May 14, 2013

Dr. Brian R. Moore
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SUBJECT: REQUEST FOR ADDITIONAL INFORMATION RE: GLOBAL NUCLEAR FUEL - AMERICAS, LLC (GNF) TOPICAL REPORT (TR) NEDC-33406P, REVISION 2, ADDITIVE FUEL PELLETS FOR GNF FUEL DESIGNS (TAC NO. ME3082)

Dear Dr. Moore:

By letter dated December 18, 2009 (Agencywide Documents Access and Management System Accession No. ML093560115), GNF submitted for U.S. Nuclear Regulatory Commission (NRC) staff review TR NEDC-33406P, Revision 2, "Additive Fuel Pellets for GNF Fuel Designs." Upon review of the information provided, the NRC staff has determined that additional information is needed to complete the review. On May 8, 2013, James F. Harrison, Vice President - Fuel Licensing and I agreed that the NRC staff will receive your response to the enclosed Request for Additional Information (RAI) questions by June 14, 2013. If you have any questions regarding the enclosed RAI questions, please contact me at 301-415-2365 or Stephen.Philpott@nrc.gov.

Sincerely,

/RA/

Stephen S. Philpott, Project Manager
Licensing Processes Branch
Division of Policy and Rulemaking
Office of Nuclear Reactor Regulation

Project No. 712

Enclosures:
1. RAI questions (Non-Proprietary)
2. RAI questions (Proprietary)

cc w/encl 1 only: See next page

NOTICE: Enclosure 2 transmitted herewith contains proprietary information. When separated from Enclosure 2, this document is decontrolled.

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REQUEST FOR ADDITIONAL INFORMATION

BY THE OFFICE OF NUCLEAR REACTOR REGULATION

NEDC-33406P, REVISION 2, "ADDITIVE FUEL PELLETS FOR GNF FUEL DESIGNS"

GLOBAL NUCLEAR FUEL - AMERICAS, LLC

PROJECT NO. 712

By letter dated December 18, 2009, Global Nuclear Fuel (GNF) submitted Licensing Topical Report (LTR) NEDC-33406P, Revision 2, "Additive Fuel Pellets for GNF Fuel Designs" (Agencywide Documents Access and Management System Package Accession No. ML093560114). GNF desires to introduce aluminosilicate (SiO_2:Al_2O_3) additive fuel pellets into its fuel products to increase the reliability and operational flexibility of GNF nuclear fuel. This LTR focuses on the relevant fuel material properties and in-core behavioral characteristics that are affected by the addition of this additive to the UO_2 fuel. The material properties considered include melting, density, thermal expansion, thermal conductivity, grain size and grain strength, stored thermal energy, creep yield strength, elastic modulus, strain hardening coefficient and tangent modulus, plastic Poisson's ratio, and swelling, and were analyzed using GNF's "PRIME" thermal-mechanical code.

The NRC staff has reviewed LTR NEDC-33406P, Revision 2, and has determined that additional information is needed to complete its evaluation. Please provide the following additional information with regard to the indicated sections of the LTR.

1. Section 1.0 - Introduction

Table 1-1 indicates that the target range of concentration in percent by weight (wt%) ([ ]) and composition of SiO_2:Al_2O_3 by weight (wt) ([ ]) are [ ] for the American Society for Testing and Materials (ASTM) C776-00 impurity limits ([ ]). Please explain the discrepancy between this and your statement that the impurity level "[ ]."

ENCLOSURE 1

2. Section 2.0 - Material Properties

The opening paragraph of this section states that "some calculations in the PRIME methodology require gadolinia content as an input. [ ]"

Please clarify whether [ ]?

3. Section 2.2.1 - Melting Temperature Overview

The LTR states, "[ ]" Please provide the test methods, test results, and corresponding database to support GNF's claim that [ ] Please explain the meaning of "[ ]"

4. Sections 2.2.1 and 2.2.3

(a) Please explain in detail the "[ ]" that is referred to in these sections.

(b) Please provide the database that is the basis for Figure 2-9.

(c) Figure 2-9 is plotted for zero exposure and no gadolinia content. Please explain in detail, the impact of exposure and gadolinia content on the behavior of UO_2 fuel with additives (aluminosilicate compounds).

(d) Please provide details of the experiment that determined "[ ]" and its associated database.

5. Section 2.4 - Thermal Expansion

Figure 2-13 illustrates the strain as a function of temperature for non-additive fuel and additive fuel with an additive concentration of [ ].

(a) Please discuss the behavior of the additive fuel at other concentrations of additive above and below the [ ].

(b) What is the effect of adding gadolinia to the additive fuel with regard to thermal expansion?

6. Section 2.5 - Thermal Conductivity

(a) Figure 2-14 of Section 2.5 illustrates the behavior of thermal conductivity of unirradiated non-additive and additive fuel as a function of temperature from PRIME and experiments. Please provide the results for irradiated non-additive and additive fuel for various concentrations of additive (aluminosilicate).

(b) If [ ], what is the impact on thermal conductivity of unirradiated and irradiated fuel?

7. Section 2.6 - Grain Size and Growth

   Section 2.6.1 of NEDC-33406P describes the grain growth model for gadolinia ((U,Gd)O_2). Please provide data comparisons for this model that predicts grain growth for UO_2 and UO_2 – Gd_2O_3. If this model is applied explicitly to additive UO_2 fuel with Al_2O_3-SiO_2, provide the results to show how well the grain growth model will predict the grain growth.

8. Section 2.7 - Stored Energy

   Please provide detailed results from the model that calculates the fuel stored energy in the presence of aluminosilicate additive for various additive concentrations. How are the results from this model [ ] in addition to aluminosilicate?

9. Sections 2.8 through 2.14

   (a) Some sections state that uniaxial compression and other tests have been performed to determine creep and other characteristics of [ ]. Also this section states that [ ]. Has GEH tested UO_2 fuel with [ ]? If not, what are the plans to test the fuel with both additives?

   (b) Please provide results from tests and the related database that will confirm the implications of the expected behavior of the Al-Si-O additive in UO_2 fuel on the High Burnup Structure stated in points 1 through 5 in Section 2.14 of NEDC-33406P, Revision 2.

10. Section 3.3 - Reactivity Insertion Accident Characteristics

    (a) This section indicates that the additive compositions tested include [ ]. Please provide information to show that these additives are similar to the aluminosilicate that is the subject of LTR NEDC-33406P, Revision 2.

    (b) Please provide complete details of the tests discussed in this section, including the procedures, type of additive fuels tested, and the results obtained from the tests. Show that the test results clearly simulate the behavior of aluminosilicate as an additive.

11. Please provide the results from PRIME analysis of theoretical density of UO_2, and (U,Gd)O_2 fuel with and without aluminosilicate additive at different concentrations.

12. Section 3.4 - In-Reactor Densification

    GEH states that the methodology for densification testing and qualification of additive fuel will follow the approved methodology for standard UO_2 fuel as described in LTR NEDE-33214P-A, "Densification Testing," dated February 2007. NRC approval of NEDE-33214 is subject to a condition 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." Please describe how this condition is met for the additive fuel and provide the details of the test measurements and the results from these measurements.

13. Section 5.1 - Licensing Criteria Assessment - Fuel Melting

    (a) Please provide the details of the analysis procedure to determine the additive fuel pellet centerline temperature for the bounding licensed duty fuel rod using PRIME.

    (b) Explain how the fuel system damage criteria and fuel failure criteria per Standard Review Plan 4.2 (NUREG-0800, Section 4.2) are satisfied for the additive fuel.

14. Section 5.3 - Cladding Plastic Strain

    Please provide details of the analysis and results that show that the cladding circumferential strain does not exceed the [ ] for the additive fuel.

15. Section 5.7 - Impact of Nuclear Design Requirements

    Please provide details of the analysis and results that show compliance with Title 10 of the *Code of Federal Regulations* Part 50, Appendix A, General Design Criteria (GDC) 11. GDC 11 stipulates that the reactor core and associated coolant systems shall be designed so that in the power operating range the net effect of the prompt inherent nuclear feedback characteristics tends to compensate for a rapid increase in reactivity. Discuss the impact of additive fuel on the key reactivity coefficients and confirm that there is no adverse impact on reactor operation.

The Pacific Northwest National Laboratory staff has been performing confirmatory calculations to verify the results provided in the LTR. The following additional information is needed to complete this evaluation of the LTR.

16. Please provide more details about how the acceptable concentration of additive from ASTM C776-00 impurity limits is derived. ASTM C776-06 specifies 250 ppm Al and 500 ppm Si.

17. The following are concerning models that are noted in the submittal to have been compared to data from fuel with additives; however, no actual data have been provided to verify that the proposed model adequately represents the additive fuel data.

    a. Please provide a comparison of yield strength data for additive fuel to the model for yield strength, identifying the concentration and ratio of $Si:Al_2O_3$. Of particular concern are the high temperature predictions. For example, the PRIME model [ ] Page 2-36 states that yield strength has a strain rate dependence; however, the model provided (Equation 2-23) does not include a strain rate dependence. Please explain why this is acceptable. How does the code determine when to switch from Equation 2-28 and implement the creep model? What is the ductile brittle transition temperature assumed for additive fuel?

b. Please provide a comparison of elastic moduli data for additive fuel to the elastic moduli model, identifying the concentration and ratio of $Si:Al_2O_3$ for each set of data.

c. Please provide a comparison of fuel rim formation (thickness) data from high burnup additive fuel to the UO_2 model for rim formation, identifying the concentration and ratio of $Si:Al_2O_3$ for each set of data. Also, provide data to show that the structure and chemical concentration of the $Si:Al_2O_3$ does not change on the (old) grain boundaries in the rim due to restructuring.

d. Section 3.4 suggests that both in-reactor densification and swelling are expected to be the same as for UO_2. Both densification and swelling are easily determined from fuel measurements. Please provide a comparison of fuel densification data at low burnups for additive fuel (both ex-reactor and in-reactor) to the UO_2 fuel densification model, identifying the concentration and ratio of $Si:Al_2O_3$ for each set of data. Please provide a comparison of fuel swelling data for additive fuel at high burnups to that for UO_2.

18. The following are related to licensing analyses with additive fuel.

a. What grain size (identify whether 3-D or mean linear intercept (MLI)) is assumed for additive fuel in relation to fission gas release and cladding strain for licensing analyses? [ ] Please confirm that this is the case for additive fuel. Page 2-28 states that a much larger limiting grain diameter is set in PRIME. Please provide a description of how the fission gas release model is applied for additive fuel.

b. Does the grain growth model impact licensing analyses? If so, what grain growth coefficients are used for additive fuel? Are they the coefficients for $(U,Gd)O_2$? If grain growth impacts licensing analyses, please provide a comparison of grain growth data to PRIME predictions from power ramped rods. (Grain growth is easily measured from micrographs.)

c. Section 5.6 provides difference in licensing predictions between additive and non-additive fuel. Please provide comparisons of stored energy for a plant where loss-of-coolant-accident peak cladding temperatures are limiting due to stored energy and/or where stored energy is high.

19. Section 6.2, Page 6-3 suggests that fuel relocation (or residual remaining gap after relocation) is significantly different (factor of 2) for additive fuel than for UO_2, however, no additive fuel relocation model is provided. Does this mean PRIME utilizes the UO_2 relocation model? If so please explain why this is acceptable given the discussion that relocation is significantly different between these two fuel types. Could the difference in gap size be due to fuel densification and/or swelling?

20. The LTR states that: “The additive fission gas release [FGR] data are well within the scatter of the non-additive data.” [

] Fuel rods with high release are those of primary concern in a core because these rods are those with limiting rod internal pressure. [

] Please provide the terminal ramp powers for the IFA-635 rods. Also, for the non-power ramped rods (NFD [Nippon Fuel Development] Halden and NUPEC [Nuclear Power Engineering Corporation] Step 3 lead use assembly tests) provide the maximum rod power (peak and average) at beginning, middle and latter one third of irradiation.

21. The following are related to demonstrating that pellet-clad interaction (PCI) and cladding strain criteria are met for additive fuel.

a. There is very little cladding strain data from additive fuel, particularly for power ramped rods which are of interest for verifying cladding strain predictions during anticipated operational occurrence (AOO) events. [

] This makes it difficult to assess the appropriateness of the calculations in Section 5.3 that show a large margin to the mechanical overpower (MOP) limit with additive fuel, when there are no assessments of ramped rods where large strains are measured, and those that are provided are underpredicted. Please identify each ramp tested data shown in Figure 6-2 with additive concentration, Si:Al_2O_3 ratio and terminal power hold times. Are the ramp terminal powers rod average or axial peak powers? Please provide measured (usually measured following a ramp test) and predicted plastic strains for these ramped rods (Figure 6-2). Are the axial locations provided in Table 6-1 axial peak locations?

b. Please provide a plot of delta power change at the terminal power versus exposure for the data presented in Figure 6-2 (peak terminal power plotted) because PCI thresholds have been shown to also be dependent on delta power change.

c. Will additive fuel with and without barrier cladding have different LHGR operating limits than non-additive fuel with and without barrier cladding to prevent PCI failures?

d. Pages 6-6 and 6-7 suggest that PCI resistance of additive fuel as compared to UO_2 is due to the increased retention of fission products on the grain boundaries and further notes that this is confirmed from electron probe micro-analysis (EPMA) data. Please provide this EPMA data for cesium and cadmium comparing it to UO_2 EPMA data with similar in-reactor operation. Also, provide krypton-85 EPMA data for additive and non-additive fuel, if measured. Was any micro-gamma scanning performed across the fuel radius of irradiated additive pellets? If so, please provide this data.

e. Was the amount of dish filling or axial fuel column increase measured in the power ramped rods with additive and non-additive fuel? If so, please provide this data as this provides a measure of the amount of fuel creep experienced during these tests that can be used to confirm fuel creep model differences between additive and non-additive fuel for an AOO event.

f. What was the assumed grain size for PRIME cladding strain analyses of the ramped rods?

g. Permanent strain values for setting the MOP limit provided in Figure 5-3 do not reflect the differences in [

] Please provide a figure of margin to strain limit for a given MOP limit as a function of exposure.

22. The following are related to clarifying the equations given in the LTR.

a. The PRIME thermal conductivity model does not appear to be valid for the case with no Gd_2O_3 and zero burnup. In this case, the parameter χ is 0, which leads to undefined values for K in equation 2-11 and 2-12. Please provide details for how the thermal conductivity of unirradiated UO_2 is calculated.

b. The value of thermal conductivity calculated by the PRIME model appears to [

] Please confirm this behavior of the model and explain how this is acceptable.

c. The variable, ρ, in the equation on Page 2-42 is not defined. Based on its use, it is assumed that this variable is the percent theoretical density (as-fabricated?) of the fuel pellet. Please confirm this assumption.

d. The value of the modulus of elasticity of $(U,Gd)O_2$ at room temperature, E_U, in equation 2-26 is not provided. Please provide this value.

23. Section 2.14, Page 2-44 and Section 3.3 suggest that the existence of $Si:Al_2O_3$ on grain boundaries will result in similar behavior to non-additive fuel in a reactivity insertion accident (RIA). It appears that the RIA tests provided in Figure 3-6 for additive fuel utilized fresh fuel (no base irradiation, essentially zero burnup). Is this interpretation correct? It is known that the increase in fission gas bubbles on the grain boundaries with burnup has a significant impact on fuel dispersal when the cladding fails during a RIA. Because the $Si:Al_2O_3$ also exists on the grain boundaries and weakens this boundary there may be some interaction of the fission gas/products with $Si:Al_2O_3$ that could impact the strength of the grain boundaries, which in turn may lead to an increase in additive fuel dispersal. This scenario is reasonable considering that EPMA measurements suggest that cesium is retained in larger amounts on the grain boundaries than for UO_2 due to the presence of $Si:Al_2O_3$ on the grain boundaries of additive fuel. In addition, the Electric Power Research Institute (EPRI) December 2010 technical report number 1021036, "Fuel Reliability Program: Proposed RIA Acceptance Criteria," suggests that mixed oxide (MOX) fuel has a significant amount of gaseous swelling during a RIA that reduces the RIA failure threshold compared to that for UO_2. MOX fuel has a similar situation to additive fuel where a significant number of gas bubbles exist within a matrix (PuO_2) of MOX that has a higher creep rate than UO_2. The EPRI report suggests this will lead to greater gaseous swelling than for UO_2. The additive fuel has a significant amount of gas bubbles on the grain boundaries with $Si:Al_2O_3$ that also exhibits a high creep rate. Have out-of-reactor fast heating tests been performed on high burnup additive and non-additive fuel to demonstrate similarities or differences in grain boundary strength? Are there other tests that could be used to examine grain boundary strength of high burnup additive fuel?

24. Please provide the radial volume fraction of additive fuel melt versus fuel radius at the peak axial temperature locations for thermal overpower and MOP limits. The weight of the fuel column is significant for a 12-foot length. Has fuel slumping for additive fuel been examined for full-length (12-foot) fuel columns?

25. Page 3-3 notes that corrections were made to the fuel oxidation data to account for the effect of surface defects. Please explain how this was done. How many additive pellets prototypic of those for commercial reactor operation have been examined for to confirm that no surface defects exist in production additive fuel? It appears that the cause of the surface defects is unknown. Will sampling be performed on production fuel batches of additive fuel to confirm that no surface defects exist?

26. The following are related to the fuel creep model and how it is applied in the code.

a. It is noted that a large increase in the magnitude of creep model predictions exists between fuel with no additives and fuel with additives. This difference is especially large at high stress values relevant to AOO conditions. For example, at high stress and high temperature the model predicts a [ ] Please provide data to justify the use of [ ]

b. Please provide measured creep strains versus time for temperatures of 1673K at approximately 4 kilo-pounds per square inch (ksi) stress [ ], 1573K at approximately 6 ksi stress [ ] 1473K at approximately 9 ksi [ ], and 1673K at approximately 5 ksi stress [ ] Also provide the model predictions for this data.

c. In order to conserve fuel mass, where does the code assume the fuel moves if it does not expand in the radial or hoop directions when hard contact is established between the fuel and cladding? Does it expand in the axial direction or by dish filling once a fraction of the as-fabricated porosity is filled? Has this movement of the fuel been confirmed experimentally?