December 5, 2006

Andrew A. Lingenfelter, Manager
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Global Nuclear Fuels - Americas, LLC
P.O. Box 780, M/C F12
Wilmington, NC 28402

SUBJECT: FINAL SAFETY EVALUATION FOR GLOBAL NUCLEAR FUEL (GNF) TOPICAL REPORT (TR) NEDE-33214P, "DENSIFICATION TESTING" (TAC NO. MC8679)

Dear Mr. Lingenfelter:

By letter dated October 3, 2005, GNF submitted TR NEDE-33214P, “Densification Testing” to the U.S. Nuclear Regulatory Commission (NRC) staff. By letter dated July 14, 2006, an NRC draft safety evaluation (SE) regarding our approval of NEDE-33214P was provided for your review and comments. By letters dated August 29, 2006, and September 26, 2006, GNF commented on the draft SE. The NRC staff's disposition of GNF’s comments on the draft SE are discussed in the attachment to the final SE enclosed with this letter.

The NRC staff has found that NEDE-33214P is acceptable for referencing in licensing applications for General Electric fueled boiling water reactors to the extent specified and under the limitations delineated in the TR and in the enclosed final SE. The final SE defines the basis for acceptance of the TR.

Our acceptance applies only to material provided in the subject TR. We do not intend to repeat our review of the acceptable material described in the TR. When the TR appears as a reference in license applications, our review will ensure that the material presented applies to the specific plant involved. License amendment requests that deviate from this TR will be subject to a plant-specific review in accordance with applicable review standards.

In accordance with the guidance provided on the NRC website, we request that GNF publish accepted proprietary and non-proprietary versions of this TR within three months of receipt of this letter. The accepted versions shall incorporate this letter and the enclosed final SE after the title page. Also, they must contain historical review information, including NRC requests for additional information and your responses. The accepted versions shall include a "-A" (designating accepted) following the TR identification symbol.

If future changes to the NRC's regulatory requirements affect the acceptability of this TR, GNF and/or licensees referencing it will be expected to revise the TR appropriately, or justify its continued applicability for subsequent referencing.

Sincerely,

**/RA/**

Ho K. Nieh, Deputy Director
Division of Policy and Rulemaking
Office of Nuclear Reactor Regulation

Project No. 712

Enclosure: Final Safety Evaluation

cc w/encl: See next page

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Sincerely,

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**ADAMS ACCESSION NO.: ML062930264 *No major changes to SE input. NRR-043**

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FINAL SAFETY EVALUATION BY THE OFFICE OF NUCLEAR REACTOR REGULATION

TOPICAL REPORT NEDE-33214P, “DENSIFICATION TESTING”

GLOBAL NUCLEAR FUEL

PROJECT NO. 712

## 1.0 INTRODUCTION AND BACKGROUND

In letter dated October 3, 2005, Global Nuclear Fuel (GNF) submitted to the U. S. Nuclear Regulatory Commission (NRC) Topical Report (TR) NEDE-33214P, "Densification Testing," (Reference 1) for review and approval. TR NEDE-33214P describes the intent to eliminate routine testing of pellet densification. The routine testing of pellet densification is described in the NRC Regulatory Guide (RG) 1.126, "An Acceptable Model and Related Statistical Methods for the Analysis of Fuel Densification" (Reference 2). TR NEDE-33214P intends to demonstrate that the elimination of the routine testing of pellet densification will not adversely affect the in-reactor densification performance and the fuel pellets continue to meet licensing criteria of RG 1.126.

Since the discovery of in-reactor densification of oxide nuclear fuel pellets, the impact of the densification on safety has been analyzed routinely in fuel designs and addressed for fuel fabrication. The safety analyses of in-reactor densification include the effects on linear heat generation rate due to the shortening fuel column and creation of axial gaps, fuel stored energy due to the increasing fuel cladding gap, and flattening of the cladding due to the formation of axial gaps along the fuel column. The NUREG-0800, "Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants," Section 4.2 "Fuel System Design," (Reference 3) states that if axial gaps in the fuel column occur due to densification, the cladding has the potential of collapsing into a gap and collapsed cladding is assumed to fail. This phenomenon is called creep collapse.

The in-reactor densification is a function of the temperature, irradiation history, porosity, and material characteristics including initial density. The extent of the in-reactor densification is found to be closely correlated to the out-of-reactor densification tests or thermal sintering tests. A thermal sintering test subjects fuel pellets in a heated furnace to a constant elevated temperature for an extended period of time to simulate the reactor operation. The RG 1.126 states that the thermal sintering tests, also called re-sintering tests, be performed at 1700 °C for 24 hours to ensure a density change that bounds most in-reactor density changes for a wide range of fuel types.

Consistent with the RG 1.126 criteria, GNF established a densification sampling program to systematically re-sinter a statistically significant portion of production fuel pellets to obtain the

densification performance data. The GNF fuel density criteria for fuel designs and fabrication specify the maximum densification allowed for an individual pellet. The GNF fuel density history showed a trend of increasing fuel density and decreasing amount of densification.

## 2.0 REGULATORY EVALUATION

The fuel system consists of arrays of fuel rods including fuel pellets and tubular cladding, spacer grids, end plates, and reactivity control rods. The objectives of the fuel system safety review are to provide assurance that: (1) the fuel system is not damaged as a result of normal operation and anticipated operational occurrences, (2) fuel system damage is never so severe as to prevent control rod insertion when it is required, (3) the number of fuel rod failures is not underestimated for postulated accidents, and (4) coolability is always maintained. The NRC staff acceptance criteria are based on the criteria in Reference 3. These criteria include three parts: (1) design bases that describe specified acceptable fuel design limits (SAFDLs) as depicted in General Design Criterion 10 to Appendix A of Part 50 of Title 10 of the *Code of Federal Regulations*, (2) design evaluation that demonstrates that the design bases are met, and (3) testing, inspection, and surveillance plans that show that there are adequate monitoring and surveillance of irradiated fuel. The design bases include: (1) fuel system damage, (2) fuel rod failure, and (3) fuel coolability. Densification is identified as a failure mechanism that leads to creep collapse of the cladding.

## 3.0 TECHNICAL EVALUATION

### 3.1 Current Approach in Fuel Production

During fuel manufacture, there is a process called sintering that subjects all production fuel pellets to a heated furnace for certain period of time. Although the sintering temperature is close to re-sintering tests, the time involved in the sintering process usually is shorter than the re-sintering tests. The sintering process results in stable and consistent microstructure pellets, which result in less in-reactor densification. Thus, the sintering process is a very important stage during fuel fabrication. The density sampling of the sintered pellets during fuel fabrication is performed to assure that the products meet the density criteria.

In the past, GNF used several processes to produce $UO_2$ powder including the ammonium diuranate (ADU) and wet chemical recovery processes. These processes tended to have uneven powder particles that resulted in variation in the measured densification. Recently, GNF made several fundamental changes to improve $UO_2$ powder and pellet manufacture. GNF established a single $UO_2$ powder production process, the dry conversion process (DCP), which produced even and consistent powder particles. The DCP resulted in stable fuel pellets with highly uniform microstructure and high densification resistance, i.e., very limited densification.

Following the discovery of in-reactor densification and implementation of routine out-of-reactor densification (or re-sintering) testing, GNF found that it was necessary to increase the sintering temperature and time to adequately assure the pellet dimensional stability. In addition, GNF added a volatile pore former during the fuel fabrication. The pore former is an organic material which is added to $UO_2$ and $(U,Gd)O_2$ powder at the blending stage for fuel density control. During the sintering process, the pore former will escape as a gas and create large stable pores in pellets to reach the desired final density. The results show that the pore former improved the

pellet consistency and reduced fuel density uncertainties. GNF continues to use a pore former to produce a high-density fuel matrix with stable pores that are resistant to densification.

GNF has established quality control procedures to assure that the density of all pellets is within the specification criteria. Various documents control the density of natural $UO_2$, $UO_2$, and $Gd_2O_3$-$UO_2$ fuel pellets. Out-of-specification pellets will prompt corrective actions. Figure 1 in TR NEDE-33214P illustrates the historical density criteria of the fuel pellets produced by GNF. GNF manufactures pellets with a high density and therefore the pellets have little propensity for further densification. Thus, the frequent tests and multiple cross checking provide a high level of confidence that out-of-specification pellets will be excluded in the early stages.

Based on the current approach and improved procedures, the NRC staff concludes that GNF has adequately demonstrated that the fuel fabrication has produced consistently stable pellets with low densification and meets all the density criteria.

### 3.2 Elimination of Routine Densification Test

The current GNF fuel fabrication showed a strong correlation between sintered pellets and in-reactor densification performance, i.e., highly sintered and stable fuel pellets had less densification in reactors. GNF will continue the current density sampling of the sintered pellets during fuel fabrication to assure that the products meet the density criteria. Furthermore, GNF will implement additional qualification processes for any change in materials or processes that could have the potential to impact the densification performance. The additional qualification processes will verify the changes and will not result in altering the densification performance and, thus, meet the RG 1.126 criteria.

Since the current approach in the fuel fabrication produces stable and almost no out-of-specification for densification pellets, and the continued quality control checks the production pellet density, GNF contended that routine densification testing was redundant and was no longer needed to assure acceptable in-reactor densification performance. Thus, GNF proposed to eliminate routine densification testing from the fuel fabrication process.

The NRC staff reviewed the GNF proposed approach. Based on the fuel fabrication history and satisfactory in-reactor densification performance, the NRC staff concludes that the routine densification test can be removed from the fuel fabrication process and may be supplemented with additional qualification processes for meeting the RG 1.126 criteria provided that GNF continues the established monitoring program to assure that the pellet density criteria are met using a qualified measurement technique on 100 percent of pellet lots.

## 4.0 CONDITIONS AND LIMITATIONS

Based on the review, the NRC staff requires that GNF continue the established monitoring program to assure that the pellet density criteria are met using a qualified measurement technique on 100 percent of pellet lots. Figure 1 in TR NEDE-33214P depicts the fuel specification limits for pellet density. Any changes to the density specification limits relative to Figure 1 in TR NEDE-33214P which will negatively impact the fuel densification, i.e., a decrease in the nominal pellet density, will require prior approval by the NRC staff.

## 5.0 CONCLUSION

The NRC staff has reviewed the GNF submittal of the proposed elimination of routine densification test. Based on the evaluation, the NRC staff approves the proposed elimination of routine densification test in TR NEDE-33214P with the conditions and limits as described in Section 4.0 of this SE.

## 6.0 REFERENCES

1. NEDE-33214P, "Densification Testing," September 2005 (ADAMS Package Accession No. ML052850035).

2. Regulatory Guide 1.126, Revision 1, "An Acceptable Model and Related Statistical Methods for the Analysis of Fuel Densification," March 1978 (ADAMS Accession No. ML003739385).

3. NUREG-0800, "Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants," Section 4.2 "Fuel System Design."

Attachment: Resolution of Comments

Principle Contributor: S. Wu

Date: December 5, 2006

RESOLUTION OF COMMENTS

ON DRAFT SAFETY EVALUATION FOR

TOPICAL REPORT (TR) NEDE-33214P, “DENSIFICATION TESTING”

By letters dated August 29, 2006, and September 26, 2006 (Agencywide Document Access and Management System Accession Nos. ML062430305 and ML062780232, respectively), Global Nuclear Fuel (GNF) provided comments on the draft safety evaluation (SE) for TR NEDE-33214P, "Densification Testing." The following is the NRC staff resolution of those comments.

GNF Comment:

Section 1.0, Paragraph 1, Line 4: GNF has requested permission to eliminate the routine testing of pellet densification. Currently, GNF samples at a frequency that will assure that our pellets will meet the criteria set forth in Regulatory Guide (RG) 1.126.

NRC Resolution:

The NRC staff agreed to change the line to read: "…routine testing of pellet densification…."

GNF Comment:

Section 1.0, Paragraph 2, Line 1: The impact of fuel densification on the performance of the fuel in the reactor has been thoroughly analyzed. The fabrication process has been engineered so as to manufacture fuel pellets with a consistent, high density to minimize the in-reactor densification in an economical manner.

NRC Resolution:

The NRC staff agreed to change the line to read: "…analyzed routinely in fuel designs and addressed for fuel fabrication."

GNF Comment:

Section 1.0, Paragraph 2, Line 2: The shortening of the fuel column has little impact on the power peaking in the fuel rod. The creation of axial gaps in the fuel column stack causes changes in the moderation in-core.

NRC Resolution:

The NRC staff agreed to change the line to read: "…shortening fuel column and creation of axial gaps, …."

ATTACHMENT

GNF Comment:

Section 1.0, Paragraph 3, Line 3: The operation of the reactor, e.g., flux, power, and time, have the greatest affect on fuel densification in-reactor.

NRC Resolution:

The NRC staff agreed to change the line to read: "…simulate the reactor operation."

GNF Comment:

Section 1.0, Paragraph 4, Line 1: GNF established a sampling program to test for densification consistent with RG 1.126 to assure that the fuel would meet the NRC recommendations for pellet densification.

NRC Resolution:

The NRC staff agreed to change the line to read: "…a densification sampling program to systematically re-sinter a statistically significant.…"

GNF Comment:

Section 3.1, Paragraph 2, Line 2: The fuel manufactured by GNF has consistently met the criteria set forth in RG 1.126. The adjective "large" implies that fuel manufacture by GNF has failed to meet the criteria of RG 1.126. Furthermore, there has been some variation in the measured densification due to GNF's former practice of using different powders and processing. The adjective "various" implies that the densification of the fuel was not well understood.

NRC Resolution:

The NRC staff agreed to change the line to read: "…that resulted in variation in the measured densification."

GNF Comment:

Section 3.1, Paragraph 2, Line 5: The switch to dry conversion process (DCP) powder resulted in fuel with that is highly resistant to densification.

NRC Resolution:

The NRC staff agreed to change the line to read: "…uniform microstructure and high densification resistance...."

GNF Comment:

Section 3.1, Paragraph 3, Line 3: Pore former is used in the manufacture of both $UO_2$ and $(U,Gd)O_2$ fuel to assure that the densification of the sintered pellets is consistent.

NRC Resolution:

The NRC staff agreed to change the line to read: "…added to $UO_2$ and $(U,Gd)O_2$ powder…."

GNF Comment:

Section 3.1, Paragraph 3: Absent the proposed addition, the paragraph may give the impression that GNF no longer uses a pore former to manufacture fuel pellets.

NRC Resolution:

The NRC staff agreed to add the following sentence at end of the paragraph: "GNF continues to use a pore former to produce a high-density fuel matrix with stable pores that are resistant to densification."

GNF Comment:

Section 3.1, Paragraph 4, change from: "Figure 1 in TR NEDE-33214P illustrates this process." to: "Figure 1 in TR NEDE-33214P illustrates the historical density criteria of the fuel pellets produced by GNF. GNF manufactures pellets with a high density and therefore the pellets have little propensity for further densification."

NRC Resolution:

The NRC staff agreed to this change.

GNF Comment:

Section 3.2, Paragraph 1, Line 1: The stability of the microstructure is dependent on the parameters (time and temperature) used to prepare the fuel. GNF manufactures "highly" sintered fuel, which means that we use a high temperature with a sufficient dwell time to create a stable microstructure.

NRC Resolution:

The NRC staff agreed to change the line to read: "…i.e., highly sintered and stable fuel pellets…."

GNF Comment:

Section 3.2, Paragraph 2, Line 1: For clarity the phrase "for densification" was added.

NRC Resolution:

The NRC staff agreed to this change.

GNF Comment:

Section 3.2, Paragraph 2, Lines 1 and 2: For clarity the text was changed to the process rather than the method.

NRC Resolution:

The NRC staff agreed to change the lines to read: "…routine densification testing…."

GNF Comment:

Section 4.0, Paragraph 1, change: "Figure 1 in TR NEDE-33214P depicts the fuel density criteria that will prompt corrective actions for out-of-specification pellets. Any changes in the limits of Figure 1 in TR NEDE-33214P will require a prior approval by the NRC staff."
to: "Figure 1 in TR NEDE-33214P depicts the fuel specification limits for pellet density. Any changes to the density specification limits relative to Figure 1 in TR NEDE-33214P which will negatively impact the fuel densification, i.e., a decrease in the nominal pellet density, will require prior approval by the NRC staff."

NRC Resolution:

NRC staff agreed to this change.