Cost

A representative comparison of the undiscounted costs associated with transport of spent fuel by either general-freight service or dedicated service (5 to 10 cars per train) is shown in Figure B.5. The results are divided into four major cost categories: shipping, security, capital and maintenance. Each of these components is discussed below.

Shipping costs are the costs associated with the actual weight of commodity transported over a given distance. The comparison between modes of service show the shipping cost for dedicated service is approximately 1.25 times the cost associated with transport by general freight service. The difference in shipping costs is primarily due to the single-use nature of the dedicated train. The dedicated train would be assessed this rate penalty due to the exclusion of other commodities. The exclusion of other commodities from the dedicated service does allow for an overall increase in average transport speed due to a large reduction in time spent in switching or classification yards.

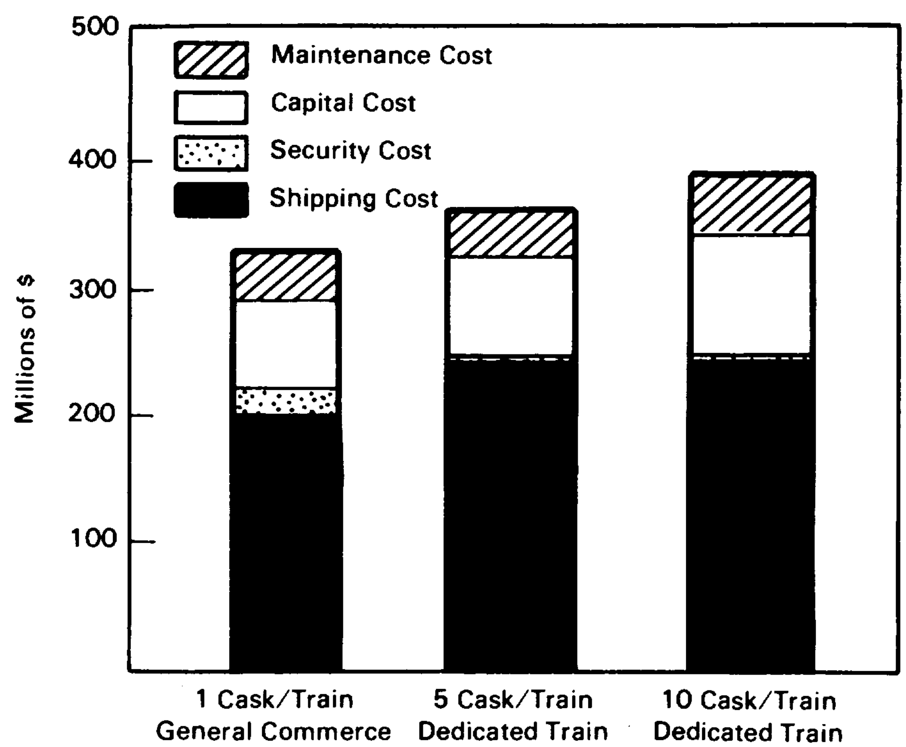


FIGURE B.5. Rail Transport Costs Between an MRS at Clinch River and a Repository at Yucca Mountain, as a Function of Transport Mode and Train Size

Security costs are the costs associated with providing security personnel to maintain visual surveillance of the spent fuel during its transport from the MRS facility to the repository. The security is assumed to be provided by the addition of a railroad caboose with two security guards to travel with each shipment. The cost of security provisions for general-freight service are five to ten times the cost for dedicated service. This cost differential is a direct function of the number of cask-cars of spent fuel on the train. General-freight service (one cask-car per train) will require an escort car for each shipment of spent fuel while dedicated service (five to ten cask-cars per train) allows a single escort car to maintain surveillance over the five to ten cask-cars transported.

Capital and maintenance costs are the costs associated with the purchase and upkeep of a fleet of rail casks to transport the spent fuel between facilities. The primary factors that control the number of rail casks required to transport a given quantity of fuel are the cask capacities and the total round-trip transit time.

The total round-trip transit speed is made up of two components: the transit time and the loading/unloading turn-around times at each facility. The overall transit speed for general-freight service for this comparison was assumed to be approximately 200 miles per day. The transit speed assumed for dedicated train service was 1.5 times the transit speed for general-freight service. The turnaround time for loading/unloading a single cask at each facility was assumed to be 1.5 days at each facility for general-freight service and between 4.5 and 7.5 days for each train load of 5 to 10 casks for dedicated service.

The total capital and maintenance costs associated with each mode of service are compared in Figure B.5. The comparison shows the impact of increasing the dedicated train length from 5 to 10 casks. The capital and maintenance costs associated with dedicated trains carrying five to ten cask-cars of spent fuel and traveling at a speed of 1.5 times that of general-freight service are roughly equivalent with the costs associated with general-freight service.

<u>Risk</u>

A comparison of the risks associated with the transport of spent fuel between facilities by either general-freight service or dedicated train service has been estimated for both radiological and nonradiological risk. These results are shown in Table B.4 and are discussed below.

The radiological risks associated with the transport of spent fuel contain components for both routine transport (direct external radiation emitted as the shipment passes by) and accident conditions. The largest portion of risks associated with spent-fuel transport would be from routine transport. The

TABLE B.4. Comparison of Radiological Exposure and Nonradiological Risk for Alternative Shipment Modes Between an MRS Facility and a Repository[(a,b)]

Shipment Mode from MRS Facility to Repository	Radiological Exposure (person-rem)[(c)]	Nonradiological Risk (fatalities)[(c)]
General Commerce/ 1 Cask per Train	346	0.6
Dedicated Train/ 5 Casks per Train	106	8.6
Dedicated Train/ 10 Casks per Train	106	4.3

(a) Repository location is assumed to be Yucca Mountain.
(b) Shipments are for spent fuel in 150-ton casks.
(c) See Section F.4 for more details on the calculation.

largest portion of routine transport risk, associated with the movement of spent fuel, occurs during periods when the spent fuel is stopped at various classification and switching yards. The use of dedicated train service, with an associated reduction in the amount of stop time during transit, will reduce the overall radiological risk for movement of spent fuel between facilities.

The nonradiological risks associated with the movement of spent fuel between facilities are primarily associated with traumatic deaths that occur from rail accidents and are not associated with the radioactive nature of the cargo. Nonradiological risks are based on nationally averaged traffic statistics and are compiled on an accident-per-kilometer-traveled basis. The largest portion of nonradiological risk is attributable to accidents occurring at rail crossings. These types of accidents are related to the total number of train miles traveled and not directly to the number of individual rail-car miles. The methodology for this study has assigned the overall nonradiological risk for individual rail cars as a percent of total commodity cars being carried. Therefore, the nonradiological risks of an individual spent-fuel cask traveling on a 70-car general freight train will have a nonradiological risk equivalent to 1/70 of the total nonradiological risk associated with the train. Utilizing this same methodology for dedicated (sole-commodity) trains results in the spent-fuel casks being assigned the total nonradiological risks for the train. If the dedicated train is carrying five spent-fuel casks, each spent-fuel cask is assigned 1/5 of the total nonradiological risk associated with the train. The methodology also conservatively assumed that the overall accident rates for a dedicated train would be equivalent to the accident rate for a train in general commerce service. This assumption was made due to a lack of data base information to support actual dedicated train operations. In actual practice the severe accident rates should be reduced by the use of dedicated trains. Because of the importance given to it, extra precautions will be taken to forestall exposure to incidents involving other trains sharing the route. The smaller train size would greatly reduce emergency stopping distances in relation to grade-crossing encounters, track defects or obstructions. The absence of many other cars in the train would reduce the probability of accident due to train-handling errors and slack action and mechanical failure of any one individual car. The dedicated train would also eliminate the severity hazards that result from the contents of other loaded cars.

B.3.4 Conclusions

The comparison between various modes of rail service show the overall cost of transporting spent fuel by dedicated train service to be roughly equivalent with the costs for general-freight service. The use of dedicated service would allow for an overall transit speed gain and the possibility of reduced numbers of shipments. Both of these factors would tend to reduce radiological exposure and risks associated with the transport of spent fuel. The nonradiological risks associated with the movement of these materials have been conservatively estimated. It is anticipated that after accounting for operational characteristics of dedicated train service the overall nonradiological risk of using dedicated train service would be low compared to the overall risks of already-existing general commerce service.

The final configuration and operational bases for transporting materials between facilities will be coordinated with input from industry, states, Indian tribes and members of the general public. The overall objective for configuring this portion of the transportation system will continue to be the transport of these materials in a safe and efficient manner.

B.4 REFERENCES

U.S. Department of Energy (DOE). 1985a. Mission Plan for the Civilian Radioactive Waste Management Program. Vol. 1., DOE/RW-0005, DOE Office of Civilian Radioactive Waste Management, Washington, D.C.

U.S. Department of Energy (DOE). 1985b. Spent Fuel Storage Requirements. DOE/RL-85-2, DOE Richland Operations Office, Richland, Washington.

U.S. Department of Energy (DOE). 1986. Report of the Task Force on the MRS/Repository Interface. DOE/RW-0044, DOE Office of Civilian Radioactive Waste Management, Washington, D.C.

APPENDIX C

SUPPLEMENTAL COST INFORMATION AND ANALYSES FOR MRS AND REPOSITORY FACILITIES

APPENDIX C

SUPPLEMENTAL COST INFORMATION AND ANALYSES FOR MRS AND REPOSITORY FACILITIES

C.1 INTRODUCTION

This appendix presents supplemental data concerning cost information and analyses discussed in Part 1 of this volume. The system cost data used have been derived from three sources: (a) MRS conceptual and advanced conceptual designs and cost estimates; (b) repository conceptual designs and cost data consolidated by the MRS/Repository Interface Task Force (DOE 1986); and (c) MRS transportation cost analyses (Appendix F). These are discussed briefly below.

C.1.1 MRS Conceptual and Advanced Conceptual Designs

Conceptual and advanced conceptual design of MRS facilities were developed for the DOE by the Ralph M. Parsons Company. These designs cover six site/design combinations (two storage designs and three sites); the documents describing those designs support the DOE proposal to Congress for MRS facility construction and operation.

C.1.2 MRS/Repository Interface Task Force

In April, 1985, the MRS/Repository Interface Task Force (DOE 1986) was established to determine the facility, design, licensing, cost and schedule impacts of an integrated waste management system. This task force produced cost data for each of the three repository media now being considered by the DOE for the first geologic repository. These data have been used in this appendix to represent the most internally-consistent and up to date estimates of repository costs.

The data supplied to the task force by R. M. Parsons for the MRS facility are consistent with the cost estimates for an integral MRS facility as outlined above. The final task force estimate for an MRS facility differs from the Parson's estimate due to differences in some cost factors (labor rates, contingencies, etc.) and differences in design and operating assumptions between scenarios.

C.1.3 Transportation Cost Analyses

Transportation costs were estimated for shipping 62,000 MTU of spent fuel to the first repository. Appendix F contains a detailed discussion of the spent-fuel logistics, cask capacities, and shipping cost assumptions for these estimates.

C.1.4 Appendix Contents

The following sections of this appendix present cost information and analyses. Section C.2 presents descriptions of the MRS facility and repository conceptual designs on which all cost information is based. Additionally, that section describes the waste management scenarios that were considered. Section C.3 presents cost information about the MRS facility, the repositories, and the waste management system scenarios. Also, in Section C.3, the cost differences between waste management systems with and without the MRS facility are given.

C.2 COST BASES: SYSTEM CONFIGURATIONS AND ASSUMPTIONS

This section describes the MRS and repository systems that serve as the basis for the cost estimates. Additionally, the waste logistics scenarios which have been considered are described.

C.2.1 MRS Facility Description

The MRS facility has been designed to include all facilities and equipment required to receive, unload, consolidate, canister, and ship to a geologic repository, receive and temporarily store onsite, or retrieve from storage and ship commercial spent fuel and high-level waste (HLW). The NWPA states that the MRS facility should be capable of handling commercial spent fuel and HLW. At this time, the DOE expects to receive only spent fuel at the MRS facility. The MRS facility has also been designed to store and ship the hardware resulting from operation of the facility. The facility has been designed to provide for lag storage of canistered spent fuel as well as for the monitoring, maintenance and management of the spent fuel and wastes stored onsite.

The MRS facility has been designed to meet the following requirements. It has the capability to receive for shipment offsite, or storage onsite, 3600 metric tons of uranium (MTU) per year primarily as spent fuel along with a small amount of HLW. Current estimates place the annual throughput at 2500-3000 MTU/year. It has an in-building lag storage capacity for 1000 MTU of spent fuel in canisters, plus an outdoor storage capacity for 15,000 MTU of spent fuel. The design is based upon a spent fuel mix of 60% PWR fuel and 40%

BWR fuel by weight of uranium, based upon 0.462 MTU per PWR assembly and 0.186 MTU per BWR assembly. The facility has been designed also for concurrent retrieval and shipment of at least 3600 MTU or equivalent per year of canistered spent fuel and waste. The facility design has included space for equipment needed to place spent fuel canisters into a repository-specific disposal container.

Site-specific conceptual designs have been developed for the Clinch River site, with primary emphasis on the storage of wastes in sealed storage casks. All facilities lie within two basic areas: 1) the limited access area; and 2) the protected area.

The limited access area contains support facilities which do not contain any radioactive material. Facilities in this area include the usual support facilities for a plant of this type, plus a facility for manufacturing storage casks which, while not part of the MRS facility per se, is co-located for convenience. The limited access area is protected by normal industrial security provisions. The limited access area covers just under 60 acres.

The protected area contains the receiving and handling building, storage areas, transportation cask parking areas, and security facilities. The protected area occupies approximately 110 acres.

The receiving and handling (R&H) building contains all facilities for receiving and handling spent fuel and wastes. The majority of the R&H building is a Category I structure, able to withstand the site design basis earthquake of 0.25 g acceleration at bedrock without loss of any safety functions. The structure is approximately 650 feet by 530 feet in plan dimensions, and is approximately 115 feet high. The R&H building contains four hot cells for the receipt, handling, consolidation and packaging of fuel and wastes. It contains a dry-storage vault for the in-process storage of up to 1000 MTU of canistered spent fuel.

The storage area uses either sealed storage casks or dry wells for waste storage, plus provisions for storage of a limited quantity of spent fuel in transportable metal casks. The storage area includes a 100-foot buffer zone between the inner and outer fences in compliance with design requirements. The minimum distance from any stored radioactive material and any point outside of the fence is approximately 400 feet. The primary storage technology is the sealed storage cask. The storage area, for the sealed storage cask concept and for the storage of up to 15,000 MTU of spent fuel occupies about 85 acres.

C.2.2 Repository Descriptions

Repository design efforts previously completed have considered a number of alternate functional requirements and media. In order to compare waste management system costs on a consistent basis, data from the MRS/Repository Interface Task Force (DOE 1986) are used throughout this analysis. While the previously described MRS facility has a well-defined set of functional requirements, the task force considered a number of alternate repository functions, relating to the waste management system scenarios that were evaluated.

In the absence of an MRS facility in the waste management system, the principal functions to be performed in the surface facilities at the repository include those involved in receiving the fuel, disassembly and consolidation, enclosure of the consolidated fuel in canisters (if required at the specific site), and placing the fuel in disposal containers. Following inspection, the containers are transferred underground for emplacement.

Design efforts for repositories in the three different disposal media (basalt, salt, tuff) have resulted in different surface facility designs. Differences in these designs are due to media-specific differences such as ventilation and mined material handling. These designs include receipt and handling capabilities for commercial spent fuel as well as defense HLW (DHLW). All handling functions previously described for the MRS facility would also be performed in these facilities.

Scenarios that include both the MRS facility and the repository have simplified handling capabilities at the repository to reduce system redundancies. Functions that may be removed from the repository may include some or all spent-fuel consolidation capacity, and some or all capacity for applying the final disposal container. Repository surface facility designs have been developed by the task force that correspond to these deletions. Details of each design are not presented here, and may be found in the task force report (DOE 1986).

C.2.3 System Scenarios and Configurations

Five primary waste management scenarios have been considered by the MRS/Repository Interface Task Force, and are presented here. Table C.1 lists the functional tradeoffs between scenarios. Figure C.1 schematically depicts each of these scenarios.

TABLE C.1. Summary of Scenarios for Waste Management System Evaluations

	Task Force Scenarios				
	No-MRS System	Systems With MRS			
	1	5	4	3	2
First Repository					
Receive:	All fuel DHLW	Western fuel DHLW MRS canisters	DHLW MRS canisters	DHLW MRS packages	MRS packages
Functions:	Consolidate, canister, & package all fuel, DHLW	Consolidate & canister Western fuel Package all fuel, DHLW	Package all fuel, DHLW	Package DHLW	None
MRS					
Receive:	None (no-MRS)	Eastern fuel	All fuel	All fuel	All fuel DHLW
Functions:	None	Consolidate & canister Eastern fuel	Consolidate & canister all fuel	Consolidate, canister & package all fuel	Consolidate, canister, & package all fuel Package DHLW

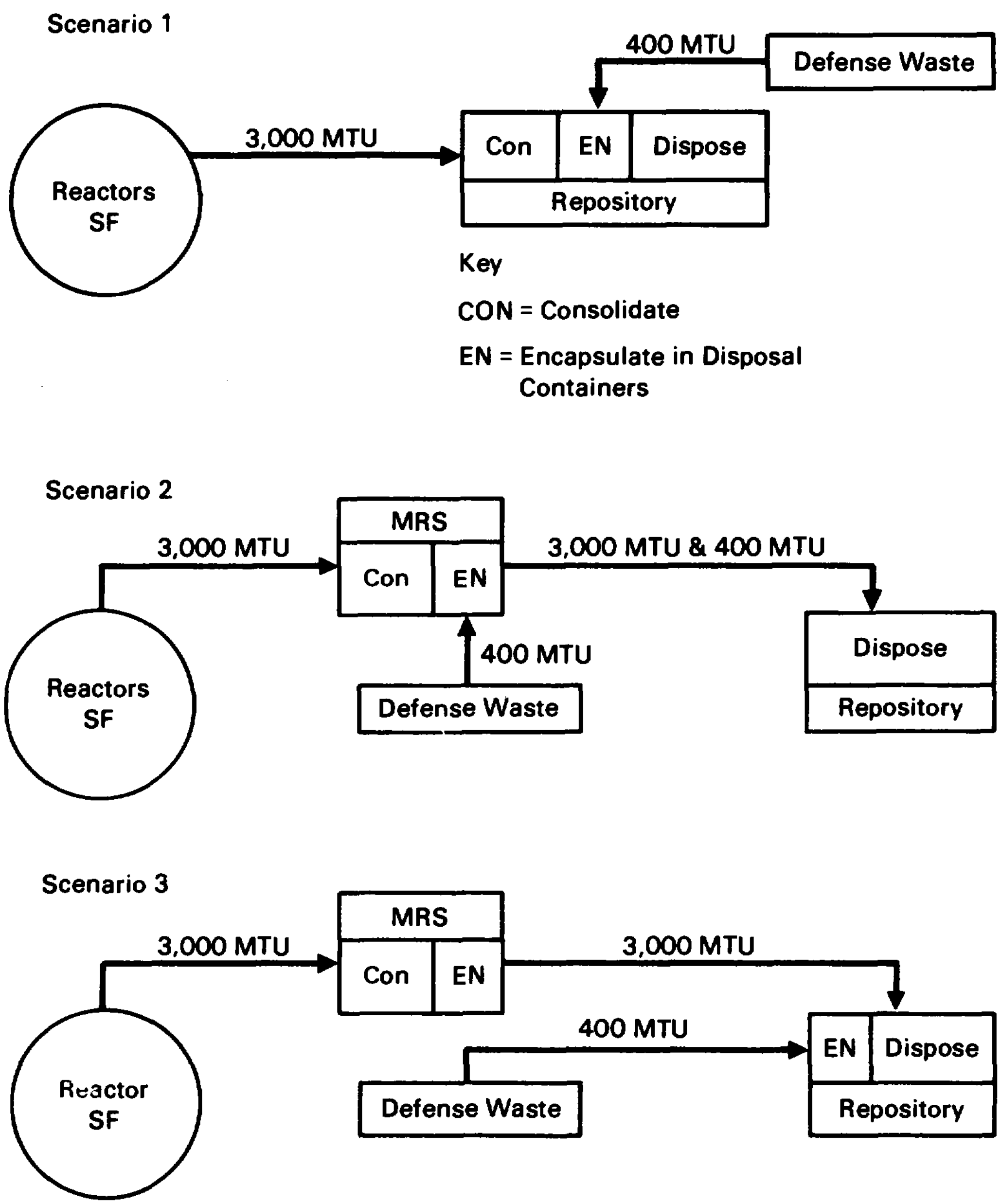
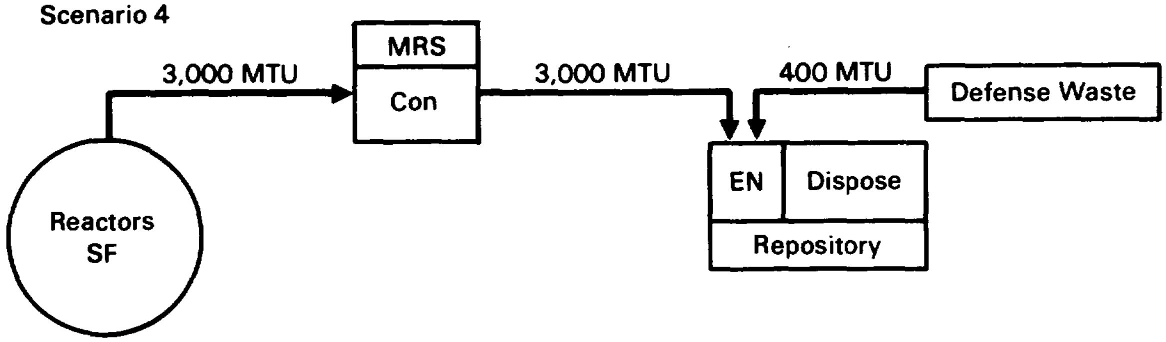


FIGURE C.1. Scenario Descriptions

Scenario 4



Scenario 5

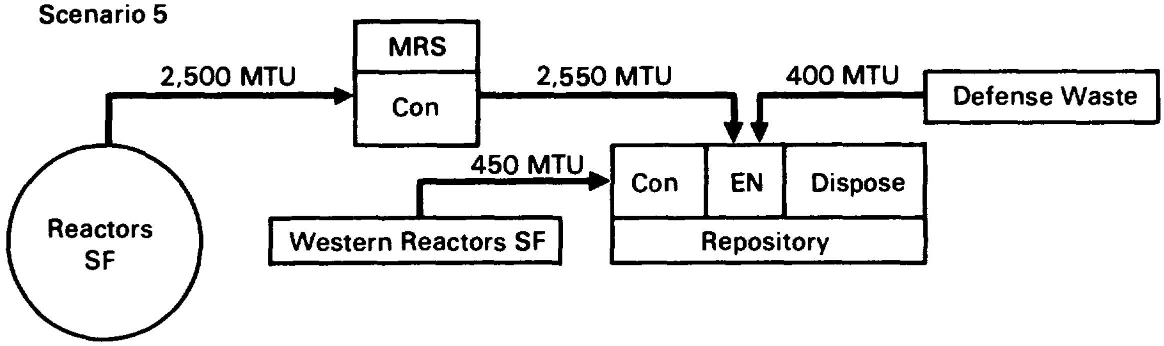


FIGURE C.1. (contd)

Scenario 1

Scenario 1 involves only a repository in the waste management system, with no MRS facility. Spent fuel and DHLW are received for disposal at the repository at the schedule presented in Table C.2. This scenario represents the "no-MRS system" described in this report.

Scenario 2

Scenario 2 is not a factor for the cost comparisons for this report, but was developed to address other issues considered by the task force. Scenario 2 is identical to Scenario 3 (see next section) except that DHLW is routed to the MRS facility where it is placed in disposal containers and then shipped to the repository. The acceptance of DHLW at the MRS facility does not affect the commercial spent-fuel MRS acceptance rates presented in Table C.3. In this case, the repository is designed to accept already-packaged spent fuel and DHLW for emplacement. Of the five scenarios considered, this case represents the one where the minimum system functions are performed at the repository and the maximum system functions are performed at the MRS facility.

TABLE C.2. Schedule for Annual Receipt of Spent Fuel and DHLW at Repository for Scenario 1

Year	Spent Fuel (MTU)	DHLW (MTU-Equiv.)	Total (MTU-Equiv.)
1998	400	0	400
1999	400	0	400
2000	400	0	400
2001	900	0	900
2002	1,800	0	1,800
2003 thru 2021	3,000	400	3,400
2022	1,100	400	1,500
Total	62,000	8,000	70,000

TABLE C.3. Schedule for Annual Receipt of Spent Fuel at the MRS Facility for Scenario 3

Year	Spent Fuel (MTU)
1996	400
1997	1,800
1998 thru 2016	3,000
2017	2,800
Total	62,000

Scenario 3

In Scenario 3, all spent fuel to be emplaced in the repository (62,000 MTU) is first transported to the MRS facility. The MRS spent-fuel acceptance rate is shown in Table C.3. Spent fuel received at the MRS will be consolidated and placed into disposal containers. The disposal containers will then be shipped to the repository for disposal.

The container designs and the transportation cask designs for the shipments from the MRS facility to the repository vary with repository medium. Spent fuel will be shipped from the MRS facility at the repository acceptance rates presented in Table C.2. DHLW will be shipped directly to the repository where it will be placed in disposal containers. Consequently, in this scenario, the repository will not have the capability to consolidate spent fuel into disposal containers but will have the capability to place DHLW into disposal containers.

Scenario 4

In Scenario 4, all spent fuel is shipped to the MRS facility for consolidation and placement into canisters, and the fuel is shipped to the repository where it is placed into disposal containers. MRS receipt and discharge rates are the same as in Scenario 3. DHLW is shipped directly to the repository where it is placed in disposal containers.

Scenario 5

This scenario represents the "MRS system" described in this report. In Scenario 5, commercial spent fuel originating from reactors located west of 100 degrees latitude is shipped directly to the first repository while all other spent fuel is first shipped to the MRS facility where it is consolidated and put into canisters for shipment to the repository. The repository provides consolidation and packaging facilities for the western fuel, plus the overpacking function for the spent fuel shipped from the MRS facility and the DHLW. The MRS facility assumes the same functions as in Scenario 4 but on a smaller scale. Assuming that western fuel will be shipped at an annual rate as shown in Table F.1, results in the repository emplacing over its lifetime 9,000 MTU of western fuel and 53,000 MTU of spent fuel from the MRS facility. The MRS facility commercial spent-fuel acceptance rate in Scenario 5 is presented in Table C.4.

The nominal MRS discharge rate is designed to be 2550 MTU (the nominal repository acceptance rate minus the annual western fuel receipt rate) per year in Scenario 5.

TABLE C.4. Schedule for Annual Receipt of Spent Fuel at the MRS Facility for Scenario 5

Year	Spent Fuel (MTU)
1996	400
1997	800
1998 thru 2017	2,500
2018	800
Total	53,000

C.3 SYSTEM COST SUMMARY AND COMPARISON

This section presents facility and life-cycle costs for each facility scenario discussed in Section C.2. These costs are combined with transportation cost estimates to compare the total costs for the alternative systems. Potential differences in development and evaluation (D&E) costs were not assessed for the alternative scenarios.

C.3.1 MRS Cost Summary

The construction, operating and decommissioning costs of operating the MRS facility (for the primary sealed storage cask concept at the preferred Clinch River site) have been calculated for the four applicable waste management scenarios presented above (Scenario 1 does not involve an MRS facility). These costs are presented below in Tables C.5 through C.8, as functions of disposal medium, (since MRS facility costs are affected by selection of disposal medium when disposal containers are installed at the MRS facility).

C.3.2 Repository Cost Summary

Repository construction and operating costs have been developed by the MRS/Repository Interface Task Force for each of the waste management scenarios discussed in Section C.2. The costs developed by the Task Force are briefly summarized in Table C.9. It should be noted that these costs focus on those associated with activities relating to the surface facilities. The costs of developing the underground workings of the repository are excluded. Similarly, repository caretaker, backfill and underground (including shafts) operation costs are not considered. These costs should be largely unaffected by the variations in surface facility operations.

C.3.3 Cost Comparison: MRS versus No-MRS

In the previous two sections, the construction and operating costs of the MRS facility and the surface facilities of the repositories have been presented for each of the five waste management scenarios presented in Section C.2. In this section, these capital and operating costs are combined with transportation system costs for each of the scenarios.

Figure C.2 illustrates the transportation costs for a single repository system. The transportation system costs are estimates for shipping 62,000 MTU of spent fuel from individual reactor sites, via an MRS facility as appropriate for the scenario, to the first repository for disposal. The cask capacities used for the spent fuel shipped from the reactors to the MRS facility or repository are 2 PWR or 5 BWR assemblies per truck cask and 14 PWR or 36 BWR assemblies per rail cask. Reactors that identified capabilities to ship spent

TABLE C.5. MRS Facility Costs for Scenario 2 (billions of mid-1985 dollars)

Cost Center	Construction and Engineering	Operations and Decommissioning[a]	Total
	Basalt Package		
Waste Handling, Site, Support and Utilities	0.7	1.7	2.4
Waste Storage for 15,000 MTU	0.5	0.0[b]	0.5
Waste Packages	0	1.2	1.2
TOTAL	1.2	2.9	4.1
	Salt Package		
Waste Handling, Site, Support and Utilities	0.7	1.7	2.4
Waste Storage for 15,000 MTU	0.5	0.0[b]	0.5
Waste Packages	0	1.1	1.1
TOTAL	1.2	2.8	4.0
	Tuff Package		
Waste Handling, Site, Support and Utilities	0.7	1.7	2.4
Waste Storage for 15,000 MTU	0.5	0.0[b]	0.5
Waste Packages	0	1.6	0.6
TOTAL	1.2	2.3	3.5

(a) Decommissioning is less than $0.05 billion.
(b) Cost is less than $0.05 billion.

TABLE C.6. MRS Facility Costs for Scenario 3 (billions of mid-1985 dollars)

Cost Center	Construction and Engineering	Operations and Decommissioning[a]	Total
	Basalt Package		
Waste Handling, Site, Support and Utilities	0.7	1.7	2.4
Waste Storage for 15,000 MTU	0.5	0.0[b]	0.5
Waste Packages	0	0.9	0.9
TOTAL	1.2	2.6	3.8
	Salt Package		
Waste Handling, Site, Support and Utilities	0.7	1.7	2.4
Waste Storage for 15,000 MTU	0.5	0.0[b]	0.5
Waste Packages	0	0.8	0.8
TOTAL	1.2	2.5	3.7
	Tuff Package		
Waste Handling, Site, Support and Utilities	0.7	1.7	2.4
Waste Storage for 15,000 MTU	0.5	0.0[b]	0.5
Waste Packages	0	0.5	0.5
TOTAL	1.2	2.2	3.4

(a) Decommissioning is less than $0.05 billion.
(b) Cost is less than $0.05 billion.

TABLE C.7. MRS Facility Costs for Scenario 4 (billions of mid-1985 dollars)

Cost Center	Construction and Engineering	Operations and Decommissioning[a]	Total
	Basalt Package		
Waste Handling, Site, Support and Utilities	0.7	1.7	2.4
Waste Storage for 15,000 MTU	0.5	0.0[b]	0.5
Waste Packages	0	0.0[b]	0
TOTAL	1.2	1.7	2.9
	Salt Package		
Waste Handling, Site, Support and Utilities	0.7	1.7	2.4
Waste Storage for 15,000 MTU	0.5	0.0[b]	0.5
Waste Packages	0	0.0[b]	0
TOTAL	1.2	1.7	2.9
	Tuff Package		
Waste Handling, Site, Support and Utilities	0.7	1.7	2.4
Waste Storage for 15,000 MTU	0.5	0.0[b]	0.5
Waste Packages	0	0.0[b]	0
TOTAL	1.2	1.7	2.9

(a) Decommissioning is less than $0.05 billion.
(b) Cost is less than $0.05 billion.

TABLE C.8. MRS Facility Costs for Scenario 5 (billions of mid-1985 dollars)

Cost Center	Construction and Engineering	Operations and Decommissioning[a]	Total
	Basalt Package		
Waste Handling, Site, Support and Utilities	0.6	1.7	2.3
Waste Storage for 12,000 MTU	0.4	0.0[b]	0.4
Waste Packages	0	0.0[b]	0
TOTAL	1.0	1.7	2.7
	Salt Package		
Waste Handling, Site, Support and Utilities	0.6	1.7	2.3
Waste Storage for 12,000 MTU	0.4	0.0[b]	0.4
Waste Packages	0	0.0[b]	0
TOTAL	1.0	1.7	2.7
	Tuff Package		
Waste Handling, Site, Support and Utilities	0.6	1.7	2.3
Waste Storage for 12,000 MTU	0.4	0.0[b]	0.4
Waste Packages	0	0.0[b]	0
TOTAL	1.0	1.7	2.7

(a) Decommissioning is less than $0.05 billion.
(b) Cost is less than $0.05 billion.

TABLE C.9. Surface Facilities Costs for Repositories (billions of mid-1985 dollars)

Waste Management Scenario	Construction and Engineering	Operations and Decommissioning[a]	Total
	Basalt Repository		
1	0.9	3.7	4.6
5	0.6	2.9	3.5
4	0.5	2.7	3.2
3	0.5	1.7	2.2
2	0.5	1.4	1.9
	Salt Repository		
1	1.2	3.1	4.3
5	0.7	2.6	3.3
4	0.7	2.3	3.0
3	0.7	1.4	2.1
2	0.7	1.0	1.7
	Tuff Repository		
1	0.8	2.7	3.5
5	0.5	2.3	2.8
4	0.5	2.0	2.5
3	0.4	1.6	2.0
2	0.5	1.4	1.9

(a) Decommissioning is less than $0.05 billion.

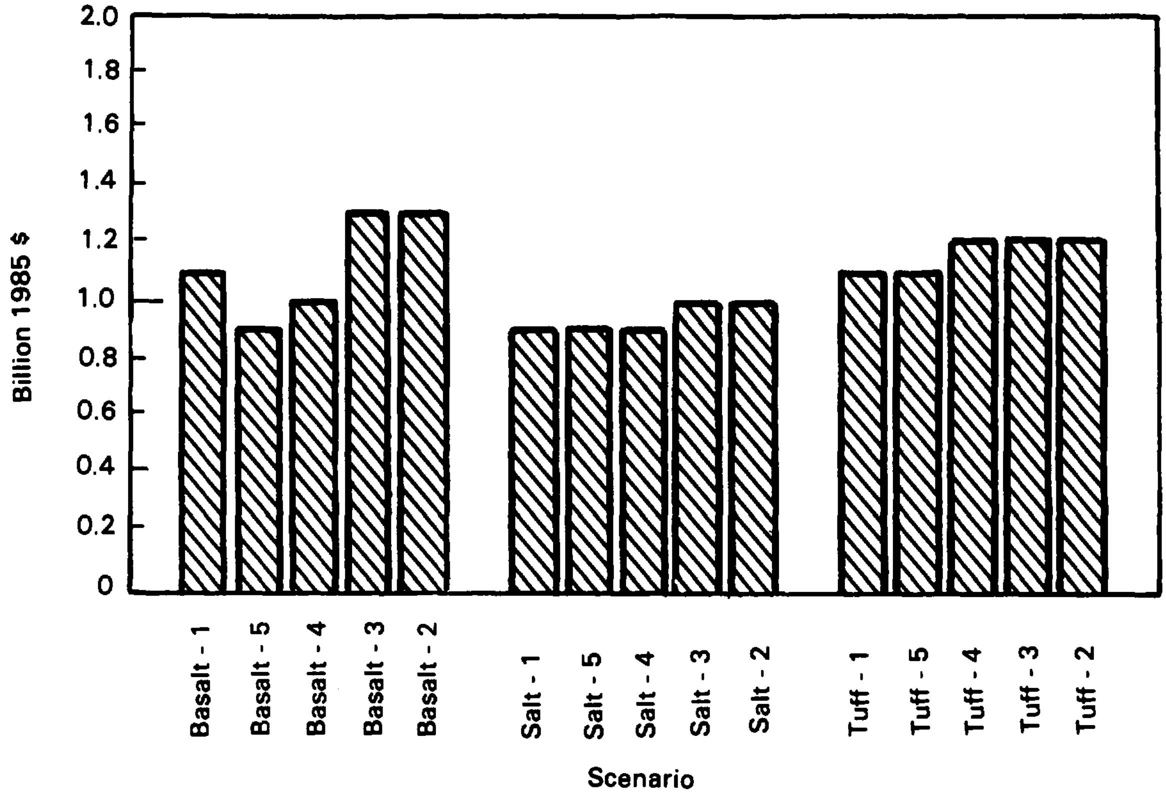


FIGURE C.2. Transportation Costs with One Repository (excluding DHLW) (See Table C.10)

fuel by rail are assumed to do so while the remaining reactors are assumed to ship by truck. The MRS facility to repository shipments are assumed to be shipped by dedicated train with 5 spent fuel cars and a maximum of 5 waste cars per train. Casks used for transporting spent fuel from the MRS facility to the repository are 150-ton with a capacity specific to the given repository media due to the different disposal containers.[a] Details for the transportation cost analysis are in Appendix F.

Table C.10 and Figure C.3 show the total construction and operating cost for each scenario. As previously noted, repository underground costs are not included and D&E costs were not estimated.

(a) Cost estimates produced by the MRS/Repository Interface Task Force (DOE 1986) assumed use of 100-ton casks between the MRS facility and the repository. Calculations reported here assumed 150-ton casks, now considered to be the most likely candidate for this service.

TABLE C.10. Total System Costs for Each Fuel Cycle Scenario (billions of mid-1985 dollars)

Scenario	System Costs For: Transportation[a]	MRS[b]	Repository Surface Facilities[c]	Total System Cost
Basalt Repository				
1	1.1	0	4.6	5.7
5	0.9	2.7	3.5	7.1
4	1.0	2.9	3.2	7.1
3	1.3	3.8	2.2	7.3
2	1.3	4.1	1.9	7.3
Salt Repository				
1	0.9	0	4.3	5.2
5	0.9	2.7	3.3	6.9
4	0.9	2.9	3.0	6.8
3	1.0	3.7	2.1	6.8
2	1.0	4.0	1.7	6.7
Tuff Repository				
1	1.1	0	3.5	4.6
5	1.1	2.7	2.8	6.6
4	1.2	2.9	2.5	6.6
3	1.2	3.4	2.0	6.6
2	1.2	3.5	1.9	6.6

(a) Transportation costs for Scenario 1 are from Table F.8 while costs for Scenarios 4 and 5 are from Table F.6. For Scenarios 2 and 3, MRS to repository transportation costs (Tables F.9 through F.11) have been adjusted in proportion to the relative cask capacities for shipping, disposal containers [basalt (40/81), salt (48/90), and tuff (42/70)] instead of thinner-walled canisters.
(b) All costs are from DOE (1986).
(c) Repository costs are for surface facility construction and operation only (DOE 1986).

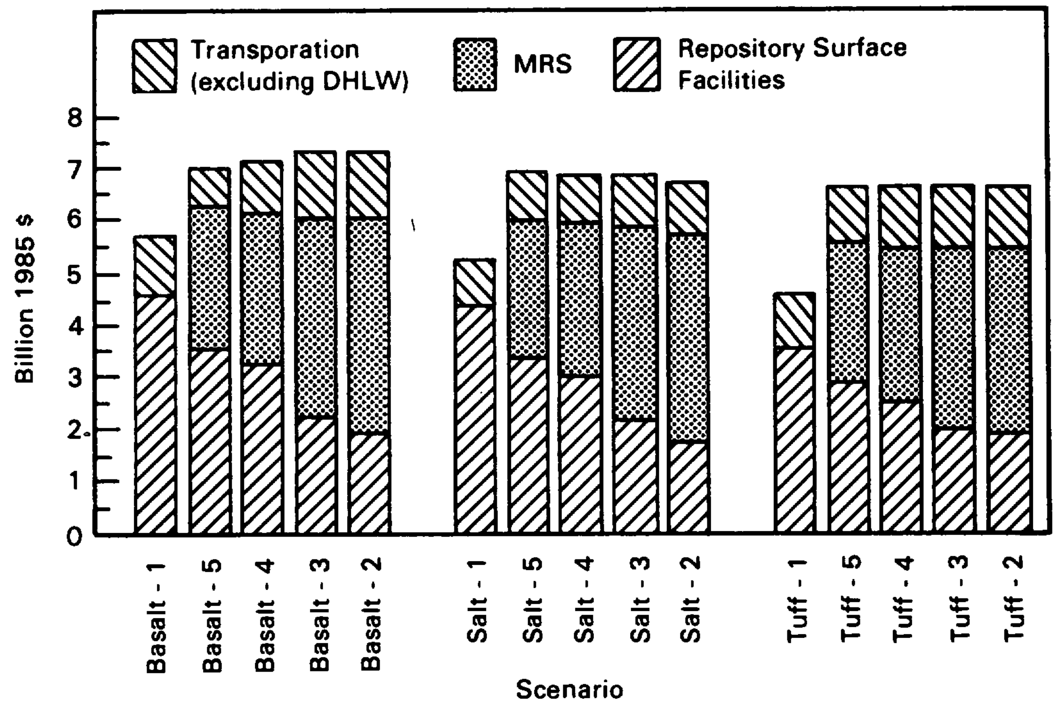


FIGURE C.3. Life-Cycle Costs for Repository Surface Facilities, MRS Facility, and Transportation

The net system costs associated with the MRS facility in each of the waste management scenarios are presented in Table C.11 and Figure C.4. In this table, the scenario and the specific function performed at the MRS facility are presented. The incremental cost for each scenario is calculated as the difference between the system cost of that scenario and the system cost for Scenario 1, that is a waste management system without an MRS facility.

TABLE C.11. Net System Cost Impact of MRS in Fuel Cycle (billions of mid-1985 dollars)

	Function at MRS:			Cost of MRS for Repository in		
Scenario	Fuel Consoli.	Fuel Overpack	DHLW Overpack	Basalt	Salt	Tuff
5 Eastern	None	None	1.4	1.7	2.0	
4 All	None	None	1.4	1.6	2.0	
3 All	All	None	1.6	1.6	2.0	
2 All	All	All	1.6	1.5	2.0	

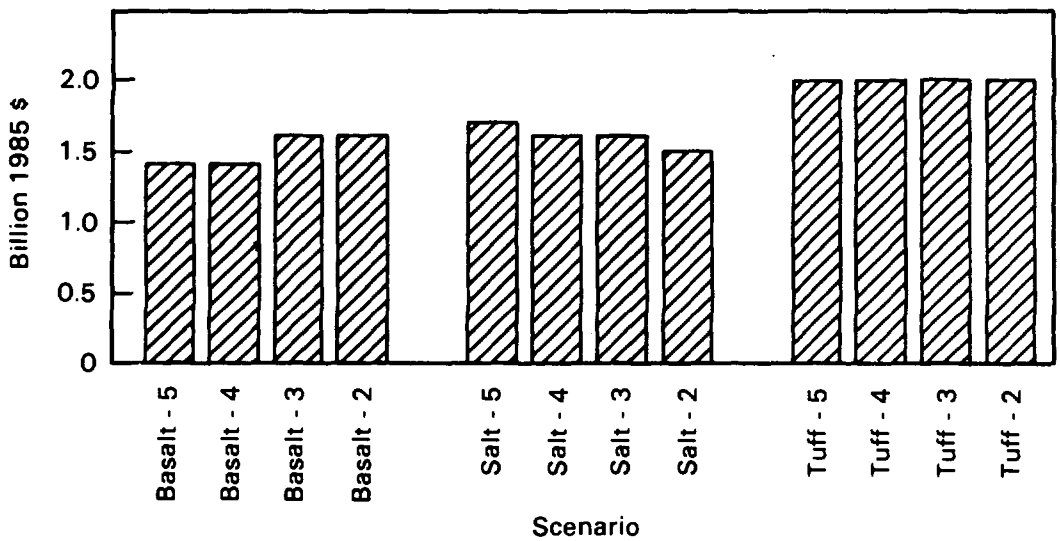


FIGURE C.4. Net System Cost Impact of MRS in Fuel Cycle (Scenario with MRS Versus No-MRS)

C.4 REFERENCE

U.S. Department of Energy. 1986. Report of the Task Force on the MRS/Repository Interface. DOE/RW-0044, U.S. Department of Energy, Washington, D.C.

APPENDIX D

SPENT-FUEL GENERATION, STORAGE REQUIREMENTS AND COSTS

APPENDIX D

SPENT-FUEL GENERATION, STORAGE REQUIREMENTS AND COSTS

This appendix describes projections of the amount of spent fuel that will be discharged by reactors, the amount of additional at-reactor spent-fuel storage capacity that will be required, and the potential costs for providing that storage.

Table D.1 compares the projected requirements for additional at-reactor storage capacity and the maximum waste management system acceptance rates for the MRS and no-MRS systems for the Energy Information Administration (EIA) mid-case spent-fuel generation scenario (Gielecki et al. 1984). These projections are based on reactor-by-reactor comparisons of projected spent-fuel generation, pool inventory, and pool capacity. The term "additional storage capacity" refers to the amount of fuel that would require either 1) consolidation for continued storage in the reactor pool, 2) transfer to onsite dry storage or 3) transfer to offsite storage in order for the utility to maintain full-core reserve (FCR) capacity in its reactor pool. The assumptions for these projections are described in the following sections.

Table D.1 shows that, for the no-MRS system, requirements for additional at-reactor storage capacity exist until 2003, when the repository reaches its planned emplacement rate of 3000 MTU per year. During that period, the system acceptance rate (repository emplacement rate) is less than the requirement for additional storage capacity. By contrast, the MRS system can begin accepting spent fuel in 1996, and operate at an annual receipt rate of up to 2500 MTU per year by 1998. This waste acceptance capacity, if allocated to reactors about to encroach on their FCR storage capacity, could eliminate the requirement for continued expansion of at-reactor storage capacity after 1996. Table D.1 shows that an MRS facility could reduce the requirement for expansion of at-reactor storage capacity by almost 4100 MTU.

Costs for a variety of at-reactor storage capacity alternatives such as in-pool consolidation, drywells, metal storage casks, vaults and others were estimated. The storage technology selected by a utility for providing additional capacity would depend on a variety of technical feasibility and economic factors, and on the utility's judgment about the relative difficulty of managing and performing the functions required for deploying and utilizing the storage capacity alternatives. A unit cost range of \$40/kg to \$110/kg encompasses a range of storage capacity alternatives that would likely provide a feasible and attractive choice for most of the utilities requiring short-term additional storage capacity.

TABLE D.1. Comparison of Additional Annual At-Reactor Storage Capacity Requirements and Maximum Waste Management System Acceptance Rate for 1984 the EIA Mid-Case Spent-Fuel Generation Scenario (MTU)

Year	No Federal Waste Acceptance	No-MRS System: Maximum Federal Waste Acceptance[a]	No-MRS System: Additional Annual Storage Capacity	MRS System: Maximum Federal Waste Acceptance[a]	MRS System: Additional Annual Storage Capacity
1995	2,882[b]	0	2,882[b]	0	2,882
1996	825	0	825	400	425
1997	896	0	896	1,800	0
1998	858	400	458	2,550	0
1999	1,292	400	892	2,550	0
2000	1,349	400	949	2,575	0
2001	1,295	900	395	2,575	0
2002	1,873	1800	73	2,600	0
2003	1,552	3,000	0	2,700	0
2004	1,659	3,000	0	2,850	0
2005	1,918	3,000	0	2,950	0
TOTAL			7370		3307

(a) Waste acceptance rates are discussed in Section 1.4 and displayed in Table 1.2.
(b) Cumulative requirement through 1995.

The following sections of this appendix describe how the results shown in Table D.1 vary as assumptions about spent-fuel generations are changed, and discuss alternative methods for utilities to provide for their additional at-reactor storage requirements. Estimates of the amount of storage capacity that can be provided by various alternatives, and the associated costs are also discussed.

D.1 SENSITIVITY OF REQUIREMENTS FOR ADDITIONAL AT-REACTOR STORAGE CAPACITY TO VARIATIONS IN SPENT-FUEL GENERATION RATES

Estimates of the requirement for additional at-reactor storage capacity are based on reactor-by-reactor projections of spent-fuel generation and current or planned spent-fuel storage capacity. This section examines the sensitivity of the requirement for additional storage capacity to variation of the projected spent-fuel generation rate.

D.1.1 Alternative Spent-Fuel Generation Scenarios

The reference EIA mid-case projection is DOE's planning base for the waste management system. In addition to the EIA mid-case, two additional projections, one based on data provided by utilities and another assuming extended fuel burnup, were used as a bases for calculating the requirement for additional at-reactor storage capacity. These three projections are described briefly below.

Utility Data

As part of their planning for waste management system development, DOE collects data annually from utilities regarding their current spent-fuel inventory, projected discharges, current storage capacity, and planned storage capacity expansions (DOE 1984). Detailed data are collected from each utility for their projected discharges, including the expected discharge date, number of assemblies, and projected burnup. These data provide the calculational basis for the two alternative projections described below.

EIA Mid-Case

The data provided to DOE by utilities reflect a large variation in assumptions made by individual utilities. The EIA Mid-Case projection is made by modifying the data provided by the utilities so that the aggregate nuclear energy generation rate matches projections made by EIA (Gielecki et al. 1984). This requires modifying the startup dates for new reactors, and modifying individual reactor capacity factors so that installed generation capacity and annual energy generation match the EIA projection (Heeb, Libby, Holter 1985). Spent-fuel discharges are then projected to occur at the dates, and with the approximate burnup, specified by the utilities. The number of assemblies discharged for this projection varies from the utility projection because of the adjustments made to the energy generation for each reactor.

Extended Burnup

Extended burnup of nuclear fuel, generating more energy per assembly, would reduce the projected number of assemblies discharged and correspondingly reduce the requirement for additional at-reactor storage capacity. The primary incentive to increase burnup for nuclear fuel is to save nuclear fuel costs, rather than to reduce storage requirements. Extended burnup may result in a net decrease in fuel costs, provided that possible decreases in the costs for fuel fabrication, uranium, and enrichment are not offset by an increase in fuel failure rates at higher burnup levels.

To determine the potential impact of increases in fuel burnup beyond the level currently identified by the utilities, a modification was made to the EIA Mid-Case projection described above. The individual utility estimates of burnup for their projected discharges were modified so that the annual average discharge burnup increased at the rate of 2% per year. An upper limit of 50,000 megawatt-days (thermal) per metric ton uranium (MWD/MTU) for pressurized water reactor (PWR) fuel and 45,000 MWD/MTU for boiling water reactors (BWR) was assumed. Although higher levels may be achievable, these values are reasonable averages for the time frame of the study (Bailey and Tokar 1984). The modified burnup assumptions were used to calculate revised spent-fuel discharge projections for each reactor, from which modified projections for the requirements for additional at-reactor storage capacity were calculated.

Spent-Fuel Inventory Projections

The three spent-fuel generation scenarios described were used to project spent-fuel inventory for each reactor, and total spent-fuel inventory. This represents the amount of fuel for which utilities would need to provide storage capacity, or alternatively, have accepted by the federal waste management system. Figure D.1 shows the projected total spent-fuel inventory for each of the three spent-fuel generation scenarios. The EIA Mid-Case inventory, which is the reference projection for DOE waste management system planning is slightly less than the utility supplied data, but greater than the inventory that would exist if the projected increases in burnup for the extended burnup scenario are realized.

D.1.2 Requirements for Additional At-Reactor Storage Capacity

Requirements for additional at-reactor storage capacity were calculated for each of the spent-fuel generation projections. These projections are based on reactor-by-reactor comparisons of projected spent-fuel generation, pool inventory, and pool capacity. The term "additional storage capacity" refers to the amount of fuel that would require 1) consolidation for continued storage in the reactor pool, 2) transfer to onsite dry storage, or 3) transfer to offsite storage in order for the utility to maintain FCR capacity in its reactor pool.

Reactor-pool capacities and inventories are based on data collected by the DOE from each utility (DOE 1984). It was assumed that sufficient storage capacity for a full reactor core would be maintained at each separate reactor to allow a complete discharge of the core if required. A single FCR is assumed to be maintained for all units at multiple-unit reactor stations employing either a single, common spent-fuel storage pool, or separate pools having interconnections for transferring spent fuel. Reactor-pool capacity is assumed to be the capacity that the utilities believe can be achieved by maximum reracking (replacing old racks with new racks that provide greater storage capacity).

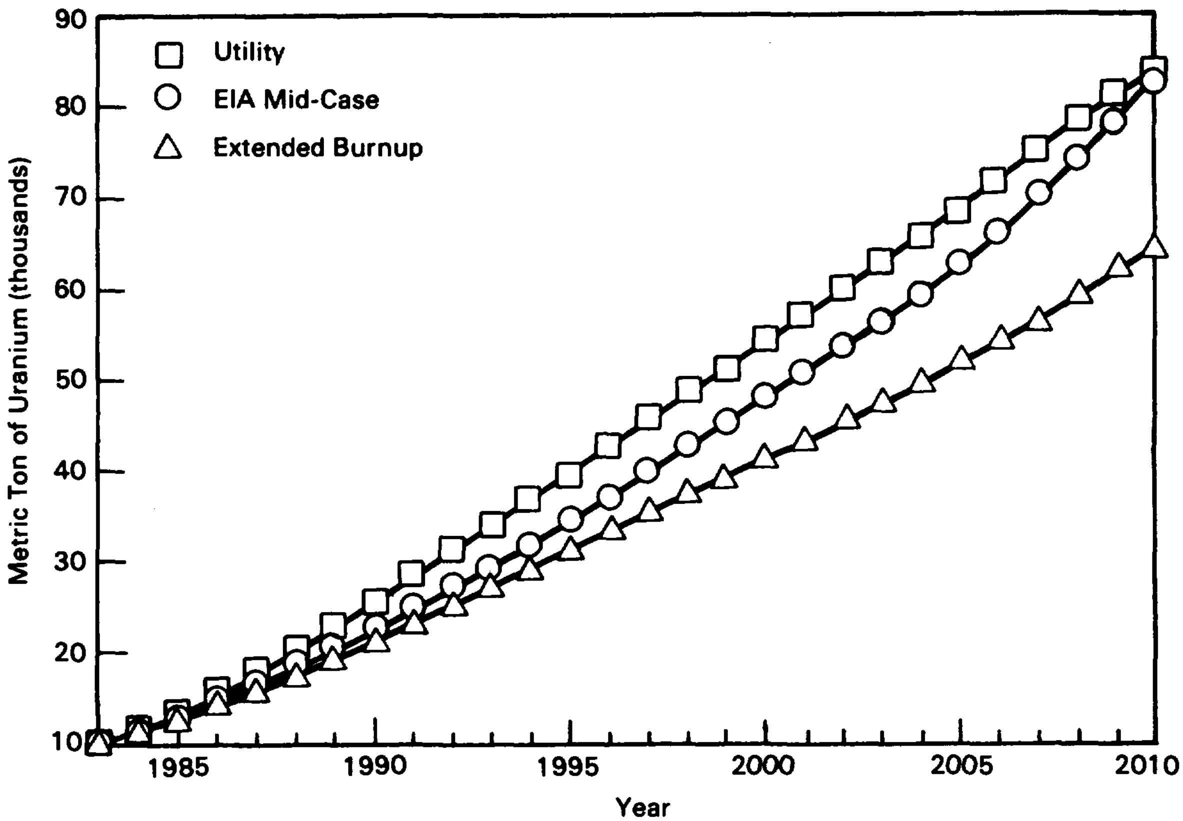


FIGURE D.1. Spent-Fuel Inventory Projections for Alternative Spent-Fuel Generation Scenarios

Additional at-reactor storage capacity requirements were calculated for both the no-MRS and MRS waste management systems. The annual waste acceptance capacity for the respective waste management systems, and the requirement for additional storage capacity were compared to determine how much of the requirement for additional storage capacity could be eliminated by federal waste acceptance. This comparison assumes that waste acceptance capacity would somehow be allocated to those utilities requiring additional storage capacity to maintain their ability to discharge a full core. This allocation is a possible result of trading acceptance rights between the utilities, as is allowed in the standard utility contract for disposal (10 CFR 961). Any other allocation of acceptance rights would result in a larger at-reactor storage capacity requirement than is shown.

The waste acceptance capacity for the no-MRS system is limited to the emplacement rate for the repository, which begins at a reduced rate in 1998, and reaches full throughput in 2003. For the MRS system, the maximum federal waste acceptance capacity is the combination of the rate at which fuel can be received at the MRS facility from eastern reactors, and the rate at which fuel is received at the repository from western reactors. The MRS system can begin accepting fuel in 1996 and reaches an acceptance capacity of 2500 MTU per year by 1998. The waste-acceptance rates for these two systems are discussed in Section 1.4.

Tables D.1, D.2, and D.3 summarize the requirements for additional at-reactor storage capacity for the no-MRS and MRS systems for the three spent-fuel generation scenarios. Table D.1 shows that, for the EIA Mid-Case projection, the MRS facility can reduce the requirement for additional at-reactor storage capacity by approximately 4100 MTU. Tables D.2 and D.3 show that the MRS facility can mitigate the requirement for approximately 6500 MTU of additional at-reactor storage capacity assuming the utility generation scenario, and approximately 1900 MTU assuming the extended burnup scenario.

Detailed examination of the requirement for additional storage capacity at each reactor site for no-MRS and MRS waste management systems indicates that,

TABLE D.2. Comparison of Additional Annual At-Reactor Storage Capacity Requirements and Maximum Waste Management System Acceptance Rate for the Utility Spent-Fuel Generation Scenario (MTU)

		No-MRS System		MRS System	
Year	No Federal Waste Acceptance	Maximum Federal Waste Acceptance[a]	Additional Annual Storage Capacity	Maximum Federal Waste Acceptance[a]	Additional Annual Storage Capacity
1995	4,000[b]	0	4,000[b]	0	4,000[b]
1996	1,294	0	1,294	400	894
1997	1,262	0	1,262	1,800	0
1998	1,339	400	939	2,550	0
1999	1,824	400	1,424	2,550	0
2000	1,719	400	1,319	2,575	0
2001	1,660	900	760	2,575	0
2002	2,197	1,800	397	2,600	0
2003	1,942	3,000	0	2,700	0
2004	2,048	3,000	0	2,850	0
2005	2,416	3,000	0	2,950	0
TOTAL			11,398		4,894

(a) Spent fuel acceptance rates are discussed in Section 1.4 and displayed in Table 1.2.
(b) Cumulative requirement through 1995.

TABLE D.3. Comparison of Additional Annual At-Reactor Storage Capacity Requirements and Maximum Waste Management System Acceptance Rate for the Extended Burnup Spent-Fuel Generation Scenario (MTU)

		No-MRS System		MRS System	
Year	No Federal Waste Acceptance	Maximum Federal Waste Acceptance[a]	Additional Annual Storage Capacity	Maximum Federal Waste Acceptance[a]	Additional Annual Storage Capacity
1995	2,167[b]	0	2,167[b]	0	2,167[b]
1996	515	0	515	400	115
1997	590	0	590	1,800	0
1998	487	400	87	2,550	0
1999	702	400	302	2,550	0
2000	795	400	395	2,575	0
2001	677	900	0	2,575	0
2002	1,040	1,800	0	2,600	0
2003	915	3,000	0	2,700	0
2004	932	3,000	0	2,850	0
2005	1,181	3,000	0	2,950	0
TOTAL			4,056		2,282

(a) Waste acceptance rates are discussed in Section 1.4 and displayed in Table 1.2.
(b) Cumulative requirement through 1995.

in addition to potentially reducing the total requirement for storage capacity expansion, introducing an MRS facility into the waste management system decreases the number of reactor sites requiring additional storage capacity. Table D.4 shows the number of reactor sites requiring additional at-reactor storage capacity with and without an MRS facility for each of the three spent-fuel generation scenarios. These results depend on the allocation of waste acceptance capacity (i.e., fuel is assumed to be accepted first from reactors encroaching on full-core reserve) and would differ if the assumed allocation of acceptance capacity were varied.

TABLE D.4. Number of Reactor Sites Requiring Additional Storage Capacity

Waste Management System	Spent Fuel Generation Projection Utility	EIA Mid-Case	Extended Burnup
No-MRS	67	57	40
MRS	45	33	24

D.2 ALTERNATIVES FOR PROVIDING ADDITIONAL AT-REACTOR STORAGE CAPACITY

The calculations from the previous section indicate that, for a broad range of spent-fuel generation projections, additions to at-reactor storage capacity will be required prior to the time that the spent-fuel acceptance rate exceeds the rate that it is generated. The options that are feasible and the costs for implementing those options vary among the utilities. The options range from modifying or reallocating existing spent-fuel capacity (reracking, transshipment, consolidation) to new onsite capacity (new basin capacity, dry storage cask or vault, etc.).

The feasibility of these options will vary depending on individual utility considerations. For example, existing basins may not be structurally equipped for accommodating additional weight loading that would occur with either reracking or consolidation. No attempt was made to assess conditions at individual reactor sites to determine which options would be preferred at specific sites.

This section estimates the potential capacity that could be provided by increased use of existing pool capacity, and the costs for these and other alternatives for providing additional at-reactor spent-fuel storage capacity.

D.2.1 Increased Use of Existing Pool Capacity

The data used to calculate the requirements for additional at-reactor storage capacity assumes that each reactor basin is reracked to the maximum extent that the utility indicates is feasible. Two alternatives for increasing the utilization of that storage capacity are transshipment of fuel between reactor pool basins and consolidation of spent fuel for more compact storage.

Transshipment

The potential impact of transshipment was estimated by assuming that there were no constraints on transshipments of spent fuel among reactors of like type (e.g., PWR, BWR). Reactors requiring additional storage capacity to maintain their FCR were assumed able to transship fuel to another reactor within the same utility having available pool capacity (DOE 1984). Figure D.2 shows the

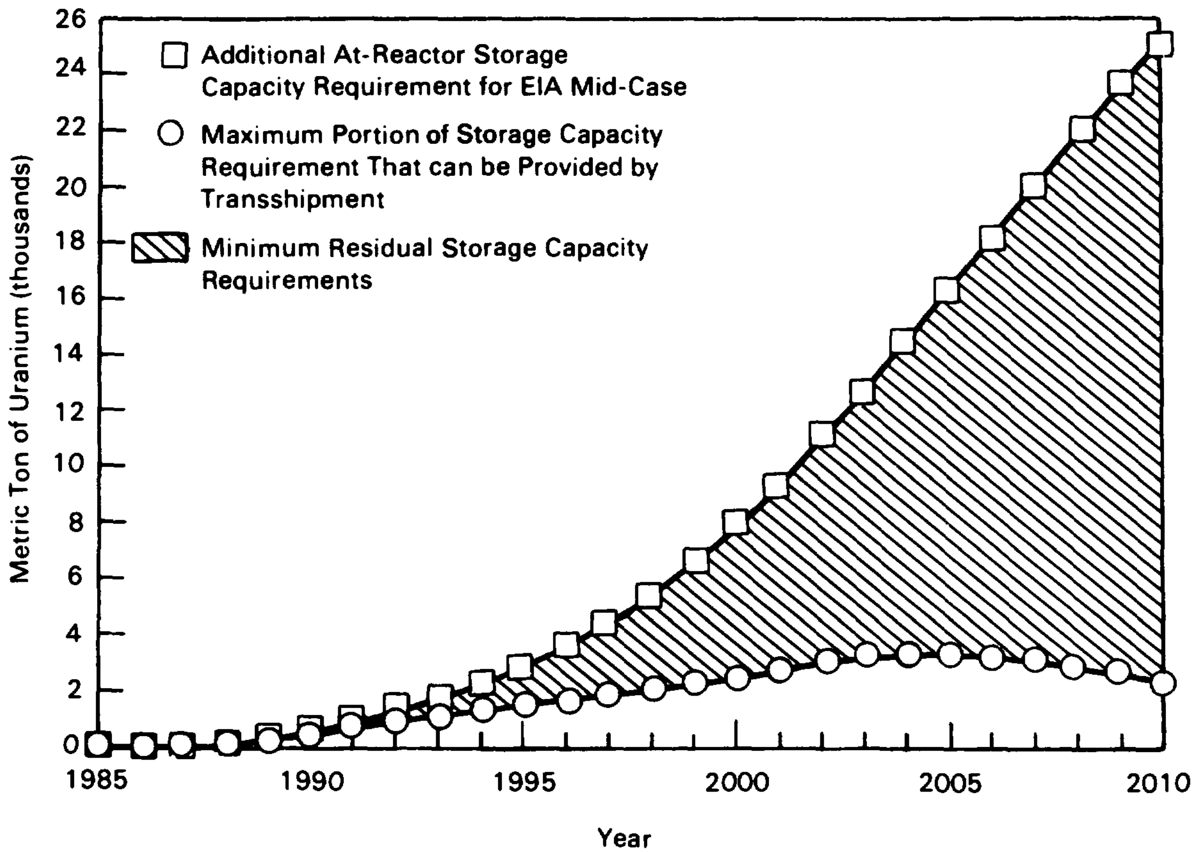


FIGURE D.2. Comparison of the Requirement for Additional At-Reactor Storage Capacity for the EIA Mid-Case and the Storage That Can Be Provided by Transshipment

total requirement for additional storage capacity for the EIA Mid-Case projection, and the amount of that storage capacity requirement that could potentially be provided by transshipping fuel. The figure shows that the potential impact of transshipment is slight relative to the total requirement.

Consolidation

The effective spent-fuel storage capacity for some spent-fuel pools could be expanded by consolidating the spent-fuel rods into more compact arrays in storage canisters in the pool, and storing the assembly hardware (nonfuel-bearing components) in separate canisters in the pool. However, this option may not be feasible or attractive to all utilities. The feasibility of performing the consolidation function and storing consolidated fuel in a particular spent-fuel storage pool depends on structural, thermal, and seismic constraints for that pool. In addition, consolidating spent fuel in a reactor pool creates the potential for degrading the water quality for the reactor pool, and adding to the background radiation level of the pool.

It is unlikely that consolidation would be a feasible or attractive option for all utilities; however, to estimate the potential contribution of consolidation for satisfying storage capacity requirements, it was assumed that consolidated spent fuel could be stored in every spent-fuel pool. It was assumed that the spent-fuel rods from 6 PWR assemblies could be consolidated into 4 canisters of the same size as the original assemblies, 3 containing spent-fuel rods and 1 containing fuel hardware. Similarly, it was assumed that 10 BWR assemblies could be consolidated into 6 assembly sized canisters, 5 with spent-fuel rods and 1 with assembly hardware.

Figure D.3 shows a comparison of the total requirement for additional at-reactor storage capacity and the potential portion of the requirement that

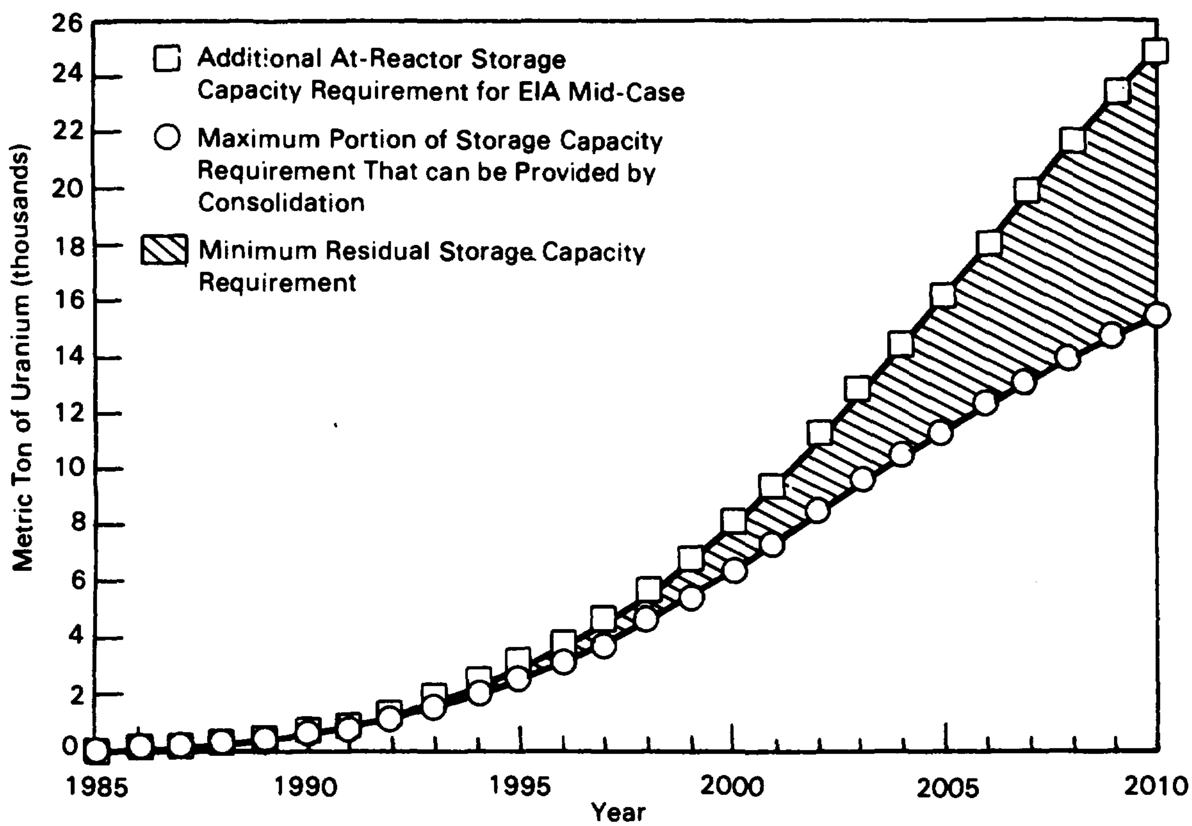


FIGURE D.3. Comparison of the Requirement for Additional At-Reactor Storage Capacity and the Capacity that Can be Provided by Consolidation.

could be met by consolidation. The figure shows that even for the extreme assumption that all reactor pools could accommodate consolidated fuel, and that all utilities would desire to perform the consolidation process in their facilities, not all of the requirement for additional capacity can be met.

D.2.2 Cost Estimates for At-Reactor Spent-Fuel Storage Capacity Alternatives

This section summarizes the costs of storage or treatment for storage of spent light water reactor (LWR) fuel at a reactor site. This information is used as the basis for the development of cost-related analyses in other sections of this report.

Cost tables show the estimated costs for each specific spent-fuel storage situation. The data are based on escalating costs given in Merrill and Fletcher (1983) from 1982 to 1985 and incorporating, where applicable, more recent estimates. Escalation of costs is based upon the Chemical Engineering plant cost index. Values of the index are given in Table D.5 along with the calculated escalation factors to obtain 1985 costs from earlier estimates. Cost of maintenance and maintenance supplies were assumed to be 1.4% of total capital costs. Property taxes and insurance were assumed to be 1% of total capital costs. The costs of labor, general supplies, and overhead were apportioned according to the number of fuel assemblies handled, number of canisters handled, and the number of storage units placed or removed or in inventory. Labor costs for both handling and storage operations assumed that the activities involved were incremental for the normal operating crew. Decommissioning costs were assumed to be 10% of the total capital cost, with cost reductions allowed for facilities storing only canned fuel.

TABLE D.5. Chemical Engineering Plant Cost Index[a]

Year	Index	Escalation Factor
1981	297.0	1.0960
1982	314.0	1.0366
1983	316.9	1.0271
1984	322.7	1.0087
1985[b]	325.5	1.0000

(a) Chemical Engineering, August 5, 1985, page 7.
(b) Preliminary estimate for June 1985.

The following sections discuss the cost of several storage technologies: reracking, in-pool canning and consolidation, metal casks, drywells, silos, horizontal modules, air-cooled vaults and a new water basin.

Reracking

Table D.6 presents typical costs for reracking an existing reactor spent-fuel storage pool. The capital costs were obtained from Clark (1981) and escalated by a factor of 1.096 to obtain 1985 dollars. Operating costs were apportioned as discussed above.

TABLE D.6. Reracking Costs[a]

	PWR	BWR
Capital Costs		
Assumed pool area	1225 sq ft	1000 sq ft
Assumed initial capacity, assemblies (MTU)	660 (360)	1300 (250)
Reracked capacity, assemblies (MTU)	1374 (637)	3016 (580)
Rack cost	$4,544,000	$5,170,000
Installation and licensing	$1,648,000	$1,648,000
Total capital costs	$6,192,000	$6,818,000
Operating Costs		
Maintenance supplies	1.4% of capital	
Labor and general supplies in inventory	$200 per assembly or canister	
Property tax and insurance	1% of capital	
Decommissioning	10% of capital	

(a) Placement or removal is not an expense for increased storage in the original pool.

In-Pool Canning and Consolidation Costs

The costs for in-pool canning spent fuel are presented in Table D.7. The canning may be done to reduce the surface contamination of the fuel to be stored or to provide a contamination barrier. The in-pool canning capital cost is derived from DOE (1981) by increasing the contingency to 25% and escalating to 1985 dollars. The operating costs were derived from E. R. Johnson Associates (1984) by using the costs for a consolidation and canning crew and applying them to the time used for the canning portions of the operations.

As shown in Table D.8, for rather modest cost increases, the advantage of reduced volume may be obtained by consolidating and canning the spent fuel. The costs for consolidation and canning are derived from E. R. Johnson Associates (1984) by increasing the contingency to 25% and escalating to 1985 dollars.

To provide a specified amount of additional storage capacity, at least twice that number of assemblies must be consolidated. Assuming a consolidation ratio of 2:1 (which is about the maximum achievable ratio) and ignoring (for the moment) the disposal of the assembly nonfuel-bearing components, storage space for one assembly would be obtained for each two assemblies consolidated. At lower consolidation ratios, even more fuel assemblies would need to be consolidated for each fuel assembly storage space obtained. In addition, storage of nonfuel-bearing components would further reduce the storage capacity obtained by consolidating a specified amount of fuel. Nonfuel-bearing components are expected to require a minimum of one assembly storage space for each

TABLE D.7. In-Pool Canning Costs

Capital Costs	$722,000 (1982 dollars)
Operating Cost	
Maintenance supplies	1.4% of capital
Labor and general supplies	$2421 PWR or $1816 BWR per canister + $20,000 per campaign setup and removal + $514 PWR or $397 BWR per assembly canned
Property tax and insurance	1% of capital
Decommissioning	10% of capital

TABLE D.8. In-Pool Consolidation and Canning Costs

Capital Costs	$1,360,000
Operating Cost	
Maintenance and supplies	1.4% of capital
Labor and general supplies	$2421 PWR or $1816 BWR per canister + $25,000 per campaign setup and removal + $1769 PWR or $983 per assembly processed
Property tax and insurance	1% of capital
Decommissioning	10% of capital

10 assemblies consolidated, depending on the method used to compact these components. (The assumptions used in this analysis are summarized in Table D.3.)

Metal Casks

Table D.9 presents typical costs for storage of spent fuel in metal casks. The capital costs for the storage yard and licensing for the site are based on Rasmussen (1982) escalated to 1985 dollars. The cost of licensing the casks is assumed to be borne by the cask vendor. The cost of the casks is taken from Westinghouse Electric Corp (1983) escalated to 1985 dollars. Labor and general supplies costs are based upon DOE (1981) escalated to 1985 dollars. The cask placement cost includes a rental fee of $1000 for mobile equipment, such as crane, lowboy trailer and truck.

Drywells

The typical costs for storage of spent fuel in drywells is shown in Table D.10. The capital costs are from Rasmussen (1982) escalated to 1985 dollars. The yard costs are higher than for the metal casks because all licensing costs are included. The costs of the drywells are taken from Westinghouse Electric Corporation (1983) escalated to 1985 dollars. The labor and general supplies costs are from DOE (1981) and are escalated to 1985 dollars. The cost of loading and unloading a drywell was assumed to be essentially the same. Each operation includes a $500 rental fee for mobile equipment.

Silos

Table D.11 presents the costs of storing spent fuel in concrete casks or silos. The capital cost of the loading facility and the labor and general

TABLE D.9. Storage Cask Costs

Capital Costs	
Yard	$1,320,000 + $2,070 per cask for each increment when built
Cost of Casks (year before needed)	$775,000 (cask holds 24 PWR or 52 BWR assemblies)
Operating Cost	
Maintenance and supplies	1.4% of cumulative capital
Labor and general supplies	$3,420 per cask placement or removal + $5,180 per cask to load or unload if not included in a canning operating + $200 per year for each cask in use
Property tax and insurance	1% of capital
Decommissioning	10% of cask capital if uncanned fuel, none for canned fuel

TABLE D.10. Drywell Storage Costs

Capital Costs	
Yard	$2,000,000 for the first 1000 + $311,000 for each subsequent 1000 drywells
Transfer equipment	$866,000
Cost of Drywells	$5,580 (one PWR or two BWR)
Operating Costs	
Maintenance and supplies	1.4% of capital
Labor and general supplies	$3,350 per drywell filled (or emptied) + $200 per year for each drywell in use
Property tax and insurance	1% of capital
Decommissioning	2% of capital since fuel is canned

TABLE D.11. Storage Costs in Silos

Capital Costs	
Yard	$1,570,000 loading facility + $2,000,000 for yard + $2070/silo
Transporters	$1,732,000 reactor basin-to-silo transporter if separate canning or disassembly facility not available
Cost of Silo	$76,500 (holds 26 intact PWR or 32 consolidated PWR in 20 canisters or 61 intact BWR or 90 consolidated BWR in 61 canisters)
Operating Cost	
Maintenance and supplies	1.4% of capital
Labor and general supplies	$9,380 per silo for placement or removal + $2,520 per canister for loading or unloading + $200 per year per silo in service
Property tax and insurance	1% of capital
Decommissioning	2% of capital since fuel is canned

supplies are based upon DOE (1981) with contingency increased to 25% and escalated to 1985 dollars. The yard costs are from Rasmussen (1982). The cost of the silo is based upon Boeing (1983) escalated to 1985 dollars. This silo is designed to the same standards as the MRS silo and can dissipate 17.8 kW of decay heat. The temperature rise associated with this heat load requires that both intact fuel and consolidated fuel be canned and the can must contain an inert atmosphere.

Horizontal Modules

Table D.12 presents the cost for storage of spent fuel in horizontal modules, specifically for the NUTECH Horizontal Modular Storage (NUHOMS) system.[a] The yard costs, which include site preparation, security, utilities, and licensing, are assumed to be the same as the costs for metal casks. The per-module costs in the yard consist of foundation and site work[a] including a 25% contingency. The cost of the transporters includes the transport cask, trailer and skid, hydraulic ram, and a 25% contingency. For consistency with the other

(a) These costs are based on data sent from D. V. Massey, Nutech Engineers, San Jose, California, to E. T. Merrill, Pacific Northwest Laboratory, Richland, Washington, June 18, 1985.

TABLE D.12. Storage Costs in Horizontal Modules

Capital Costs	
Yard	$1,320,000 + $21,000 per module
Transporters	$1,210,000
Cost of Module	$32,000 (holds 7 PWR or 16 BWR) + $80,000 dry shielded canister
Operating Cost	
Maintenance and supplies	1.4% of cumulative capital
Labor and general supplies	$19,400 per storage module loaded or unloaded + $200 per module in service
Property tax and insurance	1% of capital
Decommissioning	10% of cost of dry shielded canister if uncanned fuel, none for canned fuel

estimates in this appendix, the locally-constructed module cost includes a 25% contingency while the vendor-supplied, dry-shielded canister does not. The cost of labor and general supplies includes the truck rental and operating costs.[a]

Air-Cooled Vaults

Table D.13 presents the cost for storage of spent fuel in an air-cooled vault. An air-cooled vault is a structure containing shielded rooms with fabricated cavities to receive the fuel. Rooms can be added, but the concept is not truly modular. The cost is estimated by determining the total requirement and assuming that the entire facility is built prior to the first year of need. The costs given in Table D.13 are based upon DOE (1981) escalated to 1985 dollars.

New Water Basin

The costs for storage of spent fuel in a new water basin are given in Table D.14. These costs are based upon Clark (1981) escalated to 1985 dollars.

(a) These costs are based on data sent from D. V. Massey, Nutech Engineers, San Jose, California, to E. T. Merrill, Pacific Northwest Laboratory, Richland, Washington, June 18, 1985.

TABLE D.13. Storage Costs in an Air-Cooled Vault

Capital Costs	
Vault and transfer equipment	$20,600,000 + $31,300 canister of capacity If a high unloading rate is assumed, extra unloading equipment may be required at that time.
Operating Costs	
Maintenance and supplies	1.4% of capital
Labor and general supplies	$4930 per canister placed or removed + $200 per year per canister in inventory
Property tax and insurance	1% of capital
Decommissioning	10% of capital if fuel is uncanned, 2% of capital if fuel is canned

TABLE D.14. New Water Basin Costs

Capital Cost in Millions $$33 + 33 \left(\frac{(S)\,(C)}{1000}\right)^{0.75}$$

where S = storage capacity, MTU
C = consolidation factor (say, 0.625 if consolidated)

Operating Cost	5% of capital
Decommissioning	10% of capital if uncanned fuel 2% of capital for canned fuel

D.2.4 Unit Cost Comparisons for At-Reactor Storage Capacity Alternatives

Table D.15 summarizes the results of a comparison of the storage costs for two example storage requirements for a typical reactor. These represent the total costs for initial capital, annual operating, and decommissioning. Two storage amounts are considered, 200 assemblies (92 metric tons) accumulated

TABLE D.15. Cost of Example Storage Requirements

Storage Method	Total Costs, Millions of 1985 Dollars	
	Five Years at 40 Assemblies/Year	Fifteen Years at 40 Assemblies/Year
Consolidation into pool	3.54	7.61
Rerack	7.61	9.58
Drywell		
canned	6.84	14.07
consolidated	6.96	13.05
Silo		
canned	8.91	14.55
consolidated	9.65	15.32
NUHOMS		
as discharged	7.77	19.44
consolidated	8.20	17.39
Metal Cask		
as discharged	9.76	27.24
consolidated	9.01	21.24
Vault		
canned	33.17	61.38
consolidated	31.08	51.31
Water Basin		
as discharged	51.99	84.30
consolidated	49.27	78.37

over a 5-year period at 40 assemblies per year, and 600 assemblies (276 metric tons) accumulated over a 15-year period at 40 assemblies per year. Cost for storage of spent fuel at a particular reactor depends on specific conditions at that reactor. Therefore, the most economical method for a typical reactor is not expected to be the most economical storage option at each specific reactor. The economic comparisons made in Table D.15 are expressed in undiscounted total costs.

The costs for specific storage options (see Tables D.6 through D.14), along with those for any required fuel preparation steps, were used to calculate detailed cash flows for the cases shown in Table D.15. Table D.16 shows an example of such calculations, for a 15-year storage period using metal casks. Cost data for this example are taken from Table D.9. Some expenses (i.e., construction of the storage yard) are accrued prior to the start of storage; hence they are accounted for in "year zero". Incremental capital costs for yard expansion (pads, etc.) and for casks are accounted for in the year prior to each year's additions to storage.

Operating costs are incurred in the year the services are performed. One component of these costs, that of maintenance supplies, is assumed to be a percentage (1.4% in this case) of the cumulative capital investment in a given year. Another component, that of labor and general supplies, is estimated by combining a load/unload charge of $8600 per cask upon addition to the storage yard, with a $200 per year cost for each cask in storage. The third operating cost component, that of taxes and insurance, is levied at one percent of the prior year's cumulative capital investment.

Decommissioning costs, assumed at 10% of the capital investment in casks, are assumed to be incurred following cessation of storage requirements; for this case, they were assumed to be incurred in years 17 and 18.

The total storage costs for this example, $27.4 million, agree with the corresponding total cost on Table D.15.

For the example storage requirements, the undiscounted unit cost (Table D.17) varies depending on the method chosen to handle the storage requirement. The first two methods, consolidation into pool and rerack, have limited applicability for gaining additional storage since it is assumed that the utilities would already have used currently licensable technology such as reracking to gain additional storage space. Thus, the requirements for additional storage for the first two methods are above and beyond what has already been gained by reracking. Some reactors have limited capabilities for pool storage of consolidated fuel because of seismic and weight limitations.

Costs ranging from $40 to $110/Kg are the probable costs to utilities to provide additional at-reactor storage capacity. The wide range of costs is based upon the unit cost for consolidation and for dry modular storage methods, such as drywell, silo, NUHOMS and metal casks. These methods appear to be the most feasible for storage of the example cases. The range of $40-$110/kg was selected as the appropriate range to represent the cost to the utilities for providing additional at-reactor storage. The last two methods examined, vaults and water basin, appear to be feasible only for large volumes of fuel requiring storage.

TABLE D.16. Example Cash Flow Calculation: Storage in Metal Casks of 40 PWR Assemblies per Year for 15 Years (dollars in thousands)

Year	Cumul. Assem.	Cumul. Casks	Storage Yard Construction Costs	Cask Support Cost	Cost of Casks	Maintenance Supplies	Labor and General Supplies	Property Tax and Insurance	Decommissioning	Total
0			$1,320	$4.1	$ 1,550					$ 2,874
1	40	2		4.1	1,550	$ 40	$ 17	$ 28		1,640
2	80	4		2.1	775	62	18	44		901
3	120	5		4.1	1,550	72	9	52		1,688
4	160	7		4.1	1,550	94	18	67		1,734
5	200	9		2.1	775	116	19	83		995
6	240	10		4.1	1,550	127	10	90		1,782
7	280	12		4.1	1,550	149	19	106		1,829
8	320	14		2.1	775	170	20	122		1,089
9	360	15		4.1	1,550	181	11	129		1,877
10	400	17		4.1	1,550	203	20	145		1,923
11	440	19		2.1	775	225	21	160		1,184
12	480	20		4.1	1,550	236	12	168		1,971
13	520	22		4.1	1,550	257	21	184		2,017
14	560	24		2.1	775	279	22	199		1,278
15	600	25				290	13	207		511
16										
17									$ 930	930
18									1,007	1,007
TOTAL			$1,320	$5.3	$19,375	$2,507	$256	$1,791	$1,937	$27,238

TABLE D.17. Unit Costs of Example Storage Requirements

Storage Method	Undiscounted Unit Costs, $/Kg Five Years at 40 Assemblies/Year	Fifteen Years at 40 Assemblies/Year
Consolidation into pool[(a)]	38	28
Rerack	83	35
Drywell		
canned	74	51
consolidated	76	47
Silo		
canned	97	53
consolidated	105	56
NUHOMS		
as discharged	84	70
consolidated	89	63
Metal Cask		
as discharged	106	99
consolidated	98	77
Vault		
canned	360	222
consolidated	338	186
Water Basin		
as discharged	565	305
consolidated	536	284

(a) Unit costs for consolidation are to provide the specified amount of storage and, therefore, involve the consolidation of a greater number of intact assemblies.

The dependence of unit costs on discount rates is shown in Table D.18. The unit cost for the larger storage example was examined at 0, 2, 5, and 10% discount rates. The extra decimal places relative to Table D.17 are to illustrate the variation with discount rate and do not indicate increased accuracy.

TABLE D.18. Variation of Unit Cost with Discount Rate

Storage Method Discount Rate	Unit Costs, $/Kg			
	0%	2%	5%	10%
Consolidate into pool[a]	27.58	28.49	30.00	32.86
Rerack	34.71	38.73	45.40	58.07
Drywell				
canned	50.97	52.93	56.18	62.35
consolidated	47.30	49.67	53.61	61.09
Silo				
canned	52.72	56.41	62.53	74.15
consolidated	55.51	59.64	66.49	79.49
NUHOMS				
as discharged	70.45	71.62	73.56	77.24
consolidated	63.00	65.19	68.81	75.68
Metal Cask				
as discharged	98.69	99.30	100.33	102.26
consolidated	76.97	78.72	81.63	87.15
Vault				
canned	222.38	233.95	253.14	289.56
consolidated	185.89	198.60	219.70	259.72
Water Basin				
as discharged	305.42	327.16	363.23	431.66
consolidated	283.96	305.02	339.96	406.25

(a) Unit costs for consolidation are to provide the specified amount of storage and, therefore, involve the consolidation of a greater number of intact assemblies.

Figure D.4 graphically represents the results shown in Table D.18. This figure compares the variation in unit cost for six technologies. For technologies requiring a large initial capital expenditure, such as reracking or silos with canned fuel, the slope of the curve is sharp; thus, the costs vary greatly with the discount rate. For these technologies, the use of undiscounted cost would

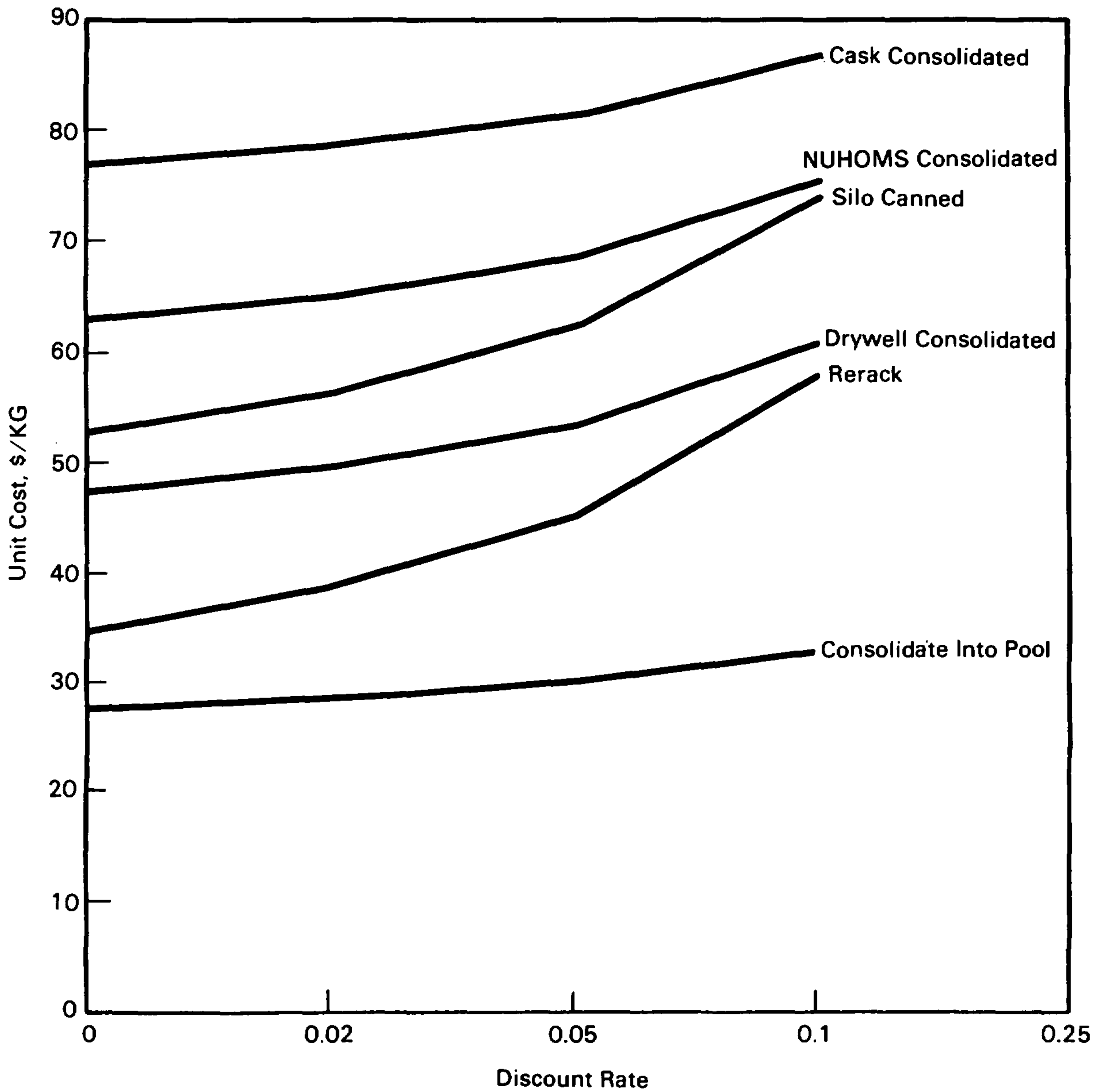


FIGURE D.4. Variation of Unit Cost as a Function of Discount Rate

tend to underestimate the actual cost of that storage technology. Since consolidation in the storage pool does not require substantial initial capital, the effect of discount rate assumption on the unit cost is small. Technologies which show moderate variation with discount rate assumptions are drywells with canned fuel, NUHOMS with fuel as discharged, and metal casks with consolidated fuel.

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APPENDIX E

RADIATION DOSES IN WASTE MANAGEMENT SYSTEMS WITH AND WITHOUT AN MRS FACILITY

APPENDIX E

RADIATION DOSES IN WASTE MANAGEMENT SYSTEMS WITH AND WITHOUT AN MRS FACILITY

This appendix examines, generically, the relative changes in public and occupational radiological dose, or risk, that would result from the introduction of the MRS facility into the waste management system. The calculational bases and additional background information specific to this appendix are provided to support the results presented in Section 2.5. The dose comparisons are limited to the spent-fuel handling activities at the reactors, the MRS facility, the surface facilities at the repository, and during the transportation of spent fuel and other waste between those facilities. In addition, there is a brief discussion of how these dose effects would differ with some alternative system configurations. The results discussed in this appendix are based on preliminary analyses of generic systems using available generic data. The results are useful for comparisons of alternatives, but are not intended as absolute values for specific sites or routes.

The doses examined in this appendix are the radiological doses to the affected public and to the workers in the waste management system. The dose estimates include the radiological doses from routine activities and those from accidents. The doses are given in units of person-rem/1000 MTU. Operation of all facilities and equipment in the waste management system must meet stringent federal regulations that have been promulgated to assure adequate protection of the health and safety of the public, the environment and the workers. These regulations set maximum radiological dose limits to individual workers or members of the public. The basic federal regulation for public environmental radiation protection for operations in the uranium nuclear fuel cycle is in EPA's regulation 40 CFR 190. The basic NRC regulation that carries out the EPA's regulation is 10 CFR 20. The specific NRC regulations for operation of reactors is 10 CFR 50, for operation of an MRS facility is 10 CFR 72, for operation of the repository is 10 CFR 60, and for operation of the transportation system are 10 CFR 71 and 10 CFR 20.

Table E.1 provides a summary of the radiological dose impacts in the waste management system with and without an MRS facility. This table shows the unit radiological dose to occupational workers and to the public from the spent-fuel handling activities at the reactor, at the repository, at the MRS facility, and during transportation of spent fuel. The no-MRS case examines spent-fuel handling operations at the reactor, spent-fuel transportation to the repository

TABLE E.1. Comparison of Radiological Dose Elements With and Without an MRS Facility[a]

System	Occupational Dose (person-rem/1000 MTU)						Public Dose (person-rem/1000 MTU)					
	At Reactors[b]	Transport. from Reactors[c,d]	At MRS[e]	Transport. from MRS[c,d]	At Repository	Total	At Reactors	Transport. from Reactors[c,d]	At MRS	Transport. from MRS[c,d]	At Repository	Total
No-MRS System	77	34	--	--	63[f]	174	<1	164	--	--	6	170
System w/MRS	77	15	72[f]	<1	17	181	<1	71	6	3	<1	80

(a) For the reference waste management systems with and without an MRS facility.
(b) At-reactor occupational doses shown do not consider the reduced at-reactor spent-fuel handling and storage in a system with an MRS facility, which can accept spent fuel earlier than a no-MRS system.
(c) Assuming 3000 km average distance between reactors or MRS and the repository, and 1300 km distance from reactors to MRS.
(d) Assuming transport from reactors is 30% truck as general commerce and 70% rail as general freight, and transport from the MRS facility is 100% rail in 5-car dedicated trains.
(e) Does not include an estimated 20 person-rem/1000 MTU for emplacement and retrieval during interim storage, or 2 person-rem/1000 MTU/yr for maintenance/monitoring of interim storage because not all fuel handled is stored.
(f) Occupational doses at the MRS facility are higher than at the repository because of the extra step of shipping out the spent fuel at the MRS facility.

(30% by truck and 70% by rail), and repository operations (handling, consolidation, overpacking). The MRS case examines spent-fuel handling operations at the reactor, spent-fuel transportation to the MRS facility (30% by truck and 70% by rail), MRS operations (handling, consolidation), spent-fuel transportation to the repository (100% rail) and repository operations (handling, overpacking).

The addition of an integral MRS facility to the waste management system effectively transfers the functions for receiving and consolidating spent fuel from the repository to the MRS facility, and adds the extra spent-fuel handling and shipping step as well as some interim storage. This transfer of functions and addition of activities, however, is not expected to increase the total dose within the waste management system. As shown in Table E.1, the system occupational dose increases slightly but the public dose decreases by about a factor of two with an integral MRS facility. The net effect of adding an MRS facility to the system is a slight reduction in radiological doses.

The subsequent subsections discuss in more detail the radiological dose elements of the waste management system with and without an MRS facility, and present a perspective on the effects on radiological dose with implementation of potential changes in the system. These bases are used specifically for generic analyses in this appendix, and may not necessarily reflect currently preferred bases. (For example, single cargo capacities were selected for each size of cask investigated, taken from the range of capacities given in Appendix F.)

The following key bases and assumptions are used in this analysis:

- Spent fuel is from PWRs and each assembly contains 0.462 MTU (based on initial fuel content)
- Spent fuel is 10 years old since discharge from the reactor
- Radiation dose rate from transportation casks is near the regulatory maximum
- Shipments from reactors are 30%/70% by general commerce truck/general freight rail, respectively, on the basis of weight of the fuel material
- Shipments from the MRS facility are by 5-car dedicated trains.
- Reference truck cask has the capacity to carry 2 intact PWR fuel assemblies

- Reference rail cask (loaded weight, approximately 100 tons) has the capacity to carry 14 intact PWR fuel assemblies

- Overweight truck cask has the capacity to carry 4 intact PWR fuel assemblies

- Large, 150-ton rail cask has the capacity to carry 36 intact PWR fuel assemblies

- Reference storage casks, storage-transportation casks, and storage-transportation-disposal casks have the capacity to hold 14 intact PWR fuel assemblies

- Consolidation increases the cask capacity for spent fuel by a factor of 2

- Consolidation results in nonfuel component hardware that is transported in canisters in spent-fuel casks at the equivalent of 9.24 MTU/reference truck cask and 46.2 MTU/reference rail cask. (This is equivalent to one volume of nonfuel component hardware to each 10 volumes of intact fuel.)

- Marshalling of rail cars from reactors results in dedicated trains with 5 casks

- The average transport distance between the reactors or the MRS facility and the repository is 3000 km; the average transport distance between the reactors and the MRS facility is 1300 km.

Further details of the bases used are given in the analyses discussed in the subsequent sections.

E.1 COMPARISON OF MRS AND NO-MRS SYSTEMS

At present, sufficient data do not exist to allow a comprehensive analysis of the system radiological dose implications of adding an MRS facility to the waste management system. However, preliminary analyses have been done using available data and models, and simplifying assumptions to derive generic information that is useful in comparing radiological doses in the waste management system with and without an MRS facility. Comparisons have been made between a reference system with an MRS facility and for a reference system without an MRS facility. The results are discussed in the following sections.

E.1.1 No-MRS System

The no-MRS case examines spent-fuel handling operations at the reactor, spent fuel transportation to the repository (30% by truck and 70% by rail), and repository operations (handling, consolidation, overpacking).

At-Reactor Spent-Fuel Operations

For the reference case, the at-reactor spent-fuel operations consist of receiving a shipping cask, transferring the cask to the spent-fuel storage pool, loading the cask, decontaminating the cask, transferring the cask to the shipping vehicle, and moving the vehicle with the cask to the site boundary. The potential occupational and public radiation doses are estimated for these operations. For comparative purposes, the doses are estimated on the basis of person-rem/1000 MTU for both occupational and public radiological dose.

The occupational dose estimates are based on existing operational data for the NAC-1 truck cask (with capacity of 1/2 PWR/BWR assemblies) and the IF-300 rail cask (with capacity of 7/18 PWR/BWR assemblies) as reported by Lambert et al. (1981). The calculated occupational doses are adjusted to reflect the sizes and characteristics of the reference casks in this analysis. The following unit occupational dose factors are estimated for the at-reactor cask handling and loading operations:

	Unit Occupational Dose (person-rem/1000 MTU)	
Operation	Truck	Rail
Cask received at reactor	1.0	0.3
Cask washed and sampled	9.2	3.3
Cask to set-down pad	5.7	1.2
Cask transferred into pool and loaded	10.0	4.5
Cask transferred to decon and decon'd	110.4	25.9
Cask transferred to vehicle and shipped out	27.1	5.3
Total	163	40

Applying the 30%/70% truck/rail shipment ratio to the above results, the occupational dose from at-reactor cask-handling and loading operations is estimated to be 77 person-rem/1000 MTU.

The routine public dose commitments from all operations at individual commercial nuclear reactors are typically less than 1 person-rem/year (Baker and Peloquin 1981). The public dose associated with only the handling of spent fuel in preparation for transport will be a small fraction of this value. DOE (1978) presents estimates of the routine public dose commitments from an independent spent-fuel storage basin. A total body dose commitment to the population of 1.4 person-rem per year is estimated for a facility with a capacity of 2000 MTU per year, resulting in an estimate of 0.7 person-rem/1000 MTU. Because of the similarity in operations, this value is assumed to apply to at-reactor spent-fuel handling operations.

The typical credible off-normal event used to predict the public dose for accident conditions during spent-fuel handling is the potential drop and rupture of a spent-fuel assembly. The spent-fuel assembly drop accident is assumed to occur in the reactor pool during loading of the fuel into a transportation cask. Erdman et al. (1979) present an analysis of accident doses for a fuel storage pool along with other fuel cycle facilities. The frequency of a fuel assembly drop and rupture is estimated to occur 0.012 times per year for a facility handling 2000 MTU per year. A public dose estimate of 0.001 person-rem per plant year is reported. This is equivalent to 0.0005 person-rem/1000 MTU. Because of the similarity in operations, this value is assumed to apply to reactor spent-fuel handling operations.

Transportation from Reactors

For the reference case, spent fuel is assumed to be transported from the reactors to the repository in the reference truck or rail cask. Transportation unit dose factors have been developed at Sandia National Laboratories.[a] Table E.2 summarizes these factors for rail and truck shipments for occupational and public radiological exposures. It is assumed that the shipping route traverses 75% rural, 24% suburban, and 1% urban areas for truck transport and 75%, 23%, and 2% for rail transport, respectively (generalized values from Appendix F). Shipping 1000 MTU of spent fuel to the repository results in 3 million MTU-km. Using the above assumptions, the occupational dose for shipping 1000 MTU of spent fuel to the repository by truck and rail is estimated to be 100 person-rem and 5 person-rem, respectively. The public dose (sum of the routine and accident dose) for truck and rail shipment is estimated to be 528 person-rem and 8 person-rem, respectively. Applying the 30%/70% truck/rail shipment ratio, the occupational dose for shipping 1000 MTU of spent fuel from reactors to the repository is estimated to be 34 person-rem, and the public dose is estimated to be 164 person-rem.

(a) Cashwell, J., K. S. Neuhauser and P. C. Reardon. 1985 (draft). Transportation Impacts of the Commercial Radioactive Waste Management Program. SAND85-2715, TTC-00633, Sandia National Laboratories, Albuquerque, New Mexico.

TABLE E.2. Unit Dose Factors for General Freight Rail and General Commerce Legal-Weight Truck Shipments of Unconsolidated Spent Fuel[a] from Reactors

Type of Shipment	Hazard Group	Population Zone	% of Travel in Pop. Zone	Unit Dose Factor[b] — To MRS Facility: person-rem/ 1.3E6 MTU-km[c]	Unit Dose Factor[b] — To MRS Facility: Weighted person-rem/ 1.3E6 MTU-km[c,d]	Unit Dose Factor[b] — To Repository: person-rem/ 3E6 MTU-km[c]	Unit Dose Factor[b] — To Repository: Weighted person-rem/ 3E6 MTU-km[c,d]
Legal-Weight Truck	Routine Occupational	Rural	75	33.06		76.30	
		Suburban	24	72.46	43.4	167.21	100.2
		Urban	1	121.00		279.22	
	Routine Public	Rural	75	199.78		461.03	
		Suburban	24	306.71	227.6	707.79	525.3
		Urban	1	419.26		967.52	
	Accident Public	Rural	75	0.003		0.006	
		Suburban	24	5.25	1.3	12.11	3.1
		Urban	1	8.58		19.81	
	Total Public	All	--	--	228.9	--	528.4
Single Rail Cask as General Freight Rail	Routine Occupational	Rural	75	2.15		4.96	
		Suburban	23	2.15	2.2	4.96	5.0
		Urban	2	2.15		4.96	
	Routine Public	Rural	75	1.16		2.67	
		Suburban	23	7.74	2.7	17.85	6.3
		Urban	2	2.59		5.98	
	Accident Public	Rural	75	0.001		0.002	
		Suburban	23	2.79	0.78	0.45	1.8
		Urban	2	6.75		15.58	
	Total Public	All	--	--	3.5	--	8.1

(a) The dose factors shown are from Cashwell (Cashwell, J., K. S. Neuhauser and P. C. Reardon. 1985 (draft). Transportation Impacts of the Commercial Radioactive Waste Management Program. SAND85-2715, TTC-00633, Sandia National Laboratories, Albuquerque, New Mexico), using the population zone assumptions shown.

(b) Accuracy of some numbers is less than indicated by the number of significant figures shown, but numbers are retained for consistency in subsequent calculations.

(c) Cask capacities are 6.47 MTU/rail shipment and 0.924 MTU/truck shipment; based on 14 PWR assemblies/rail cask and 2 PWR assemblies/truck cask. 1.3E6 MTU-km (or 1.3 million MTU-km) is for 1000 MTU transported 1300 km; 3.0E6 MTU-km (or 3 million MTU-km) is for 1000 MTU transported 3000 km.

(d) Overall value weighted for the percentage of travel in each population zone.

At-Repository Spent Fuel Operations

Without an MRS facility in the system, the repository will receive spent fuel by truck or rail, consolidate the spent fuel, encase it in disposal containers, and place the containers in a transfer cask. The potential occupational and public radiation doses are estimated for these repository surface operations.

The occupational radiation doses for repository spent-fuel receipt and unloading are assumed to be identical to those for operations as currently designed for the proposed MRS facility. Occupational dose for cask receipt and unloading is directly related to the time and personnel requirements for each operation and the respective radiation dose rates. The operating times and dose rates used in this analysis are based on the values reported for the MRS facility by Parsons (1985) and Chockie et al. (1985). The following unit occupational radiation dose factors are estimated:

	Unit Occupational Dose (person-rem/1000 MTU)	
Operation	Truck	Rail
Cask inspection	5.6	1.0
Transfer to cask handling	10.6	1.8
Off-load cask to facility cart	48.3	9.1
Prepare cask for unloading	51.4	9.3
Mate cask to cell	17.2	3.1
Unload cask	0.1	0.1
Remove and ship out empty cask	2.5	0.4
Total	136	25

Application of the 30%/70% truck/rail shipment ratio to the above results gives an average at-repository occupational dose of 58 person-rem/1000 MTU for cask receipt and unloading.

The additional spent-fuel handling operations in the surface facilities at the repository include consolidation of the spent-fuel assemblies, placement into a disposal container and placement of the container into a transfer cask for subsequent handling and emplacement. The spent-fuel consolidation operations at the repository will create an additional waste stream consisting of the hardware associated with the spent-fuel assemblies (nonfuel-bearing components, NFBC). The impact of this additional waste stream must be included in estimating the occupational exposure. The ratio of canisters of PWR spent fuel to canisters of NFBC given by Parsons (1985) is used in this analysis. The following unit occupational dose factors are estimated for consolidation and packaging of spent fuel and NFBC:

Operation	Unit Occupational Dose (person-rem/1000 MTU)
Consolidate spent fuel	3.6
Consolidate NFBC	1.1
Place in transfer casks and transfer out	<0.1
Total	5

Addition of this dose to those in the prior listing gives a total estimated occupational dose from at-repository spent-fuel receipt and consolidation operations of 64 person-rem/1000 MTU.

Under normal operating conditions at the repository, the primary sources of routine effluents are airborne releases from the venting of spent-fuel casks and consolidation of spent fuel. These releases are expected to be similar to those of the MRS facility. Studies performed in support of the MRS Environmental Assessment (see Part 2, Volume 2) estimate a 50-year dose commitment from an annual release for cask venting and consolidation operations of 20 person-rem to the surrounding population. This estimate is for an MRS facility operating at 3600 MTU/year. On a 1000 MTU basis, this dose commitment is approximately 6 person-rem per 1000 MTU. Because of the similarity in operations, this value is assumed to apply to at-repository spent-fuel operations. Since the repository will likely have a lower surrounding population density than the MRS facility, this estimate represents an upper bound of the public radiation exposure from routine releases resulting from repository preclosure operations.

The MRS Environmental Assessment (see Volume 2, Part 2) investigated potential radiological consequences from MRS operations. For the sealed storage cask design, the accident identified as resulting in the greatest total body dose to the public is that of dropping a spent-fuel assembly with subsequent assembly breakage and release. This accident was estimated to give a population dose of 0.03 person-rem, and should occur less than once per year. For the MRS operating at the rate of 3600 MTU/yr, this gives a population dose of 0.008 person-rem/yr on a 1000 MTU basis.

Erdmann et al. (1979) estimate repository preclosure radiological accident doses from the handling of spent fuel associated with generating one gigawatt-year of electricity. Erdmann's estimated total dose due to potential accidents during repository preclosure operations is 0.00005 person-rem/GWe-year. Assuming a plant at 70% operating efficiency and 30 MTU/year of spent-fuel discharge and handling for a reactor with a capacity of 1 GWe, an estimate of 0.0009 person-rem/1000 MTU is obtained for the population accident dose associated with repository preclosure operations. These two results confirm an expected public dose from accidents at repository surface facilities of less than 1 person-rem/1000 MTU.

E.1.2 MRS System

The MRS case examines spent-fuel handling operations at the reactor, spent-fuel transportation to the MRS facility, MRS operations (cask handling, consolidation, some interim storage), spent-fuel transportation to the repository in dedicated trains and repository surface operations (cask handling, applying disposal container).

At-Reactor Spent-Fuel Operations

The addition of an MRS facility to the waste management system will not significantly affect at-reactor spent fuel operations. The at-reactor occupational and public dose estimates given in Section E.1.1 also apply to the system with an MRS facility.

Transportation from Reactors

Spent fuel is assumed to be transported from the reactors to the MRS facility in the reference truck or rail casks. The transportation dose factors and assumptions developed in Section E.1.1 are applicable to this case. However, the central location of the MRS facility results in an approximate average distance of 1300 km between the reactors and the MRS facility, compared to an average distance of 3000 km between the reactors and the repository. This will result in a decrease in the occupational and public doses from transportation for this step. The occupational dose for shipping 1000 MTU of spent fuel to the MRS facility by truck and rail is estimated to be 43 person-rem and 2 person-rem, respectively. The public dose (sum of the routine and accident dose) for truck and rail shipment is estimated to be 229 person-rem and 4 person-rem, respectively. Applying the 30%/70% truck/rail shipment ratio, the occupational dose for shipping 1000 MTU of spent fuel to the MRS facility is estimated to be 15 person-rem and the public dose is estimated to be 71 person-rem.

MRS Facility Operations

The MRS facility will receive spent fuel by truck or rail, unload the spent fuel, consolidate and canister the spent fuel, and load the consolidated spent fuel into transportation casks for shipment to the repository (as well as placing in and retrieving from the storage area up to 15,000 MTU of spent fuel).

The occupational radiation exposures for spent-fuel receipt and unloading at the MRS facility were discussed and calculated doses were given in Section E.1.1 (the repository spent-fuel receipt and unloading operations are assumed to be the same as those of the conceptual design of the proposed MRS facility). Application of the 30%/70% truck/rail shipping ratio to these dose estimates, the occupational dose from MRS facility spent-fuel receipt and unloading is estimated to be 58 person-rem/1000 MTU.

The additional spent-fuel handling operations at the MRS facility include consolidation, preparing the shipping cask for loading, loading the cask and placing the cask on the shipping vehicle. The occupational doses from both the consolidated spent fuel and the nonfuel-bearing components are included. Three PWR fuel assemblies are assumed to be consolidated into one canister and the hardware from ten fuel assemblies are compacted into one 55-gallon drum. All shipments from the MRS facility are by rail. The following unit occupational dose factors are estimated for at-MRS consolidation:

Operation	Unit Occupational Dose (person-rem/1000 MTU)
Consolidate spent fuel	3.6
Consolidate NFBC	1.1
Transfer canisters to lag storage	<0.1
Total	5

The first two operations are the same as the comparable operations at the repository discussed earlier, whereas the latter operation is different.

The following unit occupational doses are estimated for at-MRS loading of consolidated and canistered fuel rods:

Operation	Unit Occupational Dose (person-rem/1000 MTU)
Inspect and transfer shipping cask	0.2
Prepare cask for loading	0.9
Mate cask to cell	0.5
Move canisters to load-out cell and load cask	<0.1
Remove cask and decon	0.9
Prepare cask to exit and ship out	6.8
Total	9

The sum of the unit occupational dose estimates for the cask receiving and handling, consolidation, and cask shipment operations at the MRS facility gives an estimate of 72 person-rem/1000 MTU.

The MRS facility is designed to store up to 15,000 MTU of spent fuel in interim storage. The handling and monitoring activities associated with this interim storage will add to the occupational dose estimates given above. If the interim-storage facility is full, it will contain 1496 casks of consolidated spent fuel, intact spent fuel and nonfuel-bearing components (Parsons 1985). The monitoring activities of interest are those associated with the annual material accountability and routine quarterly cask monitoring. The cask handling operations include those operations involved in moving and placing the cask in interim storage and returning the cask to the MRS handling facilities. Using the inventories and dose rates given in Parsons (1985) along with assumptions on the number of individuals and operating times to conduct these operations, estimates are made of the occupational doses for conducting these activities. The estimated occupational dose for maintenance/monitoring of interim storage is 2 person-rem/1000 MTU per year. The estimated occupational dose associated with emplacement and retrieval of spent fuel in interim storage is 20 person-rem/1000 MTU.

Under normal operating conditions at the MRS facility, the primary sources of routine effluents are airborne releases from the venting of spent-fuel casks and consolidation of spent fuel. Studies performed in support of the MRS Environmental Assessment (see Part 2, Volume 2) estimate a 50-year dose commitment from an annual release due to cask venting and consolidation operations of 20 person-rem to the surrounding population. This estimate is for an MRS facility operating at 3600 MTU per year. This dose commitment is approximately 6 person-rem/1000 MTU.

Studies performed in support of the MRS Environmental Assessment postulate three major potential accident scenarios at the reference MRS facility. These accidents and their resultant radiological dose commitments are:

Accident	Radiological Dose (Total Body Population Dose)
Fuel Assembly Drop	0.03 person-rem
Shipping Cask Drop	0.006 person-rem
Storage Cask Drop	0.006 person-rem

The frequency of the spent-fuel drop with a release is estimated to be no more than once per year. The frequencies of the latter two accidents are estimated to be very low in the MRS Environmental Assessment. In examining the consequences, the total dose from these postulated operations is less than 1 person-rem/1000 MTU even if the frequencies of these accidents are assumed to be as high as one per year. Because the frequencies of the shipping cask drop and storage cask drop accidents will be much smaller than the frequency of a fuel assembly drop, the dose from a fuel assembly drop is used to estimate the public dose from these accidents. As discussed in Section E.1.1 the frequency of a fuel assembly drop and rupture, multiplied by the consequence of a fuel assembly drop, results in an effective public dose estimate of much less than 1 person-rem/1000 MTU.

Transportation from the MRS Facility

For this case, consolidated spent fuel is assumed to be shipped to the repository by five-car, dedicated train shipments using the reference 100-ton rail cask in this appendix. Transportation unit dose factors have been developed at Sandia National Laboratories.[a] Table E.3 summarizes dose factors for unconsolidated spent fuel shipped by single-cask loads as general freight rail, and five-cask dedicated trains. For consolidated spent fuel, the routine dose values need to be divided by a factor of two to account for the decrease in the number of shipments for consolidated spent fuel. Sandia National Laboratories also provides dose factors for shipping the nonfuel-bearing components associated with the consolidated spent fuel.[a] The dose factors for rail shipments of NFBC contribute less than 1 person-rem/1000 MTU to the spent fuel dose factors. Using these and the other assumptions described in Section E.1.1, the occupational dose for shipping 1000 MTU of consolidated spent fuel to the repository is estimated to be less than 1 person-rem and the public dose (sum of the routine and accident dose) is estimated to be 3 person-rem.

At-Repository Spent-Fuel Operations

The repository will receive consolidated spent fuel and nonfuel-bearing components by rail, place this material in the disposal container and place the containers in the repository. The potential occupational and public radiation dose exposures are estimated for these operations.

For this analysis it is assumed that the receiving and handling operations at the repository are identical to those of the conceptual design of the proposed MRS facility. The following unit occupational radiation dose factors are estimated:

Operation	Unit Occupational Dose (person-rem/1000 MTU)
Cask inspection	0.6
Transfer to cask handling	1.1
Off-load cask to facility cart	5.8
Prepare cask for unloading	5.9
Mate cask to cell	2.0
Unload cask	<0.1
Remove, decon and ship out empty cask	0.3
Total	16

(a) Cashwell, J., K. S. Neuhauser and P. C. Reardon. 1985 (draft). Transportation Impacts of the Commercial Radioactive Waste Management Program. SAND85-2715, TTC-00633, Sandia National Laboratories, Albuquerque, New Mexico.

TABLE E.3. Unit Dose Factors for General Freight Rail and Five-Car Dedicated Train Shipments of Unconsolidated Spent Fuel[a] from an MRS Facility

Type of Shipment	Hazard Group	Population Zone	% of Travel in Pop. Zone	Unit Dose Factor[b] person-rem/ 3E6 MTU-km[c]	Unit Dose Factor[b] Weighted person-rem/ 3E6 MTU-km[c,d]
Single Rail Cask as General Freight Rail	Routine Occupational	Rural	75	4.96	
		Suburban	23	4.96	5.0
		Urban	2	4.96	
	Routine Public	Rural	75	2.67	
		Suburban	23	17.85	6.3
		Urban	2	5.98	
	Accident Public	Rural	75	0.002	
		Suburban	23	6.45	1.8
		Urban	2	15.58	
	Total Public	All	--	--	8.1
Five-Car Dedicated Train	Routine Occupational	Rural	75	0.310	
		Suburban	23	0.310	0.31
		Urban	2	0.310	
	Routine Public	Rural	75	0.386	
		Suburban	23	15.58	3.9
		Urban	2	3.70	
	Accident Public	Rural	75	0.003	
		Suburban	23	4.58	1.3
		Urban	2	11.04	
	Total Public	All	--	--	5.2

(a) The dose factors shown are derived from Cashwell (Cashwell, J., K. S. Neuhauser and P. C. Reardon. 1985 (draft). Transportation Impacts of the Commercial Radioactive Waste Management Program. SAND85-2715, TTC-00633, Sandia National Laboratories, Albuquerque, New Mexico), using the population zone assumptions shown.

(b) Accuracy of some numbers is less than indicated by the number of significant figures shown, but numbers are retained for consistency in subsequent calculations.

(c) Cask capacities are 6.47 MTU/rail shipment and 0.924 MTU/truck shipment; based on 14 PWR assemblies/rail cask and 2 PWR assemblies/truck cask. 3.0E6 MTU-km (or 3 million MTU-km) is for 1000 MTU transported 3000 km.

(d) Overall value weighted for the percentage of travel in each population zone.

The additional spent-fuel handling operations at the repository include placement of the consolidated spent fuel and nonfuel-bearing components into their respective disposal containers and placement of the containers into a transfer cask. The following unit occupational radiation dose factors are estimated:

Operation	Unit Occupational Dose (person-rem/1000 MTU)
Inspect and transfer container	0.2
Prepare container for loading	0.2
Mate container to cell	0.1
Load and seal container	0.4
Lift into transfer cask	<0.1
Total	1

The sum of the unit occupational dose estimates for the cask receiving, and overpacking and emplacement operations yields a total estimate of 17 person-rem/1000 MTU.

The public dose from routine releases and accidents will be similar to those presented in Section E.1.1. However for this case, no consolidation operations occur at the repository. Waite (1984) presents an estimate of public doses from normal preclosure operations for a repository at various salt sites. The highest value reported for no-consolidation operations is 0.0028 person-rem for a 70-year total body dose commitment for a repository receiving 3000 MTU per year. This results in an estimate of public doses from routine releases of approximately 0.001 person-rem/1000 MTU.

The dose from potential accidents during repository preclosure operations is given in Section E.1.1. The accident dose to the public for repository preclosure operations is estimated to be 0.0009 person-rem/1000 MTU.

E.1.3 Summary of Dose Impacts for MRS and No-MRS Systems

A summary of the preliminary estimates of radiological doses for the reference waste management systems in this study with and without an MRS facility was given in Table E.1. Approximate doses are given for workers in the waste management system and for the public for system activities at the reactor sites, at the MRS facility, at the repository (surface activities only), and during the transportation steps.

The system activities at the reactor involve the loading of spent fuel into transportation casks and the preparation of the loaded transportation casks for shipping. The activities at the MRS facility involve the receipt of the spent fuel in transportation casks, unloading the spent fuel from these casks, consolidating and canisterizing the spent fuel, loading the consolidated spent fuel into transportation casks for shipping, (as well as placing in and retrieving from interim storage, up to 15,000 MTU of spent fuel). The surface activities at the repository involve the receipt of spent fuel in transportation casks, unloading the spent fuel from these casks, consolidating and placing the spent fuel in a disposal container (for the case without an MRS facility) or placing the canistered spent fuel into a disposal container (for the case with an MRS facility), and handling the disposal container in preparation for emplacing it in the repository. The transportation activities include all those that take place outside the fences of the reactor, MRS facility, and repository sites. These are: moving the spent-fuel casks from the origination point to the destination, changing trains or prime mover vehicles, inspection, monitoring, safeguarding, marshalling more than one vehicle (for shipments from an MRS facility), and stopping for traffic considerations.

Occupational Dose

The occupational radiological doses from various operations at the MRS facility have been estimated from the designs that have been completed to date. The occupational doses from comparable activities at the repository are estimated to be the same as at the MRS facility, and from noncomparable activities were estimated separately. The occupational doses from waste management system-related activities at reactors were estimated from available data and analyses. The occupational doses due to transportation activities were estimated from results of transportation studies done at Sandia National Laboratories.

Occupational radiological doses at the fixed facilities in the waste management system are dominated by cask handling activities, which are outside of remotely-operated hot cells, and require close proximity of the workers to the casks. In-cell operations at an MRS facility or repository benefit from the very thick shield walls that have been designed to reduce the radiation fields in the working areas to very low levels. Shipping casks are designed to reduce the radiation from their contents to safe levels, but these levels are higher than those for fixed facilities. Conventional designs of cask handling facilities require a significant amount of hands-on activities during cask handling. Occupational doses due to transportation result from exposure of the workers (i.e., drivers, inspectors, safeguards and security staff, railyard workers, etc.) to the low levels of radiation emanating from the loaded transportation casks.

As shown in Table E.1, the system occupational radiological dose increases slightly in a waste management system with an MRS facility, mostly because of the added handling step and cask load-out at the MRS facility.[(a)] As noted in a footnote to the table, there is some additional exposure due to sealed storage cask handling and monitoring activities associated with up to 15,000 MTU of interim storage. These dose values do not reflect the potential for further occupational dose reduction through the use of more remote operations (such as increased use of robotics) made possible by the use of uniform payloads and casks with an MRS facility in the system.

The increased radiological occupational dose at the MRS facility is partly compensated by reduced transportation occupational dose and reduced occupational dose at the repository. The reduced occupational dose during transportation from the reactors is due to the shorter shipping distances to the centrally-located MRS facility, rather than to the more distant repository. The low occupational dose during transportation from the MRS facility is due to the exclusive use of large rail casks in combination with multi-car dedicated trains, compared to the use of a mixture of rail and truck casks for some shipments from reactors to the repository. The resultant total occupational radiological dose from transportation with an MRS facility in the waste management system is estimated to be reduced to about half that without an MRS facility.

The occupational radiological dose at the reactor should not change significantly whether or not there is an MRS facility, except to the extent that the early receipt capability of the MRS facility would eliminate some additional spent-fuel storage at reactors that would otherwise require in-pool consolidation or extra handling of spent-fuel storage casks outside of the reactor building. Both processes would have occupational exposures associated with them.

Public Dose

The radiological doses to the public from the activities at the proposed integral MRS facility have been estimated for the designs that have been completed to date. The radiological doses to the public from activities at the repository are assumed to be the same as those for comparable activities for the conceptual design of the proposed MRS facility, and are estimated from available data for other surface activities. The doses to the public from waste management system-related activities at reactors have been estimated

(a) The increase in occupational dose is due to the increased number of radiation workers required to perform the additional tasks, with each worker receiving no more than the maximum permissible dose.

from available data. The public doses due to transportation activities were estimated from results of transportation studies done at Sandia National Laboratories.[a]

Radiological dose to the public at the fixed facilities in the waste management system is dominated by doses resulting from airborne effluents from these facilities. These effluents contribute to public dose by direct radiation, by inhalation of the effluents, and by ingestion of foodstuffs that contain deposits from the effluents. Typically, only nonmeasurable public dose results from direct radiation from the fixed facilities. Radiological dose to the public from transportation activities results from exposure of the nearby public to the low levels of external radiation emanating from the loaded transportation casks. The public dose contribution from accidents (the sum of the frequency of accidents times their respective consequences) is not significant relative to the routine dose for fixed facilities and is much lower than the routine dose from transportation.

To place the public dose given in Table E.1 (80 to 170 person-rem/1000 MTU) in perspective, the radiological dose from background radiation to the public of about 1,000,000 people surrounding the preferred MRS facility site within a 50-mile radius is approximately 150,000 person-rem/year. As shown in the table, the low system radiological dose to the public is reduced by adding an MRS facility to the waste management system. This is primarily because of the significant reduction in transportation dose due to the shorter transportation distance between the reactors and the centrally located MRS facility and the improved transportation system from the MRS facility to the more distant repository. The resultant total radiological dose to the public from transportation with an MRS facility in the waste management system is less than half of that without an MRS facility.

The public dose from an MRS facility in Table E.1 is taken from analyses performed in support of the MRS Environmental Assessment (see Volume 2, Part 2). This dose is from airborne effluents, primarily from the venting and unloading of incoming transportation casks and from the spent-fuel disassembly and consolidation operation. Venting of the transportation casks will release to the MRS facility ventilation system some airborne radioactivity from leaking spent-fuel elements.

It is assumed that the public dose due to surface activities at the repository for the case without an MRS facility will be the same as at the pro-

(a) Cashwell, J., K. S. Neuhauser and P. C. Reardon. 1985 (draft). Transportation Impacts of the Commercial Radioactive Waste Management Program. SAND85-2715, TTC-00633, Sandia National Laboratories, Albuquerque, New Mexico.

posed MRS facility. This actual dose will be somewhat different because the affected population will be somewhat different at the repository site. The public dose from surface activities at the repository for the case with an MRS facility in the system will be extremely low because the primary source of public dose, handling and processing of individual spent fuel assemblies, would be reduced.

While the total public dose from transportation is reduced with an MRS facility in the waste management system, some areas would experience a net increase in the number of spent-fuel shipments and an increase in local public dose. These areas would be around the MRS facility and along the transportation corridors to and from the MRS facility. On the other hand, the areas in and near the transportation corridors between the bulk of reactors in the east and the candidate repository sites in the west would experience far fewer shipments and lower dose.

The radiological dose to the public from reactor operations is very low and should not change significantly whether or not there is an MRS facility, because activities there do not change between the reference cases.

E.2 SENSITIVITY TO ASSUMPTIONS AND NO-MRS SYSTEM CONFIGURATION

The radiological doses to the public and the waste management system worker are low whether or not an MRS facility is in the system. Alternative system configurations, however, may be possible that could offer the potential for further reduction of the dose. Some preliminary analyses were performed on potential changes in system configuration to obtain a perspective on the potential for reduction of radiological dose. Although these analyses were performed for system configuration options without an MRS facility, many of the options could be applicable to a system with an MRS facility but with somewhat different dose changes. These preliminary analyses are summarized here. The assessments of the feasibility or other considerations of implementating these potential options are discussed in Appendix A.

The potential changes in the waste management system (without an MRS facility) that were evaluated on a preliminary basis are:

1. All reactors that can not ship by rail (i.e., rail-limited reactors) are modified to ship by rail.

2. All truck shipments from rail-limited reactors are made in overweight trucks.

3. Rail-limited reactors wet load into rail casks that are heavy-hauled by truck to the nearest practical rail head for transfer to a rail car and transport by rail the rest of the way to the repository.

4. Reactors with rail shipment capability ship in extra large (150-ton) rail casks.

5. Rail shipments are marshalled at each reactor (that can ship by rail), then shipped in multi-car dedicated trains to the repository.

6. Rail shipments from reactors are sent to offsite marshalling points where they are combined into multi-car dedicated trains to the repository.

7. Reactors perform consolidation of spent fuel and place fuel rods in canisters.

8. All at-reactor dry storage is not in transportable rail casks, and transfer to transportation casks is by dry transfer.

9. All at-reactor dry storage is in transportable rail casks.

It should be noted that most of these potential changes are not applicable to all reactors. Thus, application of these preliminary unit dose factors for specific changes in the system requires normalization of the unit dose factors to account for the applicable portion of the waste management system. Also, some of the potential changes could be combined (e.g., at-reactor consolidation plus use of larger transportation casks) but impacts of such combinations were not evaluated.

The estimation of the unit doses for these alternative waste management system configurations were taken to a large extent from those for the comparison of the reference study systems given in Section E.1. Additional cases were evaluated by extension of the rationale and methodology used for the assessments in Section E.1. Again, the values are useful in making comparisons of alternative system configurations, but should not be taken as absolute for specific systems.

An overall numerical summary of the preliminary evaluations is given in Table E.4. The table identifies the potential system changes investigated and the occupational and public radiological dose impacts at the reactor, at the repository, and during transportation. The first column gives the reference or base condition, and the second column gives the potential change. The next column gives the approximate percent of spent fuel to which the potential

TABLE E.4. Preliminary Unit Dose for Reference and for Possible Changes in Waste Management System Without MRS

System Configuration, Reference to Potential New[a]		Approx. % of Spent Fuel that Change Could Apply	Unit Dose, person-rem/1000 MTU											
			Occupational						Public					
			At-Reactor		At-Repository		Transportation[b]		At-Reactor		At-Repository		Transportation[b]	
Reference	Potential New		Ref	New	Ref	New	Ref	New	Ref	New	Ref	New	Ref	New
1 Legal-Weight Truck	Rail Transport	30	163	40	141	30	100	5	<1	<1	6	6	528	8
2 Legal-Weight Truck	Overweight Truck Transport	30	163	83	141	73	100	72	<1	<1	6	6	528	378
3 Legal-weight Truck	Heavy-haul Truck + Rail Transport[c]	30	163	40	141	30	100	20	<1	<1	6	6	528	8
4 Conventional Rail Transport, 100-T Casks	Transport in 150-T Rail Casks	70[d]	40	17	30	15	5	2	<1	<1	6	6	8	4
5 Conventional Rail Transport, 100-T Casks	Marshalling 5 Rail Cars per Train at Reactor	70[d]	40	42	30	30	5	<1	<1	<1	6	6	8	5
6 Conventional Rail Transport, 100-T Casks	Marshalling 5 Rail Cars per Train AFR[e]	70[d]	40	40	30	30	5	1	<1	<1	6	6	8	7
7 Fuel Consolidation at Repository[f]	Fuel Consolidation at Reactors[f]	100	163 40	277 189	141 30	82 17	100 5	51 3	<1 <1	6 6	6 6	<1 <1	528 8	286 5
8 Wet Transfer from Dry Storage at Reactors[g]	Dry Transfer from Dry Storage at Reactors[g]	10	66	22	30	30	5	5	<1	<1	6	6	8	8
9 Dry Storage in Non-Transportable Casks at Reactors[g,h]	Dry Storage in Transportable Casks at Reactors[g]	10	66	16	30	30	5	5	<1	<1	6	6	8	8

(a) Based on no-MRS in the system, some values will change with MRS.
(b) Equivalent to 1000 MTU shipped an average of 3000 km.
(c) Heavy haul distance is assumed to be 20 km.
(d) Assumes applicability to all reactors with rail capability.
(e) Assume 100 km to marshalling yard.
(f) First number is for truck shipments; second is for rail.
(g) Assumes shipment by rail.
(h) Assumes wet transfer from dry storage at reactors.

change could apply (subsequent numbers in the table do not reflect this percent). The first column for at-reactor operations gives the unit occupational dose for the reference case (in person-rem/1000 MTU) and the second column gives that if the potential option were implemented. The next two columns give the same occupational dose information for at-repository operations, and the following two columns give the same occupational dose for transportation operations. The last six columns have the same information for the unit public radiological dose for at-reactor, at-repository and transportation operations.

The overall conclusions reached from these analyses are:

1. Most of the potential system changes investigated tend to reduce the unit radiological dose to the public and to the occupational personnel. This is generally because the amount of handling is reduced by the options. A notable exception to this is the option of consolidation at the reactors.

2. The public doses from the reference system activities at the reactor and the repository are very low; thus, impacts of any of the potential system changes on these doses is generally low.

3. The occupational doses resulting from most of the reference activities can be affected by most of the potential system changes investigated.

4. The largest contribution to unit radiological doses in the reference study system is from transportation in trucks, and thus the largest potential for dose reduction results from changing from use of reference legal-weight truck casks to larger casks where possible. This applies to public dose the most, but also significantly to occupational dose. Public dose is reduced because of the nearby public's exposure to the modest radiation levels from fewer shipments in larger capacity casks. Occupational dose is reduced because the occupational manpower per shipment does not change significantly with cask capacity, so fewer workers are exposed during the fewer shipments with high-capacity casks. Changing from use of reference truck casks to larger casks decreases dose throughout the system.

5. Reducing the number of transportation cask loads (i.e., increasing the cask cargo capacity) of spent fuel reduces the public and occupational dose in all cases. This applies when changing from legal-weight truck to over-weight truck, from truck to rail, or from reference rail to large rail casks. Changing from truck to rail casks

yields the most significant change; changing from reference rail casks to large rail casks yields little dose reduction because the dose from using the reference rail cask is quite low.

6. Marshalling rail cars away from the reactors to form multi-car dedicated trains has only a small effect on unit dose. This is largely because the dose from using rail transport is quite low without marshalling. Marshalling rail cars at the reactor site tends to increase dose somewhat, primarily because of the increase in occupational dose at the reactor site.

7. Consolidation of spent fuel at the reactors increases the radiological occupational dose for the consolidation activities compared to at-repository consolidation. This is because the repository will be designed to perform this function efficiently using heavily shielded hot cells, whereas it would be an add-on capability at the reactors. Transportation and at-repository fuel shipping occupational doses are reduced because of the fewer number of shipments resulting from at-reactor consolidation. Public radiological dose is reduced from at-reactor consolidation. This dose reduction is greater when the consolidated spent-fuel rods are shipped by truck than when shipped by rail.

8. Dry transfer at reactors from dry storage casks to transportation casks reduces the occupational dose somewhat compared to the conventional wet transfer because of the reduction in handling activities.

9. The use of transportable dry storage casks at the reactors reduces the occupational dose that would otherwise result from transferring spent fuel from dry storage casks for shipment offsite.

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APPENDIX F

ASSUMPTIONS AND METHODOLOGIES FOR TRANSPORTATION ANALYSES

APPENDIX F

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This appendix discusses the assumptions and methods used to calculate the costs and risks of transporting spent fuel from reactor sites to a repository site or to a monitored retrievable storage (MRS) facility, and from an MRS facility to a repository site.

Two transport legs (reactor to repository or MRS, and MRS to repository) were analyzed for various waste management system scenarios. In all scenarios a total of 62,000 MTU of spent fuel was shipped from individual reactor sites. Specific yearly amounts of spent fuel to be shipped from each reactor site were identified.

The total number of truck or rail shipments required to transport the spent fuel was calculated by dividing the number of fuel assemblies to be shipped by the assumed capacity for a truck or rail cask. Potential routes were then determined for truck and rail shipments from individual reactors to each of nine potential repository sites or to each of three candidate MRS sites, and for rail shipments from the MRS sites to the repository sites. The estimated distance for each of these routes, along with estimates of the population distribution along each route and unit risk factors for various types of risk, were used to calculate both the radiological and nonradiological risks for the projected shipments.

The estimates of the number of shipments from individual reactors were also used for estimating transportation costs. Assumed cask capacity, cask turnaround time, average cask availability, cask capital and maintenance cost and shipping cost data, in addition to the estimated distance for each trip, were used to calculate transportation costs.

Risk calculations were performed for several waste management system logistics scenarios. The key assumptions or parameters that were varied to define those alternatives are listed below:

- waste management system alternatives
  - system with an MRS facility
  - system without an MRS facility

- repository location alternatives (six first-repository locations were assumed to represent all nine potential first-repository locations)

- MRS facility location alternatives (two MRS facility locations were assumed to represent the three potential MRS facility locations)

- alternative assumptions for transport mode from reactor sites

  - 100% rail transport
  - 70% rail and 30% truck transport

- alternative strategies for disposal of fuel from western reactors

  - shipment direct to repository
  - shipment direct to MRS facility

- MRS packaging alternatives

  - consolidate spent fuel into canisters for insertion into disposal container at repository

  - consolidate spent fuel and place directly into disposal container

- MRS-to-repository cask-size alternatives

  - 100-ton rail cask
  - 150-ton rail cask

- MRS-to-repository train-configuration alternatives

  - general-freight service
  - dedicated train service

Transportation cost and risk were estimated for waste management system logistics scenarios for various combinations of these alternatives. The scenarios, the methodology, and the result of these analyses are described in the following sections.

F.1 LOGISTICS ASSUMPTIONS AND CALCULATIONS FOR THE WASTE MANAGEMENT SYSTEM

This section describes the logistics assumptions and calculations that were used as input for estimating the cost and risk of transporting spent fuel and associated wastes. Necessary inputs to these calculations include the fraction of shipments from reactors occurring by truck and rail, the truck and rail cask capacities for the various wastes forms to be shipped, the number of shipments from specific reactors for each scenario, and the distances between reactors and alternative MRS and repository sites. Assumptions for each of these topics are discussed below.

F.1.1 Spent-Fuel Logistics and Shipping-Mode Assumptions

The transportation system was divided into two separate and independent legs (reactors to repository or MRS facility and MRS facility to repository). For shipments of intact spent-fuel assemblies from reactors, two extreme sets of assumptions were assumed. One set assumed that 100% of the shipments would be made by rail and the other set assumed that 100% of the shipments would be made by truck. Actual operations would use a combination of these modes. Approximately 70% of existing or planned reactors have the capability to ship by rail. For calculations for this case, the logistics data for the all-rail and all-truck cases were weighted (70% rail and 30% truck) and then combined.

Two alternative scenarios for shipments from reactors were analyzed. The first assumed that fuel from all reactors would be shipped either directly to the repository or to the MRS facility. The second scenario assumed that fuel from western reactors (reactors within the states of Arizona, California, Oregon, and Washington) would be shipped directly to the repository and fuel from the eastern reactors would be shipped to the MRS site. In all scenarios 62,000 MTU of spent fuel would be shipped to the repository; for the second scenario, 9,000 MTU of spent fuel would be shipped directly to the repository.

Spent-fuel shipments from the MRS facility to the repository were assumed to contain consolidated spent fuel in either canisters or thicker-walled disposal containers. Two different types of rail casks were assumed for shipments between the MRS site and the repository (loaded weights of approximately 200,000 pounds and 300,000 pounds). The smaller casks were assumed for shipping consolidated spent fuel in disposal containers, while the larger casks were assumed for shipping canisters of consolidated fuel. This combination provides bounding estimates for shipping requirements from the MRS facility to the repository. Associated waste resulting from the consolidation process (e.g., spent-fuel hardware) was also assumed to be shipped from the MRS facility to the repository.

All shipments between the MRS facility and the repository were assumed to be by dedicated train (sole source commodity) containing five casks of spent fuel and a maximum of five additional cask-cars of associated waste products.

F.1.2 Numbers of Shipments from Reactors

The WASTES computer model (Shay et al. 1986) was used to calculate the number of shipments originating from reactors for each scenario. This model simulates the movement of spent fuel from its point of generation to its final destination. Shipment-handling characteristics and waste inventories at facilities (e.g., reactors, MRS facility, or repository) are specified by input parameters, which include expected cask loading and unloading rates, facility capacities, characteristics of the spent fuel, quantities of spent fuel requiring shipment, and packaging characteristics.

The assumed MRS facility and repository receiving rates are given in Table F.1. The quantities of spent fuel requiring shipment from individual reactors are calculated using spent-fuel data from the EIA mid-case projections for installed capacity and energy generation (Heeb et al. 1985). The amount of spent fuel to be shipped annually from each reactor site was identified by applying the following priorities:

1. Reactors experiencing a loss of full core reserve (FCR) capacity within a given year were given highest priority.

2. Reactors undergoing decommissioning were given priority, beginning two years after their last year of operation.

3. The oldest fuel remaining at reactors was given next priority.

At this time, future cask designs are not fully defined. The cask capacities that were used in this analysis are summarized in Table F.2. Capacities are shown for casks used to transport intact spent-fuel assemblies from reactors to an MRS facility or a repository, and for the various casks assumed for MRS facility to repository shipments. The variation in cask capacity for these latter shipments reflects the two cask sizes (100 and 150 ton), and the variation in the size of the disposal container assumed for each repository medium.

The calculations performed by the WASTES model assume that all casks are fully loaded. Because truck and rail cask capacities differ, the shipment requirements are affected by the assumed transport mode. Table F.3 shows the total numbers of shipments from individual reactors for both the 100% truck and 100% rail transport modes and three waste management system scenarios. These three scenarios correspond to all spent fuel going to the MRS facility, only eastern spent fuel going to the MRS facility, and all spent fuel going directly to the repository.

F.1.3 Transport Distances

All spent fuel from the reactors was assumed to be shipped as unconsolidated assemblies directly to the potential repository or MRS sites. Table F.3 lists the reactors used in these analyses.

Two of the MRS sites and several of the potential repository sites are closely clustered. For the MRS facility, the Oak Ridge and Clinch River sites in Tennessee are such a cluster. For the repository three such pairs of sites are Cypress Creek and Richton in Mississippi; Deaf Smith County and Swisher County sites in Texas; and Davis Canyon and Lavender Canyon sites in Utah. Each of these pairs has been treated as a single location for calculating distances. Thus, the following two MRS and six repository sites have been used in this analysis:

- MRS Sites
  - Hartsville in Tennessee
  - Oak Ridge/Clinch River in Tennessee
- Repository Sites
  - a point in the gulf interior region (GIR) near the Cypress Creek and Richton sites
  - the Vacherie site in Louisiana, which is also in the GIR, has been treated as a distinct destination point because it is too far from the other GIR sites to be included in the site cluster
  - a point in the Permian Basin near the Deaf Smith County and Swisher County sites
  - a point in the Paradox Basin near the Davis Canyon and Lavender Canyon sites
  - the Yucca Mountain site in Nevada
  - the Hanford Reservation site in Washington State.

Distances for truck shipments were calculated using the HIGHWAY routing model (Joy et al. 1982) and distances for rail shipments were calculated using the INTERLINE model (Joy et al. 1981). The HIGHWAY model is designed to simulate routes on the highway system in the United States. Its data base includes all interstates, most U.S. highways, and many roads with state, county, and local classifications. It represents approximately 240,000 miles of roadway. In the HIGHWAY and INTERLINE codes, several routing options may be selected. To derive routes for this analysis, truck routes were assumed to use the interstate highway system, except for travel between the interstate and the MRS facility or repository. No additional constraints associated with state or local restrictions on the shipment of radioactive materials were assumed in the highway routing analysis.

The INTERLINE model is designed to simulate routing on the railroad system. Originally compiled in 1974 by the Federal Railroad Administration, the data base has since been extensively reworked to reflect company mergers and line abandonments. The rail network for the model is separated into 95 distinct subnetworks, and allows links, intersections, and transfer points to be blocked for analyzing track closures and routing restrictions. For this analysis, all rail shipments were assumed to be over routes normally used for general commerce.

TABLE F.1. MRS and Repository Facility Receipt Rates of Spent Fuel

	All Reactors Shipping Fuel to an MRS Facility					Western Reactors Shipping Fuel to Repository and Eastern Reactors Shipping Fuel to an MRS Facility					
	Spent Fuel (MTU)		Associated Waste Products (MRS to Repository)			Spent Fuel (MTU)			Associated Waste Products (MRS to Repository)		
Year	All Reactors to MRS	MRS to Repository	Hardware (canisters)	HAW[a] (canisters)	CH-TRU (drums)	Reactors to Repository	Reactors to MRS	MRS to Repository	Hardware (canisters)	HAW[a] (canisters)	CH-TRU (drums)
1996	400	0	0	0	0	0	400	0	0	0	0
1997	1800	0	0	0	0	0	1,800	0	0	0	0
1998	3000	400	35	33	74	50	2,500	350	31	29	65
1999	3000	400	35	33	74	50	2,500	350	31	29	65
2000	3000	400	35	33	74	75	2,500	325	29	27	61
2001	3000	900	79	74	166	75	2,500	825	73	68	153
2002	3000	1,800	158	147	331	100	2,500	1,700	150	139	313
2003	3000	3,000	264	246	552	200	2,500	2,800	247	230	516
2004	3000	3,000	264	246	552	350	2,500	2,650	234	218	488
2005	3000	3,000	264	246	552	450	2,500	2,550	225	210	470
2006	3000	3,000	264	246	552	450	2,500	2,550	225	210	470
2007	3000	3,000	264	246	552	450	2,500	2,550	225	210	470
2008	3000	3,000	264	246	552	450	2,500	2,550	225	210	470
2009	3000	3,000	264	246	552	450	2,500	2,550	225	210	470
2010	3000	3,000	264	246	552	450	2,500	2,550	225	210	470
2011	3000	3,000	264	246	552	450	2,500	2,550	225	210	470
2012	3000	3,000	264	246	552	450	2,500	2,550	225	210	470
2013	3000	3,000	264	246	552	450	2,500	2,550	225	210	470
2014	3000	3,000	264	246	552	450	2,500	2,550	225	210	470
2015	3000	3,000	264	246	552	450	2,500	2,550	225	210	470
2016	3000	3,000	264	246	552	450	2,500	2,550	225	210	470
2017	2800	3,000	264	246	552	450	2,500	2,550	225	210	470
2018		3,000	264	246	552	450	800	2,550	225	210	470
2019		3,000	264	246	552	450	0	2,550	225	210	470
2020		3,000	264	246	552	450	0	2,550	225	210	470
2021		3,000	264	246	552	450	0	2,550	225	210	470
2022		1,100	97	90	202	450	0	650	58	54	120

(a) High-activity waste.

TABLE F.2. Reference Cask Capacities

Cask	Waste Form	Container	Capacity[a]
From Reactor			
Truck	SF (PWR/BWR)[b]	Unconsolidated assemblies	(2/5)
Rail	SF (PWR/BWR)	Unconsolidated assemblies	(14/36)
From MRS (100-ton) to			
Salt sites	SF (PWR/BWR)	Consolidated assemblies	(24/30)
Tuff sites	SF (PWR/BWR)	Consolidated assemblies	(18/42)
Basalt sites	SF (PWR/BWR)	Consolidated assemblies	(24/45)
From MRS (150-ton) to			
Salt sites	SF (PWR/BWR)	Consolidated assemblies	(72/150)
Tuff sites	SF (PWR/BWR)	Consolidated assemblies	(48/98)
Basalt sites	SF (PWR/BWR)	Consolidated assemblies	(84/171)
From MRS (Waste Products)			
to all sites (100-ton)	SF (Hardware/HAW)[c]	Canisters	4
to all sites (150-ton)	SF (Hardware/HAW)	Canisters	7
TRU container[d]	CH-TRU[e]	Drums	36

(a) Parentheses include PWR and BWR (PWR/BWR) assemblies.
(b) SF - spent fuel; PWR/BWR - pressurized water reactor/boiling water reactor.
(c) HAW - high-activity waste.
(d) Two transuranic (TRU) containers per rail car.
(e) Contact-handled transuranic waste.

TABLE F.3. Number of Shipments from Individual Reactor Sites[a]

Reactor	Scenario 1[b]		Scenario 2[c]		Scenario 3[d]	
	100% by Truck	100% by Rail	100% by Truck	100% by Rail	100% by Truck	100% by Rail
Farley-1	387	56	322	46	120	18
Farley-2	513	45	249	36	46	7
Palo Verde-1[f]	366	52	939	135	511	72
Palo Verde-2[f]	339	49	931	131	484	70
Palo Verde-3[f]	332	47	905	130	448	63
Arkansas Nucl One-1	762	108	762	108	762	108
Arkansas Nucl One-2	495	43	241	35	187	27
Calvert Cliffs-1[e]	893	127	751	127	893	127
Calvert Cliffs-2[e]	853	121	679	121	853	122
Pilgram-1[e]	761	105	761	105	761	105
Robinson-2	581	83	581	83	581	83
Brunswick-2	799	111	702	60	799	111
Brunswick-1	791	109	623	59	791	109
Harris-1	160	23	114	13		
Perry-1	722	100	740	103	806	110
Perry-2	579	80	613	85	747	104
Dresden-1	136	18	136	18	136	18
Dresden-2	909	126	909	126	909	126
Dresden-3	825	114	825	114	825	114
Quad Cities-1	862	119	862	119	862	119
Quad Cities-2	815	113	815	113	815	113
Zion-1	858	122	858	122	858	122
Zion-2	824	117	824	117	824	117
LaSalle-1	669	93	671	93	572	79
LaSalle-2	632	87	669	93	572	79
Byron-1	593	85	619	88	638	88
Byron-2	552	78	577	82	631	86
Braidwood-1	570	81	596	82	568	83
Braidwood-2	484	69	509	72	536	81
Connecticut Yankee[e]	702	100	702	100	702	100

TABLE F.3. (contd)

Reactor	Scenario 1[b] 100% by Truck	Scenario 1[b] 100% by Rail	Scenario 2[c] 100% by Truck	Scenario 2[c] 100% by Rail	Scenario 3[d] 100% by Truck	Scenario 3[d] 100% by Rail
Indian Point-1[e]	80	11	80	11	80	11
Indian Point-2[e]	762	108	762	108	762	108
Big Rock Point	104	14	104	14	104	14
Palisades	796	113	796	113	796	113
Midland-2	304	43	317	43	373	49
Midland-1	261	37	261	37	334	46
LaCrosse	143	19	143	19	143	19
Fermi-2	609	85	609	85	609	85
Oconee-1[e]	759	108	759	108	759	108
Oconee-2[e]	612	87	612	87	612	87
Oconee-3[e]	779	111	779	111	779	111
McGuire-1	334	44	252	36	115	17
McGuire-2	268	39	213	31	73	11
Catawba-1	241	31	159	23	(g)	(g)
Catawba-2	198	25	116	17	(g)	(g)
Beaver Valley-1	735	105	319	46	735	104
Beaver Valley-2	154	22	175	25	272	39
Crystal River-3[e]	676	96	676	96	676	96
Turkey Point-3[e]	695	99	695	99	695	99
Turkey Point-4[e]	694	99	694	99	694	99
St. Lucie-1[e]	914	130	550	78	894	113
St. Lucie-2[e]	375	54	375	54	486	70
Hatch-1	512	61	361	50	312	43
Hatch-2	482	57	339	47	289	40
Vogtle-1	415	59	443	63	547	78
Vogtle-2	291	41	320	45	416	60
River Bend-1	329	45	356	49	465	65
Clinton-1	407	57	407	57	528	74
Cook-1	948	135	743	135	948	135
Cook-2	933	133	703	133	933	133

TABLE F.3. (contd)

Reactor	Scenario 1[b] 100% by Truck	Scenario 1[b] 100% by Rail	Scenario 2[c] 100% by Truck	Scenario 2[c] 100% by Rail	Scenario 3[d] 100% by Truck	Scenario 3[d] 100% by Rail
Duane Arnold	572	79	261	34	562	79
Oyster Creek[e]	777	108	777	108	777	108
Wolf Creek	184	27	120	18	191	27
Shoreham[e]	201	28	174	25	270	38
Waterford-3	291	42	291	41	421	61
Maine Yankee	980	140	980	140	980	140
Three Mile Island-1	723	103	723	103	723	103
Grand Gulf-1[e]	318	45	225	32	247	35
Grand Gulf-2[e]	210	30	187	25	340	48
Cooper	771	107	771	107	771	107
Nine Mile Point-1	700	97	700	97	700	97
Nine Mile Point-2	185	26	148	21	243	33
Millstone-1	804	111	804	111	804	111
Millstone-2	949	135	616	88	805	106
Millstone-3	227	33	170	21	36	6
Monticello	693	96	693	96	693	96
Prairie Island-1	650	92	650	92	650	92
Prairie Island-2	631	90	631	90	631	90
Fort Calhoun-1[e]	534	76	534	76	534	76
Humboldt Bay[f]	86	12	86	12	86	12
Diablo Canyon-2[e,f]	209	30	753	105	236	34
Diablo Canyon-1[e,f]	252	36	796	113	279	40
Susquehanna-1	516	71	516	71	652	90
Susquehanna-2	483	67	483	67	614	85
Peach Bottom-2[e]	1,126	156	1,126	156	1,126	156
Peach Bottom-3[e]	1,126	156	1,126	156	1,126	156
Limerick-1	500	70	544	76	679	95
Limerick-2	287	40	331	45	421	59
Trojan[e,f]	805	117	828	118	330	18
Fitzpatrick	864	127	465	65	614	107

TABLE F.3. (contd)

Reactor	Scenario 1(b) 100% by Truck	Scenario 1(b) 100% by Rail	Scenario 2(c) 100% by Truck	Scenario 2(c) 100% by Rail	Scenario 3(d) 100% by Truck	Scenario 3(d) 100% by Rail
Indian Point-3(e)	714	102	714	102	714	102
Seabrook-1	343	49	371	53	486	69
Seabrook-2	177	26	206	30	320	46
Salem-1(e)	791	113	791	113	791	113
Salem-2(e)	764	109	749	109	764	109
Hope Creek-1(e)	365	51	413	58	509	71
Ginna(e)	503	71	503	71	503	71
Rancho Seco-1(f)	721	103	721	103	721	103
Summer	215	31	151	22	12	2
San Onofre-1(f)	203	29	354	50	203	29
San Onofre-2(f)	306	44	670	95	306	44
San Onofre-3(f)	348	49	631	92	347	50
South Texas Proj-1	539	77	567	81	594	82
South Texas Proj-2	453	64	481	68	592	82
Browns Ferry-1(e)	944	135	659	127	699	135
Browns Ferry-2(e)	821	140	663	114	695	140
Browns Ferry-3(e)	986	137	836	89	986	137
Sequoyah-1	588	113	435	62	444	46
Sequoyah-2	571	108	425	60	425	42
Watts Bar-1	465	66	496	66	518	74
Watts Bar-2	424	61	430	61	524	74
Bellefonte-1	315	45	315	45	444	64
Bellefonte-2	199	29	242	35	327	47
Hartsville A-1	284	40	328	46	463	65
Hartsville A-2	194	26	238	33	328	45
Yellow Creek-1	(g)	(g)	(g)	(g)	90	13
Yellow Creek-2	(g)	(g)	(g)	(g)	50	8
Comanche Peak-1	294	42	294	42	412	58
Comanche Peak-2	257	33	257	36	368	53
Davis-Besse-1	321	43	270	38	248	31

TABLE F.3. (contd)

Reactor	Scenario 1[b] 100% by Truck	Scenario 1[b] 100% by Rail	Scenario 2[c] 100% by Truck	Scenario 2[c] 100% by Rail	Scenario 3[d] 100% by Truck	Scenario 3[d] 100% by Rail
Callaway-1	260	38	281	40	360	51
Vermont Yankee	675	93	675	93	675	93
Surry-1[e]	749	106	669	67	748	102
Surry-2[e]	620	88	576	53	620	77
North Anna-1	469	58	334	47	365	47
North Anna-2	420	50	267	38	295	38
WNP-2[e,f]	605	84	1,013	140	650	90
WNP-1[e,f]	251	36	716	103	394	56
WNP-4[e,f]	448	63	921	132	617	89
Point Beach-1[e]	620	88	620	88	620	88
Point Beach-2[e]	591	84	590	84	591	84
Kewaunee[e]	634	90	634	90	634	90
Yankee-Rowe[e]	340	48	340	48	340	48
Brunswick-2 PWR Pool	72	10	72	10	72	10
Brunswick-1 PWR Pool	80	11	80	11	80	11
Morris-BWR	150	20	150	20	150	20
Morris-PWR	175	25	175	25	175	25
West Valley-BWR	17	2	17	2	17	2
West Valley-PWR	60	8	60	8	60	8
TOTALS	70,568	9,934	70,782	9,944	70,553	9,927

(a) Differences in shipments between scenarios is due to logistics differences between scenarios caused by differing receipt rates and timing of receipts.

(b) Scenario 1: All reactors ship spent fuel to an MRS facility.

(c) Scenario 2: Eastern reactors ship spent fuel to an MRS and western reactors ship fuel directly to a repository.

(d) Scenario 3: All reactors ship spent fuel directly to a repository (no MRS facility).

(e) Reactors without full rail-handling capabilities.

(f) Western reactor.

(g) Reactor did not ship for this scenario.

F.2 COST ANALYSIS

For the spent fuel and associated waste products, the total cost of transport was defined as the sum of capital costs, maintenance costs, and shipping costs. Costs such as site-specific fixed-facility costs, the costs of access roads, rail lines, and storage and handling facilities were not considered. The following sections describe the assumptions and methods used to estimate these transportation costs, and the resulting costs estimates.

F.2.1 Assumptions and Methods for Estimating Transportation Costs

This section discusses the assumptions and methods used in estimating capital and maintenance costs and shipping costs.

Capital and Maintenance Costs

To calculate the total requirements for transportation casks, average speeds, turnaround times, and availability of casks must be estimated. The following assumptions were made in estimating those factors:

- All truck shipments travel at an average rate of 56 km/h (35 mph).
- The average rate for rail shipments from reactors varies from 5 km/h (about 3 mph) for short hauls to 19 km/h (about 12 mph) for cross-country shipments. (These average rates include stop time.)
- Dedicated trains between the MRS facility and repository travel 1.5 times faster than the inbound general-freight trains.
- Turnaround time for loading casks at the reactor sites and for unloading casks at the MRS or repository is 5 days per round trip for rail casks, and 3 days per round trip for a truck cask.
- Total loading-unloading time for the dedicated train shipments between the MRS facility and repository is 9 days per round trip.
- Transport casks are used 300 days per year.

Capital costs are defined as the total costs for transportation casks, which is the cost per cask times the number of casks required. Table F.4 shows the assumed cost of each type cask. The WASTES model (Shay and Buxbaum 1986) was used to calculate the number of casks required (by year) for the spent-fuel flows defined in Table F.1 using the following equations:

$$\text{annual cask-days} = \sum_{s} \{[(2*DIS)/SPEED] + 2*TATIME\}$$

where

s = all shipments
DIS = one-way mileage (miles)
SPEED = transit speed (miles/day)
TATIME = average turnaround time at each facility (days).

$$\text{Annual Cask Requirements} = \text{CASK-DAYS}/\text{UTIL}$$

where

CASK-DAYS = annual cask-days
UTIL = cask availability (300 days/yr).

The WASTES model algorithm was used to calculate cask requirements on a yearly basis (Shay and Buxbaum 1986). The requirements were calculated with the model by comparing the number of casks required for that year with the number of casks previously purchased. If the required number of casks exceeded the number of casks previously purchased, additional casks were assumed purchased in that year. The algorithm also removed a cask from service at the end of its prescribed lifetime (assumed to be 15 years). Once a cask has reached the end of its lifetime, it was assumed either replaced (new purchase) or retired.

Shipping Costs

For comparison, shipping costs were based on published tariffs or on conservative estimates from commercial carriers when tariffs were not available. With the rapid introduction of rate deregulation (e.g., for rail rates since the 1980 Staggers Act), as well as decreased constraints on mergers and acquisitions, the importance of negotiated contracts will grow. Actual shipping charges negotiated will then depend on service conditions, operating constraints, and reporting requirements as well as the level of competition for the anticipated shipments. Actual shipping charges or contract rates will be determined during contract negotiations between the DOE or its representatives and the carriers and suppliers.

In this analysis, relative shipping costs were calculated by the WASTES model (Shay and Buxbaum 1986). The shipping rates used for this analysis were based on either 1) evaluations of published tarriffs or 2) conversations with commercial carriers. The loaded and empty cask weights used for this analysis are summarized in Table F.5. The model uses these casks weights, tariffs, and estimated shipping distances,[a] to compute shipping costs. The following equations summarize these calculations for legal-weight trucks and dedicated rail shipments.

The shipping costs of legal-weight trucks for one-way mileage less than 1,000 miles were calculated as:

$$\text{Shipping Cost (\$)} = [1.493 + 0.0033*DIS]*FWT + [0.428 + 0.0034*DIS]*EWT$$

The shipping costs of legal-weight trucks for one-way mileage greater than 1,000 miles were calculated as:

$$\text{Shipping Cost (\$)} = [0.0049*DIS - 0.16]*FWT + [0.0040*DIS - 0.19]*EWT$$

The safeguards and security costs for legal-weight trucks for all mileages were calculated as:

$$\text{Safeguards/Security Cost (\$)} = [7.93*DIS^{(-0.1855)}]*DIS$$

where

DIS = one-way mileage
FWT = loaded weight of cask (cwt)
EWT = empty weight of cask (cwt).

The shipping costs of general-freight rail for one-way mileage less than 1,000 miles were calculated as:

$$\text{Shipping Cost (\$)} = [2.32 + 0.0067*DIS]*FWT + [2.15 + 0.0063*DIS]*EWT$$

The shipping costs of general-freight rail for one-way mileage greater than 1,000 miles were calculated as:

$$\text{Shipping Cost (\$)} = [5.07 + 0.0040*DIS]*FWT + [4.72 + 0.0037*DIS]*EWT$$

(a) Shipping distances were estimated by adjusting great circle distances between sites by correction factors estimated to represent the average difference between actual truck and rail routes and great circle distances.

The safeguards and security costs for general-freight rail for all mileages were calculated as:

$$\text{Safeguards/Security Cost (\$)} = [291.65*DIS^{(-0.5987)}]*DIS$$

where

DIS = one-way mileage
FWT = loaded weight of cast (cwt)
EWT = empty weight of cask (cwt).

The shipping cost for dedicated rail shipments from the MRS facility to the repository, using 5 to 10 cask-cars per train, were assumed to be 1.25 times the shipping cost associated with general-freight movement over the same route. The security cost would be a factor of 5 to 10 times lower for a dedicated shipment because of the greater number of cask-cars per train.

F.2.2 Estimated Transportation Costs

Table F.6 displays the total transportation costs of various MRS scenarios. These scenarios include variations in the MRS site location (Hartsville and Oak Ridge/Clinch River), cask capacity (100 and 150 ton), truck/rail mix from reactors, and MRS system configuration (eastern fuel only and all fuel to MRS facility). Table F.7 presents additional detail for the portion of these shipments from reactors to the MRS facility. This table lists shipping, capital and maintenance costs, cask fleet requirements and cask-miles. Table F.8 presents the same cost and logistics information for direct shipments to repository sites from western reactors and all reactors.

Table F.9 summarizes the cost components, cask fleet requirements, cask-miles and shipment-miles for MRS-to-repository spent-fuel shipment. Table F.10 presents similar information for MRS-to-repository shipments of contact-handled transuranic wastes and Table F.11 presents this information for shipments of hardware and high-activity wastes.

TABLE F.4. Cask Capital and Maintenance Costs (million 1985 $)

Shipping Mode	Capital Cost[a]	Maintenance Cost[b]
Reactor to MRS		
Truck cask	1.5	0.075
Rail cask	2.5	0.125
MRS to Repository		
100-ton rail cask	2.5	0.125
150-ton rail cask	2.75	0.125
TRU container[b]	1.6	0.075

(a) Capital costs are for each cask and include cost of trailer or rail car.
(b) Maintenance costs are per package-year.
(c) Assumes two transuranic waste (TRU) containers per rail car.

TABLE F.5. Average Loaded and Empty Cask Weights (lb)

Cask	Empty Weight	Loaded Weight
From Reactor		
Truck	47,500	50,000
Rail	180,000	200,000
From MRS (100-ton) to		
Salt sites	136,000	200,000
Tuff sites	140,000	200,000
Basalt sites	120,000	200,000
From MRS (150-ton) to		
Salt sites	183,000	300,000
Tuff sites	198,000	300,000
Basalt sites	188,000	300,000
From MRS (waste products)		
to all sites (100-ton)	130,000	150,000
to all sites (150-ton)	190,000	225,000
TRU container[a]	70,000	100,000

(a) Two transuranic (TRU) containers per rail car.

TABLE F.6. Total Shipping Cost Summary (million 1985 $)

MRS to Repository	Eastern Fuel Shipped Through MRS and Western Fuel Directly to a Repository		All Fuel Shipped Through MRS and Then to a Repository	
	70% Rail/30% Truck From Reactors	100% Rail From Reactors	70% Rail/30% Truck From Reactors	100% Rail From Reactors
Hartsville (100-ton cask) to				
Hanford	1,295	1,295	1,450	1,450
Yucca Mt	1,365	1,370	1,550	1,550
Davis	1,325	1,330	1,440	1,440
Deaf Smith	1,230	1,235	1,320	1,320
Vacherie	1,095	1,090	1,130	1,130
Richton	1,070	1,065	1,075	1,075
Hartsville (150-ton cask) to				
Hanford	935	935	1,025	1,025
Yucca Mt	1,030	1,035	1,150	1,150
Davis	895	900	970	970
Deaf Smith	885	890	930	930
Vacherie	860	855	860	860
Richton	855	845	840	840
Oak Ridge/Clinch River (100-ton cask) to				
Hanford	1,305	1,310	1,470	1,470
Yucca Mt	1,385	1,390	1,570	1,570
Davis	1,345	1,350	1,475	1,475
Deaf Smith	1,255	1,260	1,365	1,365
Vacherie	1,140	1,140	1,185	1,185
Richton	1,085	1,080	1,100	1,100
Oak Ridge/Clinch River (150-ton cask) to				
Hanford	940	945	1,025	1,025
Yucca Mt	1,040	1,045	1,165	1,165
Davis	905	910	980	980
Deaf Smith	890	895	940	940
Vacherie	870	865	870	870
Richton	860	850	845	845

TABLE F.7. Logistics Summary for Spent-Fuel Shipments to an MRS (million 1985 $)

Shipping Mode	Shipping Cost	Capital Cost	Maint. Cost	Total Cost	Casks Required[a]	Cask-Miles (million)
Eastern Reactors to an MRS						
100% Rail to						
Hartsville	254.6	132.5	85.6	472.7	53	5.8
Oak Ridge/ Clinch River	251.5	132.5	85.5	469.5	53	5.7
100% Truck to						
Hartsville	257.2	124.1	82.0	463.2	85	35.5
Oak Ridge/ Clinch River	252.2	121.2	80.6	453.9	83	34.6
70% Rail/30% Truck to						
Hartsville	255.4	130.0	84.5	469.9	37/26[b]	14.7
Oak Ridge/ Clinch River	251.7	129.1	84.0	464.8	37/25	14.4
All Reactors to an MRS						
100% Rail to						
Hartsville	322.9	167.5	107.9	598.3	67	8.1
Oak Ridge/ Clinch River	318.4	167.5	107.9	593.8	67	8.0
100% Truck to						
Hartsville	345.1	154.8	102.9	602.8	106	49.2
Oak Ridge/ Clinch River	343.1	154.8	102.9	600.8	106	48.8
70% Rail/30% Truck to						
Hartsville	329.6	163.7	106.4	599.7	47/32[b]	20.4
Oak Ridge/ Clinch River	329.2	163.7	106.4	595.9	47/32	20.2

(a) Total casks required over the life of the facility.
(b) Cask required are listed as rail/truck.

TABLE F.8. Logistics Summary for Direct Shipment to a Repository from Western Reactors and All Reactors (million 1985 $)

	Fuel From Western Reactors						Fuel From All Reactors					
Shipping Mode	Shipping Cost	Capital Cost	Maint. Cost	Total Cost	Casks Required[a]	Cask Miles (millions)	Shipping Cost	Capital Cost	Maint. Cost	Total Cost	Casks Required[a]	Cask Miles (millions)
100% Rail to												
Hanford	46.7	27.5	13.4	87.6	11	1.2	625.8	280.0	149.9	1055.7	112	24.6
Yucca Mt	38.8	25.0	12.9	76.7	10	0.8	603.5	275.0	145.9	1024.4	110	23.2
Davis	49.5	30.0	15.3	94.7	12	1.2	533.9	250.5	133.5	917.9	100	18.8
Deaf Smith	63.0	35.0	17.8	115.7	14	1.9	477.0	232.5	123.4	832.9	93	15.4
Vacherie	81.6	40.0	20.4	142.0	16	2.9	404.7	207.5	110.4	722.6	83	11.7
Richton	89.6	42.5	21.3	153.3	17	3.4	389.7	202.5	107.6	699.8	81	11.0
100% Truck to												
Hanford	49.1	24.8	12.8	86.8	17	7.1	921.7	274.5	149.2	1345.4	188	149.7
Yucca Mt	38.9	23.4	12.1	74.4	16	5.1	875.6	265.7	145.0	1286.3	182	141.8
Davis	50.6	23.4	12.7	86.7	16	7.4	717.2	235.1	128.1	1080.4	161	115.1
Deaf Smith	72.7	29.2	15.4	117.2	20	11.3	595.4	211.7	115.5	922.6	145	94.4
Vacherie	110.6	36.5	19.2	166.3	25	17.8	466.3	186.9	101.6	754.8	128	71.7
Richton	128.0	40.9	21.4	190.3	28	20.8	442.4	181.0	98.8	722.2	124	67.4
70% Rail/30% Truck to												
Hanford	47.4	26.7	13.2	87.4	8/5[b]	3.0	714.6	278.4	149.7	1142.7	78/56[b]	62.1
Yucca Mt	38.8	24.5	12.7	76.0	7/5[b]	2.1	685.1	272.2	145.6	1102.9	77/55[b]	58.8
Davis	49.8	28.0	14.5	92.3	9/5[b]	3.1	588.9	245.9	131.9	966.7	70/48[b]	47.7
Deaf Smith	65.9	33.3	17.1	116.2	10/6[b]	4.7	512.5	226.3	121.0	859.8	65/44[b]	39.1
Vacherie	90.3	38.9	20.0	149.3	12/8[b]	7.4	423.2	201.3	107.8	732.3	58/38[b]	29.7
Richton	101.1	42.0	21.3	164.4	12/9[b]	8.6	405.5	196.1	104.9	706.5	57/37[b]	27.9

(a) Total casks required over the life of the facility.
(b) Casks required are listed as rail/truck.

TABLE F.9. Logistics Summary for Consolidated Spent-Fuel Shipments From an MRS to a Repository in Five-Car Dedicated Trains (million 1985 $)

MRS to Repository	Eastern Reactor Fuel: Shipping Cost	Capital Cost	Maint. Cost	Total Cost	Casks Required[a]	Cask-Miles (millions)	Shipment Miles (millions)	Fuel From All Reactors: Shipping Cost	Capital Cost	Maint. Cost	Total Cost	Casks Required[a]	Cask-Miles (millions)	Shipment Miles (millions)
Hartsville (100-ton cask) to														
Hanford	350.4	150.0	80.6	581.0	60	14.1	2.8	407.4	175.0	92.9	675.3	70	16.3	3.3
Yucca Mt	402.5	175.0	94.1	671.6	70	15.5	3.1	473.5	200.0	108.1	781.6	80	18.1	3.6
Davis	364.7	175.0	90.6	630.3	70	12.2	2.4	420.1	175.0	95.8	690.9	70	13.9	2.8
Deaf Smith	304.3	150.0	79.3	533.6	60	8.8	1.8	346.8	162.5	83.6	592.9	65	10.1	2.0
Vacherie	201.8	125.0	67.1	393.9	50	4.6	0.9	233.8	137.5	70.0	441.3	55	5.2	1.0
Richton	172.4	125.0	64.6	362.0	50	3.6	0.7	202.1	125.0	67.5	394.6	50	4.2	0.8
Hartsville (150-ton cask) to														
Hanford	133.7	55.0	28.1	216.8	20	3.9	0.8	158.3	55.0	28.1	241.4	20	4.5	0.9
Yucca Mt	234.3	75.0	41.3	350.6	30	6.1	1.2	276.9	82.5	41.3	400.7	30	7.2	1.4
Davis	122.0	55.0	28.8	205.8	20	3.1	0.6	144.9	55.0	28.1	228.0	20	3.6	0.7
Deaf Smith	102.1	55.0	28.1	185.2	20	2.3	0.5	121.3	55.0	28.1	204.4	20	2.6	0.5
Vacherie	67.8	55.0	28.1	150.9	20	1.2	0.2	80.8	55.0	28.1	163.9	20	1.4	0.3
Richton	55.4	55.0	24.3	134.7	20	0.9	0.2	70.0	55.0	28.1	153.1	20	1.1	0.2
Oak Ridge/Clinch River (100-ton cask) to														
Hanford	364.7	150.0	80.6	595.3	60	14.9	3.0	425.0	175.0	93.1	693.1	70	17.3	3.5
Yucca Mt	419.9	175.0	94.4	689.3	70	16.5	3.3	491.8	200.0	108.8	800.6	80	19.2	3.8
Davis	384.7	175.0	91.9	651.6	70	13.3	2.7	443.3	98.1	187.5	728.9	75	15.1	3.0
Deaf Smith	324.5	150.0	80.1	554.6	60	9.9	2.0	369.3	175.0	93.9	638.1	70	11.2	2.2
Vacherie	227.5	137.5	73.6	438.3	55	5.4	1.1	261.0	160.0	79.4	490.4	60	6.1	1.2
Richton	185.5	125.0	66.6	377.1	50	4.0	0.8	213.9	69.4	137.5	420.8	55	4.6	0.9
Oak Ridge/Clinch River (150-ton cask) to														
Hanford	138.9	55.0	28.1	222.0	20	4.1	0.8	164.8	55.0	28.1	247.9	20	4.8	1.0
Yucca Mt	244.6	75.0	41.3	360.9	30	6.6	1.3	287.9	82.5	41.3	411.7	30	7.6	1.5
Davis	128.6	55.0	28.8	212.4	20	3.4	0.7	152.6	55.0	28.1	235.7	20	3.9	0.8
Deaf Smith	108.5	55.0	28.1	191.6	20	2.5	0.5	128.8	55.0	28.1	211.9	20	2.9	0.6
Vacherie	76.1	55.0	28.1	159.2	20	1.4	0.3	90.0	55.0	28.1	173.1	20	1.6	0.3
Richton	59.3	55.0	28.1	142.4	20	1.0	0.2	74.0	55.0	28.1	157.1	20	1.2	0.2

(a) Total casks required over the life of the facility.

TABLE F.10. Logistics Summary for Shipping Contact-Handled Transuranic Waste From an MRS Facility to a Repository (million 1985 $)

MRS to Repository	Eastern Reactors Only Ship Fuel Through MRS						All Reactors Ship Fuel Through MRS					
	Shipping Cost	Capital Cost	Maint. Cost	Total Cost	Casks Required[a]	Cask-Miles (millions)	Shipping Cost	Capital Cost	Maint. Cost	Total Cost	Casks Required[a]	Cask-Miles (millions)
Oak Ridge/Clinch River to												
Yucca Mountain	4.36	1.6	3.8	9.8	2	0.67	5.1	1.6	3.8	10.5	2	0.76
Richton	1.88	1.6	3.8	7.3	2	0.16	2.2	1.6	3.8	7.6	2	0.18
Deaf Smith	3.16	1.6	3.8	8.6	2	0.39	3.7	1.6	3.8	9.1	2	0.44
Davis	3.76	1.6	3.8	9.2	2	0.53	4.4	1.6	3.8	9.8	2	0.6
Hanford	4.62	1.6	3.8	10.0	2	0.74	5.4	1.6	3.8	10.8	2	0.84
Vacherie	2.22	1.6	3.8	7.6	2	0.21	2.6	1.6	3.8	8	2	0.24
Hartsville to												
Yucca Mountain	4.19	1.6	3.8	9.6	2	0.64	4.9	1.6	3.8	10.3	2	0.72
Richton	1.80	1.6	3.8	7.2	2	0.14	2.1	1.6	3.8	7.5	2	0.16
Deaf Smith	2.99	1.6	3.8	8.4	2	0.35	3.5	1.6	3.8	8.9	2	0.4
Davis	3.59	1.6	3.8	9.0	2	0.48	4.2	1.6	3.8	9.6	2	0.54
Hanford	4.45	1.6	3.8	9.8	2	0.69	5.2	1.6	3.8	10.6	2	0.72
Vacherie	2.05	1.6	3.8	7.5	2	0.18	2.4	1.6	3.8	7.8	2	0.2

(a) Total casks required over the life of the facility.

TABLE F.11. Logistics Summary for Shipping Hardware and High-Activity Wastes From an MRS Facility to a Repository (million 1985 $)

MRS to Repository	Eastern Reactors Only Ship Fuel Through MRS						All Reactors Ship Fuel Through MRS					
	Shipping Cost	Capital Cost	Maint. Cost	Total Cost	Casks Required[a]	Cask-Miles (millions)	Shipping Cost	Capital Cost	Maint. Cost	Total Cost	Casks Required[a]	Cask-Miles (millions)
Oak Ridge/Clinch River (100-ton cask) to												
Yucca Mt	126.5	10.0	6.3	142.7	4.0	5.39	147.8	10.0	6.3	164.1	4.0	6.3
Richton	54.4	10.0	6.3	70.7	4.0	1.28	63.6	10.0	6.3	79.9	4.0	1.5
Deaf Smith	92.2	10.0	6.3	108.5	4.0	3.16	107.8	10.0	6.3	124.1	4.0	3.7
Davis	110.0	10.0	6.3	126.3	4.0	4.19	128.6	10.0	6.3	144.9	4.0	4.9
Hanford	134.6	10.0	6.3	150.9	4.0	5.90	157.4	10.0	6.3	173.7	4.0	6.9
Vacherie	64.6	10.0	6.3	80.9	4.0	1.71	75.6	10.0	6.3	91.9	4.0	2.0
Oak Ridge/Clinch River (150-ton cask) to												
Yucca Mt	103.6	16.5	9.4	129.5	6.0	3.08	121.2	16.5	9.4	147.1	6.0	3.6
Richton	44.5	22.0	12.5	79.0	8.0	0.73	52.1	22.0	12.5	86.6	8.0	0.85
Deaf Smith	75.6	22.0	12.5	110.1	8.0	1.80	88.4	22.0	12.5	122.9	8.0	2.1
Davis	90.1	22.0	12.5	124.6	8.0	2.39	105.4	22.0	12.5	139.9	8.0	2.8
Hanford	110.4	27.5	15.6	153.5	10.0	3.33	129.1	27.5	15.6	172.2	10.0	3.9
Vacherie	53.0	22.0	12.5	87.5	8.0	0.94	62.0	22.0	12.5	96.5	8.0	1.1
Hartsville (100-ton cask) to												
Yucca Mt	122.3	10.0	6.3	138.6	4.0	5.22	143.0	10.0	6.3	159.3	4.0	5.9
Richton	51.7	10.0	6.3	68.0	4.0	1.24	60.5	10.0	6.3	76.8	4.0	1.4
Deaf Smith	86.4	10.0	6.3	102.7	4.0	2.92	101.1	10.0	6.3	117.4	4.0	3.3
Davis	104.5	10.0	6.3	120.8	4.0	3.98	122.2	10.0	6.3	138.5	4.0	4.5
Hanford	129.0	10.0	6.3	145.3	4.0	5.75	150.9	10.0	6.3	167.2	4.0	6.5
Vacherie	58.9	10.0	6.3	75.2	4.0	1.50	68.9	10.0	6.3	85.2	4.0	1.7
Hartsville (150-ton cask) to												
Yucca Mt	100.4	16.5	9.4	126.3	6.0	3.01	117.4	16.5	9.4	143.3	6.0	3.4
Richton	42.4	22.0	12.5	76.9	8.0	0.69	49.6	22.0	12.5	84.1	8.0	0.78
Deaf Smith	70.9	22.0	12.5	105.4	8.0	1.68	82.9	22.0	12.5	117.4	8.0	1.9
Davis	85.6	22.0	12.5	120.1	8.0	2.30	100.1	22.0	12.5	134.6	8.0	2.6
Hanford	105.8	27.5	15.6	148.9	10.0	3.27	123.7	27.5	15.6	166.8	10.0	3.7
Vacherie	48.3	22.0	12.5	82.8	8.0	0.87	56.5	22.0	12.5	91.0	8.0	0.98

(a) Total casks required over the life of the facility.

F.3 RISK ANALYSIS

To evaluate the overall risk for both truck and rail transport, a number of component risks must be evaluated. The two major categories of risk are, 1) risk associated with accidents, and 2) risk associated with transport when the shipment proceeds without incident (i.e., normal transport). Each of these components can be evaluated by considering the radiological characteristics of the load (radiological risk) and by considering those risks that result regardless of the characteristics of the load (nonradiological risk).

For normal transport, radiological risk results from the direct external radiation from the cask. The accident component for radiological risk is determined by the probability of a shipment being involved in an accident, the response of the cask to the statistically specified accident environment, and the consequences of the estimated release (if any) of radioactive material from the cask. The nonradiological effects of normal transport include the health effects from pollutants generated by burning diesel fuel during shipments. The nonradiological effects of accidents include traumatic deaths and injuries from traffic accidents.

A further subcategorization of risk can be made according to the population groups affected. For this analysis, a distinction was made between people exposed as a result of their occupation and the general public. Persons such as crew members of trains and truck drivers are considered to be occupationally exposed; the public is the nonoccupationally exposed group.

A distinction can be made between certain categories of risk. The health effects associated with nonradiological impacts of accidents are estimates of immediate, traumatic deaths and injuries. Estimates of nonradiological accident risk are based on statistical projections for accident occurrence. These accidents occur at some frequency for every million kilometers of shipment.

The effects associated with radiological exposure from accidents, however, are estimated in terms of expected radiological exposure, as measured in person-rems. Risk is defined as the product of the consequence of an event times the likelihood of its occurrence. Consequences (radiological exposures) of a number of accidents of varying severity are evaluated and then multiplied by their respective probabilities of occurrence. The sum of the products is the radiological component of accident-related risks for the lifetime of the facilities. The methodology for this calculation is documented in RADTRAN III (Madsen et al. 1985).

F.3.1 Risk Calculation Methodology

For this evaluation, unit risk factors were calculated for all radiological and nonradiological risks. Unit risk factor is defined here as the increment of risk associated with a unit of distance traveled. All radiological unit risk factors are presented in units of person-rem per kilometer. The nonradiological unit risk factors are presented in units of latent cancer fatalities (LCFs) per kilometer for pollutants generated during normal transport in urban areas for nonoccupationally exposed persons. The remaining nonradiological unit risk factors are presented as fatalities and injuries per kilometer. The methods for calculating radiological and nonradiological unit risk factors are described in Sections F.3.2 and F.3.3, respectively. Unit risk factors were calculated for each of three population densities: urban, suburban, and rural and are shown in Tables F.12 through F.14.

The unit risk factors are combined with three other terms to give a total risk figure; those terms are: the number of shipments (Table F.3), the distance traveled per shipment (Tables F.15 through F.18), and the fractions of travel in the three population zones (Tables F.15 through F.18). Fractions of travel in each of the population zones were calculated by the method discussed in Section F.3.2 and are displayed in Tables F.15 through F.18. The products were summed according to the following formula to obtain a total risk estimate for each shipping scenario. These results are reported in F.3.5 (Tables F.19 to F.27).

$$\sum_i \sum_j \sum_k \left[(\text{unit risk factors})_{ijk} \times (\text{no. of shipments})_j \times (\text{miles per shipment})_j \times (\text{\% travel in population zone})_{ij} \right] = \text{Total Risk}$$

where

i = population density (urban, suburban, or rural)
j = waste type
k = risk component.

F.3.2 Radiological Unit Risk Factors

The radiological unit risk factors were calculated by use of a computer code, RADTRAN III (Madsen 1985) which combines the sets of parameters necessary to calculate radiological impacts. These factors are shown in Tables F.12 and F.13.

Normal Transport-Occupational Exposure. This factor was calculated by the crew model of RADTRAN III for the all-truck scenario. Rail-crew doses were not calculated because of the large amounts of shielding and the large source-to-crew distances. However, Department of Transportation regulations require railcars carrying hazardous materials to be inspected at interchanges. Therefore, the dose to an inspector was modeled.

Normal Transport-Nonoccupational Exposure. This factor was calculated by combining impacts to persons at places where a shipment stops, to persons in vehicles sharing the transport link with a shipment, and to persons within 800 m of the transport link while a shipment is moving. Exposure of pedestrians and persons in buildings are included in the latter.

Average numbers of persons and their distances from the shipment are included in the stops model of RADTRAN III, The number of times a shipment stops during transit is important to the total risk calculation. The stop-time data used for the truck mode have been obtained by observing many shipments of radioactive material. The stop time for the general-freight rail mode was calculated from the following assumptions: 1) general-freight rail shipments average 9.7 kph when stop time is included; 2) when a train is moving it averages 24 kph, 40 kph, and 64 kph in urban, suburban, and rural areas, respectively.

Detailed analysis of dedicated train operations was performed by Ostmeyer (1985). The average stop time for dedicated train shipments is assumed to be a factor of 15-30 times less than for general-freight shipments.

Accident-Nonoccupational and Occupational Exposure. The probability that an accident releasing radioactive material will occur is formulated in terms of the expected number of accidents in each of six severity categories. Cask/package response, which determines whether release of material or loss of shielding will occur, is related to the severity class for each type of cask used. Exposure resulting from the release of radionuclides to the environment are evaluated for several pathways: groundshine, cloudshine, inhalation, and ingestion. Released material is assumed to disperse according to Gaussian diffusion models, which predict downwind airborne concentrations and ground deposition. Standard dosimetric conversion factors convert downwind concentrations to expected organ doses. External exposure from ground contamination is estimated from an infinite-plane-source model.

F.3.3 Nonradiological Unit Risk Factors

Statistical data from available references were used to compile nonradiological unit risk factors, which are shown in Table F.14. Those which reflect the effects of pollutants generated during normal transport were taken from Rao et al. (1982). The values specified for these factors are only for transport in an urban population zone. The overall (occupational and nonoccupational) traumatic injury and fatality rates for truck transport are those specified by Smith and Wilmot (1982). The values used here were those specifically evaluated for truck and trailer rigs similar to those that would be used to transport spent fuel to an MRS or a repository. In order to separate the occupational (drivers) and nonoccupational values, the data from the Federal Highway Administration (DOT 1979) were used. The unit risk factors for general-freight rail transport were calculated from railcar miles given by the American Association of Railroads (1985) and fatalities and injuries recorded by the U.S. DOT (1977). The general-freight unit risk factor is based upon the premise that the spent fuel cask is part of a seventy car general-freight train. Therefore the attributable risk incurred by the spent fuel cask is one-seventieth of the total nonradiological risk for the entire train. Utilizing the same bases for a dedicated train carrying only five spent fuel cask results in each cask having one-fifth of the total nonradiological risk for the entire train. This analysis method results in the nonradiological risk for each cask on a dedicated train being higher than the same cask on a general-freight train. The methodology assigns the total non-radiological risk of dedicated train movements to the spent fuel unit risk factor. Therefore, the corresponding unit risk factors for consolidation waste products are assigned a zero value.

F.3.4 Fraction of Travel in Population Zones

Potential routes for both truck and rail shipments from individual reactors to each of nine potential repository sites or each of three potential MRS sites and rail routes from the MRS sites to the repository sites were generated by HIGHWAY (Joy et al. 1981) and INTERLINE (Joy et al. 1982). The truck routes utilized interstate highway systems exclusively (except for routes from the interstate to the MRS or repository) and the rail routes utilized normal general commerce routes.

Estimated population densities along the routes were obtained by overlapping the routes on population-density contour lines. The population density estimates were based on 1980 census data for a 3 minute x 3 minute (3 minutes is approximately 5.6 km) latitude-longitude grid system. The portion of each route that fell within each of three population-density zones is shown in Tables F.15 through F.18.

F.3.5 Results of Risk Calculations

The number of shipments of each cask type required for each logistics scenario, unit risk factors, and population density data previously discussed are combined to estimate the various components of risk using the RADTRAN III model (Madsen et al. 1985). This model and its data requirements are described in Cashwell et al.[a] The results of the risk calculations performed are shown in Tables F.19 through F.27. Radiological and nonradiological risk for each leg of the various scenarios is reported. The results are reported in terms of person-rems for radiological risk and fatalities or injuries for nonradiological risk.

Table F.19 shows the expected radiological exposure for the waste management system alternative of shipping fuel from eastern reactors for consolidation and subsequent shipment to a repository, and shipping fuel from western reactors directly to the repository. Radiological exposure estimates are presented for two candidate MRS sites and six potential repository site locations. Results are shown for 70% rail, 30% truck shipments from reactors and for 100% rail shipments from reactors. Also shown are calculated radiological exposures for 100- and 150-ton rail casks for MRS facility to repository shipments.

Table F.20 shows calculated radiological exposures for the same MRS site, repository site, reactor shipment mode, and MRS to repository cask variations. However, the results in this table were calculated assuming all fuel, from both eastern and western reactors, was shipped through the MRS facility.

Tables F.21 and F.22 are similar to Tables F.19 and F.20, respectively, except they show calculated fatalities and injuries for nonradiological risk.

Table F.23 summarizes the radiological and nonradiological risks for shipments to each of the assumed MRS locations. Risks are reported for all-truck, all-rail, or 70% rail/30% truck shipments from reactors. Table F.24 shows the same information for shipment of western fuel to the potential repository locations, and Tables F.25 and F.26 give the equivalent data for shipping consolidated spent fuel and associated waste from the MRS sites to repository locations.

Table F.27 shows the calculated radiological and nonradiological risk for shipments from reactors directly to the six representative repository locations.

(a) Cashwell, J., K. S. Neuhauser and P. C. Reardon. 1985 (draft). Transportation Impacts of the Commercial Radioactive Waste Management Program. SAND85-2715, TTC-00633, Sandia National Laboratories, Albuquerque, New Mexico.

TABLE F.12. Radiological Unit Risk Factors for Spent Fuel (person-rem/kilometer)

Zone	Hazard Group	From Reactor[a]		From MRS[b] (150-ton cask)			From MRS[b] (100-ton cask)		
		Truck	Rail	MRS-Salt	MRS-Tuff	MRS-Basalt	MRS-Salt	MRS-Tuff	MRS-Basalt
Rural	Normal Occupational	2.35 E-5[c]	1.07 E-5	3.34 E-6	3.34 E-6	3.34 E-6	3.34 E-6	3.34 E-6	3.34 E-6
Rural	Normal Nonoccupational	1.42 E-4	5.75 E-6	4.16 E-6	4.16 E-6	4.16 E-6	4.16 E-6	4.16 E-6	4.16 E-6
Rural	Accident Nonoccupational	1.55 E-9	6.70 E-9	8.80 E-8	6.10 E-8	1.01 E-7	3.29 E-8	2.44 E-8	3.28 E-8
Suburban	Normal Occupational	5.15 E-5	1.07 E-5	3.34 E-6	3.34 E-6	3.34 E-6	3.34 E-6	3.34 E-6	3.34 E-6
Suburban	Normal Nonoccupational	2.18 E-4	3.85 E-5	1.68 E-4	1.68 E-4	1.68 E-4	1.68 E-4	1.68 E-4	1.68 E-4
Suburban	Accident Nonoccupational	3.73 E-6	1.39 E-5	1.73 E-4	1.19 E-4	1.97 E-4	6.45 E-5	4.94 E-5	6.45 E-5
Urban	Normal Occupational	8.60 E-5	1.07 E-5	3.34 E-6	3.34 E-6	3.34 E-6	3.34 E-6	3.34 E-6	3.34 E-6
Urban	Normal Nonoccupational	2.98 E-4	1.29 E-5	3.99 E-5	3.99 E-5	3.99 E-5	3.99 E-5	3.99 E-5	3.99 E-5
Urban	Accident Nonoccupational	6.10 E-6	3.36 E-5	4.15 E-4	2.88 E-4	4.75 E-4	1.55 E-4	1.19 E-4	1.55 E-4

(a) Unit Risk Factors for general-commerce truck and rail transport of spent fuel; units are per kilometer for truck and per railcar-kilometer for rail.

(b) Unit Risk Factors for dedicated-rail transport of spent fuel out of an MRS packaged for shipment to either a salt repository (MRS-Salt), a tuff repository (MRS-Tuff), or a basalt repository (MRS-Basalt); expressed as risk per 5 railcar-kilometers.

(c) The exponential (for example, E-5) is a convenient way to express very large numbers and very small numbers; E-5 equals 0.00001 or 1×10^{-5}, E-6 equals 0.000001 or 1×10^{-6}, etc.

TABLE F.13. Radiological Unit Risk Factors for Casks Carrying Waste Products from Spent-Fuel disassembly process (person-rem/kilometer)

Zone	Hazard Group	From MRS (150 ton) MRS-Hrdwr.[a]	From MRS (150 ton) MRS-HAW[b]	From MRS (150 ton) MRS-TRU[c]	From MRS (100 ton) MRS-Hrdwr.[a]	From MRS (100 ton) MRS-HAW[b]	From MRS (100 ton) MRS-TRU[c]
Rural	Normal Occupational	6.7 E-7[d]	6.7 E-7	7.8 E-7	6.7 E-7	6.7 E-7	7.8 E-7
Rural	Normal Nonoccupational	8.4 E-7	8.4 E-7	1.2 E-6	8.4 E-7	8.4 E-7	1.2 E-6
Rural	Accident Nonoccupational	4.4 E-12	2.0 E-7	1.6 E-13	1.7 E-12	1.2 E-7	1.6 E-13
Suburban	Normal Occupational	6.7 E-7	6.7 E-7	7.8 E-7	6.7 E-7	6.7 E-7	7.8 E-7
Suburban	Normal Nonoccupational	3.4 E-5	3.4 E-5	4.8 E-5	3.4 E-5	3.4 E-5	4.8 E-5
Suburban	Accident Nonoccupational	4.9 E-10	1.8 E-4	1.1 E-10	1.8 E-10	1.1 E-4	1.1 E-10
Urban	Normal Occupational	6.7 E-7	6.7 E-7	7.8 E-7	6.7 E-7	6.7 E-7	7.8 E-7
Urban	Normal Nonoccupational	8.0 E-6	8.0 E-6	1.2 E-5	8.0 E-6	8.0 E-6	1.2 E-5
Urban	Accident Nonoccupational	1.0 E-9	3.3 E-3	2.0 E-9	9.0 E-10	1.9 E-3	2.0 E-9

(a) Unit Risk Factors for dedicated-rail transport of spent-fuel-assembly hardware out of MRS; packaging is the same regardless of destination repository; expressed as risk per railcar-kilometer.

(b) Unit Risk Factors for dedicated-rail transport out of MRS of high-activity waste (HAW) generated during spent-fuel consolidation; packaging of HAW is the same regardless of destination repository; expressed as risk per railcar-kilometer.

(c) Unit Risk Factors for dedicated-rail transport out of MRS of transuranic waste (TRU) generated during spent-fuel consolidation; expressed as risk per railcar-kilometer.

(d) The exponential (for example E-7) is a convenient way to express very large and very small numbers; E-7 equals 0.0000001 or 1×10^{-7}, E-8 equals 0.00000001 or 1×10^{-8}.

TABLE F.14. Nonradiological Unit Risk Factors for Spent-Fuel Casks (fatalities/kilometer or injuries/kilometer)

Zone	Hazard Group	From Reactor[a]		From MRS[b] (100- or 150-ton)		
		Truck	Rail	MRS-Salt	MRS-Tuff	MRS-Basalt
Rural	Normal Nonoccupational	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Rural	Accident Occupational	1.50E-08[c]	1.81E-09	1.27E-07	1.27E-07	1.27E-07
Rural	Accident Nonoccupational	5.30E-08	2.64E-08	1.85E-06	1.85E-06	1.85E-06
Rural	Accident Occupational Injuries	2.80E-08	2.46E-07	1.74E-05	1.74E-05	1.74E-05
Rural	Accident Nonoccupational Injuries	8.00E-07	5.12E-08	3.60E-06	3.60E-06	3.60E-06
Suburban	Normal Nonoccupational	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Suburban	Accident Occupational	3.70E-09	1.81E-09	1.27E-07	1.27E-07	1.27E-07
Suburban	Accident Nonoccupational	1.30E-08	2.64E-08	1.85E-06	1.85E-06	1.85E-06
Suburban	Accident Occupational Injuries	1.30E-08	2.46E-07	1.74E-05	1.74E-05	1.74E-05
Suburban	Accident Nonoccupational Injuries	3.80E-07	5.12E-08	3.60E-06	3.60E-06	3.60E-06
Urban	Normal Nonoccupational	1.00E-07	1.30E-07	6.50E-07	6.50E-07	6.50E-07
Urban	Accident Occupational	2.10E-09	1.81E-09	1.27E-07	1.27E-07	1.27E-07
Urban	Accident Nonoccupational	7.50E-09	2.64E-08	1.85E-06	1.85E-06	1.85E-06
Urban	Accident Occupational Injuries	1.30E-08	2.46E-07	1.74E-05	1.74E-05	1.74E-05
Urban	Accident Nonoccupational Injuries	3.70E-07	5.12E-08	3.60E-06	3.60E-06	3.60E-06

(a) Unit Risk Factors for general-commerce truck and rail transport of spent fuel; units are per kilometer for truck, per railcar-kilometer for normal rail, and per train-kilometer for rail accident cases (Note: for general-commerce rail, 1 train-kilometer is equivalent to 1 railcar-kilometer.)

(b) Unit Risk Factors for dedicated-rail transport of spent fuel out of an MRS to either a salt repository (MRS-Salt), a tuff repository (MRS-Tuff), or a basalt repository (MRS-Basalt); expressed as risk per kilometer for normal transport and risk per train-kilometer for accident cases.

(c) The exponential (for example, E-8) is a convenient way to express very large numbers and very small numbers; E-8 equals 0.00000001 or 1×10^{-8}, E-9 equals 0.000000001 or 1×10^{-9}, etc.

TABLE F.15. One-Way Rail and Truck Distances by Population Category to the Oak Ridge/Clinch River MRS Site (miles)

Reactor	Railroad Distances Rural	Railroad Distances Suburban	Railroad Distances Urban	Truck Distances Rural	Truck Distances Suburban	Truck Distances Urban
Bellefonte	89	59	0	111	54	0
Browns Ferry	134	78	0	206	57	2
Farley	302	191	8	279	135	0
Arkansas	442	178	6	456	113	10
Palo Verde	1,917	341	27	1,608	275	26
Diablo Canyon	2,340	450	77	2,037	359	37
Humboldt Bay	2,725	593	27	2,389	424	21
Rancho Seco	2,478	499	30	2,150	369	31
San Onofre	2,057	452	31	1,846	337	32
Connecticut Yankee	572	560	79	500	393	0
Millstone	464	661	103	503	426	8
Crystal River	509	181	7	436	203	0
St. Lucie	486	319	12	569	222	0
Turkey Point	493	440	42	601	296	37
Hatch	268	168	7	269	145	0
Vogtle	305	166	8	250	152	0
Arnold	700	201	7	533	270	0
Braidwood	552	121	8	366	231	10
Byron	531	164	34	392	271	15
Carroll County	655	116	7	504	238	0
Clinton	495	100	8	357	198	0
Dresden	419	239	18	370	225	10
LaSalle	440	226	41	381	233	10
Quad Cities	618	208	34	481	232	0
Zion	400	225	50	362	262	16
Marble Hill	252	59	9	191	122	2
Wolf Creek	717	228	6	598	227	2
River Bend	460	254	5	488	178	8
Waterford	431	201	16	431	182	15
Pilgrim	490	714	101	534	474	6

TABLE F.15 (contd)

Reactor	Railroad Distances Rural	Railroad Distances Suburban	Railroad Distances Urban	Truck Distances Rural	Truck Distances Suburban	Truck Distances Urban
Yankee Rowe	611	555	37	546	440	11
Calvert Cliffs	372	309	21	378	186	11
Maine Yankee	710	730	39	569	542	10
Big Rock Point	508	335	26	439	390	4
Cook	371	166	11	363	229	0
Fermi	366	210	18	261	272	12
Midland	321	307	27	295	374	4
Palisades	385	201	11	372	249	0
Monticello	896	190	26	657	356	17
Prairie Island	707	277	45	654	318	15
Callaway	505	153	14	410	173	2
Grand Gulf	376	172	3	401	156	4
Brunswick	303	221	3	361	155	0
Harris	256	199	4	206	214	0
McGuire	172	134	2	144	141	0
Cooper	946	242	11	632	226	2
Fort Calhoun	910	230	7	695	245	2
Seabrook	661	682	39	526	480	10
Hope Creek	378	397	51	366	278	12
Oyster Creek	378	497	58	466	290	1
Salem	382	399	51	386	278	12
Fitzpatrick	455	393	64	542	325	5
Ginna	429	367	63	465	364	6
Indian Point	542	518	69	495	313	0
Nine Mile Point	455	393	64	543	325	5
Shoreham	434	673	134	507	388	29
West Valley	534	338	23	435	320	0
Davis Besse	405	192	21	270	262	8
Perry	413	228	38	336	257	0
Zimmer	226	98	10	190	116	0

TABLE F.15 (contd)

Reactor	Railroad Distances			Truck Distances		
	Rural	Suburban	Urban	Rural	Suburban	Urban
Trojan	2,534	335	26	2,189	435	4
Beaver Valley	501	258	30	352	263	0
Limerick	442	443	48	416	248	0
Peach Bottom	387	360	32	395	232	1
Susquehanna	476	408	49	435	252	0
Three Mile Island	442	377	49	378	216	0
Catawba	172	170	3	133	150	0
Oconee	132	161	2	132	148	0
Robinson	249	152	3	231	138	0
Summer	195	128	2	180	109	0
Sequoyah	54	28	0	71	49	0
Watts Bar	32	15	0	46	10	0
Comanche	716	243	11	672	238	10
South Texas	795	312	22	848	278	29
North Anna	356	232	2	335	137	0
Surry	395	158	2	365	171	4
Vermont Yankee	495	599	96	513	435	11
WNP 1, 2, 4	2,322	311	18	2,061	397	4
Kewaunee	581	239	47	423	321	28
LaCrosse	773	136	8	527	312	15
Point Beach	433	297	65	419	320	32
TOTALS	49,663	23,598	2,348	44,245	20,860	632

TABLE F.16. One-Way Rail Distances by Population Category from Oak Ridge/Clinch River MRS to a Repository (miles)

Repository Location	Population Category			Total
	Rural	Suburban	Urban	
Vacherie	675	270	21	970
Deaf Smith	1,160	230	26	1,400
Davis	1,690	230	31	2,000
Hanford	2,290	300	26	2,600
Richton	360	160	4	520
Yucca Mt	2,140	290	39	2,500

TABLE F.17. One-Way Rail Miles From the Reactors to the Repository Sites

Reactor	Hanford Rural	Hanford Suburban	Hanford Urban	Yucca Mountain Rural	Yucca Mountain Suburban	Yucca Mountain Urban	Davis Rural	Davis Suburban	Davis Urban	Deaf Smith Rural	Deaf Smith Suburban	Deaf Smith Urban	Vacherie Rural	Vacherie Suburban	Vacherie Urban	Richton Rural	Richton Suburban	Richton Urban
Bellefonte, AL	2,295	303	9	2,211	340	39	1,761	275	31	1,229	274	25	657	229	20	342	117	3
Browns Ferry, AL	2,124	417	22	1,992	323	35	1,520	262	22	1,013	255	21	595	247	23	327	95	6
Farley, AL	2,533	405	13	2,422	475	47	1,969	413	39	1,441	409	33	753	266	17	437	154	1
Arkansas, AR	1,984	205	8	1,830	200	21	1,330	101	0	681	88	0	220	62	0	410	99	0
Palo Verde, AZ	1,228	421	38	585	58	8	1,397	359	31	836	87	9	1,325	234	44	1,514	374	56
Diablo Canyon, CA	837	347	41	402	167	66	1,007	284	34	1,173	225	60	1,747	343	95	1,935	482	106
Humboldt Bay, CA	955	352	34	788	314	14	1,127	287	27	1,507	305	2	2,132	487	45	2,320	627	57
Rancho Seco, CA	693	213	30	545	214	16	863	151	23	1,243	232	5	1,885	392	47	2,074	532	58
San Onofre, CA	894	445	91	298	96	25	863	130	27	1,057	156	20	1,616	286	34	1,818	414	67
Connecticut Yankee, CT	2,152	777	82	2,288	713	89	1,657	710	80	1,324	659	62	1,020	617	53	1,074	601	58
Millstone, CT	2,156	794	82	2,291	730	88	1,661	728	80	1,296	690	73	1,024	634	53	1,078	618	58
Crystal River, FL	2,615	566	30	2,482	472	43	2,008	413	30	1,260	409	28	733	255	20	462	104	3
St. Lucie, FL	2,608	597	35	2,458	588	48	1,982	531	35	1,327	539	33	798	385	25	530	233	8
Turkey Point, FL	2,612	720	66	2,463	711	78	1,985	656	67	1,334	660	64	804	507	55	537	354	38
Hatch, GA	2,543	435	21	2,388	451	47	1,936	389	39	1,407	385	33	763	296	26	447	184	9
Vogtle, GA	2,581	432	21	2,426	448	47	1,975	385	39	1,445	382	33	801	293	26	485	181	9
Arnold, IA	1,709	221	11	1,608	157	12	1,369	110	6	832	112	2	793	136	9	877	251	49
Braidwood, IL	1,755	269	33	1,798	258	38	1,391	120	11	857	212	7	744	181	5	694	153	5
Byron, IL	1,738	210	11	1,856	209	15	1,410	141	6	874	143	2	834	168	10	709	217	22
Clinton, IL	1,834	270	55	1,793	161	20	1,347	92	11	811	95	7	686	161	5	636	133	5
Dresden, IL	1,763	233	11	1,923	275	37	1,280	156	6	897	127	5	622	218	12	676	198	8
G.E. Repro Plant, IL	1,761	233	11	1,921	275	37	1,278	155	6	896	127	5	620	218	12	674	198	8
La Salle, IL	1,786	266	12	2,078	176	7	1,366	161	22	868	100	2	830	122	9	696	215	14
Quad Cities, IL	1,731	238	11	1,791	190	15	1,345	122	6	8909	124	2	769	148	9	797	260	22
Zion, IL	1,723	232	24	1,725	263	19	1,481	219	13	951	216	9	910	242	16	658	206	39
Wolf Creek, KS	1,734	154	8	1,580	149	21	1,082	47	0	468	37	0	437	86	0	685	150	0
River Bend, LA	2,432	391	13	2,280	384	26	1,830	320	17	731	191	11	242	57	0	172	94	1
Waterford, LA	2,437	296	8	2,283	291	21	1,781	193	0	765	182	11	267	60	1	180	83	18
Pilgrim, MA	2,185	844	81	2,321	780	87	1,690	778	78	1,325	741	72	1,053	684	52	1,107	668	57
Yankee-Rowe, MA	2,119	683	73	2,427	521	45	1,974	459	37	1,261	578	63	988	522	43	851	747	45
Calvert Cliffs, MD	2,144	678	62	2,206	675	69	1,651	610	59	1,315	564	38	935	584	34	612	502	29
Maine Yankee, ME	2,227	849	75	2,534	688	47	2,078	629	39	1,366	745	66	1,094	689	46	950	922	46
Big Rock Point, MI	2,005	372	33	2,161	389	49	1,518	298	30	1,144	269	24	862	331	23	916	309	24
Cook, MI	1,762	296	27	1,918	313	42	1,276	221	23	901	193	22	618	255	17	714	332	43
Fermi, MI	1,923	394	53	2,081	393	68	1,435	320	50	1,061	292	44	778	337	43	833	325	39
Midland, MI	1,879	484	35	2,034	503	51	1,389	413	32	1,020	380	30	739	421	50	712	454	46
Palisades, MI	1,775	331	27	1,932	349	42	1,288	257	23	915	228	22	632	291	17	727	367	43
Monticello, MN	1,476	150	15	1,712	183	23	1,242	129	17	1,057	164	12	1,041	211	13	985	240	31
Prairie Island, MN	1,470	158	11	2,018	243	15	1,571	176	6	1,036	177	2	996	201	9	889	327	33
Callaway, MO	1,814	168	7	1,660	163	21	1,400	117	8	700	62	0	589	101	0	592	161	11
Grand Gulf, MS	2,349	308	11	2,196	303	24	1,747	237	16	654	179	12	115	29	0	123	35	0
Brunswick, NC	2,470	583	43	2,422	551	44	1,946	495	32	1,377	389	23	924	394	32	657	241	14

TABLE F.17. (contd)

Reactor	Hanford			Yucca Mountain			Davis			Deaf Smith			Vacherie			Richton		
	Rural	Suburban	Urban	Rural	Suburban	Urban	Rural	Suburban	Urban	Rural	Suburban	Urban	Rural	Suburban	Urban	Rural	Suburban	Urban
Harris, NC	2,420	563	43	2,372	531	45	1,896	473	32	1,391	464	31	874	373	32	607	220	15
McGuire, NC	2,338	496	41	2,318	428	36	1,844	369	23	1,474	396	37	795	369	34	529	216	17
Cooper, NE	1,585	142	2	1,428	124	15	937	56	9	777	113	4	760	162	5	948	178	7
Fort Calhoun, NE	1,534	127	0	1,379	123	13	886	85	7	863	122	2	824	146	9	995	240	5
Seabrook, NH	2,173	805	74	2,480	645	47	2,025	585	39	1,315	700	66	1,042	644	45	901	874	46
Hope Creek, NJ	2,104	672	68	2,166	670	76	1,611	604	66	1,275	558	45	896	577	40	951	560	46
Oyster Creek, NJ	2,110	767	75	2,172	766	83	1,614	702	72	1,281	654	52	901	693	47	956	657	52
Salem, NJ	2,108	674	69	2,171	672	76	1,615	606	66	1,280	560	45	901	579	41	955	563	46
Fitzpatrick, NY	2,030	615	68	2,165	550	74	1,538	545	65	1,203	496	48	898	454	38	953	438	44
Ginna, NY	2,000	592	67	2,136	527	73	1,509	512	64	1,143	486	58	870	429	38	925	413	43
Indian Point, NY	2,121	736	72	2,256	672	78	1,627	668	69	1,293	618	52	989	576	43	1,043	559	48
Nine Mile Point, NY	2,029	615	68	2,164	550	74	1,537	545	65	1,202	496	48	898	454	38	952	438	44
Shoreham, NY	2,130	804	111	2,266	740	118	1,634	738	109	1,271	701	102	999	645	81	1,053	629	87
West Valley RP, NY	2,172	453	33	2,280	524	59	1,684	380	30	1,311	350	24	953	451	47	926	483	43
Davis-Besse, OH	1,975	310	35	2,067	284	20	1,619	218	11	1,088	216	7	1,048	240	14	747	336	25
Perry, OH	1,984	346	52	2,076	321	37	1,626	256	28	1,097	252	23	1,056	277	31	755	373	42
Trojan, OR	235	58	7	1,295	143	22	1,062	172	13	1,984	203	22	2,395	304	10	2,581	322	13
Beaver Valley, PA	2,014	420	33	2,164	351	28	1,714	286	20	1,184	281	15	1,144	307	22	870	306	20
Limerick, PA	2,098	649	50	2,161	646	58	1,605	581	48	1,269	535	27	890	554	23	944	538	28
Peach Bottom, PA	2,115	606	55	2,179	605	59	1,623	537	52	1,254	504	46	906	515	24	779	467	45
Susquehanna, PA	2,132	614	51	2,195	611	58	1,640	545	48	1,302	501	27	922	521	23	977	504	28
Three Mile Island, PA	2,098	583	51	2,161	580	58	1,606	514	48	1,268	470	27	888	490	23	943	473	28
Catawba, SC	2,452	472	29	2,300	464	42	1,847	403	34	1,318	399	28	709	449	27	393	337	10
Oconee, SC	2,413	461	28	2,261	454	41	1,808	393	33	1,279	388	27	665	319	26	349	208	9
Robinson, SC	2,425	605	33	2,291	512	46	1,815	455	34	1,310	445	33	794	354	34	527	201	16
Summer, SC	2,482	423	28	2,329	416	41	1,878	353	33	1,346	352	28	733	404	27	416	295	10
Sequoyah, TN	2,329	315	26	2,176	310	39	1,727	244	31	1,194	244	25	626	248	20	310	136	3
Watts Bar, TN	2,308	301	26	2,155	296	39	1,706	230	31	1,173	231	25	654	256	20	338	144	3
Comanche Peak, TX	1,943	316	25	1,520	124	5	1,190	224	29	414	47	0	272	81	14	533	171	5
South Texas, TX	2,358	356	30	2,205	350	43	1,701	254	22	666	167	22	311	118	17	444	163	14
North Anna, VA	2,282	485	40	2,322	408	44	1,794	412	37	1,421	382	35	1,020	488	33	752	335	16
Surry, VA	2,397	499	47	2,401	450	22	1,950	387	13	1,421	382	9	1,044	417	22	728	305	5
Vermont Yankee, VT	2,183	737	76	2,319	672	83	1,690	669	73	1,324	633	67	1,051	577	47	1,106	560	52
WNP 1, 2, 4, WA	10	0	0	1,145	136	13	911	165	4	1,538	179	15	2,126	218	12	2,370	298	5
Kewaunee, WI	1,758	191	11	1,821	340	35	1,520	170	20	992	238	24	972	298	22	763	288	34
La Crosse BWR, WI	1,557	176	10	1,870	196	13	1,378	129	7	969	142	2	952	191	2	860	188	14
Point Beach, WI	1,762	239	27	1,758	336	34	1,511	295	29	985	288	24	941	315	32	693	277	54
TOTAL	154,975	33,963	2,945	157,042	31,669	3,353	123,084	27,818	2,573	89,339	26,484	2,166	70,710	26,853	2,113	65,784	26,650	2,211

TABLE F.18. One-Way Truck Miles From the Reactors to the Repository Sites

Reactor	Hanford			Yucca Mountain			Davis			Deaf Smith			Vacherie			Richton		
	Rural	Suburban	Urban	Rural	Suburban	Urban	Rural	Suburban	Urban	Rural	Suburban	Urban	Rural	Suburban	Urban	Rural	Suburban	Urban
Bellefonte, AL	2,057	391	4	1,762	270	23	1,432	326	9	925	195	10	420	128	4	273	78	4
Browns Ferry, AL	2,045	380	6	1,750	259	24	1,419	315	11	912	184	11	406	120	3	259	70	3
Farley, AL	2,242	466	13	1,948	345	30	1,617	402	18	1,111	270	17	478	157	8	241	69	0
Arkansas, AR	1,824	241	4	1,322	163	13	1,058	119	5	485	87	0	265	106	1	457	123	0
Palo Verde, AZ	1,158	353	32	512	83	10	457	41	10	699	73	16	1,115	236	17	1,608	286	16
Diablo Canyon, CA	778	333	10	490	108	28	893	126	27	1,128	157	26	1,523	373	38	2,037	369	26
Humboldt Bay, CA	504	165	5	870	171	36	1,155	184	12	1,509	219	33	1,902	437	45	2,418	432	33
Rancho Seco, CA	629	233	13	613	116	28	915	129	23	1,250	165	26	1,645	381	37	2,159	377	26
San Onofre, CA	940	303	56	299	86	24	702	104	22	937	134	21	1,364	261	27	1,846	347	21
Connecticut Yankee, CT	2,196	669	18	2,170	626	17	1,744	573	19	1,310	600	8	968	566	4	820	517	4
Millstone, CT	2,198	702	27	2,173	659	26	1,745	605	28	1,313	633	17	971	598	13	823	549	13
Crystal River, FL	2,415	573	4	2,121	452	23	1,789	510	9	1,284	377	10	739	259	4	468	110	0
St. Lucie, FL	2,550	592	4	2,255	472	23	1,924	528	9	1,418	396	10	873	278	3	601	130	0
Turkey Point, FL	2,579	668	41	2,284	548	61	1,952	604	47	1,448	471	48	904	353	40	632	205	37
Hatch, GA	2,250	514	4	1,955	394	23	1,624	451	9	1,118	318	10	573	201	3	425	152	4
Vogtle, GA	2,231	521	4	1,937	400	23	1,604	457	9	1,099	324	10	556	218	4	408	169	4
Arnold, IA	1,689	171	1	1,529	189	7	1,106	132	9	818	173	0	840	234	0	827	220	0
Braidwood, IL	1,697	309	9	1,668	232	7	1,244	176	9	803	244	3	729	186	0	720	168	0
Byron, IL	1,662	248	3	1,613	221	7	1,190	165	9	903	204	0	742	273	6	733	256	6
Clinton, IL	1,842	222	1	1,683	240	7	1,259	183	9	760	219	3	660	166	0	651	148	0
Dresden, IL	1,700	304	9	1,652	227	7	1,229	171	9	812	249	3	738	191	0	729	173	0
G.E. Repro Plant, IL	1,702	304	9	1,655	227	7	1,231	171	9	814	249	3	740	191	0	731	173	0
La Salle, IL	1,812	202	1	1,653	220	7	1,230	163	9	814	242	3	739	184	0	731	167	0
Quad Cities, IL	1,722	186	1	1,563	204	7	1,139	147	9	852	187	0	784	200	0	776	182	0
Zion, IL	1,677	252	8	1,667	296	15	1,242	241	17	828	320	12	712	264	8	703	246	8
Wolf Creek, KS	1,583	191	0	1,372	116	7	970	95	7	506	83	0	551	156	1	757	232	0
River Bend, LA	2,069	476	17	1,567	391	26	1,302	349	18	731	315	13	228	78	3	156	55	4
Waterford, LA	2,098	522	25	1,596	438	33	1,331	395	26	760	361	20	256	125	11	99	60	10
Pilgrim, MA	2,228	752	24	2,203	708	23	1,775	656	25	1,343	683	14	1,002	647	10	853	598	10
Yankee-Rowe, MA	2,150	708	22	2,124	665	21	1,697	612	23	1,273	634	7	1,015	612	14	867	563	15
Calvert Cliffs, MD	2,128	631	28	2,076	538	20	1,672	517	20	1,303	388	21	844	361	14	697	311	14
Maine Yankee, ME	2,264	820	29	2,238	776	28	1,811	724	30	1,379	750	18	1,037	715	14	889	666	14
Big Rock Point, MI	1,918	525	21	1,891	482	20	1,465	428	23	1,053	504	17	941	426	12	783	440	12
Cook, MI	1,689	352	18	1,664	309	17	1,239	254	19	824	332	13	712	255	8	624	265	13
Fermi, MI	1,755	481	18	1,729	438	17	1,302	384	19	967	375	11	763	354	14	606	321	20
Midland, MI	1,774	507	21	1,748	464	20	1,322	410	23	910	486	17	799	408	12	639	422	12
Palisades, MI	1,699	372	18	1,673	329	17	1,248	274	19	834	352	13	722	275	8	634	285	13
Monticello, MN	1,382	142	1	1,619	240	8	1,195	184	10	909	223	1	954	296	2	998	341	8
Prairie Island, MN	1,417	194	3	1,613	210	7	1,190	153	9	902	193	0	947	265	1	996	303	6
Callaway, MO	1,673	233	2	1,451	188	7	1,048	167	7	678	145	0	579	195	0	570	177	0
Grand Gulf, MS	2,138	402	2	1,686	285	13	1,421	242	6	849	209	0	148	30	0	193	46	0
Brunswick, NC	2,356	614	18	2,125	431	24	1,793	489	9	1,287	356	10	739	272	3	592	223	4

TABLE F.18. (contd)

Reactor	Hanford			Yucca Mountain			Davis			Deaf Smith			Vacherie Dome			Richton Dome		
	Rural	Suburban	Urban	Rural	Suburban	Urban	Rural	Suburban	Urban	Rural	Suburban	Urban	Rural	Suburban	Urban	Rural	Suburban	Urban
Harris, NC	2,206	670	18	1,974	486	23	1,640	545	9	1,135	412	10	598	398	4	450	349	4
McGuire, NC	2,142	598	18	1,911	414	23	1,578	472	9	1,073	340	10	542	276	3	395	227	4
Cooper, NE	1,455	171	2	1,367	151	7	944	94	9	650	132	0	694	205	1	792	231	0
Fort Calhoun, NE	1,467	141	1	1,313	150	5	890	93	7	712	152	0	756	225	1	854	251	0
Seabrook, NH	2,221	757	29	2,195	713	28	1,768	661	30	1,335	688	18	994	652	14	846	604	14
Hope Creek, NJ	2,112	692	23	2,059	599	15	1,655	579	15	1,208	554	8	833	452	16	685	403	16
Oyster Creek, NJ	2,196	632	19	2,170	589	18	1,744	535	21	1,289	563	5	933	464	5	785	415	5
Salem, NJ	2,112	692	23	2,059	600	15	1,655	580	15	1,208	554	8	833	453	16	685	403	16
Fitzpatrick, NY	2,081	614	19	2,055	571	18	1,629	517	20	1,202	539	5	1,034	474	4	861	450	9
Ginna, NY	2,012	588	25	1,986	545	24	1,559	491	26	1,135	514	10	964	448	9	808	415	14
Indian Point, NY	2,191	590	18	2,165	546	17	1,739	492	19	1,305	520	8	963	486	4	815	437	4
Nine Mile Point, NY	2,082	614	19	2,056	571	18	1,630	517	20	1,206	539	5	1,035	474	4	862	450	9
Shoreham, NY	2,204	665	47	2,178	621	46	1,751	568	49	1,318	596	37	976	562	32	827	513	33
West Valley RP, NY	1,982	544	18	1,956	500	17	1,530	447	19	1,105	469	3	934	404	2	777	371	7
Davis-Besse, OH	1,830	403	18	1,805	360	17	1,379	305	19	976	365	7	772	344	11	615	311	16
Perry, OH	1,882	481	18	1,857	438	17	1,431	384	19	1,005	407	3	834	342	2	678	308	7
Trojan, OR	194	106	1	1,084	239	4	957	226	4	1,590	240	13	2,034	364	6	2,346	442	2
Beaver Valley, PA	1,917	486	18	1,892	443	17	1,466	389	19	1,024	428	3	851	347	3	695	313	8
Limerick, PA	2,146	590	18	2,121	546	17	1,695	493	19	1,239	521	3	883	422	4	735	373	4
Peach Bottom, PA	2,126	582	21	2,101	538	20	1,674	484	22	1,219	505	5	837	415	16	714	357	5
Susquehanna, PA	2,108	514	18	2,081	471	17	1,656	416	19	1,222	445	8	902	426	3	754	377	4
Three Mile Island, PA	2,108	555	18	2,083	512	17	1,656	458	19	1,201	489	3	845	390	3	697	341	4
Catawba, SC	2,131	608	18	1,899	424	23	1,566	483	9	1,061	349	10	541	273	4	394	223	3
Oconee, SC	2,180	502	4	1,885	381	23	1,553	438	9	1,048	306	10	504	207	4	357	157	3
Robinson, SC	2,227	597	18	1,996	431	23	1,663	471	9	1,158	339	10	611	255	4	463	205	4
Summer, SC	2,176	567	18	1,945	383	24	1,613	441	9	1,107	308	10	574	227	4	427	177	4
Sequoyah, TN	2,050	414	4	1,755	293	23	1,424	350	9	918	218	10	430	158	3	283	108	3
Watts Bar, TN	2,077	392	4	1,782	272	23	1,451	328	9	944	196	10	485	164	3	337	115	4
Comanche Peak, TX	1,798	275	4	1,297	190	13	1,033	147	5	459	115	0	214	107	1	674	246	0
South Texas, TX	1,955	392	23	1,511	149	35	1,267	124	11	616	231	19	390	148	20	850	287	19
North Anna, VA	2,136	655	23	2,099	414	23	1,743	444	12	1,261	338	10	801	312	4	654	262	4
Surry, VA	2,180	691	27	2,128	447	28	1,772	478	17	1,291	372	15	717	418	3	569	369	4
Vermont Yankee, VT	2,188	731	21	2,162	687	20	1,735	634	22	1,312	656	6	982	608	14	834	559	14
WNP 1,2,4, WA	29	0	0	957	200	4	830	188	4	1,463	201	13	1,906	326	6	2,218	404	2
Kewaunee, WI	1,672	243	3	1,728	356	27	1,302	301	30	888	379	24	773	323	20	765	305	20
La Crosse BWR, WI	1,601	146	1	1,656	209	7	1,233	153	9	946	193	0	879	312	6	870	295	6
Point Beach, WI	1,668	243	3	1,724	356	27	1,298	301	30	885	379	24	769	322	20	761	305	20
TOTAL	147,262	35,365	1,134	138,511	29,993	1,514	111,790	28,383	1,251	82,575	27,631	818	64,246	25,214	671	61,161	23,382	655

TABLE F.19. Summary of Radiological Exposure for Shipments of Eastern Reactor Fuel Through an MRS to a Repository and Western Reactor Fuel Directly to a Repository[(a)] (person-rem)

MRS to Repository	70% Rail/30% Truck From Reactors					100% Rail From Reactors				
	Reactor to Repository	Reactor to MRS	Spent Fuel From MRS	Consol. Waste From MRS	Total	Reactor to Repository	Reactor to MRS	Spent Fuel From MRS	Consol. Waste From MRS	Total
Hartsville (100-ton cask) to										
Hanford	952	4,391	209	143	5,695	103	555	209	143	1,010
Yucca Mt	790	4,391	199	145	5,526	81	555	199	145	981
Davis	880	4,391	165	104	5,540	110	555	165	104	934
Deaf Smith	1,235	4,391	155	95	5,876	109	555	155	95	914
Vacherie	1,820	4,391	87	51	6,349	147	555	87	51	840
Richton	2,261	4,391	100	52	6,804	177	555	100	52	884
Hartsville (150-ton cask) to										
Hanford	952	4,391	89	116	5,544	103	555	89	116	859
Yucca Mt	790	4,391	104	123	5,403	81	555	104	123	858
Davis	880	4,391	62	87	5,420	110	555	62	87	814
Deaf Smith	1,235	4,391	58	79	5,764	109	555	58	79	802
Vacherie	1,820	4,391	31	32	6,285	147	555	31	32	776
Richton	2,261	4,391	36	42	6,730	177	555	36	42	810
Oak Ridge/Clinch River (100-ton cask) to										
Hanford	952	4,376	173	127	5,625	103	555	173	127	955
Yucca Mt	790	4,376	202	151	5,519	81	555	202	151	989
Davis	880	4,376	169	120	5,545	110	555	169	120	954
Deaf Smith	1,235	4,376	158	106	5,876	109	555	158	106	929
Vacherie	1,820	4,376	169	104	6,469	147	555	169	104	975
Richton	2,261	4,376	98	47	6,782	177	555	98	47	877
Oak Ridge/Clinch River (150-ton cask) to										
Hanford	952	4,376	73	105	5,506	103	555	73	105	836
Yucca Mt	790	4,376	106	124	5,396	81	555	106	124	866
Davis	880	4,376	64	97	5,417	110	555	64	97	826
Deaf Smith	1,235	4,376	59	90	5,760	109	555	59	90	813
Vacherie	1,820	4,376	64	87	6,347	147	555	64	87	853
Richton	2,261	4,376	36	36	6,710	177	555	36	36	805

(a) Exposure data are for the entire life of the MRS facility.

TABLE F.20. Summary of Radiological Exposure for Shipments of All Reactor Fuel Through an MRS to a Repository[a] (person-rem)

MRS to Repository	70% Rail/30% Truck From Reactors				100% Rail From Reactors			
	Reactor to MRS	Spent Fuel From MRS	Consol. Waste From MRS	Total	Reactor to MRS	Spent Fuel From MRS	Consol. Waste From MRS	Total
Hartsville (100-ton cask) to								
Hanford	5,880	243	165	6,288	680	243	165	1,088
Yucca Mt	5,880	230	169	6,279	680	230	169	1,079
Davis	5,880	195	122	6,197	680	195	122	997
Deaf Smith	5,880	602	111	6,594	680	602	111	971
Vacherie	5,880	101	60	6,042	680	101	60	842
Richton	5,880	115	61	6,057	680	115	61	857
Hartsville (150-ton cask) to								
Hanford	5,880	101	132	6,113	680	101	132	913
Yucca Mt	5,880	111	143	6,140	680	111	143	940
Davis	5,880	73	100	6,054	680	73	100	854
Deaf Smith	5,880	67	92	6,039	680	67	92	839
Vacherie	5,880	38	49	5,968	680	38	49	768
Richton	5,880	43	48	5,971	680	43	48	771
Oak Ridge/Clinch River (100-ton cask) to								
Hanford	5,883	204	150	6,242	685	204	150	1,039
Yucca Mt	5,883	238	175	6,302	685	238	175	1,098
Davis	5,883	198	137	6,223	685	198	137	1,020
Deaf Smith	5,883	188	123	6,200	685	188	123	997
Vacherie	5,883	200	121	6,209	685	200	121	1,006
Richton	5,883	114	55	6,058	685	114	55	855
Oak Ridge/Clinch River (150-ton cask) to								
Hanford	5,883	86	123	6,098	685	86	123	895
Yucca Mt	5,883	124	149	6,161	685	124	149	958
Davis	5,883	75	116	6,079	685	75	116	876
Deaf Smith	5,883	70	103	6,062	685	70	103	859
Vacherie	5,883	76	100	6,064	685	76	100	861
Richton	5,883	43	42	5,973	685	43	42	770

(a) Exposure data are for the entire life of the MRS facility.

TABLE F.21. Summary of Nonradiological Risk for Shipments of Eastern Fuel Through an MRS and Western Reactor Fuel Directly to a Repository[(a)] [fatalities/(injuries)]

	70% Rail/30% Truck From Reactors				100% Rail From Reactors			
MRS to Repository	Reactor to Repository	Reactor to MRS	MRS to Repository	Total	Reactor to Repository	Reactor to MRS	MRS to Repository	Total
Hartsville (100-ton cask) to								
Hanford	0.1 (1.3)	2.5 (31)	18 (192)	21 (224)	0 1 (1.3)	0.6 (6.1)	18 (192)	19 (199)
Yucca Mt	0.1 (1.2)	2.5 (31)	19 (206)	22 (238)	0.1 (1.2)	0.6 (6.1)	19 (206)	20 (123)
Oavis	0.2 (1.8)	2.5 (31)	15 (157)	18 (190)	0.2 (1.8)	0.6 (6.1)	15 (157)	16 (165)
Deaf Smith	0.2 (1.9)	2.5 (31)	11 (111)	14 (144)	0.2 (1.9)	0.6 (6.1)	11 (111)	12 (119)
Vacherie	0.3 (2.9)	2.5 (31)	5.0 (53)	7.8 (87)	0.3 (2.9)	0.6 (6.1)	5.0 (53)	5.9 (62)
Richton	0.3 (3.4)	2.5 (31)	5.0 (53)	7.8 (88)	0.3 (3.4)	0.6 (6.1)	5.0 (53)	5.9 (63)
Hartsville (150-ton cask) to								
Hanford	0.1 (1.3)	2.5 (31)	4.9 (52)	7.5 (84)	0.1 (1.3)	0.6 (6.1)	4.9 (52)	5.6 (59)
Yucca Mt	0.1 (1.2)	2.5 (31)	7.8 (83)	10 (115)	0.1 (1.2)	0.6 (6.1)	7.8 (83)	8.5 (90)
Oavis	0.2 (1.8)	2.5 (31)	4.0 (41)	6.7 (74)	0.2 (1.8)	0.6 (6.1)	4.0 (41)	4.8 (49)
Deaf Smith	0.2 (1.9)	2.5 (31)	2.7 (29)	5.4 (62)	0.2 (1.9)	0.6 (6.1)	2.7 (29)	3.5 (37)
Vacherie	0.3 (2.9)	2.5 (31)	1.3 (14)	4.1 (48)	0.3 (2.9)	0.6 (6.1)	1.3 (14)	2.2 (23)
Richton	0.3 (3.4)	2.5 (31)	1.3 (14)	4.1 (48)	0.3 (3.4)	0.6 (6.1)	1.3 (14)	2.2 (24)
Oak Ridge/Clinch River (100-ton cask) to								
Hanford	0.1 (1.3)	2.4 (30)	19 (204)	22 (235)	0.1 (1.3)	0.6 (6.3)	19 (204)	20 (212)
Yucca Mt	0.1 (1.2)	2.4 (30)	21 (229)	24 (260)	0.1 (1.2)	0.6 (6.3)	21 (229)	22 (237)
Oavis	0.2 (1.8)	2.4 (30)	17 (181)	20 (213)	0.2 (1.8)	0.6 (6.3)	17 (181)	18 (189)
Oeaf Smith	0.2 (1.9)	2.4 (30)	13 (133)	16 (168)	0.2 (1.9)	0.6 (6.3)	13 (133)	14 (141)
Vacherie	0.3 (2.9)	2.4 (30)	8.4 (90)	11 (123)	0.3 (2.9)	0.6 (6.3)	8.4 (90)	9.3 (99)
Richton	0.3 (3.4)	2.4 (30)	4.6 (48)	7.3 (81)	0.3 (3.4)	0.6 (6.3)	4.6 (48)	5.5 (58)
Oak Ridge/Clinch River (150-ton cask) to								
Hanford	0.1 (1.3)	2.4 (30)	5.2 (56)	7.7 (87)	0.1 (1.3)	0.6 (6.3)	5.2 (56)	5.9 (64)
Yucca Mt	0.1 (1.2)	2.4 (30)	8.6 (91)	11 (122)	0.1 (1.2)	0.6 (6.3)	8.6 (91)	9.3 (99)
Oavis	0.2 (1.8)	2.4 (30)	4.5 (47)	7.1 (79)	0.2 (1.8)	0.6 (6.3)	4.5 (47)	5.3 (55)
Oeaf Smith	0.2 (1.9)	2.4 (30)	3.2 (34)	5.8 (66)	0.2 (1.9)	0.6 (6.3)	3.2 (34)	4.0 (42)
Vacherie	0.3 (2.9)	2.4 (30)	2.2 (23)	4.9 (56)	0.3 (2.9)	0.6 (6.3)	2.2 (23)	3.1 (32)
Richton	0.3 (3.4)	2.4 (30)	1.2 (12)	3.9 (45)	0.3 (3.4)	0.6 (6.3)	1.2 (12)	2.1 (22)

(a) Risk data are for the entire life of the MRS facility.

TABLE F.22. Summary of Nonradiological Risk for Shipping All Reactor Fuel Through an MRS to a Repository[a] [fatalities/injuries)]

MRS to Repository	70% Rail/30% Truck From Reactors: Reactor to MRS	MRS to Repository	Total	100% Rail From Reactors: Reactor to MRS	MRS to Repository	Total
Hartsville (100-ton cask) to						
Hanford	3.4 (43)	20 (218)	23 (261)	0.9 (8.2)	20 (218)	22 (226)
Yucca Mt	3.4 (43)	24 (242)	27 (285)	0.9 (8.2)	24 (242)	26 (250)
Davis	3.4 (43)	17 (182)	20 (225)	0.9 (8.2)	17 (182)	19 (190)
Deaf Smith	3.4 (43)	12 (132)	15 (175)	0.9 (8.2)	12 (132)	14 (140)
Vacherie	3.4 (43)	5.9 (63)	8.4 (106)	0.9 (8.2)	5.9 (63)	6.8 (71)
Richton	3.4 (43)	5.9 (63)	8.4 (106)	0.9 (8.2)	5.9 (63)	6.8 (71)
Hartsville (150-ton cask) to						
Hanford	3.4 (43)	5.7 (60)	8.2 (103)	0.9 (8.2)	5.7 (60)	6.6 (68)
Yucca Mt	3.4 (43)	9.1 (97)	12 (140)	0.9 (8.2)	9.1 (97)	10 (105)
Davis	3.4 (43)	4.6 (48)	7.1 (91)	0.9 (8.2)	4.6 (48)	5.5 (56)
Deaf Smith	3.4 (43)	3.2 (34)	5.7 (77)	0.9 (8.2)	3.2 (34)	4.1 (42)
Vacherie	3.4 (43)	1.5 (17)	4.0 (60)	0.9 (8.2)	1.5 (17)	2.4 (25)
Richton	3.4 (43)	1.5 (17)	4.0 (60)	0.9 (8.2)	1.5 (17)	2.4 (25)
Oak Ridge/Clinch River (100-ton cask) to						
Hanford	3.4 (43)	22 (230)	25 (273)	1.0 (8.5)	22 (230)	23 (239)
Yucca Mt	3.4 (43)	26 (266)	29 (309)	1.0 (8.5)	26 (266)	27 (275)
Davis	3.4 (43)	20 (216)	23 (259)	1.0 (8.5)	20 (216)	21 (225)
Deaf Smith	3.4 (43)	15 (156)	18 (199)	1.0 (8.5)	15 (156)	16 (165)
Vacherie	3.4 (43)	10 (105)	15 (148)	1.0 (8.5)	10 (105)	11 (114)
Richton	3.4 (43)	5.3 (57)	8.7 (100)	1.0 (8.5)	5.3 (57)	6.3 (66)
Oak Ridge/Clinch River (150-ton cask) to						
Hanford	3.4 (43)	6.1 (55)	8.5 (98)	1.0 (8.5)	6.1 (55)	7.1 (64)
Yucca Mt	3.4 (43)	10 (106)	13 (149)	1.0 (8.5)	10 (106)	11 (115)
Davis	3.4 (43)	5.2 (55)	8.6 (98)	1.0 (8.5)	5.2 (55)	6.2 (64)
Deaf Smith	3.4 (43)	3.7 (40)	7.1 (83)	1.0 (8.5)	3.7 (40)	4.7 (49)
Vacherie	3.4 (43)	2.6 (28)	6.0 (71)	1.0 (8.5)	2.6 (28)	3.6 (37)
Richton	3.4 (43)	1.4 (15)	4.8 (58)	1.0 (8.5)	1.4 (15)	2.4 (24)

(a) Risk data are for the entire life of the MRS facility.

TABLE F.23. Risk/Exposure Results for Shipping Spent Fuel to an MRS Facility[a]

	Only Eastern Reactor Fuel Shipped to an MRS						All Reactor Fuel Shipped to an MRS					
	Radiation Exposure (person-rem)			Nonradiological Risk [fatalities (injuries)]			Radiation Exposure (person-rem)			Nonradiological Risk [fatalities (injuries)]		
Shipping Mode	Normal Occup.	Normal Nonoccup.	Accident Nonoccup.	Normal Nonoccup.	Accident Occup.	Accident Nonoccup.	Normal Occup.	Normal Nonoccup.	Accident Nonoccup.	Normal Nonoccup.	Accident Occup.	Accident Nonoccup.
100% Rail to												
Hartsville	210	275	70	0.1	0.04/(5.0)	0.5/(1.0)	265	335	80	0.1	0.05/(6.8)	0.7/(1.4)
Oak Ridge/ Clinch River	210	275	70	0.1	0.04/(5.1)	0.5/(1.1)	270	335	80	0.1	0.05/(7.0)	0.8/(1.4)
100% Truck to												
Hartsville	2,250	11,000	90	0.2	1.4/(3.0)	5.0/(85)	2,900	15,000	110	0.2	2.0/(4.2)	7.2/(120)
Oak Ridge/ Clinch River	2,200	11,000	90	0.1	1.4/(2.8)	4.8/(81)	2,900	15,000	110	0.2	2.0/(4.1)	7.0/(120)
70% Rail/30% Truck to												
Hartsville	822	3,493	76	0.1	0.5/(4.4)	1.9/(26)	1,056	4,735	89	0.1	0.6/(6.0)	2.7/(37)
Oak Ridge/ Clinch River	807	3,493	76	0.1	0.5/(4.4)	1.8/(25)	1,059	4,735	89	0.1	0.6/(6.1)	2.7/(37)

(a) Exposure/risk data are for the entire life of the MRS facility.

TABLE F.24. Risk/Exposure for Shipping Western Reactor Fuel Directly to a Repository[a]

Shipping Mode	Radiation Exposure (person-rems) Normal Occup.	Normal Nonoccup.	Accident Nonoccup.	Nonradiological Risk [fatalities (injuries)] Normal Nonoccup.	Accident Occup.	Accident NonOccup.
100% Rail to						
Hanford	42	49	12	0.02	0.01/(1.1)	0.1/(0.2)
Yucca Mt	39	36	6	0.01	0.01/(.99)	0.1/(0.2)
Davis	50	50	10	0.01	0.01/(1.5)	0.2/(0.3)
Deaf Smith	55	47	7	0.01	0.01/(1.6)	0.2/(0.3)
Vacherie	70	65	12	0.02	0.02/(2.4)	0.3/(0.5)
Richton	80	80	17	0.03	0.02/(2.8)	0.3/(0.6)
100% Truck to						
Hanford	470	2,450	16	0.07	0.3/(0.7)	1.2/(20)
Yucca Mt	385	2,050	10	0.05	0.3/(0.7)	1.2/(19)
Davis	415	2,250	9	0.05	0.4/(0.7)	1.4/(21)
Deaf Smith	600	3,250	11	0.06	0.6/(1.1)	2.0/(32)
Vacherie	900	4,800	21	0.06	0.8/(1.6)	2.8/(45)
Richton	1,100	6,000	24	0.05	1.0/(2.0)	3.6/(57)
70% Rail/30% Truck to						
Hanford	170	769	13	0.04	0.1/(1.0)	0.4/(6.1)
Yucca Mt	143	640	7	0.02	0.1/(0.9)	0.4/(5.8)
Davis	160	710	10	0.02	0.1/(1.3)	0.6/(6.5)
Deaf Smith	219	1,008	8	0.03	0.2/(1.5)	0.7/(9.8)
Vacherie	319	1,486	15	0.03	0.3/(2.2)	1.1/(14)
Richton	386	1,856	19	0.04	0.3/(2.6)	1.3/(18)

(a) Exposure/risk data are for the entire life of the MRS facility.

TABLE F.25. Risk/Exposure for Shipping Consolidation Spent Fuel From an MRS to a Repository[a]

MRS to Repository	Only Eastern Reactor Fuel Shipped to an MRS: Radiation Exposure (person-rem)			Only Eastern Reactor Fuel Shipped to an MRS: Nonradiological Risk [fatalities (injuries)]			All Reactor Fuel Shipped to an MRS: Radiation Exposure (person-rem)			All Reactor Fuel Shipped to an MRS: Nonradiological Risk [fatalities (injuries)]		
	Normal Occup.	Normal Nonoccup.	Accident Nonoccup.	Normal Nonoccup.	Accident Occup.	Accident Nonoccup.	Normal Occup.	Normal Nonoccup.	Accident Nonoccup.	Normal Nonoccup.	Accident Occup.	Accident Nonoccup.
Hartsville (100-ton cask) to												
Hanford	19	140	50	0.05	1.1/(160)	17/(32)	23	160	60	0.06	1.3/(180)	19/(38)
Yucca Mt	22	135	42	0.1	1.3/(170)	18/(36)	26	155	49	0.1	1.5/(200)	22/(42)
Davis	18	105	42	0.06	1.0/(130)	14/(27)	21	125	49	0.08	1.1/(150)	16/(32)
Deaf Smith	14	100	41	0.06	0.7/(92)	9.8/(19)	17	115	47	0.07	0.8/(110)	11/(22)
Vacherie	10	55	22	0.03	0.3/(44)	4.7/(9.2)	11	65	25	0.04	0.4/(52)	5.5/(11)
Richton	10	65	25	0.02	0.3/(44)	4.7/(9.2)	11	75	29	0.02	0.4/(52)	5.5/(11)
Hartsville (150-ton cask) to												
Hanford	6	39	44	0.01	0.3/(43)	4.6/(8.9)	6	45	50	0.02	0.4/(50)	5.3/(10)
Yucca Mt	9	55	40	0.04	0.5/(69)	7.3/(14)	10	60	47	0.05	0.6/(80)	8.5/(17)
Davis	5	28	29	0.02	0.3/(34)	3.7/(7.1)	6	33	34	0.02	0.3/(40)	4.3/(8.3)
Deaf Smith	4	26	28	0.02	0.2/(24)	2.5/(5.0)	4	30	33	0.02	0.2/(28)	3.0/(5.8)
Vacherie	2	14	15	0.008	0.08/(12)	1.2/(2.4)	3	17	18	0.009	0.1/(14)	1.4/(2.8)
Richton	2	17	17	0.005	0.09/(12)	1.2/(2.4)	3	20	20	0.006	0.1/(14)	1.4/(2.8)
Oak Ridge/Clinch River (100-ton cask) to												
Hanford	20	110	43	0.06	1.2/(170)	18/(34)	24	130	50	0.07	1.4/(190)	21/(40)
Yucca Mt	24	135	43	0.1	1.4/(190)	20/(39)	28	160	50	0.1	1.6/(220)	24/(46)
Davis	20	105	44	0.09	1.1/(150)	16/(31)	23	125	50	0.1	1.3/(180)	19/(36)
Deaf Smith	16	100	42	0.07	0.8/(110)	12/(23)	19	120	49	0.09	0.9/(130)	14/(26)
Vacherie	13	110	46	0.06	0.5/(75)	7.9/(15)	15	130	55	0.07	0.6/(87)	9.3/(18)
Richton	9	65	24	0.01	0.3/(40)	4.3/(8.3)	11	75	28	0.01	0.3/(47)	5.0/(9.7)
Oak Ridge/Clinch River (150-ton cask) to												
Hanford	6	31	36	0.02	0.3/(46)	4.9/(9.5)	7	37	42	0.02	0.4/(54)	5.7/(11)
Yucca Mt	10	55	41	0.05	0.6/(75)	8.0/(16)	11	65	48	0.05	0.6/(88)	9.4/(18)
Davis	5	28	31	0.02	0.3/(39)	4.2/(8.1)	6	33	36	0.03	0.3/(46)	4.9/(9.5)
Deaf Smith	4	26	29	0.02	0.2/(28)	3.0/(5.9)	5	31	34	0.02	0.2/(33)	3.5/(6.9)
Vacherie	3	29	32	0.02	0.1/(19)	2.1/(4.0)	4	34	38	0.02	0.2/(23)	2.4/(4.7)
Richton	2	17	17	0.003	0.08/(10)	1.1/(2.2)	3	20	20	0.003	0.09/(12)	1.3/(2.6)

(a) Exposure/risk data are for the entire life of the MRS facility.

TABLE F.26. Risk/Exposure for Shipping Consolidation Waste From an MRS to a Repository[a]

	Consolidation Waste From Eastern Reactor Fuel Only						Consolidation Waste for Fuel From All Reactors					
	Radiation Exposure (person-rem)			Nonradiological Risk [fatalities (injuries)]			Radiation Exposure (person-rem)			Nonradiological Risk [fatalities (injuries)]		
MRS to Repository	Normal Occup.	Normal Nonoccup.	Accident Nonoccup.	Normal Nonoccup.	Accident Occup.	Accident Nonoccup.	Normal Occup.	Normal Nonoccup.	Accident Nonoccup.	Normal Nonoccup.	Accident Occup.	Accident Nonoccup.
Hartsville (100-ton cask) to												
Hanford	8	60	75	0.02	--[b]	--[b]	10	70	85	0.03	--[b]	--[b]
Yucca Mt	8	48	90	0.04	--	--	9	55	105	0.04	--	--
Davis	6	38	60	0.02	--	--	8	44	70	0.03	--	--
Deaf Smith	5	35	55	0.02	--	--	6	41	65	0.03	--	--
Vacherie	3	19	29	0.01	--	--	4	23	34	0.01	--	--
Richton	3	23	26	0.007	--	--	4	27	31	0.008	--	--
Hartsville (150-ton cask) to												
Hanford	5	37	70	0.01	--	--	6	41	85	0.02	--	--
Yucca Mt	4	29	85	0.02	--	--	6	33	100	0.03	--	--
Davis	4	23	60	0.01	--	--	5	26	70	0.02	--	--
Deaf Smith	3	22	55	0.01	--	--	3	24	65	0.02	--	--
Vacherie	2	12	29	0.006	--	--	2	14	34	0.007	--	--
Richton	2	14	26	0.004	--	--	2	16	30	0.005	--	--
Oak Ridge/Clinch River (100-ton cask) to												
Hanford	9	49	70	0.03	--	--	10	55	85	0.03	--	--
Yucca Mt	8	48	95	0.04	--	--	10	55	110	0.05	--	--
Davis	7	38	75	0.03	--	--	8	44	85	0.04	--	--
Deaf Smith	6	36	65	0.03	--	--	7	42	75	0.03	--	--
Vacherie	4	40	60	0.02	--	--	5	46	70	0.03	--	--
Richton	3	23	21	0.004	--	--	4	27	25	0.004	--	--
Oak Ridge/Clinch River (150-ton cask) to												
Hanford	5	30	70	0.02	--	--	6	33	85	0.02	--	--
Yucca Mt	5	29	90	0.02	--	--	6	33	110	0.03	--	--
Davis	4	23	70	0.02	--	--	5	26	85	0.02	--	--
Deaf Smith	3	22	65	0.02	--	--	4	25	75	0.02	--	--
Vacherie	3	24	60	0.01	--	--	3	27	70	0.02	--	--
Richton	2	14	21	0.002	--	--	2	16	24	0.003	--	--

(a) Exposure/risk data are for the entire life of the MRS facility.
(b) Nonradiological accident risks have already been included with spent fuel calculations in Table F.27.

TABLE F.27. Risk/Exposure for Shipments of Spent Fuel From All Reactors Directly to a Repository[a]

	Radiation Exposure (person-rem)			Nonradiological Risk [fatalities (injuries)]		
Shipping Mode	Normal Occup.	Normal Nonoccup.	Accident Nonoccup.	Normal Nonoccup.	Accident Occup.	Accident Nonoccup.
100% Rail to						
Hanford	550	550	120	0.2	0.1/(19)	2.1/(4.0)
Yucca Mt	550	550	115	0.2	0.1/(19)	2.1/(4.0)
Davis	455	475	100	0.1	0.1/(15)	1.7/(3.2)
Deaf Smith	370	415	90	0.1	0.09/(12)	1.3/(2.4)
Vacherie	330	395	90	0.1	0.07/(9.8)	1.1/(2.0)
Richton	315	385	90	0.1	0.07/(9.2)	1.0/(1.9)
100% Truck to						
Hanford	8,000	42,000	200	0.4	6.8/(13)	24/(380)
Yucca Mt	7,000	38,500	175	0.4	6.4/(12)	23/(360)
Davis	6,000	32,500	165	0.4	5.2/(10)	18/(290)
Deaf Smith	4,950	26,000	155	0.3	3.9/(7.7)	14/(220)
Vacherie	4,050	21,000	140	0.2	3.0/(6.1)	11/(170)
Richton	3,650	19,000	125	0.2	2.7/(5.5)	9.6/(160)
70% Rail/30% Truck to						
Hanford	2,785	12,985	144	0.3	2.1/(17)	8.7/(117)
Yucca Mt	2,485	11,935	133	0.3	2.0/(17)	8.4/(111)
Davis	2,119	10,083	120	0.2	1.6/(14)	6.6/(89)
Deaf Smith	1,744	8,091	110	0.2	1.2/(11)	5.1/(68)
Vacherie	1,446	6,577	105	0.1	1.0/(8.7)	4.1/(52)
Richton	1,316	5,970	101	0.1	0.9/(8.1)	3.6/(49)

(a) Exposure/risk data are for the entire life of the repository.

F.4 POTENTIAL MAXIMUM DOSE TO AN INDIVIDUAL

This section describes the calculated dose to the maximally exposed individual for both normal transport operations and severe accident conditions.

F.4.1 Normal Transport Operations

Tables F.28 and F.29 show the calculated maximum radiation doses that may occur to an individual as a result of selected activities for transportation operations. The activities are not related to accidents but rather could occur during normal operations. Table F.28 is for truck transport and Table F.29 is for rail transport. The dose for a number of services or activities are analyzed for each mode. The results in the tables are taken from Sandquist, et al. (1985). Sandquist represents truck and rail casks with a simple analytical model and assumes that the dose rates from the casks are at regulatory levels (i.e., at the maximum levels permitted by existing regulations).

To illustrate how these calculations were performed, the calculation of the dose to an individual changing a tire on the trailer of a truck carrying a loaded spent-fuel cask (Truck Servicing) is discussed here. The exposed individual was assumed to be 16 feet from the center of the cask while changing the tire. It was further assumed that changing the innermost tire (dual wheels) would take almost a full hour. The dose rate at the location was estimated to be 0.1 millirem (mrem) per minute, a rate which would produce a 5 mrem dose to an individual for the complete service procedure. This dose is about the same dose that would be received on a transcontinental airplane trip.

Many of the services or activities analyzed would require administrative controls if they were to happen on a routine basis. For example, if an individual could potentially change many tires on trucks carrying spent-fuel cask in a year, the DOE could impose administrative controls to minimize the accumulated dose. Routine occurrence of operations involving the potential for significant cumulative dose either would not be allowed or administrative controls would be applied to keep cumulative exposures from becoming too high. The dose for types of activities and services will be more fully analyzed during the preparation of the environmental impact statement for the MRS facility and repository.

F.4.2 Accidents

Table F.30 presents the results of an analysis performed by Sandquist et al. (1985) to estimate the dose to an individual that may result from three categories of very severe accidents, i.e., accidents which would produce conditions more severe than the regulatory test conditions. Accidents of this severity are not likely to occur during the shipment of spent fuel to an MRS facility or a repository.

Each set of results in Table F.30 is for an accident in which there is a release of material from a rail cask carrying 14 PWR assemblies of spent fuel. The releases are consistent with those assumed in past analyses [Wilmot et al. (1983)][a] and are based on release mechanisms defined by Wilmot (1981).

Accident classes (4, 5, and 6) are described in Wilmot et al. (1983). These are very severe accidents, all of which would produce conditions much greater than those specified in the NRC regulations. A Class 4 accident would require a very severe impact, i.e., the equivalent of a 100-ft drop onto a granite slab. This impact would shake adhered activation products off of the spent-fuel elements and may rupture a few spent-fuel rods. A Class 5 accident is a Class 4 impact with a subsequent very intense fire, i.e., longer and hotter than regulatory test. A Class 6 accident would result in severe oxidation of ruptured fuel rods. These are extremely unlikely to occur; they are estimated to occur once in a million vehicle accidents, and would not be expected to occur during MRS facility or repository shipments.

According to Sandquist et al. (1985) the maximum dose to an individual for the most severe accident is around 10 rem and would occur to an individual living about 230 feet from the accident scene. Furthermore, this individual would have to live there uninterrupted for 50 years. Even if the dose were accumulated over an acute exposure period, the individual would show no symptoms nor have his/her life threatened. An acute dose of around 50 rem would be required before any symptoms would be observable; a dose of more than 450 rem would be required before early death would be certain (NCRP 1971).

The dose to an individual following a potential accident from the same three severity categories analyzed by Sandquist et al. (1985), for the larger capacity MRS to repository casks may be conservatively estimated by mutiplying the results shown in Table F.21 by the ratio of cask capacities. This would result in a maximum dose, for the 150 ton MRS to Basalt repository cask, of approximately 60 rem.

(a) Also, Cashwell, J., K. S. Neuhauser and P. C. Reardon. 1985 (draft). Transportation Impacts of the Commercial Radioactive Waste Management Program. SAND85-2715, TTC-00633, Sandia National Laboratories, Albuquerque, New Mexico.

The estimated doses could be greater or smaller depending upon the accident circumstances; however, the analyses made no attempt to account for mitigating measures that would be exercised after an accident. Simple measures such as staying indoors if advised could easily reduce the doses received by a factor of 10 or more. By carefully tracking the release of material as it is dispersed by the wind, such advisories can be made.

TABLE F.28. Projected Maximum Individual Exposures From Normal Transport (truck spent-fuel cask)

Service or Activity	Mean Distance to Center of Cask (ft)	Maximum Exposure Time	Dose Rate and Total Dose
Caravan			
Passengers in vehicles traveling in adjacent lanes in the same direction as cask vehicle	35	30 min	0.04 mrem/min 1 mrem
Traffic Obstruction			
Passengers in stopped vehicles in lanes adjacent to the cask vehicle which has stopped due to traffic obstruction	15	30 min	0.1 mrem/min 3 mrem
Residents and Pedestrians			
Slow transit (due to traffic control devices through area with pedestrians)	20	6 min	0.07 mrem/min 0.4 mrem
Truck stop for drivers' rest. Exposures to residents and passers-by.	130	8 hr (assumes overnight)	0.006 mrem/min 3 mrem
Slow transit through area with residents (homes, businesses, etc.)	50	6 min	0.02 mrem/min 0.1 mrem
Truck Servicing			
Refueling (100 gallon capacity)			0.06 mrem/min
- 1 nozzle from 1 pump	25 (at tank)	40 min	2 mrem
- 2 nozzles from 1 pump	25 (at tank)	20 min	1 mrem
Load inspection/enforcement	10 (near personnel barrier)	12 min	0.2 mrem/min 2 mrem
Tire change or repair to cask trailer	16 (inside tire nearest cask)	50 min	0.1 mrem/min 5 mrem
State weight scales	15	2 min	0.1 mrem/min 0.2 mrem

TABLE F.29. Projected Maximum Individual Exposures From Normal Transport (rail spent-fuel cask)

Service or Activity	Mean Distance to Center of Cask (ft)	Maximum Exposure Time	Dose Rate and Total Dose
Caravan			
Passengers in rail cars or highway vehicles traveling in same direction and vicinity as cask vehicle	65	10 min	0.03 mrem/min 0.3 mrem
Traffic Obstruction			
Exposures to persons in vicinity of stopped/slowed cask vehicle due to rail traffic obstruction	20	25 min	0.1 mrem/min 2 mrem
Residents and Pedestrians			
Slow transit (through station or due to traffic control devices) through area with pedestrians	25	10 min	0.07 mrem/min 0.7 mrem
Slow transit through area with residents (homes, businesses, etc.)	70	10 min	0.02 mrem/min 0.2 mrem
Train stop for crew's personal needs (food, crew change, first aid, etc.)	150	2 hr	0.005 mrem/min 0.7+ mrem
Train Servicing			
Engine refueling, car changes, train maintenance, etc.	35	2 hr	0.04 mrem/min 5 mrem
Cask inspection/enforcement by train, state or federal officials	10	10 min	0.2 mrem/min 2 mrem
Cask car coupler inspection/maintenance	30	20 min	0.07 mrem/min 1 mrem
Axle, wheel or brake inspection/ lubrication/maintenance on cask car	25	30 min	0.09 mrem/min 3 mrem

TABLE F.30. Maximum Individual Radiation Dose Estimates (rail-cask accident)

Accident Class[c]	Dose (mrem)[a,b] Inhalation	Plume Gamma	Ground Gamma	Dust Inhalation	Total
4	180	11	12	0.0001	200
5	6,100	71	91	0.004	6,300
6	9,000	550	710	0.0006	10,300

(a) Accident class consistent with Wilmot et al. (1983). Class 6 is most severe and has probability of about 1 in 1 million accidents.
(b) Maximum individual dose occurs 70 m downwind of the release point.
(c) Values reported as effective whole-body dose.

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APPENDIX G

ENVIRONMENTAL IMPACT MODELS AND METHODS

APPENDIX G

ENVIRONMENTAL IMPACT MODELS AND METHODS

The mathematical models and computer programs used in calculating radiation doses, nonradiological impacts, and noise for the six alternative site-design combinations are discussed in this appendix. These models and programs have been documented separately; therefore, only brief summaries will be presented here. Because no contaminated liquid releases are anticipated for the MRS facility, only impacts from gaseous effluents to the atmosphere are addressed.

G.1 CONSTRUCTION PHASE

Nonradiological emissions from construction of the MRS facility will consist of total suspended particulate (TSP) from fugitive dust and combustion products from mobile equipment. Because the estimated fuel requirements are the same for the three sites and two concepts, only one estimate of emissions during construction is given in Table G.1.

Site preparation will disrupt only part of the site at any given time. It is assumed that at the time of maximum impact, heavy construction for the facility disturbs 100 acres (40.5 ha) for both facility types, although the total land area required for the two facility types is different. An emission factor of 220 pounds (100 kg) per acre per month of fugitive dust is based on the factor from AP-42 (EPA 1983), modified for the precipitation evaporation (PE) index of the area, and 50% credit given for application of water for dust control. Uncertainty in estimated concentrations of fugitive dust arises from the difficulty in calculating emission factors for construction and defining an "active" construction site. The adaptation of point source meteorological models to an area source using the "virtual point" method (Strenge and Bander 1981) adds additional uncertainty.

The estimated amount of TSP generated during heavy construction (Table G.1) qualifies as "significant" in 40 CFR 51. Emissions from combustion of fuel are based on equal fuel consumption rates and emission factors for heavy-duty diesel construction equipment (Kircher 1975) and highway vehicles (EPA 1981). Secondary emissions of combustion products from mobile construction equipment, which are not covered in 40 CFR 51, are included in Table G.1.

TABLE G.1. Nonradiological Emissions During Construction of an MRS Facility

Pollutant	Emission Rate (tons/yr)
TSP (Fugitive dust)[a]	>50
Cement/aggregate dust[b]	9
Combustion products:[c]	
particulate	4
NO_x	12
SO_x	5
HC	6
CO	35

(a) TSP is defined as dust particles with a diameter equal to or less than 30 mm. Calculations are based on the time of maximum impact (about 12 tons/mo) not concurrent with maximum cement production.
(b) Cement/aggregate dust is estimated for concrete required for construction. Assume maximum rate 100,000 yd/yr.
(c) Combustion emissions are based on consumption of 26,000 gal/mo unleaded gasoline, 17,500 gal/mo diesel fuel, and 5,200 gal/mo of fuel oil. Emission factors for sulfur oxide emissions and emissions from miscellaneous heavy equipment are from AP-42 (Kircher 1975). Factors for highway vehicles are from EPA 1981.

Estimated concentrations of these pollutants at the fenceline are given in Table G.2. Resultant concentrations will differ because of different site-specific dispersion factors (see Section G.4). Table G.2 shows that short-term concentrations of TSP (fugitive dust) may exceed NAAQS. All other pollutant concentrations are well below the standards. The differences in concentration among the three sites are not significant. Noise is an important aesthetic

TABLE G.2. Concentrations of Nonradiological Pollutants During Construction of an MRS Facility

Pollutant	NAAQS, μg/m	Concentration at Fenceline (μg/m^3)		
		Clinch River	Oak Ridge	Hartsville
Annual average				
TSP (fugitive dust)	75	24	27	30
NOx	100	2	3	3
SOx	80	1	1	1
24-hour maximum				
TSP	260	330	390	200
SOx	365	20	23	12
8-hour maximum				
CO	10,000	190	220	110

consideration during construction. The best descriptors of environmental noise are long-term equivalent A-weighted sound level (L_{eq}) and day/night sound level (L_{dn}), defined as follows:

- A-weighted sound level - the quantity measured by a sound-level meter with a frequency response that approximates human hearing, discriminating against sound pressures at frequencies below 500 Hz and above 10,000 Hz, known as the A-weighting scale

- L_{dn} - day/night average sound level; the 24-hour A-weighted equivalent sound level with a 10 dB penalty applied to nighttime levels (e.g., 40 dB noise at night is interpreted as 50 dB to determine the average sound level)

- $L_{eq(24)}$ - equivalent A-weighted sound level over 24 hours.

$L_{eq(24)}$ of 70 has been identified as protecting against damage to hearing. An L_{dn} level of 55 dB for outdoors level in residential areas has been identified as protecting against activity interference (EPA 1974).

Steady noise levels during construction are based on 30 heavy-duty vehicles working at the site (EEI 1978). This noise is attenuated by distance and terrain, which would reduce noise levels to about 30 to 50 dB at the residences. At the Clinch River site, attenuation is based on a distance of 4,000 feet (1,200 m) from the major noise source and a 6.2-foot (10-m) border of trees. At the Oak Ridge site, attenuation is based on a distance of

5,000 feet (1,500 m) and an intervening ridge of approximately 100 feet (160 m). At the Hartsville site, attenuation is based on a distance of 4,000 feet (1,200 m) from the accoustic center for construction.

G.2 OPERATION PHASE

Methods for calculating public exposure to radiological and nonradiological emissions and to noise during MRS operations are outlined in this section.

Normal releases of radioactivity to the atmosphere may result in offsite public exposures. Pathways of interest include: 1) external exposure to the plume, 2) inhalation of the plume, 3) external exposure to deposited radioactivity, and 4) ingestion of food products contaminated by deposited radioactivity. The computer program ALLDOS (Strenge et al. 1980) is used to estimate maximally exposed individual and population doses from these pathways. This program uses inhalation dose factors generated by the DACRIN computer program (Houston et al. 1976) and terrestrial pathway dose factors from the PABLM computer program (Napier et al. 1980). Details of the use of these programs and site-specific data are presented in Sections G.5 and G.6. Atmospheric dispersion parameters are estimated using the computer program XOQDOQ (Sagendorf et al. 1982), as described in Section G.4.

Abnormal releases are generally of short duration and require different methods to estimate public exposures. Atmospheric dispersion for short-term releases is estimated using the computer program PAVAN (Bander 1982). This program implements the methods of Regulatory Guide 1.145 (NRC 1979) in estimating the frequency of occurrence of time-integrated air concentration (E/Q) at specific locations around the site. For this study, a fenceline distance of 191 yards (175 m) was assumed for the sealed storage cask concept and 366 yards (335 m) for the field drywell concept. These distances were used for all three sites. Results of the dispersion calculation are given in Section G.4. Calculations are made using ALLDOS, DACRIN, and PABLM computer programs (as described in Chapter 6), with input parameters modified to reflect an acute exposure situation.

Nonradiological emissions from normal operation of the MRS facility are primarily from combustion of fossil fuels. Steam boilers, the only stationary sources of emissions at the facility, will consume an estimated 952,000 gallons (3.6 million L) per year of Number 2 fuel oil. In addition mobile sources will consume 110,000 gallons (416,000 L) of diesel fuel and 75,000 gallons (360,000 L) of unleaded gasoline.

All emissions from stationary sources at the facility are below significant (40 CFR 51) levels. The only difference in emission rate for the two facility types is TSP from the conrete batch plant adjacent to the sealed storage cask facility. Emissions from either type facility will be small compared with those from construction. The estimated emissions of pollutants are given in Table G.3.

Noise levels during operation of an MRS facility are based on an equipment list from the architect-engineer and data on equipment noise (EEI 1978). The sound power levels generated by noise sources located both indoors and outdoors

TABLE G.3. Nonradiological Emissions from Operation of an MRS Facility

Pollutant	Emission (tons/yr)
TSP (concrete dust)[a]	3
Boiler emissions:[b]	
particulate	1
NO_x	9
SO_x	15
HC	0.1
CO	3
Vehicle emissions[c]	
NO_x	5
HC	3
CO	13

(a) TSP is defined as dust particles with a diameter equal to or less than 30 mm. Calculations are based on dust emissions for concrete batching of 0.2 lb/yd^3. Emission for sealed storage cask facility is 3 ton/yr; for field drywell, 0.5 ton/yr.
(b) Boiler emissions are based on consumption of 952,000 gal/yr. No. 2 fuel oil; emission factors for industrial boilers are from AP-42 (EPA 1982).
(c) Vehicle emissions are based on 110,000 gal/yr diesel fuel, 75,000 gal/yr gasoline, and emission factors from EPA (1981).

(including cooling tower, exhaust fans, vehicles, etc.) were summed. Distance and sound screening hills and vegetation were considered, as in the estimate of noise during construction.

G.3 DECOMMISSIONING PHASE

The MRS facility will be decommissioned after all stored waste has been removed from the site. Residual contamination will be minimal because decontamination will be performed frequently during the operation period and because the cask/drywell monitoring system will warn of potential leakage so that contamination can be prevented. Therefore, no significant radiological or nonradiological impacts to the public have been identified for decommissioning.

G.4 ATMOSPHERIC TRANSPORT ESTIMATES

Calculating the offsite radiological impacts and the concentrations of nonradiological materials requires an estimate of atmospheric transport from the release point to various nearby locations. For releases under normal operating conditions, which are approximately continuous over the year, dispersion factors are calculated as annual averages using the computer program XOQDOQ (Sagendorf et al. 1982). The program is based on a straightline trajectory Gaussian plume model with crosswind averaging for 16 sectors of 22-1/2° each. This program was used to estimate annual average normalized dispersion factors ($\overline{X}/Q'$) as a function of distance and direction from the release point, based on site-specific joint frequency data for wind speed, wind direction, and atmospheric stability. These data were used in the XOQDOQ program to generate $\overline{X}/Q'$ tables for ground-level and elevated releases at each site. The calculated $\overline{X}/Q'$ values for ground-level releases are presented in Table G.4 for the Clinch River site, Table G.5 for the Oak Ridge site, and Table G.6 for the Hartsville site. For elevated releases, the $\overline{X}/Q'$ values are presented in Table G.7 for the Clinch River site, Table G.8 for the Oak Ridge site, and Table G.9 for the Hartsville site. The elevated release dispersion factors are based on an R&H Facility stack height of 165 m, an inside stack diameter of 3.8 m, an exit velocity of 20.4 m/sec, and a building cross-sectional area of about 5,200 m^2 (32 m high by 162 m wide).

The site-specific dispersion calculations were based on the following data bases:

- Clinch River - data collected for the Clinch River Breeder Reactor project from 2/17/77 through 2/16/78 (PMC 1975)

TABLE G.4. Clinch River Site Annual Average Dispersion Factors for Ground-Level Releases (sec/m^3)

Downwind Sector	Distance Interval (mi)									
	0-1	1-2	2-3	3-4	4-5	5-10	10-20	20-30	30-40	40-50
N	2.56E-06	8.17E-07	3.66E-07	2.23E-07	1.56E-07	7.80E-08	3.04E-08	1.53E-08	9.84E-09	7.12E-09
NNE	2.35E-06	7.47E-07	3.37E-07	2.06E-07	1.44E-07	7.30E-08	2.89E-08	1.47E-08	9.55E-09	6.95E-09
NE	4.24E-06	1.34E-06	5.95E-07	3.59E-07	2.49E-07	1.23E-07	4.73E-08	2.35E-08	1.50E-08	1.08E-08
ENE	5.12E-06	1.62E-06	7.20E-07	4.35E-07	3.01E-07	1.49E-07	5.69E-08	2.82E-08	1.80E-08	1.29E-08
E	6.79E-06	2.16E-06	9.73E-07	5.94E-07	4.15E-07	2.09E-07	8.19E-08	4.13E-08	2.67E-08	1.93E-08
ESE	8.45E-06	2.70E-06	1.22E-06	7.48E-07	5.24E-07	2.65E-07	1.05E-07	5.36E-08	3.48E-08	2.53E-08
SE	5.14E-06	1.64E-06	7.33E-07	4.46E-07	3.11E-07	1.56E-07	6.07E-08	3.05E-08	1.96E-08	1.41E-08
SSE	3.52E-06	1.12E-06	4.98E-07	3.03E-07	2.11E-07	1.05E-07	4.09E-08	2.05E-08	1.32E-08	9.52E-09
S	2.74E-06	8.69E-07	3.85E-07	2.33E-07	1.61E-07	7.95E-08	3.03E-08	1.49E-08	9.47E-09	6.78E-09
SSW	3.59E-06	1.14E-06	5.12E-07	3.12E-07	2.18E-07	1.09E-07	4.26E-08	2.14E-08	1.38E-08	9.99E-09
SW	4.78E-06	1.52E-06	6.82E-07	4.15E-07	2.90E-07	1.45E-07	5.67E-08	2.86E-08	1.84E-08	1.33E-08
WSW	6.67E-06	2.12E-06	9.57E-07	5.85E-07	4.09E-07	2.06E-07	8.13E-08	4.12E-08	2.67E-08	1.94E-08
W	7.03E-06	2.24E-06	1.01E-06	6.20E-07	4.34E-07	2.19E-07	8.68E-08	4.42E-08	2.86E-08	2.08E-08
WNW	6.16E-06	1.97E-06	8.96E-07	5.52E-07	3.88E-07	1.98E-07	7.94E-08	4.08E-08	2.66E-08	1.94E-08
NW	1.34E-05	4.28E-06	1.96E-06	1.21E-06	8.57E-07	4.40E-07	1.78E-07	9.23E-08	6.05E-08	4.43E-08
NNW	8.80E-06	2.81E-06	1.28E-06	7.86E-07	5.52E-07	2.81E-07	1.12E-07	5.76E-08	3.75E-08	2.74E-08

N = north, E = east, S = south, and W = west.

TABLE G.5. Oak Ridge Site Annual Average Dispersion Factors for Ground-Level Releases (sec/m^3)

Downwind Sector	Distance Interval (mi) 0-1	1-2	2-3	3-4	4-5	5-10	10-20	20-30	30-40	40-50
N	4.35E-06	1.38E-06	6.16E-07	3.74E-07	2.60E-07	1.30E-07	5.02E-08	2.51E-08	1.61E-08	1.16E-08
NNE	7.68E-06	2.43E-06	1.08E-06	6.53E-07	4.53E-07	2.25E-07	8.63E-08	4.29E-08	2.74E-08	1.97E-08
NE	1.55E-05	4.89E-06	2.17E-06	1.31E-06	9.11E-07	4.52E-07	1.74E-07	8.69E-08	5.57E-08	4.01E-08
ENE	1.17E-05	3.71E-06	1.66E-06	1.01E-06	6.99E-07	3.49E-07	1.36E-07	6.82E-08	4.39E-08	3.17E-08
E	6.13E-06	1.95E-06	8.76E-07	5.35E-07	3.74E-07	1.88E-07	7.42E-08	3.76E-08	2.44E-08	1.77E-08
ESE	4.88E-06	1.56E-06	7.07E-07	4.35E-07	3.06E-07	1.55E-07	6.21E-08	3.18E-08	2.08E-08	1.51E-08
SE	5.23E-06	1.67E-06	7.59E-07	4.67E-07	3.28E-07	1.67E-07	6.70E-08	3.44E-08	2.24E-08	1.64E-08
SSE	4.76E-06	1.52E-06	6.92E-07	4.26E-07	3.00E-07	1.53E-07	6.11E-08	3.14E-08	2.05E-08	1.50E-08
S	4.39E-06	1.40E-06	6.34E-07	3.89E-07	2.73E-07	1.38E-07	5.51E-08	2.81E-08	1.83E-08	1.33E-08
SSW	5.57E-06	1.78E-06	8.05E-07	4.94E-07	3.47E-07	1.76E-07	7.00E-08	3.58E-08	2.33E-08	1.70E-08
SW	7.23E-06	2.31E-06	1.05E-06	6.43E-07	4.52E-07	2.29E-07	9.13E-08	4.67E-08	3.04E-08	2.21E-08
WSW	8.16E-06	2.60E-06	1.18E-06	7.23E-07	5.07E-07	2.56E-07	1.02E-07	5.18E-08	3.36E-08	2.45E-08
W	5.38E-06	1.72E-06	7.76E-07	4.76E-07	3.34E-07	1.69E-07	6.68E-08	3.40E-08	2.20E-08	1.60E-08
WNW	3.19E-06	1.02E-06	4.59E-07	2.81E-07	1.97E-07	9.93E-08	3.91E-08	1.98E-08	1.28E-08	9.28E-09
NW	3.42E-06	1.09E-06	4.90E-07	3.00E-07	2.10E-07	1.06E-07	4.15E-08	2.10E-08	1.35E-08	9.80E-09
NNW	3.47E-06	1.11E-06	4.98E-07	3.04E-07	2.13E-07	1.07E-07	4.22E-08	2.13E-08	1.38E-08	9.98E-09

N = north, E = east, S = south, and W = west.

TABLE G.6. Hartsville Site Annual Average Dispersion Factors for Ground-Level Releases (sec/m^3)

Downwind Sector	Distance Interval (mi) 0-1	1-2	2-3	3-4	4-5	5-10	10-20	20-30	30-40	40-50
N	1.61E-06	5.04E-07	2.22E-07	1.33E-07	9.21E-08	4.55E-08	1.74E-08	8.65E-09	5.53E-09	3.98E-09
NNE	1.23E-06	3.86E-07	1.71E-07	1.03E-07	7.09E-08	3.49E-08	1.33E-08	6.55E-09	4.16E-09	2.98E-09
NE	1.40E-06	4.37E-07	1.93E-07	1.16E-07	8.00E-08	3.95E-08	1.51E-08	7.51E-09	4.80E-09	3.45E-09
ENE	1.12E-06	3.52E-07	1.55E-07	9.26E-08	6.38E-08	3.14E-08	1.19E-08	5.85E-09	3.71E-09	2.66E-09
E	1.30E-06	4.09E-07	1.80E-07	1.08E-07	7.46E-08	3.68E-08	1.41E-08	6.97E-09	4.44E-09	3.19E-09
ESE	1.61E-06	5.05E-07	2.22E-07	1.34E-07	9.25E-08	4.58E-08	1.75E-08	8.71E-09	5.56E-09	4.00E-09
SE	1.04E-06	3.29E-07	1.45E-07	8.75E-08	6.05E-08	2.99E-08	1.14E-08	5.62E-09	3.57E-09	2.56E-09
SSE	1.03E-06	3.22E-07	1.40E-07	8.33E-08	5.70E-08	2.77E-08	1.02E-08	4.94E-09	3.09E-09	2.19E-09
S	6.52E-07	2.05E-07	9.05E-08	5.44E-08	3.76E-08	1.86E-08	7.09E-09	3.51E-09	2.24E-09	1.61E-09
SSW	2.84E-06	9.04E-07	4.10E-07	2.52E-07	1.77E-07	9.02E-08	3.62E-08	1.86E-08	1.22E-08	8.89E-09
SW	8.64E-06	2.76E-06	1.24E-06	7.62E-07	5.34E-07	2.70E-07	1.07E-07	5.41E-08	3.50E-08	2.54E-08
WSW	1.74E-05	5.56E-06	2.54E-06	1.57E-06	1.11E-06	5.67E-07	2.29E-07	1.18E-07	7.73E-08	5.65E-08
W	4.56E-06	1.45E-06	6.54E-07	4.00E-07	2.80E-07	1.41E-07	5.57E-08	2.83E-08	1.83E-08	1.33E-08
WNW	2.26E-06	7.12E-07	3.17E-07	1.92E-07	1.33E-07	6.61E-08	2.55E-08	1.27E-08	8.12E-09	5.84E-09
NW	2.44E-06	7.64E-07	3.36E-07	2.02E-07	1.39E-07	6.84E-08	2.60E-08	1.28E-08	8.14E-09	5.83E-09
NNW	2.01E-06	6.29E-07	2.76E-07	1.66E-07	1.14E-07	5.61E-08	2.13E-08	1.05E-08	6.66E-09	4.77E-09

N = north, E = east, S = south, and W = west.

TABLE G.7. Clinch River Site Annual Average Dispersion Factors for Stack Releases (sec/m^3)

Downwind Sector	Distance Interval (mi) 0-1	1-2	2-3	3-4	4-5	5-10	10-20	20-30	30-40	40-50
N	1.72E-09	8.95E-09	1.56E-08	1.76E-08	1.74E-08	1.36E-08	8.18E-09	5.07E-09	3.57E-09	2.72E-09
NNE	4.28E-09	8.19E-09	1.08E-08	1.13E-08	1.09E-08	8.73E-09	5.46E-09	3.50E-09	2.52E-09	1.95E-09
NE	2.61E-08	3.33E-08	3.70E-08	3.59E-08	3.30E-08	2.42E-08	1.39E-08	8.62E-09	6.09E-09	4.65E-09
ENE	2.38E-08	3.66E-08	4.71E-08	4.82E-08	4.53E-08	3.38E-08	1.96E-08	1.20E-08	8.38E-09	6.36E-09
E	1.25E-08	2.56E-08	3.91E-08	4.32E-08	4.25E-08	3.39E-08	2.11E-08	1.35E-08	9.78E-09	7.58E-09
ESE	2.83E-08	3.98E-08	5.06E-08	5.18E-08	4.89E-08	3.71E-08	2.21E-08	1.39E-08	9.96E-09	7.69E-09
SE	1.79E-08	2.52E-08	3.34E-08	3.51E-08	3.38E-08	2.65E-08	1.65E-08	1.07E-08	7.79E-09	6.07E-09
SSE	2.27E-08	2.41E-08	2.54E-08	2.53E-08	2.40E-08	1.87E-08	1.16E-08	7.42E-09	5.34E-09	4.13E-09
S	3.08E-09	1.02E-08	1.72E-08	1.98E-08	2.01E-08	1.67E-08	1.06E-08	6.83E-09	4.87E-09	3.73E-09
SSW	3.97E-09	1.14E-08	1.80E-08	2.01E-08	2.00E-08	1.63E-08	1.03E-08	6.68E-09	4.81E-09	3.72E-09
SW	7.49E-09	1.64E-08	2.32E-08	2.51E-08	2.46E-08	1.99E-08	1.27E-08	8.31E-09	6.05E-09	4.72E-09
WSW	6.98E-09	1.73E-08	2.64E-08	2.96E-08	2.96E-08	2.45E-08	1.58E-08	1.03E-08	7.47E-09	5.80E-09
W	5.12E-09	1.62E-08	2.70E-08	3.12E-08	3.17E-08	2.67E-08	1.75E-08	1.16E-08	8.47E-09	6.63E-09
WNW	2.47E-09	7.73E-09	1.36E-08	1.63E-08	1.71E-08	1.54E-08	1.10E-08	7.74E-09	5.90E-09	4.75E-09
NW	1.15E-09	9.86E-09	1.99E-08	2.50E-08	2.68E-08	2.50E-08	1.86E-08	1.36E-08	1.06E-08	8.70E-09
NNW	8.48E-09	2.04E-08	3.08E-08	3.41E-08	3.39E-08	2.79E-08	1.82E-08	1.22E-08	9.08E-09	7.20E-09

N = north, E = east, S = south, and W = west.

TABLE G.8. Oak Ridge Site Annual Average Dispersion Factors for Stack Releases (sec/m^3)

Downwind Sector	Distance Interval (mi)									
	0-1	1-2	2-3	3-4	4-5	5-10	10-20	20-30	30-40	40-50
N	5.26E-09	8.79E-09	1.40E-08	1.70E-08	1.79E-08	1.62E-08	1.13E-08	7.71E-09	5.72E-09	4.49E-09
NNE	1.40E-08	1.97E-08	2.80E-08	3.24E-08	3.36E-08	2.98E-08	2.05E-08	1.39E-08	1.02E-08	8.00E-09
NE	4.50E-08	5.26E-08	6.42E-08	6.99E-08	7.05E-08	6.04E-08	4.06E-08	2.71E-08	1.98E-08	1.55E-08
ENE	2.72E-08	3.35E-08	4.14E-08	4.54E-08	4.62E-08	4.06E-08	2.81E-08	1.91E-08	1.42E-08	1.11E-08
E	9.57E-09	1.24E-08	1.69E-08	1.95E-08	2.03E-08	1.84E-08	1.31E-08	9.13E-09	6.86E-09	5.45E-09
ESE	4.46E-09	6.44E-09	9.38E-09	1.11E-08	1.17E-08	1.08E-08	7.98E-09	5.72E-09	4.38E-09	3.54E-09
SE	5.12E-09	6.58E-09	1.01E-08	1.24E-08	1.32E-08	1.23E-08	8.92E-09	6.34E-09	4.84E-09	3.90E-09
SSE	3.54E-09	5.66E-09	9.58E-09	1.19E-08	1.27E-08	1.14E-08	8.02E-09	5.57E-09	4.21E-09	3.38E-09
S	4.83E-09	6.48E-09	1.02E-08	1.26E-08	1.35E-08	1.23E-08	8.67E-09	6.01E-09	4.52E-09	3.60E-09
SSW	3.64E-09	6.63E-09	1.15E-08	1.42E-08	1.52E-08	1.41E-08	1.00E-08	7.06E-09	5.35E-09	4.28E-09
SW	3.85E-09	6.36E-09	1.14E-08	1.47E-08	1.62E-08	1.59E-08	1.22E-08	8.89E-09	6.85E-09	5.54E-09
WSW	2.42E-09	7.19E-09	1.50E-08	1.98E-08	2.17E-08	2.05E-08	1.51E-08	1.07E-08	8.14E-09	6.53E-09
W	1.23E-09	5.53E-09	1.23E-08	1.64E-08	1.80E-08	1.67E-08	1.19E-08	8.27E-09	6.22E-09	4.96E-09
WNW	1.00E-09	4.16E-09	8.87E-09	1.17E-08	1.27E-08	1.16E-08	8.06E-09	5.50E-09	4.09E-09	3.23E-09
NW	1.72E-09	4.31E-09	8.72E-09	1.15E-08	1.25E-08	1.15E-08	8.15E-09	5.62E-09	4.20E-09	3.32E-09
NNW	1.94E-09	4.26E-09	7.87E-09	1.00E-08	1.09E-08	1.02E-08	7.43E-09	5.24E-09	3.98E-09	3.18E-09

N = north, E = east, S = south, and W = west.

TABLE G.9. Hartsville Site Annual Average Dispersion Factors for Stack Releases (sec/m^3)

Downwind Sector	Distance Interval (mi)									
	0-1	1-2	2-3	3-4	4-5	5-10	10-20	20-30	30-40	40-50
N	3.59E-08	2.62E-08	2.34E-08	2.04E-08	1.77E-08	1.24E-08	6.96E-09	4.24E-09	2.96E-09	2.24E-09
NNE	2.72E-08	2.31E-08	2.32E-08	2.08E-08	1.81E-08	1.20E-08	6.26E-09	3.62E-09	2.47E-09	1.85E-09
NE	4.09E-08	3.00E-08	2.75E-08	2.39E-08	2.04E-08	1.34E-08	6.94E-09	4.02E-09	2.75E-09	2.06E-09
ENE	3.08E-08	2.26E-08	2.12E-08	1.90E-08	1.65E-08	1.10E-08	5.75E-09	3.32E-09	2.26E-09	1.68E-09
E	3.88E-08	2.77E-08	2.52E-08	2.21E-08	1.91E-08	1.2800-08	6.69E-09	3.90E-09	2.67E-09	2.00E-09
ESE	3.30E-08	2.54E-08	2.35E-08	2.10E-08	1.85E-08	1.30E-08	7.22E-09	4.38E-09	3.06E-09	2.32E-09
SE	1.87E-08	1.65E-08	1.72E-08	1.60E-08	1.43E-08	9.84E-09	5.26E-09	3.08E-09	2.11E-09	1.58E-09
SSE	2.54E-08	2.33E-08	2.37E-08	2.14E-08	1.86E-08	1.23E-08	6.21E-09	3.50E-09	2.34E-09	1.72E-09
S	1.32E-08	1.12E-08	1.09E-08	9.67E-09	8.33E-09	5.47E-09	2.79E-09	1.60E-09	1.09E-09	8.14E-10
SSW	2.74E-08	2.22E-08	2.26E-08	2.10E-08	1.87E-08	1.30E-08	7.11E-09	4.38E-09	3.15E-09	2.46E-09
SW	2.53E-08	3.48E-08	4.97E-08	5.43E-08	5.34E-08	4.30E-08	2.72E-08	1.78E-08	1.30E-08	1.01E-08
WSW	1.97E-08	3.26E-08	4.99E-08	5.73E-08	5.87E-08	5.13E-08	3.59E-08	2.52E-08	1.93E-08	1.56E-08
W	1.44E-08	2.06E-08	2.83E-08	2.99E-08	2.88E-08	2.26E-08	1.40E-08	9.00E-09	6.52E-09	5.07E-09
WNW	2.08E-08	2.16E-08	2.55E-08	2.51E-08	2.32E-08	1.71E-08	9.89E-09	6.10E-09	4.30E-09	3.27E-09
NW	4.48E-08	3.74E-08	3.63E-08	3.27E-08	2.89E-08	2.03E-08	1.14E-08	6.88E-09	4.79E-09	3.62E-09
NNW	5.00E-08	3.59E-08	3.28E-08	2.88E-08	2.50E-08	1.72E-08	9.39E-09	5.62E-09	3.89E-09	2.93E-09

N = north, E = east, S = south, and W = west.

- Oak Ridge - data collected for the Exxon Nuclear Fuel Recovery and Recycling Center Oak Ridge site from 8/1/75 through 7/31/77 (Exxon 1977)

- Hartsville - data collected for the Hartsville Nuclear Power Plant project from 2/1/73 through 1/31/74 (TVA 1974).

The $\overline{X}/Q'$ values are coupled with population distributions to give a population dispersion factor for the site. This dispersion factor is then used in all population dose calculations for a site. The population dispersion factor is calculated for a site as follows:

$$PM = \sum_{i=1}^{\text{distance}} \sum_{j=1}^{\text{direction}} (\overline{X}/Q')_{ij} \, P_{ij} \qquad \text{(G.1)}$$

where PM = the population dispersion factor for the site (person-sec/m^3)
$(\overline{X}/Q')_{ij}$ = the annual average dispersion factor for distance i in sector j (sec/m^3)
P_{ij} = the number of people residing in the area interval at distance i in sector j (persons).

A summary of the calculated population dispersion factors is presented in Table G.10.

The population doses from ingestion of crops and animal products is based on an area weighted dispersion factor for each site. The farms are assumed to be approximately uniformly distributed within the 50-mile radius about the site. By using an area weighted dispersion factor the average crop contamination is estimated for each site. The area weighted dispersion factor is calculated as follows:

$$AM = \frac{1}{A_T} \sum_{i=1}^{\text{distance}} \sum_{j=1}^{\text{direction}} (\overline{X}/Q')_{ij} \, A_{ij} \qquad \text{(G.2)}$$

where AM = the area weighted dispersion factor for the site (sec/m^3)
A_T = total area within 50 miles (80 km) of the site (m^2)
A_{ij} = area within spatial interval at distance i and direction j (m^2)

and $(\overline{X}/Q')_{ij}$ is as defined above.

When used in the terrestrial dose calculation with the area weight dispersion factor as the total food production for the site, the population dose is obtained.

TABLE G.10. Summary of Population Dispersion Factors

Site	Dispersion Factor[a] (person-sec/m^3) Ground Level	Elevated (165 ft)
Clinch River	4.1×10^{-2}	9.5×10^{-3}
Oak Ridge	5.2×10^{-2}	1.0×10^{-2}
Hartsville	4.1×10^{-2}	1.1×10^{-2}

(a) Based on the 50-mile populations of 831,000 for Clinch River, 841,000 for Oak Ridge, and 1,010,000 for Hartsville.

The annual average dispersion factor for the maximally exposed individual is taken from the $\overline{X}/Q'$ tables as the highest value corresponding to area intervals where people may reside. For the Clinch River site, the maximally exposed individual resides at 0.7 miles (1.2 km); for the Oak Ridge site, at 1.4 miles (2.3 km); and for the Hartsville site, at 0.6 miles (1.0 km). These $\overline{X}/Q'$ values are used in estimating annual average concentrations for nonradiological emissions. A summary of $\overline{X}/Q'$ values for the maximally exposed individual is given in Table G.11.

For postulated abnormal releases of short duration, population exposures are calculated using the same population-weighted dispersion factors as for normal releases. These factors, when applied to short-term releases, give an estimate of the probable population exposure considering likely dispersion conditions and the local population distribution.

The maximally exposed individual for abnormal releases is assumed to be located at the security fenceline. The computer program PAVAN (Bander 1982) was used to estimate the dispersion factors in all directions (Table G.12).

TABLE G.11. Summary of Dispersion Factors for the Maximally Exposed Individual for Routine Releases from the R&H Facility Stack

Site	Dispersion Factor (sec/m^3)
Clinch River	3.2×10^{-8}
Oak Ridge	5.2×10^{-8}
Hartsville	4.7×10^{-8}

TABLE G.12. Dispersion Factors for the Maximally Exposed Individual for Acute Release at Ground Level (sec/m^3)

Site/Fenceline	Storage Concept: Storage Cask	Storage Concept: Drywell
Clinch River		
R&H Facility	1.8×10^{-3}	2.0×10^{-3}
Storage Area	1.8×10^{-2}	1.8×10^{-2}
Oak Ridge		
R&H Facility	9.2×10^{-3}	7.1×10^{-3}
Storage Area	3.0×10^{-2}	3.0×10^{-2}
Hartsville		
R&H Facility	1.1×10^{-3}	1.1×10^{-3}
Storage Area	7.8×10^{-3}	7.8×10^{-3}

This program uses a bivariate straight-line trajectory Gaussian plume model to estimate the frequency of occurrence of dispersion factors at selected distances. The calculation is based on annual joint frequency data. The value selected for the maximally exposed individual corresponds to the value exceeded 5% of the time for the entire site.

Concentration of nonradioactive airborne pollutants from ground-level sources are based on a fenceline location. Both annual average (XOQDOQ) and 24-hour maximum (PAVAN) concentrations are calculated, for comparison with NAAQS. The largest quantities of emissions related to the MRS facility are from ground-level area or mobile sources: fugitive dust and combustion products from vehicles.

The "virtual point source" method (Strenge and Bander 1981) is used to model area sources such as fugitive dust with the point-source codes. In this method, additional distance is added to the downwind distance to compensate for extra dispersion. A summary of dispersion factors for ground-level area sources for the three sites is given in Table G.13.

TABLE G.13. Summary of Ground-Level Area Source Dispersion Factors for the Clinch River, Oak Ridge, and Hartsville Sites for Fenceline Location (sec/m^3)

Averaging Period	MRS Site Clinch River	Oak Ridge	Hartsville
Annual	7.0×10^{-6}	8.2×10^{-6}	9.0×10^{-6}
24-hour	1.4×10^{-4}	1.6×10^{-4}	8.5×10^{-5}
8-hour	1.9×10^{-4}	2.2×10^{-4}	1.1×10^{-4}

G.5 DOSIMETRY MODELS

This section describes the dosimetry models uses by the computer programs for radiological dose analysis. The computer program ALLDOS was used for most of the dose calculations. ALLDOS uses dose factors generated by other programs: external factors from SUBDOSA (Strenge et al. 1975), inhalation factors from DACRIN (Houston et al. 1976; Strenge 1975), and ingestion factors from PABLM (Napier et al. 1980). A summary of each of these dose factors is provided below.

G.5.1 External Dose Factors

The external dose conversion factor gives the dose from gamma radiation to an individual exposed to an infinite plume of a radionuclide. The factors are normalized to a time-integrated air concentration of one Ci•sec/m^3. The integration is over the time of plume passage.

The external dose factors calculated by SUBDOSA and used by ALLDOS are representative of the average dose to the blood-forming organs that are assumed to be at a tissue depth of 5 cm. This dose is also a good approximation for other organ doses (NCRP 1975) and is used to determine the external dose contribution to all organs.

G.5.2 Inhalation Dose Factors

Inhalation dose conversion factors give the dose commitment from inhalation uptake during plume passage. Like the external dose conversion factors, the inhalation factors are normalized to the time-integrated air concentration over the uptake period. The inhalation dose factors are given for acute and chronic releases and for a 50-year dose-commitment period. The current inhalation dose factors were generated with the computer program DACRIN. The program DACRIN uses the respiratory tract model adopted by the ICRP Task Group on Lung Dynamics (ICRP 1966, 1972). The gastronintestinal tract model and the retention model for other organs are those of the initial ICRP publication (1959).

G.5.3 Terrestrial Dose Factors

The dose factors for terrestrial pathways related to atmospheric releases give the accumulated dose from continued exposure to environmental contamination. The terrestrial dose factors for airborne releases are given for both chronic and acute releases. The dose factors are normalized to releases of 1 curie per year for chronic releases and to 1 curie for acute releases, with unit values for the atmospheric dispersion factor $\overline{X}/Q'$. The dose factors implicitly contain many assumptions about agricultural practices and lifestyle; therefore the file must be established on a site-specific basis. These dose factors are generated with the computer program PABLM (Napier et al. 1980).

The dose factor file used by ALLDOS contains accumulated dose factors for both an average and a maximum individual. The average parameters are multiplied by a population distribution to obtain a collective dose. Dose factors are included for one-year doses and accumulated doses from both acute and chronic releases. Factors for four organs are included: total body, bone, lung, and thyroid. The factors are calculated for all the identified exposure pathways and summed. Thus, all dietary and recreational habit information is incorporated into the dose factors, making them site-specific.

Individual and population exposures from terrestrial pathways for routine operations are evaluated using site-specific agricultural production data. A summary of the agricultural production within 50 miles (80 km) of the sites is given in Table G.14. The Clinch River and Oak Ridge sites are assumed to have the same production because of their geographic proximity. Data in Table G.14 are based on farm-production statistics reported in Tennessee Department of Agriculture (1984), with supplemental data from U.S. Department of Commerce (1981).

TABLE G.14. Annual Agricultural Production Within 50 Miles of Each Site (kg/yr)

Food Type	MRS Site Clinch River	Oak Ridge	Hartsville
Leafy vegetables	1.1×10^7	1.1×10^7	2.2×10^7
Other above-ground vegetables	3.1×10^6	3.1×10^6	5.9×10^6
Potatoes	9.0×10^5	9.0×10^5	1.7×10^6
Other root vegetables	5.8×10^5	5.8×10^5	1.1×10^6
Orchard fruit	6.4×10^5	6.4×10^5	1.2×10^6
Wheat	2.0×10^7	2.0×10^7	3.8×10^7
Other grain	9.1×10^7	9.1×10^7	1.7×10^8
Eggs	4.8×10^6	4.8×10^6	9.2×10^6
Milk	2.3×10^8	2.3×10^8	2.4×10^8
Beef	6.2×10^6	6.2×10^6	1.2×10^7
Pork	9.8×10^6	9.8×10^6	1.9×10^7
Poultry	5.3×10^6	5.3×10^6	1.0×10^7

G.6 TOXICITY OF PROCESS MATERIALS

Toxicity is defined as the ability of a chemical to cause injury once it reaches the body. The system of toxicity rating used in this appendix is outlined in Table G.15.

The American Conference of Governmental Industrial Hygienists (ACGIH 1983) has set levels of exposure to toxic chemicals at which no harmful effect is noted. These are called Threshold Limit Values (TLVs). TLVs refer to air concentrations of a given chemical that an individual can be repeatedly exposed to eight hours per day, five days per week. Because TLVs are time-weighted averages, limited over-exposures may be permitted if compensated for by equivalent under-exposures. In some cases, ceiling limits maximum recommended exposure concentrations are indicated. These are industrial hygiene limits rather than a relative index of hazard.

The MRS facility is designed to meet standards of industrial safety. Table G.16 lists process chemicals to be used in an MRS facility and their TLV and hazard rating.

TABLE G.15. Toxicity Rating Scale (Sax 1984)

Rating	Effects
U = unknown	Available data are insufficient for a valid assessment of toxic hazard.
None = no toxicity (0)	Exposure from any normal usage causes no toxic effects, or overwhelming doses are required to produce toxic effects.
Low = slight toxicity (1)	Exposure causes changes that are readily reversible once the exposure ceases.
Mod = moderate toxicity (2)	Exposure causes reversible changes or irreversible changes not severe enough to cause serious physical impairment or to threaten life.
High = severe toxicity (3)	Exposure may cause injury of sufficient severity to threaten life or produce permanent impairment, disfigurement or irreversible change.

TABLE G.16. Toxicity and TLV of Process Chemicals to be Used at an MRS Facility

Compound	Toxicity Rating[(a)]	TLV[(b)] (mg/m^3)
EDTA	NA	25
Freon 113	--	7,600
hydrochloric acid	3	7 C[(c)]
morpholine	3	70 (skin)
Nalco 7330	n	NA
nitric acid	3	5
sodium hydroxide	3	2 C
sodium hypochlorite[(d)]	NA	NA
sodium phosphate	2-1	NA
sulfuric acid	3	1

(a) Rating from Sax (1984).
(b) Threshold Limit Value (ACGIH 1983).
(c) C denotes ceiling limit.
(d) corrosive and irritant.
NA = Not available.

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APPENDIX H

METHODOLOGY AND ASSUMPTIONS FOR STANDARD SOCIOECONOMIC IMPACTS

APPENDIX H

METHODOLOGY AND ASSUMPTIONS FOR STANDARD SOCIOECONOMIC IMPACTS

The methodologies used for projecting the socioeconomic impact of an MRS facility at three alternative sites in Tennessee are described in this appendix. According to the current assumed project schedule, construction of the integral MRS facility would begin in fiscal year 1991 and would be completed in 1996. The operating phase would begin in 1996 and would end with the last waste being shipped out in 2022. Decommissioning would be completed in 2026. Because the facility would actually be built and operated several years from now, a projection of socioeconomic conditions was required for both a baseline scenario (without the MRS facility) and an impact scenario (with the MRS facility) to estimate future quantitative socioeconomic impacts of the facility. The analysis began with the preparation of baseline projections for the Clinch River/Oak Ridge site and the Hartsville site using a computer-based model designed for economic and demographic forecasting. The Clinch River and Oak Ridge sites were not analyzed separately (except for local land use and transportation issues) because of their geographic proximity.

The baseline forecasted growth path of the economy at each site was then changed by adding to it the direct construction, operation, and decommissioning labor and expenditures at the site. This change was translated by the computer model into estimates of additional employment, population, and income in the counties within approximately 50 miles (80 km) of the site. Further formal procedures, described in this appendix, were then applied to allocate the impacts to specific communities and to estimate impacts of economic growth on community services and state and local government revenues and expenditures.

H.1 METHODOLOGY

This section describes the methodology used in this Environmental Assessment (EA) to estimate the standard socioeconomic impacts of the MRS facility. This discussion is divided into an overview of the estimation process, with a description of the computer codes used and a description of the formal analytical procedures used. The procedures are described below.

H.1.1 General Procedures

The procedures used to forecast economic, demographic, and fiscal impacts of an MRS facility involved the linking of three elements: 1) a computer-based regional econometric model for forecasting regional employment, population, and income; 2) a local allocation procedure for forecasting the location of MRS-related employment, income, and population within the impact area analyzed by the econometric model; and 3) a fiscal impact procedure for estimating the impacts of the forecasted local changes in population and economic activity on the revenues and expenditures of state and local government. These three elements, the rationale behind them, and the steps linking them are described in this appendix.

The econometric model used in the analysis was the Metropolitan and State Economic Regions (MASTER) model (Adams et al. 1983). It was used to forecast the impact of an MRS facility's construction, operation, and decommissioning for two 28-county areas, each approximately 50 miles (80 km) in radius, comprising portions of Tennessee, Kentucky, and North Carolina. These two 28-county areas approximate the economic regions expected to be affected by an MRS facility if it were to be built at the Clinch River or Oak Ridge sites or at the Hartsville site.

The local allocation procedure used in the analysis was an adaptation of a gravity-type procedure commonly found in socioeconomic literature and commonly used for allocating population, employment, and other socioeconomic impacts of growth (Leistritz et al. 1979). This procedure allocates the impact of a development project to individual communities in proportion to their relative availability of community services (a proxy variable is population) and in inverse proportion to the cost of access to the development site (commonly measured by distance from the site) (Murdock and Leistritz 1979). The local allocation procedure was employed to forecast population, employment, and income impacts for the specific cities and counties most likely to be affected by MRS economic activity due to their size and location relative to the proposed MRS sites.

The fiscal impact procedure was based on the fiscal structure of Tennessee state and local government for the most current fiscal year for which local government data were readily available (fiscal year 1983). The procedure assumed constant real rates of collection per dollar of income for income-related taxes and other income and constant real per capita rates of collection for population-related taxes and other revenues. Local government expenditures were assumed to be constant in real per capita terms (real per-student terms for school expenditures). This procedure made unnecessary the task of forecasting future actions by Tennessee political bodies regarding taxes and budgets. Fiscal impacts were forecasted based on these revenue and expenditure rates an the forecasted city and county populations and incomes from the local allocation procedure.

H.1.2 Step-by-Step Procedures

The step-by-step procedures are outlined in Figure H.1. First, benchmark socioeconomic characteristics were assembled into a master data base for the counties surrounding the Clinch River/Oak Ridge and Hartsville sites. The data base for benchmark employment and income characteristics was assembled from magnetic data tapes produced by the Regional Economic Information System of the Bureau of Economic Analysis, United States Department of Commerce. The counties' demographic and housing characteristics came from data tapes of the 1980 Census of Population and Housing, and construction activity data came from Dodge Construction Potentials data tapes supplied by the F. W. Dodge division of McGraw-Hill Information Systems Company.

Together, these tapes contained county-level employment, income, population, housing, and construction activity data for every county in the United States. By examining previous impact assessments and previous development projects at each site, it was determined that five to six counties at each site were the most likely to receive increases in economic activity associated with the MRS facility; these we designated as "primary impact" counties. The socioeconomic impact assessment literature (e.g., Leistritz and Murdock 1981) states that the total study area ought to encompass a regional impact area. This impact area incorporates the distances and residential patterns of commuting workers and approximates the economic area or trade area of a regional wholesale-retail trade center. Data availability often dictates that this trade area be approximated with groups of counties. Based on considerations of distance from the MRS site and the location of major transportation routes and economic linkages for each site, a total impact area of approximately 50 miles (80 km) in radius was defined. According to previous studies of large energy projects, construction workers may be willing to commute up to 50 to 75 miles (80 to 121 km) one way per day, while operations workers will tend to commute only about 30 to 40 miles (48 to 64 km) (Leholm et al. 1976; Gilmore et al. 1982; Murdock and Hamm 1983). However, the majority of these direct workers tend to live closer than this to the site in towns having a population of at least 1,000 (Gilmore et al. 1982; Murdock and Hamm 1983). Workers in secondary industries serving these direct workers and supplying services to the site can be expected to locate within convenient access to their places of work, which would generally be at some distance from the MRS site. Thus, the general population impact of MRS can be expected to be more geographically dispersed than the commuting population. As a compromise, a 50-mile radius was adopted as the approximate area in which most of the socioeconomic effects would occur. Based on the examination of highway maps and Bureau of Economic Analysis maps of the substate economic areas, two counties that appeared to be integrated with Knoxville but were located just outside the Clinch River/Oak Ridge 50-mile radius were included in the study. These were Hamblen County, Tennessee, and

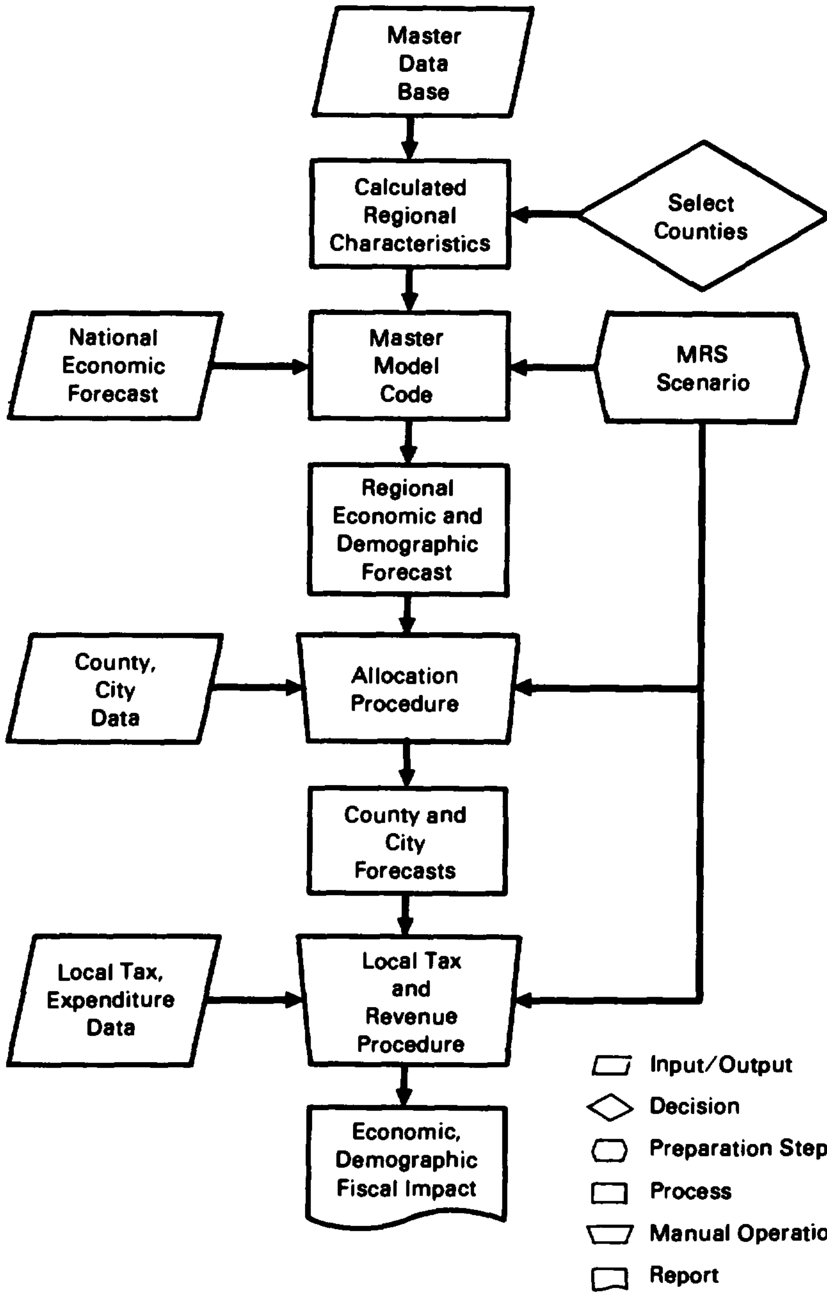

FIGURE H.1. The MRS Socioeconomic Impact Assessment Process

Bell County, Kentucky.[a] The counties incorporated in the total and primary impact areas are shown in Table H.1. Benchmark economic and demographic characteristics were then assembled for each county in Table H.1.

To produce a forecast, the MASTER model used in this analysis requires not only benchmark economic and demographic data on the local economy, but also a baseline forecast of the national economy. A moderate economic growth scenario for the United States was selected, based on a spring 1984, long-term economic forecast by Data Resources, Inc. The Data Resources assumptions were run through PNL's FORSYS computer model of the United States national economy[b] to derive average annual rates of growth in output by sector in the national economy to the year 2000. These growth rates are reported in Table H.2. The average annual rate of growth in national output between 1985 and 2000 in Table H.2 is about 2.9% per year, similar to the summer 1985 TRENDLONG forecast for 1985-1995 by Data Resources (DRI 1985). Data Resources did not perform a post-1995 forecast in the summer of 1985. The post-2000 growth rates were extrapolated to continue 1995-2000 growth trends. They are also shown in Table H.2.

H.1.2.1 MASTER Forecasts

The national forecast and the benchmark data for each site were then entered into PNL's MASTER computer model (Adams et al. 1983). This model is further described in Section H.2.1. The MASTER model was customized for each site by adjusting the intercept values in key equations to replicate 1984 employment, income, and population data as closely as possible. A base case forecast was then performed for each site. Table H.3 compares rates of growth in employment in the 12 MASTER industries to Data Resources' summer 1985 national forecast. The Hartsville site's baseline economy grows slightly faster than the national average is projected to grow. This is a result of the continued growth of the metropolitan Nashville area as a manufacturing, tourism, and service center. The Clinch River/Oak Ridge site is projected to grow at a somewhat slower rate than Hartsville in the baseline (although slightly faster than the nation), largely due to a lower forecasted growth rate in manufacturing. This reflects Nashville's relative attractiveness and is an extrapolation of the experience of the last 10 years, during which time manufacturing in the Nashville-Davidson metropolitan statistical area grew by about 21%

(a) The inclusion or exclusion of peripheral counties makes little difference to the analysis, since the effects of MRS are expected to be minimal in those counties.

(b) FORSYS Forecasting and Simulation System: U.S. Model Description (Pacific Northwest Laboratory) provides an overview of the FORSYS macroeconometric input/output model.

TABLE H.1. Counties Analyzed in the MRS Socioeconomic Impact Assessment

Clinch River/ Oak Ridge Site	Hartsville Site
Bell, KY	Allen, KY
McCreary, KY	Barren, KY
Whitley, KY	Cumberland, KY
Cherokee, NC	Logan, KY
Graham, NC	Metcalfe, KY
Swain, NC	Monroe, KY
Anderson, TN[(a)]	Simpson, KY
Bledsoe, TN	Warren, KY
Blount, TN	Bedford, TN
Campbell, TN	Cannon, TN
Claiborne, TN	Cheatham, TN
Cumberland, TN	Clay, TN
Fentress, TN	Coffee, TN
Grainger, TN	Davidson, TN[(a)]
Hamblen, TN	DeKalb, TN
Jefferson, TN	Jackson, TN
Knox, TN[(a)]	Macon, TN[(a)]
Loudon, TN[(a)]	Overton, TN
McMinn, TN	Putnam, TN
Meigs, TN[(a)]	Robertson, TN
Monroe, TN	Rutherford, TN
Polk, TN	Smith, TN[(b)]
Rhea, TN[(a)]	Sumner, TN[(a)]
Roane, TN[(b)]	Trousdale, TN[(b)]
Morgan, TN[(a)]	Warren, TN
Scott, TN	White, TN
Sevier, TN	Williamson, TN
Union, TN	Wilson, TN[(a)]

(a) Denotes primary impact area county that does not contain the MRS site.
(b) Denotes county containing a portion of the MRS site.

TABLE H.2. National Economic Growth Assumptions Used in MRS Socioeconomic Assessment

Sector Output by Sector:	Average Annual Growth Rate, 1985-2000 (%)	Average Annual Growth Rate, 2000-2030 (%)
Agriculture	2.0	2.2
Ag. Services, Forestry, Fisheries	2.3	3.0
Mining	1.7	1.5
Construction	2.4	2.0
Nondurables Manufacturing	2.4	2.7
Durables Manufacturing	3.7	2.5
Transportation Communication, Public Utilities	3.2	2.7
Wholesale Trade	2.6	2.5
Retail Trade	2.6	2.5
Finance, Insurance, Real Estate	2.6	1.5
Services	2.6	1.5
Government	3.4	3.0

and Knoxville metropolitan statistical area's manufacturing sector grew by only 9%. Both grew faster than the nation, which saw a net loss in manufacturing jobs.

The forecasting procedure was next repeated for two sets of impact conditions. In the first impact case, economic activity related to a sealed storage cask MRS facility was added to the baseline MASTER model input files, and a new forecast was calculated for the Clinch River/Oak Ridge and Hartsville sites. In the second case, a field drywell MRS facility was introduced and new forecasts produced. For each site, the MASTER model thus produced three economic and demographic forecasts for the approximately 50-mile total impact area corresponding to the list of counties in Table H.1. The difference between each impact forecast and the corresponding baseline forecast represented the economic and demographic impact of the MRS facility on the 50-mile total impact area.

H.1.2.2 Allocation Procedure

It was next necessary to estimate the portion of impact that would be felt in the primary impact area and in specific towns and cities within that smaller area. This was done with a gravity allocation procedure (Isard 1975; Leistritz et al. 1979). In this procedure, the population, income, and employment impacts of the MRS facility are allocated in direct proportion to the relative populations of each city thought to be affected by the project and in inverse

TABLE H.3. Baseline Employment Growth, 1985-1995

Sector	Clinch River/ Oak Ridge (%)	Hartsville (%)	National Rate, 1985-1995[a]	National Rate, 1973-1984[a]
Agriculture	0.1	-0.4	NA	NA
Agricultural Services, Forestry, Fisheries	0.2	0.4	NA	NA
Mining	0.6	1.6	-1.0	4.1
Construction	2.5	3.3	2.6	0.5
Nondurable Manufacturing	2.4	2.6	-0.2	-0.3
Durable Manufacturing	3.5	4.3	1.0	-0.2
Transportation, Communications, Public Utilities	1.0	1.0	0.5	1.0
Wholesale Trade	2.8	3.8	1.8	2.5
Retail Trade	2.3	3.4	1.8	2.5
Finance, Insurance, Real Estate	2.1	3.1	2.6	3.1
Services	1.5	2.7	1.9	4.4
Government:				
Federal	1.5[b]	1.5[b]	1.2	0.4
State and Local			2.0	1.6
Total, Nonagricultural Employment	2.1	2.9	1.6	1.9

(a) From Data Resources, Inc., 1985.
(b) Includes both federal, and state and local government employment sectors.
NA = Not Available.

proportion to the relative distance of each city from the MRS site. To determine the list of affected cities, it was assumed, consistent with the literature (e.g., Murdock et al. 1984) and the actual location of workers at projects of similar size in the area (SAIC 1985; TVA 1977) that most of the increase would occur in communities having at least 1,000 population at the 1980 Census. A list of the cities affected, their 1980 populations, and their distances from the MRS site are shown in Table H.4.[a]

(a) There is a small difference in road distance between the Clinch River and Oak Ridge sites [about 6 miles (10 km)]. This difference was considered to be too small to significantly affect residence patterns.

TABLE H.4. 1980 Population and Road Distance of Cities Assumed to be Affected by MRS Construction, Operation, and Decommissioning

Site/City	1980 Population	Road Distance (mi)
Clinch River/ Oak Ridge Site[a]		
Clinton	5,245	25
Norris	1,366	33
Oak Ridge	27,662	14
Oliver Springs	3,659	19
Powell	7,220	33
Knoxville	175,030	24
Lenoir City	5,446	10
Loudon	3,943	17
Wartburg	761	35
Harriman	8,303	17
Kingston	4,367	10
Rockwood	5,767	18
Hartsville Site		
Nashville	455,651	39
Lafayette	3,808	18
Carthage	2,672	12
Gallatin	17,191	23
Hendersonville	25,561	37
Lebanon	11,872	16
Mt. Juliet	2,879	31
Hartsville	2,674	4.5

(a) Distances are from the Clinch River site to the approximate city center.

Table H.5 shows the proportions of population and economic impact forecasted for each affected city for the MRS facility compared to actual residence of population related to previous projects at the site. The table also shows the proportions of the general population change in the region by city between the 1970 and 1980 census. The total population impact of MRS is less concentrated within the primary impact area than were population changes related to the workforce directly working at previous projects at the site. For example, Anderson County is forecasted to capture 12.2% of MRS-related population growth while about 22.2% of the population forecasted to migrate out of the area as a

TABLE H.5. Comparison of Proportions of MRS-Related Population and Economic Activity Compared to Previous Projects (%)

Site/County/City	Forecasted Proportion of MRS-Related Population	Proportion of Project Population at Previous Project	Share of 1970-1980 Population Growth
Clinch River/ Oak Ridge Site			
Anderson:	12.2	22.2[(a)]	3.7
Clinton	1.0	2.0	--
Norris	0.2	NA	--
Oak Ridge	10.0	11.7	--
Oliver Springs	1.0	0	--
Loudon:	4.0	0.8	2.3
Lenoir City	2.8	0	--
Loudon	1.2	NA	--
Morgan:	0.1	4.4	1.6
Wartburg	0.1	NA	--
Roane:	6.3	20.2	5.0
Harriman	2.4	1.6	--
Kingston	2.3	3.2	--
Rockwood	1.6	1.2	--
Knox:	38.2	29.1	22.8
Powell	1.1	NA	--
Knoxville	37.1	8.4	--
TOTAL, Primary Impact Counties	61.0[(b)]	76.7	35.3
Hartsville Site			
Davidson:	39.4	19.0[(c)]	13.8
Nashville	39.4	12.6	--
Macon:	0.7	6.2	1.6
Lafayette	0.7	5.0	--
Smith:	0.8	10.2	1.1
Carthage	0.8	4.4	--
Sumner:	4.8	23.7	13.7
Gallatin	2.5	13.9	--
Hendersonville	2.3	4.5	--
Wilson:	2.9	13.0	8.8
Lebanon	2.5	10.1	--
Mt. Juliet	0.4	2.0	--
Trousdale:	2.0	7.8	0.5
Hartsville	2.0	7.3	--
TOTAL, Primary Impact Counties	50.5[(b)]	80.0	39.5

(a) Percent of K-25 Plant involuntary reduction-in-force migrant population; SAIC (1985), p. v-11, v-12. This population is believed to have demographic characteristics closest to those of the MRS-related population.

(b) Detail does not add to total due to rounding error.

(c) Percent of Hartsville Nuclear Plant employees as of March 31, 1977. See TVA 1977.

result of closing the existing K-25 Plant line in Anderson County. Overall, the primary impact counties are forecasted to capture 61% of the MRS-related population increase, compared with 76.7% for the K-25 Plant. This is because many of the purchases of the MRS facility, which account for about half the impact in some years, would likely be made from suburban suppliers in the Knoxville and Nashville metropolitan areas--suppliers not within the primary impact area. The MRS-related total activity should be more concentrated in the major metropolitan area of each primary impact area than are the direct workers at the MRS site. For example, a higher proportion of MRS-related workers should live in Knoxville than current K-25 Plant direct workers. This again is due to the effect of indirect and induced purchases, which should create jobs and income and lead to population increases at the regional service centers, not at the MRS site. Thus, although Knoxville and Nashville appear in Table H.5 to receive a high share of activity, the proportions are consistent with the available evidence on previous projects at the site. Finally, the MRS site-related activity should be more concentrated within the primary impact area than was general urban population growth between 1970 and 1980. General urban growth between 1970 and 1980 was related to developments in all directions from Nashville and Knoxville, whereas MRS-related activity applies to a single project. Section H.2.2 further describes the allocation procedure.

H.1.2.3 State and Local Government

Once the level of population, income, and employment increase for each city was estimated by the MASTER model and the gravity allocation procedure applied, the impact of growth on state and local government revenues and expenditures was estimated. Because it is unclear what tax changes and expenditure policy changes might be adopted by local governments before the MRS project is proposed to be built, the estimates of government revenue and expenditure impacts were based on revenue and expenditure data for the most current year available (fiscal years 1983 and 1984).

The MRS facility itself would not be taxable under current law because it would be a federal facility. However, the general increase in economic activity related to the construction, operation, and decommissioning of an MRS facility would generate additional revenue for state and local government. The MRS-associated population increase could cause some increase in the value of residential property; in addition, increases in commercial activity should increase the sale value of commercial property. Any negative effect, if any, of the MRS facility on the perception of the area as undesirable is assumed to be very temporary (see Chapter 6), so that the net effect on total property value is assumed to be positive, at least in the short run. For purposes of estimating impacts on property taxes, the analysis assumes constant assessed value per capita and constant tax rates at 1983 levels. The additional retail sales generated by the increase in economic activity related to MRS would also increase local option sales tax revenue. For simplicity, real local-option sales tax revenue is assumed to increase in the same proportion as real personal income. These two taxes are the principal local sources of revenue that would be affected by MRS-related activity.

Collections of several state taxes would also be affected by the increase in general economic activity that would accompany an MRS facility. Portions of these taxes are also shared with county and city governments. Section H.2.4 further describes the estimation procedure.

H.2 MODEL DESCRIPTIONS

This section describes the individual models used in the socioeconomic analysis. Section H.2.1 further describes the MASTER model; Section H.2.2, the local allocation procedure; and Section H.2.3, the state and local government fiscal procedures.

H.2.1 Metropolitan and State Economic Regions (MASTER) Model

The Metropolitan and State Economic Regions (MASTER) Model is a computer code designed for 1) forecasting economic activity in substate geographic areas, and 2) planning and policymaking in energy-related fields. MASTER forecasts economic activity in 268 metropolitan statistical areas (MSAs), 48 rest-of-state areas (ROSAs), and the District of Columbia. A variation of MASTER Version 1.0 (Adams, Moe and Scott 1983) was used in the MRS analysis. Version 1.0 consists of four submodels, one for each United States census region (Northeast, North Central, West, South).[a] Each submodel can be used to forecast annual economic activity in any MSA or ROSA in the corresponding census region. Each submodel contains 53 stochastic equations linked together by more than 100 definitional or accounting identity equations.[b] MASTER is an econometric model; the stochastic equations were estimated statistically using time-series/cross-section multiple regression techniques suggested by Kmenta (1971) on pooled time-series/cross-section of economic and demographic

(a) The version used for this analysis was Version 1.0 MRS, which contains a full-scale cohort-component population survival module and makes use of the demographic characteristics of interstate migrants. The differences from Version 1.0 are documented in L. T. Clark, Jr., User's Guide to Modify MASTER for Non-SMSA Use and to Install Cohort-Component Population Model (Draft), Pacific Northwest Laboratory, Richland, Washington.

(b) For example, local resident personal income is by definition equal to labor and proprietor income, plus property income (including interest and dividends) and government monetary transfers such as Social Security payments, less employee payments for social insurance items, plus a residence adjustment to allow for commuters.

data for the years 1967-1976 for each MSA/ROSA in the corresponding census region. The endogenous or dependent variables forecasted by MASTER for any MSA/ROSA are shown in Table H.6.

The functional forms and variables used in the MASTER model equations were selected primarily based on their consistency with economic theory, and the applicability of resulting equations to a wide range of local conditions. For example, the dependent variable in each employment equation is the annual percentage change in employment, because this functional form could be readily adapted to both large and small regions. When a forecast is prepared, the starting value for each dependent variable is adjusted automatically in two rounds to incorporate area-specific differences between the behavior of the dependent variable in an average MSA/ROSA in the census region and the actual benchmark value in the area for which the forecast is prepared.[a]

The MASTER model can forecast for any county or group of counties in the United States. This is accomplished by selecting appropriate start-up values for the model's dependent variables for the group of counties. The model treats the group of counties as it would any MSA/ROSA and produces a forecast. For this report, start-up values were selected and data sets constructed for a group of 28-counties at each site.

A simple schematic diagram of MASTER is shown in Figure H.2. The MASTER forecast begins with exogenous (outside the model) forecasts of sector real wage rates (adjusted for inflation), consumer price index, national unemployment rate, and the historical ratio of local to national wage rates. Local wage rates are calculated and fed into the employment equations, along with estimates of local real personal income, national real output by sector, and cost variables such as energy prices and interest rates. Local employment is thus determined by a mix of local and national conditions. Employment is, in turn, a key input into the model's estimate of real income (which includes wage and nonwage income by component) and population. Construction is determined by interest rates, local construction prices per square foot, and the level of employment by sector or population, as appropriate. Employment, income, construction, and population are all simultaneously solved for in each forecast year to ensure internal forecast consistency.

(a) These adjustments are equivalent to inserting dummy variables in the pooled regression and adjusting for autocorrelation (systematic time-dependent error) in the forecast. See Adams et al. (1983) for elaboration on this point.

TABLE H.6. MASTER Forecast Output

Employment and Annual Wages, by Sector

- Agriculture
- Agricultural services, forestry, and fishing
- Mining
- Construction
- Nondurable manufacturing
- Durable manufacturing
- Public utilities, transportation, and communications
- Wholesale trade
- Retail trade
- Finance, insurance, and real estate
- Services
- Government

Income, by Source

- Wage bill (labor and proprietor income)
- Rent, interest, and dividends
- Transfer payments
- Social insurance payments
- Residence adjustment
- Total personal income
- Per capita income

Population, by Category

- Births
- Deaths
- Net migration
- Population, age less than 5 years
- Population, age 5-13 years
- Population, age 14-17 years
- Population, age 18-20 years
- Population, age 21-24 years
- Population, age 25-34 years
- Population, age 35-44 years
- Population, age 45-64 years
- Population, age 65+ years
- Population, age 18-64 years

Construction of New Commercial Buildings, by Building Category

- Retail/wholesale
- Office
- Auto repair
- Warehouse
- Education
- Health
- Public
- Religious
- Hotel/motel
- Miscellaneous

Commercial Construction, Additions and Alterations, by Building Category

- Same as new commercial construction categories

Residential Construction, by Building Categories

- Apartments, five or more units, one to three stories
- Apartments, five or more units, four or more stories
- Apartments, three to four units
- Single family, detached
- Duplexes

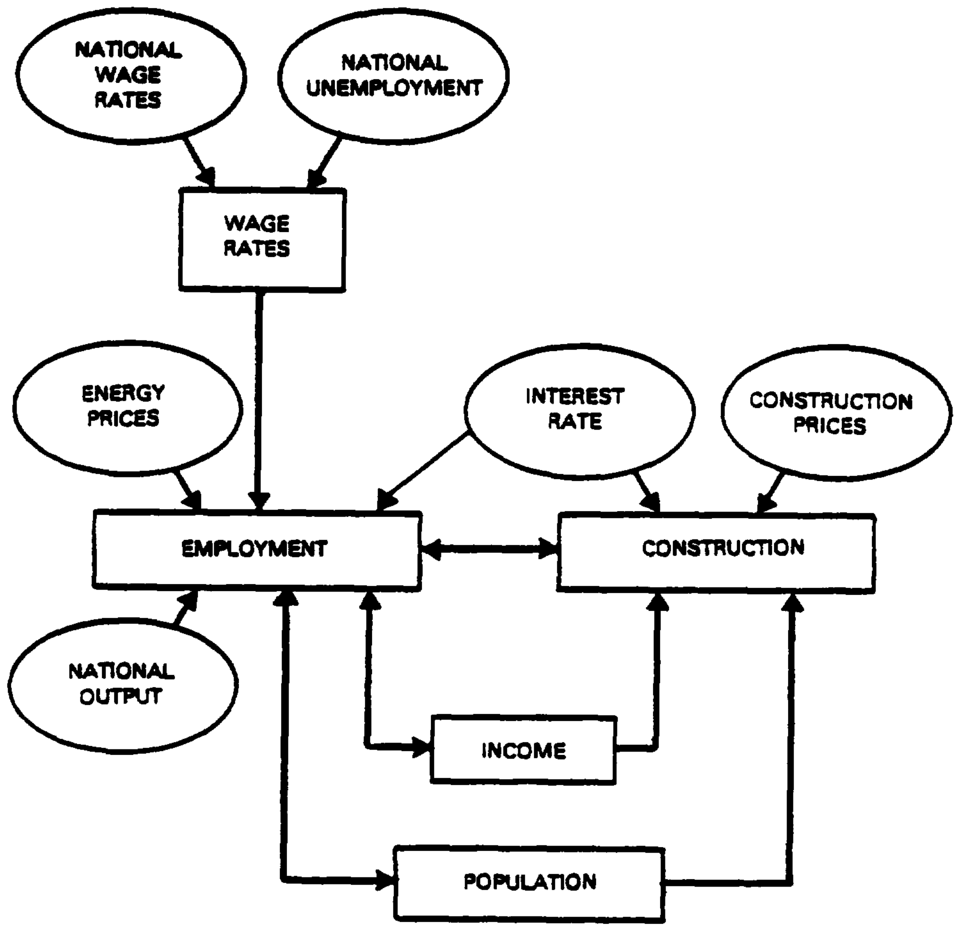

FIGURE H.2. MASTER Model: Simple Model Schematic

H.2.2 Geographical Allocation Procedure

Two methods were available for geographically allocating projected impacts. The first method was based on the assumption that economic activity would follow the pattern of geographic distribution indicated for workers during previous projects at the site, including both primary and secondary workers. Although some residence records were available for the K-25 Plant at Clinch River/Oak Ridge and for the Hartsville Nuclear Plants at Hartsville, these records did not take account of possible indirect economic effects of MRS facility purchases from businesses in the local community. While the distribution of such effects would depend on which suppliers were eventually chosen, purchases would likely be made primarily in the larger communities and trade centers in the impact area, with greater distance from the MRS facility adding to supplier cost to some degree.

The second method considered was the so-called gravity allocation model. [See Murdock, Wieland and Leistritz (1978) for a survey of the literature on this methodology.] In gravity allocation models, the new economic activity generated by a project is assumed to be geographically concentrated in proportion to the relative population of each community surrounding the project and in inverse proportion to the relative distance of each community from the project site. The validity of this procedure has been widely evaluated (Murdock, Wieland and Leistritz 1978; Murdock et al. 1984). In general, the accuracy of such models improves greatly if areas having a population of under 1,000 are excluded (Isserman 1977; Murdock et al. 1984). Empirical analyses have also shown that most workers at a development project (and hence, most secondary economic and population effects) will be within 30 miles (48 km) of the site in areas of at least 1,000 people (Murdock and Hamm 1983; Gilmore et al. 1982).

Gravity allocation models take several closely related forms. The form actually used was adopted from Leistritz et al. (1979). As stated there, the gravity model is:

$$M_i = \frac{\left(\frac{P_i}{D_i^a}\right) W_i}{\sum_{i=1}^{n} \left(\frac{P_i}{D_i^a} \; W_i\right)}$$

where M_i = fraction of total in-migrants locating in city (i)

P_i = population of city (i)

D_i^a = distance between city (i) and the work site, raised to the power (a)

W_i = the relative qualitative attraction of city (i).

In this version of the gravity allocation model, the sum of the M_i for all i equals 1.0. The model user may specify the distance exponent (a) and the value of the community attraction index (W_i) for each city. User specifications of values other than 1.0 for W_i have generally been based on specific local information on the relative availability of housing and key community services. Since housing and community services appear to be adequate at all of the proposed MRS sites, W_i was set equal to 1.0 for all cities.

In the version of the gravity allocation model used in this analysis, the distance coefficient was set equal to 1.0. In the literature, values have generally ranged from 0.5 to 2.0 (Murdock, Wieland and Leistritz 1978). To check the validity of the assumed distance coefficient of 1.0, a sensitivity analysis was performed using 0.5 and 2.0 as alternative values. The resulting shares of MRS-related population were compared to the residence pattern for other projects at the sites and to general population growth between 1970 and 1980 for each site. Because the proposed MRS facility and its workers would buy goods and services from firms located at some distance from the MRS site, any MRS-related population increases that include employees of the supplier firms and their families should be more geographically removed from the site than population directly employed at the proposed, or any other, facility at the site. Also, such MRS-related population increases might be expected to be more geographically concentrated in the impact area's service and trade centers for the same reason. Conversely, MRS-related population increases should be more geographically concentrated in counties near the proposed MRS site than are 1970 to 1980 popluation increases in the impact area. This is because between 1970 and 1980, population growth in both the Clinch River/Oak Ridge and Hartsville impact areas was motivated by economic growth in most of the counties; MRS-related population impacts, on the other hand, are related only to the MRS project and (for at least the project employees) only a few counties.

Table H.7 shows the results of the sensitivity analysis by county. The table shows for the Clinch River/Oak Ridge site that a distance coefficient of either 1.0 or 0.5 generally yields population proportions between those for the previous project and those for the historical period 1970 through 1980. Values between 0.5 and 1.0, therefore, pass the test by yielding these proportions. Both also show impacts more concentrated in Knox County and thus pass the test. The distance coefficient of 2.0 shows more impact in the primary impact counties and in Anderson County, in particular, than the existing K-25 project, and so fails the test. For the Hartsville site, all of the coefficients produce total primary impact county proportions that are between those in the last two columns. The distance coefficient of 2.0 produces what appears to be too large an impact in Trousdale County, however.[a] To distinguish whether

(a) Except in Trousdale County, none of the coefficients result in forecasted proportions of impact for the individual counties in the Hartsville area that are between the two historical values in the last two columns. This is due to the heavy historical concentration of population growth in Sumner and Wilson counties, which may be due to relative, historical housing availability in the primary impact counties (Mid-Cumberland 1983). No basis was available, however, for selecting appropriate future values for the qualitative relative attractiveness index, W_i, discussed above. Were such values available, Davidson County's forecasted proportion of impact probably would be lower and the proportions for Sumner and Wilson counties, higher.

TABLE H.7. Sensitivity Test of Distance Coefficient in the Geographical Allocation Procedure (%)

County	Forecasted Proportion of MRS-Related Population			Proportion of Project Population at Previous Project	Share of 1970-1980 Population Growth
	Distance Coefficient 2.0	Distance Coefficient 1.0	Distance Coefficient 0.5		
Clinch River/ Oak Ridge Site					
Anderson	22.2	12.2	9.0	22.2[b]	3.7
Loudon	9.3	4.0	2.6	0.8	2.3
Morgan	<0.1	0.1	0.1	4.4	1.6
Roane	12.5	6.3	4.5	20.2	5.0
Knox	42.5	38.2	35.2	29.1	22.8
TOTAL, Primary Impact Counties[a]	86.6	61.0	51.5	76.7	35.3
Hartsville Site					
Davidson	26.5	39.4	42.8	19.0[c]	13.8
Macon	1.0	0.7	0.5	6.2	1.6
Smith	1.6	0.8	0.5	10.2	1.1
Sumner	4.5	4.8	4.5	23.7	13.7
Wilson	4.4	2.9	2.1	13.0	8.8
Trousdale	11.3	2.0	0.7	7.8	0.5
TOTAL, Primary Impact Counties[a]	49.3	50.5	51.1	80.0	39.5

(a) Detail does not add to total due to rounding error.
(b) Percent of K-25 plant involuntary reduction-in-force migrant population, SAIC 1985, p. v-11, v-12. This population is believed to have demographic characteristics closest to those of the MRS-related population.
(c) Percent of Hartsville Nuclear Plant employees as of March 31, 1977. See TVA (1977).

1.0 or 0.5 was a "better" distance coefficient, more detailed comparisons were done. The coefficient 1.0 produced closer to the expected results in Roane, Macon, Smith, Sumner, Davidson, Wilson, and Trousdale counties; the coefficient 0.5 was closer in Loudon and Knox. It was impossible to determine relative superiority in Anderson and Morgan counties. On balance, 1.0 was judged to be the better value. No attempt was made to "fine-tune" a value between 0.5 and 1.0; this was not considered worthwhile.

To compute the gravity index required multiple steps. First, a relative shares index was calculated for the primary impact area, for each city assumed to be affected by the MRS facility; this shares index was based on its 1980 census population compared to the sum of all the cities affected. Next, a shares index was computed for each city based upon its relative distance to the MRS site compared to the population-weighted average distance to the site. The population-shares index was next divided by the distance-shares index, and the total of the index values reweighted to sum to 1.0. This procedure is computationally equivalent to that in Leistritz et al. (1979). The resulting indices were used to allocate impacts within the primary impact area. The proportion of total activity (within the 50-mile impact area) that occurs in the primary impact area also was estimated using the gravity index. To do this, it was necessary to estimate the 1980 population-weighted average distance from the MRS site for all population within the total 28-county impact area. To avoid computing the distance and population for all cities within the 28-county impact area, a simplified weighted average distance was computed, consisting of three parts: the population and population-weighted average distance of the non-metropolitan portion of the primary impact area's affected cities (see Table H.4),[a] the population and distance from the MRS site of the major metropolitan center in each of the 28-county impact areas, and the population of the remainder of the 28-county impact area, assumed to be at an average distance of 37.5 miles (60.5 km). The latter figure was obtained by noting that the population in the remainder of the 28 counties was located between 25 and 50 miles (40 to 80 km) from the MRS site and using the average of the 25 and 50 miles. The three parts of the weighted average were next combined to obtain a population-weighted average distance for the total population within 50 miles (80 km) from the MRS site. Finally, the index of population over weighted average distance for the combined primary impact area population was divided by the corresponding weighted average for the total population. Impacts on employment, personal income, total population, and the population by age group were all allocated first to the primary impact area and then to individual cities using the population/distance gravity indices described above.

(a) The population of the entire primary impact counties and the metropolitan county (Davidson or Knox) was assumed to be concentrated at the population-weighted average distance of the principal cities contained in the county in order to perform this analysis.

H.2.3 Impact Estimation Procedures for State and Local Revenues and Expenditures

The impacts of an MRS facility on state and local government expenditures were obtained by assuming that revenue collection and expenditure rates would be constant in real terms in the future. Current rates of collection were then computed for income-related and population-related revenues. Income-related revenues are those revenues such as income taxes and sales taxes that are related directly to either the level of local income or to the level of local consumption expenditures, which is, in turn, a function of the level of income. All expenditures were assumed to remain constant in real per capita terms (in the case of education, constant per enrolled-student real terms). The forecasted changes in future income, population, and school-age population were then multiplied times the appropriate revenue collection and expenditure rates to obtain estimates of the impact of the MRS facility. Table H.8 shows the ratio of fiscal year 1983 tax collections to 1983 personal income, by revenue source, by county in the two primary impact areas. Information is not available on resident income for individual cities, so income-related tax receipts of individual cities were estimated on a per capita basis.

Table H.9 shows the fiscal year 1983 per capita rates of collection of population-related taxes collected by county government (property tax) and the two major state taxes shared on a population basis: the gasoline and alcoholic beverages taxes. These taxes are actually collected and dispersed according to more complex procedures and formulas, but population is a major factor in most of the formulas. To simplify the analysis, since specific formulas are subject to future change, constant per capita collections were used as the basis for projection. Federal aid to local government is generally declining and based on changing needs tests; it was therefore excluded from the analysis where possible.

Some revenues of local government are clearly related to population subgroups. School aid funds, for example, are dispersed to school districts by the state and federal government according to a series of formulas that include numbers of participating students and a series of tests of "need" for the funds. Needs tests and other qualifications tests for specific formulas are subject to change, and the number of students can be expected to figure prominently in any future formula. Therefore, for simplicity, the state portion of these funds was calculated based on the existing rate of disbursement per student and the forecasted number of students. For purposes of estimating aid per child it was assumed that 100 percent of children between the ages of 5 and 17 were enrolled in school in their home county and district. The computation of aid per child is shown in Table H.10 by school district. This computation excludes federal aid, which is a substantial source of funding. However, much of the federal aid is earmarked for special programs whose future participation

TABLE H.8. Rates of Collection of Local Income-Related Taxes and State Shared Income-Related Taxes, Primary Impact Counties, FY 1983 (Tennessee Taxpayers Association 1984) (10^3 $)

Site/County	Local Option Sales Tax (FY 1984)	Special Petroleum Products Tax[a]	Income Tax	TVA Tax Replacement	Other[b]	Total 1983 Income-Related Collections	Estimated 1983 Income[c]	Collection Rate[d] (decimal)
Clinch River/ Oak Ridge Site								
Anderson	$ 2,889.0	$ 67.2	$ 29.1	$311.8	$ 251.7	$ 3,548.8	$ 736,000	0.0048
Knox	31,434.6	318.8	347.8	697.1	31.7	32,830.0	3,355,000	0.0097
Loudon	1,271.8	28.5	108.5	502.7	13.1	1,924.6	292,000	0.0066
Morgan	441.4	16.6	3.8	116.2	219.3	797.3	105,000	0.0076
Roane	3,062.9	48.3	26.6	540.6	17.0	3,695.4	462,000	0.0080
Hartsville Site								
Davidson	$85,779.4	$465.6	$434.7	$ 854.6	$1,442.7	$88,977.0	$5,815,000	0.0153
Macon	554.7	15.7	2.4	138.7	12.1	723.6	125,000	0.0058
Smith	799.2	14.9	6.3	186.3	19.7	1,026.4	112,000	0.0092
Sumner	5,515.5	85.6	47.9	272.4	21.6	5,943.0	878,000	0.0068
Trousdale	312.8	6.1	6.3	157.9	11.9	495.0	52,000	0.0095
Wilson	2,785.7	55.9	42.7	215.9	21.6	3,121.8	559,000	0.0056

(a) Yield of this tax is shared with counties for county road maintenance.
(b) Includes severance tax, mixed drink tax, beer tax, federal flood control funds, alcoholic beverage contraband tax.
(c) From U.S. Department of Commerce (1985).
(d) Dollars per dollar of local income.

TABLE H.9. Rates of Collection of Population-Related Taxes and State Shared Taxes, Primary Impact Counties, FY 1983 (Tennessee Taxpayers Association 1984) (10^3 $)

Site/County	Local Property Tax	Gasoline Tax	Alcoholic Beverage Tax	Total 1983 Population-Related Collections	1983 Estimated Population	1983 Collections Per Capita (1985 $)[a]
Clinch River/ Oak Ridge Site						
Anderson	$ 8,426.0	$ 758.7	$ 65.3	$ 9,250.0	68,400	$146
Knox	41,492.6	1,782.8	277.3	43,552.7	323,600	145
Loudon	3,078.0	571.4	30.6	3,680.0	30,100	132
Morgan	2,168.3	652.8	29.9	2,851.0	17,300	178
Roane	3,680.6	693.7	50.3	4,424.6	49,500	97
Hartsville Site						
Davidson	$94,473.8	$2,379.0	$406.8	$97,259.6	484,700	$217
Macon	1,291.0	551.0	22.1	1,864.1	16,100	125
Smith	1,202.9	556.1	22.0	1,781.0	14,700	131
Sumner	11,426.6	911.6	86.5	12,424.7	88,900	151
Trousdale	598.2	435.4	8.5	1,042.1	5,700	197
Wilson	7,256.4	813.4	63.1	8,132.9	58,300	151

(a) 1983 Collections converted to 1985 dollars using relative values of the Consumer Price Index (1.08).

TABLE H.10. Rates of Collection of School Population-Related State Aid to Schools, Primary Impact Counties, FY 1984 (Tennessee Department of Education 1984)

Site/ School District	State Aid to Public Schools in County[a]	School-Age Population[b]	Aid Per Child	Aid Per Child (1985 $)[c]
Clinch River/ Oak Ridge Site				
Anderson County	$ 6,263,938	7,592	$825	$854
Clinton	642,605	919	699	724
Oak Ridge	3,746,450	4,823	777	804
Knox County	19,146,721	29,636	646	669
Knoxville	18,569,294	26,959	689	713
Loudon County	2,852,950	3,942	723	749
Lenoir City	1,223,866	1,867	656	678
Morgan County	2,378,192	3,462	687	711
Roane County	5,024,991	6,846	734	760
Harriman	1,878,313	2,236	840	869
Hartsville Site				
Davidson County	$44,821,290	66,520	$674	$697
Macon County	1,966,258	2,931	671	694
Smith County	1,808,525	2,637	686	710
Sumner County	12,245,515	18,593	659	682
Trousdale County	704,891	1,042	676	700
Wilson County	6,114,989	9,105	671	695
Lebanon	1,459,192	2,325	628	650

(a) Excluding funds for capital outlay.
(b) Assumed to be the same as net enrollment in kindergarten through 12th grade, plus special education.
(c) Inflated to 1985 dollars by the relative consumer price index (1.035).

rate and needs tests cannot be predicted; thus, it was not certain that federal aid would increase if MRS activity resulted in an increase in school-age population. Federal aid to schools was not counted in the analysis of local fiscal impact.

Table H.11 shows the rates of collection of city revenues from their own local sources and state-shared revenues to cities, excluding funds distributed to local schools. Local sources include property and sales taxes, plus some miscellaneous taxes and fees. Shared revenues include income tax, gas tax, beer tax, sales tax, street and transportation aid, alcoholic contraband and mixed drink taxes, and TVA tax replacement funds. In addition, shared revenues include taxes collected by counties and distributed directly to cities, e.g., county property taxes distributed to a city school system.

Table H.12 shows rates of population-related expenditures by local governments and by school systems within the boundaries of the local jurisdictions. For most categories of expenditures, the rate of expenditure is assumed to be constant in real per capita 1985 dollars. For school systems, the rate of expenditure is assumed to be constant in real terms per enrolled student. Thus, the relevant population base for education expenditures is the population between 5 and 17 years of age.

Table H.13 shows state revenue collection rates used in the socioeconomic analysis. Most such revenues in Tennessee are related to general business volume, with the largest sources being sales and use taxes, excise taxes, gasoline and motor fuels taxes, and automobile registrations. (Table H.13 does not show the portion of state taxes distributed as state aid to local governments. This aid is reflected in Tables H.8 through H.11.) Table H.13 also excludes revenues obtained from sources that are not directly related to the level of state economic activity, such as earnings on investments, intergovernmental and interdepartmental charges, and aid from the federal government.

Table H.14 shows operating expenditures likely to be affected by MRS-related population increases. For purposes of this analysis, capital outlay expenditures and debt service are excluded. To estimate additional capital investments, a detailed study would have to be performed of each area's capital needs on a case-by-case basis. This level of detail was judged to be beyond the scope of the Environmental Assessment (EA). Table H.14 shows an estimate of state education expenditures that includes state aid, but excludes shared taxes. This implies some double-counting of aid to counties and cities, but shows (appropriately) the effect of MRS-related growth on state financial balances.

TABLE H.11. Rates of Collection of Local Taxes and State Shared Taxes, Primary Impact Area Cities, FY 1983 (10^3 $) (Tennessee Taxpayers Association 1984)

Site/City	FY 1983 Collections State and Local Sources	1983 Population Estimate	Collections Per Capita[a]
Clinch River/ Oak Ridge Site			
Oak Ridge	$ 14,371.2	27,662	$561
Norris	67.2	1,374	53
Clinton	2,545.0	5,724	480
Oliver Springs	356.6	3,659	105
Powell	NA	7,220[b]	NA
Knoxville	103,069.8	175,045	636
Lenoir City	2,900.9	5,709	549
Loudon	1,421.8	4,054	379
Wartburg	33.7	761[b]	48
Harriman	3,246.8	8,303	422
Kingston	865.0	4,441	210
Rockwood	1,492.8	5,855	275
Hartsville Site			
Nashville	$ 45,409.7	344,273	$142
Lafayette	851.6	3,808	242
Carthage	533.7	2,672	216
Gallatin	4,502.7	17,191	283
Hendersonville	4,403.5	26,805	177
Lebanon	2,829.2	12,275	249
Mt. Juliet	142.3	3,018	51
Hartsville	202.4	2,674	82

(a) Converted to 1985 dollars by multiplying 1983 collections per capita by the relative consumer price index (1.08).
(b) No 1983 estimate available. 1980 Census population used.
NA = data not available.

TABLE H.12. Rates of Population-Related Expenditure by Local Government in Primary Impact Counties (Tennessee Taxpayers Association 1984; U.S. Department of Commerce 1985; University of Tennessee 1985)

Jurisdiction	Current Operating Expenditures, FY 1983	Estimated Population 1983	Per Capita Expenditures (1985 $)	School, Per Student Expenditures (1985 $)
Clinch River/ Oak Ridge Site				
Anderson County	$ 6,443,606	68,400	$102	$2,356
Oak Ridge	4,915,051	27,662	192	2,912
Norris	NA	1,374	NA	2,356
Clinton	1,853,364	5,724	350	1,637
Oliver Springs	NA	3,659	NA	2,356
Knox County	43,306,069	323,600	145	1,691
Powell	NA	7,220[(a)]	NA	1,691
Knoxville	83,757,063	175,045	517	2,014
Loudon County	3,461,229	30,100	124	1,752
Lenoir City	1,143,988	5,709	216	1,690
Loudon	1,813,917	4,054	483	1,752
Morgan County	2,219,983	17,300	139	1,572
Wartburg	NA	761[(a)]	NA	1,572
Roane County	4,018,269	49,500	88	1,615
Harriman	1,999,003	8,303	260	1,729
Kingston	836,878	4,441	204	1,615
Rockwood	1,501,383	5,855	277	1,615
Hartsville Site				
Davidson County	$189,943,074	484,700	$423	$2,347
Nashville	45,674,218	344,273	143	2,347
Macon County	1,718,795	16,100	115	1,353
Lafayette	1,134,797	3,808	322	1,353
Smith County	1,836,848	14,700	135	1,511
Carthage	602,490	2,672	225	1,511
Sumner County	5,918,840	88,900	72	1,472
Gallatin	4,485,337	17,191	282	1,472
Hendersonville	4,541,280	26,805	183	1,472
Wilson County	4,913,744	58,300	91	1,333
Lebanon	2,877,063	12,275	253	1,552
Mt. Juliet	NA	3,018	NA	1,333
Trousdale County	1,186,619	5,700	225	1,622
Hartsville	NA	2,674	NA	1,622

(a) Estimate not available. 1980 population used.
NA = data not available.

TABLE H.13. State Revenue Collection Rates, State of Tennessee, FY 1983 (Tennessee Taxpayers Association 1984)

Revenue Source	State Revenue Collections, (10^3 1985 $)[a]	Estimated Collection Rate[b]
Sales and Use Taxes	$1,106,186	0.0248
Unemployment Taxes	278,004	0.0062
Excise Taxes	202,558	0.0045
Gasoline and Motor Fuel Taxes	164,860	0.0037
Gross Receipts Tax	105,787	0.0024
Motor Vehicle Registration Tax	104,607	0.0024
Other Taxes	363,605	0.0082
Licenses, Fees, Permits	47,601	0.0011
Charges to the Public	64,312	0.0014
TOTAL	$2,437,520	0.0547

(a) Excludes revenues distributed to local governments and revenues not affected by level of economic activity (earnings on investments, intergovernmental and interdepartmental charges and federal aid).
(b) Based on Tennessee 1983 personal income of $44,580 million.

TABLE H.14. Estimated Rates of Operating Expenditure by Tennessee State Government, FY 1983 (Tennessee Taxpayers Association 1984)

Function	State Operating Expenditures (10^3 $)[a]	Per Capita Expenditures[b]	Per Capita Expenditures (1985 $)
General Government	$ 129,279	$ 28	$ 30
Education[c]	990,727	211	228
Health and Social Service	1,105,191	236	255
Law, Justice, and Public Service	193,347	41	45
Recreation and Resource Development	64,691	14	15
Business Regulation	16,643	4	4
Transportation	427,695	91	99
Unemployment Payments and Refunds	458,649	98	106
Other	28,020	6	6
TOTAL	3,414,242	729	787

(a) Excludes debt service and capital projects funds.
(b) Based on an estimated 1983 population of 4,685,000 (U.S. Department of Commerce 1985).
(c) Includes state aid to local school districts but excludes shared taxes.

H.3. MRS ECONOMIC INPUT ASSUMPTIONS

This section describes the MRS economic inputs utilized to estimate the impacts of the MRS facility. Two different MRS concepts were examined. Except for the prevailing annual wage rates in various industries, which were supplied by the MASTER model simulation, the direct impact and first-round indirect impact[a] of the MRS facility was assumed to be invariant by site. Table H.15 shows the level of direct MRS employment and first-round indirect employment assumed each year for both the sealed storage cask and field drywell designs. This employment was estimated for each industry and added to the base case forecast in each year. Indirect employment was estimated for each year by first taking dollars of first-round indirect purchases by industry per million dollars of output from the Regional Input-Output Modeling System (RIMS)[b] Tennessee input-output table for the construction sector (construction phase) and public utilities (operations and decommissioning phases). These dollars were then multiplied by employment per million dollars of output from industry. The resulting estimate of total first-round indirect employment is shown in the last column of Table H.15. The MASTER model was run at the two sites with the changes to direct and first-round indirect employment shown in Table H.15 as input.

In most cases, this procedure probably overestimates impacts, since the RIMS input-output table for the state of Tennessee was used to obtain estimates of first-round indirect impacts for the smaller 28-county impact area. Some of the goods and services required by the facility may be supplied from outside the impact area, although from within the state. Furthermore, though it is implicitly assumed that the Tennessee economy would supply most of the required business services and materials to the MRS site, this may not be the case. In fact, the bulk of required services and materials (such as insurance, freight forwarding, specialized equipment, structural steel, etc.) may be supplied from outside the state, resulting in an overstatement of indirect employment. Conversely, if more local manufacturing of steel, cement, machinery, and lumber were performed, the procedure followed in this document would result in an underestimate of socioeconomic impacts.

(a) First-round indirect impact consists of sales, jobs, and income of those industries directly selling goods and services to the MRS facility. It excludes purchases by these supplying industries.

(b) United States Department of Commerce, Bureau of Economic Analysis publishes input-output tables for every state in the United States. The system is collectively known as the Regional Input-Output Modeling System (RIMS). See Cartwright et al. (1981) for a description.

TABLE H.15. Employment and Expenditure Estimates for an MRS Facility

Year	Sealed Storage Cask			Field Drywell		
	Onsite Direct Employment	Direct Expenditure (million 1985 $)	First-Round Indirect Employment[a]	Onsite Direct Employment	Direct Expenditure (million 1985 $)	First-Round Indirect Employment[a]
1991	101	$ 13.3	83	102	$ 13.0	81
1992	505	100.7	634	565	117.4	732
1993	918	191.8	1,190	1,026	223.7	1,387
1994	1,025	210.5	1,241	1,129	243.9	1,437
1995	805	169.1	974	842	170.9	1,051
1996	594	103.5	437	512	59.6	210
1997	601	102.5	301	678	80.9	302
1998	776	134.9	438	847	101.2	346
1999	750	123.7	360	847	102.0	346
2000	884	146.2	461	883	112.5	368
2001	793	101.1	291	755	81.5	180
2002	755	81.5	179	755	81.5	179
2003	647	71.0	155	647	71.0	155
2004	647	71.0	155	647	71.0	155
2005	647	71.0	154	647	71.0	154
2006	647	71.0	153	647	71.0	153
2007	647	71.0	153	647	71.0	153
2008	647	71.0	152	647	71.0	152
2009	647	71.0	152	647	71.0	152
2010	647	71.0	151	647	71.0	151
2011	647	71.0	150	647	71.0	150
2012	647	71.0	150	647	71.0	150
2013	647	71.0	149	647	71.0	149
2014	647	71.0	149	647	71.0	149
2015	647	71.0	148	647	71.0	148
2016	647	71.0	148	647	71.0	148
2017	647	57.0	118	647	57.0	118
2018	400	25.0	53	405	25.2	53
2019	400	25.0	52	405	25.2	53
2020	400	25.0	52	405	25.2	53
2021	410	25.0	56	415	26.1	57
2022	345	25.8	89	345	24.4	83
2023	245	19.1	81	245	17.4	74
2024	230	17.9	76	230	16.3	69
2025	185	12.4	53	185	11.3	48
2026	140	10.8	46	140	9.9	42

(a) First-round indirect employment is the employment that is necessary to produce the goods and services purchased directly by the MRS facility. It excludes second-order employment effects further back in the supply line. For example, it includes employment in concrete batching plants but excludes employment in cement manufacture. The latter effect is captured by the MASTER model simulation.

H.4. VALIDATION

Extensive validation tests have been done on the MASTER model. These tests have included accuracy tests for both in-sample and out-of-sample historical forecasts. In model development, data from 1967 to 1976 were used to estimate the model equations. Four years of data (1977 through 1980) were held back from the data set used in estimation to perform the out-of-sample test. For the in-sample test, the model was simulated over the in-sample historical period for each MSA/ROSA in the United States, as if actual values for the model's dependent variables were unknown.

The MASTER model "predicted" a series of historical values for each dependent variable. Period-to period percentage changes in the predicted values of each dependent variable were compared to actual historical period-to-period percentage changes. A summary statistic, Theil's U_1 (Theil 1966), was calculated for each dependent variable and region. A value of $U_1 = 0$ indicates a perfect forecast, while $U_1 = 1$ would indicate that MASTER forecasts percentage changes in dependent variables no better than a "naive" model in which period-to-period percentage changes were predicted as constant. To cite one typical example of the outcome, the Orlando, Florida, MSA U_1 was never larger than 0.06 (very close to perfect). For almost all variables, U_1 was less than 0.004.

In the out-of-sample historical forecasts, the model was also simulated over the period 1976-1980 as if the historical data at each MSA/ROSA were unknown; then the forecasted values were compared to actual values. Forecasts were prepared for several medium-sized MSAs selected at random. The mean absolute percent error (MAPE) of the forecast was estimated for each dependent variable. Some key results are shown in Table H.16.

These results are as reliable as other regional models' in-sample MAPEs,[a] except for Orlando. In the Orlando case, a large, exogenous increase in construction employment occurred in the actual historical data because of the construction of Walt Disney World and related facilities. This was not included in the MASTER test forecast; even so, the forecast was fairly accurate.

To determine if accurate forecasts could be produced for small-to-medium sized economic areas undergoing rapid exogenous economic change, MASTER was used to perform an out-of-sample forecast for the Richland-Kennewick-Pasco MSA (Benton and Franklin Counties, Washington). This was an especially challenging test because the area's economy has depended historically on rapidly-changing construction of major energy projects and on federal government funding cycles

(a) See, for example, Glickman 1977, p. 69.

TABLE H.16. Mean Absolute Percent Error of Out-of-Sample Forecast, 1976-1980 (From Adams et al. 1983)

MSA/Variable	Mean Absolute % Error of Forecast
Albany, New York	
Total Employment	3.88
Personal Income	2.35
Population	2.80
Akron, Ohio	
Total Employment	3.88
Personal Income	3.27
Population	1.58
Portland, Oregon	
Total Employment	3.38
Personal Income	1.79
Population	1.53
Orlando, Florida	
Total Employment	6.77
Personal Income	9.24
Population	5.36

at the Hanford Nuclear Reservation. In addition, a significant portion of Hanford's construction and nuclear workers commute from outside the two-county area--from Walla Walla and Yakima, Washington; Umatilla, Oregon; and even Spokane, Washington. Since very little data were available on the residence of exogenous workers, no adjustment was made for this factor in the historical forecast, which would likely introduce an upward bias on predicted population and predicted wage income. At the Washington Public Power Supply System Plants, no adjustment was made for overtime or travel pay, which tends to cause income to be underpredicted. In spite of this, the MASTER model performed very well in this out-of-sample validation test. Results are shown for key variables in Table H.17. The fact that the model effectively forecasts the level of economic activity during an impact period is not conclusive evidence that it effectively forecasts impacts themselves. However, the model's performance is encouraging evidence that it is likely to capture the effects of a future project.

TABLE H.17. Validation Test Forecast Results of the MASTER Model Versus Actual Values for Key Variables, Richland-Kennewick-Pasco Metropolitan Statistical Area, 1976-1981

	Total Employment[a]			Wage Bill (million $)			Real Personal Income (million $)			Resident Population		
Year	Actual Value	Forecast Value	Error of Forecast	Actual Value	Forecast Value	Error of Forecast	Actual Value	Forecast Value	Error of Forecast	Actual Value	Forecast Value	Error of Forecast
1976	50,254	49,705	-549	489.802	502.124	+12.3	669.761	593.413	-69.9	112,800	113,006	+206
1977	54,726	57,541	+2,815	549.971	602.862	+52.9	745.419	707.253	-79.0	119,600	123,398	+3,798
1978	61,464	64,449	+2,985	640.643	685.402	+44.8	847.131	803.054	-56.2	129,200	134,620	+5,420
1979	67,866	68,263	+397	676.571	735.000	+58.4	892.941	865.048	-23.6	137,900	142,701	+4,801
1980	67,971	68,346	+375	636.234	730.513	+94.3	857.121	870.552	+13.4	146,000	147,718	+1,718
1981	72,188	72,949	+761	NA	791.454	NA	NA	943.483	NA	149,300	152,645	+3,345
1982	NA	71,251	NA	NA	770.474	NA	NA	933.244	NA	NA	158,457	+4,798
Mean Absolute Percent Error:			2.21%			8.52%			5.28%			2.41%

(a) Includes both wage and salary employment and self-employed.
NA = Not Available.

The MASTER model forecasts well for the Richland-Kennewick-Pasco MSA, in spite of the serious difficulties in the actual economic data series for the area. Note that for employment, the most reliable of these series and the last affected by residence considerations, MASTER is very accurate. It thus appears that MASTER is an adequate model for small area impact analysis.

Forecasts were also performed for the two MRS impact areas and the forecasts were compared to actual values for the most important variables. Table H.18 summarizes these results. The last year of actual data used to estimate the MASTER equations was 1976. Thus, the values in Table H.18 represent valid out-of-sample forecasts of variables five to eight years after the period used to develop the model. As such, the comparisons in Table H.18 constitute a fairly strong test. As Table H.18 shows, the model forecasts well for employment and population variables, but more poorly for total income. However, no effort was made during this project to calibrate the components of personal income to local values by adjusting intercepts. Thus, the values for income reflect average economic conditions for the entire southeastern part of the United States.

Finally, the MASTER model impact results were tested for plausibility against impact results of other models and impacts of similar projects. The impact multipliers derived in Table H.19 for the sealed storage cask concept construction, operation, and decommissioning are shown in the first two parts of the table. Line 1 shows, for example, that in 1994 every job gained in construction and indirect MRS purchases generates only about 0.2 additional support sector jobs (1.2 jobs shown in the table, less 1.0 direct jobs) within the primary impact area. This is because almost 40% of the increase in employment is expected to be outside the five-county primary impact area. The more familiar comparison of direct construction employment to total employment on line 2 indicates that 1.7 secondary jobs (2.7 minus 1.0) are created per direct job in the primary impact area. Many of these are created by the direct purchases of the facility, however. If most of the actual purchases were from outside the primary impact area, the employment impact would be considerably reduced. Lines 3 and 4 show the corresponding larger employment impacts of the facility within 50 miles of the facility.

For comparison, the estimated five-county employment multiplier for closure of the K-25 Plant at the Oak Ridge Reservation can be examined (SAIC 1985). This multiplier of 1.5 is roughly equivalent in concept to the MRS operations period multiplier shown on line 2, which has a value of 1.8. The 0.3 difference is primarily due to the fact that the MRS facility is assumed to buy slightly more on the local economy per dollar of output than does the K-25 Plant. The MRS income multipliers describe the portion of total purchases of factors of production (total local expenditures) that ultimately become local household earnings. During the construction phase this is only 37% for the

TABLE H.18. Comparison of MASTER Forecast to Actual Values for 50-Mile Impact Areas[a]

Impact Category	Clinch River/Oak Ridge Forecast	Clinch River/Oak Ridge Actual	Clinch River/Oak Ridge % Error of Forecast	Hartsville Forecast	Hartsville Actual	Hartsville % Error of Forecast
Total Employment (10^3 Persons)						
1980	401.3	423.0	-5.1	567.5	578.3	-1.9
1982	414.7	414.7	0	588.3	570.9	3.0
1984	421.7	421.1	0.1	598.7	627.7	4.8
Total Real Personal Income (10^6 1985 $)						
1981	11,558	9,791	18.0	15,683	13,379	17.2
1983	11,844	10,290	15.1	16,064	14,260	12.7
Total Population (10^3 Persons)						
1980	1,125	1,076	4.6	1,308	1,270	3.0
1984	1,180	1,124	5.0	1,384	1,327	4.3
Population by Age Group, 1980 (10^3 Persons)						
Age <5 yr	73	73	0	96	89	7.9
Age 5-17 yr	241	230	4.8	261	260	0.4
Age 18-64 yr	688	650	5.8	810	777	4.2
Age 65+ yr	123	123	0	140	144	-2.7

(a) Sources of actual data were the Tennessee Department of Labor for employment, U.S. Department of Commerce for income and population.

TABLE H.19. Analysis of MRS Impacts for the Sealed Storage Cask Concept at the Clinch River/Oak Ridge Site

	1994	Operations Average, 2003-2016	Decommissioning Average, 2022-2025
MRS Employment Multipliers			
Ratio of Total Primary Impact Area Employment Impact to Direct plus First-Round Indirect Employment	1.2	1.5	1.5
Ratio of Total Primary Impact Area Employment Impact to Direct Employment Only	2.7	1.8	1.9
Ratio of Total Employment Impact to Direct plus First-Round Indirect Employment	2.0	2.4	2.4
Ratio of Total Employment Impact to Direct Employment	4.4	3.0	3.2
MRS Income Multipliers			
Ratio of Primary Impact Area Income Impact to Direct Expenditures	0.37	0.56	0.85
Ratio of Total Income Impact to Direct Expenditures	0.60	0.92	1.40
Comparison Figures (SAIC 1985, Chapters II and IV)			
Employment Multiplier, closure of the K-25 Plant at Oak Ridge, 5-County Primary Impact Area	1.5		
Income Multipliers for Tennessee RIMS II Input-Output Tables			
Construction	0.75		
Stone, Clay, Glass Products	0.70		
Utilities	0.38		

primary impact area and 60% for the 50-mile impact area. It is somewhat higher in the operations period. For comparison, Table H.19 also presents the equivalent income multipliers for changes in the output of three Tennessee industries: new construction; manufacture of stone, clay, and glass products; and public utility operations. The MRS facility is expected to be similar to a combination of these industries in its pattern of purchases, although the MASTER multiplier should be larger for the same geographic area because it incorporates effects of business investment generated by economic growth while input-output tables make business investment part of final demand. Relative to the Tennessee input-output multiplier, the MRS multiplier is significantly lower during construction (due to specialized equipment and structural steel purchases outside of the 50-mile impact area and due to the fact that the input-output multiplier applies to all of Tennessee). However, the multiplier increases during operations because of investment effects and a different pattern of purchases. It is actually slightly lower than the input-output income multiplier during operations and during declining employment periods such as decommissioning. SAIC found a five-county income multiplier of 0.98 for loss of K-25 Plant purchases and payrolls (SAIC 1985).

In Table H.19, the MRS multiplier in the first and third lines is shown to be smaller during construction than during operations and decommissioning, while in the second and fourth lines, the MRS multiplier is shown to be larger during construction. The magnitude of a regional multiplier depends on the nature of an autonomous change in the economy, sector in which the change originates, size and other characteristics of the regional economy, and the time span over which the change is measured. For example, the first line shows the ratio of total employment during construction to be the sum of direct and indirect employment. Most of the employment during construction is in the construction sector or supplying industries. For these industries, much of the direct spending leaks out of the local economy relatively quickly due to the temporary nature of direct employment (service sector businesses are more reluctant to increase employment than if the increase were permanent) and the nature of purchases (many supplied from outside of Tennessee). During operations, the direct employment effect is longer term and associated with government rather than construction activity, which results in a larger ratio of total employment. During decommissioning, the relatively large multiplier is at least partially due to a lag in the adjustment of the service sector to the reduced level of direct spending in the area.

In the second line, the construction multiplier is larger than during operations and decommissioning due to the high level of indirect purchases of construction materials and services during construction. After operations start, most expenditures are for labor, so there are fewer indirect impacts. The decommissioning period is more like the construction period, but with a far lower level of indirect effects.

In summary, the validation tests of the MASTER model output show that the model is effective in forecasting the level of economic activity in both in-sample and out-of-sample tests, and is fairly effective in forecasting economic activity in many local economies as well as the Clinch River/Oak Ridge and Hartsville area economies. Further, the tests show that the multiplier response of the MASTER model for the Clinch River/Oak Ridge and Hartsville economies is reasonable and comparable to what might be expected from other models, given the same inputs. One may conclude from this that the model is producing reasonable forecasts, given the input. This is true whether actual data are compared to forecasts or whether the impacts of the model are compared to those for similar models.

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APPENDIX I

POTENTIALLY APPLICABLE FEDERAL LAWS AND REGULATIONS GUIDANCE

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POTENTIALLY APPLICABLE FEDERAL LAWS AND REGULATIONS GUIDANCE

NUCLEAR RELATED STATUES, REGULATIONS, ORDERS AND GUIDES

- Nuclear Waste Policy Act (NWPA) of 1982, 42 U.S.C. Sections 10101 et seq.
- Atomic Energy Act of 1954 (as amended), 42 U.S.C. Sections 2011 et seq.
- Energy Reorganization Act of 1974, 42 U.S.C. Sections 5811 et seq.
- Department of Energy Organization Act of 1977, 42 U.S.C. Section 7101 et seq.
- Hazardous Materials Transportations Act, 49 U.S.C. Sections 1801 et seq.
- Clean Air Act (as amended) (National Emission Standards for Hazardous Air Pollution), 42 U.S.C. Section 7412

Regulations

- 10 CFR Part 2, Rules of Practice for Domestic Licensing Proceedings
- 10 CFR Part 961, Standard Contract for Disposal of Spent Nuclear Fuel and/or High-Level Radioactive Waste
- 10 CFR Part 20, Standards for Protection Against Radiation
- 10 CFR Part 21, Reporting of Defects and Noncompliance
- 10 CFR Part 30, Rules of General Applicability to Domestic Licensing of By-Product Material (This will probably be incorporated into 10 CFR 72)
- 10 CFR Part 33, Specific Domestic Licenses of Broad Scope for By-Product Material (This will probably be incorporated into 10 CFR 72)
- 10 CFR Part 50, Appendix B, Quality Assurance Criteria
- 10 CFR Part 51, Licensing and Regulatory Policy and Procedures for Nuclear Power Plants and Fuel Reprocessing Plants for Environmental Protection

- 10 CFR Part 60, Disposal of High-Level Radioactive Wastes in Geologic Repositories
- 10 CFR Part 71, Packaging and Transportation of Radioactive Material
- 10 CFR Part 72, Licensing Requirements for the Independent Storage of Spent Fuel and High-Level Radioactive Waste (amendments forthcoming relating to MRS)
- 10 CFR Part 73, Physical Protection of Plants and Materials
- 10 CFR Part 140, Financial Protection Requirements and Indemnity Agreements
- 40 CFR Part 190, Environmental Radiation Protection Standards for Nuclear Power Operations (the language of Part 190 is incorporated into 10 CFR 72)
- 40 CFR Part 191, Environmental Standards for Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes
- 40 CFR Part 141, National Interim Primary Drinking Water Regulations (40 CFR 141.15 and 141.16 specify radioactivity standards)

Executive Orders

(To date, no applicable Executive Order identified)

DOE Orders

- DOE 4320.1A, Site Development and Facility Utilization Planning
- DOE 5480.1A, Environmental Protection, Safety and Health Program for DOE Operations
- DOE 5480.2, Hazardous and Radioactive Mixed Waste Management
- DOE 5481.1A, Safety Analysis and Review System
- DOE 5484.2, Unusual Occurrence Reporting System
- DOE 5500.3, Reactor and Non-Reactor Nuclear Facility Emergency Planning, Preparedness, and Response Program for DOE Operations
- DOE 5630.1, Control and Accountability of Nuclear Materials

- DOE 5630.2, Control and Accountability of Nuclear Materials, Basic Principles

- DOE 5630.3, Documentation of Nuclear Material Transactions

- DOE 5630.4, Nuclear Materials Balance Report

- DOE 5630.5, Nuclear Materials Inventory Reporting

- DOE 5631.1, Safeguards and Security Awareness Program

- DOE 5632.2, Physical Protection of Special Nuclear Materials

- DOE 5632.3, Operations Security

- DOE 5700.6A, Quality Assurance

- DOE 5820.1, Management of Transuranic Contaminated Material

- DOE 6410.1, Management of Construction Projects

NRC Regulatory Guides (Reg. Guide)

These Regulatory Guides refer directly to an independent Spent Fuel Storage Installation. The applicability of other Regulatory Guides will be determined as the design of the MRS, if authorized, proceeds.

- Reg. Guide 3.54, Spent Fuel Generation in an Independent Spent Fuel Storage Installation (January 1983)

- Consult Reg. Guides, Division 7, Transportation Guides

- Consult Reg. Guides, Division 8, Occupational Health Guides

- Reg. Guide 10.1, Compilation of Reporting Requirements for Persons Subject to NRC Regulations

- Reg. Guide 3.44, Standard Format and Content for the Safety Analysis Report for an Independent Spent Fuel Storage Installation (Water Basin Type) (MRS design will determine applicability)

- Reg. Guide 3.48, Standard Format and Content for the Safety Analysis Report for an Independent Spent Fuel Storage Installation (Dry Storage) (MRS design will determine applicability)

- Reg. Guide 3.50, Guidance on Preparing a License Application to Store Spent Fuel in an Independent Spent Fuel Storage Installation

- Reg. Guide 3.53, Applicability of Existing Regulatory Guides to the Design and Operation of an Independent Spent Fuel Storage Installation

AIR QUALITY STATUTES, REGULATIONS, ORDERS AND GUIDES

Statutes

- Clean Air Act (as amended) 42 U.S.C. Sections 7401-7642 (Supp. 1979)

  - Air Quality and Emission Limitations, 42 U.S.C. Sections 7401-7428

  - General Provisions, 42 U.S.C. Sections 7601-7626

  - Prevention of Significant Deterioration of Air Quality, 42 U.S.C. Sections 7470-7479

  - Plan Requirements for Nonattainment Areas, 42 U.S.C. Section 7501-7508

Regulations

- 40 CFR Part 50, National Primary and Secondary Ambient Air Quality Standards

- 40 CFR Section 52.21, Prevention of Significant Deterioration of Air Quality

- 40 CFR Section 52.21, (Plan Disapproval)

- 40 CFR 58, Ambient Air Quality Surveillance Regulations

- 40 CFR Part 60, Standards of Performance for New Stationary Sources

- 40 CFR Part 61, National Emission Standards for Hazardous Air Pollutants: Standards for Radionuclides, Subpart H - National Emission Standard for Radionuclide Emissions from the Department of Energy (DOE) Facilities (50 Fed. Reg. 5194)

Executive Orders

- E.O. 12088, Federal Compliance with Pollution Control Standards, 43 Fed. Reg. 47707, October 13, 1978

DOE Orders

- DOE 5484.1, Environmental Protection, Safety and Health Protection Information Reporting Requirements
- DOE 5480.1A, Environmental Protection, Safety and Health Protection Program for DOE Operations
- DOE 5482.1A, Environmental Protection, Safety and Health Protection Appraisal Program

DOE Environmental Compliance Guide

- Volume 2, TAB A, Clean Air (PSD)
- Volume 3E, PSD (Prevention of Significant Deterioration, OOE/EP-0062)
- Volume 3F, Nonattainment Areas (DOE/EP-0065)

WATER QUALITY STATUTES, REGULATIONS, ORDERS AND GUIDES

Statutes

- Federal Water Pollution Control Act, as amended by the Clean Water Act of 1977, 33 U.S.C. Sections 1251-1376 (Supp. 1979)
  - Standards and Enforcement, 33 U.S.C. Sections 1311-1328
  - Permits and Licenses, 33 U.S.C. Sections 1341-1345
  - General Provisions, 33 U.S.C. Section 1361-1376
- Rivers and Harbors Act, 33 U.S.C. Sections 401-413 (1970) (applicable to extent permits required from Army Corps of Engineers)
- Safe Drinking Water Act, 42 U.S.C. Sections 300f-300j-10 (applicable to extent drinking water standards used as guidelines)

Regulations

- 40 CFR Part 122, EPA Administered Permit Programs: National Pollutant Discharge Elimination System
- 40 CFR Part 401, General Provisions
- 40 CFR Part 403, General Pretreatment Regulations for Existing and New Sources of Pollution
- 40 CFR Sections 129.1-129.105, Toxic Pollutant Effluent Standards
- 40 CFR Part 121, State Certification of Activities Requiring a Federal License or Permit
- 33 CFR Parts 320-330, Army Corps of Engineers Permit Program Regulations
- 40 CFR Part 123, State Program Requirements

Executive Orders

- E.O. 12088, Federal Compliance with Pollution Control Standards

DOE Orders

- DOE 5420.1, Environmental Development Plans

DOE Environmental Compliance Guide

- Volume 2, Tab B, Clean Water NPDES
- Volume 2, Tab C, Safe Water Drinking Act
- Volume 3B, Compliance with The Clean Water Act: National Pollutant Discharge Elimination System (NPDES, OOE/EP-0061)
- Volume 3C, Compliance with Corps of Engineering Permits on Dredging and Filling Activities (DOE/EP-0060)

ENVIRONMENTAL ASSESSMENT STATUTES, REGULATIONS, ORDERS AND GUIDES

Statutes

- National Environmental Policy Act (NEPA), 42 U.S.C. Sections 4321 et seq. (applicable if MRS authorized)
- MRS EIS Pursuant to Section 141(c) Nuclear Waste Policy Act, 42 U.S.C. Section 10161(c)

Regulations

- 40 CFR 1500, CEQ Regulations for complying with NEPA
- 10 CFR 1021, DOE Guidelines for complying with NEPA
- DOE Compliance with National Environmental Policy Act, Final Guidelines (as amended) 45 Fed. Reg. 20694, 47 Fed. Reg. 7976

Executive Order

- E.O. 12088, Federal Compliance with Pollution Control Standards

DOE Orders

- DOE 5440.1B, Implementation of the National Environmental Policy Act (NEPA)

DOE Environmental Compliance Guide

- Vol. I, Environmental Compliance Planning

CULTURAL RESOURCES STATUTES, REGULATIONS, ORDERS AND GUIDES

Statutes

- National Historic Preservation Act of 1966 (as amended), 16 U.S.C. Sections 470-470w-6
- American Antiquities Act, 16 U.S.C. Sections 432-433
- Historic Sites, Buildings and Antiquities Act (as amended) (Historic Sites Act), 16 U.S.C. Sections 461-468(d)

- Archaeological and Historic Preservation Act of 1974, 16 U.S.C. Sections 469-469c

- Archaeological Resources Protection Act of 1979, 16 U.S.C. Sections 470aa-470ii

- American Indian Religious Freedom Act, 42 U.S.C. 1996

Regulations

- 36 CFR Part 800, Protection of Historic and Cultural Properties (Advisory Council on Historic Preservation)

- 36 CFR Part 60, National Register of Historic Places

- 36 CFR Part 63, Determinations of Eligibility for Inclusion in the National Register of Historic Places

- 36 CFR Part 296, Protection of Archaeological Resources: Uniform Regulations

- 43 CFR Part 3, Preservation of American Antiquities

- 43 CFR Part 7, Protection of Archaeological Resources: Uniform Regulations

Executive Order

- E.O. 11593, Protection and Enhancement of the Cultural Environment, 36 Fed. Reg. 8921 (May 13, 1971)

DOE Orders

(To date, no applicable DOE Order identified)

DOE Environmental Compliance Guide

- Vol. I, Flow III-9 (Historic Preservation)

- Vol. 390, Compliance with National Historic Preservation (AOE IEP-0098)

- Draft Guidance Manual on DOE Compliance with American Indian Religious Freedom Act

ECOLOGY/WILDLIFE PROTECTION STATUTES, REGULATIONS, ORDERS AND GUIDES

Statutes

- Endangered Species Act of 1973 (as amended), 16 U.S.C. Sections 1531-1543
- Migratory Bird Treaty Act (as amended), 16 U.S.C. Section 703-711
- Bald and Golden Eagle Protection Act, 16 U.S.C. Sections 668-668d
- Fish and Wildlife Coordination Act (as amended), 16 U.S.C. Sections 661-666c

Regulations

- 50 CFR Section 10.13, List of Migratory Birds
- 50 CFR Part 402, Interagency Cooperation - Endangered Species Act of 1973
- 50 CFR Subchapter C, Endangered Species Exemption Process
- 50 CFR Part 17, Endangered and Threatened Wildlife and Plants
- 50 CFR Part 222, Endangered Fish or Wildlife
- 50 CFR Part 226, Designated Critical Habitat
- 50 CFR Part 227, Threatened Fish and Wildlife

Executive Orders

(To date, no applicable Executive Order identified)

DOE Orders

- DOE 5420.1, Environmental Development Plans

DOE Environmental Compliance Guide

- Vol. 3P
- Vol. 3A - Compliance with Endangered Species Act (DOE/EP-005811)
- Compliance with Fish and Wildlife Coordination Act (DOE/EP-0059)

LAND USE STATUTES, REGULATIONS, ORDERS AND GUIDES

Statutes

- Farmland Protection Policy Act, 7 U.S.C. Sections 4201-4209 et seq.

Regulations

- Prime and Unique Farmlands, 7 CFR Sections 657.1-657.5
- Objects Affecting Navigable Airspace, 14 CFR Sections 77.1-77.75
- Farmland Protection Policy, (7 CFR 658) 49 Fed. Reg. 27716 (July 5, 1984)
- DOE Compliance with Floodplain/Wetlands Environmental Review Requirements, 10 CFR Sections 1022.1-1022.21

Executive Orders

- E.O. 11990, Protection of Wetlands
- E.O. 11988, Floodplain Management (as amended by E.O. 12148)

DOE Orders

- DOE 5420.1, Environmental Development Plans

DOE Environmental Compliance Guide

(Not applicable)

NOISE CONTROL STATUTES, REGULATIONS, ORDERS AND GUIDES

Statutes

- Noise Control Act of 1972, 42 U.S.C. Sections 4901-4918

Regulations

(To date, no applicable regulations identified)

Executive Orders

- E.O. 12088, Federal Compliance with Pollution Control Standards

DOE Orders

(To date, no applicable DOE Order identified)

DOE Environmental Compliance Guide

(Not applicable)

WASTE DISPOSAL STATUTES, REGULATIONS, ORDERS AND GUIDES (NONRADIOACTIVE)

Statutes

- Resource Conservation and Recovery Act (RCRA) of 1976 as amended, 42 U.S.C. Sections 6901 et seq.

Regulations

(To date, no applicable regulations identified)

AESTHETICS STATUTES, REGULATIONS, ORDERS AND GUIDES

Statutes

- Clean Air Act (as amended), 42 U.S.C. Section 7491

Regulations

- Department of Interior Internal Procedures for Determinations of Adverse Impact under Section 165(d)(2)(C)(ii) and (iii) of Clean Air Act, 47 Fed. Reg. 30226 (1982)
- Implementing Control Strategies, 40 CFR Section 51.302
- National Park Service, Identification of Integral Vistas (associated with Federal Class I Areas) (proposed) 46 Fed. Reg. 3646 (1981)
- Protection of Visibility, 40 CFR Part 51, Subpart P
- Identification of Mandatory Class I Federal Areas where Visibility is an Important Value, 40 CFR Part 81, Subpart D

OCCUPATIONAL HEALTH AND SAFETY STATUTES, REGULATIONS, ORDERS AND GUIDES

Statutes

(Not applicable)

Regulations

(Not applicable)

Executive Orders

(To date, no applicable Executive Order identified)

DOE Orders

- DOE 3790.1, Occupational Safety and Health Program for Federal Employees
- DOE 3791.1, Federal Employee Occupational Safety and Health Program, Safety and Health Inspection and Abatement Procedures
- DOE 5480.1A, Environmental Protection Safety and Health Protection Program for DOE Operations

TRANSPORTATION STATUTES, REGULATIONS, ORDERS AND GUIDES

Statutes

- Hazardous Materials Transportation Act, 49 U.S.C. Sections 1801 et seq.

Regulations

- 49 CFR Parts 171-179, Hazardous Materials Regulations

DOE Orders

- DOE 1540.1, Materials Transportation and Traffic Management
- DOE 5480.1, Chapter 3, Safety Requirements for the Packaging of Fissile and Other Radioactive Materials
- DOE 5632.2, Physical Protection of Special Nuclear Materials

EMERGENCY PLANNING OTHER THAN NRC REQUIREMENTS

Regulations

- 44 CFR Part 351, Radiological Emergency Planning and Preparedness

APPENDIX J

ENVIRONMENTAL DOCUMENTATION FOR THE MONITORED RETRIEVABLE STORAGE FACILITY

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ENVIRONMENTAL DOCUMENTATION FOR THE MONITORED RETRIEVABLE STORAGE FACILITY

The Nuclear Waste Policy Act (NWPA, Section 141) directs the Secretary of Energy to prepare an Environmental Assessment (EA) on at least five alternative combinations of proposed sites and facility designs. The EA is to analyze the relative advantages and disadvantages among the site/concept combinations. This MRS EA was prepared to fulfill that requirement.

This Environmental Assessment represents one component of the total environmental documentation for the MRS facility. The total environmental documentation ranges from consideration of environmental factors during the site screening process (DOE 1985b) to preparation of an Environmental Impact Statement (EIS). Some of these documents are required under the National Environmental Policy Act (NEPA). Each component of the environmental documentation process is described below. The first four documents have been completed; the License Application and EIS are additional documents required before construction.

ENVIRONMENTAL ASSESSMENT ON 10 CFR 72 PROPOSED REVISION

The NWPA states that any MRS facility must be licensed by the Nuclear Regulatory Commission (NRC). Any MRS facility must, therefore, meet the requirements of 10 CFR 72, "Licensing Requirements for the Independent Storage of Spent Fuel and High-Level Radioactive Waste."

To establish licensing requirements specifically for an MRS facility, the NRC is proposing revisions to 10 CFR 72. The NRC has prepared an Environmental Assessment on this proposed action. The purpose of the NRC EA was "to insure that environmental values receive appropriate consideration in the development and promulgation of these proposed rules" (NRC 1984).

REFERENCE-SITE ENVIRONMENTAL DOCUMENT

Before selecting candidate sites for an MRS facility, the DOE evaluated environmental impacts of an MRS facility with a throughput of 1,800 MTU per year (backup waste-management option). Facility impacts were evaluated for three reference sites (hypothetical sites representing general climatic types in the United States). The results showed that climate is not a discriminating factor in siting an MRS facility (Silviera et al. 1985).

SITE SCREENING AND EVALUATION REPORT

The DOE's site-screening process included consideration of environmental factors. Eleven potentially acceptable candidate sites were identified and then evaluated in detail for identification of significant strengths and weaknesses. Environmental, geotechnical, and socioeconomic considerations were included in the evaluation. In particular, 10 environmental attributes were considered for each of the 11 sites: aesthetic characteristics, air quality, cultural resources, ecology, health and safety, land use, meteorology, noise and vibration, transportation, and water quality. The results of these evaluations are presented in Monitored Retrievable Storage Site Screening and Evaluation Report (Golder et al. 1985).

REGULATORY ASSESSMENT DOCUMENT

After three candidate sites were selected, two conceptual designs were developed for an MRS facility at each of the three sites. The two designs, the sealed storage cask concept and the field drywell concept, were based on site-specific data such as topography, flood potential and seismic conditions (Parsons 1985). A Regulatory Assessment Document (RAD) was prepared to document the results of an evaluation of the MRS conceptual designs against the NRC requirements of 10 CFR 72, to the degree that such an evaluation is meaningful at this stage of the design process (Parsons 1985). The results of this preliminary design assessment have been used in developing the radiological impacts presented in this EA. The RAD also complies with DOE Orders 6430.1 and 5481.1A, which require that a preliminary safety evaluation of new projects be conducted to identify hazards or potential accidents and to describe and analyze the adequacy of the design so as to eliminate, control or mitigate those hazards or accidents and/or their consequences.

LICENSE APPLICATION

Various documents are required to accompany the license application. (The required documents are listed in 10 CFR 72.21.) Many of these documents contain information related to environmental impacts; for example, the Safety Analysis Report, Decommissioning Plan, Emergency Plan, Design for Physical Protection, Physical Security Plan, Safeguards Contingency Plan, and the Environmental Report. The Environmental Report, in particular, typically contains detailed environmental data. In accordance with NRC requirements, the ER will discuss the potential environmental impacts (and mitigation of impacts) resulting from the construction and operation of an MRS facility at a given site.

The ER will discuss alternative designs, consistent with the requirements of the NWPA and any additional requirements that Congress may impose as conditions in approving the MRS proposal.

ENVIRONMENTAL IMPACT STATEMENTS

The most comprehensive form of environmental analysis listed by the Council on Environmental Quality (40 CFR 1500-1510) is an EIS. The federal agency preparing an EIS first initiates a formal scoping process, which may include public hearings. After the scope has been determined, the agency prepares and issues a formal draft EIS for comment by the public and by other government agencies. After responding to comments received, a final EIS is issued, followed by a record of decision by the federal agency preparing the EIS.

The NWPA states that if Congress authorizes construction of an MRS facility, the requirements of NEPA apply, except that any EIS prepared shall not have to consider the need for such facility nor any alternative to the design criteria listed in the NWPA.

REFERENCES

Golder Associates, Inc., et al. 1985. Monitored Retrievable Site Screening and Evaluation Report. U.S. Department of Energy, Richland Operations, Richland, Washington.

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

Ralph M. Parsons Company (Parsons). 1985. Regulatory Assessment Document. Vol. II of Integral Monitored Retrievable Storage (MRS) Facility. Conceptual Design Report (Draft Final Report), Book II. MRS-11, Ralph M. Parsons Company, Pasadena, California.

Silviera, D. J., et al. 1985. Reference-Site Environmental Document for a Monitored Retrievable Storage Facility: Backup Waste Management Option for Handling 1800 MTU Per Year. PNL-5476, Pacific Northwest Laboratory, Richland, Washington.

U.S. Code of Federal Regulations, Title 40, Parts 1500-1510 (40 CFR 1500-1510). "Regulations for Implementing the Procedural Provisions of the National Environmental Policy Act."

U.S. Department of Energy (DOE). 1985. Screening and Identification of Sites for a Proposed Monitored Retrievable Storage Facility. DOE/RW-0023, Washington, D.C.

U.S. Nuclear Regulatory Commission (NRC). 1984. Environmental Assessment for 10 CFR Part 72 - Licensing Requirements for the Independent Storage of Spent Fuel and High-Level Radioactive Waste. NUREG-1092, Washington, D.C.

APPENDIX K

LIST OF TENNESSEE RARE PLANT AND ANIMAL SPECIES

APPENDIX K

LIST OF TENNESSEE RARE PLANT AND ANIMAL SPECIES

This appendix lists rare or endangered species at the Clinch River/Oak Ridge site and the Hartsville site in the State of Tennessee. This list (see Table K.1) is provided by the State of Tennessee. A similar list of species in adjoining counties is available upon request from the Department of Conservation in Hartsville.

TABLE K.1. Tennessee Rare and Endangered Species

CLINCH RIVER AND OAK RIDGE SITES	
Plants	
Aster sericeus	Eastern silvery aster
Aureolaria patula	False foxglove
Carex oxylepis	Sedge
Cimicifuga rubifolia	Bugbane
Delphinium exaltatum	Tall larkspur
Diervilla lonicera	Bush honeysuckle
Draba ramosissima	Branching Whitlow grass
Fothergilla major	White alder
Hydrastis canadensis	Golden seal
Lilium canadense	Canada lily
Lilium michiganense	Michigan lily
Marshallia grandiflora	Barbara's buttons
Meehania cordata	Meehania
Panax quinquefolius	Ginseng
Platanthera flava	Southern Rein orchid
Saxifraga careyana	Carey's saxifrage
Spiraea virginiana	Virginia spiraea
Spiranthes ovalis	Lesser ladies tresses
Trichomanes petersii	Dwarf filmy-fern
Animals	
Cnemidophorus sexlineatus	Six-lined racerunner
Cryptobranchus a. allaganiensis	Hellbender
Gyrinophilus palleucus	Tennessee cave salamander
Hemidactylium scutatum	Four-toed salamander
Myotis grisescens	Gray bat
Neotoma floridana	Eastern woodrat
Ophisaurus attenuatus	Eastern slender glass lizard
Sorex fumeus	Smoky shrew
Sorex longirostris	Southeastern shrew
Birds	
Accipiter striatus	Sharp-shinned hawk
Aimophila aestivalis	Bachman's sparrow
Ammodramus savannarum	Grasshopper sparrow
Buteo lineatus	Red-shouldered hawk
Coragyps atratus	Black vulture
Limnothlypis swainsonii	Swainson's warbler
Pandion haliaetus	Osprey
Thryomanes bewickii	Bewick's wren

TABLE K.1. (contd)

Aquatic, Fish and Invertebrates	
Anguilla rostrata	American eel
Athearnia anthonyi	Anthony's River snail
Chrysemys scripta	Cumberland turtle
Cumberlandia monodonta	Spectical case pearly mussel
Cycleptus elongatus	Blue Sucker
Dromus dromas	Dromedary mussel
Epioblasma f. florentina	Yellow-blossom pearly mussel
Epioblasma torulosa gubernaculum	Green-blossom pearly mussel
Epioblasma turgidula	Turgid-blossom pearly mussel
Fusconaia cor (=F. edgariana)	Shiny pigtoe pearly mussel
Fusconaia cuneolus	Fine-rayed pigtoe pearly mussel
Hybopsis cahni	Slender chub
Hybopsis monacha	Spotfin chub
Io fluvialis	Spiney River snail
Lampsilis orbiculata	Pink mucket pearly mussel
Lampsilis virescens	Alabama lamp pearly mussel
Lemiox rimosus	Birdwing pearly mussel
Lithasia geniculata	A river snail
Phoxinus oreas	Mountain redbelly dace
Plethobasus cicatricosus	Bullhead pearly mussel
Plethobasus cooperianus	Orange-footed pimpleback pearly mussel
Pleurobema plenum	Rough pigtoe pearly mussel
Pseudemeys scripta troosti	Cumberland turtle
HARTSVILLE SITE	
Plants	
Lesquerella globosa	Short's bladderpod
Talinum calcaricum	Limestone fameflower
Animals	
Birds	
Ammodramus savannarum	Grasshopper sparrow
Melanerpes erythrocephalus	Red-headed woodpecker
Thryomanes bewickii	Bewick's wren
Aquatic, Fish and Intertebrates	
Lampsilis orbiculata	Pink mucket pearly mussel
Quadrula sparsa	Appalachian monkey face pearly mussel