May 31, 2005

Mrs. Margaret Harding, Manager
Nuclear Fuel Engineering
Global Nuclear Fuel
P. O. Box 780
Wilmington, NC 28402

SUBJECT: FINAL SAFETY EVALUATION FOR NEDC-33139P, "CLADDING CREEP COLLAPSE" (TAC NO. MC1798)

Dear Mrs. Harding:

On January 9, 2004, Global Nuclear Fuel (GNF) submitted Licensing Topical Report (LTR) NEDC-33139P, "Cladding Creep Collapse," for U.S. Nuclear Regulatory Commission (NRC) staff review. In this LTR, GNF proposed a revised methodology for cladding creep collapse analysis. On May 9, 2005, an NRC draft safety evaluation (SE) regarding our approval of NEDC-33139P was provided to allow GNF to conduct a proprietary information and factual error review. By letter dated May 23, 2005, GNF replied that there were no issues with the technical content and that there was no proprietary information in the draft SE. This letter transmits the staff's final SE.

The staff has found that NEDC-33139P is acceptable for referencing in licensing applications to the extent specified and under the limitations delineated in the LTR and in the enclosed SE. The SE defines the basis for acceptance of the LTR.

Our acceptance applies only to material provided in the subject LTR. We do not intend to repeat our review of the acceptable material described in the LTR. When the LTR 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 LTR 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 LTR within three months of receipt of this letter. The accepted versions shall incorporate this letter and the enclosed 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 LTR identification symbol.

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

Sincerely,

/RA/
Herbert N. Berkow, Director
Project Directorate IV
Division of Licensing Project Management
Office of Nuclear Reactor Regulation

Project No. 712

Enclosure: Final SE

cc w/encl: See next page

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SAFETY EVALUATION BY THE OFFICE OF NUCLEAR REACTOR REGULATION

NEDC-33139P, “CLADDING CREEP COLLAPSE”

GLOBAL NUCLEAR FUEL

PROJECT NO. 712

1.0 INTRODUCTION

In a letter dated January 9, 2004 (Agencywide Documents and Access Management System (ADAMS) Accession No. ML051230473), Global Nuclear Fuel (GNF) submitted licensing topical report (LTR) NEDC-33139P, “Cladding Creep Collapse,” for NRC staff review and approval. GNF also submitted a non-proprietary version of this report in a letter dated January 9, 2004 (ADAMS Accession No. ML051230474). NEDC-33139P describes a revised methodology for cladding creep collapse analysis. The cladding creep collapse methodology analyzes the potential of flattening a fuel rod within a given time period for fuel designs in licensing applications. Through NEDC-33139P, GNF intends to demonstrate that the revised methodology continues to meet the licensing requirement of no clad flattening for all fuel designs.

Fuel pellets in light water reactors are subject to a densification effect during irradiation. The densification effect increases pellet density, which could result in pellet shrinkage and generate axial gaps along the fuel column. The axial gap size is generally proportional to the amount of densification. The large coolant system pressure causes the cladding to creep inward, closing the fuel-clad radial gap, and eventually collapsing the axial gap. To prevent the cladding from collapsing, the staff requires licensees to perform a creep collapse analysis considering combined effects of coolant pressure, temperature, fast neutron flux, cladding ovality, pellet hangup, and pellet densification. The cladding ovality measures the difference between the maximum and minimum diameters of a tube for quantifying the deviation from tube roundness.

Historically, the creep collapse analysis involves an assumption that depicts a free-standing and hollow tube, i.e., the cladding is unsupported by fuel pellets. The analysis starts with an initial ovality, then the ovality would gradually increase due to the combined effects. When the ovality reaches a critical value of imminent unstable geometry indicating that the tube could no longer maintain its roundness due to a large difference between the maximum and minimum diameters, the tube would deform and collapse during a pressurization event. The condition of imminent unstable geometry is called an elastic instability.

The GNF creep collapse methodology includes three components: (1) basic assumption, (2) supporting modeling, and (3) computer code. The basic assumption, as indicated above, refers to an unsupported cladding. The supporting modeling includes models of fission gas release, effective cladding overpressure, and oxide thickness for input to the creep collapse analysis. The computer code is the GNF creep collapse analytical tool described in

NEDE-20606-P-A, entitled “Creep Collapse Analysis of BWR Fuel Using CLAPS Model,” previously approved by the NRC staff. GNF has been using the CLAPS code to confirm that creep collapse of a free-standing cladding would not occur for all fuel designs. Recently, based on new densification data, GNF proposed to revise the methodology for cladding creep collapse analysis. The revisions to the methodology proposed by GNF only affect the basic assumption and supporting modeling. The CLAPS code remains unchanged.

2.0 REGULATORY BASIS

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 NUREG-0800, “Standard Review Plan (SRP),” Section 4.2 “Fuel System Design.” 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 Title 10 of the *Code of Federal Regulations* (10 CFR), Part 50, (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. Cladding collapse is identified as a failure mechanism and part of the SAFDLs.

3.0 TECHNICAL EVALUATION

As indicated above, the revised methodology includes the basic assumption and supporting modeling. The CLAPS code remains unchanged. This NRC staff evaluation addresses the revisions only.

3.1 Revised Basic Assumption

The basis of the creep collapse mechanism is that fuel pellets could undergo anisotropic densification that results in a large axial gap along the fuel column. During the manufacturing process, various tubing ovalities could occur in the final cladding products. The combination of reactor coolant pressure, operating temperature, and fast neutron fluence will increase the cladding creep, and thus worsen the tubing ovality. If the cladding is assumed to be unsupported by the fuel column, which is a very conservative assumption, the ovality soon becomes large enough to induce elastic instability that leads to cladding flattening or collapse during a pressurization transient.

Through the years, improvements in fuel manufacturing processes have significantly reduced the densification potential, i.e., the maximum densification is controlled to only a few percent in the nuclear industry. The reduced densification potential, together with greater pellet uniformity, reduces the likelihood of large axial gap formation in the fuel column resulting from the in-reactor densification. GNF periodically examined the irradiated fuel for axial gaps using neutron radiography technique. Neutron radiography, similar to x-ray radiography in principle, creates high resolution negative images using thermal neutron source beaming on fuel rods. The resulting neutrograph is an image of the fuel pellets including gaps between pellets. GNF confirmed that the axial gaps in the examined neutrographs were small, as expected. GNF also established a monitoring program to assure no pellet hangup using 100 percent scanning on finished rods during fuel fabrication.

GNF stated that the axial gaps, if they do occur, will be short enough and, in combination with the fuel pellets at each end of the gap, will provide sufficient mechanical support to prevent the cladding from collapsing. Accordingly, GNF revised the basic assumption from a free-standing cladding to a pellet-supported cladding. GNF commits to continue the monitoring program to validate the revised basic assumption.

The NRC staff reviewed densification data including neutrographs. Based on the recent history of no creep collapse observed and supporting densification data, the NRC staff concludes that the revised basic assumption of pellet-supported cladding maintains adequate conservatism, and is therefore acceptable for the creep collapse analysis.

3.2 Revised Supporting Modeling

The revised supporting modeling involves three models: (1) athermal fission gas release, (2) effective cladding overpressure, and (3) oxide thickness.

3.2.1 Athermal Fission Gas Release

The rod internal gas consists of initial helium-filled gas and fission gas released during irradiation. The rod pressure is the result of the accumulation of these gases. Initially, there is only helium gas within unirradiated fuel pins. As the fuel pins are irradiated, fission gas release from the fuel pellets will occur and the fission gas concentration will reach its peak value at the end of the irradiation. There are two components in fission gas release, one is thermal-dependent and another is athermal (non-thermal) -dependent. The athermal fission gas release is usually burnup dependent. For calculating the internal pressure in the fueled cladding in the revised supporting model, GNF selected only one component, the athermal component, from the approved fuel performance GESTR-Mechanical code. For creep collapse analysis, it is a conservative approach to minimize the internal pressure and hence maximize the external pressure.

Based on the approved GESTR-Mechanical code, the NRC staff concludes that the athermal fission gas release model is acceptable for the creep collapse analysis.

3.2.2 Effective Cladding OverPressure

In the approved creep collapse analysis, the external coolant system pressure is the main driving force for the unfueled cladding. The fueled cladding is supported internally by fuel pellets which partially offset the effect of external pressure. The resulting net effect of fuel pellet support and external pressure is the effective cladding overpressure, which becomes the driving force for the fueled cladding.

Based on the standard textbook “Theory of Plates and Shells,” authored by Timoshenko and Woinowsky-Krieger, GNF derived an effective cladding overpressure solution. GNF then calculated the effective overpressure numerically using bounding fuel design parameters. The result showed that the effective overpressure of the fueled cladding is a fraction of the external coolant system pressure. For conservatism, GNF increased the effective overpressure of the fueled cladding, thus increasing the external forces on the cladding used in the safety analysis.

The NRC staff reviewed the GNF technical derivation and solution. Based on the standard textbook results, the staff concludes that the effective cladding overpressure model is acceptable for the creep collapse analysis.

3.2.3 Oxide Thickness

The oxide buildup on the cladding outer surface generally results in high temperature and thinning for the cladding. In the approved creep collapse analysis, GNF assumed a small amount of corrosion. Based on the recent fuel experience including high burnup, long cycle length, and water chemistry, GNF derived a new oxide thickness model with the intention to bound all operating conditions. The new model format is consistent with the model in the approved GESTR-Mechanical code with the new model predicting higher corrosion, which is conservative for the creep collapse analysis. The data base used in the oxide thickness model was derived from measurements performed by GNF on fuel rod cladding under a range of operating conditions, including plant water chemistry.

The NRC staff reviewed the oxide thickness model including data base and found that the model is conservative in predicting the results. Based on the conservative results, the NRC staff concludes that the oxide thickness model is acceptable for the creep collapse analysis.

3.3 Bounding Fuel Design Analysis

To examine the stability in creep collapse analyses, GNF applied an over-pressurization transient at the end of fuel rod lifetime when the cladding ovality reaches its peak. The over-pressurization transient simulates a core wide pressurization event. An increasing ovality after the transient would mean that the cladding becomes elastically unstable and will eventually collapse.

GNF exercised the revised creep collapse methodology using a conservative fuel rod design including mechanical parameters and operating conditions. The selected fuel rod design mechanical parameters bound all existing fuel designs through GE14 and also the next generation fuel design (GNF2). The operating conditions include high burnup regime, high linear heat generation rate, and an over-pressurization transient. The result shows that the cladding ovality reaches its maximum prior to the transient, and then returns to the same value after the transient. The result indicates that there is no elastic instability and thus no cladding collapse occurs for the selected bounding fuel design.

The NRC staff reviewed the analytical results. Based on the conservative mechanical parameters and operating conditions, the NRC staff concludes that the bounding fuel design is acceptable for the creep collapse analysis.

4.0 CONCLUSIONS

In NEDC-33139P, “Cladding Creep Collapse,” GNF has revised the cladding creep collapse methodology that analyzes the potential of flattening a fuel rod within a given time period for fuel designs in licensing applications. The NRC staff has reviewed NEDC-33139P and, based on the staff evaluation discussed above, approves the proposed revised methodology for creep collapse analysis contained in this LTR.

The NRC staff finds NEDC-33139P, “Cladding Creep Collapse,” to be acceptable for referencing in licensing applications. The NRC staff does not intend to repeat our review of the matters described in NEDC-33139P when the report appears as a reference in licensing applications, except to ensure that the material presented is applicable to the specific plant involved. The NRC staff's acceptance applies only to the cladding creep collapse methodology described in NEDC-33139P.

5.0 LIMITATIONS AND CONDITIONS

NEDC-33139P, "Cladding Creep Collapse," is based on generic analyses. The topical report demonstrates that creep collapse will not occur for GNF fuel designs within specified ranges of design and operation parameters. In addition to these recognized conditions in NEDC-33139P, the staff's approval is subject to the following condition:

1. GNF will continue to implement the established monitoring program to assure that no pellet hangup will occur during fuel fabrication using a 100 percent scanning technique on finished rods.

Principal Contributor: S. Wu

Date: May 31, 2005

cc:

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