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

Spent Fuel and Waste Science and Technology (SFWST)

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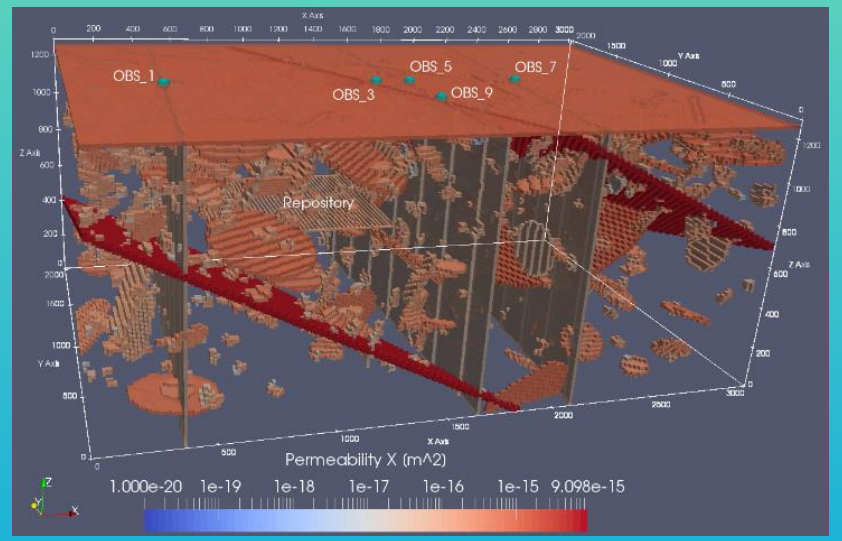

Investigations into Back End of the Nuclear Fuel Cycle (BENFC) Issues for Advanced Reactor (AR) Fuels and Accident Tolerant Fuels (ATF)

SAND2022-12207 PE

IAEA Technical Meeting on Back End of the Fuel Cycle Considerations for Small Modular Reactors (SMRs)

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Spent Fuel and Waste Science and Technology Campaign (SFWST)

- Mission: Identify alternatives and conduct scientific research and technology development to enable storage, transportation, and disposal of used nuclear fuel and wastes generated by existing and **future** nuclear fuel cycles
- Emergence of AR fuel and ATF technologies has prompted the U.S. Department of Energy (DOE), the U.S. Nuclear Regulatory Commission, and the commercial nuclear power industry to investigate technical issues associated with BENFC of AR fuels and ATF
- Small Modular Reactor (SMR) concepts range from integral Light Water Reactors (LWRs) to more advanced reactors with lower technology readiness levels
- SFWST Research & Development approach applies to BENFC considerations for SMRs
  - Example application: Integral LWR – similar fuel/clad system to a 1 GWe commercial PWR but containing ATF as well as SMR-like safety features (integral configuration)

AR Fuel and ATF Storage & Transportation High-Level Gap Analysis

- Focus: perform storage and transportation gap analysis for proposed AR fuels and ATFs currently being irradiated in commercial reactors
  - SMR concepts include proposed fuels
- Significant testing and modeling conducted to establish initial performance metrics, with additional metrics to be determined once AR fuels and ATFs have reached end-of-life burnup
- Primary preliminary conclusions
  - Current storage and transportation canister/cask systems are capable of handling rod/assembly AR fuel and ATF systems that are similar to existing spent nuclear fuel (SNF)
  - Significantly different fuel systems (TRISO fuels, uranium alloys) may require new storage, transportation, and disposal container designs

Disposal Considerations for ATF and AR Fuel

- Focus: identify opportunities for reducing disposal impact of waste generated by AR fuel cycles
- Sandia, and other National Laboratories, worked with DOE's Advanced Research Projects Agency to Scope the Workshop for Advanced Reactors
- Waste form characteristics and requirements used to define "disposal impact" were identified
  - chemical form of waste,
  - expected lifetime upon package failure,
  - radionuclide inventory of waste,
  - thermal characteristics,
  - physical characteristics,
  - waste package type,
  - reaction to water,
  - generation of gas,
  - safeguards and security issues

Integrated High-Level Strategy

- Focus:
  - Provide overview of AR SNF and other potential waste streams
  - Include a survey and description of existing and projected waste forms with disposition pathways previously evaluated
  - Map precedents to projected waste streams from ARs to use as a basis for an initial BENFC disposition strategy and identify differences to be evaluated
- SFWST Campaign initiated development of integrated high-level strategy to identify additional storage, transportation, and disposal issues for AR SNF and ATF from existing and future fuel cycles
- Strategy development will guide detailed gap analyses for storage, transportation, and disposal options for AR SNF and ATF, which will delineate further R&D to close those gaps

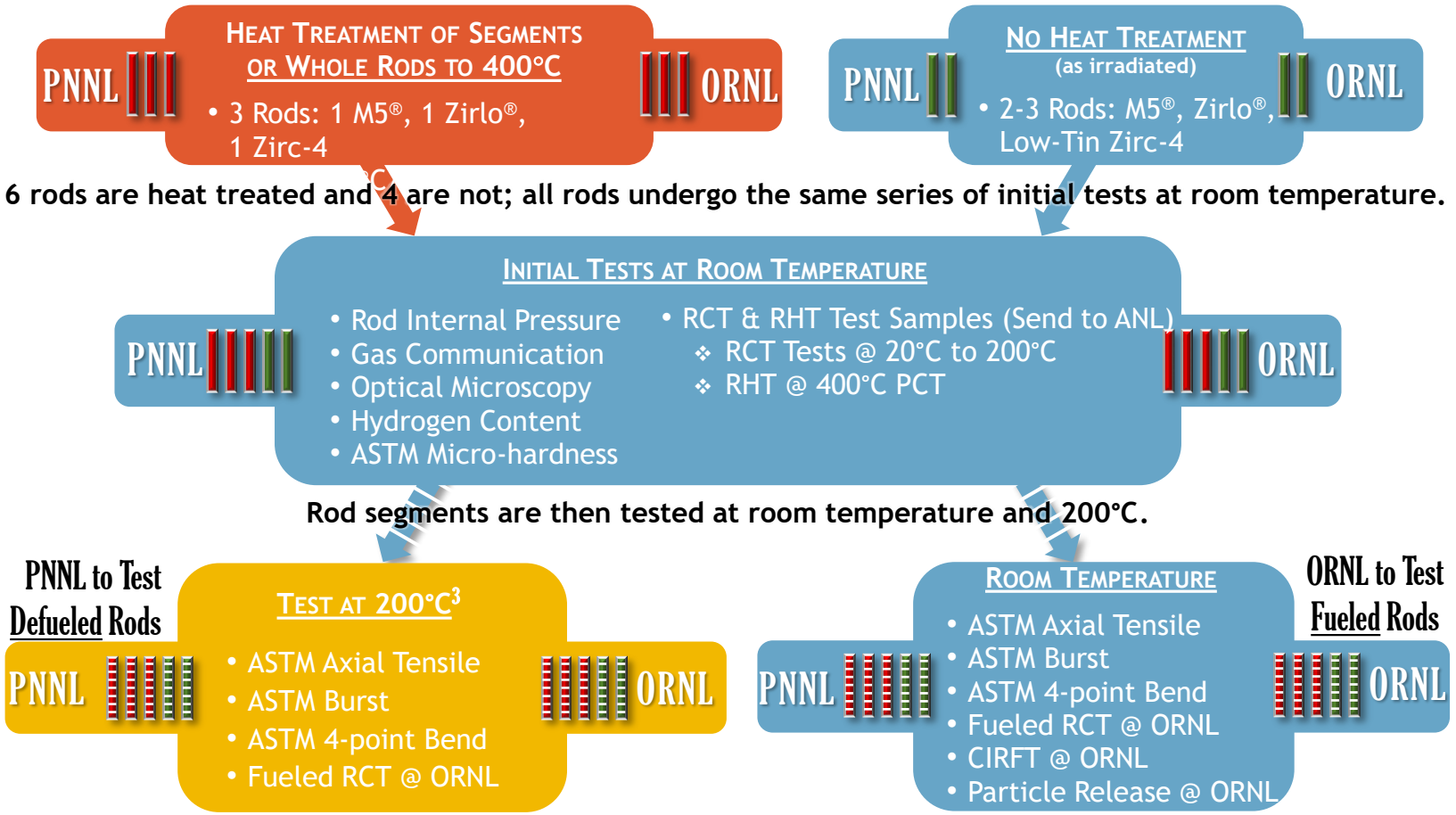
Testing of Representative ATF and AR Fuel

- Focus: test rods representative of end-of-life burnup of AR fuel and ATF (for components of comparable form) following procedures used for testing high burnup LWR Sibling Pins
- Collaborative DOE effort with Electric Power Research Institute
- Establish technical bases to determine accommodations needed for AR fuel and ATF storage, transportation, and disposal
- Parameters of interest
  - AR fuel and ATF particulate size and quantity;
  - cladding coating robustness;
  - potential corrosion and hydride formation in areas of damaged cladding coatings;
  - increased container weight,
  - temperatures,
  - radiation levels

Testing of High-Burnup LWR SNF and Similar AR and ATF Fuels

High-Burnup Spent Fuel Rod Phase 1 Test Plan Visualization

We start with 25 rods. Both labs will perform similar tests, but Oak Ridge National Laboratory (ORNL) will test fueled rods and Pacific Northwest National Laboratory (PNNL) will test defueled rods. Argonne National Laboratory (ANL) will perform Ring-Compression Tests (RCTs) and Radial Hydride Treatment (RHT) on rod segments.



1) ORNL may use multiple M5® or Zirlo® rods as well as Low-Tin Zirc-4 rod segments for testing.
2) Tests will be conducted on samples from multiple axial regions of each fuel rod.
3) Not all tests may be able to be performed at 200°C.

- Deviations from this test plan will be based on continuous learning and approved before execution.
- As test results are obtained, our community reviews the data, and DOE determines a path forward.

CIRFT (Cyclic Integrated Reversible Bending Fatigue Tester)

Summary

- Previous SFWST Campaign work addressing technical BENFC issues for AR fuels and ATF:
  - ATF and AR fuel storage and transportation high-level gap analysis concluded new storage, transportation, and disposal systems needed for some new and different fuel systems
  - Disposal considerations for ATF and AR fuel identified waste form issues for disposal and include considerations for post-closure criticality and safety
- Ongoing work addressing technical BENFC issues for AR fuels and ATF:
  - Ongoing: Integrated high-level strategy document currently in progress
  - Future: Analyses/testing of representative ATF and AR fuel after end-of-life burnup
  - Future: Presentation of paper accepted at International High Level Radioactive Waste Management (IHLRWM) conference in November 2022
    - Evaluating Geologic Disposal Pathways for Advanced Reactor Fuels – Sassani *et al.*

References

PETROVIC, B., Integral Inherently Safe Light Water Reactor (I^2S-LWR) Final Report, I2S-FT-16-01, Rev. 0, performed under NEUP-12-4733, Georgia Institute of Technology, Atlanta, Georgia, 2016.

HONNOLD, P., MONTGOMERY, R., BILLONE, M. HANSON, B., SALTZSTEIN, S., High Level Gap Analysis for Accident Tolerant and Advanced Fuels for Storage and Transportation, SAND2021-4732, SFWST milestone number M3SF-21SN010201062, Sandia National Laboratories, Albuquerque, New Mexico, 2021.

PRICE, L., SWIFT, P., SASSANI, D., Geologic Disposal of High Activity Radioactive Waste, Waste Forms, and Waste Streams: Considerations for Disposal. SAND2022-2534 C, presented at Waste Management 2022, Sandia National Laboratories, Albuquerque, New Mexico, 2022.

SALTZSTEIN, S., SORENSON, K., HANSON, B., BILLONE, M., SCAGLIONE, J. MONTGOMERY, R. BEVARD, B., EPRI/DOE High Burnup Fuel Sister Pin Test Plan Simplification and Visualization, SAND2017-7597, Sandia National Laboratories, Albuquerque, New Mexico, 2017.

SALTZSTEIN, S., BILLONE, M., HANSON, B., SCAGLIONE, J., Visualization of the High-Burnup Spent Fuel Rod Phase 1 Test Plan: Technical Memo, SAND2018-8042 O, Sandia National Laboratories, Albuquerque, New Mexico, 2018.

SASSANI, D., PRICE, L., PARK, H., MATTEO, E., MARINER, P., Evaluating Geologic Disposal Pathways for Advanced Reactor Spent Fuels, SAND2022-10737 C, Sandia National Laboratories, Albuquerque, New Mexico, 2022.