United States Nuclear Regulatory Commission

*Protecting People and the Environment*

# NUREG-2224
# Dry Storage and Transportation of High Burnup Spent Nuclear Fuel

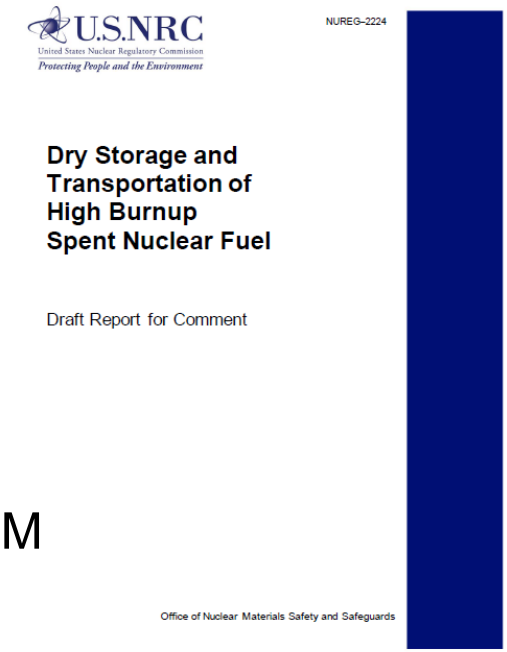
## Draft Report for Comment

September 6, 2018

U.S. NRC, Rockville, MD

# NUREG-2224
# Draft Report for Comment

- ADAMS Accession No.: ML18214A132


U.S.NRC
United States Nuclear Regulatory Commission
Protecting People and the Environment

NUREG–2224

Dry Storage and Transportation of High Burnup Spent Nuclear Fuel

Draft Report for Comment

Office of Nuclear Materials Safety and Safeguards

- Public comment period ends September 24
  - Comment via website: http://www.regulations.gov, Docket ID: NRC-2018-0066
  - Mail comments to:

    May Ma
    Office of Administration, Mail Stop: TWFN-7-A60M
    U.S. Nuclear Regulatory Commission
    Washington, DC 20555-0001
  - Questions about material in NUREG-2224:

    Wendy.Reed@nrc.gov

# Safety Review Objectives Spent Fuel Assemblies

U.S.NRC
United States Nuclear Regulatory Commission
*Protecting People and the Environment*

**Heat Removal**
Controlled fuel temperature and internal stresses

**Subcriticality**
Unsustainable fission reaction

**Structural Performance**
Maintain analyzed configuration
Ready retrieval

**Radiation Shielding**
On-site worker and public dose limits

**Confinement / Containment**
No release of radioactive material

# Spent Fuel Assembly Review Guidance Framework

U.S.NRC
United States Nuclear Regulatory Commission
*Protecting People and the Environment*

## Initial Licensing / Certification

**Standard Review Plans**

Dry Storage:
NUREG-2215 (2018)

Transport:
NUREG-1617 (2000)

**Interim Staff Guidance**

ISG-1, Rev. 2 (2007)
ISG-2, Rev. 2 (2016)
ISG-11, Rev. 3 (2003)
ISG-19 (2003), ISG-22 (2006)
ISG-24 (initial/ renewal, 2014)

## Renewal (Dry Storage)

**Standard Review Plans**

NUREG-1927, Rev. 1 (2016)

**Technical Report**

NUREG-2214 (2018)

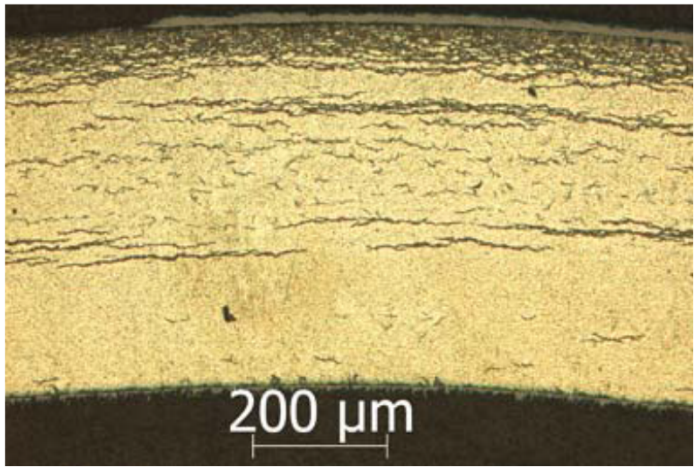
# ISG-11, Rev. 3
# Cladding Considerations

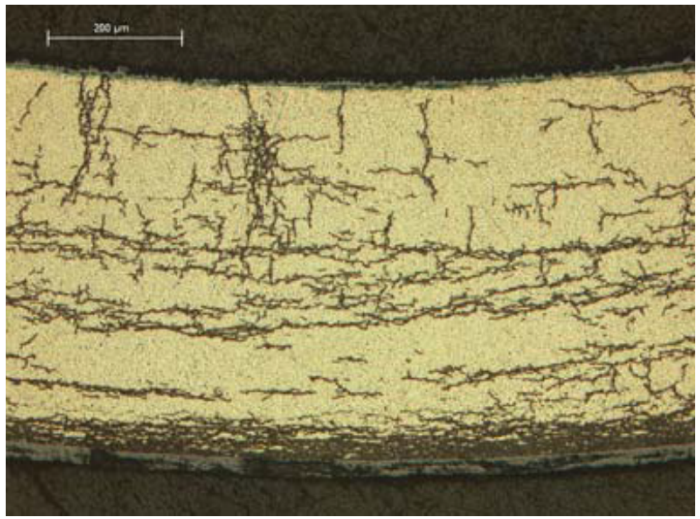
U.S.NRC
United States Nuclear Regulatory Commission
*Protecting People and the Environment*

- Defines SNF cladding temperature limits that provide reasonable assurance that creep and hydride reorientation will not compromise SNF cladding integrity during transportation and dry storage
- Research conducted since issuance of ISG-11, Rev. 3, suggested that hydride reorientation could not be prevented in HBU SNF cladding
- Since then, both NRC and DOE have conducted extensive testing to understand the effects of hydride reorientation on the mechanical performance of HBU SNF

# Hydride Reorientation

- What is it?
  - Hydrogen in the cladding dissolves during drying/short-term loading operations
  - As the fuel cools down, hydrides precipitate in a different orientation
- Why has it been a concern?
  - Impact to cladding mechanical properties
  - Fuel performance under bending and pinch-type loads
- How has NRC addressed it?
  - Separate-effects testing (NUREG/CR-7198)
  - Draft Regulatory Information Summary (2015)
  - NUREG-2224 (2018)



# Purpose of NUREG-2224

- Updates NRC staff's technical basis on HBU SNF cladding performance
  - Provides an engineering assessment of results on mechanical performance of HBU SNF following cladding hydride reorientation
- Efficiency in the preparation and review of storage renewal applications
  - Provide example licensing/certification approaches for dry storage and transportation of HBU SNF

# Contents of NUREG-2224

Front Matter

1. Introduction
2. Assessment of Static Bending and Fatigue Strength Results on HBU SNF (per NUREG/CR-7198, Rev. 1)
3. Dry Storage of HBU SNF (licensing/certification)
4. Transportation of HBU SNF (certification)
5. Conclusions
6. Glossary
7. References

# Introduction

- Background / Regulatory requirements
- Staff review guidance on fuel cladding performance
- Cladding creep
- Hydride reorientation
  - Dissolution / Precipitation
  - Fuel cladding fabrication effects
  - End-of-life rod internal pressures / Cladding hoop stresses
  - Ring compression testing (RCT)
  - Staff's assessment of RCT results

# Assessment of Static Bending / Fatigue Strength Results

U.S.NRC
United States Nuclear Regulatory Commission
*Protecting People and the Environment*

- Introduction / CIRFT background
- Application of static test results
  - Spent fuel rod behavior in bending
  - Composite behavior of spent fuel rod
  - Calculation of cladding strains
  - Applicability to dry storage and transportation
- Application of fatigue test results
  - Lower bound fatigue S-N (strain vs no. cycles) curves
  - Fatigue cumulative damage model
  - Applicability to dry storage and transportation

# Assessment Conclusions Static Bending (Zircaloy-4)

U.S.NRC
United States Nuclear Regulatory Commission
*Protecting People and the Environment*

- CIRFT results for HBU SNF rod specimens confirmed that hydride reorientation does not impact the fuel's flexural rigidity for expected bending moments due to drop accidents
- Hydride-reoriented HBU SNF rod specimens showed markedly higher bending moment resistance compared to the calculated cladding-only response
  - Confirmed that use of cladding-only mechanical properties is adequate for the evaluation of drop accidents (all cladding types)
- Proposed new approach for crediting flexural rigidity of the pellet in the drop accident safety analyses (all cladding types)

# Assessment Conclusions Fatigue Endurance (Zircaloy-4)

U.S.NRC
United States Nuclear Regulatory Commission
*Protecting People and the Environment*

- Hydride-reoriented HBU SNF rod specimens failed at similar equivalent strains than non-reoriented HBU SNF rod specimens
- Lower-bound fatigue S-N curve developed per NUREG/CR-7198, Rev. 1 results
  - Approach can be replicated with CIRFT dynamic test data obtained for other HBU SNF cladding types
  - DOE to acquire additional HBU SNF materials performance data (CIRFT dynamic/static, uniaxial tensile/pressure burst testing/4 point bend testing) under their ongoing Sister Rod Program

# Assessment Conclusions Licensing and Certification

- Developed example licensing and certification approaches based on the assessment conclusions per NUREG/CR-7198, Rev. 1 results (see Tables 3-1 and 4-1, NUREG-2224)
  - Ensured consistency with new consolidated SRPs for dry storage and transportation, and Managing Aging Processes in Storage Report (NUREG-2214)
  - Approaches vary depending on the condition of the fuel (undamaged vs. damaged) and length of time in dry storage
- Applicants may propose and demonstrate alternative approaches to be acceptable

# Dry Storage of HBU SNF Licensing and Certification

U.S.NRC
United States Nuclear Regulatory Commission
*Protecting People and the Environment*

- Introduction
- Uncanned fuel (intact and undamaged fuel)
  - Leaktight confinement
  - Non-leaktight confinement (HBU SNF release fractions)
  - Dry storage up to 20 years
  - Dry storage beyond 20 years
    - Results from confirmatory demonstration (NUREG-1927, Rev. 1)
    - Supplemental safety analyses (per NUREG/CR-7203)
- Canned fuel (damaged fuel)

# Transportation of HBU SNF Certification

U.S.NRC
United States Nuclear Regulatory Commission
*Protecting People and the Environment*

- Introduction
- Uncanned fuel (intact and undamaged fuel)
  - Leaktight containment
  - Non-leaktight containment (HBU SNF release fractions)
  - Shipment of directly-loaded fuel / previously dry-stored fuel (up to 20 years)
  - Shipment of previously dry-stored fuel (beyond 20 years)
    - Results from confirmatory demonstration (NUREG-1927, Rev. 1)
    - Supplemental safety analyses (per NUREG/CR-7203)
- Canned fuel (damaged fuel)

# Conclusions

- NRC has assessed results on mechanical testing of hydride-reoriented HBU SNF rod specimens and confirmed that current approaches for evaluating drop accidents are conservative
- NRC expects that additional data obtained under complementary research programs will provide additional confirmation and needed results to assess vibration normally incident to transport
- NUREG-2224 improves the existing technical basis supporting the staff's conclusion that radial hydride reorientation will not compromise HBU SNF cladding integrity during transportation and dry storage up to 60 years

# Questions in *Federal Register* Notice

- Are NRC's assumptions regarding the performance of other cladding alloys based on data obtained from HBU SNF with Zircaloy-4 cladding for evaluating design basis drop accidents reasonable? If not, please explain why not.
- Are the described licensing and certification approaches easy to follow and practical? If not, please explain why not.
- Is the proposed approach for evaluation of vibration normally incident to transport clear? If not, please explain why not.
- Are the discussions on consequence analyses due to hypothetical fuel reconfiguration clear and meaningful? If not, please explain why not.

# Questions in *Federal Register* Notice

- Are there any potential conflicts between NUREG-2215, Standard Review Plan for Spent Fuel Dry Storage Systems and Facilities, Draft for Comment (ADAMS Accession No. ML17310A693) and this document? If so, please describe any conflicts.
- Is the NRC's reassessment of the ductility transition temperature as measured by ring compression testing of defueled HBU SNF specimens reasonable? If not, please explain why not.

# Next Steps

- Evaluate comments: Fall/Winter 2018
- ACRS public meeting: Winter 2018/Spring 2019
- Publish final report and document comment resolution: Spring/Summer 2019

# Abbreviations

- ACRS: Advisory Committee on Reactor Safeguards
- ADAMS – Agencywide Documents Access and Management System
- CIRFT: Cyclic Integrated Reversible-Bending Fatigue Tester
- DOE: Department of Energy
- HBU: high burnup
- ISG: interim staff guidance
- No.: number
- NRC: Nuclear Regulatory Commission
- RCT: ring compression testing
- Rev.: revision
- SNF: spent nuclear fuel
- SRP: Standard Review Plan

# References


- 10 CFR Part 71, “Packaging and Transportation of Radioactive Material,” Washington, DC.
- 10 CFR Part 72, “Licensing Requirements for the Independent Storage of Spent Nuclear Fuel, High Level Radioactive Waste, and Reactor-Related Greater than Class C Waste,” Washington, DC.
- NRC, “A Quantitative Impact Assessment of Hypothetical Spent Fuel Reconfiguration in Spent Fuel Storage Casks and Transportation Packages.” NUREG/CR-7203, Washington, DC, 2015, ADAMS Accession No. ML15266A413.
- NRC, “Cladding Considerations for the Transportation and Storage of Spent Fuel,” ISG-11, Rev. 3, Washington, DC, 2003, ADAMS Accession No. ML033230335.
- NRC, “Classifying the Condition of Spent Nuclear Fuel for Interim Storage and Transportation Based on Function,” ISG-1, Rev. 2, Washington, DC, 2016, ADAMS Accession No. ML071420268.
- NRC, “Dry Storage and Transportation of High Burnup Spent Nuclear Fuel,” Draft NUREG-2224, Washington, DC, 2018, ADAMS Accession No. ML18214A132.
- NRC, “Fuel Retrievability,” ISG-2, Rev. 2, Washington, DC, 2016, ADAMS Accession No. ML100550861.
- NRC, “Managing Aging Processes in Storage (MAPS) Report,” Draft NUREG-2214, Washington DC, 2017. ADAMS Accession No. ML17289A237.
- NRC, “Mechanical Fatigue Testing of High-Burnup Fuel for Transportation Applications,” NUREG/CR-7198, Revision 1, Washington, DC, 2017. ADAMS Accession No. ML17292B057.

# References


- NRC, “Standard Review Plan for Renewal of Specific Licenses and Certificates of Compliance for Dry Storage of Spent Nuclear Fuel,” NUREG-1927, Revision 1, Washington, DC, 2016, ADAMS Accession No. ML16179A148.
- NRC, “Standard Review Plan for Spent Fuel Dry Storage Systems at a General License Facility,” NUREG-1536, Rev. 1, Washington, DC, 2010, ADAMS Accession No. ML101040620.
- NRC, “Standard Review Plan for Spent Fuel Dry Storage Facilities,” NUREG-1567, Rev. 0, Washington, DC, 2000, ADAMS Accession No. ML003686776.
- NRC, "Standard Review Plan for Transportation Packages for Spent Nuclear Fuel,” NUREG-1617, Washington DC, ADAMS Accession No. ML003696262.NRC. 2000.