December 6, 2006

MEMORANDUM TO: E. William Brach, Director
Spent Fuel Project Office, NMSS

THROUGH: William H. Ruland, Deputy Director
Licensing and Inspection Directorate
Spent Fuel Project Office, NMSS

Edwin Hackett, Deputy Director
Technical Review Directorate
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FROM: Gordon Bjorkman, Chief /RA/
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SUBJECT: PROPOSED INTERIM STAFF GUIDANCE MEMORANDUM NO. -1, DAMAGED SPENT NUCLEAR FUEL, REVISION 2

Attached is draft Interim Staff Guidance (ISG) No. 1, “DAMAGED SPENT NUCLEAR FUEL,” Revision 2, for issuance for public comment. This ISG provides the staff’s position concerning classifying spent nuclear fuel as either (1) damaged, (2) undamaged, or (3) intact prior to interim storage or transportation. This ISG will be used in conjunction with NUREG-1536, “Standard Review Plan for Dry Cask Storage Systems,” January 1997; NUREG-1567, “Standard Review Plan for Spent Fuel Dry Storage Facilities,” March 2000; and NUREG-1617, “Standard Review Plan for Transportation Packages for Spent Nuclear Fuel,” March 2000, until such time as this ISG is incorporated into these NUREGs.

This ISG has been reviewed by the Spent Fuel Project Office Technical Review and the Licensing and Inspection Directorates staff members. All comments received have been dispositioned; therefore, we recommend that this draft ISG be issued for public comment.

Enclosure: ISG-1, Rev. 2

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Spent Fuel Project Office
Interim Staff Guidance - 1, Revision 2
DAMAGED SPENT NUCLEAR FUEL

Issue

This Interim Staff Guidance (ISG) provides guidance to the staff on classifying spent nuclear fuel as either (1) damaged, (2) undamaged, or (3) intact, before interim storage or transportation. This is not a regulation or requirement and can be modified or superseded by an applicant with supportable technical auguments.

Regulatory Basis

Fuel-Specific Regulations:

A fuel specific regulation means a characteristic or performance requirement of the fuel specifically named in the applicable Code of Federal Regulations (CFR). These are regulations that specify capabilities that the spent nuclear fuel (SNF) must have. Examples include:

10 CFR 71.55(d) states, in part: "A package used for the shipment of fissile material must be so designed and constructed and its contents so limited that under the tests specified in 10 CFR 71.71 ('Normal conditions of transport')"

(1) The contents would be subcritical.
(2) The geometric form of the package contents would not be substantially altered."

10 CFR 72.44(c) states, in part "Technical specifications must include requirements in the following categories: (1) Functional and operating limits ... (I)... for an ISFSI or MRS are limits on fuel or waste handling and storage conditions that are found to be necessary to protect the integrity of the stored fuel or waste container, to protect employees against occupational exposures and to guard against the uncontrolled release of radioactive materials..."

10 CFR 72.122(h)(1) states: "The spent fuel cladding must be protected during storage against degradation that leads to gross ruptures or the fuel must be otherwise confined such that degradation of the fuel during storage will not pose operational safety problems with respect to its removal from storage. This may be accomplished by canning of consolidated fuel rods or unconsolidated assemblies or other means as appropriate."

10 CFR 72.122(l) states: "Retrievability. Storage systems must be designed to allow ready retrieval of spent fuel, ... for further processing or disposal."

System-Related Regulations:

A transportation and storage system must satisfy all applicable regulations in 10 CFR Parts 71 or 72. A system-related regulation is a performance requirement placed on the fuel for the system (i.e., transportation or storage cask) to meet a regulation that does not specifically require performance capabilities of the SNF. Examples include:

10 CFR 71.55(e) states in part: "A package used for the shipment of fissile material must be so designed and constructed and its contents so limited that under the tests specified in 10 CFR 71.73 ('Hypothetical accident conditions'), the package would be subcritical." Note: This regulation does not place a specific requirement on the SNF. However, if the package requires the SNF to maintain its geometric configuration to ensure subcriticality, then a function is imposed on the SNF.

10 CFR 72.122(h)(5) states: "The high-level radioactive waste and reactor-related GTCC waste must be packaged in a manner that allows handling and retrievability without the release of radioactive materials to the environment or radiation exposures in excess of Part 20 limits..."

10 CFR 72.124(a) states: "Design for criticality safety. Spent fuel handling, packaging, transfer, and storage systems must be designed to be maintained subcritical and to ensure that, before a nuclear criticality accident is possible, at least two unlikely, independent, and concurrent or sequential changes have occurred in the conditions essential to nuclear criticality safety. The design of handling, packaging, transfer, and storage systems must include margins of safety for the nuclear criticality parameters that are commensurate with the uncertainties in the data and methods used in calculations and demonstrate safety for the handling, packaging, transfer, and storage conditions and in the nature of the immediate environment, under accident conditions". Note: If the SNF must have certain characteristics or behave in a specified manner to maintain the required margins, a function is placed on the SNF.

10 CFR 72.128 states in part: "Spent fuel storage ... must be designed to ensure adequate safety under normal and accident conditions. These systems must be designed with (2) suitable shielding for radioactive protection under normal and accident conditions, (3) confinement structures and systems..." Note: If proper functioning of the shielding or containment requires that the SNF maintain its configuration, then a function is placed on the SNF.

Applicability

This guidance applies to reviews of dry cask storage systems and transportation casks conducted in accordance with NUREG-1536, "Standard Review Plan for Dry Cask Storage Systems" (January 1997); NUREG-1567, "Standard Review Plan for Spent Fuel Dry Storage Facilities" (March 2000); or NUREG-1617, "Standard Review Plan for Transportation Packages for Spent Nuclear Fuel" (March 2000). This revision of ISG-1 supersedes any definitions of damaged, grossly damaged, or intact fuel in the above Standard Review Plans.

This revision supersedes ISG-1, Revision 1, in its entirety, and is applicable to both as-built and reconstituted fuel assemblies.

Definitions

1. Spent Nuclear Fuel (SNF) - See 10 CFR Part 72.3 for definition. This term has been used in the nuclear industry, at different times, to mean the fuel pellets, the rod, or entire fuel assembly. Unless specifically modified, the term will refer to both the rods and fuel assembly.

2. Damaged SNF - Any fuel rod or fuel assembly that can not fulfill its function.

3. Undamaged SNF - SNF that can meet all fuel-specific and system related functions. As shown in Figure 1, undamaged fuel may be breached.

4. Breached spent fuel rod - Spent fuel rod with cladding defects that permit the release of gas from the fuel rod. A breach may be limited to a pinhole breach or hairline crack, or may be a gross breach.

5. Pinhole leaks or hairline cracks - Minor cladding defects that will not permit significant release of particulate matter from the spent-fuel rod, and therefore present a minimal, as low as is reasonably achievable, concern, during fuel handling and retrieval operations. (See discussion of gross defects for size concerns.)

6. Grossly breached SNF rod - A subset of breached rods. A breach in spent-fuel cladding that is larger than a pinhole leak or a hairline crack. An acceptable examination for a gross breach is a visual examination that determines the fuel pellet surface may be seen through the breached portion of the cladding. (See discussion for size concerns.)

7. Intact SNF - Any fuel that can fulfill all fuel-specific and system-related regulations, and that is not breached. Note that all intact SNF is undamaged, but not all undamaged fuel is intact, since under most situations, breached spent fuel rods that are not grossly breached will be considered undamaged.

8. Damaged fuel can - A metal enclosure that is sized to confine one damaged spent-fuel assembly. The can must be designed so that all the following requirements are met: (a) the can, with its contents, is readily retrievable[1] from the dry storage system using normal spent fuel handling methods (e.g., crane and grapple); (b) the can, with its contents, is removable as a unit from a dry storage system;(c) there is no potential for adverse chemical, galvanic, or other (e.g., pyrophoric) reactions; and (d) the can design facilitates draining, drying, and back-filling. Note: The can may use a mesh screen to achieve gross particulate confinement, but still allow water drainage, depending on the system-related functional requirements.

9. Assembly Defect - Any change in the physical as-built condition of the assembly with the exception of normal in-reactor degradation such as elongation from irradiation growth or assembly bow. Examples include: (a) missing rods; (b) broken or missing grids or grid straps (spacers); and c) missing or broken grid springs, etc. An assembly with a defect is damaged only if it can't meet its fuel-specific and system-related regulations.

Note: See Appendix A for default definition of damaged SNF.

Background

Damaged Fuel

Previous definitions of damaged fuel have identified specific characteristics of the fuel that classify it as damaged, irrespective of the stage of the back end of the fuel cycle and independent of the design of the storage or transportation system. In this guidance, damaged fuel is defined in terms of the characteristics needed to perform the fuel-specific or system-

[1]Retrievability is discussed in ISG-2. Fuel Retrievability {1}

related regulatory functions. Thus, the characteristics of damaged spent fuel may depend on (1) which stage the fuel is in within the back end of the fuel cycle, and (2) the design of the storage or transportation system.

The materials properties, and possibly the physical condition, of a fuel rod or assembly can be altered during irradiation, storage, or transportation. If this alteration is large enough to prevent the fuel or assembly from performing its regulatory functions during the period (i.e., irradiation, storage, transportation), or during a subsequent period, for which the fuel performance is defined, then the fuel assembly is considered damaged.

To determine whether a fuel assembly is undamaged, the following should be delineated:

1) The phase of the back end of the fuel cycle for which the definition is applicable (storage, transportation, or both);

2) The functions the applicant has imposed on the fuel rods and assembly by either fuel-specific regulations or system-related regulations to meet a regulatory requirement for the designated phase;

3) The mechanisms of change (alteration mechanisms) or the characteristics of the fuel that could potentially cause the fuel to fail to meet its functions;

4) An acceptable analysis showing that the fuel with the designated characteristics will meet the fuel-specific and system-related regulations when the mechanisms considered in item #3, above, are evaluated; and

5) The physical characteristics of the fuel, based on item #4, above, that could cause the fuel or assembly to be classified as "damaged."

The "Discussion" section illustrates this methodology in the example.

Damaged SNF, as defined in this guidance, will only be approved for the activity (storage or transportation) for which the application is being submitted. Note that the "default" definition of damaged SNF, derived from ANSI N14.33-2005 is provided in the appendix of this guidance for those that do not want perform the assessment outlined in items number 1 through 5 above [2]. The default definition, however, may not take full advantage of the flexibility of the performance-based definition of damaged fuel provided in this guidance. This default definition may be more restrictive than necessary, depending on the design of the storage or transportation cask. For example, the default definition of damaged SNF indicates that SNF must be classified as damaged if an individual fuel rod is missing from an assembly. However, if an analysis shows that subcriticality will be maintained and that the SNF assembly will be retrievable and that the structural properties of the assembly are not compromised by the missing rod, the assembly may be classified as undamaged, per this ISG, if the storage or transportation system meets all applicable regulatory requirements.

Discussion

The performance-based definition [3,4] of damaged SNF provided in this ISG minimizes the quantity of damaged fuel requiring alternative handling paths, while still addressing applicable system-related regulations concerning criticality control, thermal limitations, structural integrity, confinement, and shielding.

A. Grossly Breached SNF Cladding

The regulations in 10 CFR 72.122(h) states "The spent fuel cladding must be protected during storage against degradation that leads to gross ruptures or the fuel must be otherwise confined such that degradation of the fuel during storage will not pose operational safety problems with respect to its removal from storage. However, there is no such requirement in 10 CFR 71. Hence, grossly breached fuel is always considered damaged for storage but may or may not be considered damaged for the purposes of transportation depending on whether other regulations such as criticality can be met.

In dry cask storage and transportation systems, a gross cladding breach should be considered as any cladding breach that could lead to the release of fuel particulate greater than the average size fuel fragment. A pellet is ~1.1 centimeters in diameter in 15 x 15 Pressurized-Water Reactor (PWR) assemblies. Pellets from a Boiling-Water Reactor (BWR) are somewhat larger, and those from 17 x 17 PWR assemblies are somewhat smaller. The pellet's length is slightly longer than its diameter. During the first cycle of irradiation in-reactor, the pellet fragments into 25-35 smaller interlocked pieces, plus a small amount of finer powder, due to, pellet-to-pellet abrasion. When the rod breaches, about 0.1 gram of this fine powder may be carried out of the fuel rod at the breach site [5]. Modeling the fragments as either spherical- or pie-shaped pieces indicates that a cladding-crack width of at least 2-3 millimeters would be required to release a fragment. Hence, gross breaches should be considered any cladding breach greater than 1 millimeter.

A review of reactor operating records can be used to classify rods and assemblies as unbreached, breached, or grossly breached. Evidence of only gaseous or volatile decay products (no heavy metals) in the reactor coolant system is accepted as evidence that a cladding breach is no larger than a pinhole leak or hairline crack. Records that show the presence of heavy metal isotopes that are characteristic of fuel release in the reactor coolant system indicate gross breaches in the cladding. Likewise, visual examination may also be used to determine if a cladding breach is gross, if the breached rod can be positively identified. Because cladding openings larger than 1 millimeter should expose the fuel pellet to visual sighting, visual examination of the breached rod can be used to determine if a breach is gross.

It should be noted; however that undamaged spent-fuel rods with pinhole leaks and/or hairline cracks will expose the fuel pellets to the canister or cask atmosphere. If that atmosphere is oxidizing, then the fuel pellet may oxidize and expand, placing stress on the cladding. The expansion may eventually cause a large split in the cladding, resulting in spent fuel that must be classified as damaged (for storage and possibly also for transportation) due to gross breaches in the cladding. Since fuel oxidation and cladding splitting follow Arrhenius time-at-temperature behavior, fuel rods with pinholes or hairline cracks that are exposed to an oxidizing atmosphere may experience this type of additional cladding damage. ISG-22 ‘Potential Rod Splitting Due to Exposure to an Oxidizing Atmosphere During Short-Term Cask Loading Operations in LWR or other Uranium Oxide Based Fuels” [6] provides information regarding prevention of this phenomenon. Before handling undamaged rods with pinhole leaks and/or hairline cracks in an oxidizing atmosphere, the potential fuel and cladding degradation at the temperature of interest for the duration of the process should be assessed.

B. Fuel Assembly with Defects

Damage under this guidance refers to alterations of the fuel assembly that prevent it from fulfilling its fuel-specific or system-related regulatory functions. Defects such as dents in rods, bent or missing structural members, small cracks in structural members, missing rods, etc., need not be considered as damage if the applicant can show that the fuel assembly with these defects still fulfils its regulatory functions. This may be done using calculations based on approved codes, situation-specific data, or reasoned engineering arguments.

C. Canning Damaged Fuel

Spent fuel that has been classified as damaged for storage must be placed in a damaged fuel can, or in an acceptable alternative. The purpose of a damaged fuel can is to (1) confine gross fuel particles, debris, or damaged assemblies to a known volume within the cask,: (2) to demonstrate that compliance with the criticality, shielding, and thermal requirements are met,: and (3) permit normal handling and retrieval from the cask. The damaged-fuel can may need to contain neutron-absorbing materials, if results of the criticality safety analysis depend on the neutron absorber to meet the requirements of 10 CFR 72.124(a).

D. Relationship of Spent Fuel Populations

The applicant will designate the population of spent fuel for which the cask system was designed (e.g., type of fuel, minimum cooling time, burnup limitations, arrays, manufacturers, cladding types, etc). This population may contain breached rods. Some of these breached rods may be grossly breached. It may also contain assemblies with defects, such as missing rods, missing grid spacers, or damaged spacers. The populations of breached rods, grossly breached rods, and assemblies with defects are determined by in-reactor behavior and ex-reactor handling.

Each of these populations must be classified as damaged or undamaged after the storage or transportation system has been designated. For example, if a storage cask will operate at a sufficiently high temperature for a long enough period within an air atmosphere, then all

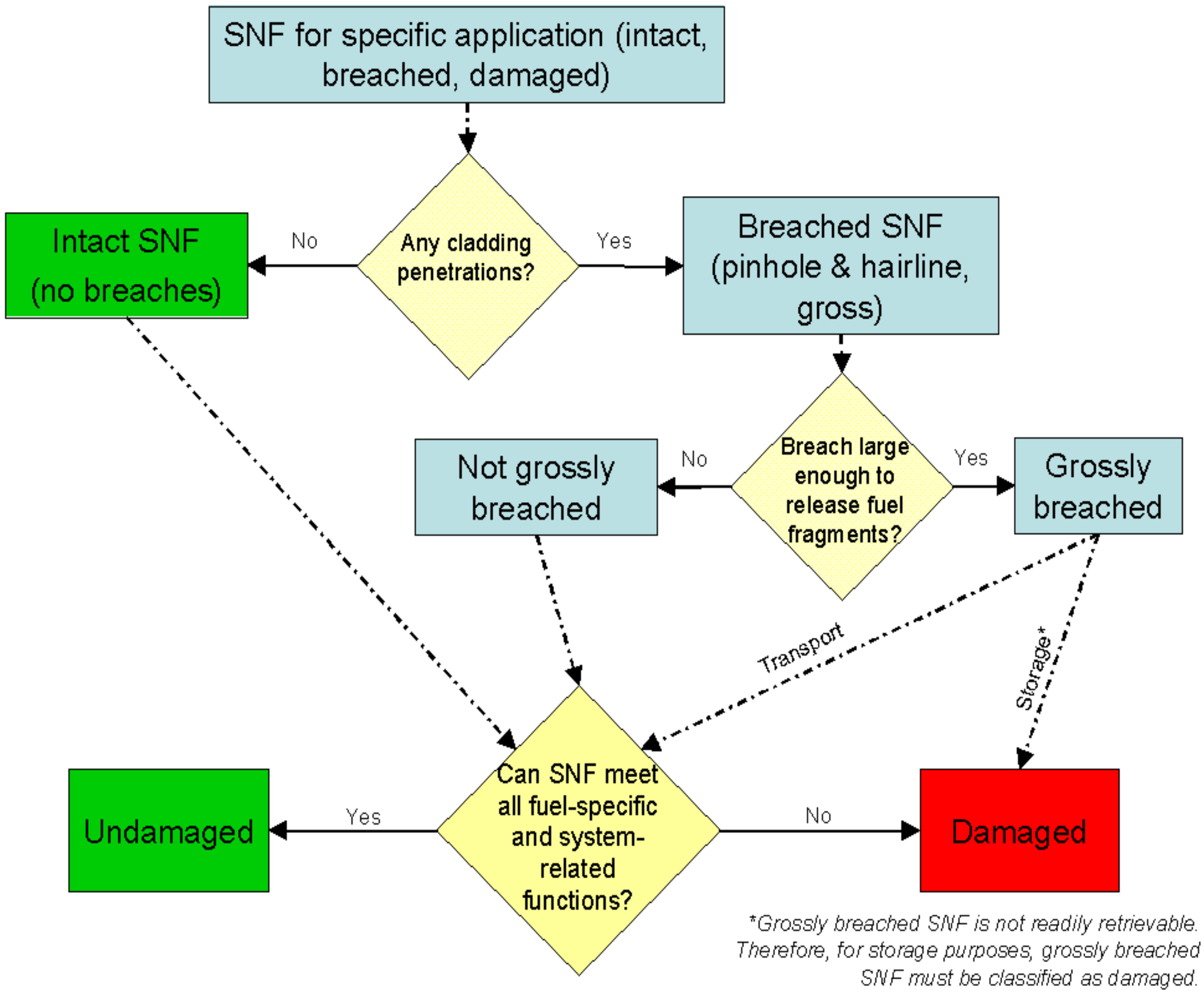

Figure 1. Relationship of Spent Fuel Populations

breached rods may be considered damaged since the grossly breached rods do not meet 10 CFR 72.122(h)(1), and other breached rods will become grossly breached. For a transportation cask, these rods would also be considered damaged, since 10 CFR 71.55(d) would not be met. On the other hand, had an inert atmosphere been used, only the grossly breached rods would have been considered damaged. This concept is illustrated in Figure 1, "Relationship of Spent Fuel Populations."

E. Example of Methodology

The following example is given to illustrate the general methodology adopted in this ISG. This is only an example of the methodology and should not be construed as approved characterization of damaged fuel.

Example:

Situation - The vendor of a dual-purpose cask wants to store and transport low burnup PWR fuel in an inert atmosphere and within the temperature limits recommended in ISG-11, Revision 3 Cladding Considerations for the Transportation and Storage of Spent Fuel [7]. The vendor wants to store assemblies having rods with breaches containing only pinholes or tight cracks, and assemblies having one or more outer grid straps with defects at three or more grid locations without canning them. The vendor is only applying for a storage license at this time but wants to be reasonably certain that the fuel will also be transportable.

Activity - Storage and transportation

Function imposed on rods and assemblies - 10 CFR 72.122(h)(1), regarding gross ruptures, and 10 CFR 72.122(l), concerning retrievability, must be met for storage. 10 CFR 71.55(d), requiring the system to remain subcritical and unchanged during normal transport, must be met. The vendor believes that all the remaining system requirements, except for the subcriticality requirement, can be met, without imposing any limitations on the fuel, if the fuel is within the bounds stated in the situation.

Mechanisms - There are no mechanisms for the pinhole leaks and hairline cracks to evolve into gross breaches since the atmosphere is inert and the temperature is controlled. To be retrievable, the assemblies with missing grid straps must be able to withstand design basis events in a storage cask. Since the applicant also wants these assemblies to be considered undamaged for transportation, the behavior of the assemblies under both normal and hypothetical accident transportation conditions in 10 CFR 71 must be evaluated. For example, for normal transportation conditions, the applicant must show that the assemblies with the most missing grid straps in the worst locations can withstand both normal vibration and a one-foot drop and remain in their original physical configuration. Additionally, for hypothetical accident conditions, the analysis must indicate, among other things, that the system will meet shielding and subcriticality requirements when placed under the mechanical and thermal loads specified in 10 CFR 71.

Analysis - The applicant conducts an analysis to satisfactorily demonstrate that the assembly with three missing grid straps in the worst configuration remains intact for 1) normal transportation conditions; 2) cask tip-over; and 3) regulatory accident conditions. Further acceptable analysis indicates that all the system-related regulations are met, if the fuel with the characteristic limitations, below, stays structurally intact.

Characteristics - Assemblies containing breached rods with up to three grid straps missing will be considered undamaged for the purposes of storage. Analysis shows that these assemblies could probably also be considered undamaged for transportation, but fuel with these characteristics will be evaluated and approved as part of a later application for the transportation cask certification.

Records

Records documenting the classification of spent fuel shall comply with the provisions of 10 CFR 72.174, “Quality Assurance Records”; 10 CFR 72.72, "Material Balance, Inventory, and Records Requirements for Stored Material”; 10 CFR 71.91, “Records”; and 10 CFR 71.135, "Quality Assurance Records." Inspection records will be maintained for the lifetime of the container. This includes all forms and all analog and digital information used during the inspection of the fuel.

Quality Assurance:

Activities related to inspection, evaluation, and documentation of damaged spent fuel for dry storage shall be performed in accordance with a quality assurance program, as required in 10 CFR Part 72, Subpart G, "Quality Assurance.” Activities related to inspection, evaluation, and documentation of damaged spent fuel for transport shall be performed in accordance with a quality assurance program, as required in Part 71, Subpart H, “Quality Assurance."

Recommendations

The staff recommends that: (1) the definitions in NUREG-1536, NUREG-1567, NUREG-1617, ISG-8 (Rev 2) and ISG-11 (Rev 3) be revised to incorporate the definitions listed above; and (2) the appropriate chapters of each NUREG be revised to include the discussion section of this ISG.

In addition, the suggestion in NUREG-1617 (canning damaged fuel is necessary for the purposes of transportation) should be modified to be consistent with this ISG, unless required by the applicant to meet the requirements of 10 CFR Part 71.

The words "intact fuel," in the applicability section of Revision 2 of ISG-8, “Burnup Credit in the Criticality Safety Analyses of PWR Spent Fuel in Transport and Storage Casks,” should be replaced by "undamaged fuel." "Intact commercial spent fuel" in the last paragraph of the “Issue” section of Revision 3 of ISG-11, “Cladding Considerations for the Transportation and Storage of Spent Fuel,” should read "undamaged commercial spent fuel."

Approved :

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E. William Brach, Director   Date

Spent Fuel Project Office

Attachment: Appendix

APPENDIX

Default Definition of Damaged Fuel[2]

"Default" definition of damaged Spent Nuclear Fuel (SNF) - SNF assemblies must be classified as damaged, for both dry storage and/or transportation purposes, if any one of the following conditions exist:

1. On removal of SNF selected for dry storage or transport from the spent fuel pool, any of the following apply:

    1.1 there is visible deformation of the rods in the SNF assembly. Note: that this is not referring to the uniform bowing that occurs in the reactor. This refers to bowing that significantly opens up the lattice spacing.

        1.1.1 Individual fuel rods are missing from the assembly. (Note: The assembly may be reclassified as intact if a dummy rod that displaces a volume equal to, or greater than, the original fuel rod, is placed in the empty rod location.)

        1.1.2 The SNF assembly has missing, displaced, or damaged structural components such that either:

            1.1.2.1 Radiological and/or criticality safety is adversely affected (e.g., significantly changed rod pitch).

            1.1.2.2 The assembly cannot be handled by normal means (i.e., crane and grapple).

    1.2 Reactor operating records (or other records) indicate that the SNF assembly contains fuel rods with gross breaches.

    1.3 Incipient damage exists (e.g., the spent fuel assembly must be classified as damaged if any rod has either a localized cladding hoop stress (σ) or a distributed cladding hoop stress over more than 450 millimeters of cladding length that exceeds the stress limit at the maximum temperature in ISG-11. Indications that incipient damage may exist include, but are not limited to, the following:

        1.3.1 The SNF assembly experienced a thermal transient or unusual event (such as excessive CRUD buildup);

        1.3.2 The SNF assembly was located adjacent to an assembly with a gross rod breach; or

        1.3.3 The SNF assembly was reconstituted after the removal of a rod with a

[2]Derived from ANSI Standard N14.33-2005, "Storage and Transport of Damaged Spent Nuclear Fuel," September, 2005.

gross breach.

1.4 The SNF assembly is no longer in the form of an intact fuel bundle (e.g., consists of, or contains, debris such, as loose fuel pellets or rod segments).

REFERENCES

1. NRC Spent Fuel Program Office Interim Staff Guidance - 2, "Fuel Retrievability."

2. ANSI Standard N14.33-2005, "Storage and Transport of Damaged Spent Nuclear Fuel," September, 2005.

3. RE Einziger, CL Brown, GP Hornseth, SR Helton, NL Osgood, and CG Interrante, "Damage in Spent Nuclear Fuel Defined by Properties and Requirements," Presented at IAEA Technical Workshop on Damaged Fuel, Dec 2005, Vienna, Austria, Proceedings of IAEA International Conference on Management of Spent Fuel from Nuclear Power Reactors, Vienna, Austria, June 2006.

4. MW Hodges, "Status of Technical Issues in Storage and Transportation," Proceedings of Spent Fuel Management Seminar XXIII, Washington, D.C,, Institute for Nuclear Materials Management, January, 2006.

5 RA Lorenz, et.al., "Fission Product Release from BWR Fuel Under LOCA Conditions, " Oak Ridge National Laboratory, Oak Ridge, TN, NUREG/CR-1773, July 1981

6. NRC Spent Fuel Program Office Interim Staff Guidance - 22, "Potential Rod Splitting Due to Exposure to an Oxidizing Atmosphere During Short-Term Cask Loading Operations of LWR or Other Uranium Oxide Based Fuels," May 2006

7. NRC Spent Fuel Program Office Interim Staff Guidance - 11, Rev 3, "Cladding Considerations for Transportation and Storage of Spent Fuel," November 2003.