INL/CON-22-69437-Revision-0

Overview of System Integration Analysis Activities for Integrated Waste Management

November 2022

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Changing the World's Energy Future

Idaho National Laboratory

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Prepared for the
U.S. Department of Energy
Under DOE Idaho Operations Office
Contract DE-AC07-05ID14517

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Overview of System Integration Analysis Activities for Integrated Waste Management

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International High-Level Radioactive Waste Management Embedded Conference
Phoenix, Arizona
November 17, 2022

Disclaimer

This is a technical presentation that does not take into account contractual limitations or obligations under the Standard Contract for Disposal of Spent Nuclear Fuel and/or High-Level Radioactive Waste (Standard Contract) (10 CFR Part 961). For example, under the provisions of the Standard Contract, spent nuclear fuel in multi-assembly canisters is not an acceptable waste form, absent a mutually agreed to contract amendment.

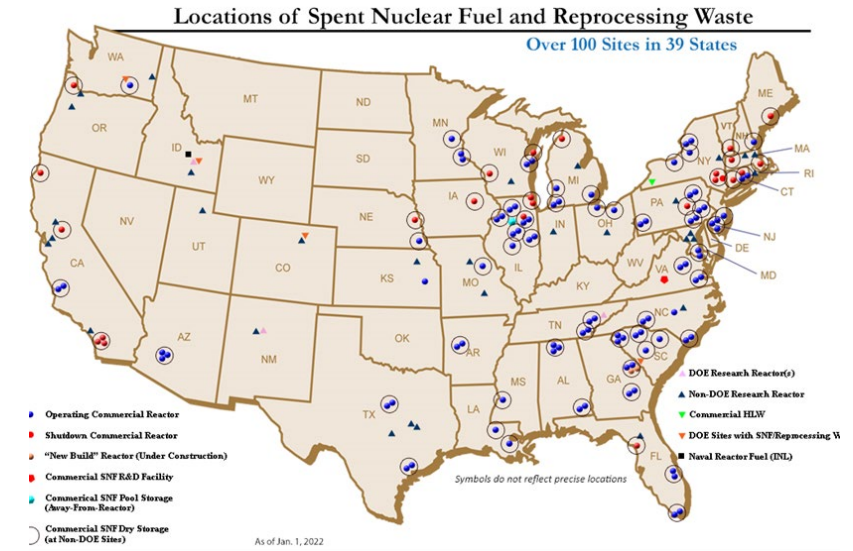
To the extent discussions or recommendations in this presentation conflict with the provisions of the Standard Contract, the Standard Contract governs the obligations of the parties, and this report in no manner supersedes, overrides, or amends the Standard Contract.

This presentation reflects technical work which could support future decision making by the US Department of Energy (DOE or Department). No inferences should be drawn from this presentation regarding future actions by DOE, which are limited both by the terms of the Standard Contract and Congressional appropriations for the Department to fulfill its obligations under the Nuclear Waste Policy Act including licensing and construction of a spent nuclear fuel repository.

This presentation does not necessarily reflect final classifications for the DOE-managed SNF material being discussed; for example, material referred to as “HLW” or “SNF” may be managed as HLW and SNF, respectively, without having been actually classified as such for disposal.

System integration analysis works across the entire Integrated Waste Management Program

- The Integrated Waste Management (IWM) program is evaluating options to establish an IWM system for the eventual disposition of the nation's spent nuclear fuel (SNF)
- The system analysis team is performing research in two main areas:
  - Special studies, analyses, and assessments
  - Data and tools development, validation, and maintenance
- The systems team integrates with the other four major research areas in IWM:
  - Transportation
  - Facilities and equipment capabilities
  - Consent-based siting
  - Nuclear waste management IT solutions and support



Nearly all existing commercial SNF is stored at the reactor sites where the waste was generated.

Of the over 70 commercial nuclear power reactors sites with SNF, about one quarter have ceased reactor operations.

Outline

- Introduction
- Overview of system integration analysis work
- Systems team integration with other IWM research areas
- Conclusions

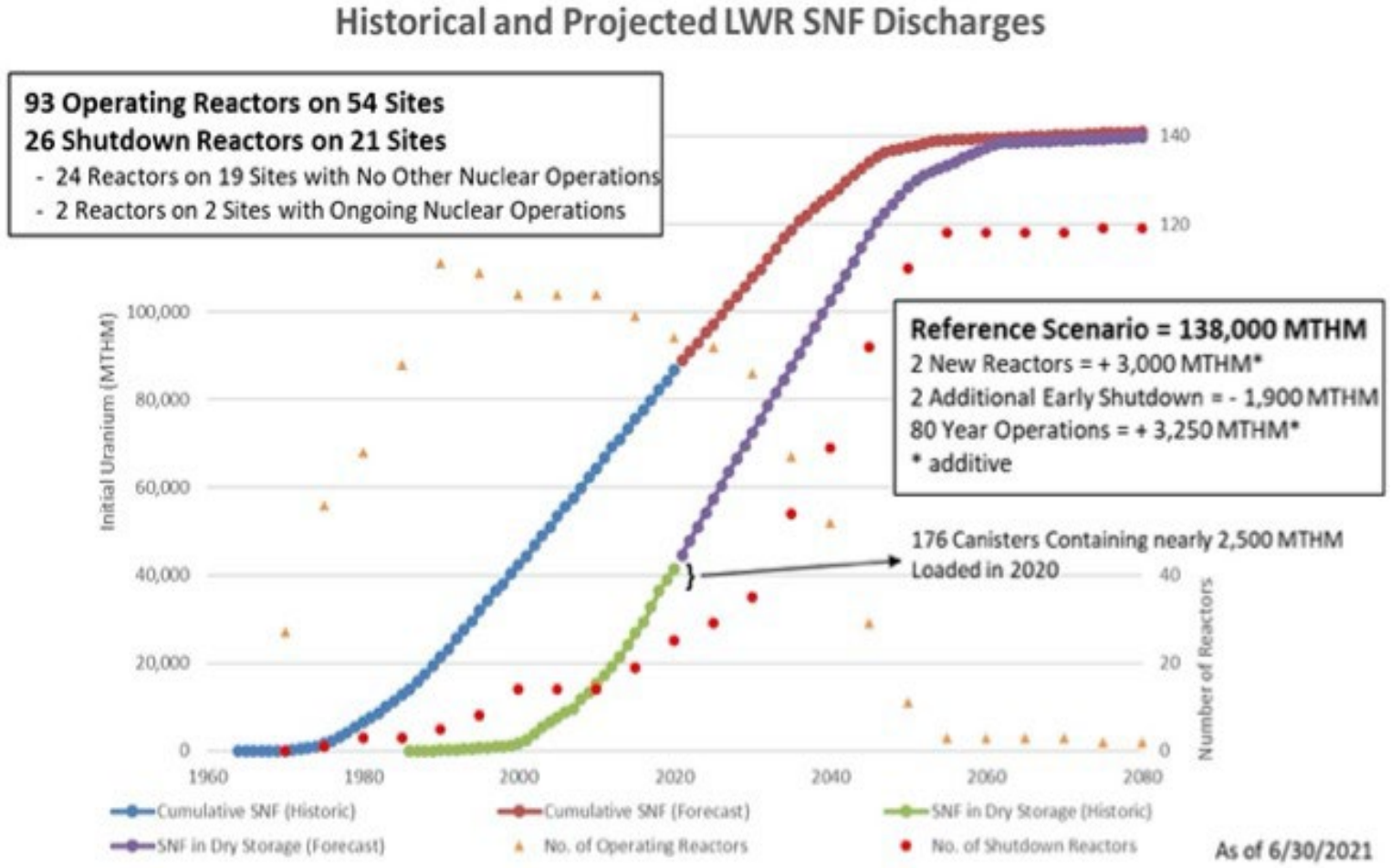
Multi-laboratory, multi-disciplinary team:

- Argonne National Laboratory (ANL)
- Idaho National Laboratory (INL)
- Oak Ridge National Laboratory
- Pacific Northwest National Laboratory (PNNL)
- Savannah River National Laboratory
- Sandia National Laboratories

Co-authors: Gordon Petersen (INL), Kaushik Banerjee (PNNL), Brian Craig (ANL)

Why system integration? The existing U.S. light-water reactor fleet has and continues to generate SNF that must be managed

- Almost 90,000 metric tons of heavy metal (MTHM) of SNF discharged and in interim storage at reactor sites
- About 2,000 MTHM discharged per year
- Over 3,500 dry storage canisters (over 45,000 MTHM)
- About 200 dry storage canisters added per year
- Potential growth to ~138,000 MTHM



System analysis is used to compare numerous alternatives to answer "what if" questions

Implications of various strategies investigated including removal strategies, number and locations of consolidated interim storage facilities (ISFs) and mined geologic repositories (MGR), repackaging, packaging, storage transportation, aging, and disposal canisters (STADs), and bare fuel transport

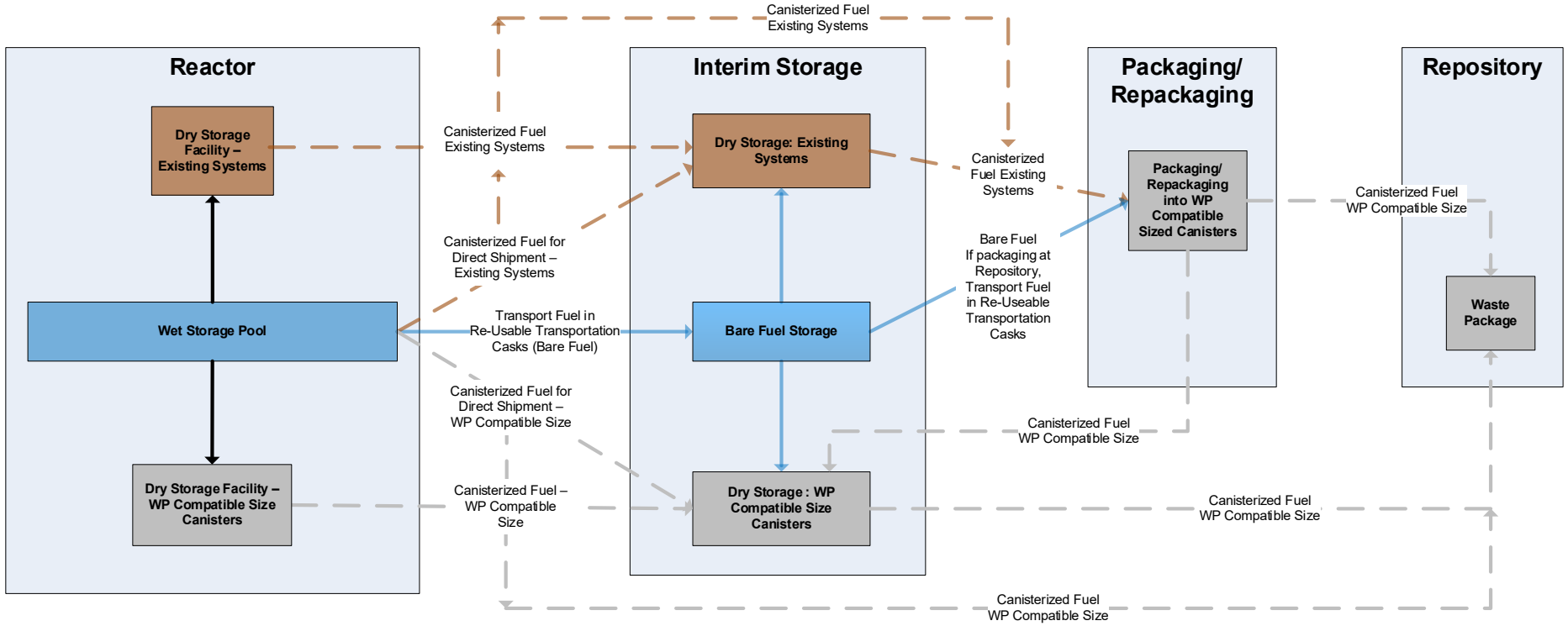
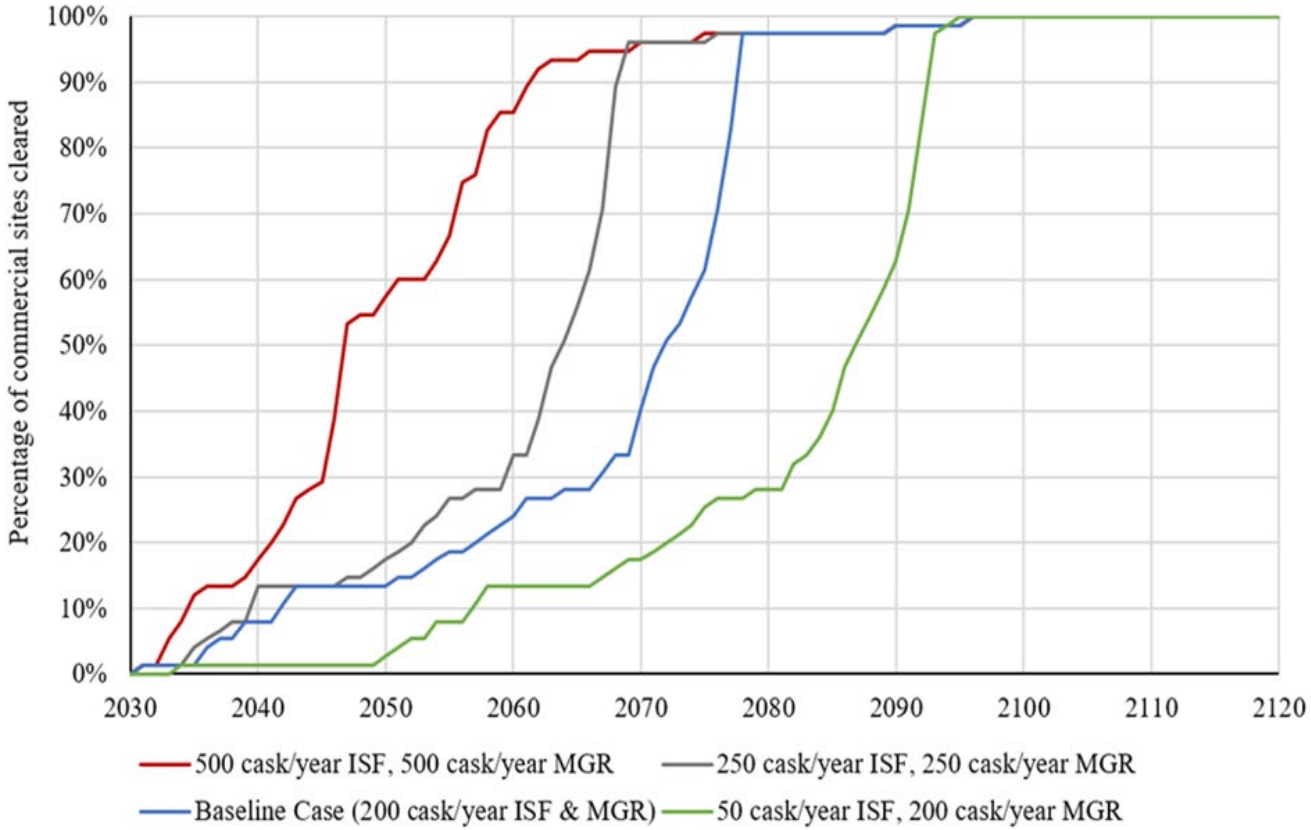


Illustration of potential alternatives in a future waste management system

Illustrative system analysis: SNF receipt rates can affect how quickly sites are cleared

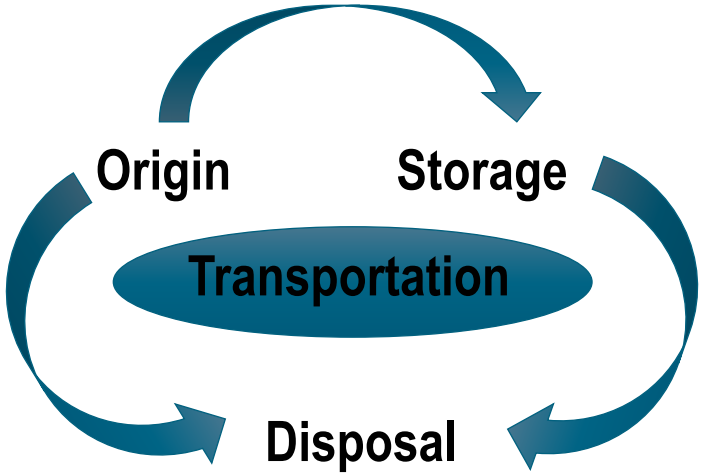
- The higher the SNF receipt rates at an ISF and MGR, the faster that sites can be cleared of SNF
- Increased receipt rates would also require additional infrastructure capabilities at receiving facilities and within the transportation system
- MGR opened 20 years after ISF for these scenarios

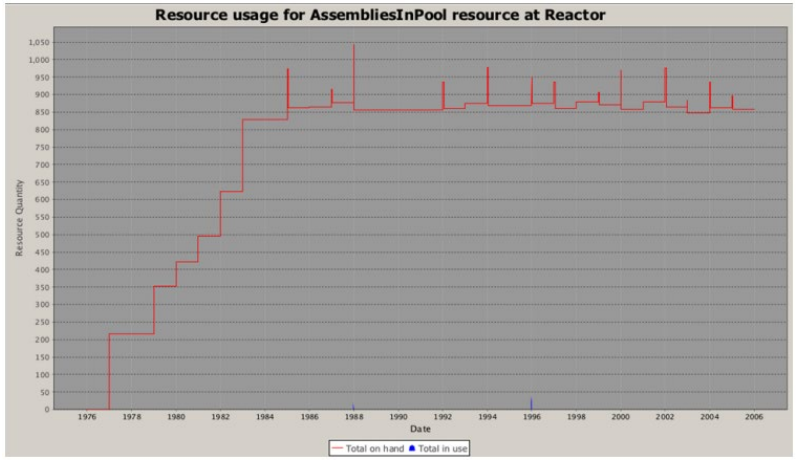


Percentage of commercial sites cleared as a function of time

NGSAM models SNF from origin sites to disposition site(s) including transportation and interim storage

- The Next-Generation System Analysis Model (NGSAM) models the backend for SNF and high-level waste (HLW)
- NGSAM allows detailed customization for options such as:
  - Storage facilities (dry/wet)
  - Packaging options
  - Previous records of decision (RODs) and assumptions
  - Costs
  - Throughputs
  - Transportation assets
- NGSAM can help answer questions related to:
  - Shared resources required (e.g., transportation assets)
  - Consolidated interim storage facilities and options
  - Multiple repositories scenarios
  - Alternative allocation and acceptance strategies





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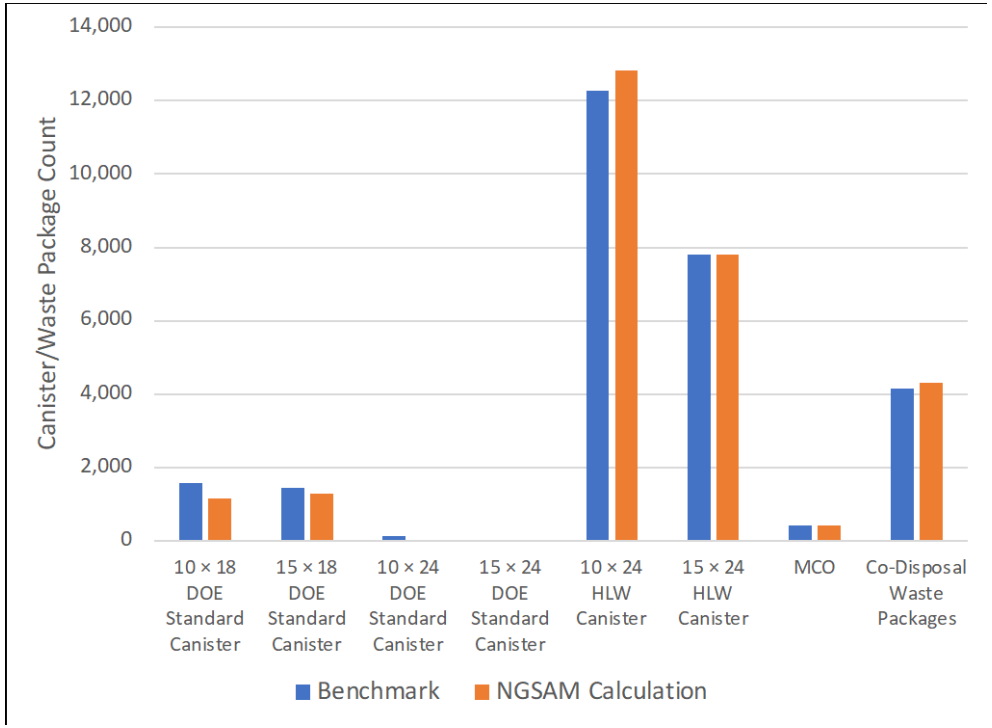
NGSAM results for canister and waste packages compares well to benchmarks

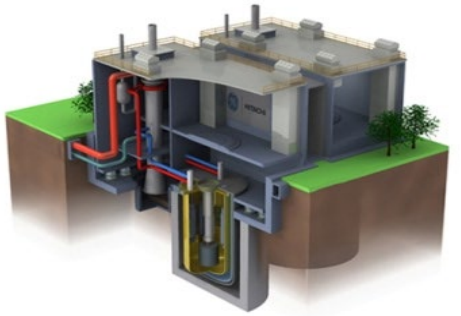
- The canister and waste package count constitutes a key metric in determining the effectiveness of modeling DOE-managed SNF and HLW in NGSAM
- Benchmarks for canister and waste package counts were calculated using the method described in *Co-Disposal Waste Package Loading Options for DOE SNF and HLW*
- NGSAM simulates the packing of DOE-managed SNF in canisters, then simulates the packing of canisters into waste packages
- Small variances are expected but should be and were found to be minimal



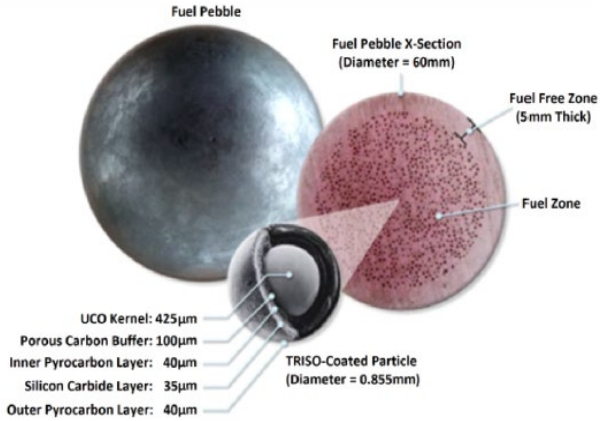
Comparing canister and waste packaging results from NGSAM to benchmarks

Advanced reactor SNF planning ongoing

- Collaborate and integrate with the fuel cycle system analysis campaign and advanced reactor campaign to provide tools, knowledge, and subject-matter expertise
- Explore the generic activities and milestones for deploying advanced reactor spent fuel management facilities
- Evaluate the storage, transportation, and disposition of SNF and HLW from advanced nuclear reactors (demonstrations and commercial deployments) and for advanced fuel cycles such as:
  - Examining advanced (molten-salt, sodium-cooled, gas-cooled, etc.) reactor spent fuel management approaches
  - Evaluating the impact of high-assay low-enriched uranium (HALEU) and accident tolerant fuel on transportation from criticality, dose, and thermal perspective
  - Updating NGSAM to model potential advanced reactor fuel cycles and reprocessing



Prism Schematic View
(Source: IAEA-2013)



Xe-100 Fuel Pebble and TRISO-coated fuel particles
(Source: Xenergy-2020)

Preliminary requirements for modeling the back-end of advanced reactor fuel cycles considered

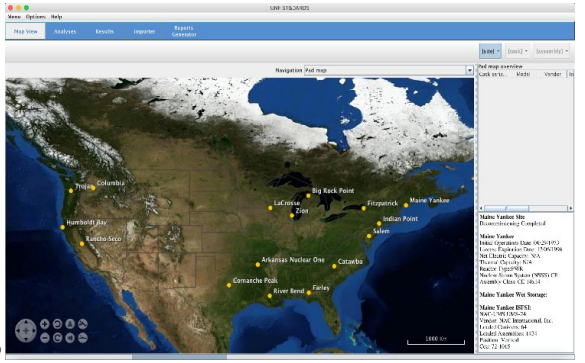
- Preliminary requirements developed for modeling advanced reactor fuels, reprocessing, treatment, and conditioning
- Other nuclear fuel cycle system analysis tools sponsored by DOE's Office of Nuclear Energy might be better suited for initial high-level analysis
- NGSAM could add value by modeling in greater detail the transport, storage, and disposal of SNF and waste from advanced reactors at the fuel element and waste container levels
  - It is envisioned NGSAM could estimate reprocessing and/or treatment/conditioning facility capability needs

System analysis is necessary to better understand various possible options, approaches, and strategies to inform all stakeholders and future decisions about advanced reactor fuel cycles

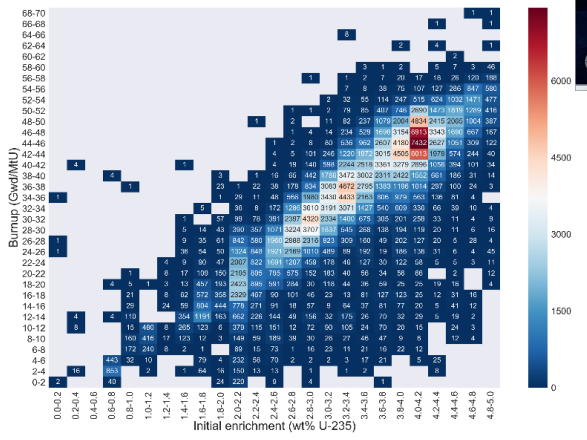
UNF-ST&DARDS is being developed as an integrating (storage, transportation, and disposal) foundational resource

- Used Nuclear Fuel-Storage, Transportation, & Disposal Analysis Resource and Data System (UNF-ST&DARDS) provides a SNF database and integrated analysis tools
- Objective is to develop a comprehensive system for analyzing the SNF from the time it is discharged from the reactor through its final disposition
- Applications (current and potential future) include:
  - Identification of potential issues and prioritization of R&D
  - Supply of fundamental data for informed decision-making at various stages of SNF management
  - Fuel cycle analysis as well as safeguard and security determination
  - Various licensing/certification activities (e.g., integration between storage and transportation licensing practices)

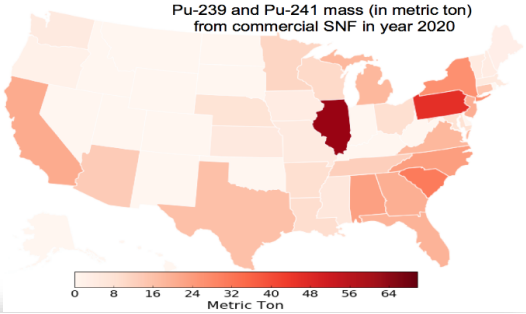
UNF-ST&DARDS graphical user interface



SNF inventory discharge characteristics

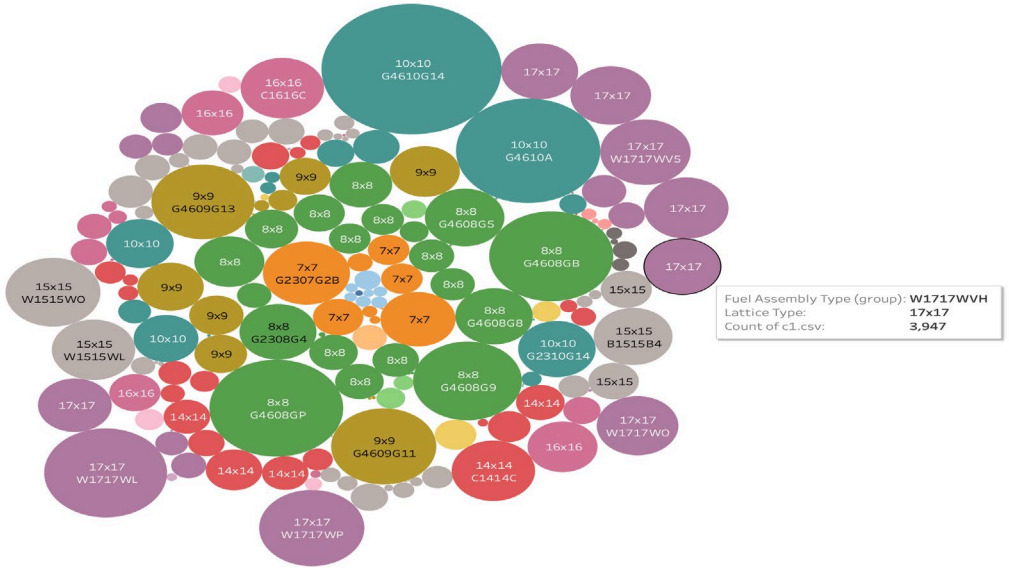


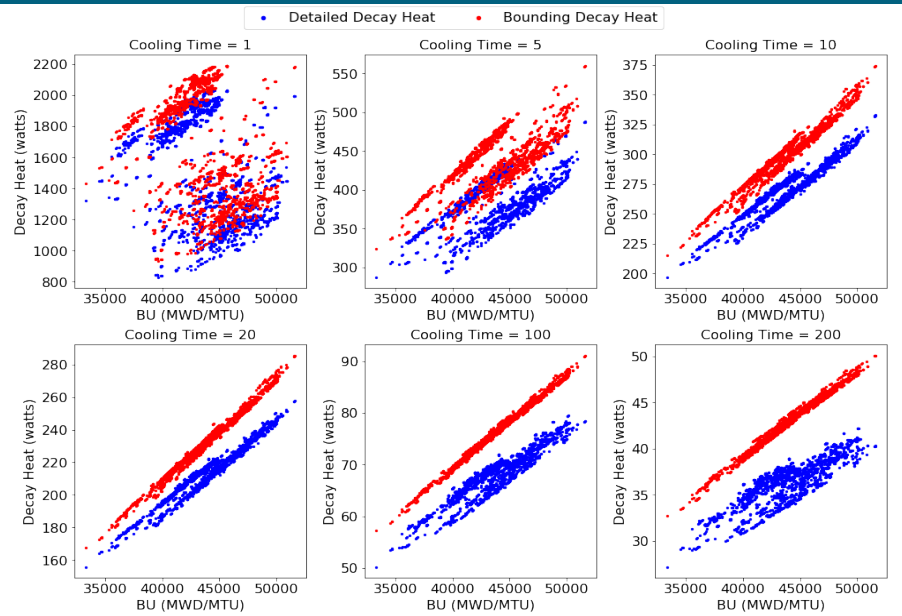
U.S. states colored by Pu mass



UNF-ST&DARDS and the Unified Database can be used for analysis, visualization, and communication purposes

- Detailed analysis was performed within UNF-ST&DARDS using discharged data from 10 cycles of a boiling-water reactor
  - These data were compared with the UNF-ST&DARDS generic-assembly-specific decay heat results
- In all cases, the bounding decay heat calculated using the UNF-ST&DARDS generic approach is higher than the detailed decay heat
- Bounding indicates the UNF-ST&DARDS generic assembly-specific analysis approach using conservative reactor operational parameters





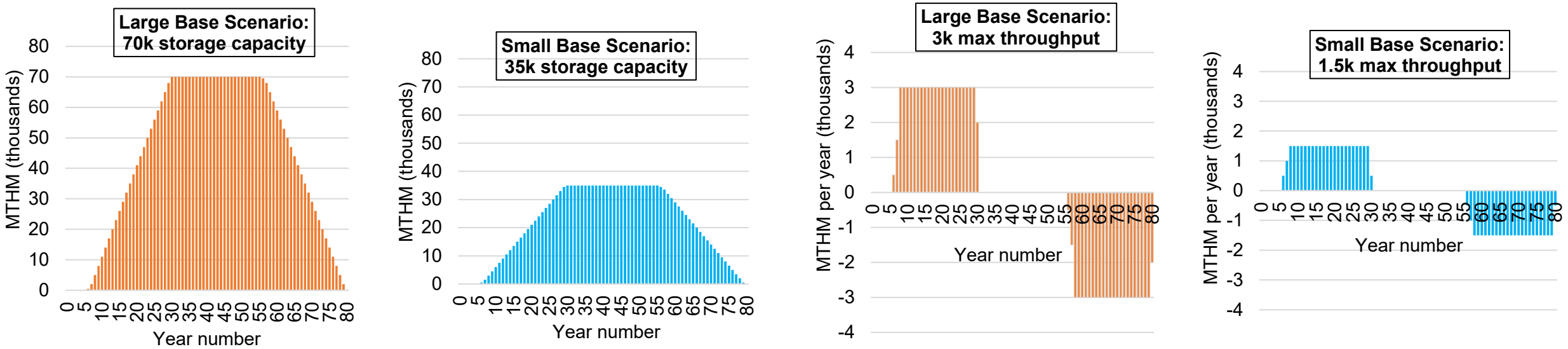
Detailed and bounding decay heat values vs. burnup for 1, 5, 10, 20, 100, and 200 years of cooling time

Each bubble presents an assembly type

The large SNF volumes and diverse systems in the United States make system-wide planning a complex undertaking

System analysis studies can inform on-going consent-based siting activities

- Example system analysis results shown below can be used to:
  - Support DOE's consolidated interim storage facility (CISF) efforts
  - Inform stakeholders and decision-makers
  - Compare different options



Comparing scenarios with varied CISF capacities and acceptance rates over time

System analysis team collaborates with transportation work

- Resulting data and information from nuclear power plant site infrastructure evaluations serves as input to system analysis tools
  - Other input data about transportation system also provided
- Recently explored updating the representation of intermodal transfer options in NGSAM
- System analysis studies estimate how much transportation infrastructure may be needed
  - Examples: railcars, buffer cars, escort vehicles, transportation overpacks, fleet maintenance facilities, etc.

Transfer From	Transfer To	Casks Loaded (Y/N)	Transfer Time (h)
Rail	Barge	N	2
Rail	Barge	Y	10
Rail	HHT	N	2
Rail	HHT	Y	8
Barge	Rail	N	2
Barge	Rail	Y	10
Barge	Barge	N	3
Barge	Barge	Y	6
HHT	HHT	N	2
HHT	HHT	Y	8
HHT	Rail	N	3
HHT	Rail	Y	6

Proposed model transfer times for NGSAM (preliminary)

The systems team integrates across the entire IWM program

- The IWM program is evaluating options to establish an integrated waste management system for the eventual disposition of the nation's commercial SNF
- The systems team is performing research in two main areas:
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  - Special studies, analyses, and assessments
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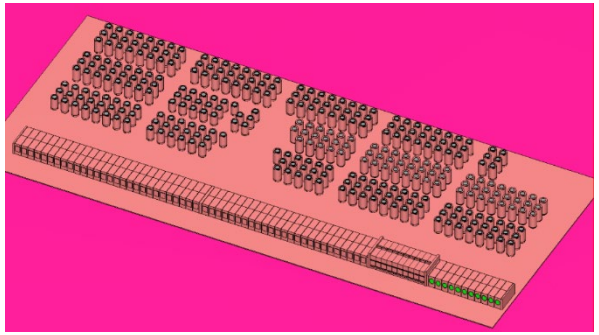

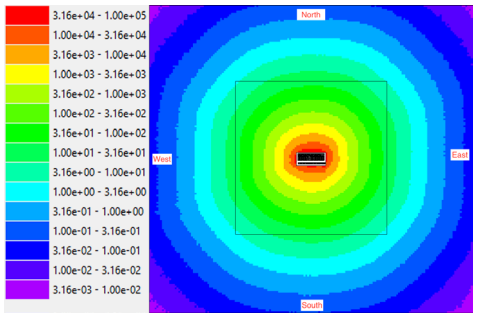

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Questions?

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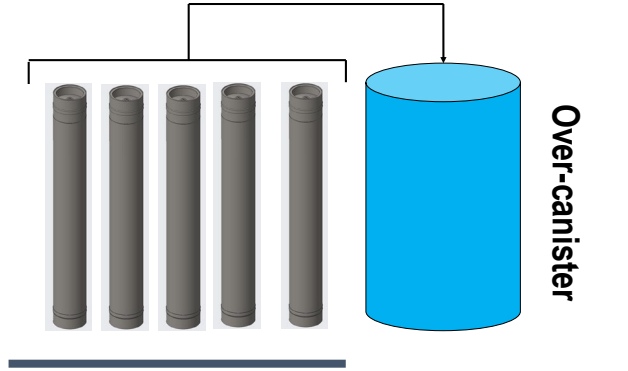
Backup Slides

Planning to integrate DOE-managed SNF into the WMS

- DOE manages 350+ types of SNF across the DOE complex
  - Stored in both wet and dry storage
- Preparing for demonstration to package SNF in a road-ready dry-storage (RRDS*) condition at INL
  - Using existing INL facilities
  - SNF to be packaged in a DOE standard canister
    - Robust container that confines radionuclides
  - DOE standard canisters to be loaded into commercial vendor supplied over-canister and overpack
    - Equivalent to commercial multi-purpose canister and overpack
- Assessing integration of over-canister into integrated waste management system (IWMS)

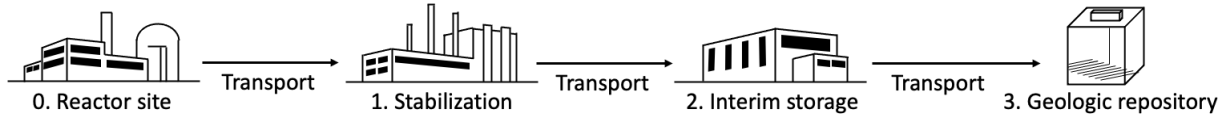
*RRDS: Capable of long-term storage, transportation, and eventual disposal



Storage/Transportation Overpack

Planning for future integration activities with the System Analysis Campaign

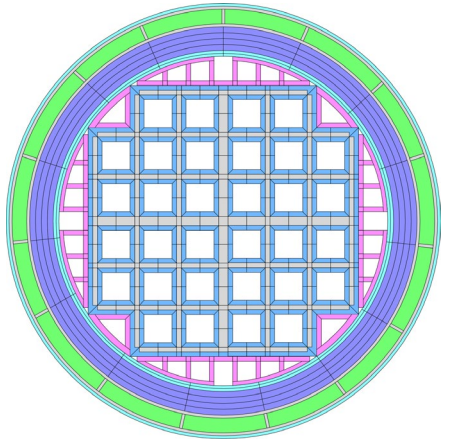
- Interlaboratory team meets monthly to plan potential collaboration opportunities
- Team includes:
  - Fuel cycle system analysis campaign contributors (including Deputy National Technical Director)
  - IWM contributors (including System Integration CAM)
  - Spent Fuel and Waste Science and Technology R&D program contributor
- Potential collaboration areas include:
  - Assessing SNF transportation
  - Investigating back-end fuel cycle economics
  - Exchanging isotopic composition data
  - Projecting nuclear energy capacity expansion
  - Recycling system study



Generic SNF management flow sheet, assuming no reprocessing and transportation required between all facilities

The COBRA-SFS thermal analysis code is purpose built for SNF storage and transportation

- Thermal capability for UNF-ST&DARDS
- Streamlined methodology models large numbers of casks with reasonable computing resources compared to commercial software
- DOE has over 20 years of validation and application experience
- Current efforts focus on modernization to increase the flexibility and efficiency of model input development



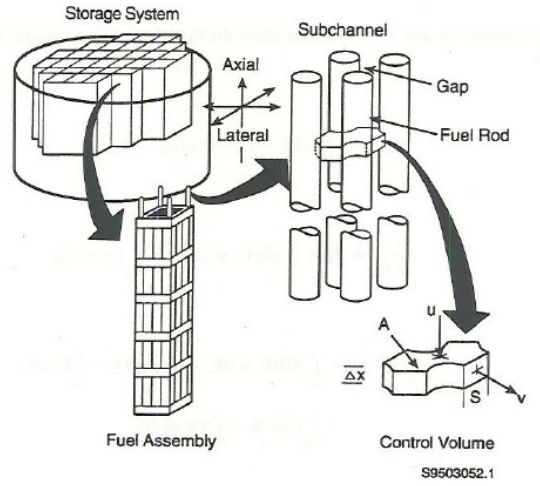


Figure 2.1. Relation of Subchannel Control Volume to Storage System