Westinghouse

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
Our ref: LCPT-08-1

4 January 2008

Dear Mr. E. William Brach:

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

In accordance with Subpart D-Application for Package Approval, 10 CFR 71.31, Contents of application, Westinghouse Electric Company hereby submits an application for modification of the authorized contents as specified in existing Certificate of Compliance number 9239. This request is for authorization for a one-time shipment of a 15X15 (Type B) OFA fuel assembly that is modified by replacing fuel rods in locations O10 through O15 and N15 with solid stainless steel rods (see Figure 1).

The 17X17 OFA is the most reactive of the Type B fuel assemblies (15X15 and 17X17) and was used in the evaluation of the MCC package for the application. Replacing seven fuel rods with solid stainless steel rods results in a decrease in the reactivity of the 15X15 (Type B) OFA. This modification to a 15X15 (Type B) does not alter conclusions and assumptions in the MCC package assessments. An evaluation of the modified 15X15 (Type B) OFA with seven solid stainless steel rods is included as Enclosure 1.

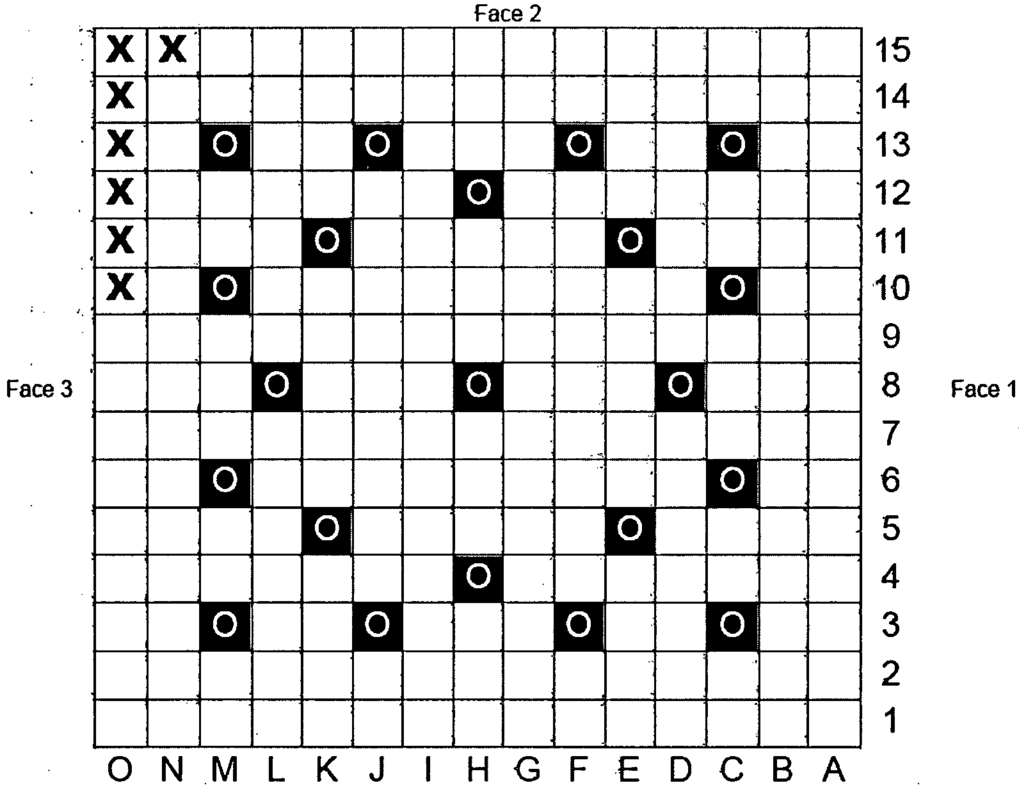
Westinghouse requests the one time approval of the modified fuel assembly in order to meet a scheduled ship date of 9 February 2008.

NMSS24

Figure 1: Fuel Assembly Orientation (from Top & Bottom View Perspective)

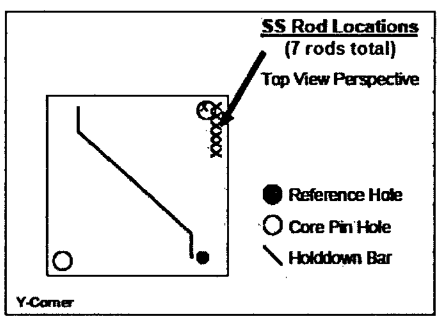
15x15 Loading Pattern
Bottom View Perspective

Reference: Mechanical Operating Procedure Sketch 730102-1, Final Assembly Area



"Y"-Corner

O Thimble tube location
X Stainless steel rod location



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

Phone: +1 (803) 647-3167
Fax: +1 (803) 695-4146
Cell: +1 (803) 979-7347
Email: vescovpj@westinghouse.com
www.westinghousenuclear.com

cc: N. Kent, Westinghouse, Manager, Transport Licensing and Compliance
B. Bayley, Westinghouse, Manager, Regulatory and International Logistics
J. Leonelli, Westinghouse, Fuel Business Manager, U.S. Fuel Commercial Operations
J. St. John, Westinghouse , Principle Project Engineer, U.S. Fuel Commercial Operations
R. Nelson, U.S. NRC Chief, NMSS/DSFDT/Licensing and Inspection Directorate
S. Brown, U.S. NRC Project Manager, NMSS/DSFDT/LID/Licensing Branch

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Enclosure 1 - Evaluations, Analysis and Detailed Calculations

The calculations documented in Table 6-2-1 of the Application for Approval of Packaging of Fissile Radioactive Material (MCC Shipping Containers), Package Identification Numbers USA/9239/AF, Revision 12, August 2006, were performed using a 227 energy group cross-sections processed by running a sequence of AMPX system codes. An evaluation of the unpackaged individual fuel assembly types (Appendix 6-2 of the application) was used to determine the most reactive contents to use in the evaluation of the package (Appendix 6-3 of the application). The 15X15 (Type B) OFA fuel assembly that is modified by replacing seven fuel rods with solid stainless steel rods is evaluated as an unpackaged individual fuel assembly as don in Appendix 6-2 of the application.

The current calculation methodology is SCALE 4.4 CSAS25 using the 44-group cross-sections. The 15X15 (Type B) OFA result reported in Table 6-2-1 of the application is validated using the current calculation method, and the relative difference of less than 0.01% is acceptable. Evaluation of the modified 15X15 (Type B) OFA with 7 stainless steel rods demonstrates that the reactivity of the fuel assembly is less than that for the 15X15 (Type B) OFA used for the evaluation in the application.

Table 1 - Comparison results for 15X15 (Type B) OFA

Case	KENO V.a keff
Application for Approval, USA/9239/AF, Revision 12 (Table 6-2-1)	0.94672
15X15 (Type B) OFA- SCALE4.4 CSAS25 using 44 group library	0.9467
Modified 15X15 (Type B) OFA with 7 SS Rods – SCALE4.4 CSAS25 using 44 group library	0.9319

The input file for the 15X15 (Type B) OFA - SCALE4.4 CSAS25 using 44 group library is as follows:

```
#csas25
Adapted 15X15 OFA
44groupndf5 latticecell
uo2      1 0.9650   293  92235 5   92238 95     end
zirc4    2 1        293 end
h2o      3 1        293   end
end comp
squarepitch 1.4300 0.9294 1 3 1.0719 2 0.9484 0 end
Adapted 15X15 OFA
READ PARAMETERS
    TME=6.0   RUN=YES   PLT=YES
```

```
    GEN=900   NPG=300   NSK=005
    XS1=YES   NUB=YES
END PARAMETERS

READ GEOMETRY

  UNIT 1
  COM=" 15X15 OFA FUEL ROD "
  CYLINDER     1  1     0.4647   30.0  0.0
  CYLINDER     0  1     0.4742   30.0  0.0
  CYLINDER     2  1     0.5359   30.0  0.0
  CUBOID       3  1   4P0.7150   30.0  0.0

  UNIT 2
  COM=" 17X17 OFA GUIDE TUBE & INSTRUMENT TUBE "
  CYLINDER     3  1     0.6337   30.0  0.0
  CYLINDER     2  1     0.6769   30.0  0.0
  CUBOID       3  1   4P0.7150   30.0  0.0

  GLOBAL
  UNIT 3
  COM=" 17X17 OFA ASSEMBLY IN H2O "
  ARRAY  1  -10.7251 -10.7251 0.0
  CUBOID 3  1  4P25.9651    30.0  0.0
END GEOM

READ ARRAY
  ARA=1 NUX=15 NUY=15 NUZ=1 COM=" 15X15 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
     1  1  2  1  1  2  1  1  1  2  1  1  2  1  1
     1  1  1  1  1  1  1  2  1  1  1  1  1  1  1
     1  1  1  1  2  1  1  1  1  1  2  1  1  1  1
     1  1  2  1  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  2  1  1  1  2  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  1  1  1  1  1  1  1  2  1  1
     1  1  1  1  2  1  1  1  1  1  2  1  1  1  1
     1  1  1  1  1  1  1  2  1  1  1  1  1  1  1
     1  1  2  1  1  2  1  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  1  1
end fill
END ARRAY

read plot
```

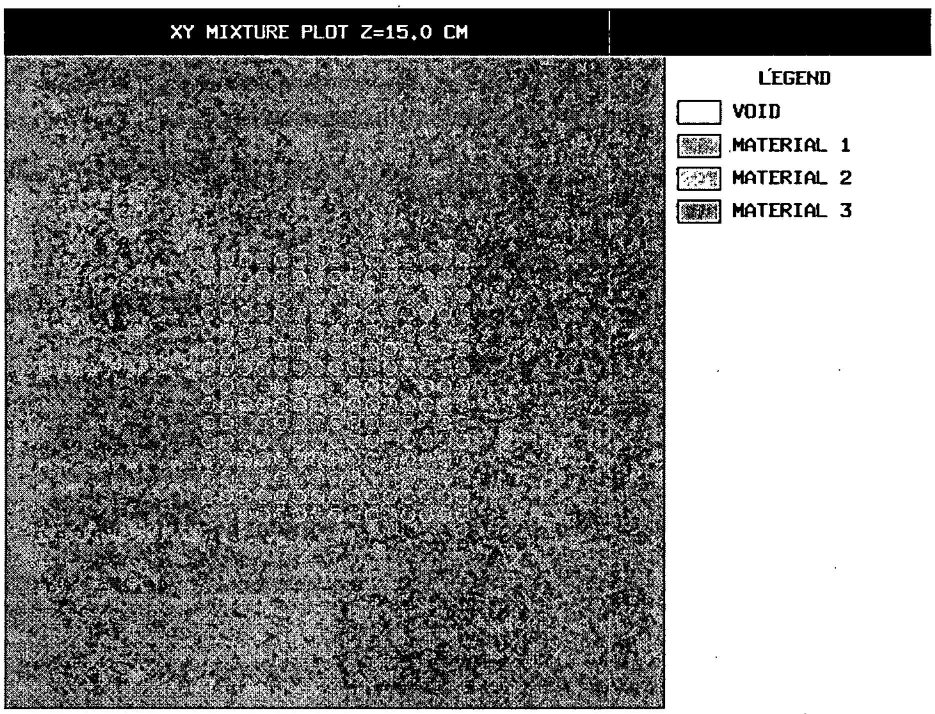
```
 scr=yes
 ttl='XY Mixture plot z=15.0 cm'
 pic=mix
 xul=-25.9651  yul= 25.9651   zul=15.0
 xlr= 25.9651  ylr=-25.9651   zlr=15.0
 nax=500
 clr= -1  255   0   0    0  255 255 255    1  200 200 200
       2  255 255   0    3  135 206 235
 end color
 uax=1 vdn=-1
 end
end plot

READ BOUNDS
  ALL=SPECULAR
END BOUNDS

end data
end
```

A cross section plot of the input file is reproduced below:

Figure 1 Plot of 15x15OFA Uncontained Assembly



The input file for the 15X15 (Type B) OFA with 7 stainless steel dummy fuel rods in positions O-10, O-11, O-12, O-13, O-14, O-15, and N-15 is as follows:

```
#csas25
Adapted 15X15 OFA with 7 SS rods
44groupndf5 latticecell
uo2      1 0.9650   293  92235 5   92238 95     end
zirc4    2 1        293 end
h2o      3 1        293 end
ss304    4 1        293 end
end comp
squarepitch 1.4300 0.9294 1 3 1.0719 2 0.9484 0 end
Adapted 15X15 OFA with 7 SS rods
READ PARAMETERS
    TME=6.0    RUN=YES    PLT=YES
    GEN=900    NPG=300    NSK=005
    XS1=YES    NUB=YES
END PARAMETERS

READ GEOMETRY

  UNIT 1
  COM=" 15X15 OFA FUEL ROD "
  CYLINDER    1  1    0.4647   30.0  0.0
  CYLINDER    0  1    0.4742   30.0  0.0
  CYLINDER    2  1    0.5359   30.0  0.0
  CUBOID      3  1  4P0.7150   30.0  0.0

  UNIT 2
  COM=" 17X17 OFA GUIDE TUBE & INSTRUMENT TUBE "
  CYLINDER    3  1    0.6337   30.0  0.0
  CYLINDER    2  1    0.6769   30.0  0.0
  CUBOID      3  1  4P0.7150   30.0  0.0

  UNIT 3
  COM=" 15X15 OFA SS ROD "
  CYLINDER    4  1    0.5359   30.0  0.0
  CUBOID      3  1  4P0.7150   30.0  0.0

  GLOBAL
  UNIT 4
  COM=" 17X17 OFA ASSEMBLY IN H2O "
  ARRAY  1  -10.7251 -10.7251 0.0
  CUBOID 3  1  4P25.9651    30.0  0.0
END GEOM

READ ARRAY
  ARA=1 NUX=15 NUY=15 NUZ=1 COM=" 15X15 OFA ASSEMBLY "
  fill
     3  3  1  1  1  1  1  1  1  1  1  1  1  1  1
     3  1  1  1  1  1  1  1  1  1  1  1  1  1  1
     3  1  2  1  1  2  1  1  1  2  1  1  2  1  1
     3  1  1  1  1  1  1  2  1  1  1  1  1  1  1
     3  1  1  1  2  1  1  1  1  1  2  1  1  1  1
     3  1  2  1  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  2  1  1  1  2  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  1  1  1  1  1  1  1  2  1  1
     1  1  1  1  2  1  1  1  1  1  2  1  1  1  1
     1  1  1  1  1  1  1  2  1  1  1  1  1  1  1
     1  1  2  1  1  2  1  1  1  2  1  1  2  1  1
```

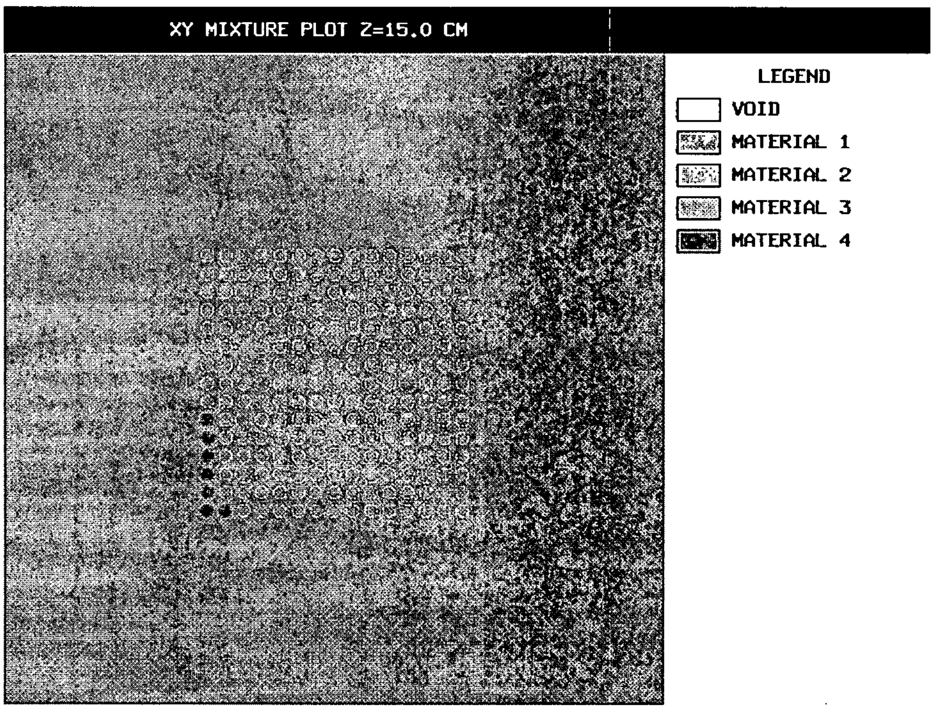
```
     1  1  1  1  1  1  1  1  1  1  1  1  1  1  1
     1  1  1  1  1  1  1  1  1  1  1  1  1  1  1
end fill
END ARRAY

read plot
 scr=yes
 ttl='XY Mixture plot z=15.0 cm'
 pic=mix
 xul=-25.9651  yul= 25.9651   zul=15.0
 xlr= 25.9651  ylr=-25.9651   zlr=15.0
 nax=500
 clr= -1  255   0   0    0  255 255 255    1  200 200 200
       2  255 255   0    3  135 206 235    4   92 172 238
 end color
 uax=1 vdn=-1
 end
end plot

READ BOUNDS
  ALL=SPECULAR
END BOUNDS

end data
end
```

Figure 2 Cross Section Plot of 15x15OFA Assembly with 7 SS Rods



Enclosure 3 - Evaluations, Analysis and Detailed Calculations – Annular Pellet Blankets

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 geometry of the annular pellet designs is shown in Figure 1.

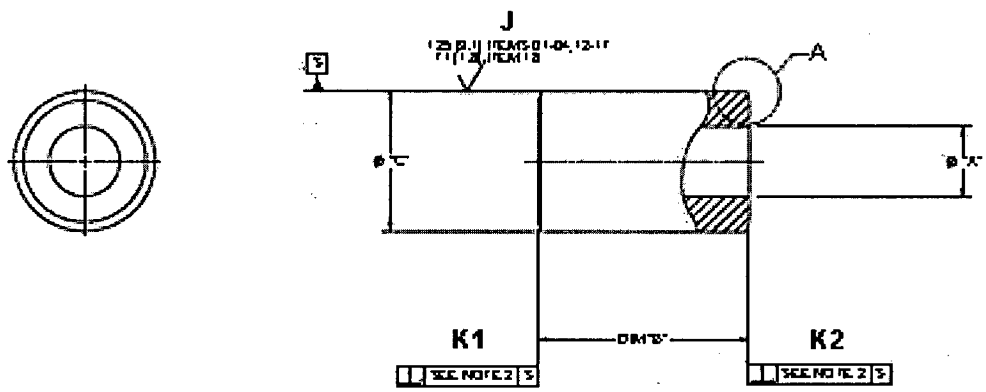


Figure 1-Annular Pellet Geometry

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. A package evaluation subsequent to the original application considered moderation in the fuel rod diametric gap (area between fuel pellet and cladding) for Type A, Type B, and Type C fuel assemblies contained in the MCC packaging. These results are summarized in Table 6-3-1 of the application as "Fuel Pin Gap Flooding with Annular Fuel Blankets". The evaluation also considered the effect of the annular pellet zone, but this was done coincident with the effect of water moderation in the fuel rod diametric gap. Increased moderation from water in the diametric gap will increase k_{eff}, but the effect of the annular pellet is to decrease k_{eff}. The combined effect resulted in a small increase in k_{eff} relative to the condition of void in the diametric gap and solid pellets. Consequently, the application was revised to limit the length of the annular pellet zones at the top and bottom of any fuel rod. In fact, fuel rods with no annular pellet zone are the configuration that should be use to demonstrate maximum reactivity for the accident transport condition, thereby making it unnecessary to limit the annular pellet zone length.

Enclosure 3

Analysis

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 causes an increase in the resonance integral that results in resonance escape probability decreasing, thereby reducing the reactivity.

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

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

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

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

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; however, detailed transport calculations are necessary to evaluate the magnitude of the effect on reactivity.

Calculations

The calculations for the annular pellets are documented in Appendix 6-3 of the Application for Approval of Packaging of Fissile Radioactive Material (MCC Shipping Containers), Package Identification Number USA/9239/AF, Revision 12, August 2006. A new evaluation using the same methodology 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 design.

Methodology

The calculations documented in Table 6-2-1 of the Application for Approval of Packaging of Fissile Radioactive Material (MCC Shipping Containers), Package Identification Number USA/9239/AF, Revision 12, August 2006, were performed using a 227 energy group cross-sections processed by running a sequence of AMPX system codes to prepare a working library for cross sections and KENO-Va to provide a transport solution. An evaluation of the unpackaged individual fuel assembly types (Appendix 6-2 of the application) was used to demonstrate the most reactive contents to use in the evaluation of the package (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.

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. The 14X14 W-OFA (Type A) results using the SCALE 5.1 method are validated by comparison to the same cases reported in Table 6-3-1 of Application for Approval, USA/9239/AF, Rev 12. The relative differences are less than 0.42% $\Delta k_{eff} / k_{eff}$ and the maximum absolute difference of 0.0038 ± 0.0025 Δk_{eff} is not so statistically significant. Therefore, it is considered acceptable to use the SCALE 5.1 CSAS25 method for the purpose of evaluating the effect of annular pellets and moderating the diametric gap.

Table 1 - Comparison results for 14X14 (Type A) W-OFA

Case	KENO V.a keff
Type A – Solid pellets, fuel pin gap void	
Application for Approval, USA/9239/AF, Rev 12 Reference Table 6-3-2	0.90486 ± 0.00462
SCALE4.4 CSAS25 using 44 group library	0.9054 ± 0.00044
Type A -Fuel Pin Gap Flooding with Annular Fuel Blankets	
Application for Approval, USA/9239/AF, Rev 12 Reference Table 6-3-18	0.9080 ± 0.00241
SCALE4.4 CSAS25 using 44 group library	0.9118 ± 0.00044

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 2 for the purpose of providing self-shielded cross section parameters.

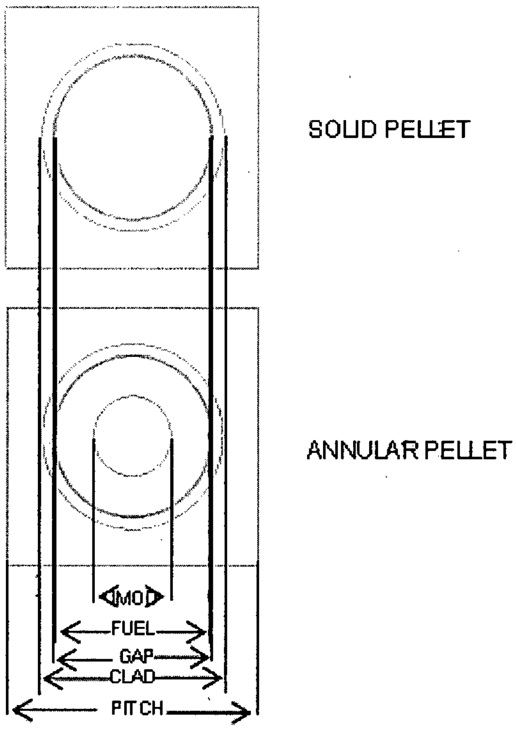


Figure 2 - Lattice Cell model for Fuel rods

An input file from the current application (Table 6-3-18) is modified to use SCALE 5.1 CSAS25 methodology. The annular pellet effect is only revealed if the center annulus of the pellet is moderated because changes in resonance escape probability are due to neutrons slowing down in a moderator. Therefore, the model keeps 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 following 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.

Enclosure 3

```
'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-154      10 0 0.0009679722 300   end
 gd-155      10 0 0.001347313 300   end
 gd-156      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
 uo2         12 0.965 293
                                92235 5
                                92238 95   end
 zirc4       13 1 293   end
 h2o         14 1 293   end
 h2o         15 1 293   end
end composition
read celldata
  latticecell squarepitch fuelr=0.392176 1 gapr=0.40005 3 cladr=0.4572 2 hpitch=0.62992 4
end
  latticecell asquarepitch imodr=0.218694 8 fuelr=0.392176 5 gapr=0.40005 6 cladr=0.4572
7 hpitch=0.62992 15 end
  latticecell asymslabcell imodr=0.3922 12 fuelr=0.4572 13 gapr=0.7988 14 cladr=0.809 10
hpitch=0.8534 11 end
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   182.87       0
 zcylinder 2 1 0.446278   182.87       0
 zcylinder 3 1   0.508   182.87       0
 cuboid 4 1  0.70612  -0.70612  0.70612  -0.70612   182.87       0
unit 2
com='14x14 ofa guide tube - enriched region'
 zcylinder 4 1 0.62484   182.87       0
 zcylinder 3 1 0.66802   182.87       0
 cuboid 4 1  0.70612  -0.70612  0.70612  -0.70612   182.87       0
unit 3
com='14x14 ofa instrument tube - enriched region'
 zcylinder 4 1 0.44704   182.87       0
 zcylinder 3 1 0.50673   182.87       0
```

```
 cuboid 4 1  0.70612  -0.70612  0.70612  -0.70612   182.87        0
unit 4
com='14x14 ofa fuel rod - blanket region'
 zcylinder 8 1 0.218694      0.01        0
 zcylinder 5 1 0.437388      0.01        0
 zcylinder 6 1 0.446278      0.01        0
 zcylinder 7 1   0.508      0.01        0
 cuboid 15 1  0.70612  -0.70612  0.70612  -0.70612      0.01        0
unit 5
com='14x14 ofa guide tube - blanket region'
 zcylinder 15 1 0.62484      0.01        0
 zcylinder 3 1 0.66802      0.01        0
 cuboid 15 1  0.70612  -0.70612  0.70612  -0.70612      0.01        0
unit 6
com='14x14 ofa instrument tube - blanket region'
 zcylinder 15 1 0.44704      0.01        0
 zcylinder 3 1 0.50673      0.01        0
 cuboid 15 1  0.70612  -0.70612  0.70612  -0.70612      0.01        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 8 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 8 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
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 8 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 plot
 scr=yes
 ttl='box slice through cask'
 pic=units
 xul=-4
 yul=30.1
 zul=66.52
 xlr=45
 ylr=-40
 zlr=66.52
 nax=130
 uax=1 vdn=-1
  end
 scr=yes
 ttl='box slice through cask'
 pic=mixtures
 xul=-4
 yul=30.1
 zul=66.52
 xlr=45
```

```
 ylr=-40
 zlr=66.52
 nax=130
 uax=1 vdn=-1
  end
 scr=yes
 ttl='box slice through assembly'
 pic=units
 xul=0
 yul=20
 zul=66.52
 xlr=20
 ylr=0
 zlr=66.52
 nax=130
 uax=1 vdn=-1
  end
 scr=yes
 ttl='mat slice through annular pellet'
 pic=mixtures
 xul=1.41
 yul=4.24
 zul=180
 xlr=4.24
 ylr=1.41
 zlr=180
 nax=130
 uax=1 vdn=-1
  end
 scr=yes
 ttl='mat slice through annular pellet'
 pic=mixtures
 xul=-1
 yul=18
 zul=180
 xlr=-0.5
 ylr=0
 zlr=180
 nax=130
 uax=1 vdn=-1
  end
end plot
read bnds
 +xb=mirror
 -xb=mirror
 +yb=mirror
 -yb=mirror
 +zb=mirror
 -zb=mirror
  end bnds
end data
end
```

Results

The resonance integrals calculated for U-235 and U-238 by the Nordheim integral method used in NITAWL are summarized in Table 2. The resonance integrals for annular pellets are greater than for solid pelts. 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 2 - Integrals of resonance for uranium fuel from NITAWL

(Diametric Gap – Void, Diametric Gap – H2O)

U-235 process	Solid pellet		Annular pellet		Ref Inf dilute
	Void	H_2O	Void	H_2O	
n-gamma	8.4519E+01	8.4528E+01	8.9445E+01	8.9450E+01	1.0055E+02
Fission	1.3291E+02	1.3292E+02	1.3899E+02	1.3900E+02	1.5278E+02
Scattering	3.6918E+02	3.6918E+02	3.7014E+02	3.7014E+02	3.7187E+02
Absorption	2.1743E+02	2.1745E+02	2.2844E+02	2.2845E+02	2.5333E+02
Total	5.8660E+02	5.8663E+02	5.9858E+02	5.9859E+02	6.2520E+02

U-238 process	Solid pellet		Annular pellet		Ref Inf dilute
	Void	H_2O	Void	H_2O	
n-gamma	1.8835E+01	1.8841E+01	2.4728E+01	2.4734E+01	2.7593E+02
Fission	8.3425E-04	8.3433E-04	8.8602E-04	8.8607E-04	1.2961E-03
Scattering	1.8760E+02	1.8760E+02	1.9426E+02	1.9426E+02	3.5716E+02
Absorption	1.8836E+01	1.8842E+01	2.4729E+01	2.4735E+01	2.7593E+02
Total	2.0643E+02	2.0644E+02	2.1898E+02	2.1900E+02	6.3309E+02

The resonance integrals are used in a detailed transport calculation that accounts for the geometry and material composition of the fuel rod lattice. Results for these calculations as summarized in Figure 3 and Table 2 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 0.005 Δk_{eff}, and the change in k_{eff} due to annular pellets is on average -0.00002 Δk_{eff} per inch of annular pellet zone length. Evaluating both effects separately demonstrates that solid pellets are the most reactive fuel configuration; therefore, imposing a limit on annular pellet zone length is not necessary.

Figure 3 - Effect of Annular Pellets and Moderating Diametric Gap

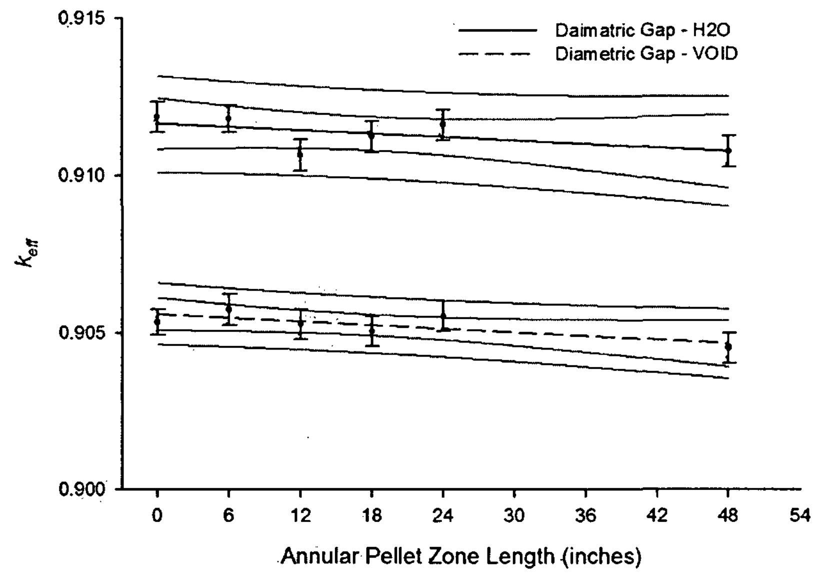


Table 3 – KENO-Va Results
(Diametric Gap – Void, Diametric Gap – H2O)

Annular Pellet Zone Length (inches)	Diametric Gap – H2O		Diametric Gap – Void	
	k_{eff}	σ	k_{eff}	σ
0	0.9118	0.00049	0.9054	0.00042
6	0.9118	0.00044	0.9058	0.00049
12	0.9106	0.00049	0.9053	0.00049
18	0.9112	0.00049	0.9051	0.00049
24	0.9116	0.00048	0.9055	0.00048
48	0.9107	0.00049	0.9045	0.00049
72	0.9075	0.00047	0.9031	0.00046