Execution Strategy Analysis (ESA) Origin Sites Readiness Model - 19073

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ABSTRACT[1]

This is a technical paper that does not take into account the contractual limitations under the Standard Contract for Disposal of Spent Nuclear Fuel and/or High-Level Radioactive Waste (Standard Contract) (10 CFR Part 961). Under the provisions of the Standard Contract, DOE does not consider spent nuclear fuel in multi-assembly canisters to be 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 provisions prevail.

The DOE Office of Nuclear Energy (DOE-NE) Office of Spent Fuel and Waste Disposition (SFWD) Integrated Waste Management System (IWMS) program is developing an Execution Strategy Analysis (ESA) Origin Sites Readiness Model using the Goldsim™ software application to provide information on potential future approaches for removing SNF and HLW from origin sites such as commercial nuclear power plant sites. The purpose of this ESA model is to apply integrated waste management system analysis, system engineering, and decision analysis principles to inform future decisions regarding potential future nuclear waste management system architectures.

The ESA Origin Sites Readiness Model is a dynamic simulation modeling capability. It is developed for use in the analysis and comparison of potential future implementation strategies associated with an integrated nuclear waste management program. The model is designed to be independent of the destination of the SNF or HLW so the results from the Origin Sites Readiness Model are equally applicable to a wide range of scenarios involving shipments to generic destinations in an integrated waste management system. The model explicitly takes significant assumptions, uncertainties, and risks into account.

Currently, the ESA Origin Sites Readiness Model includes 14 shutdown sites (Maine Yankee, Yankee Rowe, Connecticut Yankee, Vermont Yankee, La Crosse, Big Rock Point, Zion, Kewaunee, Fort Calhoun, Trojan, Rancho Seco, Humboldt Bay, San Onofre, and Crystal River) and is designed to be modular so that other sites can be added in the future. The model also includes multiple transportation modes (heavy haul truck, rail, and barge), activities related to the acquisition of transportation assets such as railcars and transportation casks, and site-specific considerations of on-site and near-site transportation infrastructure. The model was developed using the ESA process with Subject Matter Experts (SME); it incorporates uncertainty and risks and provides a structured, systematic methodology for evaluating potential SNF campaign scenarios. The model also complements other system-level logistics tools being developed by SFWD.

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[1] This technical paper reflects concepts which could support future decision-making by DOE. No inferences should be drawn from this paper regarding future actions by DOE. To the extent this technical paper conflicts with the provisions of the Standard Contract, the Standard Contract provisions prevail.

INTRODUCTION

DOE-NE's IWMS program is developing and applying a variety of IWMS analysis capabilities and tools for the identification and evaluation of options for the future deployment of a comprehensive nuclear waste management system. Systems analysis and systems engineering principles are being applied to evaluate an integrated approach to transportation, storage, and disposal in the waste management system with an emphasis on providing flexibility to respond to evolving national policy/direction. These analyses support the establishment of functional and operational requirements for the SNF and HLW management system, provide the framework for future planning activities (e.g., transportation hardware procurements), and provide information to inform potential future decisions regarding IWMS deployment and operational strategies.

Beginning in mid-2013 DOE-NE began developing the ESA tool that is both a SME elicitation process and a dynamic simulation modeling capability. The ESA approach provides risk assessment and project management tools for evaluating the future deployment of an integrated nuclear waste management system (i.e., following the guidance in DOE G 413.3-7A, Risk Management Guide) and provides important information to other system analysis tools. The ESA capabilities are intended for use in the analysis of alternative execution/implementation strategies and plans associated with an IWMS program. Early ESA models complemented other system-level logistics tools being developed by the system analysis team to evaluate potential alternatives for deploying consolidated interim storage for commercial SNF and HLW [1].

There have been three main iterations of the ESA tool. Version 1.0 involved a limited number of SMEs leading to the development of a simulation model to demonstrate the utility of the ESA process and the insights that could be gained. Utilizing a broader group of SMEs, including those within the commercial nuclear industry, Version 2.0 enhanced the ESA tool through the identification of additional activities and milestones to improve implementation performance and the quantification of input factors; additional positive and negative risks based upon industry experience were also identified [2]. Version 2.1 enhanced the ESA model's usefulness in several areas: risk mitigation strategies; adding capability to analyze constrained funding scenarios; deployment of multiple interim storage facilities (ISFs) with different capabilities, including phased expansion of multiple ISFs; and, including multiple dry canister storage design concepts.

Versions 1.0 and 2.0 of the ESA model followed the federal facility licensing process steps in 10 CFR 72 for an ISF. It included steps to acquire the necessary assets to transport SNF from reactor sites to an ISF, including transportation casks having 10 CFR 71 certificates of compliance and cask and buffer railcars that are certified to meet Association of American Railroads (AAR) standard S-2043. Also, the ESA model included steps to establish transportation routes between the shutdown reactor sites and potential destinations at one or more ISFs and for the training of emergency responders along the routes.

A stand-alone ESA Origin Sites Readiness Model was developed to further enhance the ESA model. This new model was constructed to capture all of the activities and milestones necessary to establish at-reactor and near-reactor site infrastructure at shutdown sites. By complementing the main ESA model and other IWMS logistics tools, this new stand-alone model provides a structured, systematic methodology for evaluating potential SNF transportation campaigns associated with comprehensive disposition strategy alternatives.

This paper describes the development of the stand-alone ESA Origin Sites Readiness Model. It includes key insights that were gained during the model's development and subsequent analyses.

There are likely to be multiple alternatives to meet the goals for an integrated nuclear waste management system. Because the approach for implementation has not yet been determined, the ESA tool is being used to evaluate a range of potential future implementation scenarios. The scenarios and assumptions described in this report should not be viewed as defining DOE policy or a path-forward for implementation, but rather as potential approaches whose performance attributes are being evaluated to inform future decisions regarding implementation.

DEVELOPMENT OF THE ORIGIN SITES READINESS MODEL

At the end of FY2016 the ESA Model Version 2.0 could be used to assess strategic approaches for initiating operations at one or more interim storage facilities over multiple phases. It was recognized that the ESA Model Version 2.0 contained only a highly-simplified representation of the activities and risks associated with origin site readiness, and that this portion of the IWMS could significantly impact the acceptance of SNF and the rate it could be shipped. Therefore the evolving ESA model was further enhanced by developing a stand-alone ESA Origin Sites Readiness Model; this model was required to represent all of the activities and milestones necessary to establish at-reactor and near-reactor site transportation infrastructure as well as having the capability to represent establishment of the transportation infrastructure at multiple shutdown sites. The model's development in a series of four interactive workshops followed the established ESA process.

A workshop was held to begin revising the ESA model to include multiple at-reactor and near-reactor site transportation infrastructure deployment scenarios; consideration was given also to the possibility that the model might be a stand-alone version to run concurrently with the main ESA model. Generic origin site Success Precedence Diagrams (SPD) and a milestone definition worksheet were created for consideration by a small working group. The review of the first draft of the model requirements document identified several areas for enhancements, including the need for a separate transportation cask model where there is the potential for the same cask type to be used at multiple sites. As the result of the workshop, the generic SPDs were updated and first steps were taken to identify activities between milestones. In addition, an initial set of risks was identified and a spreadsheet template was developed for all input data, including a separate data sheet for each origin site to be included within the model.

A second workshop was held with a small working group of Subject Matter Experts (SME) to achieve the following objectives:

1. Review the ESA model requirements document updates from the previous workshops and discuss resource allocation and cost issues to prevent duplication with analyses performed by the Next-Generation Systems Analysis Model (NGSAM) [3], another of the system analysis tools.
2. Review the generic SPDs, the milestone definitions, the generic activity data sheets and formats, and the risk register from the previous workshop.
3. Develop activity inputs (durations, costs) for 2 selected shutdown origin sites (Maine Yankee and Trojan) using the DOE-developed shutdown sites report [4] and de-inventory reports [5,6]. Discuss how these concepts can be applied to gathering data from resource sets of the remaining 12 shutdown origin sites, especially focusing on the 9 sites that have been shut down the longest.
4. Quantify the identified risks for the 2 initial origin sites, including describing the potential consequences to cost and duration of specific activities and the likelihood of those consequences occurring.

The third workshop was held for a larger group of SMEs to demonstrate a preliminary version of the ESA Origin Sites Readiness Model featuring a single origin site to obtain feedback on the user interface and the model outputs. The model requirements document was updated to include specific user-selected options and the potential for origin sites to include not only the current 14 shutdown sites but also the possibility that the first SNF shipment could be from an operating reactor site; a modular approach in the stand-alone model's structure was determined to best take this campaign option into account. The model's SPDs and data input sheets were reviewed in the context of multiple questions raised by a new group of SMEs who were seeing the results of the development process for the first time. Key issues included potential ways to accelerate transportation cask procurements, clarification of the importance of consultations with States and Tribes, and the need for traceability of costs between the ESA model and the NGSAM tool.

The fourth and final workshop was held for a small working group before delivery of the model for use. Further actions were discussed for the model's development including scenarios for analysis and its interface with ESA Interim Storage Deployment Model Version 2.1 that was under parallel development. A preliminary analysis of two scenarios using the primary transportation mode for each of the 14 shutdown origin sites was presented to the working group to demonstrate the model's usefulness and to stimulate further discussion about how SNF campaign scenarios could be created. Feedback focused on how to improve the model's user interface and outputs as well as confirming the core assumptions upon which the model's logic was based. The cask acquisition logic was updated and changes were made to the input data files. Consideration was also given for a future workshop to develop a specific scenario in which the first origin site to ship SNF is not a shutdown site but rather an operating site; coordination with the NGSAM tool would be included in developing this scenario.

The stand-alone ESA Origin Sites Readiness Model was delivered with all input data sheets, a user manual and a GoldSim™ Player version of the model. When the users began to create and analyze SNF campaign scenarios, the initial results prompted re-consideration of certain logic links pertaining to cask procurement issues and other activities; changes to the model were proposed in order to provide more flexibility to analyze scenarios and to add additional outputs from the model's Monte Carlo simulations to better understand the results. The small working group of users quickly reached consensus about the proposed changes which were made in short order to the model, a reflection of the flexibility and adaptability in using the ESA process and tool to incorporate new information and critical thinking and to support continuing real-time analysis of SNF campaign scenarios.

ORIGIN SITES READINESS MODEL SCENARIOS

The stand-alone model was developed to represent all of the activities and milestones necessary to establish at-reactor and near-reactor transportation infrastructure at multiple origin sites. It provides a structured systematic methodology for evaluating potential SNF campaigns. The current model supports the development of up to 14 origin sites and 9 transportation cask types and allows the general parameters of each origin site and cask type to be specified by the model user.

The model was built using the standard ESA framework comprised of milestones, activities, and risks. Detailed logic was developed to represent the on-site and near-site activities associated with a generic origin site. Two separate flowcharts were developed to represent various aspects of the project:

- Origin Site On-site Readiness
- Origin Site Off-site Readiness

Branched logic was developed to represent the activities associated with the development of the infrastructure and approvals necessary for the following potential modes of transport across the boundary of the origin site:

- Direct rail
- Barge
- Heavy-haul truck (HHT)

Additionally, the model supports up to two transloads for each origin site, to allow for a change of mode during transport:

- The following near-origin transload combinations are supported:
  - HHT to rail
  - Barge to rail
  - Barge to HHT
  - HHT to Barge

- The following intermediate location transload combinations are supported (an intermediate location would represent a port):
  - Barge to rail
  - Barge to HHT

Additionally, a cask acquisition model was developed to simulate the licensing and fabrication activities associated with transportation casks and associated hardware. The following nine transportation cask types are currently supported in the model: NAC-UMS UTC, NAC-STC, HI-STAR HB, TS125, MP187, HI-STAR 100, MAGNATRAN, MP197HB, and HI-STAR 190. The model tracks the availability of each type of cask and matches cask types to origin sites as defined by the model's user. At least one cask of the selected type must have been manufactured before each origin site can achieve the readiness to transport milestone.

Available options include both programmatic assumptions, coordination with stakeholders, and site-specific options such as when on-site and near-site infrastructure development would commence, transportation modes, and cask types.

The model is structured such that the user can configure each selected origin site to evaluate a wide variety of start dates, transportation modes and cask types. The activity costs, durations, and risks associated with transportation planning and hardware for each site are assigned as a function of the inputs below. The following information can be provided to describe the origin site configuration:

- Begin On-site work (not before date)
- Begin Off-site work (not before date)
- On-site Primary Originating Mode
- Transload Required Near Origin
- Transload Required at Intermediate Location
- Begin Cask Acquisition Activities (not before date)
- Primary Cask Type to Include.

Cost and duration inputs are based on information provided by IWMS program control key account managers and the professional judgment of SMEs that have been engaged in the process through participation in workshops, coupled with relevant published data where applicable. Activity costs are structured according to standardized IWMS cost categories and phases (i.e., each Origin Sites Readiness Model activity is mapped to a single cost category and phase) and cost results are available for each category and phase in the model's results. The model costs do not include the following:

- Additional capital costs associated with other assets purchased subsequent to the initial transfer.
- Operational costs associated with the origin sites or transportation system.

Using the ESA process, a risk register was developed with input from SMEs through the series of workshops. The risk register is intended to capture the list of potential issues that could arise during the course of the project and materially impact the program cost and/or schedule relative to the base assumptions (including "opportunities" for cost and/or schedule reduction). During the workshops, the prior assessments from earlier versions of the ESA model were reviewed with consideration of newly available information, and adjustments were made as necessary based on consensus of the SMEs. Additionally, new risks were identified and added to the register through the course of discussions.

At the conclusion of the four workshops, 45 risks had been identified. Of those, 24 were quantified for inclusion in the Origin Sites Readiness Model as discrete events. Another 10 risks were considered adequately addressed in the base uncertainty ranges and/or other risks. The remaining risks were excluded from or outside of the scope of the Origin Sites Readiness Model at this time or were retired. Those risks that were individually quantified were characterized in terms of the potential impact to program cost and/or schedule, along with associated probability of those impacts occurring. The impacts are intended to be separate from and consistent with the base values (including uncertainties) and were mapped to specific activities on the flowcharts.

ORIGIN SITES READINESS MODEL SCENARIO ANALYSIS

Two scenarios were developed for initial analysis. The scenarios are based on the following common assumptions:

- Start dates for major origin site readiness initiating activities, including National Environmental Policy Act (NEPA) clearance and SNF campaign priorities, were based on generic planning assumptions for this particular analysis.
- Work at all 14 included origin sites begins simultaneously.
- The ISF is constructed and ready for receipt when the first origin site is ready to transport.
- Risks associated with legislative authorization or funding delays are not included.
- Otherwise, all identified risks are included in the analyses.

Table I summarizes the two scenarios currently analyzed to demonstrate the model's usefulness. Numerous alternative scenario options can be created through various combinations of mode selections for each origin site; however, the two identified scenarios were created to encompass current IWMP planning assumptions.

TABLE I. Summary of Scenarios Analyzed in Origin Sites Readiness Model

Site	Transport Mode Option	
	Scenario 1	**Scenario 2**
Big Rock Point	HHT to Rail	Barge to Rail
Crystal River	Direct Rail	Barge to Rail
Connecticut Yankee	Barge to Rail	HHT to Rail
Fort Calhoun	Direct Rail	Barge to Rail
Humboldt Bay	HHT to Rail	HHT to Barge to Rail
Kewaunee	HHT to Rail	HHT to Barge to Rail
La Crosse	Direct Rail	Barge to Rail
Maine Yankee	Direct Rail	Barge to Rail
Rancho Seco	Direct Rail	Direct Rail
San Onofre	Direct Rail	HHT to Barge to Rail
Trojan	Direct Rail	Barge to Rail
Vermont Yankee	HHT to Rail	HHT to Rail
Yankee Rowe	HHT to Rail	HHT to Rail
Zion	Direct Rail	Barge to Rail

Figure 1 depicts the probability of completing an initial transport milestone as a function of time for two different scenarios that were analyzed. From this figure, the following observations can be made:

- The assumed transportation modes assigned to sites for Scenario 1 allows the first occurrence of transport from one of these sites to occur earlier than for Scenario 2 with its associated transport modes
- Both scenarios exhibit a long “tail” in the upper percentiles due to low probability / risk impact risk events.

From critical path analysis, NEPA clearance was likely to be on critical path for either scenario. Figure 2 depicts the critical path analysis results for transportation activities and milestones leading up to the readiness to transport milestone for Scenario 1. The result in the box next to each milestone or activity number shows the decimal percentage of all the Monte Carlo realizations run for which the milestone or activity was on the critical path for the first site ready to transport. The red bar next to the result box shows this information graphically, from 0 to 1, left to right, with a full red bar indicating that the milestone or activity is critical 100 percent of the time.

From Figure 2, the following observations can be made:

- The activities and milestones most likely to be critical to origin site “readiness to ship” date (milestone TRI-G-16) for this scenario include the following (each with a probability of being critical of 70% or greater):
  - Site campaign priority and transportation asset establishment (TRI-I-0, and TRH-I-1).
  - Cask acquisition activities (TRH-G-1 through TRH-G-8).
  - Final preparations for transport (TRI-G-14 through TRI-G-16).
- On-site infrastructure readiness (TRI-G-8-9) has only about a 5% likelihood of being on critical path.
- Near-site infrastructure readiness (TRI-G-13-4) has about an 8% likelihood of being on critical path.

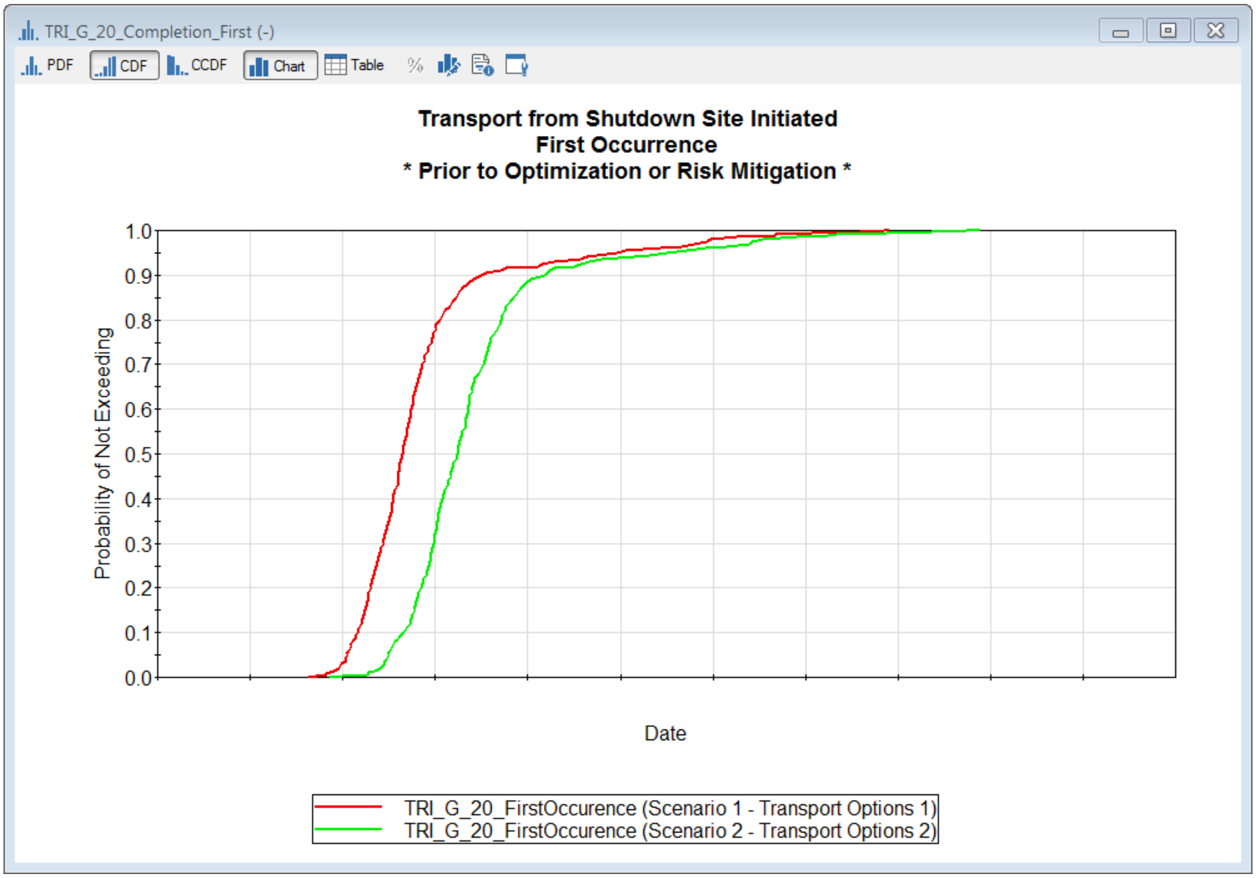

Fig. 1. Comparison of Timing for Initial Transport Milestone Completion for Scenario 1-2

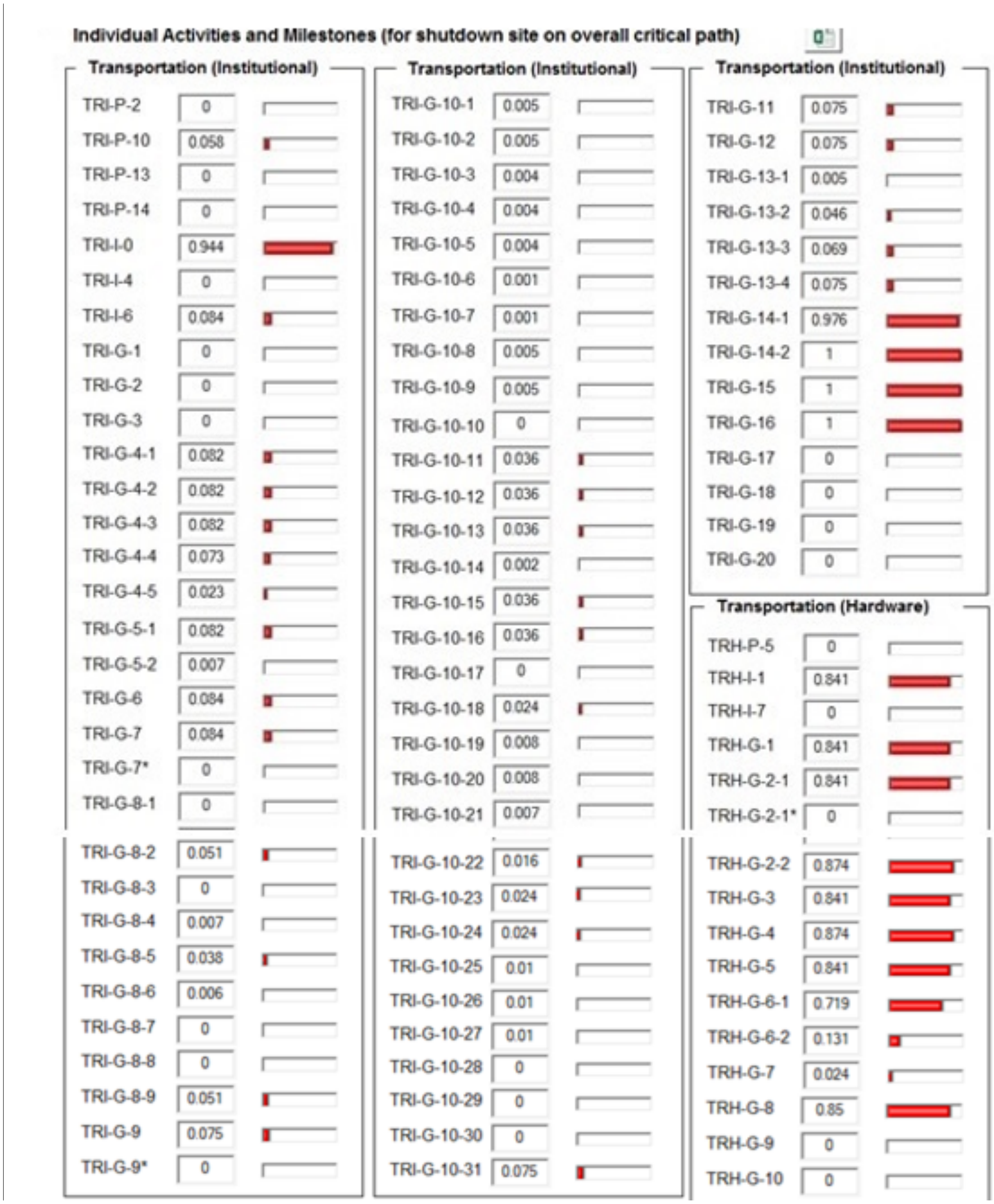

Fig. 2. Critical Path Analysis Results (Scenario 1: Primary Transport Modes)

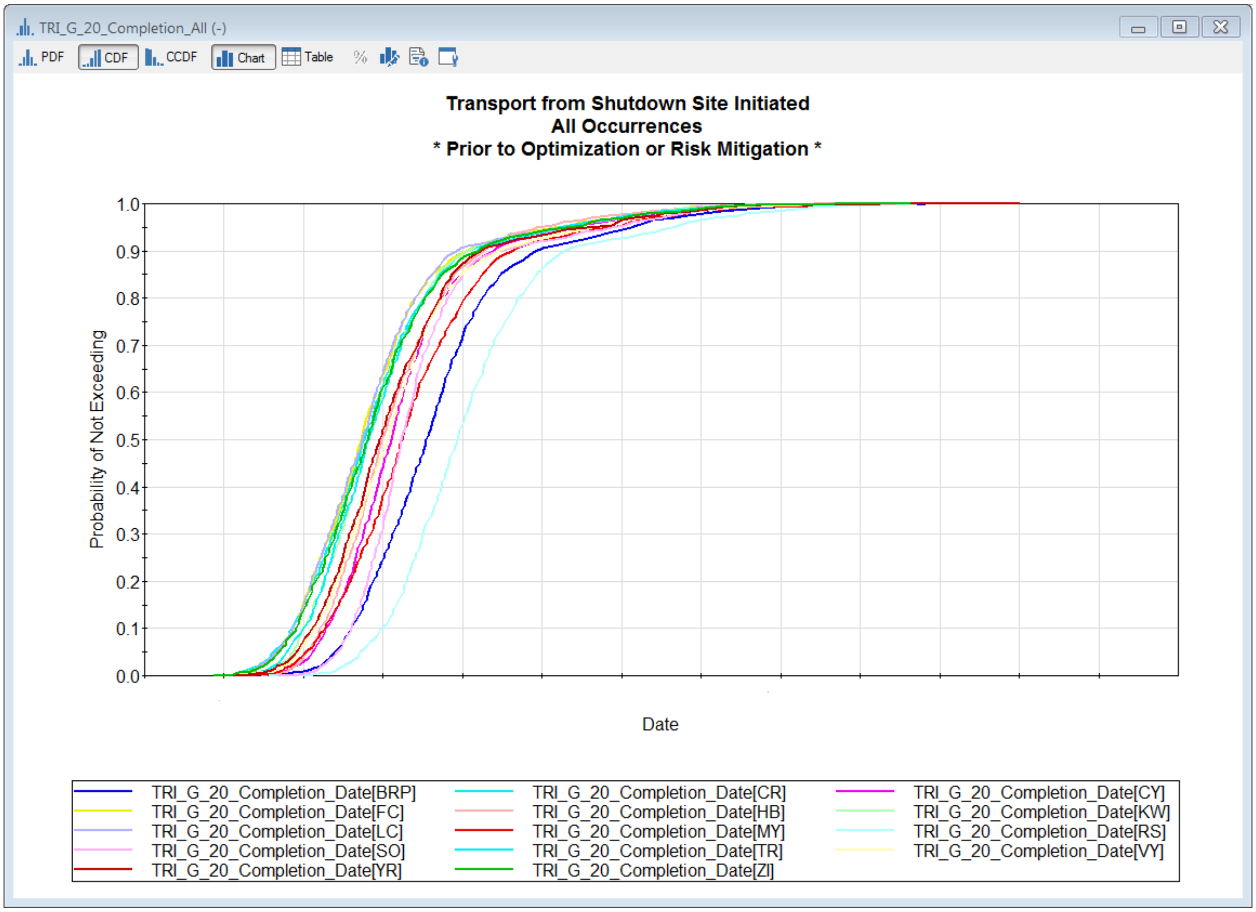

Fig. 3. Comparison of Timing for Initial Transport across Origin Sites, Scenario 1

The model also has the capability to compare milestones for a given scenario across origin sites. Figure 3 contains a summary of the transport initiation (milestone TRI-G-20) for each of the 14 origin sites for Scenario 1.

From Figure 3 the following observations can be made:

- Significant differences exist among origin sites with respect to the duration necessary to achieve initial transport.
- All sites exhibit long "tails" at the upper percentiles due to low-probability but high-impact risks.

Figure 4 contains a summary of the transportation cask availability milestone (TRH-G-8), for each of the 9 transportation cask types also for Scenario 1. From Figure 4 the following observations can be made:

- As with the origin sites, significant differences exist among transportation cask types with respect to the timing of availability for initial transport;
- Significant uncertainty exists with respect to the projected availability date for each cask type.

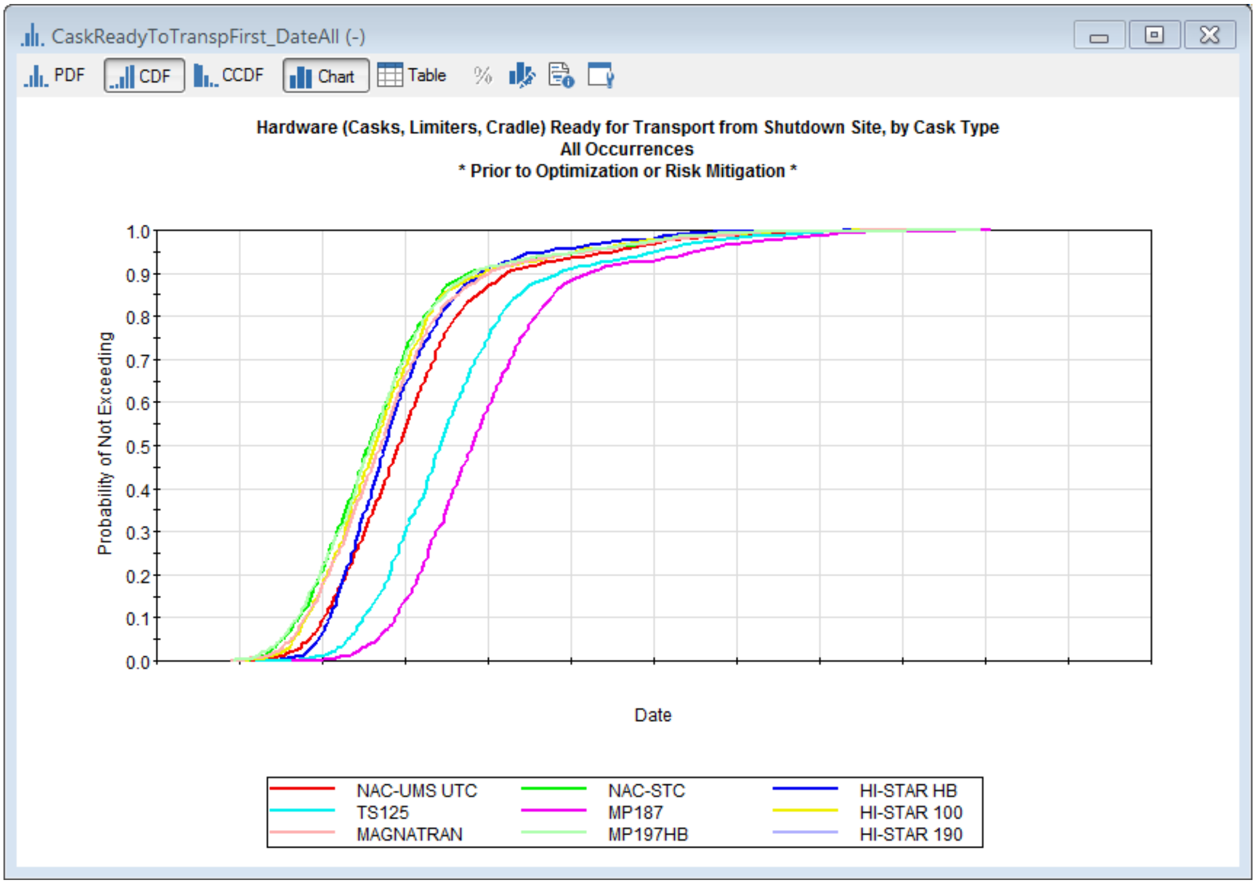

Fig. 4. Time History of Canisters Ready to Transportation by Cask Type, Scenario 1

In addition, sensitivity analyses can be run to identify the significant risks and uncertainties associated with specific schedule milestones or cost components. Each risk and uncertainty input is varied independently from its 5th to 95th percentiles and the resulting impact to the analyzed result is recorded. The sensitivity analyses can be used to identify which input parameters are having the greatest impact on model results in order to identify areas of focus for input refinement and risk mitigation efforts.

ORIGIN SITES READINESS MODEL – KEY INSIGHTS

As mentioned previously, the Origin Sites Readiness Model currently includes 14 shutdown sites (Maine Yankee, Yankee Rowe, Connecticut Yankee, Vermont Yankee, La Crosse, Big Rock Point, Zion, Fort Calhoun, Trojan, Trojan, Humboldt Bay, San Onofre, and Crystal River) and includes multiple transportation modes, activities related to the acquisition of transportation assets, and site-specific considerations of on-site and near-site transportation infrastructure. Critical in the development of the Origin Sites Readiness Model has been the on-going collection of site-specific data to parameterize the model [4]. Collection of this data included:

- Characterizing the SNF and GTCC waste inventory.
- Describing the on-site infrastructure at the shutdown sites.
- Evaluating the near-site transportation infrastructure and transportation experience at the shutdown sites.

The key insight obtained from the ESA model development and data collection activities has been the need to carefully distinguish among the assumptions in the model and the data used to parametrize the model, i.e., "what do we know and why do we know it?" Other key insights include:

- The importance of integrating transportation resource acquisition activities with on-site and near-site transportation infrastructure activities, so that transportation resources and infrastructure are available "in time".
- The importance of preserving all modal options for a given site while at the same time explicitly evaluating the activities and risks associated with each modal option.
- The importance of having SMEs with diverse nuclear industry experience participate in developing the structure of the model and identifying/quantifying the data and risks associated with activities in the model. This insight was especially important in avoiding "group think" during the development of the model.

CONCLUSIONS

The DOE-NE Integrated Waste Management System (IWMS) program is developing and applying a variety of IWMS analysis capabilities and tools to evaluate various architectures and approaches that could inform future decisions about how to best manage the SNF and HLW from nuclear power reactors.

As a part of the IWMS effort, a stand-alone ESA Origin Sites Readiness Model was developed to analyze what actions will be required to achieve readiness of on-site and near-site infrastructure at commercial reactor sites to support SNF campaign alternatives.

The model allows evaluation of one or more scenarios against others. For each scenario, it allows evaluation of critical path activities, key risks, costs and durations. The initial focus of the model was on the 14 shutdown sites but it also considers the possibility that SNF in a campaign might be removed from operating reactor sites.

The ESA model can be used not only on its own but also in combination with other tools in the IWMS analysis toolset. For example, this ESA model is also designed to provide input data for the Next-Generation Systems Analysis Model (NGSAM) that is being designed to analyze IWMS configurations involving multiple facilities.

It must again be recognized that there are likely to be multiple alternatives for implementing an integrated nuclear waste management system. Because the approach for implementation has not yet been determined, ESA is being used to evaluate a range of potential future scenarios. The scenarios and assumptions described in this report should not be viewed as defining DOE policy or a path-forward for implementation, but rather as potential approaches whose performance attributes are being evaluated to inform future decisions regarding implementation. Results produced by the ESA model for a particular scenario are also assumption-dependent and thus they may vary should the set of inputs be altered by another user.

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ACKNOWLEDGEMENTS

This work is supported by the U.S. Department of Energy, Office of Nuclear Energy, Office of Spent Fuel and Waste Disposition under contract #DE-AC02-06CH11357.