ENCLOSURE 2

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NEDO-33173 Supplement 5 – GNF3 Supplement

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GE Hitachi Nuclear Energy

NEDO-33173 Supplement 5
Revision 0
June 2017

Non-Proprietary Information – Class I (Public)

Licensing Topical Report

Applicability of GE Methods to Expanded Operating Domains - Supplement for GNF3 Fuel

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The design, engineering, and other information contained in this document is furnished for the purpose of obtaining Nuclear Regulatory Commission (NRC) approval of the Applicability of GE Methods to Expanded Operating Domains - Supplement for GNF3 Fuel. The only undertakings of GEH with respect to information in this document are contained in the contracts between GEH and its customers or participating utilities, and nothing contained in this document will be construed as changing that contract. The use of this information by anyone for any purpose other than that for which it is intended is not authorized; and with respect to any unauthorized use, GEH makes no representation or warranty, and assumes no liability as to the completeness, accuracy, or usefulness of the information contained in this document.

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REVISION SUMMARY

Revision Number	Description of Change
0	Initial Issue

EXECUTIVE SUMMARY

NEDC-33173P, *Applicability of GE Methods to Expanded Operating Domains* (Methods Licensing Topical Report (LTR)) (Reference 1), documents the adequacy of the GEH analytical methods at expanded operating domains (e.g., Extended Power Uprate (EPU) and Maximum Extended Load Line Limit Analysis Plus (MELLLA+)). The NRC originally approved the Methods LTR as documented in its Safety Evaluation (SE) dated July 21, 2009 (Reference 2). NEDC-33173P, Section 4.2, "Applicability" states, in part, that the Methods LTR is applicable to current General Electric (GE) Boiling Water Reactor (BWR) fuel designs (i.e., GE14 and earlier). The NRC SE states in Section 8.2 and Limitation and Condition 9.22 that the NRC's review of the Methods LTR is limited to the current GE Hitachi Nuclear Energy (GEH) fuel designs (i.e., GE14 and earlier). This limitation was subsequently revised based on the approval of NEDC-33173P Supplement 3 to also cover the GNF2 fuel design (Reference 3).

Global Nuclear Fuel (GNF) has developed a new fuel design, GNF3, which is described in GNF report NEDC-33879P, Revision 0, March 2017, "GNF3 Generic Compliance with NEDE-24011-P-A (GESTAR II)," (Reference 4). The purpose of this supplement is to document the adequacy of the GEH analytical methods relative to GNF3 fuel when used for expanded operating domains. The GNF3 fuel product is based primarily on the proven GNF2 10x10 design. The major, relevant new features implemented in GNF3 are [[

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The evaluations presented in Sections 2 and 3 demonstrate the adequacy of the GEH methods for GNF3 when used in the expanded operating domains. Further, the assessment in Appendix A documents the applicability of the existing limitations in the NRC SE for the Methods LTR (Reference 2) for GNF3 fuel.

The outline and format of the report is identical to the original document NEDC-33173P (Reference 1), in which the methods uncertainty effect on the key core safety parameters is evaluated. This consistent format is chosen to facilitate the clarity and completeness of the supporting information. This supplement does not depend on other supplements to NEDC-33173P. Other supplements to NEDC-33173P will support GNF3 fuel, as necessary.

ACRONYMS AND ABBREVIATIONS

Term	Definition
2D	Two-Dimensional
3D	Three-Dimensional
AOO	Anticipated Operational Occurrence
APRM	Average Power Range Monitor
APS	Axial Power Shape
[[	
	]]
BOC	Beginning of Cycle
BT	Boiling Transition
BWR	Boiling Water Reactor
COLR	Core Operating Limits Report
CPPU	Constant Pressure Power Uprate
CPR	Critical Power Ratio
ΔCPR	Delta Critical Power Ratio
DSS-CD	Detect and Suppression Solution – Confirmation Density
ECCS	Emergency Core Cooling System
ECPR	Ratio of Calculated to Measured Critical Power
ELLLA	Extended Load Line Limit Analysis
EOC	End of Cycle
EOL	End-of-Life
EPU	Extended Power Uprate
FLR	Full Length Rod
FSAR	Final Safety Analysis Report
GC	Gd_2O_3 Concentration, percent by weight
GE	General Electric
GEH	GE Hitachi Nuclear Energy
GESTAR	General Electric Standard Application for Reactor Fuel
GEXL	GE Boiling Transition Correlation
GNF	Global Nuclear Fuel

Term	Definition
GSF	Geometric Stacking Factor
LHGR	Linear Heat Generation Rate
LOCA	Loss-of-Coolant Accident
LPLR	Long Part Length Rod
LPRM	Local Power Range Monitor
LTR	Licensing Topical Report
MAPLHGR	Maximum Average Planar Linear Heat Generation Rate
MCPR	Minimum Critical Power Ratio
MELLLA	Maximum Extended Load Line Limit Analysis
MELLLA+	Maximum Extended Load Line Limit Analysis Plus
MFLCPR	Ratio of Bundle Critical Power to OLMCPR
MIP	MCPR Importance Parameter
MOC	Middle of Cycle
MOP	Mechanical Overpower
NRC	Nuclear Regulatory Commission
OLMCPR	Operating Limit Minimum Critical Power Ratio
OLTP	Original Licensed Thermal Power
OPRM	Oscillation Power Range Monitor
[[	
	]]
PCT	Peak Cladding Temperature
PD	Pellet Density
PLR	Part Length Rod
RAI	Request for Additional Information
RMS	Root Mean Square
SAFDL	Specified Acceptable Fuel Design Limit
SDM	Shutdown Margin
SE	Safety Evaluation
SLMCPR	Safety Limit Minimum Critical Power Ratio

Term	Definition
SPLR	Short Part Length Rod
SRLR	Supplemental Reload Licensing Report
TIP	Traversing In-Core Probes
T-M	Thermal-Mechanical
TOP	Thermal Overpower
TS	Technical Specification

1.0 INTRODUCTION

1.1 BACKGROUND

NEDC-33173P, *Applicability of GE Methods to Expanded Operating Domains* (Methods LTR) (Reference 1), documents the adequacy of the GEH analytical methods at expanded operating domains (e.g., EPU and MELLLA+). The NRC originally approved the Methods LTR as documented in its SE dated July 21, 2009 (Reference 2). NEDC-33173P, Section 4.2, "Applicability" states, in part, that the Methods LTR is applicable to current GE BWR fuel designs (i.e., GE14 and earlier). The NRC SE states in Section 8.2 and Limitation and Condition 9.22 that the NRC's review of the Methods LTR is limited to the current GEH fuel designs (i.e., GE14 and earlier). This limitation was subsequently revised based on the approval of NEDC-33173P Supplement 3 to also cover the GNF2 fuel design (Reference 3).

GNF has developed a new fuel design, GNF3, which is described in GNF report NEDC-33879P, Revision 0, March 2017, "GNF3 Generic Compliance with NEDE-24011-P-A (GESTAR II)," (Reference 4). Reference 4 provides a description of the GNF3 design and analyses that demonstrate GNF3 meets the requirements specified in GESTAR II.

GNF2 and GNF3 design parameters are compared in Reference 4 and summarized in Table 1-1. The major differences between GNF2 and GNF3 are:

- [[

]]

1.2 PURPOSE

The purpose of NEDC-33173P Supplement 5 is to document the adequacy of GEH analytical methods for GNF3 fuel when used in expanded operating domains (e.g., EPU and MELLLA+). This supplement is limited to the application of GEH analytical methods as documented in NEDC-33173P and not to the GNF3 fuel design itself, which meets the GESTAR II requirements for introduction of the fuel product (Reference 4). The applicability of NEDC-33173P to GNF3 fuel is supported by the following technical evaluations:

- TGBLA06 required no modifications to model GNF3 beyond those implemented for GNF2. The code has been compared to MCNP based Monte Carlo results and exhibits similar pin power, criticality, and void coefficient biases as established for previous 9x9 and 10x10 lattice designs. These comparisons support the continued use of current Methods LTR biases for pin power and void coefficient for GNF3 applications.

- PANAC11 required no modifications to model GNF3. The code has been compared to MCNP based Monte Carlo results and exhibits similar radial power distribution, cold critical eigenvalue, and rod worth predictive capability as established for previous 10x10 lattice designs. These comparisons support the continued use of the current Methods LTR for [[ ]] and shut down margin uncertainties for GNF3.
- The accuracy of the ISCOR and TASC thermal-hydraulic models, which are relevant to methods based analyses and embedded in GEH thermal-hydraulic steady-state and transient models, is supported by full-scale critical power and pressure drop tests. The correlation uncertainties are incorporated into Safety Limit Minimum Critical Power Ratio (SLMCPR) evaluations in accordance with NRC-approved procedures. (Reference 5)

1.3 ANALYSIS PROCESS

The approach used to confirm the applicability of GEH Methods to the GNF3 fuel design follows the same process used in the original Methods LTR (Reference 1).

The subsequent sections of this supplement to the Methods LTR provide a review of GEH methodologies, uncertainties, and biases for acceptability to GNF3 applications for expanded operating domains (e.g., Constant Pressure Power Uprate (CPPU), EPU, and MELLLA+). This format and outline is identical to the original Methods LTR (Reference 1). The effect of uncertainty parameters of interest is identified and their applicability to GNF3 analysis is evaluated. The adequacy of the existing margin and, as applicable, augmented margin for each of these safety parameters is provided.

The GEH nuclear methods are based on three levels of detail, as indicated below:

- **The Individual Fuel Rod:** Individual fuel rod analysis concerns heat transfer, stress conditions, and fission gas buildup in an individual fuel rod. The GNF3 fuel pellets are the same as the GNF2 fuel pellets, and the GNF3 fuel rods are nearly identical to the GNF2 fuel rods. [[

  ]] The current design basis for GNF3 fuel included in Reference 4 is based on the PRIME methodology (Reference 6).

- **The Bundle Lattice:** The major new features of the GNF3 design are accounted for at the bundle lattice level in two main categories: nuclear and thermal-hydraulic. From a nuclear perspective, each Two-Dimensional (2D) lattice explicitly evaluated by TGBLA accounts for the [[ ]] diameter, channel thickness/design, and fuel rod inventory that are integral to the bundle design. No changes to TGBLA were required to model the new features of GNF3 beyond those implemented for GNF2. The output of the TGBLA code is transferred to the core-wide simulation programs in the form of lattice average nuclear parameters and pin power peaking factors. From the thermal-hydraulic perspective, changes related to both the spacer design and the fuel rod arrangement affect bundle pressure drop and critical power performance. Both pressure drop and critical power performance have been measured at the Stern Laboratory full-scale thermal-hydraulic test facility and correlated with NRC-approved correlations. The thermal-hydraulic output consists of pressure drop and critical power correlations based on the above-mentioned Stern Laboratory tests.

- **Core Wide Models:** The core wide models use the lattice average nuclear parameters, critical power correlation, pressure drop correlation, and limits established by the fuel rod performance models to construct a Three-Dimensional (3D) power distribution and establish margin to limits. The steady-state core simulator model (PANACEA), transient models (ODYN and TRACG), and stability model (ODYSY) all use lattice average outputs from TGBLA and thermal-hydraulic correlations. The overall uncertainties assigned to the steady-state core-wide models, the transient models, and stability models are dominated by the uncertainties in the detailed lattice and fuel rod models.

The justification for using GEH analytical methods in GNF3 applications at expanded operating domains focuses on the physics and thermal-hydraulic effect of the GNF3 design changes reflected in the lattice model TGBLA and the thermal-hydraulic correlations.

Section 2 focuses on the evaluation of the effect of the TGBLA and thermal-hydraulic uncertainties in the determination of safety parameters for CPPU and EPU applications. Section 3 extends the Section 2 basis to the MELLLA+ operating domain. The analysis presented in Sections 2 and 3 of this document confirm that the fuel design limits and associated methods for GNF3 analysis are identical to Table 1-1 of Reference 1, as modified by the conclusions of Supplement 4 (Reference 7). The conclusions regarding the applicability of the revised limits and methods table appears below as Table 1-2. Appendix A provides an assessment of the limitations in the NRC SE (Reference 2) relative to GNF3 fuel.

Table 1-1 GNF2 and GNF3 Parameters

Fuel Assembly	**GNF2**	**GNF3**
Total Number of Fuel Rods	92	[[
Full Length	78	
Partial Length	14 total, Two Lengths	
LPLR	8	
SPLR	6	]]
Lattice Array	See Figure 2-2 of Reference 8	See Figure 2-2 of Reference 4
Rod to Rod Pitch (cm)	[[	]]
Number of Water Rods	2	[[ ]]
Typical Assembly Weight (kgU)	[[	
Typical Full Length Rod (mm)		
LPLR (mm)		
SPLR (mm)		]]
Fuel Rod		
Cladding Material	[[	
Typical Assembly Active Fuel Length (mm)		
LPLR Active Fuel Length (mm)		
SPLR Active Fuel Length (mm)		
Cladding Tube Diameter, Outer (cm)		
Cladding Tube Wall Thickness (cm)		
Pellet Diameter, Outer (mm)		
Typical Fuel Pellet Density (PD)		
Fuel Column Geometric Stacking Factor (GSF)		
Helium Backfill Pressure		
Fuel Column Stack Density[1] (g/cc)		]]
Water Rod		
Cladding Material	[[	
Cladding Diameter, Outer (cm)		
Cladding Wall Thickness (cm)		]]
Spacer		
Number of Spacers	8	[[ ]]
Axial Locations	See Figure 2-5 of Reference 8	See Figure 2-9 of Reference 4
Material	Alloy X-750	Same

[1] Gd_2O_3 Concentration, percent by weight (GC)

Table 1-2 Fuel Design Limits and Associated Methods

Limit	Primary Technology	Description	Evaluation Frequency and Notes
SLMCPR	SLMCPR, PANACEA	The SLMCPR is a Minimum Critical Power Ratio (MCPR) value at which 99.9% of the fuel rods in the core are expected to avoid Boiling Transition (BT). This value considers the core power distribution and uncertainties.	The limit is evaluated on a plant/cycle specific basis (i.e., each core design).
OLMCPR	ODYN, TRACG, PANACEA	The Operating Limit Minimum Critical Power Ratio (OLMCPR) is additional margin above the SLMCPR to account for the MCPR change due to Anticipated Operational Occurrences (AOOs). Adherence to the limit assures that in the event of an AOO, 99.9% of the fuel rods are expected to avoid BT.	The limit is evaluated on a plant/cycle specific basis. The Final Safety Analysis Report (FSAR) transients that are limiting or potentially limiting with respect to pressure and fuel thermal limits are analyzed for each reload. Transients are confirmed to be within the Linear Heat Generation Rate (LHGR) basis.
SDM	PANACEA	Shutdown Margin (SDM) is maintained regardless of the core design (the value of the limit does not vary with core characteristics like SLMCPR or OLMCPR). The SDM requirement assures that the reactor can be brought and held subcritical with the control system alone. Most BWRs have a Technical Specification (TS) value of 0.38%. The “working definition” of SDM is the quantity of reactivity needed to reach criticality in a xenon free core with the strongest worth control rod fully withdrawn and all other control rods inserted.	Each core is designed to conform to this limit. SDM margin is demonstrated on a plant/cycle specific basis.
LHGR	PRIME	LHGR operating limits represent an envelope of acceptable LHGRs, as a function of exposure, designed to maintain fuel integrity during normal operation, including AOOs. The LHGR limits reflect the application of Specified Acceptable Fuel Design Limits (SAFDLs) on the following fuel performance parameters: • Fuel temperature • Cladding stress • Cladding strain • Cladding fatigue usage • Fuel rod internal pressure • Cladding creep	LHGR operating limits are developed generically for each fuel product line (e.g., GNF3). They are determined from T-M considerations and independent of any particular core design. The current LHGR operating limits for GNF3 fuel included in Reference 4 are based on the PRIME methodology.
MAPLHGR	SAFER	Maximum Average Planar Linear Heat Generation Rate (MAPLHGR) is an average planar LHGR limit that is a product of the plant Emergency Core Cooling System (ECCS) – Loss-of-Coolant Accident (LOCA) evaluation performed to demonstrate compliance with 10 CFR 50.46 acceptance criteria.	ECCS-LOCA evaluations are performed as plant specific, cycle independent analyses. These analyses are typically performed for each initial introduction of new fuel product lines. The analysis output is a licensing basis Peak Cladding Temperature (PCT) and a set of parameters that are confirmed every cycle to ensure applicability of the analysis.
Stability	ODYSY TRACG	There are several accepted stability solutions, each designed to protect the SLMCPR. The solutions include prevention and detect and suppress strategies, as well as combinations of both elements.	The stability methodologies are applied and/or confirmed for every reload (every cycle).
Exposure	PRIME	The licensed exposure limit is a result of the LHGR evaluation methodology discussed above.	The exposure limit is developed generically for each fuel product line from T-M considerations. It is independent of the core design. The current LHGR operating limits for GNF3 fuel included in Reference 4 are based on the PRIME methodology.

2.0 SAFETY PARAMETERS INFLUENCED BY UNCERTAINTIES

2.1 INTRODUCTION

Section 2 of Reference 1 listed the safety parameters influenced by nuclear, thermal-hydraulic, and T-M methods uncertainties and biases. These safety parameters are unchanged for the GNF3 fuel design.

The analysis presented in Section 2 of Reference 1 showed that the allowances for methods uncertainties are adequate to ensure that the fuel design limits are met for fuel designs up to and including GE14 for power uprate conditions. The uncertainties were justified as adequate for GNF2 in Reference 3. The analysis presented in this section extends this conclusion to the GNF3 fuel design.

2.2 CRITICAL POWER

The components of the critical power (SLMCPR and OLMCPR) are unchanged for GNF3 fuel design.

2.2.1 Safety Limit Critical Power Ratio

The methods and uncertainties used to evaluate the SLMCPR have been validated in Reference 1 by considering pin and bundle power combined with critical power, void fraction, and pressure drop correlations. These topics are covered below, with emphasis on GNF3 results.

2.2.1.1 Fuel Parameters That Affect SLMCPR

Table 2-1 and Table 2-2 of Reference 1 contain a summary of the uncertainties relevant to the evaluation the SLMCPR. These parameters are unchanged for GNF3.

2.2.1.2 Treatment of Fuel Parameter Uncertainties

The bundle power is a combination of [[ ]] Uncertainties in local pin power peaking, [[ ]] are explicitly included in the SLMCPR determination and considered separately, then cumulatively in Section 2.2.1.2 of Reference 1. The extension of these uncertainties to the GNF3 design is discussed below.

Pin Power Peaking

A key method related uncertainty is the local (pin) peaking factor uncertainty. This value is primarily associated with the lattice code TGBLA (Reference 9). The 1σ uncertainty was evaluated to be [[ ]] in NEDE-32601P-A (Reference 5), based on comparisons with MCNP Monte Carlo evaluations. The overall pin peaking uncertainty, including operational, flux gradient, and manufacturing effects was confirmed by comparison to pin gamma scan measurements performed in an 8x8 lead use assembly. The data presented in NEDE-32601P and in the Request for Additional Information (RAI) responses were for the most part based on GE14 and earlier fuel designs. TGBLA06-MCNP (Reference 10) comparisons carried out on other vendor's fuel designs show results consistent with those obtained with the GE designs. The results in NEDE-32601P-A show the overall TGBLA06 pin power accuracy to be similar for the non-GE designs and the GE 9x9 and 10x10 designs. These pin power accuracies were further confirmed for modern 10x10 fuel designs in Reference 11.

No changes to TGBLA were required to model the new features of GNF3 beyond those implemented for GNF2.

Figure 2-1 and Figure 2-2 demonstrate the applicability of TGBLA06 to GNF3 using direct comparison to MCNP for uncontrolled cases at 0 and 65 GWd/STU lattice exposure. The Root Mean Square (RMS) deviation between TGBLA06 and MCNP fission density distribution is plotted against the lattice averaged moderator density. [[

]]

In addition to the GNF3 results, the difference range for GE14 and GNF2 lattices are provided as a reference. For the GE14 and GNF2 values the TGBLA/ MCNP RMS differences are computed for each lattice and for each moderator density. For each density, the differences are averaged and the standard deviation is evaluated. The dashed lines in the graph represent the average GE14 or GNF2 differences with the standard deviations added and subtracted.

The consistency of the GNF3 TGBLA06 to MCNP comparisons with previous designs justifies the use of GE14/GNF2 pin power uncertainties for GNF3 R-factor and LHGR evaluations.

Bundle Power [[ ]]

As described in NEDC-33173P-A, bundle power uncertainties that affect the SLMCPR and have a potential fuel product line dependence fall into two categories: [[

]] An uncertainty of [[ ]] has previously been approved in Reference 12. These values were demonstrated as applicable at expanded operating domains for GE14 in Reference 1 and for GNF2 in Reference 3. The [[ ]] uncertainties were historically determined using TIP radial RMS and bundle gamma scan comparisons, which both are dependent upon the ability of the lattice physics/core simulator package to accurately predict infinite lattice reactivities, and subsequently power distributions, in the core. The continued applicability of these uncertainties to GNF3 is assessed using three techniques, which are listed below and expanded upon in the sections that follow:

1) TIP Comparisons

2) TGBLA to MCNP Infinite Lattice Reactivity Comparisons
3) PANAC11 to MCNP Power Distribution Comparisons

The consistency of the GNF3 PANAC11 to MCNP comparisons with previous designs justifies the use of GE14/GNF2 [[ ]] uncertainties for GNF3 SLMCPR evaluations.

TIP Comparisons

GNF3 lead use assemblies have been operating in a BWR/5 and a BWR/6 for one cycle. TIP comparisons of calculated versus predicted powers for instrument strings adjacent to the lead use assemblies demonstrate no unusual or adverse trends at any point in the cycles which would be indicative of a method issue for the new fuel type.

TGBLA to MCNP Infinite Lattice Reactivity Comparisons

Bundle power related uncertainties for a new fuel design are sensitive to changes in the reactivity of each lattice as a function of moderator density and fuel exposure. Reference 1 contains a significant amount of data comparing TGBLA06 and MCNP (Reference 10) reactivity responses to a variety of moderator densities and exposures. Similar comparisons of the TGBLA06 reactivity response relative to a more modern version of MCNP (Reference 13) have been performed for GNF3.

[[

]] In addition to the GNF3 results, the difference range for GE14 and GNF2 lattices are provided as a reference. These reference values are expressed as the average ± the standard deviation of the differences of the variable under consideration for the given reference fuel product (e.g., the red dotted lines in Figure 2-3 represent the average ± 1 standard deviation of the reactivity differences between TGBLA and MCNP at Beginning of Cycle (BOC)).

Results of these comparisons are shown in Figure 2-3 through Figure 2-5. Figure 2-3 shows the reactivity differences between TGBLA06 and MCNP for uncontrolled cases at 0 GWd/STU for several relative moderator densities, including for 90% in-channel void extrapolated conditions. Figure 2-4 shows the corresponding differences at 65 GWd/STU. Figure 2-5 shows the differences for controlled cases at 0 GWd/STU.

It is notable that, in Figure 2-4, [[

]]

The TGBLA06 infinite lattice reactivity calculation performance for GNF3 fuel is consistent with the corresponding GNF2 (red dotted line) and GE14 (black dotted line) performance.

PANAC11 to MCNP Power Distribution Comparisons

While consistent TGBLA infinite lattice reactivity calculation performance for GNF3 compared to GE14/GNF2 provides good confidence that PANAC11 power prediction fidelity will be consistent across these fuel product lines, an additional study was performed to further demonstrate power distribution assessment capability at the core analysis level.

To perform this additional confirmation, a PANAC11 core region was compared directly to a 3D core modeled in MCNP. [[

]] The benchmark cores developed for use in this study represent exposed, hot, voided conditions from PANAC11 defined equilibrium cycles.

Power distributions can then be calculated [[

]].

These evaluations were performed for GE14, GNF2, and GNF3 equilibrium cycles at BOC, Middle of Cycle (MOC), and End of Cycle (EOC) statepoints for [[
]]. The intent of these comparisons is to determine if there is any degradation in power distribution prediction capability for fuel and cycle designs defined by GNF3 features versus the previously approved and operated fuel products (GE14 and GNF2).

Comparisons are performed by taking an RMS difference between the integrated bundle powers as calculated by PANAC11 and MCNP. Because this power comparison is performed on a bundle specific basis instead of through a combination of TIP comparisons and bundle gamma scans, [[
]]. Results are provided as a function of cycle exposure for all three fuel product lines in Figure 2-6.

These results indicate consistent bundle power distribution prediction performance in PANAC11 for GE14, GNF2, and GNF3.

Thermal-Hydraulic Methods

The axially varying features of GNF3, such as multiple Part Length Rod (PLR) heights, [[ ]] can be readily handled by the steady-state and transient analysis programs because model parameters can be [[ ]] in the lattice at different axial locations. The single bundle thermal-hydraulic code, ISCOR09, employs both the void correlation and pressure drop correlation combined with the mass and energy solution to the heat transfer equations. The ISCOR09 methods are embedded in the PANACEA steady-state 3D simulator and the stability analysis tools.

Void Correlation

The GEH (Findlay-Dix) void correlation has been shown to be applicable for existing GNF BWR fuel designs, including 10x10 lattices with PLRs (Reference 1). The new features of the GNF3 design include [[ ]]. Qualification of GNF3 has been evaluated with full-scale experimental pressure drop data (Reference 4). Correct prediction of the pressure drop requires an accurate prediction of the void fraction throughout the length of the bundle. In addition, the void fraction correlation is indirectly qualified via (1) comparison with sub-channel analysis method (COBRAG) as shown in Figure 2-7, and (2) calculated void fraction error based on pressure drop measurements for low flow, low power GNF3 tests shown in Figure 2-8 and Figure 2-9. Note that for low flow, low power tests, the elevation pressure drop, which is a direct measure of void fraction, dominates the total pressure drop. For easier understanding of legends in Figure 2-9, the pressure tap locations for the GNF3 test assembly for the cosine Axial Power Shape (APS) are shown in Figure 2-10. Also, in Figure 2-9, ‘I’, ‘O’, and ‘C’ designate the inlet-peaked, outlet-peaked, and cosine APS, respectively.

Void fractions calculated by the GEH (Findlay-Dix) void correlation and the higher-order COBRAG method, as shown in Figure 2-7, are quite close to each other over the entire range of void fraction and axial height with variation of flow areas due to short and long PLRs, and the [[ ]] Such small differences in void fractions have no significant effect on downstream calculations of bundle and critical powers and finally the OLMCPR.

Figure 2-8 shows that there is no bias for GNF3 with respect to other GE/GNF 10x10 fuels on the use of Findlay-Dix void correlation for void fraction calculation.

Figure 2-9 shows no bias in calculated void fraction error based on the Findlay-Dix void correlation regarding the axial segments, whether full length (including the bottom fully rodded section) or middle section or top section of GNF3.

Based on Figure 2-7 through Figure 2-9, the GEH Findlay-Dix void fraction correlation (Reference 15), which forms the basis for currently approved methodologies, is applicable to GNF3 fuel designs.

Pressure Drop

The GNF3 fuel assembly design incorporates the use of nickel-based, Ni-Cr-Ti alloy grid type spacers with flow wings to improve critical power performance. The pressure drop characteristics of the GNF3 spacers are based on the pressure drop data from full-scale testing of the GNF3 fuel assembly as documented in Reference 4. Production spacers were used in the full-scale test assembly with no modifications. The measured pressure drops include static head, wall friction, acceleration pressure drop, and form losses. The loss coefficients were evaluated in a manner consistent with the steady-state thermal-hydraulic analysis methodology documented in Section 4.2 of GESTAR II. The test assembly and the measurement scheme for obtaining differential pressures are shown in Figure 2-10. [[ ]]

Measured pressure drops across the bundle height from [[ ]] for cosine power shape and [[ ]] for inlet and outlet peaked power shapes are compared to the predictions in Figure 2-11. The comparison of the predicted versus measured pressure drop for [[ ]] tests over a range of thermal-hydraulic conditions resulted in a mean error for the total pressure drop of [[ ]]. It is instructive to note from Figure 2-11 that the same small pressure drop error is maintained over the entire range of bundle powers. The zero bundle power results, shown as the green diamonds in the figure, represent the single-phase portion of the pressure drop and are consistent with all the data. The pressure drop correlation is able to accurately model the split between single phase and two phase pressure drop, which is an important characteristic in the thermal-hydraulic stability. The ISCOR09 model with the pressure drop correlation also predicts the axial pressure profile in the bundle. Figure 2-12 compares the measured and calculated accumulated pressure drop for a high power and moderate flow condition. The pressure profile shows that the effects of the PLRs and advanced spacers are accurately simulated by the ISCOR09 model, the steady-state, stability, and transient analysis tools.

The GNF3 fuel assembly hydraulic characteristics have been developed and confirmed by the test comparisons discussed above. These GNF3 hydraulic characteristics are used in all analysis models and methods where the fuel assembly hydraulics are needed. For cores of mixed assembly types, the hydraulics are uniquely represented for each assembly type. Therefore, the flow-pressure drop characteristics for each fuel assembly type (including GNF3) present in a plant are included in all plant cycle-specific analyses for the calculation of the OLMCPR.

Critical Power Correlation

The GNF3 fuel assembly has a different PLR configuration and spacer design relative to previous fuel designs. The new correlation, GEXL21, has been established based on significant new data for the GNF3 fuel design.

The GEXL21 (Reference 16) database was obtained from Stern Laboratory tests of full-scale GNF3 bundle simulations. A statistical analysis has been performed for the GNF3 database used to develop the GEXL21 correlation, consisting of [[ ]] data points for [[ ]] different local peaking patterns. This correlation statistics were based on [[ ]] data points. The GEXL21 correlation is valid for GNF3 fuel over the following range of state conditions:

- Pressure: [[ ]]
- Mass Flux: [[ ]]
- Inlet Subcooling: [[ ]]
- R-factor: [[ ]]

[[ ]] This is demonstrated in Figure 2-13.

In addition, there is an additive constant applied to each fuel rod location [[ ]] For GNF3, the additive constants used in the design process are provided in Reference 4. The terms that comprise the form of the correlation have been previously approved by the NRC and have been in use for the past eight GE fuel product designs.

Based on the [[ ]] data points used to develop and verify the GEXL21 correlation statistics, the mean Ratio of Calculated to Measured Critical Power (ECPR), μ, was determined to be [[ ]], with a standard deviation, σ, of [[ ]] In addition to the overall statistics mentioned above, the GEXL21 correlation is accurate over the entire flow range. The ECPR statistics are shown as a function of bundle inlet mass flux in Figure 2-14, where the error bars represent one standard deviation of the ECPR for each flow. The average ECPR is within [[ ]] relative to the data mean ECPR of [[ ]] over the entire flow range expected in EPU and MELLLA+ operation, ensuring accurate Critical Power Ratio (CPR) modeling of both steady-state and transient operation.

2.2.1.3 Adequacy of Existing Treatment and Alternate Approach

The design limits and methods associated with evaluation of SLMCPR as specified in Table 1-2 can be used for the GNF3 design under EPU conditions. This conclusion is based on the following:

- The TGBLA06 nuclear evaluations have been shown to yield similar pin power and reactivity behavior relative to MCNP benchmark calculations as the previously documented GE14 analyses (Reference 1).
- PANAC11 evaluations have been shown to yield similar power distribution calculation fidelity relative to MCNP benchmarks when compared to previously approved fuel products (GE14 and GNF2).
- Full-scale thermal-hydraulic pressure drop and critical power tests have been performed and correlated with NRC-approved correlations. The GNF3 GEXL21 critical power correlation uncertainty is incorporated into the determination of the SLMCPR. The range of the pressure drop and critical power test data is sufficient to cover thermal-hydraulic conditions present during EPU and MELLLA+ operations. The correlation forms and implementation methods remain unchanged for GNF3.

2.2.2 Operating Limit Critical Power Ratio

The analysis of AOOs examines the change in CPR relative to the initial conditions and determines the most limiting event. The definition of the OLMCPR is unchanged for GNF3.

2.2.2.1 Fuel Parameters That Affect OLMCPR

Reference 1 contains a detailed discussion of the fuel parameters that affect OLMCPR. These parameters are unchanged for GNF3.

2.2.2.2 Treatment of Fuel Parameter Uncertainties

A new fuel design can potentially affect transient response. The three most important parameters are:

- **Core APS:** As stated in Reference 1, the core APS can influence the transient response. Uncertainties in the APS are not directly included in the transient response uncertainty. Rather, the input conditions for the transient are developed in a way that ensures that the axial shape is conservative. This is not changed for the GNF3 design.
- **Void and Moderator Density Reactivity Response:** Both the ODYN and TRACG transient methodologies (References 17, 18, and 19) have established application ranges for void coefficient uncertainty. The basis for these methodologies rests upon a comparison of calculations for a wide variety of plant transients in which the nominal

void coefficient is used. The acceptable performance of these codes relative to the data justifies that no large errors in void coefficient exist. As described in Section 2.2.1.2 above, TGBLA06 and MCNP have been utilized to generate reactivity differences for representative GE14, GNF2, and GNF3 10x10 lattices for the full range of instantaneous void conditions. Differences have also been evaluated for cold conditions. Figure 2-3 through Figure 2-5 show the TGBLA06/MCNP bias as a function of moderator density. The GNF3 results follow the same trend with moderator density as the GE14 and GNF2 results, and therefore yield similar void coefficient biases. The consistent moderator density behavior between hot zero void and cold conditions ensure consistent behavior for cold water events as well.

- **Thermal-Hydraulic Behavior:** Transient conditions require both the critical power and pressure drop correlations be accurate for the full range of flow conditions. This accuracy is demonstrated in Figure 2-11 for the GNF3 pressure drop correlation and in Figure 2-14 for the GEXL21 critical power correlation.

In compliance with Limitation and Condition 4.17 from the NRC SE of Reference 20, the void coefficient bias and uncertainty are re-calculated explicitly for GNF3 fuel. This updated uncertainty information was transmitted to the NRC via Reference 21.

Because inputs to the OLMCPR analysis are conservative, and the pressurization transients that typically establish the limiting ΔCPRs are conservatively analyzed by TRACG or ODYN, the conservatisms in the process of determining OLMCPRs is appropriate and sufficient for application to GNF3.

2.2.2.3 Adequacy of Existing Treatment and Alternate Approach

The design limits and methods associated with evaluation of OLMCPR as specified in Table 1-2 can be used for the GNF3 design under EPU conditions. For applications that utilize TGBLA06 based modeling (PANAC11, ODYN, TRACG, and ODYSY), the TGBLA06/MCNP GNF3 comparisons showed a behavior consistent with GE14/GNF2 behavior. The GNF3 thermal-hydraulic correlations are robust and accurately describe pressure drop and critical power margins over the entire flow range.

Figure 2-1 TGBLA06 Fission Density Benchmark for GNF3 at 0 GWD/STU

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Figure 2-2 **TGBLA06 Fission Density Benchmark for GNF3 at 65 GWD/STU**

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Figure 2-3 TGBLA06 Reactivity Benchmark for GNF3 Uncontrolled Cases at 0 GWD/STU

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Figure 2-4 TGBLA06 Reactivity Benchmark for GNF3 Uncontrolled Cases at 65 GWd/STU

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Figure 2-5 TGBLA06 Reactivity Benchmark for GNF3 Controlled Cases at 0 GWD/STU

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Figure 2-6 Bundle Power Comparisons: RMS% (PANAC11-MCNP)

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Figure 2-7 Axial Void Calculation on GNF3 at High Power Conditions from the Findlay-Dix Correlation and Sub-Channel Based Calculation

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Figure 2-8 Calculated Void Fraction Error versus Quality by Fuel Type (GE12, GE14, GNF2 and GNF3)

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Figure 2-9 Calculated Void Fraction Error for GNF3 for Various Bundle Segments vs. Quality

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Figure 2-10 GNF3 Test Assembly Along With Pressure Tap Locations for Cosine APS

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Figure 2-11 GNF3 Calculated vs. Measured ΔP

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Figure 2-12 GNF3 ΔP (Calculated or Measured) Versus Elevation

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Figure 2-13 Mass Flux versus R-Factor Plane

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Figure 2-14 GEXL21 ECPR as a Function of Bundle Inlet Mass Flux

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2.3 SHUTDOWN MARGIN

The required TS for SDM are unchanged for GNF3.

2.3.1 Fuel Parameters That Affect SDM

The fuel parameters that affect SDM are unchanged for GNF3.

2.3.2 Treatment of Fuel Parameter Uncertainties

A SDM demonstration experiment is performed at the beginning of each operating cycle. This demonstration is performed in the cold criticality condition. The demonstration configuration attempts to simulate the most reactive rod out condition. In order to obtain a critical condition, other rods are also withdrawn. The 3D simulator (Reference 9) is used to calculate the demonstration condition. Reference 1 presented the results of 39 critical experiments performed over five cores, for which multiple cold critical experiments were performed on the same core. The standard deviation of the critical eigenvalues for the cores in Reference 1 relative to the average obtained for the same core is [[ ]]. This standard deviation can be compared to the TS allowance of 0.38% Δk/k, indicating that for application to high power density cores, the data supports the continued use of the current TS limit.

The continued applicability of this uncertainty to GNF3 is assessed using two techniques, which are listed below and expanded upon in the sections that follow:

1) TGBLA to MCNP Infinite Lattice Reactivity Comparisons

2) PANAC11 to MCNP Cold Critical Comparisons

TGBLA to MCNP Infinite Lattice Reactivity Comparisons

The ability of GEH/GNF analytic methods to accurately predict system reactivity is largely dependent on the ability of the methods to assess reactivity on a local (i.e., nodal) level. Figure 2-3 through Figure 2-5 provide details on TGBLA06 to MCNP reactivity comparisons at different exposures, control states, and moderator densities. These comparisons indicate that TGBLA06 infinite lattice reactivity calculation for GNF3 fuel is consistent with the corresponding GNF2 and GE14 performance, including moderator densities associated with the cold critical conditions of interest for SDM assessments.

PANAC11 to MCNP Cold Critical Comparisons

While consistent TGBLA infinite lattice reactivity calculation performance for GNF3 compared to GE14/GNF2 provides good confidence that PANAC11 cold critical prediction capability will be consistent across these fuel product lines, an additional study was performed to further demonstrate consistency at the core analysis level. To perform this additional confirmation, a similar comparison technique was leveraged as described in Section 2.2.1.2. [[

]] was used for GE14, GNF2, and GNF3, but in this case five different exposures points were selected across the cycles for investigation. At these five exposed conditions, three control blade configurations were analyzed:

1) Critical control rod configuration
2) All rods in
3) One rod out

These cases were used to evaluate two quantities important to SDM: uncertainty in cold critical eigenvalue and uncertainty in strong rod worth.

Uncertainty in cold critical eigenvalue was defined as the standard deviation of the difference between PANAC11 and MCNP based eigenvalue results for the [[ ]]. Results from the comparison are provided in Figure 2-15 and Table 2-1.

Uncertainty in strong rod worth was defined as the standard deviation of the difference between the calculated rod worth for one rod in [[ ]]. The worth of a rod is defined as the system eigenvalue difference with all rods in and with one rod out. Results from the comparison are provided in Figure 2-16 and Table 2-1.

These results indicate consistent eigenvalue and rod worth prediction performance in PANAC11 for GE14, GNF2, and GNF3. The magnitudes of the differences shown in Figure 2-15 and Figure 2-16 are consistent with those observed for cold, infinite lattices comparisons between TGBLA06 and MCNP demonstrated in Figure 2-3 through Figure 2-5.

The uncertainties of the cold critical eigenvalue differences for GNF3 reported in Table 2-1 remain below the accepted eigenvalue uncertainty of [[ ]] reported in Reference 1.

2.3.3 Adequacy of Existing Treatment and Alternate Approach

The design limits and methods associated with evaluation of SDM as specified in Table 1-2 can be used for the GNF3 design under EPU conditions.

This evaluation is based on consistent TGBLA06/MCNP infinite lattice reactivity comparisons compared to previously approved fuel designs, consistent small core cold critical eigenvalue and rod worth calculation performance against MCNP across GNF3 and other previously approved fuel designs, and calculated cold critical eigenvalue uncertainties for GNF3 that are below the accepted eigenvalue uncertainty of [[ ]] reported in Reference 1.

Table 2-1 Shutdown Margin Related Uncertainty Comparisons Across Fuel Products

	Standard Deviation of Difference (PANAC11 – MCNP)	
Product Line	**Cold Critical Eigenvalue**	**Rod Worth**
GE14	[[	
GNF2		
GNF3		]]

Figure 2-15 PANAC11 to MCNP Cold Critical Comparisons

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Figure 2-16 PANAC11 to MCNP Rod Worth Comparisons

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2.4 FUEL ROD THERMAL-MECHANICAL PERFORMANCE

For each GNF fuel design, T-M based LHGR limits (LHGR operating limits) are specified for each fuel rod type (for both UO_2 and gadolinia-bearing rods) such that, if each rod type is operated within its LHGR limit, the T-M design and licensing criteria, including those which address response to AOOs, are explicitly satisfied and fuel rod integrity is maintained. The licensing criteria for determining T-M design have not changed for GNF3.

2.4.1 Fuel Parameters That Affect Thermal-Mechanical Limits

The fuel parameters that affect thermal-mechanics limits have not changed for GNF3.

2.4.2 Treatment of Fuel Parameter Uncertainties

The effect of the GNF3 design on the uncertainty in local peaking and 3D power distribution is discussed in Section 2.2.1.2, where the revised uncertainties as shown in Table 2-11 of Reference 1 are shown to be appropriate for GNF3 analysis. The GNF3 fuel pellet and rod diameter design is identical to the GNF2 fuel rod design. GNF3 fuel rods, however, operate at a higher peak power, while still maintaining the same peak discharge exposure. The current design basis for GNF3 fuel included in Reference 4 is based on the PRIME methodology.

2.4.3 Adequacy of Existing Treatment and Alternate Approach

The design limits and methods associated with evaluation of T-M limits as specified in Table 1-2 can be used for the GNF3 design under EPU conditions. The standard GE methodology for determining LHGR limits includes conservative consideration for, and provides reasonable assurance of adequate margin to address, the power uncertainties in question and is not affected by the GNF3 design. PRIME provides an appropriate basis for the use of GNF3 in the EPU and MELLLA+ extended operating domains.

2.5 LOCA RELATED NODAL POWER LIMITS

The purpose of the MAPLHGR limits is to assure adequate protection of the fuel during a postulated LOCA with the defined operation of the ECCS. This is unchanged for GNF3.

2.5.1 Fuel Parameters That Affect LOCA Related Nodal Power Limits

The fuel parameters that affect LOCA related nodal power limits are unchanged for GNF3.

2.5.2 Treatment of Fuel Parameter Uncertainties

The ECCS-LOCA analysis follows the NRC-approved SAFER/PRIME application methodology documented in Volume III of NEDE-23785-1-PA (Reference 22), augmented with NEDC-33256P-A, NEDC-33257P-A, and NEDC-33258P-A (Reference 6). The analytical models used to perform ECCS-LOCA analyses are documented in Volume II of

NEDE-23785-1-PA (Reference 23) together with NEDE-30996P-A (Reference 24) and NEDC-32950P (Reference 25). Reference 1 contains a discussion of the relationship of peak power uncertainties and their application to fuel parameter analysis. The analysis presented in Section 2.2.1.2, showing the uncertainty in pin and bundle power for GNF3 is the same as for GNF2, GE14 and previous designs.

2.5.3 Adequacy of Existing Treatment and Alternate Approach

The design limits and methods associated with evaluation of T-M limits as specified in Table 1-2 can be used for the GNF3 design under EPU conditions. The conservatism of the present ECCS-LOCA methodology used to determine MAPLGHR limits adequately considers the effects of the uncertainties in local and bundle power and provides adequate and reasonable assurance that those limits provide adequate margin to protect the fuel. This assurance is extended to GNF3. The ECCS-LOCA methodology is fully capable of simulating the necessary features of the GNF3 fuel design and design basis uncertainties for the GE14 fuel design are adequate in like manner as has been determined previously applicable to GNF2 analyses.

2.6 STABILITY

Thermal-hydraulic stability analyses are performed to assure that the SLMCPR is protected in the event of a thermal-hydraulic instability event. Specific analyses are associated with each of the long-term stability solutions. These long-term solutions include Option I-D, Option II, Option III, and Enhanced Option I-A. The stability analyses and the applicability of these stability solution options remain unchanged for GNF3.

2.6.1 Fuel Parameters That Affect Stability

The fuel parameters identified previously in Reference 1 are unchanged for GNF3.

2.6.2 Treatment of Fuel Parameter Uncertainties

The treatment of the fuel parameter uncertainties in Reference 1 for each of the long-term stability solutions is unchanged for GNF3. Sections 2.6.2.1 through 2.6.2.4 of Reference 1 discuss the stability effect of nuclear and thermal-hydraulic uncertainties for each of the four stability long-term solutions listed above, namely Option 1-D, Option II, Option III, and Enhanced Option I-A. In general, the stability models used to evaluate the options and issues described above imbed the basic bundle nuclear and thermal-hydraulic models from the TGBLA, ISCOR and PANACEA programs. Other transient models are consistent with these basic models. Stability performance depends on the following parameters:

- **Moderator void coefficient**: The TGBLA06/MCNP comparisons for the GNF3 design show the same bias with moderator density as previous 10x10 designs. There is no change in moderator void coefficient bias and uncertainty with GNF3.

- **Local pin power peaking**: The TGBLA06/MCNP comparisons for the GNF3 design also show the same pin power accuracy for GNF2 as previous 10x10 designs, and the same stability uncertainty effect as previous designs.

- [[ ]]: The GNF3 reactivity biases relative to Monte Carlo results are consistent with previous 10x10 designs, showing no change needed in stability effect for [[ ]].

- **Bundle pressure drop**: The bundle pressure drop model is based on GNF3 full-scale pressure drop measurements. In addition to the total bundle pressure drop, the axial pressure profile is accurately modeled (see Figure 2-12) by the ISCOR model, which is embedded in the stability evaluations.

2.6.3 Adequacy of Existing Treatment and Alternate Approach

The design limits and methods associated with evaluation of Stability as specified in Table 1-2 can be used for the GNF3 design under EPU conditions. All models related to stability have the same uncertainties for the GNF3 design as the GE14 and GNF2 designs, and are acceptable for GNF3-related stability analysis.

2.7 LICENSED EXPOSURE

PRIME (Reference 6) and associated GNF3 specific limits provided in Reference 4 provide an appropriate basis for the use of GNF3.

The licensed peak pellet exposure limit is specified and applied in the process computer to assure that fuel is not operated beyond its analyzed basis. In this application, the best estimate value of the local exposure condition is monitored against the specified exposure limit.

2.7.1 Fuel Parameters That Affect Pellet Exposure

The fuel parameters that affect pellet exposure are unchanged for GNF3.

2.7.2 Treatment of Fuel Parameter Uncertainties

The overall pin power uncertainties are unchanged for GNF3 (Section 2.2.1.2).

2.7.3 Adequacy of Existing Treatment and Alternate Approach

The design limits and methods associated with evaluation of licensed exposure as specified in Table 1-2 can be used for the GNF3 design under expanded operating domains. As noted previously, PRIME (Reference 6) provides an appropriate basis for the use of GNF3 in the EPU and MELLLA+ extended operating domains.

3.0 EXTENSION OF SAFETY PARAMETER BASES TO THE MELLLA+ OPERATING DOMAIN

3.1 INTRODUCTION

MELLLA+ operation allows the reactor to be at full power down to 80% flow (Reference 26). Like EPU, these conditions increase the amount of steam voids in the core. The total steam void level in a given bundle is a direct function of the power to flow ratio. Raising the average bundle power (EPU) or lowering the flow (MELLLA+) have the same effect, and for the most part raise similar technical issues. The use of GNF3 fuel does not change the application of the GEH methods for MELLLA+.

3.2 CRITICAL POWER

3.2.1 Safety Limit Critical Power Ratio

Section 3.2.1 of Reference 1 describes the process for determining the SLMCPR for MELLLA+ operating conditions. This analysis has shown that use of uncertainties at rated conditions is appropriate for MELLLA+ conditions. Design limits and methods associated with evaluation of SLMCPR as specified in Table 1-2 can be used for the GNF3 design under MELLLA+ conditions. The justification for the use of GEH methods for GNF3 SLMCPR evaluations is given in Section 2.2.1.

3.2.2 Operating Limit Critical Power Ratio

MELLLA+ evaluation procedures require consideration of OLMCPR values for each limiting corner of the power flow map. If changes are required to account for OLMCPR at different flow points, this change is reflected in the core monitoring algorithm for MFLCPR (ratio of bundle critical power to OLMCPR) for each bundle. The same conservatisms apply for the nuclear inputs to the transient evaluations. Sensitivities developed for transients initiated from full power can be applied to those initiated from other conditions. This is not changed for the GNF3 design. Design limits and methods associated with evaluation of OLMCPR as specified in Table 1-2 can be used for the GNF3 design under MELLLA+ conditions.

3.3 SHUTDOWN MARGIN

The data in Section 2.3 of Reference 1 supports a 2σ demonstration margin criteria of 0.38% $\Delta k/k$. Justification for the continued applicability of this margin to GNF3 appears in Section 2.3.2 of this report. Design limits and methods associated with evaluation of SDM as specified in Table 1-2 can be used for the GNF3 design under MELLLA+ conditions.

3.4 FUEL ROD THERMAL-MECHANICAL PERFORMANCE

The fuel rod T-M analyses explicitly address the variation in the axial power distribution that may occur as a result of spectral shift operation, and therefore the specified LHGR operating limits and exposure limit are directly applicable to MELLLA+ operation and unaffected by the GNF3 fuel design. Design limits and methods associated with evaluation of fuel rod T-M performance as specified in Table 1-2 can be used for the GNF3 design under MELLLA+ conditions.

3.5 LOCA RELATED NODAL POWER LIMITS

There are no differences in the ECCS-LOCA methodology between EPU and MELLLA+ except that for MELLLA+ the ECCS-LOCA analyses are performed for at least two additional state points. These are unchanged for GNF3. Design limits and methods associated with evaluation of LOCA related nodal power limits as specified in Table 1-2 can be used for the GNF3 design under MELLLA+ conditions.

3.6 STABILITY

The GE BWR Detect and Suppress Solution – Confirmation Density (DSS-CD) (NEDC-33075P) is a licensed stability solution for operation in the MELLLA+ domain (References 27 and 28). The GNF3 pressure drop and critical power correlations described in Section 2.2.1.2 are accurate to low flow conditions and accurately represent the pressure profile in the fuel bundle. Design limits and methods associated with evaluation of stability as specified in Table 1-2 can be used for the GNF3 design under MELLLA+ conditions.

3.7 LICENSED EXPOSURE

PRIME (Reference 6) and associated GNF3 specific limits provided in Reference 4 provide an appropriate basis for the use of GNF3 in the MELLLA+ operating domain. Design limits and methods associated with evaluation of licensed exposure as specified in Table 1-2 can be used for the GNF3 design under MELLLA+ conditions.

4.0 LICENSING APPLICATION

4.1 OVERVIEW

The purpose of this supplement is to extend the application of Reference 1 to GNF3 fuel.

4.2 APPLICABILITY

The Methods LTR basis is applicable to current GEH BWR product lines licensed with GEH nuclear and safety analysis methods. The Methods LTR is applicable to plants that include current GNF fuels including GNF3. The application of these codes complies with the limitations, restrictions and conditions specified in the approving NRC SE for each code.

The parameters establishing the Methods LTR applicability envelope are:

Parameter	Generic Value
BWR Product Line	BWR/2-6[1]
Fuel Product Line	GE fuel designs using square arrays of fuel rods, including 7x7, 8x8, 9x9, and 10x10 designs, inclusive of GNF2 and GNF3
Licensing Methodology	GEH nuclear and safety analysis methods
Operating Domain	CPPU, EPU, with MELLLA+ including currently licensed operating domains (e.g., Extended Load Line Limit Analysis (ELLLA) and Maximum Extended Load Line Limit Analysis (MELLLA)) and operational flexibility features
Maximum Rated Power Level	120% Original Licensed Thermal Power (OLTP)
Stability Solution	GE stability solutions

Note:

1. MELLLA+ is not applicable to BWR/2 plants consistent with NEDC-33006P-A (Reference 26)

4.3 PLANT SPECIFIC APPLICATION PROCESS

Each plant seeking to apply the Methods LTR must provide information supporting the application that demonstrates that the plant parameters are within the applicability definition in Section 4.2.

5.0 SUMMARY AND CONCLUSION

The evaluations presented in Sections 2 and 3 demonstrate the adequacy of the GEH methods for GNF3 when used in the expanded operating domains. Further, the assessment in Appendix A documents the applicability of the limitations in the NRC SE for the Methods LTR (Reference 2) for GNF3 fuel.

Safety Limit Critical Power Ratio

The SLMCPR evaluation procedure and methods are not changed due to introduction of GNF3 fuel.

Operating Limit Critical Power Ratio

The OLMCPR evaluation procedure and methods are not changed due to introduction of GNF3 fuel.

Shutdown Margin

The TS limit for the SDM of 0.38 % $\Delta k/k$ is not increased for CPPU or EPU and MELLLA+ applications where GNF3 is utilized. The SDM evaluation procedure and methods are unchanged due to the introduction of GNF3 fuel.

Fuel Rod Thermal-Mechanical Performance

The licensing criteria for fuel rod T-M performance are unchanged. PRIME (Reference 6) methodology provides an appropriate basis for the use of GNF3. GNF3 specific limits derived with PRIME are provided in Reference 4.

LOCA Related Nodal Power Limits

The LOCA evaluation procedure and methods are unchanged due to introduction of GNF3 fuel.

Stability

The stability evaluation procedure and methods are unchanged due to introduction of GNF3 fuel.

Licensed Exposure

The licensing criteria for fuel rod maximum licensed exposure are unchanged. PRIME (Reference 6) methodology provides an appropriate basis for the use of GNF3. GNF3 specific limits derived with PRIME are provided in Reference 4.

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APPENDIX A – LIMITATIONS FROM SAFETY EVALUATION FOR LTR NEDC-33173P

Limitation Number from NRC SE	Limitation Title	Limitation Text	Disposition	Comments
9.1	TGBLA/PANAC Version	The neutronic methods used to simulate the reactor core response and that feed into the downstream safety analyses supporting operation at EPU/MELLLA+ will apply TGBLA06/PANAC11 or later NRC-approved version of neutronic method.	Unchanged	EPU/MELLLA+ applications utilizing GNF3 fuel will use TGBLA06/PANAC11 or later NRC-approved version of neutronic methods.
9.2	3D Monicore	For EPU/MELLLA+ applications, relying on TGBLA04/PANAC10 methods, the bundle RMS difference uncertainty will be established from plant-specific core-tracking data, based on TGBLA04/PANAC10. The use of plant-specific trend line based on the neutronic method employed will capture the actual bundle power uncertainty of the core monitoring system.	Not Applicable	EPU/MELLLA+ applications utilizing GNF3 fuel will not use TGBLA04/PANAC10 as the neutronic methods. See Limitation 9.1.
9.3	Power to Flow Ratio	Plant-specific EPU and expanded operating domain applications will confirm that the core thermal power to core flow ratio will not exceed 50 MWt/Mlbm/hr at any state point in the allowed operating domain. For plants that exceed the power-to-flow value of 50 MWt/Mlbm/hr, the application will provide power distribution assessment to establish that neutronic methods axial and nodal power distribution uncertainties have not increased.	Unchanged	This limitation is not dependent on fuel type. Consistent with Reference 29.

Limitation Number from NRC SE	Limitation Title	Limitation Text	Disposition	Comments
9.4	SLMCPR1	This limitation has been removed according to Appendix I of the Safety Evaluation for LTR NEDC-33173P.	Unchanged	No disposition required
9.5	SLMCPR2	This limitation has been revised according to Appendix I of the Safety Evaluation for LTR NEDC-33173P. For operation at MELLLA+, including operation at the EPU power levels at the achievable core flow state-point, a 0.01 value shall be added to the cycle-specific SLMCPR value for power-to-flow ratios up to 42 MWt/Mlbm/hr, and a 0.02 value shall be added to the cycle-specific SLMCPR value for power-to-flow ratios above 42 MWt/Mlbm/hr.	Unchanged	This limitation will be implemented for all fuel types, including GNF3.
9.6	R-Factor	The plant specific R-factor calculation at a bundle level will be consistent with lattice axial void conditions expected for the hot channel operating state. The plant-specific EPU/MELLLA+ application will confirm that the R-factor calculation is consistent with the hot channel axial void conditions.	Unchanged	This limitation will be implemented for all fuel types, including GNF3.

Limitation Number from NRC SE	Limitation Title	Limitation Text	Disposition	Comments
9.7	ECCS-LOCA 1	For applications requesting implementation of EPU or expanded operating domains, including MELLLA+, the small and large break ECCS-LOCA analyses will include top-peaked and mid-peaked power shape in establishing the MAPLHGR and determining the PCT. This limitation is applicable to both the licensing bases PCT and the upper bound PCT. The plant-specific applications will report the limiting small and large break licensing basis and upper bound PCTs.	Unchanged	This limitation will be implemented for all fuel types, including GNF3.
9.8	ECCS-LOCA 2	The ECCS-LOCA will be performed for all state points in the upper boundary of the expanded operating domain, including the minimum core flow state points, the transition state point as defined in Reference 26 and the 55 percent core flow state point. The plant-specific application will report the limiting ECCS-LOCA results as well as the rated power and flow results. The SRLR will include both the limiting state point ECCS-LOCA results and the rated conditions ECCS-LOCA results.	Unchanged	This limitation will be implemented for all fuel types, including GNF3.

Limitation Number from NRC SE	Limitation Title	Limitation Text	Disposition	Comments
9.9	Transient LHGR 1	Plant-specific EPU and MELLLA+ applications will demonstrate and document that during normal operation and core-wide AOOs, the T-M acceptance criteria as specified in Amendment 22 to GESTAR II will be met. Specifically, during an AOO, the licensing application will demonstrate that the: (1) loss of fuel rod mechanical integrity will not occur due to fuel melting and (2) loss of fuel rod mechanical integrity will not occur due to pellet–cladding mechanical interaction. The plant-specific application will demonstrate that the T-M acceptance criteria are met for the both the UO_2 and the limiting GdO_2 rods.	Unchanged	This limitation will be implemented for all fuel types, including GNF3.
9.10	Transient LHGR 2	Each EPU and MELLLA+ fuel reload will document the calculation results of the analyses demonstrating compliance to transient T-M acceptance criteria. The plant T-M response will be provided with the SRLR or COLR, or it will be reported directly to the NRC as an attachment to the SRLR or COLR.	Unchanged	This limitation will be implemented for all fuel types, including GNF3.

Limitation Number from NRC SE	Limitation Title	Limitation Text	Disposition	Comments
9.11	Transient LHGR 3	To account for the impact of the void history bias, plant-specific EPU and MELLLA+ applications using either TRACG or ODYN will demonstrate an equivalent to 10 percent margin to the fuel centerline melt and the 1 percent cladding circumferential plastic strain acceptance criteria due to pellet-cladding mechanical interaction for all of limiting AOO transient events, including equipment out-of-service. Limiting transients in this case, refers to transients where the void reactivity coefficient plays a significant role (such as pressurization events). If the void history bias is incorporated into the transient model within the code, then the additional 10 percent margin to the fuel centerline melt and the 1 percent cladding circumferential plastic strain is no longer required.	Unchanged	This limitation will be implemented for all fuel types, including GNF3.

Limitation Number from NRC SE	Limitation Title	Limitation Text	Disposition	Comments
9.12	LHGR and Exposure Qualification	In MFN 06-481, GE committed to submit plenum fission gas and fuel exposure gamma scans as part of the revision to the T-M licensing process. The conclusions of the plenum fission gas and fuel exposure gamma scans of GE 10x10 fuel designs as operated will be submitted for NRC staff review and approval. This revision will be accomplished through Amendment to GESTAR II or in a T-M licensing LTR. PRIME (a newly developed T-M code) has been submitted to the NRC staff for review (Reference 6). Once the PRIME LTR and its application are approved, future license applications for EPU and MELLLA+ referencing LTR NEDC-33173P must utilize the PRIME T-M methods.	Unchanged	PRIME has been approved and GNF3 utilizes PRIME.

Limitation Number from NRC SE	Limitation Title	Limitation Text	Disposition	Comments
9.13	Application of 10 Weight Percent Gd	Before applying 10 weight percent Gd to licensing applications, including EPU and expanded operating domain, the NRC staff needs to review and approve the T-M LTR demonstrating that the T-M acceptance criteria specified in GESTAR II and Amendment 22 to GESTAR II can be met for steady-state and transient conditions. Specifically, the T-M application must demonstrate that the T-M acceptance criteria can be met for TOP and MOP conditions that bounds the response of plants operating at EPU and expanded operating domains at the most limiting state points, considering the operating flexibilities (e.g., equipment out-of-service). Before the use of 10 weight percent Gd for modern fuel designs, NRC must review and approve TGBLA06 qualification submittal. Where a fuel design refers to a design with Gd-bearing rods adjacent to vanished or water rods, the submittal should include specific information regarding acceptance criteria for the qualification and address any downstream impacts in terms of the safety analysis. The 10 weight percent Gd qualifications submittal can supplement this report.	Unchanged	This limitation will be implemented for all fuel types, including GNF3. GEH has no current plans to apply 10 weight percent Gd to GNF3 fuel.

Limitation Number from NRC SE	Limitation Title	Limitation Text	Disposition	Comments
9.14	Part 21 Evaluation of GESTR-M Fuel Temperature Calculation	Any conclusions drawn from the NRC staff evaluation of the GE's Part 21 report will be applicable to the GESTR-M T-M assessment of this SE for future license application. GE submitted the T-M Part 21 evaluation, which is currently under NRC staff review. Upon completion of its review, NRC staff will inform GE of its conclusions.	Not applicable.	PRIME has been approved and GNF3 utilizes PRIME. This limitation is related to GESTR-M is therefore not applicable to GNF3.
9.15	Void Reactivity 1	The void reactivity coefficient bias and uncertainties in TRACG for EPU and MELLLA+ must be representative of the lattice designs of the fuel loaded in the core.	Unchanged	This limitation will be implemented for all fuel types, including GNF3.

Limitation Number from NRC SE	Limitation Title	Limitation Text	Disposition	Comments
9.16	Void Reactivity 2	A supplement to TRACG /PANAC11 for AOO is under NRC staff review (Reference 20). TRACG internally models the response surface for the void coefficient biases and uncertainties for known dependencies due to the relative moderator density and exposure on nodal basis. Therefore, the void history bias determined through the methods review can be incorporated into the response surface "known" bias or through changes in lattice physics/core simulator methods for establishing the instantaneous cross-sections. Including the bias in the calculations negates the need for ensuring that plant-specific applications show sufficient margin. For application of TRACG to EPU and MELLLA+ applications, the TRACG methodology must incorporate the void history bias. The manner in which this void history bias is accounted for will be established by the NRC staff SE approving NEDE-32906P, Supplement 3, "Migration to TRACG04/PANAC11 from TRACG02/PANAC10," May 2006 (Reference 20). This limitation applies until the new TRACG/PANAC methodology is approved by the NRC staff.	Unchanged	The void history bias model has been incorporated into TRACG and accepted by the NRC. This is described in the SE for NEDE-32906P, Supplement 3, "Migration to TRACG04/PANAC11 from TRACG02/PANAC10," Section 3.20.2. Applications with GNF3 continue to implement this approved model.

Limitation Number from NRC SE	Limitation Title	Limitation Text	Disposition	Comments
9.17	Steady-State 5 Percent Bypass Voiding	The instrumentation specification design bases limit the presence of bypass voiding to 5 percent (LRPM levels). Limiting the bypass voiding to less than 5 percent for long-term steady operation ensures that instrumentation is operated within the specification. For EPU and MELLLA+ operation, the bypass voiding will be evaluated on a cycle-specific basis to confirm that the void fraction remains below 5 percent at all LPRM levels when operating at steady-state conditions within the MELLLA+ upper boundary. The highest calculated bypass voiding at any LPRM level will be provided with the plant-specific SRLR.	Unchanged	This limitation will be implemented for all fuel types, including GNF3.
9.18	Stability Set points Adjustment	The NRC staff concludes that the presence bypass voiding at the low-flow conditions where instabilities are likely can result in calibration errors of less than 5 percent for OPRM cells and less than 2 percent for APRM signals. These calibration errors must be accounted for while determining the set points for any detect and suppress long-term methodology. The calibration values for the different long-term solutions are specified in the associated sections of this SE, discussing the stability methodology.	Unchanged	This limitation will be implemented for all fuel types, including GNF3.

Limitation Number from NRC SE	Limitation Title	Limitation Text	Disposition	Comments
9.19	Void-Quality Correlation 1	For applications involving PANACEA/ODYN/ISCOR/TASC for operation at EPU and MELLLA+, an additional 0.01 will be added to the OLMCPR, until such time that GE expands the experimental database supporting the Findlay-Dix void-quality correlation to demonstrate the accuracy and performance of the void-quality correlation based on experimental data representative of the current fuel designs and operating conditions during steady-state, transient, and accident conditions.	Unchanged	This limitation will be implemented for all fuel types, including GNF3.
9.20	Void-Quality Correlation 2	The NRC staff is currently reviewing Supplement 3 to NEDE-32906P, “Migration to TRACG04/PANAC11 from TRACG02/PANAC10,” dated May 2006 (Reference 20). The adequacy of the TRACG interfacial shear model qualification for application to EPU and MELLLA+ will be addressed under this review. Any conclusions specified in the NRC staff SE approving Supplement 3 to LTR NEDC-32906P (Reference 20) will be applicable as approved.	Unchanged	This limitation will be implemented for all fuel types, including GNF3.

Limitation Number from NRC SE	Limitation Title	Limitation Text	Disposition	Comments
9.21	Mixed Core Method 1	Plants implementing EPU or MELLLA+ with mixed fuel vendor cores will provide plant-specific justification for extension of GE's analytical methods or codes. The content of the plant-specific application will cover the topics addressed in this SE as well as subjects relevant to application of GE's methods to legacy fuel. Alternatively, GE may supplement or revise LTR NEDC-33173P (Reference 1) for mixed core application.	Not applicable	The purpose of the supplement is to address GNF3 fuel, not mixed fuel vendor cores. Therefore, this limitation is not applicable to this supplement.
9.22	Mixed Core Method 2	This limitation has been revised according to Appendix K of the NEDC-33173P SE: For any plant-specific applications of TGBLA06 with fuel type characteristics not covered in this review, GE needs to provide assessment data similar to that provided for the GE fuels. The Interim Methods review is applicable to all GE lattices up to GNF2. Fuel lattice designs, other than GE lattices up to GNF2, with the following characteristics are not covered by this review: • Square internal water channels water crosses • Gd rods simultaneously adjacent to water and vanished rods • 11x11 lattices • MOX fuel	Comply	This supplement is intended to address this limitation for GNF3 fuel. GNF3 does not use: • Square internal water channels water crosses • Gd rods simultaneously adjacent to water and vanished rods • 11x11 lattices • MOX fuel GNF3 fuel does not have significant changes in the Gd rod optical thickness

Limitation Number from NRC SE	Limitation Title	Limitation Text	Disposition	Comments
		The acceptability of the modified epithermal slowing down models in TGBLA06 has not been demonstrated for application to these or other geometries for expanded operating domains. Significant changes in the Gd rod optical thickness will require an evaluation of the TGBLA06 radial flux and Gd depletion modeling before being applied. Increases in the lattice Gd loading that result in nodal reactivity biases beyond those previously established will require review before the GE methods may be applied.		or in Gd loading that would result in a nodal reactivity bias beyond those previously established for GE14 fuel.
9.23	MELLLA+ Eigenvalue Tracking	In the first plant-specific implementation of MELLLA+, the cycle-specific eigenvalue tracking data will be evaluated and submitted to NRC to establish the performance of nuclear methods under the operation in the new operating domain. The following data will be analyzed: • Hot critical eigenvalue, • Cold critical eigenvalue, • Nodal power distribution (measured and calculated TIP comparison), • Bundle power distribution (measured and calculated TIP comparison), • Thermal margin, • Core flow and pressure drop uncertainties, and • The MIP Criterion (e.g., determine if core and fuel design selected is expected to	Unchanged	This limitation will be implemented as clarified in Reference 30. It is not affected by fuel type.

Limitation Number from NRC SE	Limitation Title	Limitation Text	Disposition	Comments
		produce a plant response outside the prior experience base). Provision of evaluation of the core-tracking data will provide the NRC staff with bases to establish if operation at the expanded operating domain indicates: (1) changes in the performance of nuclear methods outside the EPU experience base; (2) changes in the available thermal margins; (3) need for changes in the uncertainties and NRC-approved criterion used in the SLMCPR methodology; or (4) any anomaly that may require corrective actions.		
9.24	Plant Specific Application	The plant-specific applications will provide prediction of key parameters for cycle exposures for operation at EPU (and MELLLA+ for MELLLA+ applications). The plant-specific prediction of these key parameters will be plotted against the EPU Reference Plant experience base and MELLLA+ operating experience, if available. For evaluation of the margins available in the fuel design limits, plant-specific applications will also provide quarter core map (assuming core symmetry) showing bundle power, bundle operating LHGR, and MCPR for BOC, MOC, and EOC. Since the minimum margins to specific limits may occur at exposures other than the traditional BOC, MOC, and EOC, the data will be provided at these exposures.	Unchanged	This limitation will be implemented for all fuel types, including GNF3.