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PROPRIETARY INFORMATION – WITHHOLD UNDER 10 CFR 2.390

October 5, 2022 10 CFR 50.90

RS-22-108

U.S. Nuclear Regulatory Commission
ATTN: Document Control Desk
Washington, D.C. 20555-0001

Quad Cities Nuclear Power Station, Units 1 and 2
Renewed Facility Operating License Nos. DPR-29 and DPR-30
NRC Docket Nos. 50-254 and 50-265

Subject: Response to Request for Additional Information RE: LaSalle County Station, Units 1 and 2 and Quad Cities Nuclear Power Station, Units 1 and 2 License Amendments Related to Fuel Storage

References:
1. Letter from P.R. Simpson (Exelon Generation Company, LLC) to U.S. NRC, "License Amendment Request Regarding New Fuel Storage Vault and Spent Fuel Storage Pool Criticality Methodologies with Proposed Change to Technical Specifications Section 4.3.1," dated October 25, 2021 (ADAMS Accession No. ML21298A168)
2. Email from R. Kuntz (U.S. NRC) to R. Steinman (Constellation Energy Generation), "Request for Additional Information RE: LaSalle County Station, Units 1 and 2 and Quad Cities Nuclear Power Station, Units 1 and 2 License Amendments Related to Fuel Storage," dated September 12, 2022 (ADAMS Accession No. ML22256A011)

In Reference 1, Constellation Energy Generation, LLC (CEG) requested an amendment to Renewed Facility Operating License Nos. DPR-29 and DPR-30 for Quad Cities Nuclear Power Station (QCNPS), Units 1 and 2, respectively. The proposed changes support the transition from Framatome (formerly AREVA) ATRIUM 10XM fuel to Global Nuclear Fuel – Americas, LLC (GNF-A) GNF3 fuel by allowing a different methodology to be used for the criticality safety evaluation for the spent fuel pool (SFP) and the new fuel vault (NFV).

In Reference 2, the NRC requested additional information that is needed to complete review of the proposed methodology change. Attachment 1 provides the additional information requested for QCNPS. CEG will submit a separate letter to address the LaSalle County Station aspects of Reference 2. Attachments 2 (non-proprietary) and 4 (proprietary) are vendor reports that support the additional information provided in Attachment 1. A signed affidavit from the owner of the information, GNF-A, is included as Attachment 3. The affidavit sets forth the basis on which GNF-A's information may be withheld from public disclosure by the NRC and addresses

Attachment 4 contains Proprietary Information. Withhold from public disclosure under 10 CFR 2.390. When separated from Attachment 4, this document is decontrolled.

with specificity the considerations listed in paragraph (b)(4) of 10 CFR 2.390, "Public inspections, exemptions, requests for withholding." Accordingly, it is respectfully requested that the information in Attachment 4, which is proprietary to GNF-A be withheld from public disclosure.

CEG has reviewed the information supporting the finding of no significant hazards consideration, and the environmental consideration that were previously provided to the NRC in Reference 1. The additional information provided in this submittal does not affect the bases for concluding that the proposed license amendments do not involve a significant hazards consideration. In addition, the information provided in this submittal does not affect the bases for concluding that neither an environmental impact statement nor an environmental assessment needs to be prepared in connection with the proposed amendment.

CEG is notifying the State of Illinois of this supplement to a previous application for a change to the operating license by sending a copy of this letter and its attachments to the designated State Official in accordance with 10 CFR 50.91, "Notice for public comment; State consultation," paragraph (b).

There are no regulatory commitments included in this letter.

Should you have any questions concerning this letter, please contact Ms. Rebecca L. Steinman at 630-657-2831.

I declare under penalty of perjury that the foregoing is true and correct. Executed on the 5th day of October 2022.

Respectfully,

Patrick R Simpson

Patrick R. Simpson
Sr. Manager Licensing
Constellation Energy Generation, LLC

Attachments:

1. Response to Request for Additional Information (**Non-Proprietary**)
2. GEH Report 003N7421-NP, Revision 1, "Generic Criticality Safety Analysis of GE New Fuel Storage Racks for GNF3 Fuel," dated September 2022 (**Non-Proprietary**)
3. Global Nuclear Fuels – Americas, LLC 10 CFR 2.390 Affidavit for Attachment 4
4. GEH Report 003N7421-P, Revision 1, "Generic Criticality Safety Analysis of GE New Fuel Storage Racks for GNF3 Fuel," dated September 2022(**Proprietary**)

cc: Regional Administrator – NRC Region III
NRC Senior Resident Inspector – Quad Cities Nuclear Power Station
Illinois Emergency Management Agency – Department of Nuclear Safety

ATTACHMENT 1
RS-22-108

Response to Request for Additional Information

ATTACHMENT 1

Response to Request for Additional Information

REQUEST FOR ADDITIONAL INFORMATION

TO SUPPORT REVIEW OF CRITICALITY SAFETY ANALYSIS THAT SUPPORT

LICENSE AMENDMENT REQUESTS FOR

LASALLE COUNTY STATION, UNITS 1 AND 2, AND

QUAD CITIES NUCLEAR POWER STATION, UNITS 1 AND 2

DOCKET NOS. 50-373, 50-374, 50-254, AND 50-265

By applications dated June 30 and October 25, 2021 (Agencywide Document Access and Management System (ADAMS) Accession Nos. ML21183A169 and ML21298A168), Exelon Generation Company, LLC, submitted similar license amendment requests (LARs) for LaSalle County Station, Units 1 and 2 (LaSalle), and Quad Cities Nuclear Power Station, Units 1 and 2 (Quad Cities) respectively. The LaSalle LAR was supplemented by letters dated November 4, 2021 (ML21312A457) and June 17, 2022 (ML22172A175). The Quad Cities LAR was supplemented by letters dated November 3, 2021 (ML22194A086), and July 13, 2022 (ML22194A085). On February 1, 2022 (ADAMS Accession No. ML22032A333), Exelon Generation Company, LLC was renamed Constellation Energy Generation, LLC (the licensee). The proposed amendments would allow the licensee to use a new criticality safety analysis (CSA) methodology for GNF3 and legacy fuel types in the spent fuel pool. The proposed amendments would also change the CSA for the new fuel vault (NFV) to use the GESTAR II methodology for the storage of new GNF3 fuel in the NFV racks.

On August 2, 2022 (ML22214A004) the NRC issued a plan for the audit of the LaSalle and Quad Cities, as well as a similar amendment submitted by letter dated June 8, 2022 (ML22159A310) for Dresden Nuclear Power Station, Units 2 and 3. The audit was conducted to increase the NRC staff's understanding of the criticality information. The audit was conducted via virtual discussions and the use of an online portal from August 4 through September 2, 2022.

RAI-SFNB-8

Regulatory Requirements

Paragraph 50.68(a) of Title 10 of the *Code of Federal Regulations* (10 CFR) requires "each holder of a construction permit or operating license for a nuclear power reactor issued under this part or a combined license for a nuclear power reactor issued under Part 52 of this chapter, shall comply with either 10 CFR 70.24 of this chapter or the requirements in paragraph (b) of this section." The licensee has chosen to comply with 10 CFR 50.68(b).

Paragraph 50.68(b)(2) of 10 CFR states: "The estimated ratio of neutron production to neutron absorption and leakage (k-effective) of the fresh fuel in the fresh fuel storage racks shall be calculated assuming the racks are loaded with fuel of the maximum fuel assembly reactivity and flooded with unborated water and must not exceed 0.95, at a 95 percent probability, 95 percent confidence level. This evaluation need not be performed if administrative controls and/or design features prevent such flooding or if fresh fuel storage racks are not used."

Paragraph 50.68(b)(3) of 10 CFR states: "If optimum moderation of fresh fuel in the fresh fuel storage racks occurs when the racks are assumed to be loaded with fuel of the maximum fuel assembly reactivity and filled with low-density hydrogenous fluid, the k-effective corresponding to this optimum moderation must not exceed 0.98, at a 95 percent probability, 95 percent confidence level. This evaluation need not be performed if administrative controls and/or design features prevent such moderation or if fresh fuel storage racks are not used."

Background

In Section 2.3 of the LARs, the licensee states that the LaSalle and Quad Cities updated final safety analysis reports (UFSARs) will be updated as part of implementation of the amendments. The licensee stated that these updates would include changes to reflect the proposed revisions to the NFV CSA.

By emails dated May 18 (ML22172A175) and June 13 (ML22164A785), 2022, the NRC staff requested, in part, that the licensee provide the following information for LaSalle and Quad Cities, respectively:

- NFV criticality safety analysis methodology used in the analysis.
- Criticality safety analysis that sets the limits for the NFVs.
- Criticality safety analysis that demonstrates GNF3 meets the limits for the NFVs.

The licensee's June 17 and July 13, 2022, letters provided additional information regarding the analysis performed to support the license amendment requests but did not provide the CSA methodology or the CSAs. During the regulatory audit, the NRC staff identified that information needed to support the review was included in a GNF3 fuel design specific NFV criticality safety analysis.

Request

Provide the GNF3 fuel design specific NFV criticality safety analyses that would apply to LaSalle and Quad Cities. Confirm that proposed changes to the UFSARs include incorporating these CSAs (e.g., by reference).

CEG Response

The fuel design specific new fuel vault (NFV) criticality safety analysis for GNF3 fuel is provided in Attachments 2 (non-proprietary version) and 4 (proprietary version). The fuel-type-specific analysis is applicable for GNF3 fuel stored in GE-designed NFV racks with cell pitches equal to or greater than those shown in Table 1-1, "New Fuel Vault Rack Dimensions" of the attached reports. The installed QCNPS NFV racks are bounded by Concept 2 dimensions provided in the referenced table. The analysis demonstrates that storage of GNF3 fuel, with maximum cold, uncontrolled in-core eigenvalue (k_{inf}) of 1.31, in the QCNPS NFV racks results in a storage rack maximum k-effective within a 95/95 confidence interval ($k_{max(95/95)}$) of less than 0.90 for dry normal storage conditions, and less than 0.95 for credible abnormal operation with tolerances and uncertainties considered.

The QCNPS Updated Final Safety Analysis Report (UFSAR) will be updated in accordance with 10 CFR 50.71(e) as part of implementation of the approved amendment. In response to this request for information, UFSAR Section 9.1.1.3 will be revised as shown below. Strikeout indicates proposed deletions and underlined text indicates proposed additions to the existing Section 9.1.1.3 text.

9.1.1.3 Safety Evaluation

The new fuel storage racks are designed in accordance with Draft General Design Criterion 66 to prevent an accidental critical array, even in the event the vault becomes flooded. [9.1-4]

The spacing of fuel bundles in the new fuel storage vault maintains $k_{\{eff\}}$ <0.90 dry and $k_{\{eff\}}$ <0.95 flooded. [9.1-5] These conditions can be met for any GNF3 fuel lattice with k_{inf} in the standard cold core geometry less than or equal to 1.31, which meets the licensing criteria defined by GESTAR (Reference 19). Additional details regarding the NFV criticality safety analysis for GNF3 fuel is found in 003N7421 (Reference 20).

The vault floor drain prevents flooding. A radiation monitor at the new fuel storage vault provides warning of any radiation level increase. Since the vault opens only at the top, the new fuel elements are afforded maximum protection. Grating is provided below the hatches such that, with the hatches removed, only one row of stored fuel will be exposed. Seismic design for the new fuel storage vault is described in Section 3.7.

~~ATRIUM 10XM assemblies can be safely stored in the Quad Cities Unit 1 and Unit 2 new fuel storage vault and meet the criteria of k_{eff} less than 0.90 for the dry condition and less than 0.95 for the fully flooded with un-borated water condition. Reference 18 provides the lattice enrichment and gadolinia loading criteria for ATRIUM 10XM assemblies to be safely stored in the Quad Cities Unit 1 and Unit 2 new fuel storage vault.~~

In addition, controls have been implemented to further reduce the probability of a criticality occurrence, i.e., the storage array will be in a moderation controlled area. A moderation control area limits the amount of hydrogenous material in the area. Administrative controls as generally defined in SIL 152[9] have been incorporated for the area.

ATTACHMENT 2
RS-22-108

GEH Report 003N7421-NP, Revision 1, "Generic Criticality Safety Analysis of GE New Fuel Storage Racks for GNF3 Fuel," dated September 2022

(Non-Proprietary)

GE Hitachi Nuclear Energy

003N7421-NP

Revision 1

September 2022

Non-Proprietary Information

Generic Criticality Safety Analysis of GE New Fuel Storage Racks for GNF3 Fuel

Captured in PLM Spec. # 007N3330 R0

INFORMATION NOTICE

Proprietary information of GNF has been removed from this non–proprietary version of 003N7421-P, Revision 1. The information removed was contained between opening double brackets ([[ ) and closing double brackets ( ]]).

IMPORTANT NOTICE REGARDING CONTENTS OF THIS REPORT

Please Read Carefully

REVISION SUMMARY

Rev.	Section Modified	Revision Description
0	--	Initial Release
1	Multiple	• Revised Table A-3 for CR-27347. • Minor administrative editorial changes.

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ACRONYMS

Acronym	Explanation
AOA	Area of Applicability
BOL	Beginning of Life
BWR	Boiling Water Reactor
CFR	Code of Federal Regulations
EALF	Energy of the Average Lethargy Causing Fission
GDC	General Design Criteria
GEH	GE Hitachi
GNF	Global Nuclear Fuel
H/U	Hydrogen to Uranium Ratio
H/X	Hydrogen to Fissile Material Ration
IN	Information Notice
MOX	Mixed Oxide
NFV	New Fuel Vault
SIL	Service Information Letter
SS	Stainless Steel

1.0 INTRODUCTION

This report describes the criticality analysis and results for a generic New Fuel Vault (NFV) for storage of 10x10 GNF3 fuel bundles. 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. This report is intended to conservatively bound all existing plants with cell pitches equal to our greater than those shown in Table 1-1.

Table 1-1: New Fuel Vault Rack Dimensions

GE Rack Type	Cell Pitch (inches)
Concept 2: Aluminum I-beams	[[ ]]x10.5
Concept 3: Three tier aluminum castings	[[ ]]

The NFV racks are analyzed using the MCNP-05P Monte Carlo neutron transport program with the ENDF/B-VII nuclear cross section libraries and the infinite multiplication factor (k_∞) criterion methodology. A maximum cold, uncontrolled peak in-core k_∞ of 1.31 as defined by the lattice physics code TGBLA06 is specified as the rack design limit for GNF3 fuel in the NFV racks.

This report covers both Service Information Letter (SIL) 152 (1) compliant and non-compliant plants. For non-compliant plants, an optimum moderation study is required in the criticality analysis. As a fully loaded rack under optimum moderation conditions does not meet regulatory reactivity limits, an alternate storage configuration must be used for non-compliant plants. As a result, the following two configurations were analyzed:

1. Fully loaded assuming SIL 152 compliance
2. One fuel bundle out of three in either linear direction checkerboard with consideration given to optimum moderation conditions

Both analyses resulted in a storage rack maximum k-effective within a 95/95 confidence interval ($K_{max(95/95)}$) less than 0.90 for dry normal storage conditions, and less than 0.95 for credible abnormal operation with tolerances and uncertainties taken into account, as demonstrated in Table 1-2. **If a plant is not SIL 152 compliant, a checkerboard array must be employed where only one out of every three storage locations in either linear direction contains a fuel bundle.**

Table 1-2: Summary $K_{max(95/95)}$ Result

Configuration	Peak in-core K_∞	$K_{max(95/5)}$ for Abnormal Operation
Full loading (assuming SIL 152 compliance)	1.31	0.93919
Checkerboard loading	1.31	0.93152

2.0 REQUIREMENTS

Title 10 of the Code of Federal Regulations (CFR) Part 50 defines the requirements for the prevention of criticality in fuel storage and handling at Nuclear Power Plants. 10 CFR 50.68 (2) 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. For cases where optimum moderation is a credible event for the storage of fresh fuel (i.e. non-compliant with SIL 152), the $K_{max(95/95)}$ corresponding to the optimum moderation condition must not exceed 0.98. The limit of 0.95 is conservatively assumed for all abnormal cases in this study. Reference (3) outlines the standards that must be met for these analyses. These requirements are supplemented by General Design Criterion (GDC) 62 (4) and Information Notice (IN) 2011-03 (5). 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 GEH/GNF (Global Nuclear Fuel) 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 the Los Alamos National Laboratory code MCNP5 (6). 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 $S(\alpha,\beta)$ 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 $S(\alpha,\beta)$ 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 2D 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

MCNP-05P has been compared to [[ ]] critical experiments for validation purposes using ENDF/B-VII.0 nuclear cross-section data. The experiments cover a number of moderator-to-fuel ratios and poison materials that represent material and geometric properties similar to that of a BWR fuel lattice both in and out of fuel racks. The critical experiments to which MCNP-05P has been compared are provided in Table 3-1. All are either low-enriched UO_2 or Mixed Oxide (MOX) pin lattice in water experiments. The Area of Applicability (AOA) considered covered by this validation is listed in Table 3-2, along with the parameters which characterize the NFV rack system for comparison. The critical experiment modeling results, along with the calculation of the associated bias and bias uncertainty terms at the 95/95 confidence level using NUREG-6698 guidance, are provided in Appendix A (7). The study concluded that the appropriate bias to apply to systems covered by this AOA is [[ ]], and the appropriate uncertainty of that bias is [[ ]].

Table 3-1: Summary of the Critical Benchmark Experiments

[[		
		]]

Table 3-2: Area of Applicability Covered by Code Validation

Parameters	Validation Area of Applicability	New Fuel Rack Characteristics
Fissionable Material	Uranium, Plutonium, Actinides	Uranium, Actinides
Chemical Form	UO_2, MOX	UO_2, MOX
Enrichment (wt% U-235)	wt% U-235 ≤ 4.9	2.8 ≤ wt% U-235 ≤ 4.9
Enrichment (wt% Pu-239)	wt% Pu-239 ≤ 5.3	wt% Pu-239 ≤ 4.9
Physical Form	Solid Compound	Solid Compound
Temperature	~20ºC up to 100 ºC	4-20ºC
Moderator (in fuel region)	H_2O	H_2O
Physical Form	Solution	Solution
Temperature	~20ºC up to 100 ºC	4-20ºC
Reflector (in fuel region)	H_2O	H_2O
Physical Form	Solution	Solution
Temperature	~20ºC up to 100 ºC	4-20ºC
Absorbers	None/Boron/Gadolinium/ Stainless Steel/Copper	Gadolinium/ Fission Products
Neutron Energy Spectrum	Thermal	Thermal
Energy of Average Lethargy Causing Fission (MeV)	6.8E-8 – 8.6 E-7	(Limiting In-rack) 2.1E-07

Table 3-2 demonstrates that the AOA of this validation encompasses the majority of storage characteristics of the NFV.

An additional uncertainty is also added to the fuel rack studies related to eigenvalue calculations performed using TGBLA06. A bias of [[ ]] and the 95%/95% tolerance level [[

]]. The uncertainty is applied to the fuel racks' $K_{max(95/95)}$ value to cover uncertainty in the assignment of in-core k_∞ values.

3.4 IN-CORE K_∞ METHODOLOGY

The design of the fuel storage racks provides for a subcritical k_∞ for both normal and credible abnormal storage conditions. In all cases, the storage rack k_∞ must be ≤ 0.95 (3). 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 GE-supplied racks, including those in NFV storage.

The analysis performed to calculate the lattice k_∞ to confirm compliance with the above criterion uses the NRC-approved lattice physics methods encoded into the TGBLA06 Engineering

Computer Project. One of the outputs of the TGBLA06 solution is the lattice k_∞ of a specific nuclear design for a given set of input state parameters (void fraction, control state, fuel temperature, etc.).

Compliance of GNF3 fuel with specified k_∞ limits will be confirmed for each new lattice as part of the bundle design process. The process for validating that specific assembly designs are acceptable for storage in the GE NFV racks is to compare peak in-core reactivity of the bundle to the in-core reactivity limit.

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 gadolinia 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 axial nuclear characteristics of the individual rods are unchanged.

BASE Lattice – An axial zone of a GNF3 fuel assembly located in the bottom third of the bundle within which all possible fuel rod locations ([[ ]]) are occupied.

MID Lattice – [[

]]

VAN Lattice – An axial zone of a GNF3 fuel assembly located in the top third of the bundle within which a number of possible fuel rod locations ([[ ]]) are unoccupied and [[

]].

Rack Efficiency – The ratio of in-rack k_∞ to its associated lattice nominal in-core k_∞ at a given exposure statepoint. 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 DESIGN METHOD AND CONSERVATISMS

The NFV storage rack criticality calculations are performed with the following design methods and conservatisms to ensure the true system reactivity is always less than the calculated reactivity:

- [[

]]

No credit is taken for the natural blanket [[
]].

- **Design basis lattices with in-core k_∞ values greater than the proposed 1.31 in-core k_∞ limit are used for all criticality analyses.**
  [[
  ]]
- **Neutron absorption in minor bundle components is neglected (e.g. spacer grids).** These structures act as neutron absorbers, neglecting them yields a higher calculated system reactivity, and therefore a more conservative result.
- [[
  ]]
- **The storage system is modeled with periodic boundary conditions** [[
  ]]
- [[
  ]]

4.0 FUEL DESIGN BASIS

Criticality safety analyses to determine storage system reactivity are performed using the GNF3 fuel design. The most reactive lattice for each fuel storage configuration will then be evaluated in the GE NFV design.

4.1 GNF3 FUEL DESCRIPTION

The GNF3 fuel lattice configuration is a 10x10 fuel rod array, [[
]], as shown in Figure 4-1 with corresponding dimensions in Table 4-1 and Table 4-2. Figure 4-1 also demonstrates the part-length rod locations. Fuel channel dimensions are provided in Figure 4-2 and Table 4-3. [[

]]

[[ ]]

Figure 4-1: GNF3 Lattice Configuration

Table 4-1: Lattice Dimensions

Item			Dimension	
			mm	**in**
Channel	[[			
Fuel Rod				
Pellet				]]
[[				]]
Bundle Lattice	Rod-to-rod pitch	M	12.95	0.510
	Rod-to-rod gap	N	2.69	0.106
	Edge rod-to-channel gap	O	3.695	0.145

[[

]]

Table 4-2: Cell Dimensions

Lattice Type	Channel Name	½ Wide Gap, Q		½ Narrow Gap, R		Control Blade Pitch, S	
		mm	**in**	**mm**	**in**	**mm**	**in**
[[							
							]]

[[ ]]

Figure 4-2: Channel $^{1}/_{8}$ Cross Sections

Table 4-3: Channel Dimensions

Channel Name		**83AV**				**93AV**			
Channel Section		**zone 1**		**zone 2**		**zone 1**		**zone 2**	
Dimension		**mm**	**in**	**mm**	**in**	**mm**	**in**	**mm**	**in**
[[									
									]]

[[

]]

4.2 FUEL MODEL DESCRIPTION

The fuel models considered include 3D geometric modeling of all fuel material, cladding, water rods, and channels. [[

]] Neutron absorption in

minor structural members is also neglected (i.e., spacer grids are ignored). [[

]] An example of a GNF3 MID lattice model in MCNP-05P is depicted in Figure 4-3.

[[ ]]

Figure 4-3: GNF3 Lattice in MCNP-05P

The fuel loadings considered for each lattice span a range of average enrichments, number of gadolinia rods, gadolinia concentration, and void histories considered to be reasonably representative of any GNF3 fuel design. Each lattice type is analyzed at an exposure of 0 GWd/ST. The lattice type and 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 NEW FUEL VAULT

5.1 DESCRIPTION OF NEW FUEL VAULT STORAGE RACKS

This report analyzes a NFV containing GE low-density fuel storage racks with the dimensions in Table 5-1. There are two types of NFV racks designed by GE, which will be referred to as Concept 2 and Concept 3. Models were created for both rack designs to demonstrate the most reactive rack type. Both GE NFV racks have ten positions for channeled or unchanneled fuel assemblies in a rack. The number of racks can vary from plant to plant. Thus a set of 10 racks was assumed with periodic boundary conditions to simulate an infinite number of racks in the [[ ]]. The Concept 2 racks maintain the fuel in geometrically safe locations by I-beam shaped aluminum structural guides. The fuel assemblies are introduced to the storage rack through the top and are fully supported at the bottom. In Concept 3, the fuel bundles are supported by three tier aluminum castings [[ ]]. A description of the rack models used is found in Section 5.2.

Table 5-1: GE NFV Rack Features

	Construction	Cell Pitch	
		inches	cm
Concept 2	Aluminum I-beams	[[ ]] x 10.5	[[ ]] x 26.67
Concept 3	Three tier aluminum castings	[[	]]

5.2 NEW FUEL VAULT STORAGE RACK MODELS

Three-dimensional models have been defined to conservatively describe the NFV storage systems in MCNP-05P. A drawing (not to scale) of a Concept 2 storage rack element is provided in Figure 5-1, with dimensions and tolerances presented in Table 5-2. Figure 5-2 shows the rack element for Concept 3, with dimensions and tolerances presented in Table 5-2. Both elements were used to populate a 10x10 rack array. An image (not to scale) of the entire fuel vault in the Y – Z direction is provided in Figure 5-3. An image of the Y-X direction is provided in Figure 5-4. A sensitivity study was performed [[ ]]. This analysis investigates two different rack loadings:

1. Fully loaded assuming SIL-152 compliance
2. One in three in either linear direction checkerboard array with consideration given to optimum moderation conditions

[[ ]]

Figure 5-1: Concept 2 GE NFV Storage Rack Element (X-Y Plane)

[[ ]]

Figure 5-2: Concept 3 NFV Storage Rack Element (X-Y Plane)

Table 5-2: GE NFV Rack Element Dimensions and Drawing Specified Tolerances

		Tolerances	
	Nominal	**Plus**	**Minus**
	(inch)	***(inch)***	***(inch)***
Concept 2 Short Inside Width	[[		
Concept 2 Long Inside Width			
Concept 2 Channel Lip Width			
Concept 2 Channel Half Thickness			
Concept 2 Channel Thickness			
Concept 2 Intra-Row Pitch			
Concept 2 Inter-Row Pitch			]]

[[ ]]

Figure 5-3: New Fuel Vault Layout and Dimensions (Y-Z direction)

[[ ]]

Figure 5-4: New Fuel Vault Layout and Dimensions (Y-X direction)

5.3 FUEL RACK SELECTION

A comparison study was performed to determine the highest rack efficiency and thus the most limiting rack design between Concept 2 and Concept 3. The same fuel bundle lattice was used in both cases, under dry conditions in the full loading pattern. As shown in Table 5-3, Concept 2 has the highest rack efficiency. The Concept 2 rack design was used for the rest of this analysis.

Table 5-3: Rack Efficiency Comparison for Concept 2 and Concept 3 Rack Designs

Rack Concept	In-Core k_∞	In-Rack k_∞	Error (1σ)	Rack Efficiency
2	[[	0.69291	[[	
3	]]	0.66775		]]

5.4 [[ ]]

[[

]]

Table 5-4: [[ ]]

[[		
		]]

5.5 DESIGN BASIS LATTICE SELECTION

Table 5-5 and Table 5-6 define the lattice designs and loading patterns that were explicitly studied in the Concept 2 NFV in order to determine the design basis lattice. The different lattice types and the effects of varying average enrichment coupled with gadolinia concentration were investigated. This study demonstrates that, in general, [[ ]].

This meets expectations, as Beginning of Life (BOL) fuel does not experience the spectral shift associated with plutonium build-up in spent fuel, and therefore the selection of a design basis lattice is of less significance than in spent fuel rack studies. Cases 2 and 7 demonstrated the highest rack efficiencies in their given configurations, as shown in Table 5-5 and Table 5-6. Case 2 will be used to define all bundles in the remaining NFV analyses in the full loading pattern, while Case 7 will be used to define all bundles in the remaining NFV analyses in the checkerboard loading pattern.

Table 5-5: Fuel Parameters Studied in NFV- Full Loading, Dry

Case Number	Lattice Type	Average Lattice Enrichment (U-235 wt%)	Number of Gad Rods	Gad Enrichment (Gd wt%)	TGBLA06 Defined In-Core k_∞	MCNP-05P Defined In-Rack k_∞	Rack Efficiency
1	[[					0.69131	[[
2						**0.69291**	
3						0.68900	
4						0.65366	
5						0.65043	
6					]]	0.65853	]]

Table 5-6: Fuel Parameters Studied in NFV- Checkerboard Loading, Dry

Case Number	Lattice Type	Average Lattice Enrichment (U-235 wt%)	Number of Gad Rods	Gad Enrichment (Gd wt%)	TGBLA06 Defined In-Core k_∞	MCNP-05P Defined In-Rack k_∞	Rack Efficiency
7	[[					**0.57970**	[[
8						0.57979	
9						0.57024	
10						0.55896	
11						0.55278	
12					]]	0.55494	]]

5.6 NORMAL CONFIGURATION ANALYSIS

5.6.1 Analytic Models

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

- Storage of non-channeled assemblies
- Eccentric loadings
  - [[
  -
  -]]
- Bundle Rotation
  - [[
  -]]

All of the above normal configurations were studied for the full loading pattern. In the checkerboard array (Figure 5-5), only the unchanneled and channeled cases were studied, [[

]]. The normal conditions examined for each fuel loading pattern were studied in both dry and flooded conditions, [[ ]] (see Figure 5-3) [[ ]].

[[

]]

Figure 5-5: Checkerboard NFV Loading Pattern

5.6.2 Results- Dry Conditions

The results of the normal configuration studies in dry storage are provided in Table 5-7 for the full loading, and Table 5-8 for the checkerboard loading. This information demonstrates that the removal of the channels from the storage assemblies increases the system reactivity over the nominal, centered, channeled case by a statistically significant amount under normal (dry) conditions. Due to this increased reactivity effect, all eccentric, abnormal and tolerance studies were performed with unchanneled fuel for dry conditions. The case with the highest in-rack reactivity was chosen as the design basis case for each loading pattern. The in-rack k_∞ associated with the unchanneled [[ ]] bundles is hereafter referred to as K_{Normal} for the full loading under dry conditions and the in-rack k_∞ associated with unchanneled assemblies is hereafter referred to as K_{Normal} for the checkerboard loading under dry conditions.

Table 5-7: Normal Configuration In-Rack K_∞ Results- Full Loading, Dry Air

Term	**Configuration**	**In-Rack k_∞**	**Error (1σ)**	**ΔK**
Base	Nominal - Centered, Channeled	0.69291	[[	--
ΔK_{N1}	Non-Channeled Assemblies	**0.70459**		0.01168
ΔK_{N2A}	[[	0.70435		-0.00024
ΔK_{N2B}		0.70381		-0.00078
ΔK_{N2C}		0.70403		-0.00056
ΔK_{N3A}	]]	0.70465		0.00006
ΔK_{N3B}	**Normal-** [[ ]]	**0.70471**	]]	0.00012

Table 5-8: Normal Configuration In-Rack K_∞ Results- Checkerboard Loading, Dry Air

Term	Configuration	In-Rack k_∞	Error (1σ)	ΔK
Base	Nominal - Centered, Channeled, [[ ]]	0.57970	[[	--
ΔK_{N1}	**Non-Channeled Assemblies**	**0.58422**	]]	0.00452

5.6.3 Results- Flooded Conditions

The results of the flooded condition study for the full loading is provided in Table 5-9. This information demonstrates that the channeled fuel is more reactive than unchanneled fuel under flooded conditions. All subsequent eccentric, abnormal and tolerance studies under flooded conditions were performed with channeled fuel. The case with the highest in-rack reactivity was chosen as the design basis case for the full loading flooded configuration. The in-rack k_∞ associated with the channeled [[ ]] is hereafter referred to as K_{Normal} for the flooded full loading configuration.

Table 5-9: Normal Configuration In-Rack K_∞ Results- Full Loading, Flooded

Term	Configuration	In-Rack k_∞	Error (1σ)	ΔK	ΔK Uncertainty (2σ)+
Base	Nominal - Centered, Channeled, [[ ]]	**0.91722**	[[	--	[[
ΔK_{N1}	Non-Channeled Assemblies	0.91240		-0.00482	
ΔK_{N2A}	[[ ]]	0.91641		-0.00081	
ΔK_{N2B}	**Normal-**[[ ]]	**0.92420**		0.00698	
ΔK_{N2C}	[[	0.89595		-0.02127	
ΔK_{N3A}		0.91742		0.00020	
ΔK_{N3B}	]]	0.91733	]]	0.00011	]]

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

+ [[ ]]

5.7 ACCIDENT/ABNORMAL CONFIGURATION ANALYSIS

5.7.1 Analytic Models

The following abnormal configurations of the NFV were considered for credible accident scenarios.

- **Water Flooding**

  The consequences of this would be different for the two unique rack loadings, as specified below:

  - ***Full Loading with SIL-152 Compliance***
    Compliance with SIL-152 obviates the requirement to perform an optimum

moderation study in the new fuel vault. However, flooding of the vault with full density water is still considered a credible scenario. As such, the NFV with a full loading of fuel is analyzed flooded with unborated water. Water densities corresponding to 4 and 20°C were studied. The high temperature flooding of the new fuel vault is considered two abnormal events (flooding of the vault and increased temperature of the flood water), and as such was not analyzed, per the double contingency principle.

- ***Checkerboard Array with Optimum Moderation***
  If a plant is not SIL-152 compliant, it is necessary to consider the system with optimum moderation throughout the vault cavity (i.e. all volumes marked "air" in Figure 5-3). The peak reactivity as a function of water density is identified in this study and reported as a bias in the final statistical roll-up.

The following abnormal configurations are considered bounded or non-credible:

- **Abnormal Assembly Location**

The consequences of this would be different for the two unique rack loadings, as specified below:

- ***Full Loading***
  No location within the rack array or next to rack is available to place additional fuel. Thus, the abnormal assembly location is not credible for the full-loading condition.

- ***Checkerboard Array***
  Per the double contingency principle, it is not considered credible to have two single accident scenarios simultaneously (NFV at optimum moderation and a misplaced fuel assembly). The increase in reactivity introduced by optimum moderation bounds the potential increase in reactivity for the abnormal assembly location scenario. As these scenarios do not have the same initiator, it is not considered credible for both events to occur simultaneously. Therefore, it is only necessary to model the bounding condition (optimum moderation).

- **Dropped Assembly**

Per the double contingency principle, it is not considered credible to have two single accident scenarios simultaneously (NFV at optimum moderation or flooded conditions and a dropped fuel assembly). The increase in reactivity introduced by optimum moderation or flooding bounds the potential increase in reactivity for a dropped fuel assembly scenario. As these scenarios do not have the same initiator, it is not considered credible for both events to occur simultaneously. Therefore, it is only necessary to model the bounding condition (optimum moderation or flooding).

- **Rack Sliding**
  In either fuel loading configuration, the racks are modeled infinitely in the y-direction with no inter-module water gaps. This essentially assumes all racks are close-fitting and bounds possible reactivity effects of rack sliding.

- **Damaged Fuel Assembly**
  The dropped/damaged fuel scenario [[

  ]] Per the double contingency principle, it is not considered credible to have two single accident scenarios simultaneously (NFV at optimum moderation or flooded conditions and a damaged fuel assembly). The increase in reactivity introduced by optimum moderation or flooding bounds the potential increase in reactivity for a damaged fuel assembly scenario. As these scenarios do not have the same initiator, it is not considered credible for both events to occur simultaneously. Therefore, it is only necessary to model the bounding condition (optimum moderation or flooding).

5.7.2 Results

The results of the abnormal studies are provided in Table 5-10 for the full loading and Table 5-11 for the checkerboard array. The ΔK term for the perturbed temperature case in the full loading flooded condition represents the difference in system reactivity from the nominal temperature flooded condition detailed in Section 5.6.3. The ΔK term for the damaged fuel case represents the difference in system reactivity from the normal dry condition, unchanneled, as detailed in Section 5.6.2. The ΔK term for the optimum moderation cases in the checkerboard loading represents the difference in system reactivity from the corresponding (un)channeled case in Section 5.6.2.The total contribution from these independent conditions to the maximum $K_{max(95/95)}$ of each NFV rack loading is found using Equation (5-1). In this equation, a ΔK_{Bi} value must be both positive and the largest for its respective term to be considered.

$$\Delta \mathrm{K}_{\mathrm{Bias}} = \sum_{i=1}^{n} \Delta K_{Bi} \tag{5-1}$$

Table 5-10: Abnormal Configuration In-Rack K∞ Results- Full Loading

Term	Configuration	In-Rack k∞	Error (1σ)	ΔK	ΔK Uncertainty (2σ)+
ΔK_{B1}	Flood - Full Density Water (4°C)	0.92420	[[ ]]	0.00000	[[ ]]
ΔK_{B2}	[[ ]]	[[			
ΔK_{B3}	MCNP Bias				
ΔK_{B4}	Normal Condition Sensitivity Adder				]]
ΔK_{Bias}				[[	]]

+ [[ ]]
++ The positive ΔK uncertainties from Table 5-9 included in the ΔK_{Bias} uncertainty roll-up

Table 5-11: Abnormal Configuration In-Rack K∞ Results- Checkerboard Loading

Term	Configuration	In-Rack k∞	Error (1σ)	ΔK	ΔK Uncertainty (2σ)+
ΔK_{B1A}	Channeled Flood- Optimum Density Water (0.10 g/cc, 20°C) *	0.91049	[[	0.33079	[[
ΔK_{B1B}	Non-Channeled Flood- Optimum Density Water (0.10 g/cc, 20°C)	0.91396	]]	0.32974	]]
ΔK_{B2}	[[ ]]	[[			
ΔK_{B3}	MCNP Bias				]]
ΔK_{Bias}				[[	]]

* For conservatism, only positive values that are the largest for their respective term are considered
+ [[ ]]

Figure 5-6 provides a graph of the optimum moderation results with the checkerboard array loading of non-channeled fuel assemblies. This study demonstrates that the highest reactivity occurs with a water density of 0.10 g/cc.

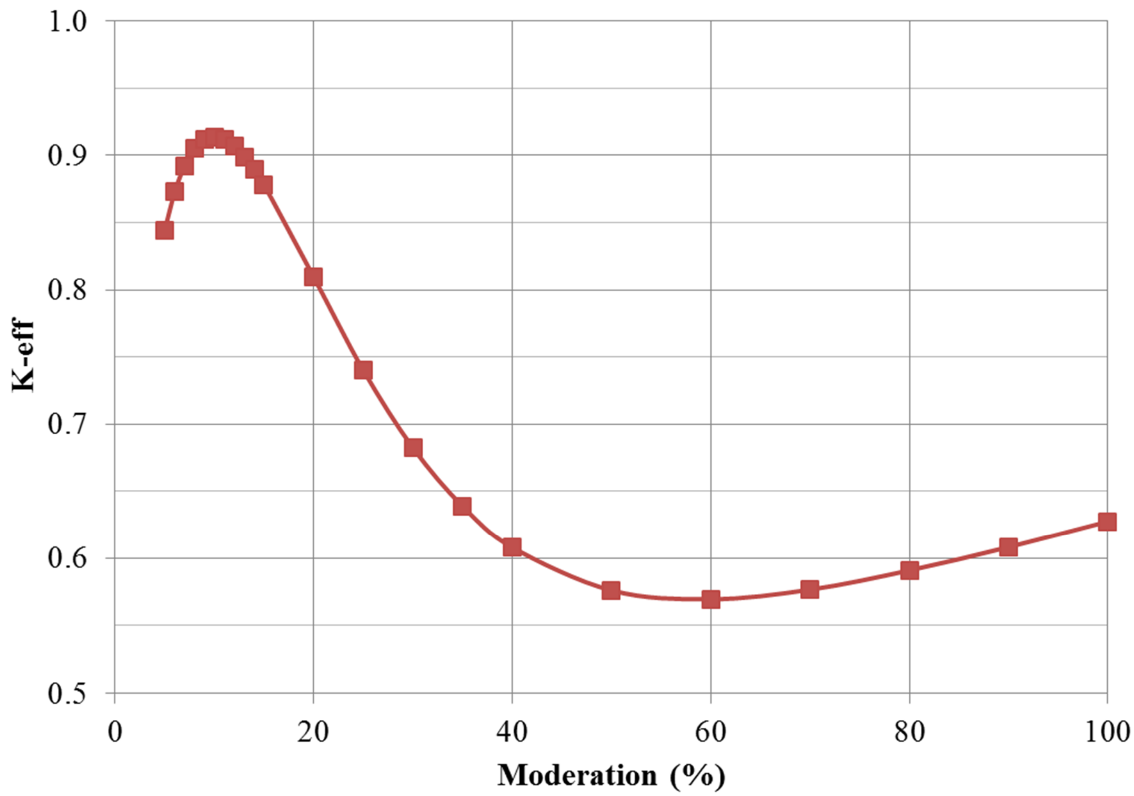

Figure 5-6: Optimum Moderation Results – K_{eff} vs Percent Water Moderation

5.8 TOLERANCE ANALYSIS

5.8.1 Analytic Models

The following tolerance study configurations were explicitly considered for the NFV:

- Fuel enrichment increases by [[ ]] U-235
- Fuel pellet density increased by [[ ]] of nominal value
- Gadolinia wt% decrease from nominal by [[ ]]
- Rod cladding thickness increase by [[ ]]
- Rod cladding thickness decrease by [[ ]]
- Rack wall thickness decrease by [[ ]]
- Rack wall thickness increase by [[ ]]
- Rack pitch decrease by [[ ]]
- Rack pitch increase by [[ ]]
- Inter-rack pitch decrease by [[ ]]

- Inter-rack pitch increase by [[ ]]

The models developed for these studies were all based off the normal configuration presented in Section 5.6 for the full loading configuration (both dry and flooded). As the full loading will maximize the reactivity effects of these changes, the ΔK values will be applied to both the full loading and the checkerboard array based on this study.

5.8.2 Results- Dry Conditions

The results of the tolerance studies are provided in Table 5-12. The ΔK term in this table represents the difference between the system reactivity with the specified tolerance perturbation and the K_{Normal} associated with the full loading of full in dry conditions. The total contribution from these independent tolerances to $K_{max(95/95)}$ of the NFV under dry conditions was found using Equation (5-2). In this equation, a ΔK_{Ti} value must be both positive and the largest for its respective term to be considered.

$$\Delta K_{\text{Tolerance}} = \sqrt{\sum_{i=1}^{n} \Delta K_{Ti}^{2}} \tag{5-2}$$

Table 5-12: Tolerance Study In-Rack K∞ Results- Full Loading, Dry

Term	Configuration	In-Rack k∞	Error (1σ)	ΔK	ΔK Uncertainty (2σ)+
ΔK_{T1}	Fuel Enrichment Increase by [[ ]]	0.70860	[[	0.00389	[[
ΔK_{T2}	Fuel Pellet Density Increase by [[ ]]	0.70620		0.00149	
ΔK_{T3}	Gadolinia wt% Decrease by [[ ]]	0.70517		0.00046	
ΔK_{T4A}	Rod Clad Thickness Increase by [[ ]]	0.70316		-0.00155	
ΔK_{T4B}	Rod Clad Thickness Decrease by [[ ]] *	0.70621		0.00150	
ΔK_{T5A}	In-Rack Pitch Increase	0.70411		-0.00060	
ΔK_{T5B}	In-Rack Pitch Decrease *	0.70498		0.00027	
ΔK_{T6A}	Between-Rack Pitch Increase	0.70402		-0.00069	
ΔK_{T6B}	Between-Rack Pitch Decrease *	0.70518		0.00047	
ΔK_{T7A}	Wall Thickness Increase	0.69747		-0.00724	
ΔK_{T7B}	Wall Thickness Decrease *	0.71207	]]	0.00736	
$\Delta K_{Tolerance}$				0.00862	]]

* For conservatism, only positive values that are the largest for their respective term are considered

+ [[ ]]

5.8.3 Results- Flooded Conditions

The results of the tolerance studies are provided in Table 5-13 for flooded conditions. The ΔK term in this table represents the difference between the system reactivity with the specified tolerance perturbation and K_{Normal} associated with the full loading of fuel in flooded conditions. The total contribution from these independent tolerances to the maximum $K_{max(95/95)}$ of the NFV under flooded conditions was found using Equation (5-2). In this equation, a ΔK_{Ti} value must be both positive and the largest for its respective term to be considered.

Table 5-13: Tolerance Study In-Rack K∞ Results- Full Loading, Flooded

Term	Configuration	In-Rack k∞	Error (1σ)	ΔK	ΔK Uncertainty (2σ)+
ΔK_{T1}	Fuel Enrichment Increase by [[ ]]	0.92795	[[	0.00375	[[
ΔK_{T2}	Fuel Pellet Density Increase by [[ ]]	0.92591		0.00171	
ΔK_{T3}	Gadolinia wt% Decrease by [[ ]]	0.92538		0.00118	
ΔK_{T4A}	Rod Clad Thickness Increase by [[ ]] *	0.92457		0.00037	
ΔK_{T4B}	Rod Clad Thickness Decrease by [[ ]]	0.92384		-0.00036	
ΔK_{T5A}	In-Rack Pitch Increase	0.92172		-0.00248	
ΔK_{T5B}	In-Rack Pitch Decrease *	0.92734		0.00314	
ΔK_{T6A}	Between-Rack Pitch Increase	0.91887		-0.00533	
ΔK_{T6B}	Between-Rack Pitch Decrease *	0.92847		0.00427	
ΔK_{T7A}	Wall Thickness Increase *	0.92517		0.00097	
ΔK_{T7B}	Wall Thickness Decrease	0.92164	]]	-0.00256	
$\Delta K_{Tolerance}$				0.00690	]]

* For conservatism, only positive values that are the largest for their respective term are considered

+ [[ ]]

5.9 UNCERTAINTY VALUES

The total contribution to $K_{max(95/95)}$ of each NFV configuration from the problem and code specific uncertainties was found using Equation (5-3) and the values in Table 5-14 through Table 5-17.

$$\Delta K_{Uncertainty} = \sqrt{\sum_{i=1}^{n} \Delta K_{Ui}^2} \tag{5-3}$$

Table 5-14: Uncertainty ΔK Values- Full Loading, Dry

Term	Description	Value
ΔK_{U1}	Critical Benchmark Uncertainty (95/95) (MCNP)	[[
ΔK_{U2}	TGBLA Eigenvalue Uncertainty (95/95)	
ΔK_{U3}	Uncertainty on K_{Normal} (2σ)	
ΔK_{U4}	Uncertainty of ΔK_{Bias} Contributors (2σ)	
ΔK_{U5}	Uncertainty of $\Delta K_{Tolerance}$ Contributors (2σ)	
	$\Delta K_{Uncertainty}$	]]

Table 5-15: Uncertainty ΔK Values- Full Loading, Flooded

Term	Description	Value
ΔK_{U1}	Critical Benchmark Uncertainty (95/95) (MCNP)	[[
ΔK_{U2}	TGBLA Eigenvalue Uncertainty (95/95)	
ΔK_{U3}	Uncertainty on K_{Normal} (2σ)	
ΔK_{U4}	Uncertainty of ΔK_{Bias} Contributors (2σ)	
ΔK_{U5}	Uncertainty of $\Delta K_{Tolerance}$ Contributors (2σ)	
	$\Delta K_{Uncertainty}$	]]

Table 5-16: Uncertainty ΔK Values- Checkerboard Loading, Dry

Term	Description	Value
ΔK_{U1}	Critical Benchmark Uncertainty (95/95) (MCNP)	[[
ΔK_{U2}	TGBLA Eigenvalue Uncertainty (95/95)	
ΔK_{U3}	Uncertainty on K_{Normal} (2σ)	
ΔK_{U4}	Uncertainty of ΔK_{Bias} Contributors (2σ)	
ΔK_{U5}	Uncertainty of $\Delta K_{Tolerance}$ Contributors (2σ)	
	$\Delta K_{Uncertainty}$	]]

Table 5-17: Uncertainty ΔK Values- Checkerboard Loading, Flooded

Term	Description	Value
ΔK_{U1}	Critical Benchmark Uncertainty (95/95) (MCNP)	[[
ΔK_{U2}	TGBLA Eigenvalue Uncertainty (95/95)	
ΔK_{U3}	Uncertainty on K_{Normal} (2σ)	
ΔK_{U4}	Uncertainty of ΔK_{Bias} Contributors (2σ)	
ΔK_{U5}	Uncertainty of $\Delta K_{Tolerance}$ Contributors (2σ)	
	$\Delta K_{Uncertainty}$	]]

5.10 MAXIMUM REACTIVITY

The $K_{max(95/95)}$ considering all biases, tolerances, and uncertainties, was calculated using Equation (5-4). The final values are presented in Table 5-18 through Table 5-21.

$$K_{\max(95/95)} = K_{Normal} + \Delta K_{Bias} + \Delta K_{Tolerance} + \Delta K_{Uncertainty} \tag{5-4}$$

Table 5-18: NFV Rack Results Summary- Full Loading, Dry

Term	Value
K_{Normal}	0.70471
ΔK_{Bias}	[[ ]]
$\Delta K_{Tolerance}$	0.00862
$\Delta K_{Uncertainty}$	[[ ]]
$K_{max(95/95)}$	0.72116

Table 5-19: NFV Rack Results Summary- Full Loading, Flooded

Term	Value
K_{Normal}	0.92420
ΔK_{Bias}	[[ ]]
$\Delta K_{Tolerance}$	0.00690
$\Delta K_{Uncertainty}$	[[ ]]
$K_{max(95/95)}$	0.93919

Table 5-20: NFV Rack Results Summary- Checkerboard Loading, Dry

Term	Value
K_{Normal}	0.58422
ΔK_{Bias}	[[ ]]
$\Delta K_{Tolerance}$	0.00862
$\Delta K_{Uncertainty}$	[[ ]]
$K_{max(95/95)}$	0.60068

Table 5-21: NFV Rack Results Summary- Checkerboard Loading, Optimum Moderation

Term	Value
K_{Normal}	0.58422
ΔK_{Bias}	[[ ]]
$\Delta K_{Tolerance}$	0.00862
$\Delta K_{Uncertainty}$	[[ ]]
$K_{max(95/95)}$	0.93152

6.0 CONCLUSIONS

The GE Low Density Fuel Storage racks have been analyzed for the storage of GNF3 fuel in the new fuel vault using the MCNP-05P Monte Carlo neutron transport program and the k_∞ criterion methodology. A maximum cold, uncontrolled in-core eigenvalue (k_∞) of 1.31 as defined by TGBLA06 is specified as the rack design limit for GNF3 fuel stored in the new fuel vault. Full loading of fuel (assuming SIL-152 compliance) and a checkerboard array loading of fuel with consideration given to optimum moderation have been analyzed. All analyses resulted in a storage rack maximum k-effective ($K_{max(95/95)}$) less than 0.90 for dry storage conditions, and less than 0.95 for credible abnormal operation with tolerances and uncertainties taken into account. Furthermore, for cases where optimum moderation is a credible event for the storage of fresh fuel (i.e. non-compliant with SIL 152), the analyses resulted in a $K_{max(95/95)}$ less than 0.98.

If a plant is not SIL-152 compliant, a checkerboard array must be employed where only one out of every three storage locations in either linear direction contains a fuel bundle.

7.0 REFERENCES

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Appendix A - MCNP-05P Code Validation

Table A-1 presents the results of the [[ ]] benchmark calculations. 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).

$$k_{norm} = k_{calc}/k_{exp} \tag{A-1}$$

$$\sigma_t = \sqrt{\sigma_{calc}^2 + \sigma_{exp}^2} \tag{A-2}$$

Table A-1: MCNP-05P Benchmark Calculation Results

#	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)

#	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)
								]]

To determine if any trend is evident in this pool of experiments, the parameters listed in Table A-2 were considered as independent variables.

Table A-2: Trending Parameters

Energy of the Average Lethargy causing Fission (EALF)
Uranium Enrichment (wt% U-235)
Plutonium Content (wt% Pu239)
Atom of ratio of hydrogen to fissile material (H/X)

To 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_{norm}) and x is any of the predictor variables from Table A-2. Unweighted k_{norm} values were used in this evaluation, though it is noted that, due to the very similar σ values reported in Table A-1, using weighted values would produce very similar results. This regression was performed using the built-in regression analysis tool in Excel. A useful tool to validate data correlation 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 A-3.

A second method to test for goodness of fit is the chi squared test (χ^2). This method is explained in detail in Reference (8). 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.

$$\chi^2 = \sum_{1}^{N} \left(\frac{k_{calc,i} - f(x_i)}{\sigma_{calc^i}} \right)^2 \tag{A-3}$$

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.

$$\tilde{\chi}^2 = \chi^2 / d \tag{A-4}$$

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 A-3.

Table A-3: 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 A-3 clearly demonstrate that there are no statistically significant or valid trends of k_{norm} with any of the trending parameters.

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 AOA 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. A graphical image of the results for this normality test, including the p-value for the distribution, is provided in Figure A-1. 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.

[[ ]]

Figure A-1: Normality Test of k_{norm} Results

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

$$Bias = \bar{k}_{norm} - 1 \tag{A-5}$$

$$\bar{k}_{norm} = \frac{\sum_{i=1}^{n} \frac{k_{norm_i}}{\sigma_t^2}}{\sum_{i=1}^{n} \frac{1}{\sigma_t^2}} \tag{A-6}$$

$$Bias\ Uncertainty = U \cdot S_p \tag{A-7}$$

$$S_P = \sqrt{s^2 + \bar{\sigma}^2} \tag{A-8}$$

$$\bar{\sigma}^2 = \frac{n}{\sum_{i=1}^{n} \frac{1}{\sigma_t^2}} \tag{A-9}$$

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

Where:

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

S_P = Pooled standard deviation

s^2 = Variance about the mean

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

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

n = number of data points [[ ]]

Table A-4 summarizes the results of these calculations.

A validation of MCNP-05P using ENDF/B-VII.0 nuclear cross section data has been performed according to the general methodology described in NUREG/CR-6698 "Guide for Validation of Nuclear Criticality Safety Calculational Methodology" for BWR fuel lattices both in and out of fuel storage racks (7). As seen in Table A-4, [[

]]. The recommended bias and bias uncertainty for use with evaluations within the prescribed AOA provided in Table 3-2 are summarized in Table A-5.

Table A-4: Bias and Bias Uncertainty for MCNP-05P with ENDF/B-VII

Bias (weighted)	[[
Bias Uncertainty(95/95 level)	
Variance About the Mean	
Average Total variance	
Pooled Standard Deviation (1σ)	
One-Sided Tolerance Factor	]]

.

Table A-5: Recommended Bias and Bias Uncertainty

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

ATTACHMENT 3
RS-22-108

Global Nuclear Fuels – Americas, LLC 10 CFR 2.390 Affidavit for Attachment 4

Global Nuclear Fuel – Americas, LLC

AFFIDAVIT

I, Kent Halac, state as follows:

(1) I am the Senior Engineer, 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 the letter from P. R. Simpson (Constellation Energy Generation, LLC) to the Nuclear Regulatory Commission, RS-22-108, "Response to Request for Additional Information RE: LaSalle County Station, Units 1 and 2 and Quad Cities Nuclear Power Station, Units 1 and 2 License Amendments Related to Fuel Storage," dated October 5, 2022. GNF-A proprietary information in RS-22-108 is identified by a dotted underline inside double square brackets. [[This sentence is an example {3}]]. GNF-A proprietary information in figures and large objects is identified by double square brackets before and after the object. In each case, 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 it is the owner or licensee, GNF-A relies upon the exemption from disclosure set forth in the *Freedom of Information Act* ("FOIA"), 5 U.S.C. §552(b)(4), and the *Trade Secrets Act*, 18 U.S.C. §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 F.2d 871 (D.C. Cir. 1992), and Public Citizen Health Research Group v. FDA, 704 F.2d 1280 (D.C. Cir. 1983).

(4) The information sought to be withheld is considered to be proprietary for the reasons set forth in paragraphs (4)a and (4)b. 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 a license from GNF-A constitutes a competitive economic advantage over other companies;

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

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

d. Information that discloses trade secret or potentially patentable subject matter for which it may be desirable to obtain patent protection.

(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 information sought to be withheld has, to the best of my knowledge and belief, consistently been held in confidence by GNF-A, not been disclosed publicly, and not been made 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 for proprietary or confidentiality agreements or both that provide for maintaining the information in confidence. 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).

(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.

(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) is classified as proprietary because it contains the detailed GNF-A methodology for fuel analyses for the GNF-A Boiling Water Reactor (BWR). These methods, techniques, and data along with their application to the design, modification, and analyses associated with the fuel analyses were achieved at a significant cost to GNF-A.

The development of the evaluation processes along with the interpretation and application of the analytical results is derived from the extensive experience databases that constitute 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 there 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 is true and correct.

Executed on this 5th day of October 2022.

Kent Halac
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