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Waste Management System Reliability Analysis

L. L. Clark
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Prepared for the U.S. Department of Energy
under Contract DE-AC06-76RLO 1830

Pacific Northwest Laboratory
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ABSTRACT

This is one of nine studies undertaken by contractors to the U.S. Department of Energy (DOE), Office of Civilian Radioactive Waste Management (OCRWM), to provide a technical basis for re-evaluating the role of a monitored retrievable storage (MRS) facility. The study evaluates the relative reliabilities of systems with and without an MRS facility using current facility design bases. Due to time and study constraints the analysis is limited to a consideration of just two systems. The first system features a full-function MRS that receives, stores, consolidates and canisters spent fuel and sends it to a repository for containerization and disposal. The second system is a comparable repository-only system that receives, consolidates, and containerizes spent fuel at the repository before placing it underground for disposal.

In this study, reliability is defined as the ability to accomplish two major waste system functions: waste acceptance from waste generators and waste disposal in the geologic repository in accordance with the OCRWM Mission Plan (DOE 1985). For each of these functions DOE requested that reliability be examined from the standpoint of 1) the ability to start each function on schedule and 2) the ability to successfully carry out each function at the Mission Plan operating rates once startup is achieved.

The principal finding of this report is that the MRS system has several operational advantages that enhance system reliability. These are: 1) the MRS system is likely to encounter fewer technical issues - such as unanticipated geologic characteristics - that could delay or interrupt waste acceptance, 2) the MRS would assure adequate system surface storage capacity to accommodate repository construction and startup delays of up to five years or longer if the Nuclear Waste Policy Amendments Act (NWPAA) were amended, 3) the system with an MRS has two federal acceptance facilities with parallel transportation routing and surface storage capacity, and 4) the MRS system would allow continued waste acceptance for up to a year after a major disruption of emplacement operations at the repository.

The results of a simulation analysis of facility operating characteristics indicate that both systems should be able to maintain acceptance at Mission Plan operating rates of 3000 MTU/year under normal conditions. Because the MRS system has a larger capacity than the repository-only system at design operating rates, it could have somewhat better operating reliability under off-normal conditions. Reliability of the disposal function is about the same for both systems, since they use the same geologic site requiring the same licensing and acceptance activities and employ the same equipment in disposal operations.

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1.0 INTRODUCTION

Since the passage of the Nuclear Waste Policy Amendments Act (NWPAA), it has become apparent that a re-examination of the role of the monitored retrievable storage (MRS) facility in the federal radioactive waste management system is appropriate. As a result, the U.S. Department of Energy (DOE), Office of Civilian Radioactive Waste Management (OCRWM), has undertaken a series of short-term analyses that will provide information for an updated evaluation of the MRS. This effort is being conducted in a time frame such that the results of these studies will be available to the MRS Commission in its evaluation of the need for the MRS for its report to the Congress.

As part of the MRS Systems Study, developed by OCRWM to carry out these analyses, OCRWM commissioned the Systems Integration Program at Pacific Northwest Laboratory (PNL) to analyze the reliability of the waste management system with and without an MRS facility. This report presents the findings of this study, designated Task I.

The two system alternatives compared in this analysis are the MRS and the Repository-only systems. In the Repository-only system, spent fuel is shipped by DOE from commercial reactors directly to a federally-owned repository. In the MRS system, DOE ships spent fuel from commercial reactors to a federally-owned MRS facility that would store and possibly process the spent fuel before shipment to the repository. A number of system process functions may be carried out either at the MRS or at the repository before the radioactive wastes are emplaced underground. These functions include possible fuel consolidation, waste containerization and interim waste storage. The MRS Systems Study considers alternatives for performing these functions at an MRS or at the repository, as well as other system alternatives such as siting alternatives for the proposed MRS, high-level waste (HLW) processing at the MRS, western fuel processing options and various facility startup schedules. Table 1.1 gives the postulated waste management system functional configurations identified in the MRS Systems Study scenarios.

TABLE 1.1. Postulated Waste Management System Functional Configurations

Number	MRS Functions	Repository Functions
1	None (No-MRS)	Consolidate and containerize
2	None (No-MRS)	Containerize intact
3	Storage only	Consolidate and containerize
4	Storage only	Containerize intact
5	Consolidate and canister	Containerize
6	Containerize intact	Check containers
7	Containerize intact	Check and repair containers
8	Consolidate and containerize	Check containers
9	Consolidate and containerize	Check and repair containers

1.1 DEFINITION OF RELIABILITY

Reliability in a broad sense is defined as the likelihood of accomplishing a specific goal in a specified time period. In the waste management system, reliability is defined as the ability to accomplish two major waste system functions: waste acceptance from waste generators and waste disposal in the geologic repository in accordance with the schedule defined in the OCRWM Mission Plan (DOE 1985, 1987). For each of these functions, the DOE requested that reliability be examined from the standpoint of 1) the ability to start each function on the scheduled startup date, and 2) the ability to successfully carry out each function at specified Mission Plan (DOE 1985, 1987) operating rates once startup is achieved. Operational capabilities were examined for routine operations and for operations during and after a major disruptive event such as a natural disaster.

1.2 SCOPE OF ANALYSIS

In the time available for this study, it was not possible to evaluate all of the various system configurations defined for the MRS Systems Study. The number of configurations to be considered was reduced by identifying a bounding case for the set of MRS configurations and a bounding case for the set of Repository-only configurations. The two most complex systems identified in the MRS Systems Study configurations were chosen for these bounding cases. These are: the MRS system with consolidation and canistering at the MRS and containerizing at the repository (Configuration 5 in Table 1.1); and the Repository-only system with consolidation and containerizing at the repository (Configuration 1 in Table 1.1). Since the operational reliability of a system is dependent on the number of consecutive serial processes required in the system, these most complex systems (in terms of serial processes) should provide a lower bound on reliability.

The MRS facility in the Configuration 5 MRS system is taken from the MRS Conceptual Design Report (Parsons 1985). The repository facility in this system is based on a conceptual layout developed by PNL's Systems Integration system description task,[a] and closely resembles a repository facility design postulated by the Tuff Repository Project for a system containing an MRS facility (Sandia 1988).

The Repository-only system represented by Configuration 1, being the most complex Repository-only system, was chosen for comparison with the MRS system. In addition, both systems have similar functions and comparable products. The design basis for the repository in this system is taken from the Site Characterization Plan Conceptual Design Report for the Yucca Mountain repository in tuff (Sandia 1987).

Flow diagrams for the above two systems are shown in Figures 1.1 and 1.2. These diagrams show acceptance at waste generators, transportation to federal facilities, and disposal. The scope of this analysis is limited to the reliability of the waste acceptance and disposal functions. Transportation system reliability falls under the scope of the Transportation task. Transportation elements were modeled in this study based on currently accepted functions for shipping times. The validity of the distributions and

(a) McKee, R. W., et al. October 1988. Conceptual Descriptions of the Waste Management System for Model Development. Draft Revision 2.3, Pacific Northwest Laboratory, Richland, Washington.

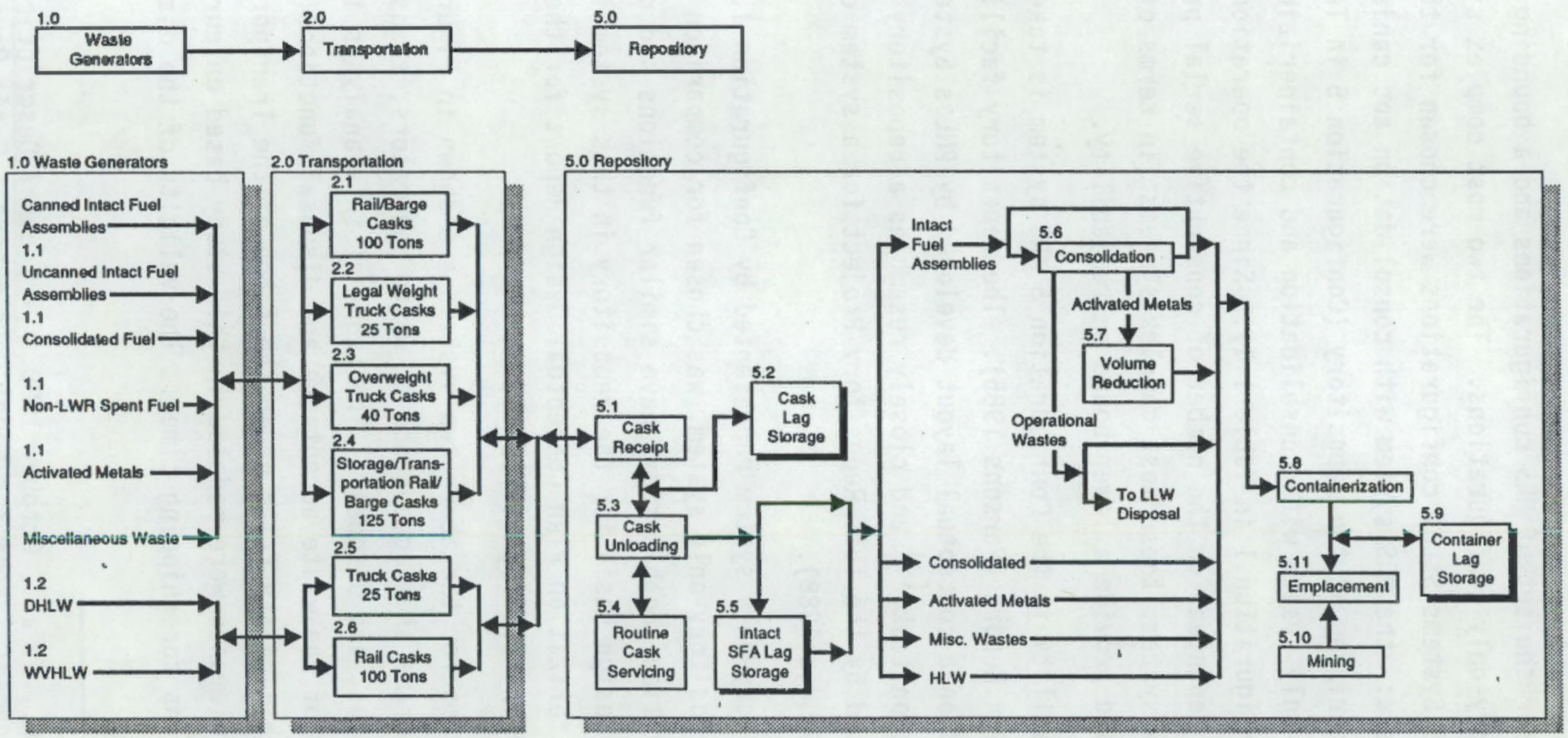

FIGURE 1.1. Repository-Only System Level 1 Functional Flow Diagram

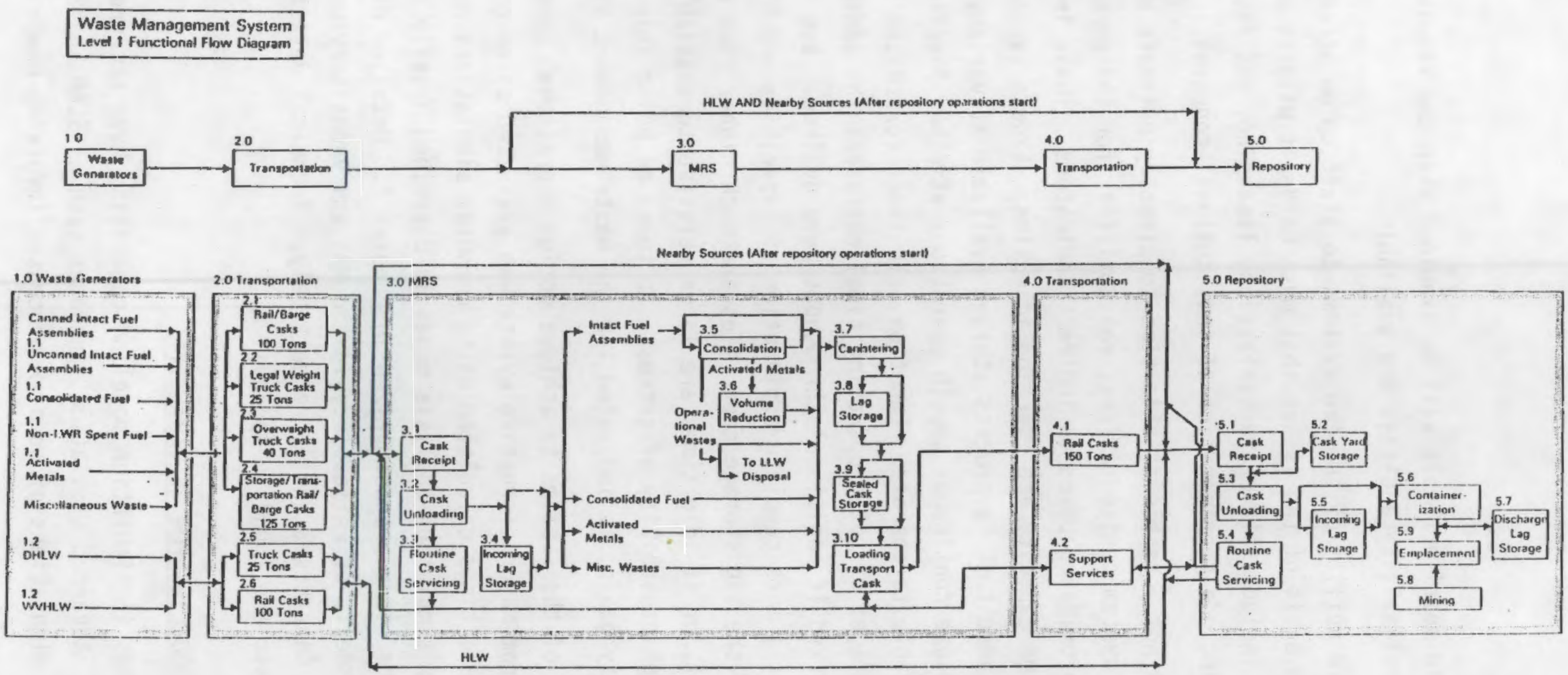

FIGURE 1.2. MRS-Based System Level 1 Functional Flow Diagram

functions used to model arrivals will be examined when the results of a transportation reliability analysis are available.

The relative ability of the two systems to start up on schedule is evaluated on the basis of the issues that must be dealt with to achieve startup. These include site characterization, licensing, and facility construction, and include consideration of institutional concerns.

While it is not possible at this time to directly estimate reliabilities for the various system configurations, reliabilities for the conceptual designs were approximated based on indirect indicators. These indicators are excess lag storage capacity and function idle time. Excess lag storage capacity is the amount of in-process storage available at various points in the system to ensure continuous smooth operations at other functions when one function is not able to operate. Function idle times (expressed in this report as percentages of total operating time) represent the additional time that could be worked if additional throughput were desired. See Section 1.3 in Appendix A for a more complete explanation of capacities and times used in this report. If the lag storage capacities are much higher than required for normal throughput, or if idle times are large relative to available operating times, then a high probability of success, in terms of being able to meet design operability goals, is indicated for the waste management system.

The ability of the systems to achieve design operational throughputs and to recover from major disruptive events was evaluated based on functional capacities and idle times calculated using computer simulations developed for each system. The simulation analysis model is described briefly below, while the results of the study are summarized in Chapter 2. Detailed discussions of the various aspects of reliability in the MRS and Repository-only systems are presented in Chapters 3 and 4, respectively. Technical details of the simulation analysis are found in Appendix A.

1.3 SIMULATION MODELING FOR RELIABILITY

Great advances in simulation modeling capability have occurred during the last decade. Advanced simulation languages such as SLAM and SIMAN have allowed detailed simulations of complex processes involving usage of machines and process stations. These simulations use operating data, various types of probability distributions and random-event processes to simulate actual operation of a system. Some of the key results obtained from these simulations are the equipment or process utilization, the equipment idle and maintenance times, the lag storage requirements and the function throughput capacities.

For the federal waste management system, a simulation model based on the SIMAN simulation language was developed under the Systems Integration Program at PNL to perform quantitative reliability, availability and maintainability (RAM) studies. This undocumented program, named FASIT, incorporates current simulation technology and has the capability of estimating system reliability and throughput capability at the system level.

The FASIT model consists of routines that simulate various generic types of activities such as storage, machine processing, splitting processes (such as unloading multiple fuel assemblies from a single cask), and combining processes (such as loading a single container with multiple consolidated fuel assemblies). Simulation descriptions are assembled that define the waste management system by linking together the various generic routines in ways that represent the system being modeled. These descriptions are then processed with the model using the SIMAN compiler to generate the program results. A more extensive discussion of the MRS and Repository-only operations simulations and the simulation results is presented in Appendix A.

2.0 SUMMARY OF RESULTS

Based on current designs, the MRS system analyzed has significantly greater potential for assuring that the federal system will be able to accept wastes as scheduled than a repository-only system. This improvement is limited by the constraints imposed by the Nuclear Waste Policy Amendments Act (NWPAA). The MRS has several operational advantages that enhance system reliability. First, the MRS siting, design, and licensing process is less likely to encounter technical issues - such as unanticipated geologic characteristics - that could delay or interrupt waste acceptance. Second, the MRS would assure adequate system surface storage capacity to accommodate repository construction and startup delays of up to five years, or longer if the NWPAA were amended. Third, the MRS system has two acceptance facilities in the federal system with parallel transportation routing and surface storage capacity. Fourth, the MRS system would allow continued waste acceptance for up to a year after a major disruption of emplacement operations at the repository.

With respect to the reliability of the waste disposal function, reliability of waste disposal is essentially the same for the two systems because the same geologic site requiring the same licensing and acceptance activities and employing the same equipment is used for both systems. The only discernable difference in disposal in the two systems is that the Repository-only system emplaces about 500 fewer containers per year due to differences in canistering and containerizing in the two systems. This difference is well within the routine emplacement capacity of the two systems.

2.1 MRS SYSTEM RELIABILITY

The MRS's primary function is waste acceptance and interim storage, although it can contribute to waste disposal by accomplishing some or all of the waste preparation functions.

The principal uncertainties in the ability to begin waste acceptance on schedule involve 1) institutional issues surrounding the siting of the MRS, and 2) provisions in the NWPAA. Licensing is not considered to be a principal issue, because the MRS will utilize tested technology. (Much of this same technology will be used in the repository surface facilities.) Siting of the MRS may be a protracted process depending on the ability to find a host state. However, even after agreement on a site is reached and the site is characterized and found acceptable, NWPAA restrictions result in additional uncertainty since construction of the facility may be delayed until a construction authorization is received for the repository. Removing this restriction and decoupling construction of the MRS from construction of the repository would enhance acceptance reliability.

In regards to operational reliability, one of the important observations of this study is that reliability criteria for waste management system operations have not been defined. Such criteria are needed so that advanced conceptual designs incorporate sufficient processing and storage capacity to cover normal and off-normal operations. Because of this lack of reliability criteria, the current MRS and Repository-only designs specify widely divergent operating parameters such as excess throughput capacity, and in-process lag storage capacities.

The reliability of normal operations is estimated by determining the limiting idle capacities of process functions in the processing sequence, and by examining the unused lag storage capacities since these quantities give an indication of the ability of the system to "catch up" after normal short-term failures. Idle times for MRS process functions are never less than 36% out of a scheduled 71% availability, indicating a large contingency capacity. This results in a high probability that the MRS facility could accept waste at the 3000 MTU/year Mission Plan rate (DOE 1985, 1987) under normal operations since the facility could be idle for almost half of the time and still meet the target throughput. Minimum idle times for repository receiving and containerizing functions in the MRS system are about 10% out of a scheduled 47% availability, indicating adequate capacity to containerize the wastes.

The ability of the MRS system to maintain acceptance for long time periods under conditions of major disruption is one of the major differentiating factors found in this study. Major disruptions might be caused by natural disasters, fires, explosions, or political events. If the disruptive event occurs at the repository, the MRS system has the ability to maintain fuel acceptance because of the storage capability of the MRS facility. The storage capacity of the MRS is currently limited by the NWPAA to 15,000 MTU of spent fuel. At an acceptance rate of 3000 MTU/year, this allows continued acceptance for up to 5 years, depending on the inventory at time of failure. For current postulated Action Plan cases, the maximum MRS inventories range from 5000 MTU for concurrent MRS and repository facility startup (because of a postulated more rapid ramp-up to full capacity in the MRS facility) to 13,000 MTU for a 4-year difference in startup times. Based on the above scenarios, the MRS facility could continue to accept waste from 8 months to 3.6 years after a repository shutdown at the Mission Plan acceptance rate under current NWPAA constraints. If the NWPAA requirements are changed so that the storage ceiling is removed, the ability to continue acceptance would be increased.

It is also important to note that the disposal capacity of the repository plays a role in the storage capability of the MRS system. The simulation analyses indicate that the repository in the MRS system has a throughput capacity of 4000 MTU (2 shift/day operation) to 6000 MTU (3 shift/day operation) per year. The 1000 to 3000 MTU/year excess repository disposal capacity could be used to draw down storage cask inventory levels at the MRS to provide a greater contingency storage capability. This would allow early startup of the MRS (assuming the NWPAA restrictions on early MRS construction were removed) without the burden of being near peak storage limits over the life of the MRS facility. Analysis of the ability of the MRS system to recover from a major disruptive event indicates that the high throughput capacity of the system also plays a major role in being able to return to normal operations.

The MRS system in scenario 5 also has a high acceptance reliability because it has two facilities that could accept fuel directly from reactors, the MRS facility itself and the repository. The repository is postulated to receive 350 MTU/year of western fuel and the simulation analysis indicates that the design would permit considerably higher spent fuel processing rates (possibly as much as 1500 MTU/year) if the need should arise. With two facilities capable of acceptance, reliability is increased since there is a lower probability that both facilities would experience long outages simultaneously.

The second major function of the system addressed in this report is disposal of the waste in accordance with the schedule and rates specified in the Mission Plan (DOE 1985, 1987). In both the MRS and the Repository-only systems, completing this function depends on the ability to excavate the repository and emplace the wastes on schedule. The main factors affecting reliability of this function are the uncertainties in the qualification and licensing of the repository because analysis of the operating characteristics for waste emplacement indicates high operating capacities and significant idle times, suggesting that the actual waste emplacement activities should be highly reliable. Proving the radionuclide release and safety performance of the underground portion of the repository to the NRC's satisfaction may well require an extension of the time period now planned for licensing of the repository. Even after the repository is licensed, geologic anomalies may be found underground that would delay underground excavation, force redesign of the underground layout, force operation at reduced throughput rates, or even disqualify the site.

2.2 REPOSITORY-ONLY SYSTEM RELIABILITY

Factors potentially delaying startup of the waste acceptance function in the Repository-only system are the same as those responsible for potential delays in startup of the disposal function in the MRS system (i.e., extensions of the time period required to qualify the repository and uncertainties in licensing the site). The major difference between systems is that the Repository-only system is not currently designed to accept waste for long time periods if the disposal function is not operative. The MRS system, on the other hand, is designed to decouple the acceptance function from the disposal function and can maintain acceptance for long time periods when disposal is not possible. Because of the uncertainties surrounding startup of the repository, there is therefore less certainty in the ability to start the Repository-only system on schedule than there is in starting up the MRS system on schedule.

The simulation results show that the conceptual Repository-only system, given the designs and operations currently postulated, should be able to process wastes at rates specified in the Mission Plan (DOE 1985, 1987) under normal conditions. However, the conceptual Repository-only system is judged to have somewhat less reliability for acceptance operations than the MRS system for the following reasons:

- As currently designed, the Repository-only system has lower throughput capacities and less lag storage capability than the MRS system, indicating a greater likelihood of interruption of the acceptance function following a major disruption.
- There is a greater probability of disruptive events such as construction accidents, discovery of faults, etc., at the repository than at the MRS facility.
- The repository is the only acceptance facility in the Repository-only system, thus its ability to continue acceptance in case of disruptive events is limited to its storage capacity. This storage capability has been tentatively identified in preliminary design criteria as 3 months' worth of receipts, or about 750 MTU.
- The simulation analyses indicate that the Repository-only system has greater difficulty in working off a system backlog after a long outage because its design throughput capacity (based on two-shift-per-day operation) is not much greater than the normal acceptance rate.

The waste disposal function in the Repository-only system is essentially the same as the waste disposal function in the MRS system since the two systems assume the same geologic site requiring the same licensing and acceptance activities and employing the same equipment. The difference in canistering and containerizing functions between the two systems does result in 500 fewer containers per year requiring disposal in the Repository-only system (the MRS system does not consolidate western fuel and has slightly less packaging efficiency than the repository-only system), but simulation analysis of the disposal capacities indicates substantial excess capacity in both systems.

3.0 MRS SYSTEM RELIABILITY ANALYSES

This chapter explains in more detail the analyses and conclusions summarized in Chapter 2.1.

3.1 RELIABILITY OF WASTE ACCEPTANCE FUNCTION

The reliability of the waste acceptance function is defined as the probability of being able to accept waste from the waste generators in accordance with the schedule and rates defined in the OCRWM Mission Plan (DOE 1985, 1987) with little or no interruption. This includes the probability of meeting the schedule for startup of the facilities, the probability of maintaining waste acceptance rates during normal operations, the ability of the system to continue waste acceptance in the face of major disruptions and the ability of the system to recover from disruptive events. These factors are discussed in the following sections.

3.1.1 Startup Schedule Uncertainties for Acceptance

The major schedule milestones for startup of the waste acceptance function in the MRS system are the siting, construction, and licensing of the MRS facility itself. In these areas, no major unresolved technical issues with regards to storage and processing of the fuel are evident. Storage of spent fuel in dry casks and in drywells has been demonstrated at the EMAD facility in Nevada and in joint DOE/utility ventures. Construction of storage and processing facilities is known technology and offers little uncertainty. The greatest uncertainties in the startup schedule for an MRS facility involve the institutional issues surrounding the siting of the facility and the provisions in the Nuclear Waste Policy Amendments Act (NWPAA). Siting of the MRS may be a protracted process, depending on the willingness of states to accept such a facility within their borders. Once agreement on a site is reached, construction of the facility and preparation for acceptance of waste from utilities should be relatively straightforward. However, even after agreement on a site is reached and the site is characterized and found acceptable, construction of the facility may be delayed until a construction authorization is received for the repository, in accordance with the current restrictions in the NWPAA.

3.1.2 Operational Uncertainties for Acceptance

Every processing system involving a series of dependent processes has normal processing uncertainties associated with random arrivals, equipment failures and processing strategies such as batch processing. In the federal waste management system, the ability to meet a target throughput, such as the Mission Plan receipt rate from utilities of 3000 MTU/year, depends on the facility designs, the processes performed and the diversity of the waste streams processed. The number of serial processes performed and the waste stream diversity determine the complexity of the system, and the facility design determines system capacity and operating efficiency.

The current conceptual facility designs in both the MRS and Repository-only systems address processing and disposal of consolidated and intact PWR and consolidated and intact BWR spent fuel, non-fuel-bearing-hardware (NFBH), defense high-level waste (DHLW), and West Valley high-level waste (WVHLW). In the designs examined in this report, most of the spent fuel is consolidated and all of the wastes are placed in containers designed for long-term disposal. These designs therefore address the most complex waste management system currently envisioned. The facility designs do differ markedly, however, in their system capacity and operating efficiency, as shown in the analysis of operating reliability in this study. These differences arise because of different levels of conservatism in the design and because of lack of specified reliability criteria. Reliability criteria are needed because they assure that the designs will have sufficient throughput capacities and lag storage provisions to meet throughput goals under both normal and disruptive conditions.

Although facility designs are still preliminary and could be changed to be more comparable in terms of reliability, an analysis determining their relative operating reliabilities was needed in the time frame of this study, since other comparisons are being made on the basis of current designs. These types of reliability analyses are also usually performed to develop reliability criteria for the next phase of design. This analysis was performed using simulation techniques and is reported in detail in Appendix A.

For the MRS system, the current conceptual designs assume three-shift/day operations at the MRS facility and two-shift/day operations at the repository. The simulation analyses performed for this study suggest that for comparable reliability, the repository surface facility could also operate three shifts/day; however, we have chosen to compare the systems on their design basis operations since there may be other possible considerations not modeled (such as underground operation limitations). Simulation results for three-shift repository operation have also been calculated and are discussed qualitatively.

Since the time frame of this study did not allow the volume of computer simulation runs needed to directly determine operating reliabilities, the reliability of normal operations is indirectly determined (with fewer runs) by examining the idle times of equipment in process functions and lag storage usages associated with normal operations. Processes with very low idle times and lag storage areas near capacity result in operations that are less likely to meet throughput requirements and are, therefore, less reliable.

Equipment idle times for the various functional processes in the MRS system are summarized in Table 3.1. Idle times for MRS facility process functions are never less than 36% out of a scheduled 71% availability, indicating substantial excess capacity for the MRS facility. This excess capacity means that the MRS could operate only half of the time currently postulated and still meet its throughput goals. This indicates a high probability that the MRS facility could accept waste at the 3000 MTU Mission Plan rate with normal failure and repair expectations.

The repository in the MRS system is simpler than its counterpart in the Repository-only system, because the consolidation functions are performed at the MRS and because more of the waste stream (that part coming from the MRS) is standardized. This should improve the ability of the repository in the MRS system to process the wastes on schedule and maintain disposal rates.

Table 3.2 provides a summary of the maximum lag storage capacities and the peak storage requirements in the MRS system. Peak requirements are much

TABLE 3.1. Process Function Idle Times for the MRS Facility in the MRS System, Percent of Total Available Time[(a)]

MRS Facility	Idle Time (%)
Cask Receipt	79.2
Cask Unloading	
Unloading Cell 1	49.6
Unloading Cell 2	48.2
Unloading Cell 3	51.7
Unloading Cell 4	52.9
Routine Cask Servicing	
Servicing Cell 1	43.8
Servicing Cell 2	42.7
Servicing Cell 3	51.7
Servicing Cell 4	52.9
Consolidation	
Hot Cell 1	48.7
Hot Cell 2	47.6
Hot Cell 3	35.9
Hot Cell 4	40.5
Volume Reduction	
Station 1	51.2
Station 2	48.8
Canistering	
NFBH PWR Side	64.8
NFBH BWR Side	67.3
Hot Cell 1	37.3
Hot Cell 2	36.0
Hot Cell 3	47.3
Hot Cell 4	51.4
Load/Unload Storage Casks	
Station 1	49.6
Station 2	54.3
Loading Transport Casks	
Station 1	60.0
Station 2	60.0
Station 3	59.5
Station 4	59.5

(a) Scheduled availability of all process functions is 3 shifts/day, 5 days/week or 71.4% except for cask receipt, which is scheduled 100% of the time.

TABLE 3.2. Lag Storage Operations Summary Report, for the MRS System

Station	Peak Requirement, MTU	Maximum Capacity, MTU	Maximum Outage Time w/o Work Stoppage, days
MRS Rail Cask Lag	19.4	194	104
MRS Truck Cask Lag	9.7	39	27
MRS Hot Cell 1 SFA Lag	18.5	83	20
MRS Hot Cell 2 SFA Lag	14.3	83	22
MRS Hot Cell 3 SFA Lag	13.2	60	25
MRS Hot Cell 4 SFA Lag	12.1	60	25
MRS PWR Canister Lag	74.2[(a)]	342[(a)]	44
MRS BWR Canister Lag	79.8[(a)]	382[(a)]	36
Repository Rail Cask Lag	55.6	167	13
Repository Truck Cask Lag	1.4	35	56
Repository PWR SFA Lag	5.1	9.7	4
Repository BWR SFA Lag	0.4	8.9	60
Repository Surface Vault	17.8	214	13

(a) Storage capacities reported include space for NFBH canisters from the consolidation process. These canisters are assumed to have 0 MTU values in this analysis and so dilute the reported MTU capacity. The maximum capacity, if reported for just spent fuel assemblies, would be about 500 MTU for both PWR and BWR canisters.

lower than maximum capacities in all cases (with the possible exception of PWR assembly hot cell storage), indicating a very low probability of storage-related outages. The far column in Table 3.2 shows maximum outage times without work stoppage for each function. These numbers give an indication of the relative abilities of the process functions to continue processing given a failure downstream at the time of the function's peak storage requirement. The results show that all MRS functions could continue operations for about a calendar month (20 operating days) under such conditions. Mean machine repair times are on the order of 1 hour to 5 days (Table 3.3 in Appendix A), which indicates a high probability that scheduled throughputs could be maintained under normal failure conditions.

3.1.3 Acceptance Contingency Capability for Major Disruptions

The analysis of acceptance reliability during normal operations (above) showed a high probability of reliable operations for the MRS system under normal failure conditions. The ability of the MRS system to maintain acceptance under conditions of major disruption is discussed in this section. Major disruptions may occur for any of the following reasons:

- fires, industrial accidents, or contamination events caused by human errors or mechanical failures
- external events such as earthquakes, floods or plane crashes
- political activities such as demonstrations at the facilities or state or local government actions
- sabotage.

Major disruptive events may occur at either the MRS facility or the repository or at both facilities. If the disruptive event occurs at the repository, the MRS system still has the ability to maintain fuel acceptance because of the storage capability of the MRS facility. The length of time that the system could continue receiving fuel at the Mission Plan rate depends on the storage capacity of the MRS and its inventory at time of disruption. The storage capacity of the MRS is currently set by the NWPAA at not more than 15,000 MTU of spent fuel. At an acceptance rate of 3000 MTU/year, this allows continued acceptance for up to 5 years, depending on the inventory at time of repository shutdown. The inventory at time of shutdown depends on the difference in startup periods between the MRS and the repository and on the waste receipt and disposal rate at the repository. The MRS Systems Study identifies several acceptance scenarios postulating different startup times. Table 3.3 summarizes those scenarios that result in different MRS inventories.

For MRS and repository startups in the same year (schedule 2), a small inventory of fuel resides at the MRS because of differences in initial operating ramp-up rates between the two facilities. For startup separations of 3 to 4 years (schedules 3 and 4), the MRS inventory reaches 12,275 to 13,025 MTU. For facility startup separations of 6 years or greater (the rest

TABLE 3.3. MRS Inventories for Sustems Study Acceptance Scenarios, Western Strategy[a]

Schedule No.[b]	MRS Start Date	Repository Start Date	MRS Peak Inventory, MTU
2	2003	2003	4,175
3	2000	2003	12,275
4	1999	2003	13,025
6	1997	2003	20,375[c]
7	1996	2003	21,125[c]
12	2000	2008	25,775[c]
13	1997	2008	33,875[c]
15	1996	2008	34,625[c]
21	2000	2013	39,275[c]
22	1997	2013	47,375[c]
24	1996	2013	48,125[c]

(a) Results shown are for western strategy cases. For cases with no western strategy, the inventories are about 900 MTU higher for all cases because the MRS accepts the western fuel instead of the repository.
(b) Schedule numbers are from the MRS Systems Study Task A report, dated 8/2/88.
(c) Requires an increase in the maximum inventory allowed by the NWPAA.

of the schedules), the inventory requirements exceed the limit set by the NWPAA and thus would require additional legislation.

Based on the above scenarios, the MRS facility could continue to accept waste for 8 months to 3.6 years after a repository shutdown at the Mission Plan acceptance rate under current NWPAA rules. If the NWPAA storage ceiling is increased, the ability to continue acceptance could be increased.

It is also important to note that the disposal rate capability of the repository plays a role in the "buffering" ability of the MRS system. The detailed analyses in Appendix A indicate that the repository in the MRS system has a throughput capacity of 4000 MTU (2 shift/day operation) to 6000 MTU (3 shift/day operation) per year. The 1000 to 3000 MTU/year excess repository disposal capacity could be used to draw down storage inventory levels at the MRS to provide greater contingency storage capability. This capability would allow early startup of the MRS (assuming the NWPAA restrictions on early MRS startup were relaxed) without the burden of being near peak storage limits over the life of the MRS facility.

Because the repository must excavate a large underground area with the potential for unknown anomalies as well as containerize, store, and emplace the waste, the potential for disruptive events is greater at this facility than at the MRS. For this reason, the repository shutdown case has been examined first. There is, of course, some potential for a disruptive event at the MRS facility; however, it is deemed to not be nearly as great as that for the repository. The repository in the Configuration 5 MRS case (Table 1.1) also provides a contingency acceptance capability in this event, since it has the capability of taking western fuel. The analyses in Appendix A indicate that the western fuel acceptance functions in the repository have significant amounts of idle capacity, thus it is possible that substantial acceptance rates could be maintained by the repository for some period of time. In this case, larger quantities of spent fuel would be emplaced intact than planned. The existence of two facilities capable of taking fuel also increases system acceptance reliability, because there is a lower probability that both facilities will be shut down simultaneously.

If both facilities fail to accept fuel, the impact on waste generators will depend on the timing of the outages. If the outage occurs soon after facility startup before backlogs of spent fuel at reactor locations are depleted significantly, additional storage capacity requirements may be placed on utilities. On the other hand, if the outage occurs when reactor storage inventories have largely been depleted (and before large numbers of reactors have been retired and their storage pools decommissioned), then the impact on utilities will be minimal.

The ability of the system to recover from a major disruption is just as important as the ability to maintain acceptance. System recoverability is determined largely by the system capacity. A simulation of the design-basis MRS system was run assuming a failure at the repository lasting one year. At the end of the year the repository was allowed to operate at capacity in order to "catch up" on some of the storage inventory. The analysis (reported in Appendix A) showed that the repository in the MRS system was able to reduce lag storage backlogs quickly and emplace wastes at rates near peak capacity.

3.2 WASTE DISPOSAL RELIABILITY WITH THE MRS SYSTEM

Disposal reliability is the probability that the system can dispose of the spent fuel at the rates specified in the Mission Plan. This reliability depends on the ability to excavate the repository and emplace the wastes on schedule. An operational simulation of the reliability of excavation functions was not in the scope of this analysis; however, this reliability should be the same for either system. The reliability of the emplacement function depends on the waste operations performed on the surface and the ability to emplace wastes underground. Since both the MRS and Repository-only systems assume the same equipment and operating times for underground operations (and therefore have the same reliabilities), the discussion emphasis is placed on the surface waste operation reliabilities.

3.2.1 Startup Schedule Uncertainties for Disposal

The uncertainty in the startup schedule for waste emplacement in the repository hinges mainly on two factors. The first element of uncertainty is acceptance of the site performance (i.e., the ability to prove to the NRC that the radionuclides can be safely contained within the release limits specified). Proving this to the NRC's satisfaction may be a long and potentially difficult process. Once it is approved and construction and excavation begin, there is a second element of uncertainty in that undiscovered underground anomalies may exist that may either disqualify the site, require operations at reduced throughput rate, or result in additional delays that might require repository redesign (i.e., an event similar to the discovery of an unsuspected brine pocket in the WIPP facility when it was constructed). Either or both of these uncertainties has the potential for substantially slipping the schedule for emplacement of the waste. In this respect, the existence of the NWPAA-imposed storage limit on the MRS could significantly hamper the ability of the DOE to meet its waste acceptance obligations if such schedule slippages do occur.

3.2.2 Operational Uncertainties for Disposal

Results of the technical simulation analysis of MRS system operational reliability performed for the repository in the MRS system are shown in Table 3.4. The process functions with the least reliability are the cask unloading and containerization processes with idle times of 11-14%. If the repository surface facilities operate at three shifts/day (71% availability), minimum idle times increase to 34% for the limiting operations, and the operational capability of the repository would approach that of the MRS.

Results of the analysis show that the repository in the MRS system emplaces about 1300 containers of MRS waste, 700 containers of HLW and 200 containers of western spent fuel per year. The data also show high idle times for the emplacement operations, indicating substantial excess capacity and therefore a high probability of success for this operation. As explained above, an analysis of the reliability of normal excavation operations was not included in the scope of this task.

TABLE 3.4. Process Function Idle Times for the Repository Facility in the MRS, Percent of Total Available Time[(a)]

Repository Facility	Idle Time (%)
Cask Receipt	89.4
Cask Unloading	
Unloading Western SF	37.2
Unloading MRS & HLW	13.9
Routine Cask Servicing	
Servicing Cell 1	22.4
Servicing Cell 2	22.4
Containerization	
Western SF	40.8
HLW and MRS Cans	10.9
Emplacement	32.6

(a) Scheduled availability of process functions is 2 shifts/day, 5 days/week, or 47.6%.

3.2.3 Disposal Contingency Capability for Major Disruptions

Since the NWPAA constrains the DOE from doing parallel work on a second repository, there is currently no contingency capability to enhance the reliability of the waste disposal function in case of a major disruption in operations or schedule.

4.0 REPOSITORY-ONLY SYSTEM RELIABILITY ANALYSES

This chapter explains in more detail the analyses and conclusions summarized in Section 2.2. The Repository-only system defined for this study is the Configuration I system shown in Table 1.1. This system receives spent fuel from commercial reactors all across the U.S. in 100-ton rail casks and 25-ton truck casks as well as defense and West Valley HLW shipments. At the repository, the spent fuel is consolidated (except for about 5%, which is considered failed or non-standard fuel and is packaged intact) and all wastes are containerized. Following containerization, the waste containers are transported underground for geologic emplacement. This is the most complex of the Repository-only system configurations in the Systems Study and is comparable in terms of system functions and final products to the MRS system configuration previously analyzed.

4.1 RELIABILITY OF WASTE ACCEPTANCE FUNCTION

As noted in Section 3.1, the reliability of the waste acceptance function is defined as the probability of being able to accept waste from the waste generators at the rates defined in the Mission Plan with little or no interruption. This depends on the probability of meeting the schedule for startup of the facilities, the probability of maintaining waste acceptance rates during normal operations, the ability of the system to continue waste acceptance in the face of major disruptions and the ability of the system to recover from disruptive events. These factors are discussed below.

4.1.1 Startup Schedule Uncertainties for Acceptance

The startup schedule uncertainties are essentially the same as those outlined for the repository in the MRS system. Either licensing delays stemming from difficulty in proving site performance or problems in qualifying the repository after excavation begins could substantially delay startup of the repository. The difference in the case of the Repository-only system is that there is no backup (i.e., no federal facility that could receive and store waste so that the federal government could keep its acceptance commitments.) In light of the delays the repository program has experienced to date, there is considerable uncertainty in avoiding further delays in waste acceptance if the repository is the only acceptance facility in the system.

4.1.2 Operational Uncertainties for Acceptance

For waste acceptance, operational reliability is the ability to meet a goal throughput objective such as the Mission Plan receipt rates. This ability depends on the facility designs, the processes performed and the diversity of the waste streams processed.

One of the major factors affecting facility operating reliability is facility operating schedule. The design-basis operating schedule for the repository in the Repository-only system is two shifts/day, 5 days/week. The simulation analysis performed for this study suggests that 3 shift/day operations similar to MRS facility operations are possible. We have used the design-basis 2-shift/day schedule for our analysis comparisons in order to make comparisons of design-basis systems.

Operational reliability is determined with a process simulation by examining the idle times (of machines in process functions) and lag storage usages associated with normal operations. Results of the simulation analysis identifying the system operating reliabilities are given in Table 4.1. Cask unloading and consolidation processes have idle time fractions of only 9-10%, indicating that these processes are approaching their capacity at a throughput of 3000 MTU/year. Therefore, this system is judged to have less reliability for acceptance operations than the MRS system, which has idle time fractions of at least 36% for all of its processes. Comparing Table 4.2 with Table 3.2 shows that lag storage margins are smaller for the acceptance facility in the Repository-only system than for the acceptance facility in the MRS system. This indicates a higher likelihood of processing delays that may affect the acceptance schedule in the Repository-only system. Comparing maximum process times without work stoppages between Table 4.2 and Table 3.2 indicates that most of the Repository-only system functions would experience a work stoppage much sooner than the MRS functions. This also indicates a higher likelihood that process delays would delay the acceptance schedule for the Repository-only system.

TABLE 4.1. Process Function Idle Times for the Repository in the Repository-Only System, Percent of Total Available Time[(a)]

Repository	Idle Time (%)
Cask Receipt	82.6
Cask Unloading	
WH82 Spent Fuel	9.2
Unloading HLW	39.0
Routine Cask Servicing	
WHB2 Rail	43.2
WHB2 Truck	36.9
WHB1	45.2
Cask Fleet Maintenance	39.2
Consolidation	
PWR SFA HC1	11.1
PWR SFA HC2	11.4
BWR SFA HC3	11.0
BWR SFA HC4	10.8
Canning (and welding)	
HC1, Intact SFA	22.2
HC2, Intact SFA	22.2
HC3, Intact SFA	36.3
HC4, Intact SFA	36.4
Defective SFA	45.5
Consolidated SFA	46.5
Canister Overpack	
HLW Cans	5.2
Emplacement	35.8

(a) Scheduled availability of process functions is 2 shifts/day, 5 days/week, or 47.6%.

4.1.3 Acceptance Contingency Capability for Major Disruptions

Conditions causing major disruptions include natural disasters, fires or explosions and political events. Such events have the potential for causing long-term outages in some or all of the facilities operations.

TABLE 4.2. Lag Storage Summary for the Repository in the Repository-Only System

Station	Peak Requirement, MTU	Maximum Capacity, MTU	Maximum Outage Time w/o Work Stoppage, days
Repository Rail Cask Lag	19.40	370	28
Repository Truck Cask Lag	10.84	38	6
WHB1 HLW Canister Lag	0.00	10	2
WHB2 PWR HC1 Lag	18.48	31	3.5
WHB2 PWR HC2 Lag	18.94	31	3.5
WHB2 BWR HC3 Lag	23.53	33	12
WHB2 BWR HC4 Lag	7.07	33	12.5
Vault Storage, WHB1	2.13	16	4.5
Vault Storage, WHB2	9.47	380	30

Because the repository is the only facility that can accept fuel in the Repository-only system, its ability to maintain acceptance rates from waste generators in the face of a major disruption is limited to the storage capability at the repository site. This storage capability has been tentatively identified in preliminary design criteria as 3 months' worth of receipts, or about 750 MTU. Current legislation does not specifically limit this storage quantity other than to prohibit siting of an MRS in the same state as the repository, indicating that storage quantities should be less than those allowable at the MRS. This analysis assumes the 750 MTU capability, thus limiting the maximum continued acceptance time to 3 months in case of a disruption.

Previous discussions in Section 3.1.3 have indicated that the repository facility, because of its underground functions, is more prone to some disruptive events such as explosions, discovery of faults, etc., than the MRS facility. Since the repository storage capability is much smaller than the MRS facility's capability, the probability of failure to meet acceptance rates is significantly greater in the Repository-only system. The impacts of failure to meet acceptance rates on waste generators are the same as those discussed in Section 3.1.3.

4.2 WASTE DISPOSAL RELIABILITY WITH THE REPOSITORY-ONLY SYSTEM

Waste disposal reliability for the Repository-only system is essentially the same as the waste disposal reliability reported for the repository in the MRS system. The repository in the Repository-only system emplaces about 1000 containers of spent fuel and 700 containers of HLW per year. Results of the simulation analysis determining the reliability of the disposal activity at the repository are included in Table 4.1. There appears to be substantial excess capacity in the emplacement function designs.

5.0 REFERENCES

Nuclear Waste Policy Act (NWPA) of 1982. Public Law 97-425.

Nuclear Waste Policy Amendments Act (NWPAA) of 1987. Public Law 100-203.

Ralph M. Parsons Company (Parsons). September 1985. Conceptual Design Report - Integral Monitored Retrievable Storage. Prepared by Ralph M. Parsons Company for the U.S. Department of Energy, Vol. 6, Book 1, Design Study 2, Report No. MRS 11.

Sandia National Laboratories (Sandia). February 1987. Site Characterization Plan Conceptual Design Report - Comment Resolution Draft. SAND84-2641, Albuquerque, New Mexico.

Sandia National Laboratories (Sandia). December 1988. OGR Repository-Specific Rod Consolidation Study: Effect on Costs, Schedules and Operations at the Yucca Mountain Repository. SAND86-2357, Albuquerque, New Mexico.

U.S. Department of Energy (DOE). 1985. Mission Plan for the Civilian Radioactive Waste Management Program. DOE/RW-0005, Washington, D.C.

U.S. Department of Energy (DOE). 1987. OCRWM Mission Plan Amendment. DOE/RW-0128, Washington, D.C.

APPENDIX A

DETAILED TECHNICAL ANALYSES OF RELIABILITY FOR NORMAL AND OFF-NORMAL OPERATIONS IN THE MRS AND REPOSITORY-ONLY SYSTEMS

1.0 INTRODUCTION

This appendix presents the results of simulation analyses conducted in support of the MRS Systems Study Task I reliability study. The analyses and their results are presented here in the form of a stand-alone report. The analyses address operational reliability of the MRS and No-MRS systems for both normal operations and operations surrounding a major disruptive event causing a long-term outage.

1.1 DEFINITION OF RELIABILITY

Normal operational reliabilities are defined as the probabilities of a facility meeting its design throughput goals. This probability is a function of the facility design, operating times to perform facility functions, failure rates for facility equipment, time to restore equipment to full operation and operating schedules.

Long-term outage reliabilities are defined as the ability of the system to handle abnormal outages of long duration (contingency capability) without affecting fuel receipts from reactors. This probability is a function of the system storage capacity and its throughput capability.

1.2 REVIEW AND RECOMMENDATIONS OF JBF ASSOCIATES

A subcontractor, JBF Associates of Oak Ridge, Tennessee, was retained by Pacific Northwest Laboratory (PNL) to assist in determining a feasible method for estimating reliabilities as defined above within the short time frame available for this study. JBF Associates was selected to assist in this capacity because they had recently completed a compilation of guidelines for the application of reliability, availability, and maintainability (RAM) within the U.S. Department of Energy (DOE). JBF reviewed the system configurations, the reliability study scope of work, and the previously developed PNL simulations of the MRS system using the FASIT model described in Section 3.0 of this appendix. Extracts from JBF's recommendations for proceeding with the reliability study are summarized below.

"The results ... (of PNL's previous MRS simulations) indicate that, for normal operat' ns during a year, the time required for each function to process the desired amount of waste is relatively low while the idle time is relatively high. Based on these results, we believe that any analysis using the existing model and data will indicate a very high probability of successfully achieving the desired throughput for the repository facility and MRS facility, regardless of the specific configuration selected.

While the Level 1 evaluation did address routine mechanical failures for the functions, it did not address the following categories of events that could, by themselves, result in a repository facility or an MRS facility failing to meet its throughput requirements.

- Fires, explosions, or contamination events caused by human errors or mechanical failures
- External events, such as earthquakes, floods or plane crashes
- Political activities, such as demonstrations at the facilities or state or local government actions
- Sabotage.

With the current design, such events will likely be the dominant contributors to the probability that the repository facility or the MRS facility will fail to meet an annual goal."

Following their analysis given above, JBF concluded that a large number of simulation runs with PNL's Level 1 FASIT model could give confidence in estimating system reliability, but that they did not recommend this approach because of the September deadline. Instead, they indicated that three indicators could be indirectly used to estimate high-probabilities-of-success (reliability). These indicators are the postulated system throughput versus the actual system capacity for the various functions, the idle time versus the normal operating time for the system functions and the time the function can be down before a failure-to-accept occurs versus the normal failure time for each system function.

> In recommending the number of cases to be evaluated, JBF noted that "it is not possible to evaluate all of the various system configurations by September 1. Thus, the number of configurations to be considered must be significantly reduced. This can be accomplished by identifying a bounding case for the set of repository-only configurations and a bounding case for the set of repository/MRS configurations. The bounding cases should be those that are the most complex (i.e., the configurations that have the highest number of serial functions); these configurations should thus have the lowest probabilities of success. For the repository-only case, the bounding configuration has six main serial functions, including consolidating and containerizing. For the repository and MRS case, the bounding configuration has 11 main serial functions, including both consolidating and canistering at the MRS and containerizing at the repository."
>
> JBF concluded their report as follows
> "we recommend, for the September 1 deliverable, that each of the three indicators (throughput, idle time, and out-of-service time) of the probability of success be evaluated for each of the two bounding configurations. We also recommend that these analyses be performed, first using the data in PNL's existing simulation model, then using the pessimistic data described above (increasing failure rates and times to repair equipment by factors of 2, 4, 6, 8, and 10)."

1.3 SIMULATION MODELING FOR RELIABILITY

Great advances in simulation modeling capability during the last decade have resulted in tremendous advances in state-of-the-art simulation modeling for industrial processes. Advanced simulation languages such as SLAM and SIMAN have allowed detailed simulations of complex processes involving usage of machines and process stations. These simulations use three primary types of operating data, various types of distributions and random-event processes to simulate actual operation of a system. The first two types of operating data are failure and repair rates for machines. A large body of data is becoming available for various industrial processes on the failure and repair rates for various types of equipment. The other key parameter in simulations is process times. Process times for various operations are generally not as generic as machine failures and repair and are usually obtained through experience. These times are more nearly related to the specific functions performed in the facility and to the facility design.

Some of the key results obtained from these simulations is the machine or process utilization, the machine idle and maintenance times, the lag storage requirements and the function throughput capacities. Process utilization is the fraction of total operating time (24 hours/day, 365 days/yr) the machine is actually busy performing its process function. Machine availability is limited by the scheduled work time and depends on the number of shifts worked. This scheduled work time is termed availability and is also expressed as a fraction of total operating time. For example, working two 8-hour shifts per day, 5 days per week, 52 weeks per year gives an annual availability of 0.475 (2x8x5x52/8760). If process utilization approaches 0.475 under these conditions, the machine is fully scheduled and no further throughput can be achieved unless the scheduled work time (availability) is increased. Availability may also be decreased by machine failure if the failure occurs during the scheduled work time. Down-time due to machine failure consists of time to effect the repairs and time to get the machine back on line. This total down-time is called maintenance time. Maintenance time may begin during a scheduled work time and extend into an off-shift (i.e., nonscheduled) time. In this case, the availability is only reduced by maintenance worked during the scheduled work time. Idle time is the difference between the availability (after maintenance) and the process utilization. Idle time, therefore, represents the additional time that could be worked if greater throughput were needed. Using these measures, process reliability can be estimated and improvements in design can be made to increase throughput efficiency.

For the federal waste management system, a simulation model based on the SIMAN simulation language named FASIT was developed under the Systems Integration Program at PNL to perform RAM studies. This program incorporates the operating data and reliability measures outlined above and has the capability of estimating system reliability and throughput capability at the system level.

The FASIT model consists of generic routines which simulate various types of stations such as cask allocation, storage, machine processing, splitting processes(such as cask unloading), and combining processes (such as containerization). Experiments are built which define the waste management system by linking together the various generic routines in ways which represent the system being modeled. The experiments are then processed with the model using the SIMAN compiler to generate the program results. A more extensive discussion of the MRS and No-MRS experiments is presented in Section 3 of this appendix.

1.4 SCOPE OF ANALYSIS

Based on JBF Associates recommendations outlined in Section 1.3, PNL decided to limit the scope of analysis to the two most complex systems identified in the MRS Systems Study configurations. These are: the MRS system with consolidation and canistering at the MRS and containerizing at the repository and the No-MRS system with consolidation and containerizing at the repository. As indicated by JBF, these cases contain the most serial functions and therefore would be less reliable than other, simpler configurations. If the reliability of these most complex systems is high then all of the system configurations are expected to be highly reliable.

In order to test the sensitivity of the results to the machine failure and repair data, a series of cases were run for each of the above configurations. In these cases, the times to failure were reduced and the times to repair were increased by factors of 2, 4 and 6, respectively. These cases should give good data as to the reliability of the system for normal operations.

In order to evaluate the ability of the systems to deal with long term-failures, a series of cases was first run to identify actual system capacities as the systems are currently designed. These cases allow a range of maximum rates to be estimated. These data allow estimations of recovery times in the systems after long-term outages. Subsequent cases were run to simulate failures of 1-year duration. Following the failures, the facilities were allowed to operate at estimated peak capacities to illustrate recovery times and the effect on system storage inventories. Additional delay cases were planned to give more extensive data on delay impacts, but could not be completed within the time frame of this study. Table 1.1 shows a listing of the cases completed.

TABLE 1.1. Listing of Cases for Task I, System Reliability Study

Case Description	No-MRS	MRS
1. Design basis design and data	X	X
2. 2 X failure rate and repair time	X	X
3. 4 X failure rate and repair time	X	X
4. 6 X failure rate and repair time	X	X
5. 3500 MTU/yr process rate	X	X
6. 4000 MTU/yr process rate	X	X
7. 5000 MTU/yr process rate	X	X
8. 6000 MTU/yr process rate		X
9. Repository emplacement failure for 1 year	X	X

2.0 SUMMARY OF RESULTS

This section summarizes the results of the simulation cases identified in Section 1.5 above and explained in more detail in Section 4.

2.1 RELIABILITY OF NORMAL FACILITY OPERATIONS

The reliability of normal operations is determined by examining the idle times (of machines in process functions) and lag storage usages associated with normal operations and then comparing them for the two design basis systems. Processes with very low idle times and lag storage areas near capacity result in operations which are more subject to failure-to-meet throughput requirements and are, therefore, less reliable. Since these data are highly dependent on the design of the facilities, it should be emphasized that the results presented here are for preliminary designs and that future design changes could significantly change these conclusions. It is believed that these analyses should form part of the basis for examining and implementing such design changes.

Machine idle times for the various functional processes in the MRS and No-MRS design basis cases are summarized in Table 2.1. Idle times for MRS process functions are never less than 36%, indicating substantial excess capacity for the MRS facility. Idle times for process functions in the repository in the No-MRS system are as low as 8-9% for the cask unloading and consolidation processes. These results indicate that short-term failures are much more likely to impact the ability of the No-MRS system to maintain reactor fuel receipts than for the MRS system.

Tables 2.2 and 2.3 show the relative peak lag storage requirements and maximum capacities for the MRS and No-MRS design basis systems respectively. Lag storage capacities appear more than adequate for the MRS system and probably sufficient to allow campaigning and other operating optimizations. The last two columns in these tables show calculations of maximum shifts and days of operating time until storage capacity is exceeded, assuming that an outage occurred at the time of peak storage requirements. This worst-case condition gives a very conservative measure of the system's ability to absorb

TABLE 2.1. Comparison of Station Idle Times for the Design Basis MRS and No-MRS Systems

MRS Facility	Idle (%)
Cask Receipt	79.2
Cask Unloading	
Unloading Cell 1	49.6
Unloading Cell 2	48.2
Unloading Cell 3	51.7
Unloading Cell 4	52.9
Routine Cask Servicing	
Servicing Cell 1	43.8
Servicing Cell 2	42.7
Servicing Cell 3	51.7
Servicing Cell 4	52.9
Consolidation	
Hot Cell 1	48.7
Hot Cell 2	47.6
Hot Cell 3	35.9
Hot Cell 4	40.5
Volume Reduction	
Station 1	51.2
Station 2	48.8
Canistering	
NFBH PWR Side	64.8
NFBH BWR Side	67.3
Hot Cell 1	37.3
Hot Cell 2	36.0
Hot Cell 3	47.3
Hot Cell 4	51.4
Load/Unload Storage Casks	
Station 1	49.6
Station 2	54.3
Loading Transport Casks	
Station 1	60.0
Station 2	60.0
Station 3	59.5
Station 4	59.5

Repository	Idle (%)
Cask Receipt	82.6
Cask Unloading	
WHB2 Spent Fuel	9.2
Unloading HLW	39.0
Routine Cask Servicing	
WHB2 Rail	43.2
WHB2 Truck	36.9
WHB1	45.2
Cask Fleet, Special	39.2
Consolidation	
PWR SFA HC1	11.1
PWR SFA HC2	11.4
BWR SFA HC3	11.0
BWR SFA HC4	10.8
Canning (and welding)	
HC1, Intact SFA	22.2
HC2, Intact SFA	22.2
HC3, Intact SFA	36.3
HC4, Intact SFA	36.4
Defective SFA	45.5
Consolidated SFA	46.5
Canister Overpack	
HLW Cans	5.2
Emplacement	35.8

TABLE 2.2. Design Basis MRS System Lag Storage Summary

Station	Peak Requirement	Maximum Capacity	Maximum Outage Time Without Work Stoppage (days)
MRS Rail Cask Storage, Casks	2.00	20.00	104
MRS Truck Cask Storage, Casks	7.00	28.00	27
MRS Hot Cell 1 Storage, PWR Assemblies	40.00	180.00	20
MRS Hot Cell 2 Storage, PWR Assemblies	31.00	180.00	22
MRS Hot Cell 3 Storage, BWR Assemblies	71.00	320.00	25
MRS Hot Cell 4 Storage, BWR Assemblies	65.00	320.00	25
MRS PWR Canister Storage, Canisters	117.00	540.00	44
MRS BWR Canister Storage, Canisters	115.00	550.00	36
MRS Silo Cask Storage, Casks	474.00	1280.00	--
Repository Rail Cask Storage, Casks	4.00	12.00	13
Repository Truck Cask Storage, Casks	1.00	25.00	56
Repository Hot Cell Storage, PWR Assemblies	11.00	21.00	4
Repository Hot Cell Storage, BWR Assemblies	2.00	48.00	60
Repository Surface Vault Storage, Containers	10.00	120.00	13

short term outages. For the MRS system, the limiting capacity is the PWR hot cell lag storage in the MRS (20 days) and the PWR hot cell in the repository (4 days).

For the No-MRS system, storage margins also appear adequate although the margins are less than for the MRS system. The PWR assembly hot cell lag storage appears to be the lag storage "pinchpoint" in the system. Since the

TABLE 2.3. No-MRS System Lag Storage Summary

Station	Peak Requirement	Maximum Capacity	Maximum Outage Time Without Work Stoppage (days)
Repository Rail Cask Storage, Casks	2.00	38.00	28
Repository Truck Cask Storage, Casks	8.00	28.00	6
WHB1 HLW Canister Storage, Canisters	0.00	5.00	2
WHB2 Hot Cell 1 Storage, PWR Assemblies	40.00	68.00	3.5
WHB2 Hot Cell 2 Storage, PWR Assemblies	41.00	68.00	3.5
WHB2 Hot Cell 3 Storage, BWR Assemblies	45.00	175.00	12
WHB2 Hot Cell 4 Storage, BWR Assemblies	38.00	172.00	12.5
WHB1 Vault Storage, Canisters	2.00	15.00	4.5
WHB2 Vault Storage, Canisters	3.00	120.00	30

facility normally processes about 1950 MTU of intact PWR fuel per year or about 4200 assemblies, the No-MRS system has about 2 days of outage capacity at its weakest point. These results reinforce the conclusion reached from analysis of idle times that the MRS system has better reliability in terms of ability to absorb short-term outages and maintain system flow rates.

The sensitivity of the above conclusions to failure and repair rate data was examined by progressively doubling the failure <u>and</u> repair rates for three iterations. The results show that the MRS system is more stable under high failure rates chiefly because of greater redundancy in stations and machines. Operating at only two shifts per day does allow both the No-MRS system and the MRS system to operate at very high failure rates although at reduced capacity. In this case, the higher capacity of the MRS design would still mean that the MRS system has a higher probability of maintaining acceptance from reactors.

2.2 SYSTEM CONTINGENCY CAPABILITY

One of the important parameters affecting system contingency capability is the system throughput capability. Higher throughput capabilities provide redundant operating capacity in case of higher than usual machine failures, allowing normal operations to continue. Throughput capability significantly higher than planned operating rates also provides a contingency capability which allows system backlogs to be processed while continuing to take spent fuel at planned rates from utilities. This would be a necessity in recovering from outages in which all of the system lag storage areas were full (such as long term outages for institutional reasons or catastrophic events). Excess system process capacity is also useful for regulating system storage inventories. For example, excess repository process capacity could be used to draw down storage cask inventory levels at the MRS to provide greater contingency storage capability. This would allow early startup of the MRS (assuming the NWPAA restrictions on early MRS startup were relaxed) without the burden of being near peak storage limits over the life of the MRS facility.

This analysis examined the throughput capabilities of the MRS and No-MRS systems for throughput rates up to 6000 MTU/year. (The No-MRS system case at 6000 MTU/yr was not run because the 4000 and 5000 MTU/yr No-MRS cases had already indicated that the No-MRS system could not sustain those throughput rates.) The MRS facility, which operates 3 shifts per day on a design basis, has a maximum capability between 5000 and 6000 MTU/yr based on design basis operating times and repair data from Conceptual Design Report (Parsons 1985). The repository in the MRS system, which in the FASIT model is based on a conceptual design developed by the systems description task of the Systems Integration Program, has a maximum sustained throughput capability near 4000 MTU of spent fuel per year (besides 400 MTU/year of HLW), assuming the same design operating schedule of 2 shifts/day used by Sandia in the No-MRS repository design. If the scheduled acceptance rate from reactors is 3000 MTU/year, the repository in the MRS system would be able to reduce MRS inventories by 1000 MTU/year to provide more contingency storage or to recover from a long-term failure in the repository. The high throughput capability of the MRS also provides a significant degree of assurance that fluctuations in acceptance rates can be easily absorbed by the system.

The No-MRS repository (based on the Tuff repository CDR) shows a maximum sustained capacity between 3000 and 3500 MTU of spent fuel (besides the 400 MTU/year of HLW) at the maximum two shift per day operation assumed by Sandia. Because the design capacity is so near the scheduled acceptance rate, the probability of not meeting the desired rate is much greater and the system also has less flexibility in operating strategy in meeting operational contingencies.

One of the MRS systems' greatest advantages is its ability to accept fuel early and buffer fuel acceptance operations through the use of concrete cask storage. Early acceptance of fuel (if allowed) relieves some of the fuel storage pressure on utilities and allows DOE to meet contractual obligations. The ability to buffer acceptance operations becomes important if outages occur which would otherwise limit the ability to accept fuel at the desired rate. Calculation of the maximum facility down-time before fuel acceptance is reduced depends on the system storage capacity at the time of failure and on the definition of maximum capacity.

The system storage capacity at time-of-failure depends on a number of factors, the most important of which are the relative startup times of the MRS and repository facilities (for the MRS system) and the repository receipt rate. Longer offsets between MRS facility startup and repository facility startup mean larger storage quantities in MRS cask storage. Most of the MRS Systems Study cases result in MRS spent fuel storage quantities of 4,000 to 13,000 MTU (although some early acceptance cases show quantities in the 20,000+ MTU range).

An analysis of the effect of long-term failures (1 year) in repository emplacement shows that the MRS system is able to maintain acceptance from reactors and recover fairly quickly from the effects of the failure, while the No-MRS system can only maintain acceptance for about 3 months and has difficulty in working off storage backlogs after such failures.

3.0 DESCRIPTION OF SIMULATION MODELS

This section describes the MRS and No-MRS systems analyzed, gives a description of the MRS and No-MRS experiments used with the FASIT model and shows the data used in the experiments to generate the results shown in Section 4.

3.1 MRS SYSTEM

The MRS systems description, simulation experiment and data are contained in this section. The MRS facility is taken from the MRS Conceptual Design Report (CDR) (Parsons 1985).

3.1.1 MRS System Description

The MRS system used in this analysis is essentially the Configuration 5 system shown in Table 1.1. This system receives, consolidates, and canisters eastern spent fuel (both intact and consolidated) at the MRS and then stores it (and the non-fuel bearing hardware generated during consolidation) in on-site concrete storage casks until the repository is ready to receive the waste. At the repository, the waste is containerized and then sent underground for final emplacement.

Initially, federal rail and truck spent fuel casks are sent to individual commercial reactors for loading of the spent fuel. After loading, the casks are transported by rail or truck to the MRS facility. At this facility, the shipping casks are received and inspected on the transport vehicles when they come in the security gate and are then routed to a temporary cask holding (lag storage) area.

When space is available, the cask vehicle is then moved into the MRS waste handling building. Figures 3.1 and 3.2 show first and second-level floor plans of this building. Cask receiving, unloading and hot cell processing areas are duplicated on both sides of the building. On the first level, the casks and vehicles are taken through washdown areas and the casks are then unloaded from the transport vehicles in receiving and inspection areas. The casks are moved by cask carts to cask unloading areas underneath the hot cells. The casks are mated to ports in the hot cells, the cask lids

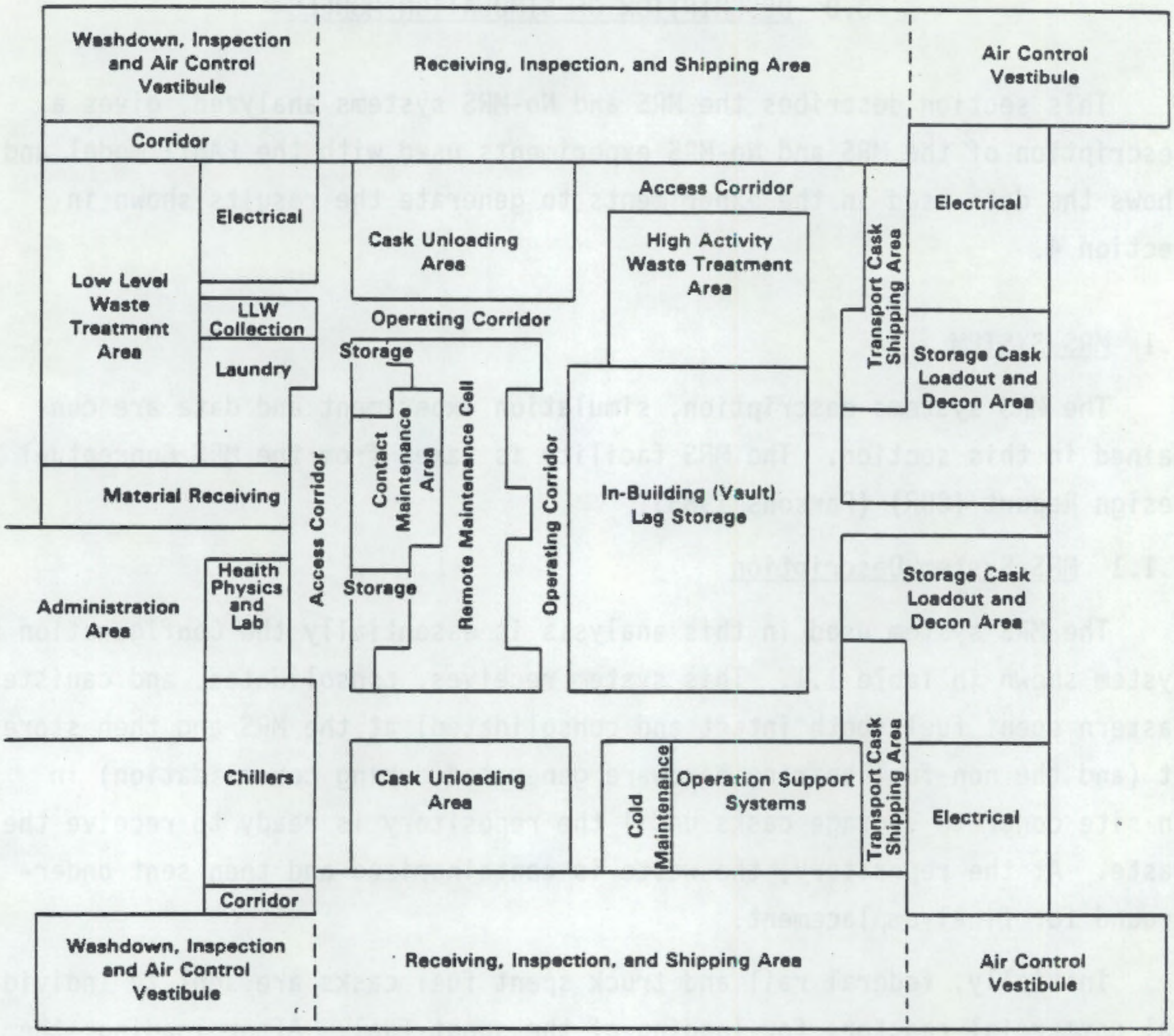

FIGURE 3.1. Schematic First-Level Plan for the MRS Receiving and Handling Building

are removed and the spent fuel is removed by cranes to lag storage areas within the hot cells. Four hot cells are used to consolidate, and canister the fuel. Spent fuel bundle skeletons from the consolidation process are also compacted and put in canisters.

Following canisterization, the waste canisters are placed in a large vault storage area near the center of the building and located adjacent to storage cask loadout and transport cask shipping areas. When sufficient canisters have collected in the storage vault, concrete storage casks are moved to the loadout area, the waste canisters are transferred to the storage

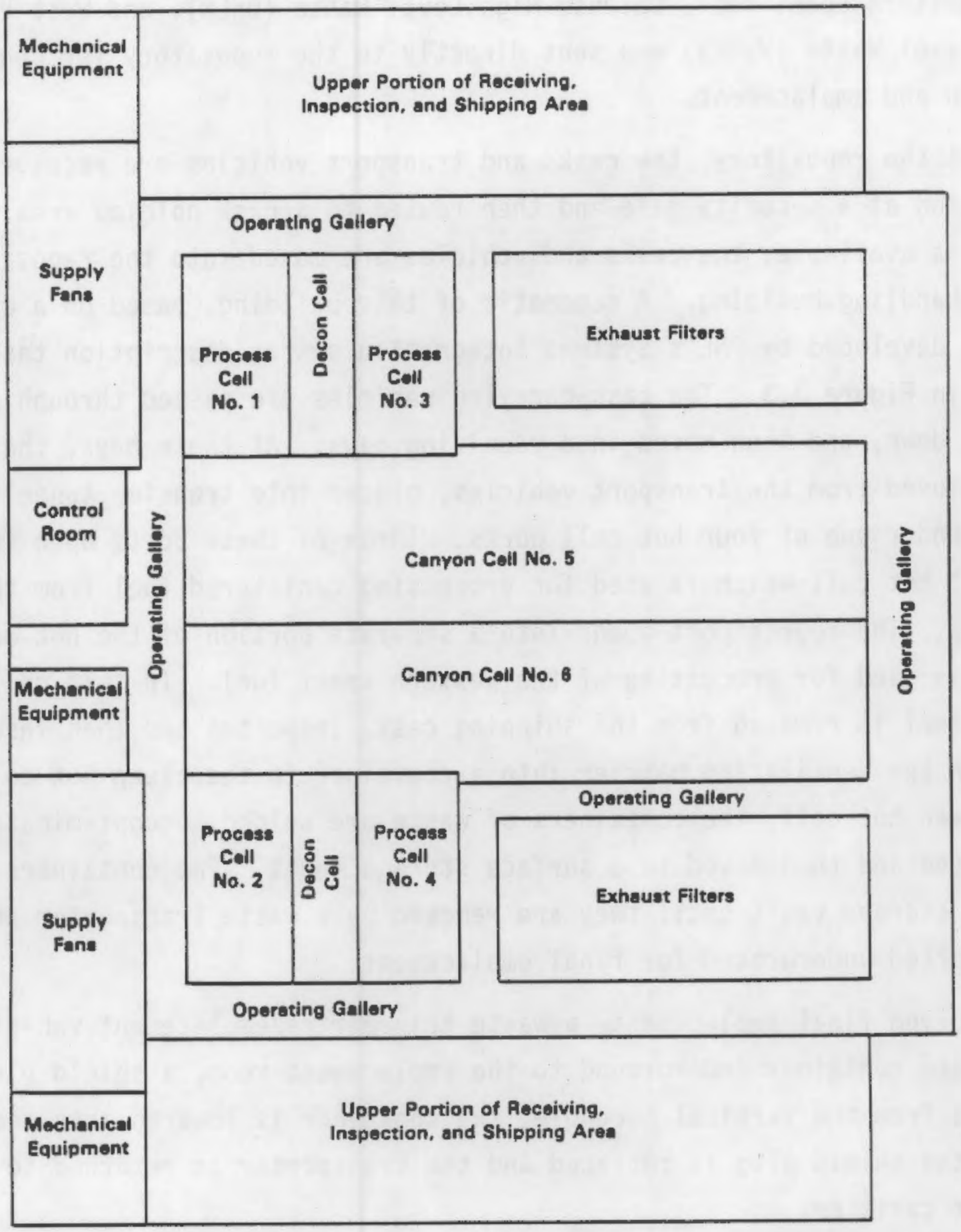

FIGURE 3.2. Schematic Second-Level Plan for the MRS Receiving and Handling Building

casks and the casks are moved out to storage pads. When the repository is ready to receive waste shipments, the waste canisters are either removed from vault storage or the concrete storage casks are returned to the canyon cells and the canisters transferred to large 150-ton rail shipping casks for shipment to the repository.

Western spent fuel, Defense High Level Waste (DHLW), and West Valley High Level Waste (WVHLW) are sent directly to the repository for containerization and emplacement.

At the repository, the casks and transport vehicles are received and inspected at a security gate and then routed to a cask holding area. When space is available, the casks and vehicles are moved into the repository waste handling building. A schematic of this building, based on a conceptual layout developed by PNL's Systems Integration system description task is shown in Figure 3.3. The cask-carrying vehicles are passed through airlocks, washed down, and then moved into receiving bays. At these bays, the casks are removed from the transport vehicles, placed into transfer tunnels and moved under one of four hot cell ports. Three of these ports open into a "clean" hot cell which is used for processing canistered fuel from the MRS and HLW. The fourth port opens into a separate portion of the hot cell, which is used for processing of the western spent fuel. In this cell, the spent fuel is removed from the shipping cask, inspected and then inserted through the ventilation barrier into a container in the clean hot cell. In the clean hot cell, the containers of waste are welded, decontaminated and inspected and then moved to a surface storage vault. The containers remain in the storage vault until they are removed by a waste transporter and transported underground for final emplacement.

During final emplacement, a waste transporter/emplacement vehicle moves the waste container underground to the emplacement room, a shield plug is removed from the vertical borehole, the container is lowered into the borehole, the shield plug is replaced and the transporter is returned to pick up another canister.

3.1.2 Experiment Description and Data

A flowsheet for the MRS experiment based on the above description is shown in Figures 3.4 and 3.5. The flowsheet shows the sequence of process functions and storage areas modeled. The circled numbers in blocks in the flowsheet are correlated with the process function numbers in Table 3.1, which lists the process times, failure times and repair times of the functions. This allows easy moving back and forth between the flowsheet and the

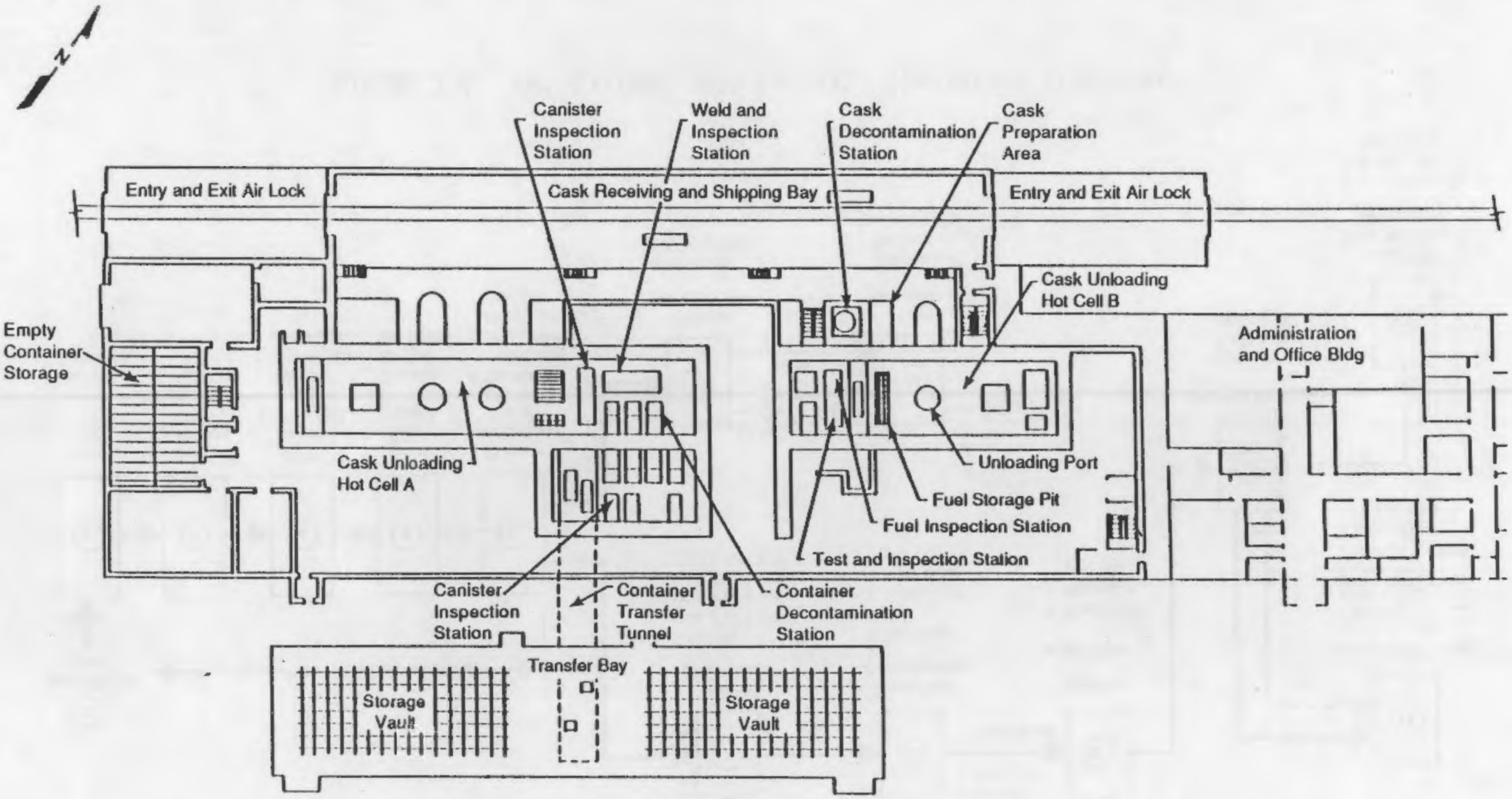

FIGURE 3.3. Repository Waste Handling Building for the MRS System

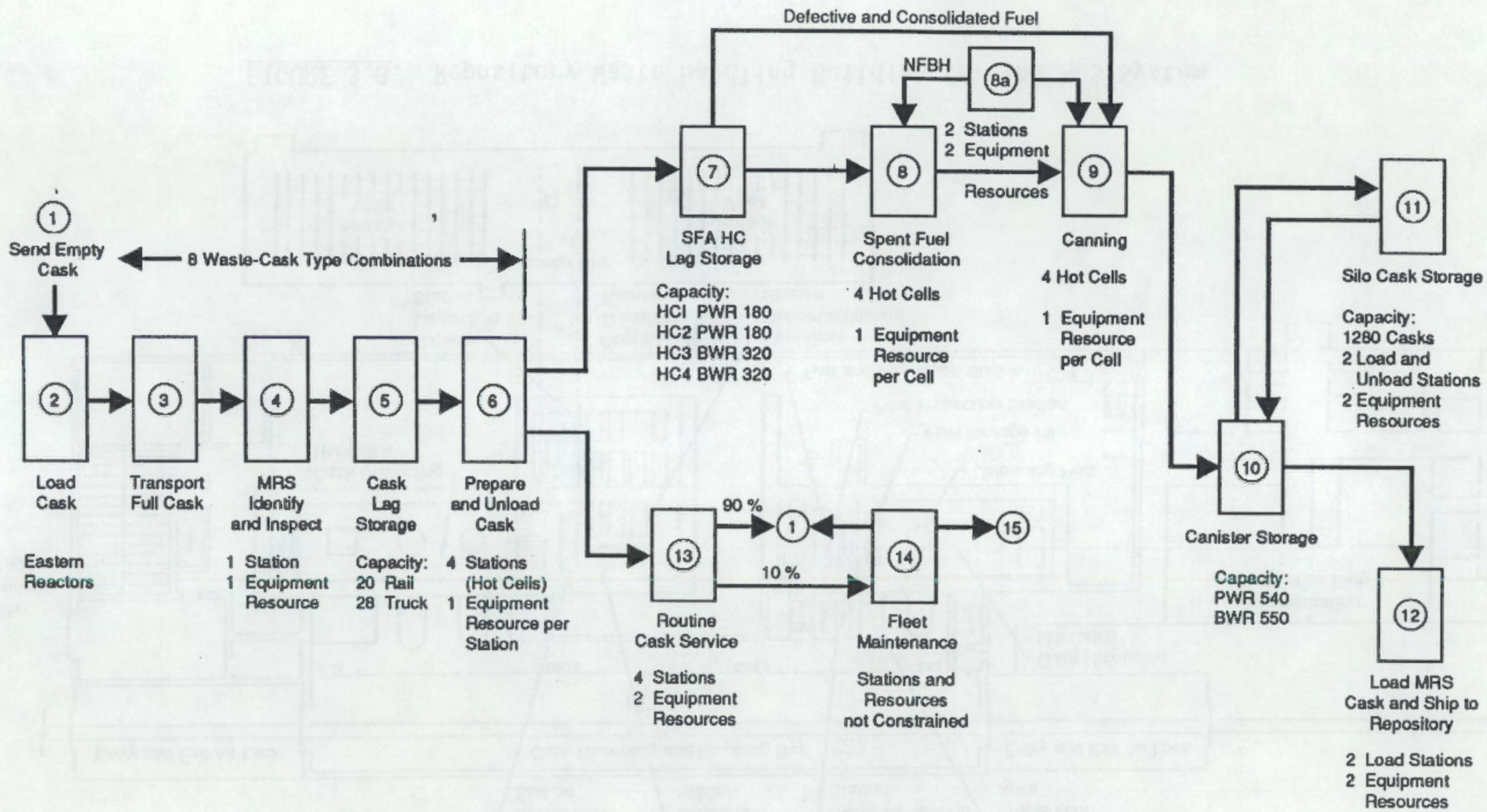

FIGURE 3.4. MRS System: MRS Facility Simulation Flowsheet

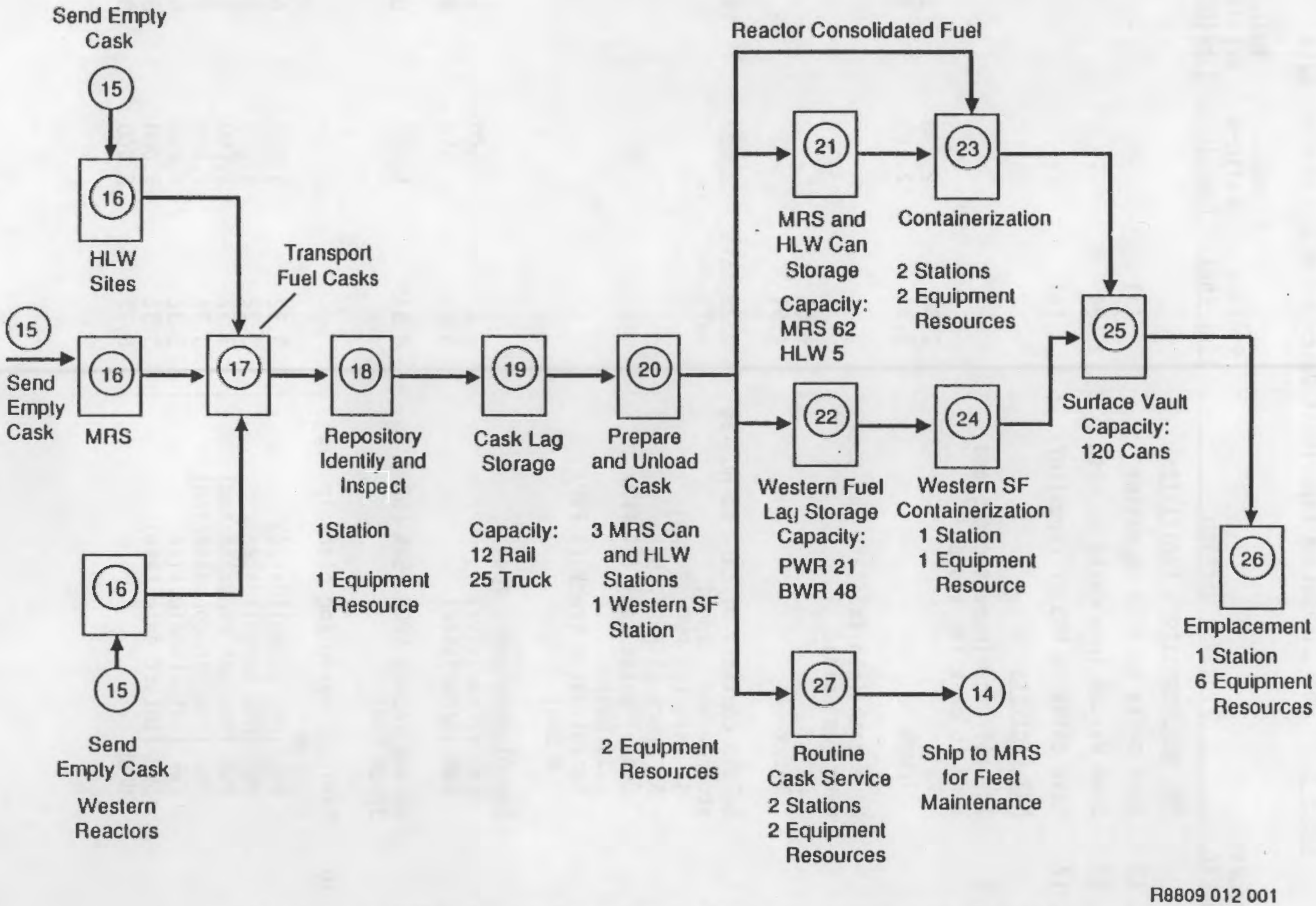

FIGURE 3.5. MRS System Simulation Flowsheet, Repository Facility

TABLE 3.1. MRS Simulation Experiment Description and Process Data

Process Number	Process Function	Process Time (hr)	Mean Failure Time (hr)	Mean Repair Time(hr)
	MRS and Repository Facilities			
1, 15	Move casks to pick up wastes	(a)	--	--
2, 16	Load Wastes into casks at site	22.84	--	--
3, 17	Move casks to MRS or repository	(a)	--	--
	MRS Facility			
4, 5	Identify and inspect casks and send to cask lag storage			
	Rail	2.33	2,200	1
	Truck	1.83	2,200	1
6	Move cask into facility and prepare for unload			
	Rail	6.00	--	--
	Truck	4.91	--	--
6, 7	Unload contents of cask to HC lag storage and inspect	0.25/unit unloaded	2,000	24
	SF rail (21 PWR/48 BWR)			
	SF truck (3 PWR/7 BWR)			
	Consolidated rail (14 PWR/ 36 BWR)			
	Consolidated truck (1 PWR/ 3 BWR)			
8	Consolidate spent fuel			
	PWR (2/canister)	2.2	500	8
	BWR (5/canister)	5.4	500	8
8a	Volume-reduce NFBH (50% PWR 37.5% BWR)	0.375	5,000	8
9, 10	Canister waste and place in lag storage			
	PWR (MRS consolidated)	3.32	1,000	8
	BWR (MRS consolidated)	3.32	1,000	8
	PWR (reactor consolidated)	3.32	1,000	8
	BWR (reactor consolidated)	3.32	1,000	8
	PWR (intact-defective)	3.32	1,000	8
	BWR (intact-defective)	3.32	1,000	8
	NFBH	0.77	2,000	8

TABLE 3.1. (contd)

Process Number	Process Function	Process Time (hr)	Mean Failure Time (hr)	Mean Repair Time (hr)
	MRS Facility (continued)			
11	Bring in storage cask, load cask, and move to storage yard (18 canisters per cask)	7.91	8,760	120
11	Retrieve storage cask and prepare for unload	4.75	8,760	120
11	Unload storage cask (18/cask)	0.10/unit	8,760	120
12	Load MRS/Repository Rail Cask 28 canisters per cask	26.5	2,000	24
12	Move train to repository	(a)	--	--
	Repository Facility			
18, 19	Identify and inspect shipments and move to lag storage			
	Western spent fuel--rail	2.33	2,200	1
	Western spent fuel--truck	1.83	2,200	1
	HLW--rail	2.33	2,200	1
	MRS canisters--rail	2.33	2.200	1
20	Move casks from lag storage and prepare for unload			
	Rail	6.00	--	--
	Truck	4.91	--	--
20, 21 22	Unload casks into lag storage (same SF capability as MRS casks)	0.25/unit	2,000	24
	DHLW (5 canisters/cask)			
	WVHLW (5 canisters/cask)			
23, 24 25	Move wastes to canning stations containerize and move to vault storage	3.00	1,000	8
	MRS waste (3 canisters per container)			
	Intact PWR (4 assemblies per container)			
	Consolidated PWR (4 canisters per container)			
	Consolidated BWR (10 canisters per container)			

TABLE 3.1. (contd)

Process Number	Process Function	Process Time (hr)	Mean Failure Time (hr)	Mean Repair Time(hr)
	Cask Servicing			
26	Pick up containers from vault storage, transport canisters underground, emplace waste and return transporter	3.42	1,000	16
13	Routine--at MRS			
	Rail	11.25	2,000	24
	Truck	7.82	2,000	24
27	Routine--at repository			
	Rail	11.25	2,000	24
	Truck	7.82	2,000	24
14	Fleet Maintenance (once every 10 trips)	10.00	2,000	24

(a) Transport times to ship empty and full casks between waste sites and federal facilities vary because of distance, shipping mode and other factors. Cask shipment times are modelled in PNL's WASTES model. For this analysis cumulative probability distributions of shipping times were developed from WASTE runs for the MRS and No-MRS systems by waste type and shipment mode. The FASIT model randomly samples these distributions in order to develop shipping times. These probability distributions are shown below.

Shipments to MRS (Oak Ridge, Tennessee)

Eastern PWR--Rail		Eastern PWR--Truck		Eastern BWR--Rail		Eastern BWR--Truck	
Cumulative (%)	Time (hr)	Cumulative (%)	Time (hr)	Cumulative (%)	Time (hr)	Cumulative (%)	Time (hr)
0.019	84.95	0.049	2.22	0.105	134.84	0.195	10.82
0.072	112.17	0.124	5.36	0.214	159.88	0.311	21.85
0.142	118.77	0.224	21.85	0.265	160.48	0.572	27.58
0.188	140.71	0.341	24.80	0.353	175.41	0.669	34.62
0.387	159.50	0.423	25.17	0.490	180.93	0.794	35.80
0.563	172.88	0.704	35.74	0.535	188.54	0.802	38.09
0.682	182.41	0.795	35.99	0.645	204.37	0.840	42.93
0.759	208.83	0.825	38.11	0.646	211.56	0.912	43.21
0.876	249.17	0.988	41.67	0.951	220.35	0.944	45.45
1.000	313.06	1.000	45.81	1.000	266.48	1.000	46.92

TABLE 3.1. (contd)

Shipments to Repository (Yucca Mountain, Nevada)

Western PWR--Rail		Western PWR--Truck		Western BWR--Rail		Western BWR--Truck	
Cumulative (%)	Time (hr)	Cumulative (%)	Time (hr)	Cumulative (%)	Time (hr)	Cumulative (%)	Time (hr)
0.488	26.11	0.311	129.15	0.000	236.76	0.000	45.10
0.761	30.98	0.750	167.06	0.500	246.76	0.500	46.10
1.000	46.10	1.000	300.46	1.000	256.67	1.000	47.10

DHLW--Rail		WVHLW--Rail		Dedicated Rail from MRS	
Cumulative (%)	Time (hr)	Cumulative (%)	Time (hr)	Cumulative (%)	Time (hr)
0.375	186.33	0.000	489.0	0.000	80.50
0.516	273.10	0.500	539.0	0.500	85.50
1.000	520.0	1.000	589.0	1.000	90.50

data table to extract and understand the data. The process time data in Table 3.1 for all operations up to and including cask loading was derived from the ALARA study of radiation doses (DOE 1987). Process time data for operations following cask loading and for all mean repair times was obtained from Parson's Conceptual Design report for the MRS facility (Parsons 1985). Equipment failure times were based on failure times of components found in mechanical design handbooks.

The model sequence begins by sending empty casks to eastern reactors to pick up spent fuel. The model uses 100-ton rail casks containing 21 PWR or 48 BWR assemblies and 25-ton truck casks containing 3 PWR or 7 BWR assemblies to ship spent fuel to the MRS. Frequencies of shipments are governed by the relative receipt rates of the different kinds of fuel-cask combinations which are specified as input. These inputs sum to the overall receipt rate of the facility. Table 3.2 below lists these receipt rates for the base 2650 MTU/yr receipt rate assumed for the MRS as well as for accelerated receipt rates used in several cases.

The shipping times for each waste/cask shipment are calculated from cumulative probability distributions as explained in footnote (a) in Table 3.1. Both the receipt rate and shipping time distributions are taken from data generated by the WASTES computer model for the design basis cases.

TABLE 3.2. Receipt Rate Schedules by Waste/Cask Type for MRS Cases

Waste/Cask Type	2650 MTU/yr	3500 MTU/yr	4000 MTU/yr	5000 MTU/yr	6000 MTU/yr
To MRS					
Intact PWR/Rail	1010.2	1334.3	1524.8	1906.1	2287.3
Intact PWR/Truck	633.5	836.7	956.2	1195.3	1434.4
Intact BWR/Rail	580.7	767.0	876.5	1095.7	1314.8
Intact BWR/Truck	398.4	526.2	601.3	751.7	902.1
Consol PWR/Rail	10.2	13.5	15.4	19.3	23.1
Consol PWR/Truck	6.4	8.5	9.7	12.1	14.5
Consol BWR/Rail	5.9	7.8	8.9	11.1	13.7
Consol BWR/Truck	4.0	5.3	6.0	7.6	9.1
To Repository					
From MRS/Rail	2650	3500	4000	5000	6000
West. Intact PWR/Rail	189.0				
West. Intact PWR/Truck	120.9				
West. Intact BWR/Rail	7.3				
West. Intact BWR/Truck	30.2		Same as for		
West. Consol PWR/Rail	1.9		2650 MTU/yr		
West. Consol PWR/Truck	1.2		Case		
West. Consol BWR/Truck	.07				
West. Consol BWR/Truck	.03				
Defense HLW	344.8				
West Valley HLW	55.2				

After the wastes have been transported to the MRS, they follow the sequence of operations shown in Figure 3.4. Capacities of all lag storage locations and numbers of stations and equipment resources are shown for each process function. Where combinations of units occur, the data used in the model are shown in the corresponding function in Table 3.1.

Inspection of the flowsheet and the corresponding table shows a convention used in all experiments of including time to move into and out of lag storage in the process times of the processes adjacent to the storage locations.

After the waste has moved through the MRS process functions in Figure 3.4 it is picked up again in Figure 3.5 as MRS shipments to the repository. Also coming to the repository are shipments of Western spent fuel and HLW. These wastes flow through the repository as indicated until they are finally disposed of in the emplacement function.

One important assumption to note is that the repository pulls fuel from the MRS at a rate independent of the MRS process rate. This allows differences in repository and MRS receipt rates to be modeled. Another important assumption which was made for ease of modeling is that the fuel flows through the facility on an oldest-fuel-first basis. This requires that storage casks be emptied for each shipment of fuel to the repository. The model assumes that the storage casks are emptied into the canister storage pool before the MRS rail casks are loaded. This assumption does not have a great impact on the results shown in this study because of the very large canister storage in the current MRS design.

3.2 NO-MRS SYSTEM

The No-MRS systems description, experiment and data are contained in this section.

3.2.1 No-MRS System Description

The MRS system used in this analysis is essentially the Configuration 1 system shown in Table 1.1. This system receives spent fuel from commercial reactors all across the U.S. in 100-ton rail casks and 25-ton truck casks. Defense and West Valley HLW shipments are also received. At the repository, the spent fuel is consolidated (except for about 1% which is considered failed fuel and is packaged intact) and all wastes are containerized. Following containerization the waste containers are sent underground for final emplacement.

Initially, federally owned casks are sent to commercial reactor sites and HLW site locations to pick up the spent fuel. The spent fuel is loaded into the casks and the casks are transported by truck and rail to the repository. At the repository, all casks and transport vehicles enter a receiving and inspection gate for initial inspection. The casks and vehicles are then routed to a cask holding (lag storage) area. From this point the spent fuel casks are routed to the main waste handling building (WHB 2), while the HLW casks are routed to a smaller waste handling building (WHB 1).

At WHB 1 the HLW is unloaded from the transport cask, inspected and placed in lag storage. From lag storage the HLW canisters are sent to the containerization station. Following containerization the high-level waste container is decontaminated and placed in a storage vault in WHB 1 where it waits for a transporter carry it down into the repository for emplacement.

At WHB 2 the spent fuel casks are moved into an airlock and washed down prior to being moved into the cask receiving and shipping bays. A conceptual layout of this waste handling building is shown in Figure 3.6. In the receiving bays, the casks are unloaded from the transport vehicles and placed on carts. A cart is moved under one of eight ports in the unloading hot cell and the cask is mated to the port. In the unloading hot cell, the cask lid is removed and the spent fuel is taken out of the shipping cask.

In those cases where the fuel is failed or when previously consolidated fuel is received from the reactor site, the fuel is placed in a packaging area in the fuel unloading hot cell. In this area, these wastes are containerized directly, decontaminated and the containers are placed in special lag storage carts. These carts move through a transfer tunnel to a WHB 2 surface storage vault where these wastes await transfer underground.

Normal fuel in the cask unloading process is placed in lag storage carts which are routed through transfer tunnels to the process hot cells of which there are four. The fuel is lifted through transfer ports in the hot cell floor and placed in the consolidation station. After the fuel rods have been removed from the fuel assembly skeletons, they are placed in a container which is welded, decontaminated and inspected. This container is then placed in another transfer cart which is sent to the WHB 2 surface storage vault.

At both the WHB 1 and WHB 2 storage vaults, the containers wait until a transport/emplacement vehicle arrives to carry the containers underground for final emplacement. The final emplacement sequence is the same as that described for the MRS system in Section 3.1.1.

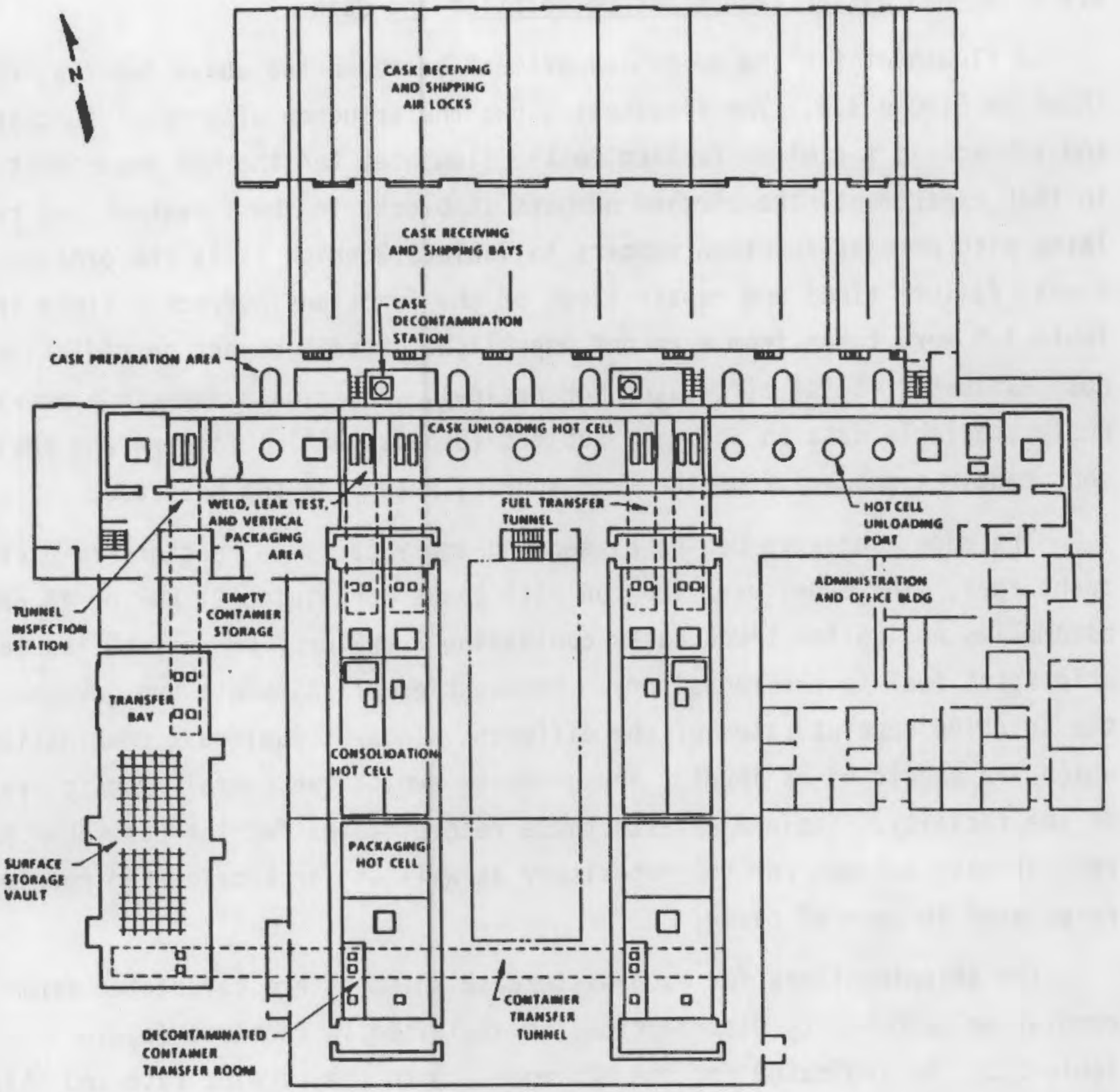

FIGURE 3.6. Repository Waste Handling Building 2 for the No-MRS System

3.2.2 No-MRS System Experiment Description and Data

A flowsheet for the No-MRS experiment based on the above description is shown in Figure 3.6. The flowsheet shows the sequence of process functions and storage in a similar fashion to the flowsheet for the MRS experiment. As in that experiment, the circled numbers in blocks in the flowsheet are correlated with process function numbers in Table 3.3 which lists the process times, failure times and repair times of the functions. Process times in Table 3.3 were taken from a recent unpublished Sandia report on radiation dose estimates (being circulated for review). These data supersede previously available data on the same subject (Dennis 1984). Failure and equipment repair times are from the same sources noted for the MRS case.

The model sequence begins by sending empty casks to reactors to pick up spent fuel. The model uses 100-ton rail casks containing 21 PWR or 48 BWR assemblies and 25-ton truck casks containing 3 PWR or 7 BWR assemblies to ship spent fuel to the repository. Frequencies of shipments are governed by the relative receipt rates of the different kinds of fuel-cask combinations which are specified as input. These inputs sum to the overall receipt rate of the facility. Table 3.4 lists these receipt rates for the base 3000 MTU/yr receipt rate assumed for the repository as well as for accelerated receipt rates used in several cases.

The shipping times for each waste/cask shipment are calculated from cumulative probability distributions as explained in footnote (a) in Table 3.3. As indicated for the MRS model, both the receipt rate and shipping time distributions are taken from data generated by the WASTES computer model for the design basis cases.

After the wastes have been transported to the repository, they follow the sequence of operations shown in Figure 3.7. Capacities of all lag storage locations and numbers of stations and equipment resources are shown for each process function. Where combinations of units occur, the data used in the model are shown in the corresponding function in Table 3.3.

After the wastes leave cask lag storage, the HLW casks are moved to WHB 1 while the spent fuel wastes enter WHB 2. In WHB 2 the spent fuel wastes are split into two streams. One stream going to function #12 consists

TABLE 3.3. No-MRS Simulation Experiment Description and Process Data

Process Number	Process Function	Process Time (hr)	Mean Failure Time (hr)	Mean Repair Time (hr)
	Repository Facilities			
1	Move casks to sites to pick up waste	(a)	--	--
2	Load wastes into casks at site	22.84	--	--
3	Move casks to repository	(a)	--	--
4, 5	Identify and inspect casks and send to cask lag storage			
	Rail	1.25	2,200	1
	Truck	1.25	2,200	1
	Move cask into facility and prepare for unload			
6	WHB 1	4.5	--	--
11	WHB 2	4.5	--	--
	WHB 1			
6, 7	Unload HLW into HLW lag storage (5 canisters/cask)	0.08/unit	2,000	24
	Move HLW to containerization cell, containerize and move to vault storage	5.25	1,000	8
10	Remove HLW container from vault storage, transport underground, emplace container and return transporter	3.42	1,000	16
	WHB 2			
11, 13	Unload spent fuel into lag storage carts			
	Intact fuel--rail (21 PWR/48 BWR)	0.17/unit	2,000	24
	Intact fuel--truck (3/7)	0.2/unit	2,000	24
	Reactor consolidated fuel (14/36 rail) (1.3 truck)	0.17/unit	2,000	24
12	Containerize defective and consolidated fuel in unloading hot cell and move canisters to vault storage (3 PWR/canister, 6 BWR/canister)	6.33	1,000	8

TABLE 3.3. (contd)

Process Number	Process Function	Process Time (hr)	Mean Failure Time (hr)	Mean Repair Time (hr)
	WHB 2 (continued)			
14	Move lag storage carts to process hot cells and consolidate fuel			
	PWR (6/canister)	9.0	500	8
	BWR (18/canister)	21.0	500	8
15, 16	Containerize consolidated fuel and move to surface vault storage			
	PWR	6.33	1,000	8
	BWR	6.33	1,000	8
10	Unload waste from surface vault storage, transport underground, emplace container in vertical borehole and return transporter	3.42	1,000	16
	Cask Servicing			
17	Routine at repository, all casks	5.0	2,000	24
18	Fleet maintenance (once every 10 trips)	10.0	2,000	24

(a) Transport times to ship empty and full casks between waste sites and federal facilities are calculated using the distributions below as explained in Table 3.1, footnote (a).

Shipments to Repository (Yucca Mountain, Nevada)

PWR--Rail Cumulative (%)	PWR--Rail Time (hr)	PWR--Truck Cumulative (%)	PWR--Truck Time (hr)	BWR--Rail Cumulative (%)	BWR--Rail Time (hr)	BWR--Truck Cumulative (%)	BWR--Truck Time (hr)
0.080	398.40	0.142	59.76	0.168	610.56	0.111	102.72
0.125	538.08	0.192	67.20	0.201	619.44	0.156	122.64
0.178	590.16	0.216	74.88	0.389	646.80	0.204	134.40
0.436	618.00	0.231	119.28	0.434	688.32	0.263	143.76
0.459	656.16	0.274	139.20	0.532	702.00	0.371	154.80
0.572	679.92	0.339	156.72	0.588	709.92	0.384	172.56
0.843	704.40	0.376	168.48	0.967	711.84	0.670	191.76
0.899	717.60	0.518	180.96	1.000	731.04	1.000	197.28
0.973	733.68	0.735	191.76				
1.000	746.16	0.861	198.00				
		0.946	204.96				
		1.000	213.12				

TABLE 3.3. (contd)

DHLW--Rail		WVHLW--Truck	
Cumulative (%)	Time (hr)	Cumulative (%)	Time (hr)
0.375	186.33	0.00	489.0
0.516	273.10	0.50	539.0
1.000	520.0	1.00	589.0

TABLE 3.4. Receipt Rate Schedules by Waste/Cask Type for No-MRS Cases

Waste/Cask Type	3000 MTU/yr	3500 MTU/yr	4000 MTU/yr	5000 MTU/yr
To Repository				
Intact PWR/Rail	1199.2	1598.3	1998.7	2398.4
Intact PWR/Truck	754.4	1005.9	1257.3	1508.8
Intact BWR/Rail	588.0	784.0	980.0	1176.0
Intact BWR/Truck	428.6	571.5	714.3	857.2
Consol PWR/Rail	12.1	16.1	20.2	24.2
Consol PWR/Truck	7.6	10.1	12.7	15.2
Consol BWR/Rail	6.0	8.0	10.0	12.0
Consol BWR/Truck	4.0	5.3	6.7	8.0
Defense HLW	344.8	344.8	344.8	344.8
West Valley HLW	55.2	55.2	55.2	55.2

of defective and reactor-consolidated western fuel. This waste is containerized immediately in the unloading hot cell and transferred to vault storage. The normal spent fuel waste stream is placed in lag storage carts (function 13) and transferred to the processing hot cells as shown on the diagram. The empty casks are serviced in function #17.

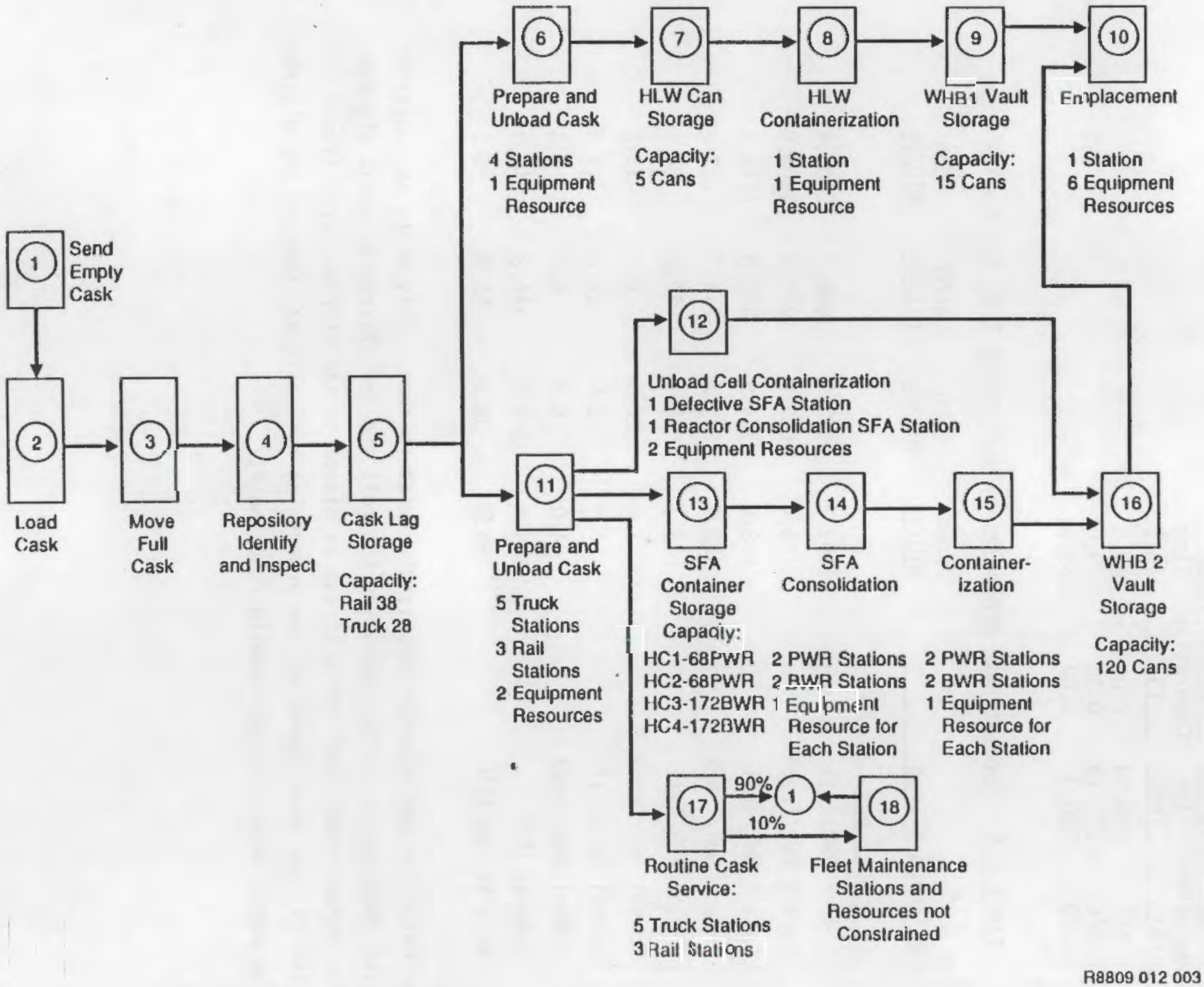

FIGURE 3.7. No-MRS System: Repository Facility Simulation Flowsheet

4.0 RESULTS

This section contains the results of the MRS and No-MRS system simulations to determine reliability.

4.1 RELIABILITY OF NORMAL OPERATIONS

The reliability of normal operations is determined in this simulation analysis by examining the idle times and lag storage usages and then comparing them for the two design basis systems. Since these data are highly dependent on the design of the facilities, it should be emphasized that these results are for preliminary designs and that future design changes could significantly change these conclusions. It is believed that these analyses should form part of the basis for examining and implementing such design changes.

For this analysis, the design basis MRS and No-MRS systems identified in Section 1.5 are compared. Table 4.1 shows the operating data for the stations in the MRS. As explained previously in Section 1.4, utilization refers to the percent of total operating time that a machine performing a function in a station is busy, maintenance is the percentage of time that the machine is down for repairs, and idle time is the scheduled time remaining (expressed as a percentage). For the MRS system, the MRS facility design operating schedule (3 shifts/day, 5 days/week) results in a scheduled availability of 71% (except for cask receipt which available all of the time). Table 4.1a shows idle times of 36 to 67% for all of the facility processes, indicating that there is a high probability that the facility can operate as designed. Those operations which are most vulnerable appear to be BWR consolidation in hot cells 3 and 4 and PWR canistering in hot cells 1 and 2. Maintenance times only average about 1% of the available time and are not a significant factor assuming that the failure and repair times are reasonable. The above results indicate that the MRS facility is highly reliable in terms of maintaining a steady flow of receipts from reactors.

Table 4.1b shows the utilizations and idle times for the repository in the MRS system. The cask unloading and the MRS and HLW containerization

TABLE 4.1a. MRS System Operations Summary Report, MRS Facility

Case: Design Basis MRS System

Facility Schedule: 3 shifts/day, 5 days/week*
Maximum Availability: 71.4%

MRS Facility	Utilization (%)	Idle (%)	Maintenance (%)
Cask Receipt	20.7	79.2	0.0
Cask Unloading			
Unloading Cell 1	20.9	49.6	1.4
Unloading Cell 2	22.3	48.2	1.3
Unloading Cell 3	19.4	51.7	0.3
Unloading Cell 4	17.9	52.9	1.0
Routine Cask Servicing			
Servicing Cell 1	26.3	43.8	1.7
Servicing Cell 2	28.3	42.7	0.8
Servicing Cell 3	18.6	51.7	1.7
Servicing Cell 4	17.9	52.9	0.6
Consolidation			
Hot Cell 1	21.6	48.7	1.7
Hot Cell 2	22.6	47.6	1.6
Hot Cell 3	34.7	35.9	1.2
Hot Cell 4	30.0	40.5	1.3
Volume Reduction			
Station 1	20.0	51.2	0.2
Station 2	22.5	48.8	0.2
Canistering			
NFBH PWR Side	6.2	64.8	0.4
NFBH BWR Side	3.8	67.3	0.3
Hot Cell 1	33.5	37.3	0.7
Hot Cell 2	34.6	36.0	0.9
Hot Cell 3	23.3	47.3	1.1
Hot Cell 4	19.4	51.4	0.8
Load/Unload Storage Casks			
Station 1	20.9	49.6	1.1
Station 2	16.3	54.3	1.4
Loading Transport Casks			
Station 1	10.8	60.0	1.2
Station 2	10.8	60.0	1.2
Station 3	10.9	59.5	1.1
Station 4	10.9	59.5	1.1

* Except for Cask Receipt which is available 24 hr/day, 7 days/week (1

TABLE 4.1b. MRS System Operations Summary Report, Repository

Case: Design Basis MRS System

Facility Schedule: 2 shifts/day, 5 days/week*
Maximum Availability: 47.6%

Repository Facility	Utili- zation	Idle	Mainten- ance
Cask Receipt	10.5	89.4	0.0
Cask Unloading			
Unloading Western SF	10.3	37.2	0.3
Unloading MRS & HLW	32.9	13.9	1.5
Routine Cask Servicing			
Servicing Cell 1	25.1	22.4	0.7
Servicing Cell 2	25.1	22.4	0.7
Containerization			
Western SF	6.6	40.8	0.6
HLW and MRS Cans	36.5	10.9	0.0
Emplacement			
Transporter 1	14.6	32.6	1.1

* Except for Cask Receipt which is available 24 hr/day, 7days/week (100%)

stations have the highest utilizations (lowest idle times) in this facility. The idle times for these limiting facilities are about 12-15%. However, since this facility only accepts a small amount of spent fuel directly from reactors, the lower reliability of the repository in this system does not have as much impact on acceptance ability as it would in the No-MRS system.

Table 4.2 shows similar data for the No-MRS system. The fewer process functions reflect the less complex nature of this system. For this system, the design operating schedule is 2 shifts/day, 5 days/week (47% availability). The results shown in Table 4.2 indicate that the facility will meet its throughput goals as designed, but it has much lower idle times, on the order of 8-9 %, for the cask unloading and consolidation processes. This lower operating margin indicates that this system as designed has less redundancy and is likely to be significantly less reliable in maintaining steady receipts from utilities than the MRS system. Idle times in WHB 1 are even lower for canisterization of HLW (because only one containerization station and welding station are shown in the design) indicating that WHB 1 HLW operations are near their peak throughput capability. (We have not assumed any increase in HLW receipt rates in this study so this constraint is not limiting in any of the analyses reported here.)

Tables 4.3 and 4.4 show the relative peak lag storage requirements and maximum capacities for the two design basis systems. Lag storage capacities appear more than adequate for the MRS system and probably sufficient to allow campaigning and other operating optimization. Significant storage quantities are observed for the canister lag storage and the hot cell lag storage. The last two columns in these tables show calculations of maximum shifts and days of operating time until storage capacity is exceeded assuming that an outage occurred at the time of peak storage requirements. This worst-case condition gives a very conservative measure of the system to absorb short term outages.

For the No-MRS system, storage also appears adequate, although the margins are less than for the MRS system. The PWR assembly hot cell lag storage appears to be the lag storage "pinchpoint" in the system. Since the facility normally processes about 1950 MTU of intact PWR fuel per year or 4200 assemblies, the No-MRS system only has 4 shifts or 2 days of outage capacity at

TABLE 4.2. No-MRS System Operations Summary Report, Repository

Case: Design Basis No-MRS System

Facility Schedule: 2 Shifts/day, 5 days/week*
Maximum Availability: 47.62%

Repository	Utilization (%)	Idle (%)	Maintenance (%)
Cask Receipt	17.4	82.6	0.0
Cask Unloading			
WHB2 Spent Fuel	37.6	9.2	1.7
Unloading HLW	7.9	39.0	1.6
Routine Cask Servicing			
WHB2 Rail	3.7	43.2	1.5
WHB2 Truck	10.1	36.9	1.4
WHB1	2.0	45.2	1.1
Cask Fleet, Special	7.7	39.2	1.7
Consolidation			
PWR SFA HC1	35.8	11.1	1.3
PWR SFA HC2	35.9	11.4	1.2
BWR SFA HC3	35.9	11.0	1.7
BWR SFA HC4	36.0	10.8	1.8
Canning (and welding)			
HC1, Intact SFA	25.2	22.2	0.6
HC2, Intact SFA	25.2	22.2	0.8
HC3, Intact SFA	10.8	36.3	1.0
HC4, Intact SFA	10.9	36.4	0.8
Defective SFA	1.7	45.5	1.0
Consolidated SFA	0.9	46.5	0.7
Canister Overpack			
HLW Cans	42.2	5.2	0.6
Emplacement	11.3	35.8	1.2

*Except for Cask Receipt which is available 24 hr/day, 7days/

TABLE 4.3. MRS System Operations Summary Report, Lag Storage

Case: Design Basis MRS System

Facility Schedule: 3 shifts/day, 5 days/week*
Maximum Availability: 71.4%

Station	Peak Requirement	Maximum Capacity	Maximum Outage Time	
			Shifts	Days
MRS Rail Cask Lag	2.00	20.00	447	149
MTUs	19.40			
MRS Truck Cask Lag	7.00	28.00	93	31
MTUs	9.70			
MRS Hot Cell 1 SFA Lag	40.00	180.00	60	20
MTUs	18.48			
MRS Hot Cell 2 SFA Lag	31.00	180.00	66	22
MTUs	14.32			
MRS Hot Cell 3 SFA Lag	71.00	320.00	75	25
MTUs	13.21			
MRS Hot Cell 4 SFA Lag	65.00	320.00	75	25
MTUs	12.09			
MRS PWR Canister Lag	117.00	540.00	132	44
MTUs	74.18			
MRS BWR Canister Lag	115.00	550.00	108	36
MTUs	79.83			
MRS Silo Cask Lag	474.00	1280.00	2820	940
MTUs	5547.54			
Repository Rail Cask Lag	4.00	12.00	39	13
MTUs	55.59			
Repository Truck Cask Lag	1.00	25.00	168	56
MTUs	1.39			
Repository PWR SFA Lag	11.00	21.00	8	4
MTUs	5.08			
Repository BWR SFA Lag	2.00	48.00	120	60
MTUs	0.37			
Repository Surface Vault	10.00	120.00	26	13
MTUs	17.80			

* Except for Cask Receipt which is available 24 hr/day, 7 days/week (100%)

TABLE 4.4. No-MRS System Operations Summary Report, Lag Storage

Case: Design Basis No-MRS System

Facility Schedule: 2 Shifts/day, 5 days/week*
Maximum Availability: 47.62%

Station	Peak Requirement	Maximum Capacity	Maximum Outage Time	
			Shifts	Days
Repository Rail Cask Lag	2.00	38	84	28
MTUs	19.40			
Repository Truck Cask Lag	8.00	28	18	6
MTUs	10.84			
WHB1 HLW Canister Lag	0.00	5	4	2
MTUs	0.00			
WHB2 PWR HC1 Lag	40.00	68	7	3.5
MTUs	18.48			
WHB2 PWR HC2 Lag	41.00	68	7	3.5
MTUs	18.94			
WHB2 BWR HC3 Lag	45.00	172	24	12
MTUs	23.53			
WHB2 BWR HC4 Lag	38.00	172.00	25	12.5
MTUs	7.07			
Vault Storage, WHB1	2.00	15.00	9	4.5
MTUs	2.13			
Vault Storage, WHB2	3.00	120.00	60	30
MTUs	9.47			

*Except for Cask Receipt which is available 24 hr/day, 7 days/week (100%)

its weakest point. These results reinforce the conclusion reached from analysis of idle times that the MRS system has slightly better reliability in terms of ability to absorb short term outages and maintain system flow rates.

4.2 SENSITIVITY TO FAILURE ASSUMPTIONS

In any complex system, the system operability depends to some extent on the ability to absorb small peaks and valleys in system flow rates. These peaks and ebbs can result from system design and from short-term machine failures. Task G of the MRS Systems Study requested that an analysis be made on the relative lag storage requirement due to imperfect system design and those due to short term machine failures. To fulfill this request, cases were run with no machine failures in order to determine the lag storage requirements under no failure conditions. These cases showed that about 90% of the lag storage requirements were due to system design and about 10% resulted from machine failures. Further details on these results are available in the Task G report.

As indicated in JBF Associates report, another measure of reliability is the sensitivity of the system to increased failure rates and repair times, since these are generally difficult to predict. For this study we have doubled the failure rates <u>and</u> repair times for three successive iterations. These cases are referred to as the 2, 4 and 6 times-failure cases. The high failure cases almost certainly overstate failure and repair rates likely to be experienced since at the 6x case the times between failures begin to approach the times to repair (i.e., the machines fail again almost as soon as they are repaired). The operating results for these cases are shown in Tables 4.5 through 4.7 for the MRS system. Examination of these results indicates that the MRS system could operate normally with failure and repair rates four times those estimated in the data (although at 4x rates most of the off-shift time is spent in repair). At 6x the normal failure and repair rates, the machine utilizations drop way off indicating that the system is overloaded. These results are confirmed by examining the peak lag storage requirements in Tables 4.8 through 4.10. Lag storage requirements

TABLE 4.5. MRS System Operations Summary Report, MRS Facility

Case: MRS System, 2x Failure Rates

Facility Schedule: 3 shifts/day, 5 days/week*
Maximum Availability: 71.4%

MRS Facility	Utilization (%)	Idle (%)	Maintenance (%)
Cask Receipt	20.7	79.1	0.0
Cask Unloading			
Unloading Cell 1	21.3	47.9	4.0
Unloading Cell 2	21.8	45.7	5.3
Unloading Cell 3	18.7	49.6	4.0
Unloading Cell 4	18.5	48.3	6.3
Routine Cask Servicing			
Servicing Cell 1	27.1	39.9	6.1
Servicing Cell 2	27.5	40.2	5.7
Servicing Cell 3	18.5	50.4	3.5
Servicing Cell 4	18.0	50.8	4.6
Consolidation			
Hot Cell 1	20.8	46.4	6.2
Hot Cell 2	23.2	44.5	5.6
Hot Cell 3	32.3	34.0	6.8
Hot Cell 4	32.1	35.7	5.1
Volume Reduction			
Station 1	20.0	51.0	0.7
Station 2	22.4	48.2	0.8
Canistering			
NFBH PWR Side	6.2	63.8	2.2
NFBH BWR Side	3.8	66.2	2.0
Hot Cell 1	32.4	36.1	3.7
Hot Cell 2	35.8	33.1	3.4
Hot Cell 3	21.4	48.4	2.4
Hot Cell 4	21.5	47.0	3.3
Load/Unload Storage Casks			
Station 1	20.9	49.1	1.6
Station 2	16.3	49.8	7.3
Loading Transport Casks			
Station 1	10.9	58.3	3.3
Station 2	10.9	58.3	3.3
Station 3	10.8	59.4	1.7
Station 4	10.8	59.4	1.7

* Except for Cask Receipt which is available 24 hr/day, 7 days/week (100%)

TABLE 4.6. MRS System Operations Summary Report, MRS Facility

Case: MRS System, 4x Failure Rates

Facility Schedule: 3 shifts/day, 5 days/week*
Maximum Availability: 71.4%

MRS Facility	Utilization (%)	Idle (%)	Maintenance (%)
Cask Receipt	20.7	78.7	0.0
Cask Unloading			
Unloading Cell 1	22.3	39.2	13.4
Unloading Cell 2	20.8	36.6	18.1
Unloading Cell 3	18.8	39.8	17.2
Unloading Cell 4	18.6	40.7	16.4
Routine Cask Servicing			
Servicing Cell 1	28.2	32.5	15.1
Servicing Cell 2	26.4	32.5	17.9
Servicing Cell 3	18.3	43.3	13.5
Servicing Cell 4	18.1	42.0	15.5
Consolidation			
Hot Cell 1	23.0	34.3	20.1
Hot Cell 2	20.0	36.8	19.7
Hot Cell 3	32.8	22.2	22.6
Hot Cell 4	32.2	25.4	20.5
Volume Reduction			
Station 1	19.9	49.9	1.9
Station 2	22.6	46.9	2.9
Canistering			
NFBH PWR Side	6.1	62.4	3.6
NFBH BWR Side	3.9	62.7	6.4
Hot Cell 1	35.6	27.2	11.9
Hot Cell 2	32.3	30.5	11.5
Hot Cell 3	21.3	39.2	13.9
Hot Cell 4	21.7	40.2	12.8
Load/Unload Storage Casks			
Station 1	20.9	37.8	18.4
Station 2	16.3	43.3	16.2
Loading Transport Casks			
Station 1	10.9	48.8	16.5
Station 2	10.9	48.8	16.5
Station 3	11.1	50.4	14.9
Station 4	11.1	50.4	14.9

* Except for Cask Receipt which is available 24 hr/day, 7 days/week (100%)

TABLE 4.7. MRS System Operations Summary Report, MRS Facility

Case: MRS System, 6x Failure Rates

Facility Schedule: 3 shifts/day, 5 days/week*
Maximum Availability: 71.4%

MRS Facility	Utilization (%)	Idle (%)	Maintenance (%)
Cask Receipt	1.9	96.8	0.0
Cask Unloading			
Unloading Cell 1	2.0	49.7	28.0
Unloading Cell 2	2.6	47.8	30.2
Unloading Cell 3	1.9	45.2	34.3
Unloading Cell 4	2.1	45.9	32.9
Routine Cask Servicing			
Servicing Cell 1	2.3	50.9	24.9
Servicing Cell 2	3.1	50.1	25.9
Servicing Cell 3	1.6	48.5	30.1
Servicing Cell 4	1.9	50.5	26.0
Consolidation			
Hot Cell 1	2.6	42.6	36.9
Hot Cell 2	3.9	43.4	35.5
Hot Cell 3	2.9	42.2	37.3
Hot Cell 4	3.0	43.1	36.2
Volume Reduction			
Station 1	3.2	64.9	5.2
Station 2	3.0	64.3	5.9
Canistering			
NFBH PWR Side	1.0	61.6	13.4
NFBH BWR Side	0.5	62.6	12.0
Hot Cell 1	4.0	48.4	25.8
Hot Cell 2	5.9	47.6	24.2
Hot Cell 3	1.9	52.5	24.3
Hot Cell 4	2.0	54.7	21.2
Load/Unload Storage Casks			
Station 1	8.1	39.9	32.8
Station 2	7.2	35.0	40.9
Loading Transport Casks			
Station 1	8.7	46.9	22.3
Station 2	8.7	46.9	22.3
Station 3	8.3	39.8	32.6
Station 4	8.3	39.8	32.6

* Except for Cask Receipt which is available 24 hr/day, 7 days/week (100%)

TABLE 4.8. MRS System Operations Summary Report, Lag Storage

Case: MRS System, 2x Failure Rates

Facility Schedule: 3 shifts/day, 5 days/week*
Maximum Availability: 71.4%

Station	Peak Requirement	Maximum Capacity
MRS Rail Cask Lag	14.00	20.00
MTUs	2.00	
MRS Truck Cask Lag	1.00	28.00
MTUs	1.00	
MRS Hot Cell 1 SFA Lag	1.00	180.00
MTUs	3.00	
MRS Hot Cell 2 SFA Lag	0.00	180.00
MTUs	2.00	
MRS Hot Cell 3 SFA Lag	0.00	320.00
MTUs	2.00	
MRS Hot Cell 4 SFA Lag	4.00	320.00
MTUs	27.00	
MRS PWR Canister Lag	1.00	540.00
MTUs	1.00	
MRS BWR Canister Lag	1.00	550.00
MTUs	1.00	
MRS Silo Cask Lag	0.00	1280.00
MTUs	1.00	
Repository Rail Cask Lag	0.00	12.00
MTUs	1.00	
Repository Truck Cask Lag	1.00	25.00
MTUs	0.00	
Repository PWR SFA Lag	1.00	21.00
MTUs	0.00	
Repository PWR SFA Lag	1.00	48.00
MTUs	1.00	
Repository Surface Vault	1.00	120.00
MTUs	1.00	

* Except for Cask Receipt which is available 24 hr/day, 7 days/week (100%)

TABLE 4.9. MRS System Operations Summary Report, Lag Storage

Case: MRS System, 4x Failure Rates

Facility Schedule: 3 shifts/day, 5 days/week*
Maximum Availability: 71.4%

Station	Peak Requirement	Maximum Capacity
MRS Rail Cask Lag	4.00	20.00
MTUs	38.81	
MRS Truck Cask Lag	12.00	28.00
MTUs	16.46	
MRS Hot Cell 1 SFA Lag	68.00	180.00
MTUs	31.42	
MRS Hot Cell 2 SFA Lag	85.00	180.00
MTUs	39.27	
MRS Hot Cell 3 SFA Lag	137.00	320.00
MTUs	25.48	
MRS Hot Cell 4 SFA Lag	139.00	320.00
MTUs	25.85	
MRS PWR Canister Lag	241.00	540.00
MTUs	166.35	
MRS BWR Canister Lag	177.00	550.00
MTUs	117.37	
MRS Silo Cask Lag	474.00	1280.00
MTUs	5473.27	
Repository Rail Cask Lag	8.00	12.00
MTUs	126.82	
Repository Truck Cask Lag	3.00	25.00
MTUs	4.07	
Repository PWR SFA Lag	16.00	21.00
MTUs	7.39	
Repository PWR SFA Lag	3.00	48.00
MTUs	0.56	
Repository Surface Vault	120.00	120.00
MTUs	200.18	

* Except for Cask Receipt which is available 24 hr/day, 7 days/week (100%)

TABLE 4.10. MRS System Operations Summary Report, Lag Storage

Case: MRS System, 6x Failure Rates

Facility Schedule: 3 shifts/day, 5 days/week*
Maximum Availability: 71.4%

Station	Peak Requirement	Maximum Capacity
MRS Rail Cask Lag	13.00	20.00
MTUs	116.42	
MRS Truck Cask Lag	18.00	28.00
MTUs	24.95	
MRS Hot Cell 1 SFA Lag	180.00	180.00
MTUs	83.16	
MRS Hot Cell 2 SFA Lag	180.00	180.00
MTUs	83.16	
MRS Hot Cell 3 SFA Lag	320.00	320.00
MTUs	59.52	
MRS Hot Cell 4 SFA Lag	320.00	320.00
MTUs	59.52	
MRS PWR Canister Lag	540.00	540.00
MTUs	387.20	
MRS BWR Canister Lag	550.00	550.00
MTUs	376.88	
MRS Silo Cask Lag	304.00	1280.00
MTUs	3365.87	
Repository Rail Cask Lag	12.00	12.00
MTUs	160.61	
Repository Truck Cask Lag	4.00	25.00
MTUs	5.54	
Repository PWR SFA Lag	21.00	21.00
MTUs	9.70	
Repository PWR SFA Lag	39.00	48.00
MTUs	7.25	
Repository Surface Vault	120.00	120.00
MTUs	224.59	

* Except for Cask Receipt which is available 24 hr/day, 7 days/week (100%)

slightly increase at failure rates of up to 4x normal. However, at 6x normal failure rates all the lag storage areas are filled, indicating system overload.

For the No-MRS system, the operating results for the 2x,4x and 6x failure cases are shown in Tables 4.11 through 4.13. Examining the results for these cases indicates that the system operates normally at 2x failure rates, but utilizations, in cask unloading, consolidation and containerizing begin to drop off at 4x normal failure rates. The ability to sustain normal operations under increasing failure rate conditions is not as great in the No-MRS system as in the MRS system (which can sustain normal operations at 4x failure rates), because of the greater design capacity of the MRS system. At 6x failure rates utilizations have fallen off still further, but are much higher than MRS utilizations at the 6x rate. This is due to the much greater availability of maintenance time in the 2 shift per day No-MRS system which allows greater throughput capability at high failure rates (this difference between systems is not important since the MRS could operate at 2 shifts day and exhibit similar failure characteristics while maintaining throughput.) Examining the lag storage results in Tables 4.14 through 4.16 reaffirms the above conclusions. At 4x failure rates the No-MRS system has reached maximum capacity in the hot cell three lag storage area and in rail cask loading and is near maximum capacities in the hot cell one and two lag storage areas.

The above results indicate less sensitivity to normal machine failures (and therefore greater reliability) as a result of the higher capacity of the MRS system as currently designed.

4.3 CONTINGENCY SYSTEM THROUGHPUT CAPACITY

One of the key aspects of system reliability is the system throughput capability. As noted above, higher throughput capabilities provide redundant operating capacity in case of higher than usual machine failures allowing normal operations to continue. Throughput capability significantly higher than planned operating rates also provides a contingency capability which allows system backlogs to be processed while continuing to take spent fuel at planned rates from utilities. This would be a necessity in recovering from

TABLE 4.11. No-MRS System Operations Summary Report, Repository

Case: No-MRS System, 2x Failure Rates

Facility Schedule: 2 Shifts/day, 5 days/week*
Maximum Availability: 47.62%

Repository	Utilization (%)	Idle (%)	Maintenance (%)
Cask Receipt	17.4	82.4	0.2
Cask Unloading			
WHB2 Spent Fuel	37.5	8.0	3.9
Unloading HLW	7.9	37.4	4.9
Routine Cask Servicing			
WHB2 Rail	3.6	41.5	5.8
WHB2 Truck	10.1	34.8	5.5
WHB1	2.0	43.5	4.7
Cask Fleet, Special	7.1	39.4	2.4
Consolidation			
PWR SFA HC1	35.9	8.5	7.3
PWR SFA HC2	35.5	9.8	5.6
BWR SFA HC3	35.6	9.7	5.5
BWR SFA HC4	36.2	9.1	5.4
Canning (and welding)			
HC1, Intact SFA	25.3	21.1	2.4
HC2, Intact SFA	25.1	21.2	3.0
HC3, Intact SFA	10.8	35.4	3.6
HC4, Intact SFA	10.9	35.4	2.5
Defective SFA	1.7	44.7	2.4
Consolidated SFA	0.9	45.3	3.4
Canister Overpack			
HLW Cans	42.1	4.0	3.1
Emplacement	11.3	33.8	4.6

*Except for Cask Receipt which is available 24 hr/day, 7days/

TABLE 4.12. No-MRS System Operations Summary Report, Repository

Case: No-MRS System, 4x Failure Rates

Facility Schedule: 2 Shifts/day, 5 days/week*
Maximum Availability: 47.62%

Repository	Utilization (%)	Idle (%)	Maintenance (%)
Cask Receipt	17.1	82.0	0.8
Cask Unloading			
WHB2 Spent Fuel	35.9	3.7	17.1
Unloading HLW	7.8	31.2	18.2
Routine Cask Servicing			
WHB2 Rail	3.3	37.4	15.1
WHB2 Truck	10.0	29.9	15.1
WHB1	2.0	37.8	16.8
Cask Fleet, Special	7.0	32.6	16.4
Consolidation			
PWR SFA HC1	32.9	3.4	22.9
PWR SFA HC2	33.5	3.0	22.7
BWR SFA HC3	34.0	3.5	20.6
BWR SFA HC4	34.1	3.1	21.1
Canning (and welding)			
HC1, Intact SFA	23.2	18.9	12.4
HC2, Intact SFA	23.6	19.3	10.4
HC3, Intact SFA	10.2	30.8	13.2
HC4, Intact SFA	10.3	31.7	11.5
Defective SFA	1.7	41.7	9.7
Consolidated SFA	0.9	41.5	11.8
Canister Overpack			
HLW Cans	42.2	0.0	11.3
Emplacement	10.9	27.8	19.6

*Except for Cask Receipt which is available 24 hr/day, 7days/

TABLE 4.13. No-MRS System Operations Summary Report, Repository

Case: No-MRS System, 6x Failure Rates

Facility Schedule: 2 Shifts/day, 5 days/week*
Maximum Availability: 47.62%

Repository	Utilization (%)	Idle (%)	Maintenance (%)
Cask Receipt	11.0	87.6	1.4
Cask Unloading			
WHB2 Spent Fuel	26.2	5.6	33.0
Unloading HLW	1.2	35.3	24.0
Routine Cask Servicing			
WHB2 Rail	2.5	29.7	32.5
WHB2 Truck	7.0	24.5	33.9
WHB1	0.4	41.7	43.1
Cask Fleet, Special	4.2	29.9	29.4
Consolidation			
PWR SFA HC1	24.0	5.8	38.0
PWR SFA HC2	25.7	5.3	35.1
BWR SFA HC3	25.3	3.8	39.5
BWR SFA HC4	25.8	4.9	35.4
Canning (and welding)			
HC1, Intact SFA	16.8	19.4	22.9
HC2, Intact SFA	18.1	18.8	22.2
HC3, Intact SFA	7.6	30.0	19.9
HC4, Intact SFA	7.8	28.4	23.5
Defective SFA	1.1	34.6	25.7
Consolidated SFA	0.7	34.2	26.1
Canister Overpack			
HLW Cans	6.1	31.0	21.6
Emplacement	5.3	25.9	35.4

*Except for Cask Receipt which is available 24 hr/day, 7days/

TABLE 4.14. No-MRS System Operations Summary Report, Lag Storage

Case: No-MRS System, 2x Failure Rates

Facility Schedule: 2 Shifts/day, 5 days/week*
Maximum Availability: 47.62%

Station	Peak Requirement	Maximum Capacity
Repository Rail Cask Lag	5.00	38
MTUs	38.81	
Repository Truck Cask Lag	10.00	28
MTUs	13.61	
WHB1 HLW Canister Lag	0.00	5
MTUs	0.00	
WHB2 PWR HC1 Lag	57.00	68
MTUs	26.33	
WHB2 PWR HC2 Lag	54.00	68
MTUs	24.95	
WHB2 BWR HC3 Lag	67.00	172
MTUs	22.67	
WHB2 BWR HC4 Lag	67.00	172.00
MTUs	12.46	
Vault Storage, WHB1	6.00	15.00
MTUs	3.63	
Vault Storage, WHB2	7.00	120.00
MTUs	20.56	

*Except for Cask Receipt which is available 24 hr/day, 7 days/week (100%)

TABLE 4.15. No-MRS System Operations Summary Report, Lag Storage

Case: No-MRS System, 4x Failure Rates

Facility Schedule: 2 Shifts/day, 5 days/week*
Maximum Availability: 47.62%

Station	Peak Requirement	Maximum Capacity
Repository Rail Cask Lag	38.00	38
MTUs	362.59	
Repository Truck Cask Lag	19.00	28
MTUs	25.83	
WHB1 HLW Canister Lag	0.00	5
MTUs	0.00	
WHB2 PWR HC1 Lag	63.00	68
MTUs	29.11	
WHB2 PWR HC2 Lag	63.00	68
MTUs	29.11	
WHB2 BWR HC3 Lag	172.00	172
MTUs	62.45	
WHB2 BWR HC4 Lag	117.00	172.00
MTUs	21.76	
Vault Storage, WHB1	8.00	15.00
MTUs	8.40	
Vault Storage, WHB2	13.00	120.00
MTUs	38.34	

*Except for Cask Receipt which is available 24 hr/day, 7 days/week (100%)

TABLE 4.16. No-MRS System Operations Summary Report, Lag Storage

Case: No-MRS System, 6x Failure Rates

Facility Schedule: 2 Shifts/day, 5 days/week*
Maximum Availability: 47.62%

Station	Peak Requirement	Maximum Capacity
Repository Rail Cask Lag	38.00	38
MTUs	363.08	
Repository Truck Cask Lag	19.00	28
MTUs	25.31	
WHB1 HLW Canister Lag	0.00	5
MTUs	0.00	
WHB2 PWR HC1 Lag	63.00	68
MTUs	29.11	
WHB2 PWR HC2 Lag	63.00	68
MTUs	29.11	
WHB2 BWR HC3 Lag	159.00	172
MTUs	30.83	
WHB2 BWR HC4 Lag	118.00	172.00
MTUs	21.95	
Vault Storage, WHB1	5.00	15.00
MTUs	6.40	
Vault Storage, WHB2	22.00	120.00
MTUs	59.13	

*Except for Cask Receipt which is available 24 hr/day, 7 days/week (100%)

outages in which all of the system lag storage were full (such as long-term outages for institutional reasons or catastrophic events). Excess system process capacity is also useful for regulating system storage inventories. For example, excess repository process capacity could be used to draw down storage cask inventory levels at the MRS to provide greater contingency storage capability. This would allow early startup of the MRS (assuming the NWPAA restrictions on early MRS startup were relaxed) without the burden of being near peak storage limits over the life of the MRS facility.

For this analysis, the MRS and No-MRS systems were operated at various throughput rates to determine maximum throughput rates that could be sustained for each design basis. We have limited the repository operations in both systems to two shifts per day to be consistent with Sandia's design operating schedule. Being able to operate at three shifts per day would significantly improve the reliabilities of the repositories reported here.

Operations summaries for the MRS facility for throughputs of 3500, 4000, 5000 and 6000 MTU/year are shown in Tables 4.17 through 4.20. As expected, machine utilizations increase and machine idle times decrease at successively higher throughputs. Examination of idle times for the different stations indicates that BWR consolidation and PWR canistering are the limiting functions. However, even at 6,000 MTU/yr there is still a small amount of machine idle time in these stations indicating that the facility could operate at this rate for short periods of time. Tables 4.21 through 4.24 show the lag storage summaries for the above cases. At throughputs of up to 5000 MTU/year there are sufficient storage capacities to operate normally (although the maximum outage time has declined substantially indicating more susceptibility to throughput interruption). However, at 6000 MTU/year the lag storage is at full capacity and large numbers of truck and rail casks are needed, indicating that the facility could not operate at this rate for long time periods.

The repository operating summaries for the MRS system are shown in Tables 4.25 through 4.28. The results show that the repository can operate normally at spent fuel throughputs of 3500 MTU/year. At 3500 MTU/yr there is still idle time in the containerization function. However, at throughputs of

TABLE 4.17. MRS System Operations Summary Report, MRS Facility

Case: MRS System, 3500 MTU/Year Receipt Rate

Facility Schedule: 3 shifts/day, 5 days/week*
Maximum Availability: 71.4%

MRS Facility	Utilization (%)	Idle (%)	Maintenance (%)
Cask Receipt	26.7	73.1	0.0
Cask Unloading			
Unloading Cell 1	27.5	42.5	1.8
Unloading Cell 2	28.6	42.1	1.2
Unloading Cell 3	24.1	46.2	1.2
Unloading Cell 4	23.9	47.2	0.8
Routine Cask Servicing			
Servicing Cell 1	34.6	35.9	1.3
Servicing Cell 2	36.1	35.1	0.3
Servicing Cell 3	23.5	47.5	0.5
Servicing Cell 4	23.3	47.6	0.8
Consolidation			
Hot Cell 1	28.9	42.0	1.2
Hot Cell 2	29.3	40.9	1.5
Hot Cell 3	42.0	28.6	1.1
Hot Cell 4	41.3	29.0	1.7
Volume Reduction			
Station 1	26.3	45.1	0.1
Station 2	28.9	42.6	0.0
Canistering			
NFBH PWR Side	8.1	63.0	0.4
NFBH BWR Side	4.9	66.3	0.3
Hot Cell 1	45.0	26.1	0.4
Hot Cell 2	46.0	25.2	0.6
Hot Cell 3	27.6	43.5	0.6
Hot Cell 4	27.1	43.6	1.0
Load/Unload Storage Casks			
Station 1	26.3	44.3	1.4
Station 2	20.2	51.3	0.0
Loading Transport Casks			
Station 1	12.7	58.3	0.7
Station 2	12.7	58.3	0.7
Station 3	13.1	57.9	1.4
Station 4	13.1	57.9	1.4

* Except for Cask Receipt which is available 24 hr/day, 7 days/week (100%)

TABLE 4.18. MRS System Operations Summary Report, MRS Facility

Case: MRS System, 4000 MTJ/Year Receipt Rate

Facility Schedule: 3 shifts/day, 5 days/week*
Maximum Availability: 71.4%

MRS Facility	Utilization (%)	Idle (%)	Maintenance (%)
Cask Receipt	30.5	69.4	0.0
Cask Unloading			
Unloading Cell 1	31.5	38.5	1.8
Unloading Cell 2	31.8	38.8	1.2
Unloading Cell 3	27.9	42.4	1.2
Unloading Cell 4	27.7	43.4	0.8
Routine Cask Servicing			
Servicing Cell 1	39.5	31.1	1.3
Servicing Cell 2	40.7	30.5	0.3
Servicing Cell 3	27.4	43.6	0.5
Servicing Cell 4	26.6	44.4	0.8
Consolidation			
Hot Cell 1	33.7	37.2	1.2
Hot Cell 2	31.8	38.4	1.5
Hot Cell 3	47.3	23.4	1.1
Hot Cell 4	50.0	20.3	1.7
Volume Reduction			
Station 1	29.7	41.8	0.1
Station 2	33.6	37.9	0.0
Canistering			
NFBH PWR Side	9.1	62.0	0.4
NFBH BWR Side	5.8	65.5	0.3
Hot Cell 1	52.5	18.6	0.4
Hot Cell 2	49.0	22.3	0.6
Hot Cell 3	31.5	39.7	0.6
Hot Cell 4	32.7	38.0	1.0
Load/Unload Storage Casks			
Station 1	30.7	40.0	1.4
Station 2	25.1	46.4	0.0
Loading Transport Casks			
Station 1	15.7	55.3	0.7
Station 2	15.7	55.3	0.7
Station 3	17.3	53.7	1.4
Station 4	17.3	53.7	1.4

* Except for Cask Receipt which is available 24 hr/day, 7 days/week (100%)

TABLE 4.19. MRS System Operations Summary Report, MRS Facility

Case: MRS System, 5000 MTU/Year Receipt Rate

Facility Schedule: 3 shifts/day, 5 days/week*
Maximum Availability: 71.4%

MRS Facility	Utilization (%)	Idle (%)	Maintenance (%)
Cask Receipt	30.9	68.9	0.0
Cask Unloading			
Unloading Cell 1	31.8	38.2	1.8
Unloading Cell 2	33.0	37.7	1.2
Unloading Cell 3	27.9	42.4	1.2
Unloading Cell 4	27.7	43.4	0.8
Routine Cask Servicing			
Servicing Cell 1	40.4	30.2	1.3
Servicing Cell 2	41.2	30.0	0.3
Servicing Cell 3	26.9	44.1	0.5
Servicing Cell 4	27.4	43.5	0.8
Consolidation			
Hot Cell 1	31.2	39.6	1.2
Hot Cell 2	35.4	34.8	1.5
Hot Cell 3	50.0	20.6	1.1
Hot Cell 4	47.3	23.0	1.7
Volume Reduction			
Station 1	30.4	41.0	0.1
Station 2	33.8	37.7	0.0
Canistering			
NFBH PWR Side	9.4	61.8	0.4
NFBH BWR Side	5.8	65.5	0.3
Hot Cell 1	48.7	22.4	0.4
Hot Cell 2	54.4	16.8	0.6
Hot Cell 3	32.2	38.9	0.6
Hot Cell 4	30.9	39.9	1.0
Load/Unload Storage Casks			
Station 1	33.4	37.3	1.4
Station 2	27.7	43.8	0.0
Loading Transport Casks			
Station 1	18.8	52.2	0.7
Station 2	18.8	52.2	0.7
Station 3	21.0	49.9	1.4
Station 4	21.0	49.9	1.4

* Except for Cask Receipt which is available 24 hr/day, 7 days/week (100%)

TABLE 4.20. MRS System Operations Summary Report, MRS Facility

Case: MRS System, 6000 MTU/Year Receipt Rate

Facility Schedule: 3 shifts/day, 5 days/week*
Maximum Availability: 71.4%

MRS Facility	Utilization (%)	Idle (%)	Maintenance (%)
Cask Receipt	41.8	58.1	0.0
Cask Unloading			
Unloading Cell 1	42.9	27.1	1.8
Unloading Cell 2	45.7	25.0	1.2
Unloading Cell 3	37.6	32.6	1.2
Unloading Cell 4	36.3	34.7	0.8
Routine Cask Servicing			
Servicing Cell 1	53.9	16.6	1.3
Servicing Cell 2	58.2	13.0	0.3
Servicing Cell 3	36.3	34.7	0.5
Servicing Cell 4	35.6	35.4	0.8
Consolidation			
Hot Cell 1	45.2	25.6	1.2
Hot Cell 2	45.4	24.8	1.5
Hot Cell 3	67.6	3.0	1.1
Hot Cell 4	66.5	3.9	1.7
Volume Reduction			
Station 1	41.2	30.3	0.1
Station 2	44.8	26.7	0.0
Canistering			
NFBH PWR Side	12.7	58.4	0.4
NFBH BWR Side	7.7	63.6	0.3
Hot Cell 1	70.5	0.6	0.4
Hot Cell 2	70.1	1.1	0.6
Hot Cell 3	45.3	25.8	0.6
Hot Cell 4	43.2	27.5	1.0
Load/Unload Storage Casks			
Station 1	43.4	27.3	1.4
Station 2	34.0	37.5	0.0
Loading Transport Casks			
Station 1	22.7	48.3	0.7
Station 2	22.7	48.3	0.7
Station 3	23.1	47.9	1.4
Station 4	23.1	47.9	1.4

* Except for Cask Receipt which is available 24 hr/day, 7 days/week (100%)

TABLE 4.21. MRS System Operations Summary Report, Lag Storage

Case: MRS System, 3000 MTU/Year Receipt Rate

Facility Schedule: 3 shifts/day, 5 days/week*
Maximum Availability: 71.4%

Station	Peak Requirement	Maximum Capacity
MRS Rail Cask Lag	3.00	20.00
MTUs	28.33	
MRS Truck Cask Lag	8.00	28.00
MTUs	10.92	
MRS Hot Cell 1 SFA Lag	50.00	180.00
MTUs	23.10	
MRS Hot Cell 2 SFA Lag	34.00	180.00
MTUs	15.71	
MRS Hot Cell 3 SFA Lag	59.00	320.00
MTUs	10.97	
MRS Hot Cell 4 SFA Lag	89.00	320.00
MTUs	16.55	
MRS PWR Canister Lag	94.00	540.00
MTUs	63.39	
MRS BWR Canister Lag	148.00	550.00
MTUs	74.25	
MRS Silo Cask Lag	662.00	1280.00
MTUs	7746.11	
Repository Rail Cask Lag	10.00	12.00
MTUs	133.27	
Repository Truck Cask Lag	2.00	25.00
MTUs	2.69	
Repository PWR SFA Lag	14.00	21.00
MTUs	6.47	
Repository PWR SFA Lag	1.00	48.00
MTUs	0.19	
Repository Surface Vault	9.00	120.00
MTUs	12.95	

* Except for Cask Receipt which is available 24 hr/day, 7 days/week (100%)

TABLE 4.22. MRS System Operations Summary Report, Lag Storage

Case: MRS System, 4000 MTU/Year Receipt Rate

Facility Schedule: 3 shifts/day, 5 days/week*
Maximum Availability: 71.4%

Station	Peak Requirement	Maximum Capacity
MRS Rail Cask Lag	3.00	20.00
MTUs	29.11	
MRS Truck Cask Lag	8.00	28.00
MTUs	10.92	
MRS Hot Cell 1 SFA Lag	55.00	180.00
MTUs	25.41	
MRS Hot Cell 2 SFA Lag	41.00	180.00
MTUs	18.94	
MRS Hot Cell 3 SFA Lag	79.00	320.00
MTUs	14.69	
MRS Hot Cell 4 SFA Lag	83.00	320.00
MTUs	15.44	
MRS PWR Canister Lag	128.00	540.00
MTUs	87.12	
MRS BWR Canister Lag	133.00	550.00
MTUs	88.41	
MRS Silo Cask Lag	671.00	1280.00
MTUs	7837.99	
Repository Rail Cask Lag	12.00	12.00
MTUs	209.12	
Repository Truck Cask Lag	3.00	25.00
MTUs	4.07	
Repository PWR SFA Lag	12.00	21.00
MTUs	5.54	
Repository PWR SFA Lag	11.00	48.00
MTUs	2.05	
Repository Surface Vault	6.00	120.00
MTUs	11.10	

* Except for Cask Receipt which is available 24 hr/day, 7 days/week (100%)

TABLE 4.23. MRS System Operations Summary Report, Lag Storage

Case: MRS System, 5000 MTU/Year Receipt Rate

Facility Schedule: 3 shifts/day, 5 days/week*
Maximum Availability: 71.4%

Station	Peak Requirement	Maximum Capacity
MRS Rail Cask Lag	5.00	20.00
MTUs	48.51	
MRS Truck Cask Lag	9.00	28.00
MTUs	12.14	
MRS Hot Cell 1 SFA Lag	59.00	180.00
MTUs	27.26	
MRS Hot Cell 2 SFA Lag	55.00	180.00
MTUs	25.41	
MRS Hot Cell 3 SFA Lag	106.00	320.00
MTUs	19.72	
MRS Hot Cell 4 SFA Lag	74.00	320.00
MTUs	13.76	
MRS PWR Canister Lag	151.00	540.00
MTUs	105.74	
MRS BWR Canister Lag	154.00	550.00
MTUs	93.05	
MRS Silo Cask Lag	599.00	1280.00
MTUs	6981.38	
Repository Rail Cask Lag	12.00	12.00
MTUs	226.16	
Repository Truck Cask Lag	4.00	25.00
MTUs	5.54	
Repository PWR SFA Lag	11.00	21.00
MTUs	5.08	
Repository PWR SFA Lag	1.00	48.00
MTUs	0.00	
Repository Surface Vault	5.00	120.00
MTUs	10.19	

* Except for Cask Receipt which is available 24 hr/day, 7 days/week (100%)

TABLE 4.24. MRS System Operations Summary Report, Lag Storage

Case: MRS System, 6000 MTU/Year Receipt Rate

Facility Schedule: 3 shifts/day, 5 days/week*
Maximum Availability: 71.4%

Station	Peak Requirement	Maximum Capacity
MRS Rail Cask Lag	29.00	20.00
MTUs	281.36	
MRS Truck Cask Lag	100.00	28.00
MTUs	138.60	
MRS Hot Cell 1 SFA Lag	180.00	180.00
MTUs	83.16	
MRS Hot Cell 2 SFA Lag	180.00	180.00
MTUs	83.16	
MRS Hot Cell 3 SFA Lag	320.00	320.00
MTUs	59.52	
MRS Hot Cell 4 SFA Lag	320.00	320.00
MTUs	59.52	
MRS PWR Canister Lag	161.00	540.00
MTUs	106.80	
MRS BWR Canister Lag	142.00	550.00
MTUs	91.62	
MRS Silo Cask Lag	926.00	1280.00
MTUs	10758.98	
Repository Rail Cask Lag	12.00	12.00
MTUs	205.76	
Repository Truck Cask Lag	5.00	25.00
MTUs	6.85	
Repository PWR SFA Lag	12.00	21.00
MTUs	5.54	
Repository PWR SFA Lag	17.00	48.00
MTUs	3.16	
Repository Surface Vault	6.00	120.00
MTUs	12.03	

* Except for Cask Receipt which is available 24 hr/day, 7 days/week (100%)

TABLE 4.25. MRS System Operations Summary Report, Repository

Case: MRS System, 3500 MTU/Year Receipt Rate

Facility Schedule: 2 shifts/day, 5 days/week*
Maximum Availability: 47.6%

Repository Facility	Utili-zation	Idle	Mainten-ance
Cask Receipt	11.4	88.6	0.0
Cask Unloading			
Unloading Western SF	10.1	37.4	0.3
Unloading MRS & HLW	37.9	9.0	1.5
Routine Cask Servicing			
Servicing Cell 1	27.3	20.2	0.7
Servicing Cell 2	27.3	20.2	0.7
Containerization			
Western SF	6.4	41.0	0.6
HLW and MRS Cans	41.8	5.5	0.0
Emplacement			
Transporter 1	16.6	30.6	1.1

* Except for Cask Receipt which is available 24 hr/day, 7days/week (100%)

TABLE 4.26. MRS System Operations Summary Report, Repository

Case: MRS System, 4000 MTU/Year Receipt Rate

Facility Schedule: 2 shifts/day, 5 days/week*
Maximum Availability: 47.6%

Repository Facility	Utilization	Idle	Maintenance
Cask Receipt	12.1	87.9	0.0
Cask Unloading			
Unloading Western SF	9.5	38.0	0.3
Unloading MRS & HLW	43.4	3.4	1.5
Routine Cask Servicing			
Servicing Cell 1	28.9	18.5	0.7
Servicing Cell 2	28.9	18.5	0.7
Containerization			
Western SF	6.2	41.2	0.6
HLW and MRS Cans	47.3	0.0	0.0
Emplacement			
Transporter 1	18.7	28.5	1.1

* Except for Cask Receipt which is available 24 hr/day, 7days/week (100%)

TABLE 4.27. MRS System Operations Summary Report, Repository

Case: MRS System, 5000 MTU/Year Receipt Rate

Facility Schedule: 2 shifts/day, 5 days/week*
Maximum Availability: 47.6%

Repository Facility	Utilization	Idle	Maintenance
Cask Receipt	11.5	88.5	0.0
Cask Unloading			
Unloading Western SF	8.1	39.4	0.3
Unloading MRS & HLW	43.4	3.4	1.5
Routine Cask Servicing			
Servicing Cell 1	27.4	20.1	0.7
Servicing Cell 2	27.4	20.1	0.7
Containerization			
Western SF	5.2	42.2	0.6
HLW and MRS Cans	47.3	0.0	0.0
Emplacement			
Transporter 1	18.6	28.6	1.1

* Except for Cask Receipt which is available 24 hr/day, 7days/week (100%)

TABLE 4.28. MRS System Operations Summary Report, Repository

Case: MRS System, 6000 MTU/Year Receipt Rate

Facility Schedule: 2 shifts/day, 5 days/week*
Maximum Availability: 47.6%

Repository Facility	Utilization	Idle	Maintenance
Cask Receipt	11.5	88.4	0.0
Cask Unloading			
Unloading Western SF	8.7	38.8	0.3
Unloading MRS & HLW	43.7	3.1	1.5
Routine Cask Servicing			
Servicing Cell 1	27.3	20.1	0.7
Servicing Cell 2	27.3	20.1	0.7
Containerization			
Western SF	5.3	42.1	0.6
HLW and MRS Cans	47.3	0.0	0.0
Emplacement			
Transporter 1	18.6	28.5	1.1

* Except for Cask Receipt which is available 24 hr/day, 7days/week (100%)

4000 MTU/yr to 6000 MTU/yr there is not containerization idle time for processing of MRS and HLW containers. The corresponding data on lag storage quantities (not shown) shows all lag storages upstream from containerization to be filled to capacity indicating that the containerization function is acting as a "pinch point" in the system at throughputs of 4000 MTU and higher. Therefore, the MRS containerization function is limiting the facility throughput to between 3500 and 4000 MTU/yr. (NOTE: results not shown here indicate that if the repository could operate 3 shifts/day, throughput rates near 6000 MTU/year would be achievable.)

Table 4.29 shows the 3500 MTU operating summary for the No-MRS system. The cask unloading station and the consolidation stations show very low idle times indicating that the system is near capacity. The lag storage summary in Table 4.30 indicates that significant additional cask lag storage is being required an indication that significant additional transport casks are being required. The No-MRS system could therefore operate at this rate, but only for short time periods. Because the system is at capacity at the 3500 MTU/year operating rate, additional runs at higher rates are not reported.

In summary, the MRS facility, operating under design assumptions, has a peak throughput capacity of 5000 to 6000 MTU/yr, and can therefore be reliably expected to meet the system acceptance goals of 3000 MTU/year. The repository in the MRS system has a peak capacity of around 4000 MTU/year indicating that the entire system is limited to about this peak capacity on a long-term basis. The MRS could operate at higher rates if needed until its cask storage capacity limits (determined by physical limits or institutional mandate) are reached. With a peak system capacity of about 4000 MTU/year, the MRS system could work down storage inventories at the MRS at the rate of about 1000 MTU/year and still maintain acceptance rates of 3000 MTU from utilities.

In the No-MRS system the peak system capacity is about 3500 MTU/year although long-term operation is limited to about 3000 MTU per year. Because the design system capacity is so near the desired acceptance rate, the

TABLE 4.29. No-MRS System Operations Summary Report, Repository

Case: No-MRS System, 3500 MTU/Year Receipt Rate

Facility Schedule: 2 Shifts/day, 5 days/week*
Maximum Availability: 47.62%

Repository	Utilization (%)	Idle (%)	Maintenance (%)
Cask Receipt	19.7	80.2	0.0
Cask Unloading			
WHB2 Spent Fuel	43.4	3.4	1.7
Unloading HLW	8.1	38.9	1.6
Routine Cask Servicing			
WHB2 Rail	4.3	42.5	1.5
WHB2 Truck	11.6	35.4	1.4
WHB1	2.1	45.1	1.1
Cask Fleet, Special	8.2	38.7	1.7
Consolidation			
PWR SFA HC1	41.4	5.5	1.3
PWR SFA HC2	42.1	5.2	1.2
BWR SFA HC3	42.4	4.4	1.7
BWR SFA HC4	42.0	4.9	1.8
Canning (and welding)			
HC1, Intact SFA	29.2	18.2	0.6
HC2, Intact SFA	29.6	17.8	0.8
HC3, Intact SFA	12.8	34.4	1.0
HC4, Intact SFA	12.7	34.6	0.8
Defective SFA	2.1	45.1	1.0
Consolidated SFA	1.0	46.4	0.7
Canister Overpack			
HLW Cans	43.6	3.8	0.6
Emplacement	12.6	34.5	1.2

*Except for Cask Receipt which is available 24 hr/day, 7days/week (100%)

TABLE 4.30. No-MRS System Operations Summary Report, Lag Storage

Case: No-MRS System, 3500 MTU/Year Receipt Rate

Facility Schedule: 2 Shifts/day, 5 days/week*
Maximum Availability: 47.62%

Station	Peak Requirement	Maximum Capacity
Repository Rail Cask Lag	6.00	38
MTUs	47.74	
Repository Truck Cask Lag	14.00	28
MTUs	19.07	
WHB1 HLW Canister Lag	0.00	5
MTUs	0.00	
WHB2 PWR HC1 Lag	49.00	68
MTUs	22.64	
WHB2 PWR HC2 Lag	46.00	68
MTUs	21.25	
WHB2 BWR HC3 Lag	77.00	172
MTUs	31.67	
WHB2 BWR HC4 Lag	58.00	172.00
MTUs	10.79	
Vault Storage, WHB1	2.00	15.00
MTUs	2.13	
Vault Storage, WHB2	3.00	120.00
MTUs	8.89	

*Except for Cask Receipt which is available 24 hr/day, 7 days/week (100%)

probability of not meeting the desired rate is much greater in this system. This system also has much less flexibility in operating strategy in meeting operational contingencies.

4.4 CONTINGENCY CAPABILITY DUE TO SYSTEM STORAGE CAPACITY

The most obvious of the MRS systems' advantages is the ability to accept fuel early and to buffer fuel acceptance operations through the use of concrete cask storage. Early acceptance of fuel (if allowed) relieves some of the fuel storage pressure on utilities and allows DOE to meet contractual obligations. The ability to buffer acceptance operations becomes important if outages occur which would otherwise limit the ability to accept fuel at the desired rate. Calculation of the maximum facility down-time before fuel acceptance is reduced depends on the system storage capacity at the time of failure and on the definition of maximum capacity. For this analysis we assume that maximum storage capacities defined by the NWPA as amended by the NWPAA mean maximum amount of fuel in all lag storage onsite. This definition excludes all work in process, but includes all fuel in in-process storage. These quantities are limited to 15000 MTU for the MRS and 750 MTU for the repository.

The system storage capacity at time-of-failure depends on a number of factors, the most important of which are the relative startup times of the MRS and repository facilities (for the MRS system) and the repository receipt rate. Longer offsets between MRS facility startup and repository facility startup mean larger storage quantities in MRS cask storage. Most of the MRS Action Plan cases result in MRS spent fuel storage quantities of 4,000 to 13,000 MTU (although some early acceptance cases show quantities in the 20,000+ MTU range).

For the reliability analysis, we have set up two cases (one each for the MRS and No-MRS systems) in which the repository fails for a period of one year to examine the impacts on system storage and to examine the abilities of the systems to recover from backups in their lag storage queues. The MRS system assumes early MRS startup and design basis MRS and repository receipt rates resulting in about 10,000 MTUs of storage at time of failure. The No-MRS system operates normally at a 3,000 MTU receipt rate (at equilibrium) until repository failure. Figures 4.1 and 4.2 show the MTU emplacement as a function of time for the MRS and No-MRS systems respectively. The figures show normal emplacement rates until time of failure. After failures of one year, emplacement resumes as the facilities attempt to work down their backlogs. The MRS system is able to emplace waste more quickly after failure than the No-MRS system because of its higher throughput capability (as explained in Section 4.2) and so is able to recover more quickly. Figure 4.2 shows that the No-MRS system is not able to emplace waste even at the previous 3,000 ton rate for up to two years after emplacement.

Figures 4.3 through 4.5 illustrate the spent fuel MTU throughput rate into the facilities in both systems. In the MRS case (Figure 4.3), the MRS is able to continue receiving fuel normally from reactors (by building up its cask storage) during the entire outage. The repository in the MRS case is assumed not to receive any more fuel from the MRS during the outage (Figure 4.4a), but does continue to receive western reactor fuel during the 1-year failure time (Figure 4.4b) although the rate drops considerably as the cask lag storage areas fill up. These figures show that both facilities are able to receive during the outage time (the repository stores the western fuel in its cask lag storage).

The effect of the one-year long-term outage on cask lag storage (chosen to be illustrative of all lag storage locations in the facilities in each system) are illustrated in Figures 4.6 through 4.9 for the two systems. Figure 4.6 shows no changes in cask lag storage at the MRS since fuel can be passed through to concrete cask storage. Figure 4.7a shows that the repository in the MRS system has reached its maximum truck cask capacity soon after the start of the outage period. Figure 4.7b shows that maximum rail cask storage capacity at the same facility is not reached until near the end of the outage period. Figure 4.8 shows that the No-MRS system rapidly reaches its cask storage limit and remains there until processing can resume. After processing resumes the backlog fluctuates but generally stays near its maximum, indicating that the system remains overloaded.

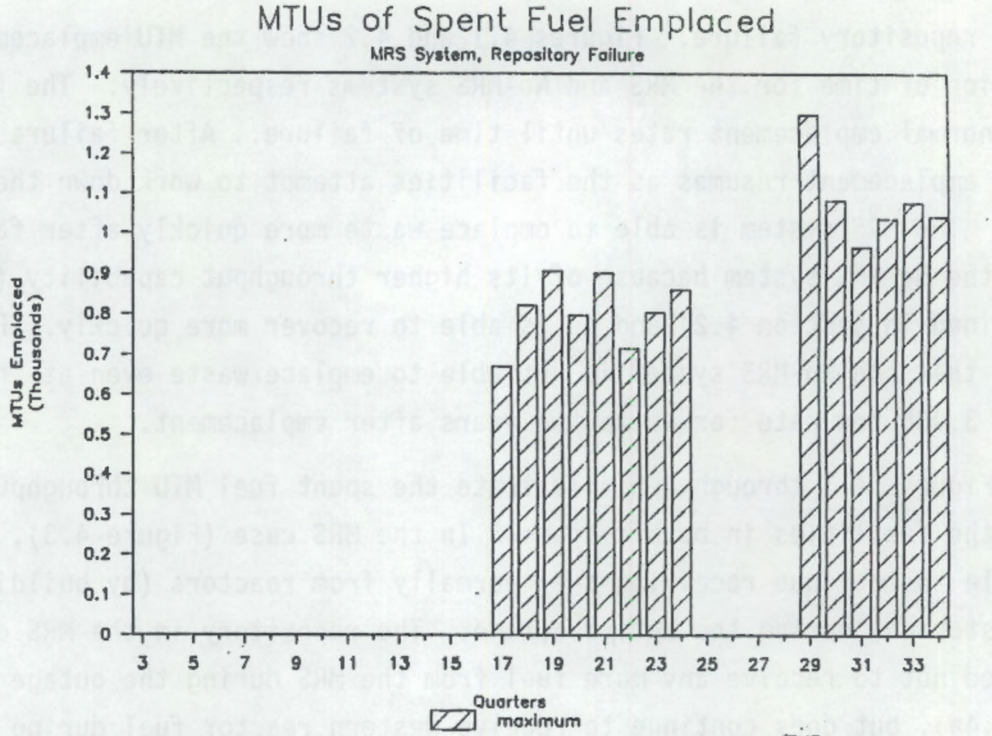

FIGURE 4.1. Waste Emplacement, MRS System, 1-Year Failure Case

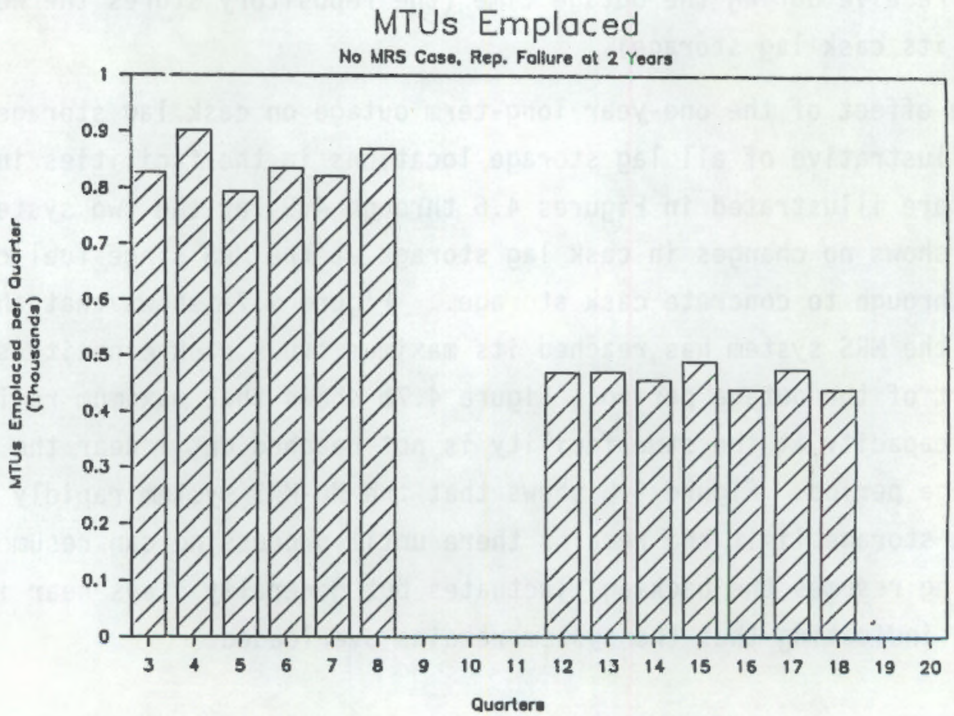

FIGURE 4.2. Waste Emplacement, No-MRS System, 1-Year Failure Case

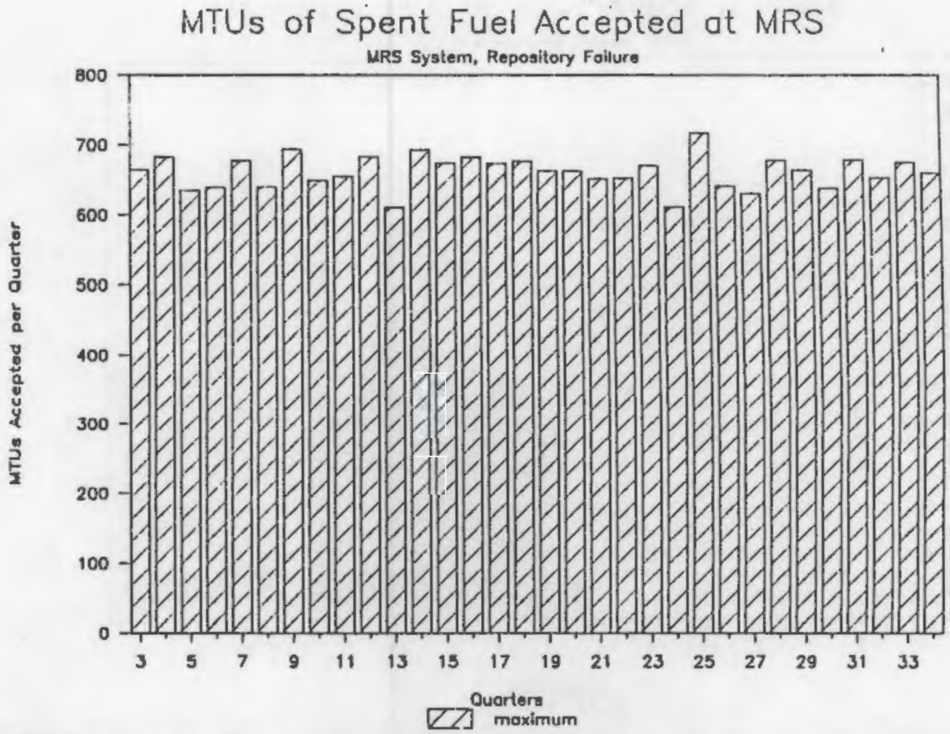

FIGURE 4.3. MRS Facility Acceptance from Reactors, 1-Year Failure Case

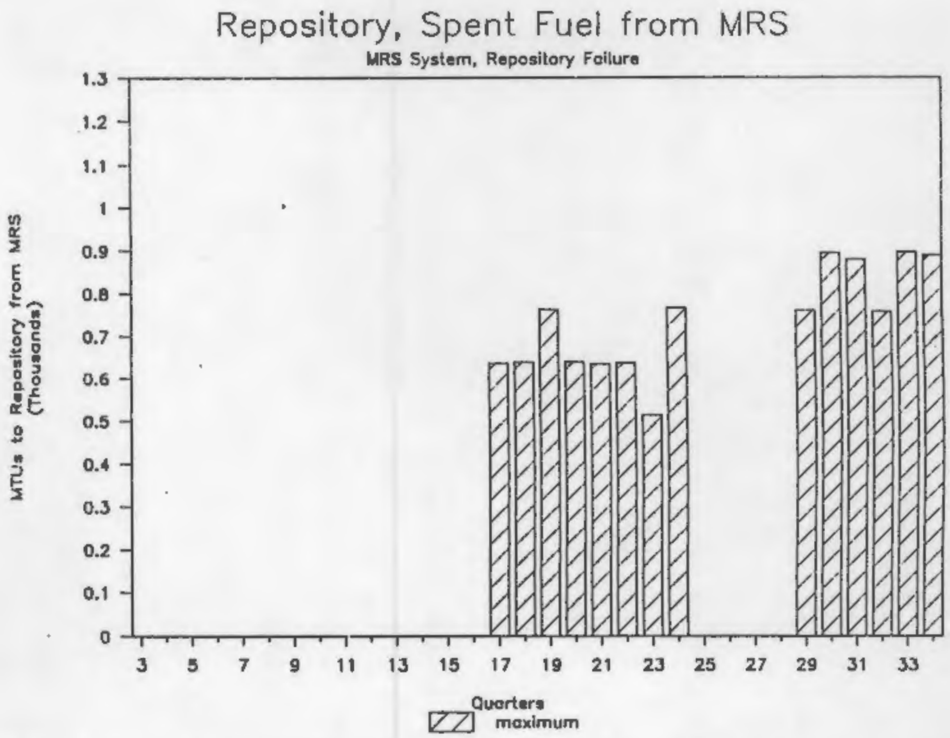

FIGURE 4.4a. Repository Fuel Acceptance from MRS, 1-Year Failure Case

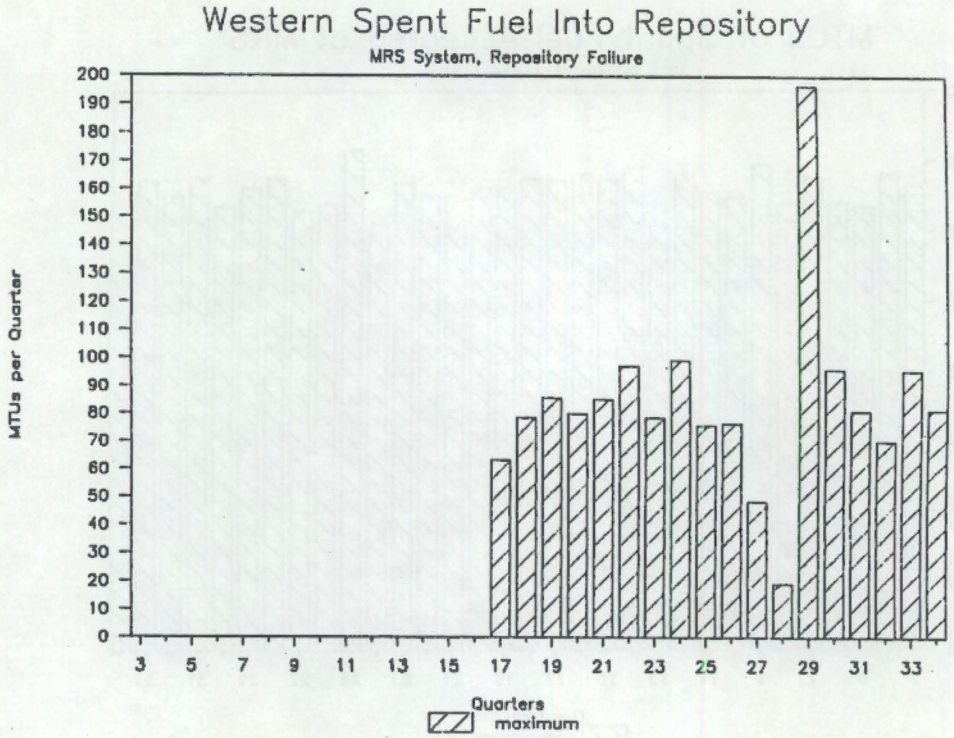

FIGURE 4.4b. Repository Fuel Acceptance from Western Reactors MRS System, 1-Year Failure Case

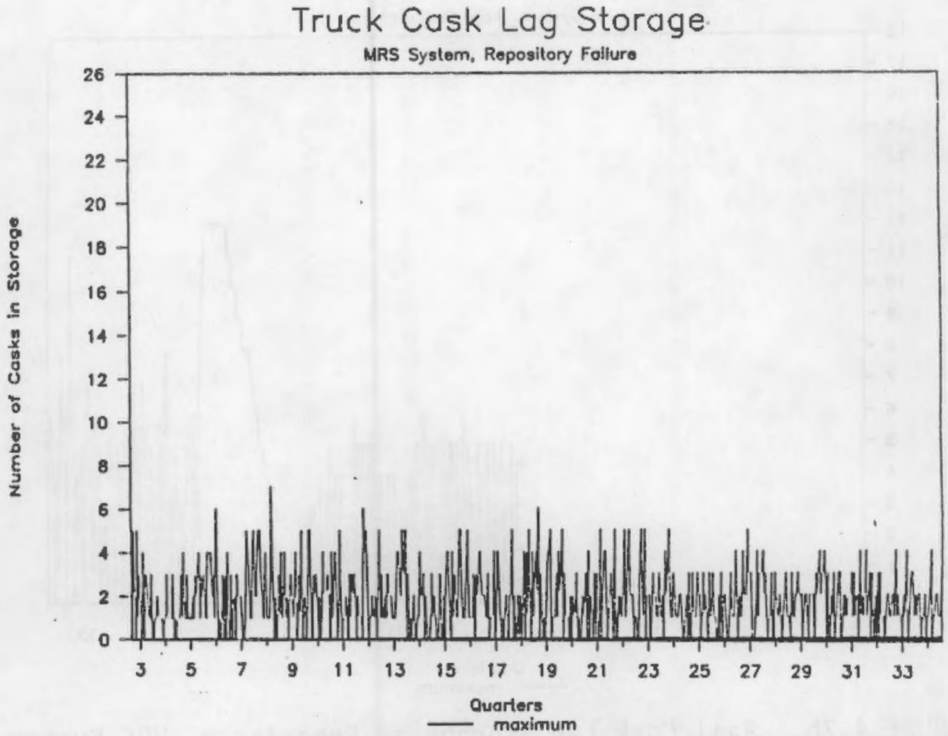

FIGURE 4.6. Truck Cask Lag Storage at MRS, 1-Year Failure Case

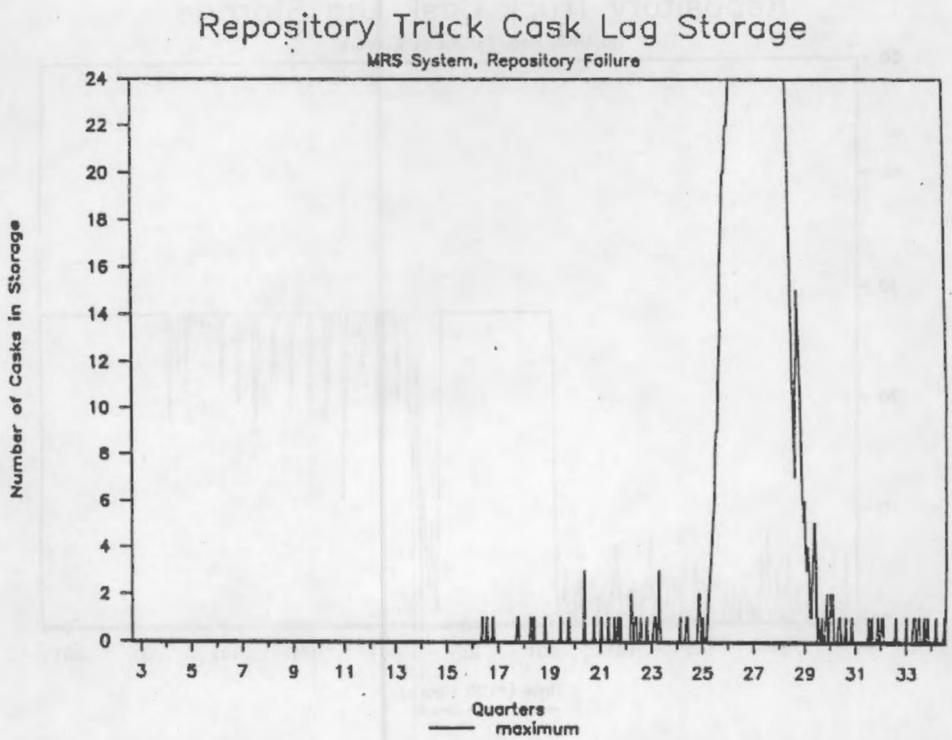

FIGURE 4.7a. Truck Cask Lag Storage at Repository, MRS System, 1-Year Failure Case

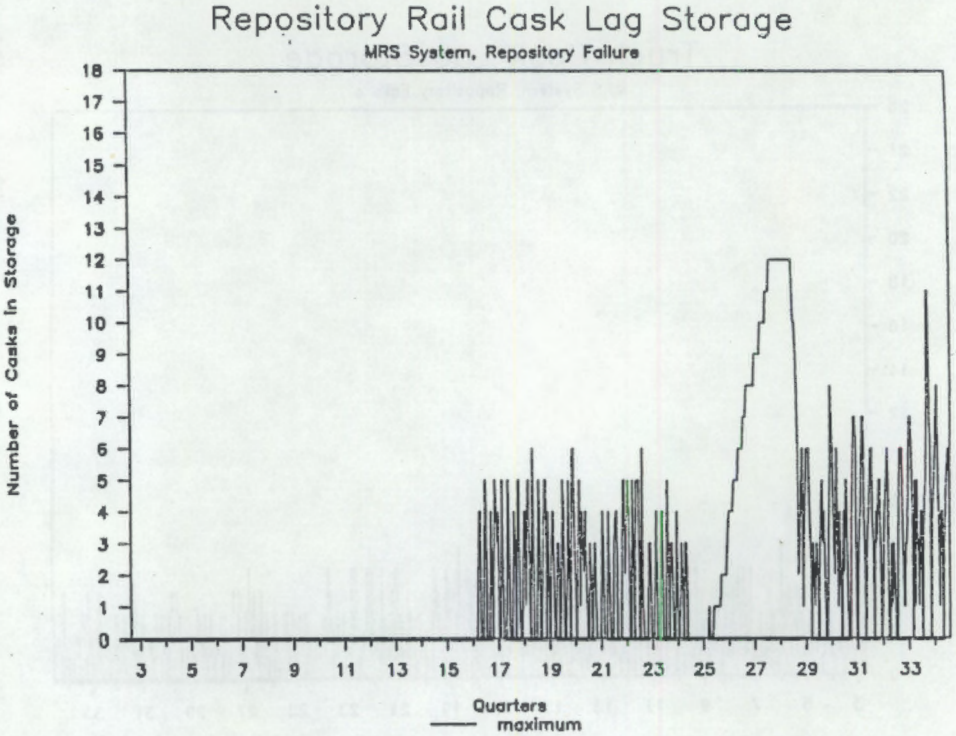

FIGURE 4.7b. Rail Cask Lag Storage at Repository, MRS System, 1-Year Failure Case

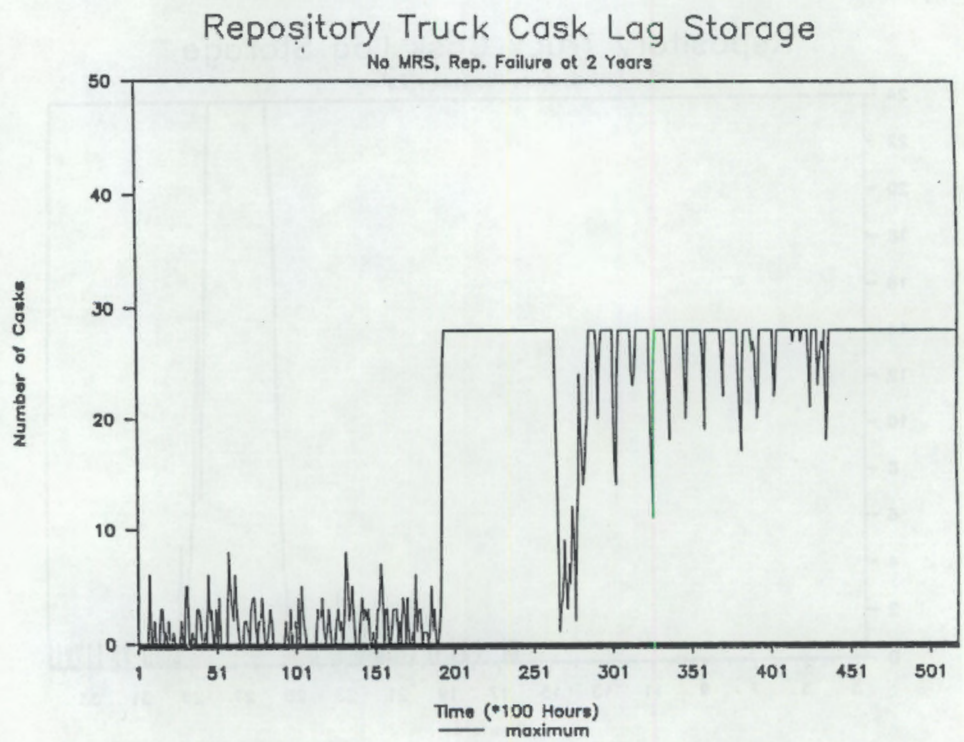

FIGURE 4.8. Truck Cask Lag Storage at Repository, No-MRS System 1-Year Failure Case

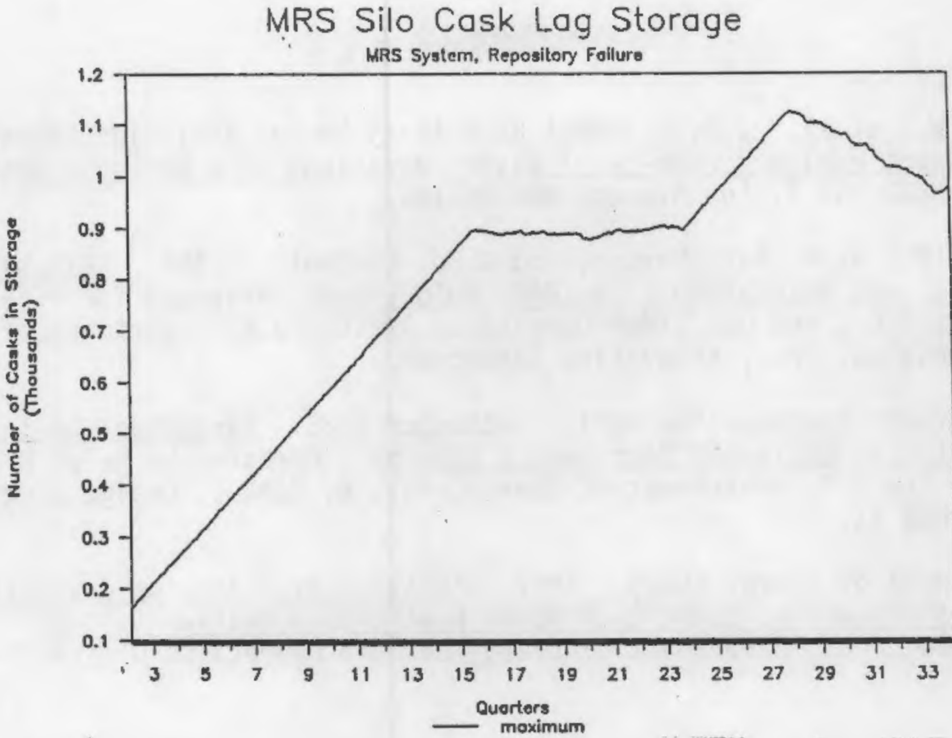

FIGURE 4.9. MRS Cask Lag Storage, 1-Year Failure Case

Figure 4.9 illustrates the effect on the MRS cask storage on the long-term outage and recovery. Initially the cask inventory rises until the repository begins accepting fuel. The storage requirements then level off until the time of emplacement failure. At time of failure the concrete cask storage inventory again rises gradually until the outage is over. After the repository begins receiving fuel again (at a 4000 MTU/yr rate), the concrete cask storage is gradually reduced.

The preceding analysis illustrates the significantly greater ability of the MRS system to handle long-term outages of approximately 1 year at the repository because of its greater storage and throughput capacities. Longer outages could also be handled, depending on legislative restrictions and on the amount of fuel in the MRS cask storage at the time of failure. These results indicate a significantly greater reliability in the MRS system than in the No-MRS system for contingency situations.

REFERENCES

Dennis, A. W., et al. 1984. "NNWSI Repository Worker Radiation Exposure." Volume 1, Spent Fuel and High-Level Waste Operations in a Geologic Repository in Tuff, SAND83-743/1, Los Alamos, New Mexico.

Guthrie, V. H., J. A. Farquharson, and D. J. Campbell. 1988. Reliability, Availability, and Maintainability (RAM) Guidelines. Prepared for PEER Consultants, P.C., and Oak Ridge Operations Office, U.S. Department of Energy by JBF Associates, Inc., Knoxville, Tennessee.

Ralph M. Parsons Company (Parsons). September 1985. Conceptual Design Report - Integral Monitored Retrievable Storage. Prepared by Ralph M. Parsons for the U.S. Department of Energy, Vol. 6, Book 1, Design Study 2, Report No. MRS 11.

U.S. Department of Energy (DOE). 1987. Analysis of Radiation Doses from Operation of Postulated Commercial Spent Fuel Transportation Systems. DOE-CH/TPO-001, U.S. Department of Energy Chicago Operations Office, Argonne, Illinois.

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