Identification of Potential Degradation Phenomena for Spent Fuel Dry Cask Storage Systems

G. Oberson, D. Dunn, M. Hiser, R. Torres, B. Tripathi, J. Wise, E. Wong
U.S. Nuclear Regulatory Commission

Y. Pan, X. He, A. Chowdhury, R. Page, L. Caseres
Southwest Research Institute

C. Jones
Sandia National Laboratories

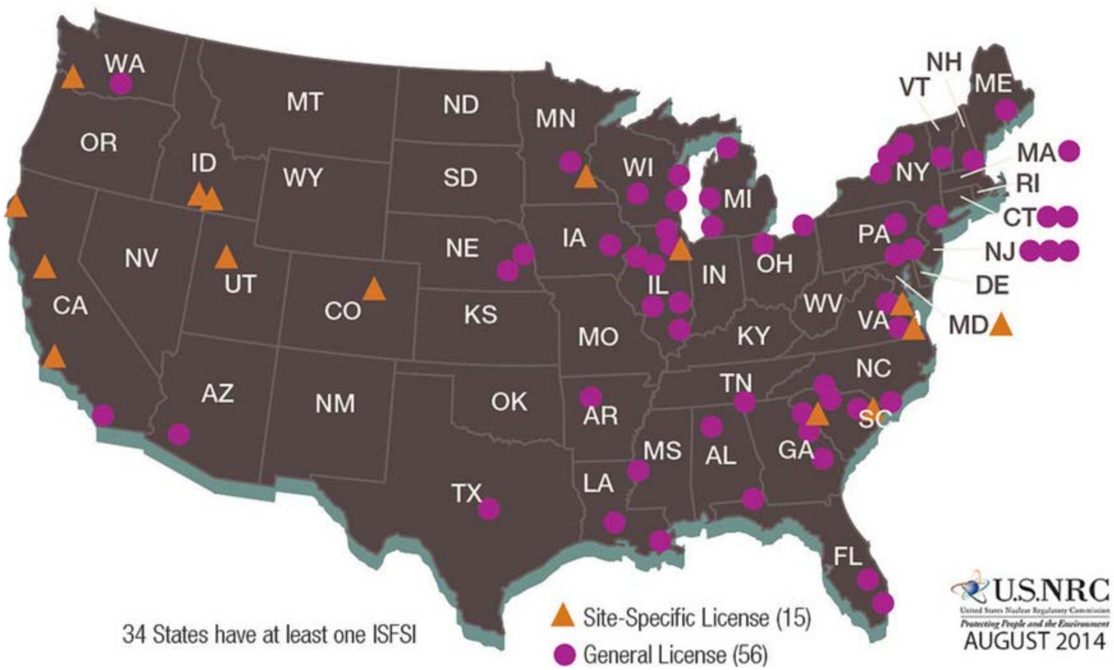
17th International Conference on Environmental Degradation of Materials in Nuclear Power Systems – Water Reactors
Ottawa, Canada – August 9-14, 2015

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

Dry Storage Overview

- Involves storage of spent nuclear fuel (SNF) or other waste in dry, inert, confined, and shielded systems
- Intended as approach to manage pool inventory and allow plant decommissioning until availability of permanent repository
- Used in U.S. since the 1980s and at currently at more than 70 licensed facilities
- Different dry cask storage system (DCSS) designs developed by various vendors

Dry Storage Deployment



Regulatory Context

- Title 10, Code of Federal Regulations, Part 72 gives dry storage licensing requirements
  - Initial up to 40 year license term, 20 year typical
  - Renewal up to 40 year term
- NRC anticipates large number of license renewal applications over the next 10 years
- License renewal applicants identify analyses or programs to address aging-related degradation of safety-related structures, systems, and components (SSCs)
- Regulatory needs:
  - Independent technical basis to review and confirm licensee aging management approaches
  - Consistent guidance for NRC technical reviewers and industry to support efficient licensing process

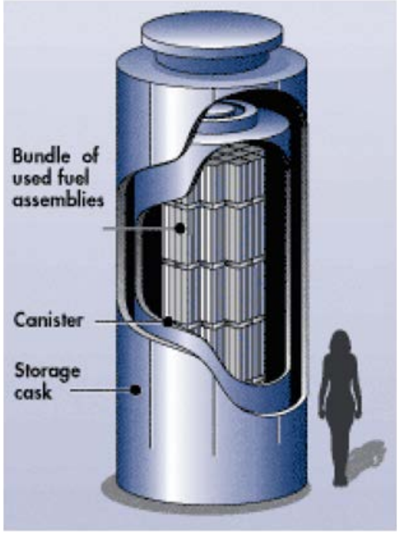
Research Approach

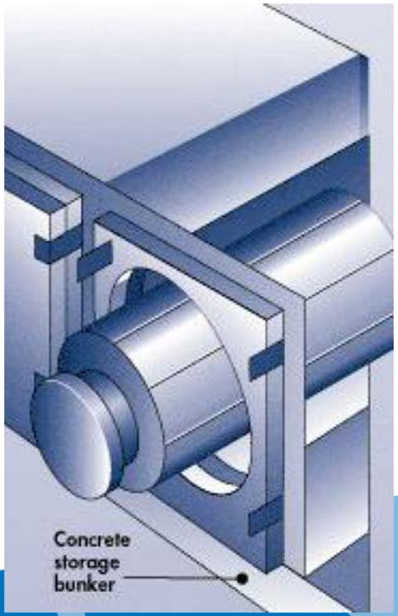
U.S.NRC
United States Nuclear Regulatory Commission
Protecting People and the Environment

- Review various DCSS designs to develop listings of SSCs and their intended safety functions
- Identify common materials of construction and exposure environments for SSCs
- Survey technical literature and operating experience for reactors and DCSS to identify aging-related degradation phenomena that could be "reasonably expected" to occur within certain timeframes:
  - Within first license renewal period – 60 years
  - Within "extended storage" period – 300 years
- Intended uses:
  - Support development of generic guidance for aging management of DCSS analogous to NUREG-1801, "GALL Report" for reactor license renewal
  - Identify issues for which further research is needed to address uncertainties in progression of degradation

Scope of Evaluation

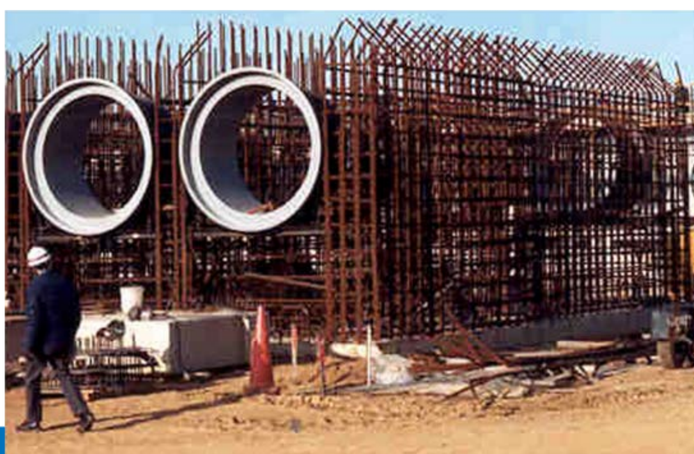
- Fuel cladding (not discussed in this presentation)
  - High burnup fuel issues addressed in Interim Staff Guidance 11, Revision 3
  - NRC following progress of DOE/EPRI High Burnup Dry Storage Cask Research and Development Project
- Pool to pad transfer cask (not discussed in this presentation)
- Canister
  - Internal components
  - External surfaces
- Casks/overpacks/storage modules
  - Shielding material
  - Reinforcing bar
- Storage pad
  - Structural concrete
  - Reinforcing bar

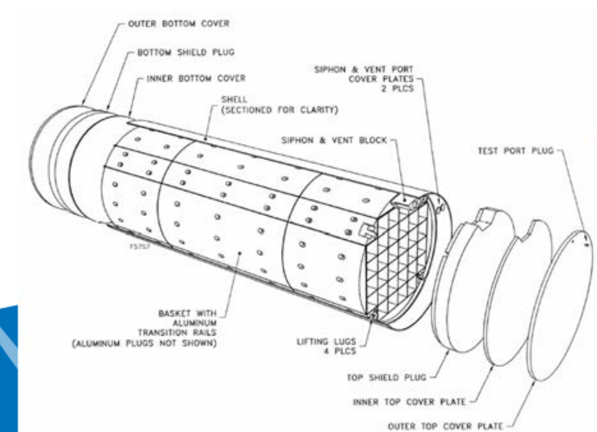




Materials Evaluated

Material	Representative Specs.	Use
Austenitic stainless steel	304, 304L, 316, 316L	Canister shell, lid, canister internal basket structures, concrete heat shields
Aluminum	1100, 6061	Canister internal basket structures, concrete heat shields
Carbon steel	SA-533, SA-537, SA-36 , SA-516, A615, A706	Canister internal basket structures, concrete reinforcing bar, concrete structural liner, hardware
Metal matrix composites and cerments	Boralyn, Boral, Metamic	Neutron absorbers
Concrete	ASTM C33 aggregate	Overpack/storage module, pad

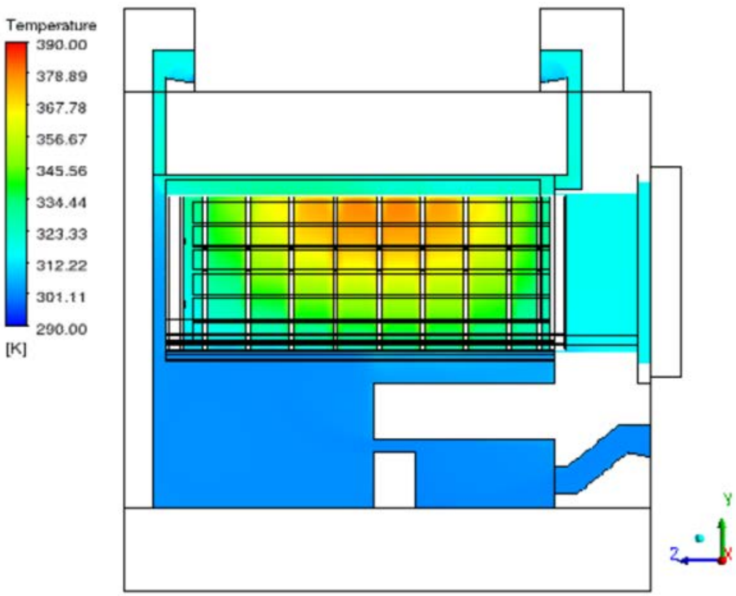




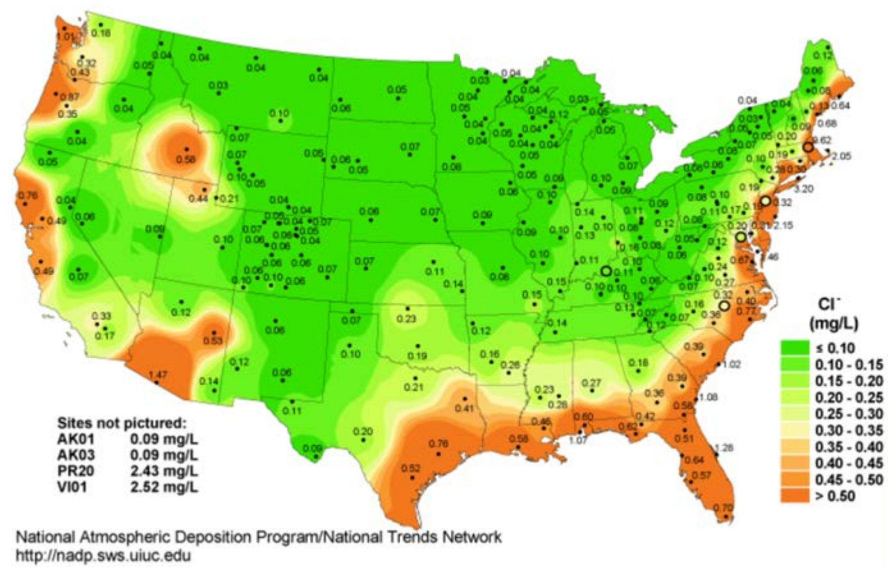
Environments Evaluated

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

- Canister internal
- Inside air (outside canister, within confined space of shielding structure)
- Outside air (outside shielding structure)
- Below grade



Cask System Temperature Profile Model



Atmospheric Chloride Concentration Map

Preliminary Findings

- Phenomena listed below are thought to have significance that will potentially require aging management

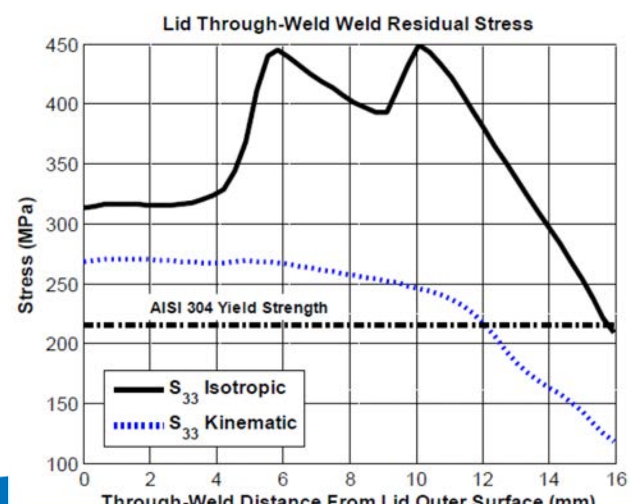
- Metallic materials
  - Chloride-induced stress corrosion cracking (CISCC) or localized corrosion of austenitic stainless steel in indoor air
  - Creep, thermal aging of aluminum in canister internal
  - Corrosion of carbon steel in indoor air
  - Corrosion, blistering of Boral in canister internal

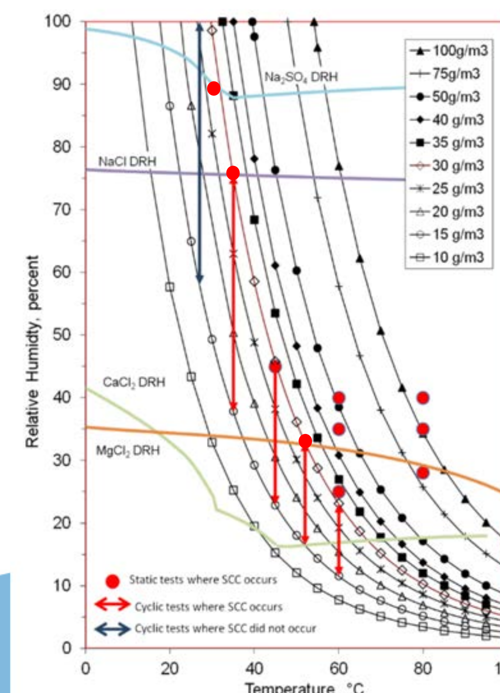
- Concrete
  - Freeze-thaw degradation in outside air and below grade
  - Aggregate reactions in inside air, outside air, and below grade
  - Aggressive acid/ion attack of concrete and reinforcing bar in inside air, outside air, and below grade
  - Carbonation and leaching in inside air, outside air, and below grade
  - Differential settlement

- Examples analyses described in following slides

Example Case – CISCC

- Operational experience review – SCC of outdoor tanks and piping attributed to atmospheric chloride exposure at number of nuclear plants
- Postulated mechanism – deliquescence of salts deposited on canister surfaces at high humidity along with high weld residual stress
- Laboratory testing – number of NRC-sponsored and international studies examining effects of temperature, humidity, salt chemistry, salt quantity, stress level, etc.





Example Case – Boral Degradation

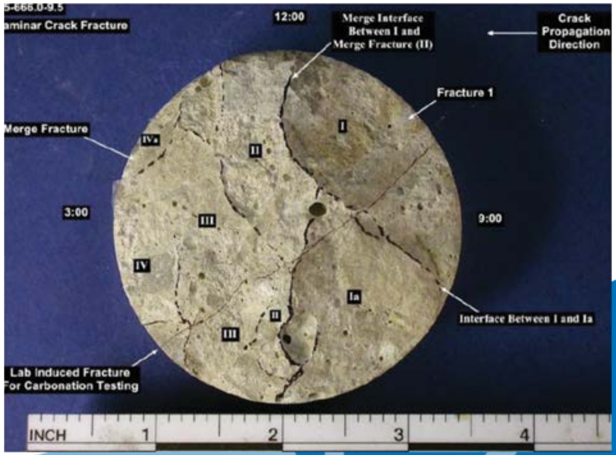
- Boral is made from core of B_4C and 1100 Al particles in 1100 Al cladding
- Operational experience review – Bulging and blistering of Boral reported in spent fuel pools (Information Notices 1983-29, 2009-26)
- Postulated degradation process – reactions between water and aluminum in the pores which generate aluminum oxide and hydrogen gas
- Laboratory testing – beginning NRC/ EPRI project to harvest and test Boral from decommissioned Zion plant spent fuel pools

Example Case – Freeze/Thaw Degradation

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

- Operational experience review – evidence of freeze/thaw damage to concrete structures for dry storage (TMI-2 fuel at INL, Information Notice 2013-07) and reactors (Davis Besse shield building)

- Postulated degradation process – expansion upon freezing of moisture entrained in pore network of concrete.

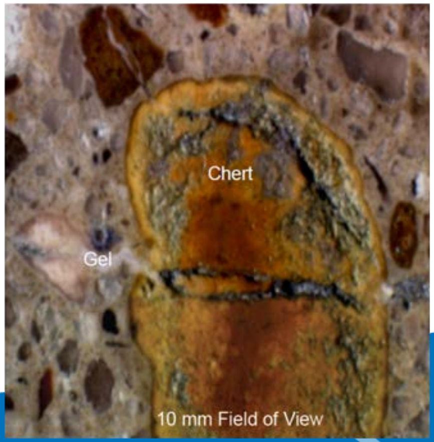


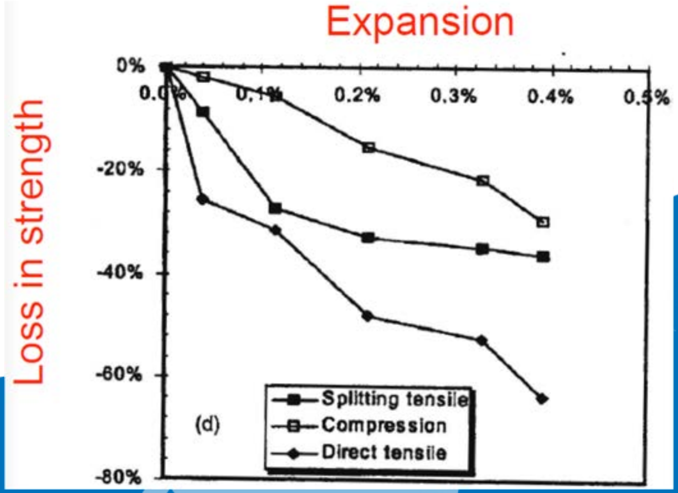
Example Case – Alkali-Silica Reaction (ASR)

- Operational experience review – evidence of ASR, such as pattern cracking, in containment and other concrete structures as Seabrook plant, Information Notice 2011-20

- Postulated degradation process – reactions between hydroxyl ions in cement and reactive forms of silica in aggregate to form gel that exerts expansive pressure

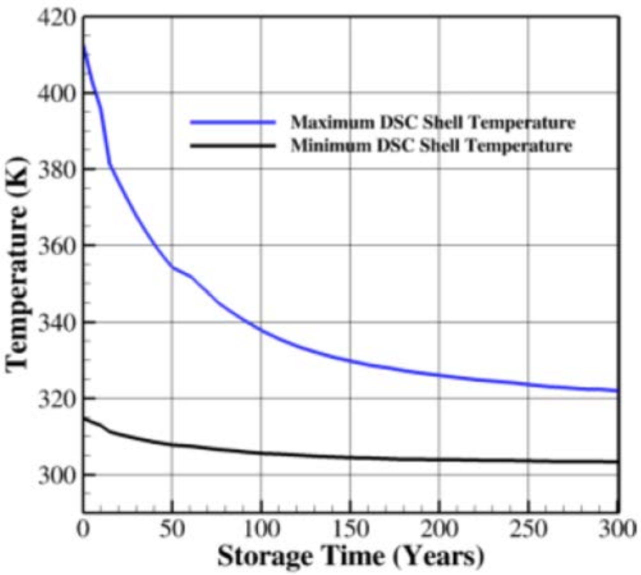
- Laboratory testing – ongoing NRC research program at NIST to examine effects of ASR on nuclear structures





Phenomena of Lesser Significance

- Some potential degradation phenomena, as listed below, could have little effect and would not require aging management



- Metallic materials
  - Thermal fatigue
  - Thermal embrittlement
  - Irradiation-induced damage
  - Microbiologically-influenced corrosion

- Concrete
  - Creep
  - Shrinkage cracking
  - High-temperature dehydration
  - Radiation damage

- Mitigating factors
  - Passive design
  - Decreasing temperature over time
  - Radiation field decay
  - Evacuated canister + inert gas backfill

Path Forward

- Complete systems analysis and publish technical basis reports
  - Analysis for timeframe up to 60 years – Spring 2016
  - Analysis for timeframe up to 300 years – Summer/Fall 2016

- Initiate work on Managing Aging Processes for Storage (MAPS) report for DCSS license renewal – analogue to GALL Report for reactors
  - Draft report with generic aging management reviews and aging management programs – Spring 2016
  - Plans for public comment period and Advisory Committee for Reactor Safety review

- Interface with consensus codes and standards organizations on development of in-service inspection requirements
  - ASME Boiler and Pressure Vessel Code for canisters
  - ACI for concrete structures

Figure References

- Slide 3
  - Top left (map): NUREG-1350, Volume 26, "Information Digest," U.S. Nuclear Regulatory Commission, Washington, DC 20555. ADAMS Accession Number ML14240A482.
  - Top right: P. Cowan, "Calvert Cliffs ISFSI License Renewal," 2015 Regulatory Information Conference, U.S. Nuclear Regulatory Commission, Washington DC, 20555. Hyperlink: http://www.nrc.gov/public-involve/conference-symposia/ric/past/2015/docs/abstracts/cowanp-t11-hv.pdf
  - Middle right: "Spent Fuel Dry Cask," U.S. Nuclear Regulatory Commission, Washington DC 20555. Hyperlink: https://www.flickr.com/photos/nrcgov/6946374745/
  - Bottom right: "Dry Storage of Spent Nuclear Fuel," U.S. Nuclear Regulatory Commission, Washington DC 20555. Hyperlink: https://www.flickr.com/photos/nrcgov/7845746956/
  - Bottom left: Fact Sheet, "Storage of DOE SNF at the Idaho National Laboratory," Idaho National Laboratory, Idaho Falls, ID 84315. Hyperlink: http://nsnfp.inel.gov/program/strategymtg/Fact%20sheets/INL_factsheet_final.pdf

- Slide 6
  - "Design of a Typical Dry Cask Storage System," U.S. Nuclear Regulatory Commission, Washington, DC 20555. Hyperlink: http://www.nrc.gov/waste/spent-fuel-storage/diagram-typical-dry-cask-system.html

- Slide 7
  - Bottom left: "Storage Cask Horizontal," U.S. Nuclear Regulatory Commission, Washington DC 20555. Hyperlink: https://www.flickr.com/photos/nrcgov/6800267656/
  - Bottom center: NUREG-1350, Volume 26, "Information Digest," U.S. Nuclear Regulatory Commission, Washington, DC 20555 ADAMS Accession Number ML14240A482.
  - Bottom right: M. Manrique, "CoC Renewal: CoC Holder Perspectives," 2014 Regulatory Information Conference, U.S. Nuclear Regulatory Commission, Washington, DC 20555. Hyperlink: http://www.nrc.gov/public-involve/conference-symposia/ric/past/2014/docs/abstracts/Manriquem-w20-r1-pv.pdf

Figure References

- Slide 8
  - Bottom left: NUREG/CR-7191, Thermal Analysis of Horizontal Storage Casks for Extended Storage Applications," U.S. Nuclear Regulatory Commission, Washington, DC 20555. ADAMS Accession Number ML14352A098.
  - Bottom right: National Atmospheric Deposition Program, Champaign, IL 61820. Hyperlink: http://nadp.isws.illinois.edu/

- Slide 10
  - Bottom left and bottom right: NUREG/CR-7170, ""Assessment of Stress Corrosion Cracking Susceptibility for Austenitic Stainless Steels Exposed to Atmospheric Chloride and Non-Chloride Salts," U.S. Nuclear Regulatory Commission, Washington, DC 20555. ADAMS Accession Number ML14051A417.
  - Bottom center: Technical Letter Report, "Dry Cask Storage System Canister Weld Residual Stress Finite Element Analysis," U.S. Nuclear Regulatory Commission, Washington, DC 20555. ADAMS Accession Number ML1330A512.

- Slide 11
  - March 1, 2011 Staff Commission Briefing, "Reactor Materials Aging Management Issues," U.S. Nuclear Regulatory Commission, Washington, DC 20555. Hyperlink: http://www.nrc.gov/reading-rm/doc-collections/commission/slides/2011/20110301/staff-20110301.pdf

- Slide 12
  - Bottom left and bottom center: "Three Mile Island, Unit 2, ISFSI – NRC Inspection of the Independent Spent Fuel Storage Installation – Inspection Report 07200020/2012-001," U.S. Nuclear Regulatory Commission, Washington, DC 20555. ADAMS Accession Number ML12228A457.
  - Bottom right: "Notification of Documents Related to the Davis-Besse Shield Building," U.S. Nuclear Regulatory Commission, Washington, DC 20555. ADAMS Accession Number ML14189A452.

Figure References

- Slide 13
  - Bottom left: December 18, 2013 Public Meeting Slides, "Seabrook Station Alkali-Silica Reaction Testing Program," U.S. Nuclear Regulatory Commission, Washington, DC 20555. ADAMS Accession Number ML13357A041.
  - Bottom center and bottom right: September 19, 2014 Advisory Committee for Reactor Safety Meeting Slides, "Concrete Degradation," U.S. Nuclear Regulatory Commission, Washington, DC 20555. ADAMS Accession Number ML14282A172.

- Slide 14:
  - NUREG/CR-7191, Thermal Analysis of Horizontal Storage Casks for Extended Storage Applications," U.S. Nuclear Regulatory Commission, Washington, DC 20555. ADAMS Accession Number ML14352A098.