Safety of Spent Nuclear Fuel with Gross Ruptures

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Workshop on Spent Fuel Performance Margins –Gross Ruptures

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Background

- 10 CFR 72.122(h)(1) requires that 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.
  - Gross ruptures are not defined in the regulations (i.e., in 10 CFR 72.3).
  - NRC has historically issued guidance to define gross ruptures (i.e., ISG-1, Revision 2 – current guidance).
  - Gross ruptures are not mentioned or defined in Part 71. More specific performance-based requirements are defined in Part 71.
  - Other 10 CFR Part 71 and Part 72 regulatory requirements are indirectly impacted by fuel cladding performance.

Problem Statement

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- Current guidance on gross ruptures has led to difficulties in fuel selection and appropriate loading in transportation packages and dry storage systems
  - Term is defined both qualitatively and quantitatively in current guidance. Both definitions are not readily actionable during fuel selection practice.
- NRC seeking additional stakeholder's input on significance of design and operational impacts of gross ruptures
  - NEI Letter May 13, 2020: Concern that highly conservative thermal limits are applied to spent fuel, which increase burdens on design analyses and regulatory review
    - Design for thermal in lieu of shielding
    - Potential for reduced maintenance and inspection activities
    - Thermal limitations for spent fuel off-load

Benefit for Addressing Problem

- Simplification and streamlining of fuel selection and loading practices
  - Both NRC and industry agree that there is an opportunity to clarify and evaluate new definitions/metrics for gross ruptures that are focused on maintaining adequate safety while being actionable in practice.
    - Informed by limitations of fuel selection practices as discussed in IN 2018-01, "Noble Fission Gas Releases During Spent Fuel Cask Loading Operations"
  - The evaluation of new definitions/metrics may reveal some regulations could warrant revision per a risk-informed approach, which could lead to efficiencies for both NRC and industry.
- NRC seeking stakeholder's input on other potential operational and practical benefits

Preliminary Qualitative Assessment

- The staff performed a preliminary qualitative assessment of the implications/consequences of gas and fuel particulate releases through cladding breaches.

- **The assessment relied on staff's engineering judgment and additional work would need to be done to quantify the staff's conclusions.**

Preliminary Qualitative Assessment

- ***Radiation dose impacts:***
  - A significant amount of particulate material would have to relocate during normal/off-normal conditions to result in a safety issue. The safety concern is likely more relevant during reopening of a cask/canister or transportation package.
- ***Criticality impacts:***
  - Multiple pellets (i.e., rod quantity) would be necessary to result in a safety concern. The safety concern would be relevant during cask reflooding or fuel assembly removal/repackaging (i.e., when moderator would be reintroduced).

Preliminary Qualitative Assessment

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- ***Thermal impacts:***
  - A significant amount of particulate material would have to relocate during normal/off-normal conditions to result in safety issue. The release of gases does not likely represent a safety issue.
- ***Containment/confinement impacts:***
  - A significant amount of particulate material would have to relocate during normal/off-normal conditions to result in safety issue. The release of gases does not represent a safety issue since it is already evaluated in the design basis.

Safety Objective

- Per the prior qualitative assessment, the staff developed the following Safety Objective for the prevention of gross ruptures:

Gross ruptures should be prevented to avoid releases of particulate material that result in doses exceeding limits or safety concerns during eventual reflooding/repackaging.

Proposed Next Steps

- NRC should reexamine the intent and considerations of regulations addressing fuel integrity, directly or indirectly (i.e., Statements of Consideration for e.g. 72.122(h)(1), 72.122(l), 72.236(m), including any risk information provided at the time).
- Industry should evaluate historical operating experience related to breached fuel. The review should consider failure occurrence rate, measured releases (if any), impacts to plant and package user operations, measured radiation doses, associated time loses (inefficiencies during operations).

Proposed Next Steps (*cont.*)

- NRC/industry should identify completed PRAs and consequence analyses to assist justification for new definition(s)/metric(s).
  - Safety objective may need to be reevaluated based on the conclusions of these reviews.
- NRC/industry should assess whether guidance on specific regulatory limits is needed (e.g., personnel and accident doses in 10 CFR Part 20 and Part 72) and quantitatively assessing the safety impacts during reflooding/repackaging operations.
- NRC/industry should assess whether additional safety concerns associated with gross ruptures are not captured by the current regulations that would require review.
  - NRC/industry should assess potential changes to current regulatory framework, which would be risk informed per prior activities.

Proposed Next Steps (*cont.*)

- NRC/ industry should evaluate the potential for new definition(s) or metric(s). Revisions should:
  - Meet the historical intent of the regulation in a risk-informed manner.
  - Enhance the NRC's review process while limiting additional encumbrances to NRC's inspectors.
  - Assist industry in minimizing assumptions and conservative decisions, which do not necessarily increase safety of operations.
  - Be properly informed by impacts to all safety disciplines and ensure no unintended consequences of any revision.
  - Be informed by all stakeholders, including impacts to future delivery to DOE.

Benefits of a PIRT Process

- Allows for experts to openly discuss the implications of gross ruptures to dry storage and transportation
  - Focus in a specific issue in a condensed time frame
  - Evaluate direct and indirect implications to performance-based requirements
  - Generically rank the safety consequences (radiation dose, criticality, structural performance, thermal and material limitations)
  - Consider implications to both licensing/certification and implementation/operations.
  - Prioritize information needs and future activities requiring further work

Proposed Activity Timeline

Activity	Pre- or Post- PIRT	Owner	Completion
Pre-PIRT Regulatory Assessment	Pre-	NRC	8/2020
Operating Experience Assessment	Pre-	Industry	8/2020
PRA / Consequence Assessment	Pre-	NRC/Industry	9/2020
Dose Limits/ Repackaging/Reflooding Guidance Assessment	Pre-	NRC/Industry	10/2020
PIRT	-	Industry (NRC support)	11/2020
Post-PIRT Regulatory Assessment	Post-	NRC/Industry	12/2020

Backup Slides

Regulatory Requirements

- **Dry storage**
  - Fuel-specific:
    - 72.122(h)(1), 72.122(l) → 72.44(c), 72.236(a)
  - DSS-specific:
    - 10 CFR 72.124(a), 72.128, 72.236(h),(m)
- **Transportation**
  - Fuel-specific:
    - 10 CFR 71.33(b)(3)
  - Package-specific:
    - 10 CFR 71.55(d), 71.55(e), 71.71, 71.73, 71.89

Dry Storage Requirements

- **10 CFR 72.44(c) and 72.236(a) (Specific License/CoC):** Identification and compliance with license/CoC Technical Specifications
- **10 CFR 72.122(h)(1) (Specific/General License):** *…spent fuel cladding must be protected during storage against degradation that leads to gross ruptures or the fuel must be otherwise confined… This may be accomplished by canning of consolidated fuel rods or unconsolidated assemblies or other means as appropriate*.
- **10 CFR 72.122(l) (Specific/General License):** *Storage systems must be designed to allow ready retrieval of spent fuel, . . . for further processing or disposal.*
  - *Applicable to normal and off-normal conditions (ISG-3)*

Dry Storage Requirements (*cont.*)

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- **10 CFR 72.124(a) (all licenses/CoCs):** *SNF handling, packaging, transfer, and storage systems must be designed to be maintained subcritical…*
- **10 CFR 72.128 (specific license):** *SNF storage… must be designed to ensure adequate safety under normal and accident conditions.*
- **10 CFR 72.236(h) (CoC):** *The spent fuel storage cask must be compatible with wet or dry spent fuel loading and unloading facilities.*
- **10 CFR 72.236(m) (CoC):** *To the extent practicable in the design of spent fuel storage casks, consideration should be given to compatibility with removal of the stored spent fuel from a reactor site, transportation, and ultimate disposition by the Department of Energy.*

Transportation Requirements

- **10 CFR 71.33(b)(3):** *With respect to contents of the package… identification and maximum radioactivity of radioactive constituents… identification and maximum quantities of fissile constituents… chemical and physical form… maximum amount of decay heat…*
- **10 CFR 71.55(d):** *…packaged designed and constructed… that under the tests specified in 10 CFR 71.71 ('Normal conditions of transport'), the contents would be subcritical and the geometric form of the package contents would not be substantially altered.*
- **10 CFR 71.55(e):** *…package 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.*

Transportation Requirements (*cont.*)

- **10 CFR 71.71, Normal conditions of transport,** *(a) Evaluation of each package design under normal conditions of transport must include a determination of the effect on that design of the conditions and tests specified in this section. Separate specimens may be used for the free drop test, the compression test, and the penetration test, if each specimen is subjected to the water spray test before being subjected to any of the other tests*

- **10 CFR 71.73, Hypothetical accident conditions,** *(a) Test procedures. Evaluation for hypothetical accident conditions is to be based on sequential application of the tests specified in this section, in the order indicated, to determine their cumulative effect on a package or array of packages.*

- **10 CFR 71.89:** *…special instructions needed to safely open the package…*

Fuel Classification
NRC Guidance - ISG-1, Rev. 2

Undamaged Fuel: rod/assembly able to meet all fuel-specific and system-related regulations

Intact:	No breaches
Breached:	Pinhole leak or hairline crack that do not permit significant release of particulate matter

Damaged Fuel: rod/assembly cannot fulfill all fuel-specific and system-related regulations

Grossly-Breached:	Any cladding breach exceeding pinholes or hairline cracks (width greater than 1 mm [0.0394 in])

Damaged Fuel Cans
NRC Guidance - ISG-1, Rev. 2

- **DFC Definition:**
  - Metal enclosure sized to confine one damaged SNF assembly
  - Must satisfy fuel-specific and system-related functions for undamaged fuel

Damaged Fuel Cans
NRC Guidance - ISG-1, Rev. 2

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- **DFC Purpose:**
  - Confine gross fuel particles, debris, or damaged assemblies to a known volume within the DSS (geometric configuration control)
  - Demonstrate compliance with DSS criticality, shielding, thermal and structural requirements
  - Permit normal handling and retrieval from the cask
    - If ready-retrieval is defined on a single-assembly basis
  - Design can incorporate neutron absorber materials in order to meet 10 CFR 72.124(a)

Damaged Fuel Cans
NRC Guidance

- **Safety Review (NUREG-1536, Rev. 1):**
  - Analyze potential reconfiguration of damaged fuel within the DFC and demonstrate compliance with the dose limits of normal and design basis events of storage.
    - Shielding analysis should assume a worst case or bounding configuration of the canned fuel.
  - Include operating procedures for placing damaged fuel in DFC and loading/unloading in DSS

Ready-Retrieval
NRC Guidance - ISG-2, Rev. 2

- Reasonable assurance of ready-retrieval defined in the approved design bases of the DSS (CoC) or the Independent Spent Fuel Storage Installation (specific license).
- **Options for demonstrating ready-retrieval:**

  A. Removal of individual or canned SNF assemblies from wet or dry storage,

  - Considers adequate cladding performance

  B. Removal of a canister loaded with SNF assemblies from a DSS cask or overpack, or

  C. Removal a DSS cask loaded with SNF assemblies from its storage location.

Fuel Classification / Selection NRC Guidance - ISG-1, Rev. 2

- 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.
- Ultrasonic testing and sipping (if done in a timely manner) can be used to classify rods as unbreached or breached.
- Visual examination considered acceptable for gross breaches if can determine the fuel pellet surface through the breached portion of the cladding.
  - No consideration to accessibility/ line of sight.

Fuel Classification / Selection Information Notice 2018-01

- Highlights follow-up actions due to noble fission gas releases
  - Ensure compliance with design-basis fuel temperature limits and cask closure time requirements
  - No inadvertent ingress of oxidizing species to cask
  - Reasonable assurance of compliance with license or CoC
    - Secondary review of fuel selection records, root-cause or apparent-cause analyses
    - Assess operating experience and limitations of fuel selection methods; assess need for secondary characterization method
    - Revise operating procedures accordingly if a technique is found unsuitable