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MRS Systems Study, Task F: Transportation Impacts of a Monitored Retrievable Storage Facility

Technical Report

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ABSTRACT

The passage of the Nuclear Waste Policy Amendments Act of 1987 (NWPAA) modified the basis from which the Office of Civilian Radioactive Waste Management (OCRWM) had derived and developed the configuration of major elements of the waste system (repository, monitored retrievable storage, and transportation). While the key aspects of the Nuclear Waste Policy Act of 1982 remain unaltered, NWPAA provisions focusing site characterization solely at Yucca Mountain, authorizing a monitored retrievable storage (MRS) facility with specific linkages to the repository, and establishing an MRS Review Commission make it prudent for OCRWM to update its analysis of the role of the MRS in the overall waste system configuration.

This report documents the differences in transportation costs and radiological dose under alternative scenarios pertaining to a nuclear waste management system with and without an MRS, to include the effect of various MRS packaging functions and locations. The analysis is limited to the impacts of activities related directly to the hauling of high-level radioactive waste (HLW), including the capital purchase and maintenance costs of the transportation cask system. Loading and unloading impacts are not included in this study because they are treated as facility costs in the other task reports. Transportation costs are based on shipments of 63,000 metric tons of uranium (MTU) of spent nuclear fuel and 7,000 MTU equivalent of HLW.

FOREWORD

The National Waste Terminal Storage Program was established in 1976 by the U.S. Energy Research and Development Administration. In September 1983, this program became the Civilian Radioactive Waste Management Program. Its purpose is to develop technology and provide facilities for safe, environmentally acceptable, permanent disposal of high-level waste (HLW). HLW includes wastes from both commercial and defense sources, such as spent (used) fuel from nuclear power reactors, accumulations of wastes from production of nuclear weapons, and solidified wastes from fuel processing.

The information in this report pertains to the monitored retrievable storage system studies of the Office of Systems Integration and Regulations of the Office of Civilian Radioactive Waste Management.

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1.0 INTRODUCTION

The passage of the Nuclear Waste Policy Amendments Act of 1987 (NWPAA) modified the basis from which the Office of Civilian Radioactive Waste Management (OCRWM) had derived and developed the configuration of major elements of the waste system (repository, monitored retrievable storage, and transportation). While the key aspects of the Nuclear Waste Policy Act of 1982 remain unaltered, NWPAA provisions focusing site characterization solely at Yucca Mountain, authorizing a monitored retrievable storage (MRS) facility with specific linkages to the repository, and establishing an MRS Review Commission, make it prudent for OCRWM to update its analysis of the role of the MRS in the overall waste system configuration.

The scope of this update is described in the "Action Plan for Systems Study to Support the MRS Commission" (Ref. 1). The Action Plan outlined 10 tasks (Tasks A through J), which together comprise the MRS Systems Study.

Chapter 2 defines the objectives and scope of the transportation analysis, including a definition of the spent fuel and high-level waste cases examined and reported in the study. Chapter 3 describes the methodology and data used. The results are presented in Chapter 4 with several sensitivity analyses described in Chapter 5. The conclusions drawn from the transportation analysis are presented in Chapter 6. Chapter 7 lists the references. Supplementary information and detailed results are presented in appendices.

2.0 OBJECTIVE AND SCOPE OF STUDY

The objective of this report is to document the differences in transportation costs and radiological dose under alternative scenarios pertaining to a nuclear waste management system with and without an MRS, to include the effect of various MRS packaging functions and locations. The analysis is limited to the impacts of activities related directly to the hauling of high-level radioactive waste (HLW), including the capital purchase and maintenance costs of the transportation cask system. Loading and unloading impacts are not included in this study because they are treated as facility costs in the other task reports. As prescribed in the Task A Report (Ref. 2), this study assumed that 63,000 metric tons of uranium (MTU) of spent fuel (SF) and 7,000 MTU of HLW are to be transported.

The Task A report identified several parameters that impact at least one of the system elements. Of these, the following parameters impact transportation and are considered in the present study:

1. **The configuration of the Federal Waste Management System (FWMS).**

   Two basic FWMS configurations are considered in the following analysis:

   - FWMS without an MRS (base case)
   - FWMS with an MRS

   The analyses in this report assume that given an FWMS with an MRS, all spent fuel and HLW are processed through the MRS facility (the exception being an MRS system with a Western strategy as described in number 4 below).

2. **Alternative MRS functions.**

   The need for an MRS facility may depend on the functions it performs as part of an FWMS. Four alternative MRS packaging functions were identified in the Task A Report. These four functions, listed below, are the basis for evaluation of every FWMS element, including Transportation:

   - Store Only: Storing the waste for subsequent shipment to the repository in larger rail casks
   - Consolidate and Canister: Consolidating SF and loading it into canisters that are placed into a final disposal container at the repository
   - Containerize Intact SF: Loading SF into disposal containers, in the form received, i.e., intact assemblies
   - Consolidate and Containerize: Consolidating SF and loading it into disposal containers.

3. **Alternative MRS Locations.**

The Task A report specified that in order to evaluate the effect of location on MRS evaluation, transportation impacts were to be calculated for two geographically diverse generic locations, representative of an Eastern and a Western MRS.

4. **Shipment strategy for fuel from Western reactors[1].**

When an MRS is included, Eastern reactors are assumed to ship all their fuel through the MRS, regardless of MRS location. But, when an Eastern MRS is involved, it may be efficient in some cases to ship fuel from Western reactors directly to the repository. Therefore, alternative strategies for the Western fuel shipments are considered as follows:

- Shipments through the MRS, en route to the repository
- Shipments directly to the repository.

2.1 SPENT FUEL CASES

Eleven basic cases were used to characterize the impacts of spent fuel transportation, as depicted in Table 1. Figure 1 displays these eleven cases as a tree-diagram.

Note that four transportation networks (i.e., sets of origin-destination pairs) are implicit in these eleven cases:

1. All reactors shipping to the repository.
2. All reactors shipping to the generic Eastern MRS.
3. All reactors shipping to the generic Western MRS.
4. Western reactors shipping directly to the repository and the remaining reactors shipping to the generic Eastern MRS.

---

[1] Western reactors are defined in the Task A Report as those located west of 100 degrees longitude. Twelve reactors fall in this category under the Energy Information Administration (EIA) No-New-Orders scenario:

Palo Verde 1
Palo Verde 2
Palo Verde 3
San Onofre 1
San Onofre 2
San Onofre 3
Diablo Canyon 1
Diablo Canyon 2
Rancho Seco
Humboldt Bay
Trojan
Washington Nuclear 2

Table 1. Spent Fuel Cases

	MRS Function	MRS Location	Destination of Spent Fuel From Eastern Reactors	Destination of Spent Fuel From Western Reactors
1.	No-MRS	---	Repository	Repository
2.	Store Only	East	MRS	MRS
3.	Store Only	East	MRS	Repository
4.	Store Only	West	MRS	MRS
5.	Consolidate & Canister	East	MRS	MRS
6.	Consolidate & Canister	East	MRS	Repository
7.	Consolidate & Canister	West	MRS	MRS
8.	Containerize Intact SF	East	MRS	MRS*
9.	Containerize Intact SF	West	MRS	MRS*
10.	Consolidate & Containerize	East	MRS	MRS*
11.	Consolidate & Containerize	West	MRS	MRS*

*When the MRS function is to containerize SF and HLW, it is assumed that the repository would not have containerization capability and therefore, fuel from all waste sources would be processed through the MRS.

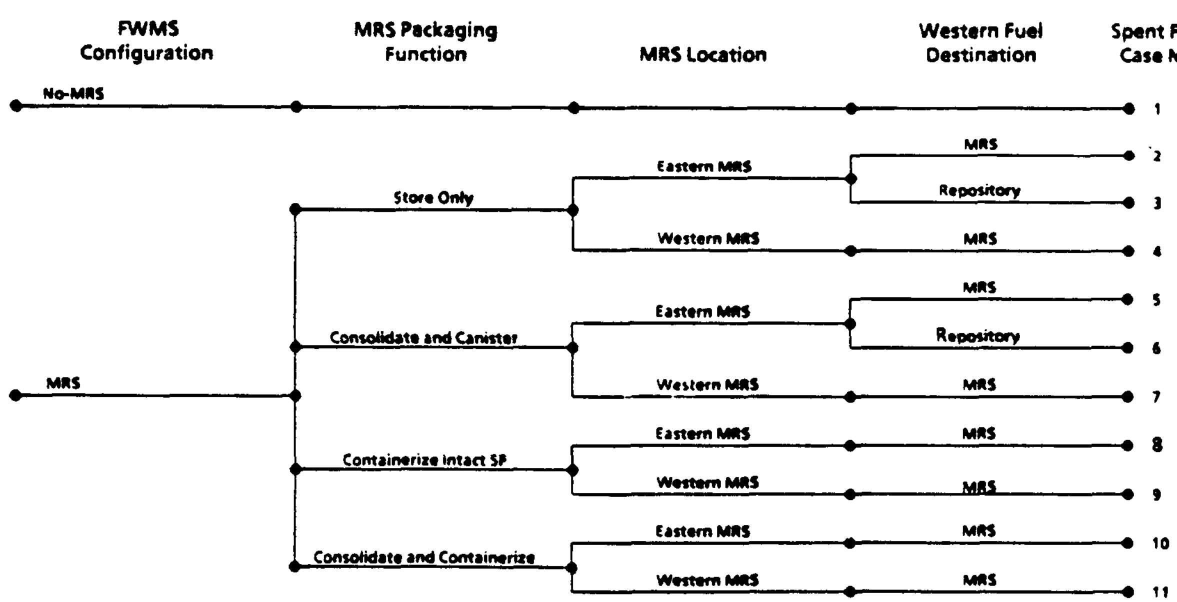

Figure 1. Schematic of Spent Fuel Cases

Network 4 is referred to as the Western strategy. (Note that the Western strategy applies only when the MRS is in the East.) For convenience, the other networks are referred to as no-Western strategy.

The MRS Systems Study assumptions specify that shipments from reactors are to be scheduled according to the oldest-fuel-first (OFF) shipping rule. Another assumption is that transportation costs do not recognize inflation. Together, these two assumptions imply that transportation impacts for this study are independent of facility startup dates, within a given set of parameters (i.e., system configuration, MRS function, MRS location, and Western strategy). This is because, although the timing of shipments could vary for different facility startup schedules, the total quantity shipped from individual reactors would not. And if the same quantities are shipped over the same network, then the inflated costs will not change.

Therefore, the transportation impacts can be calculated for one facility/startup combination as well as for other combinations being examined in the MRS Systems Study. For simplicity, concurrent MRS and repository startups are used in this study (see Tables 2 through 4). These tables show the SF quantities to be shipped annually under the No-MRS system, the No-Western-strategy, and the Western-strategy cases, respectively.

2.2 HIGH-LEVEL WASTE CASES

Three cases are sufficient to characterize the transportation impacts for HLW:

- HLW shipped through an Eastern MRS
- HLW shipped through a Western MRS
- HLW shipped directly to the repository.

The study specifications call for shipment of 7,000 MTU of HLW from West Valley and the three defense sites, which include Hanford, Savannah River, and the Idaho Chemical Processing Plant (ICPP). This quantity is to be shipped according to a set schedule, over 18 years. The acceptance and shipment schedules are shown in Table 5. Again, note that the transportation impacts calculated for this schedule are directly applicable to the variety of the facility startup dates being examined under the other Tasks of the MRS System Study.

Table 2. Spent Fuel Acceptance Schedule for No-MRS System (Network 1)

Year	SF to be Accepted at Repository from all Reactors (MTU)
1	400
2	900
3	1,500
4	2,250
5	2,250
6	3,000
7	3,000
8	3,000
9	3,000
10	3,000
11	3,000
12	3,000
13	3,000
14	3,000
15	3,000
16	3,000
17	3,000
18	3,000
19	3,000
20	3,000
21	3,000
22	3,000
23	3,000
24	1,700
	63,000

Source: Pacific Northwest Laboratory, 1988 (see MRS Action Plan [Ref. 1], Schedule 1, data files, August 26).

Table 3. Spent Fuel Acceptance Schedule for No-Western-Strategy Cases (Networks 2 and 3)

Year	SF to be Accepted at MRS from all Reactors (MTU)	SF to be Accepted at Repository from the MRS (MTU)
1	1,350	400
2	2,025	900
3	3,000	1,500
4	3,000	2,250
5	3,000	2,250
6	3,000	3,000
7	3,000	3,000
8	3,000	3,000
9	3,000	3,000
10	3,000	3,000
11	3,000	3,000
12	3,000	3,000
13	3,000	3,000
14	3,000	3,000
15	3,000	3,000
16	3,000	3,000
17	3,000	3,000
18	3,000	3,000
19	3,000	3,000
20	3,000	3,000
21	3,000	3,000
22	2,625	3,000
23	0	3,000
24	0	1,700
	63,000	63,000

Source: Pacific Northwest Laboratory, 1988 (see MRS Action Plan [Ref. 1], Schedule 26 NOWEST, data files, September 1).

Table 4. Spent Fuel Acceptance Schedule for Western-Strategy Cases (Network 4)

Year	SF to Be Accepted at MRS From Eastern Reactors (MTU)	SF to Be Accepted at Repository From Western Reactors (MTU)	SF to Be Accepted at Repository From MRS (MTU)
1	1,350		400
2	2,025		900
3	2,700		1,500
4	2,700		2,250
5	2,700		2,250
6	2,700	300	2,700
7	2,700	300	2,700
8	2,700	300	2,700
9	2,700	300	2,700
10	2,700	300	2,700
11	2,700	300	2,700
12	2,700	300	2,700
13	2,700	300	2,700
14	2,700	300	2,700
15	2,700	300	2,700
16	2,700	300	2,700
17	2,700	300	2,700
18	2,700	300	2,700
19	2,700	300	2,700
20	2,700	300	2,700
21	2,700	300	2,700
22	2,700	300	2,700
23	225	300	2,700
24	0	0	1,700
	57,600	5,400	57,600

Source: Pacific Northwest Laboratory, 1988 (see MRS Action Plan [Ref. 1] Schedule 2 WEST, data files, September 2).

Table 5. High-Level Waste Acceptance and Shipment Schedule

Year	Quantity of HLW to Be Accepted at MRS or Repository (MTU)	Shipment Schedule			
		West Valley	Savannah River	ICPP (Idaho)	Hanford
1	400		400		
2	400		400		
3	400		368		32
4	400		295		105
5	400		306		94
6	400		312		88
7	400		266		134
8	400		241		159
9	400		231		169
10	400		145	106	149
11	400		57	343	
12	400		48	352	
13	400		37	363	
14	400		34	366	
15	400		34	366	
16	400	40	30	330	
17	400	400			
18	200	200			
	7,000	640	3,204	2,226	930

Source: Pacific Northwest Laboratory, 1988 (see MRS Action Plan (Ref. 1], High-Level Waste, September).

3.0 METHODOLOGY AND DATA

The Transportation Risk and Cost Analysis Model (TRICAM) was used in this study to estimate transportation impacts. As previously noted, the investigation was limited to activities related directly to the transport of the waste. Specifically, loading and unloading activities were not considered because these are included in the facility impacts being examined under the other MRS System Study tasks. TRICAM is described in a paper (Ref. 3) that is included as Appendix C for the readers' convenience.

Briefly, the type of cask used to ship waste between each origin/destination (O/D) pair is specified according to modal capability, waste form, and packaging. Using the route-specific data described in Section 3.2 and the mode of service involved, the cost and radiological dose are calculated for every O/D pair. (Appendix A describes salient assumptions underlying the cost calculations.) These per-shipment costs and doses are multiplied by the quantities to be shipped to estimate annually cost and dose for every O/D pair. The transportation impacts for the duration of the shipping program are then calculated by summing up the annual impacts.

3.1 COST AND DOSE DATA

The categories of cost included in this analysis are:

- Capital cost of transportation casks
- Cask maintenance cost
- Hauling cost
- Inspection cost at the origin point
- In-transit security cost.

The categories of public dose included in this analysis are:

- Incident-free, off-link[1]
- Incident-free, on-link[2]
- Incident-free, at stops
- Accident-related, off-link
- Accident-related, on-link
- Accident-related, ingestion.

3.2 ROUTE-SPECIFIC DATA

Route-specific data for highway and rail transportation are generated using the routing models, HIGHWAY and INTERLINE respectively. These models have been described in the literature (Refs. 4, 5). Route data are provided on computer tapes in a format compatible with TRICAM.

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[1] Off-link refers to population surrounding the highway or railroad track on which the shipment moves.

[2] On-link refers to population sharing the highway or railroad track on which the shipment moves.

The route data contain information for the entire route connecting every O/D pair in the transportation network, i.e., each reactor to the repository, each waste site to the MRS, and the MRS to the repository. The information for each O/D pair includes:

- The States through which the route passes
- Type of highways (not applicable to rail)
- Length of the route in miles
- Miles through each of 11 population density categories.

This level of detail is required for calculating route-specific costs and doses. Several hundred routes are typical in a TRICAM application.

3.3 MODE OF SERVICE

The type of transportation cask that would be used for shipments from individual waste generator sites depends on (1) cask-handling capability (which is primarily constrained by crane capacity) and (2) rail access to the loading bay. A reactor that has adequate crane capacity and rail access to the loading bay is assumed to be served by rail, using the 100-ton rail casks. Otherwise, the reactor is assumed to be served by truck, using the 28-ton truck casks. Table 6 shows the mode of service assumed in this study, for reactors in the EIA No-New-Orders scenario (Ref. 8). As indicated in the table, about 54% of the reactors are designated as rail-served and about 46% are truck-served, resulting in an MTU split of about 55% rail and 45% truck. Table 6 is based on current information about rail access and infrastructure at reactors. These conditions may change, leading to different modal assignments over time. All HLW sites are assumed to qualify for rail service using the above criteria. The MRS and repository are assumed to be designed to handle up to 150-ton rail casks.

3.4 TRANSPORT CASK DATA

Table 7 lists all of the cask systems used in this study. Shipments from reactors are made in either 100-ton 21/48 rail casks or 28-ton 3/7 truck casks, depending on modal access. Sensitivity analyses were performed as described in Chapter 5 for overweight 40-ton truck casks and various capacity from-reactor and from-MRS rail casks to show the effects of difference in cask capacity.

The four MRS packaging functions analyzed in this study produce three forms of waste: intact SF, consolidated SF, and non-fuel-bearing components (NFBC) resulting from disassembly of the fuel elements. One or more of the six SF casks listed in Table 7 for MRS-to-Repository shipments can be involved in shipping these waste forms, as clarified in Table 8.

HLW shipments use the 100-ton rail casks with five canisters per cask for shipments from the HLW sites and 150-ton rail casks with seven canisters per cask for shipments from the MRS to the repository.

Tables 9 and 10 give additional data on the transportation casks used in this study.

Table 6. Mode of Service at Reactors in the EIA No-New-Orders Scenario (Page 1 of 3)

Reactor Name	State	Mode of Service
ARK NUCLEAR 1	AR	Rail
ARK NUCLEAR 2	AR	Rail
BEAVER VALLEY 1	PA	Rail
BEAVER VALLEY 2	PA	Rail
BELLEFONTE 1	AL	Rail
BIG ROCK 1	MI	Truck
BRAIDWOOD 1	IL	Rail
BRAIDWOOD 2	IL	Rail
BROWNS FERRY 1	AL	Truck
BROWNS FERRY 2	AL	Truck
BROWNS FERRY 3	AL	Truck
BRUNSWICK 1 PWR POOL	NC	Truck
BRUNSWICK 2 PWR POOL	NC	Truck
BRUNSWICK 1	NC	Truck
BRUNSWICK 2	NC	Truck
BYRON 1	IL	Rail
BYRON 2	IL	Rail
CALLAWAY 1	MO	Truck
CALVERT CLF 1	MD	Truck
CALVERT CLF 2	MD	Truck
CATAWBA 1	SC	Rail
CATAWBA 2	SC	Rail
CLINTON 1	IL	Rail
COMANCHE PK 1	TX	Truck
COMANCHE PK 2	TX	Truck
COOK 1	MI	Rail
COOK 2	MI	Rail
COOPER STN	NE	Truck
CRYSTAL RVR 3	FL	Truck
DAVIS-BESSE 1	OH	Rail
DIABLO CANYON 1	CA	Truck
DIABLO CANYON 2	CA	Truck
DRESDEN 1	IL	Truck
DRESDEN 2	IL	Rail
DRESDEN 3	IL	Rail
DUANE ARNOLD	IA	Truck
ENRICO FERMI 2	MI	Rail
FARLEY 1	AL	Rail
FARLEY 2	AL	Rail
FITZPATRICK	NY	Rail
FORT CALHOUN	NE	Truck
GINNA	NY	Truck
GRAND GULF 1	MS	Truck
HADDAM NECK	CT	Truck
HARRIS 1 BWR POOL	NC	Truck

Table 6. Mode of Service at Reactors in the EIA No-New-Orders Scenario (Page 2 of 3)

Reactor Name	State	Mode of Service
HARRIS 1	NC	Truck
HATCH 1	GA	Rail
HATCH 2	GA	Rail
HOPE CREEK	NJ	Truck
HUMBOLDT BAY	CA	Truck
INDIAN PT 1	NY	Truck
INDIAN PT 2	NY	Truck
INDIAN PT 3	NY	Truck
KEWAUNEE	WI	Truck
LACROSSE	WI	Truck
LASALLE CTY 1	IL	Rail
LASALLE CTY 2	IL	Rail
LIMERICK 1	PA	Rail
MAINE YANKEE	ME	Rail
MCGUIRE 1	NC	Rail
MCGUIRE 2	NC	Rail
MILLSTONE 1	CT	Truck
MILLSTONE 2	CT	Rail
MILLSTONE 3	CT	Rail
MONTICELLO	MN	Truck
MORRIS-BWR	IL	Rail
MORRIS-PWR	IL	Rail
NINE MILE PT 1	NY	Rail
NINE MILE PT 2	NY	Rail
NORTH ANNA 1	VA	Rail
NORTH ANNA 2	VA	Rail
OCONEE 1	SC	Truck
OCONEE 2	SC	Truck
OCONEE 3	SC	Truck
OYSTER CRK 1	NJ	Truck
PALISADES	MI	Truck
PALO VERDE 1	AZ	Rail
PALO VERDE 2	AZ	Rail
PALO VERDE 3	AZ	Rail
PEACHBOTTOM 2	PA	Truck
PEACHBOTTOM 3	PA	Truck
PERRY 1	OH	Rail
PILGRIM 1	MA	Truck
POINT BEACH 1	WI	Truck
POINT BEACH 2	WI	Truck
PRAIRIE ISL 1	MN	Rail
PRAIRIE ISL 2	MN	Rail
QUAD CITIES 1	IL	Rail
QUAD CITIES 2	IL	Rail
RANCHO SECO 1	CA	Truck

Table 6. Mode of Service at Reactors in the EIA No-New-Orders Scenario (Page 3 of 3)

Reactor Name	State	Mode of Service
ROBINSON 2	SC	Truck
RVR BEND 1	LA	Rail
SALEM 1	NJ	Truck
SALEM 2	NJ	Truck
SAN ONOFRE 1	CA	Truck
SAN ONOFRE 2	CA	Rail
SAN ONOFRE 3	CA	Rail
SEQUOYAH 1	TN	Rail
SEQUOYAH 2	TN	Rail
SOUTH TEXAS 1	TX	Rail
SOUTH TEXAS 2	TX	Rail
ST LUCIE 1	FL	Truck
ST LUCIE 2	FL	Truck
SUMMER 1	SC	Rail
SURRY 1	VA	Truck
SURRY 2	VA	Truck
SUSQUEHANNA 1	PA	Rail
SUSQUEHANNA 2	PA	Rail
THREE MILE ISL 1	PA	Rail
TROJAN	OR	Rail
TURKEY PT 3	FL	Truck
TURKEY PT 4	FL	Truck
VOGTLE 1	GA	Rail
VOGTLE 2	GA	Rail
VT YANKEE 1	VT	Rail
WASH NUCLEAR2	WA	Truck
WATERFORD 3	LA	Rail
WATTS BAR 1	TN	Rail
WATTS BAR 2	TN	Rail
WEST VALLEY-BWR	NY	Rail
WEST VALLEY-PWR	NY	Rail
WOLF CREEK 1	KS	Rail
YANKEE-ROWE 1	MA	Truck
ZION 1	IL	Rail
ZION 2	IL	Rail

Summary:	Number of Reactors:	68 Rail	(54%)
		57 Truck	(46%)
		125 Total	(100%)
	Amount of SF (MTU):	34,863 Rail	(55%)
		28,137 Truck	(45%)
		63,000 Total	(100%)

Table 7. Cask Systems Used in the Transportation Analysis

Cask ID	Mode	Loaded Weight	Waste Form	Packaging
Waste Generators to MRS or Repository:				
R1	Rail	100 Tons	Intact SF	Bare Assemblies
T1	Truck	28 Tons	Intact SF	Bare Assemblies
T2	Truck	40 Tons	Intact SF	Bare Assemblies
TSC	Rail	125 Tons	Intact SF	Bare Assemblies
R2	Rail	100 Tons	HLW	Canisters
MRS to Repository:				
R3	Rail	150 Tons	Intact SF	Canisters/Bare Assemblies
R4	Rail	150 Tons	Consolidated SF	Canisters
R5	Rail	133 Tons	Intact SF	Containers
R6	Rail	138 Tons	Consolidated SF	Containers
R7	Rail	125 Tons	Intact SF	Containers
R8	Rail	120 Tons	NFBC	Canisters
R9	Rail	150 Tons	HLW	Containers

3.5 GENERIC MRS LOCATIONS

The Task A Report (Ref. 2) requires that Eastern and Western MRS locations be used to examine how the location of the MRS facility might impact the transportation system for the various MRS configurations studied.

Identification of the generic MRS locations used in this analysis involved two steps. In the first step, six locations around the country were identified by dividing the geological coordinates (latitudes and longitudes) containing the continental United States into six regions of approximately equal dimensions and identifying the centroids of these regions. The coordinates of the regions and their centroids are shown in Table 11. This information is also presented in Figure 2. The second step is to average the two Eastern centroids (Fig. 2, centroids 5 and 6) to represent the generic Eastern MRS and the two Western centroids (Fig. 2, centroids 1 and 2) to represent the generic Western MRS, using the procedure below.

In TRICAM, every route (i.e., from every origin to every destination) is presented as a series of links. There is one link for every State, road type (Interstate, Primary U.S. Highway, and Secondary U.S. Highway), and population density zone (11 zones) traversed by that route. Mileage data are presented for each link.

Table 8. Cask Systems Used for Shipments From MRS to Repository

Waste Forms Shipped	Packaging	Cask Type: Cask ID	Cask Type: Mode	Cask Type: Loaded Weight
Store Only:				
Intact SF	Bare Assemblies	R3	Rail	150 Tons
Consolidate & Canister:				
Consolidated SF	Canisters	R4	Rail	150 Tons
Intact SF (5% category)*	Canisters	R3	Rail	150 Tons
NFBC	Canisters	R8	Rail	120 Tons
Containerize Intact SF:				
Intact SF	Containers	R5	Rail	133 Tons
Consolidate & Containerize:				
Consolidated SF	Containers	R6	Rail	138 Tons
Intact SF (5% category)*	Containers	R7	Rail	125 Tons
NFBC	(Transported in central voids of the 138-ton cask)			

* An underlying assumption of the MRS System Study is that 5% of SF will not be consolidated (Ref. 2, p. 11).

Table 9. Data for Casks Used in Shipments From Waste Generators to MRS/Repository

Data Element	From-Reactor Cask Type R1	T1	T2	R2
Physical Data:				
Waste Form	Intact SF	Intact SF	Intact SF	HLW
Cask Capacity(1)	21/48	3/7	5/12	5 canisters
Loaded Weight (lb)	200,000	56,000	80,000	200,000
Empty Weight (lb)	168,000	51,500	72,500	177,000
Logistics Data:				
Mode	Rail	Truck	Truck	Rail
Cask Life (yr)	20	20	20	20
Availability (days/yr)	280	310	310	310
Cask Days at Origin (cask days/shipment)	18.0(2)	2.0	2.0	37.5(3)
Cask Days at MRS/Repository (cask days/shipment)	6.0(2)	1.5	1.5	37.5(3)
Cost Data ($/cask):				
Purchase Price	$2.0 M	$800K	$1.0M	$1.8M
Annual Maintenance Cost	$125 K	$75K	$85K	$90K

(1) SF cask capacities are stated in PWR/BWR assemblies. For HLW, cask capacity is stated in canisters.

(2) Calculated for 3 casks per shipment, which is assumed to represent an average amount of fuel removed from a reactor in an annual re-fueling. See Appendix A for additional information on the 3 casks per shipment assumption. At this point, dedicated trains have been used for analytical purposes to provide a conservative cost estimating assumption. The eventual operation of the transportation for the FWMS may or may not utilize dedicated trains as opposed to other forms of rail transport. It is assumed in this report that loaded casks are shipped in dedicated trains and empty casks arrive at reactors individually, by regular train.

(3) Round-trip dedicated trains of 5 casks per train are assumed for high-level waste transport. The 5 cask shipping group reflects some reduction in shipping cost (as compared to smaller cask shipments) without severely impacting receiving facility capital cost or cask turnaround time. See Appendix A for additional information on the 5 cask per shipment assumption.

Table 10. Data for Rail Casks Used in Shipments From MRS to Repository

Data Element	From-MRS Cask Types R3	R4	R5	R6	R7	R8	R9
Physical Data:							
Waste Form	Intact SF	Consol SF	Intact SF	Consol SF	Intact SF	NFBC[e]	HLW
Cask Capacity[a]	34/80	56/140	12+16	24/72	12/24	20 drums	7
Canister/Container Type[b]	4a,4b	4a	2a	1a,1b	1c,1d	55 gal.	1a
Canisters/cask	n/a[c]	28	4	4	4	4	7
Loaded Weight (lb)	300,000	300,000	265,000	275,000	250,000	240,000	300,000
Empty Weight (lb)	250,000	225,000	225,000	225,000	225,000	225,000	250,000
Logistics Data:							
Mode	Rail	Rail	Rail	Rail	Rail	Rail	Rail
Cask Life (yr)	20	20	20	20	20	20	20
Availability (days/yr)	310	310	310	310	310	310	310
Cask Days at MRS (cask days/shipment)[d]	22.5	22.5	22.5	22.5	22.5	22.5	37.5
Cask Days at Repository (cask days/shipment)[d]	22.5	22.5	25.5	22.5	22.5	22.5	37.5
Cost Data ($/cask):							
Purchase Price	$2.75M	$2.75M	$2.75M	$2.75M	$2.75M	$2.75M	$2.75M
Annual Maintenance Cost	$150K	$150K	$150K	$150K	$150K	$150K	$150K

(a) MRS-repository rail cask capacity estimates developed/verified by Pacific Northwest Laboratory (see Ref. 2). SF cask capacities are stated in PWR/BWR assemblies. NFBC cask capacity is stated in 55-gallon drums. HLW cask capacity is stated in canisters.
(b) See Task A Report (Ref. 2) for descriptions of the canisters/containers.
(c) In the consolidate and canister cases, the 5% category of SF that cannot be canistered will be shipped in single-assembly canisters. Source: Memo from Dick Smith, Pacific Northwest Laboratory, December 9, 1988.
(d) Calculated for 5 casks per shipment. It is assumed that shipments from the MRS and defense sites to the repository are made in (round-trip) dedicated trains. See Appendix B for additional information on the multiple-cask shipment assumption.
(e) It is assumed that 2 NFBC casks are transported in the same dedicated train with 5 consolidated spent fuel 56/140 casks.

Table 11. Six Regions and Their Centroids

Region Number	Bounding Latitudes (degrees)	Bounding Longitudes (degrees)	Centroids Latitude (degrees)	Centroids Longitude (degrees)
1	39 and 48	106 and 124	43.5	115.0
2	30 and 39	106 and 124	34.5	115.0
3	39 and 48	88 and 106	43.5	97.0
4	30 and 39	88 and 106	34.5*	97.0
5	39 and 48	68 and 88	43.0*	78.0
6	30 and 39	68 and 88	35.0	78.0

(*) These latitudes were adjusted slightly to ensure that the locations fall within U.S. land area.

Thus, each link represents a highway type, with the population density within the given State traversed. In calculating route data for the generic Eastern or Western MRS, route data from the two corresponding centroids are averaged--i.e., route data for the two Eastern centroids, 5 and 6, are averaged for a generic Eastern MRS, and route data for the two Western centroids, 1 and 2, are averaged for the generic Western MRS. Thus, a composite set of route data is created representing an average of miles, with population densities, and, where applicable, highway types between the respective centroids. Accordingly, the generic Eastern MRS and the generic Western MRS do not necessarily represent any one location. Detailed examples of the averaging method used in defining the two generic MRS locations are provided in Appendix B.

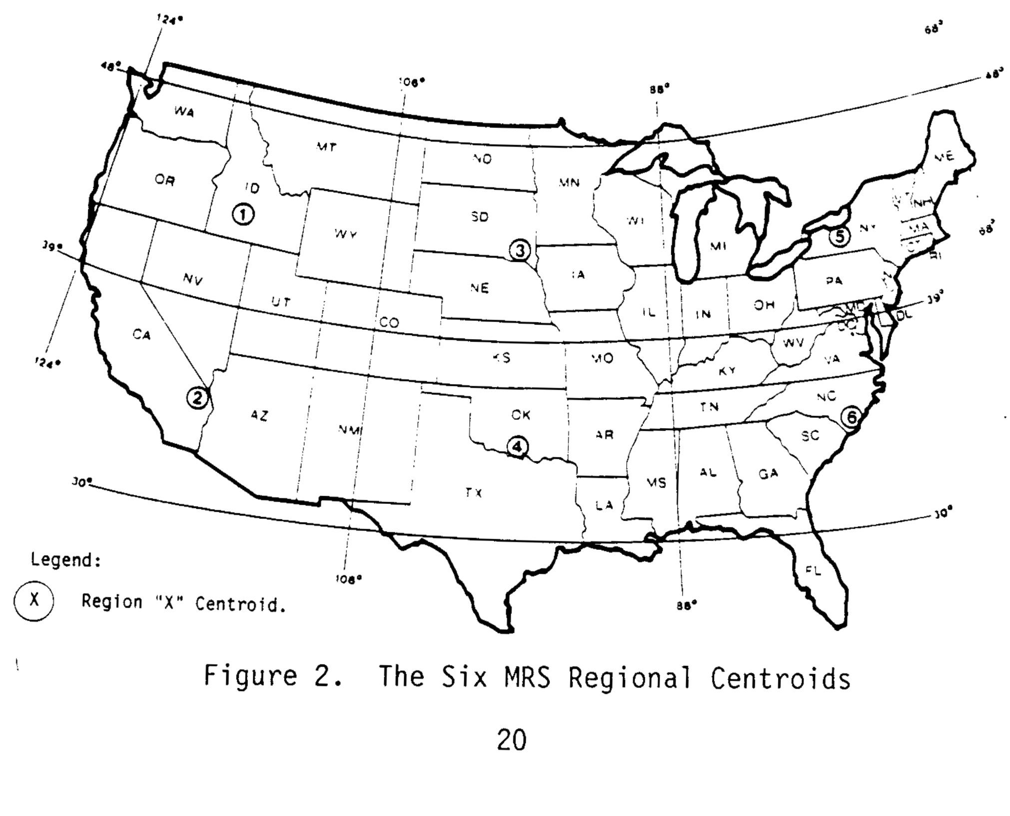

Figure 2. The Six MRS Regional Centroids

4.0 RESULTS

4.1 SPENT FUEL CASES

The results of the eleven spent fuel (SF) cases are presented in this chapter.[1] Additional results from sensitivity analysis of SF transportation are given in Chapter 5. The summary results--cost, dose, number of shipments, shipment-miles, cask-miles, and MTU-miles--are supported by a series of detailed tables, Tables 12 through 20, organized by transportation link (reactors to MRS, by mode and MRS to repository), to aid in interpreting the results. Information on cask days in transit, shipment days in transit, and average number of in-transit shipments per day for each case is given in Table 14. The summary information presented in Tables 12 and 14 is disaggregated by mode and transportation link in Tables 15 through 20.

Table 12 shows the summary transportation cost and dose results for the eleven SF cases, organized by MRS packaging function, MRS location, and Western fuel strategy. The transportation cost for the No-MRS case--the base case for comparison purposes--is $832 million. MRS packaging function is an important determinant of transportation cost. Regardless of MRS location, the least-cost option is where the MRS consolidates and canisters the SF ($634-862 million), followed by a store-only MRS ($741-896 million). The least attractive MRS option from the transportation cost perspective is an MRS that containerizes intact SF ($996-1,120 million). This results because in the latter case (containerization of intact fuel), cask capacity is reduced, thus requiring more shipments.

The transportation costs for an MRS that consolidates and containerizes SF fall between $942 and $965 million, depending on location. The consolidate-and-canister case allows for very efficient loading of spent fuel (approximately 26 MTU per cask). The two casks carrying non-fuel-bearing components (NFBC) travel in the same dedicated train with the five SF casks. A shipping charge is added for the two NFBC casks, but they do not incur a separate dedicated rail charge. As a result, the consolidation at MRS increases the MTU carried in each shipment without significantly affecting the per shipment cost. The cask carrying intact elements without containers (store-only MRS), is the next most efficient, with a capacity of about 15 MTU per cask.

The cases that involve carrying repository containers incur a transportation cost penalty due to the inefficiency of the repository container when used in transportation casks. The repository container is a cylinder with a larger diameter than the square boxes of fuel pins transported in the consolidate-and-canister case or the intact fuel elements carried in the store-only case. The large cylindrical repository containers do not pack efficiently into the shipping casks, resulting in reduced cask capacity. A cask carrying intact fuel in repository containers has a double penalty in that the intact fuel does not efficiently use the space inside the container. Also, the containers do not efficiently fit into the shipping cask. This results in lower capacity for the

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[1]It should be noted that the cost and doses generated for the store only MRS assume all fuel destined for the first repository (63,000 MTU) would be processed by the MRS. If a lesser amount were shipped to a store only MRS, cost and dose results would change.

Table 12. Summary of Life-Cycle Transportation Costs and Doses for 24-Year Shipping Campaign (Spent Fuel Cases)

Cases	Total Cost ($million)	Total Dose (1000 person-rem)
No-MRS:	832	2.6
Store Only:		
Eastern MRS	835	1.6
Eastern MRS/ Western Strategy	741	1.5
Western MRS	896	2.5
Consolidate & Canister:		
Eastern MRS	718	1.5
Eastern MRS/ Western Strategy	634	1.4
Western MRS	862	2.5
Containerize Intact SF:		
Eastern MRS	1,120	1.9
Western MRS	996	2.6
Consolidate & Containerize:		
Eastern MRS	965	1.8
Western MRS	942	2.5

Table 13. Summary of Life-Cycle Transportation Cost and Dose by MRS Location for 24-Year Shipping Campaign (Spent Fuel Cases)

	MRS Location			
	East		West	
	Cost ($million)	Dose (1000 p-rem)	Cost ($million)	Dose (1000 p-rem)
Consolidate & Canister: Western Strategy	634	1.4	--	--
Consolidate & Canister:	718	1.5	862	2.5
Store Only: Western Strategy	741	1.5	--	--
Store Only:	835	1.6	896	2.5
Consolidate & Containerize:	965	1.8	942	2.5
Containerize Intact SF:	1,120	1.9	996	2.6

Table 14. Measures of Life-Cycle Transportation Impacts for 24-Year Shipping Campaign (Spent Fuel Cases)

Cases	Total Number of Shipments	Total Shipment Miles (1,000s)	Total Cask Miles (1,000s)	Total MTU Miles (1,000s)	Total Cask Days In Transit	Total Shipment Days In Transit	Total Average Shipments Per Day
No-MRS:	23,836	54,235	60,685	148,685	65,627	58,762	6.7
Store Only:							
Eastern MRS	24,649	25,951	37,777	242,403	42,033	28,794	3.6
Eastern MRS/ Western Strategy	24,635	20,151	30,893	216,617	34,913	22,686	2.8
Western MRS	24,649	49,847	57,464	173,591	65,139	54,522	6.8
Consolidate & Canister:							
Eastern MRS*	24,336	25,041	33,257	242,403	37,539	27,895	3.5
Eastern MRS/ Western Strategy*	24,348	19,321	26,673	216,617	30,804	21,865	2.7
Western MRS*	24,336	49,647	56,484	173,591	63,139	54,122	6.7
Containerize Intact SF:							
Eastern MRS	25,308	27,851	47,277	242,403	51,482	30,683	3.8
Western MRS	25,308	50,257	59,534	173,591	69,342	55,362	6.9
Consolidate & Containerize:							
Eastern MRS	24,959	26,841	42,237	242,403	46,467	29,680	3.7
Western MRS	24,959	50,042	58,439	173,591	67,111	54,916	6.8

* Includes only spent fuel casks. The two NFBC casks per spent fuel shipment from the MRS are not included.

Table 15. Life-Cycle Cost by Transportation Link ($millions) for 24-Year Shipping Campaign (Spent Fuel Cases)

Case	From Reactor to MRS/Repository		From MRS to Repository
	Rail	Truck	Rail
No-MRS:	260	572	--
Store Only:			
Eastern MRS	135	326	374
Eastern MRS/ Western Strategy	126	273	342
Western MRS	241	524	131
Consolidate & Canister:			
Eastern MRS	135	326	257
Eastern MRS/ Western Strategy	126	273	235
Western MRS	241	524	97
Containerize Intact SF:			
Eastern MRS	135	326	659
Western MRS	241	524	231
Consolidate & Containerize:			
Eastern MRS	135	326	504
Western MRS	241	524	177

cask in the containerize intact case (8.6 MTU per cask) than in other cases, and thus higher costs. The consolidate-and-containerize case increases the container capacity by loading it with consolidated fuel pins and compacted NFBC, so the cask capacity increases (12 MTU per cask) in comparison to the containerize-intact case. However, capacity is still lower and costs higher than for the store-only or consolidate-and-canister cases.

With the store-only and consolidate/canister packaging cases, the generic Eastern MRS is less expensive than the generic Western MRS because of the reduced shipment-miles. The Western strategy further reduces the shipment-miles and enhances the Eastern MRS advantage. However, in the other two cases that involve containerization, the Western MRS is less costly because the total shipment-mile reduction is not adequate to compensate for the three-fold increase of the cross-country shipments from the Eastern MRS to the repository when compared to the noncontainerizing packaging options. This increase in the number of shipments is a result of inefficient packaging of the disposal containers in the transportation casks.

For total transportation dose, MRS location is the dominant factor because location affects shipping distance and the distance traveled (i.e., cask-miles) directly impacts the total number of individuals exposed. Dose estimates for the cases where the MRS is located in the East fall within a narrow band of 1.4 to 1.9 thousand person-rem over the operational life of the system. The no-MRS

Table 16. Dose by Transportation Link (1,000s person-rem) for 24-Year Shipping Campaign (Spent Fuel Cases)

Case	From Reactor to MRS/Repository		From MRS to Repository
	Rail	Truck	Rail
No-MRS:	0.7	1.9	--
Store Only:			
Eastern MRS	0.4	0.9	0.3
Eastern MRS/ Western Strategy	0.4	0.8	0.3
Western MRS	0.7	1.7	0.1
Consolidate & Canister:			
Eastern MRS	0.4	0.9	0.2
Eastern MRS/ Western Strategy	0.4	0.8	0.2
Western MRS	0.7	1.7	0.1
Containerize Intact SF:			
Eastern MRS	0.4	0.9	0.6
Western MRS	0.7	1.7	0.2
Consolidate & Containerize:			
Eastern MRS	0.4	0.9	0.5
Western MRS	0.7	1.7	0.1

and Western MRS options also fall within a narrow, but higher, band (2.5 to 2.6 thousand person-rem). The dose is related to cask-miles traveled. The higher dose for the no-MRS and Western MRS options is explained by the increased cask-miles traveled. These two cases require about 60 million cask-miles each, whereas the various Eastern MRS cases require about 35 million cask-miles each. All casks are assumed to operate at the regulatory limit (10 mrem per hour at 2 meters) regardless of design or payload, and the dose per cask mile is independent of the cask type.

Table 13 addresses the question of whether packaging function has an effect on the transportation cost with respect to the Eastern or Western MRS location. If the MRS is to be located in the East, then the choice of packaging function can noticeably impact transportation costs ranging from an MRS that consolidates and canisters ($634 million) to one that containerizes intact spent fuel ($1,120 million). Thus, when packaging functions increase MRS cask capacity, the number of shipment-miles is reduced particularly in the East where MRS casks are shipped across the country. Alternatively, if an MRS is to be located in the West, then the choice of packaging function is by comparison less significant in terms of transportation cost ($862-996 million). Note that, in general, the use of the Western strategy with an Eastern MRS results in additional cost savings of less than $100 million. The Western strategy reduces cost by eliminating transportation of spent fuel from Western reactors

Table 17. Number of Shipments by Transportation Link for 24-Year Shipping Campaign (Spent Fuel Cases)

	From Reactor to MRS		From Reactor to Repository		From MRS to Repository
	Rail	Truck	Rail	Truck	Rail
No-MRS:	--	--	1,286	22,550	--
Store Only:					
Eastern MRS	1,286	22,550	--	--	813
Eastern MRS/ Western Strategy	1,204	19,894	80	2,713	744
Western MRS	1,286	22,550	--	--	813
Consolidate & Canister:					
Eastern MRS	1,286	22,550	--	--	500
Eastern MRS/ Western Strategy	1,204	19,894	80	2,713	457
Western MRS	1,286	22,550	--	--	500
Containerize Intact SF:					
Eastern MRS	1,286	22,550	--	--	1,472
Western MRS	1,286	22,550	--	--	1,472
Consolidate & Containerize:					
Eastern MRS	1,286	22,550	--	--	1,123
Western MRS	1,286	22,550	--	--	1,123

across the country to the MRS located in the East and then return-shipping the spent fuel back across the country from the MRS to the repository.

Table 14 shows the effects of transportation packaging function and MRS location with respect to the following seven categories: number of shipments, shipment-miles, cask-miles, MTU-miles, cask days in transit, shipment days in transit, and the average number of shipments in transit per day. The number of shipments is the total MTU transported divided by cask capacity and the number of casks per shipment. A fixed quantity of fuel (63,000 MTU) is transported in all 11 cases, and thus, variations in the total number of shipments are due to the choice of an MRS packaging function. As shown in Table 17, the number of from-reactor shipments is approximately the same for all MRS cases (rail 1,286 and truck 22,550), and the number of from-MRS shipments ranges from 457 to 1,472. For the MRS-system options, the total number of shipments varies from 24.3 to 25.3 thousand, and for the no-MRS option, total shipments is about 24 thousand.

Total number of shipment-miles reported in Table 14 is the number of shipments from each facility multiplied by the one-way distance from that facility to an MRS/repository. Variations in total shipment-miles are due to MRS packaging function, MRS location, and the use of a Western strategy. The

Table 18. Shipment-Miles by Transportation Link (1,000s) for 24-Year Shipping Campaign (Spent Fuel Cases)

	From Reactor to MRS		From Reactor to Repository		From MRS to Repository
	Rail	Truck	Rail	Truck	Rail
No-MRS:	--	--	3,095	51,140	--
Store Only:					
Eastern MRS	1,218	22,383	--	--	2,350
Eastern MRS/ Western Strategy	1,011	15,234	70	1,686	2,150
Western MRS	2,788	46,549	--	--	510
Consolidate & Canister:					
Eastern MRS	1,218	22,383	--	--	1,440
Eastern MRS/ Western Strategy	1,011	15,234	70	1,686	1,320
Western MRS	2,788	46,549	--	--	310
Containerize Intact SF:					
Eastern MRS	1,218	22,383	--	--	4,250
Western MRS	2,788	46,549	--	--	920
Consolidate & Containerize:					
Eastern MRS	1,218	22,383	--	--	3,240
Western MRS	2,788	46,549	--	--	705

no-MRS and the Western-MRS options result in relatively similar shipment-miles (54 million and about 52 million, respectively).

For the MRS cases, location is the most dominant factor in determining total shipment-miles. As seen in Table 18, from-reactor shipment-miles are the same for all Eastern MRS/no Western strategy cases (about 1 million for rail and 22 million for truck), for Eastern MRS/Western strategy cases (about 1 million for rail and 15 million for truck), and for Western MRS cases (about 3 million for rail and 46 million for truck). This is expected because the packaging function remains the same for all reactor-to-MRS shipments under any MRS packaging scenario. Estimates of shipment-miles for from-MRS transport constitute only about 1% to 7% of the total shipment-miles for all 11 SF cases reported in Table 14. From-reactor shipment-miles are a function of MRS location and application or nonapplication of a Western strategy. The MRS packaging function does not affect shipments from reactors to the MRS. The transfer of fuel from rail or truck casks to the larger capacity MRS casks greatly reduces the number of shipments from the MRS, thus reducing the contribution of MRS shipments to total shipment-miles.

Total cask-miles is the number of cask loads shipped from each facility multiplied by the one-way distance from that facility to an MRS/repository. Similar to shipment-miles, total cask-miles varies with MRS location. Total cask-miles for the no-MRS and Western-MRS cases are relatively equivalent

Table 19. Cask-Miles by Transportation Link (1,000s) for 24-Year Shipping Campaign (Spent Fuel Cases)

	From Reactor to MRS		From Reactor to Repository		From MRS to Repository
	Rail	Truck	Rail	Truck	Rail
No-MRS:	--	--	9,286	51,399	--
Store Only:					
Eastern MRS	3,654	22,383	--	--	11,740
Eastern MRS/ Western Strategy	3,033	15,234	211	1,685	10,730
Western MRS	8,365	46,549	--	--	2,550
Consolidate & Canister:					
Eastern MRS*	3,654	22,383	--	--	7,220
Eastern MRS/ Western Strategy*	3,033	15,234	211	1,685	6,600
Western MRS*	8,365	46,549	--	--	1,570
Containerize Intact SF:					
Eastern MRS	3,654	22,383	--	--	21,240
Western MRS	8,365	46,549	--	--	4,620
Consolidate & Containerize:					
Eastern MRS	3,654	22,383	--	--	16,200
Western MRS	8,365	46,549	--	--	3,525

* Includes only spent fuel casks. The two NFBC casks per shipment are not included.

60 million and 57 to 60 million, respectively) and serve as a proxy to the total dose estimates reported in Table 12. Again, it can be seen that from-reactor transport measured in cask-miles is strictly a function of MRS location and Western strategy. As shown in Table 19, variations in cask-miles from an MRS (like variations in shipment-miles) are due to packaging function and MRS location. For Eastern MRS-to-repository shipments, the number of cask-miles is between 22% and 45% of the total cask-miles for all 11 SF cases.

The MTU-miles reported in Table 14 are calculated as the quantity of fuel shipped from each facility multiplied by the one-way distance from that facility to an MRS/repository. The detailed estimates of MTU-miles presented in Table 18 indicate that MRS location and Western strategy are the only two sources of variation in MTU-miles.

The calculation of cask days in transit is reported in Table 14. Cask days in transit is calculated by multiplying the number of cask loads required to transport an annual given amount of waste by the number of days that the loaded cask is in transit. For from-reactor transportation, cask days in transit is calculated on an annual basis for each reactor and then totaled.

Table 20. MTU-Miles by Transportation Link (1,000s) for 24-Year Shipping Campaign (Spent Fuel Cases)

	From Reactor to MRS		From Reactor to Repository		From MRS to Repository
	Rail	Truck	Rail	Truck	Rail
No-MRS:	--	--	84,032	64,653	--
Store Only:					
Eastern MRS	33,082	27,525	--	--	181,796
Eastern MRS/ Western Strategy	27,560	18,865	1,909	2,070	166,213
Western MRS	75,564	58,462	--	--	39,565
Consolidate & Canister:					
Eastern MRS	33,082	27,525	--	--	181,796
Eastern MRS/ Western Strategy	27,560	18,865	1,909	2,070	166,213
Western MRS	75,564	58,462	--	--	39,565
Containerize Intact SF:					
Eastern MRS	33,082	27,525	--	--	181,796
Western MRS	75,564	58,462	--	--	39,565
Consolidate & Containerize:					
Eastern MRS	33,082	27,525	--	--	181,796
Western MRS	75,564	58,462	--	--	39,565

For MRS-to-repository transportation, estimates are calculated on an annual basis and then summed over the 24 years of MRS-to-repository shipping.

The number of shipment days in transit, presented in Table 14, is calculated by dividing the cask days in transit by the number of casks per shipment for each transportation link. The average number of shipments in transit for a typical day during the spent fuel transportation campaign, also shown in Table 14, is calculated by dividing the total number of shipments by the total number of days in the shipping campaign. As expected, the average number of shipments in transit per day for an Eastern MRS system is approximately half of the corresponding number of shipments in transit for the no-MRS or Western MRS system. A similar pattern can be seen for shipment-days in transit and cask-days in transit, following a pattern that is also seen in estimates of total dose. This reflects the elimination of truck and 100-ton rail cask shipments from reactors across the country to the repository or Western MRS.

4.2 HIGH-LEVEL WASTE CASES

The results of the transportation analysis of HLW cases are presented in this section. As noted previously, three cases are analyzed in this study, representing the three transportation networks involved:

- HLW shipped through an Eastern MRS
- HLW shipped through a Western MRS
- HLW shipped directly to the repository.

The transportation impacts calculated and presented in Table 21 for HLW cases include number of shipments, shipment-miles, cask-miles, MTU-miles, and cost. Transportation dose is not included because HLW unit-risk factors have not yet been generated in a manner consistent with the SF unit-risk factors used in this study.

When HLW is shipped through the MRS, the number of HLW shipments increases because each shipment to the repository is broken down into two shorter shipments, one from the HLW site to the MRS, and one from the MRS to the repository. Because of the higher capacity of the from-MRS HLW cask, however, the increase is less than two-fold. This pattern holds for the other measures of transportation activity--shipment-miles, cask-miles, and MTU-miles--as well as for cost.

The controlling factor for HLW impacts is the diversity of location of the HLW sites relative to the generic Eastern MRS, the generic Western MRS, and the repository. An Eastern MRS noticeably increases the transportation activity, and consequently the cost, because it causes over half of the HLW (54%) which is generated in the West, to be shipped across the country to the MRS in the east, and then again to be hauled back to the repository in the west. Table 22, which shows the distances from each of the four HLW sites to the repository directly and through the generic Eastern and Western MRSs, illustrates this point. The mileage from the two Western HLW sites (Idaho Chemical Processing Plant and Hanford) through the Eastern MRS to the repository is five to seven times higher than the direct distance to the repository. This mileage increase, combined with the aforementioned increase in the number of shipments results in doubling of the shipment-miles and costs of transportation, see Table 21, when an Eastern MRS is used. The effects to shipment-miles and cost are smaller because the mileage increase is smaller.

The net effect is that the cost for transportation of HLW is lowest for a FWMS without an MRS, followed by a FWMS with an MRS in the West.

4.3 COMPARISON WITH PREVIOUS DOE ANALYSES

An evaluation of the MRS was completed by the DOE in November 1987 (Ref. 7). The purpose was to provide additional information to address issues raised by the General Accounting Office and others "concerning the need for an MRS facility and the feasibility of achieving comparable performance for the overall waste management system without an MRS facility." Sections 4.3.1 and 4.3.2 provide a comparison between this earlier study and the transportation results presented above. The comparison is limited to spent fuel results only, as the previous study did not evaluate HLW.

4.3.1 No-MRS System

The November 1987 report examined a Reference No-MRS system and five Alternative No-MRS systems. The alternative systems explored scenarios with different cask capacity assumptions as well as scenarios with varying amounts

Table 21. Transportation Life-Cycle Cost and Measures of Activity - High-Level Waste Cases

	Number of Shipments	Shipment Miles (1,000s)	Cask Miles (1,000s)	MTU Miles (1,000s)	Total Cost ($million)
Shipments to Repository	**560**	**1,076**	**5,378**	**13,444**	**172**
Shipments through Eastern MRS:	**960**	**2,028**	**10,140**	**31,122**	**343**
To Eastern MRS	560	874	4,369	10,922	148
MRS to Repository	400	1,154	5,771	20,200	195
Shipments through Western MRS:	**960**	**1,238**	**6,191**	**16,734**	**237**
To Western MRS	560	987	4,936	12,339	161
MRS to Repository	400	251	1,256	4,396	76

Table 22. Distances (Miles) From High-Level Waste Sites

	Distance to Repository		
HLW Site	Direct to Repository	Through Generic Eastern MRS	Through Generic Western MRS
West Valley	2,652	3,382	3,075
Savannah River	2,763	3,618	3,295
Idaho Chemical Processing Plant	756	5,339	1,213
Hanford	1,302	5,885	1,622

of at-reactor consolidation. However, the varying amounts of at-reactor consolidation are beyond the scope of the present analysis; comparison with the present analysis is limited to the Reference No-MRS system.

The previous study reported a total of 39,300 (Ref. 6, Table A-4.6) shipments, comprising 33,500 shipments by truck and 5,800 shipments by rail. This compares with 23,836 shipments in the present report (Table 14), comprising 22,550 truck shipments and 1,286 rail shipments (Table 17). The following factors explain the differences in number of shipments:

- Total quantity of SF shipped in the previous study was 65,360 MTU, compared to 63,000 MTU in the present analysis.
- The capacity of from-reactor rail casks was assumed to be 14 PWR or 36 BWR assemblies, compared to 21 PWR or 48 BWR assumed in the present work.
- The capacity of from-reactor truck casks was assumed to be 2 PWR or 5 BWR assemblies, compared to 3 PWR or 7 BWR assumed in the present work.
- The previous study assumed that all from-reactor shipments are made as single cask/vehicle units in general freight service whereas in the present work, it is assumed[1] that rail shipments from reactors are made in dedicated trains of three casks.

[1] Appendix A addresses the assumption of 3 casks per dedicated train and explains the cost assumptions/algorithms. This assumption provides a conservative estimate of transportation costs for the FWMS. The eventual use or nonuse of dedicated trains to transport NWPA waste will be determined as a result of cost, risk, logistical, and institutional analyses to be performed later.

rail shipments from reactors are made in dedicated trains of three casks.

The previous study reported 67 million shipment-miles by truck (Ref. 7, Table A-4.6), compared to 51 million in the present work (Table 18). This difference is accounted for by the different capacity and dedicated train assumptions noted above. Rail shipment-miles were reported at 13 million, compared with 3 million in the present study. (Note that in the previous study, shipment-miles are synonymous with cask-miles.) This difference is explained by the larger capacity rail casks and the assumption of three casks per shipment in the present work, as noted above. In addition, distance calculations in the previous study were made on a "point-to-point basis using the methodology developed for the WASTES program" (Ref. 6, Sec. A.3, p. A-6). In the present study, distances were generated using the HIGHWAY and INTERLINE computer programs (Refs. 4 and 5). The difference in these methods may explain some variation in the results, although it cannot be demonstrated on the basis of information available from the previous report.

The total transportation costs were reported in the previous study at $1,120 million, compared to $832 million in the present analysis, reflecting the differences in assumptions noted above.

4.3.2 MRS System

The Reference MRS System of the previous study (Ref. 6, Table A-4.11) was used as the basis for comparison with this report. That study used the same differing assumptions for the from-reactor shipments that are listed in the preceding discussion. Differences in from-reactor shipment results for the MRS System case have been addressed in the preceding discussion. Both analyses assumed that the MRS consolidates and canisters the spent fuel. The results for from-MRS shipments are similar in that both studies report around 500 shipments from the MRS. However, in comparing the two studies, the from-MRS shipment-miles are noticeably different (the previous study reports 1 million shipment-miles and this study indicates about 1.4 million shipment-miles for transportation from the MRS to repository). This difference is attributable to different estimates of rail distance from the MRS to the repository. This report uses a generic Eastern MRS with a rail distance of 2,885 miles to the repository, whereas the previous study used the Clinch River MRS site near Oak Ridge, Tennessee. The previous study reported a total transportation cost of $893 million, compared to $718 million in this report for the generic Eastern location.

5.0 SENSITIVITY ANALYSES

Four sets of sensitivity analyses were conducted for this study to provide additional insights into the transportation impacts reported in earlier sections of this report. The purpose of the first sensitivity is to further examine the impact of MRS location on spent nuclear fuel transportation, using the six regional centroids (see Figure 2) as hypothetical MRS locations. The second sensitivity analysis further addresses this issue by examining the transportation costs associated with an analytically selected MRS site which approximates a minimum shipment-mile location. The third sensitivity examines the impact of replacing the legal-weight truck (LWT) with overweight truck (OWT) casks for shipments from reactors. The fourth sensitivity analysis examines whether variations in spent fuel transportation cask capacities affect the relative comparison of MRS packaging and location options.

5.1 SENSITIVITY ANALYSIS - SIX MRS CENTROID LOCATIONS

Transportation impacts were calculated for the six hypothetical centroids identified in Figure 2 in Chapter 4. Each centroid was evaluated using the four MRS packaging functions listed below, resulting in a total of 24 cases:

- Store only
- Consolidate and canister
- Containerize intact spent fuel
- Consolidate and containerize.

The waste acceptance schedule depicted in Table 3 (in Chapter 2) was used for this sensitivity analysis. The resulting estimates of cost, dose, shipment-miles, cask-miles, and MTU-miles are presented in Tables 23 through 29.

It can be observed from Table 23 that the largest cost difference within a specific packaging function occurs in the case of a MRS that containerizes intact spent fuel. In this case, the cost difference is $185 million between Centroid 2 ($962 million) and Centroid 6 ($1,147 million). In general, the Western centroids (Centroids 1 and 2) have higher total dose in the range of 2,400 to 2,600 person-rem. By comparison, the two Eastern centroids (Centroids 5 and 6) exhibit total doses in the range of 1,500 to 2,000 person-rem. The central centroids fall between these extremes, as expected. These differences, particularly between Eastern and Western centroids, result primarily because of the large increase in shipment-miles traveled by Western fuel traveling to the Eastern MRS site and then back to the Western repository.

Table 24 presents the results for total shipment-miles, cask-miles, and MTU-miles. Note that shipment numbers are not reported in this table because they are identical to those reported earlier in Table 14. Note also that, as expected, MTU-miles vary only with the centroid location and not with packaging function. The Western centroids (Centroids 1 and 2) have higher cask-miles and shipment-miles than the Eastern centroids, as would be expected, because the smaller capacity from-reactor casks travel over longer distances.

These data are also presented at the disaggregated level, i.e., by transportation link, in Tables 25 through 29.

Table 23. Summary of Transportation Cost and Dose by MRS Location - Sensitivity Cases - Six MRS Centroids

Cases	Total Cost ($millions)	Total Dose (1000 person-rem)
Store Only:		
Centroid 1	909	2.4
Centroid 2	882	2.6
Centroid 3	780	1.9
Centroid 4	816	1.8
Centroid 5	821	1.6
Centroid 6	847	1.7
Consolidate & Canister:		
Centroid 1	866	2.4
Centroid 2	856	2.6
Centroid 3	706	1.8
Centroid 4	735	1.7
Centroid 5	710	1.5
Centroid 6	724	1.6
Containerize Intact SF:		
Centroid 1	1,027	2.5
Centroid 2	962	2.6
Centroid 3	970	2.1
Centroid 4	1,021	2.0
Centroid 5	1,092	1.9
Centroid 6	1,147	2.0
Consolidate & Containerize:		
Centroid 1	963	2.5
Centroid 2	919	2.6
Centroid 3	867	2.0
Centroid 4	910	1.9
Centroid 5	945	1.8
Centroid 6	985	1.9

Table 24. Measures of Transportation Activity - Sensitivity Cases - Six MRS Centroids

Cases	Shipment Miles (1000's)	Cask Miles (1000's)	MTU Miles (1000's)
Store Only:			
Centroid 1	49,822	57,923	184,042
Centroid 2	49,876	57,015	163,145
Centroid 3	32,272	40,806	184,592
Centroid 4	31,876	41,273	198,365
Centroid 5	26,279	37,313	229,335
Centroid 6	25,619	38,236	255,488
Consolidate & Canister:			
Centroid 1	49,560	56,612	184,042
Centroid 2	49,745	56,358	163,145
Centroid 3	31,742	38,159	184,592
Centroid 4	31,290	38,342	198,365
Centroid 5	25,433	33,085	229,335
Centroid 6	24,657	33,424	255,488
Containerize Intact SF:			
Centroid 1	50,373	60,679	184,042
Centroid 2	50,152	58,395	163,145
Centroid 3	33,385	46,370	184,592
Centroid 4	33,109	47,436	198,365
Centroid 5	28,056	46,201	229,335
Centroid 6	27,642	48,352	255,488
Consolidate & Containerize:			
Centroid 1	50,081	59,216	184,042
Centroid 2	50,005	57,663	163,145
Centroid 3	32,794	43,417	184,592
Centroid 4	32,455	44,165	198,365
Centroid 5	27,113	41,484	229,335
Centroid 6	26,658	42,983	255,488

Table 25. Cost by Transportation Link ($millions) - Sensitivity Cases - Six MRS Centroids

Case	From Reactor to MRS		From MRS to Repository
	Rail	Truck	Rail
Store Only:			
Centroid 1	234	519	156
Centroid 2	247	530	105
Centroid 3	156	374	250
Centroid 4	166	381	269
Centroid 5	128	338	355
Centroid 6	141	314	392
Consolidate & Canister:			
Centroid 1	234	519	113
Centroid 2	247	530	79
Centroid 3	156	374	176
Centroid 4	166	381	188
Centroid 5	128	338	244
Centroid 6	141	314	269
Containerize Intact:			
Centroid 1	234	519	274
Centroid 2	247	530	185
Centroid 3	156	374	440
Centroid 4	166	381	474
Centroid 5	128	338	626
Centroid 6	141	314	692
Consolidate & Containerize:			
Centroid 1	234	519	210
Centroid 2	247	530	142
Centroid 3	156	374	337
Centroid 4	166	381	363
Centroid 5	128	338	479
Centroid 6	141	314	530

Table 26. Dose by Transportation Link (1,000s person-rem) - Sensitivity Cases - Six MRS Centroids

Case	From Reactor to MRS Rail	From Reactor to MRS Truck	From MRS to Repository Rail
Store Only:			
Centroid 1	0.7	1.6	0.1
Centroid 2	0.7	1.8	0.1
Centroid 3	0.5	1.1	0.2
Centroid 4	0.5	1.1	0.2
Centroid 5	0.4	0.9	0.3
Centroid 6	0.4	0.9	0.3
Consolidate & Canister:			
Centroid 1	0.7	1.6	0.8
Centroid 2	0.7	1.8	0.1
Centroid 3	0.5	1.1	0.1
Centroid 4	0.5	1.1	0.1
Centroid 5	0.4	0.9	0.2
Centroid 6	0.4	0.9	0.2
Containerize Intact:			
Centroid 1	0.7	1.6	0.2
Centroid 2	0.7	1.8	0.1
Centroid 3	0.5	1.1	0.4
Centroid 4	0.5	1.1	0.4
Centroid 5	0.4	0.9	0.6
Centroid 6	0.4	0.9	0.6
Consolidate & Containerize:			
Centroid 1	0.7	1.6	0.2
Centroid 2	0.7	1.8	0.1
Centroid 3	0.5	1.1	0.3
Centroid 4	0.5	1.1	0.3
Centroid 5	0.4	0.9	0.5
Centroid 6	0.4	0.9	0.5

Table 27. Shipment-Miles by Transportation Link (1,000s)
Sensitivity Cases - Six MRS Centroids

Case	From Reactor to MRS		From MRS to Repository
	Rail	Truck	Rail
Store Only:			
Centroid 1	2,689	46,452	681
Centroid 2	2,888	46,647	341
Centroid 3	1,518	29,379	1,375
Centroid 4	1,653	28,701	1,522
Centroid 5	1,125	22,958	2,196
Centroid 6	1,311	21,809	2,499
Consolidate & Canister:			
Centroid 1	2,689	46,452	419
Centroid 2	2,888	46,647	210
Centroid 3	1,518	29,379	845
Centroid 4	1,653	28,701	936
Centroid 5	1,125	22,958	1,350
Centroid 6	1,311	21,809	1,537
Containerize Intact SF:			
Centroid 1	2,689	46,452	1,232
Centroid 2	2,888	46,647	617
Centroid 3	1,518	29,379	2,488
Centroid 4	1,653	28,701	2,755
Centroid 5	1,125	22,958	3,973
Centroid 6	1,311	21,809	4,522
Consolidate & Containerize:			
Centroid 1	2,689	46,452	940
Centroid 2	2,888	46,647	470
Centroid 3	1,518	29,379	1,897
Centroid 4	1,653	28,701	2,101
Centroid 5	1,125	22,958	3,030
Centroid 6	1,311	21,809	3,448

Table 28. Cask-Miles by Transportation Link (1,000s)
Sensitivity Cases - Six MRS Centroids

Case	From Reactor to MRS		From MRS to Repository
	Rail	Truck	Rail
Store Only:			
Centroid 1	8,066	46,452	3,405
Centroid 2	8,664	46,647	1,704
Centroid 3	4,553	29,379	6,874
Centroid 4	4,960	28,701	7,612
Centroid 5	3,376	22,958	10,979
Centroid 6	3,932	21,809	12,495
Consolidate & Canister:			
Centroid 1*	8,066	46,452	2,094
Centroid 2*	8,664	46,647	1,047
Centroid 3*	4,553	29,379	4,227
Centroid 4*	4,960	28,701	4,681
Centroid 5*	3,376	22,958	6,751
Centroid 6*	3,932	21,809	7,683
Containerize Intact SF:			
Centroid 1	8,066	46,452	6,161
Centroid 2	8,664	46,647	3,084
Centroid 3	4,553	29,379	12,438
Centroid 4	4,960	28,701	13,775
Centroid 5	3,376	22,958	19,867
Centroid 6	3,932	21,809	22,611
Consolidate & Containerize:			
Centroid 1	8,066	46,452	4,698
Centroid 2	8,664	46,647	2,352
Centroid 3	4,553	29,379	9,485
Centroid 4	4,960	28,701	10,504
Centroid 5	3,376	22,958	15,150
Centroid 6	3,932	21,809	17,242

*Includes only spent fuel casks. The two NFBC casks per shipment from the MRS are not included.

Table 29. MTU-Miles by Transportation Link (1,000s)
Sensitivity Cases - Six MRS Centroids

Case	From Reactor to MRS Rail	From Reactor to MRS Truck	From MRS to Repository Rail
Store Only:			
Centroid 1	72,918	58,386	52,738
Centroid 2	78,209	58,539	26,397
Centroid 3	41,278	36.842	106,472
Centroid 4	44,641	35,811	117,913
Centroid 5	30,810	28.467	170,058
Centroid 6	35,354	26,582	193,552
Consolidate & Canister:			
Centroid 1	72,918	58,386	52,738
Centroid 2	78,209	58,539	26,397
Centroid 3	41,278	36,842	106,472
Centroid 4	44,641	35,811	117,913
Centroid 5	30,810	28,467	170,058
Centroid 6	35,354	26,582	193,552
Containerize Intact SF:			
Centroid 1	72,918	58,386	52,738
Centroid 2	78,209	58,539	26,397
Centroid 3	41,278	36,842	106,472
Centroid 4	44,641	35,811	117,913
Centroid 5	30,810	28,467	170,058
Centroid 6	35,354	26,582	193,552
Consolidate & Containerize:			
Centroid 1	72,918	58,386	52,738
Centroid 2	78,209	58,539	26,397
Centroid 3	41,278	36,842	106,472
Centroid 4	44,641	35,811	117,913
Centroid 5	30,810	28,467	170,058
Centroid 6	35,354	26,582	193,552

5.2 SENSITIVITY ANALYSIS - MINIMUM SHIPMENT-MILE LOCATION

To further understand the sensitivity of transportation cost and dose to location, a minimum shipment-mile location was developed. A number of arbitrary points within an area bounded by 36 and 40 degrees north latitude and 79 and 85 degrees west longitude were selected as hypothetical MRS locations. The selection of the area was based on the previous MRS study (Ref. 6), the six centroid sensitivity assessments described in the previous section, and the high density of Eastern reactors.

For each hypothetical location within the selected area, the total number of shipment-miles was estimated. It was assumed that the MRS packaging function was the MRS consolidate and canister configuration. Mileage estimates from reactors to the MRS and from the MRS to repository were developed by identifying the corresponding shortest distance connecting each origin/destination pair on the spherical surface of the earth. With an estimate of total shipment-miles calculated for each hypothetical MRS location, the area resulting in the minimum number of shipment-miles was identified in the mid-Atlantic region, an area approximated by 38 degrees north latitude and 81 degrees west longitude. The nearest common node, in the HIGHWAY and INTERLINE data bases, was then used to calculate route-specific data for the truck and rail distances that were the basis for generating the life-cycle costs.

The transportation costs corresponding to the minimum shipment-miles MRS location that consolidates and canisters spent fuel are given in Table 30. Additional costs were calculated for this MRS location assuming different packaging functions and are also given in Table 30. The number of shipments, shipment-miles, and cask-miles for each packaging function of the minimum shipment-miles MRS location are provided in Tables 31 to 33.

The results indicate that a store-only MRS and an MRS that consolidates and canisters have a lower cost than the reference no-MRS case. Cost savings range from $93 million for the MRS store-only case to $267 million for the MRS consolidate-and-canister with Western strategy case.

The minimum shipment-mile MRS location results in smaller total cost than the generic Eastern MRS location for all packaging functions as shown by comparing the values in Table 30 to the corresponding numbers in Table 12. The differences, ranging from approximately $80 to $120 million, are a direct consequence of the decrease in the shipment-miles involved in the minimum shipment-miles location. For example, both the cost and the shipment-miles for the consolidate-and-canister case of the minimum shipment-miles location are reduced by the similar amounts (13 to 14%) from the corresponding values of the generic Eastern MRS.

The shipment-miles difference between the minimum shipment-miles location and the generic Eastern MRS is a direct consequence of the difference in the average distance from the reactors to the MRS and from the MRS to the repository. The average reactor to MRS distances[1] for the minimum shipment-miles location and the generic Eastern MRS are approximately 870 and 990 miles,

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[1] These average distances are obtained by dividing the shipment-miles by the number of shipments.

Table 30. Cost by Transportation Link ($millions)
Minimum Shipment-Miles MRS Location - Spent Fuel Cases

Case	From Reactor to MRS/Repository		From MRS To Repository	Total
	Rail	Truck	Rail	
Store Only:				
Eastern MRS	122	282	335	739
Eastern MRS/ Western Strategy	115	238	306	659
Consolidate & Canister:				
Eastern MRS	122	282	231	635
Eastern MRS/ Western Strategy	115	238	212	565
Containerize Intact SF:				
Eastern MRS	122	282	591	995
Consolidate & Containerize:				
Eastern MRS	122	282	452	856

Table 31. Number of Shipments by Transportation Link
Minimum Shipment-Miles MRS Location - Spent Fuel Cases

Case	From Reactor to MRS/Repository		From MRS To Repository	Total
	Rail	Truck	Rail	
Store Only:				
Eastern MRS	1,286	22,550	813	24,649
Eastern MRS/ Western Strategy	1,284	22,607	744	24,635
Consolidate & Canister:				
Eastern MRS	1,286	22,550	500	24,336
Eastern MRS/ Western Strategy	1,284	22,607	457	24,348
Containerize Intact SF:				
Eastern MRS	1,286	22,550	1,472	25,308
Consolidate & Containerize:				
Eastern MRS	1,286	22,550	1,123	24,959

Table 32. Shipment-Miles by Transportation Link (1,000s)
Minimum Shipment-Miles MRS Location - Spent Fuel Cases

Case	From Reactor to MRS/Repository Rail	From Reactor to MRS/Repository Truck	From MRS To Repository Rail	Total
Store Only:				
Eastern MRS	1,035	19,681	2,038	22,754
Eastern MRS/ Western Strategy	923	14,860	1,863	17,676
Consolidate & Canister:				
Eastern MRS	1,035	19,681	1,253	21,969
Eastern MRS/ Western Strategy	923	14,860	1,146	16,929
Containerize Intact SF:				
Eastern MRS	1,035	19,681	3,688	24,404
Consolidate & Containerize:				
Eastern MRS	1,035	19,681	2,813	23,529

Table 33. Cask-Miles by Transportation Link (1,000s)
Minimum Shipment-Miles MRS Location - Spent Fuel Cases

Case	From Reactor To MRS/Repository Rail	From Reactor To MRS/Repository Truck	From MRS To Repository Rail	Total
Store Only:				
Eastern MRS	3,105	19,681	10,191	32,977
Eastern MRS/ Western Strategy	2,770	14,861	9,317	26,948
Consolidate & Transfer:				
Eastern MRS	3,105	19,681	6,266	29,052
Eastern MRS/ Western Strategy	2,770	14,861	5,729	23,360
Containerize Intact SF:				
Eastern MRS	3,105	19,681	18,441	41,227
Consolidate & Containerize:				
Eastern MRS	3,105	19,681	14,063	36,849

respectively. Similarly, the MRS to repository average distances are 2,505 and 2,885 miles, i.e., the minimum shipment-miles location is 380 miles closer to the repository than the generic Eastern MRS.

5.3 SENSITIVITY ANALYSIS - OVERWEIGHT TRUCK

Shipment of spent fuel from truck-served reactors in overweight truck (OWT) casks has been cited as an option for reducing the number of truck shipments (and hence cost and dose). The use of OWT is not certain at this time due to unresolved legal, operational, and institutional issues. However, a sensitivity analysis was conducted for OWT casks using the following cases:

- All truck shipments directly to repository
- All truck shipments to generic Eastern MRS
- All truck shipments to generic Western MRS
- Truck shipments from Eastern reactors to generic Eastern MRS; from Western reactors to repository.

Note that this sensitivity analysis affects only the cost and dose associated with from-reactor truck shipments. All other impacts are unchanged.

The results of this sensitivity analysis are presented in Table 34. In terms of cost, the use of OWT leads to cost savings ranging from $82 to $160 million depending on MRS location and Western strategy. In percentage terms, the cost savings from using OWT are roughly 30% when compared to LWT.

As can be seen in Table 34, use of the OWT casks leads to about 9,200 fewer shipments as compared to the use of LWT casks, in direct correspondence to the higher capacity of OWT casks. A similar pattern is exhibited in estimates of shipment-miles and cask-miles, which are equal for truck transport.

The reduction in the number of truck shipments by about 40% results in roughly the same percentage reduction in total dose. As expected, the dose per cask mile for OWT casks is the same as for LWT casks. This is because dose calculations for both casks are based on the regulatory dose limit of 10 mrem per hour at 2 meters from the cask, and therefore dose per cask mile is not a function of cask capacity.

5.4 SENSITIVITY ANALYSIS - CASK CAPACITIES

The casks that will eventually be used to transport SF under the OCRWM program are currently in the preliminary or conceptual design phase. As such, their projected capacities could change as the design and fabrication effort progresses. Past analyses have indicated that cask capacity may be the most important determinant of transportation cost and dose. It was not known, however, whether different cask capacities would also affect the <u>relative</u> comparisons of MRS packaging and location options, which are the focus of this study.

To examine this issue, transportation costs and dose estimates for the 11 spent fuel cases (Figure 1) were re-calculated using lower and upper bounding values from cask capacity, as shown in Tables 35 and 36 for from-reactor and from-MRS casks, respectively.

Table 34. Transportation Cost, Dose, and Measures of Activity
Sensitivity Case - Overweight Truck

Case	Overweight Truck Cask					
	MTU-Miles (1,000s)	Cask-Miles (1,000s)	Shipment-Miles (1,000s)	Number of Shipments	Total Cost ($millions)	Total Dose (1,000s per-rem)
No-MRS	64,653	30,510	30,510	13,392	412	1.2
Eastern MRS	27,525	13,311	13,311	13,392	230	0.5
Eastern MRS/ Western Strategy	20,930	10,047	10,047	13,425	192	0.5
Western MRS	58,462	27,641	27,641	13,392	378	1.0
	Legal-Weight Truck Cask					
	MTU-Miles (1,000s)	Cask-Miles (1,000s)	Shipment-Miles (1,000s)	Number of Shipments	Total Cost ($millions)	Total Dose (1,000s per-rem)
No-MRS	64,653	51,400	51,400	22,550	572	1.9
Eastern MRS	27,525	22,383	22,383	22,550	326	0.9
Eastern MRS/ Western Strategy	20,935	16,920	16,920	22,607	273	0.8
Western MRS	58,462	46,550	46,550	22,550	524	1.7

Table 35. From-Reactor Cask Capacity Used for Sensitivity Analysis

	CASK ID	
	R1	T2
Cask Capacity (PWR/BWR Assemblies)		
Lower	16/40	2/6
Reference	**21/48**	**3/7**
Higher	26/52	4/9

Table 36. From-MRS Cask Capacity Used for Sensitivity Analysis

	CASK ID					
	R4	R5	R6	R7	R71	R8
Cask Capacity (PWR/BWR Assemblies)(1)						
Lower	28/61	48/120	12+16	24/72	12/24	20
Reference	**34/80**	**56/140**	**12+16**	**24/72**	**12/24**	**20**
Higher	44/98	78/195	15+20	30/90	15/30	25
Canisters/Containers per Cask						
Lower	n/a	24	4	4	4	4
Reference	**n/a**	**28**	**4**	**4**	**4**	**4**
Higher	n/a	39	5	5	5	5

(1) SF cask capacities are stated in PWR/BWR assemblies. NFBC cask capacity is stated in 55-gallon drums. HLW cask capacity is stated in canisters.

The sensitivity analysis was conducted by assuming that higher (lower) capacities are the result of design improvements (constraints) or different materials (such as steel, lead, depleted uranium). For simplicity, it is further assumed that such capacity changes do not affect loaded or empty cask weights, cask capital costs, and processing times.[1] Further, a major portion of the transportation costs, such as security costs for truck shipments or dedicated train costs for rail shipments, are independent of shipping weight. As a result, small changes in cask empty weight are assumed to have little effect on hauling costs. A major additional assumption for this analysis is that capacity gains resulting from improved analysis/material applications with cask designs of similar complexity leave capital costs for casks unaffected.

The results are shown in Tables 37 through 41. As expected, lower cask capacities result in systematically higher costs and dose; higher cask capacities similarly result in lower costs and dose. Other salient findings are:

- Containerization at the MRS of intact spent fuel remains the more costly option from a transportation perspective due to low cask capacity.
- An Eastern MRS system generally results in lower transportation costs over the no-MRS system when the MRS packaging function is to consolidate and canister or store only due to reduced shipment-miles.
- The relative rankings of the 11 cases is fairly stable. Thus, there appears to be no compelling reason to qualify the study findings based on the results of this sensitivity analysis.

5.5 SENSITIVITY ANALYSIS - TRANSPORTABLE STORAGE CASK

Approximately 750 MTU of spent fuel is postulated in the MRS System Study to be transported in transportable storage casks (TSCs) from reactors in the first year of the three-phased MRS deployment mode. Given the OFF shipment rule, some of these shipments originate at reactors that do not have the crane capacity and/or the rail access required to handle the 125-ton TSCs. Systems such as dry-transfer to TSCs, the use of heavy-haul truck to transport TSCs to the railhead have not been adequately defined as yet; neither has the disposition of TSCs, or their integration with the transport-only cask fleet been established. Therefore, TSCs were not included in the transportation analysis presented in earlier sections, and the implementation of TSCs in an MRS/no-MRS system is considered beyond the scope of this analysis. In addition, the relatively small percentage (1.2%) that 750 MTU is of the total quantity (63,000 MTU), indicates that TSCs would not be a significant discriminator in the comparison of alternative MRS functions and locations from a transportation cost and dose perspective.

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[1] Variations in cask weights, cask capital cost, and processing times due to cask capacity changes are assumed to change total cost by less than 10%.

Table 37. Summary of Transportation Costs and Doses for Reference, Lower, and Higher Cask Capacities

	Total Cost ($million) Cask Capacity			Total Dose (1,000 p-rem) Cask Capacity		
	Ref	Lower	Higher	Ref	Lower	Higher
No-MRS:	832	1117	656	2.6	3.5	2.0
Store-Only:						
Eastern MRS	835	1092	656	1.6	2.2	1.4
Eastern MRS/ Western Strategy	741	963	584	1.5	2.1	1.1
Western MRS	896	1192	707	2.5	3.3	2.0
Consolidate & Canister:						
Eastern MRS	718	927	548	1.5	2.0	1.2
Eastern MRS/ Western Strategy	634	812	485	1.4	1.9	1.0
Western MRS	862	1141	674	2.5	3.3	1.9
Containerize Intact SF:						
Eastern MRS	1120	1285	889	1.9	2.4	1.6
Western MRS	996	1259	789	2.6	3.2	2.1
Consolidate & Containerize:						
Eastern MRS	965	1130	765	1.8	2.2	1.4
Western MRS	942	1205	745	2.6	3.3	2.0

Table 38. Cost by Transportation Link ($millions) - Reactors to MRS/Repository

	Cask Capacity					
	Reference		Lower		Higher	
	Rail	**Truck**	Rail	Truck	Rail	Truck
NO MRS:	**260**	**572**	330	787	221	435
Store Only:						
Eastern MRS	**135**	**326**	173	453	114	248
Eastern MRS/ Western Strategy	**126**	**273**	161	376	107	208
Western MRS	**241**	**524**	306	722	205	399
Consolidate & Canister:						
Eastern MRS	**135**	**326**	173	453	114	248
Eastern MRS/ Western Strategy	**126**	**273**	161	376	107	208
Western MRS	**241**	**524**	306	722	205	399
Containerize Intact SF:						
Eastern MRS	**135**	**326**	173	453	114	248
Western MRS	**241**	**524**	306	722	205	399
Consolidate & Containerize:						
Eastern MRS	**135**	**326**	173	453	114	248
Western MRS	**241**	**524**	306	722	205	399

Table 39. Cost by Transportation Link ($millions) - MRS to Repository

		Cask Capacity	
	Reference	Lower	Higher
No MRS:	---	---	---
Store Only:			
Eastern MRS	**374**	466	294
Eastern MRS/ Western Strategy	**342**	426	269
Western MRS	**131**	164	103
Consolidate & Canister:			
Eastern MRS	**257**	301	186
Eastern MRS/ Western Strategy	**235**	275	170
Western MRS	**96**	113	70
Containerize Intact SF:			
Eastern MRS	**659**	659	527
Western MRS	**231**	231	185
Consolidate & Containerize:			
Eastern MRS	**504**	504	403
Western MRS	**177**	177	141

Table 40. Risk by Transportation Link (1,000 person-rem) - Reactors to MRS/Repository

	Cask Capacity					
	Reference		Lower		Higher	
	Rail	**Truck**	Rail	Truck	Rail	Truck
No MRS:	**0.7**	**1.9**	0.9	2.6	0.6	1.4
Store Only:						
Eastern MRS	**0.4**	**0.9**	0.6	1.2	0.4	0.7
Eastern MRS/ Western Strategy	**0.4**	**0.8**	0.5	1.2	0.3	0.6
Western MRS	**0.7**	**1.7**	0.9	2.3	0.6	1.3
Consolidate & Canister:						
Eastern MRS	**0.4**	**0.9**	0.6	1.2	0.4	0.7
Eastern MRS/ Western Strategy	**0.4**	**0.8**	0.5	1.2	0.3	0.6
Western MRS	**0.7**	**1.7**	0.9	2.3	0.6	1.3
Containerize Intact SF:						
Eastern MRS	**0.4**	**0.9**	0.6	1.2	0.4	0.7
Western MRS	**0.7**	**1.7**	0.7	2.3	0.6	1.3
Consolidate & Containerize:						
Eastern MRS	**0.4**	**0.9**	0.6	1.2	0.4	0.7
Western MRS	**0.7**	**1.7**	0.9	2.3	0.6	1.3

Table 41. Risk by Transportation Link (1,000 person-rem) - MRS to Repository

	Cask Capacity		
	Reference	Lower	Higher
No MRS:	---	---	---
Store Only:			
Eastern MRS	**0.3**	0.4	0.3
Eastern MRS/ Western Strategy	**0.3**	0.4	0.2
Western MRS	**0.1**	0.1	0.1
Consolidate & Canister:			
Eastern MRS	**0.2**	0.2	0.1
Eastern MRS/ Western Strategy	**0.2**	0.2	0.1
Western MRS	**0.1**	0.1	0.0
Containerize Intact SF:			
Eastern MRS	**0.6**	0.6	0.5
Western MRS	**0.2**	0.2	0.2
Consolidate & Containerize:			
Eastern MRS	**0.5**	0.4	0.3
Western MRS	**0.2**	0.1	0.1

6.0 CONCLUSIONS

The principal conclusions of this study are listed below. These conclusions are based on the analyses presented in Chapters 4 and 5.

6.1 TRANSPORTATION COSTS

In general, from a transportation standpoint, the MRS is economically more favorable than a no-MRS system when its packaging function maximizes MRS-to-repository cask capacity and minimizes reactor-to-MRS shipment-miles. When evaluating the generic Eastern and Western MRS locations, only the generic Eastern MRS that stores and ships intact fuel with a Western strategy or consolidates and canisters fuel realizes these above efficiencies to the extent that they provide a net transportation cost savings over a no-MRS system. Savings range from $100-200 million over the 24-year life of the project. Note the sensitivity cases assessing six regional centroid results in figures consistent with the generic MRS analysis (see Table 23 in Chapter 5).

In the store-only case with the generic Eastern MRS, Western strategy would be needed to minimize cross-country shipping to bring system transportation costs closer to the no-MRS system. For the consolidate-and-containerize and containerize-intact cases, the from-MRS cask efficiency is low, so an Eastern MRS location causes increased costs. The Western MRS does not significantly reduce cross-country shipping miles, so none of the Western MRS cases gives lower costs than the no-MRS case.

A comparison between the generic Eastern MRS and the generic Western MRS indicates that the generic Eastern MRS provides the following (from Table 12 in Chapter 4). The cost variation depends on whether or not the Western strategy is used.

- 5 to 15% cost savings for the store-only case because an MRS location in the East maximizes cross-country spent fuel shipment in from-MRS casks and carrying intact fuel allows good packing efficiency in the from-MRS cask.

- 15 to 25% cost savings for the consolidate and canister case because an MRS location in the east maximizes cross-country spent fuel shipment in from-MRS casks and carrying canisters with consolidated fuel allows very good packing efficiency in the from-MRS cask.

- 2 to 10% increase for the containerized intact spent fuel case because an MRS location in the East maximizes cross-country spent fuel shipments in from-MRS casks and carrying repository containers, either with or without consolidated fuel, results in low packing efficiency.

The minimum shipment-mile MRS location, described in Section 5.2, when compared to the generic Eastern MRS location indicates:

- 15 to 25% cost savings for the store-only case

- 25 to 35% cost savings for the consolidate-and-canister case
- 1 to 10% cost savings for the consolidate-and-containerize case.

The minimum shipment-mile MRS location moves the MRS to give a reduced average distance from the reactors in comparison to the generic Eastern MRS location. Because the minimum shipment-mile MRS location is west of the generic MRS location, the MRS to repository distance also decreases. The reduced distance gives a cost decrease of more than 10% for the minimum shipment-mile MRS location, compared to the generic MRS location. This shifts all costs for the minimum shipment-mile MRS location about 10% lower, so there is an improvement of 10% in the comparison of the minimum shipment-mile MRS location with the generic Eastern MRS.

In terms of packaging function, an MRS that consolidates and canisters spent fuel appears superior in terms of reducing transportation cost than the three other alternatives analyzed in this study because consolidation of fuel into canisters allows efficient use of the cask interior space. It is worth noting that the cost differential among packaging functions is somewhat sensitive to MRS location because the location affects shipping distance and, thus, the degree of utilization of a particular efficient (or inefficient) cask type. Specifically, for the generic Eastern MRS the choice of packaging function can lead to cost savings of up to $490 million compared to $135 million for the generic Western MRS because the Western MRS is closer to the repository, giving a shorter shipping distance than the Eastern MRS. The shorter shipping distance makes the Western MRS less sensitive to changes in packaging function and the resulting variation in cask loading efficiency. In addition, for the minimum shipment-mile MRS location, the choice of packaging function can lead to a cost savings of up to $430 million. Because the minimum shipment-mile MRS location is closer to the repository than the generic Eastern MRS, the packaging function has slightly less effect on cost.

For a given packaging function, the choice between the generic Eastern and generic Western MRS locations can impact transportation cost by as little as $20 million and up to $150 million. Similarly, for a given packaging function, the choice between the minimum shipment-mile MRS and the generic Western MRS location can impact tranportation cost by as little as $1 million and up to $230 million. The large transportation cost difference ($150 million for the generic or $230 million for the minimum shipment-mile location) occurs for the consolidate-and-canister case where the Eastern MRS locations gain a major advantage over the Western MRS locations, due to the high capacity of the MRS cask. With a Western MRS location, shipments from reactors travel across the U.S. in the lower capacity truck or rail casks, and are then placed into the higher-capacity MRS cask. The minimum shipment-mile MRS location is further enhanced because the shipping distance from the reactors to the MRS is less in the minimum shipment-mile MRS case than with the generic Eastern location. For the packaging functions that result in transporting repository containers (i.e., containerization cases), the MRS cask efficiency drops and the Western MRS is, thus, more favorable than the Eastern MRS.

With a generic Eastern MRS location, a Western strategy reduces transportation cost by about $95 million for an MRS that stores only and about $85 million for an MRS that consolidates and canisters. This is due to the reduction in total shipment-miles resulting from not shipping from the Western reactors to an Eastern MRS and then back to the Western repository.

In addition to lower transportation costs, an Eastern MRS system results in a reduced number of shipments and shipment-miles when compared to a Western MRS or a no-MRS system. Table 14 in Chapter 4 contains information on the cask days in transit, shipment-days in transit, and an estimate of the average number of shipments per day for both generic Eastern and Western MRS locations and the no-MRS system. As expected, the average number of shipments in transit per day for an Eastern MRS system is approximately half of the corresponding number of shipments in transit for the no-MRS or Western MRS system. A similar pattern can be seen for shipment-days in transit and cask-days in transit. This reflects the elimination of truck and 100-ton rail cask shipments from reactors across the country to the repository or Western MRS.

The use of overweight truck casks (5 PWR/12 BWR assemblies) can reduce the cost of from-reactor shipments by approximately $80 to $160 million when compared to legal-weight truck casks (3 PWR/7 BWR assemblies), depending on the FWMS configuration and MRS location due to the increased capacity and, therefore, fewer shipments.

Variations in cask capacities do not appear to affect the relative comparisons of MRS packaging and location options.

The option of shipping HLW directly to the repository is noticeably more cost-effective than shipping through an Eastern MRS, and marginally more cost-effective than shipping through a Western MRS. As shown in Table 22 in Chapter 4, the total shipping distance for ICPP and Hanford increases significantly for the Eastern MRS compared to the no-MRS case. These two sites ship about 45% of the HLW. The Western MRS also results in an increase in shipping distance. The increased shipping distances translate into higher transportation costs.

6.2 TRANSPORTATION DOSE

The total transportation dose for the 11 core cases indicates that the transport of spent fuel results in an in-transit dose varying from 1,400 person-rem for spent fuel consolidation and canistering at an Eastern MRS with a Western strategy to 2,600 person-rem for a no-MRS system. An Eastern MRS provides a dose reduction of from 25 to 45% over a Western MRS (depending on the selection of packaging function) or a no-MRS system, because of the reduced number of cross-country shipments.

For perspective, the average annual dose from natural background radiation has been estimated to be about 0.1 person-rem. Using the conversion given in the 1986 Repository Environmental Assessment for Yucca Mountain, Nevada (Ref. 9) that 1 person-rem equals 0.0002 latent-cancer fatality (LCF), then roughly 5,000 LCFs result annually in the United States from background radiation. The radiation exposures from transporting spent fuel directly to the repository would result in about 0.02 additional LCF per year over the 24-year transportation program involving the first repository. An Eastern MRS with the Western spent fuel strategy results in a reduction in total dose by nearly half of the dose for the no-MRS case or the generic Western MRS cases. This is because the number of cross-country shipments is reduced.

6.3 TRANSPORTATION NONRADIOLOGICAL RISK

Nonradiological risk was not calculated in this study. However, estimates for similar high-level waste shipping activities indicate that nonradiological risk is much higher than the radiological risk (DOE, 1986). Some results of the Monitored Retrievable Storage Submission to Congress are summarized as follows. Nonradiological risk for transportation of spent fuel from reactors and then to a repository at Yucca Mountain was reported as 12 fatalities and 140 - injuries with 30% of from-reactor shipments transported by truck and 70% by rail, and all from-MRS shipments in 150-ton casks. Application of a Western strategy reduces shipment-miles and was reported to reduce fatalities to 10 and injuries to 120.

7.0 REFERENCES

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APPENDIX A

COST ALGORITHMS

APPENDIX A

COST ALGORITHMS

This appendix contains a listing of the cost algorithms used to calculate transportation costs for spent nuclear fuel and high-level waste.

A.1 ANNUAL SHIPPING COSTS

The annual shipping costs for each reactor consist of the annual transportation cost and the cask costs. The annual transportation cost is calculated from the annual number of shipments and the route cost per shipment. The cask costs depend on the number of cask trips per year and the cask use, maintenance, and handling costs.

A.1.1 Annual Number of Cask Trips

The annual number of cask trips per reactor is calculated from the MTU scheduled for shipment from each reactor each year, the cask capacity in assemblies, and the MTU per assembly. For each year and for each reactor, the equations used are:

Number of Assemblies = MTU(year,rx) / MTU per Assembly (1)

The "**rx**" and "**year**" are the year and reactor indexes, respectively.

Annual Number of Cask Trips = Number of Assemblies / Cask Cap(mode,rxtype) (2)

Cask Cap is the cask capacity in assemblies for each transportation mode **(mode)** and reactor type **(rxtype)**.

A.1.2 Annual Number of Shipments

The annual number of shipments per reactor is

Annual Number of Shipments = Annual Number of Cask Trips / Casks per Shipment(mode,rx) (3)

A.1.3 Annual Transportation Cost

The annual transportation cost for each reactor is

Transp Cost(year,rx) = Annual Number of Shipments * Route Cost(mode,rx) (4)

where **Route Cost** is the round trip hauling cost for each route (reactor to repository) and for each transportation mode (truck or rail). This cost includes shipping security, demurrage, and second driver charges, but excludes cask-related charges, i.e., cask capital cost, maintenance, and handling.

A.1.3.1 Rail Route Costs

The rail route costs consist of hauling, security, and inspection costs, given by

Route Cost(rail,rx) = Hauling Cost (rail,rx) + Security Cost(rail,rx) + Inspection Cost (5)

The hauling costs are

Hauling Cost = [(9/40) * 0.1616*Distance(0.586)] * (WF + WE)* Casks per Shipment + RSopt*96*Distance** (6)

Distance is the route distance (in miles).

WF,WE are the cask weights loaded and empty, respectively [in hundredweight (cw)]

Casks per Shipment is an input specified for each transportation mode.

RSopt is the user-defined service option:
RSopt = 0 indicates regular services
RSopt = 1 indicates round-trip dedicated train
RSopt = 0.5 indicates one-way dedicated train.

Spent fuel is assumed to be transported from reactors via one-way dedicated trains with a consist of 3 casks.

It has been assumed that an average amount of fuel removed from-reactor in an annual refueling is about 30 MTU, which represents about 3 rail caskloads.

Reactors typically discharge about 30 MTU of spent fuel annually. At steady state the oldest fuel first (OFF) pickup scenario implies picking up one years spent fuel from each reactor each year, e.g., some 100 reactors producing about 30 MTU per year gives the expected 3,000 MTU per year of spent fuel shipped to the MRS/repository. An examination of the OFF schedule used to specify the annual shipments for the TRICAM from reactor calculations shows most reactors shipping about 15 to 40 MTU per year with the exceptions of a few anomalies caused by reactor startups or shutdowns.

A typical rail shipping campaign at a reactor would be expected to pick up the annual OFF allotment each year, that is, about 30 MTU of spent fuel. Because a rail cask carries about 9.5 MTU, this gives a campaign size of 3.1 (30 divided by 9.5). Due to the large fixed overhead involved in loading a cask, it would be very unlikely that a cask would be partially filled, so 3.1 is rounded to 3. The actual campaign size will vary depending on the amount of fuel shipped from a reactor in a particular year and the availability of crews to carry out loading at the reactor sizes. The actual consist size may vary from shipment to shipment, and the question of optimum consist size will require a study of the trade-offs involved in the economics of rail shipments, requirements of OFF scheduling, and the loading capabilities at reactors. The campaign size of three casks selected for this study is not an optimized value

[1] X**Y means raise X to the Y power.

but is consistent with typical annual shipment sizes for the OFF schedule, would not overcommit personnel resources at reactors, and is sufficiently accurate for the scoping of transportation costs.

For from-MRS rail shipment, a 5-cask round-trip dedicated train is used. Selection of shipping campaign size must also reflect the effect of the need to efficiently unload the group of casks when they arrive at the receiving facility (MRS or repository). Due to the high dedicated rail charge, the rail transportation cost is generally decreased by increasing the campaign size. However, the receiving facility capital cost is generally decreased by steady arrivals. In order to turn around a large group of casks arriving at one time in an expeditious fashion, more parallel unloading bays are needed than steady-state operation would require. Thus, a large shipping campaign size will increase receiving facility costs. If large shipping groups arrive at a facility designed for steady-state receiving, the cask turnaround time increases. Increased turnaround time will cause fleet size to increase, resulting in higher transportation costs. In either case, the interface between the nuclear waste transportation system and the receiving system favors near steady-state operation, i.e., small shipping groups.

The rail campaign size for from-reactor shipments is more constrained by the single loading bay at reactor, reactor crew capabilities, and the quantity of fuel shipped annually. In from-MRS to repository shipments, the from-reactor shipping constraints do not apply. However, cask loading/unloading facility capital requirements still push in the direction of small shipping campaigns. A selection of 5 casks in the MRS to repository loop was not the result of a detailed optimization study of transportation/facility interfaces, but does reflect consideration of typical repository receiving system and transportation system operating characteristics to select a reasonable shipping campaign size.

The security costs are calculated by

$$\text{Security Cost(rail,rx)} = 0.76*\text{Distance} + 500 * \text{Trip Time} + 500*\text{Loading Time at rx} \quad (7)$$

The **Loading Time at rx** (in days) is the loading time at reactors for each cask type. **Trip Time** is defined by Equation 14.

The inspection cost is

$$\text{Inspection Cost} = 470*\text{Loading Time at rx}*\text{Casks per Shipment} \quad (8)$$

where the loading time is in days.

A.1.3.2 Truck Route Costs

The route costs for truck transport are

$$\text{Route Cost(truck,rx)} = \text{Hauling Cost} + \text{Second Driver Charge} + \text{Demurrage Charge at rx} + \text{Inspection Cost} + \text{Security Cost(truck,rx)}. \quad (9)$$

The hauling costs are given by

$$\text{Hauling Cost} = [(1.1614 + 0.004764*\text{Distance}) * \text{WF} + (0.3954 + 0.00402*\text{Distance}) * \text{WE}] * \text{Casks per Shipment} \quad (10)$$

The second driver cost is

$$\text{Second Driver Cost} = 0.5*\text{Distance}*\text{Casks per Shipment} \quad (11)$$

Demurrage charges at the reactors are based on the cask loading and unloading times and the following sliding scale:

Load Time (Hours)	Charge
0-3	0
3-24	$20/cask/hr for each hour over 3 hours
> 24	$420 + $25/cask/hour for each hour over 24 hours

Inspection and security costs are calculated by

$$\text{Inspection Cost} = 470*\text{Loading Time at rx}*\text{Casks per Shipment} \quad (12)$$

$$\text{Security Cost(truck,rx)} = 1.47*\text{Distance}*\text{Casks per Shipment} + 2*\text{Truck Security Cost(rx)} \quad (13)$$

The **Truck Security Cost** is calculated by assuming a $1.50/mile for each security escort through the urban areas and $200/engagement. The number of engagements is optimized.

A.1.3.3 Travel Time Calculation

Travel time is estimated in days using the following equations:

$$\text{Trip Time} = (\text{Travel Time} + \text{Time Stopped}) / 24 \quad (14)$$

$$\text{Travel Time} = \text{Distance} * (1/\text{Speed Loaded} + 1/\text{Speed Empty}) \quad (15)$$

$$\text{Time Stopped} = \text{Stopped Loaded} + \text{Stopped Empty} \quad (16)$$

The stopped times are specified by the user in hours/mile; the code multiplies the hours/mile and the **Distance** to obtain the stopped time. The loaded and empty speed are calculated using equation

$$\text{Speed Loaded} = \text{Coef}*\text{Distance}**\text{Exp} \quad (17a)$$

$$\text{Speed Empty} = \text{Coef}*\text{Distance}**\text{Exp} \quad (17b)$$

The empty and loaded coefficients and exponents are user-specified for truck and rail.

A.1.4 Annual Cask Use Costs

The annual cask use costs consist of the capital charges, the cask maintenance charges, and the cask handling charges at the reactors and repository.

The annual capital charges for the casks used by each reactor are:

Cask Capital Charge (year,rx) = Cask Days * Cask Use Fee per Day(mode) (18)

The transportation mode is determined by the rail availability at each reactor. If the reactor is accessible by rail, the mode is rail; otherwise, the mode is truck.

The cask days are

Cask Days = Annual Number of Cask Trips * (Travel Time + (N+1)/2* Cask Turnaround Time at Reactor + Cask Turnaround Time at Storage Facility) (19)

where N is the number of casks per shipment.

The daily cask use fee is

Cask Use Fee per Day(mode) = CRF*Cask Cost(mode) / Cask Utilization(mode) (20)

where **Cask Cost** is in dollars and **Cask Utilization** is the number of days per year a cask is used. The capital recovery factor **(CRF)** is

CRF = [ROR * (1 + ROR)**Cask Life(mode)] / [(1 + ROR)**Cask Life(mode)-1] (21)

where **ROR** is the rate of return in percent on the cask investment.

If ROR = 0.0, then

CRF = 1.0/Cask Life(mode) (22)

The annual cask maintenance charges are:

Cask Maintenance Charge(year,rx) = Cask Days * Cask Maint Fee per Day(mode) (23)

Cask Maint Fee per Day(mode) = Cask Maintenance Cost(mode) / Cask Utilization(mode) (24)

The **Cask Maintenance Cost** is specified in dollars as an input.

A.2 ACCUMULATED ANNUAL COSTS

The annual costs are accumulated for all reactors and for all years that spent fuel shipments are specified. The results are total costs by transportation mode--truck and rail--and their sum.

The accumulated cost parameters are:

- Hauling cost,
- Security cost,
- Cask capital charges, and
- Cask maintenance charges.

The sum of all of these cost parameters is the total transportation cost.

APPENDIX B

GENERIC MRS ROUTE AVERAGING METHOD

APPENDIX B

GENERIC MRS ROUTE AVERAGING METHOD

In TRICAM, every route (i.e., from every origin to every destination) is presented as a series of links. There is one link for every State road type and population density zone traversed by that route. Mileage data are presented for each link. Figure B-1 shows an example of the links of a route traversing one State boundary. If the State were the only route attribute, then the link designation would change each time a State boundary is crossed. The route from R to A consists of:

Link A_1 through State 1 for	7 miles
Link A_2 through State 2 for	5 miles
Total through States 1 and 2	12 miles

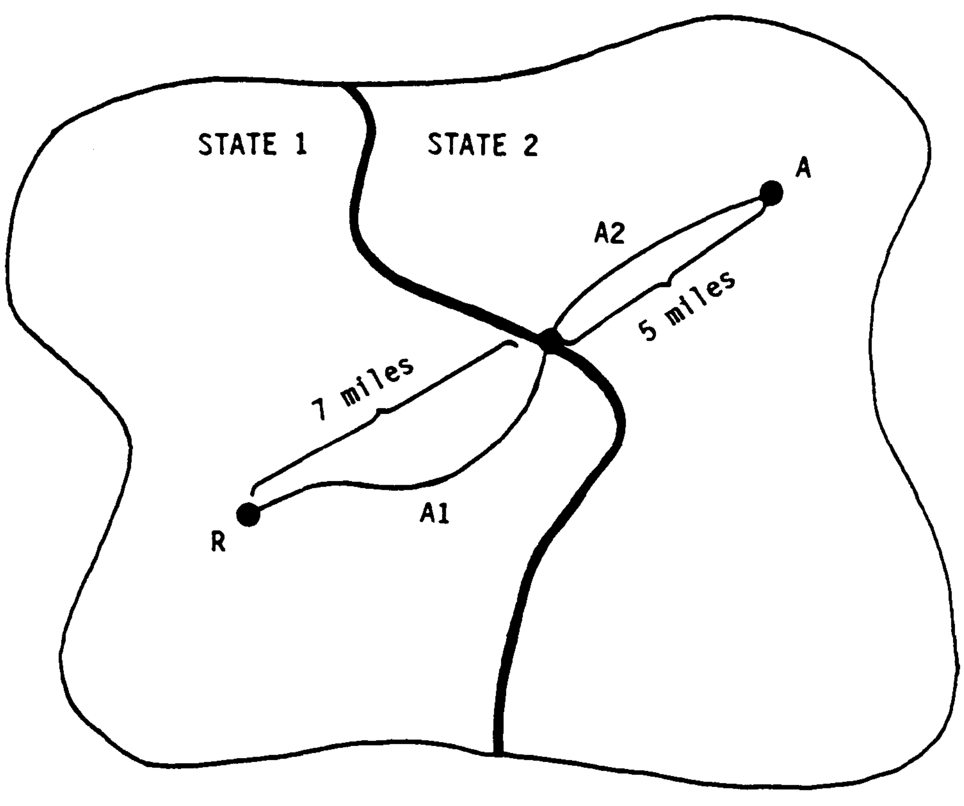

Figure B-1. Example of the TRICAM Route Links for a Route Transversing One State Boundary

Figure B-2 shows the same route in a more detailed link representation. This time the link designation changes each time a State boundary <u>or</u> a population zone boundary is traversed. Thus route RA consists of the following links:

Link	State	Population Zone	Miles
A_{19}	1	P_9	4.5
A_{16}	1	P_6	2.5
A_{26}	2	P_6	3.0
A_{23}	2	P_3	2.0
Total	1 and 2	P_9, P_6, P_3	12.0

Note that the first subscript in A_{13} refers to the State and the second subscript to the population zone. Also note that the total route mileage is the same (12) in both link representation schemes.

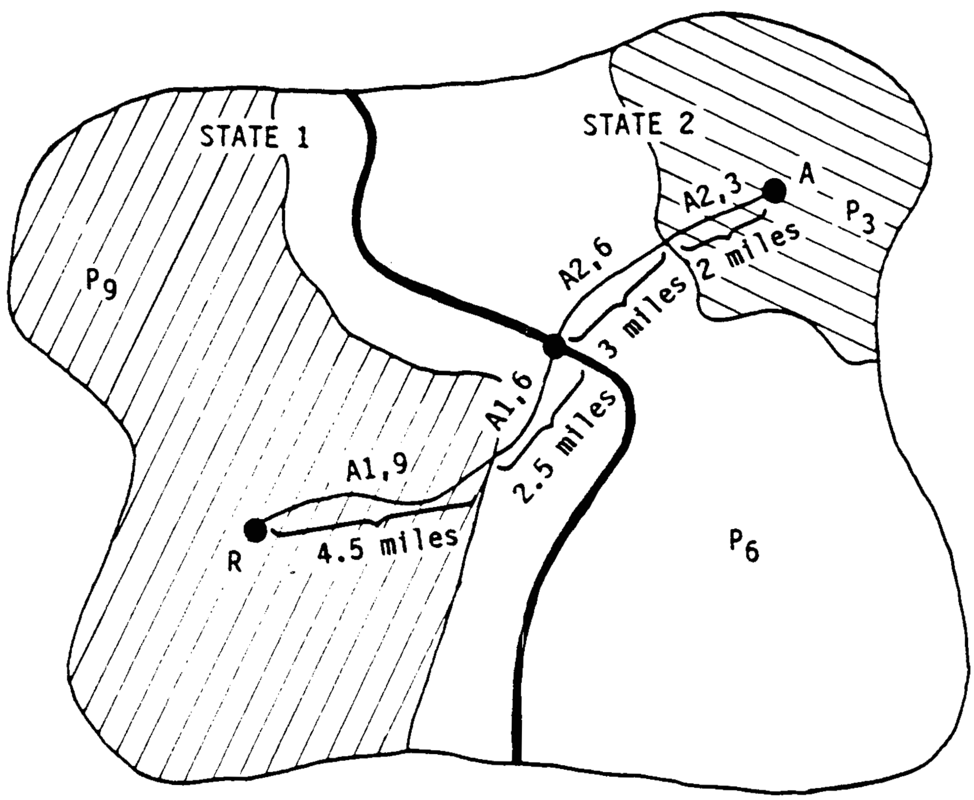

Figure B-2. Example of the TRICAM Route Links for a Route Transversing One State Boundary and Three Population Zones

TRICAM uses a third index to designate road type and an identifier of urban/rural links. For simplicity this discussion will be continued with only the State and population zone indexes.

The link-by-link route data of the two Eastern (Western) MRS centroids are used to simulate the attributes of the average route for the corresponding generic Eastern (Western) MRS. The averaging process is presented through the examples depicted in Figures B-3 and B-4. Figure B-3 shows one reactor origin, at R, and two MRS centroids at A and B. The routes are characterized by links.

A_1 through State 1	7 miles
A_2 through State 2	5 miles
B_1 through State 1	8 miles
B_2 through State 2	6 miles

The generic MRS falls somewhere between the two MRS locations A and B. Let G_1 and G_2 represent the generic MRS route links through State 1 and State 2, respectively. The mileage of link G_1 through State 1 is the sum of one half of the mileage for A_1 and one half of the mileage of B_1, as

$$\text{Miles of } G_1 = \frac{1}{2} \text{ miles of } A_1 + \frac{1}{2} \text{ miles of } B_1$$

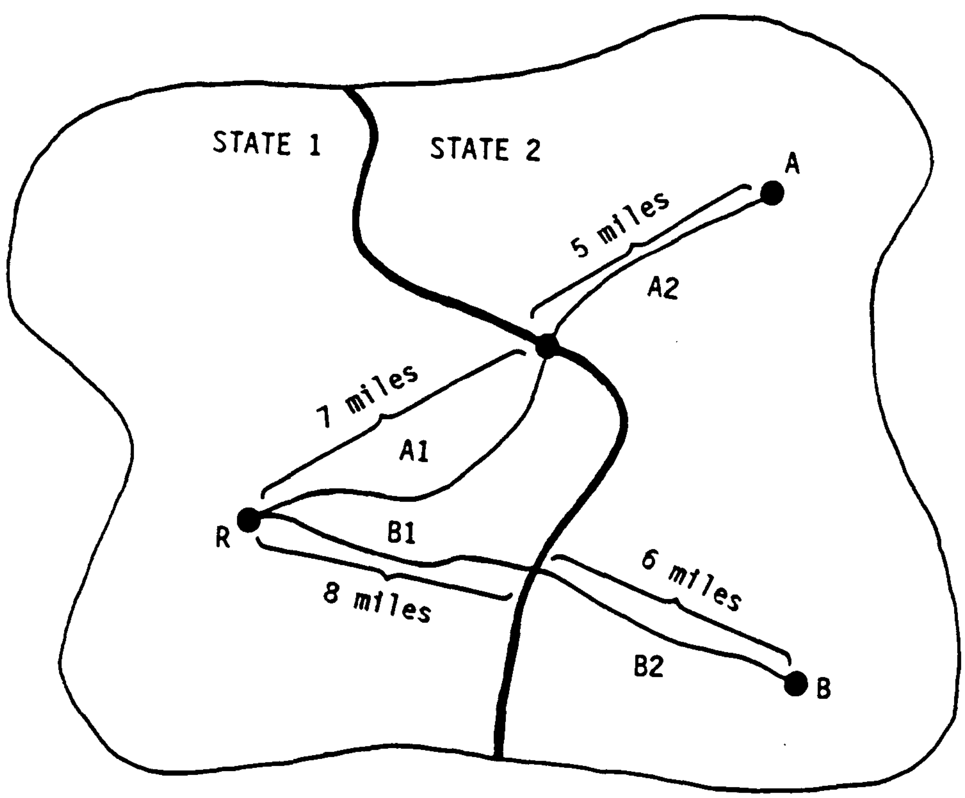

Figure B-3. Example of the TRICAM Route Links for Two Routes Transversing One State Boundary

Similarly for link G_2 for State 2. So the generic route consists of links

$$G_1 \text{ through State 1 for } \frac{7 + 8}{2} = 7.5 \text{ miles}$$

$$\text{Total } \frac{G_2}{(G_1 + G_2)} \text{ through State 1 and 2 for } \frac{5 + 6}{2} = \frac{5.5}{13} \text{ miles}$$

Note that the total length of the generic route is the average of the lengths of the two centroid routes.

Total miles of route	A	12
Total miles of route	B	14

Total miles of generic route $\overline{13}$.

Figure B-4 expands the example of Figure B-3 by considering links that traverse three population zones and one State boundary.

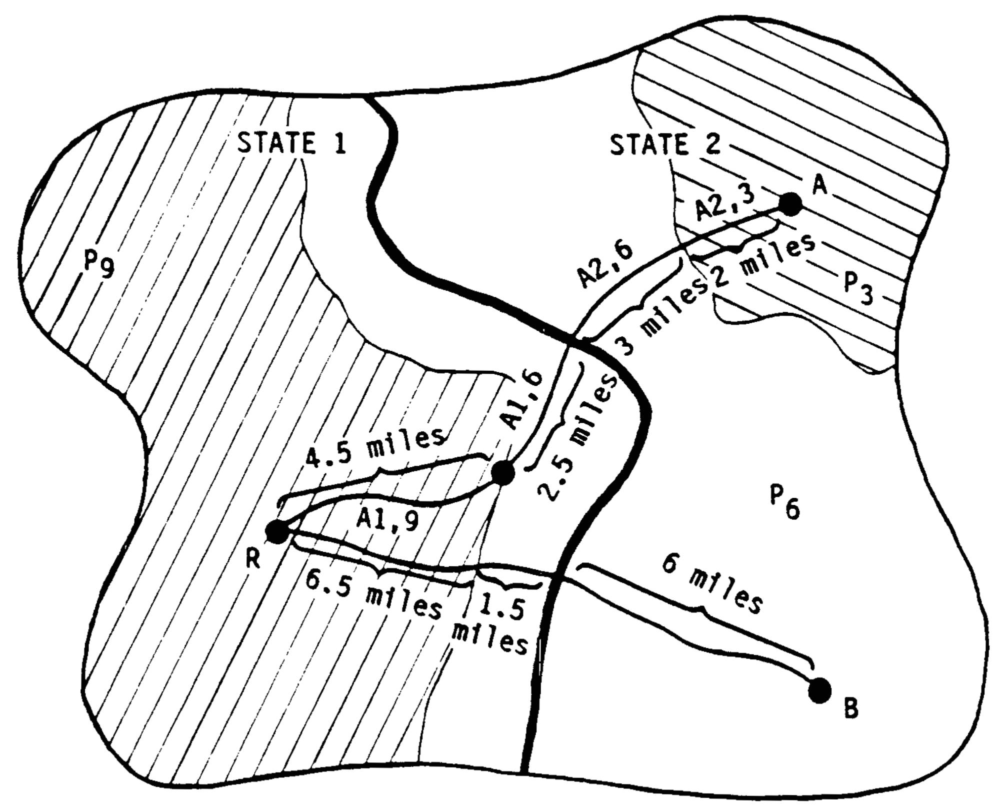

Figure B-4. Example of the TRICAM Route Links for Two Routes Transversing One State Boundary and Three Population Zones

If the generic link for State 1 and population zone Pg is designated as G_{19}, the mileage of G_{19} is the average of the mileages of A_{19} and B_{19}, e.g.,

$$\text{Miles of } G_{19} = \frac{1}{2} \text{ miles of } A_{19} + \frac{1}{2} \text{ miles of } B_{19}$$

$$= \frac{1}{2} \cdot 4.5 + \frac{1}{2} 6.5 = 5.5$$

Similarly the mileage for G_{16}, G_{26}, and G_{23} is

$$\text{Miles of } G_{16} = \frac{1}{2} \cdot 2.5 + \frac{1}{2} \cdot 1.5 = 2$$

$$\text{Miles of } G_{26} = \frac{1}{2} \cdot 3 + \frac{1}{2} \cdot 6 = 4.5$$

$$\text{Miles of } G_{23} = \frac{1}{2} \cdot 2 + \frac{1}{2} \cdot 0 = 1$$

Total miles of all links = 13

Note again that the total miles of all links is the average of the distances from R to the two MRS centroids A and B.

APPENDIX C

TRICAM: THE TRANSPORTATION RISK AND COST ANALYSIS MODEL FOR THE CIVILIAN RADIOACTIVE WASTE MANAGEMENT PROGRAM

TRICAM: THE TRANSPORTATION RISK AND COST ANALYSIS MODEL

FOR THE CIVILIAN RADIOACTIVE WASTE MANAGEMENT PROGRAM

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ABSTRACT

This is the second paper on the subject of the application of optimization techniques to decision making in the Transportation Program of the Office of Civilian Radioactive Waste Management (OCRWM). The first paper (1) described at a conceptual level the optimization approach and its application to decision making. The earlier paper also presented a general description of TRICAM, under development at that time, which would enable the comparison of transportation system alternatives on the basis of the optimal costs and risks achievable under each alternative. TRICAM has since been completed and the present paper is intended to document its features and capabilities at a detailed level.

INTRODUCTION

While the 1987 amendment to the Nuclear Waste Policy Act of 1982 (2) gave a new direction to the overall radioactive waste disposal program, the transportation component of the program remained virtually unchanged in scope but with increased attention to potential impacts, reflecting the reality that however the rest of the program develops, the radioactive waste will need to be transported safely and cost-effectively from reactors to the disposal site.

Moreover, since the sources of the waste are located predominantly in the East, and the permanent disposal facility is likely to be located in the West, the waste will have to be transported across wide sections of the country. Thus, transportation remains an important component of the waste management system and one in which there is a great deal of interest among the public, the Congress, and the utilities.

During the next several years, the OCRWM transportation program will need to make significant system, equipment, and operational decisions. This will require the evaluation of a wide range of options, from which the option to be implemented will be selected. A rational and defensible decision-making process is critically needed, to ensure that the transportation system eventually selected will receive the approval and support of the public, the Congress, and the utilities, all of whom will undoubtedly continue to scrutinize the program closely.

Thus, it is important that the decisions made in the selection of the transportation system are sound, and demonstrably based on defensible comparisons of alternatives. Furthermore, the basis of selection must give due regard to the two policy objectives of safety and cost-effectiveness. Optimization techniques provide a basis for accomplishing this.

THE OCRWM SYSTEM AS MODELED IN TRICAM

TRICAM is designed to optimize the transportation component of the OCRWM system which consists of the transportation system, one or more repositories, and possibly monitored retrievable storage (MRS) or some other interim storage facilities. Although reactors are not part of the OCRWM system, they are, nevertheless, modeled in TRICAM. The spent fuel to be transported by OCRWM is generated and stored there so inclusion of the reactors is necessary to "close" the system modeled in TRICAM. Recognizing that the focus in TRICAM is on transportation, however, the costs and risks incurred at the reactors and the other OCRWM components are modeled in general terms compared to transportation costs and risks which are modeled in considerable detail.

Figure 1 is a schematic representation of the OCRWM system as modeled in TRICAM. It depicts, for a single year, the various 'paths' available to move the SNF from a reactor pool to the repository, which is the *permanent* disposal site. Fuel discharged from reactors is placed in a storage pool for cooling. After it has been cooled sufficiently, it can be placed into dry casks stored in the open at the reactor site. The transfer of SNF into the dry casks takes place in the pool. Under existing technology, the SNF would be transferred back into the pool for loading into a transport cask for shipment.

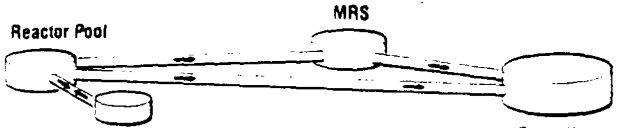


Figure 1. Schematic Representation of Spatial Network Modeled in TRICAM (*single reactor shown*)

As an alternative to extended storage at the reactor, SNF can be shipped to the repository directly, or to a temporary storage facility from which it can be shipped to the final disposal site at a later date.

Inventories in the reactor pools, in dry storage at reactors, at the MRS, and at the repository provide the year-to-year linkage in TRICAM. The combined spatial-temporal network (for a single reactor) may be depicted schematically as shown in Fig. 2. Clearly, there are innumerable 'paths' through space and time along which SNF from a reactor can reach its final destination at the repository. The number of paths run into the millions for the complete network containing all the reactors. TRICAM searches for the set of paths that would involve the least risk and/or cost for accomplishing the transfer of the SNF to the repository. Obviously, capacity limits at the facilities constrain the solution space.

Table I is a summary of the risks and costs that are included in TRICAM, indicating the scope of the optimization performed in TRICAM. As indicated above, TRICAM is designed to optimize only the transportation component of the OCRWM system, and not the total OCRWM system. Therefore, certain risks and costs that may be important in a system-wide optimization are specifically excluded from TRICAM. An example of such excluded risks and costs are those associated with repository and MRS operations.

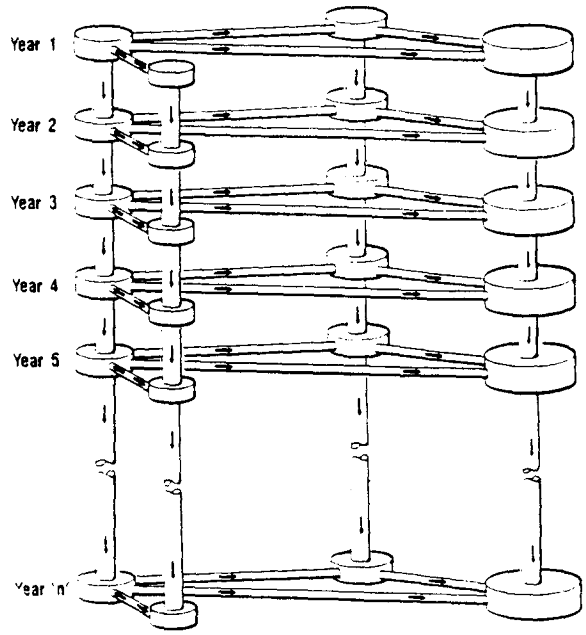


Figure 2. Schematic Representation of Spatial-Temporal Network Modeled in TRICAM (single reactor shown)

Table I
Risks and Costs Included in TRICAM

Risks and Costs Associated with Transportation:
- Loading
- Shipping
- En-route Security
- Cask Maintenance (cost only)
- Cask Capital Cost (cost only)
- Unloading

Other Risks and Costs at Reactors:
- Transfers between pool and dry storage casks
- Dry Storage Inventory (cost only)
- Pool Inventory (post-decomissioning costs only)

Other Risks and Costs at an MRS:
- Placement in yard storage
- Yard Inventory (cost only)
- Removal from yard storage

TRICAM INTERFACE WITH OTHER OCRWM CODES

An important feature of TRICAM is that it utilizes data generated by existing models which have been developed for OCRWM by other contractors. While this approach requires careful integration of extensive data from several external models, it has the advantage of ensuring consistency across the OCRWM program and of minimizing duplication. For example, Oak Ridge National Laboratory (ORNL) has generated rail and highway routes for the OCRWM program for many years using the INTERLINE (3) and HIGHWAY (4) models. ORNL is the source of route-specific data in TRICAM. Risk data are presently obtained from Argonne National Laboratory (ANL). Reactor data, comprising reactor names, pool capacities, locations, and historical and projected discharges are obtained from Battelle's Pacific Northwest Laboratories (PNL), which has had the responsibility of maintaining this database for the OCRWM program for many years (5). Only the transportation cost data, for which Battelle's Office of Transportation Systems & Planning (OTSP) has the responsibility, is generated internally. Figure 3 is a schematic representation of the interfaces between these various models and the integration of the external data in TRICAM.

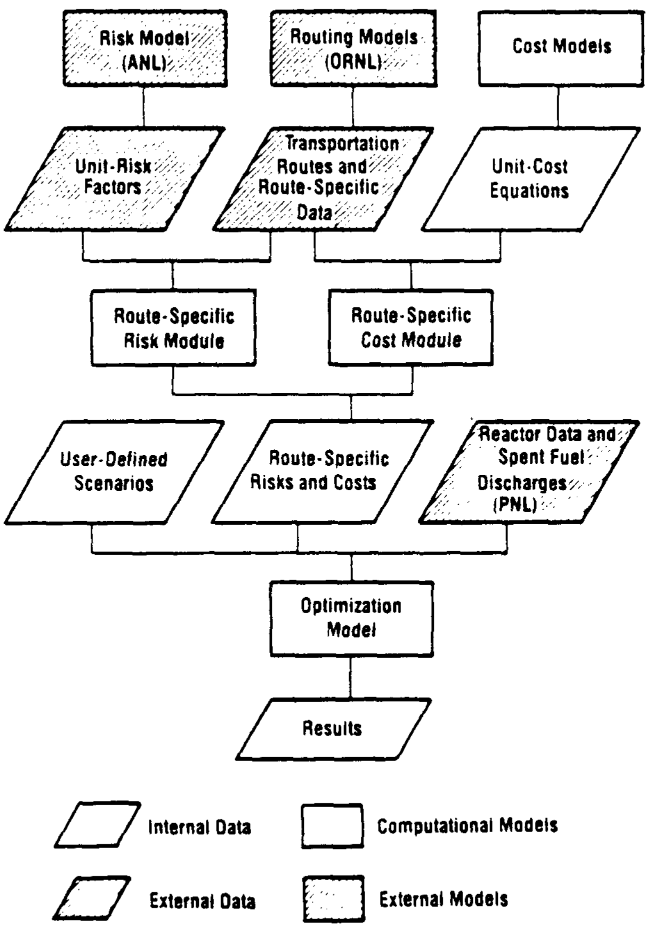


Figure 3. TRICAM's Interfaces with External Codes and Data

CODE DESCRIPTION

In this section, the five modules comprising TRICAM (see Fig. 4) are described in terms of their input requirements, the outputs, and their operation. The following section is a more detailed description of TRICAM's menu-driven user interface through which a user defines the scenario to be analyzed, including the data to be used. The five modules in TRICAM are:

- The SCREENER module which is the menu-driven user interface used to define the scenario to be analyzed.
- The MAKERSF module which calculates the route-specific risk and cost data for the user-defined scenario.
- The RDBB module which condenses the detailed route-specific data provided by ORNL. The condensed route database is accessed by MAKERSF.
- The OPTIMIZER module[a] which performs the optimization and outputs the results of the analysis in a series of tables.
- The CATALOG module which is an archiving system for the scenarios defined and analyzed using TRICAM. It is TRICAM's tracking and retrieval system for all analyses conducted using TRICAM.

The OPTIMIZER is the only module that uses large amounts of computer memory and requires a computer system with virtual memory, like the VAX family of computers. All the other TRICAM modules have been designed for implementation on an IBM Personal Computer. Once the scenario is defined and the input files necessary for the OPTIMIZER constructed on a personal computer, control is presently transferred to a mainframe VAX where the OPTIMIZER is executed. This arrangement has been found very cost-effective, especially during the developmental stage. It is also convenient from an application standpoint, since analysts can specify and set up a TRICAM analysis entirely on their personal computers. TRICAM has been developed in a manner to simplify transfer to a VAX, should potential users express interest an all-VAX version of TRICAM.

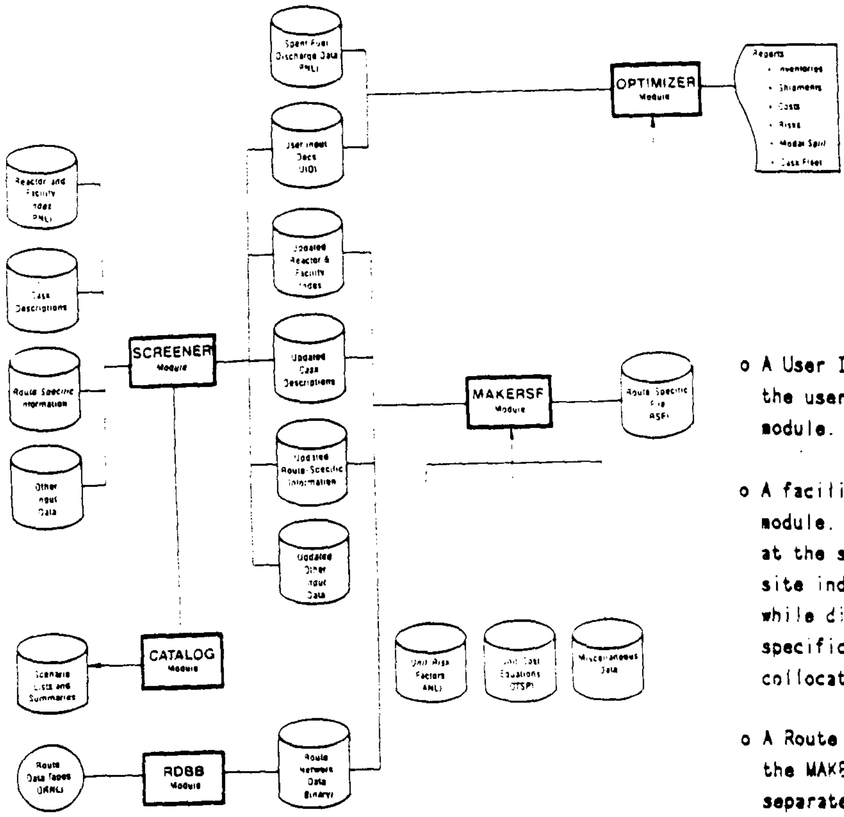


Figure 4. TRICAM Data Flow Structure

The SCREENER Module

SCREENER is a menu-driven editor through which a user defines the scenario to be analyzed. Recognizing that users will often want to analyze variants of a basic scenario, SCREENER is designed for creating entirely new scenarios, as well as modifying previously defined scenarios quickly and conveniently. A complete TRICAM scenario definition involves specification of the following four sets of data:

- o The OCRWM system, including the OCRWM facilities to be considered, the spent fuel discharge forecast to be used, and the reactors to be included in the scenario,

- o The CASK system,

- o The TRANSPORTATION system, including the origin-destination (O/D) network, and the available modes, service options, and number of casks per shipment,

- o Other input data, such as the minimum age of fuel to be transported, the relative weighting of the optimization criteria, namely risk and cost, the period of analysis, and the specification of the level of output detail desired, etc.

SCREENER generates four output files, corresponding to the scenario defined by the user, one of which is used in the OPTIMIZER module and the other three in the MAKERSF module. These are:

- o A User Input Deck (UID) file. This file contains the user-defined data required to run the OPTIMIZER module.

- o A facility and reactor index, used by the MAKERSF module. The index maps individual reactors located at the same geographic coordinates into a common site index. This mapping is required because while discharge and other data is reactor specific, the transportation routes from collocated reactors are identical.

- o A Route Specific Information (RSI) file, used by the MAKERSF module. The default RSI contains separate records for all possible O/D pairs for each of the two available modes, rail and truck. The records define each O/D pair in terms of the following data:

    - INIS number of the originating reactor
    - Identification code for the destination
    - Service option, such as regular or dedicated rail service
    - Transportation mode (truck or rail)
    - Number of casks per shipment
    - Cask identification code (CASK ID)
    - Route identification code

- o A file containing data on the cask systems defined by the user in the current scenario. These data are used in the MAKERSF module.

The data flows from SCREENER to the MAKERSF and the OPTIMIZER modules are depicted in Fig. 4. The operations performed in the SCREENER module are described in further detail in the next section, using sample screens.

The MAKERSF Module

The MAKERSF module generates, for the specified scenario, a route-specific file (RSF), which is one of the two data files required by the OPTIMIZER module. The input data used by MAKERSF include the following:

- o The three files generated by SCREENER, as described above
- o A set of unit-risk factors
- o A set of unit-cost equations
- o O/D-specific mileage data generated by RDBB, described below
- o A set of miscellaneous data

Unit-risk factors. Only the route-specific transportation risks, i.e., risks associated with shipping between a given O/D pair are used in the MAKERSF. The other risks listed in Table I are associated with activities at the reactors and the facilities and are incorporated directly in the OPTIMIZER module.

For each of the two modes (truck and rail) eight categories of route-specific risk are required as inputs to the MAKERSF module. Six of these pertain to radiological exposure and two to non-radiological risks[b]. The route-specific risk data consist of a set of Unit Risk Factors (URFs) for each of the eight categories of risk included. The eight unit-risk factors, denoted URF1 to URF8, are classified into two categories relating to incident-free transportation and accident-related conditions, as shown in Table II.

Table II
Transportation Unit-risk Factors

	Incident Free	Accident Related
Radiological Risk:		
Off-Link Exposure	URF1	URF4
On-Link Exposure	URF2	URF5
Exposure at Stops	URF3	--
Ingestion	--	URF6
Non-Radiological Risk:	URF7	URF8

Separate URFs are provided for three land-use zones (urban, suburban, and rural), reflecting the differing construction and traffic density patterns, etc., in these zones. (For a detailed discussion of how these differences are incorporated, see Ref. 6). Additionally, the accident-related URFs are state-specific as they are based on state-level accident data for the 48 contiguous states.

Unit-cost equations. The route-specific transportation costs, i.e., the costs associated with shipping (which includes hauling, inspection at origin, and detention), and en-route security are used in the MAKERSF. Cask-specific costs, namely maintenance and capital cost, and the costs associated with activities at the reactors and the facilities (see Table I), are incorporated directly in the OPTIMIZER module.

Separate cost equations are available in the MAKERSF module for each of the two modes. Depending on the service option selected by the user for each O/D pair, truck costs can be calculated for shipments in individual trucks or in truck convoys. Likewise, rail costs can be calculated for regular or dedicated service.

Route data. The route data used in the MAKERSF provides a breakdown of the total mileage for the route by the States, road types, and population density categories traversed. The data is in binary form, and is created by the RDBB module (described below) from the route-data supplied by Oak Ridge. Although an exhaustive set of route data is computed, i.e., for all rail and truck routes from all origin sites (collocated reactors are combined into a single origin site) and destinations, MAKERSF operates on a subset of this data corresponding to the RSI file created for the user-specified scenario.

Miscellaneous Data. The miscellaneous data file used in MAKERSF contains the following data:

- o A table assigning, for each state, the twelve population density categories used in TRICAM to one of the three zones (urban, suburban, and rural).
- o Average values of population density for each of the twelve zones. It is these average values that are used in calculating the route-specific risk (described below).
- o Miscellaneous constants and parameters, such as the intercepts and slopes for the cost, speed and stop-time equations.

The output of the MAKERSF module is the Route Specific File (RSF), one of the two files required by the OPTIMIZER module. The RSF consists of two parts. The first part contains data for each CASK ID, as defined by the user. The second part consists of a series of route-specific records for each mode and route activated in the RSI. For each route, the RSF contains data on the per-shipment costs, the per-shipment risks, round-trip transit time, number of casks per shipment, and one-way mileage.

MAKERSF generates RSF route records for those RSI records corresponding to the reactors included in the analysis. For each such RSI record, MAKERSF performs the following operations:

a. Reads the origin, destination, mode, and CASK ID specified in the RSI record.
b. For the given O/D pairs, identifies the corresponding site using the site index, and obtains the requisite route-specific mileage data (for the appropriate mode) from the route database. (At this point, all information required to calculate route-specific risks and costs is available in memory).
c. Calls the route-specific risk sub-program and calculates the per-shipment risk for the O/D pair.
d. Calls the route-specific cost sub-program and calculates the per-shipment costs for the O/D pair.
e. Writes the record pertaining to this O/D pair to the RSF file.

This process continues until the RSI records are exhausted. At completion, there is one RSF record for every user-selected O/D pair, mode, and CASK ID.

The RDBB Module

The RDBB (route database build module) condenses route-data supplied by ORNL and stores it in binary form for use in TRICAM. This makes the input-output (I/O) operations direct and efficient.

The input to the RDBB module is in the form of magnetic tapes supplied by ORNL. These tapes contain route data from all possible origin sites (including generic reactor sites identified by PNL for the lower- and upper-reference spent fuel discharge projections). The route-data describes each link of every route, by the state in which the link falls, the road type, the mode, an urban/rural classification flag, and sundry other characteristics. In addition, the total mileage on each link is provided, and this is further disaggregated into the miles traversed through each of the twelve population density categories. This results in an extremely large data base, which would be difficult to manipulate in its received form.

The link-by-link data supplied by ORNL is intended to support other OTSP activities other than TRICAM analyses, such as map generation. All TRICAM calculations can be performed if the route mileage data is available by state, road type, and population density. Therefore, the extensive ORNL data is aggregated by state, road type, and population density, and translated into two binary files. The first file contains a multidimensional table that holds the address of the data stored in the second file. The second file contains the actual mileage data.

The OPTIMIZER Module

The algorithm used to perform the actual optimization in TRICAM is NETFLO, which is a network optimization model that has been documented in the literature (7). The inputs to the OPTIMIZER are:

o The RSF file generated by MAKERSF
o The UID file generated by SCREENER
o The reactor data and spent-fuel discharges provided by PNL. These data are updated annually by PNL. The latest of these series (5) is incorporated in TRICAM currently, and will be replaced when updated data becomes available.

With this data, the OPTIMIZER computes a solution that minimizes the value of the objective function which can range from pure-cost to pure-risk, or any weighted combination in between. A discussion of the objective function in TRICAM is provided in the earlier paper (1). The solution includes, in addition to the optimal risks and costs, information on the inventories at the reactors and the facilities in each year, annual shipment quantities, the transportation modes, modal split, and cask fleet mix. Through the SCREENER module, the user can either obtain this data in the form of annual summary tables or on a reactor-by-reactor basis. Due to limitations on manuscript length, a detailed description of the various tables generated by TRICAM is not provided here. Instead, interested readers are urged to write to the authors who would be happy to supply a complete sample set of the output tables.

The CATALOG Module

CATALOG is TRICAM's scenario archiving and tracking system that, in the authors view, will prove invaluable to users over the long run. In the OCRWM program, retrievability and duplicability of results is an important consideration. In that sense, CATALOG serves as a "QA manager" for analyses conducted using TRICAM.

This module collects and catalogs information describing the TRICAM scenarios. Once a scenario has been defined, the user can elect to catalog it. This action causes CATALOG to prompt the user for a brief description characterizing the scenario which is stored along with the scenario name in a text file.

This text file is the single output of the CATALOG module. Associated with this scenario, CATALOG keeps all the input files constructed by the user for this particular scenario, including the UID which defines the reactor and spent fuel discharge data used in the scenario.

TRICAM USER-INTERFACE

One of the prime design objectives for TRICAM was to expand the user base as much as possible. This has been accomplished by designing a menu-driven user-friendly interface for TRICAM, referred to as the SCREENER module. Some codes developed for OCRWM in the past require extensive data input in a manner that is quite cumbersome. Thus, few people outside the code development teams have found these codes practical to use. By making its codes accessible and user-friendly, OCRWM can facilitate the use of common data and models by its various contractors, as well as other interested groups. In the author's view, this will engender confidence in OCRWM's analyses and facilitate reconciliation of any parallel analyses that different groups may perform.

The SCREENER module has been described in general terms above. In this section, the reader is 'walked' through an exemplary session, using examples of some of the menus available to specify a TRICAM run.

After the welcome screen (Fig. 5), the main menu (Fig. 6) appears. This screen allows the user to modify a previously defined scenario, generate a new scenario, or review any scenario. In the example shown on Fig. 6, the user has chosen to create a new scenario named 'SAMPLER'. When the 'Create New Scenario' option is selected, the screens come up with the set of default data which represents the 'reference' transportation system.

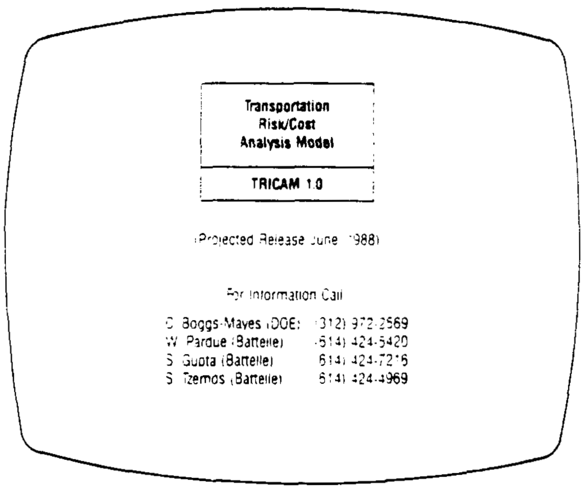


Figure 5. Welcome Screen

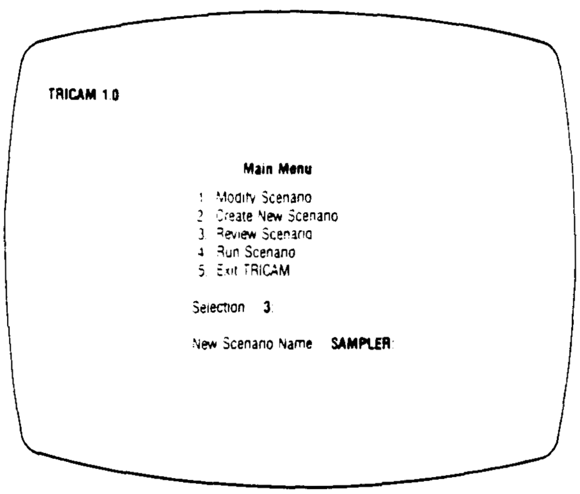


Figure 6. Main-Menu

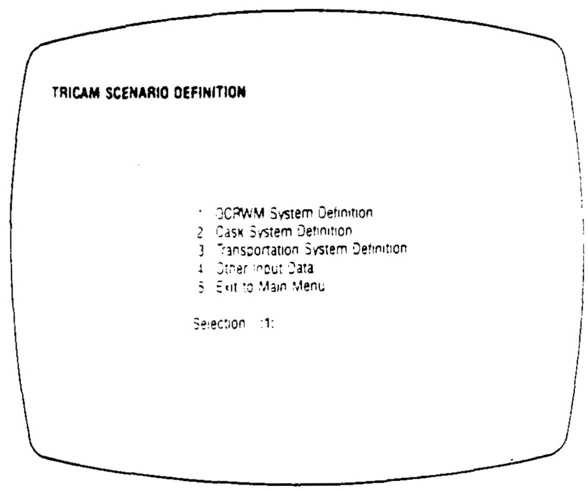


Figure 7. Scenario Definition Process

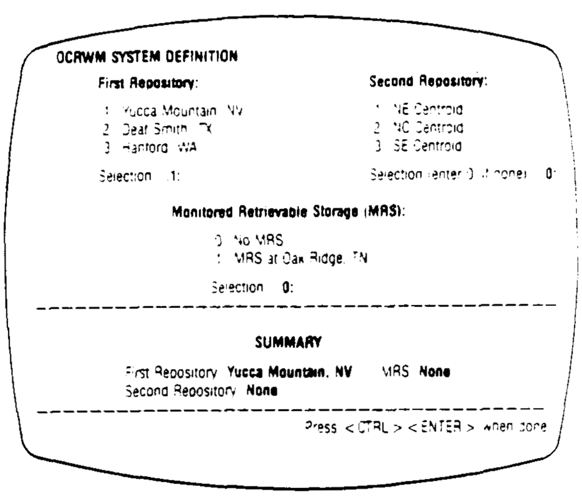
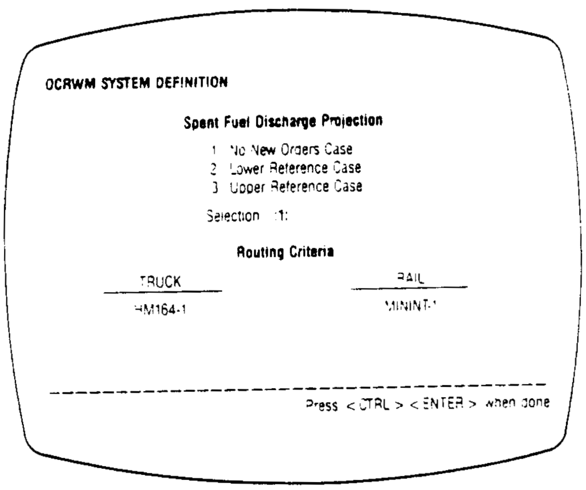


Figure 8. OCRWM Sytem Definition: Facilities

The next screen starts the scenario definition process (Fig. 7). The scenario definition is complete only when all four options have been exercised. Figs. 8 through 10 are the three main screens for defining the OCRWM system. With these screens, the user specifies the facilities and reactors to be included, and the spent fuel discharge forecast to be used in the analysis. The cask system is defined with the screen shown in Fig. 11. The transportation system is defined through two screens (Figs. 12, 13), which are repeated for every destination included in the scenario. The first screen allows the user to set default values for type of service, number of casks per shipment, and the CASK ID. The second screen comes up with these default values, which the user can change on a reactor-by-reactor basis, if necessary.



OCRWM SYSTEM DEFINITION

Spent Fuel Discharge Projection

1 No New Orders Case
2 Lower Reference Case
3 Upper Reference Case

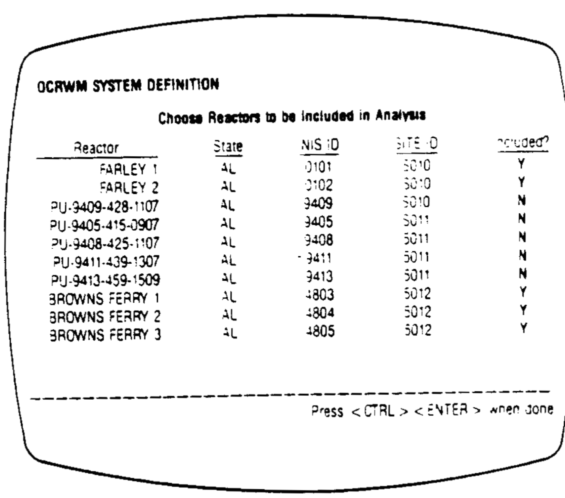
Selection :1:

Routing Criteria

TRUCK	RAIL
HM164-1	MININT-1

Press <CTRL> <ENTER> when done

Figure 9. OCRWM Sytem Definition: Spent Fuel Discharge Forecast



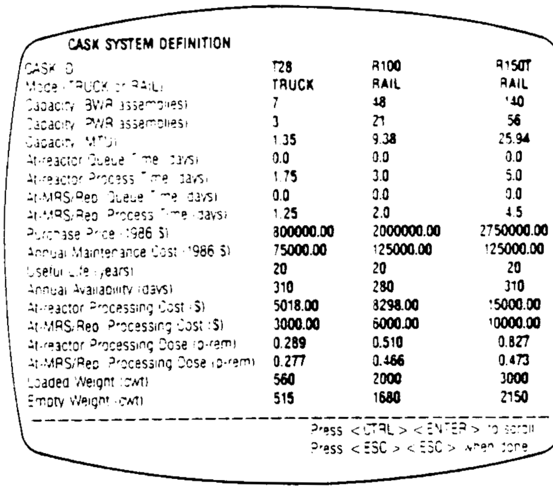
OCRWM SYSTEM DEFINITION

Choose Reactors to be Included in Analysis

Reactor	State	NIS ID	SITE ID	Included?
FARLEY 1	AL	0101	5010	Y
FARLEY 2	AL	0102	5010	Y
PU-9409-428-1107	AL	9409	5010	N
PU-9405-415-0907	AL	9405	5011	N
PU-9408-425-1107	AL	9408	5011	N
PU-9411-439-1307	AL	9411	5011	N
PU-9413-459-1509	AL	9413	5011	N
BROWNS FERRY 1	AL	4803	5012	Y
BROWNS FERRY 2	AL	4804	5012	Y
BROWNS FERRY 3	AL	4805	5012	Y

Press <CTRL> <ENTER> when done

Figure 10. OCRWM Sytem Definition: Reactors Included

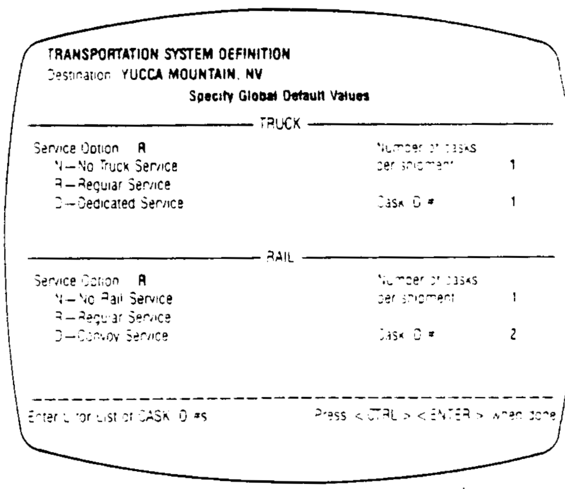


CASK SYSTEM DEFINITION

CASK ID	T28	R100	R150T
Mode (TRUCK or RAIL)	TRUCK	RAIL	RAIL
Capacity (BWR assemblies)	7	48	140
Capacity (PWR assemblies)	3	21	56
Capacity (MTU)	1.35	9.38	25.94
At-reactor Queue Time (days)	0.0	0.0	0.0
At-reactor Process Time (days)	1.75	3.0	5.0
At-MRS/Rep Queue Time (days)	0.0	0.0	0.0
At-MRS/Rep Process Time (days)	1.25	2.0	4.5
Purchase Price (1986 $)	800000.00	2000000.00	2750000.00
Annual Maintenance Cost (1986 $)	75000.00	125000.00	125000.00
Useful Life (years)	20	20	20
Annual Availability (days)	310	280	310
At-reactor Processing Cost ($)	5018.00	8298.00	15000.00
At-MRS/Rep Processing Cost ($)	3000.00	6000.00	10000.00
At-reactor Processing Dose (p-rem)	0.289	0.510	0.827
At-MRS/Rep Processing Dose (p-rem)	0.277	0.466	0.473
Loaded Weight (cwt)	560	2000	3000
Empty Weight (cwt)	515	1680	2150

Press <CTRL> <ENTER> to scroll
Press <ESC> <ESC> when done

Figure 11. Cask System Definition



TRANSPORTATION SYSTEM DEFINITION
Destination **YUCCA MOUNTAIN, NV**

Specify Global Default Values

TRUCK

Service Option **R**
N—No Truck Service
R—Regular Service
D—Dedicated Service

Number of casks per shipment 1
Cask ID # 1

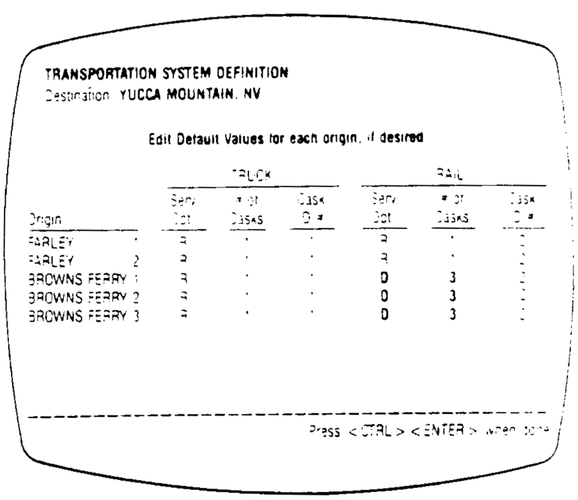
RAIL

Service Option **R**
N—No Rail Service
R—Regular Service
D—Convoy Service

Number of casks per shipment 1
Cask ID # 2

Enter L for List of CASK ID #s
Press <CTRL> <ENTER> when done

Figure 12. Transportation System Definition: Global Defaults



TRANSPORTATION SYSTEM DEFINITION
Destination **YUCCA MOUNTAIN, NV**

Edit Default Values for each origin, if desired

	TRUCK			RAIL		
Origin	Serv Opt	# of Casks	Cask ID #	Serv Opt	# of Casks	Cask ID #
FARLEY 1	R	[illegible]	[illegible]	R	[illegible]	[illegible]
FARLEY 2	R	[illegible]	[illegible]	R	[illegible]	[illegible]
BROWNS FERRY 1	R	[illegible]	[illegible]	D	3	[illegible]
BROWNS FERRY 2	R	[illegible]	[illegible]	D	3	[illegible]
BROWNS FERRY 3	R	[illegible]	[illegible]	D	3	[illegible]

Press <CTRL> <ENTER> when done

Figure 13. Transportation System Definition by Individual Origin-Destination

Finally, the screen shown in Fig. 14 is used to specify the remaining input data to complete the scenario and define the run parameters, such as the minimum age of fuel to be transported, cost/risk weighting factors, output tables, etc. Once this screen has been completed, the user is returned to the main menu. The user can review the scenario and/or select the "Run Scenario" option. This executes the MAKERSF module, which prepares the input files required to execute the OPTIMIZER module on the VAX computer.

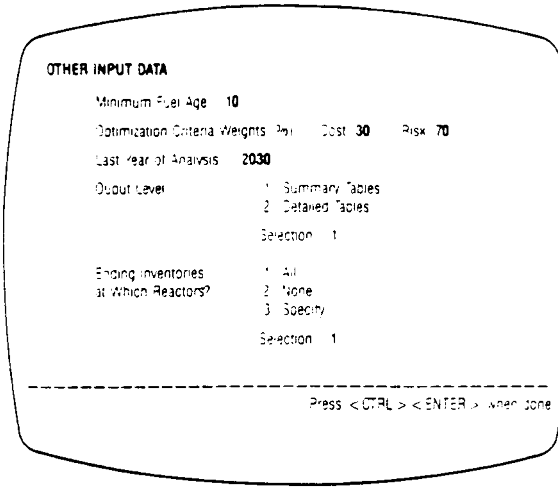


Figure 14. Other Input Parameters

Notes:

a. This module was developed for OTSP by Battelle's Pacific Northwest Laboratories.

b. In the current version of TRICAM, optimization can be performed only for radiological risk. To combine radiological risk (measured in person-rem) with non-radiological risks (measured in fatalities), the former needs to be converted to fatalities. While this transformation is simple, presently the risks not directly associated with transportation (see Table I) are hardcoded in units of person-rem. Thus, some (minor) re-coding is required to enable optimization on combined risk. This capability will be provided in TRICAM if it is found to be of interest to users.

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