Spent Fuel Project Office
Interim Staff Guidance - 19

Moderator Exclusion under Hypothetical Accident Conditions and Demonstrating Subcriticality of Spent Fuel under the Requirements of 10 CFR 71.55(e)

ISSUE

This Interim Staff Guidance (ISG) provides review guidance for meeting the fissile material package standards in 10 CFR 71.55(e). The provisions of 71.55(e) require that a fissile material package be subcritical under hypothetical accident conditions assuming that the fissile material is in the most reactive credible configuration consistent with the damaged condition of the package and the chemical and physical form of the contents, and water moderation occurs to the most reactive credible extent consistent with the damaged condition of the package and the chemical and physical form of the contents.

Current regulatory guidance for addressing the requirements of 10 CFR 71.55(e) for spent fuel are included in

- NUREG-1617, "Standard Review Plan for Transportation Packages for Spent Nuclear Fuel," and

- NUREG/CR-5661, "Recommendations for Preparing the Criticality Safety Evaluation of Transportation Packages."

The guidance in these two documents does not specifically and separately address the requirements of 71.55(e). This ISG is intended to clarify the review of the criticality safety evaluation for a single package under hypothetical accident conditions.

APPLICABILITY

This ISG addresses the transport of spent fuel from commercial light water reactors. Due to effects of irradiation, the cladding of spent fuel, and particularly high burnup fuel (i.e., fuel with a burnup greater than 45,000 MWD/MTU) may become brittle. If excessively brittle, the cladding could fracture under impact loads currently associated with hypothetical accident free drop test conditions. Consequently, criticality safety of the reconfigured fuel assembly must be demonstrated.

Spent fuel with non-brittle cladding that is undamaged (see ISG-1, Rev. 1) has been shown to remain intact under current impact loads associated with hypothetical accident conditions. Therefore, the evaluation of intact spent fuel under the provisions of 71.55(b), which requires a fissile material package to be subcritical with water inleakage, serves to show that the requirements of 71.55(e) are met; however, changes in the packaging under the test conditions of 71.73 that could cause the reactivity to increase need to be addressed.

No changes to review practices with respect to damaged fuel are included within the scope of this ISG. Fissile materials other than spent fuel are specifically excluded from this alternative approach.

The International Atomic Energy Agency (IAEA) Safety Series 6, "Regulations for the Safe Transport of Radioactive Material," 1985 Edition (As Amended 1990), includes similar, but not identical, requirements for fissile material packages. The compatibility of this ISG with the IAEA provisions is being evaluated.

TECHNICAL REVIEW GUIDANCE

The provisions of 71.55(e) require subcriticality of a single damaged package. The applicant may choose different approaches to address these requirements. In general the two basic approaches are: (1) showing that reconfigured fuel is subcritical even with water inleakage, and (2) showing that the package excludes water under hypothetical accident conditions. These approaches are summarized in Table 1.

1. General Information

No significant technical review changes for Chapter 1 of NUREG-1617.

2. Structural

As mentioned above, an applicant must choose one of two basic approaches to show subcriticality under 71.55(e).

(1) Approvals Based on Reconfigured Fuel

For applicants who choose to show that the reconfigured fuel is subcritical, assuming water inleakage, the review should include one of the following:

- Structural evaluation to determine reconfigured fuel geometries: – The reconfigured fuel geometries would be developed based on the material properties of the spent fuel cladding and the impact loads imposed on the fuel assemblies. It is judged that, at this time, there is insufficient material property information for high burnup fuel to allow this type of evaluation.

- Criticality evaluation of bounding reconfigured fuel geometries: – Criticality analyses may be performed for postulated fuel reconfigurations that do not strictly rely on the material properties of the fuel cladding but are judged to be appropriately bounding for criticality.

(2) Approvals Based on Moderator Exclusion

For applicants who choose to show that there will be no water inleakage under accident conditions, the review should include:

- Physical testing of the water exclusion boundary. See Table 1 for parameters that can be used to demonstrate the water-tight boundary under hypothetical accident conditions.

In addition, for all applicants, regardless of the approach taken, the review should include:

- Conformance with NUREG/CR-6007 guidance for closure bolts. This includes an analysis that shows that the bolt stresses do not exceed the material yield condition. In particular, the applicant should address the recommendations in Section 8 of the NUREG.

- Structural integrity of the closure system. The applicant should show that there would be no inelastic deformation of the containment closure system (e.g., bolt closure, or seal region) under hypothetical accident conditions.

3. Thermal

For high burnup fuel, the thermal evaluation should consider credible or bounding fuel reconfigurations, for example, possible accumulation and relocation of damaged fuel near temperature-sensitive components such as elastomeric seals.

4. Containment

For high burnup fuel, the containment evaluation should consider fuel fragmentation and releasable fines.

5. Shielding

For high burnup fuel, the shielding analysis should identify and evaluate credible or bounding reconfigurations of fuel under hypothetical accident conditions.

6. Criticality

The criticality analysis should identify and evaluate credible or bounding configurations of fuel under hypothetical accident conditions.

If structural analyses are not performed for the fuel cladding based on material properties, a bounding credible fuel configuration should be used and justified.

Spent fuel that is intact and undamaged when loaded into a transportation cask can be assumed to be in its intact, "as loaded" configuration when showing compliance with the general design requirements in 10 CFR 71.55(b).

7. Package Operations

The operational guidance provided in Section 8 of NUREG/CR-6007 should be included, such as specified torquing sequences, lubrication, and torque values.

8. Acceptance Tests and Maintenance Program

The guidance provided in Section 8 of NUREG/CR-6007 should be included, such as a testing program to preclude the use of counterfeit bolts and bolt replacement based on a fatigue analysis.

Table 1. Summary of approaches for demonstrating subcriticality of spent fuel under the requirements of 10 CFR 71.55(e).

(1) APPROVALS BASED ON RECONFIGURED FUEL		
Approach	**Characteristics**	**Objective**
Criticality Assessment of Bounding or Credible Reconfigured Fuel Geometries Based on Criticality Assuming Water Inleakage	1. Postulate bounding fuel configurations for criticality. 2. Evaluate criticality and credibility of bounding configurations based on basic structural and material behavior. 3. Reduced reliance on material properties of high burnup fuel cladding and failure criteria. 4. Criticality analyses of reconfigured fuel from criticality bounding configurations.	With water inleakage, demonstrate subcriticality of defined set of credible or bounding fuel configurations based on criticality.
Criticality Assessment of Reconfigured Fuel Geometries Based on Actual Structural and Material Behavior Assuming Water Inleakage	1. Need material properties of high burnup fuel cladding and failure criteria. 2. Requires nonlinear finite element analysis of fuel assemblies and fuel rods under drop impact conditions. 3. Failure modes and fuel rod failure distributions to be addressed (probabilistic approach to the distribution of material properties among fuel rods). 4. Develop credible fuel reconfiguration geometries. 5. Criticality analyses of reconfigured fuel from structural analysis results.	With water inleakage, demonstrate subcriticality of credible fuel configurations based on actual structural and material behavior . This requires extensive data for irradiated hydrided cladding material properties for high burnup fuels. These data are currently not available. Therefore it is judged that this approach is currently not practical.

(2) APPROVALS BASED ON MODERATOR EXCLUSION		
Approach	**Characteristics**	**Objective**
Criticality Assessment of Reconfigured Fuel Assuming Moderator Exclusion	1. Demonstrate water-tight barrier under hypothetical accident conditions. 2. Perform drop test of cask (i) OR inner canister (ii) as described below.	
(i) For Welded Canister-Based Systems: Canister Drop Test as Part of Impact Limiter Testing	1. Include scale model of canister and contents in transport cask impact limiter 30-foot drop tests. 2. Perform relative leak rate testing by testing before and after each drop. 3. Demonstrate leakage rate acceptable to prevent water inleakage.	Physical test of scaled canister to provide added assurance of moderator exclusion under accident conditions.
(ii) For Canister-Based Cask Systems and Direct-Loaded Casks: Bolt Closure System Test as Part of Impact Limiter Testing	1. Include transport cask bolt closure system in scale model of cask in 30-ft drop tests of the impact limiter. 2. Perform relative leak rate testing by testing before and after each drop. 3. Demonstrate leakage rate acceptable to prevent water inleakage.	Physical test of scaled bolt closure system to provide added assurance of moderator exclusion under accident conditions.

Recommendation

The staff recommends that the appropriate chapters of NUREG-1617 be revised to incorporate the guidance described above.

Approved /RA/ May 2, 2003
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