Cask Storage of High Burn-up Fuel

Industry Perspective

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Objectives and scope

- Meeting objectives
  - Discuss current regulatory basis
  - Determine if an issue exists
  - Identify potential paths forward
- Scope of topic
  - High burn-up fuel (>45 GWd/MTU)
  - Cask storage up to 80 years
  - Does not include
    - Transportation
    - Extended storage (>80 years)
    - Potential regulatory changes

Background information

- CoCs/licenses for high burn-up fuel storage to be renewed over next few years
  - 2012 Prairie Island-TN-40HT, Calvert Cliffs-NUHOMS[1]
  - 2015 Transnuclear-NUHOMS 1004
  - 2020 NAC-UMS; Holtec-Hi-STORM
- Storage of high burn-up fuel is relatively recent
  - 9 years – Maine Yankee[2] (since 2003) up to 49.5 GWd/MTU
  - 7 years – Robinson (since 2005) up to 56.9 GWd/MTU
  - 6 years – Oconee (since 2006) up to 55 GWd/MTU
  - <4 years for most – up to 53.8 GWd/MTU
- ~ 200 loaded-casks contain high burn-up fuel
- Most fuel in pools for future loading is high burn-up

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1) Since 1992, allowable burn-up to 47 GWd/MTU, since 2010, up to 52 GWd/MTU
2) All high burn-up fuel is in damaged fuel cans

Industry's conclusion on high burn-up fuel storage

Current data and practices, consistent with NRC guidance, support the conclusion that there is reasonable assurance that high burn-up fuel can be stored safely and in compliance with the regulations for at least 80 years.

Bases

- Relevant regulations
- NRC guidance
- Loading and storage condition
- Technical data

Details

- Prevent gross clad rupture
- Peak Clad Temp < 400C
- Adhere to guidance, Inert atmosphere, no significant loads
- Basis for NRC guidance, no additional concerns identified

Relevant requirement is to prevent gross cladding rupture

- Relevant regulation
  - 72.122(h)(1) – Protect clad against gross rupture or damage fuel can
    - Most limiting requirement for directly loaded fuel
    - Canned high burn-up fuel do not need to demonstrate clad performance
- Other regulations often cited
  - 72.122(l) – retrievability[1]
    - Meeting 72.122(h)(1) ensures pellets integral with assembly/can
    - Cladding not part of handling structure (only nozzles and guide tubes)
  - 72.124(a) – criticality design[1]
    - Meeting 72.122(h)(1) ensures fuel remains in analyzed condition
  - 72.122(h)(5) – handling and retrieval
    - Not relevant to spent fuel, only to HLW and GTCC

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1) 72.122(l) and 72.124(a) become relevant only if exemption from 72.122(h)(1) is granted; here it is assumed that no exemption is granted

NRC regulatory basis for fuel in storage is clear and risk informed[1]

- **Regulatory framework doesn't require the fuel or cask internals to be inspected, or monitored**
  - Difficulty to access interior
  - Safety considerations (e.g. minimize worker dose, handling risks)
- **Basis is reasonable assurance no degradation mechanism of concern for storage license terms**
  - Inspection data not required at time of renewal
  - No commitments to monitor, inspect, detect or mitigate clad integrity or unexpected degradation are required

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1) 76FR8872 – Amended Part 72 to increase initial license and CoC terms to 40 years, further expressed in NUREG-1927 and NUREG/CR-7116 on aging management focus for external components

NRC statements of consideration for increasing license/CoC terms (76FR08874, 2011)

"Commission concludes that, with appropriate aging management and maintenance programs, license terms not to exceed 40 years are reasonable and protect public health and safety."

- SOC states no safety concerns for any fuel storage up to 80 years (40yr + 40yr)
  - "...no compelling safety concern...that warrant removal of spent fuel from a cask design..."
- Limits inspection and monitoring to only external components
- Bases for conclusions
  - Clad temperature limits and inert atmosphere
  - INL study, Surry and H.B. Robinson experience
  - NRC guidance, including on storage renewal (NUREG-1927)
  - Does not identify exceptions to findings re: high burn-up fuel

NRC guidance establishes acceptability of high burn-up fuel storage up to 80 years

- As a requisite action, NRC reviewed guidance and updated if necessary during rulemaking to extend license terms
  - No changes were identified or made by NRC to SRPs or ISGs[1]
  - NUREG-1927 was developed in conjunction with rulemaking
- Initial licensing up to 40 years
  - SRPs and ISGs establish guidance on limits that assure no cladding concerns in initial license period up to 40 years
- Renewal of license for up to additional 40 years
  - Standard review plan reinforces need to consider ISG-11, does not indicate any cladding concerns for renewal to a total 80 yr period
  - No data regarding potential long term degradation
  - Applicant should present any new supporting data demonstrating high-burnup fuel performance during extended storage

1) NUREG-1536 and NUREG-1567; ISG-11 Rev 3

Technical bases support conclusion of reasonable assurance of safety for high burn-up fuel storage[1]

- NRC Program Plan (1998-2003) to develop technical bases for high burnup in reactor, storage and transportation[2]
- Significant effort to develop technical bases/guidance in early 2000's
  - Potential degradation mechanisms sufficiently understood
  - Degradation mechanisms are mitigated by establishing loading/storage limits
  - Guidance (ISGs) developed based on these technical bases

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1) See Appendix for list of technical references
2) NRC Memorandum from W. Travers EDO to NRC Commission, August 21, 2003

NRC guidance establishes limits that provide reasonable assurance for storage of fuel

- ISG-15 (2001), (superseded[1] but provides insight)
  - Establish that conditions (temperature and environment) provide reasonable assurance that ensure compliance with 72.122(h)(1)

"The cladding temperature should be maintained below maximum allowable limits, and an inert environment should be maintained inside the cask cavity to maintain reasonable assurance that the spent fuel cladding will be protected against degradation that may lead to gross rupture, loss of retrievability, or severe degradation."

  - Identify that different temperature limit may be needed for high burn-up fuel

"For short-term off-normal and accident conditions, the staff accepts Zircaloy fuel cladding temperatures maintained typically below 570C. …This limit may be lowered for high burnup fuel due to increased internal rod pressure from fission gas buildup."

1) Superseded by ISG 11, Revision 3

NRC guidance establishes limits that provide reasonable assurance for storage of high burnup fuel[1]

- ISG-11, Revision 3 (2003), (supersedes ISG-15)
  - Establish limits for high burnup fuel, which provide reasonable assurance that ensure compliance with 72.122(h)(1)

"In general, a temperature limit of 400 °C that is specified for normal conditions of storage and for short-term fuel loading and Part 72 storage operations (which includes drying, backfilling with inert gas, and transfer of the cask to the storage pad) will limit cladding hoop stresses and limit the amount of soluble hydrogen available to form radial hydrides. The use of a 400 °C temperature limit for normal conditions of storage and for short-term fuel loading and storage operations will simplify the calculations in SARs while assuring that hydride reorientation will be minimized."

  - Indicates that only transport applications have remaining concern

"For high burnup cladding material, cladding performance during hypothetical accident conditions of transport will require further information on the impact properties."

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1) This is a generic determination for all fuel cladding types.

Reinforcement of acceptability of high burn-up fuel for storage terms in regulations

- NRC safety evaluation reports for CoCs
  - No indication of concern for storage
  - Only note considerations for future transportation

"For the fuel assemblies, the allowable temperature limits are based on Interim Staff Guidance-11, (ISG-11), Revision 3 (U.S. Nuclear Regulatory Commission, November, 2003). The 400C maximum temperature recommended in ISG-11 limits mechanisms that can lead to breach of the cladding under normal storage. The applicant should note that the phenomenon known as hydride reorientation may occur in high burnup fuel during storage and change the cladding material properties. This change may affect the potential performance of the cladding during future transportation." (Magnastor Amendment 1 SER, 2009)

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NRC guidance on license renewal reinforces acceptability of high burn-up fuel up to 80 years

- **NUREG-1927 Storage renewal, (2011)**
  - Reinforces adequacy of NRC guidance for renewal term
  - Applicant only needs to provide new data, if available

"The staff should assess whether the applicant has considered the most recent revision of ISG-11 and research results in this area, especially with respect to high-burnup fuel. Research into fuel performance in storage is ongoing. It is expected that the applicants would monitor these developments to ensure that they have identified potential degradation effects. There are presently no data regarding potential long-term degradation of high-burnup fuel cladding. Thus, the applicant should provide any new supporting data demonstrating high-burnup fuel performance during extended storage. As an example, should an applicant have the opportunity for a DCSS interior and cladding inspection, the licensee should report any inspection findings in its evaluations."

NRC guidance on fuel classification provides additional clarity for meeting regulations

- ISG-1, Revision 2 (2007)
  - Clarifies cladding performance criteria
    - Intact SNF – can meet all functions and is not breached
    - Undamaged SNF, including breached - can meet all functions
    - Breached SNF, not including gross breach – clad defect permit release of gas, pinhole or hairline
- In accordance with 72.122(h)(1)
  - NRC guidance supports fuel loaded as “undamaged” would continue to be so for license terms up to 80 years
  - Canning is required prior to loading damaged fuel

No significant change to technical bases resulting from more recent data

1. "Development of a Metal/Hydride Mixture Model for Zircaloy Cladding with Mixed Hydride Structure," EPRI – 1009694, June 2004
2. "Failure Criteria for Zircaloy Cladding Using a Damage-based Metal/Hydride Mixture Model," EPRI-1009693, December 2004
3. "Spent Fuel Transportation Applications: Fuel Rod Failure Evaluation Under Simulated Cask Side Drop Conditions," EPRI-1009929, June 2005
4. "Application of Critical Strain Energy Density to Predicting High-Burnup Fuel Rod Failure," EPRI-1011816, September 2005
5. "Radial-Hydride-Induced Embrittlement of High-Burnup ZIRLO Cladding Exposed to Simulated Drying Conditions," T.A. Burtseva, et. al, ANL, 2010
6. "Delayed Hydride Cracking Considerations Relevant to Spent Nuclear Fuel Storage," EPRI-1022921, July 2011

Use of guidance provides reasonable assurance of safety and regulatory compliance

- **Actions in initial license period**
  - Ensure cladding does not exceed 400C
  - Ensure inert atmosphere
  - Classify fuel based upon ability to fulfill design functions
- **Actions for license renewal**
  - Compliance to initial license criteria is sufficient
  - Consider most recent revision of ISG-11
  - If any new data on high burnup long term clad performance, should be provided to NRC

Additional conservatisms have not been credited[1]

- Max clad temperature over-predicted by 40C to more than 90C
  - 10C to over 40C over-prediction (depends on design/method) – primarily due to modeling assumptions
  - 30C to over 50C over-prediction – due to actual fuel vs design basis fuel
- Most cladding temperature much less than max clad temp
  - 35C to 100C radial thermal gradients
  - Up to 240C axial gradient
- Increased confidence in no gross rupture

1) These are estimations only based upon knowledge of thermal analyses, and have not been rigorously calculated.

Potential path forward (1)

- **If current regulatory basis adequate to provide reasonable assurance of safe storage and regulatory compliance of high burnup fuel for at least 80 years:**
  - No changes to NRC guidance necessary
  - No NRC generic communications necessary
  - No need for CoC/license commitments or conditions for renewals
  - No RAIs are expected for renewals on high burn-up fuel

Potential path forward (2)

- If issue exists for high burnup fuel up to 80 years of storage:
  - Generic Issue Program should be used
    - Affects all licensees and CoC holders
    - Potentially significant impacts (e.g. repackage, canning)
    - May influence regulatory changes
  - If guidance is insufficient, should be revised
    - Applicant may not need to address issue in interim; consider 72.62
  - Generic communications may be needed
    - Need to evaluate safety significance
    - Need to evaluate impact on existing casks

Conclusion

- Regulatory bases support reasonable assurance of adequate public health and safety for high burn-up fuel for terms of at least 80 years
  - NRC guidance limits (temperature and inert environment)
  - No concern of internal degradation mechanisms
  - Focus of aging management on external components
  - Additional fuel monitoring not required
- Generic Issue Program should be invoked if appropriate

APPENDIX

References for technical bases

1. "Creep as the Limiting Mechanism for Spent Fuel Dry Storage," EPRI-1001207, 2000
2. "Creep Modeling and Analysis Methodology for Spent Fuel In Dry Storage," EPRI-1003135, 2001
3. "Dry Storage of High-Burnup Spent Fuel: Responses to Nuclear Regulatory Commission Requests for Additional Information and Clarification," EPRI – 1009276, November 2003
4. "Development of a Metal/Hydride Mixture Model for Zircaloy Cladding with Mixed Hydride Structure," EPRI – 1009694, June 2004
5. "Failure Criteria for Zircaloy Cladding Using a Damage-based Metal/Hydride Mixture Model," EPRI-1009693, December 2004
6. "Spent Fuel Transportation Applications: Fuel Rod Failure Evaluation Under Simulated Cask Side Drop Conditions," EPRI-1009929, June 2005
7. "Application of Critical Strain Energy Density to Predicting High-Burnup Fuel Rod Failure," EPRI-1011816, September 2005
8. "Examination of Spent PWR Fuel Rods after 15 years in Dry Storage," NUREG/CR-6831, August 2003
9. "Fundamental Metallurgical Aspects of Axial Splitting in Zircaloy Cladding," Proceedings of International Topical Meeting on LWR Fuel Performance, ANS, April 10-13, 2000.
10. "Low Temperature Rupture Behavior of Zircaloy-Clad Pressurized Water Reactor Spent Fuel Rods under Dry Storage Conditions," Nuclear Technology, v. 67, p. 107

References for technical bases (cont'd)

11. "Long Term Behaviour of the Spent Fuel Cladding in Dry Storage Conditions," 8th International Conference on RWMER, October 2001
12. "Short-Term Creep and Rupture Tests on High Burnup Fuel Rod Cladding," Journal of Nuclear Materials, v. 289, p. 247
13. "Radial-Hydride-Induced Embrittlement of High-Burnup ZIRLO Cladding Exposed to Simulated Drying Conditions," T.A. Burtseva, et. al, ANL, 2010
14. "Spent Fuel Transportation Applications – Assessment of Cladding Performance," EPRI-1015048, December 2007
15. "Delayed Hydride Cracking Considerations Relevant to Spent Nuclear Fuel Storage," EPRI-1022921, July 2011
16. ""Hydrogen Pick-up Fraction for ZIRLO Cladding Corrosion and Resulting Impact on the Cladding Integrity" A. Garde et al, Top Fuel Paper, 2009

If potential issue, questions to consider

- Is the existing regulatory basis incomplete or is there new data since guidance was developed that contradicts the regulatory basis?
- How will this issue be identified, communicated, and what process will be used to address this generically?
- How does this issue affect future CoC/license, existing CoC/license, and previously loaded casks?
- What is the best risk informed approach to issue resolution for already loaded casks?
- Is the concern about storage, or is this really a concern about transportation? Guidance, and even the draft EST gap report, only identifies an issue with transportation after long periods of storage?

If potential issue, questions to consider (cont'd)

- What is the basis for 400C, what assurances does it provide, and for what storage term? What are the concerns beyond this term?
- If 400C does not provide assurance for at least 80 years, then what limits would? A different temperature limit, stress limit, other type of limit (e.g. time at temperature and stress)?
- What is the gap between current knowledge and what is required for reasonable assurance?
- If the knowledge gap necessitates more data, what is the scope, quantity, and type of the minimum data needed for reasonable assurance?
- Is confirmatory data needed for reasonable assurance, or is it only requested to provide increased confidence?