



Regulatory Perspectives of Neutron Absorbing Materials: Wet Storage, Dry Storage, and Packaging and Transportation

Emma Wong
Nuclear Regulatory Commission
ASTM C26: Short Course
June 12, 2016



Disclaimer

NRC staff views expressed herein do not constitute a final judgment or determination of the matters addressed or of the acceptability of any actions that may be under consideration at the NRC.



Overview

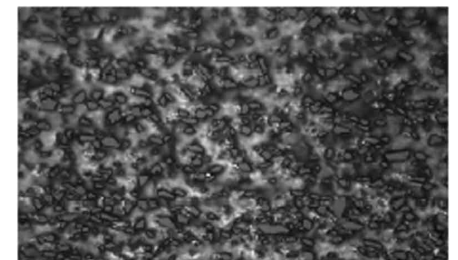
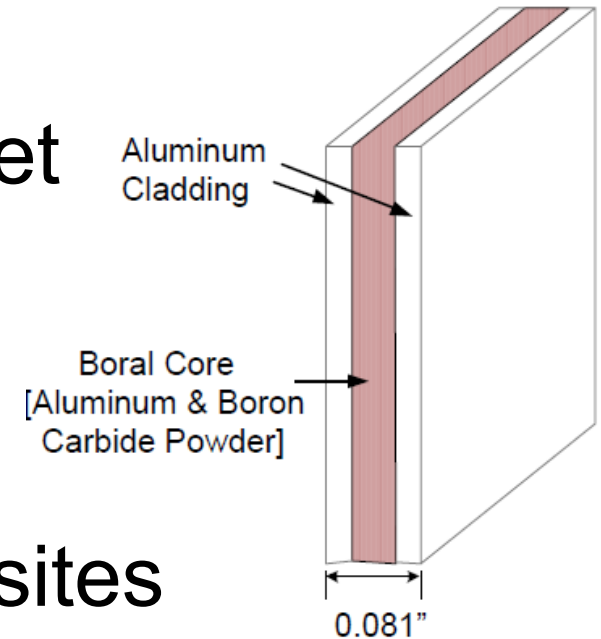
- U.S. Common Materials
- Applicable Regulations
- Wet Storage
- Dry Storage
- Packaging and Transportation
- References
- Abbreviations

U.S. Common Materials

Material Type	Wet Storage	Dry Storage and Transportation
Non-metal matrix composites (Boraflex, Carborundum, TETRABOR®)	X	
Aluminum boron carbide cermet (BORAL®)	X	X
Aluminum metal matrix composites (METAMIC®, Boralyn, Talbor™, BORALCAN™, MAXUS®)	X	X
Boron stainless steels	X	X
Boron aluminum alloys		X

U.S. Common Materials

- Aluminum Boron Carbide Cermet
 - BORAL®
- Non-metal Matrix Composites
 - Polymer based & B₄C imbedded
- Aluminium Metal Matrix Composites
 - Aluminum alloy (1100/6XXX) with B₄C incorporated
- Boron Stainless Steels
 - Stainless steels with B₄C imbedded
- Boron Aluminum Alloys
 - Aluminum alloys with B₄C imbedded



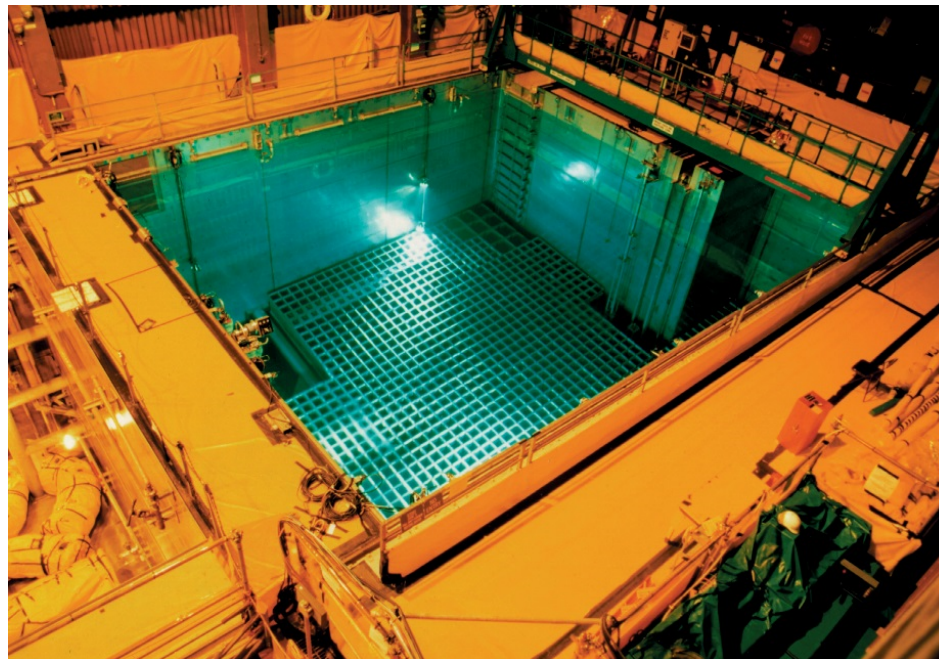
EPRI Report TR1019110

Applicable Regulations

Requirement	Wet Storage (10 CFR Part 50)	ISFSI Storage (10 CFR Part 72)	Transportation (10 CFR Part 71)
Subcriticality	10 CFR 50.68, 10 CFR Part 50 Appendix A, GDC for Nuclear Power Plants Criterion 62	10 CFR 72.124(b), 10 CFR 72.236(c)	10 CFR 71.55 (b), 10 CFR 71.55 (d), 10 CFR 71.55 (e), 10 CFR 71.59 (a)(1), 10 CFR 71.59 (a)(2), 10 CFR 71.64(a)(1)(iii)
Retrievability		10 CFR 72.122(l), 10 CFR 72.236(m)	
Quality assurance, conformance, design detail	10 CFR Part 50 Appendix B	10 CFR 72.24(c)(3), 10 CFR 72.154(a)	10 CFR 71.33(a)(5)(ii), 10 CFR 71.33(b)(4), 10 CFR 71.85(a), 10 CFR 71.87(g), 10 CFR 71.115(a)

Wet Storage

- Subcriticality can be managed by geometry and spacing
- Re-racking with tighter geometry and neutron absorbing materials to increase the capacity





Safety Significance

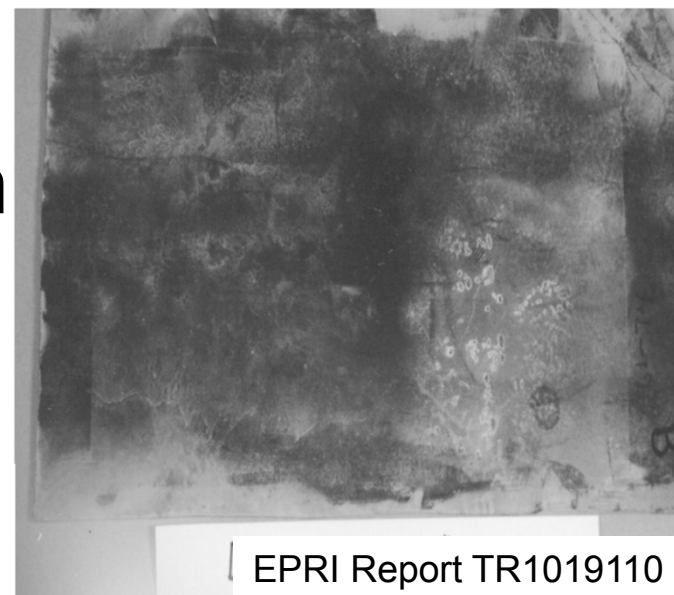
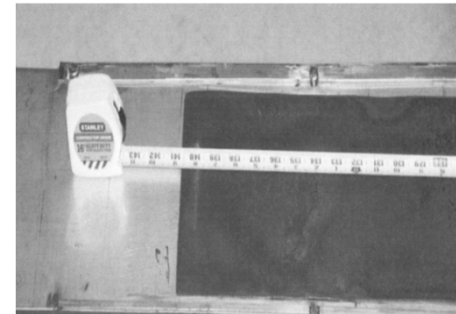
- Prevent the occurrence of any inadvertent criticality events in the SFP
- Neutron absorbing materials have a direct impact on safety
 - Unidentified and unmitigated degradation poses a criticality and safety concern
 - Challenges compliance with NRC subcriticality requirements: 10 CFR 50.68 and GDC 62
- NRC staff has identified this issue as potentially safety significant

Guidance

- GL-78-11 dated April 14, 1978
 - Suggested an in-service surveillance program
 - Verification of long-term stability by actual tests
- NUREG-0800 Standard Review Plan
 - 9.1.1 “Criticality Safety Of Fresh And Spent Fuel Storage And Handling Review Responsibilities”
 - 9.1.2 “Spent Fuel Storage”
- Generic Aging Lessons Learned Report (NUREG-1801, Rev. 2)
 - AMP XI.M22, Boraflex Monitoring
 - AMP XI.M40, Monitoring of Neutron-Absorbing Materials Other than Boraflex
- LR-ISG 2009-01 – incorporated in NUREG-1801 Rev. 2

Boraflex Experience

- Silica polymer matrix degradation
- Cracking, shrinking, & gaps
- INs: 87-43, 93-70, 95-38
- GL 96-04: Maintain 5% margin
 - Surveillance program
 - BADGER testing
 - RACKLIFE predictive program
 - Corrective actions
- Many plants stopped crediting Boraflex



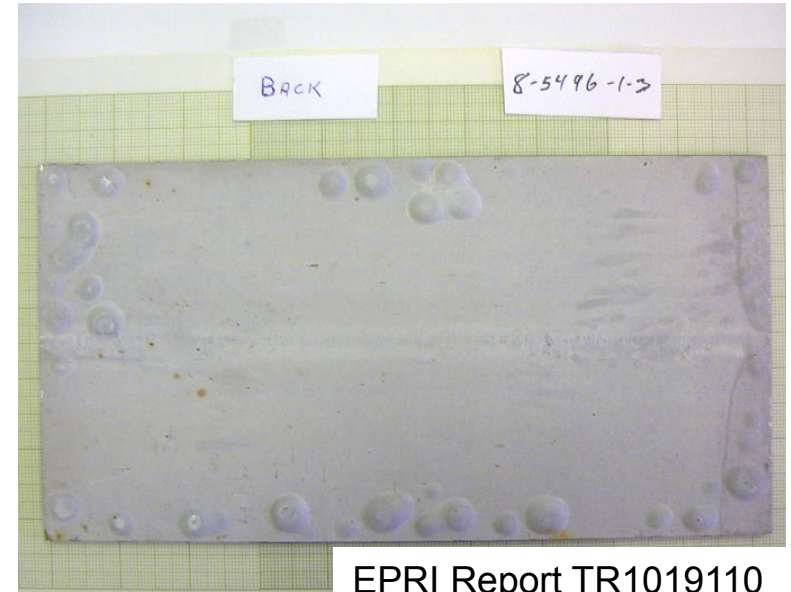


Boraflex Experience (con't)

- IN 12-13
 - Turkey Point Unit 3, 2010
 - Areal density was less than the licensing basis
 - Ineffective implementation of corrective actions
 - Ineffective in identifying and mitigating degradation
 - Peach Bottom Unit 2, 2010
 - Panels degraded below the TS requirements
 - Ineffective implementation of corrective actions
 - Monitoring and mitigating the degradation not adequate

BORAL Experience

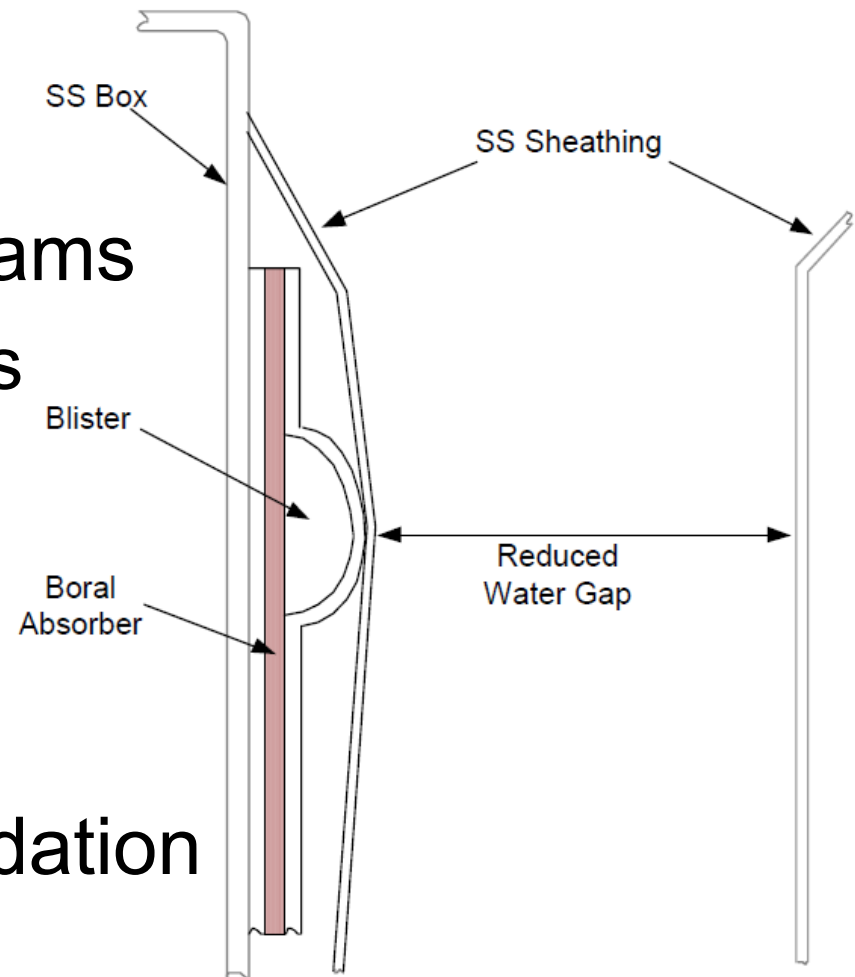
- Pre-1980's BORAL®
- IN 83-29
- Blistering & bulging
 - Gas accumulation
 - Caused stuck fuel assemblies and unusable cells
 - Clad separates from the core and is plastically deformed outward away from the core.
- Many plants with BORAL® drilled holes or clipped the corners in their fuel storage racks to allow gas to escape



EPRI Report TR1019110

BORAL Experience (con't)

- IN 09-26, Beaver Valley and Susquehanna
 - Blistering and bulging operating experience
- IN 12-13, Monitoring programs
 - Some ineffective programs in identifying & mitigating degradation
- Monitoring programs are important to detect and monitor the onset of degradation



Picture: Blister/Bulge

Carborundum Experience

- IN 09-26, Palisades 2008
 - Stuck fuel assemblies
 - BADGER testing found up to 70% degradation
 - Received a “White” finding in 2010
 - Lessons learned from recent events:
 - Surveillance program important to detect onset of degradation
 - Effective operating experience evaluation can lead to early identification
 - Unknown degradation mechanisms and rates could result in reduced subcriticality margins.





Other Materials

- **METAMIC**
 - Used since the mid-2000's
 - No adverse operating experience
- **BORALCAN**
 - Used since early 2010's
 - No adverse operating experience
- **MAXUS**
 - 1st application submitted November 2015 by Palo Verde
 - Used internationally
- **Boron stainless steel**
 - Limited use in the U.S.



Assessment Criteria

- Materials in each SFP and monitoring method
- Program to monitor and mitigate material degradation
- Degree of accuracy of in-situ neutron attenuation measurements
- Surveillance intervals to monitor degradation
- Material degradation effect on the criticality analysis



NRC Actions

- NRC evaluated material degradation mechanisms, surveillance techniques, and predictive modeling
 - Literature knowledge base
 - Confirmatory research on the surveillance methodology
 - Confirmatory research on the surveillance interval adequacy



Knowledge Base

- Current NRC state of knowledge
 - Commercial and decommissioned SFPs
 - Lists materials in each SFP
 - Periodically updated
- Issued public
 - Technical Letter Report: ML113550241
 - Spreadsheet: ML13212A064



U.S.NRC Surveillance Methodologies

- Boraflex methodologies (predictive code and in-situ method) examined
- Reports published
 - TLR on Boraflex, RACKLIFE, and BADGER methodologies: ML12216A307
 - TLR on BADGER tool: ML12254A064
- BADGER report applies to all neutron absorbing materials



U.S.NRC Surveillance Methodologies

- Visual inspection
- Coupon monitoring
 - Representative of the rack panel material
 - Test methods/procedures
- Predictive modeling methodology
 - RACKLIFE
- In-situ testing methodology
 - Blackness testing
 - BADGER testing
- Other methods



Surveillance Frequencies

- Material degradation mechanisms and rate
- Frequency acceleration/deceleration
- Indicators of degradation between surveillances

Criticality Aspects

- Material degradation that could affect the criticality analysis of record
 - Loss of material – neutron absorbing capability
 - Deformation – blistering, bulging, pitting, warping
 - Gaps, cracks, shrinkage, densification
 - Voids
 - Structural integrity
 - Wear/mechanical damage
- Local effects are important



Generic Letter 2016-01

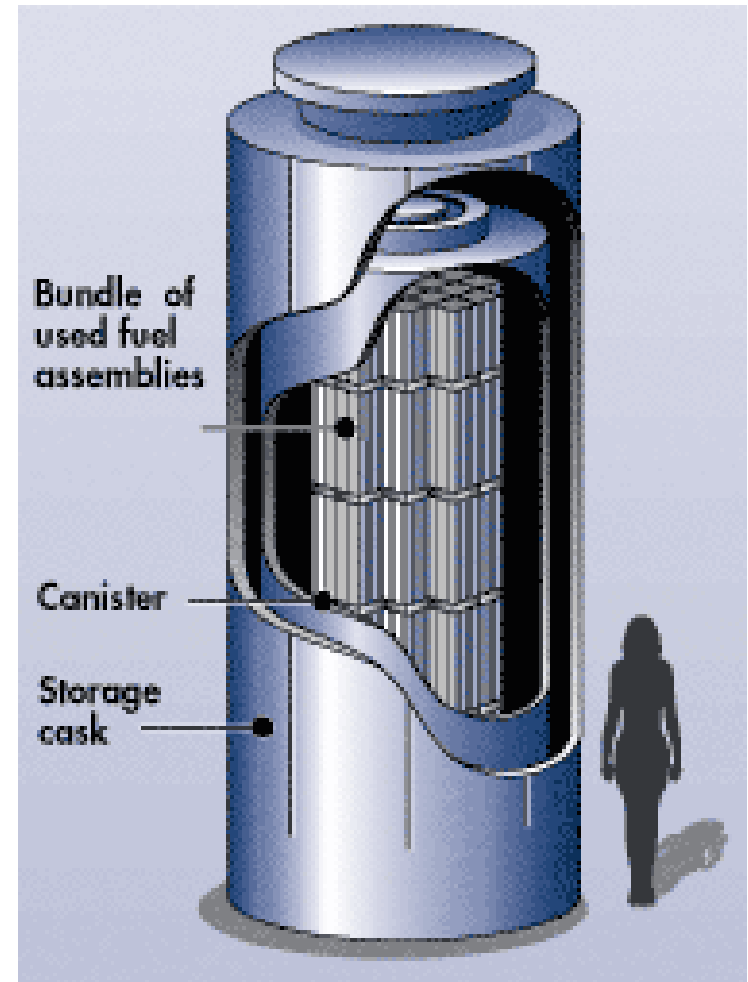
- Requests information on:
 - the neutron-absorbing material
 - monitoring or surveillance program
 - how the monitoring/surveillance program results are used to confirm continued regulatory compliance
- Tiered approach
- Templates for responses
- No new research, analyses, or programs are being requested
- [ML16097A169](#)

Summary

- Surveillance program important to detect onset of degradation
- Effectiveness of surveillance monitoring programs impact management of the SFP
- Effective operating experience evaluation can lead to early identification
- Unknown degradation mechanisms and rates could result in reduced subcriticality margins

Dry Storage

- Provide more storage capacity in addition to SFPs
- Neutron absorbing materials required for criticality control while cask/canister is flooded for loading/unloading/repair
- Breach of containment barriers and subsequent accidental flooding is **not** considered a credible accident



Guidance

- ISG – 15, “Materials Evaluation”
- ISG – 23, “Application of ASTM Standard Practice C1671-07 when performing technical reviews of spent fuel storage and transportation packaging licensing actions”
 - In process to be updated to ASTM 1671-15
- Standard Review Plans: NUREG-1536, -1567, and -1927
- NUREG-XXXX, Managing Aging Processes in Storage (MAPS) Report



Packaging & Transportation

- Criticality control function is significant in the presence of a moderator
 - Loading of fuel under water
 - Water ingress from accident conditions
- Accidental breach of the cask followed by flooding must be considered

Guidance

- ISG – 15, “Materials Evaluation”
- ISG – 23, “Application of ASTM Standard Practice C1671-07 when performing technical reviews of spent fuel storage and transportation packaging licensing actions”
 - In process to be updated to ASTM 1671-15
- Regulatory Guide 7.7
- Standard Review Plans
 - NUREG -1609 and Supplement 1
 - NUREG -1617 and Supplement 1

ISG-23: ASTM C1671-07

- Clarification on use of Section 5.2.1.3:
 - This clarification describes certain physical properties of the neutron absorbing material which, when shown not to change, should not need requalification of the neutron absorbing material with regards to corrosion or thermal degradation behavior.
- Exception to Section 5.2.3:
 - New suppliers should perform a limited requalification of the neutron absorbing material. Additional guidance on use of Section 5.2.5.3: Testing should be added to simulate vacuum drying after submersion.

ISG-23: ASTM C1671-07

- Clarification on use of Section 5.2.6.2:
 - Acceptance testing sampling is dependent on the statistical validity of qualification testing. Previously approved sampling programs for acceptance tests are presented.
- Additional guidance on use of Section 5.2.6.2 and 5.3.4.1:
 - Methods other than neutron attenuation may be appropriate for acceptance testing of the neutron absorbing material, depending on the amount of “credit” taken for the neutron absorber.

ISG-23: ASTM C1671-07

- Exception to Section 5.2.6.2(1):
 - Heterogeneous materials are permitted as neutron attenuation calibration standards if they are traceable to a widely recognized source, such as a national laboratory.
- Additional guidance on use of Section 5.2.6.2(2):
 - The neutron beam diameter used for attenuation measurements is limited to 1-inch with 10- percent tolerance.

ISG-23: ASTM C1671-07

- Additional guidance on use of Section 5.2.6.3:
 - A visual inspection procedure for 100-percent of the plates of neutron absorbing material should be specified in the application.
- Additional guidance on use of Section 5.2.6.3:
 - Maximum possible thickness variations in the neutron absorbing material should be discussed in the application.
- Clarification of use of Sections 5.2.7 and 5.3:
 - Key processes and testing criteria should be placed in Chapter 8 of the Part 71 application or in the Technical Specifications of a Part 72 application.

ISG-23: ASTM C1671-07

- Additional guidance on use of Section 5.2.7.1:
 - Changes to processing which may adversely affect the microstructure of the matrix may require requalification of the neutron absorbing material.
- Additional guidance on use of Section 5.4:
 - For Part 71 and Part 72 applications, neutron absorbing materials should be given a safety classification of “A”, under the guidance of NUREG/CR-6407.

BORAL Experience

- Blister formation
 - 1980's AECL Chalk River Laboratory
 - 2000 Spain operating experience
 - Tests conducted by Equipos Nuclear S.A. (ENSA)
- EPRI testing/results
 - Porosity is a factor
 - Suitable for one or two wetting/drying cycles
- NRC Generic Issue – 196 (dry storage)



Other Materials

- **METAMIC**
 - Used since the mid-2000's
 - No adverse operating experience
- **Boralyn/Talbor**
 - Boralyn used in the early 2000's
- **MAXUS**
 - Used internationally
- **Boron stainless steel**
- **METAMIC HT (structural material)**
 - Used since late-2000's
 - No adverse operating experience

Summary

- Neutron absorbers required for criticality control while the canister/cask/package is flooded with water
 - Initial fuel loading
 - Technical Specification requirements for re-flooding
 - Repairs
 - Unloading
- Accidental breach of the package followed by flooding must be considered for Part 71 CoCs



Questions/Comments

Contacts:

Emma Wong: (301) 415-7091

emma.wong@nrc.gov



Wet Storage References

- Generic Letter 1996-04, “Boraflex Degradation in Spent Fuel Pool Storage Racks,” June 26, 1996, ADAMS Accession No. ML031110008.
- Generic Letter 2016-01, “Monitoring of Neutron-Absorbing Materials in Spent Fuel Pools” April 7, 2016, ADAMS Accession No. ML16097A169
- Information Notice 1987-43, “Gaps in Neutron-Absorbing Material in High-Density Spent Fuel Storage Racks,” September 8, 1987, ADAMS Accession No. ML031130349.
- Information Notice 1993-70, “Degradation of Boraflex Neutron Absorber Coupons,” September 10, 1993, ADAMS Accession No. ML031070107.
- Information Notice 1995-38, “Degradation of Boraflex Neutron Absorber in Spent Fuel Storage Racks,” September 8, 1995, ADAMS Accession No. ML031060277.
- Information Notice 1983-29, “Fuel Binding Caused by Fuel Rack Deformation,” May 6, 1983, ADAMS Accession No. ML14043A291.
- Information Notice 2009-26, “Degradation of Neutron-Absorbing Materials in the Spent Fuel Pool,” October 28, 2009, ADAMS Accession No. ML092440545.
- Information Notice 2012-13, “Boraflex Degradation Surveillance Programs and Corrective Actions in the Spent Fuel Pool,” August 10, 2012, ADAMS Accession No. ML121660156.
- LR-ISG-2009-01, Final License Renewal Interim Staff Guidance, “Aging Management of Spent Fuel Pool Neutron-Absorbing Materials Other than Boraflex,” April 27, 2010, ADAMS Accession No. ML100621321.



Wet Storage References con't

- NUREG-0800, “Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants: LWR Edition”
- NUREG-1801, Revision 2, “Generic Aging Lessons Learned (GALL) Report,” December 2010, ADAMS Accession No. ML103490041.
- TR 1019110, “Handbook on Neutron Absorber Materials for Spent Nuclear Fuel Transportation and Storage Applications,” EPRI, 2009 Edition
- Spent Fuel Pool Criticality Management Database - ML13212A064
- Spent Fuel Pool Criticality Management Technical Letter Report - ML113550241
- Technical Letter Report, “Boraflex, RACKLIFE and BADGER: Description and Uncertainties,” September 30, 2012, ADAMS Accession No. ML12216A307.
- Technical Letter Report, “Initial Assessment of Uncertainties Associated with BADGER Methodology,” September 30, 2012, ADAMS Accession No. ML12254A064.
- Technical Letter Report, “Monitoring Degradation of Phenolic Resin-Based Neutron Absorbers in Spent Nuclear Fuel Pools,” June 5, 2013, ADAMS Accession No. ML13141A182.

NRC Public Website Summary: <http://www.nrc.gov/waste/spent-fuel-storage/pools.html>



Dry Storage References

- ASTM C1671-07, “Standard Practice for Qualification and Acceptance of Boron Based Metallic Neutron Absorber Materials for Nuclear Criticality Control for Dry Cask Storage Systems and Transportation Packaging,” ASTM International, August 2007.
- Interim Staff Guidance 15, “Materials Evaluation,” January 2000, ADAMS Accession No. ML010100170.
- Interim Staff Guidance 23, “Application of ASTM Standard Practice C1671-07 when performing technical reviews of spent fuel storage and transportation packaging licensing actions,” January 2011, ADAMS Accession No. ML103130171.
- NUREG-1536, Revision 1, “Standard Review Plan for Spent Fuel Dry Cask Storage Systems at a General Facility,” 2010, ADAMS Accession No. ML091060180.
- NUREG-1567, Revision 0, “Standard Review Plan for Spent Fuel Dry Storage Facilities,” 2000, ADAMS Accession No. ML003686776.
- Draft NUREG-1927, Rev. 1, “Standard Review Plan for Renewal of Specific Licenses and Certificates of Compliance for Dry Storage of Spent Nuclear Fuel,” 2015, ADAMS Accession No. ML15180A011.
- NUREG-1927, Revision 0, U.S. Nuclear Regulatory Commission. 2011. “Standard Review Plan for Renewal of Specific Licenses and Certificates of Compliance for Dry Storage of Spent Nuclear Fuel,” 2011, ADAMS Accession No. ML111020115.
- TR 1019110, “Handbook on Neutron Absorber Materials for Spent Nuclear Fuel Transportation and Storage Applications,” EPRI, 2009 Edition.
- Results of Initial Screening of Generic Issue 196, “BORAL DEGRADATION,” November 2004, ADAMS Accession No. ML042670379.



Packaging and Transportation References

- ASTM C1671-07, “Standard Practice for Qualification and Acceptance of Boron Based Metallic Neutron Absorber Materials for Nuclear Criticality Control for Dry Cask Storage Systems and Transportation Packaging,” ASTM International, August 2007.
- Interim Staff Guidance 15, “Materials Evaluation,” January 2000, ADAMS Accession No. ML010100170.
- Interim Staff Guidance 23, “Application of ASTM Standard Practice C1671-07 when performing technical reviews of spent fuel storage and transportation packaging licensing actions,” January 2011, ADAMS Accession No. ML103130171.
- NUREG-1609, “Standard Review Plan for Transportation Packages for Radioactive Material”. March 1999. <http://www.nrc.gov/reading-rm/doc-collections/nuregs/staff/sr1609/final/index.html>
- NUREG-1617, “Standard Review Plan for Transportation Packages for Spent Nuclear Fuel,” March 2000. <http://www.nrc.gov/reading-rm/doc-collections/nuregs/staff/sr1617/1617/sr1617.pdf>
- NUREG/CR-6407, “Classification of Transportation Packaging and Dry Spent Fuel Storage System Components According to Importance to Safety,” February 1996, ADAMS Accession No. ML15127A114.
- Regulatory Guide 7.7, “Administrative Guide for Verifying Compliance with Packaging Requirements for Shipping and Receiving of Radioactive Material,” March 2012, ADAMS Accession No. ML112160407.
- TR 1019110, “Handbook on Neutron Absorber Materials for Spent Nuclear Fuel Transportation and Storage Applications,” EPRI, 2009 Edition.



Abbreviations

- ACRS – Advisory Committee on Reactor Safeguards
- AECL – Atomic Energy Canada Limited
- AMP – Aging Management Program
- ASTM – American Society for Testing and Materials
- CFR – Code of Federal Regulations
- CoC – Certificate of Compliance
- ENSA – Equipos Nuclear S. A.
- EPRI – Electric Power Research Institute
- GDC – General Design Criteria
- GL – Generic Letter
- IN – Information Notice
- ISFSI – Independent Spent Fuel Storage Installation
- ISG – Interim Staff Guidance
- NRC – Nuclear Regulatory Commission
- SFP – Spent Fuel Pool
- TLR – Technical Letter Report
- TS – Technical Specification