Spent Nuclear Fuel Characterization

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Technical Meeting on Spent Fuel Characterization

November 12-14, 2019
Vienna, Austria

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Spent fuel characterization questions and issues

- What characteristics are you interested in and why the data is required?
- What methods are available to you for characterisation (currently and planned), what can they be used for and any limitations? This could include:
  - Destructive analysis;
  - Non-destructive analysis;
  - Modelling.
- Data & knowledge management issues, such as:
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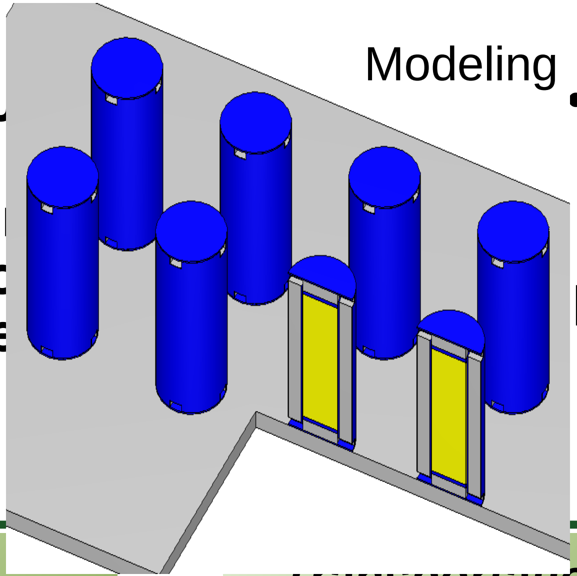
  - Records management;
- Developing & maintaining a skilled capability.

Different characteristics are used for different evaluations to meet different requirements

Data

- **Base characteristics: fu... dimensions, materials, ... histories (e... cycle le... power), c... tem c... patterns ... ged fue...**

Modeling



Safety

- **Deri... ay heat, isot... ion sources, criti... rates, inve...**

Courtesy of Entergy

Storage

- *Radiation Protection/ Shielding*
- *Confinement*
- *Struct...*
- *The...*
- *Critic...*
  - *Integrity...*

Transportation

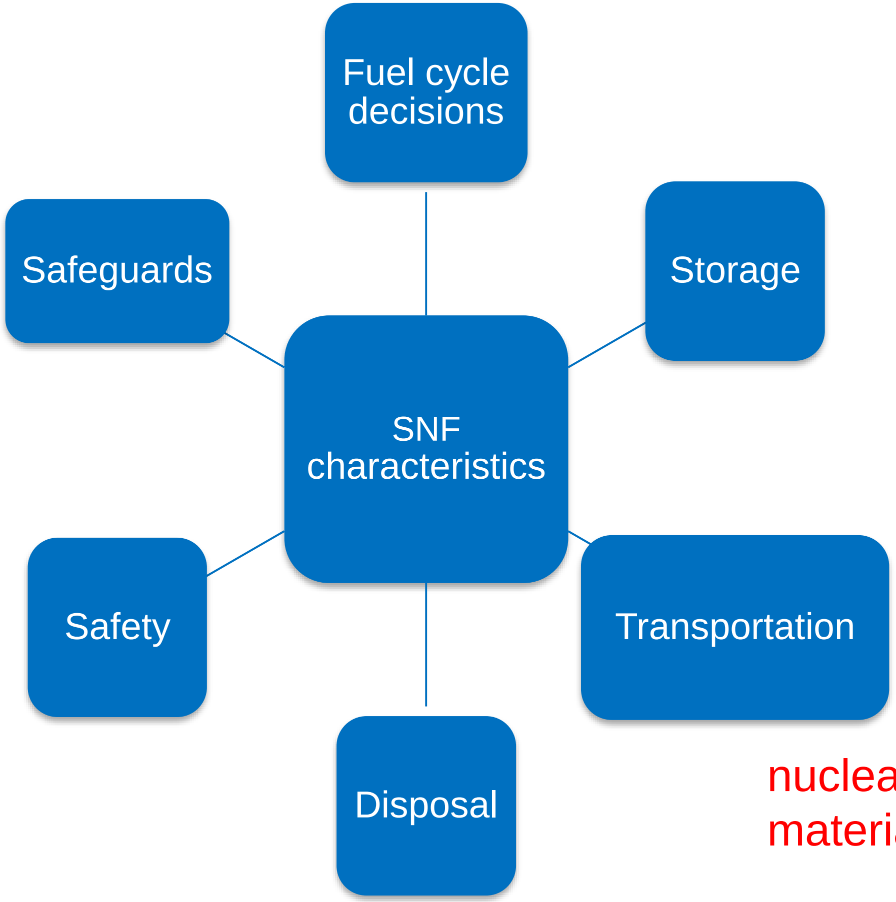
- *Shielding*

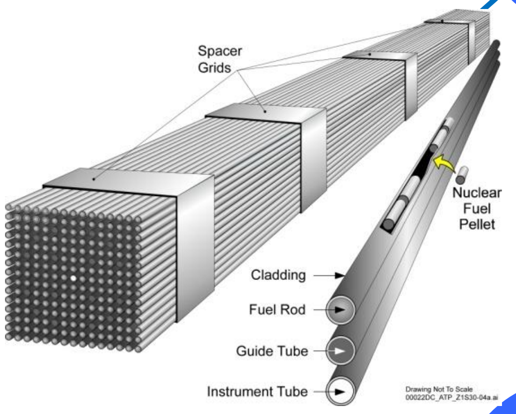
Disposal

- *Limit dose and release*
- *Media thermal ...aints*
- *...limits*
- *...e?*
- *...ent*

Fundamental safety objective is to ensure doses are below prescribed regulatory limits, maintain subcriticality, and ensure confinement/containment of radionuclides

All spent fuel management activities start with an understanding of the characteristics of the SNF

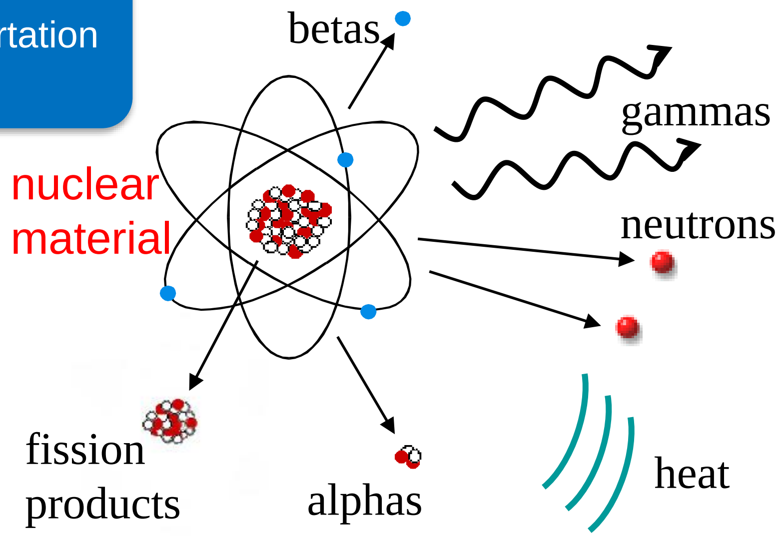


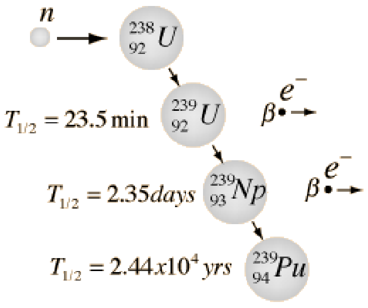


Decay Heat
- Corrosion / degradation
- Structural integrity

Radiation source
- Dose
- Containment
- Self-protection

Composition
- Criticality safety
- Material accountability
- Material recovery





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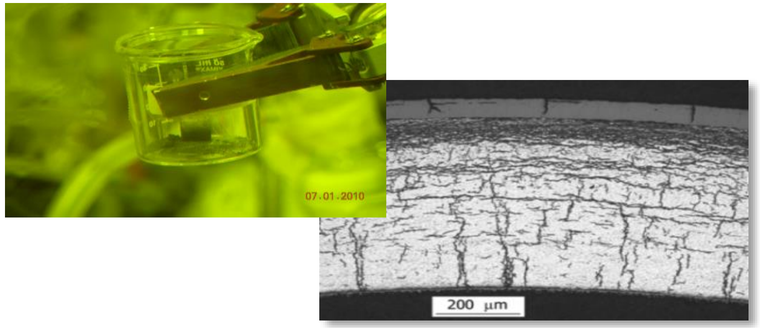
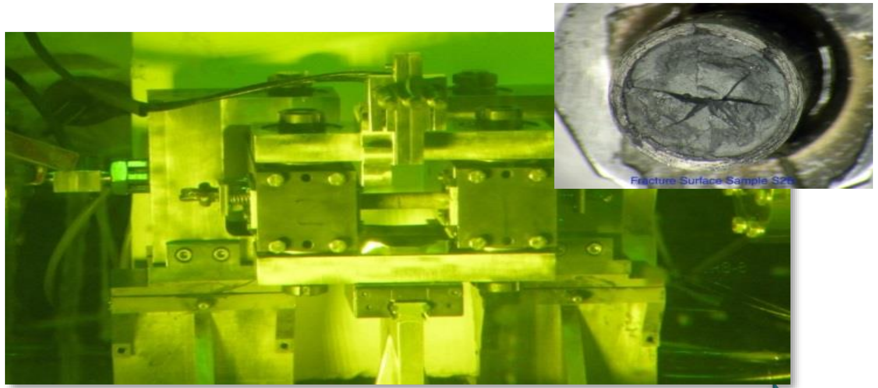
Many methods and techniques are available for SNF research & development (R&D)

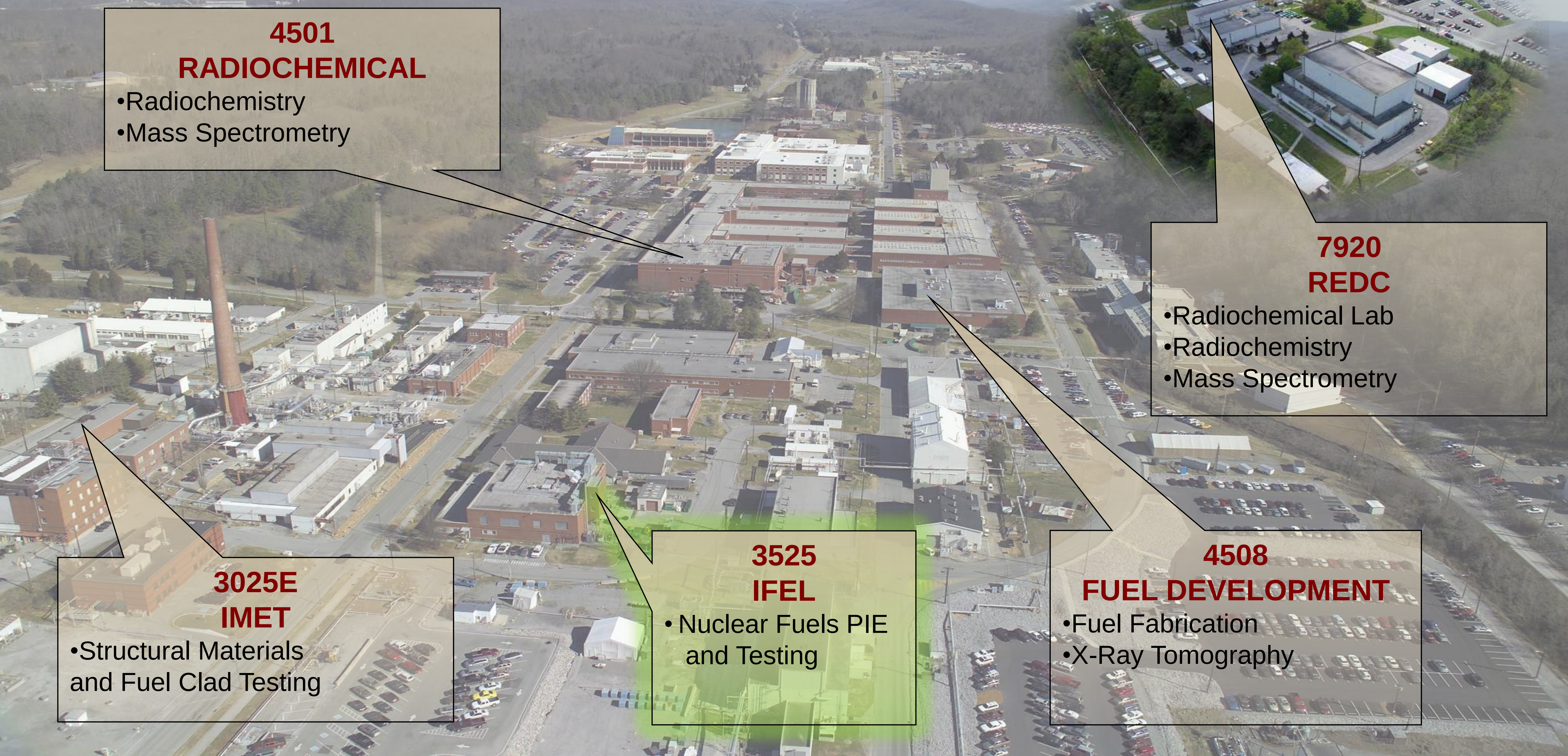
Staff: Providing outcome-focused leadership	Facilities and resources: Enabling outcomes	Result: Delivering technical solutions
• Leadership roles in DOE and NRC spent fuel programs • Developing and applying validated nuclear analyses tools and data • Supporting NRC with regulatory research and licensing support	• HFIR: Cladding irradiation and nondestructive neutron scattering for advanced understanding and predictive model development • Hot cells: Critical to R&D with actual SNF • Developed fatigue testing device and process to understand mechanical performance UNF during transport • Staff experience and computational tools to assess system performance	• Improved fundamental understanding of SNF mechanical properties • Science-based engineering solutions for safety and integrity issues related to used fuel • Characterization of used fuel inventory • Establishing knowledge, data, and tools for enabling SNF disposition





Integration of data, experiments, and analysis

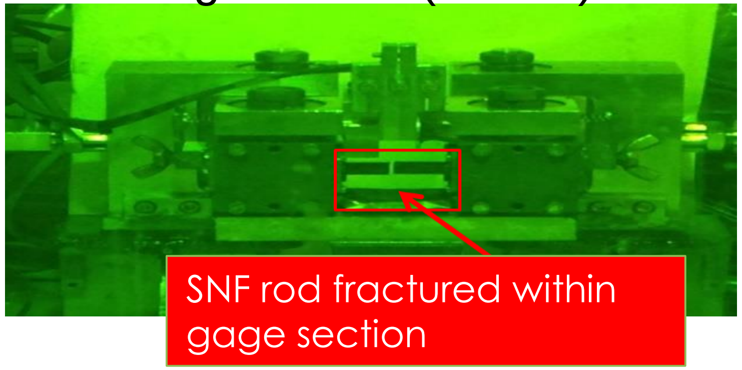
ORNL Nuclear Fuels Complex has many capabilities for characterizing SNF

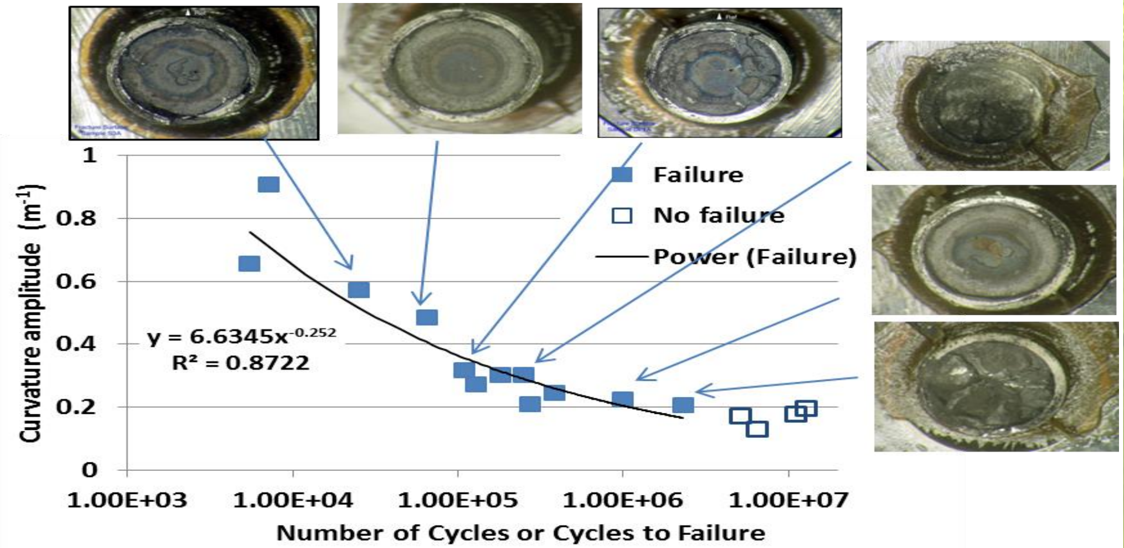


ORNL hot cells are highly flexible and support non-destructive examination and destructive testing of full-length fuel rods (complimentary capabilities at some other US National Laboratories)

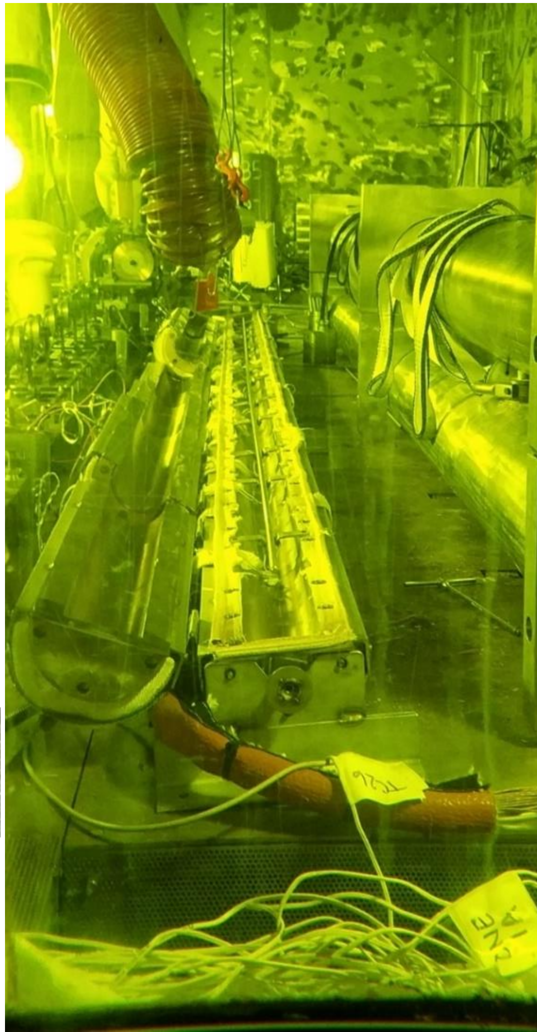
- Full Length Fuel Rod PIE Capabilities
- Automated High-Volume Digital Photography
- 1D Gamma Ray Scanning
- Axial Measurements accurate to .25 mm
- Radial Measurements accurate to 0.5 degree
- Eddy Current Gross Clad Inspection
- Rod Surface Temperature Measurements
- Fuel Rod Plenum Pressure (4% Accuracy)
- Fuel Rod Plenum Volume (6% Accuracy)
- Fission Gas Isotopic Determination
- Precision Cutting Saw for Accurate Sample Lengths
- Electronic Data Transfer

Cyclic integrated reversible bending fatigue tester (CIRFT)



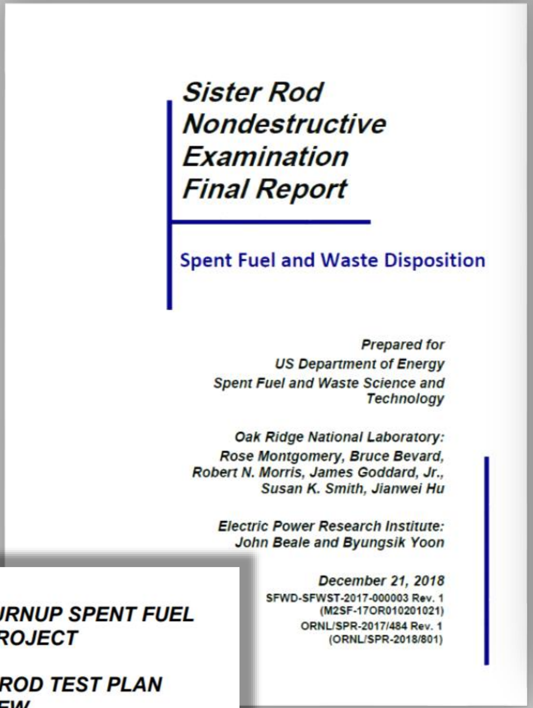


7-zone full length fuel rod heater



Active programs are underway to characterize high burnup spent fuel rods using series of nondestructive and destructive tests

- US Department of Energy
- US Nuclear Regulatory Commission
- Test plans, recent results, and future testing are available in published reports
  - Mechanical properties of cladding and fuel rod composite (fuel and clad)
  - Rod internal pressures
  - Fuel isotopic compositions
  - Aerosolized particulate
  - Fatigue testing
  - Fracture toughness
  - LOCA for testing under loss-of-coolant accident conditions


Sister Rod Nondestructive Examination Final Report

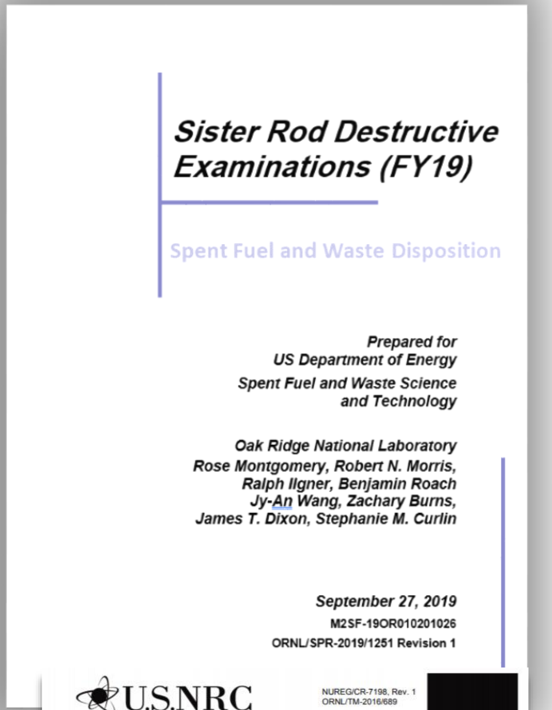
Spent Fuel and Waste Disposition

Prepared for
US Department of Energy
Spent Fuel and Waste Science and Technology

Oak Ridge National Laboratory:
Rose Montgomery, Bruce Bevard, Robert N. Morris, James Goddard, Jr., Susan K. Smith, Jianwei Hu

Electric Power Research Institute:
John Beale and Byungsik Yoon

December 21, 2018
SFWD-SFWST-2017-000003 Rev. 1
(M2SF-17OR010201021)
ORNL/SPR-2017/484 Rev. 1
(ORNL/SPR-2018/801)

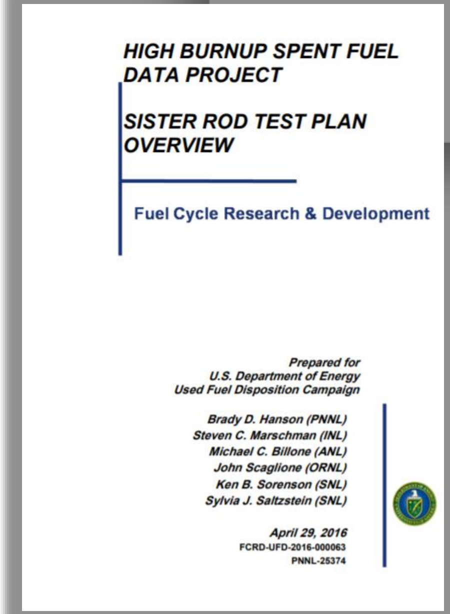

Sister Rod Destructive Examinations (FY19)

Spent Fuel and Waste Disposition

Prepared for
US Department of Energy
Spent Fuel and Waste Science and Technology

Oak Ridge National Laboratory
Rose Montgomery, Robert N. Morris, Ralph Ilgner, Benjamin Roach, Jy-An Wang, Zachary Burns, James T. Dixon, Stephanie M. Curlin

September 27, 2019
M2SF-19OR010201026
ORNL/SPR-2019/1251 Revision 1


HIGH BURNUP SPENT FUEL DATA PROJECT

SISTER ROD TEST PLAN OVERVIEW

Fuel Cycle Research & Development

Prepared for
U.S. Department of Energy
Used Fuel Disposition Campaign

Brady D. Hanson (PNNL)
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John Scaglione (ORNL)
Ken B. Sorenson (SNL)
Sylvia J. Saltzstein (SNL)

April 29, 2016
FCRD-UFD-2016-000063
PNNL-25374


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

NUREG/CR-7198, Rev. 1
ORNL/TM-2016/689

Mechanical Fatigue Testing of High-Burnup Fuel for Transportation Applications

Office of Nuclear Regulatory Research

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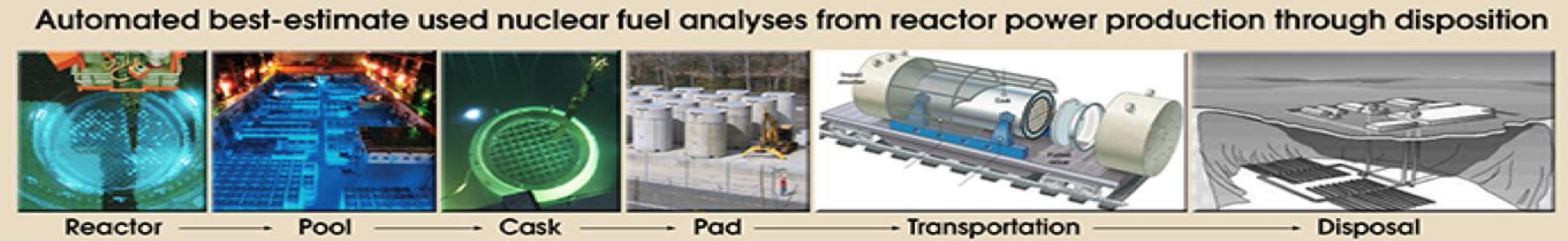
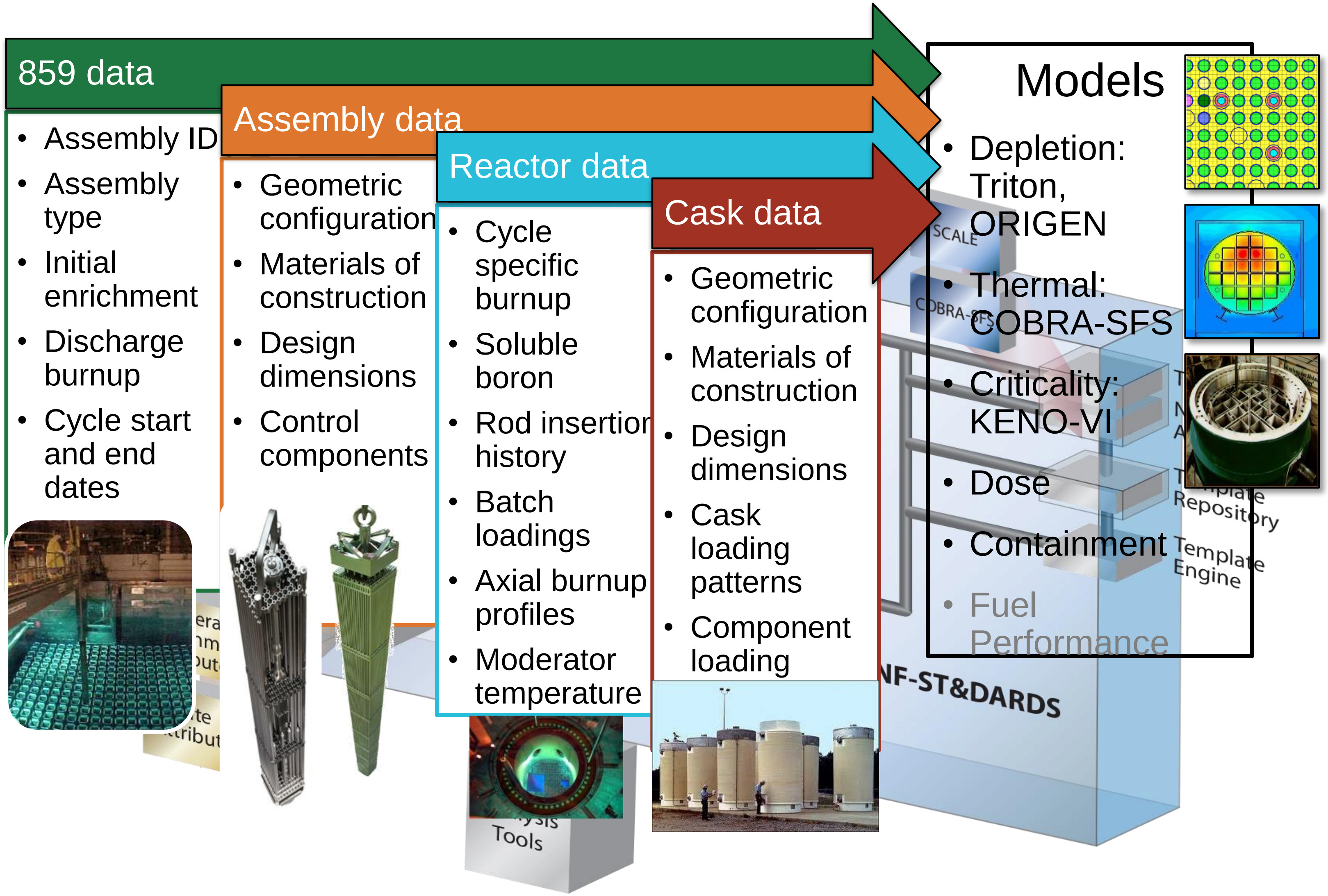
Used Nuclear Fuel Storage, Transportation & Disposal Analysis Resource and Data System (UNF-ST&DARDS) was established to characterize spent fuel



- A comprehensive system for analysis of the SNF from the time it is discharged from the reactor to the time it is disposed of in a geologic repository
- Unified Database (UDB)
  - Supports data needs for various analyses (storage, transportation, and disposal) and provides essential resources for informed decision making
  - Characterizes the input to the waste management system
  - Provides data at an assembly- and cask-specific level
- Broad applicability
  - Fuel cycle decisions
  - Safeguards and security
  - Waste management
  - Safety

UNF-ST&DARDS is data and analysis system that can be sustained for the long-term

- **Unified Database consolidates, controls, and archives key information from multiple sources**
- **Integration of data with analysis capabilities enables automated characterization of eventually all SNF assemblies and canisters/casks in the domestic inventory**



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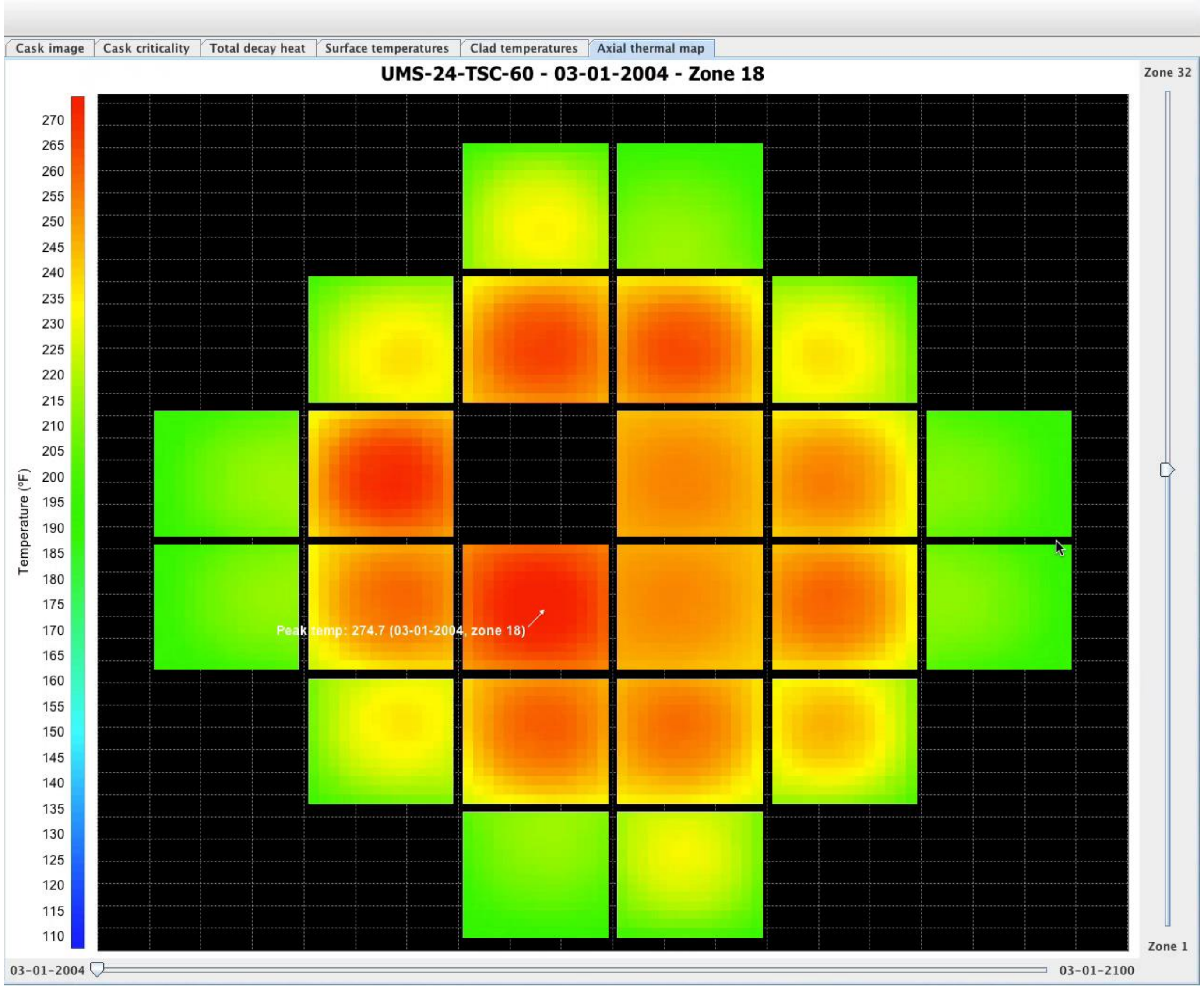
The UDB contains derived SNF and related systems characteristics

- Derived characteristics are calculated data based on SNF and related systems inventory and base characteristics data
- Derived characteristics include
  - Assembly-specific decay heat
  - Assembly-specific isotopic composition
  - Assembly-specific radiation sources
  - Cask-specific criticality
  - Cask-specific thermal attributes (e.g., clad temperature, canister surface temperature)
  - Cask-specific transportation dose rates



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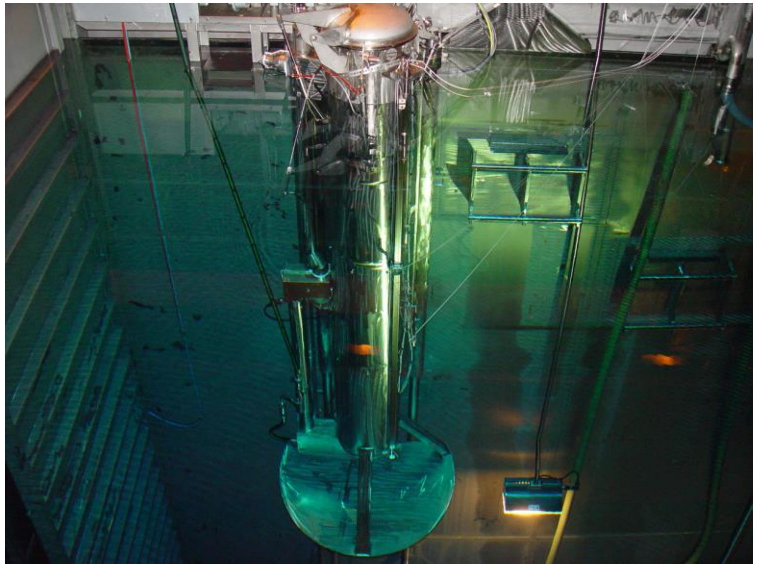
Opportunities are available for continuing to develop & maintain skilled workforce

- Active research of irradiated fuel
  - High Burnup SNF Data Project will experimentally define the effects of long-term storage and transportation on HBU SNF
  - Developing and testing Advanced Technology Fuel with industry
- Gateway for Advanced Innovation in Nuclear (GAIN)
  - Program providing the nuclear community with access to the technical, regulatory, and financial support necessary to move innovative nuclear energy technologies toward commercialization https://gain.inl.gov/SitePages/Home.aspx
- Nuclear Science User Facilities
  - World-class nuclear research facilities, technical expertise from experienced scientists and engineers, and assistance with experiment design, assembly, safety analysis and examination https://nsuf.inl.gov/
- Modeling tools are available through Radiation Safety Information Computational Center (RSICC)
  - https://rsicc.ornl.gov/Default.aspx
- Undergraduate and graduate programs are available at ORNL to work with prospective students
  - https://orise.orau.gov/ornl/undergraduates/default.html
  - https://orise.orau.gov/ornl/graduate-students/default.html

Backup Material

Sources of Decay Heat Validation Data

- **Hanford Engineering Development Laboratory assembly calorimeter measurements** (1980)
  - Boil-off (steam) calorimeter design
  - 15x15 assemblies measured (4 assemblies)
- **GE Morris Facility calorimeter measurements** (1985)
  - Static mode calorimeter design (temperature increase)
  - 14x14 and 7x7 assemblies (75 assemblies)
- **SKB Swedish Central Interim Spent Fuel Storage Facility (Clab) assembly calorimeter measurements** (2003 – current)
  - GE calorimeter design
  - PWR – 15x15, 17x17 designs (34 assemblies)
  - BWR – 8x8, SVEA-64, SVEA-100 (31 assemblies)



Calorimeter at the SKB Clab facility

G. Ilas and I.C. Gauld, **SCALE analysis of CLAB decay heat measurements for LWR spent fuel assemblies**, Annals of Nuclear Energy vol.35, no.1, p. 37-48 (2008). https://doi.org/10.1016/j.anucene.2007.05.017

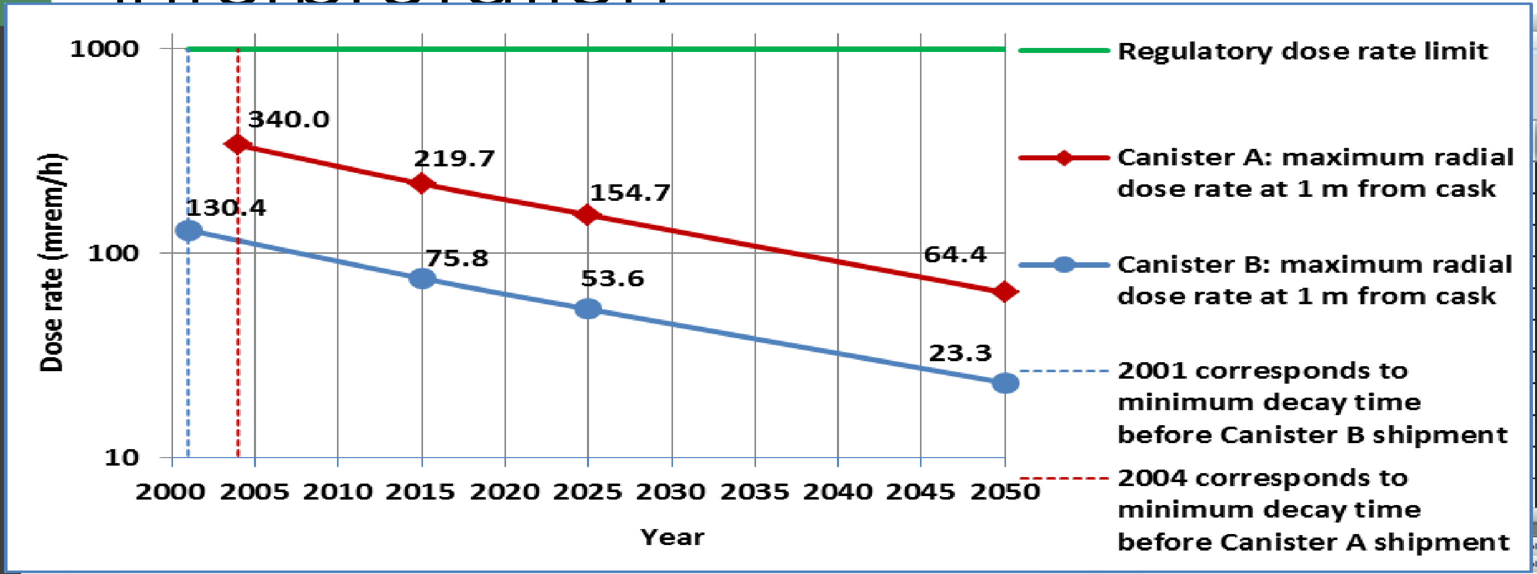
G. Ilas, I. C. Gauld, and H. Liljenfeldt, **Validation of ORIGEN for LWR used fuel decay heat analysis with SCALE**, Nuclear Engineering and Design, vol. 273, p. 58-67 (2014) https://doi.org/10.1016/j.nucengdes.2017.05.009

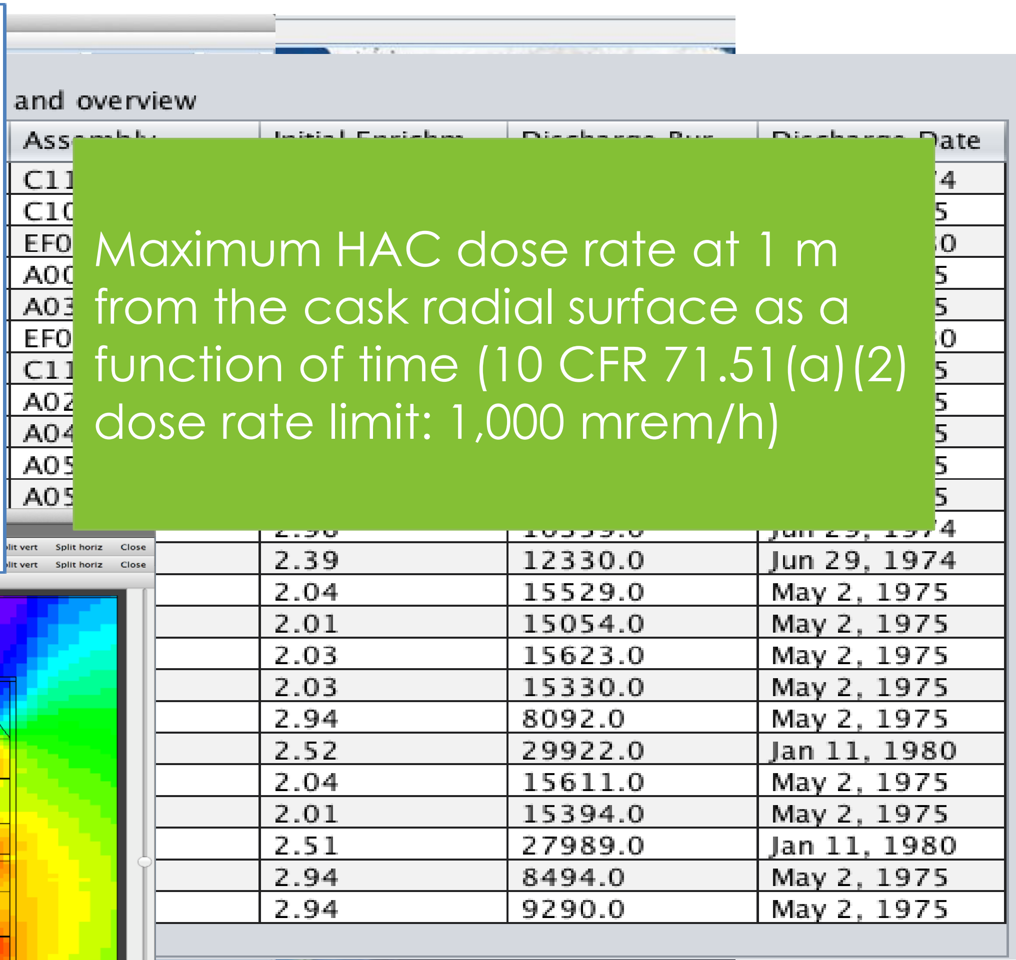
I. C. Gauld, G. Ilas, B. D. Murphy, and C. F. Weber, **Validation of SCALE 5 Decay Heat Predictions for LWR Spent Nuclear Fuel**, NUREG/CR-6972, U.S. Nuclear Regulatory Commission Office of Nuclear Regulatory Research (2010) www.nrc.gov/reading-rm/doc-collections/nuregs/contract/cr6972/

Sources of Radiochemical Assay Data

- Public resources
  - OECD/NEA Expert Group on Assay data
    https://www.oecd-nea.org/science/wpncs/ADSNF/index.html
  - OECD/NEA Data Archives
  - Spent Fuel Composition Database SFCOMPO (OECD/NEA web database)
    https://www.oecd-nea.org/sfcompo/
  - SFCOMPO 2.0
    - International reactor designs
    - 44 fuel assembly designs
    - More than 700 spent fuel samples
    - More than 80 different nuclides measured
- Commercial proprietary programs
  - ARIANE International program (Belgonucleaire)
  - REBUS International program (Belgonucleaire)
  - MALIBU International program (SCK•CEN)
  - Spanish Fuel Program (ENUSA/CSN)
  - Many others

UNF-ST&DARDS provides interactive visualization capabilities to facilitate data analysis and results interpretation





Maximum HAC dose rate at 1 m from the cask radial surface as a function of time (10 CFR 71.51(a)(2) dose rate limit: 1,000 mrem/h)