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Spent Fuel Acceptance Scenarios Devoted to Shutdown Reactors: A Preliminary Analysis

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SPENT FUEL ACCEPTANCE SCENARIOS DEVOTED TO
SHUTDOWN REACTORS: A PRELIMINARY ANALYSIS

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EXECUTIVE SUMMARY

Spent fuel acceptance schedules and the allocation of federal acceptance capacity among commercial nuclear power reactors have important operational and cost consequences for reactor operators. Alternative allocation schemes were investigated to some extent in DOE's MRS Systems Study (DOE 1989a). The current study supplements these analyses for a class of acceptance schemes in which the acceptance capacity of the federal radioactive waste management system^(a) is allocated principally to shutdown commercial power reactors, and extends the scope of analysis to include considerations of at-reactor cask loading rates.

The operational consequences of these schemes for power reactors, as measured in terms of quantity of spent fuel storage requirement above storage pool capacities and number of years of pool operations after last discharge, are estimated, as are the associated utility costs. This study does not attempt to examine the inter-utility equity considerations involved in departures from the current oldest-fuel-first (OFF) allocation rule as specified in the "Standard Contract for Disposal of Spent Nuclear Fuel and/or High-Level Radioactive Waste" (DOE 1988b). In the sense that the alternative allocations are more economically efficient than OFF, however, they approximate the allocations that could result from free exchange of acceptance rights among utilities. Such a process would result in the preservation of inter-utility equity.

This study shows that a scenario that grants exclusive spent fuel acceptance rights to shutdown reactors in order of shutdown date could substantially reduce the average time between last discharge and completion of spent fuel removal for currently operating power reactors and those under construction and expected to be completed. Implementing such a scheme, using a strict "longest-shutdown-first" priority rule, would require at-reactor cask loading rates in excess of preliminary estimates of capabilities.

(a) As presently planned by the DOE, this system would include a transportation element, a monitored retrievable storage facility, and one or more geologic repositories.

Because of the relative timing for reactor shutdown and federal acceptance as currently planned, this scenario would not fully utilize the spent fuel acceptance capacity planned for the federal system. In addition, the requirements for additional at-reactor storage would be much greater under such a scheme than under an allocation of acceptance based on spent fuel age.

A modified shutdown priority scenario is developed that grants first priority to reactors with imminent storage capacity needs, second priority to shutdown reactors, and third priority based on spent fuel age and individual at-reactor cask loading constraints as currently estimated. This scenario is shown to have lower at-reactor storage impacts in terms of both capacity requirements and average time between last discharge and fuel pickup than an allocation based on age of spent fuel, and would fully utilize the planned acceptance capacity of the waste management system.

All of the scenarios studied would have some impact on the characteristics of the spent fuel accepted. The effects of fuel characteristics on transportation cask capacity and fleet requirements are treated here in a qualitative fashion.

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1.0 INTRODUCTION

In June 1988, the U.S. Department of Energy's (DOE) Office of Civilian Radioactive Waste Management (OCRWM) initiated a series of studies to provide a technical basis for a re-evaluation of OCRWM policy on development of a monitored retrievable storage (MRS) facility. These studies covered several topics, and are described in a summary report (DOE 1989a). Together, these studies address the effects of various alternative MRS configurations, storage capacities, and deployment dates on the functioning and cost of both the federal waste management system and spent fuel storage at commercial power reactors. This analysis is framed comparatively, against a series of reference cases for a system without an MRS facility. These repository-only cases include cases with initial facility operation in the year 2003 and sensitivity cases for delayed repository development (as late as 2013) and for a repository emplacing intact rather than consolidated spent fuel.

In January 1989, testimony before the MRS Review Commission by the Environmental Defense Fund (EDF) suggested that a valid comparative analysis of an MRS facility should include a case in which a repository-only system was formulated around "single, dedicated shipping campaigns of fuel from each reactor at the time of its decommissioning." Previous comments on the Initial Version Dry Cask Storage Study (DOE 1988a) suggested a system that "would entail mostly single bulk shipping campaigns from each reactor to a repository, preferably immediately after reactor decommissioning." While the study on system storage conducted as part of DOE's MRS Systems Study (Wood et al. 1989) included analysis of granting priority to decommissioning reactors as an alternative to priority based on fuel age, the specific scenario suggested had not been analyzed. The current study was initiated as a supplemental effort to analyze the specific scenario suggested by EDF, and to develop an acceptance scenario incorporating the general principles suggested and resulting in low costs to utilities.

The acceptance scenarios developed in this report involve allocations of spent fuel acceptance rights other than the current oldest-fuel-first (OFF) allocation established by the "Standard Contract for Disposal of Spent Nuclear Fuel and/or High-Level Radioactive Waste" (DOE 1988b). Although

there is a provision in the Contract that provides for shutdown reactor priority in acceptance allocations, this study does not advocate implementation of such a policy as an administrative action by the DOE. In the sense that the alternative allocations are more economically efficient than OFF, however, they approximate the allocations that could result from free exchange of acceptance rights among utilities. Such a process would result in the preservation of inter-utility equity.

The evaluation of system effects in this study includes many of the same figures of merit developed and applied in the evaluation of system storage (Task G) and transportation (Task F) in the MRS Systems Study, and was conducted by staff involved in these efforts, using essentially the same analysis framework. Specific aspects of this evaluation included 1) quantity, duration, and cost of at-reactor storage, 2) logistical feasibility and cost of spent fuel transportation, and 3) spent fuel characteristics. The study developed these measures for several repository-only cases based on the general scheme described above, and compares them with the standard repository-only reference case used in the MRS Systems Study. Although results presented here may be validly compared with MRS scenario results previously reported, such comparisons were not undertaken in this report.

The cost measures and other results reported herein are measures of utility impacts as a result of alternative acceptance allocations. Some of these alternative acceptance allocations would result in the receipt of younger spent fuel in the system than would an OFF allocation. The analysis of impacts of this younger fuel on the other elements of the system was beyond the scope of this study, although aspects of this problem have been qualitatively addressed for the transportation element of the system in Section 4.3.1. More detailed analysis of the impacts to the transportation element, as well as analysis of impacts on the MRS and repository elements, is ongoing. The results of the study reported herein provide important information regarding aspects of various acceptance allocations with respect to the transportation and waste generator elements of the system. However, it is important to realize that the reported cost impacts or savings to the utilities from the allocation schemes developed in this report do not represent potential impacts on the entire waste management system.

2.0 THE DECOMMISSIONING SEQUENCE FOR POWER REACTORS

Spent fuel removal from a power reactor site is a necessary prerequisite to site decommissioning. Although some alternative decommissioning sequences involve storage of spent fuel at reactor sites for prolonged periods, spent fuel removal is required prior to final closure of a site. Thus, the suggested removal of spent fuel "immediately after decommissioning" is interpreted in this report as immediately after shutdown (e.g., the last discharge to a particular spent fuel pool). A reactor that has completed its last discharge is referred to as "shutdown" in this report, and a reactor pool or dry storage yard that serves only shutdown reactors is referred to as a "decommissioning" pool or yard.

A reference decommissioning sequence giving shipping priority to shutdown reactors 5 years after last discharge was developed for Task G of the MRS Systems Study (Wood et al. 1989). For the current study, shipping priority was given to shutdown reactors immediately after last discharge with the constraint that the spent fuel had to be cooled a minimum of a specified number of years before it could be shipped. Schedules with 5- and 10-year minimum ages were formulated.

Although the specifics of power reactor decommissioning plans remain to be developed in most cases, projected dates of last discharge are available based on operating license data, and were used as a basis for this study. Figure 2.1 illustrates the schedule of last discharge dates for spent fuel pools. These dates assume a 40-year life after granting of reactor operating license except in cases where earlier shutdowns have already occurred.

FIGURE 2.1. Schedule of Last Discharge Dates to Reactor Spent Fuel Pools

3.0 SCENARIO DEVELOPMENT

3.1 THE REFERENCE ACCEPTANCE SCENARIO

The repository-only case used most broadly as a reference point for calculation of MRS benefits in the MRS Systems Study (DOE 1989a) is a scenario in which the repository is developed and deployed on the schedule shown in the Draft 1988 Mission Plan Amendment (DOE 1988c), but without the MRS facility described in that document. This case assumes initial acceptance in the year 2003 at a rate of 400 MTU, ramping up to a design rate of 3000 MTU by the year 2008. The reference allocation of this acceptance capacity among reactors is based on the OFF rule as specified in the "Standard Contract for Disposal of Spent Nuclear Fuel and/or High-Level Radioactive Waste" (DOE 1988b). Although this rule does allocate substantial acceptance capacity to shutdown reactors, it does not maximize the ability of the federal system to assure timely decommissioning, since reactors relatively early in their service lives (e.g., 10 years after initial criticality) will have fuel as old as shutdown reactors whose pools are being drawn down in preparation for decommissioning.

3.2 BASIC CONSIDERATIONS IN FORMULATING A SHUTDOWN PRIORITY

ACCEPTANCE SCENARIO

Evaluation of the proposal to dedicate federal waste management system acceptance to shutdown reactors requires the formulation of specific cases or scenarios for quantitative analysis, and calculation of the at-reactor storage and transportation consequences of these scenarios. Because of some considerations unique to shutdown priority scenarios, these consequences are sensitive to the details of acceptance scenario definition, and a very literal interpretation of the EDF proposal is much less desirable than one in which relatively minor adjustments are made for these considerations. This section introduces two considerations of this type--the aggregate quantity of spent fuel eligible for shipment from shutdown reactors and the possible limitation of system acceptance by at-reactor cask loading rate constraints.

In each case, the consequences of these considerations under a literal interpretation of the EDF proposal are developed, and adjustments are made which circumvent undesirable features of these scenarios.

3.2.1 Spent Fuel Availability

The data on projected last discharge dates illustrated in Figure 2.1 can be combined with spent fuel discharge data to show the quantity of spent fuel available from shutdown reactors as a function of time. Figure 3.1 shows the result of this calculation, over which is superimposed the planned cumulative spent fuel acceptance schedule from the Draft Mission Plan Amendment (repository-only system), which calls for initiation of acceptance in 2003 and full-rate acceptance of 3000 MTU per year by 2008. As shown by the figure, restricting acceptance of spent fuel to only shutdown reactors would not provide a supply of spent fuel adequate to operate the planned federal system at full rate. A cumulative shortfall of almost 20,000 MTU would occur by 2012,

FIGURE 3.1. Spent Fuel Inventory Accumulation and Planned Acceptance

after which the system could operate at design rate. In practice, such a situation would be an inefficient use of plant and operating staff. Should it be desirable to restrict acceptance to shutdown sites, spent fuel availability could be insured by either 1) reformulation of the aggregate acceptance schedule for either later initiation of acceptance or 2) a different aggregate acceptance rate. The spent fuel availability problem could also be solved by reallocation of the acceptance capacity remaining after acceptance of available fuel from shutdown reactors.

Of these possibilities, two were analyzed in this study: 1) the delay (until 2013) of initial acceptance, and 2) the allocation of unused system acceptance capacity to other reactors. The later first-repository start date was used as a sensitivity case in the MRS Systems Study (DOE 1989a) and has been suggested (DOE 1989b) as a reasonable initial date for spent fuel acceptance in a scenario devoted to shutdown reactors (state of Nevada's comments on DOE's Dry Cask Storage Study). Three reasons argued against analysis (during the current study) of a case in which system acceptance rate was altered. First, a complete evaluation of this case requires extensive consideration of alternative facility designs, at least at a preconceptual design level. Second, this sort of evaluation is now planned for inclusion in a comprehensive study of system processing rate, to be conducted in fiscal year 1990. Lastly, although the cumulative spent fuel available from shutdown reactors is less than system acceptance capacity for intermediate years, the cumulative availability is almost exactly equal to the planned 70,000 MTU capacity at the planned end of the emplacement period.

3.2.2 At-Reactor Cask Loading Rate Constraints

The allocation of acceptance to only shutdown reactors tends to concentrate any given year's acceptance in a few reactors relative to the reference OFF case where smaller quantities are loaded at many sites. The extent of this concentration will vary with the details of the shutdown priority rule considered, but in some cases could exceed preliminary estimates of loading rate capabilities of some sites. This problem can be circumvented by reallocation of acceptance among other shutdown pools or to pools serving operating reactors.

The current reference assumption on spent fuel pool availability for loading of transport casks at an operating reactor is a single 10-hour shift per day, 365 days per year. While this may be a conservative assumption for a pool serving only shutdown reactors, re-evaluation of this assumption requires a detailed analysis of decommissioning sequence operations. The approach taken in the current study was to: 1) demonstrate the extent of this loading rate constraint on system throughput for a shutdown priority scheme, and 2) show that even the loading rate limits imposed by the single 10-hour shift assumption can provide for planned system acceptance rates if acceptance is suitably reallocated among sites.

3.3 OTHER ASSUMPTIONS

Other general assumptions, adopted from MRS Systems Study Tasks G and F, are discussed in the following sections.

3.3.1 Repository Capacity and Second-Repository Timing

Although the timing of the second repository, and particularly the continuity of acceptance between the first and second repositories, can affect the time required for spent fuel removal after shutdown, no explicit second-repository assumptions were made for this study. It was assumed that all of the 86,760 MTU of spent fuel projected to be generated under the 1988 EIA no-new-orders increasing burnup case could be accepted at a continuous rate of 3000 MTU per year once the first repository was fully operational. (This could be accomplished with any set of first- and second-repository capacities totaling 86,760 MTU, provided first- and second-repository acceptance were properly coordinated.) The first-repository operation was assumed to ramp up to full rate in the pattern 400 MTU/yr, (3 years), 900 MTU/yr, 1800 MTU/yr.

3.3.2 Pool Capacity and Spent Fuel Inventory

Pool capacity data were taken from the Energy Information Administration's RW 859 survey (DOE 1988d). Appendix A summarizes the cumulative projected pool and dry storage inventories in order of reactor shutdown.

3.3.3 Minimum Spent Fuel Age Since Discharge

As noted in Section 2.0, spent fuel younger than 5 years is classified as non-standard. Thus, 5 years is typically assumed as a minimum age of spent fuel acceptance in simulations of the federal waste management system. A significant portion of the current designs for waste management system components is based on spent fuel of 10 years age since discharge (DOE 1986a, 1986b). In practice, this difference between minimum contractually acceptable age and design basis spent fuel age has not been regarded as problematic, since under an OFF allocation and spent fuel selection scheme, the actual average age of spent fuel at time of receipt is about 20 years.

Under an acceptance scenario devoted to shutdown reactors, however, a greater quantity of "young" spent fuel is eligible for shipment than under OFF, even with similar selection rules, and it is possible for the average age of spent fuel accepted to be closer to the minimum acceptable age. For this reason, a case was formulated with a minimum spent fuel age of 10 years rather than 5 years.

3.3.4 Allocation of Acceptance Among Shutdown Reactors

Two methods of allocating acceptance among shutdown reactors were analyzed. The first, which is a standard assumption in the system simulation model WASTES-II (Ouderkerk 1988) used for the study, is priority based on order of pool shutdown. This is the "Longest Shutdown First," or LSF rule. A second method analyzed was allocation of capacity to those shutdown sites with the smallest spent fuel inventory remaining (the "Smallest Inventory First," or SIF rule). This rule was an attempt to minimize the system aggregate cost of pool operations after last discharge. Since these costs are independent of the quantity of spent fuel onsite (Wood et al. 1989), such a rule will tend to allocate limited capacity to those sites where it will have the greatest impact in terms of reduced operational costs.

3.3.5 Allocation of Residual Acceptance Capacity

In those cases where the assumed limits on cask loading constrain the quantity of annual acceptance, residual acceptance capacity would either go unused or be allocated to other pools. The standard assumption used here is

that acceptance capacity that would normally have been allocated to a given pool but is above the logistically feasible allocation would be reallocated to the next sites in the shutdown reactor queue (e.g., either the pool with the next shutdown date under the LSF rule or the next smallest inventory under the SIF rule). If decommissioning pools are not available, the acceptance capacity is allocated to operating reactors under various alternative priority schemes. (One case is analyzed under the assumption that this system acceptance capacity is unused in order to illustrate the problem with this approach.)

3.3.6 Shipment Dedication and Size

The cases in which the repository is dedicated to shutdown reactors assume that when a pool is serviced, all the eligible spent fuel (up to system capacity) in its inventory is transported to the repository in 1 year. This does not imply that this fuel is shipped in a single shipment. If the reactor is rail-served, it is assumed that the spent fuel is loaded onto a series of dedicated trains each having three casks per train. This assumption of dedicated trains is the reference assumption for all spent fuel transportation scenarios (Brentlinger et al. 1989). The three-casks-per-train assumption is based on the fact that in an oldest-fuel-first pickup scenario the average amount of spent fuel transported from reactors per year is about three cask loads.

Three casks per train may not be the optimum shipment size from a transportation economics point of view. Because of the dedicated train charge per shipment (a three-cask train is considered one shipment), per-shipment costs fall as the shipment size increases. Although larger shipment sizes are possible in a shutdown priority scenario than under OFF, it is not clear that the implications of larger shipment sizes on the overall waste management system or on cask fleet requirements are desirable. Shipment sizes large enough to deplete a reactor's inventory of spent fuel in one very large shipment per year would tend to require larger amounts of lag storage at the repository than would smaller, more frequent shipments. Such large shipments could tax the repository's cask unloading capacity, forcing large numbers of casks to sit idle while waiting to be unloaded. Since the logistics questions related

to shipment size are beyond the scope of the present effort, the three-casks-per-shipment assumption was used.

3.3.7 Other Transportation Assumptions

The following assumptions for the physical characteristics, logistics data, and cost data were taken from MRS System Study Task F assumptions:

- Cask Physical Characteristics

- Casks are designed for 10-year-old spent fuel having burnup of 35K MWd/MTU
- Rail cask capacity (assemblies): 21(PWR)/48(BWR)
- Truck cask capacities (assemblies): 3(PWR)/7(BWR)
- Rail cask weight(lb): 200,000(loaded)/168,000(unloaded)
- Truck cask weight(lb): 56,000(loaded)/51,500(unloaded)

- Logistics Data

- Rail cask life (yr): 20
- Truck cask life (yr): 20
- Rail cask availability (days/yr): 280
- Truck cask availability (days/yr): 310
- Rail cask turnaround time (days): 2.5(PWR)/3.5(BWR)
- Truck cask turnaround time (days): 2.0(PWR)/2.0(BWR)

- Cost Data

- Cask purchase price (\$ million): 2.0(rail)/0.8(truck)
- Annual maintenance cost (\$ million): .125(rail)/.075(truck)

It is further assumed that shutdown reactors can support a continual cask loading activity throughout the year. That is, because the shutdown reactors are no longer generating electricity, they can allow their pools to be used exclusively for loading spent fuel into transportation casks; cask loading is assumed to take place at these reactors 365 days per year on a one 10 hour shift per day basis. This is the current reference assumption for an operating reactor.

The above assumptions establish, for the purposes of this study, an upper limit on the annual spent fuel quantity loaded into transportation casks at each pool. For example, it takes 2.5 days to load a PWR rail cask with 21 assemblies. Thus, with continual loading, 146 PWR casks (3066 assemblies) can be loaded over 1 year's time. Table 3.1 summarizes the upper limits for rail, truck, PWR, and BWR casks.

TABLE 3.1. Derivation of Estimated Maximum Feasible Cask Loading Rates

<u>Cask Loading Constraints</u>	<u>PWR-Truck</u>	<u>BWR-Truck</u>	<u>PWR-Rail</u>	<u>BWR-Rail</u>
Turnaround Time (days)	2.0	2.0	2.5	3.5
Casks Loaded/year	182	182	146	104
SF assemblies/cask	3	7	21	48
SF assemblies loaded/yr	546	1274	3066	4992
MTU loaded per year	251	229	1410	899

Note: Cask loading rates are based upon one 10-hr shift/day. If more shifts per day are assumed, the maximum feasible loading rate would increase.

At the site of a shutdown reactor, it may be possible and desirable to exceed the cask loading rates assumed in Table 3.1. Since definitive data on the extent to which this would occur is not available, the approach taken in this study is to use the estimates in Table 3.1, even if lower than might actually be achieved, and show that any resulting constraints on system throughput can be mitigated by reallocation among reactors.

3.4 SUMMARY OF CASES ANALYZED

Table 3.2 summarizes the nine cases formulated for analysis in this study in terms of the assumptions discussed above. Cases 2 through 7 document the development of a shutdown priority scenario that is feasible and has relatively low costs to utilities, beginning with a very literal construction of the EDF suggestion in Case 2 and making refinements in the allocation rules. Cases 8 and 9 are sensitivity analyses for the form of allocation among shutdown reactors and the minimum acceptable fuel age. Results are discussed in Section 4.0.

In each of these cases, the repository's receipt requirements are satisfied by applying the allocation and priority rules to the set of reactors to determine a reactor pickup schedule (sequence in which the reactors are serviced and the amount of spent fuel picked up at each). For example, in Case 8 the order in which the reactors are serviced and the amount of spent fuel transported are based upon several criteria. First, those reactors that

TABLE 3.2. Description of Cases Analyzed

<u>Case Number</u>	<u>Repository Start Date</u>	<u>Shipping Allocation Rule</u>	<u>Shutdown Pool Priority Rule</u>	<u>Minimum Cooling Time (years)</u>
1	2003	DFF	N/A	5
2	2003	DECOM	LSF(a)	5
3	2013	DECOM	LSF	5
4	2003	DECOM/FCR/OFF	LSF	5
5	2013	DECOM[R](b)	LSF	5
6	2003	DECOM[R]/FCR/OFF	LSF	5
7	2003	FCR/DECOM[R]/OFF	LSF	5
8	2003	FCR/DECOM[R]/OFF	SIF(c)	5
9	2003	FCR/DECOM[R]/OFF	LSF	10

- (a) Longest Shutdown First (LSF) - pools at shutdown reactors that have been waiting the longest to be emptied have highest shipping priority.
- (b) DECOM[R] indicates a case in which acceptance rights are based on shutdown status but have been reallocated among shutdown sites so that estimated cask loading rates are not exceeded in any year.
- (c) Smallest Inventory First (SIF) - pools at shutdown reactors that have the smallest inventory of spent fuel have highest shipping priority.

cannot satisfy the full core reserve (FCR) margin within their pools are granted first shipping rights, reactors that are shut down are granted shipping rights for any remaining system capacity and, if there is any system capacity still available, additional shippings rights are granted to reactors on an OFF basis. Second, for any given year, the shutdown reactors are ranked according to the size of their spent fuel inventory, smallest inventory first. Third, starting at the top of the ranking, spent fuel that is at least 5 years old is loaded into casks and shipped to the repository until the reactor's inventory of eligible fuel is exhausted or until the repository receipt rate is satisfied, whichever comes first. Reactor pickup schedules for the other cases are determined in analogous ways, except that the allocation and priority rules differ.

4.0 ANALYSIS OF EFFECTS

4.1 FIGURES OF MERIT ASSOCIATED WITH AT-REACTOR STORAGE

The two principal effects of federal acceptance capacity and allocation policy on commercial power reactors are 1) their impacts on the quantity of "additional" at-reactor storage required to be deployed and 2) the length of time that a reactor must await spent fuel removal (and hence decommissioning) after its last discharge. These two effects are analyzed for a broad spectrum of cases in the MRS Systems Study (DOE 1989a), and both can have significant cost consequences. To some extent, these effects must be traded off against each other in setting priorities for allocation of acceptance capacity. FCR priority allocations tend to reduce the costs of additional storage, but will generally result in longer average times between last discharge and completion of spent fuel removal than do shutdown priority schemes. The current standard reference allocation of acceptance, based on Oldest-Fuel-First, gives intermediate results for both of these effects (i.e., neither capacity needs nor time between last discharge and fuel removal is minimized or maximized).

4.1.1 Additional Storage Capacity

The class of acceptance allocations analyzed here represent a limiting case in this spectrum of allocation schemes. By devoting capacity to shutdown reactors, these schemes tend to preclude acceptance at operating reactors which could benefit from acceptance to limit the need for additional storage. Thus, additional at-reactor storage requirements and costs tend to be higher for these cases. (Using assumptions and methods from MRS Systems Study [Task G], projected additional storage requirements are on the order of 29,000 MTU for Case 2, compared with about 10,600 MTU for the reference OFF scenario [Case 1].) This increment of storage capacity would cost roughly \$1.4 billion using the "lower bound 1" cost estimates from Task G.

4.1.2 Duration and Cost of Pool Operations After Last Discharge

Acceptance scenarios in which only shutdown reactors are served will tend to minimize the time required for spent fuel removal and thus the length of pool operations after last discharge. Since the operations costs are

sensitive to the presence of spent fuel, this analysis began by calculating the number of pool-years of operations after last discharge required by each scenario. Several spent fuel pools serve more than a single reactor, as shown in Table 4.1. Since the duration of pool operations is governed by the last reactor to shut down, pool-years after last discharge were measured based on the last discharge from the last reactor at each pool-sharing site.

TABLE 4.1. Reactors Sharing Pools

<u>Reactors Sharing Pools</u>	<u>Sharing Type^(a)</u>
Braidwood 1&2	A
Browns Ferry 1&2	B
Byron 1&2	A
Calvert Cliffs 1&2	B
Comanche Peak 1&2	B
Cook 1&2	A
Hatch 1&2	B
LaSalle City 1&2	B
Limerick 1&2	B
North Anna 1&2	A
Oconee 1&2	A
Point Beach 1&2	A
Prairie Island 1&2	A
Quad Cities 1&2	B
San Onofre 1, 2, & 3	E
Sequoyah 1&2	A
Surry 1&2	A
Susquehanna 1&2	B
Turkey Point 3&4	E
Vogtle 1&2	B
Zion 1&2	A

-
- (a) A = Common pool shared between 2 pools.
 B = Pools connected by a transfer canal.
 E = Pools requiring cask transfer.

The cost of a year of spent fuel pool operation was estimated in Task G at about \$2.2 million per site for a site with no operating reactors and about \$0.5 million per site for a site with at least one operating reactor. These costs are independent of the quantity of spent fuel in inventory. This is a first-order estimate of operations cost but is considered as reliable as the unit cost estimate for additional at-reactor storage capacity.

4.2 RESULTS OF ANALYSIS

Table 4.2 summarizes the results of at-reactor impact and transportation analyses for the nine cases developed in this study. The following sections discuss the significance of these results and their implications for formulation of an acceptance rights allocation policy.

4.2.1 The Reference Case

Case 1 is the reference OFF case from the MRS systems studies. This case results in significant costs to utilities for spent fuel management at reactor sites in terms of both storage capacity above currently estimated maximum pool capacities (\$.82 billion) and pool operations cost after last discharge (\$2.01 billion).

4.2.2 Case 2 - A Literal Construction of EDF

Case 2 was formulated as the starting point in analysis of shutdown priority scenarios. It assumes that the restriction on acceptance of spent fuel from only shutdown pools is strictly observed. As a result, there is insufficient fuel to fully utilize system acceptance capacity for several years (see Column 2 in Table 4.3) in this case, resulting in a total of 8850 MTU of acceptance capacity being unused.

In addition, the allocation of acceptance priorities on a strict "Longest-Shutdown-First" basis in many cases implies that the individual pool annual cask loading constraints (Table 3.1) would be exceeded. This "allocation in excess of shipping capacity" problem occurs in almost all years of repository operation, as shown in Column 3 in Table 4.3, and involves a significant fraction of the spent fuel--over 20,000 MTU. Thus, this scenario is an infeasible one from a logistics perspective if these estimates are

TABLE 4.2. Pool Maintenance Cost and Logistics Impacts of Alternative Acceptance Scenarios

Case Number	Start Date	Shipping Allocation Rule	Shutdown Pool Priority Rule	Minimum Cooling Time (yrs)	Cumulative Shutdown Time (pool-years)	Average Shutdown Time per Pool (yrs)	Operations Cost (\$B)	Infeasible Allocation (MTU)	Unused System Capacity (MTU)	Additional At-Reactor Storage Costs (\$B)	Total Cost (\$B)
1	2003	OFF	n/a	5	1,220	12.7	2.01	0	0	0.82	2.83
2	2003	DECOM	LSF ^(a)	5	570	5.9	--(c)	20,100	8,850	--(c)	--(c)
3	2013	DECOM	LSF	5	1,110	11.5	--(c)	25,600	0	--(c)	--(c)
4	2003	DECOM/FCR/OFF	LSF	5	550	5.7	--(c)	11,700	0	--(c)	--(c)
5	2013	DECOM(R) ^(d)	LSF	5	1,180	12.3	1.99	0	0	2.24	4.23
6	2003	DECOM(R)/FCR/OFF	LSF	5	555	5.8	0.91	0	0	1.30	2.21
7	2003	FCR/DECOM(R)/OFF	LSF	5	614	6.4	1.00	0	0	0.55	1.55
8	2003	FCR/DECOM(R)/OFF	SIF ^(b)	5	672	7.0	1.11	0	0	0.55	1.66
9	2003	FCR/DECOM(R)/OFF	LSF	10	1,025	10.7	1.71	0	0	0.68	2.39

(a) Longest Shutdown First (LSF) - pools at shutdown reactors that have been waiting the longest to be emptied have highest shipping priority.

(b) Smallest Inventory First (SIF) - pools at shutdown reactors that have the smallest inventory of spent fuel have highest shipping priority.

(c) Costs not reported since this scenario is infeasible as configured.

(d) DECOM(R) means reallocation of a strict shutdown pool priority allocation to other shutdown pools if a shutdown pool with allocation rights is incapable of shipping out its entire allocation.

TABLE 4.3. Pickup Schedules and Quantities of Spent Nuclear Fuel Infeasible for Pickup in Case 2

Year	Scheduled Pickup (MTU)	Infeasible Allocation (MTU)
2003	400	13
2004	400	0
2005	180	0
2006	0	0
2007	471	246
2008	16	0
2009	1,913	382
2010	1,311	503
2011	2,381	782
2012	2,979	516
2013	3,000	1,549
2014	3,000	1,081
2015	3,000	754
2016	3,000	476
2017	3,000	1,027
2018	3,000	502
2019	3,000	1,298
2020	3,000	1,205
2021	3,000	400
2022	3,000	139
2023	3,000	354
2024	3,000	595
2025	3,000	1,390
2026	3,000	567
2027	3,000	498
2028	3,000	1,228
2029	3,000	212
2030	3,000	502
2031	3,000	267
2032	3,000	1,279
2033	3,000	596
2034	3,000	175
2035	3,000	0
2036	3,000	237
2037	3,000	0
2038	1,544	1,323
2039	24	0
2040	24	0
2041	24	0
2042	91	0
2043	0	0
2044	0	0
2045	0	0
2046	0	0
2047	0	0
Total	86,758	20,096

accurate. This is a consequence of the fact that shutdown priority tends to concentrate a large fraction of annual acceptance in a few reactors relative to an OFF allocation, as illustrated in Figures 4.1 through 4.4.

Since the problems of unused acceptance capacity and allocation in excess of shipping capacity are fundamental ones, the figures of merit for at-reactor costs are not displayed for Case 2. Cases 3 through 6 were formulated to show how these problems could be circumvented and are discussed below.

4.2.3 Delayed Acceptance

One obvious solution to the problem of unused system acceptance capacity in Case 2 is delayed first-repository operation. This option was analyzed in Case 3, assuming a 2013 start date for the first repository and the same ramp-up pattern as in Cases 1 and 2. In effect, this case assumes the federal system "waits" until sufficient spent fuel is accumulated to fully utilize system capacity. In the process, however, this case exacerbates the extent to which estimated cask-loading rates would be exceeded, increasing the allocation in excess of shipping capacity cumulative total of 25,600 MTU.

FIGURE 4.1. Distribution of Annual Rail Caskloadings for Case 1

FIGURE 4.2. Distribution of Annual Truck Caskloadings for Case 1

FIGURE 4.3. Distribution of Annual Rail Caskloadings for Case 2

FIGURE 4.4. Distribution of Annual Truck Caskloadings for Case 2

More importantly, any scenario involving such delayed acceptance would severely impact those reactors with needs for additional storage needs prior to 2013. (Although this cost is not shown for Case 3, a slightly refined late acceptance scenario in Case 5 results in additional at-reactor storage costs of \$2.2 billion - almost three times the reference OFF cost for additional storage capacity.)

4.2.4 Secondary Priorities

While the emphasis in this study is on acceptance scenarios devoted to shutdown reactors, accomplishing this exclusive allocation of acceptance and assuring full utilization of the federal system capacity by delaying acceptance has severe drawbacks. An alternative reformulation of Case 2 in which unused system capacity is reallocated to operating reactors was analyzed in Case 4. The specific priority scheme utilized in this case is one in which shutdown reactors are granted first priority, reactors with imminent full-core-reserve encroachment (or an immediate need for additional storage capacity) are granted secondary priority, and any remaining system acceptance

capacity is allocated according to the OFF principle. This case eliminates the unused system capacity observed in Case 2 even with a 2003 start date for the repository.

Since this case was not constrained to the maximum annual cask loading constraints in Table 3.1, it still exhibits a degree of allocation in excess of shipping capacity for the shutdown pools, amounting to 11,700 MTU over the life of the system. For this reason, at-reactor costs were not calculated for this case.

4.2.5 Loading Rate Constraints

When spent fuel pickup logistics are constrained so that annual cask loading rates at each pool do not exceed the Table 3.1 values, the allocation in excess of shipping capacity observed in Cases 2 through 4 is eliminated. This constraint was imposed by reallocation of any acceptance rights above the estimated maxima to other shutdown pools. (Since the lower annual pickup quantities dictated under FCR or OFF priorities do not exceed the Table 3.1 values in any case, no reallocation of these portions of the priority scheme is required.)

Imposing the loading rate constraint on Case 3 results in Case 5, which is feasible in the sense of using all available system capacity and not requiring greater annual cask loading capacity at any reactor than shown in Table 3.1. Even though this case circumvents these basic problems, it results in at-reactor costs substantially higher (at \$4.23 billion) than the reference OFF case.

Case 6 is the result of imposing the loading rate constraints (and reallocation of acceptance) to Case 4. This case is both feasible and arguably preferable to the reference case from a utility cost perspective. The combined cost of additional storage capacity and pool operations after last discharge is \$2.2 billion, over \$1/2 billion less than in Case 1. Although this total is less, the stream of annual costs in this case might not be preferred by utilities, since the savings is in terms of the late component of utility cost, and costs for additional storage capacity, which are incurred early, are actually increased in comparison with Case 1. Thus, a high enough rate of discount would remove the cost advantage shown for Case 6.

Case 7 results from revising Case 6 so that FCR encroachment takes priority over shutdown status. As expected, this increases the cost of operations after last discharge, but only slightly, from \$0.91 billion to \$1.00 billion. The decrease in cost of additional storage capacity more than compensates, and this case has the lowest cost to utilities of any analyzed, and results in a significant utility cost savings in comparison with the reference case.

4.2.6 Sensitivity Cases

The LSF rule utilized in Cases 2 through 7 is one possible version of a priority rule favoring shutdown reactors, but certainly not the only such rule. Another possibility is a rule in which allocation of acceptance rights within the group of reactors that are shutdown is made on the basis of remaining inventory. This "Smallest Inventory First" or SIF rule was tested in Case 8. This rule does not affect costs of additional at-reactor storage, and increases costs of operations after last discharge by about \$100 million. Based on this result, no further analyses of this rule were conducted.

Case 9 assumes that the priority structure of Case 7 is retained, but that the minimum acceptable fuel age is 10 rather than 5 years. This results in a slight increase in storage capacity costs but a more sizable increase in cost of operations after last discharge, for a combined cost impact of \$0.84 billion, as some reactors are precluded from needed acceptance by virtue of the fuel age constraint.

4.3 OTHER TRANSPORTATION CONSIDERATIONS

4.3.1 Transportation Cost and Cask Capacity

The transportation cost model (TRICAM) now in use by the Office of Transportation and System Planning (OTSP) is sensitive to changes in the distribution of spent fuel among different origins and to several unit cost factors. Since all of the cases in this study have, over the life cycle of the system, the same quantities of fuel from each origin, transportation costs estimated by this method are invariant. The estimate shown in Table 4.4 would apply to all cases. This estimate, however, makes some

TABLE 4.4. Transportation Costs (\$ millions)

<u>Cost Component</u>	<u>Rail</u>	<u>Truck</u>	<u>Total</u>
Capital	32	29	61
Hauling	306	394	700
Security	14	199	213
Maintenance	40	55	95
Total	392	677	1069

assumptions about cask capacity and utilization factors for which values do vary from case to case. The effects of these factors are discussed below.

The same PWR and BWR capacities are used for all rail casks and for all truck casks, regardless of the case being analyzed. That is, every PWR rail cask is assumed to have a capacity of 21 assemblies and every BWR rail cask is assumed to have a capacity of 48 assemblies. Every PWR truck cask is assumed to have a capacity of 3 assemblies and every BWR truck cask is assumed to have a capacity of 7 assemblies. These capacities are consistent with the ongoing cask design activities, which assume a design basis spent fuel age and burnup of 10 years, 35,000 MWd/MTU. However, the spent fuel transported in each of the cases may represent age and burnup characteristics different from the above. Consequently, the assumed capacities may not apply to all the spent fuel being transported in each of the cases. In this regard, it is important to note that fuel characteristics depend not only on the allocation rules assumed but also on the rules used to select the particular spent fuel to meet annual acceptance allocations. This study did not include consideration of alternative selection rules, but some indication of the effect of various allocation rules on fuel characteristics may be obtained by comparing characteristics for OFF selection under alternative allocations. Figure 4.5 illustrates the effect of shutdown priorities on age at time of receipt as compared with the OFF case. As shown, significantly more young fuel is received under shutdown priorities and OFF selection than under OFF allocation and selection.

Fully accounting for the implications of the spent fuel's age and burnup on the cask capacity is beyond the scope of this analysis. However, one can

FIGURE 4.5. Distribution of Spent Fuel Age at Time of Shipment; Decommissioning and OFF Priorities Compared

get some indication of the direction and magnitude of the effect by considering the age-burnup distributions of the spent fuel at time of transport. If the distributions indicate that a substantial amount of the transported spent fuel exceeds the casks' design specifications, one can conclude that the transportation costs are higher than reported in Table 4.4, since the reference cask capacities will have to be derated. If, on the other hand, the distributions indicate that very little of the transported spent fuel falls outside the casks' design specifications, then the transportation costs can be judged to be very similar to those reported in Table 4.4.

Tables 4.5 and 4.6 illustrate the age and burnup distributions for Cases 1 and 2.

4.3.2 Modal Mix Variations

The alterations of spent fuel receipt sequence among the cases in this study affect the mix of truck and rail transport from year to year. To the extent that the modal mix is affected, the transportation fleet requirements

TABLE 4.5. Age and Burnup Distributions for Case 1 (number of assemblies)

Cooling Time Range (years)	Burnup Range (MWD/MTU)													Total
	0-5000	5000-10000	10000-15000	15000-20000	20000-25000	25000-30000	30000-35000	35000-40000	40000-45000	45000-50000	50000-55000	55000-60000	60000-65000	
0 - 5	0	0	523	36	324	0	364	180	525	33	0	0	0	1985
5 - 10	0	588	1729	1518	1985	1987	3966	5368	2212	1384	222	70	0	21029
10 - 15	20	350	3118	1676	2836	3063	13476	17342	12360	5341	1366	106	0	61054
15 - 20	0	176	635	497	762	3221	28350	29346	20296	12134	2530	173	0	98120
20 - 25	1301	729	1858	3344	5219	16244	20120	17055	7539	1937	324	62	16	75748
25 - 30	100	1018	1881	5640	9071	10481	6164	1303	40	1	5	0	0	35704
30 - 35	721	746	1353	1534	532	335	97	0	0	0	0	0	0	5318
35 - 40	0	0	0	0	0	0	0	0	0	0	0	0	0	0
40 - 45	0	0	0	0	0	0	0	0	0	0	0	0	0	0
45 - 50	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>50	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	2142	3607	11097	14245	20729	35331	72537	70594	42972	20830	4447	411	16	298958

TABLE 4.6. Age and Burnup Distributions for Case 2 (number of assemblies)

Cooling Time Range (years)	Burnup Range (MWD/MTU)													Total
	0-5000	5000-10000	10000-15000	15000-20000	20000-25000	25000-30000	30000-35000	35000-40000	40000-45000	45000-50000	50000-55000	55000-60000	60000-65000	
0 - 5	20	694	4753	2698	3754	3668	5910	11632	3897	2786	508	70	0	40390
5 - 10	0	420	984	907	1513	1535	8935	9940	6534	4380	751	32	0	35931
10 - 15	0	0	216	52	470	741	10500	9753	6938	4450	702	52	0	33874
15 - 20	24	72	145	104	230	2085	10832	8876	7524	3601	857	30	0	34380
20 - 25	17	81	158	172	1511	4473	10304	9181	6330	2422	836	92	0	35577
25 - 30	43	87	360	619	1489	7654	8832	8878	5473	1767	554	54	0	35810
30 - 35	622	174	372	3021	4076	7573	8920	6509	4238	972	207	81	16	36781
35 - 40	427	1685	2600	3414	6190	5398	6403	4368	2000	438	32	0	0	32955
40 - 45	897	218	1435	2924	1374	1988	1841	1457	38	14	0	0	0	12186
45 - 50	92	176	74	330	122	214	60	0	0	0	0	0	0	1068
>50	0	0	0	4	0	2	0	0	0	0	0	0	0	6
Total	2142	3607	11097	14245	20729	35331	72537	70594	42972	20830	4447	411	16	298958

could increase and cost could be greater than that shown in Table 4.4. (The costs in Table 4.4 assume that the annual modal mix is constant.) As shown in Figures 4.6 and 4.7, Case 7 does show more variation in modal mix on a year-to-year basis than does the OFF case.

FIGURE 4.6. Comparison of Rail Cask Fleet Requirements

FIGURE 4.7. Comparison of Truck Cask Fleet Requirements

FIGURE 4-1. Comparison of Truck Load Reductions

5.0 SUMMARY OF CONCLUSIONS

As noted in the Introduction, the time available to complete this report precluded analysis of some aspects of the topic. In particular, a more detailed analysis would allow higher confidence in the maximum annual cask loading capabilities and a quantitative analysis of the effects of changes in spent fuel characteristics and possible resulting changes in transportation cask capacities. In addition, any allocation scheme that differs from the current OFF scheme, even if resulting in overall savings, will have negative impacts on some utilities unless the transition to the new allocation is accomplished through a free-exchange process. With these qualifications in mind, the following conclusions are drawn:

1. A class of spent fuel acceptance scenarios devoted to shutdown reactors has some advantages over the reference OFF scheme, in reducing the time between last discharge and completion of spent fuel removal by a system-wide aggregate of as much as 600 pool-years and estimated operations cost by as much as \$1.0 billion compared with the reference OFF scheme.
2. Such a priority scheme, interpreted strictly as limited only to shutdown reactors and subject to a minimum spent fuel age of 5 years, would make less than complete use of the currently planned acceptance capacity of the repository, resulting in about 8850 MTU of cumulative excess capacity.
3. Any allocation scheme devoted exclusively to shutdown reactors will maximize additional at-reactor storage requirements, with costs of about \$1.4 billion greater than the reference OFF case.
4. The application of an acceptance allocation scheme devoted to shutdown reactors through either a longest-shutdown-first (LSF) or smallest-inventory-first (SIF) rule distributes annual spent fuel acceptance among a few reactors, implying the need for cask loading rates exceeding preliminary estimates of reactor pool capabilities.
5. A reformulation of these priority rules to recognize these logistical constraints is possible by slight modification of the priority scheme without significantly affecting the beneficial features of these schemes.

6. An allocation scheme that combines shutdown reactor priorities with early priority for pools with imminent need for additional storage capacity could largely provide the best features of each scheme, and result in a combined at-reactor cost (for both additional storage capacity and operations after last discharge) about \$1.3 billion lower than the reference OFF case. This scheme can be formulated in such a fashion to observe the cask loading rate constraints.
7. Any of the allocation schemes that devote capacity to shutdown reactors will unavoidably result in lower spent fuel ages and greater heat and radiation output than the reference OFF case. This will result in some change in cask capacities, fleet requirements, and costs from those shown here. The extent of this effect cannot be estimated within the scope of this study. This effect can be only partially mitigated by spent fuel selection rules, since the priority rules specify removal of all spent fuel as soon as possible.

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APPENDIX A

CUMULATIVE PROJECTED POOL AND DRY STORAGE INVENTORIES
IN ORDER OF REACTOR SHUTDOWN

TABLE A.1. Projected Inventory of Spent Fuel at Reactors at Time of Shutdown

Reactor ID	Reactor Name	Reactor Type	Shutdown Date	Pool Inventory (MTU)	Cumulative Pool Inventory (MTU)	Dry Inventory (MTU)	Cumulative Dry Inventory (MTU)	Total Inventory (MTU)	Cumulative Total Inventory (MTU)
1101	INDIAN PT 1	PWR	1974	30.6	30.6	0.0	0.0	30.6	30.6
1005	DRESDEN 1	BWR	1978	69.5	100.1	0.0	0.0	69.5	100.1
3503	HUMBOLDT BAY	BWR	1984	28.9	129.0	0.0	0.0	28.9	129.0
1301	LACROSSE	BWR	1987	38.0	167.0	0.0	0.0	38.0	167.0
6401	WEST VALLEY-B&P	BWR	1998	26.8	193.8	0.0	0.0	26.8	193.8
5601	YANKEE-ROWE 1	PWR	2000	168.4	362.2	0.0	0.0	168.4	362.2
1201	BIG ROCK 1	BWR	2002	57.5	419.7	6.1	6.1	63.6	425.8
6601	MORRIS-BWR&PWR	BWR	2002	564.9	984.6	0.0	6.1	564.9	990.7
5701	HADDAM NECK	PWR	2007	443.5	1428.1	123.0	129.1	566.5	1557.2
1006	DRESDEN 2	BWR	2009	613.5	2041.6	74.4	203.5	687.9	2245.1
1903	OYSTER CRK 1	BWR	2009	463.5	2505.1	116.4	319.9	579.9	2825.0
3101	NINE MILE PT1	BWR	2009	486.6	2991.7	148.1	468.0	634.7	3459.7
4401	GINNA	PWR	2009	368.0	3359.7	63.7	531.7	431.7	3891.4
705	ROBINSON 2	PWR	2010	235.4	3595.1	244.1	775.8	479.5	4370.9
3201	MILLSTONE 1	BWR	2010	387.5	3982.6	368.8	1144.6	756.3	5127.2
3301	MONTICELLO	BWR	2010	361.0	4343.6	0.0	1144.6	361.0	5488.2
1007	DRESDEN 3	BWR	2011	610.4	4954.0	90.4	1235.0	700.8	6189.0
1102	INDIAN PT 2	PWR	2011	442.1	5396.1	223.5	1458.5	665.6	6854.6
1204	PALISADES	PWR	2011	319.3	5715.4	280.0	1738.5	599.3	7453.9
5401	POINT BEACH 1&2	PWR	2011	548.0	6263.4	319.8	2058.3	867.8	8321.7
601	PILGRIM 1	BWR	2012	414.3	6677.7	195.4	2253.7	609.7	8931.4
1010	QUAD CITIES 1&2	BWR	2012	1241.6	7919.3	243.7	2497.4	1485.3	10416.7
2801	MAINE YANKEE	PWR	2012	560.4	8479.7	213.4	2710.8	773.8	11190.5
6001	VT YANKEE 1	BWR	2012	515.4	8995.1	115.8	2826.6	631.2	11821.7
1012	ZION 1&2	PWR	2013	1039.0	10034.1	610.6	3437.2	1649.6	13471.3
1506	OCONEE 1&2	PWR	2013	691.0	10725.1	696.1	4133.3	1387.1	14858.4
1803	TURKEY PT 3&4	PWR	2013	910.5	11635.6	226.6	4359.9	1137.1	15995.5
3401	FORT CALHOUN	PWR	2013	260.4	11896.0	137.0	4496.9	397.4	16392.9
3704	PEACHBOTTOM 2	BWR	2013	679.6	12575.6	210.9	4707.8	890.5	17283.4
5203	SURRY 1&2	PWR	2013	1203.3	13778.9	0.0 ^(e)	4707.8	1203.3	18486.7
5501	KEWAUNEE	PWR	2013	365.2	14144.1	175.4	4883.2	540.6	19027.3
401	ARK NUCLEAR 1	PWR	2014	447.4	14591.5	229.8	5113.0	677.2	19704.5
702	BRUNSWICK 2&PWR	BWR	2014	409.4	15000.9	310.0	5423.0	719.4	20423.9
1508	OCONEE 3	PWR	2014	382.8	15383.7	175.1	5598.1	557.9	20981.8
1901	3 MILE ISL 1	PWR	2014	649.5	16033.2	7.4	5605.5	656.9	21638.7
2401	DUANE ARNOLD	BWR	2014	340.3	16373.5	130.2	5735.7	470.5	22109.2
3001	COOPER STW	BWR	2014	431.6	16805.1	224.4	5960.1	656.0	22765.2
3302	PRAIRIE ISL 1&2	PWR	2014	491.1	17296.2	497.8	6457.9	988.9	23754.1
3705	PEACHBOTTOM 3	BWR	2014	679.7	17975.9	226.2	6684.1	905.9	24660.0
3901	FITZPATRICK	BWR	2014	507.4	18483.3	207.6	6891.7	715.0	25375.0
4501	RANCHO SECO 1	PWR	2014	500.9	18984.2	75.4	6967.1	576.3	25951.3
4803	BROWNS FERRY1&2	BWR	2014	1261.8	20246.0	323.8	7290.9	1585.6	27536.9

TABLE A.1. (contd)

Reactor ID	Reactor Name	Reactor Type	Shutdown Date	Pool Inventory (MTU)	Cumulative Pool Inventory (MTU)	Dry Inventory (MTU)	Cumulative Dry Inventory (MTU)	Total Inventory (MTU)	Cumulative Total Inventory (MTU)
3202	HILLSTONE 2	PWR	2015	423.4	20669.4	232.5	7523.4	655.9	28192.8
3801	TROJAN	PWR	2015	655.1	21324.5	151.6	7675.0	806.7	28999.5
3902	INDIAN PT 3	PWR	2015	587.6	21912.1	0.0	7675.0	587.6	29587.1
501	CALVERT CLF 1&2	PWR	2016	657.1	22569.2	747.0	8422.0	1404.1	30991.2
701	BRUNSWICK 1&PWR	BWR	2016	408.9	22978.1	359.3	8781.3	768.2	31759.4
1601	BEAVER VALLEY 1	PWR	2016	386.7	23364.8	289.8	9071.1	676.5	32435.9
1801	ST LUCIE 1	PWR	2016	278.5	23643.3	458.0	9529.1	736.5	33172.4
4202	SALEM 1	PWR	2016	538.3	24181.6	213.7	9742.8	752.0	33924.4
4805	BROWNS FERRY3	BWR	2016	629.9	24811.5	174.3	9917.1	804.2	34728.6
101	FARLEY 1	PWR	2017	651.6	25463.1	104.3	10021.4	755.9	35484.5
1701	CRYSTAL RVR 3	PWR	2017	297.9	25761.0	284.7	10306.1	582.6	36067.1
5001	DAVIS-BESSE 1	PWR	2017	342.3	26103.3	233.1	10539.2	575.4	36642.5
5801	COOK 1&2	PWR	2017	878.3	26981.6	741.7	11280.9	1620.0	38262.5
402	ARK NUCLEAR 2	PWR	2018	412.9	27394.5	249.3	11530.2	662.2	38924.7
2001	HATCH 1&2	BWR	2018	1073.4	28467.9	495.0	12025.2	1568.4	40493.1
102	FARLEY 2	PWR	2020	651.8	29119.7	90.3	12115.5	742.1	41235.2
4203	SALEM 2	PWR	2020	539.4	29659.1	173.1	12288.6	712.5	41947.7
5201	NORTH ANNA 1&2	PWR	2020	799.0	30458.1	563.3	12851.9	1362.3	43310.0
1504	MCGUIRE 1	PWR	2021	614.3	31072.4	199.5	13051.4	813.8	44123.8
4808	SEQUOYAH 1&2	PWR	2021	635.8	31708.2	704.2	13755.6	1340.0	45463.8
2901	GRAND GULF 1	BWR	2022	693.3	32401.5	302.5	14058.1	995.8	46459.6
4601	SUMMER 1	PWR	2022	591.3	32992.8	129.0	14187.1	720.3	47179.9
4701	SAN ONOFRE 1,2&3	PWR	2022	731.0	33723.8	1121.8	15308.9	1852.8	49032.7
1008	LASALLE CTY 1&2	BWR	2023	393.1	34116.9	1542.0	16850.9	1935.1	50967.8
1505	MCGUIRE 2	PWR	2023	608.1	34725.0	256.3	17107.2	864.4	51832.2
1802	ST LUCIE 2	PWR	2023	616.3	35341.3	104.8	17212.0	721.1	52553.3
5302	WASH NUCLEAR2	BWR	2023	467.4	35808.7	416.6	17628.6	884.0	53437.3
1501	CATAWBA 1	PWR	2024	871.1	36679.8	0.0	17628.6	871.1	54308.4
2701	WATERFORD 3	PWR	2024	573.3	37253.1	234.9	17863.5	808.2	55116.6
3501	DIABLO CANYON 1	PWR	2024	563.2	37816.3	155.8	18019.3	719.0	55835.6
3601	SUSQUEHANNA 1&2	BWR	2024	981.5	38797.8	855.4	18874.7	1836.9	57672.5
5101	CALLAWAY 1	PWR	2024	571.4	39369.2	362.9	19237.6	934.3	58606.8
301	PALO VERDE 1	PWR	2025	563.8	39933.0	373.3	19610.9	937.1	59543.9
1402	ENRICO FERM12	BWR	2025	433.8	40366.8	752.3	20363.2	1186.1	60730.0
2101	RVR BEND 1	BWR	2025	586.4	40953.2	380.8	20744.0	967.2	61697.2
2501	WOLF CREEK 1	PWR	2025	620.8	41574.0	226.2	20970.2	847.0	62544.2
3502	DIABLO CANYON 2	PWR	2025	563.1	42137.1	171.7	21141.9	734.8	63279.0
302	PALO VERDE 2	PWR	2026	548.5	42685.6	376.3	21518.2	924.8	64203.8
901	PERRY 1	BWR	2026	713.2	43398.8	442.8	21961.0	1156.0	65359.8
1502	CATAWBA 2	PWR	2026	917.5	44316.3	0.0	21961.0	917.5	66277.3
3203	HILLSTONE 3	PWR	2026	847.5	45163.8	92.3	22053.3	939.8	67217.1
4201	HOPE CREEK	BWR	2026	738.3	45902.1	374.6	22427.9	1112.9	68330.0

TABLE A.1. (contd)

Reactor ID	Reactor Name	Reactor Type	Shutdown Date	Pool Inventory (MTU)	Cumulative Pool Inventory (MTU)	Dry Inventory (MTU)	Cumulative Dry Inventory (MTU)	Total Inventory (MTU)	Cumulative Total Inventory (MTU)
303	PALO VERDE 3	PWR	2027	548.0	46450.1	377.5	22805.4	925.5	69255.5
703	HARRIS 1	PWR	2027	693.6	47143.7	0.0	22805.4	693.6	69949.1
1003	BYRON 1&2	PWR	2027	1213.1	48356.8	679.9	23485.3	1893.0	71842.1
1602	BEAVER VALLEY 2	PWR	2027	502.1	48858.9	337.0	23822.3	839.1	72681.2
2301	CLINTON 1	BWR	2027	493.8	49352.7	426.9	24249.2	920.7	73601.9
3102	NINE MILE PT2	BWR	2027	682.4	50035.1	312.5	24561.7	994.9	74596.8
1001	BRAIDWOOD 1&2	PWR	2028	428.7	50463.8	1447.1	26008.8	1875.8	76472.6
2201	SOUTH TEXAS 1	PWR	2028	1067.2	51531.0	118.0	26126.8	1185.2	77657.8
2003	VOGTLE 1&2	PWR	2029	1104.8	52635.8	847.5	26974.3	1952.3	79610.1
2202	SOUTH TEXAS 2	PWR	2029	1062.3	53698.1	114.3	27088.6	1176.6	80786.7
3701	LIMERICK 1&2	BWR	2031	723.4	54421.5	1260.8	28349.4	1984.2	82770.9
4810	WATTS BAR 1	PWR	2031	595.5	55017.0	360.0	28709.4	955.5	83726.4
5901	SEABROOK 1	PWR	2031	570.0	55587.0	466.8	29176.2	1036.8	84763.2
4901	COMANCHE PK 1&2	PWR	2037	1373.2	56960.2	482.2	29658.4	1855.4	86618.6
Total				56960.7		29658.4		86619.1	

(a) No dry storage inventory is generated for Surry 1&2, even though this site currently does use dry storage, because the utility reported in the 1987 RW-859 form that the total pool capacity for the site included the projected dry storage inventory.

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