Westinghouse Electric Company
Nuclear Fuel
Columbia Fuel Site
P.O. Drawer R
Columbia, South Carolina 29250
USA

Attn: Document Control Desk
Director, Division of Spent Fuel Storage and Transport
Office of Nuclear Material Safety and Safeguards
U. S. Nuclear Regulatory Commission
Washington, DC 20555-0001

Direct tel: (803) 647-3167
Direct fax: (803) 695-4164
e-mail: vescovpj@westinghouse.com

Your ref: Docket No. 71-9239
TAC No. L24390
Our ref: LCPT-09-35

30 December 2009

Dear Mr. E. William Brach:

SUBJECT: Docket 71-9239, Model Nos. MCC-3, 4, 5 Packages, Approval for Shipment of Modified Fuel Assembly Contents

Responses to the request for additional information (RAI) in NRC letter dated December 8, 2009, pertaining to Enclosure 3 of the amendment request application dated October 28, 2009 are enclosed. In addition to the responses to RAI, a revised version of 'Enclosure 3 – Evaluations, Analysis and Detailed Calculations – Annular Pellet Blankets' that incorporates changes as discussed in the RAI responses is also provided.

Sincerely,

Electronically approved

Peter J. Vescovi
Licensing, Compliance and Package Technology

WESTINGHOUSE ELECTRIC COMPANY, LLC
Nuclear Fuel Global Supply Chain Management
5801 Bluff Road
Columbia, SC 29209, USA
www.westinghousenuclear.com

Enclosures: Responses to Request for Additional Information (3-1 through 3-7)
Enclosure 3 (Revision 1) – Evaluations, Analysis and Detailed Calculations – Annular Pellet Blankets

cc: N. Kent, Westinghouse, Manager, Licensing, Compliance and Packaging Technology
B. Bayley, Westinghouse, Manager, Transport Logistics
E. Bennner, U.S. NRC Chief, NMSS/DSFST/LID/ Licensing Branch
M. Sampson, U.S. NRC Project Manager, NMSS/DSFST/LID/Licensing Branch

By Federal Express
LCPT-09-35.doc

NMSS24

Responses to Request for Additional Information
Westinghouse Electric Company, LLC
Docket No. 71-9239
Certificate of Compliance No, 9239
Model Nos. MCC-3, MCC-4, And MCC-5

3-1: Clarify which system of codes was used to evaluate the annular pellet blankets.

Table 1 references the SCALE 4.4 system of codes, however, in the Methodology section on the same page and in the input file, it states SCALE 5.1. This clarification is needed to determine what benchmarking evaluations are applicable.

This clarification is needed to determine compliance with 10 CFR 71.55.

Westinghouse Response

SCALE 5.1 is the methodology used to evaluate the package.

3-2: Clarify whether the keff values in Table 1 include bias adjustments.

The applicant only gives a value for keff and the uncertainity in Table 1, and it is unclear whether the bias is included. As stated in Section 6.5.1.2 of NUREG-1609, the application should show that the sum of the keff from the code, two standard deviations, and the bias adjustment, should not exceed 0.95. If Table 1 does not give keff with the bias adjustment, please provide them and demonstrate that the acceptance criterion in the SRP is met.

This clarification is needed to determine compliance with 10 CFR 71.55.

Westinghouse Response

The keff values in Table 1 did not include a bias. The applicant agrees that the bias should be included to provide a valid comparison to keff values calculated using SCALE 5.1.

Values of keff that include the uncertainty and bias are reported in the application as "95/95 keff" or "final keff". This keff value is calculated by applying a one-sided tolerance limit where α=0.05 and P=0.95 and statistical propagation of the uncertainties as follows:

$$Final\ K_{eff} = K_{nom} + B_{meth} + \sqrt{(Ks_{nom})^2 + (Ks_{meth})^2}$$

where:

Final K_{eff} = the calculated K_{eff} with bias and all uncertainties included at the 95 percent confidence level;

K_{nom} = the average K_{eff} generated from KENO Va;

B_{meth} = the bias associated with the KENO methodology established from comparison with critical experiments;

Ks_{nom} = the 95/95 uncertainty on the KENO calculation result;

Ks_{meth} = the 95/95 uncertainty associated with the KENO method bias.

The standard deviation for the K_{nom} and B_{meth} is multiplied by a factor for a one-sided tolerance limit for a normal distribution to calculate Ks_{nom} and Ks_{meth}. The factor is 2.20 for the Ks_{meth} based on 32 benchmark experiments and a factor of 1.65 is used for Ks_{nom} based the large number of generations used to calculate K_{nom}.

The bias can be affected by several factors, such as versions of the codes, cross-section processing, computing environments, or other input parameters (e.g. npg, gen). A revision to Enclosure 3 provides the "95/95 keff" values that are calculated using the same method as described above and the SCALE 5.1 bias values (B_{meth} and Ks_{meth}).

3-3: Provide a benchmark analysis for the code calculations used to demonstrate compliance with the acceptance criterion in the SRP as discussed in RAI 2 above.

The benchmark analysis needs to establish a bias adjustment that is applicable to the methodology used and the system being evaluated (including the code, cross sections, code options, modeling approach and the system's components, geometry and constituents). The applicant should use the same methodology throughout the entire application. Section 6.5.7 of the SRP and NUREG/CR-6361 provide guidance on appropriate benchmarking evaluations.

This additional information is needed to determine compliance with 10 CFR 71.55.

Westinghouse Response

In the original application NITAWL was used to generate resonance self shielding corrections for a 227 group CSRL-V cross section library each fuel lattice geometry using NITAWL. A transport calculation was performed for each fuel lattice using XSDRNPM to solve for the 227 group fluxes and collapse these to 27 groups for use in KENO Va calculation. Calculations for 32 benchmark experiments in the original application were done using a CRAY XMP computer and a HP-735 workstation. The application notes a change in computing environments by stating that the bias calculated using values in Figure 6-9 applies to calculations performed prior to January 1, 1994 and values in Figure 6-11 applies to calculation performed after January 1, 1994. A benchmark analysis for the same 32 benchmark experiments has been done for versions of NITAWL and KENO Va distributed as SCALE 5.1. The values for keff were calculated by running SCALE5.1 versions of the computer codes and CSAS25 sequence on a SuSE Linux operating system. The results for these experiments are summarized in the following tables in the same format as Figure 6-9 and 6-10 in the original application.

Number of Experiments	**32**
Average Measured K_{eff} (K_m)	1.0007
Average KENO Va K_{eff} (K_c)	0.9938
KENO Va Bias ($K_m - K_c$)	0.0069
Bias Standard Deviation (s)	0.0009
One Sided Tolerance Factor for 95/95 (k)	2.20
95/95 Bias Uncertainty (ks)	0.0020

Critical Number	Enrichment ^{235}U wt%	Reflector Material	Separating Material	Soluble Boron (ppm	Measured K_{eff}	KENO Reactivity $K_{eff} \pm 1\sigma$
1	2.46	water	water	0	1.0002	0.9945 ± 0.0006
2	2.46	water	water	1037	1.0001	0.9956 ± 0.0006
3	2.46	water	water	764	1.0000	0.9975 ± 0.0007
4	2.46	water	B_4C pins	0	0.9999	0.9915 ± 0.0007
5	2.46	water	B_4C pins	0	1.0000	0.9911 ± 0.0007
6	2.46	water	B_4C pins	0	1.0097	1.0023 ± 0.0008
7	2.46	water	B_4C pins	0	0.9998	0.9920 ± 0.0007
8	2.46	water	B_4C pins	0	1.0083	0.9920 ± 0.0007
9	2.46	water	water	0	1.0030	0.9959 ± 0.0005
10	2.46	water	water	143	1.0001	0.9940 ± 0.0007
11	2.46	water	stainless steel	514	1.0000	0.9971 ± 0.0006
12	2.46	water	stainless steel	217	1.0000	0.9944 ± 0.0006
13	2.46	water	borated aluminu	15	1.0000	0.9953 ± 0.0007
14	2.46	water	borated aluminu	92	1.0001	0.9918 ± 0.0006
15	2.46	water	borated aluminu	395	0.9998	0.9870 ± 0.0005
16	2.46	water	borated aluminu	121	1.0001	0.9868 ± 0.0006
17	2.46	water	borated aluminu	487	1.0000	0.9909 ± 0.0005
18	2.46	water	borated aluminu	197	1.0002	0.9918 ± 0.0007
19	2.46	water	borated aluminu	634	1.0002	0.9927 ± 0.0006
20	2.46	water	borated aluminu	320	1.0003	0.9920 ± 0.0005
21	2.46	water	borated aluminu	72	0.9997	0.9893 ± 0.0005
22	2.35	water	borated aluminu	0	1.0000	0.9952 ± 0.0006
23	2.35	water	stainless steel	0	1.0000	0.9949 ± 0.0006
24	2.35	water	water	0	1.0000	0.9929 ± 0.0006
25	2.35	water	stainless steel	0	1.0000	0.9933 ± 0.0007
26	2.35	water	borated aluminu	0	1.0000	0.9913 ± 0.0007
27	2.35	water	B_4C	0	1.0000	0.9936 ± 0.0007
28	4.31	water	stainless steel	0	1.0000	0.9977 ± 0.0007
29	4.31	water	water	0	1.0000	0.9958 ± 0.0007
30	4.31	water	stainless steel	0	1.0000	0.9964 ± 0.0007
31	4.31	water	borated aluminu	0	1.0000	0.9972 ± 0.0007
32	4.31	water	borated aluminu	0	1.0000	0.9975 ± 0.0006

±

3-4: Justify how the modified assembly is subcritical in the package.

The application gives the keff for the modified assembly surrounded by water but does not discuss how the packaging may affect criticality. The staff request a demonstration showing that the modified assembly is subcritical when considering packaging or a demonstration showing that the modified assembly is still bounded by the Type A evaluation in the application.

This justification is needed to determine compliance with 10 CFR 71.55.

Westinghouse Response

The summary of calculations that is referenced as Table 6-3-1 of the application is for evaluation of the packaged fuel assemblies. An evaluation of the unpackaged individual fuel assembly types, provided in Appendix 6-2 of the application, was used to demonstrate the most reactive contents to use in the evaluation of the package, provided in Appendix 6-3 of the application. Calculations provided in this request are for Type A fuel assembly contents in the MCC packaging. Type A assemblies include all 14x14 and 16x16 designs, and the package evaluation is done using the 14x14 OFA since this assembly is the most reactive of the Type A assemblies as demonstrated in Appendix 6-2 of the application.

The keff value reported in Table 6-3-1 of the application for the 14X14 (Type A) OFA with solid blanket pellets and no fuel pin gap moderation (Reference, Table 6-3-2) was calculated prior to January 1, 1994. This "95/95 with bias" value for the 14X14 (Type A) OFA with no annular blanket pellets (Reference Table 6-3-2) is calculated using bias reported in Figure 6-10 as follows,

$$\begin{aligned} Final\ K_{eff} &= K_{nom} + B_{meth} + \sqrt{(Ks_{nom})^2 + (Ks_{meth})^2} \\ &= 0.90486 + 0.0074 + \sqrt{(1.65 \times 0.00462)^2 + (0.0029)^2} \\ &= 0.9204 \end{aligned}$$

The keff value reported in Table 6-3-1 of the application for the 14X14 (Type A) OFA with fuel pin gap flooding with annular fuel blankets (Reference, Table 6-3-18) was calculated after to January 1, 1994. (Note that Table 6-3-1 incorrectly references Table 6-3-1 for the later case and should reference Table 6-3-18.) The annular fuel blanket model in the application represents a 6.00 inch annular fuel pellet blanket at top and bottom of rods. This "95/95 with bias" value for the 14X14 (Type A) OFA with fuel pin gap flooding with annular fuel blankets (Reference Table 6-3-18) is calculated using bias reported in Figure 6-12 as follows,

$$\begin{aligned} Final\ K_{eff} &= K_{nom} + B_{meth} + \sqrt{(Ks_{nom})^2 + (Ks_{meth})^2} \\ &= 0.9080 + 0.0077 + \sqrt{(1.65 \times 0.00241)^2 + (0.0030)^2} \\ &= 0.9207 \end{aligned}$$

Table 1 – Summary of KENO Calculational Results
[Ref. - Application for Approval, USA/9239/AF, Revision 12 (Table 6-3-1)]

Assembly Type	Enrichment wt. %	Added Absorbers	KENO $k_{eff} \pm \sigma$	95/95 w/Bias	Reference
Type A	5.00	None	0.90486 ± 0.00462	0.9204	Table 6-3-2
Fuel Pin Gap Flooding with Annular Fuel Blankets					
Full Water Density Outside the Pins					
Type A	5.00	None	0.9080 ± 0.00241	0.9207	Table 6-3-18

The same keff values for the 14X14 OFA Type A fuel assembly were calculated using SCALE 5.1 CSAS25 and the SCALE 44 group library using the bias as described in the response to RAI 3-2.

This "95/95 with bias" value for the 14X14 (Type A) OFA with no annular blanket pellets is calculated using SCALE 5.1 methodology as follows,

$$\begin{aligned} Final\ K_{eff} &= K_{nom} + B_{meth} + \sqrt{(Ks_{nom})^2 + (Ks_{meth})^2} \\ &= 0.9009 + 0.0069 + \sqrt{(1.65 \times 0.0005)^2 + (0.0020)^2} \\ &= 0.9099 \end{aligned}$$

This "95/95 with bias" value for the 14X14 (Type A) OFA with fuel pin gap flooding with annular fuel blankets is calculated using SCALE 5.1 methodology as follows,

$$\begin{aligned} Final\ K_{eff} &= K_{nom} + B_{meth} + \sqrt{(Ks_{nom})^2 + (Ks_{meth})^2} \\ &= 0.9068 + 0.0069 + \sqrt{(1.65 \times 0.00050)^2 + (0.0020)^2} \\ &= 0.9158 \end{aligned}$$

Table 2 – Summary of KENO Calculational Results
[SCALE 5.1 CSAS25 using 44 group library]

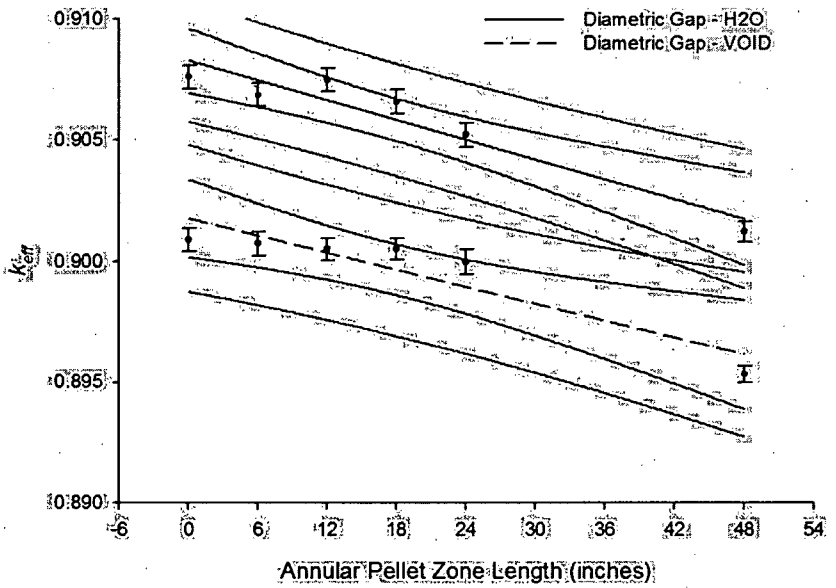
Assembly Type	Enrichment wt. %	Added Absorbers	KENO $k_{eff} \pm \sigma$	95/95 w/Bias	Reference
Type A	5.00	None	0.9009 ± 0.0005	0.9099	0 inch, VOID
Fuel Pin Gap Flooding with Annular Fuel Blankets					
Full Water Density Outside the Pins					
Type A	5.00	None	0.9068 ± 0.0005	0.9158	6 inch, H2O

The "95/95 w/Bias" values calculated using SCALE 5.1 (Table 2) are lower, but show the same effect of "fuel pin gap flooding with annular fuel blankets" as calculated in the original application (Table 1). Changes in the methods used to calculate resonance self-shielding for the cross sections and difference in the energy group structure are contributing factors to small differences in k_{eff} calculated using SCALE 5.1 CSAS25. However, it is considered acceptable to use the SCALE 5.1 CSAS25 method for the purpose of evaluating the comparative effects that annular pellets and moderating the diametric gap may have on k_{eff}.

The k_{eff} results are calculated to demonstrate these effects are shown below. The effects are evaluated using the calculated k_{eff} and statistical uncertainty in the calculation. A regression analysis is used to trend the results with respect to annular pellet blanket length, and a confidence band (α=0.05) and tolerance band (α=0.05 and P=0.95) are calculated. Moderating the diametric gap results in a significant difference of about Δk_{eff}=0.006 on average, and increasing the annular pellet stack results in a decrease in the k_{eff} value. All "95/95 w/Bias" values regardless of the annular pellet zone length are less than the maximum allowed value of k_{eff}=0.9500.

KENO-Va Results
(Diametric Gap – Void, Diametric Gap – H2O)

Annular Pellet Zone Length (inches)	Diametric Gap – H2O			Diametric Gap – Void		
	k_{eff}	σ	95/95 w/Bias	k_{eff}	σ	95/95 w/Bias
0	0.9076	0.0005	0.9166	0.9009	0.0005	0.9099
6	0.9068	0.0005	0.9159	0.9007	0.0005	0.9098
12	0.9075	0.0005	0.9165	0.9005	0.0005	0.9095
18	0.9066	0.0005	0.9156	0.9005	0.0005	0.9096
24	0.9052	0.0005	0.9143	0.9000	0.0005	0.9091
48	0.9012	0.0004	0.9103	0.8953	0.0003	0.9043
72	0.8792	0.0005	0.8883	0.8723	0.0005	0.8813



3-5: Provide dimensions for the annular pellet blanket.

Figure 1 appears to have dimensions on it, but they are not legible. Figure 2 provides a diagram of the annular pellet blanket, however the dimensions are not provided. The dimensions are necessary for the staff to do an independent confirmatory calculation.

This additional information is needed to determine compliance with 10 CFR 71.55.

Westinghouse Response

Figure 1 shows the configuration for an annular blanket pellet. There are 15 annular blanket pellet specifications with 7 unique inside and outside radial dimensions for the configuration shown in Figure 1. The fuel assembly parameters are conditions of approved contents in the CoC by reference to Tables 1-5-1 through 1-5-5 in Section 1- General Information, Appendix 1-5 of the application. The nominal pellet outside diameter and annular pellet inner diameter can be found in Appendix 1-5 for each type of the fuel assembly, and a summary of these diameter dimensions is provided in the following table. Annular inner diameter is not specified in Appendix 1-5 for fuel assembly types CE-1, CE-2, and CE. The CE fuel assembly types are shipped in the Traveller package USA/9297/AF-96 and CoC 9297 condition 5.(b)(1)(v) does not limit the length of the annular pellet blanket.

Pellet description	Outside diameter (inch)	Inner diameter (inch)	Appendix 1-5
16, 17 STD, CE 16 NGF	0.3225	0.155	Table 1-5-3 (W-STD) Table 1-5-4 (W-STD, W-STD/XL)
17 OFA	0.3088	0.155	Table 1-5-4 (W-OFA)
14 STD, 15	0.3659	0.183	Table 1-5-1 (422 V+) Table 1-5-2 (W-STD,W-OFA, B&W)
14 OFA	0.3444	0.172	Table 1-5-1 (W-OFA)
C-14	0.3765	0.183	Table 1-5-1 (CE-1)
14 CE	0.381	0.1905	Table 1-5-1 (CE-2)
16 CE	0.3250	0.1625	Table 1-5-3 (CE)

Figure 2 relates the dimensions used to specify the lattice cell parameters used by the SCALE CSAS control module to the fuel assembly type lattice dimensions in Appendix 1-5. The lattice cell model input parameters correspond to the fuel assembly description as follows,

IMOD	Annular Pellet Inner Diameter
FUEL	Nominal Pellet Diameter
GAP	Nominal Clad Outer Diameter minus (2 X Nominal Clad Thickness)
CLAD	Nominal Clad Outer Diameter
PITCH	Nominal Lattice Pitch

Radius or diameter may be specified in the CELLDATA block. The radius dimensions were specified in the CELLDATA block for consistency with the dimensions required in the GEOMTRY block.

Enclosure 3 has been revised to include the table of dimensions and relationship of the LATTICELL parameters to the lattice dimensions in Appendix 1-5 of the application.

3-6: Justify the differences in the dimensions used in the input file for the annular pellet blanket.

The dimensions used for the cross section processing in the input file are not consistent with the geometry used to describe the fuel rods. A justification of the reason behind the different dimensions used is needed.

This justification is needed to determine compliance with 10 CFR 71.55.

Westinghouse Response

The dimensions used in the CELLDATA block are for a 17X17 W-OFA fuel assembly type. The GEOMETRY block dimensions are the correct dimensions for a 14X14 W-OFA fuel assembly type.

Enclosure 3 has been revised to report the calculated values with the correct dimensions in the CELLDATA block.

3-7: Justify the use of the asymslabcell celldata card in the input file.

It is unclear why the asymslabcell was needed in the input file. A justification is needed to ensure that the code was used properly.

This justification is needed to determine compliance with 10 CFR 71.55.

Westinghouse Response

The cross section treatment in the original application was done prior to the development CSAS control modules in SCALE. Cross section processing required manually running a sequence of functional modules to calculate a DANCOFF factor (SUPERDAN), perform resonance treatments (NITAWL), calculate a flux solution to cell-weight or collapse cross-sections (XSDRNPM) to generate a working library that could be used by the Monte Carlo code KENO-Va. Resonance shielding corrections were calculated for the U-235, U-238, Mn-55, and each of the Gadolinium isotopes (Gd-152, Gd-154, Gd-155, Gd-156, Gd-157, Gd-158, and Gd-160). A separate XSDRN calculation was done in the original application for the Gadolinium absorber plate, solid pellet fuel rod lattice, and annular fuel rod lattice.

The NITAWL and XSRDNPM sequence can be replicated by running the CSAS control modules and specifying the appropriate unit cell in the CELL DATA block. The earlier version of NITAWL contained provisions for performing an unresolved resonance self-sheilding calculation, but later this was replaced with the BONAMI module that provides

better unresolved resonance techniques. The ASYMSLABCELL CELLDATA card was used in an attempt to replicate this XSDRN input in the original application in SCALE 5.1. The XSDRN input for the Gadolinium absorber plate is shown in the figure below as it relates to the actual configuration in the package. The Gadolinium absorber plate and fuel region was represented as a slab geometry in the XSDRN input as an attempt to represent within the limitation of the 1-D geometry. It may have been more accurate to have calculated a cell-weighted cross section by represent the fuel lattice as an homogenized cross section generated from a 1-D XSDRN calculation representing the fuel rod lattice. Notwithstanding, these XSDRN calculations were used in the original application to calculate a flux spectrum that would be representative of that seen by the Gadolinium absorber plate in order to weight the fine group cross sections for collapsing to a 27 group energy structure. The SCALE 44 group cross-sections are used in the calculations in this request, therefore replicating the cell-weighting flux calculation done by XSDRN in the original application is not necessary.

The choice of the geometry for the unit cell input is important to account for the effect lattice geometry by calculating the Dancoff factor that is used to modify the resonance escape probability used in the Nordheim Integral Treatment as done in NITAWL. The applicant agrees that use of ASYMSLABCELL is not appropriate for replicating the resonance calculations for the gadolinium isotopes as done in the original application. The Gadolinium absorber plate is not a repeating structure and as such should not be represented as such by a LATTICECELL, SYMSLABCELL, or ASYMSLABCELL. Instead a MULTIREGION slab geometry is more appropriate to replicate the NITAWL input for Gadolinium resonance calculations as done in the original application. The MULTIREGION option does not calculate a Dancoff factor and instead defaults the value used to zero as in the case of a homogeneous infinite medium. However, the INFHOMOGENOUS resonance treatment for Gadolinium isotopes would not account for corrections to the resonance escape probability due to the slab geometry, and it use would overstate the correction to the infinite dilute resonance integral resulting in decreased resonance absorption. Specifying LATTICECELL SQUAREPITCH for the solid pellet stack and LATTICECELL ASQUAREPITCH for the annular pellet stack does replicate the geometry used in the original NITAWL input and includes the additional treatment of the annular region not done in earlier versions of NITAWL.

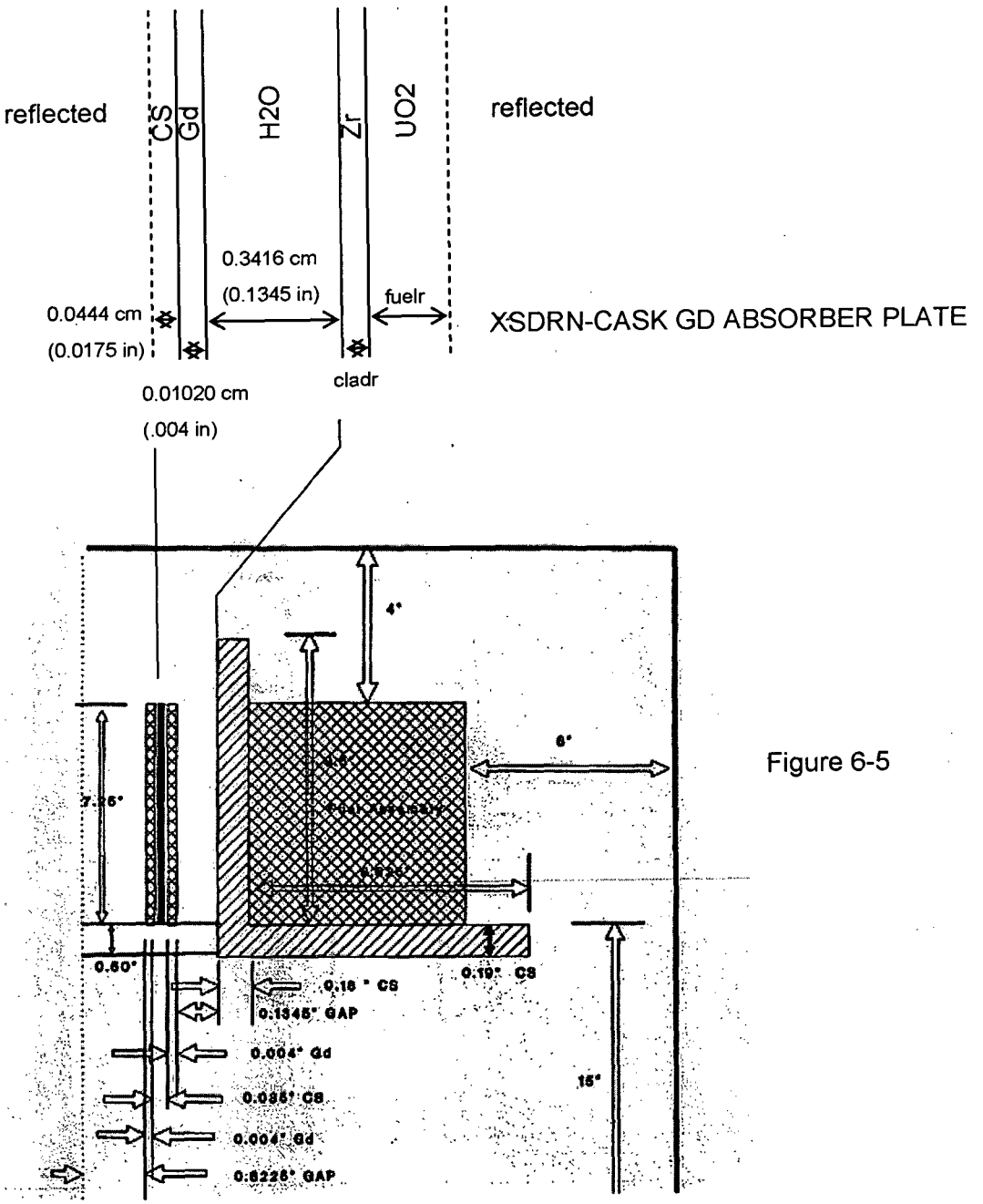

reflected
CS
Gd
H2O
Zr
UO2
reflected
0.3416 cm
(0.1345 in)
fuelr
0.0444 cm
(0.0175 in)
cladr
0.01020 cm
(.004 in)
XSDRN-CASK GD ABSORBER PLATE
4"
6"
0.60"
0.16 " CS
0.1345" GAP
0.004" Gd
0.0355" CS
0.004" Gd
0.8228" GAP
0.19" CS
15"

Figure 6-5

Enclosure 3 - Evaluations, Analysis and Detailed Calculations– Annular Pellet Blankets
(Revision 1)

Background

A main problem for fuel designers wishing to increase burnup is that of fission gas release. Fission gas is generated within the fuel during operation, and the amount is roughly proportional to the burnup. In addition, the use of boron as a burnable poison results in a buildup of helium gas as a product of the $^{10}B(n, \alpha)^{7}Li$ capture reaction. The higher quantity of fission gas and helium is of concern if it is released from the fuel pellet, causing high pressure inside the fuel rod and concerns about clad expansion. Some Westinghouse PWR fuel rod designs use annular pellets at the top and bottom of the fuel rod to increase the volume available for fission product and helium gas. The top and bottom of the fuel rod pellet stack is called the blanket zone and the fuel pellets are usually of a lower enrichment for reasons related to the nuclear core design objectives.

The fuel rod is normally pressurized with an inert gas during fabrication. Transport accident conditions may result in breaching the fuel rod cladding, thereby allowing water to fill the void spaces in the fuel rod. The application was revised to consider the effect on k_{eff} of moderator in the fuel rod diametric gap. The evaluation assessed this effect coincident with replacing solid pellets with at the top and bottom of the fuel rods. The results of the evaluation are summarized in Table 6-3-1 of the application as "Fuel Pin Gap Flooding with Annular Fuel Blankets." The combined effect resulted in a small increase in k_{eff} when compared with the fuel rod with no diametric gap moderation and no annular pellet blankets. Consequently, the application was revised to limit the length of the top and bottom annular pellet zones.

The evaluation presented herein demonstrates that moderation in the diametric gap will increase k_{eff}, but the annular pellet zones hove no significant effect on keff when compared with solid pellets. Thereby, demonstrating that imposing limit the annular pellet zone length is not required.

Annular Pellet Design

Figure 1 shows the configuration for an annular blanket pellet. There are 15 annular blanket pellet specifications with 7 unique inside and outside radial dimensions for the configuration shown in Figure 1. The fuel assembly parameters are conditions of approved contents in the CoC by reference to Tables 1-5-1 through 1-5-5 in Section 1-General Information, Appendix 1-5 of the application. The nominal pellet outside diameter and annular pellet inside diameter can be found in Appendix 1-5 for each type of the fuel assembly, and a summary of these diameter dimensions is provided in Table 1. Annular inner diameter is not specified in Appendix 1-5 for fuel assembly types CE-1, CE-2, and CE. The CE fuel assembly types are shipped in the Traveller package USA/9297/AF-96 and CoC 9297 condition 5.(b)(1)(v) does not limit the length of the annular pellet blanket.

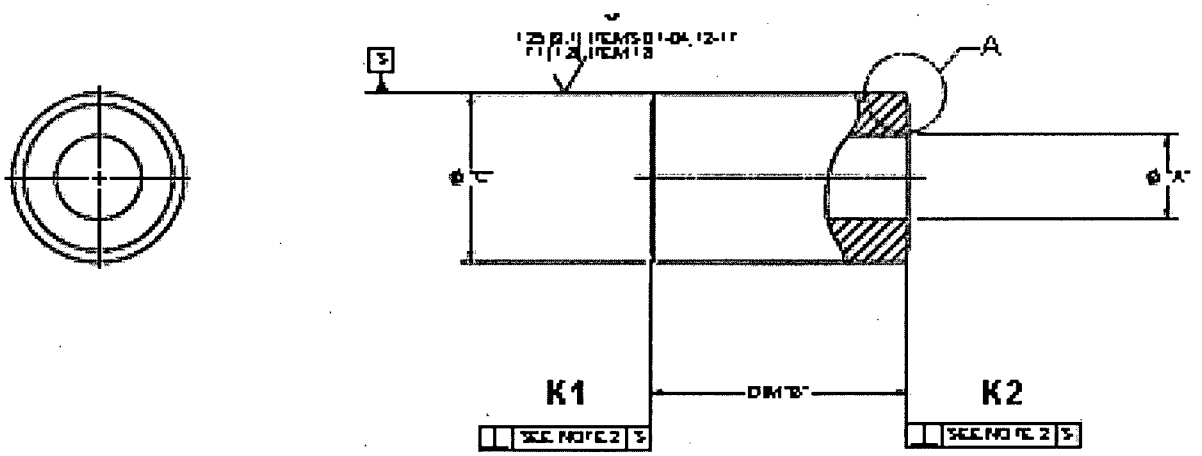


Figure 1-Annular Pellet Geometry

Table 1 - Fuel pellet dimensions

Pellet description	Outside diameter "C" (inch)	Inner diameter "A" (inch)	Appendix 1-5
16, 17 STD, CE 16 NGF	0.3225	0.155	Table 1-5-3 (W-STD) Table 1-5-4 (W-STD, W-STD/XL)
17 OFA	0.3088	0.155	Table 1-5-4 (W-OFA)
14 STD, 15	0.3659	0.183	Table 1-5-1 (422 V+) Table 1-5-2 (W-STD,W-OFA, B&W)
14 OFA	0.3444	0.172	Table 1-5-1 (W-OFA)
C-14	0.3765	0.183	Table 1-5-1 (CE-1)
14 CE	0.381	0.1905	Table 1-5-1 (CE-2)
16 CE	0.3250	0.1625	Table 1-5-3 (CE)

Analysis of relevant physics

The relevant physics can be surveyed by simply examining how terms in the six-factor formula are modified by changes to the fuel rod configuration.

$$k_{eff} = \eta f p \varepsilon P_{FNL} P_{TNL}$$

The dominant effect on neutron multiplication in fuel rod lattices is contained in the behavior of the resonance escape probability *p* and thermal utilization *f*. The most significant effect in a fuel rod lattice is a change in the resonance escape probability *p*. This change in *p* is in part the effect that geometry has on the resonance integral for the fuel. Replacement of solid pellets with annular pellets reveals an important aspect of spatial self-shielding related to the geometry of the fuel.

The effective resonance integral can be written in the form

$$I \approx a + b\left(\frac{A_F}{M_F}\right),$$

where A_F is the surface area of the fuel pellet and M_F is the mass. As A_F / M_F increases the resonance integral increases. The A_F / M_F for annular pellets is approximately 1.5 to 1.6 times greater than A_F / M_F for the solid pellets. An increase surface may cause an increase in the resonance integral and result in resonance escape probability decreasing, thereby reducing the reactivity. However, the increase in A_F / M_F may be offset by the small diameter of the annular geometry and have limited effect on the resonance escape. As neutrons slow from fission energy they are likely to transit across the annulus with few interactions and reenter the fuel region, effectively having never left the fuel region during the slowing down process.

Moderator in the diametric gap instead of void reveals the spatial shielding effect arising because of the physical separation of the fuel and the moderator that will allow some neutrons to slow down before ever encountering another fuel rod. This spatial effect increases the resonance escape probability, thereby increasing reactivity.

Increased moderator to fuel volume ratio also has an effect on thermal utilization that should be considered. Thermal utilization *f* is defined as the ratio of the rate of thermal neutron absorption in the fuel to the total rate of thermal neutron absorption in all materials and can be written in the form

$$f = \frac{\sum_a^F \bar{\phi}_F}{\sum_a^F \bar{\phi}_F + \sum_a^M (V_M / V_F)\bar{\phi}_M}.$$

Moderating the central region of the annular pellets or moderating the fuel rod diametric gap increases the moderator volume. Increasing V_M / V_F results in decreasing thermal utilization, thereby decreasing the reactivity.

Although this simple qualitative discussion of lattice effects in a thermal system reveals most of the relevant physics involved when moderating the diametric gap or replacing solid pellets with annular pellets, detailed transport calculations are necessary to evaluate the magnitude of these fuel rod and pellet features on reactivity.

Calculations

The calculations for the annular pellets are documented in Appendix 6-3 of the application. An evaluation of the unpackaged individual fuel assembly types in Appendix 6-2 of the application was used to demonstrate the most reactive contents to be used in the evaluation of the package in Appendix 6-3 of the application. The 14X14 W-OFA (Type A) fuel assembly was the most reactive contents for Type A fuel assembly designs and was used in the evaluation of the package to evaluate the effect of flooding

the pin gap with annular fuel blankets. A new evaluation has been done to demonstrate the effect of replacing the solid pellets with the annular pellet zone separate from moderation in the diametric gap. This evaluation is done for the 14X14 OFA fuel assembly contents in the MCC packaging.

Methodology

The calculation methodology for the new evaluation of the MCC package with the annular pellet contents is SCALE 5.1 CSAS25 using the 44-group cross-sections

Validation

The calculations documented in Table 6-3-1 of the application were performed by running a sequence of AMPX system codes to process cross-sections. In the original application NITAWL was used to generate resonance self shielding corrections for a 227 group CSRL-V cross section library each fuel lattice geometry using NITAWL. A transport calculation was performed for each fuel lattice using XSDRNPM to solve for the 227 group fluxes and collapse these to 27 groups for use in KENO Va calculation.

A benchmark analysis for the same 32 benchmark experiments has been done for versions of NITAWL and KENO Va distributed as SCALE 5.1. The values for k_{eff} were calculated by running SCALE5.1 versions of the computer codes and CSAS25 sequence on a SuSE Linux operating system. The results for these experiments are summarized in Tables 2 and 3 in the same format as in the original application.

Table 2 -Benchmark Calculation Statistics for SCALE 5.1 CSAS25 with SCALE 44 Group Cross Section Library / SuSE LINUX OS

Number of Experiments	32
Average Measured K_{eff} (K_m)	1.0007
Average KENO Va K_{eff} (K_c)	0.9938
KENO Va Bias ($K_m - K_c$)	0.0069
Bias Standard Deviation (s)	0.0009
One Sided Tolerance Factor for 95/95 (k)	2.20
95/95 Bias Uncertainty (ks)	0.0020

Critical Number	Enrichment ^{235}U wt%	Reflector Material	Separating Material	Soluble Boron (ppm)	Measured K_{eff}	KENO Reactivity $K_{eff} \pm 1\sigma$
1	2.46	water	water	0	1.0002	0.9945 ± 0.0006
2	2.46	water	water	1037	1.0001	0.9956 ± 0.0006
3	2.46	water	water	764	1.0000	0.9975 ± 0.0007
4	2.46	water	B_4C pins	0	0.9999	0.9915 ± 0.0007
5	2.46	water	B_4C pins	0	1.0000	0.9911 ± 0.0007
6	2.46	water	B_4C pins	0	1.0097	1.0023 ± 0.0008
7	2.46	water	B_4C pins	0	0.9998	0.9920 ± 0.0007
8	2.46	water	B_4C pins	0	1.0083	0.9920 ± 0.0007
9	2.46	water	water	0	1.0030	0.9959 ± 0.0005
10	2.46	water	water	143	1.0001	0.9940 ± 0.0007
11	2.46	water	stainless steel	514	1.0000	0.9971 ± 0.0006
12	2.46	water	stainless steel	217	1.0000	0.9944 ± 0.0006
13	2.46	water	borated aluminu	15	1.0000	0.9953 ± 0.0007
14	2.46	water	borated aluminu	92	1.0001	0.9918 ± 0.0006
15	2.46	water	borated aluminu	395	0.9998	0.9870 ± 0.0005
16	2.46	water	borated aluminu	121	1.0001	0.9868 ± 0.0006
17	2.46	water	borated aluminu	487	1.0000	0.9909 ± 0.0005
18	2.46	water	borated aluminu	197	1.0002	0.9918 ± 0.0007
19	2.46	water	borated aluminu	634	1.0002	0.9927 ± 0.0006
20	2.46	water	borated aluminu	320	1.0003	0.9920 ± 0.0005
21	2.46	water	borated aluminu	72	0.9997	0.9893 ± 0.0005
22	2.35	water	borated aluminu	0	1.0000	0.9952 ± 0.0006
23	2.35	water	stainless steel	0	1.0000	0.9949 ± 0.0006
24	2.35	water	water	0	1.0000	0.9929 ± 0.0006
25	2.35	water	stainless steel	0	1.0000	0.9933 ± 0.0007
26	2.35	water	borated aluminu	0	1.0000	0.9913 ± 0.0007
27	2.35	water	B_4C	0	1.0000	0.9936 ± 0.0007
28	4.31	water	stainless steel	0	1.0000	0.9977 ± 0.0007
29	4.31	water	water	0	1.0000	0.9958 ± 0.0007
30	4.31	water	stainless steel	0	1.0000	0.9964 ± 0.0007
31	4.31	water	borated aluminu	0	1.0000	0.9972 ± 0.0007
32	4.31	water	borated aluminu	0	1.0000	0.9975 ± 0.0006

Figure 3 – Benchmark Critical UO_2 Rod Lattice Experiments Using SCALE 5.1 CSAS25 with SCALE 44 Group Cross Section Library / SuSE LINUX OS

The 14X14 W-OFA (Type A) results using the SCALE 5.1 method (Table 2A) are validated by comparison to the same cases as reported in Table 6-3-1 of the application (Table 2B). The "95/95 w/Bias" values calculated using SCALE 5.1 as shown in Table 2A are consistent with than those calculated in the original application as shown in Table 2B. Changes in the methods used to calculate resonance self-shielding for the cross sections and difference in the energy group structure are contributing factors to differences in k_{eff} calculated using SCALE 5.1 CSAS25. However, it is considered acceptable to use the SCALE 5.1 CSAS25 method for the purpose of evaluating the comparative effects that annular pellets and moderating the diametric gap may have on k_{eff}.

Table 2A – Summary of KENO Calculational Results
[SCALE 5.1 CSAS25 using 44 group library]

Assembly Type	Enrichment wt. %	Added Absorbers	KENO $k_{eff} \pm \sigma$	95/95 w/Bias	Reference
Type A	5.00	None	0.9009 ± 0.0005	0.9099	0 inch, VOID
Fuel Pin Gap Flooding with Annular Fuel Blankets					
Full Water Density Outside the Pins					
Type A	5.00	None	0.9068 ± 0.0005	0.9158	6 inch, H2O

Table 2B – Summary of KENO Calculational Results
[Ref. - Application for Approval, USA/9239/AF, Revision 12 (Table 6-3-1)]

Assembly Type	Enrichment wt. %	Added Absorbers	KENO $k_{eff} \pm \sigma$	95/95 w/Bias	Reference
Type A	5.00	None	0.90486 ± 0.00462	0.9204	Table 6-3-2
Fuel Pin Gap Flooding with Annular Fuel Blankets					
Full Water Density Outside the Pins					
Type A	5.00	None	0.9080 ± 0.00241	0.9207	Table 6-3-18

Notes:

1. Type A assemblies include all 14x14 and 16x16 designs. Calculations were performed using the 14x14 OFA since this assembly is the most reactive of the Type A assemblies.
6. Annular fuel blanket model consists of 6.00 inches annular fuel at top and bottom of rods.

Model

The same packaging model described in Section 6.3.1 of the application is used. Annular pellets are represented by the geometry dimensions shown in Figure 4 for the purpose of providing self-shielded cross sections. The LATTICECELL input parameters shown in Figure 4 correspond to the fuel assembly description in Appendix 1-5 of the application as follows,

IMOD	Annular Pellet Inner Diameter
FUEL	Nominal Pellet Diameter
GAP	Nominal Clad Outer Diameter minus (2 X Nominal Clad Thickness)
CLAD	Nominal Clad Outer Diameter
PITCH	Nominal Lattice Pitch

Radius or diameter may be specified in the LATTICECELL parameters. The radius dimensions were specified in the LATTICECELL block for consistency with the radial dimensions as required in the GEOMTRY block.

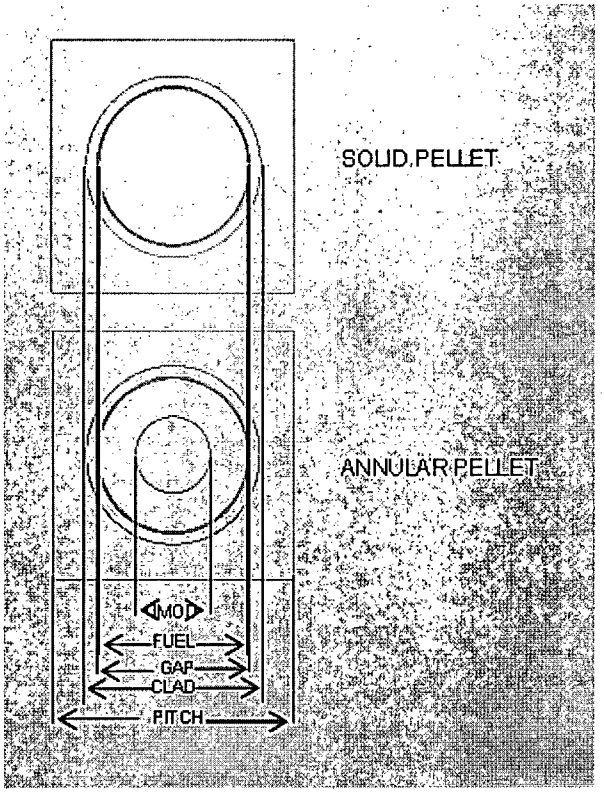


Figure 4 - Lattice Cell model for Fuel rods

The cross section treatment in the original application was done prior to the development CSAS control modules in SCALE. Cross section processing required manually running a sequence of functional modules to calculate a DANCOFF factor (SUPERDAN), perform resonance treatments (NITAWL), calculate a flux solution to cell-weight or collapse cross-sections (XSDRNPM) to generate a working library that could be used by the Monte Carlo code KENO-Va. Resonance shielding corrections were calculated for the U-235, U-238, Mn-55, and each of the Gadolinium isotopes (Gd-152, Gd-154, Gd-155, Gd-156, Gd-157, Gd-158, and Gd-160). A separate XSDRN calculation was done in the original application for the Gadolinium absorber plate, solid pellet fuel rod lattice, and annular fuel rod lattice.

The NITAWL and XSRDNPM sequence can be replicated by running the CSAS control modules and specifying the appropriate unit cell in the CELL DATA block. The earlier version of NITAWL contained provisions for performing an unresolved resonance self-shielding calculation, but later this was replaced with the BONAMI module that provides better unresolved resonance techniques. The ASYMSLABCELL CELLDATA card was used in an attempt to replicate this XSDRN input in the original application in SCALE 5.1. The XSDRN input for the Gadolinium absorber plate is shown in the Figure 5 below as it relates to the actual configuration in the package. The Gadolinium absorber plate and fuel region was represented as a slab geometry in the XSDRN input as an attempt to represent within the limitation of the 1-D geometry. It may have been more accurate to have calculated a cell-weighted cross section by represent the fuel lattice as an homogenized cross section generated from a 1-D XSDRN calculation representing the fuel rod lattice. Notwithstanding, these XSDRN calculations were used in the original application to calculate a flux spectrum that would be representative of that seen by the Gadolinium absorber plate in order to weight the fine group cross sections for collapsing to a 27 group energy structure. The SCALE 44 group cross-sections are used in the calculations in this request, therefore replicating the cell-weighting flux calculation done by XSDRN in the original application is not necessary.

The choice of the geometry for the unit cell input is important to account for the effect lattice geometry by calculating the Dancoff factor that is used to modify the resonance escape probability used in the Nordheim Integral Treatment as done in NITAWL. The applicant agrees that use of ASYMSLABCELL is not appropriate for replicating the resonance calculations for the gadolinium isotopes as done in the original application. The Gadolinium absorber plate is not a repeating structure and as such should not be represented as such by a LATTICECELL, SYMSLABCELL, or ASYMSLABCELL. Instead a MULTIREGION slab geometry is more appropriate to replicate the NITAWL input for Gadolinium resonance calculations as done in the original application. The MULTIREGION option does not calculate a Dancoff factor and instead defaults the value used to zero as in the case of a homogeneous infinite medium. However, the INFHOMOGENOUS resonance treatment for Gadolinium isotopes would not account for corrections to the resonance escape probability due to the slab geometry, and it use would overstate the correction to the infinite dilute resonance integral resulting in decreased resonance absorption. Specifying LATTICECELL SQUAREPITCH for the solid pellet stack and LATTICECELL ASQUAREPITCH for the annular pellet stack does replicate the geometry used in the original NITAWL input and includes the additional treatment of the annular region not done in earlier versions of NITAWL.

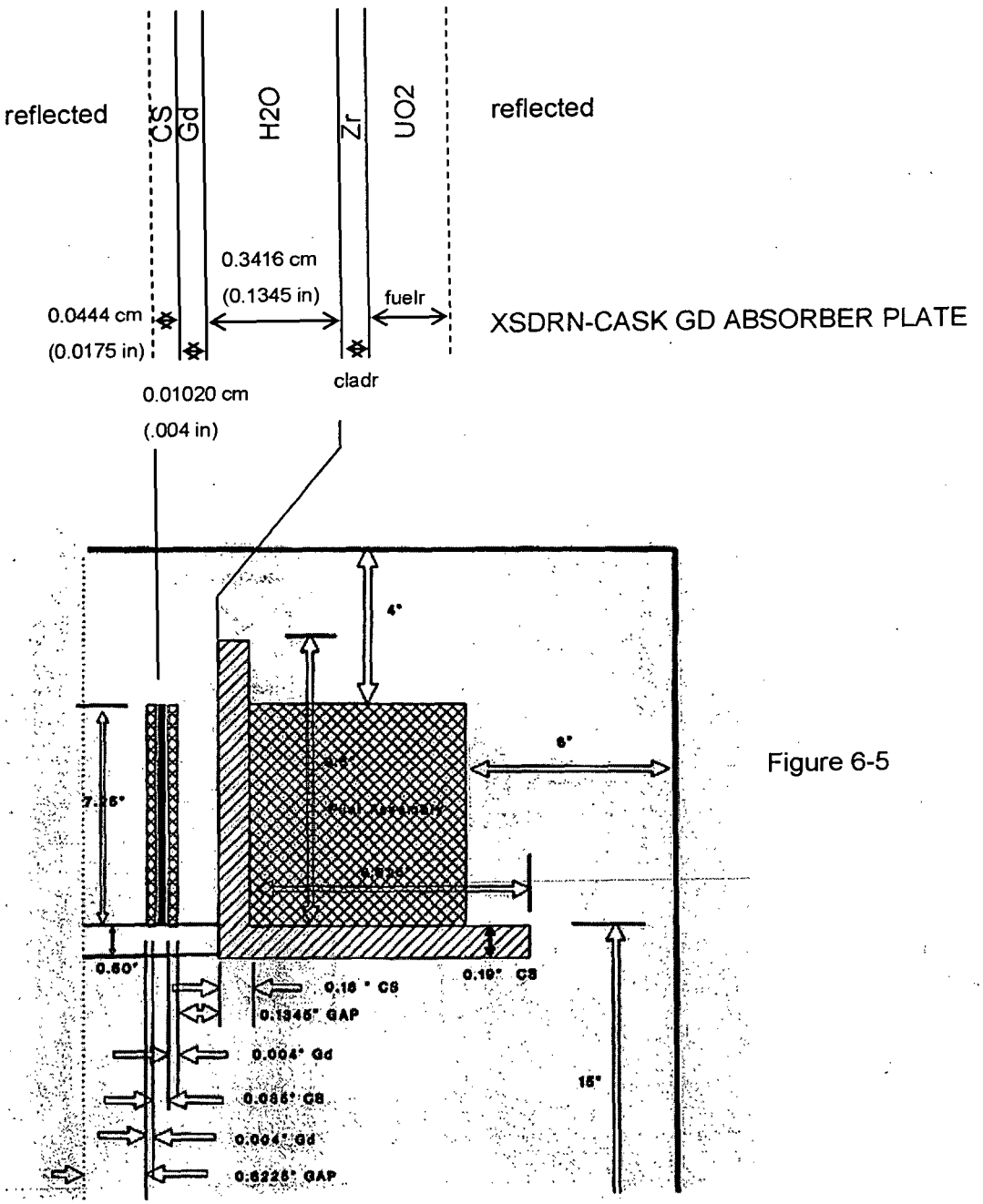


Figure 6-5

Figure 5 - XSDRN input geometry used in the original application for the Gadolinium Absorber Plate

Input File

An input file from the current application (Table 6-3-18) is modified to use SCALE 5.1 CSAS25 methodology by specifying the same number densities in the composition data block and unit cell data for resonance calculations in the cell data block. Since the annular pellet effect on resonance escape is only revealed if the center annulus is, the model has water in the center of the annulus while the diametric gap region is evaluated as void and water. The length of the solid pellet zone is specified in the input file by changing the +Z dimension in units 1, 2, and 3, and likewise for the annular pellet zone in units 4, 5 and 6. Moderator can be removed from the diametric gap by specifying the material identifier as void 0 in the respective gap regions of unit 1 or 4. The following input file is represents a 14X14OFA contents with 6.0 inch annular pellet zone length, diametric gap – H20 in an MCC package.

```
'Input generated by GeeWiz SCALE 5.1 Compiled on November 9, 2006
=csas25 parm=(nitawl)
title cask with 14x14 ofa 5.00 w/o assembly (mcc sar rev. 15 table 6-3-18)
44groupndf5
read composition
 uo2          1 0.965 293
                                92235 5
                                92238 95   end
 h2o          2 1 293   end
 zirc4        3 1 293   end
 h2o          4 1 293   end
 uo2          5 0.965 293
                                92235 5
                                92238 95   end
 h2o          6 1 293   end
 zirc4        7 1 293   end
 h2o          8 1 293   end
 c            9 0 0.0004728898 300   end
 p            9 0 5.807008e-05 300   end
 s            9 0 6.642906e-05 300   end
 mn           9 0 0.0003877064 300   end
 fe           9 0 0.08420119 300   end
 o            10 0 0.009810529 300   end
 gd-152       10 0 1.308071e-05 300   end
 gd-154       10 0 0.0001373474 300   end
 gd-155       10 0 0.0009679722 300   end
 gd-156       10 0 0.001347313 300   end
 gd-157       10 0 0.001026835 300   end
 gd-158       10 0 0.001622008 300   end
 gd-160       10 0 0.001425792 300   end
 c            11 0 0.0004728898 300   end
 p            11 0 5.807008e-05 300   end
 s            11 0 6.642906e-05 300   end
 mn           11 0 0.0003877064 300   end
 fe           11 0 0.08420119 300   end
 h2o          15 1 293   end
end composition
read celldata
  latticecell squarepitch fuelr=0.437388 1 gapr=0.446278 2 cladr=0.508 3 hpitch=0.70612 4 end
  latticecell asquarepitch imodr=0.218694 8 fuelr=0.437388 5 gapr=0.446278 6 cladr=0.508 7
hpitch=0.70612 15 end
  multiregion slab right_bdy=vacuum left_bdy=vacuum origin=0.0 end  10 0.1016  end zone
end celldata
read parameters
tme=100000 run=yes plt=no
gen=10000 npg=10000 nsk=5  sig=0.0005
xs1=yes nub=yes
end parameters
read geometry
unit 1
com='14x14 ofa fuel rod - enriched region'
 zcylinder 1 1 0.437388   167.64        0
```

```
 zcylinder 2 1 0.446278   167.64        0
 zcylinder 3 1   0.508   167.64        0
 cuboid 4 1  0.70612  -0.70612  0.70612  -0.70612   167.64        0
unit 2
com='14x14 ofa guide tube - enriched region'
 zcylinder 4 1 0.62484   167.64        0
 zcylinder 3 1 0.66802   167.64        0
 cuboid 4 1  0.70612  -0.70612  0.70612  -0.70612   167.64        0
unit 3
com='14x14 ofa instrument tube - enriched region'
 zcylinder 4 1 0.44704   167.64        0
 zcylinder 3 1 0.50673   167.64        0
 cuboid 4 1  0.70612  -0.70612  0.70612  -0.70612   167.64        0
unit 4
com='14x14 ofa fuel rod - blanket region'
 zcylinder 8 1 0.218694     15.24        0
 zcylinder 5 1 0.437388     15.24        0
 zcylinder 6 1 0.446278     15.24        0
 zcylinder 7 1   0.508     15.24        0
 cuboid 15 1  0.70612  -0.70612  0.70612  -0.70612     15.24        0
unit 5
com='14x14 ofa guide tube - blanket region'
 zcylinder 7 1 0.62484     15.24        0
 zcylinder 3 1 0.66802     15.24        0
 cuboid 15 1  0.70612  -0.70612  0.70612  -0.70612     15.24        0
unit 6
com='14x14 ofa instrument tube - blanket region'
 zcylinder 7 1 0.44704     15.24        0
 zcylinder 3 1 0.50673     15.24        0
 cuboid 15 1  0.70612  -0.70612  0.70612  -0.70612     15.24        0
unit 7
com='strong back, horizontal'
 cuboid 9 1   25.413        0   0.4572        0   204.01        0
unit 8
com='strong back, vertical'
 cuboid 9 1   0.4572        0    24.14        0   204.01        0
unit 9
com='verticle gad poison plat between assembly'
 cuboid 11 1   0.0889        0   18.415        0   204.01        0
 cuboid 10 1  0.09906  -0.01016   18.415        0   204.01        0
unit 10
com='rest of strongback and cradle'
 cuboid 8 1   7.1051   0.5149  12.1851   0.5149   204.01        0
 cuboid 9 1     7.62        0     12.7        0   204.01        0
unit 11
com='container flanges and bracket'
 cuboid 9 1    1.285        0    22.86        0   204.01        0
unit 12
com='skid angle'
 cuboid 15 1     7.62   0.9652     7.62   0.9652   204.01        0
 cuboid 9 1     7.62        0     7.62        0   204.01        0
unit 13
com='middle top clamping assembly'
 cuboid 9 1    33.02        0     5.08        0   2.5908        0
unit 14
com='middle side clamping assembly'
 cuboid 9 1    5.08        0    24.12        0   2.5908        0
unit 15
com='unistrut channel assembly'
 cuboid 15 1    1.799        0    3.556   0.7399   204.01        0
 cuboid 9 1    2.538        0    3.556        0   204.01        0
unit 16
com='top clamping assembly'
 cuboid 9 1    33.02        0     5.08        0   5.1816        0
unit 17
com='side clamping assembly'
 cuboid 9 1     5.08        0    24.12        0   5.1816        0
unit 18
com='horizontal gad poison plate below assembly, space 3, 4, 5'
 cuboid 11 1   22.225        0   0.0889        0    21.59        0
 cuboid 10 1   22.225        0  0.09906  -0.01016    21.59        0
```

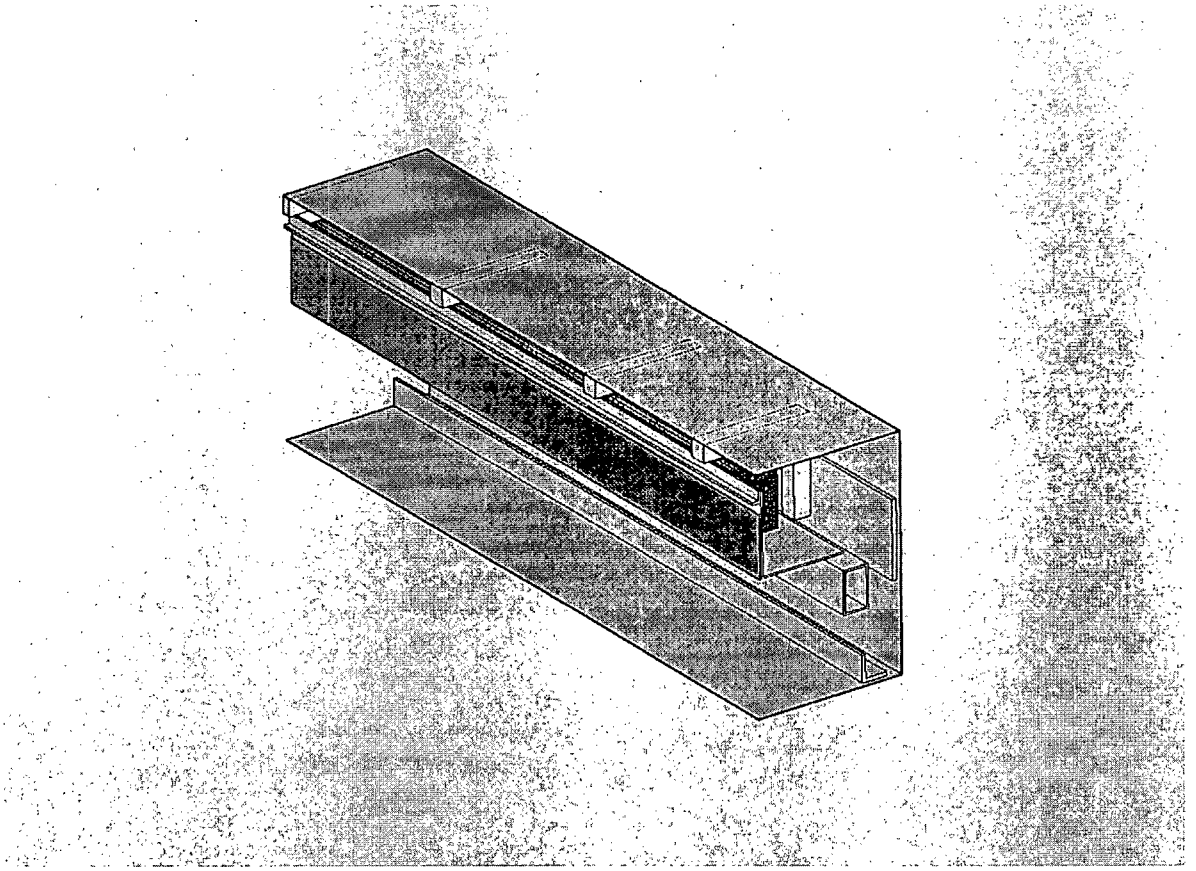
Enclosure 3 (Revision 1)

```
unit 19
com='horizontal gad poison plate below assembly, space 2 and 6'
 cuboid 11 1   22.225        0   0.0889        0    53.34        0
 cuboid 10 1   22.225        0  0.09906  -0.01016    53.34        0
unit 20
com='horizontal gad poison plate below assembly, space 1 and 7'
 cuboid 11 1   22.225        0   0.0889        0    57.33        0
 cuboid 10 1   22.225        0  0.09906  -0.01016    57.33        0
global unit 21
com='14x14 ofa assembly in cask, no horizontal gad plates '
  array 1       0        0        0
 cuboid 15 1   41.381     -3.1    29.94   -38.56   205.74        0
  hole 7 -0.4572  -0.4572        0
  hole 8 -0.4572        0        0
  hole 9 -0.8979  -0.8128        0
  hole 10  24.958  -18.237        0
  hole 11  40.091    -12.7        0
  hole 12   30.48   -38.55        0
  hole 13  -3.089    24.85        0
  hole 14   24.85   0.7213        0
  hole 16  -3.089    24.85    63.93
  hole 17   24.85   0.7213    63.93
  hole 16  -3.089    24.85    130.5
  hole 17   24.85   0.7213    130.5
  hole 16  -3.089    24.85    177.7
  hole 17   24.85   0.7213    177.7
  hole 15  -2.997    20.87        0
 cuboid 9 1   41.602     -3.1    30.16   -38.78   205.74        0
end geometry
read array
ara=1 nux=14 nuy=14 nuz=2
 com='14x14 ofa assembly '
 fill
    1    1    1    1    1    1    1    1    1    1    1    1    1    1
    1    1    1    1    1    1    1    1    1    1    1    1    1    1
    1    1    2    1    1    2    1    1    2    1    1    2    1    1
    1    1    1    1    1    1    1    1    1    1    1    1    1    1
    1    1    1    1    2    1    1    1    1    2    1    1    1    1
    1    1    2    1    1    1    1    1    1    1    1    2    1    1
    1    1    1    1    1    1    1    1    1    1    1    1    1    1
    1    1    1    1    1    1    3    1    1    1    1    1    1    1
    1    1    2    1    1    1    1    1    1    1    1    2    1    1
    1    1    1    1    2    1    1    1    1    2    1    1    1    1
    1    1    1    1    1    1    1    1    1    1    1    1    1    1
    1    1    2    1    1    2    1    1    2    1    1    2    1    1
    1    1    1    1    1    1    1    1    1    1    1    1    1    1
    1    1    1    1    1    1    1    1    1    1    1    1    1    1
    4    4    4    4    4    4    4    4    4    4    4    4    4    4
    4    4    4    4    4    4    4    4    4    4    4    4    4    4
    4    4    5    4    4    5    4    4    5    4    4    5    4    4
    4    4    4    4    4    4    4    4    4    4    4    4    4    4
    4    4    4    4    5    4    4    4    4    5    4    4    4    4
    4    4    5    4    4    4    4    4    4    4    4    5    4    4
    4    4    4    4    4    4    4    4    4    4    4    4    4    4
    4    4    4    4    4    4    6    4    4    4    4    4    4    4
    4    4    5    4    4    4    4    4    4    4    4    5    4    4
    4    4    4    4    5    4    4    4    4    5    4    4    4    4
    4    4    4    4    4    4    4    4    4    4    4    4    4    4
    4    4    5    4    4    5    4    4    5    4    4    5    4    4
    4    4    4    4    4    4    4    4    4    4    4    4    4    4
    4    4    4    4    4    4    4    4    4    4    4    4    4    4
 end fill
end array
read bnds
 +xb=mirror
 -xb=mirror
 +yb=mirror
 -yb=mirror
 +zb=mirror
 -zb=mirror
  end bnds
```

```
end data
end
```

KENO-3D Plot

The following is a KENO-3D pot of the input file shown without the water (material id 8). The package model is a one-quarter of the package with mirror boundary condition on all faces to represent a infinite array of packages.



Results

The resonance integrals calculated for U-235 and U-238 by the Nordheim integral method used in NITAWL are summarized in Table 3. As concluded earlier in the analysis, the resonance integrals for annular pellets are slightly larger but not significantly different than those for solid pellets. This result is consistent with the qualitative analysis of the effect of geometry on the resonance integral. There is no significant change in the resonance integral caused by moderating the diametric gap.

Table 3 - Integrals of resonance for uranium fuel from NITAWL-LATTICELL (Diametric Gap – Void, Diametric Gap – H2O)

U-235 process	Solid pellet		Annular pellet		Ref Inf dilute
	Void	H_2O	Void	H_2O	
n-gamma	8.3958E+01	8.4198E+01	8.8054E+01	8.8202E+01	1.0055E+02
Fission	1.3221E+02	1.3251E+02	1.3728E+02	1.3746E+02	1.5278E+02
Scattering	3.6906E+02	3.6911E+02	3.6988E+02	3.6991E+02	3.7187E+02
Absorption	2.1617E+02	2.1671E+02	2.2533E+02	2.2566E+02	2.5333E+02
Total	5.8523E+02	5.8582E+02	5.9521E+02	5.9557E+02	6.2520E+02

U-238 process	Solid pellet		Annular pellet		Ref Inf dilute
	Void	H_2O	Void	H_2O	
n-gamma	1.8340E+01	1.8488E+01	2.2811E+01	2.2962E+01	2.7593E+02
Fission	8.2885E-04	8.3095E-04	8.7079E-04	8.7228E-04	1.2961E-03
Scattering	1.8699E+02	1.8718E+02	1.9216E+02	1.9234E+02	3.5716E+02
Absorption	1.8341E+01	1.8489E+01	2.2812E+01	2.2963E+01	2.7593E+02
Total	2.0533E+02	2.0567E+02	2.1498E+02	2.1530E+02	6.3309E+02

The self-shielded cross sections are used in a detailed Monte Carlo transport calculation (KENO Va) that accounts the geometry and material composition of the fuel rod lattice and packaging components. Results for these calculations as summarized in Figure 6 and Table 4 reveal the separate effect that annular pellets and moderating the diametric gap have on reactivity. The change in k_{eff} due to moderating the diametric gap is on average 0.006 Δ k_{eff}, and k_{eff} decreases due to increasing the annular pellet zone length. Evaluating both effects separately demonstrates that increasing the annular pellet zone length causes a decrease in k_{eff} value; therefore, imposing a limit on annular pellet zone length is not necessary. All "95/95 w/Bias" values regardless of the annular pellet zone length are less than the maximum allowed value of k_{eff}=0.9500.

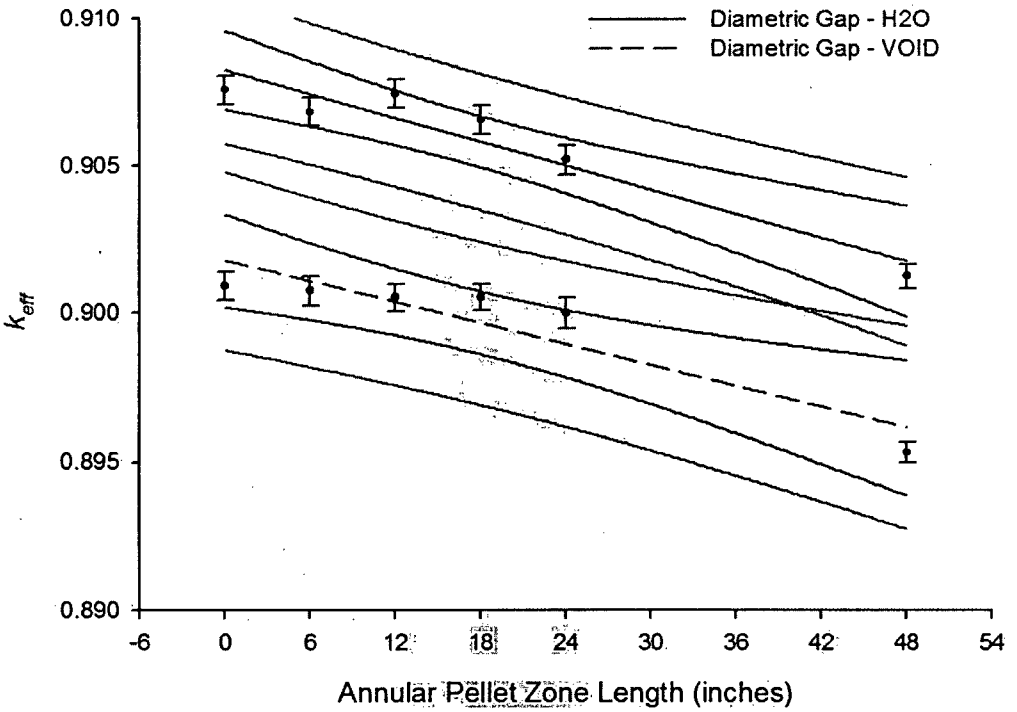


Figure 6 - Effect of Annular Pellets and Moderating Diametric Gap

Table 4 – KENO-Va Results
(Diametric Gap – Void, Diametric Gap – H2O)

Annular Pellet Zone Length (inches)	Diametric Gap – H2O			Diametric Gap – Void		
	k_{eff}	σ	95/95 w/Bias	k_{eff}	σ	95/95 w/Bias
0	0.9076	0.0005	0.9166	0.9009	0.0005	0.9099
6	0.9068	0.0005	0.9159	0.9007	0.0005	0.9098
12	0.9075	0.0005	0.9165	0.9005	0.0005	0.9095
18	0.9066	0.0005	0.9156	0.9005	0.0005	0.9096
24	0.9052	0.0005	0.9143	0.9000	0.0005	0.9091
48	0.9012	0.0004	0.9103	0.8953	0.0003	0.9043
72	0.8792	0.0005	0.8883	0.8723	0.0005	0.8813