Technical Interpretation of Gross Rupture

Fuel/Cladding Performance

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April 16, 2020

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Interpretation of Gross Rupture

- Background:
  - Relationship to recent PIRTs
- History:
  - Historical perspectives since 1978
- Goal:
  - Protect cladding against gross rupture, but, current metric non-actionable, so define gross rupture in terms of safety
- Suggested Path Forward:
  - Identify safety goal for gross rupture
  - Develop consensus definition of gross rupture
  - Establish durable metrics/limits to protect against gross rupture
  - Use similar approach to recent PIRTs with panel of subject matter experts

Background

Gross Rupture - Background

- DOE/EPRI HBU Demonstration Project:
  - Actual fuel temperatures much lower than originally thought
- What do we do with this information?
- Conducted PIRTs with technical subject matter experts:
  - Fuel cladding performance
    - Reexamine technical guidance for cladding integrity metrics
  - Thermal modeling
    - How can we get more realistic fuel temperature predictions
  - Decay heat
    - What can we do to improve this key input to thermal models

Gross Rupture - Background

- Fuel/Cladding performance PIRT
  - Criteria: Prevent gross rupture
  - Technical experts discussed/agreed:
    - By preventing gross rupture, regulatory compliance met
    - Chose not to *define* gross rupture
    - Discussed the evolving historical regulatory interpretation changes
    - Identified need for additional technical expertise to define
    - Recommended follow-on expert panel activity/PIRT to define
  - Other PIRTs also recommended a separate activity to define or provide interpretation of gross rupture
- Current metric is non-actionable

Gross Rupture History

Gross Rupture – History – Initial Rule

- **<u>Oct 6, 1978 - Proposed Initial ISFSI Rule</u>**

  72.71 (8) (i)

  The fuel cladding shall be protected against degradation and gross ruptures.

- From FR Notice for proposed rule:

  The large inventory of radionuclides in an ISFSI represents a potential hazard to public health and safety. Storage conditions must provide an environment which will insure the long-term integrity on the fuel cladding as the primary containment for the radioactive materials contained in spent fuel.

- **<u>Nov 12, 1980 – Initial Rule Published (effective Nov 28, 1980)</u>**

  72.72 (h) (1)

  The fuel cladding shall be protected against degradation and gross ruptures.

  – [No change other than rule number]

Gross Rupture – History – Revised Rule

- **<u>May 27, 1986 - Proposed Rule to add MRS and clarify certain issues</u>**

  72.92 (h) (1)

  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.

- From the FR notice for the proposed rule:

  Cladding Degradation. Section 72.72, currently requires that the fuel cladding "be protected against degradation and gross rupture." **<u>This requirement means</u>** that the cladding must be protected against degradation during normal operations and storage which could lead to gross rupture of the fuel rods and **<u>could result in the release of significant quantities of fuel material and fission products to the storage environment</u>**.

Gross Rupture – History – Revised Rule

- **May 27, 1986 - Proposed Rule to add MRS and clarify certain issues**
- From the FR notice for the proposed rule:

  A definition of gross rupture is based on the potential consequences of chemical and radioactive releases and their effect on handling of the fuel rods during loading and unloading operations. If additional filtration, confinement or handling equipment would be required because of the material released via the rupture, then the rupture may be considered excessive.

  NUREG-1092 analyzes the impact on storage and handling operations if the cladding is allowed to deteriorate. The assessment shows that for storage of spent fuel the cladding need not be maintained if additional confinement is provided. The main concern is during the handling operations involving the removal of the spent fuel from its storage structure and its transfer to casks for shipment. During these operations, if the spent fuel is not properly confined, unnecessary exposure to radioactive material could occur to the worker. One way this additional exposure could be prevented is by using a canister. The canister could act as a replacement for the cladding. Proposed § 72.92(h)(1) reflects this change.

Gross Rupture – History – Revised Rule

- **<u>Aug 19, 1988 – Final Rule Published (effective Sep 19, 1988) – Current Rule</u>**

  72.122 (h) (1)

  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.

  - [No change other than rule number]
- From the FR notice for the final rule:

  Comment: Opposition is expressed to any lowering of fuel cladding protection, as provided for in the existing § 72.122(h)(1) (§ 72.92(h)(1)).

  Response: The revision of this provision (i.e., § 72.122(h)(1) (§ 72.92(h)(1))) addressed confinement of fuel material, which is the purpose of protecting the fuel cladding. The revised provision specifically provides for additional alternative means of accomplishing this objective. This serves to enhance confinement protection capability rather than diminish it.

Gross Rupture - History

- Nov 2, 1988 - ISG-1 Rev 0

  Definition of Damaged Fuel

  Spent nuclear fuel with *known or suspected* cladding defects greater than a hairline crack or a pinhole leak.

Gross Rupture - History

- Oct 15, 2002 - ISG-1 Rev 1

  It is necessary to define damaged fuel and specify special conditions for its handling, storage, and transportation in order to accomplish several requirements:

  (1) Confine gross fuel particles that may escape from damaged cladding.

  (2) Facilitate retrieval from a storage or transportation cask.

  (3) Confine damaged fuel assemblies within a known volume to facilitate criticality control, maintain dose limits, and control thermal loads within the cask.

  Damaged fuel - Spent nuclear fuel is considered damaged for storage or transportation purposes if it manifests any of the following conditions that result in either compromise of cladding confinement integrity or rearrangement (reconfiguration) of fuel bundle geometry:

  1) The fuel contains known or suspected cladding defects greater than a pinhole leak or hairline crack that have the **potential for release of significant amounts of fuel particles** into the cask.

  Normally, when fuel is classified as damaged, it must be placed into a damaged-fuel-can prior to being loaded into a storage or transportation cask unless additional analyses can show that no reconfiguration of the fuel assembly or no gross failure of the cladding will occur.

Gross Rupture - History

- <u>May 11, 2007 - ISG-1 Rev 2</u>

  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 to be any cladding breach greater than 1 millimeter.

Gross Rupture – Key Takeaways

- Main focus establishing gross rupture as a requirement was to:
  - Prevent unnecessary exposure from release of significant quantities of fuel material and fission products
  - Ensure ready retrieval
    - Note ISG-2 Rev. 2 (2016) allows retrievability by canister/cask
- Gross rupture interpretation evolved over time from the original intent to not release significant quantities to 0.1 gram
- Fuel/Cladding Performance PIRT expert panel suggested an follow-on expert panel to define and provide a multidisciplinary technical basis for establishing a durable regulatory definition and interpretation for gross rupture

Suggested Path Forward

Gross Rupture – Current Guidance

- Current guidance drifted away from original intent which focused on:
  - Dose consequences from fuel material dispersal
  - Support ready retrieval for handling/repackaging
    - Gross failure allowed if contained to avoid unnecessary exposure
- Resulted in non-actionable metric:
  - Cannot provide confirmation BWR or interior PWR fuel rods meet 1 mm metric
  - Precludes use of modern radiochemistry techniques to determine release of fuel material during operation (IN 2018-01)
- Potential fuel material release and its impact on safety is what is important, not size of defect

Safety focused definition of gross rupture needed

Gross Rupture – Recommended Action

- Develop durable definition of gross rupture for safety considerations:
  - Identify safety goal for gross rupture
    - What are we trying to protect against and why?
  - Develop definition of gross rupture
    - Provide an independent, objective, and technical document from a committee of recognized subject matter experts

Gross Rupture – Recommended Path Forward

- Determine safety goal for gross rupture
- Conduct PIRT to define gross rupture using safety goal
  - Follow similar path to previous expert panel PIRTs:
    - Provide an independent, objective, and technical document from a committee of recognized subject matter experts
    - Establish consensus technical expert panel:
      - Composition, e.g. fuel/cladding, shielding, and criticality
      - Technical experts for the panel, observers, and facilitators
    - Coordinate with panel members' organizations for participation
  - EPRI can support/lead PIRT with similar support from stakeholders
    - Goal to initiate PIRT by early summer and draft report by end of summer
    - PIRT activity done remotely without meetings in person
    - Public meeting presentation of the results once consensus developed

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