71-9292

Westinghouse

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U. S. Nuclear Regulatory Commission
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Our ref: NMS-NRC-05-005
Your Ref:

Mr. Cuadrado:

April 18, 2005

Subject: CERTIFICATE OF COMPLIANCE NO. 9292 FOR THE MODEL NO. PATRIOT PACKAGE: SUBMISSION of Response to Request for Additional Information (RAI) – DOCKET No. 71-9292; TAC No. L23770

Attached please find our response to the Request for Additional Information (RAI) dated January 31, 2005, as clarified in the teleconferences that were held March 1 and March 8, and documented in your March 11, 2005 letter. Westinghouse appreciates USNRC allowing us two additional weeks to prepare this submittal.

Enclosed please find responses to each request and the change pages that make up revision 1 to the Patriot SAR. As agreed in earlier telephone conference, the application for loose rod transport will be submitted under separate letter.

Please direct any questions to the me at (803) 647-3552.

Sincerely,
WESTINGHOUSE ELECTRIC COMPANY, LLC

Norman A. Kent

Norman A. Kent
Manager Transport Licensing and Regulatory Compliance
Nuclear Material Supply

Enclosures:
1. RAI Responses
2. Rev 1 Change pages to SAR

NMSS01

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Enclosure 1: RAI Questions and Westinghouse Responses

RAI ITEM 6-1.
Justify the applicability of the bias used for the criticality analysis.

The applicant states the criticality analyses were performed using SCALE 4.4, CSAS25 and CSASX sequences and the 238-group ENDF/B-V library. The applicant also states that a bias and bias uncertainty ($\beta+\Delta\beta$) of 0.0123 is used for calculating the Upper Safety Limit (USL). However, this value appears to be for a 44-group library. Further, no description is provided regarding how this bias was determined nor of the benchmarks that were used.

The bias and its uncertainty should be established through a benchmark analysis performed by the applicant and not taken from other sources. This benchmark analysis and the bias determination should be described. The description should include discussion of the benchmark experiments used and justification of the benchmarks' applicability as well as discussion of any trends in the bias observed with respect to parameters such as pitch-to-rod diameter, H/U ratio, etc. The benchmarking should properly account for the computer code (including version), computer hardware, and cross-section library used to calculate the k-effective values in the package analysis. Also, the critical experiments used in the benchmark analysis should be those that most closely represent the characteristics of the package models analyzed, including solid neutron poisons, materials, configurations, and neutron spectra.

Clarification.
Submit the benchmark calculations and bias determination and revise the proposed Final Safety Analysis Report (FSAR) to specifically describe how the bias was determined, adjusting the criticality analysis as needed to account for calculation of the bias that is appropriate for the package analysis method. For completeness, the bias analysis should address any trends with respect to important parameters, such as the H/U ratio, providing justification of the benchmark's applicability for package parameters that are outside the range of the benchmarks.

Westinghouse Response:
The USL was first set using a bias and bias uncertainty ($\beta+\Delta\beta$) value from the benchmark critical experiment calculations that were done for low enriched heterogeneous systems using the SCALE/CSAS25/44-Group Library. For this calculation 44 experiments were selected that applied to low enriched heterogeneous systems. They are listed in Table 1, and are subdivided into appropriate categories in Tables 2-8. These experiments are low-enriched light-water-reactor (LWR) lattices. The series of experiments demonstrates the performance of both the cross sections and the SCALE resonance cross-section processing methodology. These experiments span a range of moderation and fuel pin arrangements that are applicable in evaluating LWR fuel storage and transport. Cases 1-44 were the original benchmark critical experiments used. Cases 45-49 were added for their applicability to Gadolinia-Urania systems.

Table 1: Benchmark Critical Experiments

Case #	Case Name		Case #	Case Name
1	bw1484-i.18332.out:		26	pnl-3314-116.1322.out:
2	bw1484-ii.358.out:		27	pnl-3314-119.19398.out:
3	bw1484-iii.24205.out:		28	pnl-3314-055.25658.out:
4	bw1484-iv.29886.out:		29	pnl-3314-070.2076.out:
5	bw1484-v.18468.out:		30	pnl-2615-008.25870.out:
6	bw1484-vi.501.out:		31	pnl-2615-004.2286.out:
7	bw1484-vii.24341.out:		32	pnl-2615-031.1792.out:
8	bw1484-viii.132.out:		33	Bw1645s1.1950.out:
9	bw1484-ix.24614.out:		34	Bw1645s2.19626.out:
10	bw1484-x.18725.out:		35	Bw1645t1.26073.out:
11	bw1484-xi.787.out:		36	Bw1645t2.19824.out:
12	bw1484-xii.981.out:		37	Bw1645t3.2556.out:
13	bw1484-xiii.24808.out:		38	Bw1645t4.26281.out:
14	bw1484-xiv.482.out:		39	Nse71h1.2773.out:
15	bw1484-xv.1214.out:		40	Nse71h2.20046.out:
16	bw1484-xvi.18974.out:		41	Nse71h3.2295.out:
17	bw1484-xvii.1419.out:		42	Nse71sq.26500.out:
18	bw1484-xviii.25026.out:		43	Nse71w1.3026.out:
19	bw1484-xix.739.out:		44	Nse71w2.26708.out:
20	bw1484-xx.25233.out:		45	BW1810A.2632.out:
21	bw1484-xxi.19182.out:		46	BW1810B.3288.out:
22	pnl-2438-020.1066.out:		47	Bw1810cr.20673.out:
23	pnl-2438-032.1655.out:		48	BW1810D.27507.out:
24	pnl-3314-002.1854.out:		49	BW1810E.3515.out:

Table 2 Descriptive statistics of Simple Lattice calculations

Description	No. of exp.	k_{eff} range	k_{eff}	$\pm\sigma$	AEF range (ev)	Case No. (Table 1)
Square	6	0.9916-0.9956	0.9936	0.0015	0.1130-0.2508	1,9,24,28,31,45

Table 3 Descriptive statistics of Separator Plate calculations

Description	No. of exp.	k_{eff} range	k_{eff}	$\pm\sigma$	AEF range (ev)	Case No. (Table 1)
Boral	3	0.9894-0.9962	0.9932	0.0030	0.0974-0.1820	22,26,32,
Boraflex	1		0.9921	0.0007	0.1823	27
Borated steel	1		0.9938	0.0007	0.0965	23
Steel	5	0.9907-0.9950	0.9932	0.0021	0.1130-0.2508	25,29.30
TOTAL	8	0.9894-0.9962	0.9930	0.0022	0.0965 0.2454	

Table 4 Descriptive statistics of Separator plate-soluble boron calculations

Description	No. of exp.	k_{eff} range	k_{eff}	±σ	AEF range (ev)	Case No. (Table 1)
Hexagonal						
Aluminum	4	0.9856-0.9962	0.9935	0.0027	0.9721-2.2802	35-38
Square						
Borated aluminum	9	0.9856-0.9942	0.9894	0.0027	0.1517-0.2039	13-21
Aluminum	2	0.9912-0.9958	0.9935	0.0033	1.3402-1.3999	33,34
Steel	2	0.9924-0.9942	0.9936	0.0017	0.1667-0.1963	11,12
TOTAL	17	0.9856-0.9962	0.9913	0.0032	0.1517 2.2802	

Table 5 Descriptive statistics of urania gadolinia rod calculations

Description	No. of exp.	k_{eff} range	k_{eff}	±σ	AEF range (ev)	Case No. (Table 1)
Gadolinia	4	0.9946-0.9990	0.9961	0.0020	0.2514-0.3414	46-49

Table 6 Descriptive statistics of Water hole calculations

Description	No. of exp.	k_{eff} range	k_{eff}	±σ	AEF range (ev)	Case No. (Table 1)
Water holes	6	0.9926-0.9995	0.9954	0.0029	0.0701-0.2704	39-44

Table 7 Descriptive statistics of Absorber Rods calculations

Description	No. of exp.	k_{eff} range	k_{eff}	±σ	AEF range (ev)	Case No. (Table 1)
B4C	5	0.9898-1.0010	0.9940	0.0054	0.1465-0.1883	4-8

Table 8 Descriptive statistics of Soluble Boron calculations

Description	No. of exp.	k_{eff} range	k_{eff}	±σ	AEF range (ev)	Case No. (Table 1)
Borated water	3	0.9927-0.9953	0.99403	0.0013	0.0503 - 0.1472	2, 3, 10

The critical experiment benchmark calculations used for determining the bias and bias uncertainty (β+Δβ) for the Patriot SAR revision were done using the SCALE/CSAS25/238-Group Library. As a result, the revised (β+Δβ) value has been changed from 0.0123 to 0.0157, an increase of 0.0034. Therefore, the revised acceptance criteria for the USL will be changed from 0.9377 to 0.9343. Revision 1 to t Patriot SAR will be revised to reflect this change.

This difference in ($\beta+\Delta\beta$) is consistent with comparisons of the performance of 44-Group ENDF/B-V and 238-Group ENDF/B-V libraries. NUREG/CR-6686 , "Experience with the SCALE Criticality Safety Cross-Section Libraries," examines in detail the performance of the SCALE criticality safety cross-section libraries on various types of fissile systems. The performance 44-Group ENDF/B-V library for heterogeneous low-enriched LWR lattice systems has shown that experiments have an average keff of about 1.00 ± 1%. The performance of 238-Group ENDF/B-V library for heterogeneous low-enriched LWR lattice systems has shown that experiments have an average keff of about 0.995 ± 1%.

The average k_{eff} is not significantly different for the categories of experiments (simple lattice, separator plate, separator plate-soluble boron, urania gadolinia rod, water hole, or absorber rods). The simple lattice, urania gadolinia rod, and water hole categories represent are the most applicable to the PATRIOT package. Mean of the energy (ev) of the average lethargy causing fission (EALF) 1.9728, and range 0.1826 to 10.9531 for the PATRIOT package applications. The energy (ev) of the average lethargy causing fission for the PATRIOT package that results in a maximum keff over the range of interspersed moderation densities and moderator configurations is approximately 0.6 ev. Only six of the critical benchmark critical experiments have EALF that is greater than 0.5 ev, but the results show no significant trend in bias vs. energy. The largest bias results from a the correlation to the enrichment parameter, and results in an upper safety limit of 0.9343 including a 0.05 arbitrary margin to ensure subcriticality.

The Patriot SAR appendix 6A was revised to reflect this change in USL.

RAI ITEM 6-2.
Specify whether the actual shipping configuration for the proposed contents may include the use of plastic inserts.

Clarification.
State in the RAI response the applicability and use of plastic inserts for the package.

Westinghouse Response:
Plastic inserts are used only when transporting unchanneled fuel bundles, to prevent damage to the rods during transport. The fuel loading sets described in Section 6A involve channeled fuel only, and therefore will not be transported with plastic inserts.

RAI ITEM 6-3.
Specify whether the fuel loadings contain partial length fuel rods or Gadolinia-Urania rods and the maximum number of each.

Clarification.
Describe in the proposed FSAR how fuel loading modeling was conservatively conducted to address partial loading.

Westinghouse Response:

The contents for which section 6A has been added to the SAR is a fuel bundle that contains twelve (12) partial length rods. Revision 1 to the SAR will revise Section 1.2.3, *Contents of Packaging*, to describe the new fuel bundle. An explanation follows.

The fuel bundle shown in figure 6A-4 contains four-1/3 length rods and eight-2/3 length rods. The 1/3 length rods are located on the outside corners of the bundle. The eight-2/3 length rods, two per mini-bundle, are located on the geometric diagonal toward the center of the bundle. The three new loading sets, #4 - #6, correspond to the upper, middle, and lower zones of the fuel bundle respectively. The criticality safety analysis was performed by analyzing each zone of the contents in its most conservative configuration as though it were a full length fuel bundle, thus bounding the actual fuel bundle.

Each zone of the actual fuel bundle also contains a different number of Gadolinia-Urania rods. In a similar manner the criticality analysis assumed the most conservative arrangement for these rods in each loading set.

Section 1.2.3 will be revised to read as follows:

1.2.3 Contents of Packaging

Each shipping package holds a maximum of two BWR fuel rod assemblies. The unirradiated UO2 fuel rod assemblies are in a 10x10 square array having a fuel cross-sectional area of approximately 25 in^2. A fuel channel, which is a zirconium alloy box that contains the fuel rod bundles inside the reactor, may also be shipped as part of the bundle. Two assembly types may be transported in the package. They are described below.

The first assembly type, shown in figure 6.2, is made up of four sub-assemblies with 24 fuel rods in each subassembly. The 96 full length fuel rods have a nominal active length of 150 inches. Fuel pellets have a nominal outside diameter (O.D.) of 0.819 cm and are encapsulated in a zirconium alloy clad fuel tube. The cladding tube has a nominal thickness of 0.063 cm and a nominal outside diameter of .962 cm with end caps welded to each end. One of the following three paragraphs describe the enrichments of the fuel rods in the assembly:

a) The maximum U235 enrichment of the fuel rod assembly is 5.0% by weight; with a maximum average U235 enrichment within any axial zone of the assembly of 4.0% by weight. In addition, there are two (2) fuel rods per quadrant containing at least 2.5% by weight gadolinium.

b) The maximum U235 enrichment of the fuel rod assembly is 5.0% by weight; with a maximum average U235 enrichment within any axial zone of the assembly of 4.73% by weight. In addition, there are two (2) fuel rods per quadrant containing at least 5.3% by weight gadolinium.

c) The maximum U235 enrichment of the fuel rod assembly is 5.0% by weight; with a maximum average U235 enrichment within any axial zone of the assembly of 4.86% by weight. In addition, there are three (3) fuel rods per quadrant containing at least 2.4% by weight gadolinium.

The second assembly type, shown in figure 6A-4, is made up of four sub-assemblies with 24 rods in each sub-assembly. The assembly contains four-1/3 length rods and eight-2/3 length rods. The 1/3 length rods are located on the outside corners of the assembly. The eight-2/3 length rods, two per sub-assembly, are located on the geometric diagonal toward the center of the assembly. The three zones (upper, middle, and lower) of the assembly correspond to the fuel loading sets #4-#6 discussed in Section 6A.

The upper zone will have a minimum of eight Gadolinia-Urania rods each having a content of at least 4.0 wt% Gd. The middle zone will have a minimum of ten Gadolinia-Urania rods each having a content of at least 4.0 wt% Gd. The lower zone will have a minimum of twelve Gadolinia-Urania rods each having a content of at least 4.0 wt% Gd.

Fuel pellets have a nominal outside diameter (O.D.) of 0.848 cm and are encapsulated in a zirconium alloy clad fuel tube. The cladding tube has a nominal thickness of 0.061 cm and a nominal outside diameter of .984 cm. The maximum U^{235} enrichment is 5.0 wt%.

RAI ITEM 6-4.

Describe how Gadolinia is incorporated into the Gadolinia-Urania rods.

The criticality model assumes that the Gadolinia is homogeneously mixed with the UO2 fuel. However, the application is not clear as to whether this model accurately describes the actual Gadolinia-Urania rods. It is known that these rods can be manufactured with the Gadolinia and fuel homogeneously mixed or with the Gadolinia placed on the pellet surface. If the rods in the model do not match the rods' actual form, provide a description of the actual form and justify how the analysis applies to and bounds this configuration.

Clarification.

State in the RAI response that the Gadolinia is homogeneously mixed with UO2 fuel.

Westinghouse Response:

The Gadolinia is homogeneously mixed with UO2 fuel.

RAI ITEM 6-5.

Justify neglecting the fuel assembly structures beyond the active fuel length in the criticality analysis.

Clarification.

Revise the proposed FSAR to specifically describe the model sensitivity with respect to the assembly structures.

Westinghouse Response:

As stated in the SAR, Section 6A.3.1.1. (pg 6A-7) the contents models were similar to the models in Section 6. That is, the no fuel rod assembly structures beyond the assumed active length of the rod are represented in the neutronics calculations. This is similar to modeling the nozzles as full density water because the array is fully reflected.

Westinghouse performed an analysis for an earlier license application to evaluate the effect on system k_{eff} if the top and bottom nozzles were modeled as solid stainless steel and half water and half stainless steel rather than full density water. This analysis was done for another package, the Traveller, (Docket No. 9297) but the findings are valid for the Patriot.

Three cases were considered. First, the baseline case for the Traveller package, which modeled the top and bottom nozzles as water. A second case was run where the nozzles were modeled as 100% stainless steel. The third case modeled the nozzles as half water / half stainless steel. Results are given below. They indicate that the material on the ends of the fuel assemblies (water or stainless steel) have no significant effect on system keff due to the relatively small axial leakage of the array. The stainless steel case is conservative because the nozzles were modeled as solid blocks, which they are not.

Traveller Case #	Ks	Sigma	keff + 2 Sigma
XL-HAC-ARRAY-100	0.9377	0.0008	0.9393
Solid Stainless Steel Top and Bottom Nozzles	0.9382	0.0008	0.9398
Half Water Half Stainless Steel Top and Bottom Nozzles	0.9366	0.0009	0.9384

The following paragraph will be added to Section 6A.3.1.1 of the SAR:

As implied above, the top and bottom nozzles were not modeled in this analysis. Westinghouse performed an analysis for an earlier license application to evaluate the effect on system keff if the top and bottom nozzles were modeled as full density water, solid stainless steel, and half water and half stainless steel. Three cases were considered, a baseline case in which the top and bottom nozzles are modeled as water; a second case in which the nozzles were modeled as 100% stainless steel; and a third case where the nozzles were modeled as a water- stainless steel mixture. Results show that the material on the ends of the fuel assemblies (water or stainless steel) have an insignificant effect (< 1 sigma) on system keff due to the relatively small axial leakage of the array.

RAI ITEM 6-6.

Provide a calculation of the Gadolinium and Oxygen densities for the Gadolinia in the Gadolinia-Urania rods.

Clarification.

Provide detail on the Gadolinium and Oxygen densities for the Gadolinia in the Gadolinia-Urania rods and revise the proposed FSAR to reflect this information.

Westinghouse Response:

The method for calculating Gadolinia-Urania pellet densities is described below. The first paragraph will be added to revision 1 of the SAR.

The Gadolinia pellet density depends on the Gd_2O_3 content. The composition for the Gadolinia-Urania pellet material is conservative for the purpose of the criticality evaluation, but bounds the specified range of Gadolinia-Urania pellet UO_2 and Gd_2O_3 contents. The actual range for Gadolinia-Urania pellet density is 10.57 to 10.43 g/cm^3 with a corresponding Gd_2O_3 content of 1.00 to 5.00 w/o. The fuel assembly content specifies a minimum of eight Gadolinia-Urania fuel rods with a Gd_2O_3 content of 4.00 w/o and the Gadolinia-Urania density that is 10.43 g/cm3. The Gadolinia-Urania material composition is specified in CSAS as a mixture of Uranium oxide (UO_2), Gadolinium (Gd), and Oxygen (O) that minimizes the Gadolinium content and maximizes the uranium oxide content. The UO_2 composition is specified as the theoretical UO_2, 10.96 g/cm^3. The Gd_2O_3 composition is specified using the standard composition for Gd and O with a density that is determined using the Gd_2O_3 density for 4.00 w/o adjusted to a minimum limit using the tolerance of a single pellet. Furthermore, the Gd density is reduced to 75 percent of this minimum limit to account for any other uncertainties in the Gadolinia-Urania fuel composition such as distribution and size of Gd_2O_3 particles.

The following method for calculating Gadolinia-Urania pellet densities is conservative with respect to uranium and gadolinia content:

1. Assume TD for the purpose of calculating UO_2content in Gadolinia-Urania pellet is 10.96 g/cc

2. Assume the minimum pellet density for the purpose of calculating Gadolinia-Urania content = 10.31 g/cc UO_2

3. Apply nominal Gd_2O_3 content to get 0.37 g/cc Gd_2O_3

4. Calculate the Gd component density and arbitrarily take 75% of the Gd content.

$$M(Gd2O3) = 362.504$$
$$A(Gd\text{-}NAT) = 157.256$$
$$2 \times \frac{157.256}{362.256} \times 0.37 = 0.322 g/ccGd$$
$$0.322 g/ccGd \times 0.75 = 0.2415 g/ccGd$$
$$0.37116 - 0.32202 = 0.04914 g/ccO$$

RAI ITEM 6-7.

Justify the partial flooding configuration in the criticality analysis as the most reactive configuration of internal moderation.

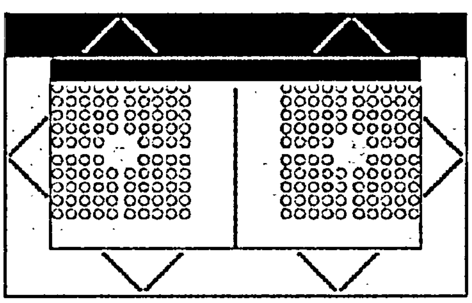
Clarification.

Verify that the chosen partial flooding configuration is the most reactive, providing information in the RAI response that shows this and revising the FSAR criticality as needed.

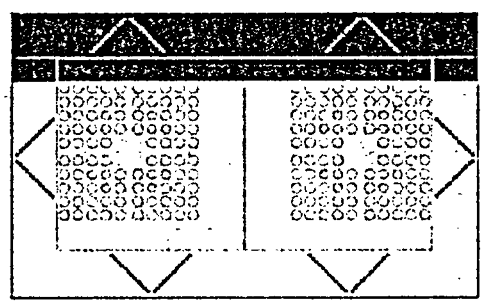
Westinghouse Response:

The exact nature of this question had to do with the fact that the partial flooding configuration, shown in figure 6A-11 of the SAR and below, shows that there is water in the outer portion of the inner container that extends above the fuel assemblies. The NRC raised the question about the effect on k_{eff} of replacing that water with void.

Westinghouse took the most limiting case in the SAR and modified the input deck to add void to that area. The most limiting case corresponds to Run #6P-1-030 in table 6A-6. The results are given in the table below. They show that adding the void to that area results in a very slight increase in k_{eff}, still below the USL of 0.9343.



SAR Table 6A-11



Revised Partial Flooding Configuration

Run #	keff
6P-1-030	0.9285±0.0007
6P-1-030 with void at edge	0.9308±0.0007

The following paragraph was added to section 6A.6.1.

Figures 6A-8 through 6A-11 show a representative sample of the three fuel loading sets and package configurations. Note that figure 6A-11 shows two partial flooding . The results in Tables 6A-6, 6A-8, and 6A-10 were calculated using the flooding model shown in Figure 6A-11a. The effect of moderator in the region above the fuel envelope was considered for the most reactive case, which was Run #6P-1-030 from Table 6A-6. The result for this run was 0.9285±0.0007. This case was run by modifying the flooding model as shown in Figure 6A-11b. The result for this run was 0.9308±0.0007. The difference is statistically insignificant, and both are below the USL.

RAI ITEM 6-8.

Justify the following discrepancies in the model and between the model and the text:

A. Table 6A-3 lists the density of the oxygen for the Gadolinia in the Gadolinia-Urania rod as ten times the value used in the actual model.

B. The cell-data data card has water in the pellet-clad gap while the geometry data cards show the pellet-clad gap containing void.

Westinghouse Response:

A. The value in Table 6A-3 is incorrect and will be changed to 0.04914.

B. The NRC correctly identified that the Lattice Cell data card has water in the pellet-clad gap while the geometry data cards show the pellet-clad gap containing void. The cell-data card should have had void in the pellet-clad gap. The most limiting case (6P-1-030) was re-run with the corrected cell-data card. The results are given below. Also, the model with void at the edge from question 6-7 above was run with void in the cell-data card. These results are also shown.

Filename	Lattice Cell - Moderator 2	Unit 1 or 3, Region 2	keff
6P-1-030	Water	Void	0.9285±0.0007
6P-1-030 with void in cell-data card	Void	Void	0.9286±0.0007
6P-1-030 with void at edge	Water	Void	0.9308±0.0007
6P-1-030 with void at edge and void in cell-data card	Void	Void	0.9312±0.0007

Enclosure 2: Revision 1 Change Pages

WESTINGHOUSE ELECTRIC COMPANY LLC

NUCLEAR FUEL

License Renewal Application

for the

PATRIOT

BWR Fuel Shipping Container

September, 2004

Revision 1: April, 2005

Westinghouse Electric Company LLC
Nuclear Fuel
4350 Northern Pike
Monroeville, PA 15146

PATRIOT SAFETY ANALYSIS REPORT
LIST OF EFFECTIVE PAGES (cont.)

Page	Revision	Page	Revision	Page	Revision	Page	Revision
i	0	2-34	0	6-30	0	6A-6	0
ii	0			6-31	0	6A-7	1
		3-1	0	6-32	0	6A-8	1
1-1	0	3-2	0	6-33	0	6A-9	1
1-2	1	3-3	0	6-34	0	6A-10	0
1-3	1	3-4	0	6-35	0	6A-11	0
1A-1	0			6-36	0	6A-12	1
1B-1	0			6-37	0	6A-13	1
1B-2	0			6-38	0	6A-14	0
		4-1	0	6-39	0	6A-15	0
2-1	0			6-40	0	6A-16	0
2-2	0	5-1	0	6-41	0	6A-17	0
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2-5	0	6-1	0	6-44	0	6A-20	0
2-6	0	6-2	0	6-45	0	6A-21	0
2-7	0	6-3	0	6-46	0	6A-22	0
2-8	0	6-4	0	6-47	0	6A-23	0
2-9	0	6-5	0	6-48	0	6A-24	1
2-10	0	6-6	0	6-49	0	6A-25	0
2-11	0	6-7	0	6-50	0	6A-26	0
2-12	0	6-8	0	6-51	0	6A-27	0
2-13	0	6-9	0	6-52	0	6A-28	0
2-14	0	6-10	0	6-53	0	6A-29	0
2-15	0	6-11	0	6-54	0	6A-30	0
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2-17	0	6-13	0	6-56	0	6A-32	0
2-18	0	6-14	0	6-57	0	6A-33	0
2-19	0	6-15	0	6-58	0	6A-34	1
2-20	0	6-16	0	6-59	0	6A-35	1
2-21	0	6-17	0	6-60	0		
2-22	0	6-18	0	6-61	0	7-1	0
2-23	0	6-19	0	6-62	0	7-2	0
2-24	0	6-20	0	6-63	0	7-3	0
2-25	0	6-21	0	6-64	0		
2-26	0	6-22	0	6-65	0	8-1	3
2-27	0	6-23	0	6-66	0	8-2	0
2-28	0	6-24	0	6-67	0	8-3	0
2-29	0	6-25	0				
2-30	0	6-26	0	6A-1	0		
2-31	0	6-27	0	6A-2	0		
2-32	0	6-28	0	6A-3	0		
2-33	0	6-29	0	6A-4	0		

1.0 GENERAL INFORMATION

1.1 Introduction

This application is submitted for approval of the Westinghouse Electric Company Nuclear Power, Inc. Boiling Water Reactor (BWR) new fuel rod assembly shipping package, designated as Model No. PATRIOT. The PATRIOT is based on the General Electric (GE) RA-series shipping package, including the RA-3 (Docket No. 71-4986), with some modifications. Differences between the PATRIOT and the GE RA-3 are intended to increase the structural integrity of the package and increase the package's ability to successfully complete the testing sequence described in 10CFR71. Further, criticality safety is assured through specific criticality analyses of the BWR fuel contents to be shipped. The package meets the applicable regulatory criteria of 10CFR71, with a Transport Index of 1 (i.e., TI = 50/52 = 0.9615 ≈ 1.0).

1.2 Package Description

1.2.1 Packaging

The PATRIOT shipping package is comprised of outer and inner packages. The outer package is constructed primarily of wood and serves as an overpack for the inner package. The inner package is a rectangular carbon steel box which sits inside the wooden outer package overpack. The maximum allowable gross weight of the complete package, which is equal to the test weight, is 2988 lbs. A detailed description of the inner and outer packages is provided in Sections 2.1.3 & 2.1.4. Drawings of the packages are provided in Appendix 1A.

1.2.2 Containment Boundary

The unirradiated fuel, in the form of uranium dioxide pellets, is encapsulated in sealed zirconium alloy tubes. These tubes are designed to withstand the operational conditions of a nuclear reactor. During transport in this package, the sealed tubes serve as the containment boundary for the fuel.

1.2.3 Contents of Packaging

Each shipping package holds a maximum of two BWR fuel rod assemblies. The unirradiated UO_2 fuel rod assemblies are in a 10 x 10 square array having a fuel cross-sectional area of approximately 25 in^2. A fuel channel, which is a zirconium alloy box that contains the fuel rod bundles inside the reactor, may also be shipped as part of the bundle. *Two assembly types may be transported in the package. They are described below.*

The first assembly *type, shown in figure 6.2,* is made up of four sub-assemblies with 24 fuel rods in each subassembly. The 96 full length fuel rods have a nominal active length of 150 inches. Fuel pellets have a nominal outside diameter (O.D.) of 0.819 cm and are encapsulated in a zirconium alloy clad fuel tube. The cladding tube has a nominal thickness of 0.063 cm and a nominal outside diameter of .962 cm with end caps welded to each end. One of the following three paragraphs describe the enrichments of the fuel rods in the assembly:

a) The maximum U^{235} enrichment of the fuel rod assembly is 5.0% by weight; with a maximum average U^{235} enrichment within any axial zone of the assembly of 4.0% by weight. In addition, there are two (2) fuel rods per quadrant containing at least 2.5% by weight gadolinium.

b) The maximum U^{235} enrichment of the fuel rod assembly is 5.0% by weight; with a maximum average U^{235} enrichment within any axial zone of the assembly of 4.73% by weight. In addition, there are two (2) fuel rods per quadrant containing at least 5.3% by weight gadolinium.

c) The maximum U^{235} enrichment of the fuel rod assembly is 5.0% by weight; with a maximum average U^{235} enrichment within any axial zone of the assembly of 4.86% by weight. In addition, there are three (3) fuel rods per quadrant containing at least 2.4% by weight gadolinium.

The second assembly type, shown in figure 6A-4, is made up of four sub-assemblies with 24 rods in each sub-assembly. The assembly contains four-1/3 length rods and eight-2/3 length rods. The 1/3 length rods are located on the outside corners of the assembly. The eight-2/3 length rods, two per sub-assembly, are located on the geometric diagonal toward the center of the assembly. The three zones (upper, middle, and lower) of the assembly correspond to the fuel loading sets #4-#6 discussed in Section 6A.

The upper zone will have a minimum of eight Gadolinia-Urania rods each having a content of at least 4.0 wt% Gd. The middle zone will have a minimum of ten Gadolinia-Urania rods each having a content of at least 4.0 wt% Gd. The lower zone will have a minimum of twelve Gadolinia-Urania rods each having a content of at least 4.0 wt% Gd.

Fuel pellets have a nominal outside diameter (O.D.) of 0.848 cm and are encapsulated in a zirconium alloy clad fuel tube. The cladding tube has a nominal thickness of 0.061 cm and a nominal outside diameter of .984 cm. The maximum U^{235} enrichment is 5.0 wt%.

The maximum decay heat load of the assemblies is negligible.

1.2.4 Operational Features

The PATRIOT package is an uncomplicated passive safety design used for the shipment of unirradiated BWR fuel rod assemblies. The PATRIOT package does not incorporate cooling systems, shielding, etc.

6A CRITICALITY SAFETY EVALUATION FOR NEW FUEL LOADING SETS

The criticality safety evaluation contained herein addresses the use of the PATRIOT shipping package for three new fuel package loading sets. The analysis demonstrates that the Patriot with these loading sets fully complies with the requirements of 10CFR71.55[1] and §71.59. There have been no changes made to the packaging.

This criticality evaluation presents the following information[2]:

1. Description of the new fuel loading sets.

2. Description of the most reactive configuration of the contents.

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

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

   a. 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.

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

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[1] Title 10, Code of Federal Regulations, Part 71 (10CFR71), Packaging and Transportation of Radioactive Material.

[2] NUREG/CR-5661, Recommendations for Preparing the Criticality Safety Evaluation of Transport Packages.

6A.1 DESCRIPTION OF CRITICALITY DESIGN

6A.1.1 Design Features

The design features of the Patriot packaging are not changed from the earlier analysis. See Section 6. The inner and outer containers are shown in photographs in Figure 6A-1. This appendix introduces three new fuel loading sets to the contents description.

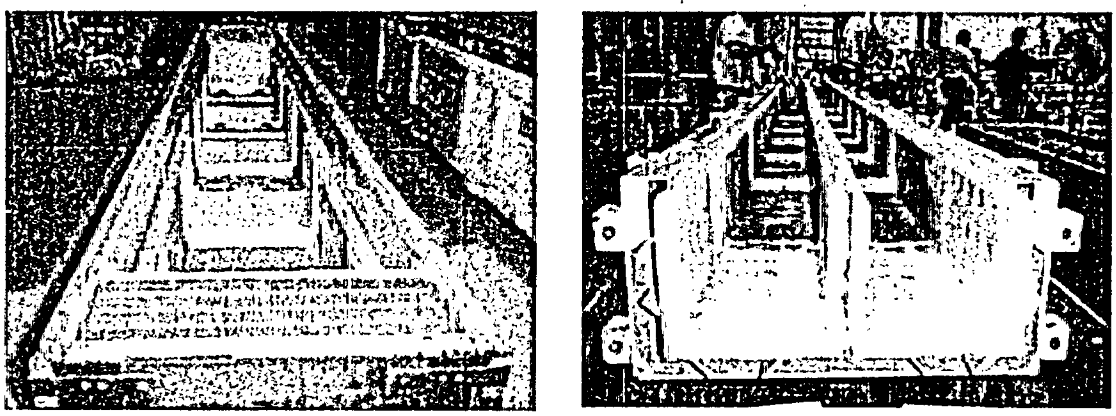

Figure 6A-1 Patriot Outer and Inner Containers

6A.1.1.1 Containment and Confinement Systems

The Containment System is described in both TSR-1 (§213) and 10CFR71.4 as, "the assembly of components of the packaging intended to retain the radioactive material during transport." The Containment and Confinement Systems for the Patriot consists of the fuel rod cladding, as stated in Section 4.

6A.1.1.2 Neutron Poisons

There are no neutron poison materials in the Patriot packaging.

6A.1.1.3 Neutron-Moderating Materials

Neutron-moderating materials in the Patriot include a wood outer container, honeycomb and ethafoam packing, and plastic inserts which are placed between the fuel rods. These are all discussed in Section 6. The wood outer container and the packing material are assumed to burn away under accident conditions. The plastic inserts, which are included in the shipping of fuel loading sets #1 - #3 described in Section 6, are not used for loading sets #4-#6. They are therefore not included in this analysis.

6A.1.1.4 Floodable Void Spaces

The Patriot inner container contains two floodable regions that flood and drain together. Coincident flooding and draining is possible because the inner basket is fabricated from perforated carbon steel as described in Section 1. See figure 6A-2. The two floodable regions are inside the basket and between the basket and inner container. These regions have been modeled at different flooding levels, and with varying water densities, in order to determine the most conservative configuration. The floodable regions are shown in Figure 6A-3.

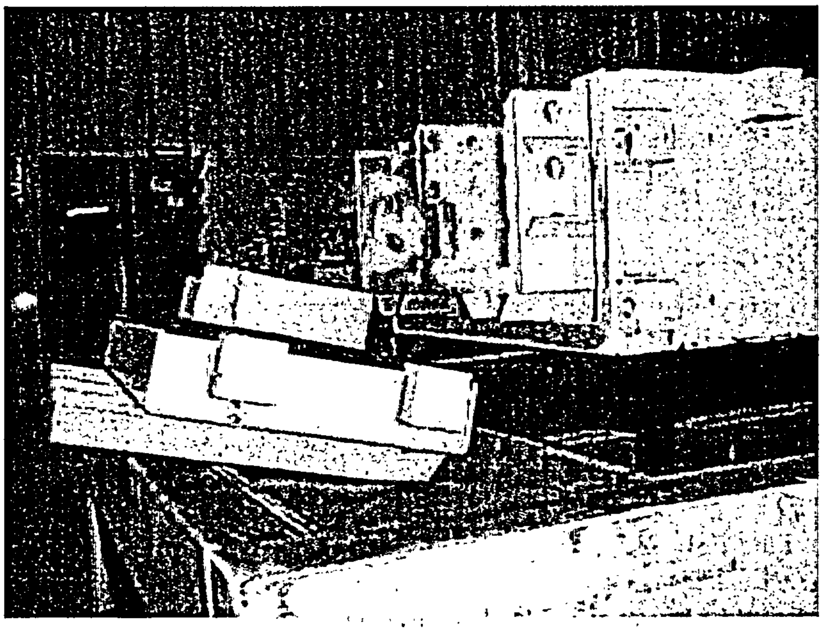

Figure 6A-2 Perforated Basket

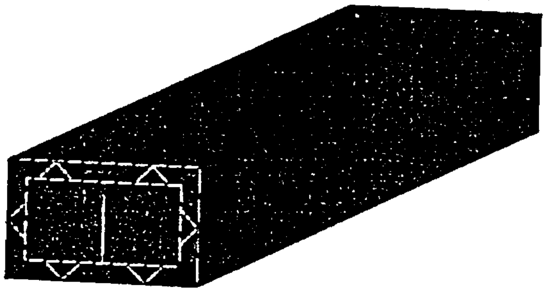

Figure 6A-3 Two Floodable Regions (perforated inner basket modeled as solid)

6A.1.1.5 Array Spacing Significant Components

Spacing does not change from that which is described in section 6.

6A.1.2 Summary Tables of Criticality Evaluation

Table 6A-1 below gives the most conservative results, rounded to three decimal places, for the Patriot when carrying Loading Sets #4 - #6. The tables give results for array configurations under hypothetical accident conditions of transport.

Table 6A-1 Summary Table for the Patriot with Fuel Loading Sets #4 - #6

Loading Set	Package Configuration	Flooding Condition	H_2O Density	$K_{eff} + 2s$
4	1	Partial	0.2	0.9257
5	1	Partial	0.2	0.9242
6	1	Partial	0.3	0.9299

6A.1.3 Criticality Safety Index (CSI)

There is no change in the CSI of the package. The Criticality Safety Index when transporting the BWR 10x10 fuel assemblies is calculated as follows, based on the provisions stated in Section 6.0. That is, the intent is to transport tup to 52 Patriot shipping packages containing 104 BWR fuel assemblies.

2 * N = Array Size
Array Size = 104
N= 104/2 → 52
Therefore, CSI = 50/52 → 1.0

6A.2 FISSILE MATERIAL CONTENTS

The package will carry heterogeneous uranium compounds in the form of BWR fuel rods in a 10x10 fuel bundle. 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 6A-2.

Table 6A-2 Uranium Isotope Distribution

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

Figure 6.2 of Section 6 illustrates the geometry of the typical 10 x 10 BWR fuel assembly and pertinent component dimensions. During shipment for the fuel analyzed in this section, the fuel assembly channel and inter-module flow channels are present. The fuel assembly consists of four mini-bundles, each containing up to 24 rods.

6A.2.1 Individual Fuel Package Loading Criteria

Three distinct new fuel package loadings are defined according to maximum ^{235}U content, number and placement of UO_2 fuel rods, number of water holes, minimum number Gd_2O_3-UO_2 rods, and the ^{235}U / Gd_2O_3-UO_2 content of the Gadolinia-Urania rods. The criteria for each loading set is given below. Note that all analyses take credit for only 75% of the Gadolinia content specified.

6A.2.1.1 Fuel Package Loading Set 4

(a) The ^{235}U enrichment of any fuel rod shall not exceed 5.0 wt%.

(b) There shall be 84 rods, 21 per mini-bundle.

(c) There shall be a minimum of eight Gd_2O_3-UO_2 rods per assembly, each having a Gadolinia content of at least 4.0 wt%. These eight Gd_2O_3-UO_2 rods shall be placed two to a mini-bundle, arrayed symmetrically about the assembly. They shall not be placed on the periphery or the outer corner.

(d) There shall be 12 water holes, three in each mini-bundle. One water hole shall be on the outside corner and the other two shall be on the geometric diagonal towards center of the assembly.

(e) The fuel pellet diameter shall be 8.48 mm nominal

6A.2.1.2 Fuel Package Loading Set 5

(a) The 235U enrichment of any fuel rod shall not exceed 5.0 wt%.

(b) There shall be 92 rods, 23 per mini-bundle.

(c) There shall be a minimum of ten Gd_2O_3-UO_2 rods per assembly, each having a Gadolinia content of at least 4.0 wt%. These ten Gd_2O_3-UO_2 rods shall be shall be arrayed symmetrically about the assembly and along a major diagonal. They shall not be placed on the periphery or the outer corner.

(d) There shall be four water holes, one in each mini-bundle, on the outside corner.

(e) The fuel pellet diameter shall be 8.48 mm nominal

6A.2.1.3 Fuel Package Loading Set 6

(a) The 235U enrichment of any fuel rod shall not exceed 5.0 wt%.

(b) There shall be 96 rods, 23 per mini-bundle.

(c) There shall be a minimum of 12 Gd_2O_3-UO_2 rods per assembly, each having a Gadolinia content of at least 4.0 wt%. These 12 Gd_2O_3-UO_2 rods shall be shall be arrayed symmetrically about the assembly. They shall not be placed on the periphery or the outer corner.

(d) The fuel pellet diameter shall be 8.48 mm nominal

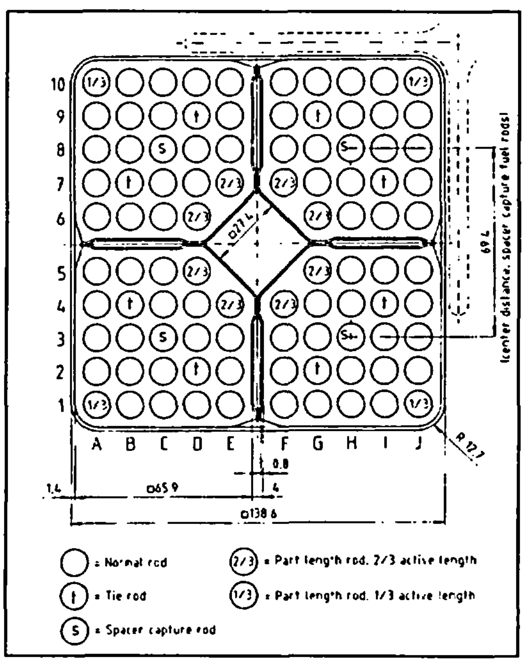

Figure 6A-4 Typical 10x10 Assembly Design

6A.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.

6A.3.1 Model Configuration

Modeling of the PATRIOT shipping package configurations was done using the SCALE 4.4 code package, as embodied in the SCALE-PC version of Reference 1. The 238 group ENDF/B-V neutron cross section library distributed with the code package was used for all analyses. Modeling was done using the both the CSAS25 calculational sequence with the exception of the generation of supplementary Dancoff factors via the CSASN sequence.

6A.3.1.1 Contents Models

Three contents models have been developed and analyzed, one for each loading set described above. The UO_2 and Gd_2O_3-UO_2 rod regions are represented explicitly by including the detail of the pellet column, gas gap, and zirconium alloy cladding. The pellet columns are modeled as a cylinder having a density of 100%TD. No effective density reduction is taken for possible pellet geometry effects such as dishing, chamfering, etc. Nominal pellet and rod parameters are used for all accident scenarios. Credit is taken for only 75% of the poison. No fuel rod assembly structures beyond the assumed active length of the rod are represented in the neutronics calculations; no grids within the active length are represented. The input parameters for the loading sets are shown in Table 6A-3.

As implied above, the top and bottom nozzles were not modeled in this analysis. Westinghouse performed an analysis for an earlier license application to evaluate the effect on system k_{eff} if the top and bottom nozzles were modeled as full density water, solid stainless steel, and half water and half stainless steel. Three cases were considered, a baseline case in which the top and bottom nozzles are modeled as water; a second case in which the nozzles were modeled as 100% stainless steel; and a third case where the nozzles were modeled as a water- stainless steel mixture. Results show that the material on the ends of the fuel assemblies (water or stainless steel) have an insignificant effect (< 1 sigma) on system keff due to the relatively small axial leakage of the array.

Table 6A-3 SCALE Input Parameters for Contents Models for Fuel Loading Sets #4 - #6	
Parameter	Fuel Loading Sets #4 - #6
CSAS	CSAS25
Cross-Section	238GROUPNDF5
UO_2 pellet	10.96 g/cc
Cladding	Zirconium (6.57 g/cc)
Water	Variable (0.08, 0.1, 0.15, 0.2, 0.3, 0.4, 0.8, 1.0)
Gd_2O_3-UO_2 pellet	UO_2 density: 10.96 g/cc Gd density: 0.2415 g/cc O density: 0.04914 g/cc
Gd_2O_3-UO_2 pellet radius	0.424 cm
Gd_2O_3-UO_2 gap radius	0.4315 cm
Gd_2O_3-UO_2 cladding radius	0.492 cm
Pitch dimension	1.353 cm
UO_2 pellet radius	0.424 cm
UO_2 gap radius	0.4315 cm
UO_2 cladding radius	0.492 cm
Pitch dimension	1.353 cm
Mini-Bundle Nominal Width	6.58 cm
Fuel Channel Outer Dimension	13.86 cm
Fuel Channel Wall Thickness	0.143 cm

6A.3.2 Packaging Model

The packaging model for this analysis is the same as that which was used for Fuel Package Loading Set #2 (A6X03) in Section 6. Slight modifications were made to introduce the fuel channel, move the fuel assemblies around within the basket, and accommodate the partial flooding scenarios with periodic finite array calculations. All accident mode calculations are performed for an array of 104 close packed inner packages. The array was an 8x13x1 configuration with 12 inches of full density water on all sides. This arrangement of packages provides an array with nearly cubical dimensions of 365.8 cm x 367.5 cm x 381.0 cm.

6A.4 MATERIAL PROPERTIES

The material properties of the packaging were not changed from Section 6. Note that the ethafoam and other packing material are not used in this analysis.

The Gadolinia pellet density depends on the Gd_2O_3 content. The composition for the Gadolinia-Urania pellet material is conservative for the purpose of the criticality evaluation, but bounds the specified range of Gadolinia-Urania pellet UO_2 and Gd_2O_3 contents. The actual range for Gadolinia-Urania pellet density is 10.57 to 10.43 g/cm^3 with a corresponding Gd_2O_3 content of 1.00 to 5.00 w/o. The fuel assembly content specifies a minimum of eight Gadolinia-Urania fuel rods with a Gd_2O_3 content of 4.00 w/o and the Gadolinia-Urania density that is 10.43 g/cm3. The Gadolinia-Urania material composition is specified in CSAS as a mixture of Uranium oxide (UO_2), Gadolinium (Gd), and Oxygen (O) that minimizes the Gadolinium content and maximizes the uranium oxide content. The UO_2 composition is specified as the theoretical UO_2, 10.96 g/cm^3. The Gd_2O_3 composition is specified using the standard composition for Gd and O with a density that is determined using the Gd_2O_3 density for 4.00 w/o adjusted to a minimum limit using the tolerance of a single pellet. Furthermore, the Gd density is reduced to 75 percent of this minimum limit to account for any other uncertainties in the Gadolinia-Urania fuel composition such as distribution and size of Gd_2O_3 particles.

6A.4.1 Computer Codes and Cross-Section Libraries

SCALE CSAS25 is used to perform the calculations of keff. The average energy of fission is in the intermediate energy range for evaluation of package arrays with fractional density water. The SCALE 238 group library is used instead of the SCALE 44 group library. Although any intermediate-energy problems are suspect because of the scarcity of critical experiments, this library performs better than any other library in SCALE. (Ref 4). The bias for the SCALE 238 group library is used in this calculation note.

6A.4.2 Demonstration of Maximum Reactivity

This analysis considers the accident transportation modes for fuel loading sets #4-#6, summarized in Table 6A-5. Fuel loading sets #4-#6 are to be transported as channeled fuel. The fuel lattice is conservatively assumed to have expanded uniformly to the inner surface of the channel for the hypothetical accident conditions. (It should be noted that drop tests performed in support of this safety analysis did not yield such results. See Section 2.) Because the fuel is shipped in channels, the plastic inserts are not included in the calculations. The ethafoam and rubber pads also are not considered because the moderating effect they would have is conservatively bounded by the variable water density calculations that were performed.

Determining maximum reactivity consisted of analyzing each loading set over the entire water density spectrum (0.08 g/cc to 1.0 g/cc) for each package configuration (i.e. placement of the assemblies in the basket), and flooding condition (full or partial). Calculations were made for the partial flooding condition for a right-side-up array and in inverted array. The inverted array means that alternating rows of packages were inverted to enable the fuel assemblies to face each other across a void. The water level for the partially flooded condition was conservatively set at the height of the fuel assemblies.

Table 6A-4 Accident Transportation Modes for Fuel Loading Sets #4-#6

Condition	Fuel Loading Set #4	Fuel Loading Set #5	Fuel Loading Set #6
Wooden outer container	Burned away	Burned away	Burned away
Inner container packing	Burned away	Burned away	Burned away
Fuel Channeled/Unchanneled	Channeled	Channeled	Channeled
Plastic inserts	No	No	No
Ethafoam / rubber pads	No	No	No
Carbon steel angle spacers	Yes	Yes	Yes
Water density	0.08 – 1.0 g/cc	0.08 – 1.0 g/cc	0.08 – 1.0 g/cc
Flooding Type	Fully Flooded Partially Flooded	Fully Flooded Partially Flooded	Fully Flooded Partially Flooded
Package Configurations	1 (Outside edge) 2 (Inside edge) 6 (Centered)	1 (Outside edge) 2 (Inside edge) 6 (Centered)	1 (Outside edge) 2 (Inside edge) 6 (Centered)
Partial Flooding Array Configurations	Right-Side-Up Inverted	Right-Side-Up Inverted	Right-Side-Up Inverted
Number Gd_2O_3-UO_2 Rods	8	10	12
Gd_2O_3-UO_2 Rod Config.	X	X & J	J
Gd_2O_3-UO_2 Loading	4.0%	4.0%	4.0%

Results are given in Tables 6A-6 through 6A-8, and plotted in Figures 6A-4 through 6A-6. Note that the curves in the graphs are presented as "eye guides" to enable the reader to discern the flow of the data for the partial and full flooded conditions.

General conclusions drawn from the data include:

- Package configuration 1 (fuel assemblies at outside edge) tended to be most reactive.
- Fully flooded arrays tended to be most reactive at lower water densities (i.e. < 0.15 g/cc).
- Partially flooded right-side-up arrays tended to be most reactive at water densities from 0.15 g/cc to ~ 0.9 g/cc.
- Partially flooded inverted arrays tended to be most reactive at water densities at 0.9g/cc - 1.0 g/cc.

6A.4.2.1 Accident Transportation Mode for Fuel Loading Set #4

Fuel loading set #4 consists of 8 Gd_2O_3-UO_2 rods, two per mini-bundle, conservatively arrayed in configuration X. There are 12 water holes, three per mini-bundle. One water hole is located on the outer corner and the other two are on the geometric diagonal toward the center of each mini-bundle. See Figure 6.6 in Section 6. Calculations were made over the entire water density range for package configurations 1, 2, and 6 for the fully flooded array, for package configuration 1 for the partial flooding right-side-up array, and for package confurations 2 and 6 for the partial flooding inverted array. This is acceptable because the right-side-up array proved to be more reactive. Results show that case 4P-1-020 (partially flooded, right-side-up array, package configuration 1, 0.2 g/cc) is most reactive.

6A.4.2.2 Accident Transportation Mode for Fuel Loading Set #5

Fuel loading set #5 consists of 10 Gd_2O_3-UO_2 rods conservatively arrayed in configuration X in two mini-bundles and configuration J in two mini-bundles. See Figures 6.6 and 6.7. There are four water holes, one per mini-bundle, located on the outer corner. Calculations were made over the entire water density range for package configurations 1, 2, and 6 for the fully flooded array, for package configuration 1 for the partial flooding right-side-up array, and for package confurations 2 and 6 for the partial flooding inverted array. This is acceptable because the right-side-up array proved to be more reactive. Results show that case 5P-1-020 (partially flooded, right-side-up array, package configuration 1, 0.2 g/cc) is most reactive.

6A.4.2.3 Accident Transportation Mode for Fuel Loading Set #6

Fuel loading set #6 was the most reactive of the loading sets. It consists of 12 Gd_2O_3-UO_2 rods, three per mini-bundle, conservatively arrayed in configuration J as shown in Figure 6.7. There are no water holes in this loading set. Calculations were made over the entire water density range for package configurations 1, 2, and 6, fully flooded and partially flooded, in botht the right-side-up and inverted arrays. Results show that case 6P-1-030 (partially flooded, right-side-up array, package configuration 1, 0.3 g/cc) is most reactive.

6A.5 SINGLE PACKAGE EVALUATION

Single package scenarios were not analyzed. The analysis in Section 6 identifies the package array to be the more limiting case.

6A.6 PACKAGE ARRAYS UNDER HYPOTHETICAL ACCIDENT CONDITIONS

6A.6.1 Results

Results are presented in Tables 6A-5 through 6A-10. Case numbers are labeled as follows:

6	P	-1-	030	-Inv or (blank)
Loading Set (4,5,6)	Flooding Type (Full / Partial)	Package Configuration (1,2,6)	Water Density (008, 010,015,020, 030,040,080,100)	(Inv - rows inverted (blank – rows right-side-up)

The results are plotted in Figures 6A-5 through 6A-7. Note that the curves are provided only as "eye guides" to enable the reader to see the trends for the fully flooded and partially flooded conditions. They were not intended to be used to pick points off the curve for various water densities.

Figures 6A-8 through 6A-11 show a representative sample of the three fuel loading sets and package configurations. Note that figure 6A-11 shows two partial flooding. The results in Tables 6A-6, 6A-8, and 6A-10 were calculated using the flooding model shown in Figure 6A-11a. The effect of moderator in the region above the fuel envelope was considered for the most reactive case, which was Run #6P-1-030 from Table 6A-6. The result for this run was 0.9285±0.0007. This case was run by modifying the flooding model as shown in Figure 6A-11b. The result for this run was 0.9308±0.0007. The difference is statistically insignificant, and both are below the USL.

6A.7 ACCEPTANCE CRITERIA

The SCALE 4.4 code package was used for all criticality calculations performed herein. Final calculations utilized the CSAS25 or CSAS2X sequence along with the 238 group ENDF/BV cross section library. The arbitrary margin to ensure the subcriticality of k_s or Δk_m shall be no less than 0.05 where k_s is the calculated allowable maximum multiplication factor, k_{eff}.

$k_s \leq k_c - \Delta k_s - \Delta k_c - \Delta k_m$, where

k_c is the k_{eff} from the calculation of benchmark criticality experiments,

Δk_s is uncertainty in the value of k_s, and

Δk_c is uncertainty in the value of k_c and identical to the uncertainty in the bias (i.e. $\Delta k_c = \Delta\beta$).

The calculation bias, β, is defined as $\beta = k_c - 1$, therefore

$k_s \leq \beta + 1 - \Delta k_s - \Delta\beta - \Delta k_m$, or

$k_s + \Delta k_s - (\beta - \Delta\beta) \leq 1 - \Delta k_m$

$k_s + \Delta k_s - (\beta - \Delta\beta) \leq 1 - 0.05$

$k_s + \Delta k_s - (\beta - \Delta\beta) \leq 0.95$

For these calculations, k_s is the average k_{eff} and Δk_s is two times the minimum standard deviation (σ) of the system that are listed at the top of the plot of average k-effective by generation skipped in the KENO-Va output, and a negative value of 0.0157 is assigned for the bias and uncertainty in the bias (β-$\Delta\beta$) associated with using SCALE 4.4 and the 238-group cross-section library. This is consistent with the validation of this computational method using low-enriched lattice critical experiments. Therefore the upper safety limit (USL) is 0.9343 and,

$\text{USL} = 1 - \Delta k_m + (\beta - \Delta\beta)$

$k_s + \Delta k_s \leq \text{USL}$

$k_{eff} + 2\sigma \leq 0.9343$

The USL was set using a bias and bias uncertainty (β+$\Delta\beta$) value from the benchmark critical experiment calculations that were done for low enriched heterogeneous systems using the SCALE/CSAS25/238-Group Library. For this calculation 49 experiments were selected that applied to low enriched heterogeneous systems. They are listed in Table 6A-12, and are subdivided into appropriate categories in Tables 6A-13. These experiments are low-enriched light-water-reactor (LWR) lattices. The series of experiments demonstrates the performance of both the cross sections and the SCALE resonance cross-section processing methodology. These experiments span a range of moderation and fuel pin arrangements that are applicable in evaluating LWR fuel storage and transport.

The average k_{eff} is not significantly different for the categories of experiments (simple lattice, separator plate, separator plate-soluble boron, urania gadolinia rod, water hole, or absorber rods). The simple lattice, urania gadolinia rod, and water hole categories represent are the most applicable to the PATRIOT package. Mean of the energy (ev) of the average lethargy causing fission (EALF) 1.9728, and range 0.1826 to 10.9531 for the PATRIOT package applications. The energy (ev) of the average lethargy causing fission for the PATRIOT package that results in a maximum keff over the range of interspersed moderation densities and moderator configurations is approximately 0.6 ev. Only six of the critical benchmark critical experiments have EALF that is greater than 0.5 ev, but the results show no significant trend in bias vs. energy. The largest bias results from a the correlation to the enrichment parameter, and results in an upper safety limit of 0.9343 including a 0.05 arbitrary margin to ensure subcriticality.

Table 6A-5 Results of Package Configuration 1 for Loading Sets #4 - #6, Fully Flooded				
Configuration 1	Water Density	K_{eff}	s	K_{eff} + 2s
Fully Flooded				
4F-1-008	0.08	0.8586	6.00e-4	0.8598
4F-1-010	0.10	0.8810	8.00e-4	0.8826
4F-1-015	0.15	0.8995	8.00e-4	0.9011
4F-1-020	0.20	0.8873	7.00e-4	0.8887
4F-1-030	0.30	0.8436	7.00e-4	0.8450
4F-1-040	0.40	0.7935	6.00e-4	0.7947
4F-1-080	0.80	0.7022	8.00e-4	0.7038
4F-1-100	1.00	0.6979	8.00e-4	0.6995
5F-1-008	0.08	0.8600	8.0000e-4	0.8616
5F-1-010	0.10	0.8828	8.0000e-4	0.8844
5F-1-015	0.15	0.9000	6.0000e-4	0.9012
5F-1-020	0.20	0.8874	7.0000e-4	0.8888
5F-1-030	0.30	0.8419	8.0000e-4	0.8435
5F-1-040	0.40	0.7918	8.0000e-4	0.7934
5F-1-080	0.80	0.7080	7.0000e-4	0.7094
5F-1-100	1.00	0.7083	8.0000e-4	0.7099
6F-1-008	0.08	0.8593	6.0000e-4	0.8605
6F-1-010	0.10	0.8844	6.0000e-4	0.8856
6F-1-015	0.15	0.9044	6.0000e-4	0.9056
6F-1-020	0.20	0.8983	7.0000e-4	0.8997
6F-1-030	0.30	0.8547	7.0000e-4	0.8561
6F-1-040	0.40	0.8073	8.0000e-4	0.8089
6F-1-080	0.80	0.7157	7.0000e-4	0.7171
6F-1-100	1.00	0.7091	8.0000e-4	0.7107

Table 6A-6 Results of Package Configuration 1 for Loading Sets #4 - #6, Partially Flooded				
Configuration 1	Water Density	K_{eff}	s	K_{eff} + 2s
Partially Flooded Right-Side-Up				
4P-1-008	0.08	0.8205	6.0000e-4	0.8217
4P-1-010	0.10	0.8558	8.0000e-4	0.8574
4P-1-015	0.15	0.9072	7.0000e-4	0.9086
4P-1-020	0.20	0.9241	8.0000e-4	0.9257
4P-1-030	0.30	0.9192	7.0000e-4	0.9206
4P-1-040	0.40	0.8923	7.0000e-4	0.8937
4P-1-080	0.80	0.7827	7.0000e-4	0.7841
4P-1-100	1.00	0.7512	7.0000e-4	0.7526
5P-1-008	0.08	0.8197	6.0000e-4	0.8209
5P-1-010	0.10	0.8555	6.0000e-4	0.8567
5P-1-015	0.15	0.9045	6.0000e-4	0.9057
5P-1-020	0.20	0.9226	8.0000e-4	0.9242
5P-1-030	0.30	0.9179	7.0000e-4	0.9193
5P-1-040	0.40	0.8915	7.0000e-4	0.8929
5P-1-080	0.80	0.7870	7.0000e-4	0.7884
5P-1-100	1.00	0.7628	7.0000e-4	0.7642
6P-1-008	0.08	0.8192	6.0000e-4	0.8204
6P-1-010	0.10	0.8554	6.0000e-4	0.8566
6P-1-015	0.15	0.9074	7.0000e-4	0.9088
6P-1-020	0.20	0.9269	7.0000e-4	0.9283
6P-1-030	0.30	0.9285	7.0000e-4	0.9299
6P-1-040	0.40	0.9036	8.0000e-4	0.9052
6P-1-080	0.80	0.7988	7.0000e-4	0.8002
6P-1-100	1.00	0.7671	8.0000e-4	0.7687
Partially Flooded Inverted				
6P-1-008-inv	0.08	0. 8114	6.0000e-4	0. 8126
6P-1-010-inv	0.10	0. 8398	6.0000e-4	0. 8410
6P-1-015-inv	0.15	0. 8769	7.0000e-4	0. 8783
6P-1-020-inv	0.20	0. 8862	6.0000e-4	0. 8874
6P-1-030-inv	0.30	0. 8735	6.0000e-4	0. 8747
6P-1-040-inv	0.40	0. 8530	7.0000e-4	0. 8544
6P-1-080-inv	0.80	0. 8063	7.0000e-4	0. 8077
6P-1-100-inv	1.00	0. 8019	8.0000e-4	0. 8035

Table 6A-7 Results of Package Configuration 2 for Loading Sets #4 - #6, Fully Flooded

Configuration 2	Water Density	K_{eff}	s	K_{eff} + 2s
Fully Flooded				
4F-2-008	0.08	0.8243	7.0000e-4	0.8257
4F-2-010	0.10	0.8392	7.0000e-4	0.8406
4F-2-015	0.15	0.8421	7.0000e-4	0.8435
4F-2-020	0.20	0.8202	6.0000e-4	0.8214
4F-2-030	0.30	0.7751	8.0000e-4	0.7767
4F-2-040	0.40	0.7407	8.0000e-4	0.7423
4F-2-080	0.80	0.7251	8.0000e-4	0.7267
4F-2-100	1.00	0.7472	8.0000e-4	0.7488
5F-2-008	0.08	0.8261	7.0000e-4	0.8275
5F-2-010	0.10	0.8414	7.0000e-4	0.8428
5F-2-015	0.15	0.8416	6.0000e-4	0.8428
5F-2-020	0.20	0.8211	8.0000e-4	0.8227
5F-2-030	0.30	0.7734	8.0000e-4	0.7750
5F-2-040	0.40	0.7396	8.0000e-4	0.7412
5F-2-080	0.80	0.7275	8.0000e-4	0.7291
5F-2-100	1.00	0.7593	8.0000e-4	0.7609
6F-2-008	0.08	0.8265	7.0000e-4	0.8279
6F-2-010	0.10	0.8413	8.0000e-4	0.8429
6F-2-015	0.15	0.8454	7.0000e-4	0.8468
6F-2-020	0.20	0.8274	7.0000e-4	0.8288
6F-2-030	0.30	0.7806	7.0000e-4	0.7820
6F-2-040	0.40	0.7458	7.0000e-4	0.7472
6F-2-080	0.80	0.7255	9.0000e-4	0.7273
6F-2-100	1.00	0.7537	8.0000e-4	0.7553

Table 6A-8 Results of Package Configuration 2 for Loading Sets #4 - #6, Partially Flooded

Configuration 2	Water Density	K_{eff}	s	K_{eff} + 2s
Partially Flooded Right-Side-Up				
6P-2-008	0.08	0.7941	7.0000e-4	0.7955
6P-2-010	0.10	0.8214	6.0000e-4	0.8226
6P-2-015	0.15	0.8517	6.0000e-4	0.8529
6P-2-020	0.20	0.8586	7.0000e-4	0.8600
6P-2-030	0.30	0.8439	7.0000e-4	0.8453
6P-2-040	0.40	0.8265	7.0000e-4	0.8279
6P-2-080	0.80	0.7936	8.0000e-4	0.7952
6P-2-100	1.00	0.7968	7.0000e-4	0.7982
Partially Flooded Inverted				
4P-2-008-inv	0.08	0.7838	7.0000e-4	0.7852
4P-2-010-inv	0.10	0.8056	6.0000e-4	0.8068
4P-2-015-inv	0.15	0.8234	7.0000e-4	0.8248
4P-2-020-inv	0.20	0.8179	7.0000e-4	0.8193
4P-2-030-inv	0.30	0.7926	7.0000e-4	0.7940
4P-2-040-inv	0.40	0.7730	8.0000e-4	0.7746
4P-2-080-inv	0.80	0.7823	7.0000e-4	0.7837
4P-2-100-inv	1.00	0.8032	8.0000e-4	0.8048
5P-2-008-inv	0.08	0.7846	6.0000e-4	0.7858
5P-2-010-inv	0.10	0.8061	7.0000e-4	0.8075
5P-2-015-inv	0.15	0.8213	7.0000e-4	0.8227
5P-2-020-inv	0.20	0.8153	8.0000e-4	0.8169
5P-2-030-inv	0.30	0.7879	7.0000e-4	0.7893
5P-2-040-inv	0.40	0.7678	7.0000e-4	0.7692
5P-2-080-inv	0.80	0.7883	8.0000e-4	0.7899
5P-2-100-inv	1.00	0.8209	8.0000e-4	0.8225
6P-2-008-inv	0.08	0.7849	7.0000e-4	0.7863
6P-2-010-inv	0.10	0.8067	7.0000e-4	0.8081
6P-2-015-inv	0.15	0.8239	7.0000e-4	0.8253
6P-2-020-inv	0.20	0.8195	6.0000e-4	0.8207
6P-2-030-inv	0.30	0.7919	6.0000e-4	0.7931
6P-2-040-inv	0.40	0.7721	7.0000e-4	0.7735
6P-2-080-inv	0.80	0.7804	8.0000e-4	0.7820
6P-2-100-inv	1.00	0.8102	8.0000e-4	0.8118

Table 6A-9 Results of Package Configuration 6 for Loading Sets #4 - #6, Fully Flooded				
Configuration 6	Water Density	K_{eff}	s	K_{eff} + 2s
Fully Flooded				
4F-6-008	0.08	0.8467	7.0000e-4	0.8481
4F-6-010	0.10	0.8683	7.0000e-4	0.8697
4F-6-015	0.15	0.8803	8.0000e-4	0.8819
4F-6-020	0.20	0.8680	7.0000e-4	0.8694
4F-6-030	0.30	0.8241	7.0000e-4	0.8255
4F-6-040	0.40	0.7854	8.0000e-4	0.7870
4F-6-080	0.80	0.7320	8.0000e-4	0.7336
4F-6-100	1.00	0.7383	8.0000e-4	0.7399
5F-6-008	0.08	0.8487	6.0000e-4	0.8499
5F-6-010	0.10	0.8675	6.0000e-4	0.8687
5F-6-015	0.15	0.8817	8.0000e-4	0.8833
5F-6-020	0.20	0.8663	7.0000e-4	0.8677
5F-6-030	0.30	0.8225	8.0000e-4	0.8241
5F-6-040	0.40	0.7814	8.0000e-4	0.7830
5F-6-080	0.80	0.7376	8.0000e-4	0.7392
5F-6-100	1.00	0.7506	7.0000e-4	0.7520
6F-6-008	0.08	0.8487	8.0000e-4	0.8503
6F-6-010	0.10	0.8687	7.0000e-4	0.8701
6F-6-015	0.15	0.8843	6.0000e-4	0.8855
6F-6-020	0.20	0.8750	7.0000e-4	0.8764
6F-6-030	0.30	0.8331	7.0000e-4	0.8345
6F-6-040	0.40	0.7932	8.0000e-4	0.7948
6F-6-080	0.80	0.7427	8.0000e-4	0.7443
6F-6-100	1.00	0.7554	8.0000e-4	0.7570

Table 6A-10 Results of Package Configuration 6 for Loading Sets #4 - #6, Partially Flooded				
Configuration 6	Water Density	K_{eff}	s	K_{eff} + 2s
Partially Flooded Right-Side-Up				
4F-6-008	0.08	0.8111	7.0000e-4	0.8125
4F-6-010	0.10	0.8425	8.0000e-4	0.8441
4F-6-015	0.15	0.8888	6.0000e-4	0.8900
4F-6-020	0.20	0.9041	6.0000e-4	0.9053
4F-6-030	0.30	0.9021	7.0000e-4	0.9035
4F-6-040	0.40	0.8838	7.0000e-4	0.8852
4F-6-080	0.80	0.8187	8.0000e-4	0.8203
4F-6-100	1.00	0.8048	8.0000e-4	0.8064
Partially Flooded Inverted				
4P-6-008-inv	0.08	0.8003	7.0000e-4	0.8017
4P-6-010-inv	0.10	0.8276	7.0000e-4	0.8290
4P-6-015-inv	0.15	0.8602	7.0000e-4	0.8616
4P-6-020-inv	0.20	0.8612	7.0000e-4	0.8626
4P-6-030-inv	0.30	0.8451	8.0000e-4	0.8467
4P-6-040-inv	0.40	0.8251	7.0000e-4	0.8265
4P-6-080-inv	0.80	0.8123	7.0000e-4	0.8137
4P-6-100-inv	1.00	0.8190	7.0000e-4	0.8204
5P-6-008-inv	0.08	0.8033	6.0000e-4	0.8045
5P-6-010-inv	0.10	0.8279	7.0000e-4	0.8293
5P-6-015-inv	0.15	0.8569	7.0000e-4	0.8583
5P-6-020-inv	0.20	0.8602	7.0000e-4	0.8616
5P-6-030-inv	0.30	0.8411	7.0000e-4	0.8425
5P-6-040-inv	0.40	0.8234	7.0000e-4	0.8248
5P-6-080-inv	0.80	0.8181	8.0000e-4	0.8197
5P-6-100-inv	1.00	0.8327	7.0000e-4	0.8341
6P-6-008-inv	0.08	0.8033	6.0000e-4	0.8045
6P-6-010-inv	0.10	0.8288	7.0000e-4	0.8302
6P-6-015-inv	0.15	0.8583	7.0000e-4	0.8597
6P-6-020-inv	0.20	0.8636	8.0000e-4	0.8652
6P-6-030-inv	0.30	0.8477	8.0000e-4	0.8493
6P-6-040-inv	0.40	0.8296	8.0000e-4	0.8312
6P-6-080-inv	0.80	0.8182	7.0000e-4	0.8196
6P-6-100-inv	1.00	0.8292	7.0000e-4	0.8306

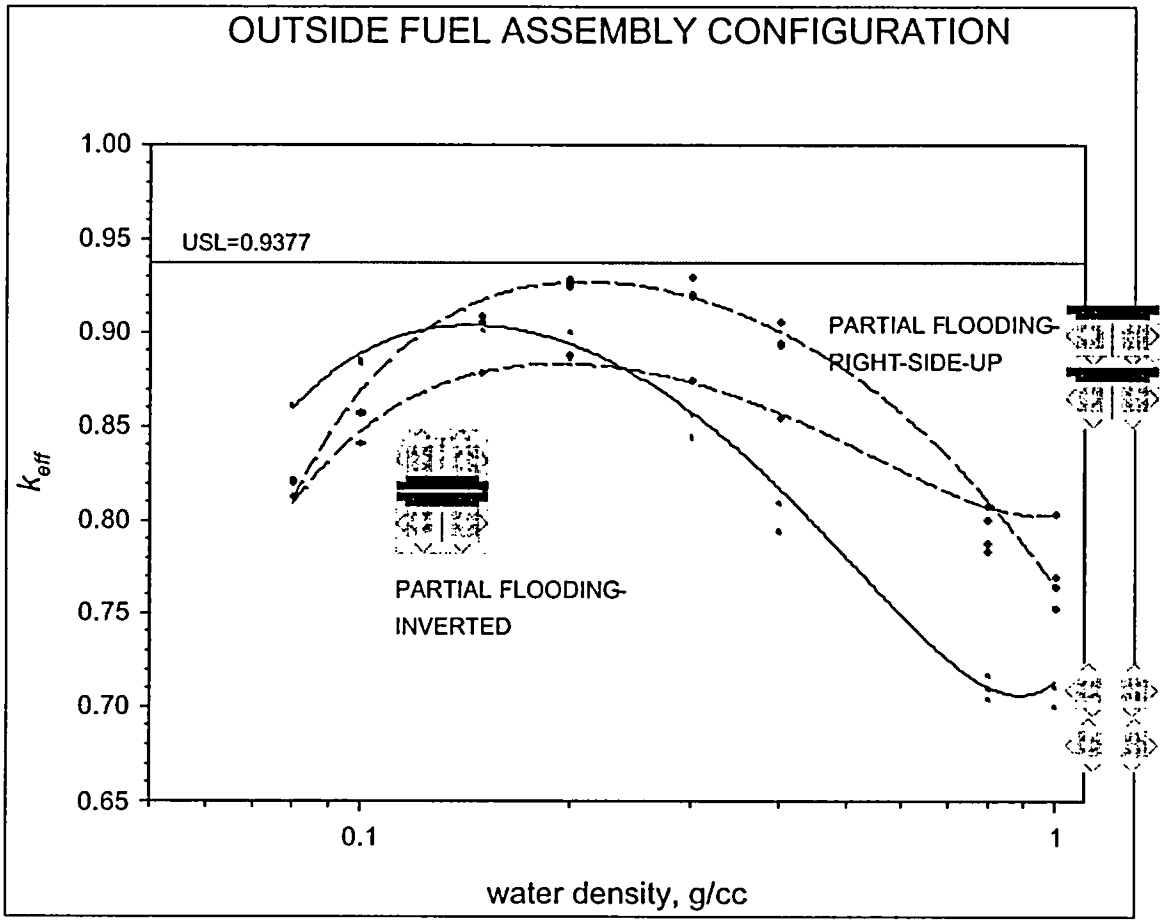

Figure 6A-5 Results for All Loading Sets, Package Configuration 1

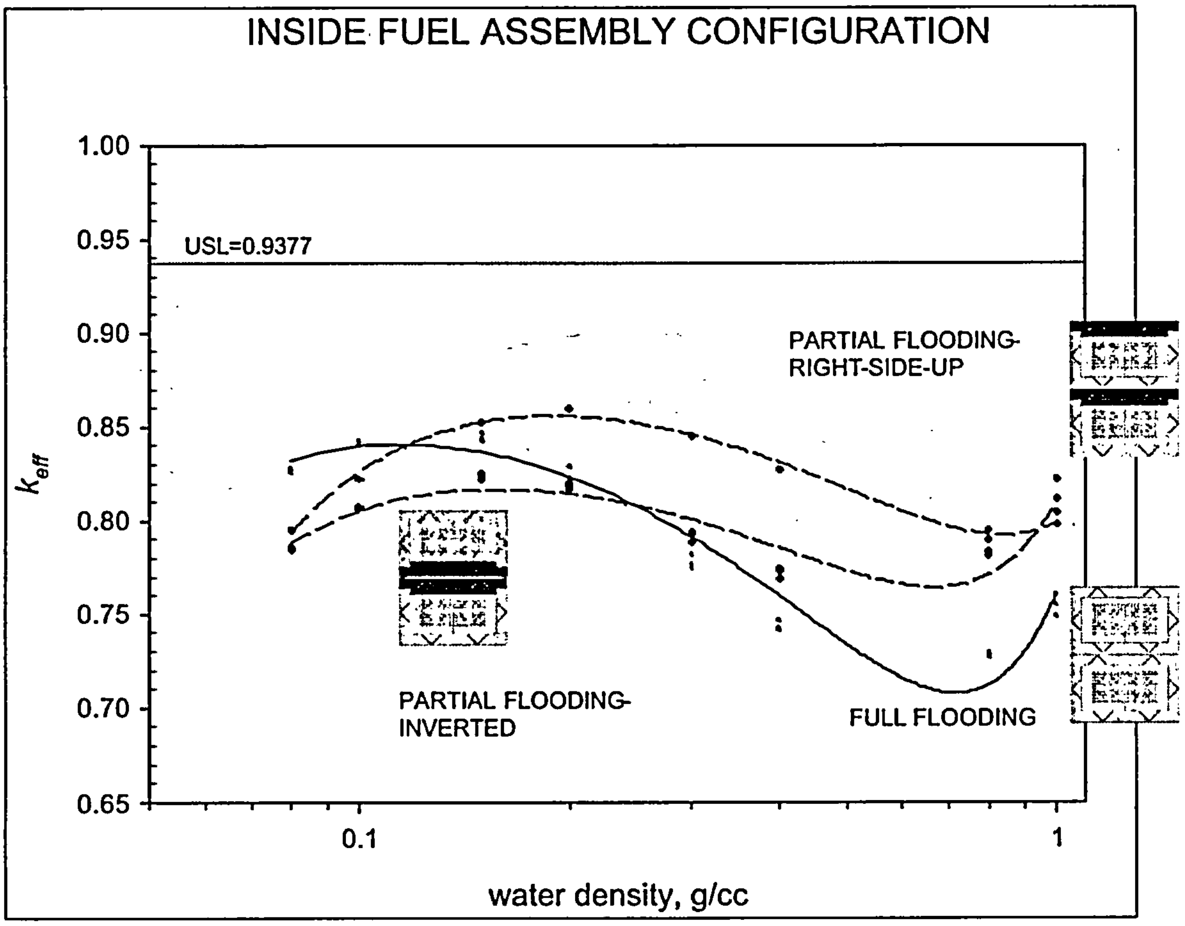

Figure 6A-6 Results for All Loading Sets, Package Configuration 2

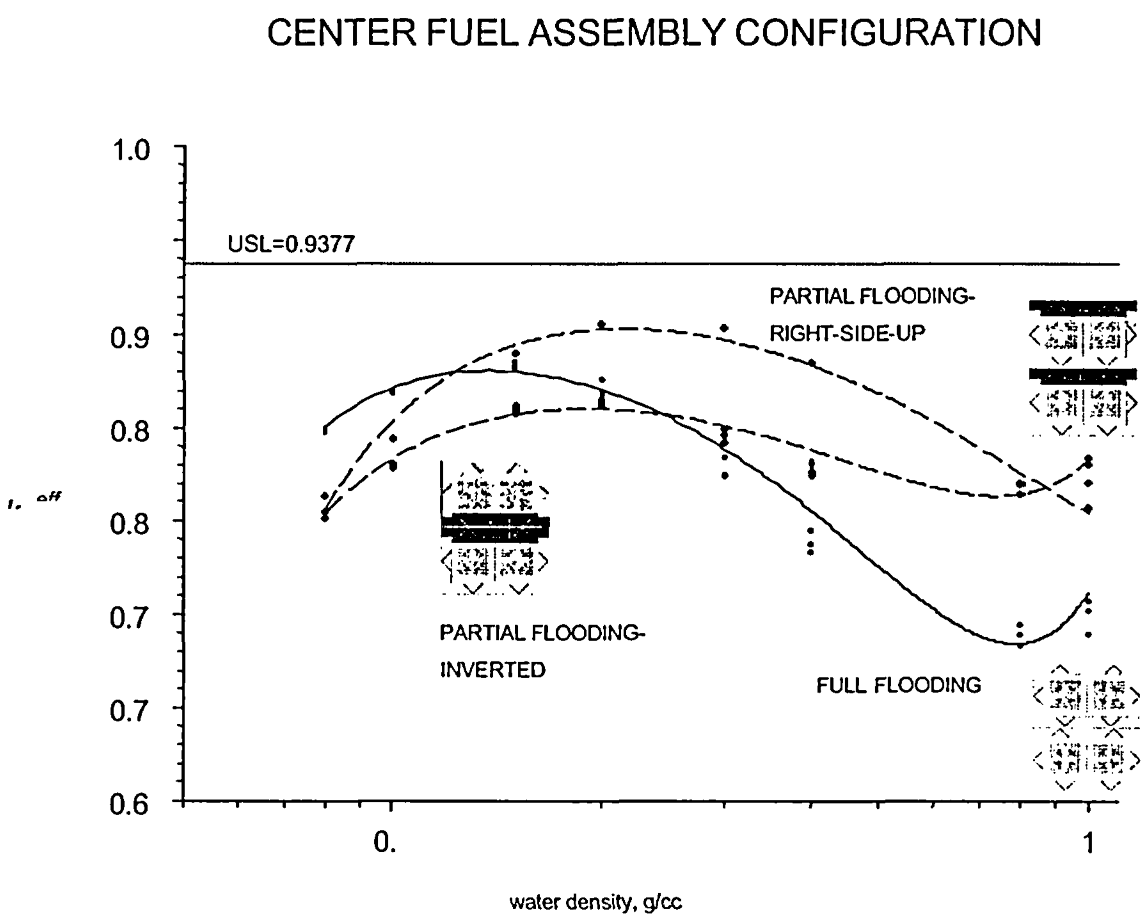

Figure 6A-7 Results for All Loading Sets, Package Configuration 6

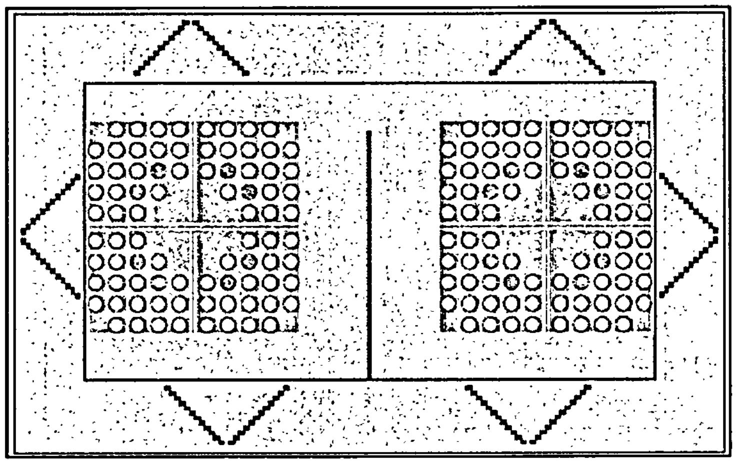

Figure 6A-8 Fuel Loading Set #4, Package Configuration 1, Fully Flooded

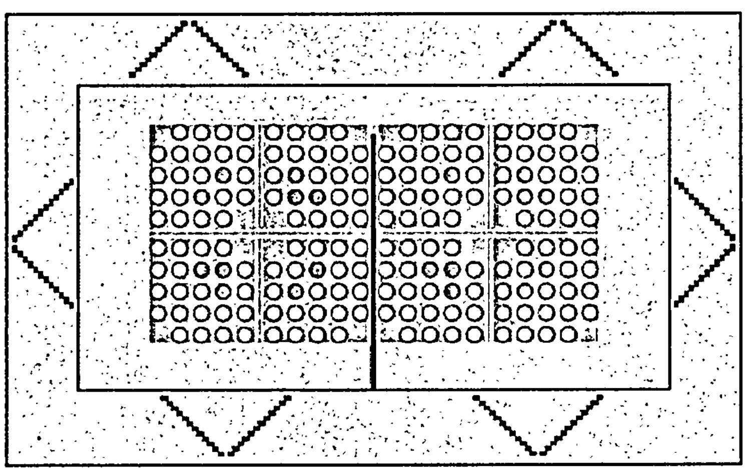

Figure 6A-9 Fuel Loading Set #5, Package Configuration 2, Fully Flooded

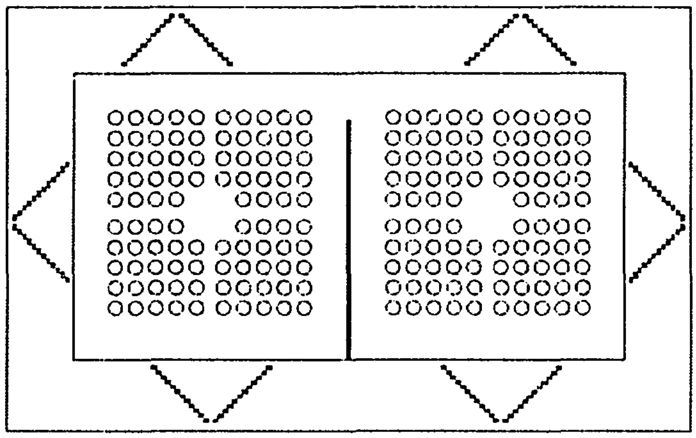

Figure 6A-10 Fuel Loading Set #6, Package Configuration 6, Fully Flooded

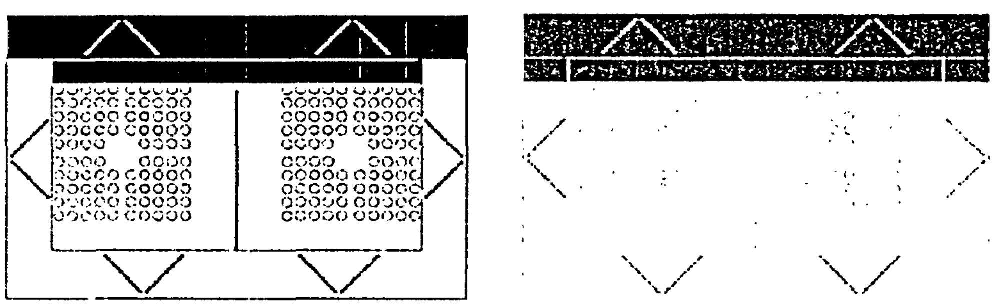

Figure 6A-11*a(left) and b(right)* Fuel Loading Set #6, Package Configuration 1, Partial Flooding

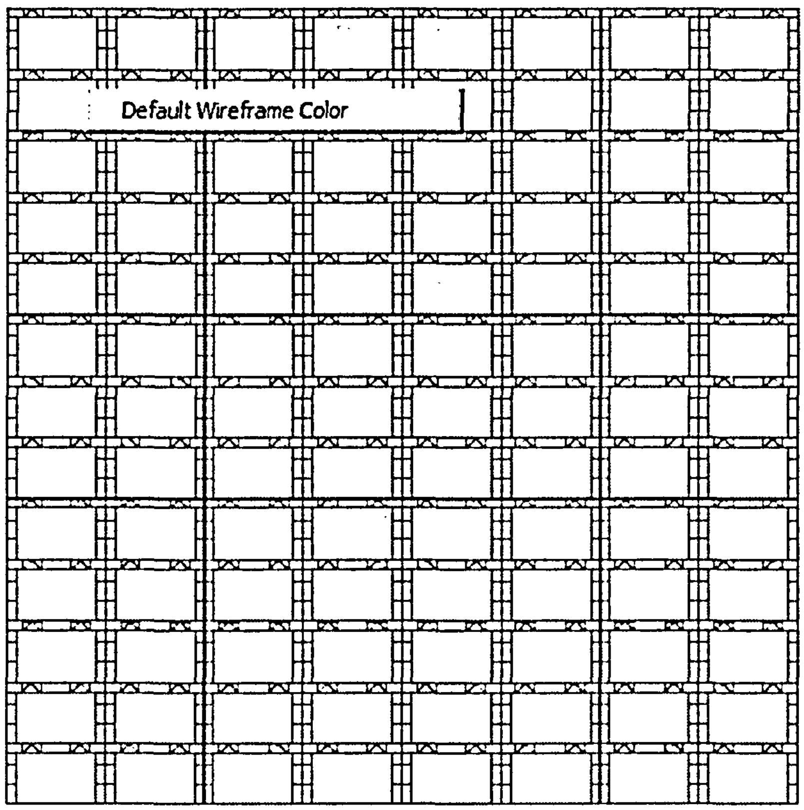

Figure 6A-12 8x13x1 Array Showing all Fuel Assemblies Right-Side-Up

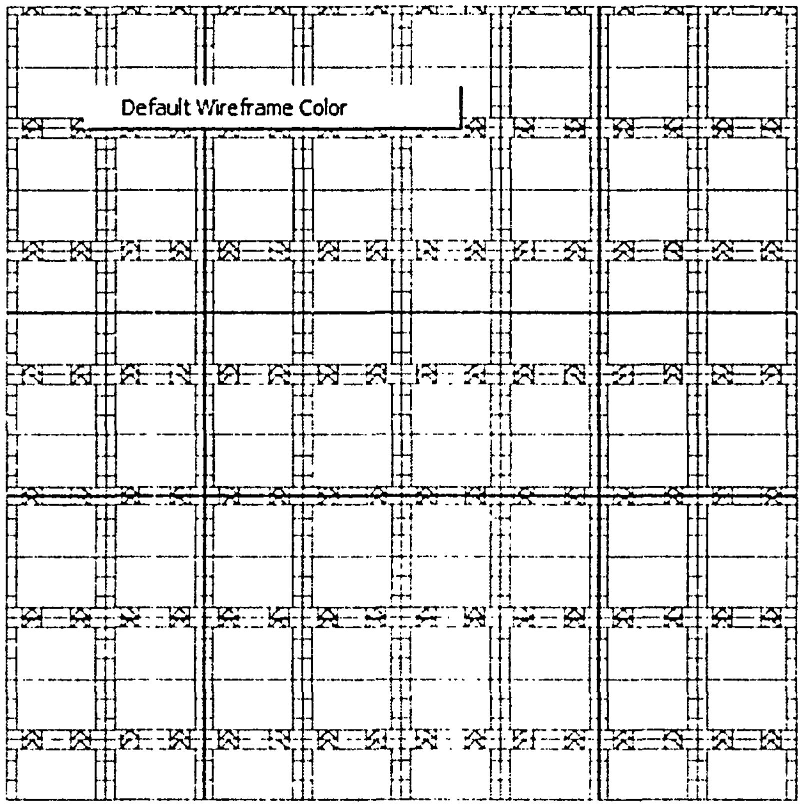

Figure 6A-13 8x13x1 Array Showing Alternating Rows of Fuel Assemblies Inverted

Table 6A-11 Input Deck for Run # 6P-1-030

```
=CSAS25   PARM=(RUN,SIZE=500000)
PATRIOT PACKAGE,OUT,12GD 4.00 w/o,ENR=5       w/o,PART DEN=0.3       g/cm3
238GROUPNDF5              LATTICECELL
UO2         1  DEN=10.96 1.0   293 92235 5     92238 95        END
ZR          2  DEN=6.57 1.0    293 END
H2O         3  DEN=0.3         1.0 293 END
UO2         4  DEN=10.96 1.0 293 92235 5           92238 95        END
GD          4  DEN=0.2415 1.0 293 END
O           4  DEN=0.04914 1.0 293 END
H2O         5  DEN=0.3           1.0 293 END
CARBONSTEEL   6  1.0           293 END
CARBONSTEEL   7  0.850           293 END
POLY(H2O)     8  DEN=0.92 1.0    293 END
POLY(H2O)     9  DEN=0.4690 1.0   293 END
UO2          10  DEN=10.96 1.0 293 92235 4.0 92238 96.0 END
UO2          11  DEN=10.96 1.0 293 92235 3.5 92238 96.5 END
UO2          12  DEN=10.96 1.0 293 92235 2.25 92238 97.75 END
CARBONSTEEL   14  1.0 293 END
CARBONSTEEL   15  1.0 293 END
POLY(H2O)     16  0.04 293 END
POLY(H2O)     17  1.0 293 END
POLY(H2O)     18  DEN=0.5064 0.85466 293 END
H2O          18  DEN=0.08 0.14534 293 END
ZR           19  DEN=6.57 1.0    293 END
END COMP
SQUAREPITCH 1.353  .848 1  3  .984  2  0.863 3 END
MORE DATA
RES=4  CYLINDER  0.4240  DAN(4)=0.53052
RES=10 CYLINDER  0.4240  DAN(10)=0.53052
RES=11 CYLINDER  0.4240  DAN(11)=0.53052
RES=12 CYLINDER 0.4105 DAN(12)=0.53052
END MORE DATA
PATRIOT PACKAGE,OUT,12GD 4.00 w/o,ENR=5       w/o,PART DEN=0.3       g/cm3
READ PARM
flx=no fdn=no far=yes pgm=yes tba=1.0 plt=yes
gen=410 npg=2500 nsk=10 wrs=52 res=1000
END PARM
READ GEOM
UNIT  1
COM=!GAD PIN!
CYLINDER 4 1 0.424  381 0
CYLINDER 0 1 0.4315 381 0
CYLINDER 2 1 0.492  381 0
CUBOID   3 1 0.492  -0.492  0.492  -0.492  381 0
UNIT  2
COM=!WATER HOLE REGION!
CUBOID   3 1 0.492  -0.492  0.492  -0.492  381 0
UNIT  3
COM=!5 W/O UO2 FUEL PIN!
CYLINDER 1 1 0.424  381 0
CYLINDER 0 1 0.4315 381 0
CYLINDER 2 1 0.492  381 0
CUBOID   3 1 0.492  -0.492  0.492  -0.492  381 0
UNIT  4
COM=!4.0 W/O FUEL PIN!
CYLINDER 10 1 0.424  381 0
CYLINDER 0 1 0.4315 381 0
CYLINDER 2 1 0.492  381 0
CUBOID   3 1 0.492  -0.492  0.492  -0.492  381 0
```

Table 6A-11 Input Deck for Run # 6P-1-030 (cont'd)

```
UNIT 5
COM=!3.5 W/O UO2 FUEL PIN!
CYLINDER 11 1 0.424 381 0
CYLINDER 0 1 0.4315 381 0
CYLINDER 2 1 0.492 381 0
CUBOID 3 1 0.492 -0.492 0.492 -0.492 381 0
UNIT 6
COM=!2.25 W/O UO2 FUEL PIN!
CYLINDER 12 1 0.424 381 0
CYLINDER 0 1 0.4315 381 0
CYLINDER 2 1 0.492 381 0
CUBOID 3 1 0.492 -0.492 0.492 -0.492 381 0
UNIT 11
COM=!HORIZONTAL ARRAY OF FUEL PINS ROW 1!
CUBOID 3 1 13.575 0.0 0.510 -0.510 381.1 0
HOLE 3 0.492 0.0 0.0
HOLE 3 1.845 0.0 0.0
HOLE 3 3.198 0.0 0.0
HOLE 3 4.551 0.0 0.0
HOLE 3 5.904 0.0 0.0
HOLE 32 6.7875 0.0 0.0
HOLE 3 7.671 0.0 0.0
HOLE 3 9.024 0.0 0.0
HOLE 3 10.377 0.0 0.0
HOLE 3 11.730 0.0 0.0
HOLE 3 13.082 0.0 0.0
UNIT 12
COM=!HORIZONTAL ARRAY OF FUEL PINS ROW 2!
CUBOID 3 1 13.575 0.0 0.510 -0.510 381.1 0
HOLE 3 0.492 0.0 0.0
HOLE 3 1.845 0.0 0.0
HOLE 3 3.198 0.0 0.0
HOLE 3 4.551 0.0 0.0
HOLE 3 5.904 0.0 0.0
HOLE 32 6.7875 0.0 0.0
HOLE 3 7.671 0.0 0.0
HOLE 3 9.024 0.0 0.0
HOLE 3 10.377 0.0 0.0
HOLE 3 11.730 0.0 0.0
HOLE 3 13.082 0.0 0.0
UNIT 13
COM=!HORIZONTAL ARRAY OF FUEL PINS ROW 3!
CUBOID 3 1 13.575 0.0 0.510 -0.510 381.1 0
HOLE 3 0.492 0.0 0.0
HOLE 3 1.845 0.0 0.0
HOLE 3 3.198 0.0 0.0
HOLE 1 4.551 0.0 0.0
HOLE 3 5.904 0.0 0.0
HOLE 32 6.7875 0.0 0.0
HOLE 3 7.671 0.0 0.0
HOLE 1 9.024 0.0 0.0
HOLE 3 10.377 0.0 0.0
HOLE 3 11.730 0.0 0.0
HOLE 3 13.082 0.0 0.0
UNIT 14
COM=!HORIZONTAL ARRAY OF FUEL PINS ROW 4!
CUBOID 3 1 13.575 0.0 0.510 -0.510 381.1 0
```

Table 6A-11 Input Deck for Run # 6P-1-030 (cont'd)

```
HOLE     3 0.492  0.0  0.0
HOLE     3 1.845  0.0  0.0
HOLE     1 3.198  0.0  0.0
HOLE     1 4.551  0.0  0.0
HOLE     3 5.904  0.0  0.0
HOLE    32 6.7875 0.0  0.0
HOLE     3 7.671  0.0  0.0
HOLE     1 9.024  0.0  0.0
HOLE     1 10.377 0.0  0.0
HOLE     3 11.730 0.0  0.0
HOLE     3 13.082 0.0  0.0
UNIT 15
COM=!HORIZONTAL ARRAY OF FUEL PINS ROW 5!
CUBOID   3 1 13.575 0.0 0.510 -0.510 381.1 0
HOLE     3 0.492  0.0  0.0
HOLE     3 1.845  0.0  0.0
HOLE     3 3.198  0.0  0.0
HOLE     3 4.551  0.0  0.0
HOLE     2 5.904  0.0  0.0
HOLE    32 6.7875 0.0  0.0
HOLE     2 7.671  0.0  0.0
HOLE     3 9.024  0.0  0.0
HOLE     3 10.377 0.0  0.0
HOLE     3 11.730 0.0  0.0
HOLE     3 13.082 0.0  0.0
UNIT 32
COM=!CHANNEL-WATER CROSS!
CUBOID   3 1 0.120 -0.120 0.509 -0.509 381.1 0
CUBOID  19 1 0.204 -0.204 0.509 -0.509 381.1 0
UNIT 16
COM=!CHANNEL-WATER CROSS [HORIZONTAL THIN POLY SHEET 0.22CM THICK]!
CUBOID   3 1 0.120 -0.120 0.3285 0.0 381.1 0
CUBOID  19 1 0.204 -0.204 0.3285 0.0 381.1 0
CUBOID   3 1 6.7875 -6.7875 0.3285 0.0 381.1 0
UNIT 17
COM=!CHANNEL-WATER CROSS [HORIZONTAL THICK POLY SHEET 1.14CM THICK]!
CUBOID   3 1 13.575 0.0  0.120 -0.120 381.1 0
CUBOID   19 1 13.575 0.0  0.204 -0.204 381.1 0
CUBOID   3 1 13.575 0.0  0.3915 -0.3915 381.1 0
UNIT 18
COM=!VERTICAL CENTER BASKET SUPPORT 1/2 THICKNESS!
CUBOID   7 1 0.1524 0.0 15.875 0.0 380.0 0.0
UNIT 19
COM=!LEFT HAND ARRAY OF FUEL PINS - [CENTERED WITH ETHAFOAM & RUBBER]!
CUBOID   5 1 16.0447 -2.2002  13.7182  -2.86070 381.1 0.0
HOLE    40 -2.0571 0.0 0.0
HOLE    18  15.8921 -2.8600 0.5
CUBOID   0 1 16.0447 -2.2002 15.96070 -2.86070 381.1 0.0
CUBOID   7 1 16.0447 -2.3526 16.11310 -3.01310 381.1 0.0
UNIT 20
COM=!RIGHT HAND ARRAY OF FUEL PINS - [CENTERED WITH ETHAFOAM & RUBBER]!
CUBOID   5 1  2.2002  -16.0447 13.7182  -2.86070  381.1 -0.0
HOLE    40 -11.5179 0  0
HOLE    18 -16.0445  -2.8600 0.5
CUBOID   0 1  2.2002  -16.0447 15.96070 -2.86070 381.1 -0.0
CUBOID   7 1  2.3526  -16.0447 16.11310 -3.01310 381.1 -0.0
UNIT 21
COM=!STACKING OF THE LEFT AND RIGHT BASKETS WITH 2 INCH GAP AROUND!
ARRAY    2  0.0 0.0 0.0
CUBOID   5 1 36.8000 -0.0   19.1262 -4.572  381.2 -0.1
HOLE    26  9.2372 -4.4500 0.0
HOLE    26  28.5572 -4.4500 0.0
UNIT 33
CUBOID   5 1 41.1047 -4.3103 19.1263 -4.573  381.25 -0.15
```

Table 6A-11 Input Deck for Run # 6P-1-030 (cont'd)

```
HOLE    21  0.0 0.0 0.0
HOLE    24  -4.3103  9.1999  0.0
HOLE    25  41.1045  9.1999  0.0
UNIT 34
CUBOID   0 1 41.1048 -4.3104 23.3934 -4.574  381.3 -0.2
HOLE    33   0.0 0.0 0.0
HOLE    27   6.9672  23.3500  0.0
HOLE    27  29.8272  23.3500  0.0
CUBOID   6 1 41.2572 -4.4628 23.5458 -4.7244 381.3 -0.2
UNIT 22
COM=!SINGLE PIECE OF ANGLE BRACKET 0.125" x 0.1740!
CUBOID  6 1 2P0.15874 2P0.220980 381.0 0.0
UNIT 23
COM=!SINGLE PIECE OF ANGLE BRACKET 0.1740"X 0.125"!
CUBOID  6 1 2P0.220980 2P0.15874 381.0 0.0
UNIT 28
COM=!SMALL--SINGLE PIECE OF ANGLE BRACKET 0.1740"X 0.055"!
CUBOID  6 1 2P0.220980 2P0.06975 381.0 0.0
UNIT 30
COM=!SINGLE PIECE OF ANGLE BRACKET 0.072 X 0.174"!
CUBOID  6 1 2P0.09140  2P0.22095 381.0 0.0
UNIT 31
COM=!SINGLE PIECE OF ANGLE BRACKET 0.174" X 0.050"!
CUBOID  6 1 2P0.22098 2P0.06340 381.0 0.0
UNIT 24
COM=!INTEGR ANGLE STRUCTURE -X SIDE OF THE BASKET 1.697 IN GAP!
CUBOID 5 1 4.3000 0.0 2P4.440 381.1  0.0
HOLE  22 0.47625 -0.3175  0.05
HOLE  22 0.47625  0.3175  0.05
HOLE  22 0.79375  0.6350  0.05
HOLE  22 0.79375 -0.6350  0.05
HOLE  22 1.11125  0.9525  0.05
HOLE  22 1.11125 -0.9525  0.05
HOLE  22 1.42875  1.2700  0.05
HOLE  22 1.42875 -1.2700  0.05
HOLE  22 1.74625  1.5875  0.05
HOLE  22 1.74625 -1.5875  0.05
HOLE  22 2.06375  1.9050  0.05
HOLE  22 2.06375 -1.9050  0.05
HOLE  22 2.38125  2.2225  0.05
HOLE  22 2.38125 -2.2225  0.05
HOLE  22 2.69875  2.5400  0.05
HOLE  22 2.69875 -2.5400  0.05
HOLE  22 3.01625  2.8575  0.05
HOLE  22 3.01625 -2.8575  0.05
HOLE  22 3.33375  3.1750  0.05
HOLE  22 3.33375 -3.1750  0.05
HOLE  22 3.65125  3.4925  0.05
HOLE  22 3.65125 -3.4925  0.05
HOLE  22 3.96875  3.8100  0.05
HOLE  22 3.96875 -3.8100  0.05
UNIT 25
COM=!INTEGR ANGLE STRUCTURE +X SIDE OF THE BASKET 1.697 IN GAP!
CUBOID 5 1 0.0 -4.3000 2P4.440 381.1 0.0
HOLE  22 -0.47625 -0.3175 0.05
HOLE  22 -0.47625  0.3175 0.05
HOLE  22 -0.79375  0.6350 0.05
HOLE  22 -0.79375 -0.6350 0.05
HOLE  22 -1.11125  0.9525 0.05
HOLE  22 -1.11125 -0.9525 0.05
HOLE  22 -1.42875  1.2700 0.05
HOLE  22 -1.42875 -1.2700 0.05
HOLE  22 -1.74625  1.5375 0.05
HOLE  22 -1.74625 -1.5875 0.05
```

Table 6A-11 Input Deck for Run # 6P-1-030 (cont'd)

```
HOLE  22 -2.06375  1.9050 0.05
HOLE  22 -2.06375 -1.9050 0.05
HOLE  22 -2.38125  2.2225 0.05
HOLE  22 -2.38125 -2.2225 0.05
HOLE  22 -2.69875  2.5400 0.05
HOLE  22 -2.69875 -2.5400 0.05
HOLE  22 -3.01625  2.8575 0.05
HOLE  22 -3.01625 -2.8575 0.05
HOLE  22 -3.33375  3.1750 0.05
HOLE  22 -3.33375 -3.1750 0.05
HOLE  22 -3.65125  3.4925 0.05
HOLE  22 -3.65125 -3.4925 0.05
HOLE  22 -3.96875  3.8100 0.05
HOLE  22 -3.96875 -3.8100 0.05
UNIT 26
COM=!INTEGR ANGLE STRUCTURE -Y SIDE OF THE BASKET 1.8 INCH GAP!
CUBOID  5 1 2P4.444  4.400 0.0 381.1 0.0
HOLE  23 -0.3175  0.47625  0.05
HOLE  23  0.3175  0.47625  0.05
HOLE  23  0.6350  0.79375  0.05
HOLE  23 -0.6350  0.79375  0.05
HOLE  23  0.9525  1.11125  0.05
HOLE  23 -0.9525  1.11125  0.05
HOLE  23  1.2700  1.42875  0.05
HOLE  23 -1.2700  1.42875  0.05
HOLE  23  1.5875  1.74625  0.05
HOLE  23 -1.5875  1.74625  0.05
HOLE  23  1.9050  2.06375  0.05
HOLE  23 -1.9050  2.06375  0.05
HOLE  23  2.2225  2.38125  0.05
HOLE  23 -2.2225  2.38125  0.05
HOLE  23  2.5400  2.69875  0.05
HOLE  23 -2.5400  2.69875  0.05
HOLE  23  2.8575  3.01625  0.05
HOLE  23 -2.8575  3.01625  0.05
HOLE  23  3.1750  3.33375  0.05
HOLE  23 -3.1750  3.33375  0.05
HOLE  23  3.4925  3.65125  0.05
HOLE  23 -3.4925  3.65125  0.05
HOLE  23  3.8100  3.96875  0.05
HOLE  23 -3.8100  3.96875  0.05
UNIT 27
COM=!INTEGR ANGLE STRUCTURE ON +Y SIDE OF THE BASKET 1.68 IN GAP!
CUBOID  0 1 2P4.444  0.0 -4.2000 381.1 0.0
HOLE  23 -0.3175  -0.47625  0.05
HOLE  23  0.3175  -0.47625  0.05
HOLE  23  0.6350  -0.79375  0.05
HOLE  23 -0.6350  -0.79375  0.05
HOLE  23  0.9525  -1.11125  0.05
HOLE  23 -0.9525  -1.11125  0.05
HOLE  23  1.2700  -1.42875  0.05
HOLE  23 -1.2700  -1.42875  0.05
HOLE  23  1.5875  -1.74625  0.05
HOLE  23 -1.5875  -1.74625  0.05
HOLE  23  1.9050  -2.06375  0.05
HOLE  23 -1.9050  -2.06375  0.05
HOLE  23  2.2225  -2.38125  0.05
HOLE  23 -2.2225  -2.38125  0.05
HOLE  23  2.5400  -2.69875  0.05
HOLE  23 -2.5400  -2.69875  0.05
HOLE  23  2.8575  -3.01625  0.05
HOLE  23 -2.8575  -3.01625  0.05
HOLE  23  3.1750  -3.33375  0.05
HOLE  23 -3.1750  -3.33375  0.05
```

Table 6A-11 Input Deck for Run # 6P-1-030 (cont'd)

```
HOLE  23 3.4925 -3.65125 0.05
HOLE  23 -3.4925 -3.65125 0.05
UNIT 35
COM=!LEFT HAND ARRAY OF FUEL PINS-UPSIDE DOWN[OUTSIDE WITH ETHAFOAM & RUBBER]!
CUBOID   5 1 16.0447 -2.2002  2.86070  -13.7182  381.1  0.0
HOLE     40 -2.0571 -13.575  0.0
HOLE     18  15.8921 -13.0143 0.01
CUBOID   0 1 16.0447 -2.2002  2.86070  -15.96070  381.1  0.0
CUBOID   7 1 16.0447 -2.3526  3.01310  -16.11310  381.1  0.0
UNIT 36
COM=!RIGHT HAND ARRAY OF FUEL PINS-UPSIDE DOWN[CENTERED WITH ETHAFOAM & RUBBER]!
CUBOID   5 1  2.2002  -16.0447 2.86070 -13.7182  381.1  0.0
HOLE     40  -11.5179 -13.575   0
HOLE     18  -16.0447 -13.0143 0.5
CUBOID   0 1  2.2002  -16.0447 2.86070 -15.96070  381.1  0.0
CUBOID   7 1  2.3526  -16.0447 3.01310 -16.11310  381.1  0.0
UNIT 37
COM=!STACKING OF THE LEFT AND RIGHT BASKETS WITH 2 INCH GAP AROUND!
ARRAY    4  0.0 -19.1262  0.0
CUBOID   5 1 36.8000 -0.0   4.572  -19.1262 381.2 -0.1
HOLE     26   9.2372  0.1500  0.0
HOLE     26  28.5572  0.1500  0.0
UNIT 38
CUBOID   5 1 41.1048  -4.3104   4.573 -19.1263 381.25 -0.15
HOLE     37  0.0 0.0 0.0
HOLE     24  -4.3103  -9.1999  0.0
HOLE     25  41.1045  -9.1999  0.0
UNIT 39
CUBOID   0 1 41.1048  -4.3104   4.574 -23.3934 381.3  -0.2
HOLE     38   0.0 0.0 0.0
HOLE     27   6.9672 -19.1500   0.0
HOLE     27  29.8272 -19.1500   0.0
CUBOID   6 1 41.2572  -4.4628   4.7244 -23.5458 381.3 -0.2
UNIT 40
COM=!ARRAY OF FUEL PINS WITH CHANNEL!
ARRAY     1 0.0 0.0 0.0
CUBOID   19 1 13.7180 -0.1430  13.7180   -0.1430   381.1  0.0
global
UNIT 29
ARRAY 3  0.0 0.0 0.0
END GEOM
READ ARRAY
ARA=1 NUX=1 NUY=19 NUZ=1
COM=!FUEL PIN ARRANGMENT!
FILL
11 16 12 16 13 16 14 16 15
       17
15 16 14 16 13 16 12 16 11
END FILL
ARA=2 NUX=2 NUY=1 NUZ=1
COM=!ARRAY OF TWO ASSY'S SIDE BY SIDE IN THE 7X7 INCH BASKET!
FILL 19 20 END FILL
ARA=3 NUX=8 NUY=13 NUZ=1
FILL  8R34 8R34 8R34 8R34
    8R34 8R34 8R34 8R34
    8R34 8R34 8R34 8R34
    8R34
END FILL
ARA=4 NUX=2 NUY=1 NUZ=1
COM=!ARRAY OF TWO ASSY'S SIDE BY SIDE IN THE 7X7 INCH BASKET!
FILL 35 36 END FILL
END ARRAY
READ BNDS +XB=H2O -XB=H2O +YB=H2O -YB=H2O +ZB=H2O -ZB=H2O
END BNDS
```

Table 6A-11 Input Deck for Run # 6P-1-030 (cont'd)
END DATA END READ PLOT TTL=!XY PLOT OF RA3! PLT=YES PIC=MAT XUL=0 YUL=29 ZUL=50 XLR=50 YLR=0 ZLR=50 UAX=1 VAX=0 WAX=0 UDN=0 VDN=-1 WDN=0 NAX=600 SCR=YES LPI=8 END PLT1 END PLOT

Table 6A-12 Benchmark Criticality Experiments				
Case #	Case Name		Case #	Case Name
1	bw1484-i.18332.out:		26	pnl-3314-116.1322.out:
2	bw1484-ii.358.out:		27	pnl-3314-119.19398.out:
3	bw1484-iii.24205.out:		28	pnl-3314-055.25658.out:
4	bw1484-iv.29886.out:		29	pnl-3314-070.2076.out:
5	bw1484-v.18468.out:		30	pnl-2615-008.25870.out:
6	bw1484-vi.501.out:		31	pnl-2615-004.2286.out:
7	bw1484-vii.24341.out:		32	pnl-2615-031.1792.out:
8	bw1484-viii.132.out:		33	Bw1645s1.1950.out:
9	bw1484-ix.24614.out:		34	Bw1645s2.19626.out:
10	bw1484-x.18725.out:		35	Bw1645t1.26073.out:
11	bw1484-xi.787.out:		36	Bw1645t2.19824.out:
12	bw1484-xii.981.out:		37	Bw1645t3.2556.out:
13	bw1484-xiii.24808.out:		38	Bw1645t4.26281.out:
14	bw1484-xiv.482.out:		39	Nse71h1.2773.out:
15	bw1484-xv.1214.out:		40	Nse71h2.20046.out:
16	bw1484-xvi.18974.out:		41	Nse71h3.2295.out:
17	bw1484-xvii.1419.out:		42	Nse71sq.26500.out:
18	bw1484-xviii.25026.out:		43	Nse71w1.3026.out:
19	bw1484-xix.739.out:		44	Nse71w2.26708.out:
20	bw1484-xx.25233.out:		45	BW1810A.2632.out:
21	bw1484-xxi.19182.out:		46	BW1810B.3288.out:
22	pnl-2438-020.1066.out:		47	Bw1810cr.20673.out:
23	pnl-2438-032.1655.out:		48	BW1810D.27507.out:
24	pnl-3314-002.1854.out:		49	BW1810E.3515.out:

Table 6A-13 Subgrouping of Benchmark Critical Experiments						
Description	*No. of exp.*	*k_{eff} range*	*k_{eff}*	*$\pm\sigma$*	*AEF range (ev)*	*Case No. (Table 6A-12)*
Simple Lattice						
Square	6	0.9916-0.9956	0.9936	0.0015	0.1130-0.2508	1,9,24,28,31,45
Separator Plate Calculations						
Boral	3	0.9894-0.9962	0.9932	0.0030	0.0974-0.1820	22,26,32,
Boraflex	1		0.9921	0.0007	0.1823	27
Borated steel	1		0.9938	0.0007	0.0965	23
Steel	5	0.9907-0.9950	0.9932	0.0021	0.1130-0.2508	25,29,30
TOTAL	8	0.9894-0.9962	0.9930	0.0022	0.09650.2454	
Separator Plate Soluble Boron Calculations						
Hexagonal						
Aluminum	4	0.9856-0.9962	0.9935	0.0027	0.9721-2.2802	35-38
Square						
Borated aluminum	9	0.9856-0.9942	0.9894	0.0027	0.1517-0.2039	13-21
Aluminum	2	0.9912-0.9958	0.9935	0.0033	1.3402-1.3999	33,34
Steel	2	0.9924-0.9942	0.9936	0.0017	0.1667-0.1963	11,12
TOTAL	17	0.9856-0.9962	0.9913	0.0032	0.15172.2802	
Urania Gadolinia Rod Calculations						
Gadolinia	4	0.9946-0.9990	0.9961	0.0020	0.2514-0.3414	46-49
Water Hole Calculations						
Water holes	6	0.9926-0.9995	0.9954	0.0029	0.0701-0.2704	39-44
Absorber Rods calculations						
B4C	5	0.9898-1.0010	0.9940	0.0054	0.1465-0.1883	4-8
Soluble Boron calculations						
Borated water	3	0.9927-0.9953	0.99403	0.0013	0.0503 - 0.1472	2, 3, 10