INL/CON-22-67898-Revision-0

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November 2022

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

Overview of System Integration Analysis Activities for Integrated Waste Management*

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I. INTRODUCTION

Spent nuclear fuel (SNF) generated by the current fleet of commercial nuclear reactors is being stored at reactor sites in spent fuel pools and in dry independent spent fuel storage installations. The U.S. Department of Energy (DOE) Office of Nuclear Energy's Integrated Waste Management (IWM) program is examining a suite of IWM system options and conducting supporting analyses to enable future informed decision-making in this area. The IWM program is currently organized into the following four major areas: (1) IWM facilities and equipment concepts and development, (2) transportation capability analysis and support, (3) information technology solutions and support, and (4) system integration analysis and support. This paper focuses on ongoing activities in the IWM system integration analysis and support area. The two main research activities in this area are data and tool development, validation, and maintenance; and special studies, analyses, and assessments.

II. UNF-ST&DARDS

One of the main tools in the system integration analysis area is the Used Nuclear Fuel-Storage, Transportation & Disposal Analysis Resource and Data System (UNF-ST&DARDS) [2]. It is being developed as a foundational resource to assist in the management of SNF data, along with several compatible analysis tools for time-dependent characterization of SNF and related systems. UNF-ST&DARDS has the unparalleled ability to track SNF through the entire backend of the fuel cycle—from the time the fuel is discharged from a reactor through its final disposition. UNF-ST&DARDS interfaces with the SCALE code system for nuclear analysis and with COBRA-SFS for thermal analysis.

These tools are essential for realistic, time-dependent characterization of SNF and its related systems (e.g., cask systems) in order to:

1. Manage SNF during extended storage at the reactor sites.
2. Support successful large-scale transportation campaigns.
3. Plan for, design, and operate interim storage facilities.
4. Support eventual geological disposal of SNF [2].

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. The UNF-ST&DARDS generic approach (i.e., bounding within UNF-ST&DARDS) is based on conservative assumptions about various reactor operational parameters such as full control blade insertion for the entire irradiation period. The UNF-ST&DARDS generic approach supports SNF characterizations with limited assembly-specific irradiation history. The detailed and bounding decay heats are plotted as a function of discharge burnup in Fig. 1. In all cases, the bounding decay heat calculated using the UNF-ST&DARDS generic approach is higher than the detailed decay heat. This confirms the conservatism associated with operating history assumptions made within the bounding sequence of UNF ST&DARDS. Bounding indicates the UNF-ST&DARDS generic-assembly-specific analysis approach using conservative reactor operational parameters. Additional UNF-ST&DARDS examples are presented in Reference [2].

* This is a technical paper 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) [1]. 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 paper conflict with the provisions of the Standard Contract, the Standard Contract governs the obligations of the parties, and this paper in no manner supersedes, overrides, or amends the Standard Contract. This paper reflects technical work which could support future decision making by DOE. No inferences should be drawn from this paper 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.

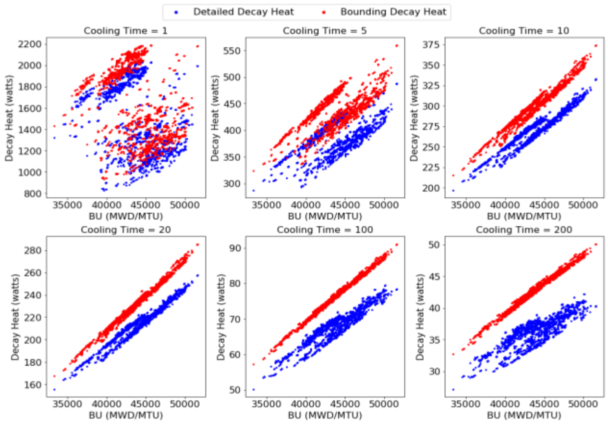

Fig. 1. Detailed and bounding decay heat values vs. burnup for 1, 5, 10, 20, 100, and 200 years of cooling time.

III. NGSAM

Another primary tool being developed is the Next Generation System Analysis Model (NGSAM) [3]. At its core, NGSAM is an agent-based discrete event simulation. This tool was developed from existing logistics models and utilizes the open-source agent-based modeling simulation platform Repast.

Utilizing the agent-based nature of the simulation, NGSAM models all parts of the integrated waste management system, from the facility level all the way down to the assembly level. Each action simulated by the model is recorded and stored in the model results. The level of granularity in the model allows for all actions, from assembly discharge to emplacement in a repository, to be recorded down to the individual assembly level. NGSAM utilizes these data to provide system analysts with the capability to analyze various potential system options for managing SNF and high-level radioactive waste (HLW).

The NGSAM simulation scenario utilizes input from a variety of sources. The main source of input data for commercial SNF is the Unified Database (UDB) [4] developed by Oak Ridge National Laboratory. The UDB houses validated data regarding the spent fuel inventory and SNF casks and canisters. The database also provides a projection for future spent fuel assembly discharges across the reactor fleet. UNF-ST&DARDS provides analysis results that are used to determine when assemblies are ready to be packed and shipped.

The main source of data for DOE-managed SNF[a] is the Spent Fuel Database [5]. The Spent Fuel Database is maintained by Idaho National Laboratory and contains spent fuel attributes for DOE-managed SNF.

Another source of data is the Stakeholder Tool for Assessing Radioactive Transportation (START) [6]. START analysis provides the detailed transportation route information for the NGSAM scenario.

The final source of data is the scenario input files. These files consist of logical procedures to be followed during the simulation, as well as a set of analyst-populated configuration files that contain additional parameters for tweaking the model during the simulation. The configuration files allow analysts to perform a multitude of what-if scenarios by finely adjusting the model behavior. Adjustments include changing parameters such as acceptance (what is shipped away from reactor sites), the number of available railcars, using user-defined transportation routes, and overriding default data contained in the UDB. NGSAM was designed to be flexible, enabling analysts to modify as many pieces of the simulation as possible without having to release new software. The scenario input files highlight that level of flexibility.

NGSAM utilizes a client-server framework to run simulations. This framework gives the analysts flexibility to design and set up scenarios on their local machines, then submit the scenarios to the NGSAM cluster to be run remotely. Each NGSAM scenario can take upward of an hour to run to completion. The current NGSAM cluster supports 12 concurrent NGSAM simulations. The current capabilities of the cluster have provided analysts with the necessary processing power to perform system analysis without any limitations. Once a scenario completes, the results are stored on the NGSAM file server and are available for the analyst to download or share with other analysts.

The NGSAM simulation results consist of a file-based database, a set of predefined comma separated value (csv) reports, and any ad-hoc user defined reports. The file-based database includes all actions taken during the simulation. This database is employed by the NGSAM user interface to provide detailed graphs and reports to the system analysts. The predefined csv reports are a set of tailored results defined by the analysts and have been pre-programed by the NGSAM development team. These reports are the most utilized output of the NGSAM simulation. Finally, the ad-hoc reports can be added by analysts during scenario setup, and NGSAM will output the results at the end of the simulation. The ad-hoc reports provide a key flexibility of getting simulation information out of NGSAM without requiring a software update to include additional pre-defined reports.

NGSAM was developed to enable informed decision making by providing the capability to analyze various potential system options for managing SNF and HLW. Using NGSAM, system architecture analyses are being conducted to evaluate scenarios for the possible future deployment of a comprehensive nuclear waste management system that considers all major backend aspects of the nuclear fuel cycle (i.e., transportation, storage, and disposal).

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[a] SNF currently being managed by DOE.

IV. SYSTEM ARCHITECTURE ANALYSIS

System analysts are developing attributes, options, and supporting analyses to enable informed choices about how to best manage SNF from commercial nuclear power reactors and how to integrate this SNF with the ultimate disposition of DOE-managed SNF and HLW. System analyses and alternatives studies to evaluate a range of facility and infrastructure waste management system (WMS) architectures are being conducted to inform future decisions. Efforts to evaluate the WMS architecture provide information on various alternatives for managing domestic commercial SNF, as well as DOE-managed SNF and HLW. The objectives of these efforts are as follows:

- Provide qualitative and quantitative information on a broad range of nuclear waste management alternatives and considerations
- Develop an integrated approach for evaluating potential WMS configurations
- Evaluate the impacts of various management choices on system development and operations
- Identify and evaluate alternative strategies with respect to cost and flexibility
- Consider a broad range of factors, including thermal constraints, packaging needs, facility deployment and transportation alternatives, and other potential system impacts.

System analyses and assessments may investigate the implications of changes to various assumptions and parameters, such as acceptance rates, receipt logic, facility capacities and capabilities, use of standardized canisters, and different assumed system operation start dates. Some example system analysis results are found in Reference [3].

These results were generated for commercial SNF; however, NGSAM may soon be capable of performing system analyses on DOE-managed SNF. NGSAM has vastly improved the modeling of DOE-managed SNF by changing the level of modeling from the canister to the individual fuel element. In contrast to U.S. commercial SNF, which is composed of large inventories of very similar SNF types (i.e., boiling-water reactor and pressurized-water reactor SNF), DOE-managed SNF comes from a wide range of reactor types, including light-/heavy-water-moderated reactors, graphite-moderated reactors, and breeder reactors—all with various fuel compounds, cladding materials, enrichments, and geometries. Modeling these unique DOE-managed fuel elements required NGSAM to utilize the Spent Fuel Database.

DOE-managed SNF can be modeled as being packaged in DOE Standard Canisters[b] and multi-canister overpacks. HLW canisters can be modeled as either a 10- or 15-ft.-long canister, with a diameter of 24 in. Lastly, SNF canisters and HLW canisters are packaged together for disposal in a co-disposal waste package[c].

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* [7].

NGSAM simulates the packing of DOE-managed SNF in canisters, then simulates the packing of canisters into waste packages. Fig. 2 compares the results from NGSAM to the canister and waste packaging count benchmarks; small variances are expected but should be minimal.

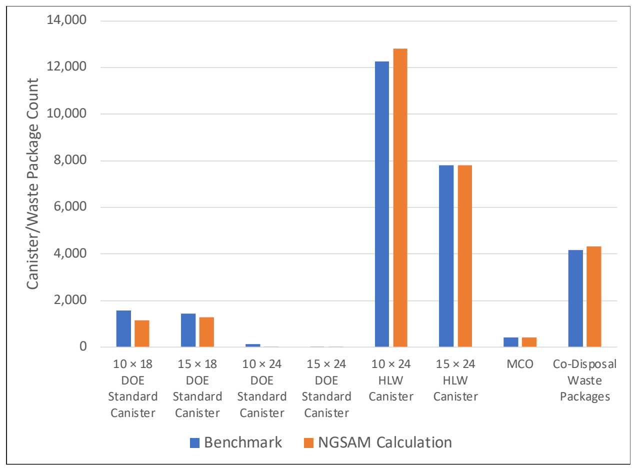

Fig. 2. Comparing canister and waste packaging results from NGSAM to benchmarks.

Recently, some system analysis efforts have also begun to explore how the waste management system might operate for advanced reactor fuel cycles. Preliminary requirements for modeling advanced reactor fuel cycles and reprocessing/treatment of SNF have been developed.

V. INTERFACES WITH OTHER IWM RESEARCH AREAS

The IWM program has three major areas with which the system integration analysis and support research area interfaces: (1) IWM facilities and equipment concepts and development, (2) transportation capability analysis and support, and (3) information technology solutions and support. Additionally, the system integration area interfaces with DOE's consent-based siting for a federal

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b Family of canisters with a length of 10 ft. or 15 ft and an outer diameter of 18 in. or 24 in.

c Analysts can change the configuration for number of SNF canisters and HLW canisters in a co-disposal waste package.

interim storage program and can perform preliminary system analyses as requested to support various aspects of the consent-based siting team's work.

The system integration team interfaces with the facilities and equipment concepts and development team in multiple areas. The facilities team produces the SNF and reprocessing waste inventory data [8] used by UNF-ST&DARDS, NGSAM, and the system analysts, and which is stored in the UDB. Additionally, federal interim storage facility concepts created by the facilities team are used by system analysts to model potential waste management system architectures.

The system integration team also interfaces with the transportation capability analysis support team in multiple areas. A major example of this is that the transportation team produces data regarding potential transportation options, and these data are used by system analysts to model potential integrated waste management systems. Additionally, system analysts estimate how much transportation infrastructure may be necessary, with different assumptions being made by the transportation team for planning purposes.

Furthermore, the system integration team interfaces with the information technology solutions and support team in multiple areas. A major example of this is that the results produced by the system integration team are used by the information technology team to generate informative graphics. Additionally, the system analysis team provides estimates from potential waste management system scenarios that are used for communication products such as potential website graphics.

VI. CONCLUSIONS AND KEY TAKE-AWAYS

This paper focuses on ongoing activities in the IWM system integration analysis and support area. Two main research activities in this area are data and tool development, validation, and maintenance; and special studies, analyses, and assessments. In the data and tools development area, the ability of UNF-ST&DARDS to track SNF through the entire backend of the fuel cycle—from the time the fuel is discharged from the reactor up to its final disposition—was highlighted.

In the special studies area, NGSAM's ability to model all levels of the waste management system, from the facility level all the way down to the assembly level, is made possible by utilizing the agent-based nature of the simulation. NGSAM is a tool for performing system analyses and assessments that investigate how potential waste management systems might behave.

From UNF-ST&DARDS to NGSAM and system analysis, system integration analysis activities consider the entire potential lifecycle of SNF and HLW for the IWM program. The tools and activities in the System Integration and Analysis area have been developed and are being performed to enable informed decision making by providing the capability to analyze various potential system options for managing SNF and HLW.

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