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# System Integration Analysis in Support of Federal Interim Storage

April 2023

Robby Anthony Joseph

Changing the World's Energy Future

Idaho National Laboratory

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**Idaho Falls, Idaho 83415**

**http://www.inl.gov**

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

# System Integration Analysis in Support of Federal Interim Storage

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Integrated Waste Management Campaign Control Account Manager
for System Integration Analysis and Support

Presented to University of Tennessee Department of Nuclear Engineering Colloquium Program
**April 5, 2023**

# 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).

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 DOE. 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.

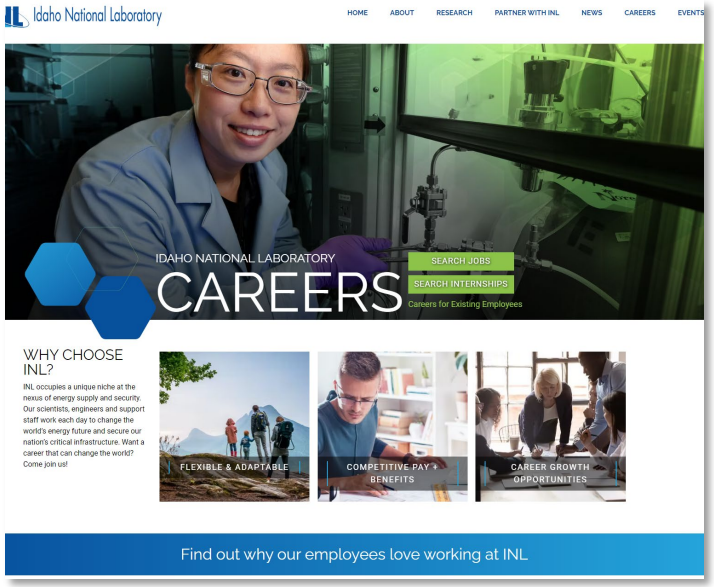
# Before the technical presentation: consider opportunities at Idaho National Laboratory

- As the U.S. Department of Energy's (DOE's) nuclear energy laboratory, Idaho National Laboratory (INL) is leading several new, exciting projects
  - Micro-reactors
  - Nuclear Reactor Innovation Center
  - Small modular reactors
- INL's spent fuel activities are diverse and the department is growing.
  - Nuclear engineering and analysis (e.g., criticality, dose)
  - Radiation chemistry (e.g., radiolytic gas generation)
  - Mechanical engineering (e.g., spent fuel package design)
  - Materials science (e.g., corrosion)
  - Industrial engineering and economics (e.g., logistics, fuel cycle/management cost comparison)
- Always looking for interns, post-docs, and early career staff!

# Internships

- Paid opportunities available in a wide range of STEM and other fields for both undergraduate and graduate students
- Internship opportunities enable collaboration with experienced scientists and engineers to develop innovative solutions for challenging, real-world projects.

Apply online at: https://inl.gov/careers/




**80%**
of time
spent working on projects and applying what you learned in the classroom to solve real work-related challenges

**20%**
of time
spent participating in enrichment and professional development activities
*(workshops, networking, etc.)*

vault TOP RANKED

***2022 Top 100 Internships***

# University partnerships' distinct programs build the future talent pipeline

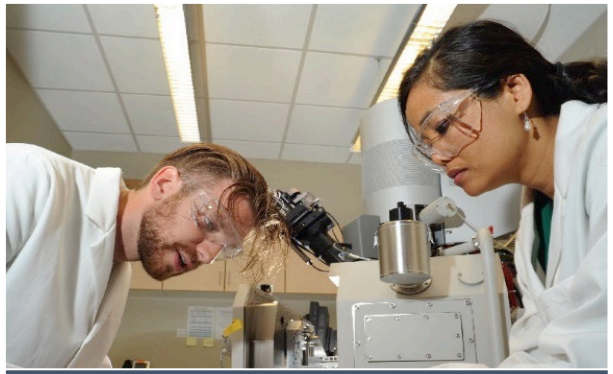
## *Developing Skills and a Talent Pipeline to Support INL's Strategic Objectives*

### Strategic Partnerships

- **Center for Advanced Energy Studies** (CAES)
- **National University Consortium** (NUC)
- **Strategic Understanding for Premier Education and Research** (SUPER) (Texas A&M and University of Texas at San Antonio)

### Student Programs

- **Interns**
- **Co-Ops**
- **Practicums**



### Research Enablement

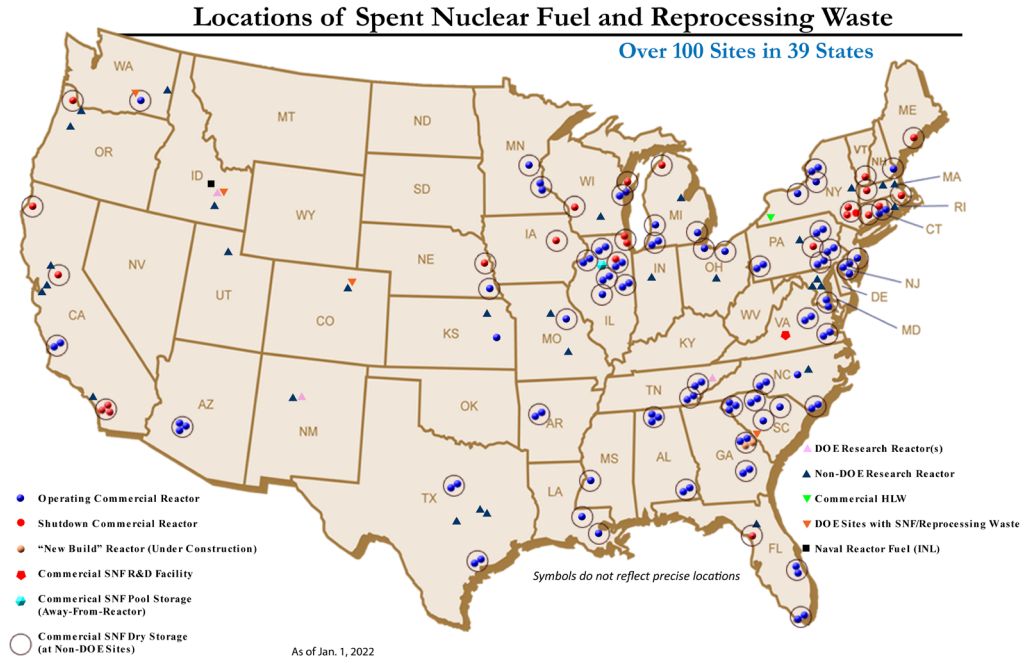
- **INL Graduate Fellowships**
- **Postdocs**
- **Joint Appointments**
- **International Researchers**
- **Academic Visitors**
- **Faculty Researchers**

### Workforce Development

- **University-related Community College Support**
- **Employee Education**
- **Mentoring Workshops**
- **Generations in the Workforce**

# System analysis work integration across multiple technical areas

- 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 various other technical and programmatic areas:
  - Consent-based siting
  - Consolidated interim storage
  - Transportation
  - Disposal
  - Advanced Fuel Cycle R&D




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.

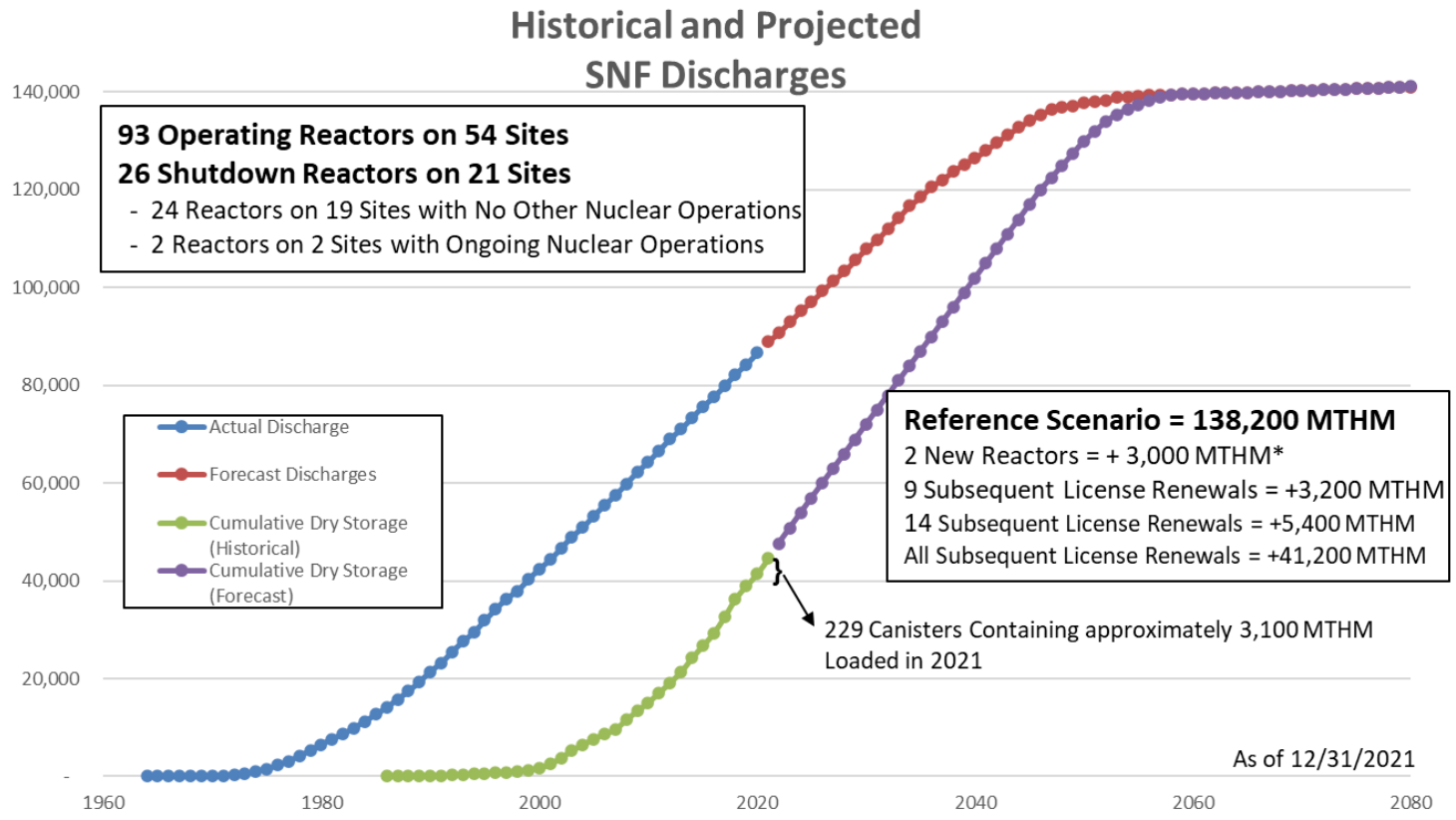
# Outline

- Introduction
- Overview of system analysis work
- Systems team integration with transportation work
- Conclusions

- Multi-laboratory, multi-disciplinary team:
  - Argonne National Laboratory
  - Idaho National Laboratory (INL)
  - Oak Ridge National Laboratory
  - Pacific Northwest National Laboratory
  - Savannah River National Laboratory
  - Sandia National Laboratories

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

- Approximately 90,000 metric tons of heavy metal (MTHM) of spent nuclear fuel (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 almost 140,000 MTHM by 2060



# 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 (CISFs) and mined geologic repositories (MGR), repackaging, packaging, storage transportation aging and disposal canisters (STADs), and bare fuel transport

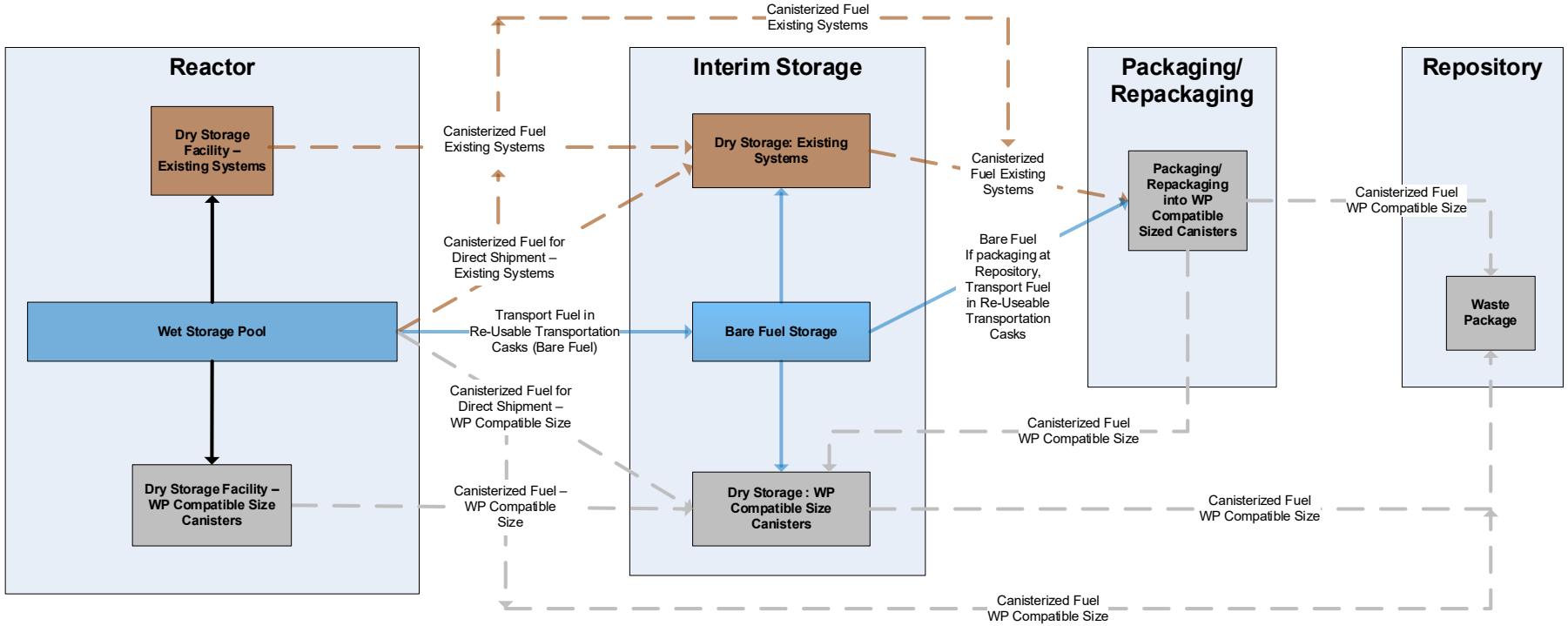



Illustration of potential alternatives in a future waste management system

# System analysis objectives

Better inform planning and decision-making by applying a wholistic approach

Collect and generate data on system attributes and alternatives

Develop and apply system analysis tools to evaluate various system architectures and scenarios

Perform parametric sensitivity and trade-off studies which could improve performance

# Consent-based siting is an approach to siting facilities that focuses on the needs and concerns of people and communities

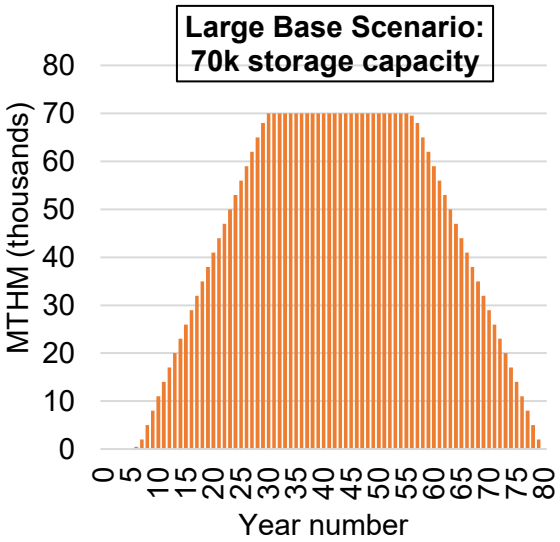
- By prioritizing communities and people, DOE believes it can find a solution to the decades-long stalemate on managing the nation's SNF
- A consent-based approach to siting interim storage, driven by each community's well-being and needs, is both the right thing to do and our best chance for success.

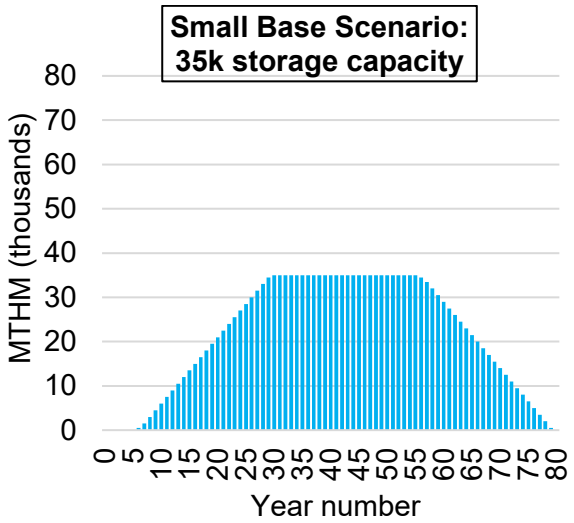
Interim storage:

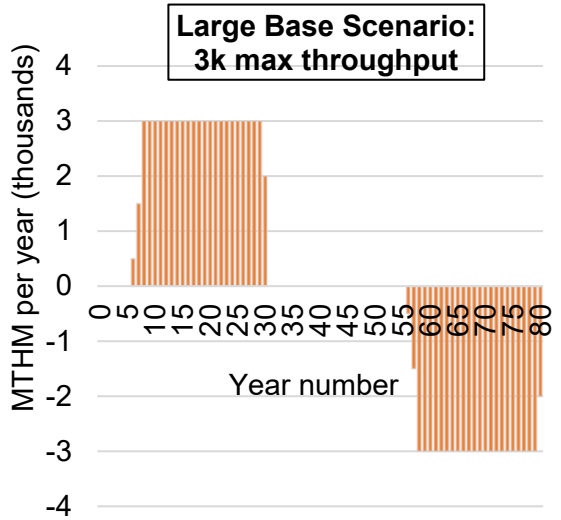
- Is an important component of a waste management system
- Allows for the removal of SNF from existing reactor sites
- Provides useful research opportunities
- Builds trust and confidence with stakeholders
- Begins to address taxpayers' liability

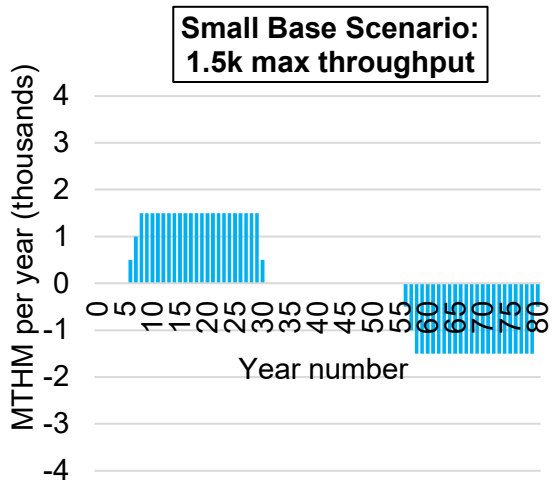
# System analysis studies can inform on-going consent-based siting activities

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



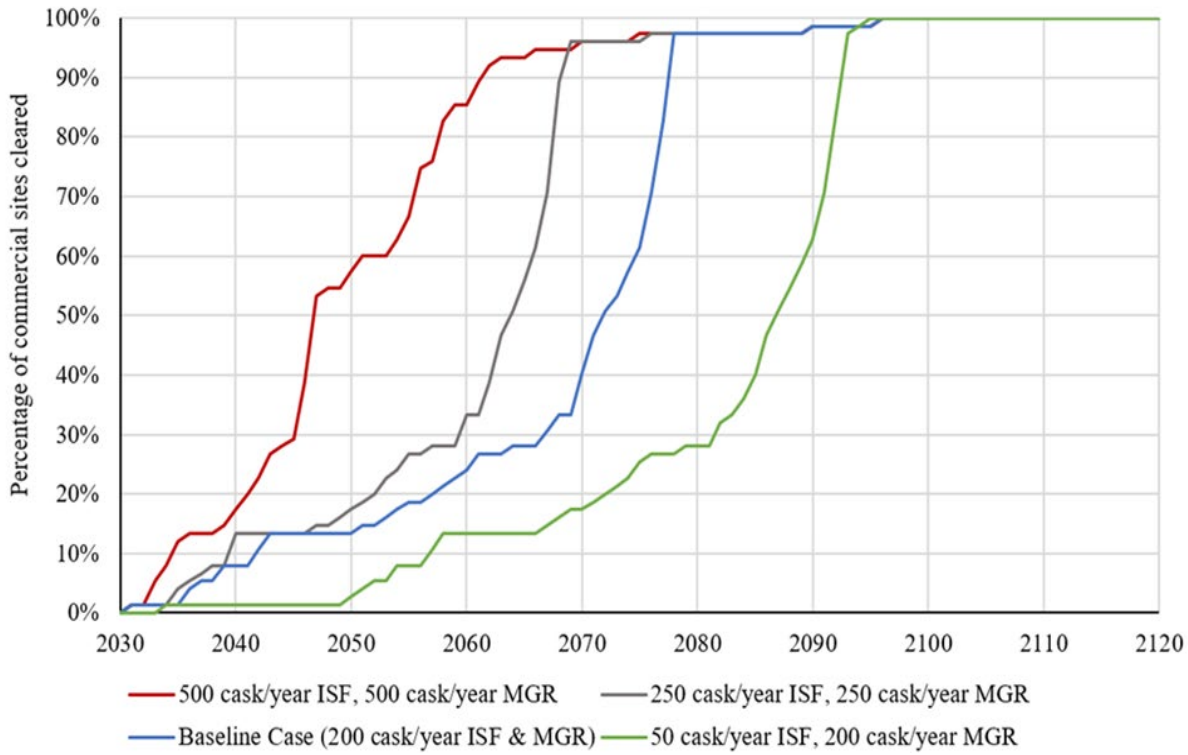




**Comparing scenarios with varied CISF capacities and acceptance rates over time**

# 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 opens 20 years after ISF for these scenarios




Percentage of commercial sites cleared as a function of time

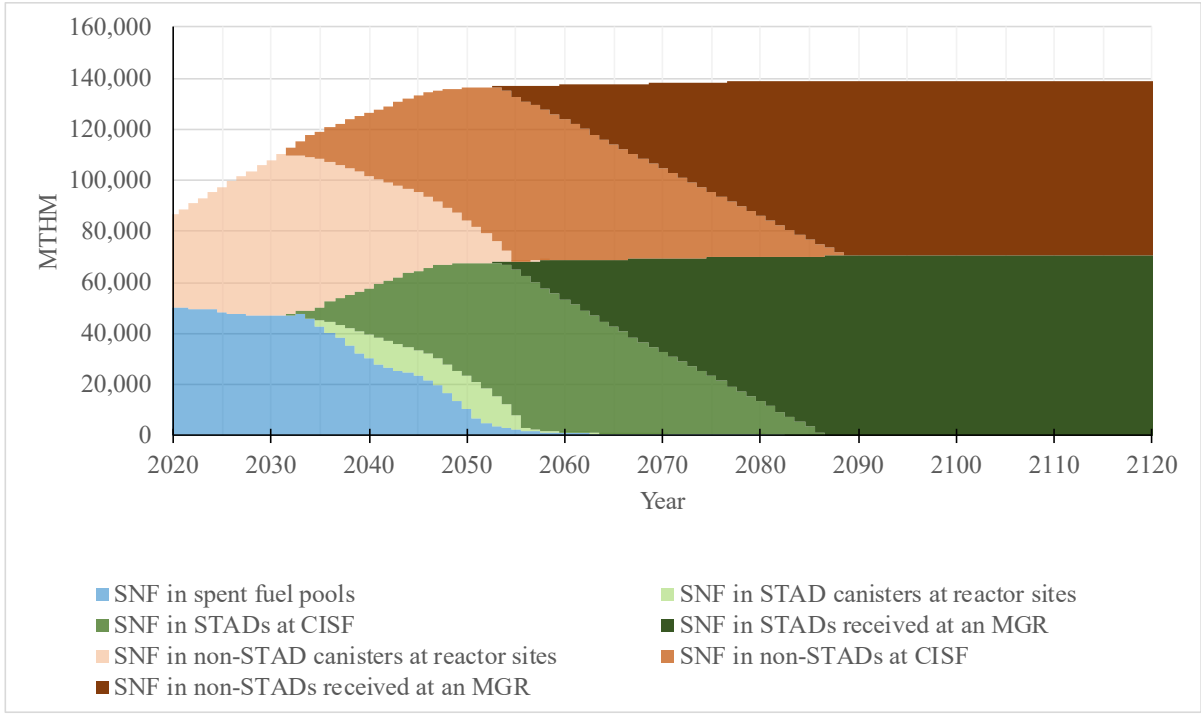
# Illustrative system analysis: higher CISF capacity can enable more reactor sites to be cleared of SNF before an MGR opens

**Maximum CISF capacity and the number of sites cleared with an CISF by the time a repository is assumed to open.**

| Scenario number | CISF receipt rate (dual purpose canisters/ year) | CISF opening date | MGR opening date | Maximum CISF capacity (MTHM) | Sites cleared by MGR opening date | Similar scenarios listed according to key difference |
|---|---|---|---|---|---|---|
| 1 | 500 | 2030 | 2050 | ~125,000 | 43 | 1–4: shipment rate |
| 2 | 250 | 2030 | 2050 | ~74,000 | 13 | 1–4: shipment rate |
| 3 | 200 | 2030 | 2050 | ~60,000 | 10 | 1–4: shipment rate<br>5–6: MGR date |
| 4 | 50 | 2030 | 2050 | ~15,000 | 2 | 1–4: shipment rate |
| 5 | 200 | 2030 | 2040 | ~29,000 | 6 | 3, 6: MGR date |
| 6 | | 2030 | 2060 | ~89,000 | 19 | 3, 5: MGR date<br>7: ISF date |
| 7 | | 2040 | 2060 | ~60,000 | 10 | 6: ISF date |

# Illustrative system analysis: implications of deploying standardized canisters

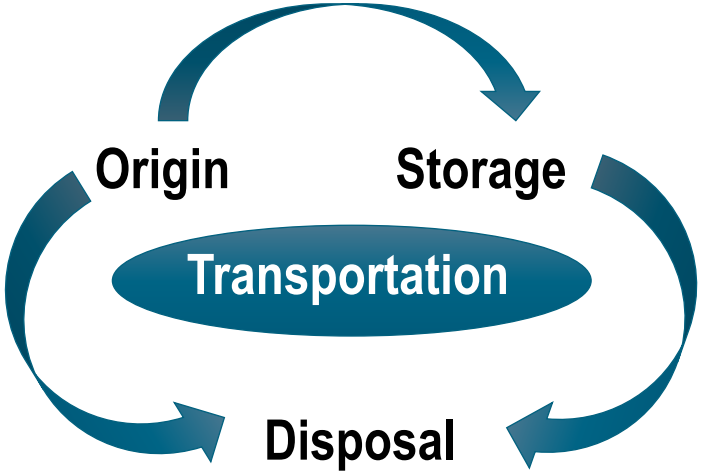
- Next Generation System Analysis Model (NGSAM) can be used to examine scenarios in which the nuclear power industry transitions
  - From dual-purpose canisters (DPCs) which may require repackaging prior to disposal
  - To STAD canisters
- A portion of a CISF, or a separate CISF, could be dedicated to receiving SNF in STAD canisters, ideally shipped directly from reactor spent fuel pools
- Results indicate some dry storage for STAD canisters at reactor sites might be needed depending on assumed CISF receipt rate, CISF start date, and reactor shutdowns with time

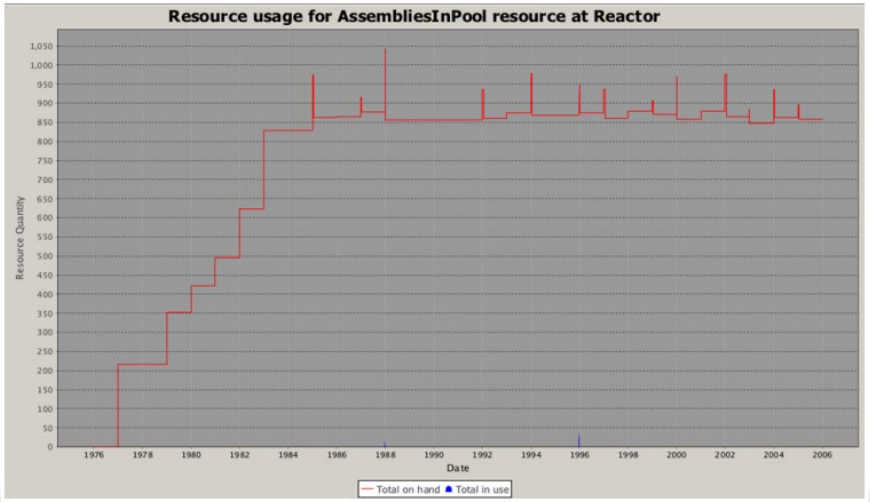



SNF inventories in non-STAD canisters (DPCs) and in STAD canisters as a function of time

# NGSAM models SNF from origin sites to disposition site including transportation and interim storage

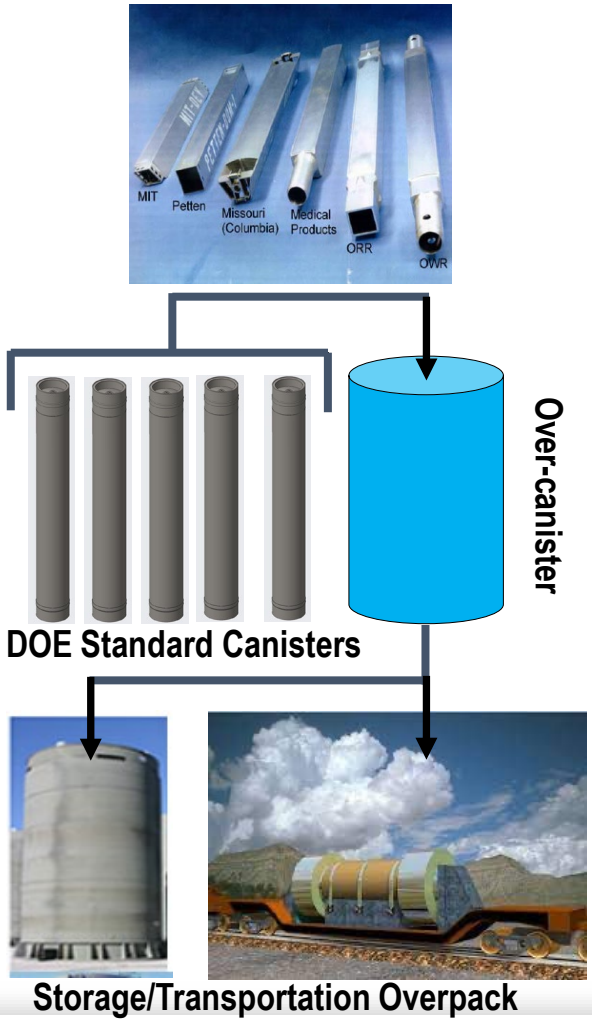
- The Next-Generation System Analysis Model (NGSAM) simulates the backend for SNF and high-level waste (HLW)
- NGSAM allows detailed customization for options such as:
  - Storage facilities (dry/wet)
  - Packaging options
  - Receipt rates
  - Facility opening dates
- NGSAM can help answer questions related to:
  - Shared resources required (e.g., transportation assets)
  - CISFs and options
  - Multiple repositories scenarios
  - SNF receipt logic
  - Throughputs
  - Costs



# Planning to integrate DOE-managed SNF into the WMS

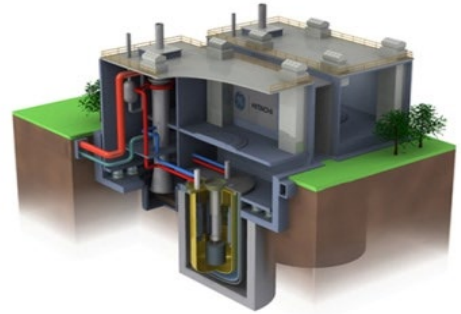
- DOE manages many diverse types of SNF across the DOE complex
  - Stored in both wet and dry storage
- Conducting packaging demonstration to package SNF in a road-ready dry-storage (RRDS*) condition at INL
  - Using existing INL facilities
  - SNF packaged in a DOE standard canister
    - Robust container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




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

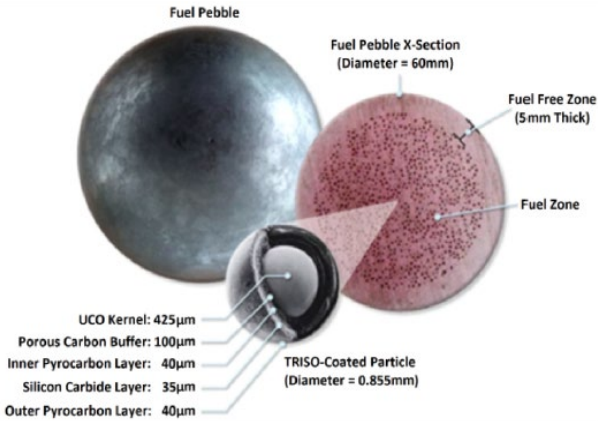
# Advanced reactor SNF planning ongoing

- Collaborate and integrate with Fuel Cycle System Analysis Campaign and Advanced Reactor Campaign to share methods, 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 from advanced nuclear reactors (demonstrations and commercial deployments) and for advanced fuel cycles such as:
  - Assessing advanced (molten-salt, sodium-cooled, gas-cooled, etc.) reactor spent fuel management
  - 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 include capabilities to model SNF and HLW from advanced reactors and fuel cycles.



**Prism Schematic View**

**(Source: IAEA-2013)**




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

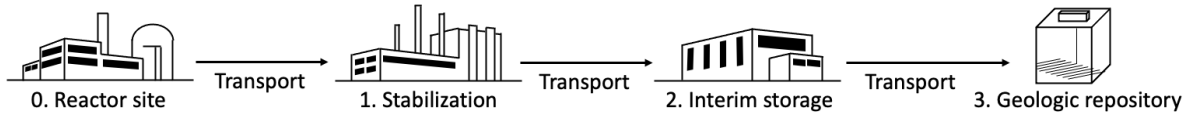
# Preliminary requirements for waste management system analysis of advanced reactor fuel cycles considered

- Preliminary requirements developed for waste management system analysis of advanced reactor fuels, reprocessing, treatment, and conditioning
- 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
- Other nuclear fuel cycle system analysis tools sponsored by DOE's Office of Nuclear Energy might be better suited for initial high-level analysis

*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.*

# Planning for potential future integration activities with fuel cycle system analysis campaign

- Interlaboratory team meets monthly to plan potential collaboration opportunities
- Team includes:
  - System analysis campaign contributors (including Deputy National Technical Director)
  - IWM contributors (including System Integration Control Account Manager)
  - 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.

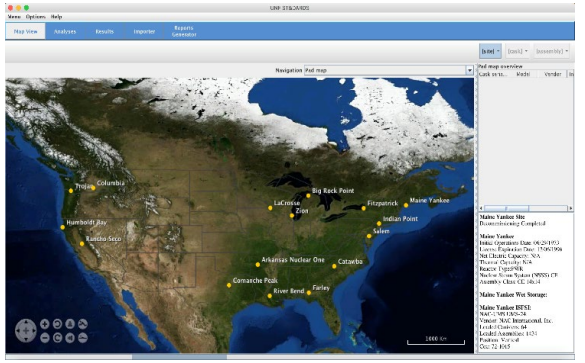


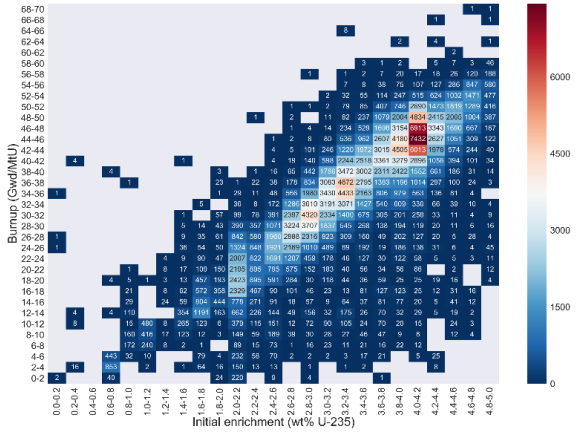

**Generic SNF management flow sheet, assuming no reprocessing and transportation required between all facilities**

# 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 analysis of 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).

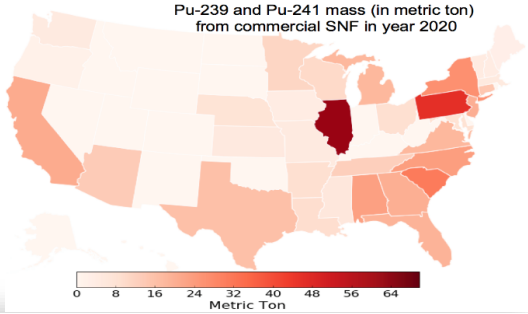
**UNF-ST&DARDS graphical user interface**





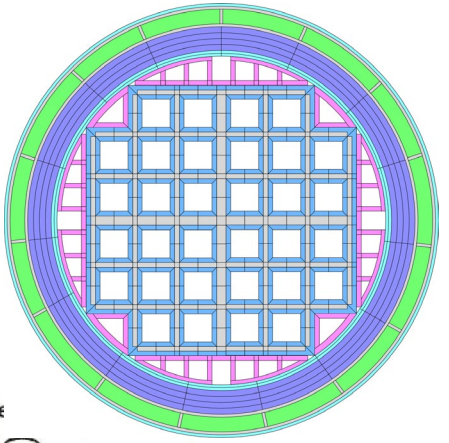

**U.S. states colored by Pu mass**

**SNF inventory discharged through June 2013**



# 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



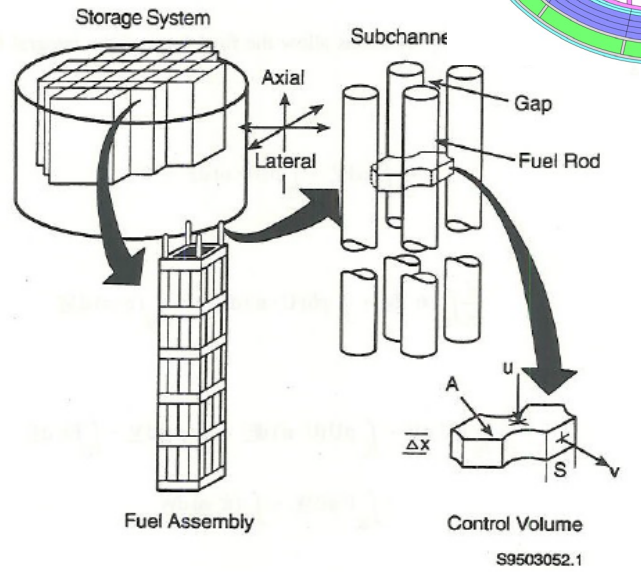



**Figure 2.1.** Relation of Subchannel Control Volume to Storage System

# 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.

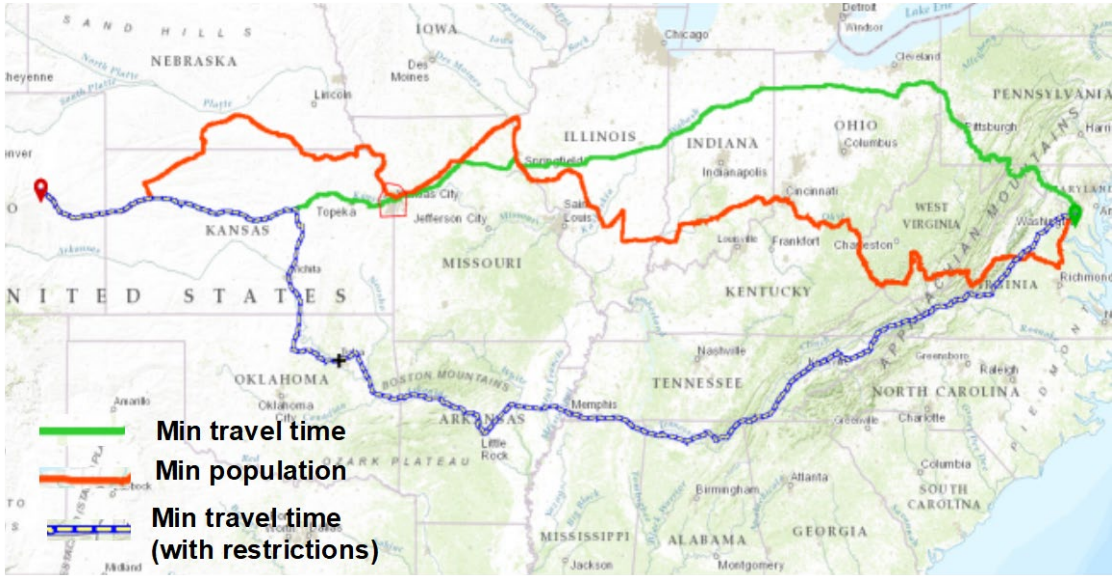
HHT= Heavy Haul Truck

| 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)

# Recent transportation-related NGSAM enhancements have expanded capabilities and improved user experience

- Tracking of simulated railroad escort car and buffer car acquisitions
- Addition of heavy haul truck and barge routes for some sites and support for user-defined intermodal routes
  - Example transportation routes incorporated from DOE's Stakeholder Tool for Assessing Radioactive Transportation (START) application
- Updates to logic that checks the transportation cask thermal limit maps prior to package transport
- Ability to model transloading (moving SNF casks from one transportation mode to another).




Example START Routes

Note: example routes are for illustrative purposes only and do not reflect a selected destination site.

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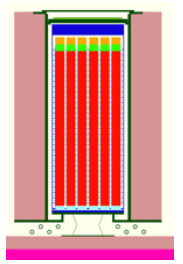

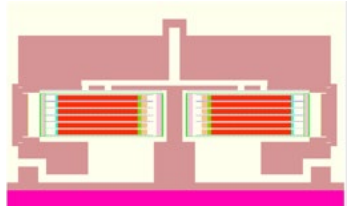

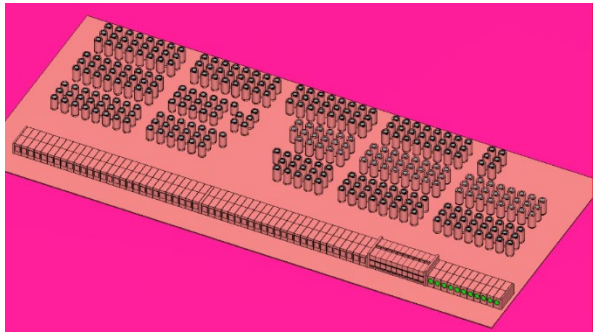

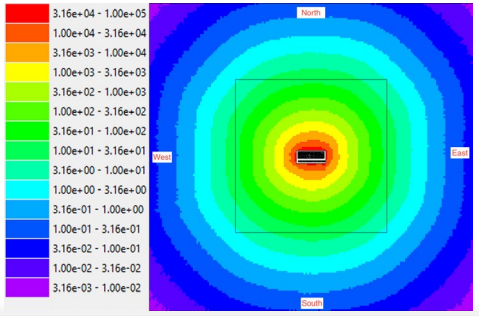

# Questions?

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