 -45 -47
media 15 1   1 -15  3  5 -17 -19 -21 -23 -29 -31 -55 -57 -33 -35
-41 -43 -45 -47
media  0 1  -1   3  5 -48 -49 -50 -51 -52 -53
media  9 1   3  -16  -17 -20 -21 -28 -29 -54 -55 -32 -33
-40 -41 -44 -45 48
media  9 1   3  -18  -19 -22 -23 -30 -31 -56 -57 -34 -35
-42 -43 -46 -47 51
media  9 1   3  -18  -22  -30  -56  -34  -42  -46  53
media  9 1   3  -16  -20  -28  -54  -32  -40  -44  52
media  9 1   3  49
media  9 1   3  50
media  8 1  -3   4   6
media  8 1   3  -5   6
media  6 1  -4   9
media  6 1   4  -6   9
media  6 1  -9  11
media  6 1  -7  10 -13
media  6 1   7  -8  10 -13  12
media  6 1 -10 -13  12
media 11 1 -11  13
media 11 1   7   8 -13  12
media  8 1 -12  14
media  0 1 16  -17 3 48
media  0 1 18  -19 3 51
media  0 1 20  -21 3 48
media  0 1 22  -23 3 51
media  0 1 28  -29 3 48
media  0 1 30  -31 3 51
media  0 1 54  -55 3 48
media  0 1 56  -57 3 51
media  0 1 32  -33 3 48
media  0 1 34  -35 3 51
media  0 1 40  -41 3 48
media  0 1 42  -43 3 51
media  0 1 44  -45 3 48
media  0 1 46  -47 3 51
media  0 1 16  -17 3 52
media 15 1 18  -19 3 53
media 15 1 20  -21 3 52
media 15 1 22  -23 3 53
media 15 1 28  -29 3 52
media 15 1 30  -31 3 53
media 15 1 54  -55 3 52
media 15 1 56  -57 3 53
```

Table 6-37D Input Deck for Partial Flooding Scenario #2 (cont.)

```
media 15 1 32  -33 3 52
media 15 1 34  -35 3 53
media 15 1 40  -41 3 52
media 15 1 42  -43 3 53
media 15 1 44  -45 3 52
media 15 1 46  -47 3 53
media 15 1 17  3
media 15 1 19  3
media 15 1 21  3
media 15 1 23  3
media 15 1 29  3
media 15 1 31  3
media 15 1 55  3
media 15 1 57  3
media 15 1 33  3
media 15 1 35  3
media 15 1 41  3
media 15 1 43  3
media 15 1 45  3
media 15 1 47  3
boundary 14

unit 11
com='fuel assembly confinement system'
cuboid 1    24.384       0 24.384       0 520.7000 2.5400
cuboid 2    25.337       -0.9525 25.337        -0.9525
 523.2400  0.0000
cuboid 3    19.812       4.572        24.429       -0.04545
 513.0800  3.81
cuboid 4    19.812       4.572        24.656       -0.27205
 513.0800  3.81
cuboid 5    19.812       4.572        24.702       -0.3175
 513.0800  3.81
cuboid 6    24.429       -0.04545      19.812       4.572
 513.0800  3.81
cuboid 7    24.656       -0.27205      19.812       4.572
 513.0800  3.81
cuboid 8    24.702       -0.3175       19.812       4.572
 513.0800  3.81
hole 20  origin  x=0  y=0  z=16.56  rotate  a1=0 a2=0 a3=0
media  0 1   1
media  7 1  -1   2  -5  -8
media  7 1  -1   3
media 12 1  -3   4
media  7 1  -4   5
media  7 1  -1   6
media 12 1  -6   7
media  7 1  -7   8
boundary 2
```

Table 6-37D Input Deck for Partial Flooding Scenario #2 (cont.)

```
unit 20
com='fuel assembly'
cuboid 1 21.072      0 21.072      0   0       -14.0208
cuboid 2 24.384      0 24.384      0   0       -14.0208
cuboid 3 24.384      0 24.384      0 504.1392   -14.0208
cuboid 4 21.072      0 21.072      0 504.1392   100.0002
cuboid 5 24.384      0 24.384      0 504.1392   100.0002
plane  6 xpl=1  con=-21.72638
hole 31 origin  x=0      y=0      z=0.0001   rotate  a1=0  a2=0 a3=0
hole 21 origin  x=0      y=0      z=100.0001 rotate  a1=0  a2=0 a3=0
hole 40 origin  x=0      y=0      z=426.7201 rotate  a1=0  a2=0 a3=0
media  15 1  1
media  15 1 -1   2  -6
media   0 1 -1   2   6
media   0 1  4
media  15 1 -4   5  -6
media   0 1 -4   5   6
media   0 1 -2  -5   3
boundary 3

unit 21
com='fuel rods - nominal pitch'
cuboid 1  21.072      0 21.072      0 326.72      0.0000
array 2 1 place 1 1 1 0.4572      0.4572      0
boundary 1

unit 22
com='solid fuel rod - nominal pitch'
cylinder 1  0.39218      426.72          0
cylinder 2  0.40005      426.72          0
cylinder 3  0.4572       426.72          0
cuboid 4  4P0.62992      426.72          0
media 1 1  1
media 2 1  2 -1
media 3 1  3 -2 -1
media 4 1  4 -3 -2 -1
boundary 4

unit 23
com='thimble tube - nominal pitch'
cylinder 1  0.56134      426.72         0
cylinder 2  0.60198      426.72         0
cuboid 3    4P0.62992     426.72         0
media 4 1 1
media 3 1 2 -1
media 4 1 3 -2 -1
boundary 3

unit 24
com='solid fuel rod - nominal pitch - dry'
cylinder 1  0.39218      426.72          0
cylinder 2  0.40005      426.72          0
```

Table 6-37D Input Deck for Partial Flooding Scenario #2 (cont.)

```
cylinder 3  0.4572       426.72          0
cuboid 4  4P0.62992       426.72          0
media 20 1  1
media 0 1  2 -1
media 21 1  3 -2 -1
media 0 1  4 -3 -2 -1
boundary 4

unit 25
com='thimble tube - nominal pitch - dry'
cylinder 1  0.56134       426.72         0
cylinder 2  0.60198       426.72         0
cuboid 3    4P0.62992      426.72         0
media 0 1 1
media 21 1 2 -1
media 0 1 3 -2 -1
boundary 3

unit 31
com='fuel rods - expanded pitch'
cuboid 1  24.384       0 24.384       0 100         0
array 3 1 place 1 1 1 0.4572       0.4572       0
boundary 1

unit 32
com='solid fuel rod - expanded pitch'
cylinder 1  0.39218       426.72          0
cylinder 2  0.40005      426.72          0
cylinder 3  0.4572       426.72          0
cuboid 4  4P0.73342       426.72          0
media 16  1 1
media 17  1 2 -1
media 18  1 3 -2 -1
media 19  1 4 -3 -2 -1
boundary 4

unit 33
com='thimble tube - expanded pitch'
cylinder 1  0.56134      426.72          0
cylinder 2  0.60198      426.72          0
cuboid 3  4P0.73342       426.72          0
media 19 1 1
media 18 1 2 -1
media 19 1 3 -2 -1
boundary 3

unit 34
com='solid fuel rod - expanded pitch - dry'
cylinder 1  0.39218       426.72          0
cylinder 2  0.40005      426.72          0
cylinder 3  0.4572       426.72          0
```

Table 6-37D Input Deck for Partial Flooding Scenario #2 (cont.)

```
cuboid 4  4P0.73342       426.72          0
media 22  1 1
media  0  1 2 -1
media 23  1 3 -2 -1
media  0  1 4 -3 -2 -1
boundary 4

unit 35
com='thimble tube - expanded pitch - dry'
cylinder 1  0.56134      426.72          0
cylinder 2  0.60198      426.72          0
cuboid 3  4P0.73342       426.72          0
media  0 1 1
media 23 1 2 -1
media  0 1 3 -2 -1
boundary 3

unit 40
com='top nozzle assembly'
cuboid 1     21.072       0 21.072       0        21.2090     0.0000
cuboid 2     21.072       0 21.072       0       41.8846     0.0000
cuboid 3     21.072       0 21.072       0        52.8193     0.0000
cuboid 4     21.072       0 21.072       0        77.4192     0.0000
cuboid 5     24.384       0 24.384       0        77.4192     0.0008
media  15 1   1
media  15 1  -1   2
media  15 1  -2   3
media  15 1  -3   4
media  15 1  -4   5
boundary 5

unit 66
com='individual package 0-deg rotation'
hexprism 1  31.75    554.1972  -20.1498
hole 10  origin  x=0 y=0  z=0  rotate  a1=0 a2=0 a3=0
media   0 1   1
boundary 1

unit 77
com='individual package 180-deg rotation'
hexprism 1  31.75    554.1972  -20.1498
hole 10  origin  x=0 y=0  z=0  rotate  a1=0 a2=0 a3=180
media   0 1   1
boundary 1

unit 88
com='dummy cell'
hexprism 1  31.75    554.1972  -20.1498
media  15 1   1
boundary 1
```

Table 6-37D Input Deck for Partial Flooding Scenario #2 (cont.)

```
global
unit 99
com='package array'
cylinder 1  432.2355   554.1972  -20.1498
cylinder 2  452.2355   574.1972  -40.1498
cuboid 3  452.2355  -452.2355  452.2355  -452.2355   574.1972  -40.1498
array 1 1  place 9 9 1 0 0 0
media  15 1  -1   2
media   0 1  -2   3
boundary 3

end geometry

read array
ara=1 typ=triangular nux=17 nuy=17 nuz=1 gbl=1
fill
88 88 88 88 88 88 88 88 88 88 88 88 88 88 88 88 88
  88 88 88 88 88 88 88 88 88 88 77 77 77 88 88 88 88
    88 88 88 88 88 88 88 88 66 66 66 66 66 66 66 88 88
      88 88 88 88 88 88 77 77 77 77 77 77 77 77 77 77 88
        88 88 88 88 88 66 66 66 66 66 66 66 66 66 66 66 88
          88 88 88 88 77 77 77 77 77 77 77 77 77 77 77 77 88
            88 88 88 66 66 66 66 66 66 66 66 66 66 66 66 66 88
              88 88 88 77 77 77 77 77 77 77 77 77 77 77 77 88 88
                88 88 66 66 66 66 66 66 66 66 66 66 66 66 66 88 88
                  88 88 77 77 77 77 77 77 77 77 77 77 77 77 88 88 88
                    88 66 66 66 66 66 66 66 66 66 66 66 66 66 88 88 88
                      88 77 77 77 77 77 77 77 77 77 77 77 77 88 88 88 88
                        88 66 66 66 66 66 66 66 66 66 66 66 88 88 88 88 88
                          88 77 77 77 77 77 77 77 77 77 77 88 88 88 88 88 88
                            88 88 66 66 66 66 66 66 66 88 88 88 88 88 88 88 88
                              88 88 88 77 77 77 77 88 88 88 88 88 88 88 88 88 88
                              88 88 88 88 88 88 88 88 88 88 88 88 88 88 88 88 88
end fill

ara=2 typ=square nux=17 nuy=17 nuz=1
fill
22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22
22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22
22 22 22 22 22 23 22 22 23 22 22 23 22 22 22 22 22
22 22 22 23 22 22 22 22 22 22 22 22 22 23 22 22 22
22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22
22 22 23 22 22 23 22 22 23 22 22 23 22 22 23 22 22
22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22
22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22
22 22 23 22 22 23 22 22 23 22 22 23 22 22 23 22 22
22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22
22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22
22 22 23 22 22 23 22 22 23 22 22 23 22 22 23 22 22
22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22
22 22 22 23 22 22 22 22 22 22 22 22 22 23 22 22 22
```

Table 6-37D Input Deck for Partial Flooding Scenario #2 (cont.)

```
22 22 22 22 22 23 22 22 23 22 22 23 22 22 22 22 22
22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22
22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22
end fill
ara=3 typ=square nux=17 nuy=17 nuz=1
fill
32 32 32 32 32 32 32 32 32 32 32 32 32 32 32 34 34
32 32 32 32 32 32 32 32 32 32 32 32 32 32 32 34 34
32 32 32 32 32 33 32 32 33 32 32 33 32 32 32 34 34
32 32 32 33 32 32 32 32 32 32 32 32 32 33 32 34 34
32 32 32 32 32 32 32 32 32 32 32 32 32 32 32 34 34
32 32 33 32 32 33 32 32 33 32 32 33 32 32 33 34 34
32 32 32 32 32 32 32 32 32 32 32 32 32 32 32 34 34
32 32 32 32 32 32 32 32 32 32 32 32 32 32 32 34 34
32 32 33 32 32 33 32 32 33 32 32 33 32 32 33 34 34
32 32 32 32 32 32 32 32 32 32 32 32 32 32 32 34 34
32 32 32 32 32 32 32 32 32 32 32 32 32 32 32 34 34
32 32 33 32 32 33 32 32 33 32 32 33 32 32 33 34 34
32 32 32 32 32 32 32 32 32 32 32 32 32 32 32 34 34
32 32 32 33 32 32 32 32 32 32 32 32 32 33 32 34 34
32 32 32 32 32 33 32 32 33 32 32 33 32 32 32 34 34
32 32 32 32 32 32 32 32 32 32 32 32 32 32 32 34 34
32 32 32 32 32 32 32 32 32 32 32 32 32 32 32 34 34
end fill

end array

read bnds
+xb=vacuum
-xb=vacuum
+yb=vacuum
-yb=vacuum
+zb=vacuum
-zb=vacuum
end bnds

end data
end
```

6.10.9.3 Annular Pellet Study Data

Table 6-37E Results for Annular Pellet Study			
Run #	**ks**	**σks**	**σks**
PA-HAC-ANNULAR	0.9274	0.0008	0.9290

Table 6-37F Input Deck for Annular Pellet Study

```
=csas26     parm=size=300000
TRAVELLER XL,17WOFA,ENV=24.384      cm,L=100      cm,B10=0.018   g/cm2
44groupndf5  latticecell
 uo2 1 1 293 92235 5 92238 95 end
 h2o 2 1 293 end
 zirc4 3 1 293 end
 h2o 4 1 293 end
 h2o 5 1 293 end
 arbmfoam 0.1602e-20  4  0  0  0 6012 70 1001 10 8016 16 7014 4  6 1 293
 end
 al 7 1 293 end
 ss304 8 1 293 end
 polyethylene 9 DEN=0.828 1.0 293 end
 arbmfoam 0.1602e-20  4  0  0  0 6012 70 1001 10 8016 16 7014 4 11 1 293
 end
 b-10 12 0 0.0047781    end
 b-11 12 0 0.019398     end
 c   12 0 0.0060439    end
 al  12 0 0.043223     end
 arbmrubber 1.59e-20  7  0  0  0 8016 46.94 13000 19.92 14000 17.54 6012
 10.79 1001 4.73 11000 0.06 26000 0.02  14 1 293 end
 h2o 15 1 293 end
 uo2 16 1 293 92235 5 92238 95 end
 h2o 17 1 293 end
 zirc4 18 1 293 end
 h2o 19 1 293 end
 uo2 20 1 293 92235 5 92238 95 end
 zirc4 21 1 293 end
 uo2 22 1 293 92235 5 92238 95 end
 zirc4 23 1 293 end
end comp
squarepitch 1.4669       0.78435      16 19 0.9144       18 0.8001       17 end
more data
res=1  cylinder 0.39218      dan(1)=0.22632
RES=21 CYLINDER 0.39218 0.19685
DAN(21)=0.28016729
RES=22 CYLINDER 0.4572 0.40005
DAN(22)=0.37575367
RES=23 CYLINDER 0.39218 0.19685
DAN(23)=0.34480012
RES=24 CYLINDER 0.4572 0.40005
DAN(24)=0.43692386 end
```

Table 6-37F Input Deck for Annular Pellet Study (cont.)

```
read parameter
gen=450
npg=2500
nsk=50
wrs=1
end parameter

read geometry
unit 10
com='individual package'
cuboid 1    16.904       -15.634       16.904       -15.634       533.1330 0
rotate  a1=45 a2=0 a3=0 origin x=0  y=-1.460 z=0
cuboid 2     21.5900   -21.5900     1.5720    -1.0310   533.1330     0
cuboid 3     20.0790   -20.0790    20.0790   -20.0790   533.1330     0
rotate  a1=45 a2=0 a3=0 origin x=0  y=-1.460 z=0
cuboid 4     20.3450   -20.3450    20.3450   -20.3450   533.3990    -0.2660
rotate  a1=45 a2=0 a3=0 origin x=0  y=-1.460 z=0
cuboid 5     21.5900   -21.590     23.1498   -23.1498   533.1330     0
cuboid 6     21.8560   -21.8560    23.4158   -23.4158   533.3990    -0.2660
cuboid 7     20.3840   -20.3840    20.3840   -20.3840   553.8922   -19.8448
rotate  a1=45 a2=0 a3=0 origin x=0  y=-1.460 z=0
cuboid 8     21.8950   -21.895     23.4548   -23.4548   553.8922   -19.8448
cylinder  9    25.1050    533.4380    -0.2660
cylinder 10    25.1050    553.9312   -19.8448
cylinder 11    31.4840    533.4380    -0.2660
cylinder 12    31.4840    553.9312   -19.8448
cylinder 13    31.4840    533.4380   -19.8448
cylinder 14    31.7500    554.1972   -20.1100
plane 15  zpl=1  con= -10.0000
cylinder 16 7.62   0 -4.5
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=494.4364
cylinder 17 3.962  0 -7.60
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=494.4364
cylinder 18 7.62   0 -4.5
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=494.4364
cylinder 19 3.962  0 -7.60
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=494.4364
cylinder 20 7.62   0 -4.5
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=448.7164
cylinder 21 3.962  0 -7.60
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=448.7164
cylinder 22 7.62   0 -4.5
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=448.7164
cylinder 23 3.962  0 -7.60
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=448.7164
cylinder 24 7.62   0 -4.5
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=402.9964
cylinder 25 3.962  0 -7.60
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=402.9964
cylinder 26 7.62   0 -4.5
```

Table 6-37F Input Deck for Annular Pellet Study (cont.)

```
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=402.9964
cylinder 27 3.962  0 -7.60
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=402.9964
cylinder 28 7.62   0 -4.5
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=357.2764
cylinder 29 3.962  0 -7.60
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=357.2764
cylinder 30 7.62   0 -4.5
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=357.2764
cylinder 31 3.962  0 -7.60
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=357.2764
cylinder 32 7.62   0 -4.5
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=174.3964
cylinder 33 3.962  0 -7.60
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=174.3964
cylinder 34 7.62   0 -4.5
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=174.3964
cylinder 35 3.962  0 -7.60
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=174.3964
cylinder 36 7.62   0 -4.5
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=128.6764
cylinder 37 3.962  0 -7.60
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=128.6764
cylinder 38 7.62   0 -4.5
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=128.6764
cylinder 39 3.962  0 -7.60
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=128.6764
cylinder 40 7.62   0 -4.5
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=82.9564
cylinder 41 3.962  0 -7.60
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=82.9564
cylinder 42 7.62   0 -4.5
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=82.9564
cylinder 43 3.962  0 -7.60
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=82.9564
cylinder 44 7.62   0 -4.5
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=37.2364
cylinder 45 3.962  0 -7.60
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=37.2364
cylinder 46 7.62   0 -4.5
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=37.2364
cylinder 47 3.962  0 -7.60
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=37.2364
hole 11 rotate  a1=45 a2=0 a3=0  origin  x=0 y=-17.700 z=5.240
media  0 1   2
media  0 1  -2   1   5  -17 -19 -21 -23 -25 -27 -29 -31 -33 -35 -37
-39 -41 -43 -45 -47
media  9 1  -1   3   5  -2 -16 -18 -20 -22 -24 -26 -28 -30 -32 -34 -36
-38 -40 -42 -44 -46 -17 -19 -21 -23 -25 -27 -29 -31 -33 -35 -37
-39 -41 -43 -45 -47
media  8 1  -3   4   6
```

Table 6-37F Input Deck for Annular Pellet Study (cont.)

```
media  8 1   3  -5   6
media  6 1  -4   9
media  6 1   4  -6   9
media  6 1  -9  11
media  6 1  -7  10 -13
media  6 1   7  -8  10 -13  12
media  6 1 -10 -13  12
media 11 1 -11  13
media 11 1   7   8 -13  12
media  8 1  -12 14
media  0 1 16  -17  5  -1  3
media  0 1 18  -19  5  -1  3
media  0 1 20  -21  5  -1  3
media  0 1 22  -23  5  -1  3
media  0 1 24  -25  5  -1  3
media  0 1 26  -27  5  -1  3
media  0 1 28  -29  5  -1  3
media  0 1 30  -31  5  -1  3
media  0 1 32  -33  5  -1  3
media  0 1 34  -35  5  -1  3
media  0 1 36  -37  5  -1  3
media  0 1 38  -39  5  -1  3
media  0 1 40  -41  5  -1  3
media  0 1 42  -43  5  -1  3
media  0 1 44  -45  5  -1  3
media  0 1 46  -47  5  -1  3
media 14 1 17  3
media 14 1 19  3
media 14 1 21  3
media 14 1 23  3
media 14 1 25  3
media 14 1 27  3
media 14 1 29  3
media 14 1 31  3
media 14 1 33  3
media 14 1 35  3
media 14 1 37  3
media 14 1 39  3
media 14 1 41  3
media 14 1 43  3
media 14 1 45  3
media 14 1 47  3
boundary 14

unit 11
com='fuel assembly confinement system'
cuboid 1    24.384       0 24.384       0 520.7000 2.5400
cuboid 2    25.337       -0.9525 25.337        -0.9525
 523.2400  0.0000
cuboid 3    19.812       4.572        24.429       -0.04545
 513.0800  3.81
```

Table 6-37F Input Deck for Annular Pellet Study (cont.)

```
cuboid 4    19.812      4.572       24.656      -0.27205
 513.0800  3.81
cuboid 5    19.812      4.572       24.702      -0.3175
 513.0800  3.81
cuboid 6    24.429      -0.04545     19.812      4.572
 513.0800  3.81
cuboid 7    24.656      -0.27205     19.812      4.572
 513.0800  3.81
cuboid 8    24.702      -0.3175      19.812      4.572
 513.0800  3.81
hole 20  origin  x=0  y=0  z=16.56  rotate  a1=0 a2=0 a3=0
media  0 1   1
media  7 1  -1   2  -5  -8
media  7 1  -1   3
media 12 1  -3   4
media  7 1  -4   5
media  7 1  -1   6
media 12 1  -6   7
media  7 1  -7   8
boundary 2

unit 20
com='fuel assembly'
cuboid 1 21.072      0 21.072      0   0       -14.0208
cuboid 2 24.384      0 24.384      0 504.1392   -14.0208
hole 34 origin  x=0      y=0      z=0.0001   rotate  a1=0  a2=0 a3=0
hole 31 origin  x=0      y=0      z=30.4802  rotate  a1=0  a2=0 a3=0
hole 21 origin  x=0      y=0      z=100.0003 rotate  a1=0  a2=0 a3=0
hole 24 origin  x=0      y=0      z=396.2404 rotate  a1=0  a2=0 a3=0
hole 40 origin  x=0      y=0      z=426.7205 rotate  a1=0  a2=0 a3=0
media  15 1  1
media   0 1 -1   2
boundary 2

unit 21
com='fuel rods - nominal pitch'
cuboid 1  21.072      0 21.072      0 296.28      0.0000
array 2 1 place 1 1 1 0.4572      0.4572      0
boundary 1

unit 22
com='solid fuel rod - nominal pitch'
cylinder 1  0.39218      426.72          0
cylinder 2  0.40005      426.72          0
cylinder 3  0.4572       426.72          0
cuboid 4  4P0.62992      426.72          0
media 1 1  1
media 2 1  2 -1
media 3 1  3 -2 -1
media 4 1  4 -3 -2 -1
boundary 4
```

Table 6-37F Input Deck for Annular Pellet Study (cont.)

```
unit 23
com='thimble tube - nominal pitch'
cylinder 1  0.56134       426.72          0
cylinder 2  0.60198       426.72          0
cuboid 3    4P0.62992      426.72          0
media 4 1 1
media 3 1 2 -1
media 4 1 3 -2 -1
boundary 3

unit 24
com='fuel rods annular - nominal pitch'
cuboid 1  21.072       0 21.072       0 30.48       0.0000
array 4 1 place 1 1 1 0.4572       0.4572       0
boundary 1

UNIT 25
COM='annular fuel rod - nominal pitch'
CYLINDER 1  0.19685 426.72  0
CYLINDER 2  0.39218  426.72  0
CYLINDER 3  0.40005  426.72  0
CYLINDER 4  0.4572  426.72  0
CUBOID 5    4P0.62992 426.72  0
media 2  1 1
media 20 1 2 -1
media 2  1 3 -2 -1
media 21 1 4 -3 -2 -1
media 4  1 5 -4 -3 -2 -1
boundary 5

unit 31
com='fuel rods - expanded pitch'
cuboid 1  24.384       0 24.384       0 69.52          0
array 3 1 place 1 1 1 0.4572       0.4572       0
boundary 1

unit 32
com='solid fuel rod - expanded pitch'
cylinder 1  0.39218       426.72          0
cylinder 2  0.40005       426.72          0
cylinder 3  0.4572       426.72          0
cuboid 4  4P0.73342       426.72          0
media 16  1 1
media 17  1 2 -1
media 18  1 3 -2 -1
media 19  1 4 -3 -2 -1
boundary 4

unit 33
com='thimble tube - expanded pitch'
```

Table 6-37F Input Deck for Annular Pellet Study (cont.)

```
cylinder 1  0.56134     426.72          0
cylinder 2  0.60198     426.72          0
cuboid 3  4P0.73342      426.72          0
media 19 1 1
media 18 1 2 -1
media 19 1 3 -2 -1
boundary 3

unit 34
com='fuel rods annular - expanded pitch'
cuboid 1  24.384       0 24.384       0 30.48          0
array 5 1 place 1 1 1 0.4572       0.4572       0
boundary 1

UNIT 35
COM='annular fuel rod - expanded pitch'
CYLINDER 1  0.19685 426.72  0
CYLINDER 2  0.39218  426.72  0
CYLINDER 3  0.40005  426.72  0
CYLINDER 4  0.4572  426.72  0
CUBOID 5    4P0.73342 426.72  0
media 17  1 1
media 22  1 2 -1
media 17  1 3 -2 -1
media 23  1 4 -3 -2 -1
media 19  1 5 -4 -3 -2 -1
boundary 5

unit 40
com='top nozzle assembly'
cuboid 1     21.072       0 21.072       0        21.2090     0.0000
cuboid 2     21.072       0 21.072       0       41.8846     0.0000
cuboid 3     21.072       0 21.072       0        52.8193     0.0000
cuboid 4     21.072       0 21.072       0        77.4192     0.0000
cuboid 5     24.384       0 24.384       0        77.4192     0.0008
media  15 1   1
media  15 1  -1   2
media  15 1  -2   3
media  15 1  -3   4
media  15 1  -4   5
boundary 5

unit 66
com='individual package 0-deg rotation'
hexprism 1  31.75    554.1972  -20.1498
hole 10  origin  x=0 y=0  z=0  rotate  a1=0 a2=0 a3=0
media   0 1   1
boundary 1

unit 77
com='individual package 180-deg rotation'
```

Table 6-37F Input Deck for Annular Pellet Study (cont.)

```
hexprism 1  31.75    554.1972  -20.1498
hole 10  origin  x=0 y=0  z=0  rotate  a1=0 a2=0 a3=180
media   0 1   1
boundary 1

unit 88
com='dummy cell'
hexprism 1  31.75    554.1972  -20.1498
media  15 1   1
boundary 1

global
unit 99
com='package array'
cylinder 1  432.2355   554.1972  -20.1498
cylinder 2  452.2355   574.1972  -40.1498
cuboid 3  452.2355  -452.2355  452.2355  -452.2355   574.1972  -40.1498
array 1 1  place 9 9 1 0 0 0
media  15 1  -1   2
media   0 1  -2   3
boundary 3

end geometry

read array
ara=1 typ=triangular nux=17 nuy=17 nuz=1 gbl=1
fill
88 88 88 88 88 88 88 88 88 88 88 88 88 88 88 88 88
 88 88 88 88 88 88 88 88 88 88 77 77 77 88 88 88 88
  88 88 88 88 88 88 88 88 66 66 66 66 66 66 66 88 88
   88 88 88 88 88 88 77 77 77 77 77 77 77 77 77 77 88
    88 88 88 88 88 66 66 66 66 66 66 66 66 66 66 66 88
     88 88 88 88 77 77 77 77 77 77 77 77 77 77 77 77 88
      88 88 88 66 66 66 66 66 66 66 66 66 66 66 66 66 88
       88 88 88 77 77 77 77 77 77 77 77 77 77 77 77 88 88
        88 88 66 66 66 66 66 66 66 66 66 66 66 66 66 88 88
         88 88 77 77 77 77 77 77 77 77 77 77 77 77 88 88 88
          88 66 66 66 66 66 66 66 66 66 66 66 66 66 88 88 88
           88 77 77 77 77 77 77 77 77 77 77 77 77 88 88 88 88
            88 66 66 66 66 66 66 66 66 66 66 66 88 88 88 88 88
             88 77 77 77 77 77 77 77 77 77 77 88 88 88 88 88 88
              88 88 66 66 66 66 66 66 66 88 88 88 88 88 88 88 88
               88 88 88 77 77 77 77 88 88 88 88 88 88 88 88 88 88
               88 88 88 88 88 88 88 88 88 88 88 88 88 88 88 88 88

end fill

ara=2 typ=square nux=17 nuy=17 nuz=1
fill 39*22 23 2*22 23 2*22 23 8*22 23 9*22 23 22*22 23 2*22 23 2*22 23
 2*22 23 2*22 23 38*22 23 2*22 23 2*22 23 2*22 23 2*22 23 38*22 23
 2*22 23 2*22 23 2*22 23 2*22 23 22*22 23 9*22 23 8*22 23 2*22 23 2*22
```

Table 6-37F Input Deck for Annular Pellet Study (cont.)

```
23 39*22
end fill
ara=3 typ=square nux=17 nuy=17 nuz=1
fill 39*32 33 2*32 33 2*32 33 8*32 33 9*32 33 22*32 33 2*32 33 2*32 33
 2*32 33 2*32 33 38*32 33 2*32 33 2*32 33 2*32 33 2*32 33 38*32 33
 2*32 33 2*32 33 2*32 33 2*32 33 22*32 33 9*32 33 8*32 33 2*32 33 2*32
 33 39*32
end fill
ara=4 typ=square nux=17 nuy=17 nuz=1
fill 39*25 23 2*25 23 2*25 23 8*25 23 9*25 23 22*25 23 2*25 23 2*25 23
 2*25 23 2*25 23 38*25 23 2*25 23 2*25 23 2*25 23 2*25 23 38*25 23
 2*25 23 2*25 23 2*25 23 2*25 23 22*25 23 9*25 23 8*25 23 2*25 23 2*25
 23 39*25
end fill
ara=5 typ=square nux=17 nuy=17 nuz=1
fill 39*35 33 2*35 33 2*35 33 8*35 33 9*35 33 22*35 33 2*35 33 2*35 33
 2*35 33 2*35 33 38*35 33 2*35 33 2*35 33 2*35 33 2*35 33 38*35 33
 2*35 33 2*35 33 2*35 33 2*35 33 22*35 33 9*35 33 8*35 33 2*35 33 2*35
 33 39*35
end fill

end array

read bnds
+xb=vacuum
-xb=vacuum
+yb=vacuum
-yb=vacuum
+zb=vacuum
-zb=vacuum
end bnds

end data
end
```

6.10.9.4 Axial Displacement Study Data

Table 6-37G Results for Axial Displacement Study

Run #	No. Rods Displaced	ks	σks	ks+2×σks
DISPLACE-0	0	0.9304	0.0008	0.9320
DISPLACE-4	4	0.9311	0.0010	0.9331
DISPLACE-8	8	0.9304	0.0008	0.9320
DISPLACE-12	12	0.9292	0.0008	0.9309
DISPLACE-20	20	0.9259	0.0009	0.9278
DISPLACE-28	28	0.9267	0.0010	0.9286
DISPLACE-56	56	0.9152	0.0009	0.9170
DISPLACE-92	92	0.8915	0.0009	0.8933
DISPLACE-132	132	0.8733	0.0008	0.8749

Table 6-37H Input Deck for Axial Displacement Study

Example of input deck for 92 displaced rods

```
=csas26     parm=size=300000
TRAVELLER XL,17WOFA,ENV=24.384      cm,L=100      cm,B10=0.018   g/cm2
44groupndf5  latticecell
 uo2 1 1 293 92235 5 92238 95 end
 h2o 2 1 293 end
 zirc4 3 1 293 end
 h2o 4 1 293 end
 h2o 5 1 293 end
 arbmfoam 0.1602e-20  4  0  0  0 6012 70 1001 10 8016 16 7014 4  6 1 293
 end
 al 7 1 293 end
 ss304 8 1 293 end
 polyethylene 9 DEN=0.828 1.0 293 end
 arbmfoam 0.1602e-20  4  0  0  0 6012 70 1001 10 8016 16 7014 4 11 1 293
 end
 b-10 12 0 0.0047781    end
 b-11 12 0 0.019398     end
 c   12 0 0.0060439    end
 al  12 0 0.043223     end
 arbmrubber 1.59e-20  7  0  0  0 8016 46.94 13000 19.92 14000 17.54 6012
 10.79 1001 4.73 11000 0.06 26000 0.02  14 1 293 end
 h2o 15 1 293 end
 uo2 16 1 293 92235 5 92238 95 end
 h2o 17 1 293 end
 zirc4 18 1 293 end
 h2o 19 1 293 end
 uo2 20 1 293 92235 5 92238 95 end
 uo2 21 1 293 92235 5 92238 95 end
end comp
squarepitch 1.4669      0.78435     16 19 0.9144      18 0.8001      17 end
more data
res=1  cylinder 0.39218      dan(1)=0.22632
res=20  cylinder 0.39218     dan(20)=0.0212
res=21  cylinder 0.39218     dan(21)=0.04987       end

read parameter   TME=360.   gen=450  npg=2500   nsk=50
wrs=1     run=NO
end parameter
```

Table 6-37H Input Deck for Axial Displacement Study (cont.)

```
read geometry
unit 10
com='individual package'
cuboid 1    16.904       -15.634       16.904       -15.634       533.1330 0
rotate  a1=45 a2=0 a3=0 origin x=0  y=-1.460 z=0
cuboid 2     21.5900   -21.5900     1.5720    -1.0310   533.1330     0
cuboid 3     20.0790   -20.0790    20.0790   -20.0790   533.1330     0
rotate  a1=45 a2=0 a3=0 origin x=0  y=-1.460 z=0
cuboid 4     20.3450   -20.3450    20.3450   -20.3450   533.3990    -0.2660
rotate  a1=45 a2=0 a3=0 origin x=0  y=-1.460 z=0
cuboid 5     21.5900   -21.590     23.1498   -23.1498   533.1330     0
cuboid 6     21.8560   -21.8560    23.4158   -23.4158   533.3990    -0.2660
cuboid 7     20.3840   -20.3840    20.3840   -20.3840   553.8922   -19.8448
rotate  a1=45 a2=0 a3=0 origin x=0  y=-1.460 z=0
cuboid 8     21.8950   -21.895     23.4548   -23.4548   553.8922   -19.8448
cylinder  9    25.1050    533.4380    -0.2660
cylinder 10    25.1050    553.9312   -19.8448
cylinder 11    31.4840    533.4380    -0.2660
cylinder 12    31.4840    553.9312   -19.8448
cylinder 13    31.4840    533.4380   -19.8448
cylinder 14    31.7500    554.1972   -20.1100
plane 15  zpl=1  con= -10.0000
cylinder 16 7.62   0 -4.5
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=494.4364
cylinder 17 3.962  0 -7.60
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=494.4364
cylinder 18 7.62   0 -4.5
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=494.4364
cylinder 19 3.962  0 -7.60
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=494.4364
cylinder 20 7.62   0 -4.5
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=448.7164
cylinder 21 3.962  0 -7.60
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=448.7164
cylinder 22 7.62   0 -4.5
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=448.7164
cylinder 23 3.962  0 -7.60
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=448.7164
cylinder 24 7.62   0 -4.5
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=402.9964
cylinder 25 3.962  0 -7.60
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=402.9964
cylinder 26 7.62   0 -4.5
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=402.9964
cylinder 27 3.962  0 -7.60
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=402.9964
cylinder 28 7.62   0 -4.5
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=357.2764
cylinder 29 3.962  0 -7.60
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=357.2764
cylinder 30 7.62   0 -4.5
```

Table 6-37H Input Deck for Axial Displacement Study (cont.)

```
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=357.2764
cylinder 31 3.962  0 -7.60
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=357.2764
cylinder 32 7.62   0 -4.5
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=174.3964
cylinder 33 3.962  0 -7.60
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=174.3964
cylinder 34 7.62   0 -4.5
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=174.3964
cylinder 35 3.962  0 -7.60
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=174.3964
cylinder 36 7.62   0 -4.5
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=128.6764
cylinder 37 3.962  0 -7.60
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=128.6764
cylinder 38 7.62   0 -4.5
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=128.6764
cylinder 39 3.962  0 -7.60
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=128.6764
cylinder 40 7.62   0 -4.5
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=82.9564
cylinder 41 3.962  0 -7.60
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=82.9564
cylinder 42 7.62   0 -4.5
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=82.9564
cylinder 43 3.962  0 -7.60
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=82.9564
cylinder 44 7.62   0 -4.5
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=37.2364
cylinder 45 3.962  0 -7.60
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=37.2364
cylinder 46 7.62   0 -4.5
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=37.2364
cylinder 47 3.962  0 -7.60
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=37.2364
hole 11 rotate  a1=45 a2=0 a3=0  origin  x=0 y=-17.700 z=5.240
media  0 1   2
media  0 1  -2   1   5  -17 -19 -21 -23 -25 -27 -29 -31 -33 -35 -37
-39 -41 -43 -45 -47
media  9 1  -1   3   5  -2 -16 -18 -20 -22 -24 -26 -28 -30 -32 -34 -36
-38 -40 -42 -44 -46 -17 -19 -21 -23 -25 -27 -29 -31 -33 -35 -37
-39 -41 -43 -45 -47
media  8 1  -3   4   6
media  8 1   3  -5   6
media  6 1  -4   9
media  6 1   4  -6   9
media  6 1  -9  11
media  6 1  -7  10 -13
media  6 1   7  -8  10 -13  12
media  6 1 -10 -13  12
media 11 1 -11  13
```

Table 6-37H Input Deck for Axial Displacement Study (cont.)

```
media 11 1    7    8 -13   12
media  8 1   -12 14
media  0 1 16  -17  5  -1  3
media  0 1 18  -19  5  -1  3
media  0 1 20  -21  5  -1  3
media  0 1 22  -23  5  -1  3
media  0 1 24  -25  5  -1  3
media  0 1 26  -27  5  -1  3
media  0 1 28  -29  5  -1  3
media  0 1 30  -31  5  -1  3
media  0 1 32  -33  5  -1  3
media  0 1 34  -35  5  -1  3
media  0 1 36  -37  5  -1  3
media  0 1 38  -39  5  -1  3
media  0 1 40  -41  5  -1  3
media  0 1 42  -43  5  -1  3
media  0 1 44  -45  5  -1  3
media  0 1 46  -47  5  -1  3
media 14 1 17  3
media 14 1 19  3
media 14 1 21  3
media 14 1 23  3
media 14 1 25  3
media 14 1 27  3
media 14 1 29  3
media 14 1 31  3
media 14 1 33  3
media 14 1 35  3
media 14 1 37  3
media 14 1 39  3
media 14 1 41  3
media 14 1 43  3
media 14 1 45  3
media 14 1 47  3
boundary 14

unit 11
com='fuel assembly confinement system'
cuboid 1    24.384       0 24.384       0 520.7000 2.5400
cuboid 2    25.337       -0.9525 25.337        -0.9525
 523.2400  0.0000
cuboid 3    19.812       4.572        24.429       -0.04545
 513.0800  3.81
cuboid 4    19.812       4.572        24.656       -0.27205
 513.0800  3.81
cuboid 5    19.812       4.572        24.702       -0.3175
 513.0800  3.81
cuboid 6    24.429       -0.04545      19.812       4.572
 513.0800  3.81
cuboid 7    24.656       -0.27205      19.812       4.572
 513.0800  3.81
```

Table 6-37H Input Deck for Axial Displacement Study (cont.)

```
cuboid 8    24.702       -0.3175       19.812       4.572
 513.0800  3.81
hole 20  origin  x=0  y=0  z=16.56  rotate  a1=0 a2=0 a3=0
media  0 1   1
media  7 1  -1   2  -5  -8
media  7 1  -1   3
media 12 1  -3   4
media  7 1  -4   5
media  7 1  -1   6
media 12 1  -6   7
media  7 1  -7   8
boundary 2

unit 20
com='fuel assembly'
cuboid 1 21.072       0 21.072       0   0         -14.0208
cuboid 2 24.384       0 24.384       0 504.1392   -14.0208
hole 31 origin  x=0       y=0       z=0.0001   rotate  a1=0  a2=0 a3=0
hole 21 origin  x=0       y=0       z=100.0001 rotate  a1=0  a2=0 a3=0
media  15 1  1
media   0 1 -1   2
boundary 2

unit 21
com='fuel rods - nominal pitch'
cuboid 1  21.072       0 21.072       0 404.1392       0.0000
array 2 1 place 1 1 1 0.4572       0.4572       0
boundary 1

unit 22
com='solid fuel rod - nominal pitch'
cylinder 1  0.39218       326.72           0
cylinder 2  0.40005      326.72           0
cylinder 3  0.4572       326.72           0
cuboid 4  4P0.62992       326.72          0
cuboid 5  4P0.62992       404.1392        0
media 1 1  1
media 2 1  2 -1
media 3 1  3 -2 -1
media 4 1  4 -3 -2 -1
media 15  1  5  -4 -3 -2 -1
boundary 5

unit 23
com='thimble tube - nominal pitch'
cylinder 1  0.56134       326.72          0
cylinder 2  0.60198        326.72          0
cuboid 3    4P0.62992      326.72          0
cuboid 4    4P0.62992      404.1392        0
media 4 1 1
media 3 1 2 -1
```

Table 6-37H Input Deck for Axial Displacement Study (cont.)

```
media 4 1 3 -2 -1
media 15  1  4  -3 -2 -1
boundary 4

unit 44
com='solid fuel rod - displaced rod at top of clamshell'

cylinder 1  0.39218       326.72          0
cylinder 2  0.39218       404.1392        0
cylinder 3  0.40005       404.1392        0
cylinder 4  0.4572        404.1392        0
cuboid 5  4P0.62992       404.1392        0
media 1 1  1
media 20 1  2 -1
media 2  1  3 -2 -1
media 3 1  4 -3 -2 -1
media 4 1  5 -4 -3 -2 -1
boundary 5

unit 31
com='fuel rods - expanded pitch'
cuboid 1  24.384       0 24.384       0 100          0
array 3 1 place 1 1 1 0.4572       0.4572       0
boundary 1

unit 32
com='solid fuel rod - expanded pitch'
cylinder 1  0.39218       77.4192         0
cylinder 2  0.39218       426.72          0
cylinder 3  0.40005      426.72          0
cylinder 4  0.4572       426.72          0
cuboid 5  4P0.73342       426.72          0
media 21  1 1
media 16  1 2 -1
media 17  1 3 -2 -1
media 18  1 4 -3 -2 -1
media 19  1 5 -4 -3 -2 -1
boundary 5

unit 33
com='thimble tube - expanded pitch'
cylinder 1  0.56134      426.72          0
cylinder 2  0.60198      426.72          0
cuboid 3  4P0.73342       426.72          0
media 19 1 1
media 18 1 2 -1
media 19 1 3 -2 -1
boundary 3

unit 45
com='solid fuel rod - expanded pitch'
```

Table 6-37H Input Deck for Axial Displacement Study (cont.)

```
cylinder 1  0.39218       426.72        77.4192
cylinder 2  0.40005      426.72         77.4192
cylinder 3  0.4572       426.72         77.4192
cuboid 4  4P0.73342       426.72           0
media 16  1 1
media 17  1 2 -1
media 18  1 3 -2 -1
media 19  1 4 -3 -2 -1
boundary 4

unit 66
com='individual package 0-deg rotation'
hexprism 1  31.75    554.1972  -20.1498
hole 10  origin  x=0 y=0  z=0  rotate  a1=0 a2=0 a3=0
media   0 1   1
boundary 1

unit 77
com='individual package 180-deg rotation'
hexprism 1  31.75    554.1972  -20.1498
hole 10  origin  x=0 y=0  z=0  rotate  a1=0 a2=0 a3=180
media   0 1   1
boundary 1

unit 88
com='dummy cell'
hexprism 1  31.75    554.1972  -20.1498
media  15 1   1
boundary 1

global
unit 99
com='package array'
cylinder 1  432.2355   554.1972  -20.1498
cylinder 2  452.2355   574.1972  -40.1498
cuboid 3  452.2355  -452.2355  452.2355  -452.2355   574.1972  -40.1498
array 1 1  place 9 9 1 0 0 0
media  15 1  -1   2
media   0 1  -2   3
boundary 3

end geometry

read array
ara=1 typ=triangular nux=17 nuy=17 nuz=1 gbl=1
fill

88 88 88 88 88 88 88 88 88 88 88 88 88 88 88 88 88
  88 88 88 88 88 88 88 88 88 88 77 77 77 88 88 88 88
    88 88 88 88 88 88 88 88 66 66 66 66 66 66 66 88 88
```

Table 6-37H Input Deck for Axial Displacement Study (cont.)

```
      88 88 88 88 88 88 77 77 77 77 77 77 77 77 77 77 88
        88 88 88 88 88 66 66 66 66 66 66 66 66 66 66 66 88
          88 88 88 88 77 77 77 77 77 77 77 77 77 77 77 77 88
            88 88 88 66 66 66 66 66 66 66 66 66 66 66 66 66 88
              88 88 88 77 77 77 77 77 77 77 77 77 77 77 77 88 88
                88 88 66 66 66 66 66 66 66 66 66 66 66 66 66 88 88
                  88 88 77 77 77 77 77 77 77 77 77 77 77 77 88 88 88
                    88 66 66 66 66 66 66 66 66 66 66 66 66 66 88 88 88
                      88 77 77 77 77 77 77 77 77 77 77 77 77 88 88 88 88
                        88 66 66 66 66 66 66 66 66 66 66 66 88 88 88 88 88
                          88 77 77 77 77 77 77 77 77 77 77 88 88 88 88 88 88
                            88 88 66 66 66 66 66 66 66 88 88 88 88 88 88 88 88
                            88 88 88 77 77 77 77 88 88 88 88 88 88 88 88 88 88
                            88 88 88 88 88 88 88 88 88 88 88 88 88 88 88 88 88
        end fill


ara=2 typ=square nux=17 nuy=17 nuz=1
 fill

 22 22 22 22 22 22 22 22  22  22 22 22 22 22 22 22 22
 22 44 22 44 22 44 22 44  22  44 22 44 22 44 22 44 22
 22 22 44 22 44 23 44 22  23  22 44 23 44 22 44 22 22
 22 44 22 23 22 44 22 44  22  44 22 44 22 23 22 44 22
 22 22 44 22 44 22 44 22  22  22 44 22 44 22 44 22 22
 22 44 23 44 22 23 22 44  23  44 22 23 22 44 23 44 22
 22 22 44 22 44 22 44 22  22  22 44 22 44 22 44 22 22
 22 44 22 44 22 44 22 44  22  44 22 44 22 44 22 44 22

 22 22 23 22 22 23 22 22  23  22 22 23 22 22 23 22 22

 22 44 22 44 22 44 22 44  22  44 22 44 22 44 22 44 22
 22 22 44 22 44 22 44 22  22  22 44 22 44 22 44 22 22
 22 44 23 44 22 23 22 44  23  44 22 23 22 44 23 44 22
 22 22 44 22 44 22 44 22  22  22 44 22 44 22 44 22 22
 22 44 22 23 22 44 22 44  22  44 22 44 22 23 22 44 22
 22 22 44 22 44 23 44 22  23  22 44 23 44 22 44 22 22
 22 44 22 44 22 44 22 44  22  44 22 44 22 44 22 44 22
 22 22 22 22 22 22 22 22  22  22 22 22 22 22 22 22 22
end fill
ara=3 typ=square nux=17 nuy=17 nuz=1
 fill
 32 32 32 32 32 32 32 32  32  32 32 32 32 32 32 32 32
 32 45 32 45 32 45 32 45  32  45 32 45 32 45 32 45 32
 32 32 45 32 45 33 45 32  33  32 45 33 45 32 45 32 32
 32 45 32 33 32 45 32 45  32  45 32 45 32 33 32 45 32
 32 32 45 32 45 32 45 32  32  32 45 32 45 32 45 32 32
 32 45 33 45 32 33 32 45  33  45 32 33 32 45 33 45 32
 32 32 45 32 45 32 45 32  32  32 45 32 45 32 45 32 32
```

Displaced rods location

Table 6-37H Input Deck for Axial Displacement Study (cont.)

```
 32 45 32 45 32 45 32 45  32  45 32 45 32 45 32 45 32

 32 32 33 32 32 33 32 32  33  32 32 33 32 32 33 32 32

 32 45 32 45 32 45 32 45  32  45 32 45 32 45 32 45 32
 32 32 45 32 45 32 45 32  32  32 45 32 45 32 45 32 32
 32 45 33 45 32 33 32 45  33  45 32 33 32 45 33 45 32
 32 32 45 32 45 32 45 32  32  32 45 32 45 32 45 32 32
 32 45 32 33 32 45 32 45  32  45 32 45 32 33 32 45 32
 32 32 45 32 45 33 45 32  33  32 45 33 45 32 45 32 32
 32 45 32 45 32 45 32 45  32  45 32 45 32 45 32 45 32
 32 32 32 32 32 32 32 32  32  32 32 32 32 32 32 32 32
end fill
end array

read bnds
+xb=vacuum
-xb=vacuum
+yb=vacuum
-yb=vacuum
+zb=vacuum
-zb=vacuum
end bnds
READ PLOT
clr=0  150  150  150
    1    0  229  238
    2  255  225  225
    3    0    0  205
    4  238  182  193
    5  255  255  224
    6  238   10    0
    7   90   40   90
    8   10    0    0
    9  255    0  255
   10  127  255    0
   11   50  130   10
   12  238  153  153
   13  255   69    0
   14  190  140  140
   15    0  100  180
   16  214  236  238
   17   25    0  100
  end color
    PIC=MAT
 TTL=' X-Z slice for 92 displaced rods'
    XUL=-17.7    YUL=13.22  ZUL=554.0   <-- Coordinates for Figure 1
    XLR=15.02    YLR=-19.6  ZLR=-20.0
    UAX=0.70711  VAX=-0.70711  WDN=-1.0  NAX=800 NDN=2000  end
 TTL='X-Y slice  for 92  displaced rods at Z=40.'
    XUL=-17.7    YUL=15.6    ZUL=+40.   <-- Coordinates for Figure 2.b
    XLR=+17.7    YLR=-19.6     ZLR=+40.
```

Table 6-37H Input Deck for Axial Displacement Study (cont.)

```
    UAX=1.0     VDN=-1.0  NAX=2000            end
 TTL='X-Y slice  for 92  displaced rods at Z=450.'
    XUL=-17.7    YUL=15.6    ZUL=+450.   <-- Coordinates for Figure 2.a
    XLR=+17.7    YLR=-19.6     ZLR=+450.
    UAX=1.0     VDN=-1.0  NAX=2000
END PLOT
end data
end
```

Table 6-38 Input Deck for Moderator Density Study

```
=csas26     parm=size=300000
TRAVELLER XL,17WOFA,ENV=24.384      cm,L=100      cm,B10=0.018   g/cm2
44groupndf5  latticecell
uo2 1 1 293 92235 5 92238 95 end
h2o 2 1 293 end
zirc4 3 1 293 end
h2o 4 1 293 end
h2o 5 1 293 end
arbmfoam 0.1602e-20  4  0  0  0 6012 70 1001 10 8016 16 7014 4  6 1 293
end
al 7 1 293 end
ss304 8 1 293 end
polyethylene 9 DEN=0.828 1.0 293 end
arbmfoam 0.1602e-20  4  0  0  0 6012 70 1001 10 8016 16 7014 4 11 1 293
end
b-10 12 0 0.0047781    end
b-11 12 0 0.019398     end
c   12 0 0.0060439    end
al  12 0 0.043223     end
arbmrubber 1.59e-20  7  0  0  0 8016 46.94 13000 19.92 14000 17.54 6012
10.79 1001 4.73 11000 0.06 26000 0.02  14 1 293 end
h2o 15 DEN=0.4 1.0 293 end
uo2 16 1 293 92235 5 92238 95 end
h2o 17 1 293 end
zirc4 18 1 293 end
h2o 19 1 293 end
h2o 20 1 293 end
end comp
squarepitch 1.4669       0.78435      16 19 0.9144       18 0.8001       17 end
more data
res=1  cylinder 0.39218      dan(1)=0.22632       end

read parameter
gen=450
npg=2500
nsk=50
wrs=1
tme=240
end parameter
```

Table 6-38 Input Deck for Moderator Density Study (cont.)

```
read geometry
unit 10
com='individual package'
cuboid 1    16.904      -15.634      16.904      -15.634      533.1330 0
rotate  a1=45 a2=0 a3=0 origin x=0  y=-1.460 z=0
cuboid 2     21.5900   -21.5900     1.5720    -1.0310   533.1330     0
cuboid 3     20.0790   -20.0790    20.0790   -20.0790   533.1330     0
rotate  a1=45 a2=0 a3=0 origin x=0  y=-1.460 z=0
cuboid 4     20.3450   -20.3450    20.3450   -20.3450   533.3990    -0.2660
rotate  a1=45 a2=0 a3=0 origin x=0  y=-1.460 z=0
cuboid 5     21.5900   -21.590     23.1498   -23.1498   533.1330     0
cuboid 6     21.8560   -21.8560    23.4158   -23.4158   533.3990    -0.2660
cuboid 7     20.3840   -20.3840    20.3840   -20.3840   553.8922   -19.8448
rotate  a1=45 a2=0 a3=0 origin x=0  y=-1.460 z=0
cuboid 8     21.8950   -21.895     23.4548   -23.4548   553.8922   -19.8448
cylinder  9    25.1050    533.4380    -0.2660
cylinder 10    25.1050    553.9312   -19.8448
cylinder 11    31.4840    533.4380    -0.2660
cylinder 12    31.4840    553.9312   -19.8448
cylinder 13    31.4840    533.4380   -19.8448
cylinder 14    31.7500    554.1972   -20.1100
plane 15  zpl=1  con= -10.0000
cylinder 16 7.62   0 -4.5
rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=494.4364
cylinder 17 3.962  0 -7.60
rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=494.4364
cylinder 18 7.62   0 -4.5
rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=494.4364
cylinder 19 3.962  0 -7.60
rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=494.4364
cylinder 20 7.62   0 -4.5
rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=448.7164
cylinder 21 3.962  0 -7.60
rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=448.7164
cylinder 22 7.62   0 -4.5
rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=448.7164
cylinder 23 3.962  0 -7.60
rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=448.7164
cylinder 24 7.62   0 -4.5
rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=402.9964
cylinder 25 3.962  0 -7.60
rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=402.9964
cylinder 26 7.62   0 -4.5
rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=402.9964
cylinder 27 3.962  0 -7.60
rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=402.9964
cylinder 28 7.62   0 -4.5
rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=357.2764
cylinder 29 3.962  0 -7.60
rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=357.2764
```

Table 6-38 Input Deck for Moderator Density Study (cont.)

```
cylinder 30 7.62   0 -4.5
rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=357.2764
cylinder 31 3.962  0 -7.60
rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=357.2764
cylinder 54 7.62   0 -4.5
rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=265.8364
cylinder 55 3.962  0 -7.60
rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=265.8364
cylinder 56 7.62   0 -4.5
rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=265.8364
cylinder 57 3.962  0 -7.60
rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=265.8364
cylinder 32 7.62   0 -4.5
rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=174.3964
cylinder 33 3.962  0 -7.60
rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=174.3964
cylinder 34 7.62   0 -4.5
rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=174.3964
cylinder 35 3.962  0 -7.60
rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=174.3964
cylinder 36 7.62   0 -4.5
rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=128.6764
cylinder 37 3.962  0 -7.60
rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=128.6764
cylinder 38 7.62   0 -4.5
rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=128.6764
cylinder 39 3.962  0 -7.60
rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=128.6764
cylinder 40 7.62   0 -4.5
rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=82.9564
cylinder 41 3.962  0 -7.60
rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=82.9564
cylinder 42 7.62   0 -4.5
rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=82.9564
cylinder 43 3.962  0 -7.60
rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=82.9564
cylinder 44 7.62   0 -4.5
rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=37.2364
cylinder 45 3.962  0 -7.60
rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=37.2364
cylinder 46 7.62   0 -4.5
rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=37.2364
cylinder 47 3.962  0 -7.60
rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=37.2364
hole 11 rotate  a1=45 a2=0 a3=0  origin  x=0 y=-17.700 z=5.240
cuboid 48    18.174    20.079   10.4238  -9.5152    533.3990    -0.2660
rotate  a1=-45 a2=0 a3=0 origin x=0  y=-1.460 z=0
cuboid 49    13.6554  -10.4238  16.904    20.079    533.3990    -0.2660
rotate  a1=45 a2=0 a3=0 origin x=0  y=-1.460 z=0
cuboid 50    16.904    20.079   13.6554  -10.4238   533.3990    -0.2660
rotate  a1=45 a2=0 a3=0 origin x=0  y=-1.460 z=0
```

Table 6-38 Input Deck for Moderator Density Study (cont.)

```
cuboid 51     9.5152  -10.4238 -18.174   -20.079    533.3990    -0.2660
rotate  a1=-45 a2=0 a3=0 origin x=0  y=-1.460 z=0
cuboid 52    15.634    18.174   12.0238 -11.9197    533.3990    -0.2660
rotate  a1=-45 a2=0 a3=0 origin x=0  y=-1.460 z=0
cuboid 53    11.9197  -12.0238 -15.634   -18.174    533.3990    -0.2660
rotate  a1=-45 a2=0 a3=0 origin x=0  y=-1.460 z=0
media 15 1   1   3  5 -17 -19 -21 -23 -29 -31 -55 -57 -33 -35
-41 -43 -45 -47
media 15 1  -1   3  5 -48 -49 -50 -51 -52 -53
media  9 1   3  -16  -17 -20 -21 -28 -29 -54 -55 -32 -33
-40 -41 -44 -45 48
media  9 1   3  -18  -19 -22 -23 -30 -31 -56 -57 -34 -35
-42 -43 -46 -47 51
media  9 1   3  -18  -22  -30  -56  -34  -42  -46  53
media  9 1   3  -16  -20  -28  -54  -32  -40  -44  52
media  9 1   3  49
media  9 1   3  50
media  8 1  -3   4   6
media  8 1   3  -5   6
media 15 1  -4   9
media 15 1   4  -6   9
media 15 1  -9  11
media 15 1  -7  10 -13
media 15 1   7  -8  10 -13  12
media 15 1 -10 -13  12
media 15 1 -11  13
media 15 1   7   8 -13  12
media  8 1 -12  14
media 15 1 16  -17 3 48
media 15 1 18  -19 3 51
media 15 1 20  -21 3 48
media 15 1 22  -23 3 51
media 15 1 28  -29 3 48
media 15 1 30  -31 3 51
media 15 1 54  -55 3 48
media 15 1 56  -57 3 51
media 15 1 32  -33 3 48
media 15 1 34  -35 3 51
media 15 1 40  -41 3 48
media 15 1 42  -43 3 51
media 15 1 44  -45 3 48
media 15 1 46  -47 3 51
media 15 1 16  -17 3 52
media 15 1 18  -19 3 53
media 15 1 20  -21 3 52
media 15 1 22  -23 3 53
media 15 1 28  -29 3 52
media 15 1 30  -31 3 53
media 15 1 54  -55 3 52
media 15 1 56  -57 3 53
media 15 1 32  -33 3 52
```

Table 6-38 Input Deck for Moderator Density Study (cont.)

```
media 15 1 34  -35 3 53
media 15 1 40  -41 3 52
media 15 1 42  -43 3 53
media 15 1 44  -45 3 52
media 15 1 46  -47 3 53
media 15 1 17  3
media 15 1 19  3
media 15 1 21  3
media 15 1 23  3
media 15 1 29  3
media 15 1 31  3
media 15 1 55  3
media 15 1 57  3
media 15 1 33  3
media 15 1 35  3
media 15 1 41  3
media 15 1 43  3
media 15 1 45  3
media 15 1 47  3
boundary 14

unit 11
com='fuel assembly confinement system'
cuboid 1    24.384       0 24.384       0 520.7000 2.5400
cuboid 2    25.337       -0.9525 25.337        -0.9525
0.0000
cuboid 3    19.812       4.572        24.429       -0.04545
3.81
cuboid 4    19.812       4.572        24.656       -0.27205
3.81
cuboid 5    19.812       4.572        24.702       -0.3175
3.81
cuboid 6    24.429       -0.04545      19.812       4.572
3.81
cuboid 7    24.656       -0.27205      19.812       4.572
3.81
cuboid 8    24.702       -0.3175       19.812       4.572
3.81
hole 20  origin  x=0  y=0  z=16.56  rotate  a1=0 a2=0 a3=0
media 15 1   1
media  7 1  -1   2  -5  -8
media  7 1  -1   3
media 12 1  -3   4
media  7 1  -4   5
media  7 1  -1   6
media 12 1  -6   7
media  7 1  -7   8
boundary 2

unit 20
com='fuel assembly'
```

Table 6-38 Input Deck for Moderator Density Study (cont.)

```
cuboid 1 21.072      0 21.072      0   0       -14.0208
cuboid 2 24.384      0 24.384      0 504.1392   -14.0208
hole 31 origin  x=0      y=0      z=0.0001   rotate  a1=0  a2=0 a3=0
hole 21 origin  x=0      y=0      z=100.0001 rotate  a1=0  a2=0 a3=0
hole 40 origin  x=0      y=0      z=426.7201 rotate  a1=0  a2=0 a3=0
media  15 1  1
media  15 1 -1   2
boundary 2

unit 21
com='fuel rods - nominal pitch'
cuboid 1  21.072      0 21.072      0 326.72      0.0000
array 2 1 place 1 1 1 0.4572      0.4572      0
boundary 1

unit 22
com='solid fuel rod - nominal pitch'
cylinder 1  0.39218      426.72          0
cylinder 2  0.40005      426.72          0
cylinder 3  0.4572       426.72          0
cuboid 4  4P0.62992      426.72          0
media 1 1  1
media 2 1  2 -1
media 3 1  3 -2 -1
media 4 1  4 -3 -2 -1
boundary 4

unit 23
com='thimble tube - nominal pitch'
cylinder 1  0.56134      426.72         0
cylinder 2  0.60198      426.72         0
cuboid 3    4P0.62992    426.72         0
media 4 1 1
media 3 1 2 -1
media 4 1 3 -2 -1
boundary 3

unit 31
com='fuel rods - expanded pitch'
cuboid 1  24.384      0 24.384      0 100         0
array 3 1 place 1 1 1 0.4572      0.4572      0
boundary 1

unit 32
com='solid fuel rod - expanded pitch'
cylinder 1  0.39218      426.72          0
cylinder 2  0.40005      426.72          0
cylinder 3  0.4572       426.72          0
cuboid 4  4P0.73342      426.72          0
media 16  1 1
media 17  1 2 -1
```

Table 6-38 Input Deck for Moderator Density Study (cont.)

```
media 18  1 3 -2 -1
media 19  1 4 -3 -2 -1
boundary 4

unit 33
com='thimble tube - expanded pitch'
cylinder 1  0.56134      426.72          0
cylinder 2  0.60198      426.72          0
cuboid 3  4P0.73342       426.72          0
media 19 1 1
media 18 1 2 -1
media 19 1 3 -2 -1
boundary 3

unit 40
com='top nozzle assembly'
cuboid 1     21.072       0 21.072      0       21.2090     0.0000
cuboid 2     21.072       0 21.072      0      41.8846     0.0000
cuboid 3     21.072       0 21.072      0       52.8193     0.0000
cuboid 4     21.072       0 21.072      0       77.4192     0.0000
cuboid 5     24.384       0 24.384      0       77.4192     0.0008
media  15 1   1
media  15 1  -1   2
media  15 1  -2   3
media  15 1  -3   4
media  15 1  -4   5
boundary 5

unit 66
com='individual package 0-deg rotation'
hexprism 1  31.75    554.1972  -20.1498
hole 10  origin  x=0 y=0  z=0  rotate  a1=0 a2=0 a3=0
media  15 1   1
boundary 1

unit 77
com='individual package 180-deg rotation'
hexprism 1  31.75    554.1972  -20.1498
hole 10  origin  x=0 y=0  z=0  rotate  a1=0 a2=0 a3=180
media  15 1   1
boundary 1

unit 88
com='dummy cell'
hexprism 1  31.75    554.1972  -20.1498
media  20 1   1
boundary 1

global
unit 99
com='package array'
```

Table 6-38 Input Deck for Moderator Density Study (cont.)

```
cylinder 1  432.2355   554.1972  -20.1498
cylinder 2  452.2355   574.1972  -40.1498
cuboid 3  452.2355  -452.2355  452.2355  -452.2355   574.1972  -40.1498
array 1 1  place 9 9 1 0 0 0
media  20 1  -1   2
media   0 1  -2   3
boundary 3

end geometry

read array
ara=1 typ=triangular nux=17 nuy=17 nuz=1 gbl=1
fill

88 88 88 88 88 88 88 88 88 88 88 88 88 88 88 88 88
88 88 88 88 88 88 88 88 88 88 77 77 77 88 88 88 88
88 88 88 88 88 88 88 88 66 66 66 66 66 66 66 88 88
88 88 88 88 88 88 77 77 77 77 77 77 77 77 77 77 88
88 88 88 88 88 66 66 66 66 66 66 66 66 66 66 66 88
88 88 88 88 77 77 77 77 77 77 77 77 77 77 77 77 88
88 88 88 66 66 66 66 66 66 66 66 66 66 66 66 66 88
88 88 88 77 77 77 77 77 77 77 77 77 77 77 77 88 88
88 88 66 66 66 66 66 66 66 66 66 66 66 66 66 88 88
88 88 77 77 77 77 77 77 77 77 77 77 77 77 88 88 88
88 66 66 66 66 66 66 66 66 66 66 66 66 66 88 88 88
88 77 77 77 77 77 77 77 77 77 77 77 77 88 88 88 88
88 66 66 66 66 66 66 66 66 66 66 66 88 88 88 88 88
88 77 77 77 77 77 77 77 77 77 77 88 88 88 88 88 88
88 88 66 66 66 66 66 66 66 88 88 88 88 88 88 88 88
88 88 88 77 77 77 77 88 88 88 88 88 88 88 88 88 88
88 88 88 88 88 88 88 88 88 88 88 88 88 88 88 88 88
end fill

ara=2 typ=square nux=17 nuy=17 nuz=1
fill 39*22 23 2*22 23 2*22 23 8*22 23 9*22 23 22*22 23 2*22 23 2*22 23
2*22 23 2*22 23 38*22 23 2*22 23 2*22 23 2*22 23 2*22 23 38*22 23
2*22 23 2*22 23 2*22 23 2*22 23 22*22 23 9*22 23 8*22 23 2*22 23 2*22
23 39*22
end fill
ara=3 typ=square nux=17 nuy=17 nuz=1
fill 39*32 33 2*32 33 2*32 33 8*32 33 9*32 33 22*32 33 2*32 33 2*32 33
2*32 33 2*32 33 38*32 33 2*32 33 2*32 33 2*32 33 2*32 33 38*32 33
2*32 33 2*32 33 2*32 33 2*32 33 22*32 33 9*32 33 8*32 33 2*32 33 2*32
33 39*32
end fill

end array

read bnds
+xb=vacuum
-xb=vacuum
```

Table 6-38 Input Deck for Moderator Density Study (cont.)

```
+yb=vacuum
-yb=vacuum
+zb=vacuum
-zb=vacuum
end bnds

end data
end
```

6.10.9.5 Boron Content Sensitivity Study

The Traveller XL was evaluated for sensitivity to varying the boron content in the absorber. Table 6-39 below gives the output data that was used to derive the curve in Section 6.7.8.

Table 6-39 Results of Boron Sensitivity Study

Run #	^{10}B Areal Density (g/cm^2)	ks	σks	ks+2×σks
B10--0050	0.0050	0.9682	0.0008	0.9698
B10-0100	0.0100	0.9478	0.0010	0.9498
B10-0162	0.0160	0.9389	0.0009	0.9405
B10-0180	0.0180	0.9377	0.0008	0.9393
B10-0240	0.0240	0.9329	0.0009	0.9347
B10-0300	0.0300	0.9295	0.0009	0.9313
B10-0350	0.0350	0.9284	0.0009	0.9302

Table 6-39A Number Densities for Boron Sensitivity Study

Run #	^{10}B Areal Density (g/cm^2)	B-10	B-11	C	Al
B10-0050	0.0050	0.0013272	0.0053882	0.0016789	0.05203
B10-0100	0.0100	0.002655	0.010776	0.003358	0.048643
B10-0162	0.0160	0.0043003	0.017458	0.0054396	0.044443
B10-0180	0.0180	0.0047781	0.019398	0.0060439	0.043223
B10-0240	0.0240	0.0063708	0.025864	0.0080586	0.039158
B10-0300	0.0300	0.0079635	0.032329	0.010073	0.035094
B10-0350	0.0350	0.0092907	0.037718	0.011752	0.031706

Table 6-39B Results of Polyethylene Sensitivity Study				
Run #	**Density (g/cc)**	**ks**	**σks**	**ks+2×σks**
POLY-069	0.690	0.9465	0.0008	0.9481
POLY-090	0.828	0.9377	0.0008	0.9393
POLY-100	0.920	0.9306	0.0009	0.9324

Table 6-39C Results of Stainless Steel Sensitivity Study				
Run #	**Thickness (cm)**	**ks**	**σks**	**ks+2×σks**
SS-MINUS	0.2490	0.9372	0.0009	0.9390
XL-HAC-ARRAY-100	0.2660	0.9377	0.0008	0.9393
SS-PLUS	0.2900	0.9368	0.0009	0.9386

Table 6-39D Results of Array Study				
Run #	**Array Size**	**ks**	**σks**	**ks+2×σks**
XL-HAC-ARR1-100	1	0.8738	0.0008	0.8754
XL-HAC-ARR7-100	7	0.9040	0.0009	0.9058
XL-HAC-ARR19-100	19	0.9187	0.0009	0.9205
XL-HAC-ARR37-100	37	0.9303	0.0009	0.9321
XL-HAC-ARR61-100	61	0.9307	0.0013	0.9327
XL-HAC-ARR91-100	91	0.9354	0.0009	0.9372
XL-HAC-ARR127-100	127	0.9362	0.0009	0.9380
XL-HAC-ARRAY-100	150	0.9377	0.0008	0.9393

Table 6-39E Results of Outerpack Diameter Study				
Run #	**Outerpack Diameter (inch)**	**ks**	**σks**	**ks+2×σks**
XL-HAC-ARRD24-100	24	0.9387	0.0009	0.9405
XL-HAC-ARRAY-100	25	0.9377	0.0008	0.9393
XL-HAC-ARRD26-100	26	0.9357	0.0008	0.9373

Table 6-39F Input Deck for Clamshell Up-Rotated Configuration

```
=csas26     parm=size=300000
TRAVELLER XL,17WOFA,ENV=24.384      cm,L=100      cm,B10=0.018   g/cm2
44groupndf5  latticecell
 uo2 1 1 293 92235 5 92238 95 end
 h2o 2 1 293 end
 zirc4 3 1 293 end
 h2o 4 1 293 end
 h2o 5 1 293 end
 arbmfoam 0.1602e-20  4  0  0  0 6012 70 1001 10 8016 16 7014 4  6 1 293
 end
 al 7 1 293 end
 ss304 8 1 293 end
 polyethylene 9 DEN=0.828 1.0 293 end
 arbmfoam 0.1602e-20  4  0  0  0 6012 70 1001 10 8016 16 7014 4 11 1 293
 end
 b-10 12 0 0.0047781    end
 b-11 12 0 0.019398     end
 c   12 0 0.0060439    end
 al  12 0 0.043223     end
 arbmrubber 1.59e-20  7  0  0  0 8016 46.94 13000 19.92 14000 17.54 6012
 10.79 1001 4.73 11000 0.06 26000 0.02  14 1 293 end
 h2o 15 1 293 end
 uo2 16 1 293 92235 5 92238 95 end
 h2o 17 1 293 end
 zirc4 18 1 293 end
 h2o 19 1 293 end
end comp
squarepitch 1.4669       0.78435      16 19 0.9144       18 0.8001       17 end
more data
res=1  cylinder 0.39218      dan(1)=0.22632       end

read parameter
gen=450
npg=2500
nsk=50  rnd=3BA304463B68
wrs=1
tme=240
end parameter

read geometry
unit 10
com='individual package'
cuboid 1    16.904       -15.634       16.904       -15.634       533.1330 0
rotate  a1=45 a2=0 a3=0 origin x=0  y=-1.460 z=0
cuboid 2     21.5900   -21.5900     1.5720    -1.0310   533.1330     0
cuboid 3     20.0790   -20.0790    20.0790   -20.0790   533.1330     0
rotate  a1=45 a2=0 a3=0 origin x=0  y=-1.460 z=0
cuboid 4     20.3450   -20.3450    20.3450   -20.3450   533.3990    -0.2660
rotate  a1=45 a2=0 a3=0 origin x=0  y=-1.460 z=0
```

Table 6-39F Input Deck for Clamshell Up-Rotated Configuration (cont.)

```
cuboid 5    21.5900   -21.590    23.1498   -23.1498   533.1330    0
cuboid 6    21.8560   -21.8560   23.4158   -23.4158   533.3990   -0.2660
cuboid 7    20.3840   -20.3840   20.3840   -20.3840   553.8922   -19.8448
rotate  a1=45 a2=0 a3=0 origin x=0  y=-1.460 z=0
cuboid 8    21.8950   -21.895    23.4548   -23.4548   553.8922   -19.8448
cylinder  9    25.1050    533.4380    -0.2660
cylinder 10    25.1050    553.9312   -19.8448
cylinder 11    31.4840    533.4380    -0.2660
cylinder 12    31.4840    553.9312   -19.8448
cylinder 13    31.4840    533.4380   -19.8448
cylinder 14    31.7500    554.1972   -20.1100
plane 15  zpl=1  con= -10.0000
cylinder 16 7.62   0 -4.5
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=494.4364
cylinder 17 3.962  0 -7.60
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=494.4364
cylinder 18 7.62   0 -4.5
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=494.4364
cylinder 19 3.962  0 -7.60
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=494.4364
cylinder 20 7.62   0 -4.5
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=448.7164
cylinder 21 3.962  0 -7.60
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=448.7164
cylinder 22 7.62   0 -4.5
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=448.7164
cylinder 23 3.962  0 -7.60
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=448.7164
cylinder 24 7.62   0 -4.5
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=402.9964
cylinder 25 3.962  0 -7.60
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=402.9964
cylinder 26 7.62   0 -4.5
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=402.9964
cylinder 27 3.962  0 -7.60
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=402.9964
cylinder 28 7.62   0 -4.5
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=357.2764
cylinder 29 3.962  0 -7.60
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=357.2764
cylinder 30 7.62   0 -4.5
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=357.2764
cylinder 31 3.962  0 -7.60
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=357.2764
cylinder 54 7.62   0 -4.5
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=265.8364
cylinder 55 3.962  0 -7.60
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=265.8364
```

Table 6-39F Input Deck for Clamshell Up-Rotated Configuration (cont.)

```
cylinder 56 7.62   0 -4.5
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=265.8364
cylinder 57 3.962  0 -7.60
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=265.8364
cylinder 32 7.62   0 -4.5
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=174.3964
cylinder 33 3.962  0 -7.60
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=174.3964
cylinder 34 7.62   0 -4.5
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=174.3964
cylinder 35 3.962  0 -7.60
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=174.3964
cylinder 36 7.62   0 -4.5
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=128.6764
cylinder 37 3.962  0 -7.60
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=128.6764
cylinder 38 7.62   0 -4.5
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=128.6764
cylinder 39 3.962  0 -7.60
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=128.6764
cylinder 40 7.62   0 -4.5
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=82.9564
cylinder 41 3.962  0 -7.60
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=82.9564
cylinder 42 7.62   0 -4.5
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=82.9564
cylinder 43 3.962  0 -7.60
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=82.9564
cylinder 44 7.62   0 -4.5
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=37.2364
cylinder 45 3.962  0 -7.60
 rotate  a1=45 a2=90 a3=0 origin x=18.7310 y=-11.1270 z=37.2364
cylinder 46 7.62   0 -4.5
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=37.2364
cylinder 47 3.962  0 -7.60
 rotate  a1=-45 a2=90 a3=0 origin x=-18.7310 y=-11.1270 z=37.2364
hole 11 rotate  a1=225 a2=0 a3=0  origin  x=0 y=21.01625 z=5.240
cuboid 48    18.174    20.079   10.4238  -9.5152    533.3990    -0.2660
rotate  a1=-45 a2=0 a3=0 origin x=0  y=-1.460 z=0
cuboid 49    13.6554  -10.4238  16.904    20.079    533.3990    -0.2660
rotate  a1=45 a2=0 a3=0 origin x=0  y=-1.460 z=0
cuboid 50    16.904    20.079   13.6554  -10.4238   533.3990    -0.2660
rotate  a1=45 a2=0 a3=0 origin x=0  y=-1.460 z=0
cuboid 51     9.5152  -10.4238 -18.174   -20.079    533.3990    -0.2660
rotate  a1=-45 a2=0 a3=0 origin x=0  y=-1.460 z=0
cuboid 52    15.634    18.174   12.0238 -11.9197    533.3990    -0.2660
rotate  a1=-45 a2=0 a3=0 origin x=0  y=-1.460 z=0
cuboid 53    11.9197  -12.0238 -15.634   -18.174    533.3990    -0.2660
rotate  a1=-45 a2=0 a3=0 origin x=0  y=-1.460 z=0
```

Table 6-39F Input Deck for Clamshell Up-Rotated Configuration (cont.)

```
media  0 1   1   3  5 -17 -19 -21 -23 -29 -31 -55 -57 -33 -35
-41 -43 -45 -47
media  0 1  -1   3  5 -48 -49 -50 -51 -52 -53
media  9 1   3  -16  -17 -20 -21 -28 -29 -54 -55 -32 -33
-40 -41 -44 -45 48
media  9 1   3  -18  -19 -22 -23 -30 -31 -56 -57 -34 -35
-42 -43 -46 -47 51
media  9 1   3  -18  -22  -30  -56  -34  -42  -46  53
media  9 1   3  -16  -20  -28  -54  -32  -40  -44  52
media  9 1   3  49
media  9 1   3  50
media  8 1  -3   4   6
media  8 1   3  -5   6
media  6 1  -4   9
media  6 1   4  -6   9
media  6 1  -9  11
media  6 1  -7  10 -13
media  6 1   7  -8  10 -13  12
media  6 1 -10 -13  12
media 11 1 -11  13
media 11 1   7   8 -13  12
media  8 1 -12  14
media  0 1 16  -17 3 48
media  0 1 18  -19 3 51
media  0 1 20  -21 3 48
media  0 1 22  -23 3 51
media  0 1 28  -29 3 48
media  0 1 30  -31 3 51
media  0 1 54  -55 3 48
media  0 1 56  -57 3 51
media  0 1 32  -33 3 48
media  0 1 34  -35 3 51
media  0 1 40  -41 3 48
media  0 1 42  -43 3 51
media  0 1 44  -45 3 48
media  0 1 46  -47 3 51
media  0 1 16  -17 3 52
media  0 1 18  -19 3 53
media  0 1 20  -21 3 52
media  0 1 22  -23 3 53
media  0 1 28  -29 3 52
media  0 1 30  -31 3 53
media  0 1 54  -55 3 52
media  0 1 56  -57 3 53
media  0 1 32  -33 3 52
media  0 1 34  -35 3 53
media  0 1 40  -41 3 52
media  0 1 42  -43 3 53
```

Table 6-39F Input Deck for Clamshell Up-Rotated Configuration (cont.)

```
media  0 1 44  -45 3 52
media  0 1 46  -47 3 53
media 14 1 17  3
media 14 1 19  3
media 14 1 21  3
media 14 1 23  3
media 14 1 29  3
media 14 1 31  3
media 14 1 55  3
media 14 1 57  3
media 14 1 33  3
media 14 1 35  3
media 14 1 41  3
media 14 1 43  3
media 14 1 45  3
media 14 1 47  3
boundary 14

unit 11
com='fuel assembly confinement system'
cuboid 1    24.384       0 24.384       0 520.7000 2.5400
cuboid 2    25.337       -0.9525 25.337        -0.9525
 523.2400  0.0000
cuboid 3    19.812       4.572        24.429       -0.04545
 513.0800  3.81
cuboid 4    19.812       4.572        24.656       -0.27205
 513.0800  3.81
cuboid 5    19.812       4.572        24.702       -0.3175
 513.0800  3.81
cuboid 6    24.429       -0.04545      19.812       4.572
 513.0800  3.81
cuboid 7    24.656       -0.27205      19.812       4.572
 513.0800  3.81
cuboid 8    24.702       -0.3175       19.812       4.572
 513.0800  3.81
hole 20  origin  x=0  y=0  z=16.56  rotate  a1=0 a2=0 a3=0
media  0 1   1
media  7 1  -1   2  -5  -8
media  7 1  -1   3
media 12 1  -3   4
media  7 1  -4   5
media  7 1  -1   6
media 12 1  -6   7
media  7 1  -7   8
boundary 2

unit 20
com='fuel assembly'
cuboid 1 21.072       0 21.072       0   0        -14.0208
```

Table 6-39F Input Deck for Clamshell Up-Rotated Configuration (cont.)

```
cuboid 2 24.384       0 24.384       0 504.1392   -14.0208
hole 31 origin  x=0       y=0       z=0.0001   rotate  a1=0  a2=0 a3=0
hole 21 origin  x=0       y=0       z=100.0001 rotate  a1=0  a2=0 a3=0
hole 40 origin  x=0       y=0       z=426.7201 rotate  a1=0  a2=0 a3=0
media  15 1  1
media   0 1 -1   2
boundary 2

unit 21
com='fuel rods - nominal pitch'
cuboid 1  21.072       0 21.072       0 326.72       0.0000
array 2 1 place 1 1 1 0.4572       0.4572       0
boundary 1

unit 22
com='solid fuel rod - nominal pitch'
cylinder 1  0.39218       426.72           0
cylinder 2  0.40005      426.72           0
cylinder 3  0.4572       426.72           0
cuboid 4  4P0.62992       426.72           0
media 1 1  1
media 2 1  2 -1
media 3 1  3 -2 -1
media 4 1  4 -3 -2 -1
boundary 4

unit 23
com='thimble tube - nominal pitch'
cylinder 1  0.56134       426.72         0
cylinder 2  0.60198        426.72         0
cuboid 3    4P0.62992      426.72          0
media 4 1 1
media 3 1 2 -1
media 4 1 3 -2 -1
boundary 3

unit 31
com='fuel rods - expanded pitch'
cuboid 1  24.384       0 24.384       0 100          0
array 3 1 place 1 1 1 0.4572       0.4572       0
boundary 1

unit 32
com='solid fuel rod - expanded pitch'
cylinder 1  0.39218       426.72           0
cylinder 2  0.40005      426.72           0
cylinder 3  0.4572       426.72           0
cuboid 4  4P0.73342       426.72           0
media 16  1 1
```

Table 6-39F Input Deck for Clamshell Up-Rotated Configuration (cont.)

```
media 17  1 2 -1
media 18  1 3 -2 -1
media 19  1 4 -3 -2 -1
boundary 4

unit 33
com='thimble tube - expanded pitch'
cylinder 1  0.56134      426.72          0
cylinder 2  0.60198      426.72          0
cuboid 3  4P0.73342       426.72          0
media 19 1 1
media 18 1 2 -1
media 19 1 3 -2 -1
boundary 3

unit 40
com='top nozzle assembly'
cuboid 1     21.072       0 21.072       0        21.2090     0.0000
cuboid 2     21.072       0 21.072       0       41.8846     0.0000
cuboid 3     21.072       0 21.072       0        52.8193     0.0000
cuboid 4     21.072       0 21.072       0        77.4192     0.0000
cuboid 5     24.384       0 24.384       0        77.4192     0.0008
media  15 1   1
media  15 1  -1   2
media  15 1  -2   3
media  15 1  -3   4
media  15 1  -4   5
boundary 5

unit 66
com='individual package 0-deg rotation'
hexprism 1  31.75    554.1972  -20.1498
hole 10  origin  x=0 y=0  z=0  rotate  a1=0 a2=0 a3=0
media   0 1   1
boundary 1

unit 77
com='individual package 180-deg rotation'
hexprism 1  31.75    554.1972  -20.1498
hole 10  origin  x=0 y=0  z=0  rotate  a1=0 a2=0 a3=180
media   0 1   1
boundary 1

unit 88
com='dummy cell'
hexprism 1  31.75    554.1972  -20.1498
media  15 1   1
boundary 1
```

Table 6-39F Input Deck for Clamshell Up-Rotated Configuration (cont.)

```
global
unit 99
com='package array'
cylinder 1  432.2355   554.1972  -20.1498
cylinder 2  452.2355   574.1972  -40.1498
cuboid 3  452.2355  -452.2355  452.2355  -452.2355   574.1972  -40.1498
array 1 1  place 9 9 1 0 0 0
media  15 1  -1   2
media   0 1  -2   3
boundary 3

end geometry

read array
ara=1 typ=triangular nux=17 nuy=17 nuz=1 gbl=1
fill
88 88 88 88 88 88 88 88 88 88 88 88 88 88 88 88 88
 88 88 88 88 88 88 88 88 88 88 77 77 77 88 88 88 88
  88 88 88 88 88 88 88 88 66 66 66 66 66 66 66 88 88
   88 88 88 88 88 88 77 77 77 77 77 77 77 77 77 77 88
    88 88 88 88 88 66 66 66 66 66 66 66 66 66 66 66 88
     88 88 88 88 77 77 77 77 77 77 77 77 77 77 77 77 88
      88 88 88 66 66 66 66 66 66 66 66 66 66 66 66 66 88
       88 88 88 77 77 77 77 77 77 77 77 77 77 77 77 88 88
        88 88 66 66 66 66 66 66 66 66 66 66 66 66 66 88 88
         88 88 77 77 77 77 77 77 77 77 77 77 77 77 88 88 88
          88 66 66 66 66 66 66 66 66 66 66 66 66 66 88 88 88
           88 77 77 77 77 77 77 77 77 77 77 77 77 88 88 88 88
            88 66 66 66 66 66 66 66 66 66 66 66 88 88 88 88 88
             88 77 77 77 77 77 77 77 77 77 77 88 88 88 88 88 88
              88 88 66 66 66 66 66 66 66 88 88 88 88 88 88 88 88
               88 88 88 77 77 77 77 88 88 88 88 88 88 88 88 88 88
               88 88 88 88 88 88 88 88 88 88 88 88 88 88 88 88 88
end fill

ara=2 typ=square nux=17 nuy=17 nuz=1
fill 39*22 23 2*22 23 2*22 23 8*22 23 9*22 23 22*22 23 2*22 23 2*22 23
 2*22 23 2*22 23 38*22 23 2*22 23 2*22 23 2*22 23 2*22 23 38*22 23
 2*22 23 2*22 23 2*22 23 2*22 23 22*22 23 9*22 23 8*22 23 2*22 23 2*22
 23 39*22
end fill
ara=3 typ=square nux=17 nuy=17 nuz=1
fill 39*32 33 2*32 33 2*32 33 8*32 33 9*32 33 22*32 33 2*32 33 2*32 33
 2*32 33 2*32 33 38*32 33 2*32 33 2*32 33 2*32 33 2*32 33 38*32 33
 2*32 33 2*32 33 2*32 33 2*32 33 22*32 33 9*32 33 8*32 33 2*32 33 2*32
 33 39*32
end fill
```

Table 6-39F Input Deck for Clamshell Up-Rotated Configuration (cont.)

```
end array

read bnds
+xb=vacuum
-xb=vacuum
+yb=vacuum
-yb=vacuum
+zb=vacuum
-zb=vacuum
end bnds

end data
end
```

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6.10.10 Benchmark Critical Experiments

Table 6-40 Summary of Available LWR Critical Experiments

Report	No. of available experiments	No. of selected experiments	Description of criticality experiments
ANS Transactions, Vol. 33, p. 362 (Ref. 5)	25	9/9	4.74 wt % ^{235}U UO_2 fuel rods in square lattices of 1.35 cm pitch; fuel 235 clusters separated by air, polystyrene, polyethylene, or water; fuel clusters submersed in aqueous $NaNO_3$ solution
BAW-1484 (Ref. 6)	37	1/10	2.46 wt % ^{235}U UO_2 fuel rods in square lattices of 1.636 cm pitch; the spacing between 3 × 3 array of LWR-type fuel assemblies is filled with water and B4C pins, stainless steel sheets, or borated stainless steel sheets; lattices with borated moderator
EPRI-NP-196 (Ref. 7)	6	3/6	2.35 wt % ^{235}U UO_2 fuel rods in square lattices of 1.562, 1.905, 235 and 2.210 cm pitch; lattices with borated moderator
NS&E, Vol. 71 (Ref. 8)	26	3/6	4.74 wt % ^{235}U UO_2 fuel rods in square lattices of 1.26 cm, 1.60 cm, 2.10 cm, and 2.52 cm pitch; triangular and triangular with pseudo-cylindrical shape lattices of 1.35, 1.72, and 2.26 cm pitch; irregular hexagonal lattices of 1.35 cm pitch; lattices with water holes
PNL-2438 (Ref. 9)	48	4/6	2.35 wt % ^{235}U UO_2 fuel rods in square lattices of 2.032 cm pitch; Cd, Al, Cu, stainless steel, borated stainless steel, Boral, and Zircaloy separator plates between assemblies
PNL-2827 (Ref. 10)	23	1/9	2.35 and 4.31 wt % ^{235}U UO_2 fuel rods in square lattices of 2.032, 235 and 2.540 cm pitch; reflecting walls of Pb or depleted uranium
PNL-3314 (Ref. 11)	142	18/27	2.35 and 4.31 wt % ^{235}U UO_2 fuel rods in square lattices of 1.684 and 1.892 cm pitch; stainless steel, borated stainless steel, Cd, Al, Cu, Boral, Boroflex, and Zircaloy separator plates between assemblies; lattices with water holes and voids
PNL-3926 (Ref. 12)	22	2/14	2.35 and 4.31 wt % ^{235}U UO_2 fuel rods in square lattices of 1.684, 235 and 1.892 cm pitch; reflecting walls of Pb or depleted uranium
WCAP-3269 (Ref. 15)	157	3/9	2.7, 3.7, and 5.7 wt % ^{235}U UO_2 fuel rods in square lattices of 1.029, 1.105, and 1.422 cm pitch; lattices with Ag-In-Cd absorber rods, water holes, void tubes

Table 6-40 Summary of Available LWR Critical Experiments (cont.)

Report	No. of available experiments	No. of selected experiments	Description of criticality experiments
WCAP-3385 (Ref. 16)	3	2/2	5.74 wt % ^{235}U UO_2 fuel rods in square lattices of 1.321, 1.422, and 2.012 cm pitch
BAW-1645 (Ref. 17)	21	2/8	2.46 wt % ^{235}U UO_2 fuel rods in close-packed triangular lattices of 1.209 cm pitch, close-packed square lattices of 1.209 cm pitch, and square lattices of 1.410 cm pitch
PNL-6205 (Ref. 20)	19	1/1	4.31 wt % ^{235}U UO_2 fuel rods in square lattices of 1.891 cm pitch; Boral flux traps
PNL-7167 (Ref. 21)	9	4/4	4.31 wt % ^{235}U UO_2 fuel rods in square lattices of 1.891 cm pitch; Boral flux traps containing voids filled with Al plates, Al rods, or UO_2 fuel rods.

Table 6-41 Critical Benchmark Experiment Classification

Report	Critical Benchmark Experiment Groups			
	Simple lattice	Separator plate	Flux trap	Water hole
ANS Transactions, Vol. 33, p. 362	ANS33SLG (8)	ANS33AL1 (1) ANS33AL2 (2) ANS33AL3 (3)	ANS33EB1 (4) ANS33EB2 (5) ANS33EP1 (6) ANS33EP2 (7) ANS33STY(9)	
BAW-1484	BW1484SL (24)			
EPRI-NP-196	EPRU65 (45) EPRU75 (47) EPRU87 (44)			
NS&E, Vol. 71, p. 154	NS&E71SQ (54)			NS&E71W1 (55) NS&E71W2 (56)
PNL-2438	P2438SLG (60)	P2438AL (57) P2438BA (58) P2438SS (61)		
PNL-2615		P2615AL (63) P2615BA (64) P2615SS (68)		
PNL-2827	P2827SLG (74)			
PNL-3314	P3314SLG (96)	P3314AL (79) P3314BA (80) P3314BC (81) P3314BF1 (82) P3314BF2 (83) P3314BS1 (84) P3314BS2 (85) P3314BS3 (86) P3314BS4 (87) P3314SS1 (97) P3314SS2 (98) P3314SS3 (99) P3314SS4 (100) P3314SS5 (101) P3314SS6 (102)		P3314W1 (103) P3314W2 (104)
PNL-3926	P3926SL1 (138) P3926SL2 (139)			
PNL-6205		P62FT231 (154)		
PNL-7167		P71F214R (158)	P71F14F3 (155) P71 F14V3 (156) P71 F14V53 (157)	
WCAP-3269	W3269SL1 (168) W3269SL2 (169)			W3269W1 (170) W3269W2 (171)
WCAP-3385	W3385SL1 (172) W3385SL2 (173)			
Total	**15**	**26**	**8**	**6**

Table 6-42 Summary Comparison of Benchmark Critical Experiment Properties to Traveller						
	Critical Benchmark Experiments					
	All	Simple lattice	Separator	Flux Trap	Water Hole	Traveller Package
Number of cases	55	15	26	8	6	19
Properties of Lattice						
Water-to-fuel volume ratio	1.196-5.067	1.196-5.067	1.6-3.883	1.6-2.302	1.495-1.932	2.21-3.49
Hydrogen-to-fissile ratio	97.6-504.2	97.6-504.2	105-398.	105-138.4	98.3-218.6	120.5-190.4
Lattice pitch	1.26-2.540	1.26-2.21	1.35-2.54	1.35-1.891	1.26-1.892	1.26-1.467
Dancoff factor	0.03889-0.3772	0.05727-0.3772	0.03889-0.20179	0.17388-0.20096	0.17284-0.25719	0.13137-0.22632
Water hole/No. pins	0.051-0.152	NA	NA	NA	0.051-0.152	0.095
Properties of UO_2 fuel rods						
Outside diameter, cm	0.86-1.4147	0.86-1.206	0.94-1.4147	0.94-1.4147	0.94-1.4147	0.9144
Wall thickness, cm	0.038-0.081	0.038-0.081	0.06-0.0762	0.06-0.0762	0.038-0.0795	0.05715
Wall material	Al Zircaloy-4 304SS	Al Zircaloy-4 304SS	Al	Al	Zircaloy-4 304SS	Zircaloy-4
Pellet diameter, cm	0.7544-1.2649	0.7544-1.2649	0.79-1.2649	0.79-1.2649	0.79-1.2649	0.7844
Total fuel length, cm	97.155-156.44	97.155-156.44	97.155-156.44	97.155-156.44	97.155-156.44	426.72
Active fuel length, cm	90.0-153.44	90.0-153.44	90.0-153.44	90.0-153.44	90.0-153.44	426.72
Enrichment, $^{235}U/U$ wt%	2.35-5.74	2.35-5.74	2.35-4.74	4.31-4.74	2.35-5.70	5.00
Fuel density, g/cm^3	9.20-10.412	9.20-10.412	9.20-10.412	10.38-10.412	9.20-10.412	10.96

Table 6-42 Summary Comparison of Benchmark Critical Experiment Properties to Traveller (cont.)

	Critical Benchmark Experiments					
	All	**Simple lattice**	**Separator**	**Flux Trap**	**Water Hole**	**Traveller Package**
Neutron Interaction Characteristics						
^{10}B areal densities, g/cm^2	0.026 -0.090	NA	0.026-0.090	0-0.073	NA	0.0203
Plate thickness, cm	0.231-0.772	NA	0.231-0.772	0.300-0.673	NA	0.3175
AGF	32.82-36.61	33.1-36.61	32.85-36.28	32.82-34.29	33.18-35.25	33.49-34.98
AEF, eV	0.0828-0.3738	0.0828-0.3240	0.0948-0.3703	0.2050-0.3738	0.1468-0.3095	0.1944-0.2759
Separation, cm	2.5-12.97	5-12.97	2.5-11.55	2.5-5.19	NA	9.5-12.54
Geometry						
Moderator height, Hc (cm)	25.54-129.65	38.61-129.65	25.54-64.2	NA	NA	NA

6.10.11 Traveller VVER Calculations

6.10.11.1 Introduction

The following calculations were performed in order to demonstrate that the Traveller package using the VVER Clamshell complies fully the requirements of 10CFR71, and TS-R-1. The VVER packaging is comprehensively described in Section 1. This section provides a description of the package (i.e., packaging and contents) that is sufficient for understanding the features of the Traveller VVER that maintain criticality safety. Specifically, this appendix presents the following information:

1. Description of the contents and packaging, including maximum and minimum mass of materials, maximum ^{235}U enrichment, physical parameters, type, form, and composition

2. Description of the calculational models, including sketches with dimensions and materials, pointing out the differences between the models and actual package design, with explanation of how the differences affect the calculations

3. Justification for the credit assumed for the fixed neutron absorber content, including reference to the acceptance tests that are implemented which verify the presence and uniformity of the absorber.

4. Justification for assuming 90% credit for fixed moderating material.

5. Description of the most reactive content loading and the most reactive configuration of the contents, the packaging, and the package array in the criticality evaluation.

6. Description of the codes and cross-section data used, together with references that provide complete information.

7. Discussion of software capabilities and limitations of importance to the criticality safety evaluations.

8. Demonstration that the effective neutron multiplication factor (k_{eff}) calculated in the safety analysis is less than the USL after consideration of appropriate bias and uncertainties for the following.

   a. A single package with optimum moderation within the containment (i.e., confinement) system, close water reflection, and the most reactive packaging and content configuration consistent with the effects of either normal conditions of transport or hypothetical accident conditions, whichever is more reactive.

   b. An array of 5N undamaged packages (packages subject to normal conditions of transport) with nothing between the packages and close water reflection of the array.

   c. An array of 2N damaged packages (packages subject to hypothetical accident conditions) if each package were subjected to the tests specified in §71.73, with optimum interspersed moderation and close water reflection of the array.

9. Calculation of the Criticality Safety Index (CSI) based on the value of N determined in the array analyses.

10. Description of the Traveller's Confinement System.

6.10.11.2 Description of Criticality Design

6.10.11.2.1 Design Features

This section describes the design features of the Traveller VVER Clamshell that are important for criticality. The Traveller shipping package with VVER clamshell carries a single VVER fuel assembly. The Clamshell is a hexagonal aluminum box that completely encloses the contents. It is mounted in the Outerpack with rubber shock mounts. Neutron absorber panels are slotted into the inner face of each Clamshell side. The Clamshell is designed such that it retains its original dimensions when subjected to the HAC tests. See Figure 6-41 for an exploded view of the Traveller-VVER.

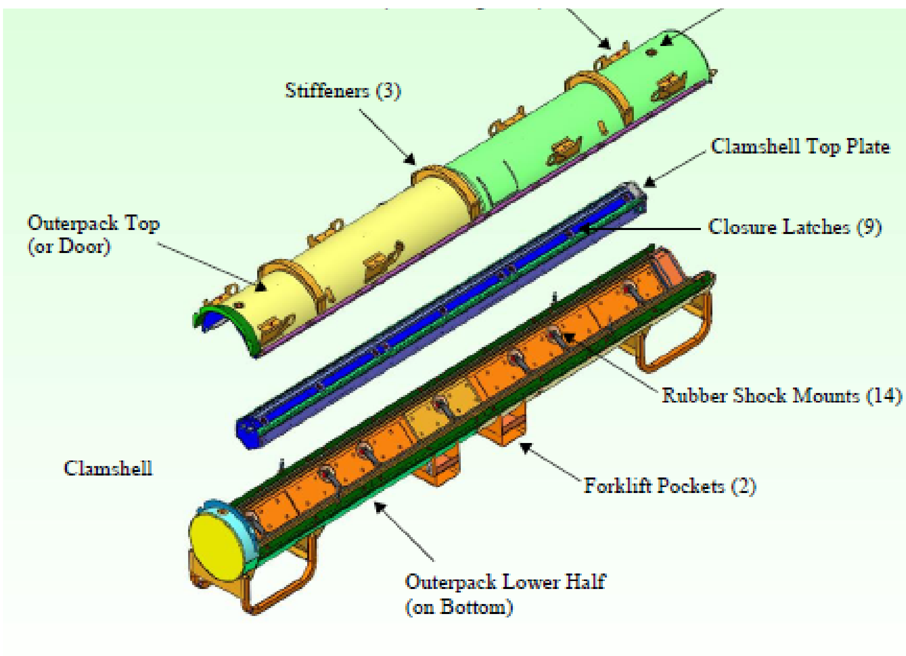

Figure 6-41 Traveller-VVER Exploded View

6.10.11.2.1.1 Containment System

The Containment System is described in both TSR-1 and 10CFR71 as, "the assembly of components of the packaging intended to retain the radioactive material during transport." The Containment System for the Traveller consists of the fuel rods, regardless of whether the Traveller is carrying a fuel assembly or rods in a rod container.

6.10.11.2.1.2 Confinement System

For a full description of the requirements used to determine the Confinement System, see Section 6.1.1.2.

The Confinement System for the Traveller-VVER consists of those assembly and packaging components that preserve criticality safety of a single package in isolation. Hence, it consists of the fuel rods, the fuel assembly (or rod container), and the VVER Clamshell assembly, including the neutron absorber panels. The Confinement System is shown in Figure 6-42.

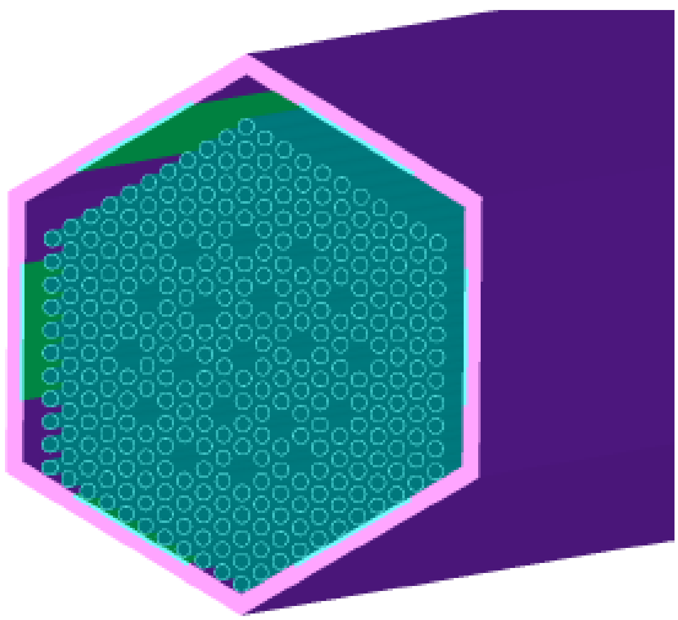

Figure 6-42 Traveller-VVER Confinement System

6.10.11.2.1.3Flux Traps

The Traveller-VVER Clamshell utilizes a similar flux trap configuration as is described in Section 6.1.1.3.

6.10.11.2.1.4 Neutron-Absorbing Materials

Neutron absorbing materials are present in the Traveller-VVER in two forms: materials of construction and neutron poisons. See Section 6.1.1.4 for full description.

6.10.11.2.1.5 Neutron-Moderating Materials

Neutron-moderating materials in the Traveller-VVER include the polyurethane foam in the Outerpack, the shock mounts, and the high-density polyethylene (UHMW) blocks. See Section 6.1.1.5 for full description.

6.10.11.2.1.6 Floodable Void Spaces

The Traveller-VVER, including packaging and contents, contains six floodable regions. These regions have been modeled in various flooding combinations, including flooding with partial density water, in order to determine the most conservative accident configuration. The floodable regions are shown in Figure 6-43. (Note that region 1, the pin-gap, is shown in Figure 6-28). Flooding is addressed in Section 6.7.1. The region numbers below correspond to the numbers used in the criticality input decks. See Section 6.1.1.6 for full descriptions of the floodable regions.

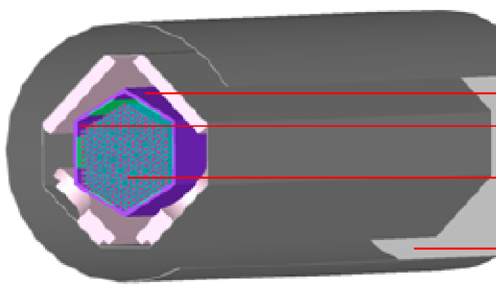

Figure 6-43 Floodable Void Spaces

6.10.11.2.1.7 Array Spacing Significant Components

The single component that affects the physical separation of the fissile material contents in package arrays is the Outerpack. The Outerpack outer radius is 12.50 inches ±1.0 inch (317.50 mm ±25.40 mm). It is a cylindrical annular shell split along the longitudinal axis to form two separate halves. See Section 6.1.1.7 for full description.

6.10.11.2.2 Summary Tables of Criticality Evaluation

Sensitivity studies were performed using the Traveller VVER to determine the most conservative configurations for the normal and hypothetical accident conditions for an individual package and package arrays. These results, rounded to three decimal places, are shown in Table 6-43.

Table 6-43 Summary Table for Traveller VVER	
Traveller VVER	**K_{eff}**
Single Package	
Normal	0.848
HAC	0.891
Package Array	
Normal	0.344
HAC	0.935

6.10.11.2.3 Criticality Safety Index (CSI)

6.10.11.2.3.1 VVER Fuel Transport Index

The Criticality Safety Index when transporting VVER fuel assemblies is calculated as follows:

2 * N = Array Size
Array Size = 150
N= 150/2 → 75
Therefore, CSI = 50/75 → 0.7

This results in the same CSI as the Traveller XL HAC Package Array.

6.10.11.3 Fissile Material Contents

The package will be used to carry heterogeneous uranium compounds in the form of fuel rods. These rods will transported as VVER fuel assemblies. The uranium enrichment shall not be greater than 5.0 wt% ^{235}U. The uranium isotopic distribution considered in the models in this criticality safety analysis is shown in Table 6-44.

Table 6-44 Uranium Isotope Distribution	
Isotope	**Modeled Wt%**
^{235}U	5.0
^{235}U	95.0

6.10.11.3.1 VVER Fuel Assemblies

There are two variations of the VVER fuel assembly to be transported in the Traveller VVER package. These two fuel assemblies are modeled with the same fuel assembly model for criticality safety, as the fuel specifications important to criticality safety (e.g., pellet diameter, fuel rod diameter, pitch, rod positions, etc) remain the same between the fuel assembly variations. The fuel assemblies are described below in Section 6.10.11.4.1.1.1.

6.10.11.4 General Considerations

The models developed for these calculations are not exact representations of the package, but they do explicitly include all of the physical features that are important to criticality safety. Modeling approximations will be shown to be either conservative or neutral with respect to the criticality safety case. This section describes the packaging and the contents models.

6.10.11.4.1 Model Configuration

Geometry input dimensions are taken directly from design drawings and are derived by stacking dimensions from design drawings or calculated using geometric relationships and dimensions shown on design drawings. Longitudinal dimensions in the model are oriented along the z-axis, and latitudinal dimensions are oriented in the x-y plane. The origin of the individual package unit is near the bottom of the package along the z-axis and at the center of the package in the x-y plane. The positive direction is from bottom to top of the package along the z-axis, the positive direction is from left to right along the x-axis when viewed from the top of the package and the positive direction is from lower to upper along the y-axis.

6.10.11.4.1.1 Contents Models

The contents models used in support of this analysis include the VVER Fuel Assembly Model.

6.10.11.4.1.1.1 VVER Fuel Assembly Models

Section 6.10.11.3.1 established that a single VVER fuel assembly will be used in all calculations. The VVER model basically consists of concentric hexagonal prisms to model the top nozzle assembly, skeleton, and fuel regions. The fuel assembly origin is at the bottom left hand corner of the fuel assembly lower nozzle. The fuel assembly is placed inside the fuel confinement with no translation of the origin.
Table 6-45 shows the parameters of the VVER fuel assembly as modeled. It is described in further detail in Section 6.10.11.9. In the following table, units are defined by inches and millimeters in parentheses.

Table 6-45 VVER Fuel Assembly Parameters	
Fuel Assembly Type	**VVER**
Nominal Pellet Diameter	0.3225 (8.192)
Annular Pellet Inner Diameter	0.155 (3.937)
Nominal Clad Thickness	0.0225 (0.572)
Clad Material	Zirconium alloy
Nominal Clad Outer Diameter	0.374 (9.499)
Maximum Stack Length	169 (4292.6)
Nominal Assembly Envelope	8.418 (213.817)
Kg's ^{235}U Assembly	28
Nominal Lattice Pitch	0.496 (12.598)
GT Diameter	0.482 (12.243)
GT Thickness	0.016 (0.406)
GT Material	ZIRC
IT Diameter	0.482 (12.243)
IT Thickness	0.016 (0.406)
IT Material	ZIRC

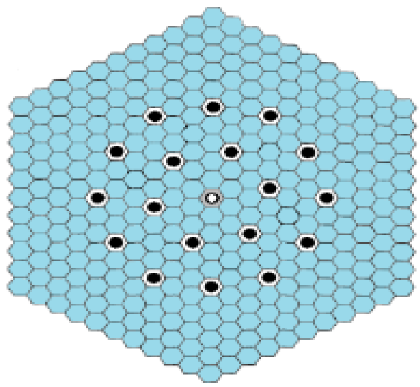

Figure 6-44 Cross Section for VVER Fuel Assembly

Any fuel assemblies which satisfy the parameters found in this section may be transported in the Traveller VVER.

6.10.11.4.1.2 Packaging Model

6.10.11.4.1.2.1 Outerpack Model

The actual Traveller VVER and Traveller XL outerpacks are identical components. For criticality modeling the shock mount configurations are different. As described in Section 6.10.5, the Traveller XL shock mounts are modeled is a more conservative configuration based on the fuel placement within the model. The criticality evaluations for the VVER use the same outerpack model as the XL calculations, with the exception of shock mount configuration, which is described in further detail in Section 6.10.11.9.

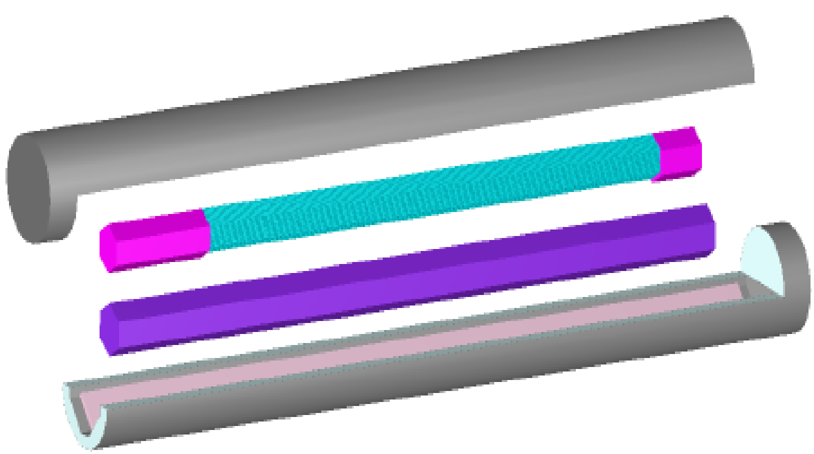

Figure 6-45 Keno 3D Rendering of Traveller VVER

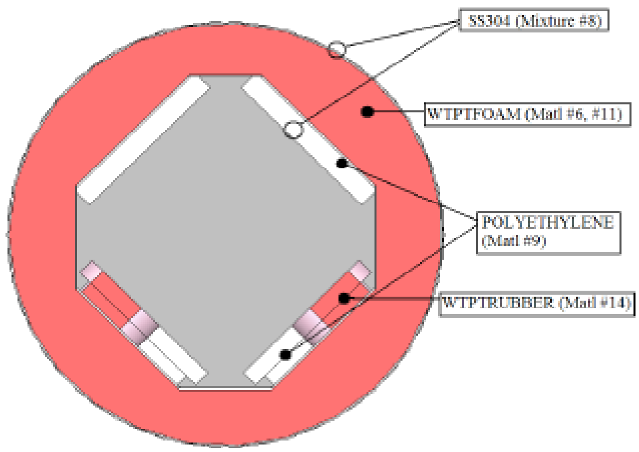

Figure 6-46 VVER Outerpack Model Showing Material

6.10.11.4.1.2.2 VVER Clamshell Model

The VVER Clamshell model consists of concentric hexagonal prisms to model the outer wall and three sets of plane pairs to model the fixed neutron absorber panels, which are inset into the walls. The VVER Clamshell origin is at the bottom left hand corner of the inside surface. The VVER Clamshell is translated in the positive z direction to position it within the Outerpack. The VVER Clamshell can be seen in Figure 6-42 and Figure 6-45. It is described in further detail in Section 6.10.11.9.

6.10.11.4.2 Material Properties

The Standard Composition Library was used to specify material and mixtures. Those not found in the library are specified using the procedures for arbitrary mixtures described in the SCALE manual. Table 6-46 shows an excerpt from an input deck showing how the material properties are described.

Table 6-46 Sample Input Showing Material Properties

```
Routi,1_pkg,Traveller_VVER,VVER_1000,nzls_h20,pin_gap_dry
'no_latt_exp  ,c_shell_dry,sway_sp_dry,foam_shk_mnts_int,no_refl
v6-238
read composition
    uo2 1 1 293 92235 5 92238 95 end
    h2o 2 1 293 end
    zirc4 3 1 293 end h2o 4 1 293 end
    h2o 5 1 293 end
    wtptfoam 6 0.1602 4 6000 70 1001 10 8016 16 7014 4 1 293
    end
    al 7 1 293 end
    ss304 8 1 293 end
    polyethylene 9 den=0.828 1.0 293 end
    h2o 10 1 293  end
    wtptfoam 11 0.1602 4 6000 70 1001 10 8016 16 7014 4 1 293
    end
    b-10 12 0 0.0047759 300  end
    b-11 12 0 0.019223 300 end
    c  12 0 0.0059998 300   end
    al 12 0 0.044238 300    end
    h2o 13 1 293  end
    wtptrubber 14 1.59 7 8016 46.94 13000 19.92 14000 17.54 6000 10.79
    1001 4.73 11000 0.06 26000 0.02 1 293 end
    h2o 15 1 293 end
    uo2 16 1 293 92235 5 92238 95 end
    h2o 17 1 293 end
    zirc4 18 1 293 end
    h2o 19 1 293 end
    end comp
    squarepitch 1.46690.7843516 19 0.914418 0.800117 end
    more data
    res=1 cylinder 0.39218dan(1)=0.22632end
```

These materials are described further in Table 6-9.

6.10.11.4.2.1 Package to Model Comparison

A comparison of the mass of materials in the package model to the actual package provides an overall assessment of differences in geometry and material composition. A small quantity of plastic in the Outerpack vent plugs and steel in the shock mount bolts are not included. Also, some of the stainless steel structure in the Outerpack is not included in the model. Over 100 kg (220 lb.) of stainless steel in the components of the package were not included in the model. The cork rubber used as spacer material in the Clamshell, and the stainless steel in the Clamshell hinge pins are not included in the model.

None of the stainless steel in the bottom and top nozzle is included in the fuel assembly. The uranium dioxide actual mass is less than the model mass because theoretical density is used in the model, but actual density is 96.5 percent the theoretical density. The zirconium mass is less in the model because the spacer grids are not included. Neither the model mass nor the actual mass for the contents includes the mass of the fuel rod bottom and top end plugs, plenum spring. Also, the skeleton stainless steel lock tube and top nozzle insert mass are not included in the comparison.

For an additional description of the conservative material assumptions made, see Section 6.10.11.4.4.5.

6.10.11.4.3 Computer Codes and Cross-Section Libraries

The 238-group ENDF/B-VI Release 8 library is a general-purpose criticality analysis library that has been generated with the AMPX cross-section processing system. In an effort to facilitate comparisons between ENDF/B-V and ENDF/B-VI libraries, the 238-group ENDF/B-VI library has been developed using the same group structure as the 238-group ENDF/B-V cross-section library. In addition, the 238-group ENDF/B-VI library was generated using the same weighting spectrum as the 238-group ENDF/B-V library. Results from the benchmark testing demonstrate that the ENDF/B-VI calculated results are consistent with the ENDF/B-V results for the same suite of benchmark problems. Therefore, the 238-group ENDF/B-VI library is acceptable for general use in criticality and reactor physics applications.

The calculations were performed utilizing KENO-VI in the SCALE5.1 package of codes. Features such as geometry intersections, body rotation, hexagonal arrays, and array boundaries are the reason that KENO-VI was chosen for this analysis. A benchmark evaluation is discussed in Section 6.10.11.10.

6.10.11.4.4 Demonstration of Maximum Reactivity

This section demonstrates the most reactive configuration of each case presented in Sections 6.10.11.5 through 6.10.11.7. Assumptions and approximations are identified and justified. The optimum combinations of internal and interspersed moderation for the different cases are also explained. For further information, see Section 6.3.4.

6.10.11.4.4.1 Evaluation Strategy

The evaluation strategy for the Traveller VVER follows the strategy developed for the Traveller STD and XL. This is presented in Section 6.3.4.1, and shown in Figure 6-8.

6.10.11.4.4.2 Baseline Case for Packaging (Routine Condition of Transport)

The baseline case is the routine condition of transport. Note that the Routine case was not modeled. It is presented in order to show the conservative differences that exist between it, the normal condition of transport, and the license-basis case, which are modeled.

For the routine case the polyurethane foam, moderator blocks, and rubber shock mounts are in place.

The ^{10}B content of the neutron absorber plates has a minimum areal density of 0.024 g/cm^2 (BORAL).

All floodable void spaces of the Outerpack are dry for the routine configuration.

The fuel assembly is undamaged. That is, there is no expansion of the lattice pitch and the pin-gap is dry.

Nominal cladding thickness is used.

Section 6.3.4.2 describes this configuration in more detail.

6.10.11.4.4.3 Most Reactive Fuel Assembly Type (Contents)

The parameters presented in Table 6-45 describe the most reactive fuel assembly type to be carried in theTraveller VVER. The following assumptions and conservatisms were included:

- Assumed 100% TD
- Assumed flooded pin-gap
- Ignored dishing, chamfering of pellets
- Ignored burnable poisons (Gd, Erbia, Boron)

6.10.11.4.4.4 Most Reactive Flooding Configurations (Flooding Case)

The most reactive flooding cases for the individual package and package array cases are summarized in Table 6-47.

For additional information, see Section 6.3.4.4.

6.10.11.4.4.5 Conservative Material Assumptions.

The following conservative material assumptions are incorporated:

- The Traveller VVER clamshell is conservatively modeled at 9.60-inches (23.384 cm), neglecting the presence of the cork liner and the manufacturing tolerance. This is a difference of 0.24 inches (0.61 cm).

- Cork liner in clamshell not considered.

- The polyethylene moderator blocks are modeled 90% actual density, or 0.828g/cc.
- The ^{10}B content is modeled at 75% areal density for BORAL (0.0180 g/cm^2).
- The shock mounts are modeled as a void.

6.10.11.5 Normal Condition of Transport

This follows a similar configuration as is provided in Section 6.3.4.6. It is also shown in Table 6-47 below:

- Outerpack dimensions are modeled as in Section 6.10.11.4.1.2.
- Clamshell is modeled as in Section 6.10.11.4.1.2.
- Fuel assembly is modeled as in Section 6.10.11.4.1.1.
- The polyurethane foam and shock mounts are modeled at nominal density. Neither is altered under normal conditions of transport.
- The moderator blocks are modeled as in Section 6.10.11.2.1.
- The neutron absorber is modeled as in Section 6.10.11.2.1.
- All floodable void spaces of the Outerpack are modeled dry.
- The package is close reflected by 20 cm water.

As required by 10CFR71 and TS-R-1, the Traveller shipping package has been designed and constructed such that under the tests specified for normal conditions of transport, the following pertains:

- The contents are subcritical.
- The geometric forms of the package contents are not altered.
- There is no inleakage of water.
- There was no reduction in effectiveness of the packaging. Section 2.12.4.2.3 describes the Certification Test Unit (CTU) following the hypothetical accident tests. From that inspection, the following can be concluded:
    - There was no reduction in the total effective volume of the packaging on which nuclear safety is assessed. Because there was no reduction in volume following the hypothetical accident condition testing, it follows that there is none during normal conditions of transport.
    - There was no reduction in the effective spacing between the fissile contents and the outer surface of the packaging. Test results report that the clamshell held the contents in place.

— There were no breeches in the Outerpack. Hence, there is no occurrence of an aperture in the outer surface of the packaging large enough to allow the entry of a 10 cm (4 in) cube.

- The loss of efficiency of built-in neutron absorbers is addressed. The calculations assume less than 100% ^{10}B for the neutron absorber.

- The loss of efficiency of built-in moderators is addressed. The calculations assume 90% actual moderator density.

- The rearrangement of the contents within the package is addressed. There was no loss of contents from the package.

- There was no reduction of space within the package.

- There was no reduction of spacing between packages.

6.10.11.6 License-Basis Case

This follows the same configuration as is provided in Section 6.3.4.8. It is also shown in Table 6-47 below.:

- Outerpack dimensions are modeled as in Section 6.10.11.4.1.2.

- Clamshell is modeled as in Section 6.10.11.4.4.5.

- Moderator is modeled as in Section 6.10.11.4.4.5.

- Neutron absorber is modeled as in Section 6.10.11.4.4.5.

- Shock mounts are modeled as a void.

- Shock mount placement is modeled as in section 6.10.11.9.

- Foam density, which differs for individual package and package array calculations, is modeled as in Table 6-47.

- Floodable void spaces are modeled as in Table 6-47.

- The fuel assembly is modeled so that it bounds the as-found condition. The model assumes lattice pitch expansion to 9.6 inches (23.384 cm) for the Traveller VVER. The lattice expansion is uniformly distributed and extends 100 cm of fuel length.

Table 6-47 Parameters for the Different Traveller Conditions

Parameter	Routine Condition (Not Modeled)	Conservative Material Assumptions (Not Modeled)	Normal Condition of Transport (Modeled)	HAC License-basis Case (Modeled)
SAR Section	6.10.4.4.2	6.10.11.4.4.5	6.10.11.5	6.10.11.6
Outerpack dimension	25.0 inches (63.5 cm)		25.0 inches (63.5 cm)	25.0 inches (63.5 cm)
Polyurethane foam density	Nominal Density		Nominal Density	Water/Void
Shock mount density	Nominal Density		Nominal Density	Void
Clamshell dimension	9.5±0.05 inches (24.13±0.127 cm)			
Cork liner in place on bottom faces	0.188 inches (0.476 cm)	Not in place	Not in place	Not in place
Effective Clamshell dimension	9.5 inches (24.13 cm)	9.6 inches (24.384 cm)	9.6 inches (24.384 cm)	9.6 inches (24.384 cm)
Neutron absorber density (B-Al/BORAL)	Nominal Density	75%	75%	75%
Moderator density	Nominal Density	90%	90%	90%
Flooding condition	(single/array)		(single/array)	(single/array)
Region 1 – Pin Gap	Dry/Dry		Dry/Dry	Flooded/Flooded
Region 2 – Fuel Assembly Envelope	Dry/Dry		Dry/Dry	Flooded/Flooded
Region 3 – Clamshell	Dry/Dry		Dry/Dry	Flooded/Dry
Region 4 – Outerpack	Dry/Dry		Dry/Dry	Flooded/Dry
Region 5 – Polyurethane Foam	Dry/Dry		Dry/Dry	H_2O/Void
Region 6 – Outside Outerpack	Dry/Dry		Dry/Dry	H_2O Reflected/Dry
Fuel Assembly Lattice Pitch Expansion	None	None	None	100 cm

6.10.11.7 Single Package Evaluation

Calculations were performed to determine the most reactive configuration for a single package in isolation under normal and hypothetical accident conditions of transport. The configurations are described below.

6.10.11.7.1 Configuration for Fuel Assemblies

6.10.11.7.1.1 Configuration Under Normal Conditions of Transport

10CFR71 and TS-R-1 require that the contents be subcritical under normal conditions of transport. TS-R-1 indicates that when it can be demonstrated that the confinement system remains within the packaging following the prescribed tests, close reflection of the package by at least 20-cm water may be assumed. Since this is the case for the Traveller, the individual package evaluation includes the close-reflection around the Outerpack.

6.10.11.7.1.2 Configuration Under Hypothetical Accident Conditions

The hypothetical accident condition requires that the most reactive flooding configuration be considered. It is generally true that the most reactive configuration for an individual package would be that in which the neutrons are moderated as close to the fuel as possible and reflected back into the fuel assembly region. They should not be allowed to escape or to reach the neutron poison where they would be absorbed.

Calculations have shown that this is the case for the Traveller. Therefore, all floodable void spaces in the package are modeled as fully flooded, and the package is close reflected by 20-cm full density water.

6.10.11.7.2 Results for Fuel Assemblies

Table 6-48 Most Reactive Configuration for a Single Traveller VVER in Isolation

Configuration	Run	k_s	Uncert.	Calculated k_{eff}
Traveller VVER - Fuel Assembly				
Normal	VVER_Traveller_XL_normal_2	0.8468	0.00056	0.84792
HAC	VVER_Traveller_XL_HAC_3	0.8881	0.0015	0.8904

6.10.11.8 Package Array Evaluation

6.10.11.8.1 Configuration for Fuel Assemblies

6.10.11.8.1.1 Configuration Under Normal Conditions of Transport

See Section 6.10.11.5 for configuration description. The array was formed from 375 Traveller VVER Packages (5N). Results are summarized in Table 6-49.

6.10.11.8.1.2 Configuration Under Hypothetical Accident Conditions

The most reactive configuration for a package array, in contrast to the individual case, is the one that allows maximum thermal neutron interaction between packages. Region 1 (pin-gap) and Region 2 (fuel assembly) are flooded to maximize reactivity inside the fuel assembly. Region 3 (Clamshell) is modeled as a void to increase the probability that neutrons escaping the fuel assembly envelope will pass through the neutron poison. The remaining floodable void spaces (Region 4 – Outerpack cavity; Region 5 – foam; Region 6 – outside Outerpack) are modeled as a described below to allow maximum interaction between packages in the array.

In order to conservatively report k_{eff} for the HAC array, several cases were run at varying inter-package moderator densities (Region 6), from 0 g/cc to 1.0 g/cc. As moderator density exceeded 0.10 g/cc, the reactivity began to decline towards the single package HAC case value, as shown in Figure 6-47. The most conservative value is represented in Table 6-49 for the HAC case.

Table 6-49 Most Reactive Configuration for a Traveller VVER Array

Configuration	Run	k_s	Uncert.	Calculated k_{eff}
Traveller VVER - Fuel Assembly				
Normal	VVER_Traveller_XL_normal_5	0.34139	0.00084	0.34307
HAC	VVER_Traveller_XL_HAC_6	0.93285	0.00080	0.93445

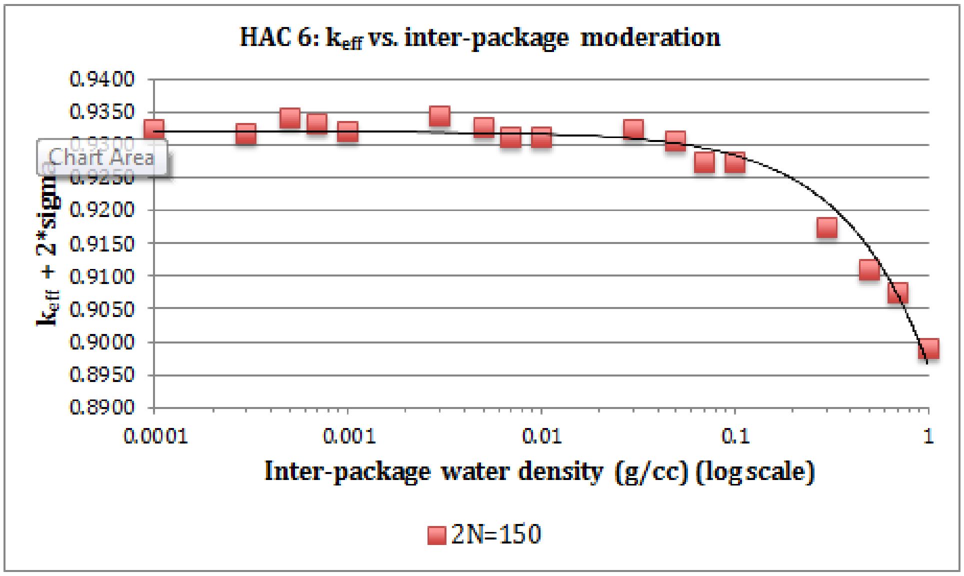

Figure 6-47 VVER HAC Package Array: Inter-Package Water Density Variation

6.10.11.9 Traveller VVER Model

6.10.11.9.1 Traveller VVER Fuel and Clamshell Model

Units #24 and #34 are used to define the VVER fuel rod arrays as contained within the VVER clamshell. The arrays are identical except that rhexprism 4 in Units #22 and #32 is sized according to either the expanded pitch (Unit #22) or the nominal pitch (Unit #32). The VVER Clamshell is also defined within Units #24 and #34, using three sets of ypplanes to define the inset BORAL plates. This input is shown in Figure 6-48.

6.10.11.9.2 Traveller VVER Outerpack Model

The Outerpack is defined in Unit #66. This unit simply defines the walls of the outerpack, leaving a hole which is filled with a stacked unit containing the fuel assembly, VVER clamshell, moderator blocks, shock mounts, sway spaces, and stainless steel. The shock mounts are spaced according to Drawing 10037E43, Sheet 08. An example of this input is shown in Figure 6-49.

```
'SOLID FUEL ROD NOMINAL PITCH FUEL SECTION
unit 32
com='solid fuel rod - nominal pitch'
cylinder 1  0.39220 253.0000 0.0000
cylinder 2  0.40005 253.0000 0.0000
cylinder 3  0.45720 253.0000 0.0000
rhexprism 4  0.63755 253.0000 0.0000
media 1 1 1
media 2 1 2 -1
media 3 1 3 -2 -1
media 4 1 4 -3 -2 -1
boundary 4

unit 33
com='water hole in hex lattice - nominal pitch'
rhexprism 2  0.63755 253.0000 0.0000
media 4 1 2
boundary 2

unit 34
com='Nominal lattice pitch right hexprism
hexprism   10 12.507      353.0000 0.0000
array 2    10 place 15 12 1 0.0000 -1.1629     0.0000
'BORAL plate inner aluminum layer
hexprism   20 12.5524 353.0000 0.0000
media 0          1 20 -10
'BORAL plate core matrix layer
hexprism   30 12.7791 353.0000 0.0000
'Plane pairs to define BORAL core matrix region
ypplane    40  3.175 -4.445
ypplane    50  3.81 -3.81 rotate a1=60
ypplane    60  3.81 -3.81 rotate a1=-60
'Media describes core matrix and aluminum
media 12 1  30 -20  40
media 12 1  30 -20  50
media 12 1  30 -20  60
media  7 1  30 -20 -40 -50 -60
'Boral plate and clamshell structural aluminum
hexprism   70 13.5560 353.0000 0.0000
media  7 1  70 -30
boundary   70
```

```
'SOLID ROD EXPANDED PITCH SECTION
unit 22
com='solid fuel rod - expanded pitch'
cylinder 1  0.39220 100.0000 0.0000
cylinder 2  0.40005 100.0000 0.0000
cylinder 3  0.45720 100.0000 0.0000
rhexprism 4 0.69570 100.0000 0.0000
media 16 1   1
media 17 1  2 -1
media 18 1   3 -2 -1
media 19 1  4 -3 -2 -1
boundary 4

unit 23
com='water hole in hex lattice - expanded pitch'
rhexprism 2  0.69570 100.0000 0.0000
media 19 1  2
boundary 2

unit 24
'Expanded Lattice pitch right hexprism
hexprism    10 12.5070 100.0000 0.0000
array 1     10 place 15 12 1 0 0 0
'BORAL Plate inner aluminum layer
hexprism    20 12.5524 100.0000 0.0000
media 7 1   20 -10
'BORAL plate core matrix layer
hexprism   30 12.7791 100.0000 0.0000
'Plane pairs to define BORAL core matrix region
ypplane    40  3.175 -4.445
ypplane    50  3.81 -3.81 rotate a1=60
ypplane    60  3.81 -3.81 rotate a1=-60
'Media describes core matrix and aluminum
media 12 1  30 -20  40
media 12 1  30 -20  50
media 12 1  30 -20  60
media  7 1  30 -20 -40 -50 -60
'Boral plate and clamshell structural aluminum
hexprism   70 13.5560 100.0000 0.0000
media  7 1 70 -30
boundary   70
```

Figure 6-48 Sample Input Lines for Fuel Rods, Fuel Assembly, and VVER Clamshell

```
unit 64
com='clamshell with all moderator blocks,sway spaces and all SS'
cuboid 1 20.5293 -21.1267 20.5293 -21.1267 521.4737 -8.3937
plane 2 XPL=-3232.7    YPL=-3232.7     CON=-104502.42
plane 3 XPL= 3331.464  YPL= 3331.464   CON=-110986.52
plane 4 XPL= 3053.3    YPL=-3053.3     CON= 93225.69
plane 5 XPL=-3053.3    YPL= 3053.3     CON= 93225.69
array 9 1 -2 -3  4  5 place 1 1 3 0 0 0
plane 12 XPL=-3270.25  YPL=-3270.25    CON=-106945.35
plane 13 XPL= 3369.03  YPL= 3369.03    CON=-113503.67
plane 14 XPL= 3090.8   YPL=-3090.8     CON= 95533.52
plane 15 XPL=-3090.8   YPL= 3090.8     CON= 95533.52
media  8 1  1  2 -12
media  8 1  1  3 -13
media  8 1  1 -4  14
media  8 1  1 -5  15
media 0  1  1  12
media 0  1  1  13
media 0  1  1 -14
media 0  1  1 -15
boundary 1

unit 66
com='individual package 0-deg rotation'
cylinder 1 31.4843 541.6662 -28.9697
hole 64 origin  x=0  y=0  z=0  rotate  a1=0 a2=0 a3=45
cylinder 2 31.7500 541.9319 -29.2354
hexprism 3 31.7500 541.9319 -29.2354
media 0  1   1
media  8 1   2 -1
media 20 1   3 -2 -1
boundary 3
```

Figure 6-49 Sample Input for Traveller VVER Outerpack

6.10.11.10 BENCHMARK EVALUATIONS

The computer code used for these criticality calculations has been benchmarked against applicable criticality experiments.

6.10.11.10.1 Applicability of Benchmark Experiments

There are approximately 180 experiments that are applicable to transport[1]. Of these, 37 were selected based on their structural, material, poison, geometry, and spectral similarities to the Traveller-VVER. Table 6-50 gives a summary of available LWR critical experiments selected for the Traveller-VVER. The selected experiments were grouped into four classifications: Simple Lattice, Separator Plate, Flux Trap, and Water Hole experiments. Table 6-51 shows the breakdown of the experiments into the four classifications.

In determining which experiments were not applicable, criteria were established by which experiments would be rejected. These criteria include:

- No separator plates made of hafnium, copper, cadmium, zirconium, or depleted uranium (include only separator plates made of stainless steel, aluminum or boron).
- No thick wall lead, steel, or uranium reflector material.
- Hexagonal fuel rod lattices.
- No burnable poison rods (Ag-In-Cd rods, B_4C rods, UO_2-Gd_2O_3 rods).
- No soluble boron.

The 37 experiments were analyzed for their applicability to the Traveller package. Table 6-52 shows a summary comparison of the benchmark critical experiment properties to the Traveller package. The range of properties for the critical experiment includes range of values for the Traveller-VVER package.

The benchmark inputs were run with KENO-VI on the SCALE 5.1 system; results were used to determine the USL for the Traveller-VVER calculations.

The analysis concluded that no single group of critical benchmark experiments (simple lattice, separator plate, flux trap, or water hole) contains all the characteristics of the Traveller-VVER shipping package. However, the four groups each represent different aspects of the package model that are important to understanding the bias associated with the package modeling. The simple lattice and water hole experiments represent the fuel region modeling (i.e., fuel enrichment, lattice pitch, water-to-fuel ratio), and the separator plate and flux trap experiments represent additional characteristics of the package modeling (i.e., moderator, neutron absorbers).

1. NUREG/CR-6361 (ORNL/TM-13211): Criticality Benchmark Guide for Light-Water-Reactor Fuel in Transportation and Storage Packages.

6.10.11.10.2 Traveller-VVER Bias Determination

After comparison of critical experiments, USLSTATS was used to assist with the statistical analysis of the benchmark experiments. It provides two methods of determining a USL, and a comparison of these two methods is shown in Figure 6-50.

Figure 6-50 shows the Upper Safety Limits (USLs) for the 37 LWR Fuel Critical Experiments. The first (referred to as USL-1) uses a confidence band calculated using a linear regression fit based on the results from the selected benchmarks, and places an additional administrative margin on the lower band, which is then used as the USL.

The second method (referred to as USL-2) is a single-sided closed interval approach, using a uniform width. The purpose of this method is to determine a uniform tolerance band over a specified closed interval, based on a linear least squares model. This method uses a statistically calculated subcritical margin (with a confidence level of 0.95 in this case), and is used to determine whether the USL-1 method is sufficiently conservative.

The trending parameter chosen for the two methods was the AEF. The AEF range in the benchmark cases provides ample coverage for the calculated average energy of fission (AEF) values of the various Traveller-VVER configurations (individual vs. package array, normal transport vs. HAC, etc). Ample coverage means that no extrapolation is required in order to determine the USL. The end result of this is shown graphically in Figure 6-19.

The results shown in Figure 6-19 indicate that a USL of 0.9350 is acceptable including an administrative margin, $\Delta k_m = 0.05$, and a bias of negative 0.015 ($\beta + \Delta\beta = -0.01$). The administrative margin is acceptable because for all grouping of experiments the minimum subcritical margin is positive, USL2-USL1 $\geq$ 0. The largest statistical bias (USL-2) is associated with the flux trap group. The application of the statistically based subcritical margin indicates the administrative margin is adequate by a margin of at least 0.0161 (USL-2 minus USL-1). Therefore, the bias determination is made by including all 37 experiments in the USLSTAT calculation.

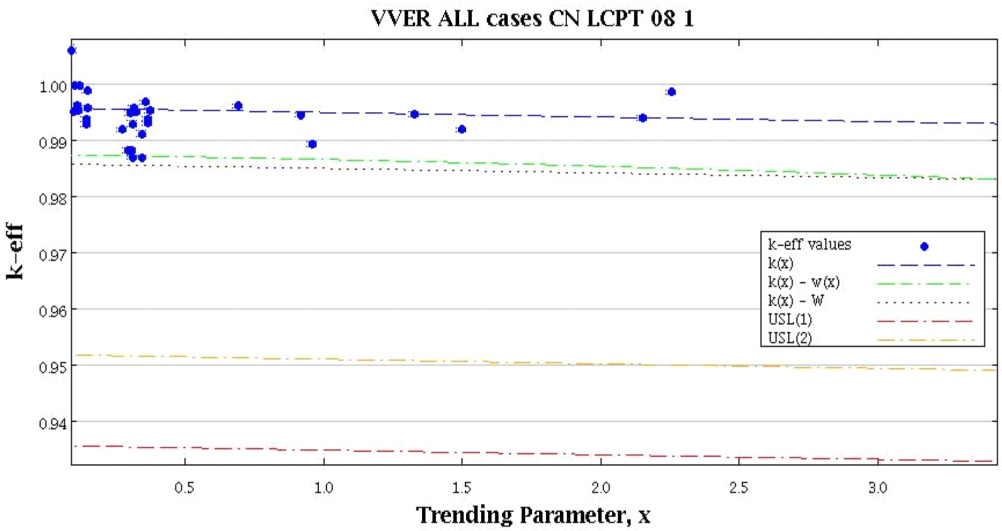

Figure 6-50 USLs for all 37 critical experiments, k_{eff} vs Average Energy of Fission

For the Traveller VVER HAC cases, the AEF is approximately 0.29. When using all the selected benchmarks, the range of AEF is much larger than the applicable range of the Traveller VVER HAC cases. Hence, to evaluate the change in USL and therefore bias of the selected benchmarks, two additional USL calculations are performed reducing the selected benchmarks to those with the AEF trending parameter closer to the applicable Traveller VVER HAC case range, i.e., AEF less than 1 and AEF less than 0.4. The resultant data for each USL calculation are normal and a qualitative comparison of parameters encompass the ranges of the Traveller VVER package system, therefore the conservative USL calculation which includes all 37 selected benchmarks is applied. The conservative USL calculation of 0.9355, rounded down to 0.9350, is applied to the Traveller VVER criticality safety case.

Table 6-50 Summary of LWR Critical Experiments

Report	No. of Available Experiments	No. of Selected Experiments	Description of Criticality Experiments
NS&E, Vol. 71 (Ref. 8)(1)	26	3	4.74 wt % ^{235}U UO_2 fuel rods in square lattices of 1.26-, 1.60-, 2.10-, and 2.52-cm pitch; triangular and triangular with pseudo-cylindrical shape lattices of 1.35-, 1.72-, and 2.26-cm pitch; irregular hexagonal lattices of 1.35-cm pitch; lattices with water holes.
PNL-2438 (Ref. 9)(1)	48	1	2.35 wt % ^{235}U UO_2 fuel rods in square lattices of 2.032-cm pitch; Cd, Al, Cu, stainless steel, borated stainless steel, Boral, and Zircaloy separator plates between assemblies.
PNL-3314 (Ref. 11)(1)	142	2	2.35 and 4.31 wt % ^{235}U UO_2 fuel rods in square lattices of 1.684- and 1.892-cm pitch; stainless steel, borated stainless steel, Cd, Al, Cu, Boral, Boroflex, and Zircaloy separator plates between assemblies; lattices with water holes and voids.
PNL-4976 (Ref. 14)(1)	17	1	4.31 wt % (2.35 wt %) ^{235}U UO fuel rods in hexagonal lattices of 2.398-, 1.801-, and 1.598-cm pitch; moderator contains Gadolinium.
BAW-1645 (Ref. 17)(1)	21	4	2.46 wt % ^{235}U UO_2 fuel rods in close-packed triangular lattices of 1.209-cm pitch, close-packed square lattices of 1.209-cm pitch, and square lattices of 1.410-cm pitch.
PNL-2615 (Ref. 19)(1)	32	1	4.31 wt % ^{235}U UO fuel rods in square lattices of 2.540-cm pitch; stainless steel, borated stainless steel, Cd, Al, Cu, Boral, and Zircaloy separator plates between assemblies.
PNL-6205 (Ref. 20)(1)	19	1	4.31 wt % ^{235}U UO2 fuel rods in square lattices of 1.891-cm pitch; Boral flux traps.

Table 6-50 Summary of LWR Critical Experiments (cont.)

Report	No. of Available Experiments	No. of Selected Experiments	Description of Criticality Experiments
PNL-7167 (Ref. 21)[(1)]	9	4	4.31 wt % ^{235}U UO2 fuel rods in square lattices of 1.891-cm pitch; Boral flux traps containing voids filled with Al plates, Al rods, or UO2 fuel rods.
PNL-3602 (Ref. 22)[(1)]	49	1	2.35 and 4.31 wt % ^{235}U UO fuel rods in square lattices of 2.032- and 2.540-cm pitch; reflecting walls of stainless steel; separator plates of stainless steel, borated stainless steel, Boral, Cu, Cd, and Boroflex between assemblies.
Haon et al., PATRAM '80 (Ref. 23)[(1)]	12	4	4.74 wt % UO fuel rods in square lattices of 1.6-cm pitch; Boral separator plates; lead, steel, or water reflecting walls.
LEU-COMP-THERM-031[(2)]	6	6	Water-moderated hexagonally pitched lattices with low enriched (approximately 5% ^{235}U) cylindrical fuel rods, zirconium clad, with a pitch of 8 mm.
LEU-COMP-THERM-032[(2)]	9	9	Water-moderated hexagonal lattices of enriched (10% ^{235}U) fuel rods with stainless steel clad, and pitch values of 0.7, 1.4, and 1.852 cm at three different temperatures (ranging from 20°C to 274°C) for each lattice.

Notes:
1. Reference numbers and case numbers shown in parentheses next to name are same as those defined in NUREG/CR-6361.
2. *International Handbook of Evaluated Criticality Safety Benchmark Experiments*, NEA/NSC/DOC(95)03 (2014).

Table 6-51 Critical Benchmark Experiment Classification				
	Critical Benchmark Experiment Groups			
Report	**Simple Lattice**	**Separator Plate**	**Flux Trap**	**Water Hole**
PNL-2438 (Ref. 9)[(1)]	--	P2438BA (61)	--	--
NUREG/CR-0073 (PNL-2615) (Ref. 19)[(1)]	--	P2615BA (67)	--	--
NUREG/CR-1547 (PNL-3314) (Ref. 11)[(1)]	--	P3314BA (83) P3314BC (84)	--	--
PNL-6205 (Ref. 20)[(1)]	--	P62FT231 (157)	--	--
PNL-7167 (Ref. 21)[(1)]	--	P71F14F3 (158) P71 F14V3 (159) P71 F14V5 (160) P71F214R (161)	--	--
BAW-1645-4 (Ref. 17)[(1)]	--	BW1645T1 (27) BW1645T2 (28) BW1645T3 (29) BW1645T4 (30)	--	--
PNL-4976 (Ref. 14)[(1)]	P49-194 (156)	--	--	--
NS&E, Vol. 71 (Ref. 8)[(1)]	NSE71H1 (54) NSE71H2 (55) NSE71H3 (56)	--	--	--
NUREG/CR-1784 (PNL-3602) (Ref. 22)[(1)]	--	P3602BA (109) [3]	--	--

Table 6-51 Critical Benchmark Experiment Classification (cont.)

Report	Simple Lattice	Separator Plate	Flux Trap	Water Hole
	Critical Benchmark Experiment Groups			
Haon et al., PATRAM ’80 (Ref. 23)[1]	--	PAT80L1 (162) PAT80L2 (163) PAT80SS1 (164) PAT80SS2 (165)	--	--
ICSBEP handbook[2]	leu-comp-therm-031, case #1 leu-comp-therm-031, case #2 leu-comp-therm-031, case #3 leu-comp-therm-031, case #4 leu-comp-therm-031, case #5 leu-comp-therm-031, case #6			
ICSBEP handbook[2]	leu-comp-therm-032, case #1 leu-comp-therm-032, case #2 leu-comp-therm-032, case #3 leu-comp-therm-032, case #4 leu-comp-therm-032, case #5 leu-comp-therm-032, case #6 leu-comp-therm-032, case #7 leu-comp-therm-032, case #8 leu-comp-therm-032, case #9			
Total = 37	**19[3]**	**18**	**0**	**0**

Note:

1. Reference numbers and case numbers shown in parentheses next to name are same as those in defined in NUREG/CR-6361.
2. Includes ICSBEP experiments.
3. *International Handbook of Evaluated Criticality Safety Benchmark Experiments*, NEA/NSC/DOC(95)03 (2014).

Table 6-52 Summary Comparison of Benchmark Critical Experiment Properties to Traveller-VVER Package

Cases	Critical Benchmark Experiments			Traveller-VVER Package
	All	Simple Lattice	Separator	
Number of cases	37	19	18	6
Properties of Lattice				
Water-to-fuel volume ratio	0.15 – 20.35	0.50 – 20.35	0.15 – 3.88	1.75 – 3.44
Hydrogen-to-fissile ratio	17.40 – 398.70	33.60 – 629.40	17.40 – 398.70	105.93(1)
Lattice pitch	0.70 – 2.54	0.70 – 2.26	1.21 – 2.54	1.28-1.40
Lattice type	Square & Hexagonal	Hexagonal	Square & Hexagonal	Hexagonal
Dancoff factor	0.0195 – 1.1737	0.0195 – 0.4943	0.0390 – 1.1737	0.1314 – 0.2263
Properties of UO2 Fuel Rods				
Outside radius, cm	0.2550 – 3.6030	0.2550 – 0.7075	0.4700 – 3.6030	0.4572
Clad thickness, cm	0.040 – 0.081	0.040 – 0.075	0.060 – 0.081	0.057
Clad material(s)	Al Zircaloy Stainless Steel	Al Zircaloy Stainless Steel	Al	Zircaloy
Pellet radius, cm	0.2080 – 0.6325	0.2080 – 0.6325	0.3950 – 0.6325	0.3922
Active fuel length, cm	59.66 – 145.64	59.66 – 91.44	91.44 – 145.64	353
Enrichment, $^{235}U/U$ wt%	2.35 – 9.83	4.31 – 9.83	2.35 – 4.31	5.00
Fuel density, g/cm^3	9.21 – 10.40	9.24 – 10.40	9.21 – 10.40	10.96
Neutron Interaction Characteristics				
Plate Boral conc (wt%)	28.7 – 39.3	N/A	28.7 – 39.3	35.37 3
Plate thickness, cm	0.08 – 3.08	N/A	0.08 – 3.08	0.3175
Plate material(s)	Al w/Boron SS w/Boron Pb w/Boron	N/A	Al w/Boron SS w/Boron Pb w/Boron	Al w/Boron
AGF	164.30 – 216.04	164.30 – 216.04	171.11 – 208.71	140.86 – 195.55(3)

Table 6-52 Summary Comparison of Benchmark Critical Experiment Properties to Traveller-VVER Package (cont.)

Cases	Critical Benchmark Experiments			Traveller-VVER Package
	All	Simple **Lattice**	**Separator**	
Assembly Separation, cm	1.78 – 8.30	--	1.78 – 8.30	~20(2)

Notes:

1. HAC cases, similar to critical configurations.
2. Approximate spacing between assemblies in touching packages within an array.
3. HAC, NCT, and Routine cases -HAC being the larger AGF.