U.S. DEPARTMENT OF ENERGY | Office of NUCLEAR ENERGY

Spent Fuel and Waste Science and Technology (SFWST)

Clean. Reliable. Nuclear.

DOE High Burnup Demonstration Project

Ned Larson

NWTRB Fall Meeting

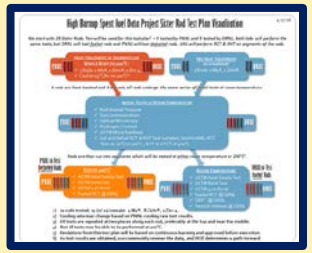
Washington, DC

November 19, 2019

S&T R&D is Driven by the 2017 Gap Analysis, NEI R&D Priorities and Is Enhanced by the Demo Data

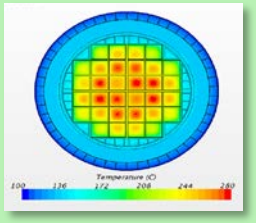
We have fuel in hot cells. (ORNL & PNNL)

We completed non-destructive tests.



Have begun destructive analysis.

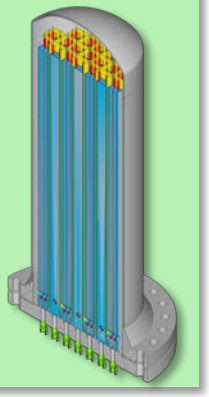
Sister Rod Mechanical Testing Data



We have thermal models.

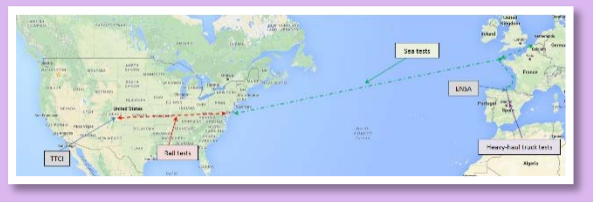
We are getting new thermal data from the Demo.

We are working to ID conservatisms & develop more realistic assumptions.

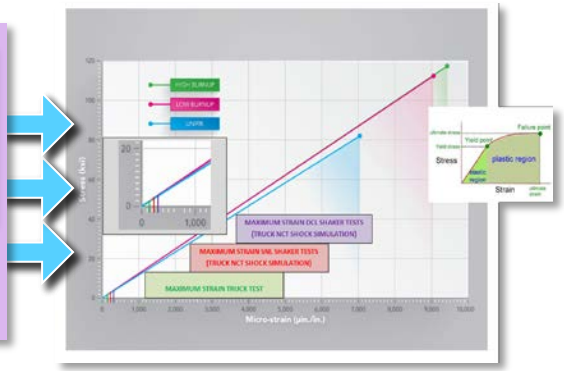


Thermal Behavior

Provides Knowledge about Spent Fuel Integrity Which is Compared to Data from the Transportation Tests



Spent Fuel Triathlon: Quantification of Normal Transport Shocks & Vibrations



High Burnup Spent Fuel Data Project Participants

- A contract was awarded to EPRI on April 16, 2013

EPRI ELECTRIC POWER RESEARCH INSTITUTE

Dominion

orano

Westinghouse

NAC INTERNATIONAL

- National Labs are performing the technical evaluations of the data

Sandia National Laboratories

INL Idaho National Laboratory

Pacific Northwest NATIONAL LABORATORY

Argonne NATIONAL LABORATORY

OAK RIDGE National Laboratory

Savannah River National Laboratory™ OPERATED BY SAVANNAH RIVER NUCLEAR SOLUTIONS

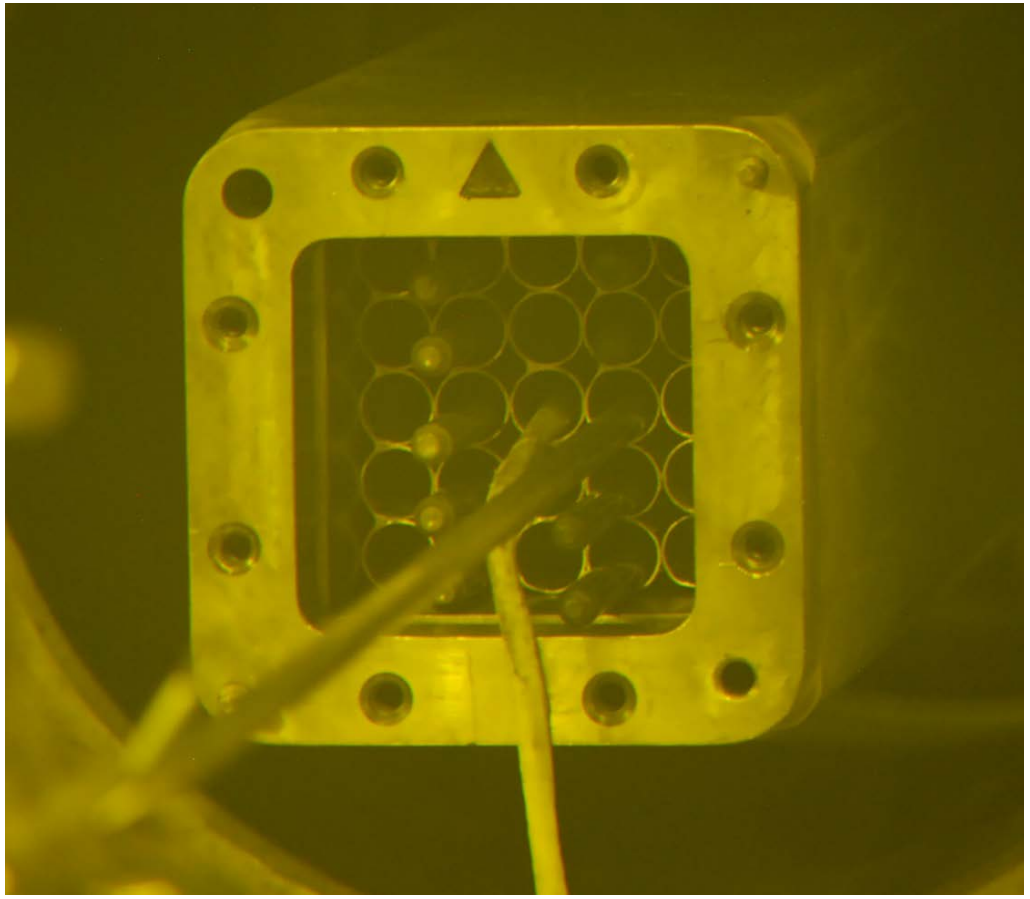
Background for High Burnup Demonstration Project

DOE/EPRI High Burnup Project

- *Initiated by DOE and industry collaborators to provide confirmatory data for models, future SNF dry storage cask designs, and to support license renewals and new licenses for ISFSIs.*
- Commercially-licensed TN-32 cask at North Anna ISFSI. Loaded with high burn-up spent fuel (4 common cladding alloys) in November, 2017.
- Cask monitored to determine thermal, environmental conditions experienced by the fuel during drying and storage.
  - Fuel cladding temperature (indirectly, via thermocouple lances)
  - Cavity gas pressure
  - Cavity gas composition (via periodic sampling after drying and filling with He backfill gas).

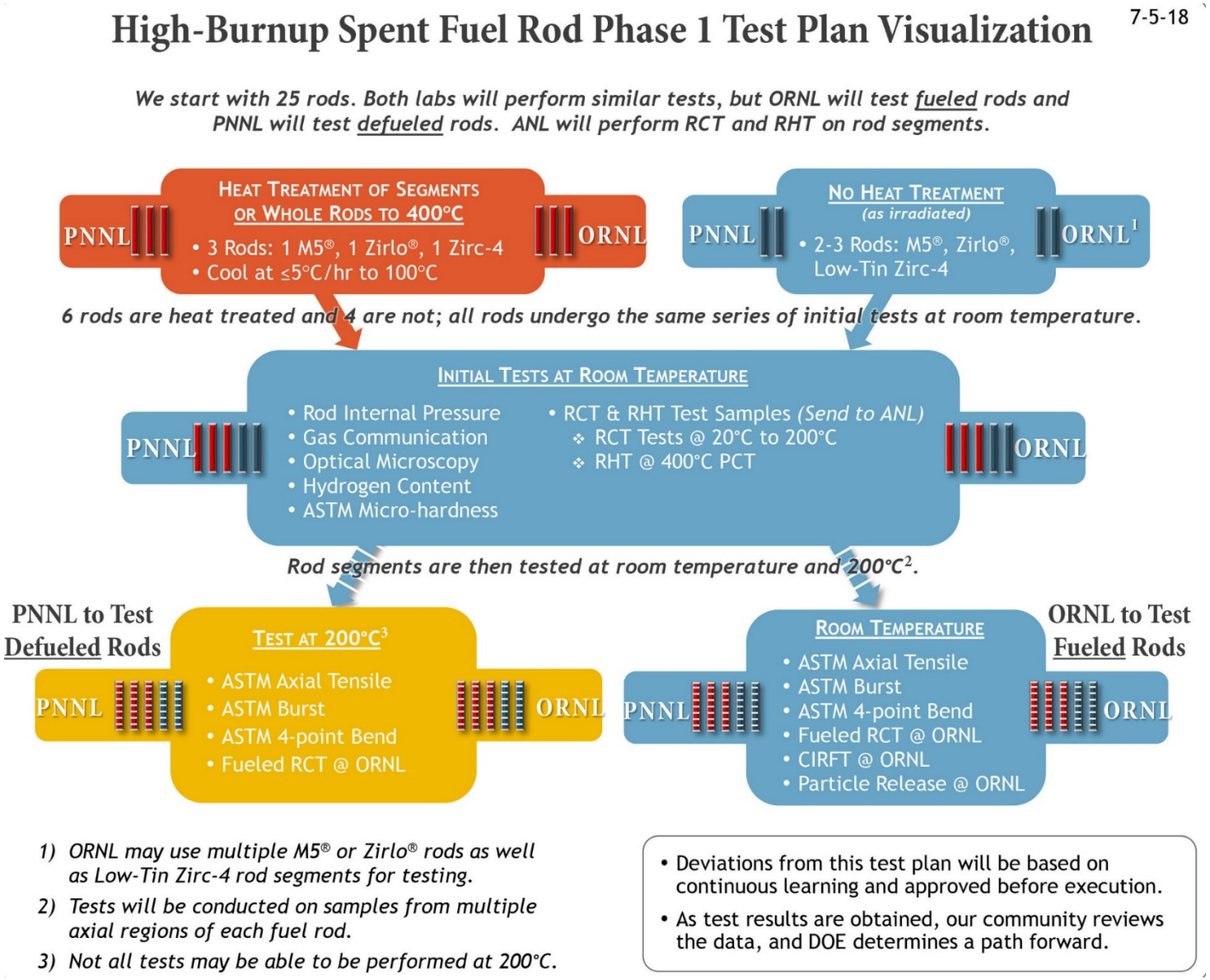
Sister Rod Selection

- Individual rods were pulled to perform characterization and material property tests
- 25 fuel rods from representative fuel assemblies were selected
- These rods will form the baseline for pre-storage characterization
- Rods or segments will be heated to simulate drying conditions to predict material properties post-drying
- 25 sister rods were shipped to ORNL in January of 2016
- 10 sister rods were shipped to PNNL in September of 2018



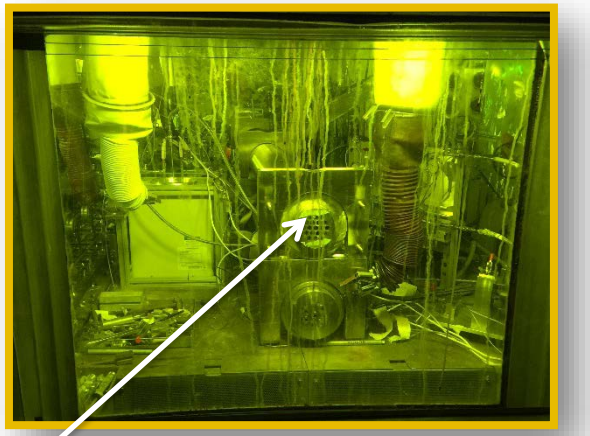
NAC LWT basket with 10 Sister Rods in PNNL hot cell

Laboratory Test Plan Summary

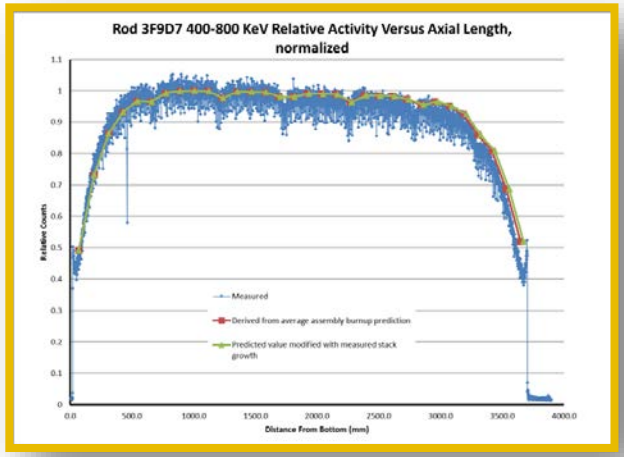


High Burnup Confirmatory Data Project – Non Destructive Testing

- "Sister Rod" Acquisition & Testing
  - AREVA and Westinghouse rods pulled in June and January 2015 from different assemblies
    - 9 AREVA M5® rods
    - 12 Westinghouse Zirlo® rods
    - 4 Westinghouse Zircaloy-4
      - 2 Low-tin
      - 2 Standard
  - Oak Ridge National Laboratory completed all the nondestructive analysis
  - Sister Rod Destructive Testing has begun
    - 14.5 Sister Rods are at ORNL
    - 10 Sister Rods are at PNNL
    - 0.5 rod equivalents at ANL



25 Sister Rods in ORNL Hot Cell
Photo: Saltzstein, SNL



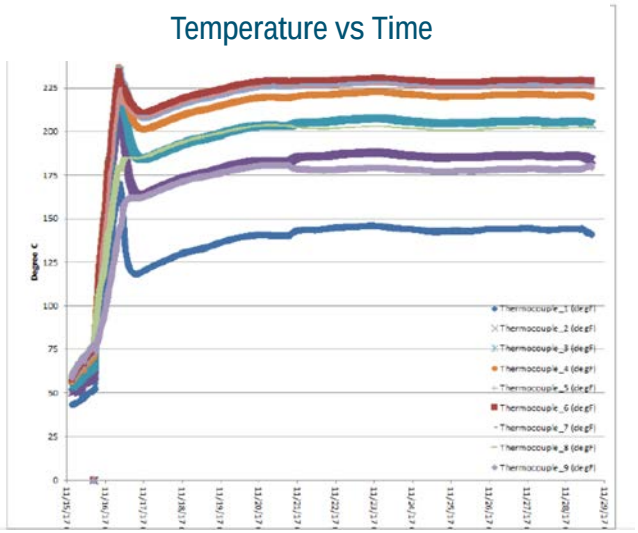
Sister Rod gamma scan results to determine the axial burnup profile and identify pellet locations (Montgomery R, 2016).

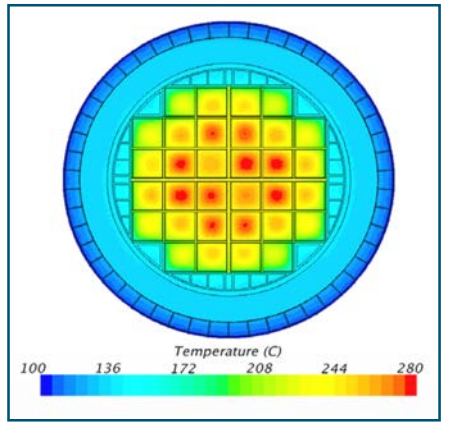
Understanding High Burn-up Cladding Performance - Thermal

Thermal Analysis

- High Burnup Demonstration Project was performed at North Anna to understand thermal behavior in a loaded cask.
- More detailed modeling shows considerable margin between design basis loading and actual loading resulting in lower temperatures than previously thought

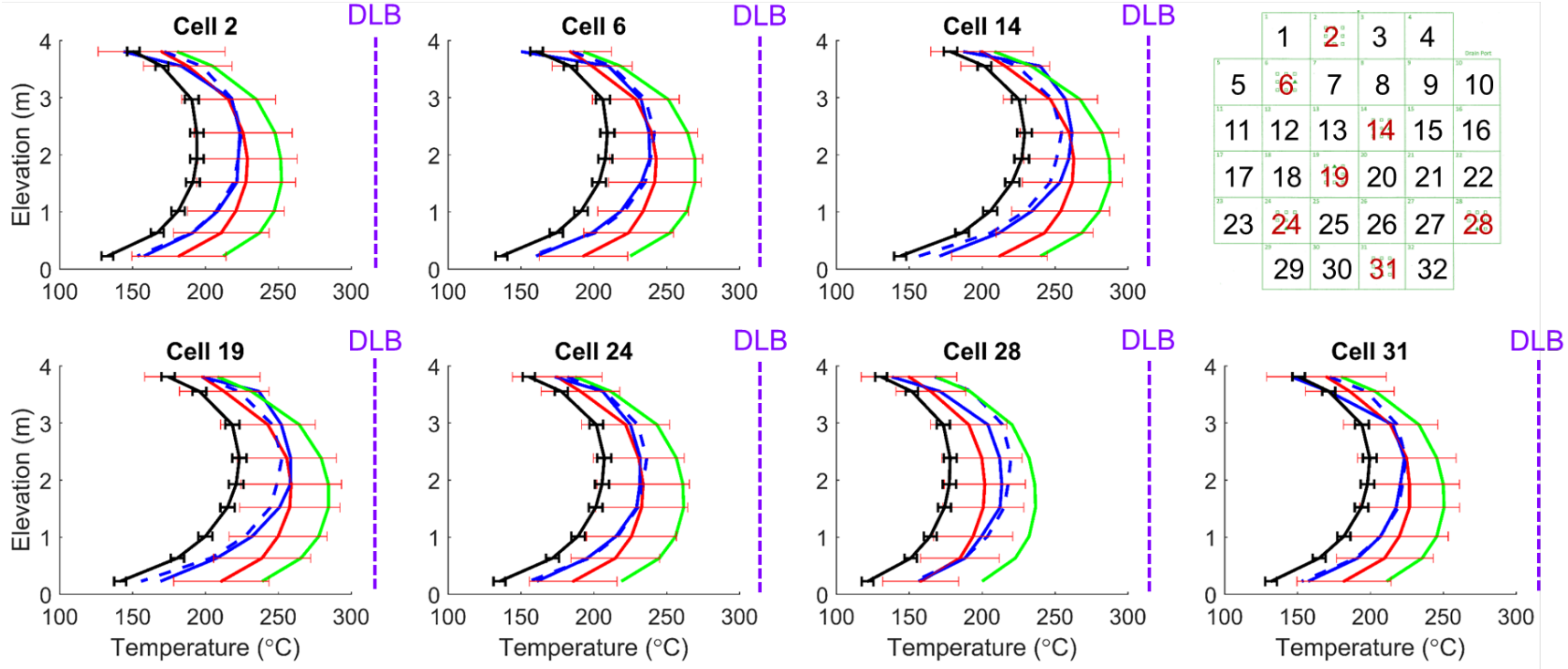
Loaded TN-32 for High Burnup Demo at North Anna





Maximum cladding surface temp. (°C) for each assembly in *one* type of licensed cask. (Fort, et al, 2016. PNNL)

Steady State Thermocouple Data Compared to Numerical Modeling

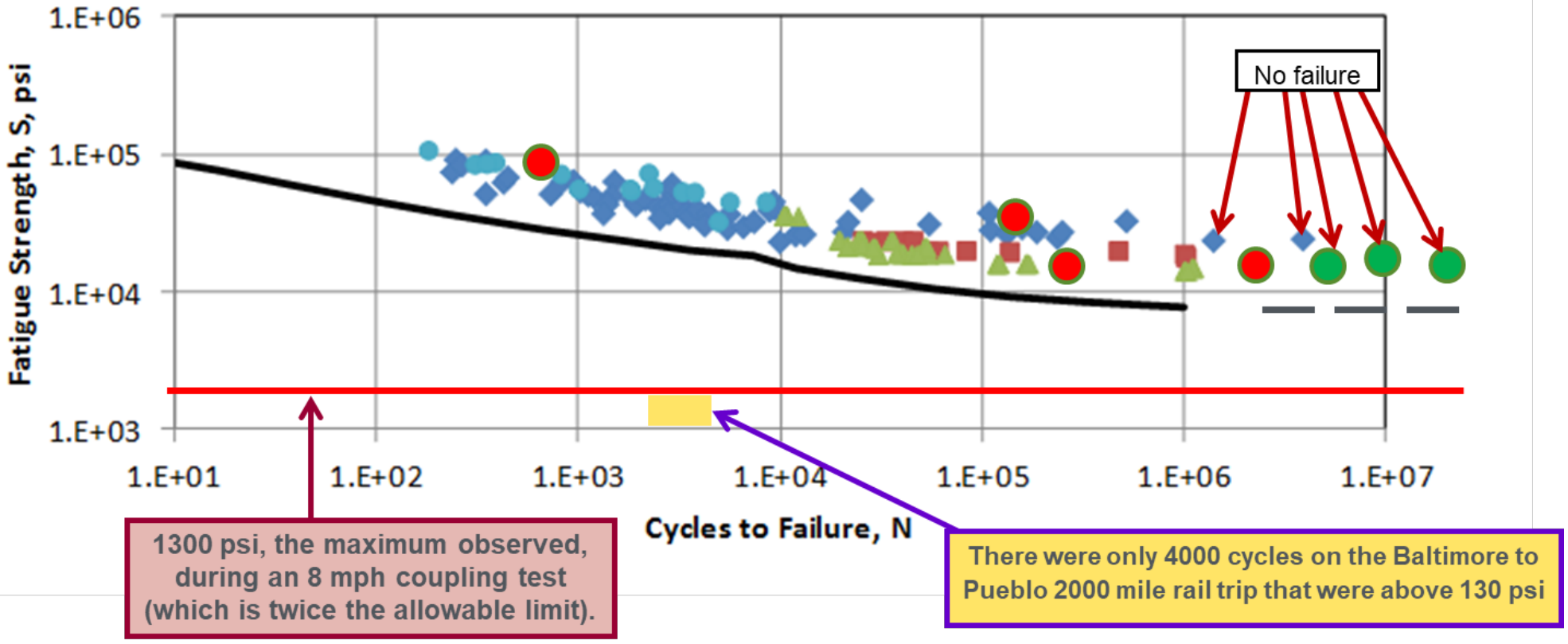


DLB: Design Licensing Basis

From Aladar Csontos, Thermal Modeling:
Phase II HBU Demo Cask Benchmarking, NEI Conf, May, 2018

Joint EPRI/DOE/Industry/NRC/National Lab Research Activity

Transporting Spent Nuclear Fuel



Fatigue design curve ( ): O'Donnel and Langer, "Fatigue Design Basis for Zircaloy Components," Nucl. Sci. Eng. 20, 1, 1964. (cited in NUREG-0800, Chapter 4)

Data plot courtesy of Ken Geelhood, PNNL
The large circles are ORNL HBR data

CONCLUSIONS

The realistic stresses fuel experiences due to vibration and shock during normal transportation are far below yield and fatigue limits for cladding. We have recently gathered actual rail data which most likely will be the prevailing transportation mode.

Understanding High Burn-up Cladding Performance – Conclusion

- With the data this is currently available, it is believed that the cladding will remain intact and its integrity will not be challenged during extended storage or transportation activities






Compositional Analysis of Evolving Cavity Gas

- He backfill gas, nominally 2.2 bars
- Sampled after filling, over a period of 12 days, to evaluate temporal changes in composition. Species analyzed:
- 85Kr
  - Indicator of damaged fuel (failed cladding)
  - Also dictates availability of other methods (radiological hazard status)
- H_2O—used to evaluate:
  - Drying efficiency (e.g., ice formation)
  - Trapped water (dash pots, within failed fuel)
  - Chemisorbed and physisorbed water
- O_2, N_2, H_2, CO_2, other gases—provide metrics for:
  - Sample contamination by air
  - Chemical reactions (e.g., radiolysis, metal corrosion)
- Samples analyzed on-site at North Anna by Dominion Energy, duplicate samples sent to Sandia National Laboratories for more thorough analysis

Picture from North Anna ISFSI

Gas Sampling Conclusions: (for now)

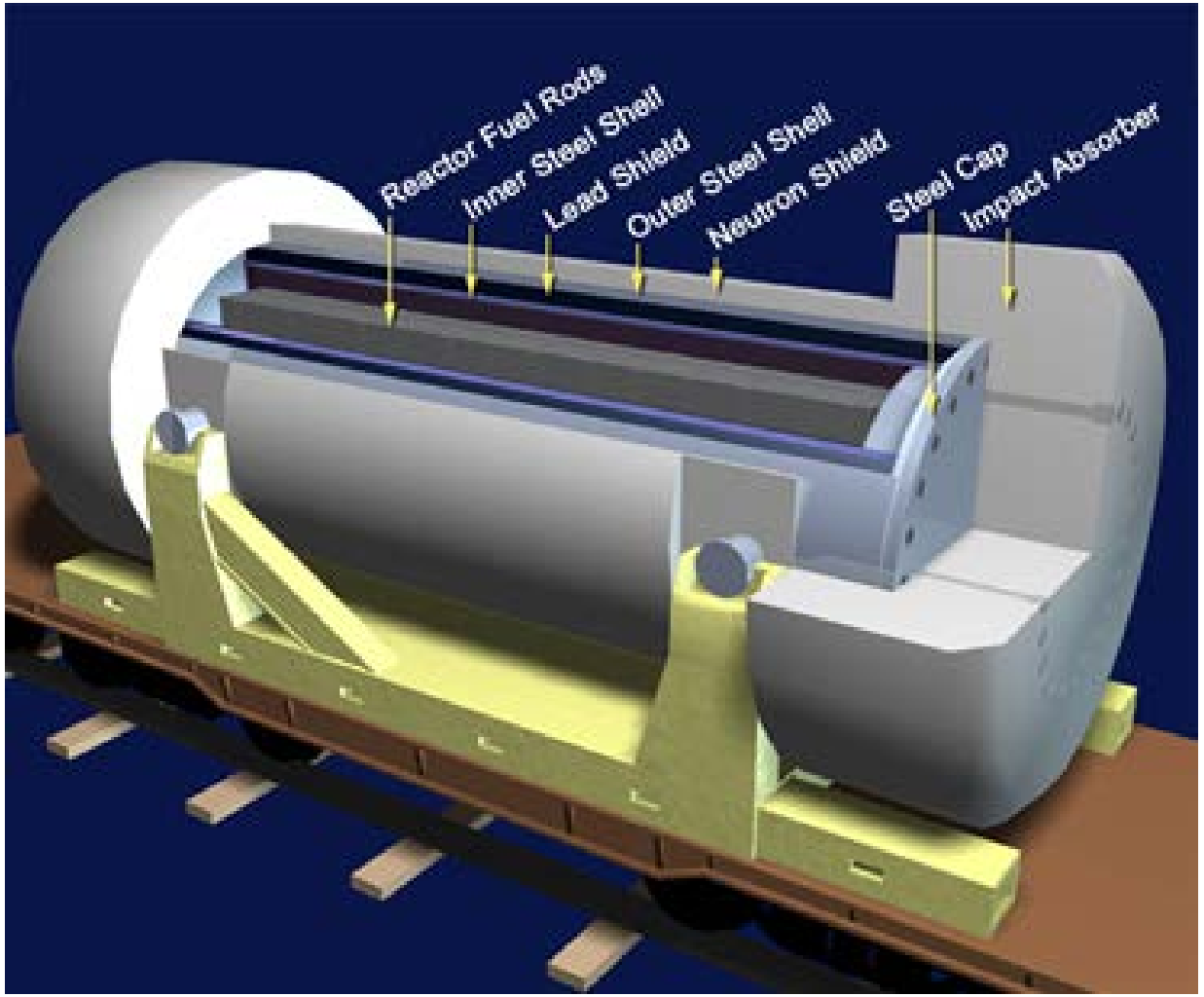
- No detectible ^{85}Kr
- High CO_2 suggests oxidation of organic material in cask (pump oil) Requires oxidizing compounds produced by radiolysis.
- O_2 variable but low. *Two* sinks for O_2 or oxidizing radicals produced by radiolysis: reactions with metal or with hydrocarbon.
- Water:
  - No condensate in sample bottles.
  - Ambient temperature values from SNL are consistent with those measured at North Anna; but sorbed water is very significant, and must be desorbed by heating prior to analysis.
- If the gas phase in the cask is well-mixed and homogeneous (which we believe is the case), then we believe there is no free water in the cask

Future Gas Sampling

- Working to obtain samples from other sites using improved sampling systems
- Working to see if we can get more gas samples from the HBU demo
  - Would tell us if more water was released after 12 days

Bottles pretreated to remove sorbed water at SNL—heated to 80-90°C while being pumped at med-high vacuum (10^{-7} Torr) for 16-24 hours. Valving modified for SNL samples to allow longer storage.

Transporting the High Burnup Demo Cask for Opening

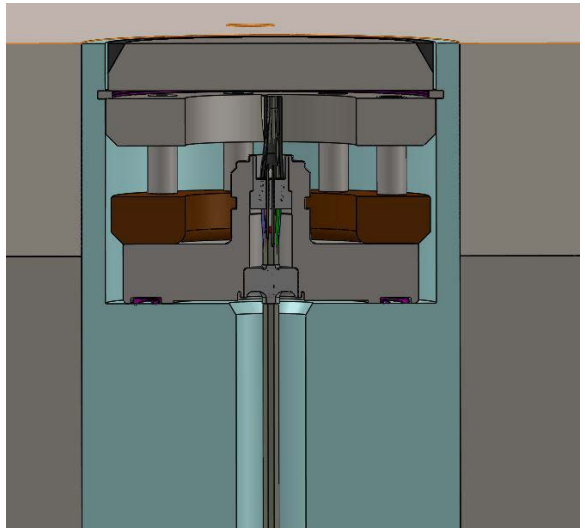


Transportation - Approach

- Rely on TN-40 transportation licensing
  - TN-32 not licensed for transportation
  - TN-32 similar to TN-40 which is licensed for transportation
- Do not want to open cask and rewet fuel prior to transport
  - Do not plan to replace seal prior to transport
  - Used high strength lid bolts for transport
- Challenge for thermocouple to maintain containment in transport accidents

Transportation – Thermocouples

- Thermocouples not required for transport
- Plan to cut cables and abandon in place
  - Weld 2.5 cm cover plate over thermocouple sleeve
  - Attach 5 cm thick plate over lid for additional protection
- Studying other options to continue temperature monitoring
  - Cut as planned and splice new connection
  - Ship in current configuration with thermocouple as containment boundary
    - Would require exception(s)



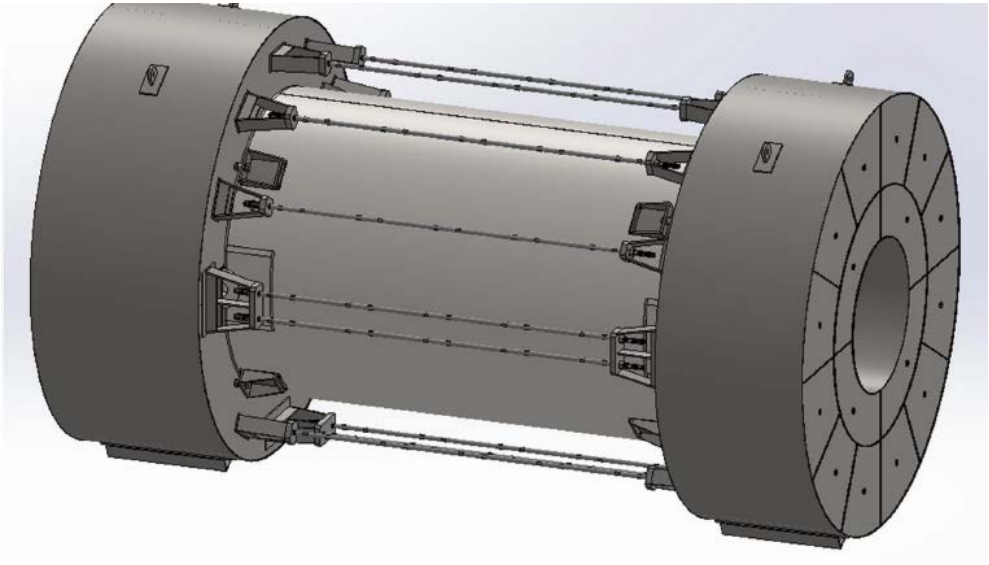
Thermocouple lance with welded cover plate

Transportation License Status

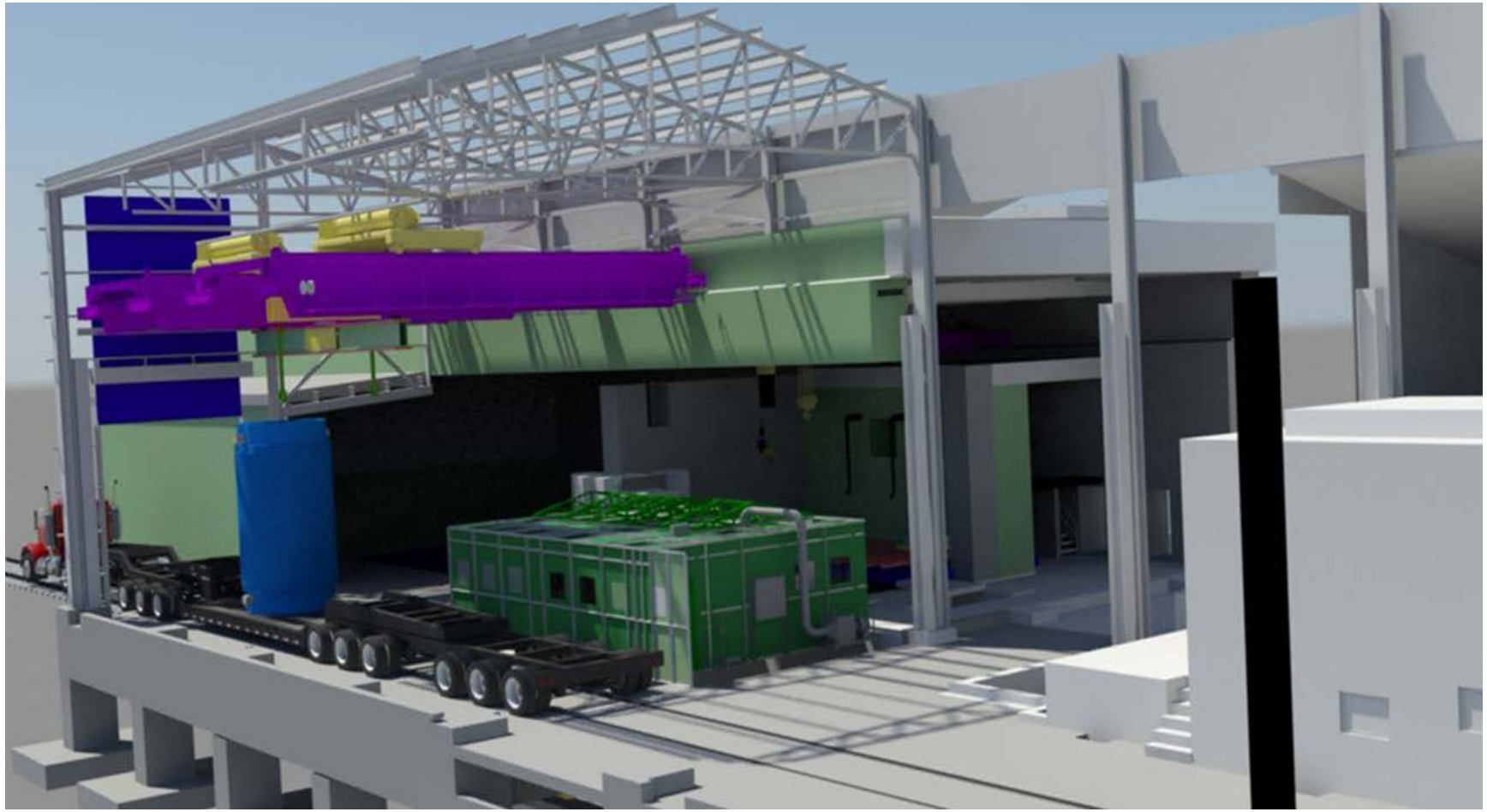
- NRC pre-application meeting July 30, 2019
  - NRC questions on use of foam as impact limiter material
  - TN-40 (similar design) uses redwood/balsa
  - Foam had been selected due to limited availability of redwood
- Re-evaluated impact limiter material and selected wood
  - Taking steps to secure supply of wood
  - Numerous calculations had to be redone
- Calculations, drawings and Safety Analysis Report are being drafted

Transportation License Schedule

- Submit request for transportation license 2nd Qtr 2020
- Receive transportation license 4th Qtr 2021
- Complete transportation plan 2nd Qtr 2022
- Fabricate transportation components 2nd Qtr 2023
- Prepare cask for shipment 3rd Qtr 2028

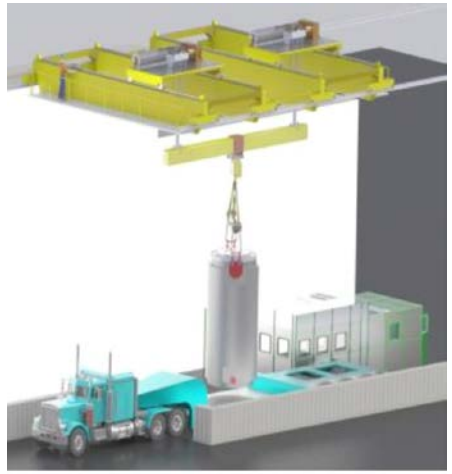


Opening the High Burnup Demo Cask



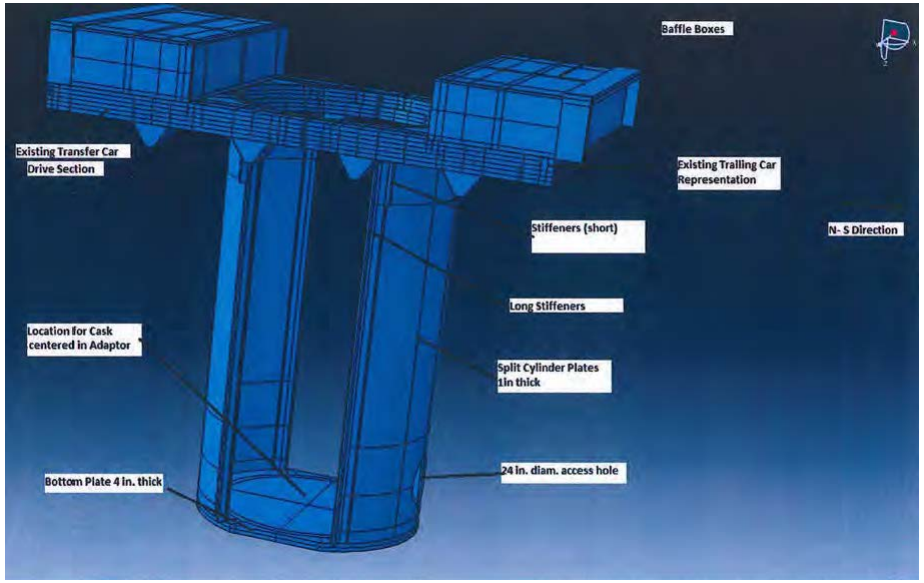
Design of the CPP-603 Facility at INL

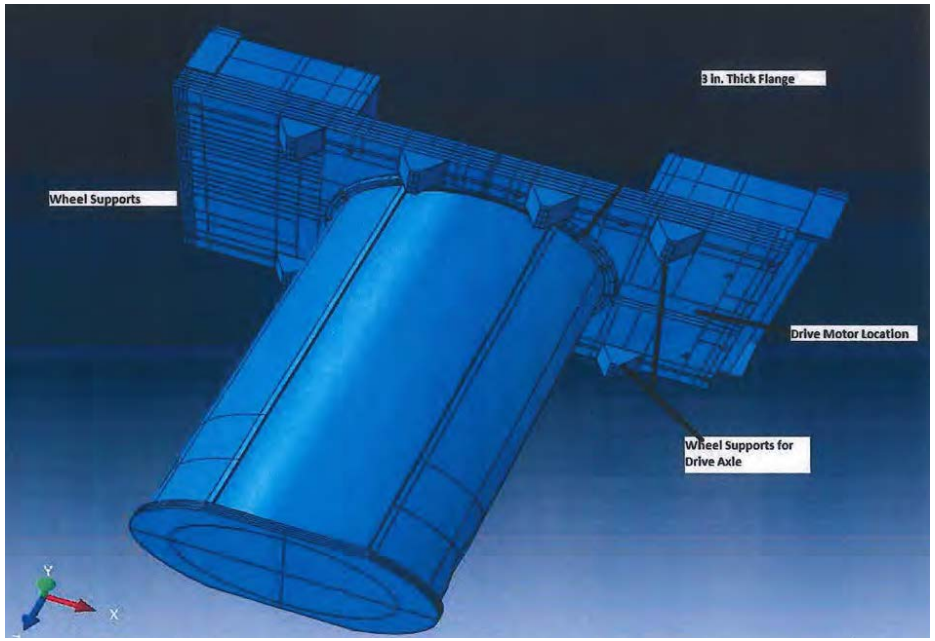
Upgrade to crane for 132 ton capacity using tandem system



Modifications to structural components to increase load capability

Trolley design to move the cask into the hot cell





Cask Mock Up of the TN-32 Cask

- Lidar was used to ensure clearance was possible
- A fit test was performed in the facility using a cask mock-up
- No problems were encountered that would indicate the facility cannot handle the real cask

The High Burnup Demonstration Continues to Give Excellent Data and Will Continue to for the Future

- Tremendous insight as to the thermal behavior of a loaded cask
- Lab testing is continuing on the sister rods to develop the baseline behavior
- When the cask is opened and rods pulled for lab testing, we anticipate even more valuable information

Questions?

Clean. **Reliable. Nuclear.**