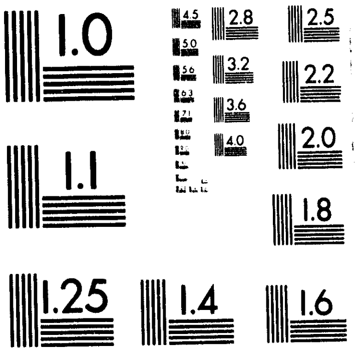
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2.8
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1 of 1

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VIM MONTE CARLO VERSUS CASMO COMPARISONS FOR BWR ADVANCED FUEL DESIGNS

Adelmo S. Pallotta[a]
Roger N. Blomquist[b]

[a]Commonwealth Edison Company
Nuclear Fuel Services
125 South Clark
Chicago, Illinois 60603
(312) 394-3862

[b]Argonne National Laboratory
9700 South Cass Avenue RA/208
Argonne, Illinois 60439-4842
(708) 252-8423

Keywords: VIM, Monte Carlo, CASMO

ABSTRACT

Eigenvalues and two-dimensional fission rate distributions computed with the CASMO-3G lattice physics code and the VIM Monte Carlo Code are compared. The cases assessed are two advanced commercial BWR pin bundle designs. Generally, the two codes show good agreement in k_{inf}, fission rate distributions, and control rod worths.

INTRODUCTION

Advanced Boiling Water Reactor (BWR) fuel bundle designs are incorporating ever more complex features to improve performance and economics. Some of these features are fuel pins of nonuniform sizes, large tubes containing unvoided water extending through the voided portions of the core, and increased gadolinium concentrations. These heterogeneities may represent departures from the domain of problems traditionally solved by standard fuel management analytical tools. In this work, we compare the results from a commonly used lattice physics code, CASMO-3G[1], with those produced by a high-accuracy Monte Carlo transport code, VIM[2].

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1 CASMO-3G - A Fuel Assembly Burnup Program, Studsvik/NFA-89-3

2 VIM, by R. N. Blomquist, Proceedings of the International Topical Meeting on Advances in Mathematics, Computations, and Reactor Physics, April 28-May 2, 1991. Pittsburgh, PA

VIM is Argonne National Laboratory's benchmark reactor neutronics Monte Carlo code, and has been used extensively over the last 20 years. Much of its application has been in the simulation of zero power critical assemblies of various types, so its eigenvalue predictions are highly reliable. Furthermore, it has been benchmarked against experimentally measured reaction rate spatial distributions[3]. It employs continuous-energy cross section data, detailed secondary energy and angular distributions, and a probability table method to treat the unresolved resonance range.

BUNDLE DESIGN DESCRIPTION

Two BWR advanced fuel designs were studied, both based on a BWR3 geometry in which the control rod water gaps are wider than the gaps opposite the control rods. The control rods, located between pin bundles, are arrays of B_4C powder in stainless steel tubes, which are in turn enclosed in stainless steel sheaths. Figure 1 shows a two-dimensional section of the IX pin bundle design from Siemens Power Corporation (SPC), which consists of a uniform 9X9 array of pins, but with the central subset of 3X3 pins replaced by a water box. The average enrichment is 3.71 w/o U^{235}, and nine pins have 3.0 w/o Gd_2O_3; the lattice enrichment distribution is shown in Figure 2. Figure 3 shows the details of the VIM geometrical representation, including the inter-bundle water gap and the positioning of the poisons in the controlled case. Figure 4 shows a two-dimensional section of General Electric's GE11 design. The GE11 bundle is a 9X9 array of pins, with seven of the central 3X3 subset of pins replaced by two water pins. The bundle duct wall's corners are thicker than their flat sections. The average enrichment is 3.47 w/o, and four pins contain 4.0 w/o Gd_2O_3, and three contain 3.0 w/o Gd_2O_3; the lattice enrichment distribution is shown in Figure 5. Figure 6 shows the details of the VIM geometrical representation, including water gaps and control rod.

BENCHMARK CASE DESCRIPTION

Since the features of interest in these computational tests are heterogeneities in the XY plane, we considered only two-dimensional geometries, but we included three different void fractions (0%, 40%, and 70%) at hot operating conditions to test the methods at different axial planes. The interbundle gaps, the water box and water pins were left unvoided, independent of the state of the coolant in the coolant channels. In the cold case, the temperature used was 300°(K); fuel and coolant temperatures of 1000°(K) and 560°(K), respectively, were assumed for the hot conditions. All cases were taken to be at beginning of life (BOL), with no Xe present, and white reflective boundary conditions were applied.

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3 "Monte Carlo Analysis of ZPR Heterogeneity," by D. C. Wade, M. J. Lineberry, and R. E. Prael, ANS Transactions, 21, p446 (1975).

COMPARISON RESULTS FROM CASES EVALUATED

Tables 1 and 2 provide the overall comparison of the VIM versus CASMO-3G k_{inf} for the eight cases evaluated for each design. In general, the comparison is good, with the largest difference of less than 0.0048 ΔK for both designs occurring for the unvoided hot uncontrolled case. Smaller differences occur at higher void fractions. Table 3 shows that the rod worths computed by the two codes are consistently in good agreement.

Comparisons were also made of the fission rate distributions. The CASMO-3G relative fission rate distributions are documented in Figures 7 and 8. These distributions are provided for 0%, 40%, and 70% voided hot uncontrolled conditions based on an assumed diagonal symmetry, and represent the relative fission rates among the fuel pins containing uranium. The VIM relative fission reaction rate distributions are documented in Figures 9 and 10, and were estimated with 1σ uncertainties of less than 1.0%. In these Figures, the control blade would be located in the upper left corner. Figures 11 and 12 provide the differences in the CASMO-3G versus VIM relative fission rates for the SPC 9X9 IX and GE11 designs evaluated. From figures 7 through 12, it can be concluded that relative to VIM, CASMO-3G underpredicts the fission rate in the corner fuel pins by about 6-7% for all three void fractions. CASMO-3G tends to predict lower fission rates relative to VIM for fuel pins along the "wide-wide" gap (left column), but higher fission rates for fuel pins along the "narrow-narrow" gap, except at the corners (bottom row). The comparisons for the internal fuel pins show no significant differences.

Tables 4 and 5 show selected fission rate comparisons for the corner fuel pins, as well as for the fuel pin with the maximum fission rate estimate by VIM. These data indicate that although VIM and CASMO-3G predictions differ significantly for the corner fuel pins, the agreement is to within 2.5% on the more important peak power fuel pin.

CONCLUSIONS

The VIM Monte Carlo results for the SPC 9X9 IX and GE 11 advanced BWR assembly designs agree well with the CASMO-3G results. The largest difference in the beginning of life k_{inf} as calculated by the two method is within 0.5% and is observed for unvoided conditions; the k_{inf} differences are significantly smaller at higher void fractions. The pin-power comparisons indicate that relative to VIM, CASMO-3G underpredicts the corner pins on the order of 6-7%, but is within 2% on the peak power pin.

The difference in these results for the two pin bundle designs evaluated is consistent with the differences seen between Monte Carlo calculations and CASMO calculations for previous, less advanced pin bundles, thus indicating that CASMO-3G does no worse in modeling advanced fuel assembly designs with more heterogeneities than it has for more homogeneous lattices.

Table 1

CASMO-3G vs VIM k_{inf} Comparison
SPC 9X9 IX

CASE	CASMO k_{inf}	VIM k_{inf}	VIM-CASMO
Unvoided Hot Uncontrolled	1.08575	1.09006 ± 0.00039	0.00431
40% Void Hot Uncontrolled	1.06942	1.07144 ± 0.00040	0.00202
70% Void Hot Uncontrolled	1.05373	1.05212 ± 0.00039	-0.00161
Unvoided Hot Controlled	0.89340	0.89665 ± 0.00039	0.00325
40% Void Hot Controlled	0.84732	0.84935 ± 0.00040	0.00203
70% Void Hot Controlled	0.80322	0.80161 ± 0.00037	-0.00161
Cold Uncontrolled	1.11977	1.11868 ± 0.00040	-0.00109
Cold Controlled	0.96867	0.96666 ± 0.00042	-0.00201

Table 2

CASMO-3G vs VIM k_{inf} Comparisons
GE11

CASE	CASMO k_{inf}	VIM k_{inf}	VIM-CASMO
Unvoided Hot Uncontrolled	1.08498	1.08973 ± 0.00039	0.00475
40% Void Hot Uncontrolled	1.06681	1.07070 ± 0.00037	0.00389
70% Void Hot Uncontrolled	1.04807	1.04818 ± 0.00039	0.00011
Unvoided Hot Controlled	0.89798	0.90111 ± 0.00042	0.00313
40% Void Hot Controlled	0.85151	0.85241 ± 0.00040	0.00089
70% Void Hot Controlled	0.80727	0.80554 ± 0.00038	-0.00173
Cold Uncontrolled	1.12496	1.12327 ± 0.00039	-0.00170
Cold Controlled	0.97563	0.97174 ± 0.00042	-0.00389

Table 3
Control Rod Worths
($k_{inf,\ uncontrolled} - k_{inf,\ controlled}$)

Case	CASMO	VIM	CASMO-VIM
GE 0% Void, Hot	0.1870	0.1886 ± 0.0006	-0.0016
GE 40% Void, Hot	0.2153	0.2183 ± 0.0005	-0.0030
GE 70% Void, Hot	0.2408	0.2426 ± 0.0005	-0.0018
GE Cold	0.1493	0.1515 ± 0.0006	-0.0022
SPC 0% Void, Hot	0.1924	0.1934 ± 0.0006	-0.0010
SPC 40% Void, Hot	0.2221	0.2221 ± 0.0006	0
SPC 70% Void, Hot	0.2505	0.2505 ± 0.0005	0
SPC Cold	0.1511	0.1520 ± 0.0006	-0.0009

Table 4
SPC 9X9 IX Corner Pin and Maximum Power Pin Peaking Factors
Hot Uncontrolled Conditions

	CASMO	VIM	CASMO - VIM
Unvoided, Corner Pin	1.009	1.065	-0.056
40% Voided Corner Pin	1.037	1.098	-0.061
70% Voided, Corner Pin	1.053	1.131	-0.078
Unvoided, Peak Pin	1.217	1.228	-0.011
40% Void Peak Pin	1.237	1.253	-0.016
70% Void Peak Pin	1.249	1.276	-0.027

Table 5
GE11 Corner Pin and Maximum Power Pin Peaking Factors
Hot Uncontrolled Conditions

	CASMO	VIM	CASMO - VIM
Unvoided, Corner Pin	1.081	1.143	-0.062
40% Voided, Corner Pin	1.103	1.163	-0.060
70% Voided, Corner Pin	1.107	1.179	-0.072
Unvoided, Peak Pin	1.330	1.305	0.025
40% Void Peak Pin	1.275	1.282	-0.007
70% Void Peak Pin	1.252	1.268	-0.016

Figure 1

SPC 9X9 IX General Geometry

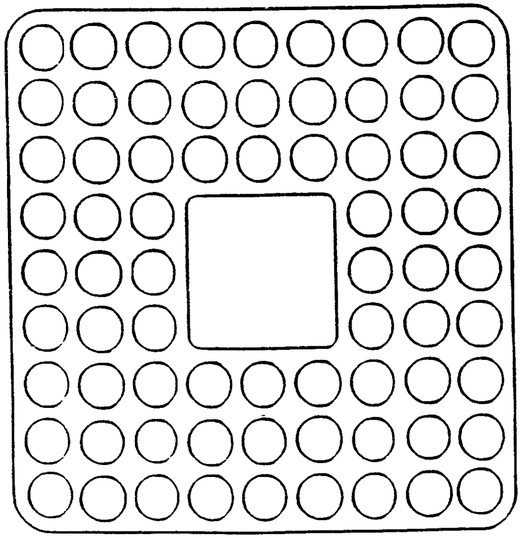

Figure 2

SPC 9X9 IX Enrichment and Gadolinia Concentration/Distribution
(Diagonal Symmetry Applies)

SPC 9X9 IX 371-9G3.0-80M

1.76								
2.55	3.12(*)							
3.12	3.32	4.31						
3.12	3.74	4.31	WATER					
3.32	3.12(*)	4.31	WATER	WATER				
3.32	3.74	4.31	WATER	WATER	WATER			
3.32	3.74	4.31	4.31	4.31	4.31	3.12(*)		
3.12	3.12(*)	4.31	4.31	3.12(*)	4.31	4.31	3.12(*)	
2.55	3.32	3.74	4.31	4.31	4.31	4.31	4.31	3.12

U-235 weight percent indicated
(*) additionally indicates 3% Gd_2O_3

Figure 3

SPC 9X9 IX Geometric Shape Layout for Controlled Conditions

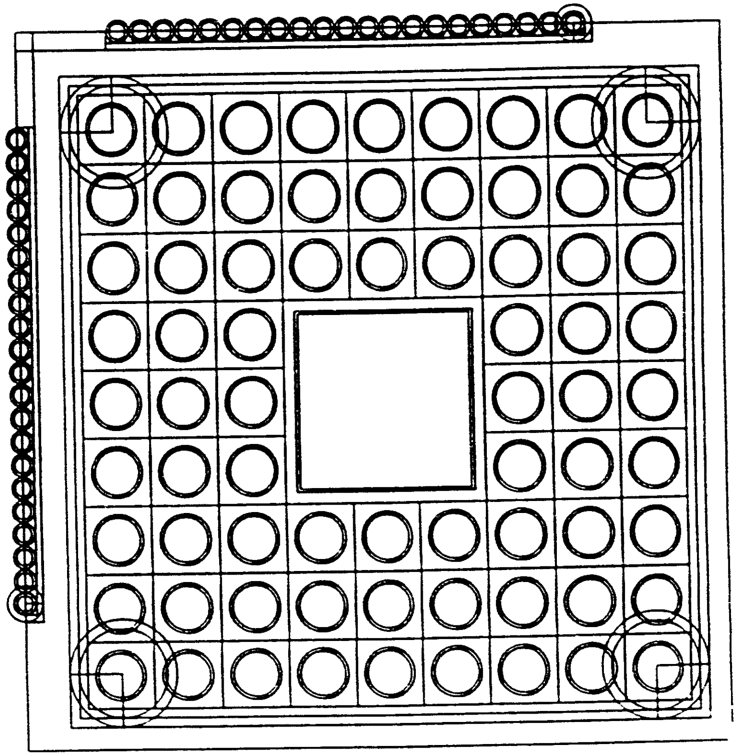

Figure 4

GE11 General Geometry

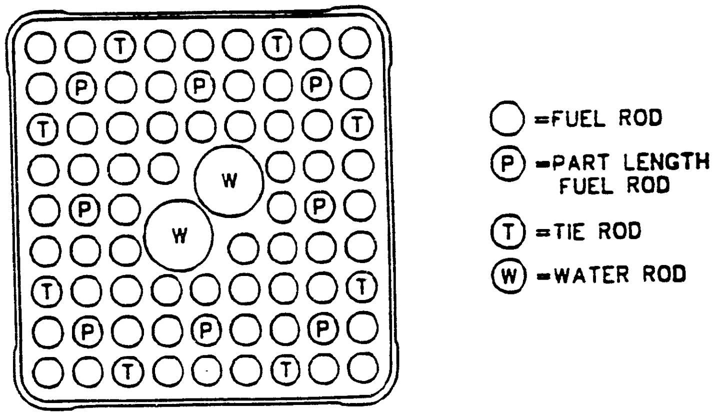

Figure 5

GE11 Enrichment and Gadolinia Concentration/Distribution
(Diagonal Symmetry Applies)

GE11 347 4G4.0/3G3.0-80M

1.80								
2.20	2.80							
2.80	3.00	3.60(#)						
3.40	3.40(*)	3.95	3.95					
3.40	3.95	3.95	WATER	WATER				
3.60	3.40(*)	3.40	WATER	WATER	3.95			
3.00	3.40	3.60	3.40	3.95	4.20	3.95		
2.60	3.40	3.60	3.60(#)	3.95	3.60(#)	3.95	3.40	
2.20	3.30	3.60	4.20	4.40	4.40	3.95	3.20	2.40

U-235 weight percent indicated
(#) additionally indicates 3% Gd_2O_3
(*) additionally indicates 4% Gd_2O_3

Figure 6

GE11 Geometric Shape Layout for Controlled Conditions

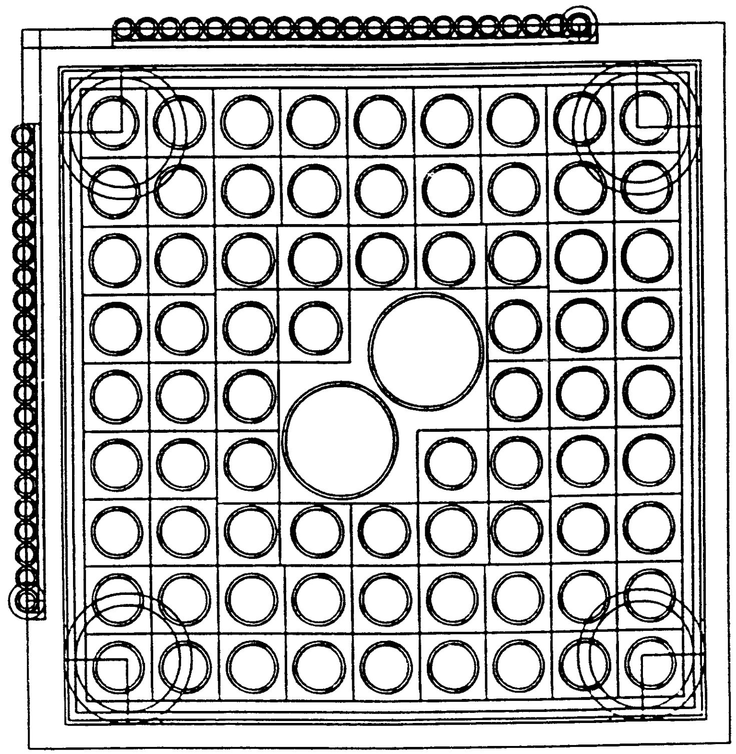

Figure 7

SPC 9X9 IX CASMO-3G Relative Fission Reaction Rate Distributions
Hot Uncontrolled Conditions

SPC 9X9 IX 371-9G3.0-80M

00 VH

1.009								
1.103	0.303							
1.217	0.922	1.140						
1.156	0.998	1.245	WATER					
1.142	0.286	1.230	WATER	WATER				
1.188	0.973	1.221	WATER	WATER	WATER			
1.214	0.965	1.076	1.180	1.158	1.053	0.260		
1.182	0.291	0.995	0.974	0.270	0.899	0.831	0.267	
1.181	1.126	1.130	1.183	1.095	1.126	1.144	1.194	1.127

40 VH

1.037								
1.141	0.357							
1.237	0.953	1.160						
1.163	1.025	1.250	WATER					
1.149	0.333	1.236	WATER	WATER				
1.184	0.987	1.211	WATER	WATER	WATER			
1.210	0.978	1.069	1.154	1.137	1.033	0.300		
1.190	0.337	0.996	0.966	0.309	0.886	0.826	0.306	
1.177	1.121	1.103	1.142	1.054	1.075	1.095	1.155	1.079

70 VH

1.053								
1.167	0.415							
1.249	0.987	1.187						
1.164	1.055	1.265	WATER					
1.148	0.383	1.249	WATER	WATER				
1.172	1.003	1.209	WATER	WATER	WATER			
1.200	0.992	1.066	1.135	1.120	1.016	0.341		
1.187	0.385	0.999	0.960	0.350	0.875	0.821	0.346	
1.161	1.113	1.079	1.104	1.015	1.027	1.047	1.112	1.026

Figure 8

GE11 CASMO-3G Relative Fission Reaction Rate Distributions
Hot Uncontrolled Conditions

GE11 347-4G4.0/5G3.0-80M

00 VH

1.081								
1.072	1.000							
1.128	0.798	0.299						
1.163	0.272	0.844	1.180					
1.161	0.886	1.045	WATER	WATER				
1.224	0.282	0.917	WATER	WATER	1.241			
1.194	0.964	0.958	0.924	1.069	0.994	0.955		
1.201	1.157	0.981	0.323	0.867	0.321	1.006	1.078	
1.212	1.290	1.279	1.257	1.289	1.283	1.330	1.290	1.204

40 VH

1.103								
1.092	1.030							
1.147	0.839	0.356						
1.185	0.325	0.862	1.151					
1.171	0.918	1.031	WATER	WATER				
1.234	0.333	0.905	WATER	WATER	1.186			
1.191	0.977	0.951	0.903	1.034	0.972	0.936		
1.194	1.156	0.986	0.373	0.870	0.368	0.991	1.046	
1.203	1.275	1.258	1.238	1.257	1.252	1.284	1.239	1.155

70 VH

1.107								
1.099	1.054							
1.156	0.879	0.418						
1.199	0.382	0.889	1.141					
1.174	0.951	1.031	WATER	WATER				
1.236	0.387	0.903	WATER	WATER	1.150			
1.179	0.989	0.952	0.893	1.011	0.959	0.924		
1.176	1.152	0.992	0.426	0.875	0.418	0.979	1.017	
1.180	1.252	1.235	1.218	1.226	1.220	1.239	1.187	1.102

Figure 9
VIM Relative Fission Rates by Pin
SPC Hot Uncontrolled

Unvoided

1.065								
1.149	0.295							
1.228	0.919	1.129						
1.155	0.997	1.236	WATER					
1.148	0.277	1.230	WATER	WATER				
1.186	0.977	1.217	WATER	WATER	WATER			
1.220	0.961	1.062	1.170	1.166	1.062	0.255		
1.212	0.282	0.981	0.966	0.261	0.897	0.833	0.260	
1.219	1.146	1.116	1.157	1.078	1.099	1.119	1.201	1.157

40% Voided

1.098								
1.200	0.351							
1.253	0.954	1.147						
1.170	1.027	1.238	WATER					
1.163	0.326	1.243	WATER	WATER				
1.186	0.986	1.187	WATER	WATER	WATER			
1.214	0.976	1.043	1.134	1.148	1.031	0.286		
1.225	0.329	0.974	0.958	0.299	0.873	0.819	0.296	
1.220	1.147	1.083	1.123	1.038	1.044	1.077	1.160	1.116

70% Voided

1.131								
1.218	0.409							
1.276	0.995	1.162						
1.176	1.061	1.252	WATER					
1.155	0.377	1.264	WATER	WATER				
1.169	1.000	1.187	WATER	WATER	WATER			
1.201	0.992	1.045	1.179	1.121	1.004	0.334		
1.223	0.377	0.986	0.950	0.343	0.863	0.816	0.335	
1.208	1.136	1.062	1.083	0.999	1.003	1.024	1.107	1.054

Figure 10
GE11 Relative Fission Rates by Pin
Hot Uncontrolled

Unvoided

1.143								
1.108	1.020							
1.139	0.830	0.293						
1.172	0.270	0.855	1.180					
1.159	0.907	1.040	WATER	WATER				
1.246	0.277	0.919	WATER	WATER	1.229			
1.190	0.969	0.938	0.923	1.049	0.978	0.923		
1.219	1.157	0.981	0.315	0.847	0.311	0.989	1.060	
1.256	1.292	1.271	1.239	1.260	1.254	1.305	1.288	1.228

40% Voided

1.163								
1.135	1.042							
1.165	0.862	0.351						
1.215	0.321	0.870	1.136					
1.180	0.936	1.019	WATER	WATER				
1.251	0.331	0.904	WATER	WATER	1.154			
1.198	0.985	0.932	0.896	1.025	0.955	0.895		
1.212	1.160	0.985	0.362	0.869	0.355	0.974	1.027	
1.249	1.282	1.243	1.215	1.224	1.226	1.258	1.237	1.190

70% Voided

1.179								
1.141	1.084							
1.181	0.897	0.412						
1.215	0.378	0.889	1.103					
1.183	0.962	1.010	WATER	WATER				
1.247	0.382	0.896	WATER	WATER	1.109			
1.190	0.998	0.935	0.896	0.984	0.945	0.890		
1.198	1.163	0.986	0.415	0.877	0.408	0.962	1.007	
1.228	1.268	1.226	1.210	1.203	1.197	1.216	1.182	1.138

Figure 11
CASMO-VIM Fission Rate Differences by Pin
SPC 9X9 IX Hot Uncontrolled

Unvoided

-0.056								
-0.046	0.008							
-0.010	0.003	-0.011						
0.0	0.001	0.009	WATER					
-0.006	0.009	0.0	WATER	WATER				
0.002	-0.004	0.004	WATER	WATER	WATER			
-0.006	0.004	0.014	0.010	-0.008	-0.009	0.010		
-0.030	0.009	0.014	0.008	0.009	0.002	-0.002	0.007	
-0.038	-0.020	0.014	0.026	0.017	0.027	0.025	-0.007	-0.030

40% Voided

-0.061								
-0.059	0.006							
-0.016	-0.001	0.013						
-0.007	-0.002	0.012	WATER					
-0.014	0.007	-0.007	WATER	WATER				
-0.002	0.001	0.024	WATER	WATER	WATER			
-0.004	0.002	0.026	-0.020	-0.011	0.002	0.014		
-0.035	0.008	0.022	0.008	0.010	0.013	0.007	0.010	
-0.043	-0.026	0.020	0.019	0.016	0.031	0.018	-0.005	-0.037

70% Voided

0.022								
-0.051	0.006							
-0.027	-0.008	0.025						
-0.012	-0.006	0.013	WATER					
-0.007	0.006	0.015	WATER	WATER				
0.003	0.003	0.022	WATER	WATER	WATER			
-0.001	0.0	0.021	-0.044	-0.001	0.012	0.008		
-0.036	0.008	0.013	0.010	0.007	0.012	0.005	0.011	
-0.047	-0.023	0.017	0.021	0.016	0.024	0.023	0.005	-0.028

Figure 12
CASMO-VIM Fission Rate Differences by Pin
GE11 Hot Uncontrolled

Unvoided

-0.062								
-0.036	-0.020							
0.011	-0.028	0.006						
-0.009	0.002	-0.011	0.0					
0.002	-0.021	0.005	WATER	WATER				
-0.022	0.005	-0.002	WATER	WATER	0.012			
-0.004	-0.005	0.020	0.001	0.020	0.016	0.032		
-0.018	0.0	0.0	0.008	0.020	0.010	0.017	0.018	
-0.044	-0.002	0.008	0.018	0.029	0.029	0.025	0.012	-0.024

40% Voided

-0.060								
-0.043	-0.012							
-0.018	-0.023	0.005						
-0.030	0.004	-0.008	0.015					
-0.009	-0.018	0.012	WATER	WATER				
-0.017	0.002	0.001	WATER	WATER	0.032			
-0.007	-0.008	0.019	0.007	0.009	0.017	0.041		
-0.018	-0.005	0.0	0.011	0.001	0.013	0.017	0.019	
-0.046	-0.007	0.015	0.023	0.033	0.026	0.026	0.002	-0.035

70% Voided

-0.072								
-0.042	-0.030							
-0.025	0.0	0.006						
-0.016	0.004	0.0	0.038					
-0.009	-0.011	0.021	WATER	WATER				
-0.011	0.005	0.007	WATER	WATER	0.041			
-0.011	-0.009	0.017	0.017	0.027	0.014	0.034		
-0.022	-0.011	0.006	0.011	-0.002	0.010	0.017	0.010	
-0.048	-0.016	0.009	0.015	0.029	0.023	0.023	0.005	-0.036

DATE
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