April 17, 2002

Lynette Hendricks
Director, Licensing
Nuclear Energy Institute
Suite 400
1776 I Street, N.W.
Washington, DC 20006-3708

SUBJECT: REQUEST FOR ADDITIONAL INFORMATION (RAI) REGARDING HIGH BURNUP FUEL CHARACTERISTICS

Dear Ms. Hendricks:

On March 5, 2002 staff from the Spent Fuel Project Management Office (SFPO) met with staff from the Nuclear Energy Institute (NEI), the Electric Power Research Institute (EPRI) and industry representatives to discuss the report entitled, “Creep Modeling and Analysis Methodology for Spent Fuel in Dry Storage.” This report, along with the two NEI reports concerning the characteristics of high burnup fuel that were previously submitted, provided the staff with significant technical information on the role of creep with respect to spent fuel cladding integrity under normal and off-normal spent fuel storage conditions. The staff understands from earlier discussions with NEI and EPRI that these three reports were not intended to address accident conditions of storage.

During the March 5th meeting, the SFPO staff stated that it would provide a set of questions to NEI based on its review of the report and consideration of other issues related to the storage of high burnup fuel. Accordingly, enclosed is the Request for Additional Information which addresses the subjects of potential fuel reconfiguration during accident conditions and the overall risks of storing high burnup fuel.

After NEI and EPRI staffs have reviewed the questions, I suggest that we have a conference call to discuss your schedule for providing responses to the questions. Additionally, I suggest that we identify potential dates for future meetings to discuss the technical issues as necessary.

We appreciate your efforts on this difficult high priority issue and look forward to continued interaction with you.

Sincerely,

/RA/

M. Wayne Hodges, Deputy Director
Technical Review Directorate
Spent Fuel Project Office
Office of Nuclear Material Safety
and Safeguards

Enclosure: Request for Additional Information

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Enclosure: Request for Additional Information

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REQUEST FOR ADDITIONAL INFORMATION

In accordance with 10 CFR 72.128(a), spent fuel storage systems, and other systems that might contain or handle radioactive materials associated with spent fuel, must be designed to ensure adequate safety under normal and accident conditions. Further, the regulations state that these systems must be designed with suitable shielding for radioactive protection, confinement structures and systems, and a heat-removal having testability and reliability consistent with its importance to safety. The regulations of 10 CFR 72.124 require that spent fuel handling, packaging, transfer and storage systems assure subcriticality under all conditions of storage. The regulations under 10 CFR 72.104 and 72.106 contain radiation protection standards for the public and the worker that must also be met under normal and accident conditions. Additionally, the regulations of 10 CFR 72.122(h)(1), 72.122(l) and 72.236(m) require that the storage system must be designed to allow ready retrieval of the spent fuel from the storage system for further processing or disposal.

At this point in time, it is conceivable that if hydride reorientation were to occur over 20 years of storage (when the fuel is cooler, e.g., 150-200°C), the ductility and fracture properties of the high burnup fuel cladding could become degraded. Accordingly, the following questions are being asked to address the effects that stresses, generated during hypothetical accident conditions (such as a tip over accident), may have on the ability of the storage system to meet the regulatory requirements described above.

A. <u>NEI's RAI Response (Letter from Lynnette Hendricks (NEI) to M. Wayne Hodges (NRC), dated 8/26/2001)</u>

The NEI response to NRC RAI question B-2 seems to indicate that radial reorientation of hydride precipitates could potentially occur at temperature of approximately 400 ^{o}C and stresses between 100- 150 MPa. The response also cites the original paper that concludes that delayed hydride cracking can be ruled out based on fracture mechanics considerations.

1. Clarify the basis for the statement "*During dry storage, the rate of precipitation of radial hydrides is a function of the drop in the solubility limit with temperature, which is no more than a few ppm per month"* which is in the last paragraph of the response. Considering that dry storage lasts 20+ years, identify the specific dry storage periods of time and the corresponding stress-temperature combination(s) that could lead to the formation of radially oriented hydrides.

2. Considering that dry storage conditions could bracket these conditions, at least for a finite period, discuss any kinetics data or other data that illustrate the role of time as well as that of amount of hydrides at a given temperature and stress. For example, are there data that indicate the fraction of hydrides that are re-oriented during a given time period for a given stress and temperature? If such data exist, show how can they be correlated with the concurrently and continuously decreasing temperature and stress which is prevalent during dry storage.

3. Garde et. al. ("Effects of Hydride precipitate localization and neutron fluence on the ductility of irradiated zircaloy-4", Zirconium in the nuclear industry, 11th Intl. Symp., ASTM STP 1295, pp. 407-430 (1996)) have reported a burst strength of 480 MPa for a

(5-cycle Calvert Cliff fuel rod) for a single specimen with spalled oxide. Samples that did not have spalled oxide had burst strength between 860 and 1010 MPa. Discuss the significance of this one strength value of 480 MPa with respect to potential hydride reorientation, if any. Indicate the thickness for the cladding that was used in calculating the burst strength of the spalled oxide. If it was not based on reduced cladding thickness to account for the oxide, then discuss the relevance of this one datum value. Also, discuss whether failure analyses were carried out to ascertain the origin of failure and whether it was hydride-related. Discuss the significance of this value with respect to the behavior of zircaloy consisting of hydride lenses. Describe literature information that correlates the strength of zircaloy cladding as a function of the ratio of radial to circumferential orientation, if it is available. Since the hydrides potentially could have higher Young's modulus, E, than zircaloy, discuss the functional dependence of E with the hydrogen content and hydride orientation.

Attachment 2. "Creep as the governing mechanism of spent fuel in dry storage", paper by Y.R. Rashid and A.J. Machiels."

4. Justify that the hoop stress of the cladding material under a hydride lens will remain well below two-thirds of the material's irradiated yield strength. Justify that cracks will not initiate in spalled cladding even if the hydrides reorient in the radial direction during dry storage conditions.

As Figure 4 shows, in such a representation to simulate the region of hydride lens, the cladding stress elevates from about 138 MPa to about 230 MPa, initially. If Garde et. al.'s data were applicable then this represents approximately 48% of the reported burst strength of 480 MPa for the spalled cladding. However, the yield strength for the spalled cladding was not reported and could have been lower than the reported burst strength. Thus, the cladding stress at the hydride lens region could either approach or exceed 2/3 of the yield strength.

B. Letter from Lynnette Hendricks (NEI) to E. William Brach (NRC), dated 10/02/01, transmitting report entitled "Creep Modeling and Analysis Methodology for Spent Fuel in Dry Storage"

1. (Waiting for Srini to reply to my question about the meaning of this question.) The statements in the last paragraph on page 23 are confusing. The staff is not sure how the suggested test would provide data to predict the capability of the cladding to withstand subsequent loading challenges, perhaps during retrieval. If the authors suggest that plastic regime during creep begins at the tertiary stage, then considering that during dry storage, because of the nature of the continuous and concurrent decrease in both temperature and stress, discuss how the suggested test will provide information that will be helpful to gain insight into the handleability of dry-stored fuel. Moreover, clarify how can tensile strength alone be expected to provide sufficient information on the handleability of a potentially "brittle" material. Accordingly, in a graphical format provide a summary of the mechanical properties for high burnup fuel cladding including, as a minimum, yield strength, tensile strength, elongation (total and uniform), hardness, and some form of (pseudo) usable fracture toughness as a function of temperature and hydrogen concentration.

2. On page 29, it has been stated that a 40 ^{o}C temperature rise during vacuum drying has been superimposed on all cases covered in Table 6. Clarify how the rate of change of temperature with time, $\Delta T/\Delta t$, during ramp up and ramp down was treated for creep calculations. Discuss the fractional contribution of the creep during this drying stage to the overall creep during dry storage.

3. Please elaborate on the technical meaning and significance of peak strain, mentioned in Table 7, and its relevance for dry storage.

4. Quantify the percentage of fuel pin failures, and the associated uncertainty, caused by stresses imparted to the high burnup fuel under hypothetical accident conditions (such as a cask tip over event) on a per storage cask basis.

   Since the applicant is requesting to store high burnup fuel with spalled rods (with a calculated maximum hoop stress of 66% of the yield strength), the effect of any additional stress on the cladding due to the stress state imparted to the cladding under a hypothetical drop accident should be additive to the hoop stress at the temperature of the cladding during the hypothetical accident. The staff considers the approach used in Appendix III of the SAND-90-2406 report, “A Method for determining the Spent Fuel Contribution to Transport Cask Containment Requirements,” to be acceptable to quantify the percentage of fuel pin failures under hypothetical accident conditions of storage. Since there is limited data for the fracture toughness and mechanical properties of high burnup fuel, the applicant should consider using a range of properties (e.g., fracture toughness, ductility, etc.) and fuel characteristics (e.g., critical flaw size, reduction in wall thickness due to oxidation and hydride rim formation) consistent with properties and characteristics that are available in the literature including the data that have measured degraded properties of high burnup fuel. A list of references should be provided along with the analysis.

5. Based on the responses provided to the preceding RAI questions, quantify the risks (i.e., assess and describe the probabilities and consequences), in terms of the total dose received by the worker and the public, associated with the storage of high burnup fuel. Specifically, assess the risks for each of the following conditions:

   (a) the ability of the high burnup fuel to be handled and retrieved from the canister in accordance with 10 CFR 72.122(h)(1), 72.122(l) and 72.236(m);

   (b) the storage system to perform its intended criticality, shielding, and confinement functions under normal conditions of storage in accordance with 10 CFR Part 72.104, 72.124, and 72.128(a); and

   (c) the storage system to perform its intended criticality, shielding, and confinement functions under hypothetical accident conditions of storage in accordance with 10 CFR Part 72.106, 72.124, and 72.128(a).

   An acceptable analysis could be conducted to assess the risks by considering a leak-before-break failure mechanism or potential fuel reconfiguration and their impacts on the integrity of the confinement boundary, shielding features, and criticality. This analysis could be used to demonstrate that any degradation of high burnup fuel during storage would not result in increased risk to the public or worker.

6. Under normal and hypothetical accident conditions, evaluate the safety margins that can be expected using, for example, fracture mechanics considerations for three cases where one assumes (1) radial orientation of hydrides in an unspalled region of the cladding, (2) the occurrence of several spalled regions over the length of the cladding (no radially oriented hydrides), and (3) the potential for a crack which originates from the inside of the cladding and propagates into a region containing a hydride lens. In the analysis, assume the hoop stress is additive to any stress imparted to the fuel during an hypothetical accident event (such as a cask tip over). Assume the worst-type flaw characteristics and assume no allowance for the potential ductility effects to blunt the crack. Also, provide information regarding the type of failure that can be expected in such a scenario, viz., pin-hole, hairline crack, fish-mouth, long running crack, etc.