August 23, 2021
Nuclear Waste Technical Review Board (NWTRB)

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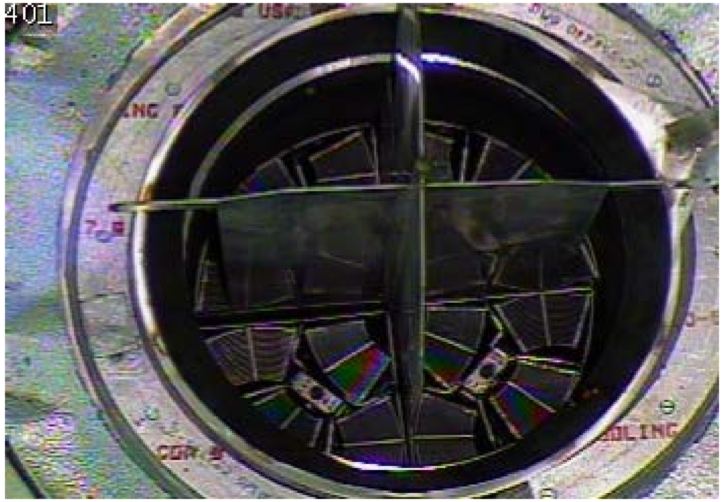
Review of the Research Program on Extended Dry Storage of Aluminum-clad SNF

Idaho National Laboratory

Background on program

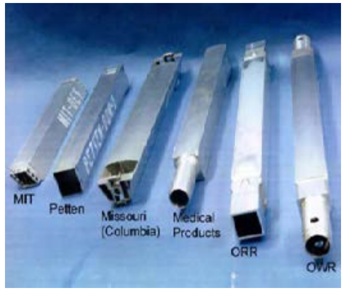
- EM Technology & Development (TD) funded-activities are a result of congressional direction
- INL, with SRNL advice, works with DOE-EM Office of Nuclear Materials (EM-4.23) and EM TD Office (EM-3.2) to define scope each year
  - Address complex wide problems, reduce risks and uncertainties, inform EM decision making, support broader strategic planning
  - Integrate with DOE-NE-funded SNF activities as appropriate
- Three primary areas include:
  - Reducing risks/uncertainties and supporting strategic planning
  - Treatment of sodium-bonded fuel/materials
  - **Ensure extended dry storage of aluminum-clad SNF**

Research reactor fuel elements


ATR elements stored in a CPP-603 storage configuration

DOE Aluminum-clad SNF (ASNF) compared to commercial SNF

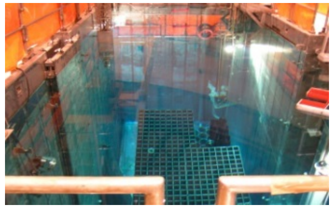
- Aluminum physical characteristics (vs. Zr or SS)
  - Susceptible to corrosion
- ASNF has surface oxide layers oxyhydroxides formed as a result of in-reactor and post-discharge conditions
  - Free, physisorbed, and chemisorbed water
  - Radiolytic gas generation
- ASNF is mostly HEU fuel
  - U-235 enrichments to 93%
- Aluminum research test reactor fuel elements
  - Experience extreme and variable reactor conditions
  - Potential for varying water storage conditions

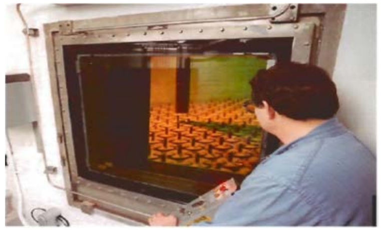


Research Reactor (RR) Fuel


Power Reactor (PR) Fuel


RR Fuel in Wet Storage


PR Fuel in Wet Storage


RR Fuel Dry Storage Facility

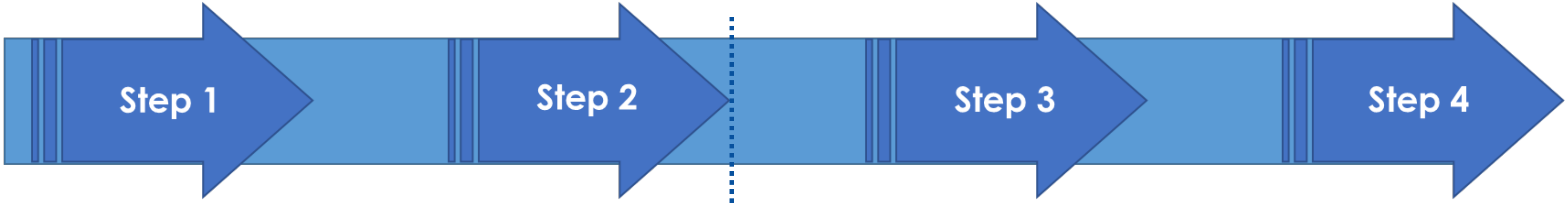

PR Fuel in Storage Casks

Storing ASNF for longer than expected

- ASNF is currently stored (wet and dry) at Idaho National Laboratory, Savannah River Site, and Hanford Reservation
  - INL has ~2.3 MTHM ASNF in dry storage, ~0.3 MTHM in wet storage, and generates ~0.08 MTHM/yr
  - SRS has ~7 MTHM ASNF in wet storage and continues to receive ASNF from ORNL and other domestic and foreign research reactors
  - Hanford has ~3 MTHM ASNF (non-RTR) in dry storage
- Hanford's dry stored ASNF is in the Canister Storage Building (CSB) in multi-canister overpacks (MCOs)
  - Sealed, inerted systems
  - Design life for CSB is 40 years (through 2040)
- INL's dry stored ASNF is in the CPP-603 vault facility in non-sealed, non-road-ready dry storage
  - Vented system
  - CPP-603 design life is through 2035

Enabling road ready dry storage of aluminum spent nuclear fuel

Today, we are here…



Identify Problem*

- DOE H-Canyon options analysis
- Al clad-SNF WG Gaps Report
- 5 technology gaps identified

Laboratory Studies

- Surrogate studies
- PIE to validate surrogates
- Modeling and simulation
- Drying studies

Develops preliminary technical basis for drying and dry storage of ASNF

Validation/Verification

- Drying + Instrumented canister demo (Validation)
- PIE post-canister demo (verification)
- Improved modeling and simulation
- Draft final technical basis

Improves the technical basis for drying and dry storage of ASNF

Deployment

- Technical basis enables licensing of a road-ready ASNF dry storage system

**"Aluminum Clad Spent Nuclear Fuel: Technical Considerations and Challenges for Extended (>50 Years) Dry Storage," DOE-ID/RPT-1575, June 2017*

ASNF tasks focus on technical gaps

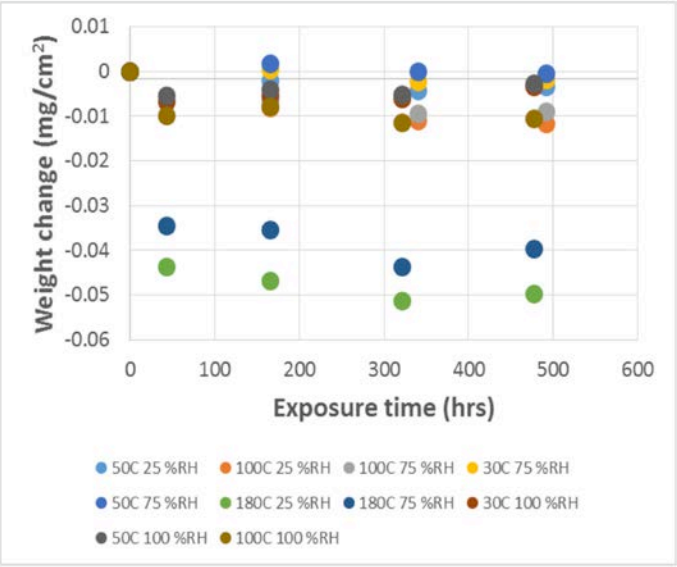
INL CPP-603 dry storage facility

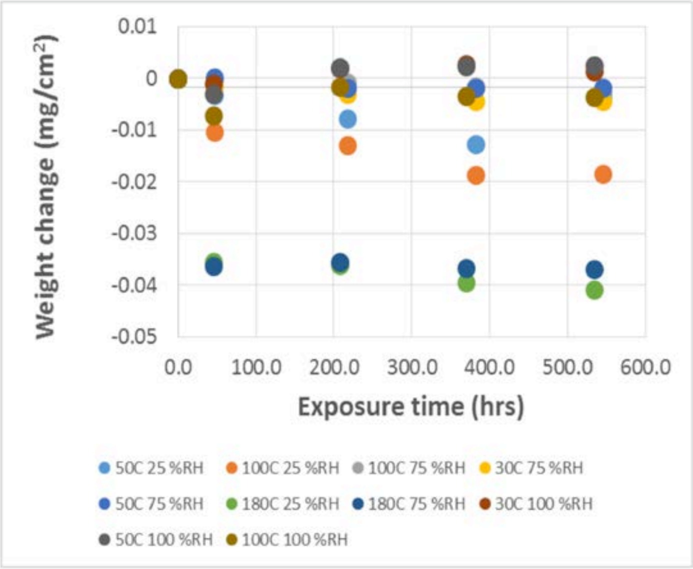
- DOE issued report* in Summer 2017 identifying 5 technical gaps
  - Behavior/chemistry of oxyhydroxide layers for the range of ASNF fuel designs and dry storage configurations
    - Task 1 – complete
  - Resolution of radiolytic gas generation data for ASNF oxyhydroxide layers
    - Task 2 – ongoing – Dr. Greg Horne
  - Combined effect of episodic breathing and radiolytic generation of potentially corrosive gases in sealed and vented systems
    - Task 3 – ongoing – Dr. Alex Abboud
  - Effects of high-temperature (>100C) drying on the chemistry and behavior of oxyhydroxide layers
    - Task 5 – mostly complete – Rebecca Smith
  - Performance of research test reactor ASNF in existing dry storage systems
    - Task 4 – complete
    - Task 6 – some complete; ongoing – Dr. Anna d’Entremont

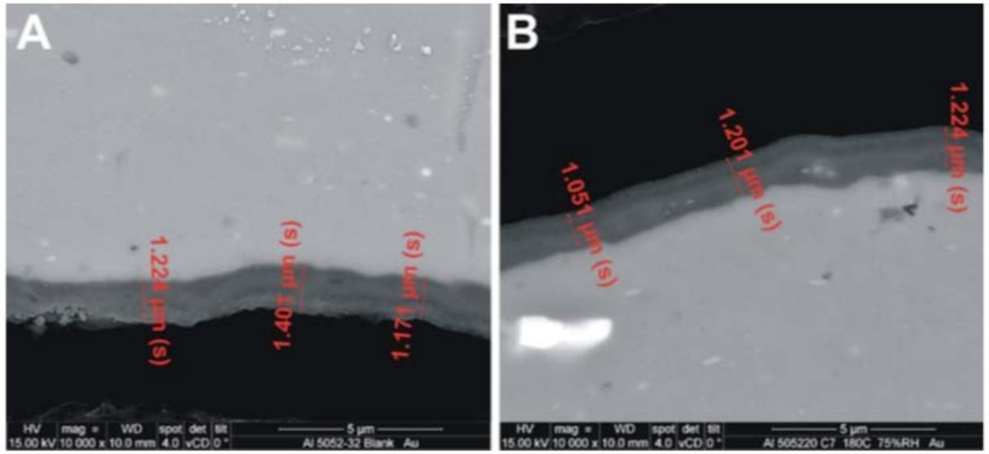
*[*Aluminum Clad Spent Nuclear Fuel: Technical Considerations and Challenges for Extended (>50 Years) Dry Storage*, DOE-ID/RPT-1575, June 2017

Chemistry/behavior of hydrated oxide layers (Task 1 – complete)

- Understand aluminum reactivity across possible temperature and humidity values through testing for both general and localized corrosion—no radiation effects
- **Conclusion:** Based on these experiments, **no hydrogen is expected to be produced** due to corrosion of the oxyhydroxide layers in a range of temperatures and the relative humidity tested which are representative of those anticipated in sealed (or vented) dry storage





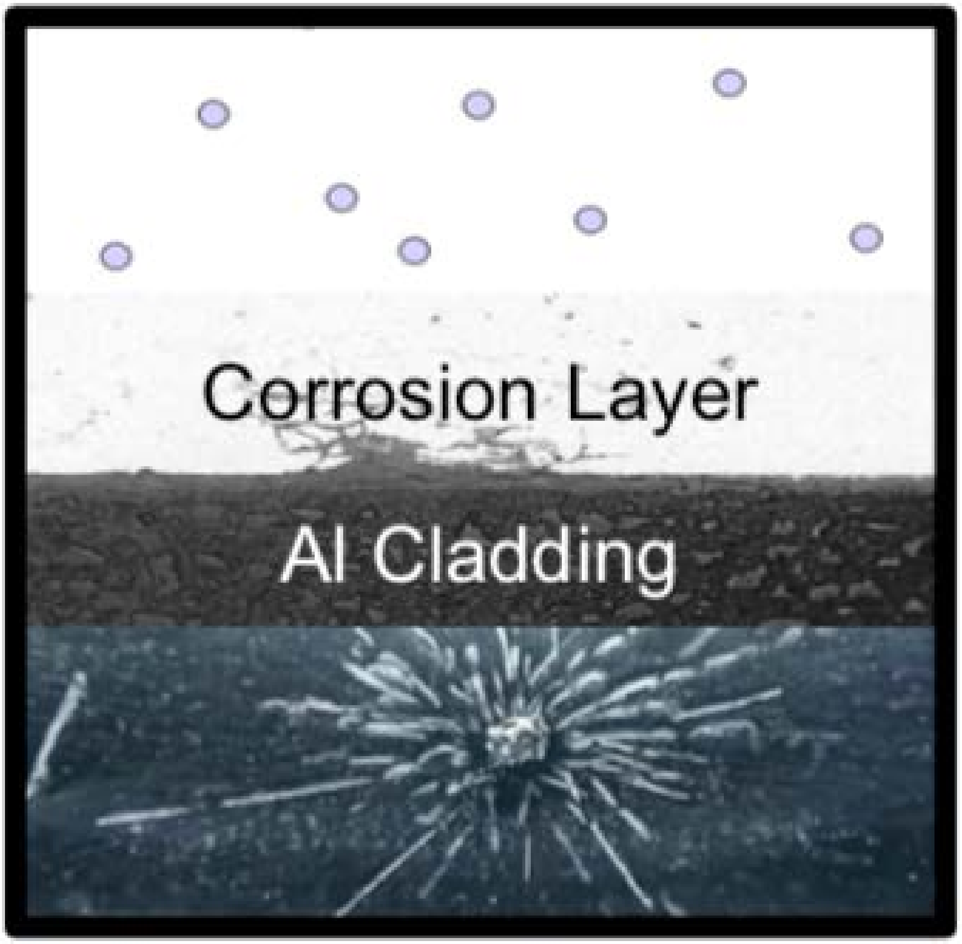


SEM images of AA5052 after (A) oxide film growth and (B) vapor phase testing at 180°C and 75% relative humidity

Plot of weight gain versus exposure time for AA1100 (left) and AA6061 (right)

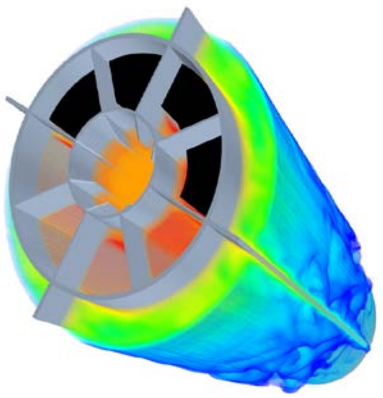
Radiolytic gas generation (Task 2 – ongoing)

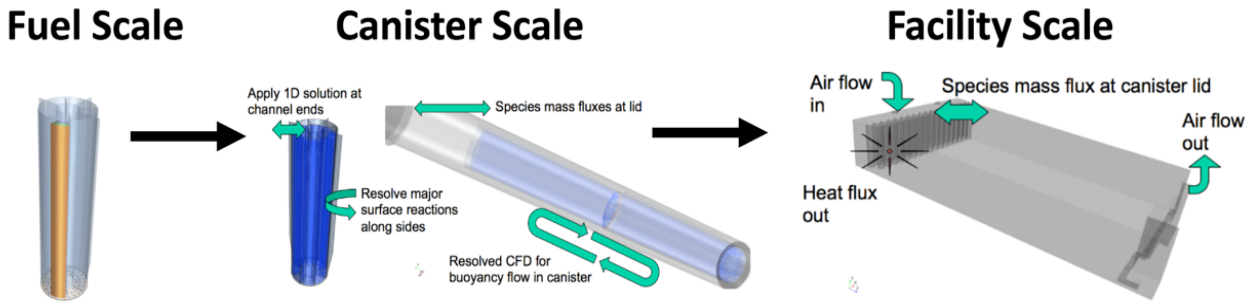
- Determine generation and reaction rates of radiolytic species produced in sealed/vented ASNF storage containers due to radiation
- Provide quantitative experimental data and insight into the rate of H2 generation from the attendant corrosion layer on aluminum alloy coupons to inform complimentary modelling efforts
- Dr. Greg Horne's presentation

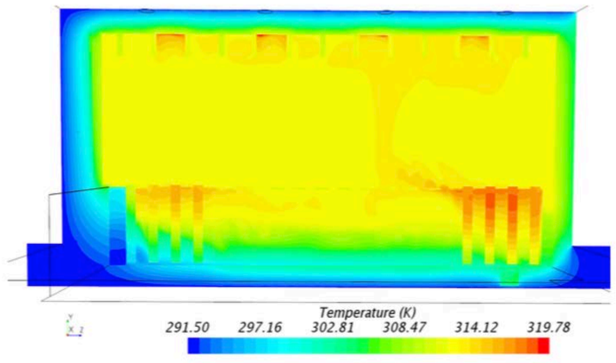


Modeling the sealed and non-sealed storage configurations (Task 3 – ongoing)

- Multiscale, multiphysics computational fluid dynamics modelling of vented as well as sealed storage systems.
  - Couple relevant processes and physics
  - Informed by experiments and actual spent fuel data collected by other tasks
- Dr. Alex Abboud’s presentation

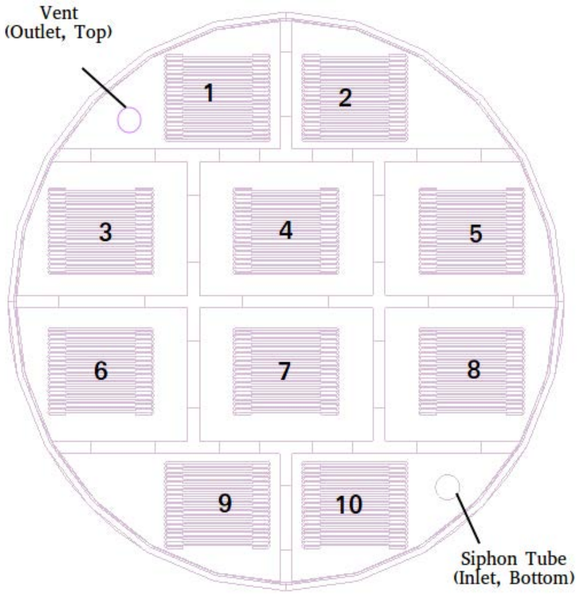






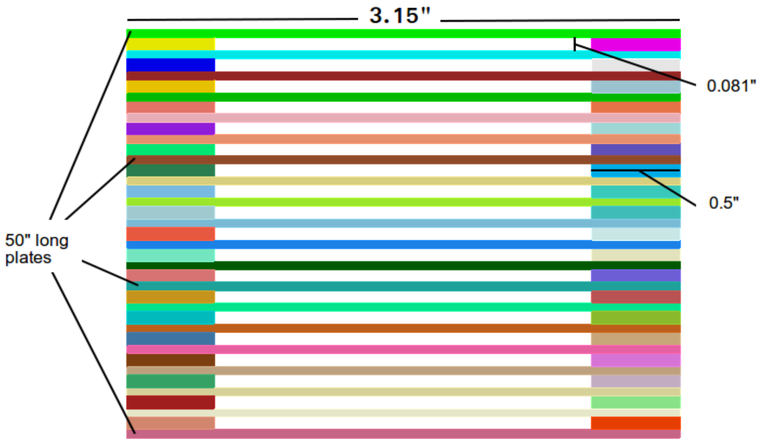
Explore drying "recipes" on corrosion layers and future hydrogen generation (Task 5 – complete)

- Objective to assess effectiveness of drying processes at elevated temperatures (>100°C)
  - Vacuum drying
  - Forced gas dehydration (FGD)
- Rebecca Smith's presentation



Chamber with Type 1A basket


Main test chamber w/view ports



Mock ASNF element

Understanding actual ASNF performance in current wet and dry storage (Task 4 – complete)

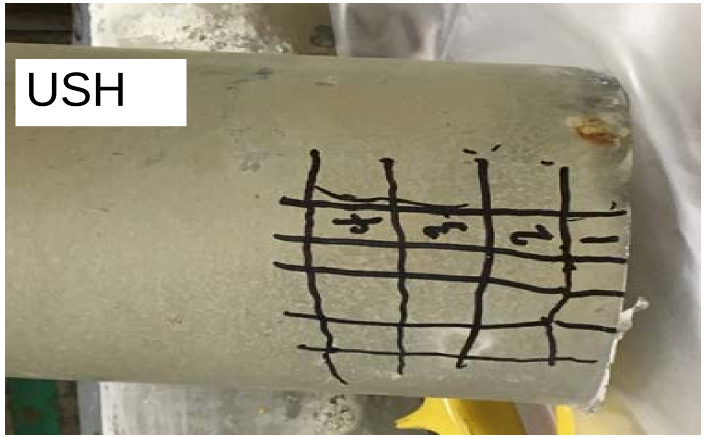
- Investigate performance of actual ASNF in dry storage
  - ATR operating canal (wet)
  - ATR fuel in INL CPP-603 facility (dry)
- Characterized surface film composition and morphology
  - Films: boehmite, bayerite, gibbsite
  - Thickness: 2–6 microns
- Characterization of ATR materials
  - Electron microscopy, thermogravimetric analysis (TGA), transmission electron microscope (TEM), Focused Ion Beam (FIB)
- Conclusion: ATR fuels show that limited corrosion changes (i.e., growth) have occurred as a result of irradiation, wet storage, or subsequent dry storage. The individual fuel plates show no sign of oxide alteration or damage.
  - Oxide growth was visible at mechanical abrasion points, where the pre-irradiation boehmite layer may have been disrupted

ATR end box and end box piece – wet storage

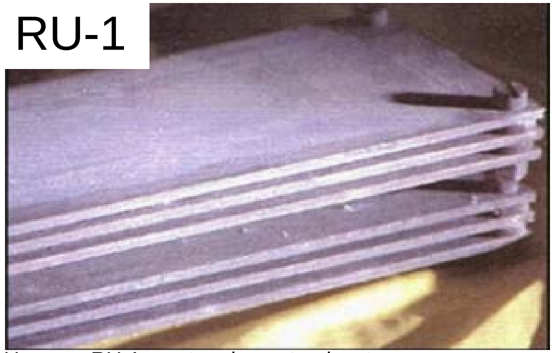

ATR element with end box removed

Understanding actual ASNF performance in current wet and dry storage (Task 6 – complete)

- Investigate performance of actual ASNF in dry storage
  - L Basin (wet and dry)
- Characterized surface film composition and morphology
  - Films: boehmite, bayerite, gibbsite
  - Thickness: Up to 15 microns
- Characterized L Basin materials w/range of service & storage
- Conclusion: Friable, non-uniform thickness, mixed hydrated oxide layers



SRS universal sleeve housing from production reactor – wet storage



Uruguay RU-1 reactor element – dry storage

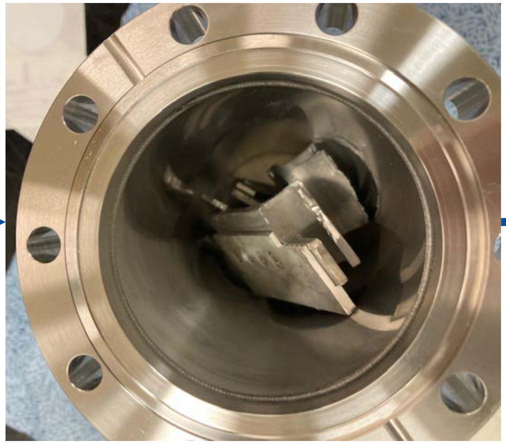
SRS Mark-16B from production reactor – wet storage

Missouri University Research Reactor element – wet storage

Online monitoring of surrogate and actual ASNF in canister-analogous environment (Task 6 - ongoing)

- Measuring radiolytic yield in a “mini-canister” allowing for in-situ gas sampling
  - Large lab-grown surrogate coupons design to approximate fuel assembly geometry
  - Service-exposed L Basin materials
- Dr. Anna d’Entremont presentation

Missouri University Research Reactor (MURR) element – wet storage



MURR sample in unsealed mini-canister

MURR sample sealed in mini-canister for radiolysis testing

Independent PNNL review

- PNNL provided an independent technical review of Task 2 (radiolytic gas generation) and Task 3 (modeling and simulation) at end of FY20
  - Generally, very supportive:
    - “the modeling approach was reasonable and gave well supported results”
    - “if the program follows the methodology and rigor outlined in the test matrices, the program will develop *G*-values for a defensible technical basis of extended storage of ASNF”
- Report identified a few follow-on refinement activities including:
  - Confirm aluminum-alloy does not significantly affect radiolytic gas generation (ongoing activity)
  - Confirm radiolytic gas generation as a function of corrosion thickness (ongoing activity)
  - Perform additional surface characterization (ongoing activity)
  - Provide better documentation of the modeling approach and coupling (completed activity)

Preliminary conclusions

- The testing and analysis results of the characterization of ATR fuel and the performance modeling in its storage configuration show the **ASNF** presently in vented interim dry storage (IFSF) **is safe for continued, extended dry storage (> 50 years) without corrosion degradation challenges.**
- The testing and analysis results of **ASNF** from L Basin **can be safely placed in a sealed canister storage without corrosion degradation, canister pressurization, and canister flammability challenges pending ultimate disposition.**
- The ASNF-in-canister performance modeling, including the H2 generate rate inputs from extensive radiolysis testing of hydrated oxides on aluminum substrate testing, allows for reliable **performance prediction of configurations** of ASNF-in-canisters including parameters of temperature, gas-space evolution, and canister pressurization.

Questions?