SAND2016-0953C

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Technical Issues Associated with Commercial Spent Nuclear Fuel Extended Storage and Transportation

A Technical Meeting on Nuclear Energy and Cyber Security
USNA Rickover Hall & Annapolis Waterfront Hotel
April 17-19, 2016

Ken Sorenson
Sandia National Laboratories
SAND 2016-XXXX

U.S. DEPARTMENT OF ENERGY | NNSA National Nuclear Security Administration

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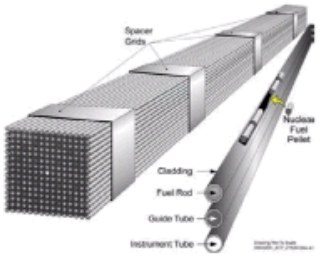

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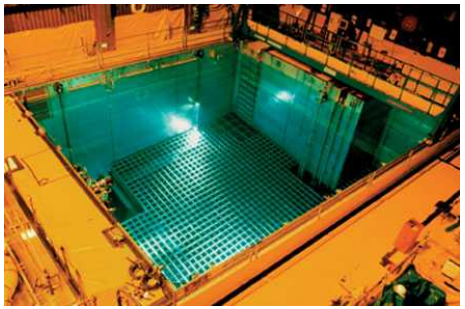
- **Department of Energy (DOE) Used Fuel Disposition (UFD) Program Technical Activities associated with high priority gaps**
  - High Burnup Fuel Cladding
  - Thermal Profiles
  - Stainless Steel Canister Corrosion
  - Transportation Loadings

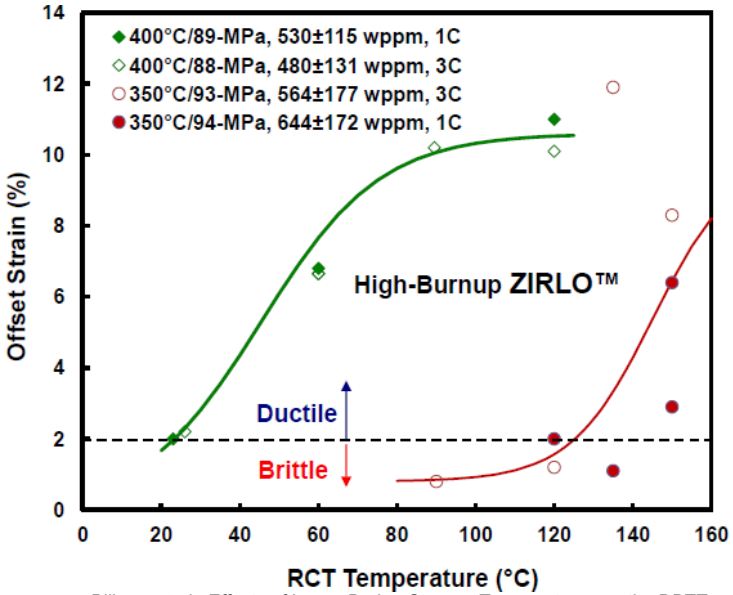


- **External Collaborations**
  - NRC meetings
  - NEI meetings
  - NWTRB meetings

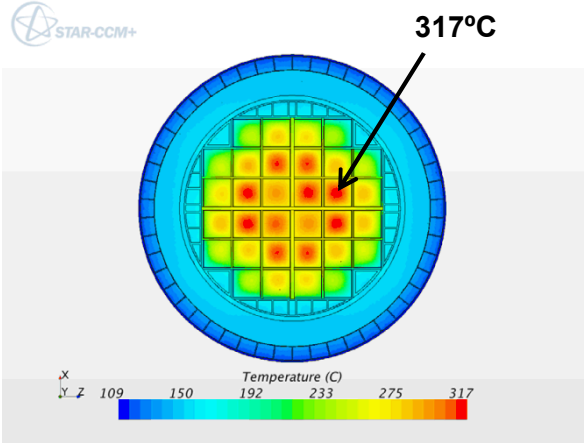
- **Conclusions**

High Burnup Fuel Cladding

- FY15 Activities:
  - RCT at lower temperature: 350º C - ANL
    - No effects of multiple drying cycles were observed for ZIRLO™ in temperature ranges of 350ºC-400ºC
    - Radial-hydride precipitation and embirttlement is sensitive to rod internal pressures and resulting hoop stresses and is relatively insensitive to peak RHT temperature between 350ºC and 400ºC
  - FRAPCON Hoop Stress Analyses on HBU – ORNL
    - 350ºC: 51 +/- 8.5 MPa (standard rods)
      86+/-14 MPa (IFBA rods)
    - 400ºC: 58 +/- 9.7 MPa (standard rods)
      98+-16 MPa (IFBA rods)
  - Confirmatory Data Project: Thermal Analyses – PNNL
    - Peak cladding temp (COBRA-SFS): 315ºC
    - Peak cladding temp (STAR-CCM+): 317ºC
  - CIRFT Testing – ORNL
    - BWR fuel: Limerick Zr-2 (lined cladding)
    - PWR fuel: HBR and NA Zr-4, and Catawba M5
    - For Normal Conditions of Transport (NCT) loadings & with good interface bonding:
      - *System remains linear-elastic*
      - *Maximum stress resides in the pellets*
    - Out-of-cell hydride reorientation tests on HBR fuel
      - *Internally pressurized to produce hoop stress = 150 MPa*
      - *Results show that radial hydrides decrease as internal pressures decrease*



Billone, et al., Effects of Lower Drying-Storage Temperatures on the DBTT of High-Burnup PWR Cladding, Argonne National Laboratory, FCRD-UFD-2015-000008,ANL-15/21, August 28, 2015



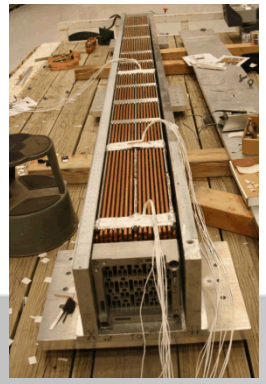
Fort, JA, et al., Thermal Modeling of Proposed TN-32B Cask for High Burnup Fuel Storage Demonstration Project, Pacific Northwest National Laboratory, FCRD-UFD-2015-000119,PNNL-24549, September 2015.

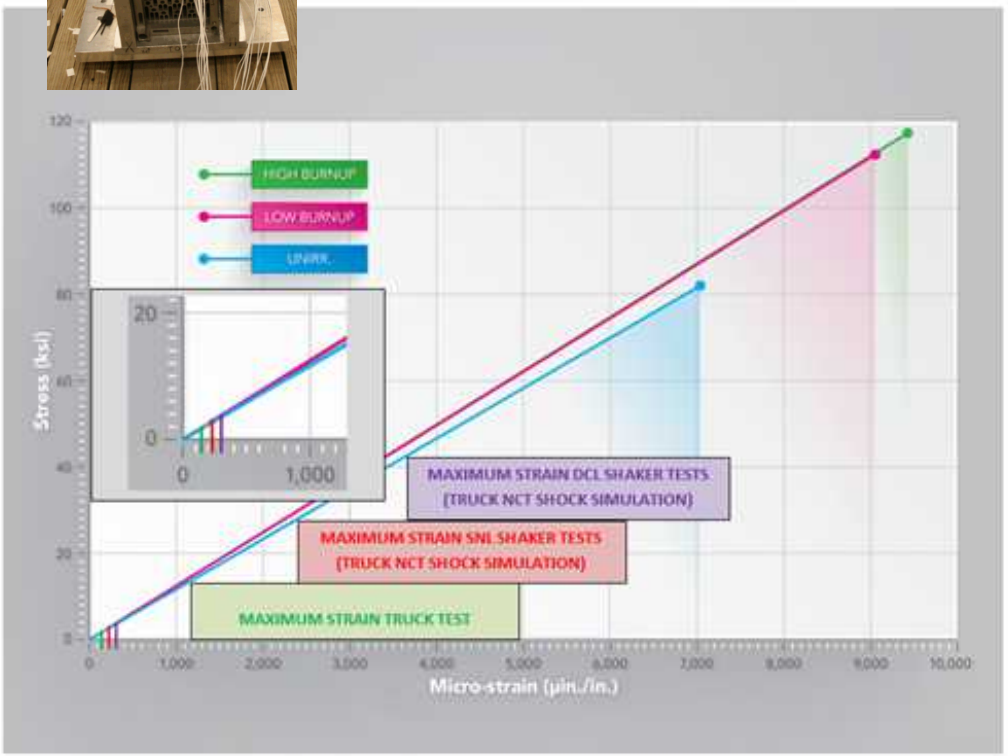
Transportation Loadings

- FY15 ACTIVITIES:
  - Normal Conditions of Transport (NCT) loadings for truck and rail using a table at Dynamic Certification Laboratories in Reno.
    - Six degrees of freedom
    - Tested down to 1 Hz
    - Surrogate rods filled with Pb rope, Pb pellets, and Moly pellets
  - Shaker table analyses - PNNL

Strain (μs)	Source	Details
14,900	Failure Limit	RT Zircaloy-4, 40 GWD/MTU
10,400	Yield Limit	RT Zircaloy-4, 40 GWD/MTU
5,561	Model	Truck Package 30-cm drop, Bonded Used Fuel, FY15
942	Model	Simulated Highway Shock, Bonded Used Fuel, FY15
752	Model	Rail NCT Modeling Estimate, Bonded Used Fuel, FY13
277	Model	Scaled Highway OTR Test, Bonded Used Fuel, FY15
265	Model	Half Sine Pulse Model, Bonded Used Fuel, FY15
241	Test Data	Rail NCT Shaker Test, Surrogate Fuel, FY15
213	Test Data	Simulated Highway Shock, Surrogate Fuel, FY13
136	Test Data	Highway OTR Test, Surrogate Fuel, FY14
130	Test Data	Half Sine Pulse, Surrogate Fuel, FY15

Klymyshyn, Nicholas, et al., Shaker Table Modeling Support Task 2015, FCRD-UFD-2015-000494, PNNL-24735





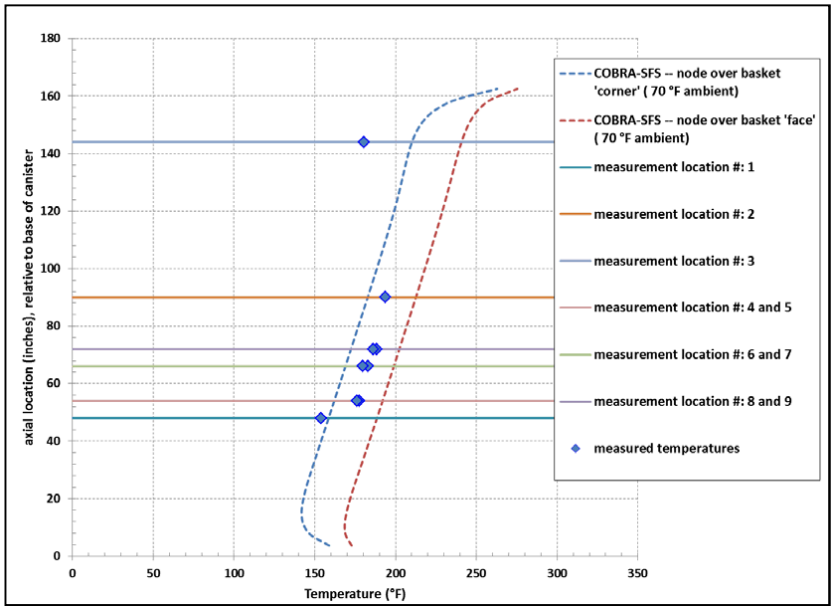
Stress/Strain results from NCT loadings on surrogate PWR assembly cladding

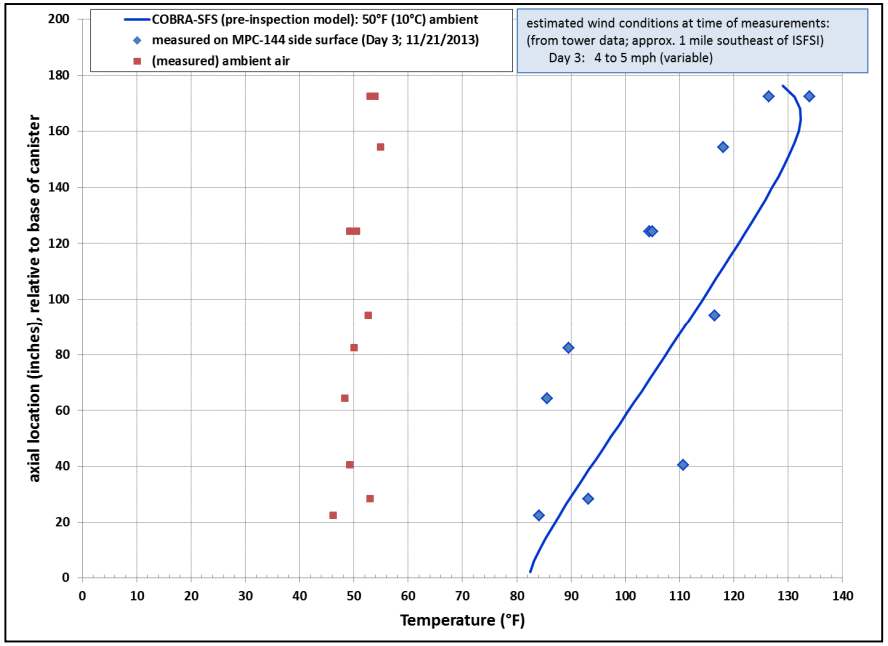
McConnell, Paul, et al., Surrogate Fuel Assembly Multi-axis Shaker Tests to Simulate Normal Conditions of Rail and Truck Transport, FCRD-UFD-2015-000128

Thermal Profiles on Spent Fuel Canisters

- FY15 Activities: PNNL
  - Thermal modeling of the Hope Creek Hi-Storm 100s-218 B Dry Storage Module
  - Thermal modeling of the Diablo Canyon Hi-Storm 100 Storage Module

- Observations:
  - Differences between measured and calculated canister surface temperatures very sensitive to measurement method and ambient weather conditions.





Hope Creek MPC-144: Measured canister side surface temperatures compared to COBRA-SFS predictions

Cuta, JM, et al., Post-inspection Evaluation: Thermal Modeling of Hi-Storm 100s-218 Version B Storage Modules at Hope Creek Nuclear Power Station ISFSI, FCRD-UFD-2015-000491, PNNL-24542, Sept. 2015.

Diablo Canyon MPC-170: Measured canister side surface temperatures compared to COBRA-SFS predictions

Cuta, JM, et al., Post-inspection Thermal Modeling of Hi-Storm 100 Storage Modules at Diablo Canyon Power Station ISFSI, FCRD-UFD-2015-000492, PNNL-24771, Sept. 2015.

Spent Fuel Canister Corrosion

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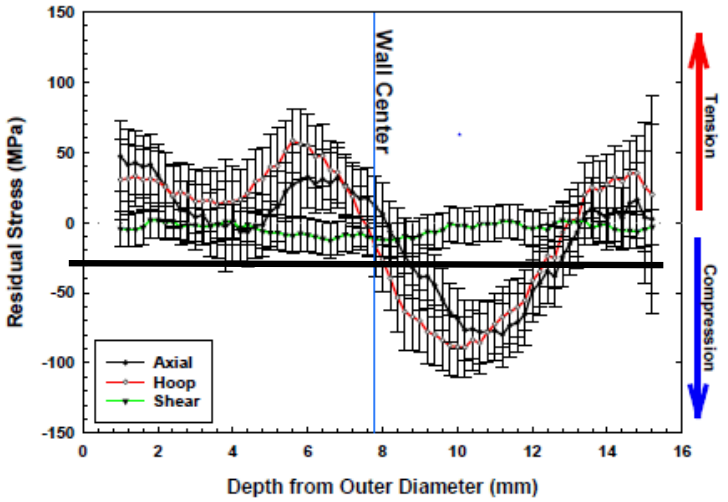
FY15 Activities:

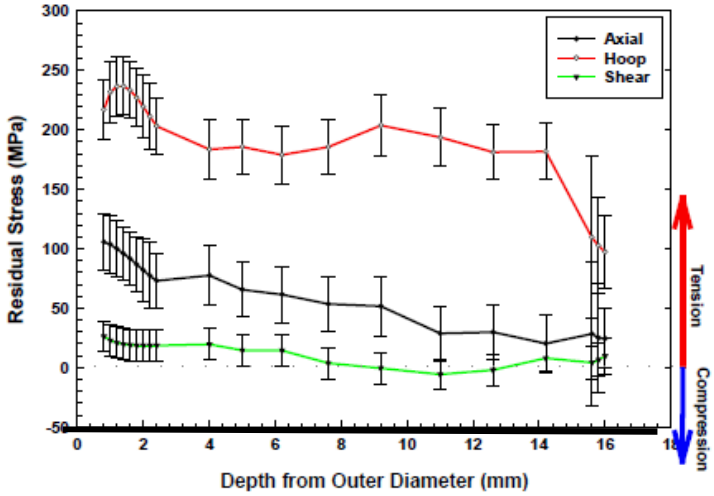
- Environmental Sampling Analyses
  - Calvert Cliffs and Hope Creek
    - do not appear to have a large sea salt component.
  - Diablo Canyon
    - Heavy wave action at the site generates abundant sea-salt aerosols. Although 400 feet above sea leve canisters have a significant amount of sea-salts on the canister surfaces.
  - Field data indicate that in some near-marine ISFSI locations, chloride-rich sea-salt aerosols comprise a large fraction of dusts deposited on canister surfaces. Once deliquescence occurs, SCC may be possible.
- Residual stress measurements on mock-up
  - Measure through-wall stress state at weld and HAZ
  - Relate environmental conditions to specific locations on the mock-up for assessment of deliquescence
- SCC Crack Propagation Modeling
  - Initial stage assumptions
    - Pitting incubation time = 0
    - Corrosive salts are always present
    - No threshold salt load
    - High through-wall tensile stresses
  - Dominant factors in the model are:
    - Crack growth rates are a function of temperature, salt load, and RH
    - Current data base is sparse with high parameter uncertainty

Parent Material



Deep hole drill thru-wall stress state in parent material

Circumferential Weld HAZ

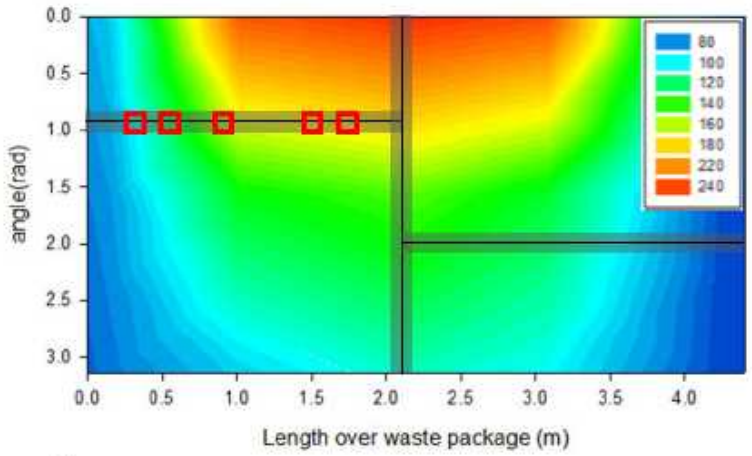


Deep hole drill thru-wall stress state @ circumferential Weld HAZ

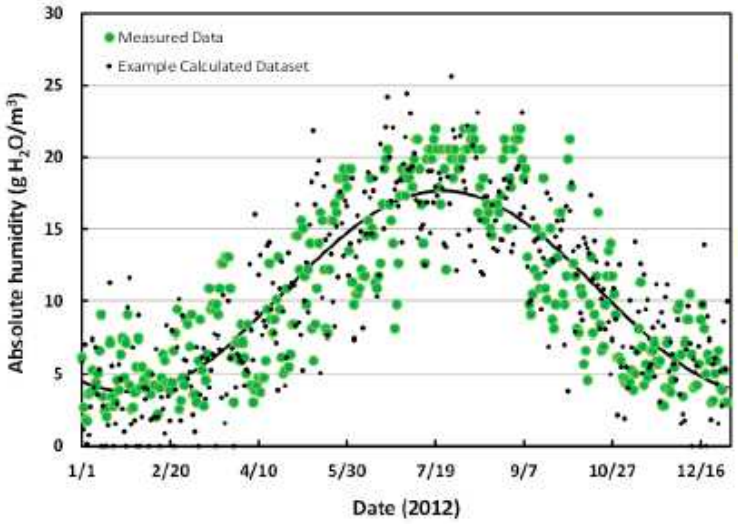
Enos, et al., "Residual Stress Measurements from the SNL Mockup Container", EPRI ESCP Meeting, December 2015, Sandia National Laboratories.

Combining Environmental and Canister Thermal Parameters

Bryan, Charles, "Fuel Integrity during Long Term Interim Storage: Evaluating SCC of SNF Storage Canisters", Sandia National Laboratories



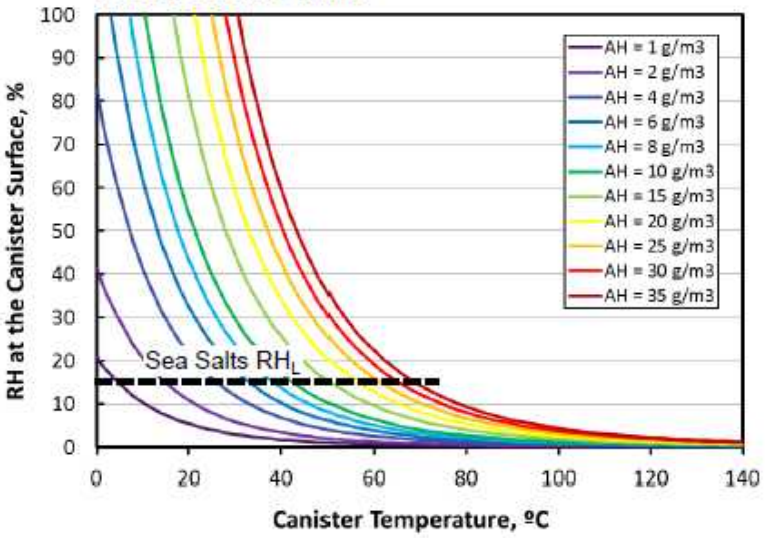
Surface temperature estimates



Site-specific National Weather Service data

Canister surface RH = *f*(Ambient AH; canister surface T)

Use weather data and predicted canister surface temperature to predict RH at any location and time.



Timing of corrosion initiation—point in time at which RH_L is first reached.

Summing time when $RH>RH_L$ provides "time of wetness"

12-hour averages in T and AH.

Weather data representing 64 ISFSI sites

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External Collaborations

- **NRC Meetings**
  - Quarterly to review respective R&D priorities and activities
    - Last meeting July 2015
    - Discussed:
      - Gas segregation
      - Cladding
      - Stress corrosion cracking

- **NEI Meetings**
  - Approximately bi-annual to review R&D priorities and activities
    - Last meeting Sept 2015 (telecon)
    - Discussed (Tier 1 thru 3 priorities)
      - Action item list (info exchange)
      - Site environmental conditions
      - Thermal analyses

- **NWTRB Meetings**
  - First meeting June 2015 in Golden, CO.
    - Supported a SCC panel session
  - Second meeting February 2016 in Knoxville, TN
    - Focus on cladding R&D
      - Cladding R&D
      - Fuel loading tests
  - Follow-on meeting in the May/June timeframe
    - Focus will be more technical than the February meeting.

Conclusions

- **UFD Storage and Transportation R&D is actively pursuing experimental and analytical work to address identified technical gaps and priorities that will support licensing for extended storage and subsequent transportation of used fuel.**

- **This work is closely coordinated with the NRC and industry to make sure that funded activities align well with a consensus perspective of needed R&D.**