PRELIMINARY ESTIMATES OF IMPACTS OF ALTERNATIVE SPENT FUEL ACCEPTANCE RATES

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ABSTRACT

The rate at which spent fuel is accepted by the federal waste management system is an important interface between the private nuclear power sector and the federal government, which will assume responsibility for spent fuel disposal. An analysis of alternative rates based on minimum age criteria indicates substantial incentives to limit acceptance rates so as to result in minimum 10 to 15 year fuel ages for repository acceptance [1500 to 2500 metric tons of uranium (MTU) per year]. These incentives include lower heat generation rates and systems costs.

INTRODUCTION

The costs and characteristics of the spent fuel waste management system being developed by the Department of Energy (DOE) Office of Civilian Radioactive Waste Management (OCRWM) are influenced by a number of factors some of which can be controlled by DOE. For instance, DOE can establish spent fuel acceptance rates, develop acceptance criteria, select the repository media, and select and develop the waste package concept. However DOE has little control over other factors such as the amount of spent fuel and the frequency of its discharge from the reactors to their storage pools, and burnup or exposure level of discharged fuel. Because of extensive interactions among them, these factors cannot be analyzed separately. As a result, a systems analysis approach is being developed to provide a rational basis for planning and decision making. A comprehensive systems analysis will indicate "preferred" strategies and design parameter values for deployment of the OCRWM waste management system.

In the latter part of FY-1985, DOE-OCRWM initiated studies at the Pacific Northwest Laboratory (PNL) to examine alternative spent fuel acceptance schedules. Logistics and life-cycle costs are compared over a range of spent fuel acceptance rates and spent fuel age acceptance criteria. The rate at which spent fuel is accepted is an important factor because it affects decisions relative to all elements of the system from reactor storage to final disposal. For example, the spent fuel acceptance rate, in part, determines the quantity of spent fuel that may have to be stored at reactor sites outside of storage pools (e.g., in dry storage casks or vaults). The spent fuel acceptance rate also affects the quantity and characteristics of fuel stored at the potential monitored retrievable storage (MRS) facility, the characteristics of fuel emplaced in repositories, and the transportation cask designs and fleet requirements. As a result, acceptance rates affect spent fuel management for both the DOE and the utility industry.

SYSTEMS DESCRIPTIONS

Currently PNL is evaluating waste acceptance rates for two systems. These systems are referred to as the "authorized" system and an "improved performance" system with an MRS facility. These systems correspond to the systems described in the 1985 Mission Plan[1] except that the acceptance rates and duration of facility operations have been varied for this analysis. The first and second repositories are postulated to begin operations in years 1998 and 2006, respectively. For the "improved performance" system, the MRS facility is assumed to start in 1996. The rate at which the facilities can receive spent fuel is assumed to "ramp up" to maximum capacity based on the Mission Plan schedules.[1]

Alternative first repositories in basalt, tuff, and salt are being evaluated. To limit the possible combinations for analysis, the only second repository medium considered is granite. In the "authorized" system, unconsolidated spent fuel is shipped from reactor sites to both the first and second repositories. For the "improved performance" system, all first repository spent fuel is shipped from reactor sites to the MRS. Spent fuel received at the second repository is shipped directly from the reactors. The spent fuel received at the MRS is packaged, temporarily stored, and then shipped exclusively to the first repository. Other reference system descriptions and conditions are as follows:

- Spent Fuel Projection--1985 EIA reference middle case (106,500 MTU in discharges through year 2020). No spent fuel discharges beyond 2020 are considered.
- Wastes included are spent fuel, defense high level waste (DHLW) (16000 canisters), and hardware from consolidation operations.
- Spent fuel assemblies are assumed to be consolidated for disposal. For systems without an MRS

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facility, consolidation, canistering and packaging will be done at the repository. For systems with an MRS, fuel will be consolidated and canistered at the MRS for the first repository only.

- Spent fuel is accepted on the basis of the following priorities: first, fuel from reactors with full-core-reserve (FCR) problems; second, fuel from decommissioned reactors; and third, oldest fuel first.

- All of the fuel discharged by 2020 will be isolated in two geologic repositories having equal acceptance rates and capacities.

- Three acceptance rate alternatives are assumed. These are based on the maximum level rate that can be maintained (except during start-up) over the entire operating period while limiting the minimum spent fuel age for shipment to the repository or MRS to either 5, 10 or 15 years.

- Transportation will be in improved-design casks. All reactor sites having rail shipping capability at the site are assumed to ship in 100-ton rail casks. All other sites are assumed to use legal weight truck casks. For systems with an MRS facility, all shipments from the MRS are made with consolidated fuel in 150-ton rail casks.

- Repository locations assumed are:
  Salt - Deaf Smith, TX
  Basalt - Hanford, WA
  Tuff - Yucca Mountain, NV
  Granite - Lake Erie[b]

Costs calculated in this study use reference repository and MRS cost estimates based on the 1986 MRS/Repository Interface Task Force report[2] and on the 1985 total system life cycle cost (TSLCC) report.[3] Transportation and at-reactor storage costs are based on MRS program study results.

Costs are calculated using two waste container options. For one option, costs are calculated assuming waste container sizes are tailored for waste characteristics in seven heat categories. For the other option, costs are calculated assuming a single container size is used for all spent fuel.

ANALYSIS--METHODOLOGY

The analysis encompasses three spent fuel projections. These three projections correspond to the EIA reference middle case, the No New Orders Case (NNOC) and the EIA middle no-increased-burnup (NIB) case. The EIA reference middle case assumes continued nuclear power industry growth and exposure levels increasing at about 2% per year. The NNOC assumes no additional nuclear plants beyond those scheduled for completion. The NIB case uses the reference EIA middle reactor growth assumptions, but assumes constant current exposure levels.

The analysis is being performed for combinations of the above three spent fuel projections, the two MRS options (no MRS vs. MRS), three repository media combinations, and three waste acceptance rate ranges. This range of parameters includes some that cannot be controlled by the federal government (spent fuel projections) as well as some that can (repository media, MRS option, waste acceptance rate). Cost calculations for the salt-granite and tuff-granite options and for the MRS-no MRS options are not completed and therefore are not included here.

The spent fuel projections selected for the analysis allow a comparison of the effects of spent fuel burnup assumptions as well as effects of fuel quantity generated. The high, medium, and low waste acceptance rate ranges correspond to levelized acceptance rates (after the initial startup ramp) such that the minimum fuel age accepted is 5, 10, and 15 years old, respectively. Table I shows the calculated values for these rates.

As shown in the table, acceptance rates can be substantially lower for higher burnup projections (EIA reference middle vs. EIA NIB). Using a minimum age criteria from 5 to 15 years decreases acceptance rates by 300 to 1300 MTU/yr, depending on the parameter assumptions. This decrease in rate allows the fuel to age (cool) more before handling and emplacement, thus saving transportation, MRS storage and repository emplacement costs. However, lower acceptance rates will result in some at-reactor storage cost increases as well as increased operating costs at MRS and repository facilities as a result of extended operating periods. This tradeoff is discussed in the "Results" section of this paper.

LOGISTICS AND COST CALCULATIONS

The waste management system logistics are calculated using the WASTES computer model.[4] WASTES is a logistics and transportation cost model developed by PNL to analyze operating strategies for complex systems. The model requires as input: a reactor-specific spent fuel data base; scenario and transport data such as facilities, facility capacities, startup dates, transport cask descriptions and routing scenarios; spent fuel acceptance rates; and data for calculating dry storage methods and costs. WASTES produces detailed tables of annual spent fuel flows and inventories in metric tonnes by age, burnup level, and heat characteristics. WASTES also generates transportation and dry storage costs assuming standard 10-year-old fuel characteristics.

A Lotus 1-2-3 spreadsheet is used for the cost analysis. The standard repository, MRS and transportation cost estimates, as well as detailed waste quantities by waste characteristics, provide input to generate systems costs adjusted for these waste characteristics. The methodology uses a standard cost accounting format developed for the repository and MRS facilities and develops factors for each cost account based on physical system parameters specific to each account. For example, reference room excavation costs for repositories are factored by the ratio of areal emplacement requirements. These emplacement requirements are calculated and summed for the quantity of wastes in each heat category based on container heat load and limiting thermal emplacement characteristics. The spreadsheet generates detailed cost tables and some adjusted systems logistics such as quantities of waste packages, number of rail and truck shipments, and other cost-sensitive parameters.

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b Location based on a centroid of sites under consideration.

TABLE I

Spent Fuel Storage Requirements as a Function of Acceptance Rate for Various Systems

Growth Projection	System Configuration	Minimum Fuel Age, yrs	Levelized Acceptance Rate, MTU/yr	Maximum MRS Storage, MTU	Maximum At-Reactor Dry Storage MTU	Maximum At-Reactor Dry Storage # Sites
1985 EIA reference middle (increasing burnup)	NO MRS	5	2,675	0	3,620	32
		10	1,945	0	3,650	32
		15	1,470	0	4,000	32
	MRS	5	2,365	10,000	1,920	19
		10	1,735	7,000	1,940	19
		15	1,340	5,000	2,060	13
1985 EIS No New Orders Case (NNOC)	NO MRS	5	1,947	0	4,010	37
		10	1,517	0	4,090	36
		15	1,255	0	4,550	34
	MRS	5	1,947	8,000	2,190	22
		10	1,475	5,650	2,220	23
		15	1,180	4,200	2,480	15
1985 middle with no increased burnup (NIB)	NO MRS	5	3,000	0	5,990	48
		10	2,320	0	6,080	47
		15	1,707	0	6,590	41
	MRS	5	2,837	12,500	2,580	23
		10	2,033	8,500	2,600	22
		15	1,537	6,000	4,420	26

RESULTS

Logistics

The primary logistical concerns in the waste management system are the quantities of spent fuel and their thermal and radiation characteristics at each point in the system. Fig. 1 shows the cumulative fraction of fuel in the first repository in each of seven heat rate categories as functions of acceptance rate and fuel projection at time of emplacement in the repository. Within any given fuel projection, the plot shows that the cooling effect associated with lower acceptance rates results in significant reductions in the quantities of fuel above the current 1.2 kW/MT waste package design point. The percentage reduction is most noticeable between a high and a medium acceptance rate (a 10-year minimum age instead of a 5-year minimum age), although significant reductions are also obtained by a low acceptance rate (15-year minimum age).

Figure 1 also illustrates the sensitivity of heat rates to fuel burnup assumptions. In the EIA reference middle and the NNOC projections, which include increasing fuel burnup assumptions, 30 to 40 percent of the fuel is above the current 1.2 kW/MT design level. In the NIB case where average burnup levels do not increase above current levels, only 10 to 25 percent of the fuel would be above the design point. Similar results are shown in Fig. 2 for the second repository except that the percentages of fuel above the current design point are significantly higher because most of the very old fuel has been isolated in the first repository. Increasing the minimum acceptance age therefore has an even greater impact on waste heat loads in this repository.

Figure 3 shows the heat characteristics of spent fuel received annually at the first repository over

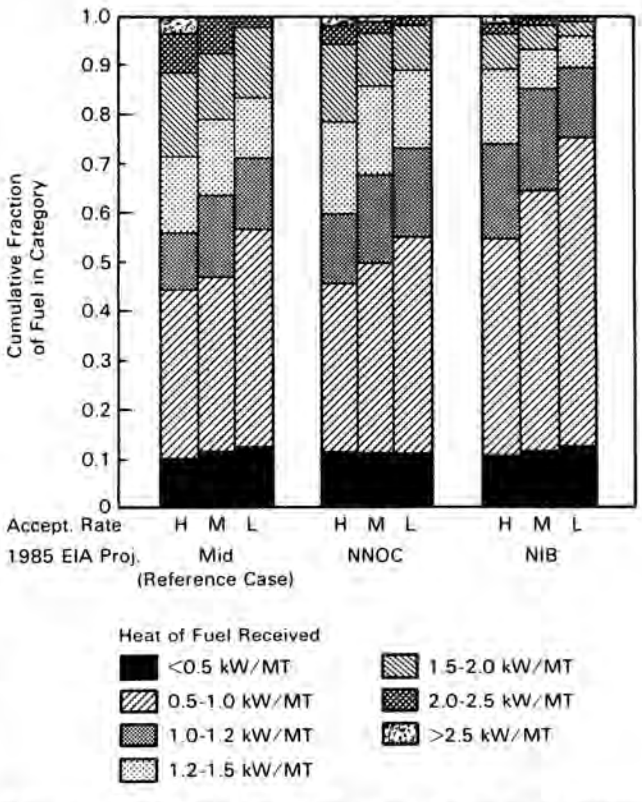

Fig. 1. The Effect of Acceptance Rate on Heat Characteristics of Spent Fuel Received at First Repository for Three Growth Projections.

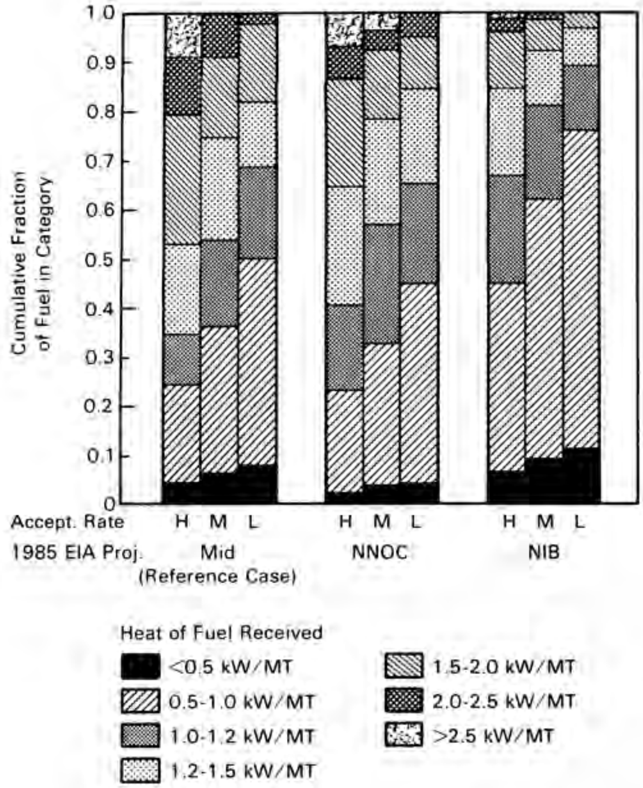

Fig. 2. The Effect of Acceptance Rate on Heat Characteristics of Spent Fuel Received at Second Repository for Three Growth Projections.

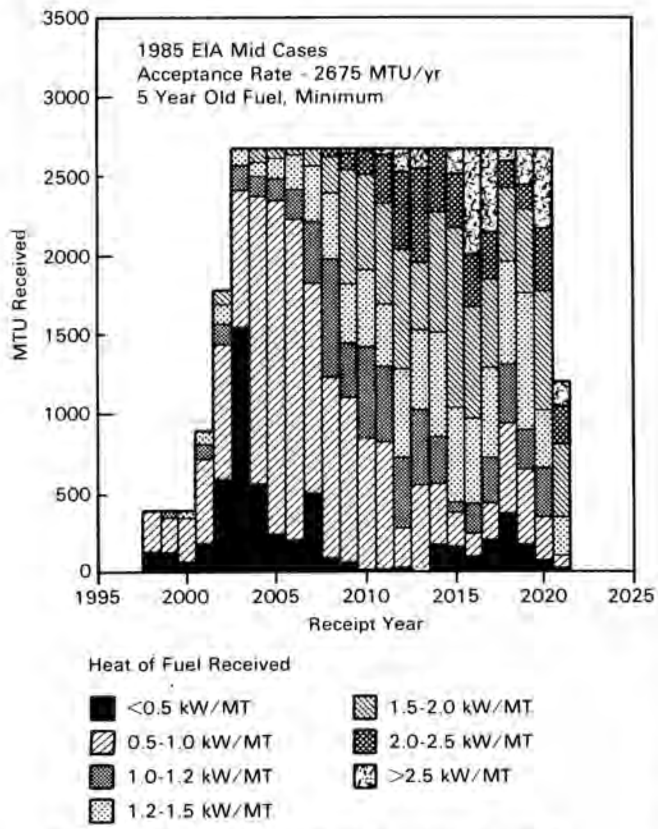

Fig. 3. Annual Spent Fuel Receipts by Heat Category--"Authorized" System.

its operating life for the reference 5-year minimum-age case. During the ramp-up period and the first six years of operations, more than 75 percent of fuel received is cooler than the current design basis. However, during the last eleven years of operation most of the fuel received is hotter than the current design basis. This graph indicates that stepwise changes in package design may be one method of dealing with the large variation in heat characteristics over time. Figure 4 shows a similar plot for the first repository for the "improved performance" system with an MRS. Comparing this plot with Fig. 3 shows that cooler fuel is sent to the first repository under the "improved performance" system. This effect is caused by the cooling associated with lag storage at the MRS and by taking more of the older fuel inventory into the first repository. More of the older fuel is taken into the first repository because of the earlier startup date and higher initial fuel receipts postulated for the MRS facility. This also results in somewhat hotter fuel at the second repository, however, this could be mitigated by delaying startup of this repository.

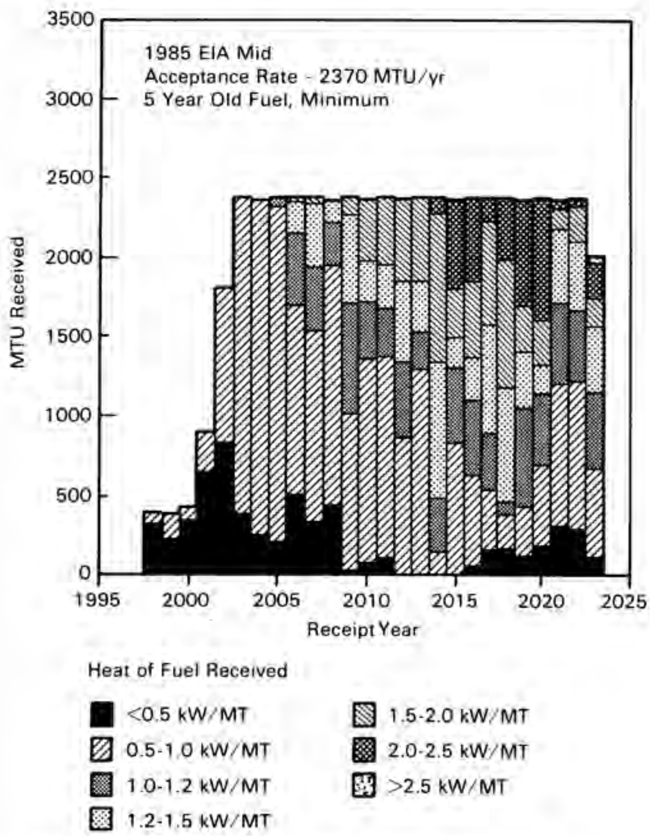

Fig. 4. Annual Spent Fuel Receipts by Heat Category--"Improved Performance" System.

One of the implications of reduced acceptance rates is a greater reliance on at-reactor storage. These storage requirements are also calculated in the WASTES model on a reactor-by-reactor basis. The impact on storage requirements of the acceptance rates corresponding to minimum 5-, 10- and 15-year-old fuel acceptance criteria is also shown in the previously referenced Table I. Maximum MRS storage requirements are also shown. Significant differences in storage requirements between fuel projections are evident because of the differences in quantities of discharged fuel in each projection. However, the table shows very little impact on ex-pool (dry storage) reactor storage requirements within each projection for a minimum acceptance age of 10 years instead of 5 years. This indicates that most reactors that can store 5 years' worth of reactor discharges can also store 10 years' worth. A minimum acceptance age of 15 years results in slightly larger at-reactor storage requirements of 120 to 1800 MTU depending on the fuel projection and MRS option. At-reactor storage requirements are, in all cases, substantially lower in the "improved performance" system and are less sensitive to reduced acceptance rates than is the "authorized" system. MRS storage requirements range from 4200 to 12,500 MTU depending on the options. Reducing the acceptance rate reduces the MRS storage requirement. As an alternative, at-reactor storage could also be minimized by increasing the MRS acceptance rates.

Costs

In the next two figures the cost results are summarized for a basalt-granite system. The effect of fuel projection on minimum-cost acceptance rates is shown in Fig. 5. All three projections show lower system costs at an acceptance rate corresponding to a 10-year minimum age. Cost minimums at acceptance rates of approximately 1500 and 2300 MTU/yr are shown for the NNOC and NIB scenarios, respectively. The EIA reference middle case also shows minimum costs near the 1500 MTU level. System costs for the NNOC projection are lower than for the other projections because there is significantly less fuel in the system.

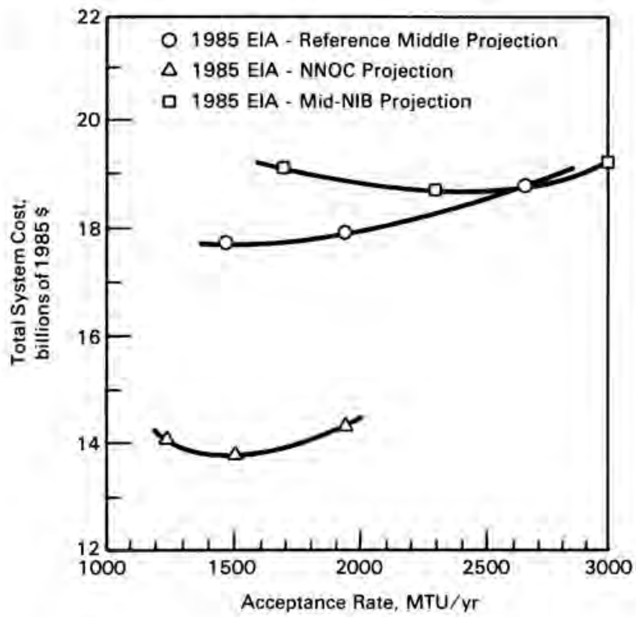

Fig. 5. The Effect of Fuel Projection on Minimum-Cost Acceptance Rate for a Basalt-Granite System.

The results just discussed assume an idealized system in which waste package sizes are tailored to heat categories (tailored container strategy). Costs were also calculated for a single container size strategy to determine the effect on acceptance rate costs. For this strategy, the largest waste container that can accommodate 80 percent of the spent fuel without exceeding the repository waste package thermal limit when fully loaded is selected. All waste containers are made the same size. To maintain the maximum heat loading, less fuel is placed in containers if the spent fuel has heat rates higher than the design basis. Spent fuel containers in categories cooler than the design basis all have the same mass loading, but have container heat rates lower than the maximum.

The effects on acceptance rate and costs of the two container strategies are shown in Fig. 6. The tailored container strategy costs are lower than those for the single container strategy because fewer waste containers are required. However, the tailored container strategy would be more difficult to implement and would require additional investments for design and deployment of variable size overpacks, shipping casks, and storage casks. One method to implement this strategy would be to use only one size waste container at any time but adjust container size every 5 to 10 years to accommodate the changing heat characteristics of the spent fuel. Additional studies are required to identify the most appropriate strategy to accommodate changing waste characteristics. There are significant cost reductions with lower acceptance rates in both container strategies because cooling effects substantially reduce the number of waste containers. Also, at lower acceptance rates, there is a substantial narrowing of the cost differential between the two container strategies.

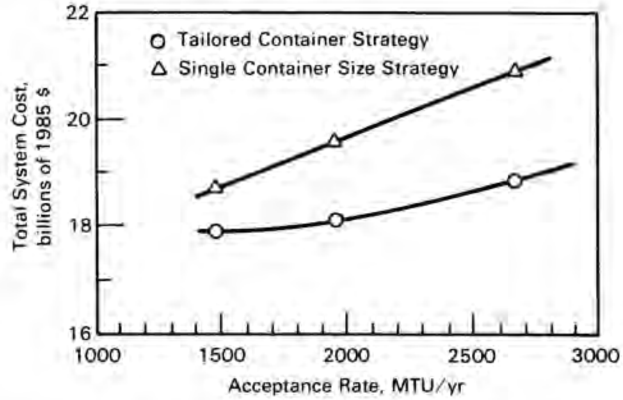

Fig. 6. The Effect of Single Container Size Strategies on Total System Costs.

The source of savings with reduced acceptance rates is primarily the reduced number of waste containers permitted with the resulting older and cooler wastes. A counteracting effect is the increased life-cycle costs resulting from the extended repository operating periods. Consideration of these results suggests the possibility of maintaining a higher acceptance rate by delaying the startup of the second repository. This strategy results in all of the advantages of cooler fuel without the negative effect of extended operating periods. This possibility is being investigated.

CONCLUSIONS

Projections to date show that a wide range of thermal output will exist for spent fuel received at the repositories. Ten to forty-five percent of the fuel at the first repository and ten to sixty-five percent of the fuel at the second repository will be hotter than 1.2 kW/MTU, depending on the burnup growth projection and acceptance rate. One strategy to help alleviate this problem is to use a lower acceptance rate based on a minimum desired fuel age. This study has shown that reducing acceptance rates to correspond to a 10-year minimum age has a substantial favorable impact on waste characteristics and overall systems costs. An incidental finding was that there appears to be a significant incentive to tailor the waste package sizes for the changing heat characteristics of the spent fuel. This incentive would need to be compared against increased costs of multiple cask and package designs and increased fleet requirements for the tailored container strategy.

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