NGSAM Transition and Benchmarking Report

Fuel Cycle Research & Development

Prepared for
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Nuclear Fuels Storage and
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SUMMARY

The Nuclear Fuels Storage and Transportation Planning Project (NFST) is developing the Next Generation System Analysis Model software (NGSAM) to model the waste management system. While this model is still in development, it has reached a point of maturity to which a benchmark of its current capabilities against legacy software is appropriate. The process of benchmarking NGSAM began at the start of FY16 and has continued since. This report is a status update on that process as well as on NGSAM's capabilities. This report fulfills the Level 3 Milestone M3FT-16AN090102043 in the Waste Management System Architecture Analysis work package FT-16AN09010204.

The benchmarking process has benefitted the NGSAM development team and NFST systems analysts. It has increased the level of interaction between these two groups which has guided the direction of NGSAM development, refined NGSAM's modeling of the waste management system, and accelerated NFST systems analysts' understanding of the software. The result of collaborations between NFST analysts and NGSAM developers resulted in four interim revisions to NGSAM that greatly improved the accuracy and usability of the software. Despite these revisions, there are still outstanding issues that have not been corrected, but have been added to NGSAM's development plan. The last of those revisions is compared to legacy software with encouraging results. NGSAM behaves as expected, and any discrepancies between NGSAM and legacy tools can be traced to yet-to-be-resolved issues, or improvements in NGSAM over legacy tools.

Going forward, NGSAM will continue along its development plan while incorporating guidance from NFST analysts wherever possible. Additionally, NFST analysts will continue using NGSAM and alerting the software developers to issues or inaccuracies as they are identified. Another report benchmarking the next portion of NGSAM development is tentatively planned for completion in the early portion of FY17.

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CONTENTS

SUMMARY iii

ACRONYMS ix

1. INTRODUCTION 1
    1.1 Outcomes of Benchmarking Process 1
    1.2 References 2

2. BENCHMARKING PROCESS 3
    2.1 Timeline 3
    2.2 Benchmark Methodology 4
    2.3 References 9

3. Benchmark results 11
    3.1 Full Scenario 11
    3.2 Shutdown Sites Scenario 18
    3.3 References 21

4. CONCLUSIONS 23
    4.1 Path Forward 23

Appendix A SHUTDOWN REACTOR SITES TEST IN SUPPORT OF NGSAM BENCHMARK A-1
    A-1. INTRODUCTION A-1
    A-2. SHUTDOWN REACTOR SITES TEST CASE A-1
    A-3. TEST EVALUATION APPROACH A-3
    A-4. DISCUSSION OF TEST RESULTS A-4
    A-5. SUMMARY A-26
    A-6. REFERENCES A-26

LIST OF FIGURES

Figure 3-1: Number of transportation packages shipped each year 12
Figure 3-2: Number of assemblies shipped each year 12
Figure 3-3: Cumulative number of accepted assemblies 13
Figure 3-4: Total number of canisters in dry storage in reactor fleet 14
Figure 3-5: Total number of sites with fuel on site and the total number of operating sites each year 14
Figure 3-6: Number of transportation packages shipped each year for CALVIN without transportation heat limits and NGSAM 16
Figure 3-7: Total number of sites with fuel on site and the total number of operating sites each year. 17
Figure A-1. De-Inventorying Schedule for Rail Mode and 3-Car Consist Scenario A-2
Figure A-2. NGSAM Time History for Pool Inventory (top) and Operating Cost (bottom) for Big Rock Point. A-6
Figure A-3. NGSAM Time History for Dry Storage Cost (top) and Dry Storage Pads (bottom) for Big Rock Point A-7
Figure A-4. NGSAM Time History for Pool Inventory for Connecticut Yankee A-9
Figure A-5. NGSAM Time History for Pool Inventory for Maine Yankee A-11
Figure A-6. NGSAM Time History for Pool Inventory for Yankee Rowe A-13
Figure A-7. NGSAM Time History for Pool Inventory for Rancho Seco A-15
Figure A-8. NGSAM Time History for Pool Inventory for Trojan A-17
Figure A-9. NGSAM Time History for Pool Inventory for Humboldt Bay A-19
Figure A-10. NGSAM Time History for Pool Inventory for La Crosse A-21
Figure A-11. NGSAM Time History for Pool Inventory for Zion A-23
Figure A-12. Pickup Dates Calculated by NGSAM (Top) and Number of Railcars in Operation (Bottom) A-25

LIST OF TABLES

Table 3-1: Sites with the greatest difference between last shipments in NGSAM and CALVIN 15
Table 3-2: Order in which sites are cleared of SNF 17
Table 3-3: Historic data for sites in shutdown scenario 19
Table 3-4: Site-Specific Issues Identified for the Shutdown Reactors Scenario 20
Table A-1: SNF Inventory at the Shutdown Reactor Sites A-1
Table A-2. Number of Canisters to Be Transported Each Year of the Transportation Campaign A-3
Table A-3. Reactor Discharge and Dry Storage Inventory Comparison for Big Rock Point A-4
Table A-4. NGSAM Transportation Schedule for Big Rock Point A-8
Table A-5. Reactor Discharge and Dry Storage Inventory Comparison for Connecticut Yankee A-8
Table A-6. NGSAM Transportation Schedule for Connecticut Yankee A-10
Table A-7. Reactor Discharge and Dry Storage Inventory Comparison for Maine Yankee A-10
Table A-8. NGSAM Transportation Schedule for Maine Yankee A-12
Table A-9. Reactor Discharge and Dry Storage Inventory Comparison for Yankee Rowe A-12
Table A-10. NGSAM Transportation Schedule for Yankee Rowe A-14
Table A-11. Reactor Discharge and Dry Storage Inventory Comparison for Rancho Seco A-14
Table A-12. NGSAM Transportation Schedule for Rancho Seco A-16
Table A-13. Reactor Discharge and Dry Storage Inventory Comparison for Trojan A-16
Table A-14. NGSAM Transportation Schedule for Trojan A-18
Table A-15. Reactor Discharge and Dry Storage Inventory Comparison for Humboldt Bay A-18
Table A-16. NGSAM Transportation Schedule for Humboldt Bay A-20
Table A-17. Reactor Discharge and Dry Storage Inventory Comparison for La Crosse A-20
Table A-18. NGSAM Transportation Schedule for La Crosse A-22
Table A-19. Reactor Discharge and Dry Storage Inventory Comparison for Zion A-22
Table A-20. NGSAM Transportation Schedule for Zion A-24
Table A-21. Site-Specific Issues Identified for the Shutdown Reactors Scenario A-26

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ACRONYMS

BWR	boiling water reactor
DOE	US Department of Energy
FY	fiscal year
ISF	interim storage facility
IV&V	independent verification and validation
JTOM	java transportation operations model
MTU	Metric Tons of Uranium
NFST	Nuclear Fuels Storage and Transportation Planning Project
NGSAM	Next Generation System Analysis Model
OFF	oldest fuel first
P-LOTS	python logistical operations tally system
PWR	pressurized water reactor
SNF	spent nuclear fuel
TOM	transportation operations model
TSL	Total System Logistics model
UDB	Unified Database

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NGSAM TRANSITION AND BENCHMARKING REPORT

1. INTRODUCTION

The Nuclear Fuels Storage and Transportation Planning Project (NFST) is developing the Next Generation System Analysis Model (NGSAM) software to model the spent nuclear fuel (SNF) waste management system. While this model is still in development, it has reached a point of maturity to which a benchmark of its current capabilities against legacy software is appropriate. The process of benchmarking NGSAM began at the start of FY16 and has continued since. This report is a status on that process as well as on NGSAM's capabilities. This report fulfills the Level 3 Milestone M3FT-16AN090102043 in the Waste Management System Architecture Analysis work package FT-16AN09010204.

The purpose of NGSAM is to provide NFST systems analysts with a tool that can accurately and flexibly model the waste management systems. As such, NFST systems analysts will be the primary users of the software. With that in mind, systems analysts were tasked with benchmarking NGSAM to assess its current set of capabilities as compared to legacy software currently being used. That tasking and the completion of this report was the impetus for an increased level of integration between NGSAM developers and NFST systems analysts. This increase over the previous level of integration and communication was necessary for the benchmark process, but also resulted in a number of other outcomes beneficial to both groups.

It should be noted that this is not a formal independent verification and validation (IV&V) process. While in-depth analysis of results are considered and communication between NGSAM developers and systems analysts is ongoing, no direct examination of source code or algorithm implementation has been conducted by systems analysts. The purpose of this report is to document the benchmarking process to date, and to provide information regarding the ability of NFST systems analysts to transition to NGSAM from the legacy software. The scope of this benchmarking process is restricted to the modeling of behavior at reactor sites, as this area was the focus of the most recent NGSAM development efforts.

1.1 Outcomes of Benchmarking Process

This benchmarking process has been beneficial in a number of respects. The software has been improved as a result of engagement with future users (NFST systems analysts), and the users have a better understanding of how to use the software and how the software works.

NGSAM is still in development and so the opportunity remains to incorporate input from future users in order to better address their needs. For example, early in the benchmarking process systems analysts were introduced to the software and provided the NGSAM development team a list of feature requests outside of the requirements to which NGSAM was already being built. Those requests were provided in a report [1] delivered in November 2015. The NGSAM development rolled those requests into their development plan. A follow-on report delivered in February 2016 [2] provided a status on those requests including a completion schedule for those request that have not yet been implemented. NGSAM is being tailored to NFST systems analysis users and will continue to be going forward.

In addition to providing direction and requests in NGSAM development, NFST systems analysts have aided in identifying inaccuracies in the model. Issues for both the model logic as well as input data were identified by systems analysts and corrected by NGSAM developers. Examples of note include problems in the oldest fuel first (OFF) allocation method, assembly locations incorrectly accounted for, and errors in the way transportation was scheduled among the reactor fleet. In fact, the version of NGSAM benchmarked in this report is the result of five revisions to the software between January and March of FY16. Though the benchmarking process is not at the level of a formal IV&V process, it has reaped some of the benefits an IV&V process would provide.

While NGSAM development has benefited from the increased collaboration with systems analysts, systems analysts have in turn benefited as well. The enhanced communication with NGSAM developers has accelerated the learning curve in using NGSAM. This goes far beyond tutorials, workshops, or user manuals. Analysts have communicated directly with NGSAM developers, often in person, on all manner and levels of detail as to how the software is used and the waste management system is modeled. This level of accessibility to software developers makes assessing the software's capabilities easier, but also establishes an informed user base before the software product is finalized. Building a set of users prior to final release of the software virtually eliminates the post development learning curve that would otherwise delay analysis with the latest software.

1.2 References

[1] Trail C., Joseph R., and Cumberland R., *Feature Requests for NGSAM*, FCRD-NFST-2016-000008, November 6, 2015.

[2] Trail C., *NGSAM Features Update for Systems Analysts*, FCRD-NFST-2016-000645, February 29, 2016.

2. BENCHMARKING PROCESS

This section describes the benchmarking process to date. This includes a high level timeline describing changes to the versions of NGSAM being benchmarked, as well as a discussion as to how the benchmarking process was conducted. Finally, a list of caveats to the comparison are provided highlighting those issues known to impact the direct comparison between NGSAM and legacy tools.

2.1 Timeline

This section includes a review of the benchmarking process's timeline to date. While the process is still ongoing, prior activities provide context into how the versions of NGSAM being benchmarked came to be, and to provide evidence of the current level of integration between NGSAM developers and NFST systems analysts.

The benchmarking process began early in FY16 with a kickoff meeting between NFST systems analysts, NGSAM developers and NFST leadership. A one and one-half day workshop focused on introducing NFST analysts to NGSAM from the ground up including a familiarization of agent-based modeling concepts, manipulating NGSAM models, and creating user-defined reports.

In the six months following the kickoff meeting, four additional workshops were conducted between systems analysts and NGSAM developers. Discussions in these workshops continued to improve systems analysts' proficiency with NGSAM, informed NGSAM developers of systems analyst needs as they were identified, discussed progress of NGSAM development and revisions, and overall increased the level communication and familiarity between NFST systems analysts and the NGSAM development team.

One outcome of the workshops was the identification of issues regarding NGSAM's modeling of the waste management system. While some of these issues were simply noted as "in development," others made the benchmarking of the software impossible and needed to be fixed. Additionally, some issues were the result of incomplete data from the unified database (UDB), which is currently also in development. Issues relating to UDB data were communicated to UDB developers who have taken their own steps to rectify those issues.

This report is not intended to be a status report of NGSAM development. However, a sample and explanation of some of the issues identified and corrected is beneficial in providing context for the breadth of issues identified by systems analysts through the benchmarking process, and the efforts of NGSAM developers to address those issues. Without the series of revisions addressing these problems, this benchmarking process could not have continued. This "review-refine-repeat" cycle is an essential part of the benchmarking process. The completion of this benchmarking process will only make future benchmarking efforts easier. A partial list of these issues is provided below.

- NGSAM has a report specifically designed to the same format as a report currently generated in legacy tools. This allows for a more direct comparison between the two models. However, initially this report was not accurately recording the movement of assemblies and canisters out of dry storage. An NGSAM revision corrected the problems, and the report now allows for direct analysis of NGSAM results using the same post processing mechanics that are used for legacy tools.
- The OFF allocation in NGSAM was calculated incorrectly and resulted in incomparable allocation discrepancies between NGSAM and legacy models. This error is corrected in a revision to NGSAM and, as shown in section 3, performs as expected.
- Dramatic improvements in memory and processing time requirements in the NGSAM software were required to perform a proper benchmark analysis in the time available for analysis. NGSAM developers were able to make significant architecture changes to the underlying software that went beyond any changes that the analysts could make on the model. The problem was so

extensive that the original plan was to only benchmark the first 20 years of fuel shipments. Those tests took over 30 hours to complete, and even longer runs would not finish. The subsequent revisions allow the entire model (all reactors, 100+ years of fleet activity) to complete its simulation in roughly 2 hours.

- The modeling of pool closures within NGSAM was not complete as of November of 2015. This behavior is crucial in benchmarking the loading of canisters for dry storage. The issue was identified in a November workshop, and the subsequent revision in January 2016 implemented an improved modeling of pool closures at reactor sites.
- Early in the process it was identified that NGSAM was not accurately modeling the number of assemblies at each reactor site. The root cause of this was the unified databases (UDB) lacking information regarding the location of assemblies discharged from reactors but stored somewhere else (e.g., assemblies from the reactor at Big Rock Point stored in the pool at Morris). This made benchmarking against legacy tools difficult, and so a revision of NGSAM was provided that reverted to a previous version of UDB that included information for these "away from original reactor" assemblies.
- A small fraction of assemblies (less than 0.1 percent) in the UDB were missing data regarding their decay heat. This caused NGSAM to model some assemblies as never cooling, and so they were never able to be shipped or packaged into dry storage. To prevent these assemblies from derailing the entire benchmark process, these assemblies were assumed to have zero heat in the simulations.
- The benchmarking process identified that transportation times were being calculated incorrectly. This resulted in the model requiring railcars to be used for a significantly longer period of time than necessary, preventing shipments from being completed, and significantly inhibiting NGSAM's ability to model the movement of SNF from reactor sites. The root cause was a simple oversight in the calculation of rail speeds for certain railroad classes, but the issue itself was not identified until systems analysts took a critical look at the software and the results it was providing. The error was corrected in the most recent NGSAM revision.

All told, NGSAM released five revisions in direct support of this benchmarking process. The first was version 2.0 released at the end of FY15. NGSAM version 2.1.0.3 was used for the shutdown scenario benchmark included in Section 3.2 as this benchmark analysis was completed prior to the release of NGSAM version 2.1.0.4 which was used in the full scenario benchmark included in Section 3.1. All of these releases were unexpected and constituted a non-trivial effort from the NGSAM development team in addition to the development efforts planned at the start of FY16. However, these revisions were found to be mutually beneficial as it provided systems analysts with versions of NGSAM increasingly comparable to legacy software and at the same time provided NGSAM developers with direct input on how to improve the software.

2.2 Benchmark Methodology

The primary method for benchmarking NGSAM was to compare it as closely as possible to legacy software. The Total System Logistics (TSL) model is the current primary tool of NFST systems analysts. It consists of two parts. The first is CALVIN, which models the logistics of SNF such as fuel handling at reactor sites, loading spent fuel into casks or canisters, repackaging spent fuel, and required shipments. The second part of TSL is the transportation operations model (TOM) which schedules assets and determines costs required to complete shipments scheduled by CALVIN. These two models are run separately with the shipping requirements from CALVIN used as inputs to TOM. This contrasts with NGSAM where transportation and logistics are all calculated together during the simulation.

Care was taken in this comparison to make each simulation as similar to one another as possible. That includes using similar canister systems at each site, using identical fuel projections and historic data, as well as shipping and allocating fuel in the same way. As noted in section 2.1, numerous software revisions to NGSAM were made in order to improve model behavior to ensure a more realistic simulation and a more direct comparison to CALVIN.

In some cases, direct examination of the simulation results was sufficient for identifying consistencies or unexpected behavior in NGSAM. Additionally, developers have created an Excel output report from NGSAM ("RxDet.xlsx") that is formatted in exactly the same way as the corresponding report in CALVIN. These identical reports allow systems analysts to use the same post processing software to examine the results of each model. To that end, a post processing script was developed in Python called the Python Logistical Operations Tally System (P-LOTS). P-LOTS organizes the data provided in the output file RxDet.xlsx into multiple formats of more direct use to systems analysts. The benefit is that the outputs of both CALVIN and NGSAM can be examined using the same post-processing tool. Moreover, since NGSAM is not ready for full release as a systems analysis tool, P-LOTS is of use in the short term as CALVIN is still being used, and in the long term once the transition to NGSAM has been completed.

Finally, as NGSAM is still in development, not all aspects of the waste management system have finished being modeled. As such, this benchmark focuses exclusively on the behavior of sites in the reactor fleet and their transportation of SNF to a notional interim storage facility (ISF). Modeling of a fully functioning ISF was developed in parallel with this benchmarking effort and so will not be included in the analysis here. However, the ISF modeling in NGSAM is expected to be completed in the later part of FY16, with the benchmarking of that model beginning in the early part of FY16.

2.2.1 Scenario assumptions

A single scenario of the waste management system was modeled in both NGSAM and CALVIN. The assumptions of that scenario are taken largely from [3] with some variations. The relevant assumptions (those pertaining to reactor operations, SNF acceptance and transportation) are listed below.

1. The inventory of SNF at reactors will continue to accumulate as those reactors discharge SNF. All SNF will continue to be loaded into the dry storage systems currently being used (as of June 2014). No system-wide change to reusable bare fuel casks will occur. Reactors currently loading bolted-lid cask systems will continue to load those systems, just as those reactors currently loading welded, canister-based systems will continue to load those systems.
2. All currently operating reactors are assumed to operate for 60 years with no early shutdowns, additional extensions, or new reactors coming online. The exceptions are those reactors that have already shut down, those that have announced a shutdown date, and SNF stored at Morris.
    a. Reactors that have already shut down: Big Rock Point, Haddam Neck, Humboldt Bay 3, La Crosse, Maine Yankee, Rancho Seco, Trojan, Yankee Rowe, Zion 1 and 2, Kewaunee, Crystal River 3, San Onofre 1, 2, and 3, Vermont Yankee, Indian Point 1, Millstone 1, Dresden 1
3. The shipment of SNF from the reactor fleet starts in 2021. This rate is a maximum of 3000 MTU/yr in CALVIN and 225 transportation packages per year in NGSAM.
4. Allocation priority determines which reactor sites ship, and how much is shipped from each site in a given year. An OFF allocation determines the amount of SNF accepted when SNF is transported away from reactor sites. Acceptance refers to which SNF and how much SNF is actually shipped by the utility and accepted by the waste management system in each year. All SNF is allocated for pickup on the basis of the SNF owner's position in the OFF allocation priority ranking.

5. It's assumed that the reactor sites prioritize shipments from the pools over shipping SNF already in dry storage. If there are not enough assemblies in the pool to satisfy the allocation, reactors will send packages out of dry storage. In other words, SNF is accepted from a site based on a Youngest Fuel First priority with a minimum of five years out of the reactor before an assembly can be shipped.
6. If SNF is taken directly from a pool for immediate transportation, the SNF will be placed in a dual purpose canister that will be loaded into a transportation overpack. The capacity of the canister is 37 pressurized water reactor (PWR) or 89 boiling water reactor (BWR) assemblies (for vertical systems) or 37 PWR or 61 BWR assemblies (for horizontal systems), and is assumed to be the same orientation (vertical or horizontal) as the system loaded at the reactor for ISFSI storage.
7. All reactor site pools are closed 5 years after the final discharge from the site's reactors. Any fuel left in the pools at that time is transferred into dry storage.
8. All canisters and casks at reactors are assumed to be transportable. Specifically, any canister or cask system without a transportation certificate of compliance is assumed to receive an exemption for transport to the ISF as well as an exemption for transport from the ISF to the repository.
9. No repackaging of SNF occurs at reactor sites.

There are some fundamental differences between the models that require parameters be set differently to satisfy these assumptions. For example, target amount of SNF accepted from the reactor fleet is set in MTU in CALVIN, but by packages in NGSAM. Thus, CALVIN tries to allocate 3000 MTU/yr to the fleet. However, this means that in some years CALVIN models the shipment of slightly more than 3000 MTU/yr in some years and slightly less in others. If the model shipped precisely 3000MTU/yr, it would have to simulate shipping fractions of a transportation package, and that is unrealistic.

Alternatively, NGSAM allocates the number of transportation packages the waste management system will accept each year. This allows NGSAM to target exactly 225 transportation packages regardless of the weight or the number of assemblies in each. This is a more accurate assumption regarding limitations on the waste management system as those are dependent largely on the number of transportation packages shipped, and less so on the amount of MTU in those packages. While NGSAM is capable of setting any value for the acceptance limit, the value was set at 225 for the comparison to CALVIN as that is the average number of transportation packages shipped by CALVIN when allocating 3000 MTU/yr (with the current assumed canister capacities).

Other caveats to the comparison between NGSAM and CALVIN are provided in sub-section 2.2.2.

2.2.2 Caveats to comparison

The nature of the two models, CALVIN and NGSAM, necessitate some differences between the ways the comparison scenario is implemented in each piece of software. Additionally, certain elements of the comparison scenario are significantly modified from what would appear to be similar scenarios evaluated in other NFST systems analysis work. Thus, the results here should be examined purely for the purpose of benchmarking NGSAM against legacy software. A list of these caveats is provided below.

2.2.2.1 Assembly information and projections

The comparison between these two software tools do not use the latest information with regards to historic data or projections of SNF. NGSAM requires heat curves for each assembly in the historic data

and in the fuel projections. The UDB has some of this information (e.g., the GC-859[a] historic data), but without all subsequent pieces (projections based on GC-859, and heat curves) NGSAM cannot realistically model the performance of the system.

A previous version of the UDB contains all necessary information, and that set of historic data (RW-859), fuel projections, and heat curves are included. Thus, the models here used this older, but more complete, set of assembly information for the sake of comparison.

Despite every effort to maintain and control for consistency between the models, there were two disparities of note between the assembly information for the two models. First, there is one assembly at Oconee in the CALVIN input data that is absent from the NGSAM input data. Second, NGSAM is missing eight assemblies that were discharged at Prairie Island. These nine disparate assemblies are an extremely small fraction of the total number of assemblies in the simulation (over 480,000) and so this inconsistency does not significantly impact our results. These issues were only identified through the benchmarking process, and the UDB development team was notified. There is every expectation that these inconsistencies will be eliminated in future releases of the UDB.

2.2.2.2 Heat Curves

Regressing to a prior version of the UDB does not eliminate all complications to the process. Because NGSAM uses assembly specific calculations for calculating assembly and package heat the UDB must have a heat curve for every assembly in the database. CALVIN uses a set of generic calculations for assembly heat and so is not bound by such a requirement. The version of the UDB being used for this benchmarking process has roughly 300 assemblies that do not have associated heat curves. The result was NGSAM modeling those assemblies as never cooling and thus never being capable of loading into canisters.

To allow the benchmarking process to go forward, NGSAM simply assumes that those assemblies have zero heat. This is such a small fraction of the total number of assemblies that this modification does not significantly impact the behavior of NGSAM beyond what is necessary for this benchmarking process. This issue is only mentioned here to note that the identification of this problem was communicated to the UDB development team, and efforts have already been taken that will prevent the propagation of this problem into the GC-859 update to the UDB.

2.2.2.3 Cask types

CALVIN can model an extensive number of cask and canister types. NGSAM is currently limited to modeling only those canister types that have been provided by the UDB. As such, some sites in the comparison use slightly different canisters in each of the two models. It should be noted however that these differences are very small relative to some of the larger differences in the simulations. As with the fuel projections, more canister and cask types with be modeled as they are included in the UDB.

2.2.2.4 Short loading of canisters

CALVIN includes versions of canisters and casks that the model permits to be loaded below their full capacity. These short loads allow for hotter assemblies to be shipped. NGSAM has functionality allowing the user to define a minimum percentage of the canister's full capacity to which a canister can be loaded. However, in this benchmark NGSAM was not permitted to use short loads, and every canister was loaded to its full capacity. In CALVIN however, the performance of the algorithm was so poor without permitting short loads that the models became difficult to compare. CALVIN's poor performance without short loads is due partially to its simplistic loading algorithm.

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[a] Form RW-859 and GC-859 are the Nuclear Fuel Data Surveys collected by the U.S. Department of Energy. Information obtained via the RW-859 surveys is in the process of being replaced by the updated data obtained through the GC-859 surveys.

2.2.2.5 Loading algorithms

NGSAM has implemented a new algorithm for loading of SNF assemblies into canisters or casks. This algorithm [4] was provided by NFST analysts at ORNL and is significantly more advanced than the loading algorithm in CALVIN. The new algorithm loads packages in a manner representative of how they are loaded at existing nuclear reactor sites. The impact of this algorithm is significant and the results in section 3.1 show the degree of this impact. It needs to be noted however that the implementation of this algorithm has not gone through an IV&V process, whereas the relatively simpler loading algorithm in CALVIN has gone through such a process.

2.2.2.6 Allocation process

For the comparison of the two models the OFF allocation is used. However, each piece of software has a different method of implementing that allocation. In CALVIN, the allocation is provided to sites as MTU permitted to ship. Within some error bound, this amount is permitted to round up or down to prevent the acceptance of partially empty transportation packages. NGSAM provides allocations to sites as a number of transportation packages that will be accepted. This difference, slight though it may appear, has a non-trivial effect on the differences between these two models and the extent of that effect is discussed in section 3.1 of this report.

It is worth noting that the OFF allocation is created by the software based on the assembly information provided by the UDB. Both CALVIN and NGSAM are capable of modeling user designed allocations that specify allocations to each site, in each year of the simulation. The NGSAM method for modeling this site specific allocation was tested in this benchmarking process, and it was found to be working according to the design requirements. Like other elements of NGSAM discussed here, this portion of the software has not gone through a formal IV&V process.

2.2.2.7 Transportation constraints

CALVIN does not consider transportation constraints (e.g., fleet size, reactor availability) as it models the waste management system. It simply determines what shipments should occur each year regardless of any constraints. The resultant shipment list is then provided to TOM where the acquisition and scheduling of assets is modeled. A major improvement in NGSAM is the modeling of transportation integrated with the rest of the simulation. This is accomplished via a java implementation of TOM (titled JTOM), that can be run monthly, annually, or over any interval within the NGSAM simulation. Thus, if the transportation requirements on the fleet are too high in a given time period, that effect will propagate throughout the rest of the simulation. Possibly delaying the shipment of SNF that would otherwise be modeled without delay in CALVIN.

Numerous issues were found with the implementation of transportation constraints in NGSAM. All of those issues were corrected in the interim releases of the software that took place throughout the effort. All known issues have been corrected in the version being benchmarked in the full scenario evaluation (Section 3.1), while some of these issues are still present in the version of NGSAM benchmarked in the shutdown site scenario (Section 3.2).

2.2.2.8 Pool capacity and differentiation

CALVIN models each pool individually at reactor sites. NGSAM does not model individual pools at sites and instead aggregates the pool capacity at a site. This affects the way NGSAM models the need to transfer SNF to dry storage, and so also impacts the comparisons here. Increasing the fidelity in modeling the pools at reactor sites is an ongoing effort in NGSAM development.

2.2.2.9 Canister assignments to reactor sites

Like CALVIN, NGSAM is capable of changing the canisters used at reactor sites over the course of the simulation. CALVIN assigns the canister and cask types to pools at reactor sites. NGSAM assigns

canister and casks types to entire sites with no differentiation within the site. This distinction becomes relevant when sites have a mixture of BWR and PWR assemblies. CALVIN differentiates these assemblies by modeling them being stored in different pools. For example, the PWR assemblies in Brunswick pool 1 are modeled as being in a different pool than the other (BWR) assemblies in Brunswick pool 1. Thus, CALVIN allows PWR canisters to be matched to PWR assemblies, and BWR canisters to be matched to BWR assemblies at Brunswick. Since NGSAM models canisters to reactor sites, it is unable to differentiate between BWR assemblies and PWR assemblies at the same site. As a result, there are some sites (e.g., Morris, Brunswick, Hatch) where assemblies are modeled as loaded into the wrong type of canister. This has significant impact as the difference between canisters used for transportation at sites are significant (37 PWR assembly canisters compared to 67 or 89 BWR assembly canisters). The results of that impact are noted in section 3.1 of this report.

A more faithful modeling of reactor sites is an ongoing effort in NGSAM. This includes differentiation of assembly types at a single reactor site, and the associated canisters necessary for their transportation or storage.

2.3 References

[3] Jarrell J., *FY15 Reference Interim Storage Facility Scenario for Systems Analyses*, February 2015.

[4] Banerjee K., Jarrell J., *Dry Storage Loading Algorithm*, FCRD-NFST-2015-000642, June 19, 2015.

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3. BENCHMARK RESULTS

Two sets of scenarios were used to benchmark NGSAM against CALVIN. The first is a scenario involving all reactor sites in the fleet and the storage pool at Morris. It is a comparison of the software at a high level addressing fleet wide characteristics such as acceptance rate of assemblies, and dry storage inventory across the fleet. The second comparison is restricted exclusively to nine shutdown reactor sites (Maine Yankee, Yankee Rowe, Connecticut Yankee, Humboldt Bay, Big Rock Point, Rancho Seco, Trojan, La Crosse, and Zion) Fewer sites in this comparison allows for a more detailed comparison at the site level. Transportation considerations are also part of the comparison between shutdown sites, but excluded from the evaluation of the larger scenario of all sites. As noted in Section 2, the shutdown sites scenario in Section 3.2 uses an older version of NGSAM (2.1.0.3) than the version used in the full scenario benchmark in Section 3.1 (2.1.0.4).

3.1 Full Scenario

To benchmark the performance of NGSAM against CALVIN at the highest level of the waste management system scenarios involving the entire reactor fleet (and the storage site at Morris) are compared. Overall the comparison is encouraging as NGSAM performs as anticipated and most discrepancies can be attributed to some of the modeling caveats mentioned above. Notably, the advanced loading algorithm implemented in NGSAM has a significant impact on how well and quickly the simulation results in the removal of fuel from the reactor fleet.

3.1.1 Acceptance of SNF

The number of transportation packages shipped from the reactor fleet in each year of the simulation are provided in Figure 3-1. NGSAM consistently ships the specified 225 transportation packages every year except 2065. This is as expected since the acceptance rate in NGSAM is set by identifying the maximum number of canisters to accept in each year. Only 144 packages are shipped in the final year of shipments, 2065, as those are the final canisters remaining in the fleet. CALVIN ships a variable number of canisters each year. Again, this is to be expected as allocation in CALVIN is set by listing setting the maximum amount of MTU accepted each year. The mass of uranium in a transportation package can vary widely (because of canister capacity and the differences between PWR and BWR canister sizes), and so there are a varying number of transportation packages shipped by CALVIN each year.

In both models, the amount of SNF shipped decreases dramatically at roughly the same time. In 2065 the NGSAM packages accepted drops from 225 to 144, and are then zero thereafter. In CALVIN the number of packages drops from over 200 packages to 80 in 2067, less than 50 in 2068, and decreases each year thereafter. All told, the number of transportation packages shipped differs by 8% (10,044 packages in NGSAM compared to 10,856 in CALVIN), and this difference can be attributed to the caveats of mismatched canisters at some sites as well as the short loads permitted by CALVIN mentioned in Section 2.

As mentioned in Section 2, NGSAM implements a new algorithm for modeling the loading of canisters. This new algorithm allows canisters loaded into dry storage to cool below their transportation thermal limits faster than those canisters loaded via the algorithm in CALVIN. Thus, these final shipments of SNF in CALVIN can almost all be attributed to canisters that have been placed into dry storage below storage thermal limits, but have not yet cooled enough to be transported. This long “tail” of shipments and reactor sites can be seen throughout the results of this benchmark comparison.

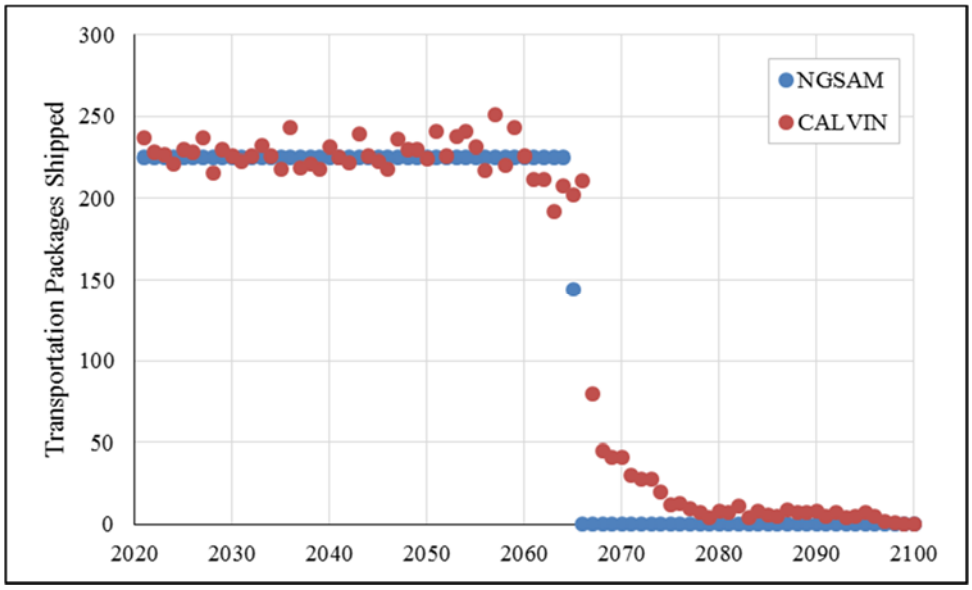

Figure 3-1: Number of transportation packages shipped each year

The number of assemblies shipped each year for each of the models is presented in Figure 3-2. As expected, the pattern is similar to that of Figure 3-1, with one exception. With just a few exceptions, the number of assemblies shipped each year by NGSAM is consistently larger than the number of assemblies shipped by CALVIN until 2065 when NGSAM finishes shipping SNF. This is an artifact of two things. The first being that CALVIN allows for a short loading of canisters, and that can result in fewer assemblies shipped despite more transportation packages being shipped. Second, as mentioned in Section 2, there is a mismatch in canisters being used at some of the sites, so a different number of assemblies are shipped.

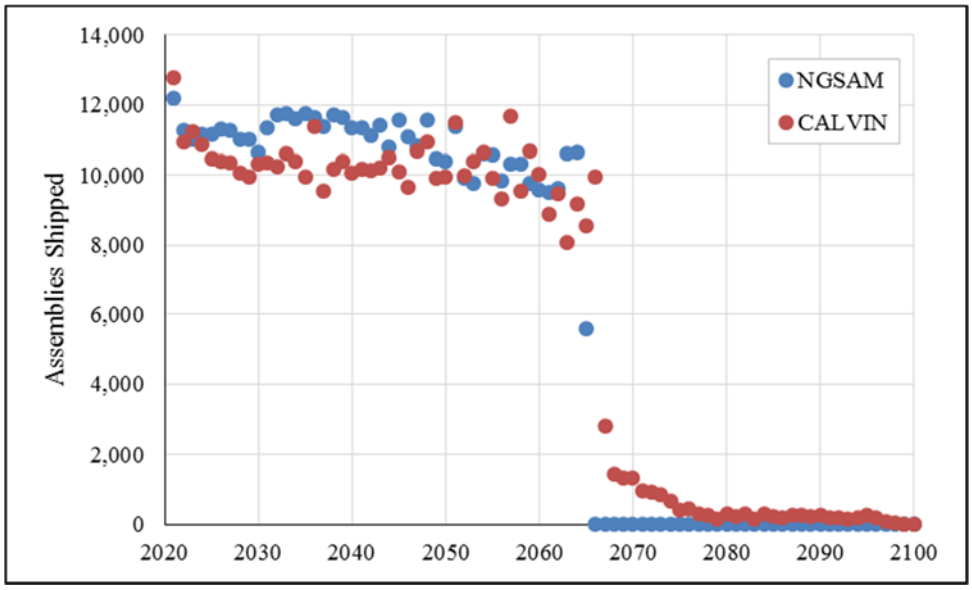

Figure 3-2: Number of assemblies shipped each year

The cumulative number of assemblies accepted over the course of the model simulations is displayed in Figure 3-3. In all cases, the total number of assemblies is the same for NGSAM and for CALVIN save for the 9 assembly discrepancy mentioned in Section 2 (8 assemblies at Prairie Island and 1 assembly at

Oconee). Furthermore, the correct number of assemblies are accepted at each individual site, again, save for the known 9 assembly discrepancy. Figure 3-3 illustrates a relatively steady acceptance rate for the NGSAM starting in the year 2021 and ending in 2065 with the last of the SNF accepted. The acceptance rate for CALVIN is steady until it drops off dramatically in 2067. Again, the SNF in CALVIN loaded into dry storage remains at reactor sites until cool enough to transport delaying acceptance of the final SNF from the reactor fleet. Note that the vast majority of the fuel in CALVIN is accepted in a similar timeframe as NGSAM with only 3.3% of the assemblies remaining in the fleet after 2065.

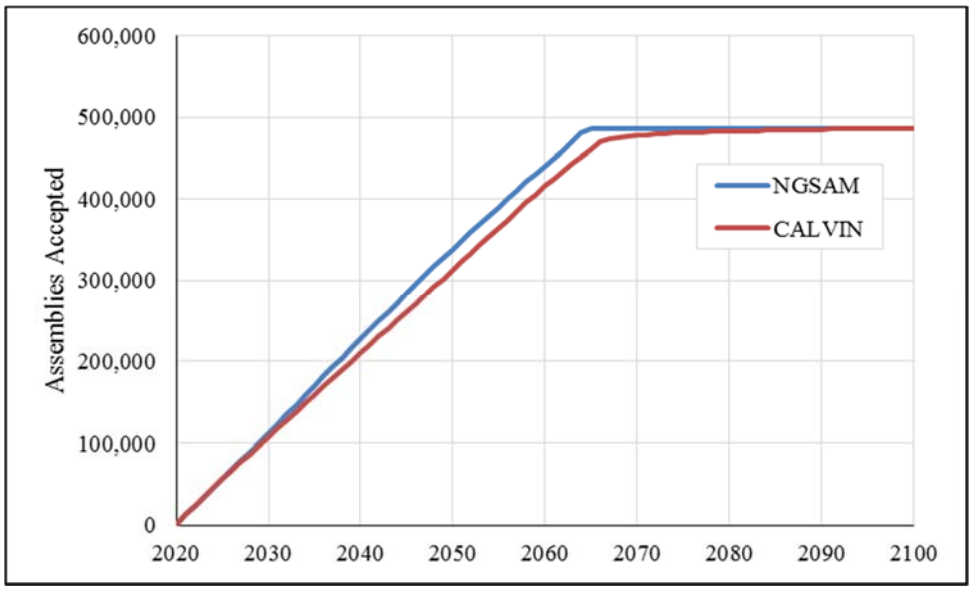

Figure 3-3: Cumulative number of accepted assemblies

3.1.2 Dry storage inventory

The dry storage inventory for the entire fleet is illustrated in Figure 3-4. NGSAM puts a significantly larger amount of canisters into dry storage (peak inventory), and does so earlier than CALVIN. This is to be expected given the caveats regarding NGSAM's ongoing efforts in modeling pool inventory, and the lack of refinement regarding transferring pool inventories to dry storage after reactor shutdown. The most glaring example of this issue occurs at Morris.

NGSAM treats Morris as a reactor site, and the last discharge date of assemblies stored in Morris are treated the same way as any other final discharge at a reactor site. Sites are anticipated to empty their pool five years after reactor shutdown, so NGSAM models this occurring at five years after the last discharge date of any assembly at the site. Thus, NGSAM has modeled Morris as "shutdown" in 1977 (the latest year of discharge from an assembly in Morris's pool), and starts transferring all of the assemblies in the pool to dry storage in 1982. This problem is then exacerbated due to the aforementioned mismatch of canisters to assemblies as Morris has a number of BWR assemblies that NGSAM loads into 37 assembly PWR canisters rather than the 89 BWR canisters that CALVIN uses.

While not as egregious as the dry storage discrepancies at Morris, there are other circumstances contributing to the earlier and larger amount of dry storage in NGSAM compared to CALVIN. While most of these discrepancies can be attributed to a mismatch of canisters to assemblies, and pool inventories, some still can be attributed to CALVIN's modeling of specific sites' dry storage campaigns more accurately than NGSAM. For example, CALVIN has modeled some of the historic dry storage loading campaigns to exactly what reactors have done, whereas NGSAM models the loading of all dry storage canisters in the same way throughout the simulation. As mentioned in Section 2, NGSAM is

expected to implement modeling at a greater level of fidelity with respect to how pools and different assembly types are modeled by the end of FY16.

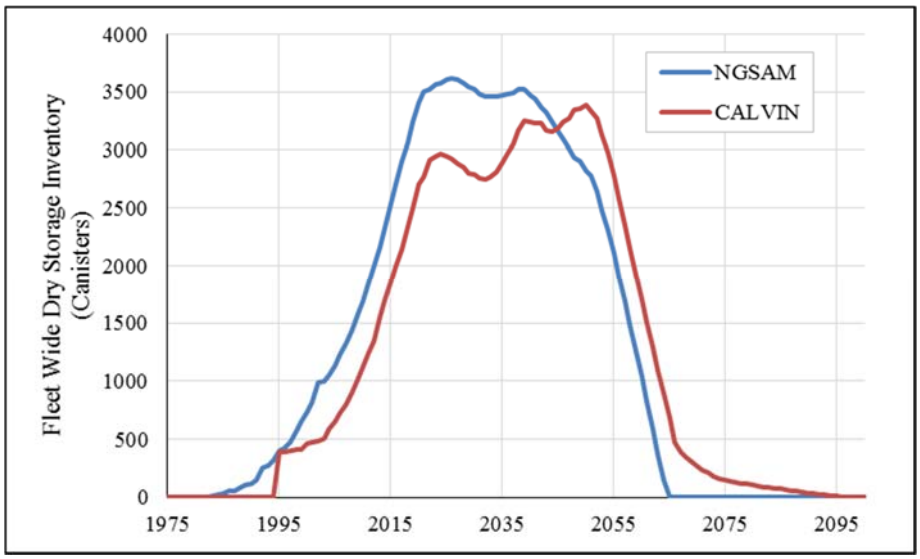

Figure 3-4: Total number of canisters in dry storage in reactor fleet

3.1.3 Clearing sites of SNF

The total number of sites with SNF on site each year is illustrated in Figure 3-5 along with the number of operating sites each year. Note, these are all sites with SNF on site, not just those that have shutdown. As mentioned in Section 2, NGSAM implements a new algorithm for modeling the loading of canisters. This new algorithm allows canisters loaded into dry storage to cool below their transportation thermal limits faster than those canisters loaded via the algorithm in CALVIN. Thus NGSAM is able to ship all of the SNF from reactor sites by 2065 and CALVIN takes significantly longer finishing in 2097. Also, the CALVIN results indicate that less than 10 sites have fuel on site from 2075 through 2097. This means that it took 22 years to ship 162 canisters. Contrasting this with the 200+ canisters shipped each year between 2021 and 2066, the impacts of canisters cooling at sites until reaching transportation thermal limits becomes obvious.

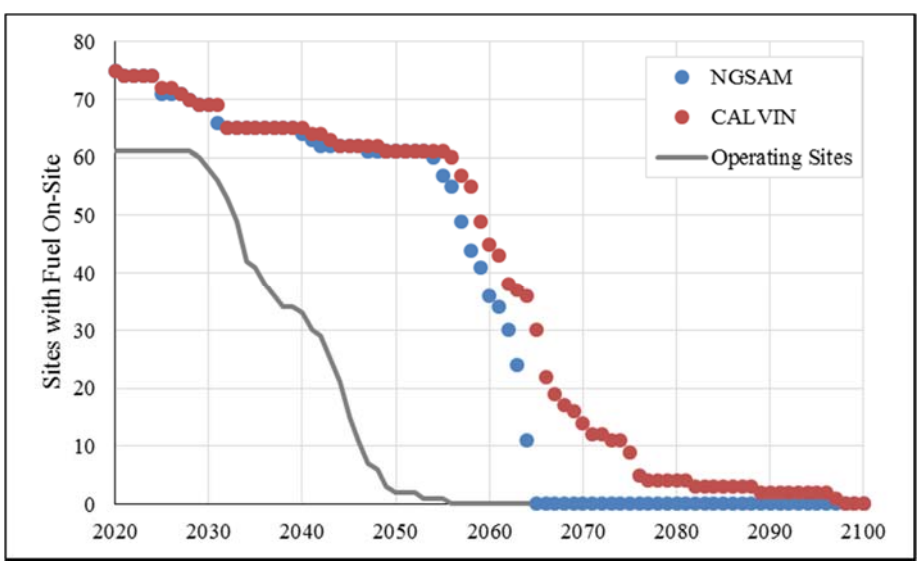

Figure 3-5: Total number of sites with fuel on site and the total number of operating sites each year

As one might expect, the last sites to be cleared by CALVIN are those with the greatest disparity between the date the site was cleared in CALVIN and the date it is cleared in NGSAM. Table 3-1 provides the 11 sites with the greatest disparity between final shipment dates. Additionally, the next 12 sites with the greatest differences are also included.

Table 3-1: Sites with the greatest difference between last shipments in NGSAM and CALVIN

	Year of Last Shipment		
	NGSAM	CALVIN	dif.
South Texas	2065	2098	-33
Watts Bar	2065	2097	-32
Beaver Valley	2065	2089	-24
Summer	2063	2082	-19
McGuire	2063	2076	-13
Comanche Peak	2065	2077	-12
Braidwood	2065	2076	-11
Byron	2065	2076	-11
Callaway	2064	2075	-11
Harris	2064	2075	-11
Vogtle	2065	2076	-11
Salem	2062	2070	-8
Seabrook	2065	2073	-8
Sequoyah	2062	2070	-8
Diablo canyon	2064	2071	-7
Indian Point	2059	2066	-7
Three Mile Island	2058	2065	-7
Wolf Creek	2064	2071	-7
Ark Nuclear	2061	2066	-5
Farley	2062	2067	-5
Waterford	2064	2069	-5
Millstone	2064	2068	-4
Clinton	2065	2068	-3

The greatest differences are clearly severe outliers. After the eleven sites with the greatest disparity, the remaining sites are all cleared within the same 10 years in NGSAM and CALVIN. Furthermore, outside of the 23 sites listed in Table 3-1 all the other sites are cleared with less than a 2 year disparity between the two models. Again, this demonstrates that the delay in shipping fuel from sites in CALVIN is due largely to a period of cooling for canisters loaded into dry storage with a few sites (less than 15% of the fleet) being the greatest offenders.

3.1.4 Isolating Impacts of Transportation Thermal Limits

To attempt to isolate the impacts of transportation thermal limits in CALVIN, a version of CALVIN was simulated assuming no thermal limits on the transportation of canisters from reactor sites. The results of that run brought the acceptance schedule in CALVIN much closer to that of NGSAM. This further supports the conclusion that the enhanced loading algorithm in NGSAM is the primary driver of the accelerated site clearance in NGSAM over CALVIN.

Figure 3-6 illustrates the number of transportation packages shipped each year for the CALVIN simulation that ignores thermal constraints on transportation packages. In contrast with the previous CALVIN results, the shipments here closely mirror those of NGSAM with all sites being cleared of SNF as of 2067 rather than 2097 when thermal limits are applied. The remaining discrepancies between

CALVIN and NGSAM are due to a combination of differences in the way SNF shipments are allocated to the fleet, the mismatches of canister to assembly type at some reactor sites, and the inconsistencies of some canisters being used between CALVIN and NGSAM.

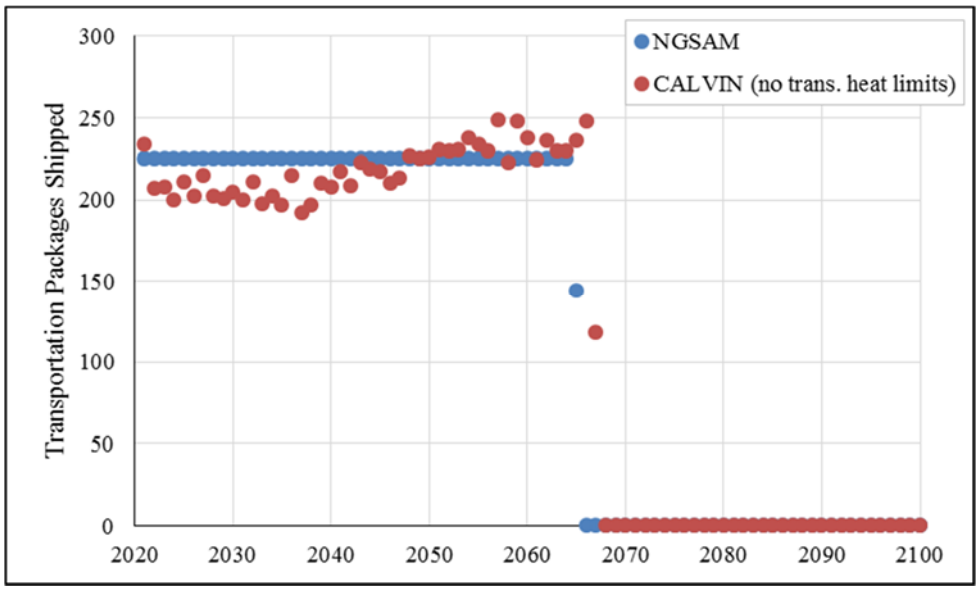

Figure 3-6: Number of transportation packages shipped each year for CALVIN without transportation heat limits and NGSAM

Removing the thermal limits in the CALVIN scenario allows for a more straightforward comparison of the sequence in which sites are cleared of SNF. The OFF allocation in CALVIN, is not identical with how it is retrieved from the sites due to the thermal constraints on transportation. These same constraints exist in NGSAM, but the loading logic algorithm in NGSAM reduces the impact of this restriction by loading canisters in such a way that they are able to satisfy those constraints. By removing the transportation thermal limits from CALVIN, we can more readily compare the order in which each site is cleared of SNF.

The first 10 and last 10 sites to be cleared of SNF in each model are provided in Table 3-2 along with the year in which the site is cleared in each simulation and the difference in those years between the two models. All sites are cleared in the same sequence between the two models. This is to be expected as both models are using the practice of OFF to allocation shipments to the sites. Note that there is a two year lag between NGSAM and CALVIN that manifests for later in the process. This is an artifact of the aforementioned issues with NGSAM loading some BWR assemblies into PWR smaller canisters. Finally, Figure 3-7 illustrates the number of sites that still have fuel on site each year. Aside from the two year lag previously mentioned in the later years of the system, the curves are identical. This provides further evidence that the impact of transportation thermal limits are the prime drivers of the discrepancies between the two models mentioned earlier in this section.

Table 3-2: Order in which sites are cleared of SNF

Order	Site	CALVIN (no trans. heat limit)	NGSAM	dif.
1	Humboldt Bay	2021	2021	0
2	Lacrosse	2025	2025	0
3	Morris	2025	2025	0
4	Rancho Seco	2027	2025	2
5	Yankee-Rowe	2028	2028	0
6	Trojan	2029	2029	0
7	Haddam Neck	2032	2031	1
8	Maine Yankee	2032	2031	1
9	Zion	2032	2031	1
10	Big Rock	2032	2032	0
	…	…	…	…
66	Beaver Valley	2067	2065	2
67	Braidwood	2067	2065	2
68	Clinton	2067	2065	2
69	Comanche Peak	2067	2065	2
70	Limerick	2067	2065	2
71	Palo Verde	2067	2065	2
72	Seabrook	2067	2065	2
73	South Texas	2067	2065	2
74	Vogtle	2067	2065	2
75	Watts Bar	2067	2065	2

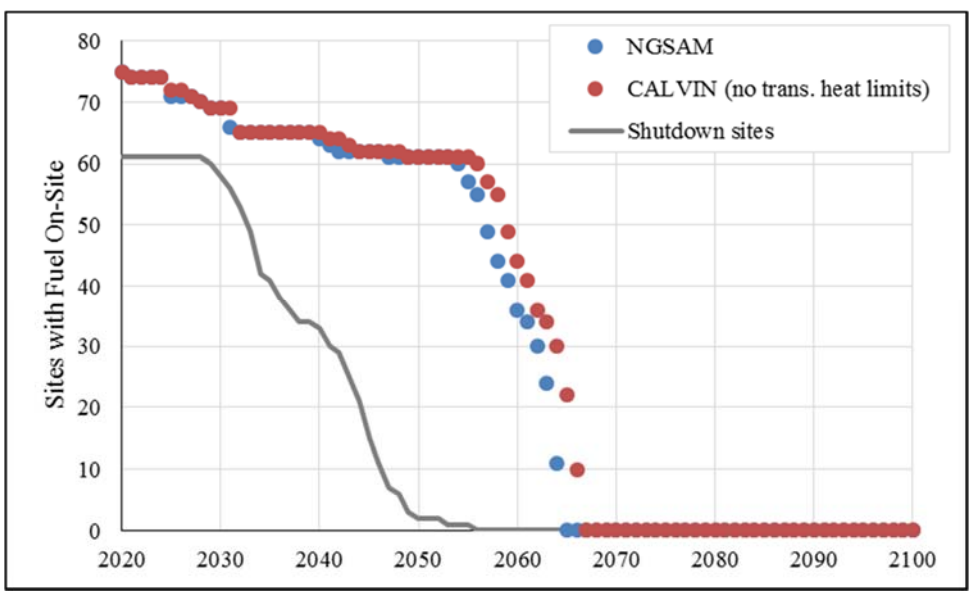

Figure 3-7: Total number of sites with fuel on site and the total number of operating sites each year.

3.1.5 Results discussion

There are a few key points to take away from the comparison of NGSAM and CALVIN in this section. The majority of the findings provided below are a direct result of the caveats presented in Section 2 of this report and, overall, support the performance of NGSAM.

- Both software tools collect the same number of assemblies from the reactor fleet save for the nine assembly disparity already accounted for as inputs to the simulations.
- NGSAM performs predictably in accepting 225 canisters per year until all fuel is cleared from the reactor fleet. Additionally, the 225 canisters per year is roughly equivalent to the 3000 MTU/yr prescribed by CALVIN. The two models match almost perfectly when the transportation thermal limits are removed from CALVIN since CALVIN's loading algorithm ends up overly constraining transportation.
- The disparity between canisters provided in each of the models and the use of short-loaded canisters in CALVIN results in NGSAM shipping a higher number of assemblies in fewer transportation packages than CALVIN.
- The improved loading logic in NGSAM results in sufficiently faster site clearance than in CALVIN. The loading logic in CALVIN requires canisters loaded to storage thermal limits to sit on site for decades before SNF has cooled sufficiently to be shipped off site. It is expected that the introduction of the improved loading algorithm would improve the ability of the waste management system to clear sites of SNF. However, the dramatic degree of this improvement necessitates a further inspection and IV&V on the loading algorithm and its results.
- The few assemblies that are delayed at reactor sites in CALVIN beyond the dates in which they were accepted in NGSAM account for a small fraction of all assemblies (3.3%) being modeled.
- Refinement of NGSAM is still required with regard to the modeling of pools at reactor sites. The current manner in which these are modeled in NGSAM is causing premature and excessive loading of SNF into dry storage at reactor sites.

3.2 Shutdown Sites Scenario

To benchmark NGSAM at a greater level of detail, a reduced scenario consisting of only the 9 shutdown sites were compared between CALVIN and NGSAM. Like the full scenario comparison, this reduced and more detailed comparison is favorable as NGSAM performs as anticipated and discrepancies can be attributed to one or more of the modeling caveats mentioned in section 2.

Nine oldest shutdown reactor sites were considered in this scenario. These reactors are: Maine Yankee (MY), Yankee Rowe (YR), Connecticut Yankee (CY), Humboldt Bay (HB), Big Rock Point (BRP), Rancho Seco (RS), Trojan (T), La Crosse (LC), and Zion (Z). The spent nuclear fuel (SNF) at these sites is already in the dry storage canisters. This allows for straightforward comparison of the calculated and actual dry storage inventory. A detailed site-by-site explanation of the results can be found in Appendix A. The results presented in this section are reduced to the relevant summary information.

Two major activities are examined in the comparison of this scenario. The first activity is transferring the SNF from the pools into dry storage. The second activity is transport of the dry storage canisters from the shutdown reactor sites to the interim storage facility (ISF). It is assumed that the transportation campaign starts in 2021 and continues for 4 years. The duration of the campaign is based on the shutdown site evaluation [5]. The results of this evaluation are preliminary, but they demonstrated that 9 shutdown reactor sites can be unloaded in four years with two 3-railcar consists.

3.2.1 Transfer to dry storage

The results of NGSAM were examined for consistency and compared to TSL (CALVIN and TOM). The comparison with CALVIN consisted of checking (1) the reactor discharges (total number of assemblies/MTU and the year of first and last discharge) and (2) dry storage inventory (type and number of dry storage canisters) at each site.

The NGSAM reactor discharges and dry storage inventory for site are compared to the historic site data in Table 3-3. The quantities calculated by NGSAM are in agreement with the site data, except the dry storage canister capacity. Again we see the result of the limited availability of canister types in the unified database as compared to what is available in CALVIN. The site-specific SNF inventory (number of assemblies and MTU) in NGSAM is consistent and correct. With a few exceptions, the dry storage canisters have the specifications consistent with the actual data. The transport of dry storage canisters from the shutdown reactor sites to the ISF was completed in four years and followed the specified pickup schedule.

Table 3-3: Historic data for sites in shutdown scenario

Site	Fuel Type	Dry Storage Canister	Canister Capacity	Number of SNF Canisters	Transportation Cask
Big Rock Point	BWR	W74	64	7	TS-125
Connecticut Yankee	PWR	MPC-26, -24	26	40	NAC-STC
Maine Yankee	PWR	UMS-24	24	60	NAC-UMS
Yankee Rowe	PWR	MPC-36	36	15	NAC-STC
Rancho Seco	PWR	FO-DSC, FC-DSC, FF-DSC	24	21	MP187
Trojan	PWR	MPC-24E/EF	24	33	HI-STAR 100
Humboldt Bay	BWR	MPC-80	80	5	HI-STAR 100
La Crosse	BWR	MPC-LACBWR	68	5	NAC-STC
Zion 1 and 2	PWR	TSC-37	37	61	NAC-MAGNATRAN

The logic of transferring SNF from pool to dry storage is implemented in accordance with the software requirements, but does not currently reflect the known behavior at reactor sites. That is, the assumptions regarding pools closing 5 years after the last discharge at the reactor site perform accurately in the software. However, these nine reactor sites did not close their pools in that timeframe. As a result, the dates in which canisters are loaded at these sites is correctly implemented, but not representative of history. Going forward, NGSAM will model the historic information regarding the loading of canisters at shutdown sites more faithfully. By incorporating the GC-859 data still being implemented into the UDB, NGSAM will start simulations with these canisters already loaded in accordance with historic information rather than simulating the loading of those algorithms.

Several issues were identified in this analysis. The site-specific issues are summarized in Table 3-4. One issue occurring at multiple sites is the forced loading of canisters immediately after the final discharge of SNF into the pool. This is a result of inaccuracies in the modeling of the pools mentioned in section 2.2.2. Specifically, the full core reserve remains in place even after the final discharge when the reactor shuts down. That means, NGSAM retains the full core reserve even after the reactor has shut down. This results in an artificially limited pool capacity. In turn, this causes the pools to unnecessarily load canisters into dry storage immediately after the last discharge in order to needlessly maintain a full core reserve. Again, this issue is relevant to the results shown here, however, this issue has been corrected in subsequent revisions of NGSAM including the version of NGSAM benchmarked in Section 3.1.

Table 3-4: Site-Specific Issues Identified for the Shutdown Reactors Scenario

Section	Site	Problem Description
A-4.1	Big Rock Point	Dry storage canister capacity is 68, should be 64.
		2 dry storage canisters are loaded shortly after last discharge.
A-4.2	Connecticut Yankee	1 dry storage canisters are loaded shortly after last discharge.
		Dry storage canister heat limits is lower than actual.
A-4.3	Maine Yankee	4 dry storage canisters are loaded shortly after last discharge.
A-4.4	Yankee Rowe	4 dry storage canisters are loaded shortly after last discharge.
		4 dry storage canisters are loaded before last discharge.
A-4.5	Rancho Seco	Last discharge occurs 2 years earlier than the actual.
A-4.6	Trojan	-
A-4.7	Humboldt Bay	3 dry storage canisters are loaded before last discharge.
A-4.8	La Crosse	1 dry storage canisters are loaded shortly after last discharge.
A-4.9	Zion	-

3.2.2 Transportation

The transportation component of NGSAM is implemented via the Java Transportation Operations Model to schedule trips and calculate transportation costs. JTOM is executed in every year of the NGSAM simulation to generate scheduled trips while the simulation is running. This is in contrast to TOM which calculates all shipment scheduling after the other logistic operations have been simulated by CALVIN.

Both JTOM and TOM use data stored in a database to define routes. However, TOM uses data generated by TRAGIS and JTOM uses routes generated by START. In TOM, the transportation vehicle speed is user-defined. For transportation by rail, the speed is defined for mainline (A, B, C) and shortline (A branch and B branch). JTOM defines rail speed in accordance with the track type obtained from START. Finally, NGSAM simulates the movement of railcars, which is not the same as simulating movement of a rail consist.

In addition to the above differences, there are also the differences between TOM and NGSAM scenarios, such as location of ISF. Because of these, some differences in the transportation results are expected. The major goal of the comparison was to check the transportation schedule for each shutdown reactor site and required transportation fleet.

The most notable issue with NGSAM's transportation modeling (Section A-4.10) is related to scheduling trips. There are long periods when no transportation takes place. Because of this, a significantly greater number of railcars are required to complete the transportation campaign in 4 years. It is not yet clear as to why this is occurring and a further examination of shipping within NGSAM is required.

3.2.3 Results discussion

There are a few key takeaways from the more detailed benchmark made on the shutdown sites. As with the full scenario, the majority of these findings provided below are a direct result of the caveats presented in section 2 of this report.

- A refinement of the pools at each reactor site was needed in NGSAM and has been corrected in a revision of NGSAM. Specifically, the handing of full core reserve upon final discharge at reactor sites, and flexibility in timing of pool closures relative to final site discharges.
- A refinement of transportation should be examined to determine the cause of the longer than expected downtime periods for railcars. While possible for these to be accurate given the current

set of information provide in JTOM (compared to that of TOM) the root cause needs to be determined.

3.3 References

[5] Maheras, S., Best, R., McConnell, P., and Kalinina, E., 2014. *Optimizing Shutdown Sites Shipping Campaigns*, FCRD-NFST-2014-000369, March 2014.

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4. CONCLUSIONS

The NGSAM benchmarking process has been beneficial beyond the assessment of NGSAM's capabilities. NFST analysts have a better understanding of the software than they did before the benchmarking process. NGSAM developers have received continuous feedback from systems analysts and have improved the both the fidelity of the models in NGSAM as well as the software's suitability in meeting analyst needs. Finally, this effort has "broken the ice" with respect to improved integration between NGSAM developers and NFST systems analysts. Communication between the two groups has improved dramatically because of this process and will continue as NGSAM development advances. Additionally this communication has also encouraged an increase in communication between the NGSAM development team and developers of the UDB.

The analysis of NGSAM's performance demonstrates the software's progress since development began. Analysis of results at the system level are largely as expected due to recent revisions to correct errors identified by the benchmarking process. Sites are cleared of SNF in the proper sequence according to the OFF allocation strategy. NGSAM models the acceptance of all assemblies from the reactor fleet. Differences in how quickly sites are cleared of SNF and how many transportation packages are shipped from the fleet are expected and explained by known discrepancies between the software (e.g., new canister loading algorithms, short loaded canisters). A more detailed inspection of the shutdown sites also shows results that should be expected from NGSAM. It should be noted that NGSAM performs much better in this report than it did at the beginning of the benchmarking process. This is further testament to the positive impact of increased integration between systems analysts and NGSAM developers.

Despite the positive performance of NGSAM in this comparison, there are still outstanding issues with NGSAM that are affecting the software's performance and fidelity in modeling the SNF waste management system. NGSAM does not accurately model the pools at reactor sites, and there is currently no way to model different canisters at the same reactor site. These issues are of particular interest as the mismatch between assemblies and the canisters being used at some sites is one of the prime drivers in the differences between the number of transportation packages shipped in NGSAM and CALVIN.

4.1 Path Forward

While this benchmarking process is beneficial in a number of respects, it is not a replacement for a formal IV&V process. A complete IV&V at this stage of NGSAM's development would not be beneficial and, for now, this results oriented benchmarking process is sufficient to inform the development of NGSAM and enhance NFST systems analysts competency with the software. Systems analysts will continue to use the software in parallel with NGSAM development to build upon the success of the current benchmarking process.

There are no remaining milestones specifically related to the benchmarking of NGSAM in FY16. NGSAM is currently developing models for the behaviors of an ISF within the waste management system. The expectation is to have a milestone, similar to this report, in the early part of FY17 focusing on benchmarking the performance of NGSAM's ISF model. Continued NGSAM use and communication between NGSAM developers and systems analysts during FY16 is necessary in preparation for such a report in FY17.

The UDB is the primary source of data for NGSAM. As the UDB continues its development, NGSAM will continue to implement new data elements as they become available. The most immediate area of focus in this regard is the update of assembly data in the UDB. The addition of historic data from the GC-859 reporting is already well underway. Calculating heat curves for each assembly in the GC-859 data has yet to be completed, as well as fuel projections based on the GC-859 data, and heat curves for the projected assemblies. The addition of this information in the UDB will allow NGSAM to start its simulation in 2012 with the known state of the system rather than simulating the history of the reactor

fleet up until that time. This will be a significant shift in the NGSAM model, and will require a benchmarking effort to evaluate the results of this model change. However, this implementation is well worth the effort as it will solidify the accuracy of the model with respect to known historic behavior of the reactor fleet.

Finally, NGSAM will continue its development in accordance with the schedule planned for the FY16 work package. This includes a detailed modeling of an ISF as part of the waste management system, and an incorporation of updated assembly information as it becomes available. Addressing the issues identified by this benchmarking process is also a significant portion of the NGSAM development effort.

Appendix A
SHUTDOWN REACTOR SITES TEST IN SUPPORT OF NGSAM BENCHMARK

A-1. INTRODUCTION

The purpose of this analysis was to develop a relatively small test case to facilitate comparison of NGSAM against CALVIN and TOM. This analysis supports the ongoing effort of the NGSAM benchmark. The tested version of NGSAM (for this Appendix) was 2.1 beta 3.

The shutdown reactors sites were selected for this test because they cover a number of representative at-reactor conditions while maintaining reasonably small scenario size. Another benefit of this test is providing support to the ongoing NFST Hardware Needs Project that evaluates different alternatives of unloading the shutdown reactor sites.

The description of the test case is provided in Section A-2. Section A-3 discusses the approach to testing. Section A-4 provides an analysis of the test results for each shutdown reactor sites. Section A-5 summarizes the findings made in Section A-4.

A-2. SHUTDOWN REACTOR SITES TEST CASE

Nine oldest shutdown reactor sites were considered in the test case scenario. These reactors are: Maine Yankee (MY), Yankee Rowe (YR), Connecticut Yankee (CY), Humboldt Bay (HB), Big Rock Point (BRP), Rancho Seco (RS), Trojan (T), La Crosse (LC), and Zion (Z). The spent nuclear fuel (SNF) at these sites is already in the dry storage canisters. This allows for straightforward comparison of the calculated and actual dry storage inventory. The GTCC inventory was not included in the test case.

The SNF inventory (Ref. 1) is summarized in Table A-1. The dry storage canisters at each site were defined in NGSAM in accordance with data in Table A-1. Note that little information is available on timing of loading and the properties of the SNF assemblies loaded into a specific dry storage canister. Consequently, only the total inventory (canisters, assemblies, and MTU) stored at each site can be checked.

Table A-1: SNF Inventory at the Shutdown Reactor Sites

Site		Fuel Type	Dry Storage Canister	Canister Capacity	Number of SNF Canisters	Transportation Cask
Eastern	Big Rock Point	BWR	W74	64	7	TS-125
	Connecticut Yankee	PWR	MPC-26, -24	26	40	NAC-STC
	Maine Yankee	PWR	UMS-24	24	60	NAC-UMS
	Yankee Rowe	PWR	MPC-36	36	15	NAC-STC
Western	Rancho Seco	PWR	FO-DSC, FC-DSC, FF-DSC	24	21	MP187
	Trojan	PWR	MPC-24E/EF	24	33	HI-STAR 100
	Humboldt Bay	BWR	MPC-80	80	5	HI-STAR 100
Central	La Crosse	BWR	MPC-LACBWR	68	5	NAC-STC
	Zion 1 and 2	PWR	TSC-37	37	61	NAC-MAGNATRAN

Two major activities are simulated in this test case. The first activity is transferring the SNF from the pools into dry storage. The second activity is transport of the dry storage canisters from the shutdown reactor sites to the interim storage facility (ISF) arbitrarily located in the eastern US. It is assumed that the transportation campaign starts in 2021 and continues for 4 years. The duration of the campaign is based on the shutdown site evaluation [Ref. 2]. This evaluation demonstrated that 9 shutdown reactor sites can be unloaded in four years with two 3-railcar consists. In this evaluation the location of ISF was arbitrarily assumed to be close to the geographic center of US. However, based on the previous studies (Ref. 3) it was concluded that location of the ISF has minor impact on the transportation analysis results. Consequently, the difference in the ISF locations was considered to be acceptable for the purpose of the test.

Note that the current version of NGSAM only has the rail routes. This affects four following sites that do not have direct access to rail: Yankee Rowe, Big Rock Point, Connecticut Yankee, and Humboldt Bay. The simulated routes from these sites to the ISF are shorter than the actual routes. Also, the routes in NGSAM are taken from START (Ref. 4) and the routes used in Ref. 2 evaluation are from TRAGIS (Ref 7).

Figure A-1 shows de-inventorying scenario for the rail mode and two 3-car consists taken from Ref. 2. The rail mode means that the rail was used wherever it was possible. However, the other modes were used as well if the site did not have direct access to the rail. The de-inventorying was done in sequential order.

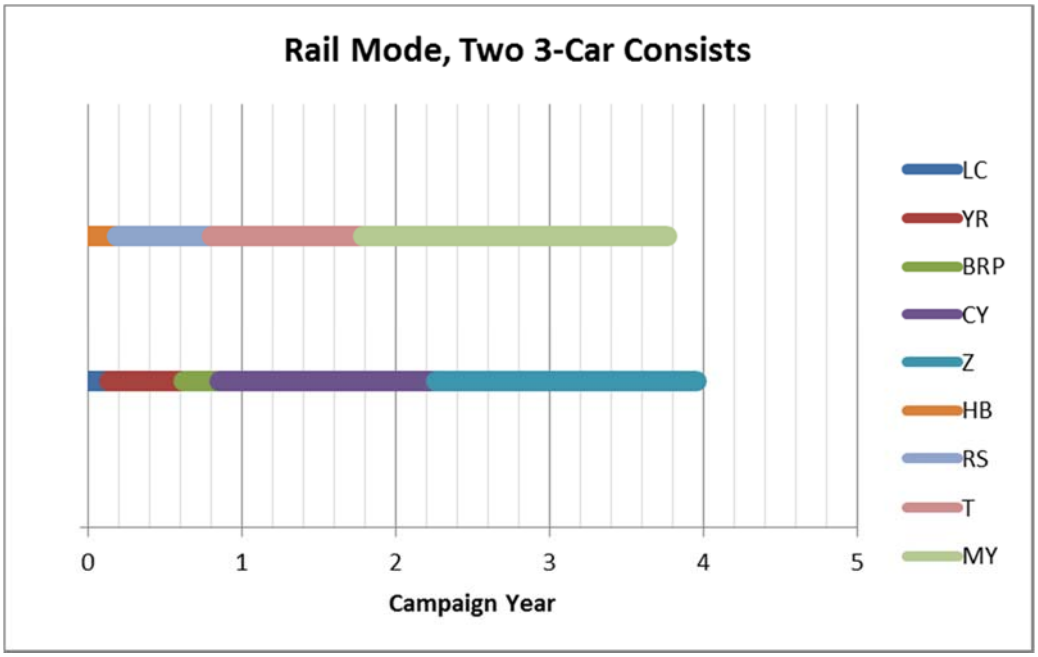


Figure A-1. De-Inventorying Schedule for Rail Mode and 3-Car Consist Scenario

The de-inventorying scenario shown in Figure A-1 was used to generate the pickup schedule for NGSAM test case (Table A-2). To implement this pickup schedule, the site allocation in NGSAM scenario was defined accordingly.

Table A-2. Number of Canisters to Be Transported Each Year of the Transportation Campaign

Site	Year 1	Year 2	Year 3	Year 4	Total	Distance to Rail
LC	5	0	0	0	**5**	0
YR	15	0	0	0	**15**	7.5 mi
BRP	7	0	0	0	**7**	12.5 - 52 mi
CY	6	34	0	0	**40**	12.5 mi
Z	0	0	30	31	**61**	0
HB	5	0	0	0	**5**	160-260 mi
RS	21	0	0	0	**21**	0
T	6	28	0	0	**34**	0
MY	0	3	30	27	**60**	0
Total					**248**	

The current version of NGSAM does not calculate the transportation fleet required to realize the pickup schedule. The number of railcars has to be specified by the user. 50 railcars were defined in the test case (6 railcars were required in Ref. 2). Note that the current version of NGSAM models the movement of a railcar or a group of railcars, it does not model the movement of a consist. The maximum number of railcars in a group was set equal to 3, which reflects the maximum consist size used in Ref. 2 scenario.

The shutdown reactors test case was implemented as a separate NGSAM scenario entitled ***Phase3Proto1NineShutdown***. In this scenario, each shutdown site represents a separate installation. The transportation is implemented via the notional Transportation Installation. The ISF is also an installation, but its functions are limited to providing an end point for transportation.

A-3. TEST EVALUATION APPROACH

The NGSAM shutdown reactors scenario described in Section A-2 was executed and the results were examined for consistency and compared to CALVIN and TOM.

A-3.1 Comparison to CALVIN

The comparison with CALVIN consisted of checking (1) the reactor discharges (total number of assemblies/MTU and the year of first and last discharge) and (2) dry storage inventory (type and number of dry storage canisters) at each site.

To check the reactor discharges, the shutdown reactor data were extracted from the CALVIN fuel projection database. Note that NGSAM simulates each discharge using the information on discharge year from the fuel projection and the actual date of discharge is not necessarily the same as in the fuel projection. The dry storage inventory was compared to the data in Table A-1. The inventory in the pool was checked for consistency with the general knowledge of the operations at the shutdown reactor sites. According to this, the number of assemblies discharged in the pool was less than pool capacity. As a result, the first transfer to dry storage occurred 5 years (or longer) after the reactor was shut down.
The unit costs in the current of NGSAM version are arbitrary values. The costs were checked for consistency with the site activities. For example, the operational costs are expected to occur each time the dry storage canister is loaded. The dry storage costs are expected to occur each time the dry storage pad is constructed.

A-3.2 Comparison to TOM

The transportation is implemented in NGSAM via notional Transportation Installation. Transportation Installation uses the Java Transportation Operations Model (JTOM) to schedule trips and calculate transportation costs. JTOM is executed every simulation year to generate scheduled trips.
JTOM is basically TOM written in Java. However, as it was previously discussed, the current version of NGSAM does not implement all the capabilities available in JTOM. For example, it does not calculate the transportation fleet. The number of railcars, escort cars, and buffer cars are defined by the user.
Both, JTOM and TOM use data in the database to define routes. However, TOM uses data generated by TRAGIS and JTOM uses data generated by START. In TOM, the transportation vehicle speed is user-defined. For transportation by rail, the speed is defined for mainline (A, B, C) and shortline (A branch and B branch). JTOM defines rail speed in accordance with the track type obtained from START. Finally, NGSAM simulates the movement of railcars, which is not the same as simulating movement of a consist.
In addition to the above differences, there are also the differences between TOM and NGSAM scenarios, such as location of ISF. Because of these, some differences in the transportation results are expected. The major goal of the comparison was to check the transportation schedule for each shutdown reactor site and required transportation fleet.

A-4. DISCUSSION OF TEST RESULTS

NGSAM generates large output because it tracks every action and every property. The time-dependent quantities (instantaneous or cumulative) are available for each installation (shutdown reactor site). These quantities were examined in accordance with the evaluation approach described in Section A-3. The results of the evaluation are considered below for each shutdown reactor site. Note that greater detail is provided for the first site (Big Rock Point) to demonstrate how the comparison was done. For the other sites, this level of details is provided only when necessary to demonstrate a specific problem.

A-4.1 Big Rock Point

The NGSAM reactor discharges and dry storage inventory are compared to the site data in Table A-3. The quantities calculated by NGSAM are in agreement with the site data, except the dry storage canister capacity. Different capacity is used in NGSAM scenario because the specifications for the actual canister type used at Big Rock Point are not available.

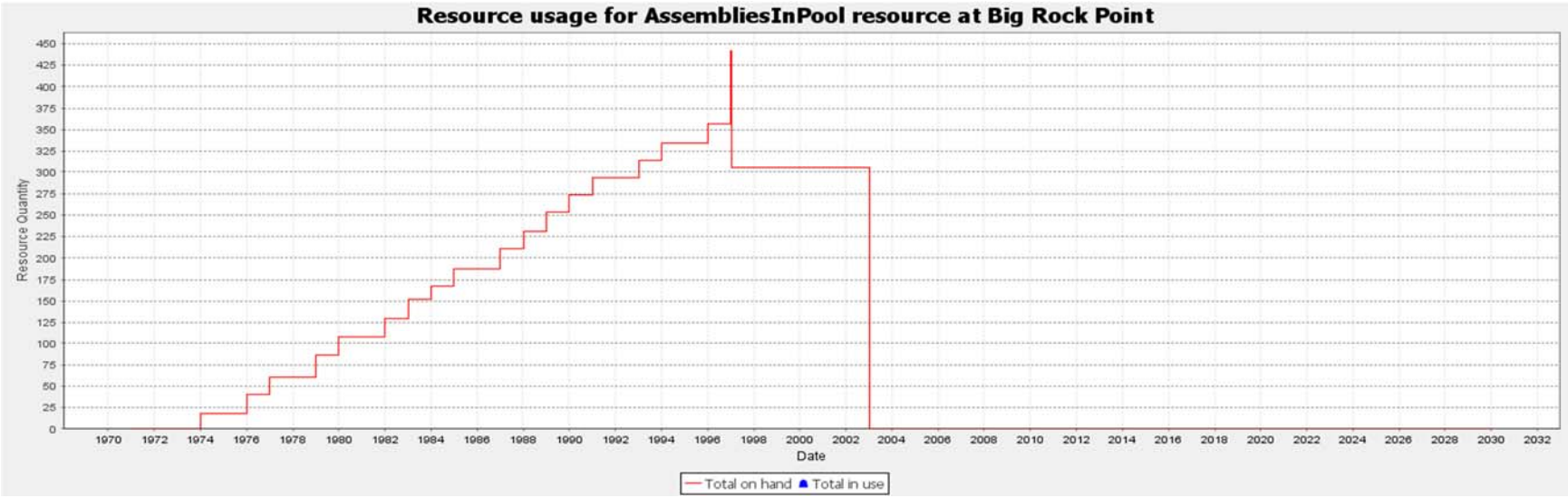
Table A-3. Reactor Discharge and Dry Storage Inventory Comparison for Big Rock Point

Quantity	Site Data	NGSAM
First Discharge	6/2/1974	1/2/1974
Last Discharge	8/30/1997	1/2/1997
Total MTU	57.92	57.92
Total Assemblies	441	441
Number of canisters	7	7
Canister capacity	64	68

The NGSAM time history of the pool inventory is shown in Figure A-2. As it can be seen from this figure dry storage canisters are loaded shortly after the last discharge. The remaining 5 dry storage canisters are loaded 6 years after the shutdown. While the actual data of loading dry storage are not available, it is unlikely that any loading occurred within the same year as the last discharge. The possible cause of this early loading in NGSAM is the pool capacity and full core reserve data.

The time history of operation cost is shown in Figure A-2. The first cost occurs shortly after the last discharge when 2 canisters are loaded. The remaining cost occurs 6 years after shutdown when the 5

canisters are loaded. The dry storage cost occurs 6 years after shutdown. The dry storage cost is associated with the construction of dry storage pads. As demonstrated in Figure A-3, 2 pads were assumed to be available at the time of the last discharge and their construction cost is not included in the dry storage cost.



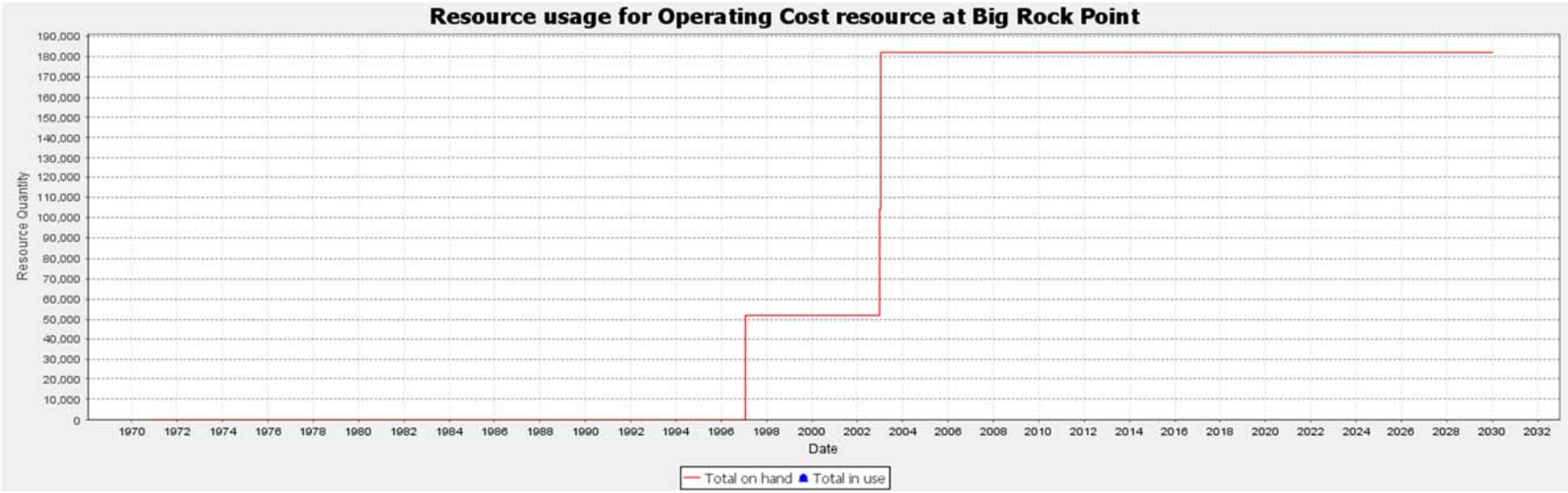


Figure A-2. NGSAM Time History for Pool Inventory (top) and Operating Cost (bottom) for Big Rock Point.

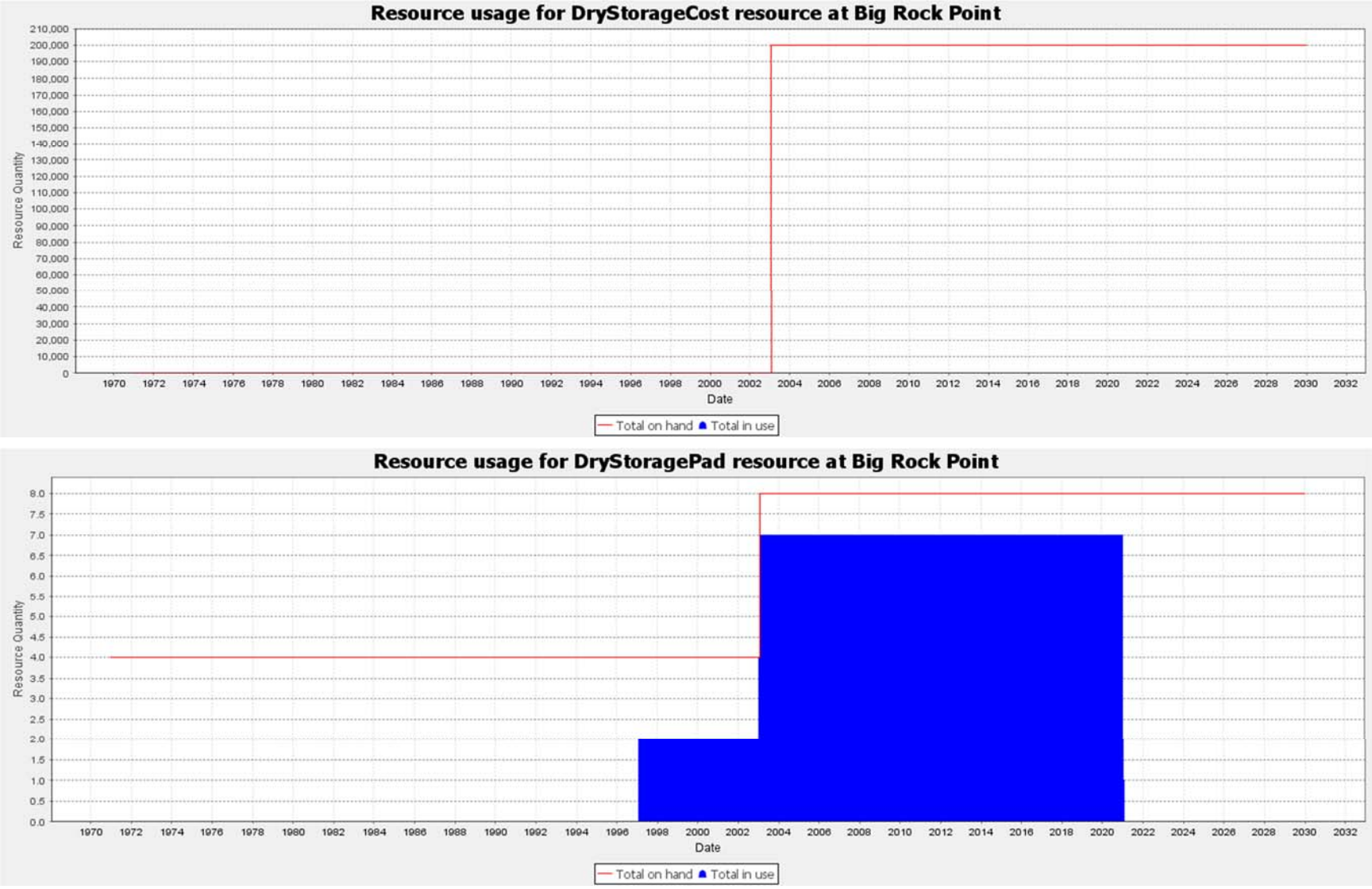


Figure A-3. NGSAM Time History for Dry Storage Cost (top) and Dry Storage Pads (bottom) for Big Rock Point.

According to Table A-2, Big Rock Point has to be unloaded during the first year of the transportation campaign. The NGSAM results (Table A-4) are in agreement with this schedule.

Table A-4. NGSAM Transportation Schedule for Big Rock Point

Pickup Date	Number of Casks
01/1/21	3
12/7/21	3
12/19/21	1
Total	**7**

A-4.2 Connecticut Yankee (Haddam Neck)

The NGSAM reactor discharges and dry storage inventory are compared to the site data in Table A-5. The quantities calculated by NGSAM are in agreement with the site data.

Table A-5. Reactor Discharge and Dry Storage Inventory Comparison for Connecticut Yankee

Quantity	Site Data	NGSAM
First Discharge	4/16/1971	1/2/1971
Last Discharge	7/22/1996	1/3/1996
Total MTU	412.29	412.29
Total Assemblies	1019	1019
Number of canisters	40	40
Canister capacity	26	26

The NGSAM time history of the pool inventory is shown in Figure A-4. As it can be seen from this figure, one dry storage canister is loaded shortly after the last discharge. The remaining 39 dry storage canisters are loaded 11 years after the shutdown. The reasons for loading dry storage canisters shortly after shutdown are probably the same as in Big Rock Point case.

Note that the attempt was made to load the dry storage canisters 6 years after shutdown, but a number of assemblies were too hot to be loaded at that time. Checking the dry storage canister type showed that the canister specified for this site have lower heat output limit that the ones that were actually used. As a result, longer time after the shutdown was required to empty the pool.

The time history of the operational costs is consistent with loading dry storage canisters. The time history of the dry storage cost is consistent with constructing new pads. The dry storage cost first occurs 11 years after shutdown because it was assumed that one pad existed at the time of the last discharge.

According to Table A-2, Connecticut Yankee has to be unloaded during the first two years of transportation campaign. The NGSAM results (Table A-6) are in agreement with this schedule.

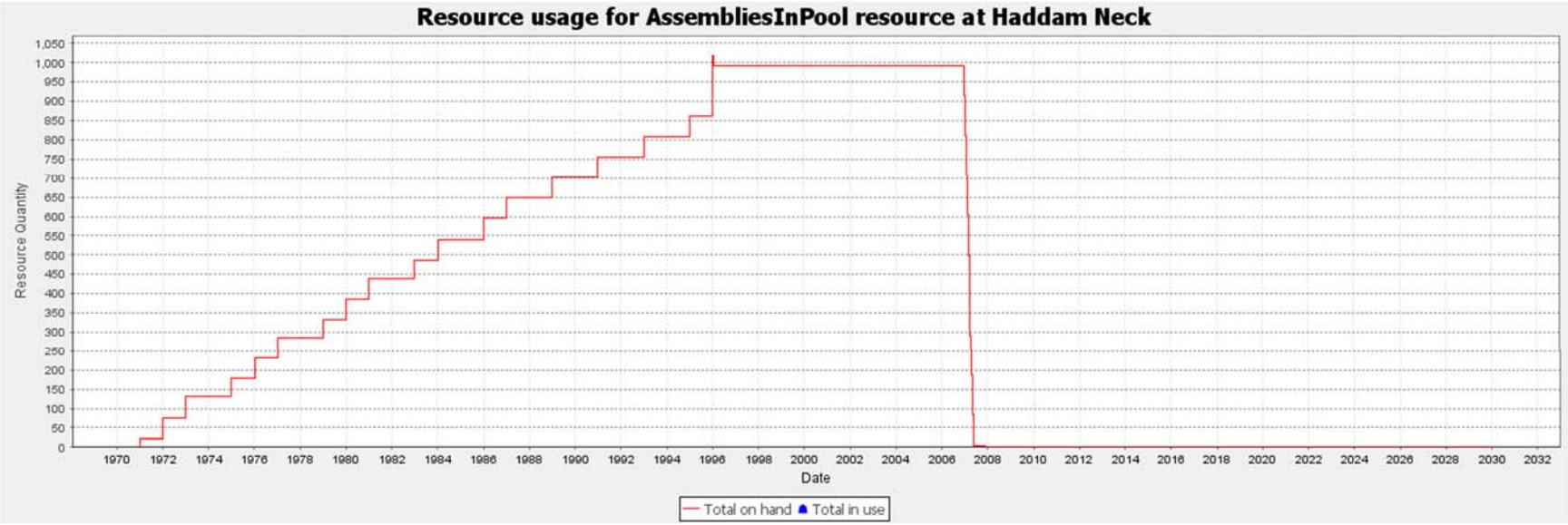


Figure A-4. NGSAM Time History for Pool Inventory for Connecticut Yankee

Table A-6. NGSAM Transportation Schedule for Connecticut Yankee

Pickup Date	Number of Casks
1/1/2021	3
1/18/2021	3
1/1/2022	3
1/7/2022	3
1/13/2022	3
1/26/2022	3
2/1/2022	3
11/6/2022	3
11/12/2022	3
11/19/2022	3
11/25/2022	3
12/1/2022	3
12/7/2022	3
12/13/2022	1
Total	**40**

A-4.3 Maine Yankee

The NGSAM reactor discharges and dry storage inventory are compared to the site data in Table A-7. The quantities calculated by NGSAM are in agreement with the site data.

Table A-7. Reactor Discharge and Dry Storage Inventory Comparison for Maine Yankee

Quantity	Site Data	NGSAM
First Discharge	6/29/1974	1/1/1974
Last Discharge	12/6/1996	1/3/1996
Total MTU	542.26	542.26
Total Assemblies	1434	1434
Number of canisters	60	60
Canister capacity	24	24

The NGSAM time history of the pool inventory is shown in Figure A-5. As it can be seen from this figure dry storage canisters are loaded shortly after the last discharge. The remaining 56 dry storage canisters are loaded 6 years after the shutdown. The reasons for loading dry storage canisters shortly after shutdown are probably the same as in Big Rock Point case.

The time history of the operational costs is consistent with loading dry storage canisters. The time history of the dry storage cost is consistent with constructing new pads. The dry storage cost first occurs 6 years after shutdown because it was assumed that 4 pads existed at the time of the last discharge.

According to Table A-2, Maine Yankee has to be unloaded during the last three years of transportation campaign. The NGSAM results (Table A-8) are in agreement with this schedule.

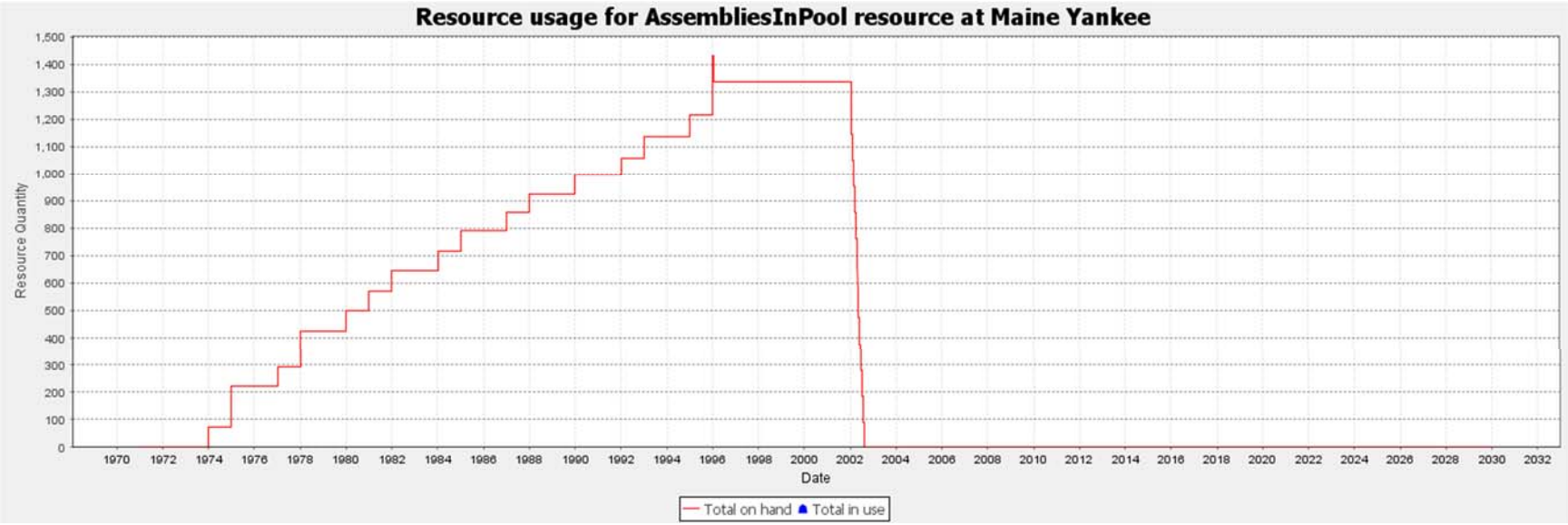


Figure A-5. NGSAM Time History for Pool Inventory for Maine Yankee

Table A-8. NGSAM Transportation Schedule for Maine Yankee

Pickup Date	Number of Casks	Pickup Date	Number of Casks
12/13/2022	3	12/13/2023	3
1/1/2023	3	1/1/2024	3
1/7/2023	3	1/7/2024	3
1/13/2023	3	1/20/2024	3
1/20/2023	3	2/4/2024	3
2/4/2023	3	11/17/2024	3
11/18/2023	3	11/23/2024	3
11/24/2023	3	11/30/2024	3
12/01/2023	3	12/6/2024	3
12/07/2023	3	12/12/24	3
		Total	**60**

A-4.4 Yankee Rowe

The NGSAM reactor discharges and dry storage inventory are compared to the site data in Table A-9. The quantities calculated by NGSAM are in agreement with the site data.

Table A-9. Reactor Discharge and Dry Storage Inventory Comparison for Yankee Rowe

Quantity	Site Data	NGSAM
First Discharge	2/12/1972	1/2/1972
Last Discharge	10/1/1991	1/3/1991
Total MTU	127.13	127.13
Total Assemblies	533	533
Number of canisters	15	15
Canister capacity	36	36

The NGSAM time history of the pool inventory is shown in Figure A-6. As it can be seen from this figure, dry storage canisters are loaded shortly after the last discharge. 8 dry storage canisters are loaded 6 years after the shutdown. The reasons for loading dry storage canisters shortly after shutdown are probably the same as in Big Rock Point case.

Four dry storage canisters are also loaded on one occasion before the shutdown. This loading is caused by the difference between the actual and simulated pool capacity.

The time history of the operational costs is consistent with loading dry storage canisters. The time history of the dry storage cost is consistent with constructing new pads. The dry storage cost first occurs 6 years after shutdown because it was assumed that 4 pad existed at the time of the last discharge.

According to Table A-2, Yankee Rowe has to be unloaded during the first year of transportation campaign. The NGSAM results (Table A-10) are in agreement with this schedule.

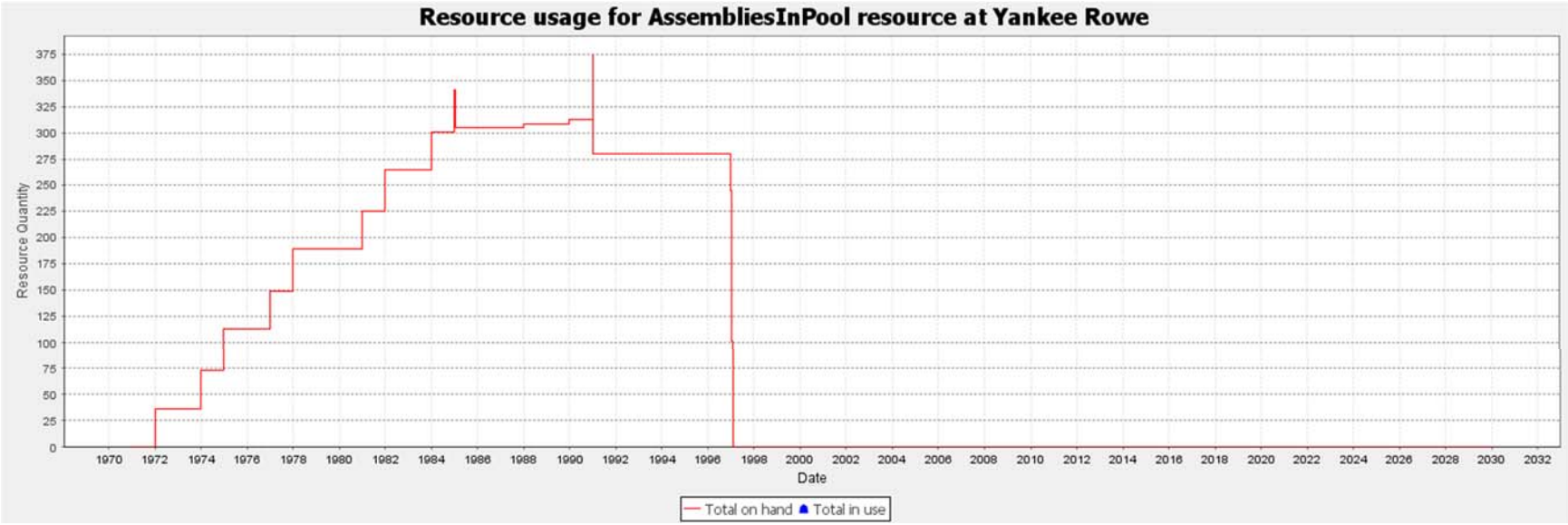


Figure A-6. NGSAM Time History for Pool Inventory for Yankee Rowe

Table A-10. NGSAM Transportation Schedule for Yankee Rowe

Pickup Date	Number of Casks
1/1/2021	3
11/24/2021	3
12/1/2021	3
12/7/2021	3
12/13/2021	3
Total	**15**

A-4.5 Rancho Seco

The NGSAM reactor discharges and dry storage inventory are compared to the site data in Table A-11. The quantities calculated by NGSAM are in agreement with the site data, except the time of the last discharge. The last discharge in NGSAM occurs in 1987, which is 2 years before the date of the actual last discharge.

Table A-11. Reactor Discharge and Dry Storage Inventory Comparison for Rancho Seco

Quantity	Site Data	NGSAM
First Discharge	8/20/1977	1/3/1977
Last Discharge	6/7/1989	1/2/1987
Total MTU	228.38	228.38
Total Assemblies	493	493
Number of canisters	21	21
Canister capacity	24	24

The NGSAM time history of the pool inventory is shown in Figure A-7. As it can be seen from this figure, 21 dry storage canisters are loaded 6 years after reactor shutdown. No dry storage canisters are loaded shortly after shutdown

The time history of the operational costs is consistent with loading dry storage canisters. The time history of the dry storage cost is consistent with constructing new pads. The dry storage cost first occurs 6 years after shutdown.

According to Table A-2, Rancho Seco has to be unloaded during the first year of transportation campaign. The NGSAM results (Table A-12) are in agreement with this schedule.

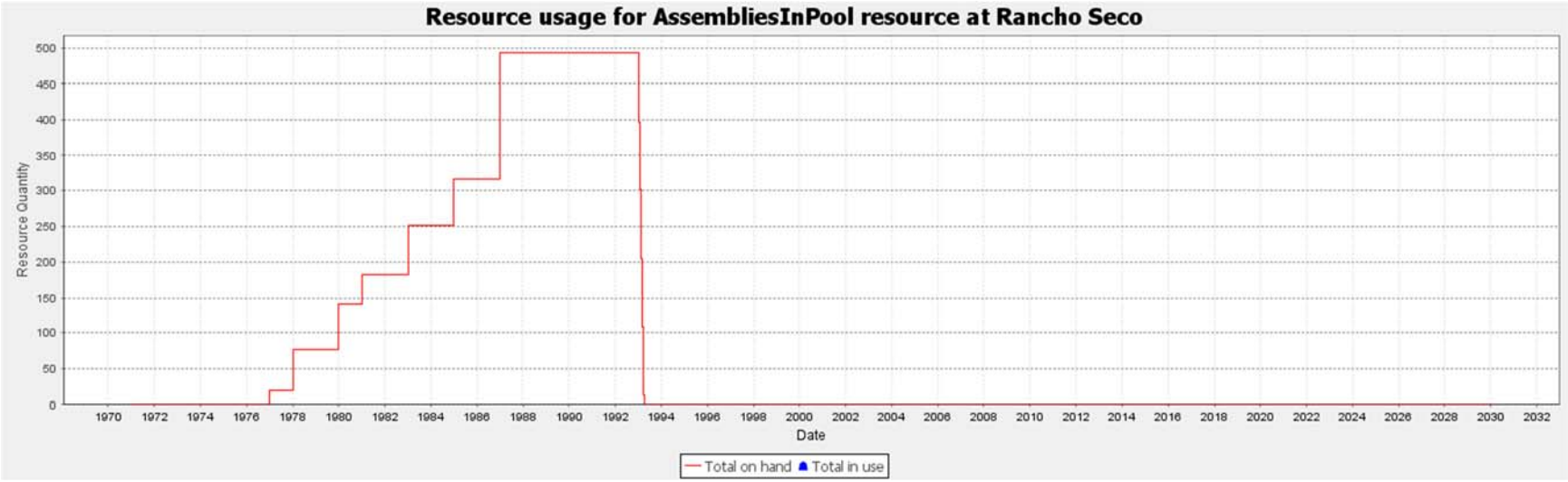


Figure A-7. NGSAM Time History for Pool Inventory for Rancho Seco

Table A-12. NGSAM Transportation Schedule for Rancho Seco

Pickup Date	Number of Casks
7/16/2021	3
7/23/2021	3
7/29/2021	3
8/5/2021	3
8/11/2021	3
8/17/2021	3
8/23/2021	3
Total	**21**

A-4.6 Trojan

The NGSAM reactor discharges and dry storage inventory are compared to the site data in Table A-13. The quantities calculated by NGSAM are in agreement with the site data.

Table A-13. Reactor Discharge and Dry Storage Inventory Comparison for Trojan

Quantity	Site Data	NGSAM
First Discharge	3/18/1978	1/2/1978
Last Discharge	11/9/1992	1/3/1992
Total MTU	358.85	358.85
Total Assemblies	780	780
Number of canisters	33	33
Canister capacity	24	24

The NGSAM time history of the pool inventory is shown in Figure A-8. As it can be seen from this figure, 33 dry storage canisters are loaded 6 years after reactor shutdown. No dry storage canisters are loaded shortly after shutdown

The time history of the operational costs is consistent with loading dry storage canisters. The time history of the dry storage cost is consistent with constructing new pads. The dry storage cost first occurs 6 years after shutdown.

According to Table A-2, Trojan has to be unloaded during the first two years of transportation campaign. The NGSAM results (Table A-14) are in agreement with this schedule.

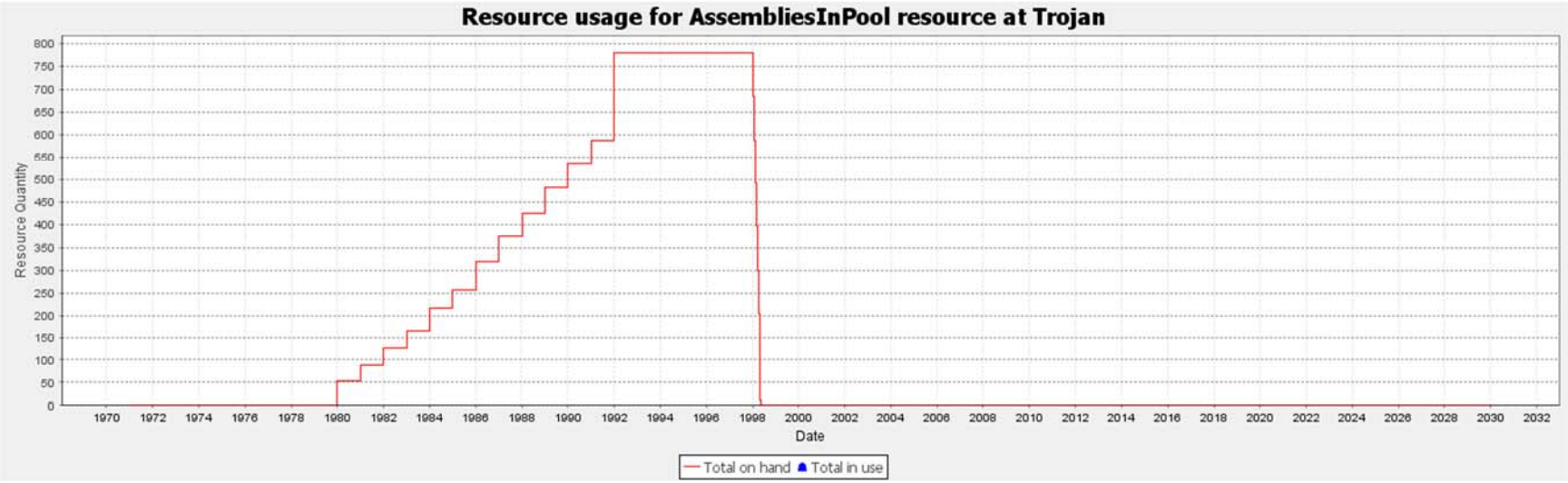


Figure A-8. NGSAM Time History for Pool Inventory for Trojan

Table A-14. NGSAM Transportation Schedule for Trojan

Pickup Date	Number of Casks
2/3/2021	3
2/9/2021	3
5/24/2022	3
5/30/2022	3
6/6/2022	3
6/12/2022	3
6/25/2022	3
7/1/2022	3
7/7/2022	3
7/13/2022	3
7/19/2022	3
Total	**33**

A-4.7 Humboldt Bay

The NGSAM reactor discharges and dry storage inventory are compared to the site data in Table A-15. The quantities calculated by NGSAM are in agreement with the site data.

Table A-15. Reactor Discharge and Dry Storage Inventory Comparison for Humboldt Bay

Quantity	Site Data	NGSAM
First Discharge	6/5/1971	1/2/1971
Last Discharge	7/3/1976	1/3/1976
Total MTU	28.94	28.94
Total Assemblies	390	390
Number of canisters	5	5
Canister capacity	80	80

The NGSAM time history of the pool inventory is shown in Figure A-9. As it can be seen from this figure, 3 dry storage canisters are loaded shortly after the last discharge. The remaining 2 dry storage canisters are loaded 6 years after the shutdown. The reasons for loading dry storage canisters shortly after shutdown are probably the same as in Big Rock Point case.

The time history of the operational costs is consistent with loading dry storage canisters. The time history of the dry storage cost is consistent with constructing new pads. The dry storage cost first occurs 6 years after shutdown because it was assumed that 3 pads existed at the time of the last discharge.

According to Table A-2, Humboldt Bay has to be unloaded during the first year of transportation campaign. The NGSAM results (Table A-16) are in agreement with this schedule.

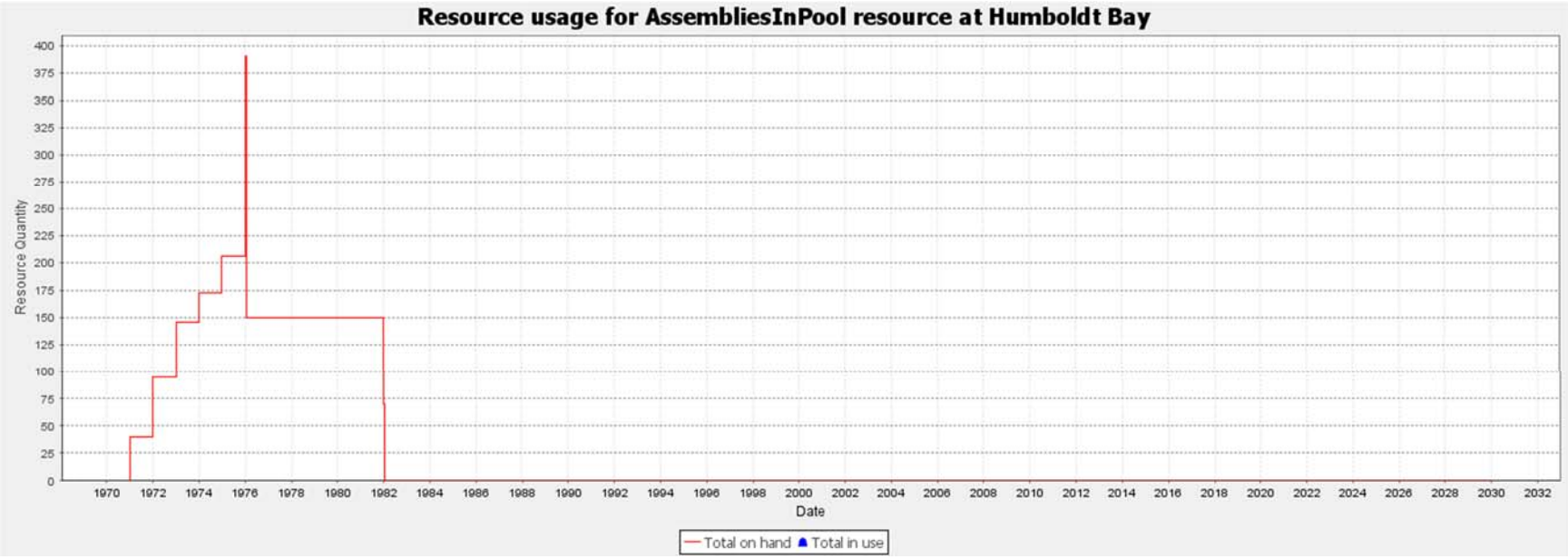


Figure A-9. NGSAM Time History for Pool Inventory for Humboldt Bay

Table A-16. NGSAM Transportation Schedule for Humboldt Bay

Pickup Date	Number of Casks
7/27/2021	3
8/6/2021	2
Total	**5**

A-4.8 La Crosse

The NGSAM reactor discharges and dry storage inventory are compared to the site data in Table A-17. The quantities calculated by NGSAM are in agreement with the site data.

Table A-17. Reactor Discharge and Dry Storage Inventory Comparison for La Crosse

Quantity	Site Data	NGSAM
First Discharge	8/19/1972	1/2/1972
Last Discharge	4/30/1987	1/2/1987
Total MTU	37.97	37.97
Total Assemblies	333	333
Number of canisters	5	5
Canister capacity	68	68

The NGSAM time history of the pool inventory is shown in Figure A-10. As it can be seen from this figure, 1 dry storage canister is loaded shortly after the last discharge. The remaining 4 dry storage canisters are loaded 6 years after the shutdown. The reasons for loading dry storage canisters shortly after shutdown are probably the same as in Big Rock Point case.

The time history of the operational costs is consistent with loading dry storage canisters. The time history of the dry storage cost is consistent with constructing new pads. The dry storage cost first occurs 6 years after shutdown because it was assumed that 1 pad existed at the time of the last discharge.

According to Table A-2, La Crosse has to be unloaded during the first year of transportation campaign. The NGSAM results (Table A-18) are in agreement with this schedule.

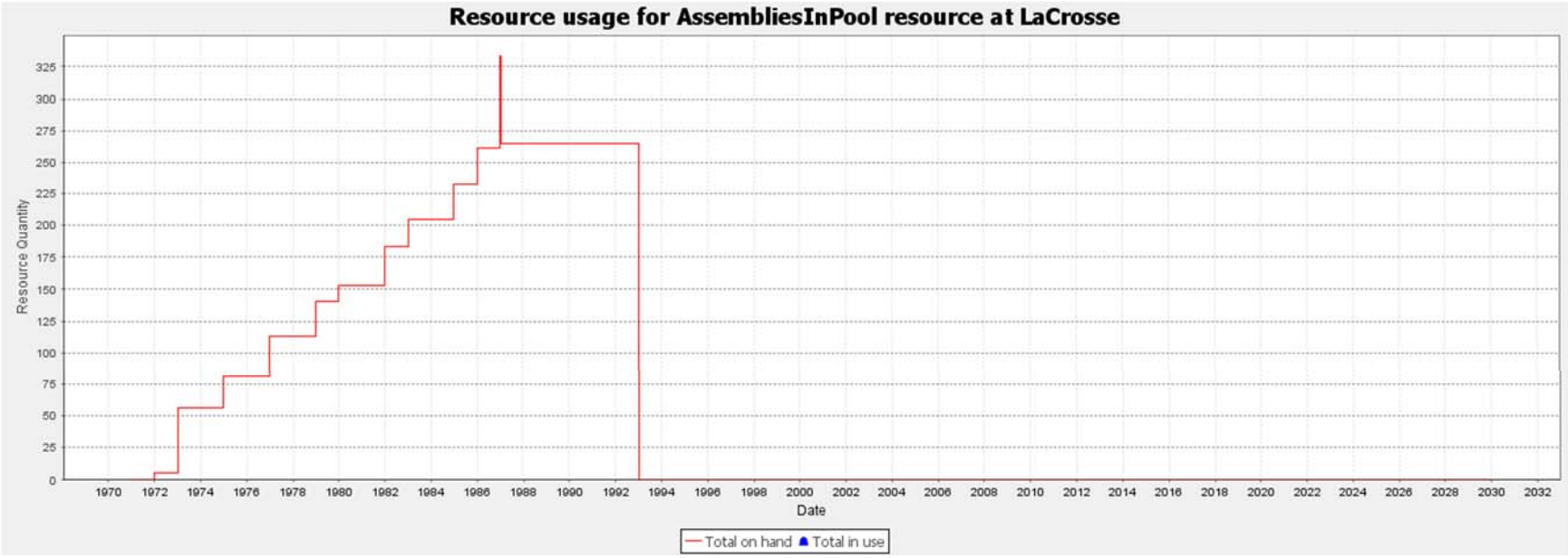


Figure A-10. NGSAM Time History for Pool Inventory for La Crosse

Table A-18. NGSAM Transportation Schedule for La Crosse

Pickup Date	Number of Casks
1/1/2021	3
12/18/2021	2
Total	**5**

A-4.9 Zion

The NGSAM reactor discharges and dry storage inventory are compared to the site data in Table A-19. The quantities calculated by NGSAM are in agreement with the site data.

Table A-19. Reactor Discharge and Dry Storage Inventory Comparison for Zion

Quantity	Site Data	NGSAM
First Discharge	3/5/1976	1/3/1976
Last Discharge	2/21/1997	1/2/1997
Total MTU	1019.43	1019.43
Total Assemblies	2226	2226
Number of canisters	61	61
Canister capacity	37	37

The NGSAM time history of the pool inventory is shown in Figure A-11 As it can be seen from this figure, 61 dry storage canisters are loaded 6 years after reactor shutdown. No dry storage canisters are loaded shortly after shutdown

The time history of the operational costs is consistent with loading dry storage canisters. The time history of the dry storage cost is consistent with constructing new pads. The dry storage cost first occurs 6 years after shutdown.

According to Table A-2, Zion has to be unloaded during the last two years of transportation campaign. The NGSAM results (Table A-20) are in agreement with this schedule.

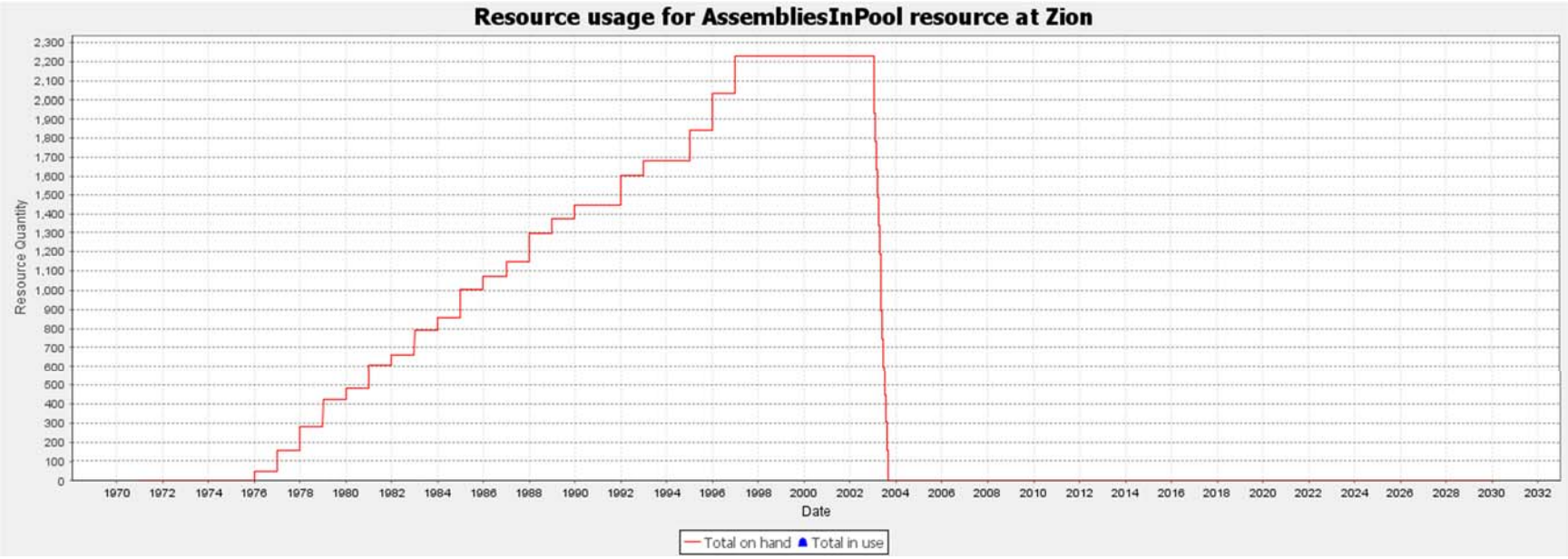


Figure A-11. NGSAM Time History for Pool Inventory for Zion

Table A-20. NGSAM Transportation Schedule for Zion

Pickup Date	Number of Casks	Pickup Date	Number of Casks
1/1/2023	3	1/7/2024	3
1/7/2023	3	1/18/2024	3
1/18/2023	3	1/24/2024	3
1/24/2023	3	11/4/2024	3
11/5/2023	3	11/10/2024	3
11/11/2023	3	11/21/2024	3
11/22/2023	3	11/27/2024	3
11/28/2023	3	12/8/2024	3
12/9/2023	3	12/14/2024	3
12/15/2023	3	12/20/2024	1
1/1/2024	3		
		Total	**61**

A-4.10 Transportation Fleet

As it was shown in Sections A4.1-A4.9, all the shutdown reactors sites were unloaded according to the schedule defined in Table A-2. However, this required twice as many railcars as it was expected. The number of railcars in use during the transportation campaign is shown in the bottom plot of Figure A-12. The maximum number of railcars that are used simultaneously is 12 (four 3-railcar consists).

The pickup dates calculated by NGSAM are shown in the top plot of Figure A-12. Both plots of Figure A-12 indicate that there are long periods when no transportation takes place (no railcars are used). This is possible cause of using greater number of railcars compared to Ref. 2.

This scenario was executed with 8 railcars instead of 50 railcars. As a result, three sites (Humboldt Bay, Trojan, and Rancho Seco) were not fully unloaded. Total of 48 canisters remained at these sites.

It is possible that this problem is caused by both data and logic.

Figure A-12. Pickup Dates Calculated by NGSAM (Top) and Number of Railcars in Operation (Bottom)

A-5. SUMMARY

The analysis of the shutdown reactors scenario results (Section A-4) demonstrated that NGSAM is capable of simulating a number of the considered activities. The site-specific SNF inventory (number of assemblies and MTU) is assigned correctly. With a few exceptions, the dry storage canisters have the specifications consistent with the actual data. The logic of transferring SNF from pool to dry storage is implemented in accordance with the software requirements. The operational and dry storage costs are consistent with dry storage loading operations. The transport of dry storage canisters from the shutdown reactor sites to the ISF was completed in four years and followed the specified pickup schedule.

Several issues were identified in this analysis. The site-specific issues are summarized in Table A-21. Some of the issues are related to the data (e.g. canister specification and pool capacity). The other issues are probably related to both data and logic. An example is loading a few dry storage canisters shortly after the last discharge.

The issue with transportation (Section A-4.10) is related to scheduling trips. There are long periods when no transportation takes place. Because of this, a significantly greater number of railcars is required to complete the transportation campaign in 4 years. It is possible that this problem is caused by both data and logic.

A few more modifications would be beneficial for making the considered scenario useful for the ongoing Hardware Needs evaluation. The pools should be unloaded 5 years after shutdown (currently it is 6 years). It should be assumed that there are no available dry storage pads until the first dry storage loads.

Table A-21. Site-Specific Issues Identified for the Shutdown Reactors Scenario

Section	Site	Problem Description	Issue Area
A-4.1	Big Rock Point	Dry storage canister capacity is 68, should be 64.	Data
		2 dry storage canisters are loaded shortly after last discharge.	Data and logic
A-4.2	Connecticut Yankee	1 dry storage canisters are loaded shortly after last discharge.	Data and logic
		Dry storage canister heat output is lower than actual.	Data
A-4.3	Maine Yankee	4 dry storage canisters are loaded shortly after last discharge.	Data and logic
A-4.4	Yankee Rowe	4 dry storage canisters are loaded shortly after last discharge.	Data and logic
		4 dry storage canisters are loaded before last discharge.	Data
A-4.5	Rancho Seco	Last discharge occurs 2 years earlier than the actual.	Data
A-4.6	Trojan	-	-
A-4.7	Humboldt Bay	3 dry storage canisters are loaded before last discharge.	Data and logic
A-4.8	La Crosse	1 dry storage canisters are loaded shortly after last discharge.	Data and logic
A-4.9	Zion	-	-

A-6. REFERENCES

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