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Nuclear Fuels Storage & Transportation Planning Project
Office of Fuel Cycle Technologies
Nuclear Energy

Managing Aging Effects on Dry Cask Storage Systems for Extended Long-Term Storage and Transportation of Used Fuel

Yung Y. Liu yylu@anl.gov

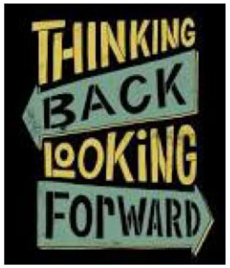
Argonne National Laboratory

Inter. Conf. on Management of Spent Fuel from Nuclear Power Reactors: An Integrated Approach to the Back End of the Fuel Cycle

Vienna, Austria, June 15–19, 2015

Outline

- **The Aging Management Report (2012 – 2014)** – "*Managing Aging Effects on Dry Cask Storage Systems for Extended Long-Term Storage and Transportation of Used Fuel,*" FCRD-UFD-2014-000476, ANL 13/15 (Rev. 2)
  - Followed an approach similar to that of the "Generic Aging Lessons Learned (GALL)" report, NUREG-1801, for aging management and license renewal of nuclear power plants
  - Incorporated stakeholder comments from U.S. industry, cask vendors, utilities, EPRI, NRC, national laboratories, and Germany (via EPRI's Extended Storage Collaboration Program).
  - Referenced in Nuclear Energy Institute (NEI) 14-03, Rev. 0 "Guidance for Operations-based Aging Management on Dry Cask Storage," which ahs been submitted for NRC endorsement in Sept. 2014.
- **Aging management needs for a pilot Interim Storage Facility and beyond (2015)**
  - Supporting storage design concepts for an Interim Storage Facility
- **Historical perspectives, ongoing development, and international context**



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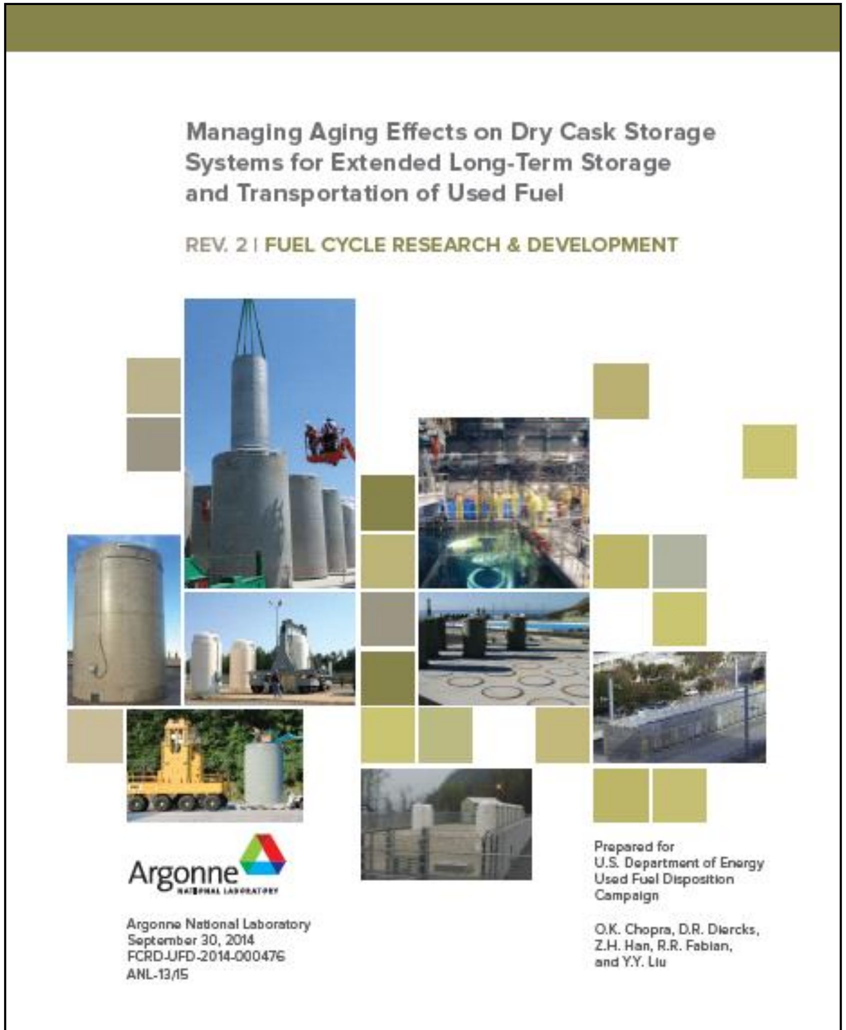
The Aging Management Report –
FCRD-UFD-2014-000476, ANL 13/15 (Rev. 2)



Contains five (5) Chapters:

I. Introduction
II. Terms & Definitions
III. Time-limited Aging Analyses (TLAAs)
IV. Aging Management Programs (AMPs)
V. Applications of TLAAs/AMPs
- NUHOMS
- HI-STORM
- TN Metal Casks
- NAC S/T Casks
- VSC-24
- MC-10
- CASTOR
- W-150

Appendix A: QA for AMPs
Appendix B: Comparison of TLAAs/AMPs (Rev. 2 vs. GALL)

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Dry Cask Storage Systems in Common Use in the United States

Vendor	System	Cask/Canister	Type[a]	Closure
EnergySolutions	FuelSolutions	VSC-24, W150	C/O	Welded
General Nuclear Systems, Inc.	CASTOR	V/21, X/33	Cask	Bolted
Holtec International	HI-STAR 100	MPC-68, MPC-80	C/O	Welded
	HI-STORM 100	MPC-24, MPC-32, MPC-68	C/O	Welded
NAC International, Inc.	S/T	NAC-I28	Cask	Bolted
	MPC	MPC-26, MPC-36	C/O	Welded
	UMS	UMS-24	C/O	Welded
	MAGNASTOR	MAGNASTOR	C/O	Welded
Transnuclear, Inc.	NUHOMS	52B, 61BT, 61BTH, 7P, 24P, 24PHB, 24PT, 24PTH, 24PT1, 32P, 32PT, 32PTH, 12T	C/O	Welded
	TN Metal Casks	TN-24, TN-32, TN-40, TN-68	Cask	Bolted
Westinghouse	MC-10	MC-10	Cask	Bolted

[a] C/O: metallic welded canister with overpack; Cask: self-contained metallic cask with bolted lid

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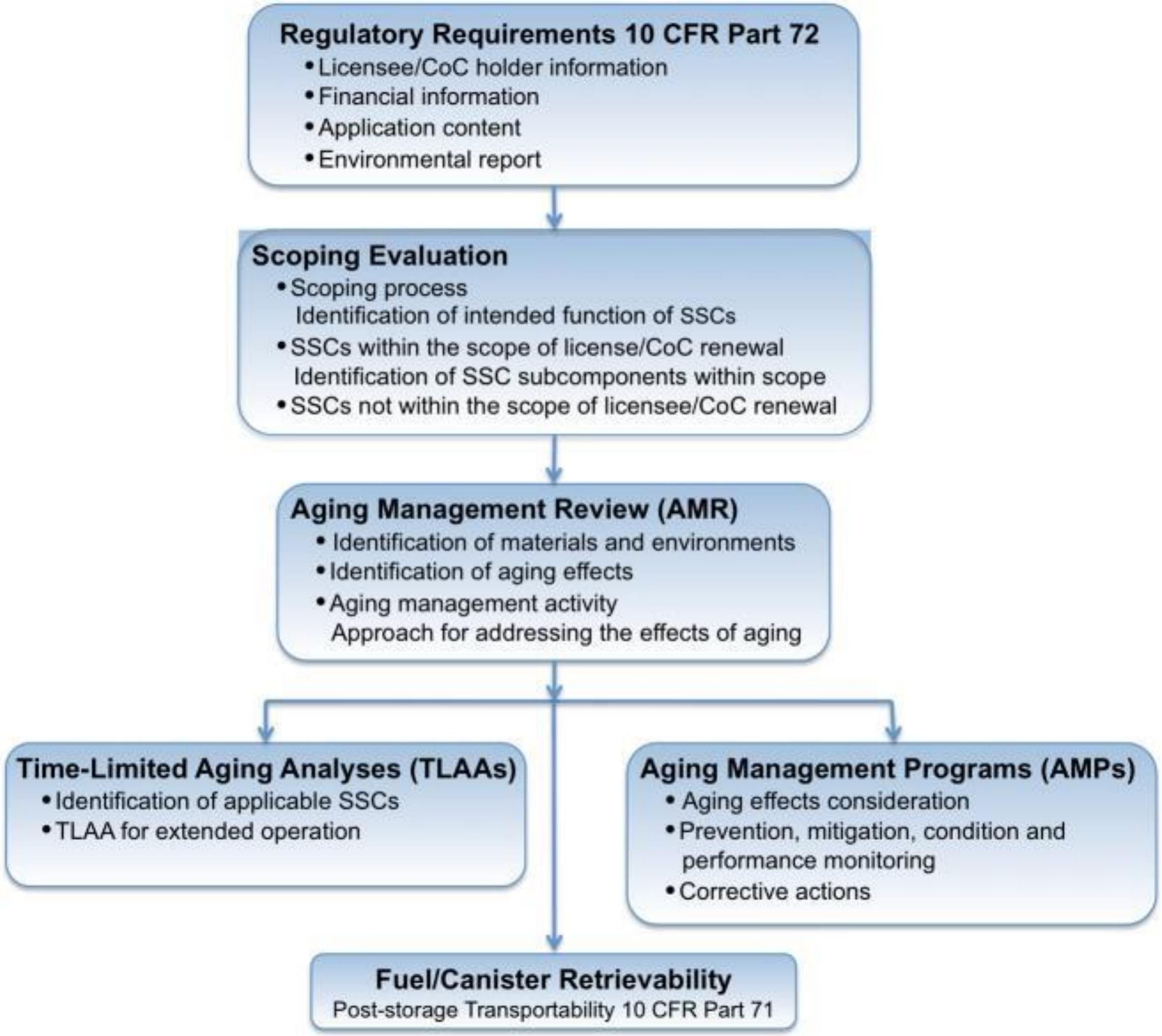
USNRC ISFSI License Renewal Process (adapted from NUREG-1927, Rev.0)



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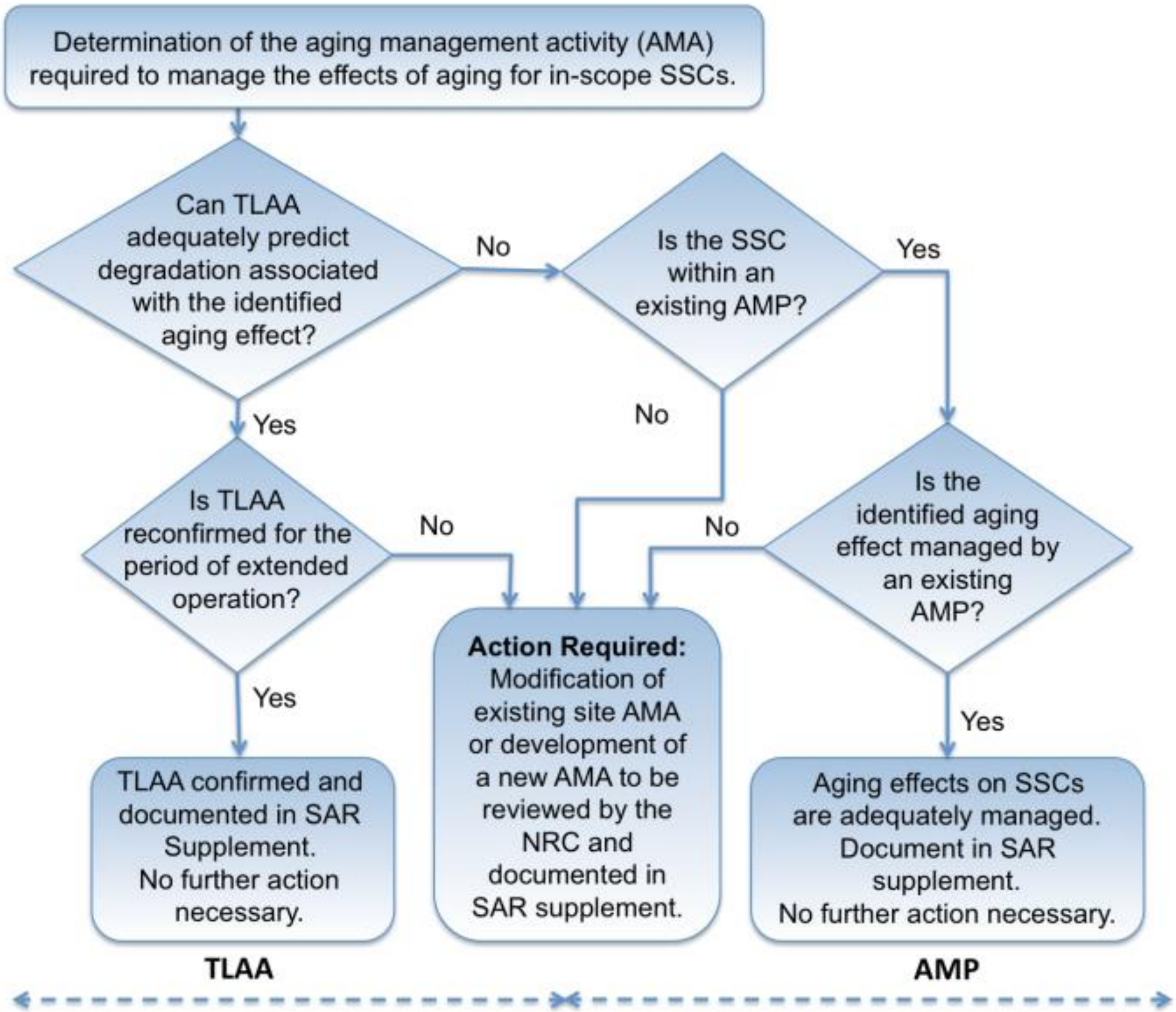
Classification of Components According to Importance to Safety (ITS)

- NUREG-1927 defines six ITS functions of SSCs as follows:
  - **CB:** Confinement boundary
  - **CC:** Criticality control
  - **HT:** Heat transfer
  - **RS:** Radiation shielding
  - **SS:** Structural support
  - **FR:** Fuel retrievability

- NUREG/CR-6407 classifies transportation and dry storage system components according to ITS:
  - **Category A:** Failure directly results in a condition adversely affecting public health & safety
  - **Category B:** Failure indirectly results in a condition adversely affecting public health & safety
  - **Category C:** Failure would not significantly reduce the storage effectiveness

Aging Management Review (AMR)



Aging Effects and Mechanisms

Table D.1 from NUREG-1927 (based on NUREG-1557)

Aging Effects of SSCs	Possible Aging Mechanism
Concrete Structures:	
1. Scaling, cracking, and spalling	Freeze-Thaw
2. Increase in porosity and permeability	Leaching of Calcium Hydroxide
3. Increase in porosity and permeability, cracking	Aggressive Chemical Attack
4. Expansion and cracking	Reaction with Aggregates
5. Loss of strength and modulus	Elevated Temperature
6. Loss of strength and modulus	Irradiation of Concrete
7. Deformation	Creep
8. Cracking	Shrinkage
9. Loss of material	Corrosion
10. Loss of material	Abrasion and Cavitation
11. Cracking	Restrain, Shrinkage, Creep and Aggressive Environment
12. Loss of strength	Concrete Interaction with Aluminum
13. Cathodic protection effect on bond strength	Cathodic Protection Current
Structural Steel:	
1. Loss of material	Corrosion Local or Atmospheric
2. Loss of strength and modulus	Elevated Temperature
3. Loss of fracture toughness	Irradiation
4. Crack Initiation and growth	Stress-Corrosion Cracking
Reinforcing Steel (Rebar):	
1. Cracking, spalling, loss of bond and material	Corrosion of Embedded Steel
2. Loss of strength and modulus	Elevated Temperature
3. Loss of strength and modulus	Irradiation
Miscellaneous:	
1. Cracking, distortion, increase in component stress	Settlement
2. Loss of fracture toughness	Strain Aging (of Carbon Steel)
3. Reduction in design margin	Loss of Prestress
4. Loss of Material	Corrosion of Steel Piles
5. Loss of Material	Corrosion of Tendons
Cask Internals:	
1. Loss of material	Corrosion, Boric-Acid Corrosion
2. Change in dimension	Creep
3. Wall thinning	Erosion Corrosion
4. Crack initiation and growth	Stress-Corrosion Cracking
5. Loss of fracture toughness	Neutron Irradiation Embrittlement
6. Loss of preload	Stress Relaxation
7. Loss of fracture toughness	Thermal Embrittlement
8. Attrition	Wear
Zircaloy Cladding (Not in NUREG-1927)	
1. Embrittlement	Hydride reorientation (High-burnup fuel only)

Aging Management Activities — TLAA and AMP

- **Time-Limited Aging Analysis (TLAA) —** To assess SSCs that have a time-dependent operating life, e.g., fatigue (cycles to failure), time limited (operating hours until replacement), or time-dependent degradation of properties (aging effects).

- **Aging Management Program (AMP) —** To ensure aging effects do not result in a loss of intended ITS function of the SSCs that are within the scope of renewal, for the term of the renewal.

AMPs are generally of four types: ***Prevention, Mitigation, Condition Monitoring and Performance Monitoring.*** **Each AMP contains 10 elements:**

- Scope of Program
- Preventive Actions
- Parameters Monitored or Inspected
- Detection of Aging Effects
- Monitoring and Trending
- Acceptance Criteria
- Corrective Actions
- Confirmation Process
- Administration Control
- Operating Experience

TLAAs and AMPs in the Aging Management Report

Time-Limited Aging Analyses (TLAAs):

- III.1: Identification of Time-Limited Aging Analyses
- III.2: Fatigue of Metal and Concrete Structure and Components
- III.3: Corrosion Analysis of Metal Components
- III.4: Time-Dependent Degradation of Neutron-Absorbing Materials
- III.5: Time-Dependent Degradation of Radiation-Shielding Materials
- III.6: Environmental Qualification of Electrical Equipment
- III.7: Other Site-Specific Time-Limited Aging Analyses

Aging Management Programs (AMPs):

- IV.S1: Concrete Structures Monitoring Program
- IV.S2: Monitoring of Protective Coatings on Carbon Steel Structures
- IV.M1: External Surfaces Monitoring of Mechanical Components
- IV.M2: Ventilation System Surveillance Program
- IV.M3: Welded Canister Seal and Leakage Monitoring Program
- IV.M4: Bolted cask Seal and Leakage Monitoring Program
- IV.M5: Canister/Cask Internals Structural and Functional Integrity

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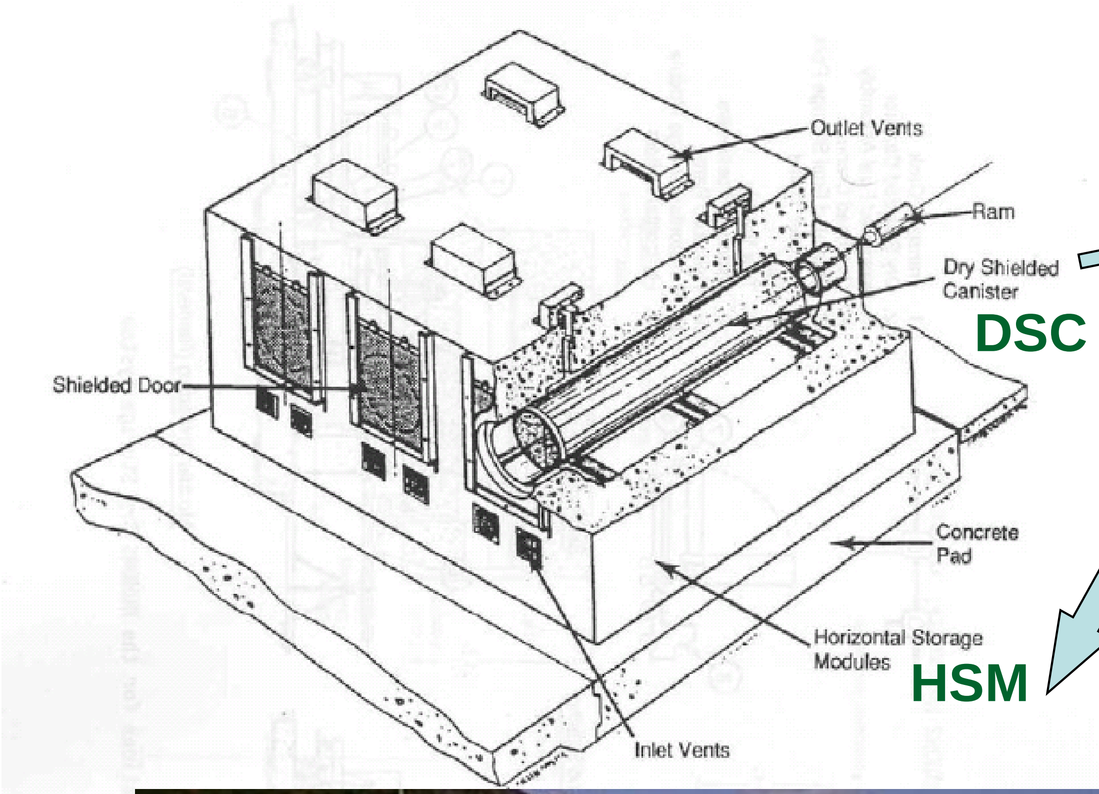
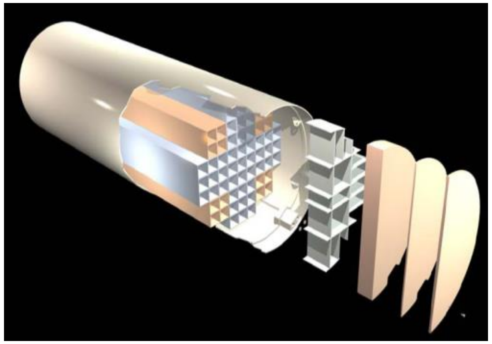
NUHOMS Dry Spent Fuel Storage

Oconee 84/2026 (24P); 50/1200 (24PHB)
Calvert Cliffs 48/1152 (24P); 28/896 (32P)





24P
24PTH
24PHB
32P
52B
61BT

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V.1 NUHOMS Dry Spent-Fuel Storage

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Table V.1.A NUHOMS Dry Spent-Fuel Storage: **Horizontal Storage Module (HSM)**							
Item	**Structure and/or Component**	**Intended Function**	**Material**	**Environ**	**Aging Effect/ Mechanism**	**Aging Management Program (AMP)**	**Program Type**
V.1.A-5	Concrete: HSM walls, roof, and floor; inlet and outlet vents shielding blocks **(A)**	RS, SS, HT	Reinforced Concrete	Air – inside the module, uncontrolled, radiation and elevated temperature	Reduction of strength and degradation of shielding performance of concrete due to elevated temperature (>150° F general, >200° F local) and long-term exposure to gamma radiation (>10^{10} rads)	The compressive strength and shielding performance of plain concrete are maintained by ensuring that the minimum concrete density is achieved during construction and the allowable concrete temperature and radiation limits are not exceeded. The implementation of 10 CFR 72 and ASME Section XI, Subsection IWL would not enable identification of the reduction of strength and modulus of elasticity due to elevated temperature and gamma radiation. Thus, for any portions of concrete in HSM that exceed specified limits for temperature and gamma radiation, further evaluations are warranted. ……	Further evaluation, if temperature and gamma radiation limits are exceeded

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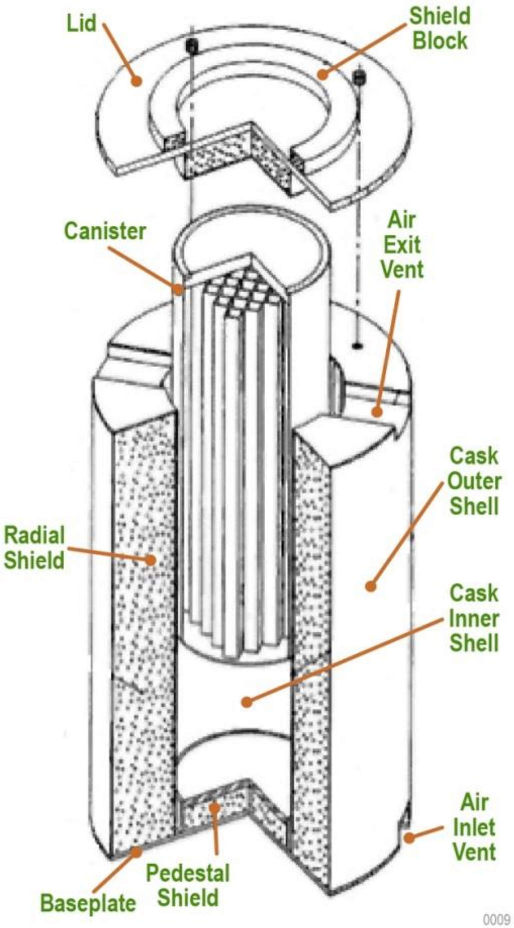
V.1 NUHOMS Dry Spent-Fuel Storage

Table V.1.B NUHOMS Dry Spent-Fuel Storage: **Dry Shielded Canister (DSC)**

Item	Structure and/or Component	Intended Function	Material	Environ	Aging Effect/ Mechanism	Aging Management Program (AMP)	Program Type
V.1.B-1	DSC: Shell (including welds) **(A)**	CB, HT, SS, FR	Stainless steel	Air – inside the HSM, uncontrolled (external), Helium (internal)	Cumulative fatigue damage due to cyclic loading	Fatigue is a TLAA to be evaluated for the requested period of extended operation. See III.2 "Fatigue of Metal and Concrete Structures and Components" for acceptable methods for meeting the acceptance criteria in Section 3.5.1 of NUREG-1927.	TLAA
V.1.B-2	DSC confinement boundary: Shell, outer top cover plate, outer bottom cover plate, and welds **(A)**	CB, HT, SS, FR	Stainless steel	Air – inside the HSM, uncontrolled (external), Helium (internal)	Cracking and leakage due to stress corrosion cracking (SCC) when exposed to moisture and aggressive chemicals in the environment (e.g., chloride in marine environment)	IV.M1, "External Surfaces Monitoring of Mechanical Components" IV.M3, "Welded Canister Seal and Leakage Monitoring Program"	Generic programs

HI-STORM 100 System



V.2.A1 HI-STORM 100 System: Storage Overpack

Table V.2.A1	HI-STORM 100 System: Storage Overpack						
Item	**Structure and/or Component**	**Intended Function**	**Material**	**Environ**	**Aging Effect/ Mechanism**	**Aging Management Program (AMP)**	**Program Type**
V.2.A1-4	Ventilation air openings: Air ducts, screens, gamma shield cross plates **(A)**	HT	Carbon or low-alloy steel	Air – inside the module, uncontrolled or Air – outdoor	Reduced heat convection capacity due to blockage	IV.M2, "Ventilation System Surveillance Program"	Generic program
V.2 A1-5	Anchor Studs (for anchored cask) **(A)**	SS	SA-193, SA-354, SA-479, SA-540, SA-564, SA-574, SA-638	Air – outdoor or marine environ (if applicable)	Loss of preload due to self-loosening; loss of material due to corrosion; cracking due to SCC	IV.M1, "External Surfaces Monitoring of Mechanical Components"	Generic program
V.2.A1-6	Anchor Studs (for anchored cask) **(A)**	SS	SA-193, SA-354, SA-479, SA-540, SA-564, SA-574, SA-638	Air – outdoor	Cumulative fatigue damage due to cyclic loading	Fatigue is a TLAA to be evaluated for the requested period of extended operation. See III.2 "Fatigue of Metal and Concrete Structures and Components" for acceptable methods for meeting the acceptance criteria in Section 3.5.1 of NUREG-1927.	TLAA

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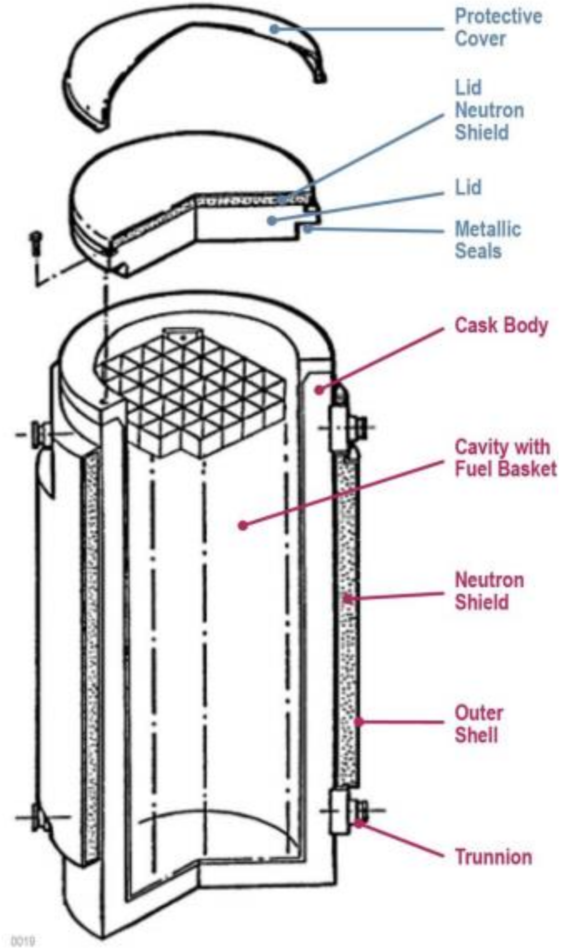
V.2.B HI-STORM 100 or HI-STAR 100 System: MPC

Table V.2.B HI-STORM 100 or HI-STAR 100 System: Multipurpose Canister (MPC)

Item	Structure and/or Component	Intended Function	Material	Environ	Aging Effect/ Mechanism	Aging Management Program (AMP)	Program Type
V.2.B-1	MPC: Baseplate, shell, lid, port cover, closure ring, and associated welds; fuel basket and fuel spacer **(A)**	CB, CC, HT, SS, FR	Stainless steel: 304 SS, 304LN SS, 316 SS, 316LN SS	Air – inside the overpack, uncontrolled (external); Helium (internal)	Cumulative fatigue damage due to cyclic loading	Fatigue is a TLAA to be evaluated for the requested period of extended operation. See III.2, "Fatigue of Metal and Concrete Structures and Components," for acceptable methods for meeting the acceptance criteria in Section 3.5.1 of NUREG-1927.	TLAA
V.2.B-2	MPC (access requires extra effort): Baseplate, shell, lid, closure ring, and associated welds; shield lid and bolting **(A)**	CB, CC, HT, SS, FR	Stainless steel: 304 SS, 304LN SS, 316 SS, 316LN SS	Air – inside the storage overpack, uncontrolled (external)	Cracking and leakage due to stress corrosion cracking when exposed to moisture and aggressive chemicals in the environment	IV.M1, "External Surfaces Monitoring of Mechanical Components" IV.M3, "Welded Canister Seal and Leakage Monitoring Program"	Generic Programs.
V.2.B-3	MPC Internals: Fuel basket, spacer, basket support; heat conduction elements; drain pipe, vent port; neutron absorber panels (in stainless steel sheathing) **(A)**	CC, CB, HT, SS, FR	Stainless steel, aluminum alloy, borated aluminum or boron carbide /aluminum alloy plate or BORAL composite	Helium, radiation, and elevated temperature	Degradation of heat transfer, criticality control, radiation shield, confinement boundary, or structural support functions of the MPC internals due to extended exposure to high temperature and radiation.	IV.M5, "Canister/Cask Internals Structural and Functional Integrity Monitoring Program" Degradation of neutron-absorbing materials is a TLAA to be evaluated for the requested period of extended operation. See III.4, "Time-Dependent Degradation of Neutron-Absorbing Materials," for acceptable methods for meeting the acceptance criteria in Section 3.5.1 of NUREG-1927.	Generic program TLAA

TN Metal Spent Fuel Storage Cask



V.3.B TN Metal Spent Fuel Storage Cask

Table V.3.B TN Metal Spent-Fuel Storage Cask: Internal Contents of the Confinement Vessel

Item	Structure and/or Component	Intended Function	Material	Environ.	Aging Effect/ Mechanism	Aging Management Program (AMP)	Program Type
V.3.B-3	Cover plates and bolting (access requires removal of overpressure tank and top lid neutron shield): Drain, vent and overpressure port **(A)**	**CB**, SS, HT	Low-alloy steel	Air – enclosed space, uncontrolled (external); Helium (internal)	Loss of material due to corrosion	IV.M1, "External Surfaces Monitoring of Mechanical Components" Further evaluation is required to determine if periodic inspection is needed to manage loss of material due to corrosion for these components.	Generic program
V.3.B-4	Helicoflex seals (includes stainless steel cladding on sealing surface): Lid, drain, vent and overpressure port closures **(A)**	CB	Aluminum, silver, stainless steel, Ni-base alloys	Air – enclosed space, uncontrolled (external), Helium (internal)	Loss of sealing forces due to stress relaxation and creep of the metallic O-rings, corrosion and loss of preload of the closure bolts	IV.M4, "Bolted Cask Seal and Leakage Monitoring Program"	Generic program

The Rev. 2 Aging Management Report

- The goal of this report is to help establish the technical basis for extended long-term storage and subsequent transportation of used fuel, which may occur multiple times before final disposal at a mined repository or geological disposal facility.

- It is suggested that future efforts should include development of additional TLAAs and AMPs that may be deemed necessary, and further evaluation of the adequacy of the recommended TLAAs and AMPs that may need augmentation.

- Industry and site-specific operating experience of the various dry cask storage systems (DCSSs) at Independent Spent Fuel Storage Installations (ISFSIs) located across the country should be periodically examined to

  (a) ascertain the potential aging effects on the SSCs in the DCSSs, thereby enabling a compilation of existing aging management activities, and

  (b) assess these activities' adequacy for extended long-term storage and subsequent transportation of used fuel.

The "GALL" Report - NUREG-1801

- The Generic Aging Lessons Learned (GALL) Report contains the staff's generic evaluation of the existing plant programs and documents the technical basis for determining where existing programs are adequate without modification and where existing programs should be augmented for the period of extended operation. …..

- The GALL Report also contains recommendations on specific areas for which existing programs should be augmented for license renewal.

- An applicant may reference the GALL Report in a license renewal application to demonstrate that the programs at the applicant's facility correspond to those reviewed and approved in the GALL Report…….

- The information in the GALL Report has been incorporated into the NUREG-1800, "Standard Review Plan for Review of License Renewal Applications for Nuclear Power Plants," as directed by the Commission, to improve the efficiency of the license renewal process.

Summary of Maintenance Rule – 10 CFR 50.65 (Nov. 1988 – July 10, 1991; EPRI report 3002002864, Mar. 2014)

- (a) (1) requires licensees to monitor the performance or condition of SSC and to establish goals to promote improved SSC performance, when warranted. Goals and monitoring are to be established commensurate with safety and are to consider industry-wide operating experience, where practical.

- (a) (2) states that monitoring pursuant to (a) (1) is not required for SSCs that are being effectively maintained by a preventive maintenance program.

- (a) (3) requires that performance- and condition-monitoring activities be evaluated at least every refueling cycle (not to exceed an interval of 24 months), taking industry-wide operation experience into account, where practical.

- (a) (4) states that licensees shall assess and manage the increase in risk that may result from proposed maintenance activities. `

NEI 14-03: Industry Guidance for Operations-Based Aging Management, September 23, 2014

- “Tollgate” is a new term created by the nuclear industry to address the fact that the applicability of potential dry cask storage aging mechanisms may not be able to be verified at the time license and CoC renewal applications are submitted.

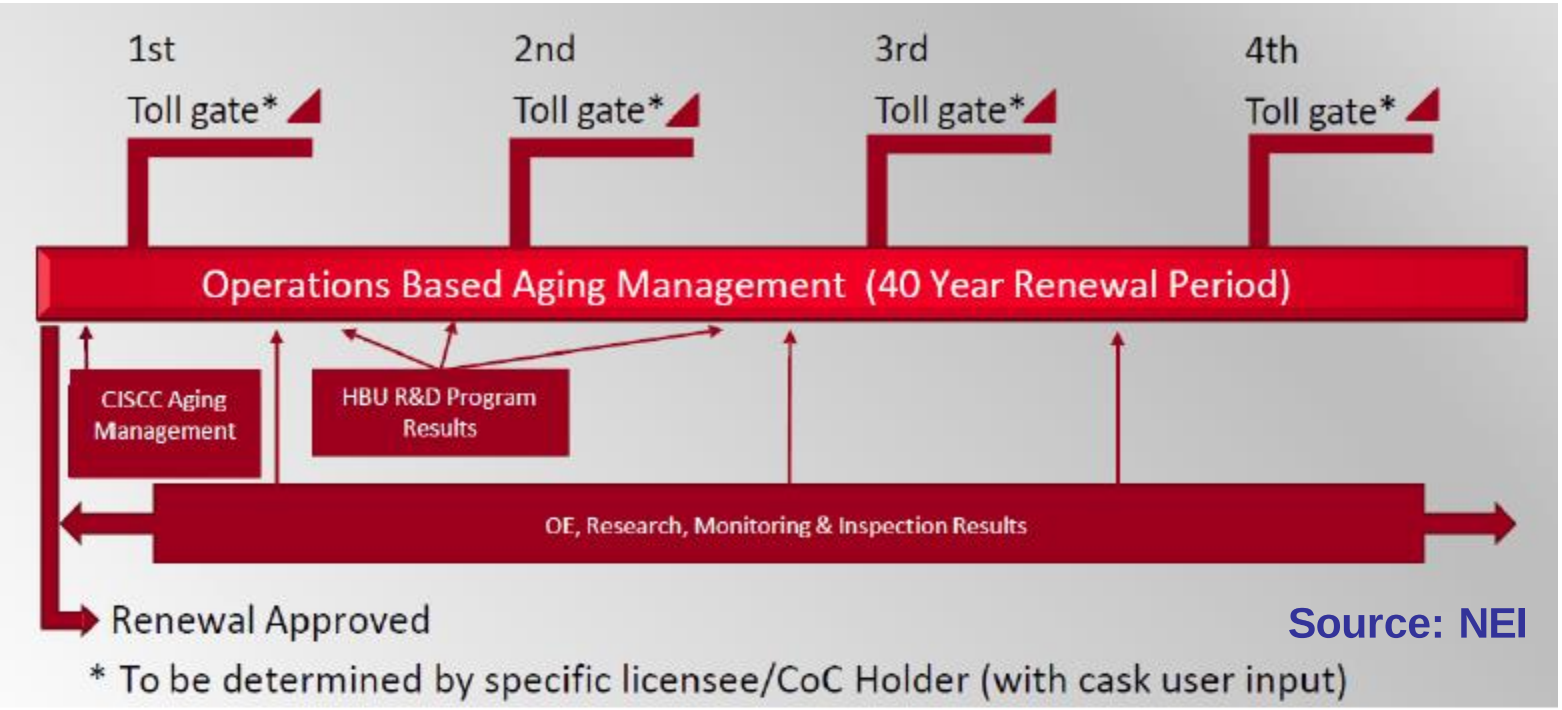
- This information would enhance the current understanding of the future state of dry spent fuel and the canisters that contain it.

- Tollgates are part of a learning, operations-based aging management program implemented by licensees via requirements in the renewed license or CoC and associated final safety analysis report.

- These requirements obligate the licensees to perform periodic assessments of the aggregate state of knowledge of aging-related operational experience, research, monitoring, and inspections to ascertain the ability of in-scope DCSS design SSCs to continue performing their intended safety functions throughout the requested period of extended operation.

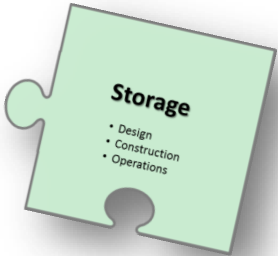
Toll Gates for ISFSI License Renewal

- NUREG-1927, Rev. 1 draft mentioned the use of "tollgates" in NEI 14-03, Rev. 0 as a structured approach for assessing operating experience and data from applicable research and industry initiatives.



- As mentioned earlier, the aging management report recommends periodic assessment of industry and site-specific operating experience of the various DCSSs/ISFSIs, which share the same basic philosophy as that of the tollgates in NEI 14-03 and NUREG-1927.

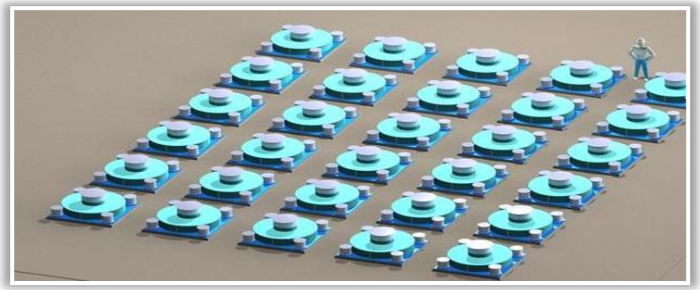
NFST is laying the groundwork for Consolidated Interim Storage



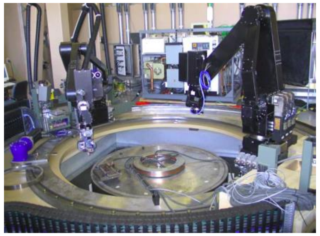
- Evaluating interim storage design concepts, with input from industry contractors
  - *Generic Design Alternatives for Dry Storage of Used Nuclear Fuel* (CB&I)
- Developed and documented facility functions and requirements

BRC recommendation:
"Perform systems analyses and design studies needed to develop a conceptual design for a spent fuel storage facility"

- Evaluated costs and impacts of opening non-disposable storage canisters (AREVA, CB&I)



- Initiated efforts related to assessing aging management needs for a pilot Interim Storage Facility (ISF) and beyond (ANL, SRNL)



Pilot ISF Capable of Handling a Wide Range of Systems at Shutdown Sites –
Storage/Transportation/Storage (72/71/72)

Storage
- Design
- Construction
- Operations

LaCrosse
5*;0**
NAC-MPC with MPC-LACBWR canister

Zion
61*;4** (est.)
NAC MAGNASTOR with TSC-37 canister

Big Rock Point
7*;1**
BFS/ES Fuel Solutions W150 with W74 canister

Trojan
34*;0**
TranStor cask with Holtec MPC-24E/EF canisters

Yankee Rowe
15*;1**
NAC-MPC with Yankee-MPC canister

Pilot

248 UNF casks
15 GTCC casks (est.)
7,649 assemblies
2813 MTHM
4 different vendors
7 storage systems

Humboldt Bay
5*;1**
Holtec HI-STAR HB with MPC-HB canister

Maine Yankee
60*;4**
NAC-UMS with transportable storage canister (TSC)

Rancho Seco
21*;1**
TransNuclear NUHOMS with FO-DSC, FC-DSC, and FF-DSC canisters

Connecticut Yankee
40*;3**
NAC-MPC with CY-MPC canister

*UNF Casks
**GTCC Casks

Aging Management Needs for a Pilot ISF and Beyond

- Comparison of TLAAs/AMPs in ISFSI/CoC Renewal Applications with those in the DOE/ANL Aging Management Report is part of an effort supporting the assessment of aging management needs for a Pilot ISF and beyond.

- The main purpose of the comparison is to assess the overall consistency and identify gaps, if any, in the TLAAs and AMPs for potential update of the aging management report, which is a key reference in NEI 14-03, "Guidance for Operations-based Aging Management on Dry Cask Storage, Sept. 2014."

- NEI 14-03, Rev. 0 was submitted for NRC endorsement in Sept. 2014, while NRC is updating its ISFSI/CoC renewal guidance in NUREG-1927 Rev. 1 that also contains three AMPs.

- Aging management guidance development is expected to remain very active in the U.S. during the next 2-3 years.

ISFSI/CoC Renewal Applications (2006 – 2015)*

- **ISFSI:**
  - Surry
  - Oconee**
  - Robinson**
  - Prairie Island (pending)
  - Calvert Cliffs**

- **CoC:**
  - VSC-24 (pending)
  - Standardized Advanced NUHOMS (pending)

*Various dry cask storage systems: Castor V/21, Castor X/33, Westinghouse MC-10, NAC I28, TN-32, TN-40/TN-40HT, VSC-24, and **NUHOMS

TLAAs/AMPs in Calvert Cliffs ISFSI LRA (DOE/ANL Rev. 2 report)

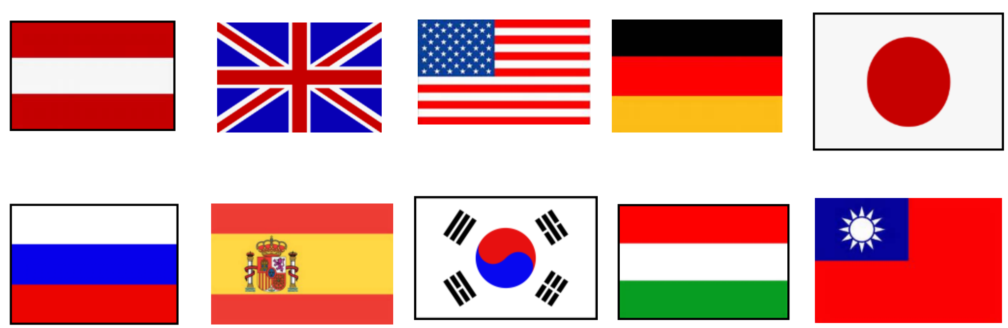
- **Four (4) TLAAs:**
  - DSC Fatigue (III.2)
  - Neutron Poison Plates B Depletion (III.4)
  - Fuel Cladding Thickness and Maximum Temperature (III.1)
  - Thermal and radiation degradation of HSM concrete (III.2, III.3, III.7)

- **Seven (7) AMPs:**
  - Dry Shielded Canister (DSC) External Surfaces (IV.M1, IV.M3)
  - Concrete HSM (IV.S1, IV.S2, IV.M1, IV.M2)
  - High Burnup Fuel (IV.M5)
  - Transfer Cask, Transfer Cask Lifting Yoke, Cask Support Platform, and Cask Handling Crane (None)

- Although the titles of TLAAs/AMPs in the ISFSI/CoC renewal applications and the aging management report are different, preliminary comparison showed them to be broadly consistent and should be applicable to a pilot ISF.

EPRI's Extended Storage Collaboration Program

- Established in 2009 to "Provide the technical bases to ensure continued safe, long term used fuel storage and future transportability"
- Bring together US and International organizations engaged with active or planned R&D to share information, Identify common goals and needs, and potential areas of "formal" collaboration
- Meeting twice a year; Dec 2014 meeting: 114 registered attendees from 10 countries, IAEA
- Six current subcommittees:
  - Concrete
  - CISCC
  - Fuels High Burnup Demo
  - International
  - NDE



- Tremendous amount of information sharing in recent years, e.g., international data gaps associated with extended storage and transportation of used fuel

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Extended "Long-Term" Storage of Used Fuel – Safe and Secure and transportable/retrievable after storage

t = 0 | t = 40 | t = 80 | t = 120 year

1986 | t = 20 | t = 60 | t = 100

NFST
NUCLEAR FUELS STORAGE & TRANSPORTATION

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Acknowledgment

Contributors:

O.K. Chopra, D.R. Diercks, D. Ma, Z.G. Han, and R.R. Fabian

The Rev. 2 report is available at:

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QUESTIONS?

Related ANL Conference Papers

Aging Management

1. D.R. Diercks, et al., “Holistic Aging Management for Extended Storage and Transportation of Used Nuclear Fuel,” Proceedings of the 55th Annual Meeting of the Institute of Nuclear Materials Management, Atlanta, GA, July 20–24, 2014.
2. D.R. Diercks, et al.,, “Degradation of Concrete Structures in Used Nuclear Fuel Dry Cask Storage Systems,” *ibid*.
3. O.K. Chopra, et al., “Role of Time-Limited Aging Analysis in Managing Aging Effects on Used Fuel Dry Storage Systems,” *ibid*.
4. Y.Y. Liu, et al., “Aging Management for Extended Storage and Transportation of Used Nuclear Fuel,” Proceedings of the International Conference on Aging of Materials and Structures, May 26–28, 2014, Delft, the Netherlands.

DBTT/Ring Compression Tests of HBU PWR Cladding Alloys

1. M.C. Billone, et al., “Characterization and Effects of Hydrides in High-Burnup PWR Cladding Alloys,” Proceedings of the International High-Level Radioactive Waste Management Conference, IHLRWM, Charleston, SC, April 12–16, 2015.
2. M.C. Billone, et al., “Baseline Properties and DBTT of High-Burnup PWR Fuel Cladding Alloys,” Proceedings of the International Conference on Packaging and Transport of Radioactive Materials, PATRAM 2013, San Francisco, CA, August 18–23, 2013.
3. M.C. Billone, et al., “Effects of Drying and Storage on High-Burnup Cladding Ductility,” International High-Level Radioactive Waste Management Conference, Albuquerque, NM, April 28–May 2, 2013.

Thermal Modeling

1. J. Li and **Y.Y. Liu**, “Thermal Performance of a Vertical Dry Cask for Storage of High Burnup Used Fuel,” Proceedings of the 55th Annual Meeting of Institute of Nuclear Materials Management, Atlanta, GA, July 20–24, 2014.
2. K. Mittal, et al., “Temperatures of Interest for the TN-32 Cask during Storage of High Burnup Fuel,” *ibid.*
3. R. Green, et al., “Experimental Benchmark of Simulations That Predict Temperatures of an 8x8 Array of Heater Rods within a Vessel Filled with Rarefied Helium Gas,” Proceedings of the International Conference on Packaging and Transport of Radioactive Materials, PATRAM 2013, San Francisco, CA, August 18–23, 2013.

Advanced Surveillance

1. **Y.Y. Liu**, et al., “Monitoring Helium Integrity in Welded Canisters,” Accepted for the ASME 2015 Pressure Vessels and Piping Conference (PVP2015), July 19–23, 2015, Boston, MA.
2. H. Tsai, et al., “ARG-US Remote Area Modular Monitoring for Dry Casks and Critical Facilities,” Proceedings of the 55th Annual Meeting of the Institute of Nuclear Materials Management, Atlanta, GA, July 20–24, 2014.
3. H. Tsai, et al**.**, “Monitoring Critical Facilities by using Advanced RF Devices,” Proceedings of the 15th International Conference on Environmental Remediation and Radioactive Waste Management, ICEM2013, Brussels, Belgium, October 3–7, 2013.
4. H. Tsai, et al**.**, “Advanced Surveillance Technologies for Used Fuel Long-Term Storage and Transportation,” Proceedings of the 14th International Conference on Environmental Remediation and Radioactive Waste Management, ICEM2011, Reims, France, September 25–29, 2011.