ATTACHMENT 12

"Peach Bottom Atomic Power Station: Fuel Storage Criticality Safety Analysis of Spent Fuel Storage Racks with Boraflex," Global Nuclear Fuel, NEDC-33686P, Revision 1, June 2012 (Non-Proprietary Version) and Affidavit

ENCLOSURE 2

CFL-EXN-HE0-12-080

Peach Bottom Atomic Power Station: Fuel Storage Criticality Safety Analysis of Spent Fuel Storage Racks with Boraflex

NEDO-33686, Revision 1

June 2012

Non-Proprietary Information – Class I (Public)

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Peach Bottom Atomic Power Station: Fuel Storage Criticality Safety Analysis of Spent Fuel Storage Racks with Boraflex

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Revision Status

Revision Number	Date	Description of Change
0	September 2011	Initial revision
1	June 2012	All changes are indicated by revision bars. Changes include: • Updated MCNP-05P validation in Appendix A and corresponding validation description in Section 3.3 and implementation in Section 5.7. • Clarified normal condition adder bias and bias uncertainty in Section 5.5.2. • Updated ΔK uncertainty for bias cases B7 and B8 in Table 11.

Table of Contents

List of Tables

List of Figures

1.0 Introduction

This report describes the criticality analysis and results for the Peach Bottom Atomic Power Station (PBAPS) spent fuel racks with credit taken for Boraflex. It includes sufficient detail on the methodology and analytical models utilized in the criticality analysis to verify that the storage rack systems have been accurately and conservatively represented.

The racks are analyzed using the MCNP-05P Monte Carlo neutron transport program and the k_∞ criterion methodology. A maximum cold, uncontrolled peak in-core eigenvalue (k_∞) of 1.235 as defined by the lattice physics code TGBLA06 is specified as the rack design limit for GNF2 fuel in the spent fuel racks. As demonstrated in Table 1, the analysis resulted in a storage rack maximum k-effective (K(95/95)) less than 0.95 for normal and credible abnormal operation with tolerances and uncertainties taken into account.

Table 1 – Summary K-95/95 Result

Region	$K_{max(95/95)}$
Spent Fuel Rack with Boraflex	[[ ]]

2.0 Requirements

Title 10 of the Code of Federal Regulations (10 CFR) Part 50 defines the requirements for the prevention of criticality in fuel storage and handling at nuclear power plants. 10 CFR 50.68 details specifically that the storage rack eigenvalue for both new and spent fuel storage racks must be demonstrated to be ≤ 0.95 for normal and credible abnormal operation with tolerances and computational uncertainties taken into account. Reference 1 outlines the standards that must be met for these analyses. These requirements are supplemented by General Design Criteria (GDC) 62 and Information Notice (IN) 2011-03. All necessary requirements are met in this analysis.

3.0 Method of Analysis

In this evaluation, in-core k_∞ values and exposure dependent, pin-by-pin isotopic specifications are generated using the GE Hitachi Nuclear Energy (GEH) / Global Nuclear Fuel (GNF) lattice physics production code TGBLA06. TGBLA06 solves two-dimensional (2D) diffusion equations with diffusion parameters corrected by transport theory to provide system multiplication factors and perform burnup calculations.

The fuel storage criticality calculations are then performed using MCNP-05P, the GEH/GNF proprietary version of MCNP5 (Reference 2). MCNP-05P is a Monte Carlo program for solving the linear neutron transport equation for a fixed source or an eigenvalue problem. The code implements the Monte Carlo process for neutron, photon, electron, or coupled transport involving all these particles, and can compute the eigenvalue for neutron-multiplying systems. For the present application, only neutron transport was considered.

3.1 Cross Sections

TGBLA06 uses ENDF/B-V cross-section data to perform coarse-mesh, broad-group, diffusion theory calculations. It includes thermal neutron scattering with hydrogen using an S(α,β) light water thermal scattering kernel.

MCNP-05P uses point-wise (i.e., continuous) cross section data, and all reactions in a given cross section evaluation (e.g., ENDF/B-VII.0) are considered. For the present work, thermal neutron scattering with hydrogen was described using an S(α,β) light water thermal scattering kernel. The cross section tables include all details of the ENDF representations for neutron data. The code requires that all the cross sections be given on a single union energy grid suitable for linear interpolation; however, the cross section energy grid varies from isotope to isotope. The libraries include very little data thinning and utilize resonance integral reconstruction error tolerances of 0.001%.

3.2 Geometry Treatment

TGBLA06 is a two-dimensional lattice design computer program for Boiling Water Reactor (BWR) fuel bundle analysis. It assumes that a lattice is uniform and infinite along the axial direction and that the lattice geometry and material are reflecting with respect to the lattice boundary along the transverse directions.

MCNP-05P implements a robust geometry representation that can correctly model complex components in three dimensions. An arbitrary three-dimensional (3D) configuration is treated as geometric cells bounded by first and second-degree surfaces and some special fourth-degree elliptical tori. The cells are described in a Cartesian coordinate system and are defined by the intersections, unions and complements of the regions bounded by the surfaces. Surfaces are defined by supplying coefficients to the analytic surface equations or, for certain types of surfaces, known points on the surfaces. Rather than combining several pre-defined geometrical bodies in a combinatorial geometry scheme, MCNP-05P has the flexibility of defining geometrical shapes from all the first and second-degree surfaces of analytical geometry and elliptical tori and then combining them with Boolean operators. The code performs extensive checking for geometry errors and provides a plotting feature for examining the geometry and material assignments.

3.3 Validation and Computational Basis

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Table 2 – Summary of the Critical Benchmark Experiments

Experiment		Experiments	Year	Where
[[				
				]]

Table 3 – Area of Applicability Covered by Code Validation

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		]]

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- BADGER/RACKLIFE uncertainty

  An additional uncertainty was also added to account for the measurement and calculational uncertainty in BADGER and RACKLIFE usage. The uncertainty was given in terms of percentage of B-10 areal density. A study was performed that assessed the in-rack reactivity difference between the design basis spent fuel bundle at nominal B-10 areal density (0.0140 g B-10/cm^2) and at a 33.2% reduction in B-10 areal density (0.00935 g B-10/cm^2). This uncertainty is applied to the spent fuel rack's maximum K(95/95) value in Table 13 to cover uncertainty in the BADGER measurements and RACKLIFE analysis.

3.4 In-Core K_∞ Methodology

The design of the fuel storage racks provides for a subcritical multiplication factor for both normal and credible abnormal storage conditions. In all cases, the storage rack eigenvalue must be ≤ 0.95 (Reference 1). To demonstrate compliance with this limit, the in-core k_∞ method is utilized.

The in-core k_∞ criterion method relies on a well-characterized relationship between infinite lattice k_∞ (in-core) for a given fuel design and a specific fuel storage rack k_∞ (in-rack) containing that fuel. The use of an infinite lattice k_∞ criterion for demonstrating compliance to fuel storage criticality criteria has been used for all GEH-supplied storage racks and is currently used for re-rack designs at a number of plants. This report demonstrates that the methodology is also appropriate for use at the PBAPS by presenting the following:

- A well-characterized, linear relationship between infinite lattice k_∞ (in-core) and fuel storage rack k_∞ (in-rack)
- The use of a design basis lattice with a conservative rack efficiency and in-core k_∞ for all criticality analyses

The analysis performed to calculate the lattice k_∞ to confirm compliance with the above criterion uses the Nuclear Regulatory Commission (NRC)-approved lattice physics methods encoded into the TGBLA06 Engineering Computer Program (ECP). One of the outputs of TGBLA06 solution is the lattice k_∞ of a specific nuclear design for a given set of input state parameters (e.g., void fraction, control state, fuel temperature).

Compliance of fuel with specified k_∞ limits will be confirmed for each new lattice as part of the bundle design process. Documentation that this has been met will be contained in the fuel design information report, which defines the maximum lattice k_∞ for each assembly nuclear design. The process for validating that specific assembly designs are acceptable for storage in the PBAPS fuel storage racks is provided below.

1. [[

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Documentation that all legacy fuel types currently in the PBAPS comply with this in-core limit is found in Appendix B.

3.5 Definitions

Fuel Assembly – A complete fuel unit consisting of a basic fuel rod structure that may include large central water rods. Several shorter rods may be included in the assembly. These are called "part length rods." A fuel assembly includes the fuel channel.

Gadolinia – The compound Gd_2O_3. The gadolinium content in integral burnable absorber fuel rods is usually expressed in weight percentage Gadolinia.

Lattice – An axial zone of a fuel assembly within which the nuclear characteristics of the individual rods are unchanged.

Dominant Lattice – An axial zone of a fuel assembly typically located in the bottom half of the bundle within which all possible fuel rod locations for a given fuel design are occupied.

Vanished Lattice – An axial zone of a fuel assembly typically in the upper half of the bundle within which a number of possible fuel rod locations are unoccupied.

Rack Efficiency – The ratio of a particular lattice statepoint in-rack eigenvalue (k_∞) to its associated lattice nominal in-core eigenvalue (k_∞). This value allows for a straightforward comparison of a rack's criticality response to varying lattice designs within a particular fuel product line. A lower rack efficiency implies increased reactivity suppression capability relative to an alternate design with a higher rack efficiency.

Design Basis Lattice – The lattice geometry, exposure history, and corresponding fuel isotopics for a fuel product line that result in the highest rack efficiency in a sensitivity study of reasonable fuel parameters at the desired in-core reactivity. This lattice is used for all normal, abnormal, and tolerance evaluations in the fuel rack analysis.

3.6 Assumptions and Conservatisms

The fuel storage rack criticality calculations are performed with the following assumptions to ensure the true system reactivity is always less than the calculated reactivity:

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- For conservatism, only positive reactivity differences from nominal conditions determined from depletion sensitivity and abnormal configuration analyses are added as biases to the final storage rack maximum K(95/95).
- Neutron absorption in spacer grids, concrete, activated corrosion and wear products (CRUD), and axial blankets is ignored to limit parasitic losses in non-fuel materials.
- TGBLA06 defined "lumped fission products" and Xe-135 are both conservatively ignored for MCNP-05P in-rack k_∞ calculations.
- [[

  ]]
- All Boraflex panels are assumed to contain an areal density of 0.0140 g B-10/cm^2.
- All Boraflex panels are assumed to be 142 inches long centered relative to active fuel height and 4.9 inches wide.

- A 3-inch gap is assumed to exist in the middle of all Boraflex panels. The gap is placed in the middle of the Boraflex panel to minimize leakage and maximize streaming between storage cells. The gaps are modeled as co-located in all panels.
- All the material in the Boraflex panels are modeled with typical Boraflex elemental compositions (Boron: 31.5 wt%, Carbon: 19 wt%, Silicon: 24.5 wt%, Oxygen: 22 wt%, Hydrogen: 3 wt%)
- The space between the inner cell wall and outer wrapper of the fuel rack which does not contain Boraflex is modeled as water. Modeling this material as water is reasonable, as the outer wrapper does not provide a water tight seal between the Boraflex and pool environment, and therefore any significant gap formations or degradation within the poison material will be filled with water.

4.0 Fuel Design Basis

4.1 GNF2 Fuel Description

Criticality safety analyses to determine storage system reactivity are performed using the GNF2 fuel design. The GNF2 fuel lattice configuration is a 10x10 fuel rod array minus eight fuel rods that have been replaced with two large water rods, as shown in Figure 1 with corresponding dimensions in Table 4. Figure 1 also demonstrates the part-length rod locations, which cannot be changed for this fuel design. Fuel channel dimensions are provided in Figure 2 and Table 5. [[

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Figure 1 – GNF2 Fuel Lattice Configuration

Table 4 – Nominal Dimensions for GNF2 Fuel Lattice

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			]]

[[

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Figure 2 – Channel Dimensions

Table 5 – Nominal Channel Dimensions for GNF2 Lattice

Dimension	mm	inches
[[		
		]]

[[

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4.2 Fuel Model Description

The fuel models considered include three-dimensional geometric modeling of all fuel material, cladding, water rods, and channels. [[

]] An example of a GNF2 vanished zone lattice model in MCNP-05P is depicted in Figure 3.

[[

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Figure 3 – GNF2 Lattice in MCNP-05P

[[

]] The lattice type and exposure history that results in the worst-case rack efficiency for an in-core k_∞ greater than the proposed limit is then used to define the design basis lattice. This lattice is assumed to be stored in every location in the rack being analyzed. Details on the determination of the design basis lattice using the process outlined above are presented in Section 5.3.

5.0 Criticality Analysis of Spent Fuel Storage Racks

5.1 Description of Spent Fuel Storage Racks

The PBAPS Boraflex storage racks manufactured by Westinghouse consist of a 304 stainless steel structure composed of a series of square vertical tubes (cells). These tubes contain 0.081-inch thick Boraflex panels sandwiched between a 0.075-inch stainless steel (SS) inner cell wall and a 0.020-inch SS outer wrapper. The Boraflex containing cells are arranged in a checkerboard pattern with the space between a 4-cell group forming a fifth bundle storage location with a center-to-center cell pitch of 6.280 inches. Rack array sizes ranging from 9x14 up to 19x20 are placed adjacent to one another in the spent fuel pools of both PBAPS Units 2 and 3. A schematic of a single storage rack unit-cell as installed is shown in Figure 4.

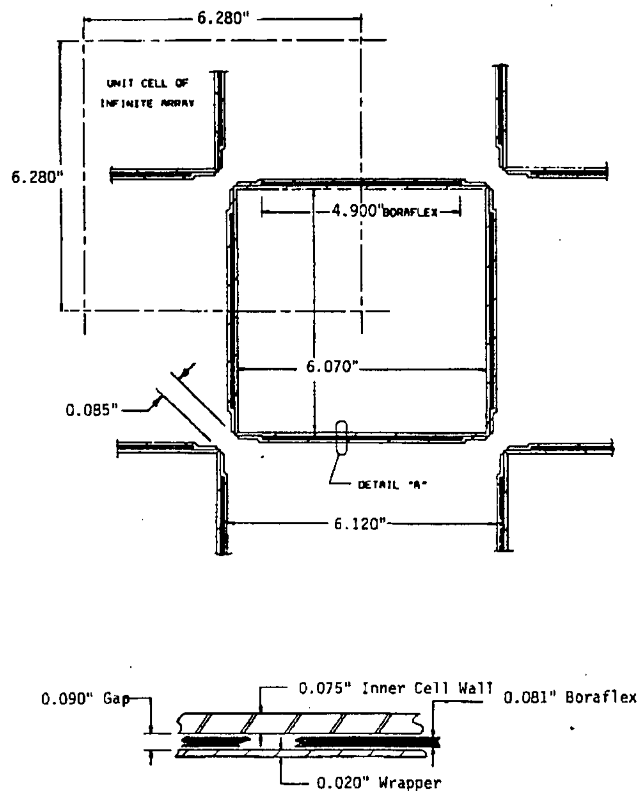

Figure 4 – Boraflex Spent Fuel Storage Rack Cell

The racks employ thermal neutron absorption in the B-10 of the Boraflex as the primary mechanism of reactivity control. Originally, the minimum certified B-10 areal density was 0.021 g B-10/cm^2; however, the Boraflex has degraded over time. Because of this, a minimum areal density of 0.0140 g B-10/cm^2 is assumed to account for partial degradation of the Boraflex in the analysis. All material between the inner cell wall and outer wrapper excluding the Boraflex is modeled as water. Modeling this material as water is reasonable, as the outer wrapper does not provide a water tight seal between the Boraflex and pool environment, and therefore any significant gap formations within the poison material will be filled with water.

Based on the Boraflex configuration, peripheral storage cells will not be completely surrounded by four panels of Boraflex. The reactivity effect of these storage limitations is assessed in Section 5.5.

5.2 Spent Fuel Storage Rack Models

A three-dimensional, semi-infinite storage array is modeled to conservatively represent the nominal spent fuel pool configuration. The array is represented as infinite in the X-Y plane by modeling a 10x10 array with periodic boundary conditions. The model is 174 inches in the axial direction, with 150 inches of active fuel and 12 inches of water on the top and bottom of active fuel for full water reflection. It is more conservative to model water than actual materials such as upper and lower tie plates because water will prevent leakage and increase k_{eff}. In addition, many of the components above and below active fuel contain SS which is an absorber of neutrons, thus it is more conservative to ignore the presence of these materials. An image of a 2x2 section of the array in the X-Y plane is provided in Figure 5 with dimensions and tolerances presented in Table 6. A representation of the X-Z direction is shown in Figure 6.

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Figure 5 – Storage Rack Model Schematic X-Y Plane

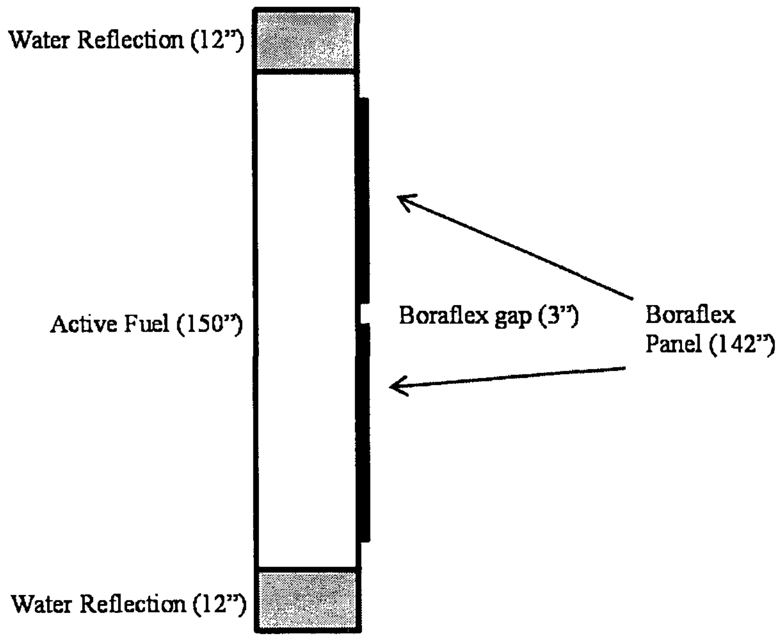

Figure 6 – Storage Rack Model Schematic X-Z Plane

Table 6 – Storage Rack Model Dimensions

		Tolerances	
	Nominal	Plus	Minus
	(inches)	*(inches)*	*(inches)*
Rack Pitch	6.280	0.025	0.025
Inner Cell Wall Thickness	0.075	0.025[1]	0.025[1]
Outer Wrapper Thickness	0.020	*	*
Primary Fuel Box Width	6.070	*	*
Resultant Fuel Box Width	6.120	*	*
Boraflex Panel Length	142.000	0.250	0.250
Boraflex Panel Width	4.900	0.075	0.075

* Important reactivity effects of these tolerances are covered by studying rack pitch and inner cell wall thickness tolerances

1 Conservatively assumed values

5.3 Design Basis Lattice Selection

Table 7 defines the lattice designs and exposure histories that were explicitly studied in the spent fuel storage rack to determine the geometric configuration and isotopic composition that results in the worst rack efficiency. Note that void state is not a relevant parameter for zero exposure

peak reactivity cases, and, therefore, only a single result is presented for these fuel loadings. Figure 7 presents a graph that demonstrates the linear nature of the in-core to in-rack results over all rack efficiency cases studied in the rack system. [[

]] The highest rack efficiency with an in-core k_∞ greater than the proposed limit of 1.235 is found to result from the parameters defined in Case 8. The geometry and isotopics defined for this case are used to define all bundles in the remaining spent fuel rack analyses.

Table 7 – Fuel Parameter Ranges Studied in Spent Fuel Rack

Case	Lattice Type	Void	Average Lattice Enrichment (U235 wt%)	Number of Gad Rods*	Gad Enrichment (Gd wt %)*	Peak-Reactivity Exposure (GWd/ST)	TGBLA06 Defined In-Core k_∞	MCNP-05P Defined In-Rack k_∞	Rack Efficiency
[[									
									]]

[[

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[[

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Figure 7 – Spent Fuel In-Core vs. In-Rack Eigenvalues

5.4 Normal Configuration Analysis

5.4.1 Analytical Models

The most reactive normal configuration was determined by studying the reactivity effect of the following credible normal scenarios:

- [[

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5.4.2 Results

The results of the study are provided in Table 8. [[

]] The in-rack k_∞ associated with this nominal combination of conditions is [[ ]], and is hereafter referred to as K_{Normal}. This configuration will be used for all abnormal and tolerance studies that are performed on an infinite basis. Any small, positive reactivity differences from this nominal condition are included in the calculation of the system bias in Section 5.5.2.

Table 8 – Spent Fuel Storage Rack In-Rack K_∞ Results – Normal Configurations

Term	Configuration	In-Rack k_∞	Error (1σ)
[[			
			]]

* Largest positive reactivity increase from nominal case for each term is included in roll-up of ΔK_{Bias}

[[

]]

Figure 8 – Nominal 10x10 Array

5.5 Accident/Abnormal Configuration Analysis

5.5.1 Analytic Models

The following abnormal configurations related to the depletion conditions of the stored bundles were explicitly considered, where each description defines an abnormal condition that all bundles in storage experience over their entire exposure histories.

- [[

]]

Finally, perturbations of the normal spent fuel rack configuration were considered for credible accident scenarios. The scenarios considered are presented in the bulleted lists that follow, with explanations of the abnormal condition provided below each listing of similar configurations.

- Dropped/Damaged Fuel

  [[

  ]]

- Misplaced 1.27 Bundle in 1.235 Region

  The in-core limit for the regions of the spent fuel rack with only Boraflex is 1.235. The regions with rack inserts can contain a bundle with an in-core limit of 1.27. Thus, there needed to be an evaluation of the effect of placing a bundle with a cold, uncontrolled in-core reactivity of 1.27 in the region of the rack system with the limit of 1.235. [[

  ]]

- No Boraflex Panels on Rack Periphery

  [[

]]

Table 9 – Rack Periphery Study Results

Description	K_{eff}	Error (1σ)	ΔK
[[			
			]]

- Abnormal Positioning of a Fuel Assembly Outside the Fuel Storage Rack

[[

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[[

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Figure 9 – Finite Corner Model Example

Table 10 – Misplaced Assembly Results

Description	K_{eff}	Error (1σ)	ΔK
[[			
			]]

The following abnormal configurations are also considered bounded, with the justification provided:

- Dropped Bundle on Rack

  Justification – For a drop on the rack, the fuel assembly will come to rest horizontally on top of the rack with a minimum separation distance from the fuel in the rack of more than 12 inches. At this separation distance the fissile material will be separated by enough neutron mean free paths to preclude neutron interactions that increase k_{eff}, and the overall effect on reactivity will be insignificant.

- Rack Sliding Which Causes Water Gap Between Racks too Close

  Justification – The racks modeled in this analysis are infinite in extent with no inter-module water gaps. This essentially assumes all racks are close-fitting and bounds possible reactivity effects of rack sliding.

- Loss of Spent Fuel Pool Cooling

  [[

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To account for partial Boraflex degradation, additional biases were considered in this analysis as described below:

- Undetected Boraflex Cracking

  Justification – The NETCO Monte Carlo analysis (Reference 5) shows that a bias of 0.004 ΔK is appropriate to apply for the effects of undetected Boraflex cracking.

- Boraflex Shrinkage and Edge Dissolution

  Justification – A 5% reduction in the Boraflex panel width was assessed and the reactivity difference between that case and the nominal case was applied as a bias to account for physical shrinkage of the Boraflex panel and edge dissolution. PBAPS BADGER results show that 5% width reduction is conservative. The relative reactivity increase from this bias (0.00703 ΔK) is included in the final ΔK bias term, as demonstrated in Table 11.

- Boraflex Particle Self-Shielding

  Justification – A bias of 0.00253 ΔK is applied for Boraflex particle self-shielding. This bias is a result of KENO studies performed by NETCO that explicitly modeled varying particle sizes.

- Gaps in Boraflex

  Justification – The rack model was developed with a 3-inch gap co-located in all Boraflex panels axially centered in the rack. The largest cumulative gap detected in official PBAPS BADGER inspection campaigns was 2.7 inches. A 3-inch gap conservatively bounds current and projected gap growth. Co-locating the gaps is more conservative than randomly distributing them throughout the rack panels because it maximizes the effect of neutron streaming.

- Non-Uniform Thinning in Boraflex

  Justification – This analysis assumes a uniform B-10 areal density of 0.0140 g B-10/cm^2; therefore, the potential for non-uniform thinning must be addressed. BADGER testing results are reported as panel average areal densities, but distributions of local dissolutions are also provided in the analysis summary. The BADGER results for PBAPS Unit 2 and

Unit 3 show that local dissolution occurs most often at the axial ends of the Boraflex panel. Having losses at the ends of the panels reduces the effect of the local dissolution due to increased neutron leakage relative to leakage associated with losses in the central axial region of the rack system. Additionally, if non-uniform thinning beyond 0.0140 g B-10/cm^2 is observed at the ends of the panels, it must be offset by areas of increased panel density to achieve the same average panel density result as is assumed in the uniform areal density approach. Having a higher areal density than is assumed in the analysis in the central axial region of the rack system will tend to result in an overall lower system reactivity. This analysis also includes a large delta K uncertainty term for the BADGER and RACKLIFE measurement uncertainties of B-10 areal density. This uncertainty term can also account for local thinning effects in the statistical rollup up. The majority of remaining, centrally located dissolutions are shown to occur near gaps in the panels. This analysis conservatively bounds current and projected gaps sizes, and thus bounds the effects of local dissolution immediately around gaps.

- Effects of a Seismic Event on Degraded Boraflex Rack

  Justification – In a seismic event, it is possible the Boraflex panels could slide together such that all the interspersed gaps accumulate at the top. The largest cumulative gap observed in either PBAPS Unit 2 or 3 was 2.7 inches. This analysis modeled 3-inch gaps to represent the accumulation of gaps in all panels co-located in the middle of the rack. This is more conservative than modeling all the gaps at the top of the panels because there is more leakage at the top of the bundle.

5.5.2 Results

The results of the abnormal studies are provided in Table 11. [[

]] The total contribution from these independent conditions to the maximum K(95/95) of the spent fuel rack is found to be [[ ]] using Equation 1. In this equation, a ΔK_{Bi} value must be both positive and the largest for its respective term to be considered.

$$\Delta K_{Bias} = \sum_{i=1}^{n} \Delta K_{Bi} \qquad (1)$$

Table 11 – Spent Fuel Storage Rack Bias Summary

Term	Description	K_{eff}	Error (1σ)	ΔK	ΔK Uncertainty $(2\sigma)^{+}$
[[					
					]]

[[

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5.6 Tolerance Analysis

5.6.1 Analytic Models

The following tolerance study configurations were explicitly considered for the spent fuel rack:

- [[

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All of the tolerances used in these analyses are at least 2σ design limits. The models developed for these studies were all based off the normal configuration presented in Section 5.4.

5.6.2 Results

The results of the tolerance studies are provided in Table 12. The ΔK term in this table represents the difference between the system reactivity with the specified tolerance perturbation and K_{Normal}. The total contribution from these independent tolerances to the maximum K(95/95) of the spent fuel rack is found to be [[ ]] using Equation 2. In this equation, a ΔK_{Ti} value must be both positive and the largest for its respective term to be considered.

$$\Delta K_{Tolerances} = \sqrt{\sum_{i=1}^{n} \Delta K_{Ti}^{2}} \tag{2}$$

Table 12 – Spent Fuel Storage Rack Tolerance Configuration ΔK Results

Term	Description	K_{eff}	Error (1σ)	ΔK	ΔK Uncertainty (2σ)*
[[					
					]]

* Independent ΔK uncertainties combined using square root of the sum of the squares for applicable terms.

5.7 Uncertainty Values

The total contribution to the maximum K(95/95) of the spent fuel rack from the problem and code specific uncertainties is found to be [[ ]] using Equation 3 and the values in

Table 13. [[
]]

$$\Delta K_{Uncertainty} = \sqrt{\sum_{i=1}^{n} \Delta K_{Ui}^{2}} \qquad (3)$$

Table 13 – Spent Fuel Storage Rack Uncertainty ΔK Values

Term	Description	Value
[[		
		]]

[[

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5.8 Maximum Reactivity

The maximum reactivity of the spent fuel rack crediting Boraflex and without rack inserts installed, considering all biases, tolerances, and uncertainties, is calculated using Equation 4. The final values are presented in Table 14.

$$K_{max(95/95)} = K_{Normal/Nominal} + \Delta K_{Bias} + \Delta K_{Tolerance} + \Delta K_{Uncertainty} \qquad (4)$$

Table 14 – Spent Fuel Storage Rack Results Summary

Term	Value
[[	
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6.0 Interfaces Between Areas with Different Storage Conditions

Rack inserts are being installed in PBAPS spent fuel storage pools to replace the poison material in the Boraflex racks. A prior analysis has demonstrated the storage pool multiplication with rack inserts is less than 0.95 for bundles with an in-core limit of 1.27 (Reference 4).

As the inserts are installed, the storage pool will become a mixture of degraded Boraflex regions and insert regions. The criticality safety evaluations for each of these loading configurations have demonstrated that, on an independent (or single region) basis, the storage pool

multiplication factor is less than the 0.95 regulatory limit. The multiplication factor for a mixture of these regions would be expected to also remain below 0.95 if the net transfer of neutrons from one region to another does not increase significantly.

In order to ensure this net transfer of neutrons between regions is limited, it can be assumed that inserts are installed in one row and one column of regions adjacent to modules with rack inserts installed, as necessary, to completely surround all non-peripheral assemblies that are part of the insert region with four wings of the NETCO-SNAP-IN inserts. As addressed in Section 3.4, the reactivity of future GNF2 fuel assemblies will not exceed the reference bounding assembly of this analysis. Appendix B provides evidence that all assemblies currently in the spent fuel pool also meet the reactivity requirements of Section 3.4.

As shown in Section 5.5.1, the effect of misplacing the higher reactivity bundle from the rack insert analysis (in-core reactivity of 1.27) in the Boraflex region was assessed and found to have negligible effect.

The overall conclusion from this multi-region analysis is that the spent fuel pool will have a K(95/95) value less than or equal to 0.95. This conclusion is reached without crediting residual boron in the Boraflex within the insert region and crediting partial degradation of the Boraflex region.

7.0 Conclusions

The PBAPS spent fuel racks have been analyzed for the storage of GNF2 fuel using the MCNP-05P Monte Carlo neutron transport program and the k_∞ criterion methodology. A maximum cold, uncontrolled peak in-core eigenvalue (k_∞) of 1.235 as defined by TGBLA06 is specified as the rack design limit for GNF2 fuel in the spent fuel racks with credit taken for Boraflex panels. Documentation that all legacy fuel types currently in the PBAPS comply with this in-core limit is found in Appendix B. The analyses resulted in a storage rack maximum k-effective (K(95/95)) less than 0.95 for normal and credible abnormal operation with tolerances and computational uncertainties taken into account.

8.0 References

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6. J. R. Taylor, "An Introduction to Error Analysis," University Science Books, 2nd Edition, 1982, pages 268-271.

Appendix A - MCNP-05P Code Validation

Table 15 presents the results of the benchmark calculations described in Section 3.3. Note that it is necessary to make an adjustment to the calculated k_{eff} value if the critical experiment being modeled was not at a critical state. This adjustment is done by normalizing the k_{calc} values to the experimental values, which is valid for small differences in k_{eff}. This normalization is reported as k_{norm} and is determined using Equation A-1. The combined uncertainty from the measurement and the calculation (σ_t) is also determined using Equation A-2.

$$k_{norm} = k_{calc}/k_{exp} \qquad \text{(A-1)}$$

$$\sigma_t = \sqrt{\sigma_{calc}^2 + \sigma_{exp}^2} \qquad \text{(A-2)}$$

Table 15 – MCNP-05P Results for the Benchmark Calculations

#	Experiment	Expt. #	Benchmark Eigenvalue (k_{exp})	Experimental Uncertainty (σ_{exp})	MCNP-05P Result (k_{calc})	MCNP-05P Uncertainty (σ_{calc})	Norm. Result (k_{norm})	Combined Uncertainty (σ_t)
[[								

#	Experiment	Expt. #	Benchmark Eigenvalue (k_{exp})	Experimental Uncertainty (σ_{exp})	MCNP-05P Result (k_{calc})	MCNP-05P Uncertainty (σ_{calc})	Norm. Result (k_{norm})	Combined Uncertainty (σ_t)

#	Experiment	Expt. #	Benchmark Eigenvalue (k_{exp})	Experimental Uncertainty (σ_{exp})	MCNP-05P Result (k_{calc})	MCNP-05P Uncertainty (σ_{calc})	Norm. Result (k_{norm})	Combined Uncertainty (σ_t)

#	Experiment	Expt. #	Benchmark Eigenvalue (k_{exp})	Experimental Uncertainty (σ_{exp})	MCNP-05P Result (k_{calc})	MCNP-05P Uncertainty (σ_{calc})	Norm. Result (k_{norm})	Combined Uncertainty (σ_t)
								]]

A.1 - Trend Analysis

To determine if any trend is evident in this pool of experiments, the parameters listed in Table 16 were considered as independent variables.

Table 16 – Trending Parameters

Energy of the Average Lethargy Causing Fission (EALF)
Uranium Enrichment (wt% U235)
Plutonium Content (wt% Pu239)
Atom Ratio of Hydrogen to Fissile Material (H/X)

Each parameter was plotted against the k_{calc} results independently for each case that was analyzed. These plots are provided in Figure 10 through Figure 13. This scatter plot of data was first analyzed by visual inspection to determine if any trends were readily apparent in the data. During this inspection, the axes of the graphs were modified to different scales to allow for a more thorough review. No clear evidence of a trend, linear or otherwise, was observed from this inspection.

[[

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Figure 10 – Scatterplot of EALF versus k_{norm}

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Figure 11 – Scatterplot of wt% U235 versus k_{norm}

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Figure 12 – Scatterplot of wt% Pu239 versus k_{norm}

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Figure 13 – Scatterplot of H/X versus k_{norm}

To further check for trends in the data, a linear regression was performed. The linear regression fitted equation is in the form y(x)= a +bx, where y is the dependent variable (k_{calc}) and x is any of the predictor variables from Table 16. Unweighted k_{calc} values were used in this evaluation, though it is noted that, due to the very similar σ_{calc} values reported in Table 15, using weighted values would produce very similar results. This regression was performed using the built in regression analysis tool in Excel. The fitted lines are included in Figure 10 through Figure 13. Again, it is noted through visual inspection that the trends do not appear to exhibit a strong correlation to the data. A useful tool to validate this claim is the linear correlation coefficient. This is a quantitative measure of the degree to which a linear relation exists between two variables. It is often expressed as the square term, r^2, and can be calculated directly using built in functions in Excel. The closer r^2 gets to the value of 1, the better the fit of data is expected to be to the linear equation. Results from this linear regression evaluation are summarized in Table 17.

A final method to test for goodness of fit is the chi squared test (χ^2). This method is explained in detail in Reference 6. In general, it can be stated that χ^2 is an indicator of the agreement between the observed (calculated) and expected (fitted) values for some variable. For linear goodness of fit testing using this method, Equation A-3 is utilized, where the expected value of $f(x_i)$ corresponds to the linear fitted equation for the trending parameter, x_i.

$$\chi^2 = \sum_1^N \left(\frac{k_{calc^i} - f(x_i)}{\sigma_{calc^i}}\right)^2 \qquad \text{(A-3)}$$

A more convenient way to report this result is the reduced chi squared value, which is denoted as $\tilde{\chi}^2$ and is defined by Equation A-4, where d is the degrees of freedom for the evaluation.

$$\tilde{\chi}^2 = \chi^2/d \qquad \text{(A-4)}$$

If a value of order one or less is obtained for this equation, then there is no reason to doubt the expected (fitted) distribution is reasonable; however, if the value is much larger than one, the expected distribution is unlikely to be a good fit. Results for each trending parameter are summarized in Table 17.

Table 17 – Trending Results Summary

Trend Parameter	Intercept	Slope	r^2	$\tilde{\chi}^2$	Valid Trend
H/X	[[				No
U-235 wt%					No
EALF					No
Pu-239 wt%				]]	No

The results in Table 17 clearly demonstrate that there are no statistically significant or valid trends of k_{calc} with any of the trending parameters.

A.2 - Bias and Bias Uncertainty Calculation – Single Sided Tolerance Limit

As no trends are apparent in the critical experiment results, a weighted single-sided tolerance limit methodology is utilized to establish the bias and bias uncertainty for this area of applicability and code package combination. Use of this method requires the critical experiment

results to have a normal statistical distribution. This was verified using the Anderson-Darling normality test. A graphical image of the results for this normality test, including the p-value for the distribution, is provided in Figure 14. Because the reported p-value is greater than 0.05, it is confirmed that the data fits a normal distribution, and the single sided tolerance limit methodology is confirmed to be applicable.

[[

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Figure 14 – Normality Test of K_{norm} Results

When using this method, the weighted bias and bias uncertainty are calculated using the following equations:

$$Bias = \bar{k}_{norm} - 1 \qquad \text{(A-5)}$$

$$Bias\ Uncertainty = U \cdot S_p \qquad \text{(A-6)}$$

$$\bar{k}_{norm} = \frac{\sum_{i=1}^{n} \frac{k_{norm_i}}{\sigma_t^2}}{\sum_{i=1}^{n} \frac{1}{\sigma_t^2}} \qquad \text{(A-7)}$$

$$S_P = \sqrt{s^2 + \bar{\sigma}^2} \qquad \text{(A-8)}$$

$$\overline{\sigma}^2 = \frac{n}{\sum_{i=1}^{n} \frac{1}{\sigma_t^2}} \quad \text{(A-9)}$$

$$s^2 = \frac{\left(\frac{1}{n-1}\right)\sum_{i=1}^{n} \frac{1}{\sigma_t^2}\left(k_{norm\,i} - \overline{k}_{norm}\right)^2}{\frac{1}{n}\sum_{i=1}^{n} \frac{1}{\sigma_t^2}} \quad \text{(A-10)}$$

Where:

$\overline{k}_{norm}$ = Average weighted k_{norm}

S_P = Pooled standard deviation

s^2 = Variance about the mean

$\overline{\sigma}^2$ = Average total variance

U = one-sided tolerance factor for n data points at (95/95 confidence/probability level)

n = number of data points (=[[ ]])

Table 18 summarizes the results of these calculations.

Using the average weighted bias and pooled standard deviation; the upper one-sided 95/95-tolerance limit was calculated for use in criticality calculations, in accordance with NUREG-6698 guidance (Reference 3). [[

]] Table 19 summarizes the recommended bias and bias uncertainty to be used in criticality calculations.

Table 18 – Bias and Bias Uncertainty for MCNP-05P with ENDF/B-VII

Bias (weighted)	[[
Variance About the Mean	
Average Total variance	
Pooled Standard Deviation (1σ)	
One-Sided Tolerance Factor	]]

Table 19 – Recommended Bias and Bias Uncertainty in Criticality Analyses for MCNP-05P with ENDF/B-VII

Bias	[[
Bias Uncertainty (95/95 confidence level)	]]

Appendix B - Legacy Fuel Storage Justification

Exposure dependent, maximum, uncontrolled in-core k_∞ results have been calculated for each fuel assembly in the PBAPS Unit 2 and Unit 3 spent fuel pools. Maximum values for each fuel type (e.g., 7x7, 8x8, 9x9, and 10x10) are presented in Table 20. These values have been calculated using the process for validating that specific assembly designs are acceptable for storage in the PBAPS fuel storage racks, as outlined in Section 3.4. Table 21 provides the name of the bundle, the name of the lattice, the lattice exposure and the corresponding void fraction that are associated with the peak reactivity legacy fuel lattice. This information demonstrates that all fuel assemblies currently in the PBAPS spent fuel pools have considerable margin to the reactivity of the GNF2 design basis bundle used in this analysis. The margin to safety was also confirmed to exist in the storage rack by analyzing the peak reactivity legacy fuel lattice (in-core [[ ]]) under normal conditions of storage, as outlined in Section 5.4. [[

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Because the GNF2 design basis bundle with an in-core k_∞ value of 1.235 has been shown to be below the 0.95 in-rack limit when analyzed in the storage racks, and because the legacy fuel types are less reactive than this design basis bundle both in-core and in-rack, it is confirmed that all legacy fuel types are safe for storage in the PBAPS spent fuel storage racks with credit for degraded Boraflex panels and without rack inserts installed.

Table 20 – Peak Cold Uncontrolled In-Core Reactivity for Legacy Fuel Types

Plant: Peach Bottom 2	Lattice Type	In-Core K-infinity
[[		
		]]
Plant: Peach Bottom 3		
[[		
		]]

Table 21 – Peak Reactivity Legacy Fuel Lattice Information

Plant	PBAPS Unit 2	PBAPS Unit 3
[[		
		]]

Appendix C – Alternate In-Core Reactivity Limit for Lower B-10 Areal Density Cells

While the peak in-core reactivity in legacy fuel bundles is 1.2344, PBAPS spent fuel storage racks hold many bundles with peak reactivities less than this value. To allow more flexibility in storage solutions for these lower reactivity bundles, a sensitivity study was performed to determine an alternate minimum B-10 areal density corresponding to a lower in-core limit of 1.2170.

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With the lower reactivity design basis bundle established, the storage system reactivity was studied over a range of B-10 areal densities using the same base rack model described in Section 5.2 of the report. The results of the sensitivity study show that a minimum B-10 areal density of 0.01113 g B-10/cm^2 results in an in-rack reactivity less than the nominal in-rack value determined in Table 7 of the report [[ ]].

It is relevant to note that the bundle design and rack model used in this assessment are nearly identical to that presented in the body of this report. Additionally, no new credible accident scenarios or tolerance studies are required to determine a maximum K(95/95) value in this study. Therefore, the reactivity adders for tolerances, biases, and uncertainties determined in Table 14 are appropriate for use in this case. The resulting maximum k-effective (K(95/95)) for the combination of an in-core k_∞ limit of 1.2170 and a minimum B-10 areal density of 0.01113 g B-10/cm^2 is less than 0.95 for normal and credible abnormal operation with tolerances and computational uncertainties taken into account.

ENCLOSURE 3

CFL-EXN-HE0-12-080

NEDC-33686P Revision 1 Affidavit

Global Nuclear Fuel – Americas
AFFIDAVIT

I, Andrew A. Lingenfelter, state as follows:

(1) I am Vice President, Fuel Engineering, Global Nuclear Fuel – Americas, LLC (GNF-A), and have been delegated the function of reviewing the information described in paragraph (2) which is sought to be withheld, and have been authorized to apply for its withholding.

(2) The information sought to be withheld is contained in GNF-A proprietary report NEDC-33686P, "Peach Bottom Atomic Power Station: Fuel Storage Criticality Safety Analysis of Spent Fuel Storage Racks with Boraflex," Revision 1, dated June 2012. GNF-A proprietary information in NEDC-33686P is identified by a dotted underline inside double square brackets. [[This sentence is an example.{3}]] GNF-A proprietary information in figures, large equation objects, and some tables is identified with double square brackets before and after the object. In all cases, the superscript notation {3} refers to Paragraph (3) of this affidavit, which provides the basis for the proprietary determination.

(3) In making this application for withholding of proprietary information of which GNF-A is the owner or licensee, GNF-A relies upon the exemption from disclosure set forth in the Freedom of Information Act ("FOIA"), 5 USC Sec. 552(b)(4), and the Trade Secrets Act, 18 USC Sec. 1905, and NRC regulations 10 CFR 9.17(a)(4), and 2.390(a)(4) for trade secrets (Exemption 4). The material for which exemption from disclosure is here sought also qualifies under the narrower definition of trade secret, within the meanings assigned to those terms for purposes of FOIA Exemption 4 in, respectively, Critical Mass Energy Project v. Nuclear Regulatory Commission, 975 F2d 871 (DC Cir. 1992), and Public Citizen Health Research Group v. FDA, 704 F2d 1280 (DC Cir. 1983).

(4) Some examples of categories of information that fit into the definition of proprietary information are:

a. Information that discloses a process, method, or apparatus, including supporting data and analyses, where prevention of its use by GNF-A's competitors without license from GNF-A constitutes a competitive economic advantage over other companies;

b. Information which, if used by a competitor, would reduce their expenditure of resources or improve their competitive position in the design, manufacture, shipment, installation, assurance of quality, or licensing of a similar product;

c. Information which reveals aspects of past, present, or future GNF-A customer-funded development plans and programs, resulting in potential products to GNF-A;

d. Information which discloses patentable subject matter for which it may be desirable to obtain patent protection.

The information sought to be withheld is considered to be proprietary for the reasons set forth in paragraphs (4)a. and (4)b.

(5) To address 10 CFR 2.390(b)(4), the information sought to be withheld is being submitted to NRC in confidence. The information is of a sort customarily held in confidence by GNF-A, and is in fact so held. The initial designation of this information as proprietary information, and the subsequent steps taken to prevent its unauthorized disclosure, are as set forth in the following paragraphs (6) and (7). The information sought to be withheld has, to the best of my knowledge and belief, consistently been held in confidence by GNF-A, no public disclosure has been made and it is not available in public sources. All disclosures to third parties, including any required transmittals to the NRC, have been made, or must be made, pursuant to regulatory provisions or proprietary and/or confidentiality agreements that provide for maintaining the information in confidence.

(6) Initial approval of proprietary treatment of a document is made by the manager of the originating component, who is the person most likely to be acquainted with the value and sensitivity of the information in relation to industry knowledge, or who is the person most likely to be subject to the terms under which it was licensed to GNF-A. Access to such documents within GNF-A is limited to a "need to know" basis.

(7) The procedure for approval of external release of such a document typically requires review by the staff manager, project manager, principal scientist, or other equivalent authority for technical content, competitive effect, and determination of the accuracy of the proprietary designation. Disclosures outside GNF-A are limited to regulatory bodies, customers, and potential customers, and their agents, suppliers, and licensees, and others with a legitimate need for the information, and then only in accordance with appropriate regulatory provisions or proprietary and/or confidentiality agreements.

(8) The information identified in paragraph (2), above, is classified as proprietary because it contains details of the nuclear fuel criticality licensing methodology for the GEH Boiling Water Reactor (BWR). Development of these methods, techniques, and information and their application for the design, modification, and analyses methodologies and processes was achieved at a significant cost GNF-A.

The development of the evaluation processes along with the interpretation and application of the analytical results is derived from the extensive experience database that constitutes a major GNF-A asset.

(9) Public disclosure of the information sought to be withheld is likely to cause substantial harm to GNF-A's competitive position and foreclose or reduce the availability of profit-making opportunities. The information is part of GNF-A's comprehensive BWR safety and technology base, and its commercial value extends beyond the original development cost. The value of the technology base goes beyond the extensive physical database and analytical methodology and includes development of the expertise to determine and apply the appropriate evaluation process. In addition, the technology base includes the value derived from providing analyses done with NRC-approved methods.

The research, development, engineering, analytical and NRC review costs comprise a substantial investment of time and money by GNF-A. The precise value of the expertise to

devise an evaluation process and apply the correct analytical methodology is difficult to quantify, but it clearly is substantial. GNF-A's competitive advantage will be lost if its competitors are able to use the results of the GNF-A experience to normalize or verify their own process or if they are able to claim an equivalent understanding by demonstrating that they can arrive at the same or similar conclusions.

The value of this information to GNF-A would be lost if the information were disclosed to the public. Making such information available to competitors without their having been required to undertake a similar expenditure of resources would unfairly provide competitors with a windfall, and deprive GNF-A of the opportunity to exercise its competitive advantage to seek an adequate return on its large investment in developing and obtaining these very valuable analytical tools.

I declare under penalty of perjury that the foregoing affidavit and the matters stated therein are true and correct to the best of my knowledge, information, and belief.

Executed on this 15th day of June 2012.

Andrew A. Lingenfelter
Vice President, Fuel Engineering
Global Nuclear Fuel – Americas, LLC