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Comparative Analyses of Spent Nuclear Fuel Transport Modal Options: Transport Options Under Existing Site Constraints

Technical Report

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ABSTRACT

The movement of nuclear waste can be accomplished by various transport modal options involving different types of vehicles, transport casks, transport routes, and intermediate intermodal transfer facilities. A series of systems studies are required to evaluate modal/intermodal spent fuel transportation options in a consistent fashion.

This report provides total life-cycle cost and life-cycle dose estimates for a series of transport modal options under existing site constraints.

FOREWORD

The National Waste Terminal Storage Program was established in 1976 by the U.S. Department of Energy's predecessor, the Energy Research and Development Administration. In September 1983, this program became the Civilian Radioactive Waste Management (CRWM) 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 reprocessing.

The information in this report covers nuclear waste transport modal option studies for the CRWM Program.

EXECUTIVE SUMMARY

Life-cycle cost and life-cycle dose estimates have been made for a series of transport modal options pertaining to the "No-New Orders-'86" nuclear waste scenario. The NNO-'86 scenario encompasses 125 reactor plants and waste pools.

Based on current cost data, the findings indicate that truck transport is considerably more expensive than rail transport. An "all legal-weight truck" case was estimated to cost 2.1 billion dollars (\$24/kg). An "all-rail" case, involving several intermodal transfers, was costed at 1.5 billion dollars (\$17/kg).

The lowest cost was obtained for a case using legal-weight (LWT), rail, and overweight truck (OWT) casks to the extent that crane capacity at the nuclear plants is adequate. The cost for this case was 1.3 billion dollars (\$14/kg). Until OWT permit issues are resolved, the results of this case must be considered as a hypothetical construct only.

Total life-cycle doses range from a high 1.0 person-rem/MTU for the LWT case to 0.18 person-rem/MTU for the rail case. Public doses are considerably less.

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ABBREVIATIONS

ALARA	as low as reasonably achievable (radiation protection criteria)
BWR	boiling-water reactor
CASKCOM	<u>Cask Cost Model (computer code)</u>
CFR	<u>Code of Federal Regulations</u>
DOE	U.S. Department of Energy
FIS	Federal Interim Storage
HHT	heavy-haul truck
HLW	high-level radioactive waste
HRC	hefty rail cask (125-ton)
IMT	intermodal transfer (e.g., truck to rail)
kg	kilogram
LCC	life-cycle cost
LCD	life-cycle dose
LCF	latent cancer fatality
LO/LO	lift-on/lift-off (type of intermodal transfer)
LWT	legal-weight truck
LWTC	legal-weight truck cask
LWT/R	legal-weight truck cask shipped by rail
MTU	metric tons of uranium
NNO	No New Orders
NRC	U.S. Nuclear Regulatory Commission
NWPA	Nuclear Waste Policy Act of 1982
NWPAA	Nuclear Waste Policy Amendments Act of 1987
OCRWM	Office of Civilian Radioactive Waste Management
OWT	overweight truck
OWTC	overweight truck cask
PNL	Pacific Northwest Laboratory
PWR	pressurized-water reactor
RADTRAN	computer code to estimate radiological dose during high-level waste transport
RC	regular rail cask (100-ton)
REP	repository
RH	rail head
RO/RO	roll-on/roll-off (type of intermodal transfer)
RR	regular rail cask (100-ton) shipped by rail
SFA	spent fuel assembly
SNF	spent nuclear fuel

1.0 INTRODUCTION

In the Nuclear Waste Policy Act (NWPA) of 1982 (P.L. 97-425), the U.S. Department of Energy (DOE) was given the responsibility for managing the disposal of spent nuclear fuel (SNF) and high-level radioactive waste (HLW) from civilian sources. The DOE Office of Civilian Radioactive Waste Management (OCRWM) was established for that purpose. In December 1987, Congress amended the NWPA by passing the Nuclear Waste Policy Amendments Act (NWPAA) of 1987 (P.L. 100-203). This act was signed into law on December 22, 1987. These two acts currently govern HLW disposal in the United States. Some parts of these acts pertain to the waste transportation system which handles the movement of wastes from designated points of origin either directly, or indirectly via intermediate facilities, to the final waste repository.

The transportation casks are to be developed by private industry and to be certified by the U.S. Nuclear Regulatory Commission (NRC). The capacities of new casks that are to be developed differ considerably from the casks in current usage. Because the SNF to be shipped in the future will be substantially cooler and less radioactive than most fuel shipped to date, cask capacities are expected to be larger than the capacities of the current casks. Also, if fuel elements were to be consolidated prior to shipment, cask capacities would differ from the current versions.

The movement of nuclear waste could be accomplished by various transport modal options involving different types of vehicles, transport casks, transport routes, and intermediate intermodal transfer facilities. A series of systems studies are required to evaluate modal/intermodal spent fuel transportation options in a consistent fashion.

As indicated in the Transportation Institutional Plan (1), the modal/intermodal spent fuel transportation mix is an important transportation issue requiring that "OCRWM continue to analyze . . . modes of transport including relative safety, efficiency, capital costs, hauling costs, . . . shipping and receiving facility operations, (and) environmental impacts." Similarly, the OCRWM Systems Engineering Management Plan (2), specifies that system studies are necessary "to support the integration, evaluation, and optimization of the system." Finally, 10 CFR Part 961 (Standard Contract for Disposal of Spent Nuclear Fuel and/or High-Level Radioactive Waste) calls for DOE to prepare a reactor-specific service plan by early calendar year 1992, which includes specification of the service mode (3).

In the current study a comparative analysis of only a subset of feasible transport modal options is made. Specifically, the study is confined to the movement of SNF via rail and/or truck in the most direct way from the nuclear reactor plants to the Nevada Yucca Mountain site.* The analyses are further restricted to transport operations under existing site constraints, primarily related to cask handling capabilities and transport access. A no-MRS system is considered, i.e., no additional capital investments are required. Future studies will examine options that do require sizeable capital outlays for at-reactor site/facilities and intermodal transfer facilities.

*The Yucca Mountain site has been designated by Congress for characterization to determine its suitability as a location for a high-level nuclear waste repository.

The comparative analyses address two aspects of the problem: risk and cost. Risk is discussed from the viewpoint of life-cycle dose (LCD) to workers and the public under normal, non-accident operating conditions. Costs are also determined and compared on an overall life-cycle basis. Costs and risks of accidents have not been included in this preliminary assessment of modal options, because the radiological risks of such accidents are extremely low and would not affect the choices of modal transport options, especially at reactor sites. Accident analyses have been extensively addressed in other studies.

In the following sections, the scope of the current study is discussed, the bases and assumptions of the study are identified, and finally, the LCD and life-cycle cost (LCC) results for various transport modal options are given and compared.

2.0 SCOPE OF STUDY

2.1 COMPONENTS OF THE WASTE TRANSPORT SYSTEM

To carry out the comparative analyses of the set of feasible transport modal/intermodal options, it is convenient to think of the waste transport system as consisting of essentially four kinds of elements:

- Vehicles,
- Casks,
- Facilities, and
- Routes.

A modal/intermodal option can then be defined as a specific combination of these elements.

The vehicle category consists of trucks (three types), railcars, and barges, i.e.,

- Legal-weight trucks,
- Overweight trucks,
- Heavy-haul trucks,
- Railcars, and
- Barges.

The casks that generally go with these vehicles are:

- Legal-weight truck casks,
- Overweight truck casks,
- Regular rail casks,
- Hefty rail casks,
- Transportable storage casks, and
- Special transfer casks.

The last category of casks is needed only in connection with dry-transfer facilities in reactors which do not have adequate crane capacity to handle large rail casks.

The key facilities that comprise the waste-transport system are:

- Reactor pools,
- Dry transfer facilities,
- Interim storage facilities,
 - Independent Spent Fuel Storage Installation (ISFSI)
 - Federal Interim Storage (FIS)
 - Monitored Retrievable Storage (MRS)
- Railheads - off site,
- Barge slips
- Barge-rail transfer - off site, and the
- Repository.

When reactors are unloaded, the SNF is placed into storage pools to cool. When the SNF is ready to be shipped, it is wet-loaded in the pool into shipping casks and shipped off site.

For long-term onsite storage, Independent Spent Fuel Storage Installations could be used in conjunction with transportable storage casks. In this case, fuel would be first stored at the ISFSI in a storage cask and then shipped off site in the same cask. In another version, the fuel would be stored on site in a storage-only cask, then transferred to a rail cask and shipped off site.

Section 131(a)(3) of the NWSA also provides for Federal Interim Storage of not more than 1,900 MTU of SNF for civilian nuclear power reactors that "cannot reasonably provide adequate storage capacity at the sites of such reactors when needed to assure the continued, orderly operation of such reactors." No FIS facilities are planned at this time.

Finally, an MRS facility is being considered as an option to provide safe and reliable management of SNF and HLW.

In the current study, reactors falling into certain kinds of categories (e.g., pressurized-water reactor (PWR), boiling-water reactor (BWR), truck-serviced, etc.) are assumed to be lumped together into single nodes. These reactor nodes are characterized by the type of applicable available at-reactor waste handling and transport service category under consideration.

Because route information is basically a given in this study (see Section 3.3), the key waste transport system parameters can be reduced further to only three variables, i.e.,

- Vehicles,
- Casks, and
- Facilities.

The current study is confined to transportation options under existing site constraints and truck-rail options only. Thus the components of the waste transport system that need to be considered can be reduced to the following items:

- Vehicles
 - Legal-weight trucks (LWT),
 - Overweight trucks (OWT),
 - Heavy-haul trucks (HHT), and
 - Railcars (R).
- Casks
 - Legal-weight truck casks (LWTC),
 - Overweight truck casks (OWTC),
 - Regular rail casks (RC), and
 - Hefty rail casks (HRC).
- Facilities
 - Pools (P),
 - Railheads (RH), and the
 - Repository (REP).

With these 11 waste-system components, 7 transportation modal/intermodal options can be constructed for evaluation. These options are presented graphically in Figure 2-1, showing the point of origin, the vehicle and cask involved, and the final repository destination. Options (5) to (7) represent

intermodal transport (IMT), because both trucks and rails are used for one shipment.

Figure 2-1. Transport Modes

2.2 STUDY CASES

The shipment options discussed in Section 2.1 have been organized into 7 cases. The cases are briefly described below.

Case I

All Truck (LWT) - This represents a somewhat artificial, but bounding case where it is postulated that all shipments from reactor pools to the repository are performed via LWTs.

Case II

Base Case (LWT/R) - In the base case, reactors that can be serviced by rail are assumed to have their SNF shipped in regular rail casks by rail; the remaining reactors are serviced by LWTs.

Case III

Overweight Trucks (LWT/OWT/R) - In this case, the truck-serviced reactors are divided into two groups: those that can handle OWTCs and those that can only handle LWTCs. The first group ships their SNF by OWT; the second group uses LWTs. The remaining casks are shipped via regular rail.

Case IV

Overweight/Hefty-Rail Casks (LWT/OWT/R/HRC) - In Case IV, the truck-serviced reactors ship by OWTs or LWTs as in Case III. The rail-serviced reactors ship in HRCs wherever adequate crane capacity permits it. The remaining rail-serviced reactors ship in regular rail casks.

Case V

Overweight by Rail (LWT/OWT[R]/R/HRC) - This is the first IMT case. OWT[R] means OWT casks are shipped long distance by rail. In this case the casks are expected to be transported by truck to the nearest railhead and transferred to railcars and then shipped by rail. The remainder of the shipments are treated as in Case IV.

Case VI

Overweight and Legal Weight by Rail (LWT[R]/OWT[R]/R/HRC) - In Case VI, an IMT case, it is assumed that all truck casks, LWTs and OWTs, are trucked to the nearest RH and transferred to rail for shipment to the repository.

Case VII

Heavy-Haul Truck (HHT) - Case VII is divided into three subcases, all involving the use of HHTs. Among the reactors that are currently not serviced by rail, there are quite a few that do have the necessary crane capacity to handle regular and heavier rail casks but do not have direct rail access. In Case VII it is assumed that heavy-haul trucks can haul 100-ton rail casks from these reactors to the nearest railhead for transfer to rail and shipment to the repository.

Case VIIa

(HHT[R]/OWT/LWT/R/HRC) - In the IMT Case VIIa, HHTs are used to haul 100-ton rail casks to the nearest railhead for transfer from otherwise truck-serviced nuclear plants. The remaining truck-serviced plants ship their SNF by LWT and OWT.

Case VIIb

(HHT[R]/OWT[R]/LWT/R/HRC) - The IMT Case VIIb is like Case VIIa, except that the residual OWTCs are transshipped by rail from the nearest railhead.

Case VIIc

(HHT[R]/OWT[R]/LWT[R]/R/HRC) - The IMT Case VIIc is like Case VIIb, except that the LWTCs are also transshipped by rail from the nearest railhead.

2.3 NUCLEAR PLANT DATA

The study encompasses the entire U.S. reactor industry, including nuclear power plants as well as nuclear waste storage pools. Several U.S. nuclear

capacity projections have been made for the intermediate term through 2000, and the long term, through 2020. These projections, summarized in Reference (4), fall under the headings of a "Lower Reference," "Upper Reference," and "Optimistic" case. One of the projections derived from these cases is the so-called "No New Orders" (NNO) case, which consists of existing nuclear plants and nuclear power generating units in the construction pipeline, i.e., committed and likely to go on line, as of December 31, 1986. For this study, the No New Orders - 1986 (NNO-1986) case has been adopted as the starting point. This is appropriate because the site/facilities constraints important to and used in this study are "known." Pacific Northwest Laboratory (PNL) has listed and described reactors and storage pools covering this case in Reference (5), as well as lifetime SNF discharge data (in MTU).

For the study, it is further assumed that all nuclear plants can be lumped together into one or more reactor nodes. Distances for both truck and rail service from these nodes to the Nevada Yucca Mountain site have been taken from References (6) and (7). The reactor node-repository distances represent MTU-weighted averages.

As part of the Reactor Data Analysis Program's reactor-specific database task, PNL has provided shipping mode capability information for each reactor. The bases for this information are 1984, 1985, and 1986 RW-859 Nuclear Fuel Data Forms provided by the utilities. The reactor-specific cask handling capabilities are derived from these data and categorized as 25 tons or 40 tons if truck is the only form of transport. In case the data indicate that rail shipments are feasible, a distinction was made between 100-ton and 125-ton capability. For purposes of this study, the PNL shipping mode capability categorization has been adopted.

All of this information is summarized for 118 nuclear reactor plants and 7 nuclear waste storage pools in Table 2-1. Using the information in Table 2-1, total SNF discharge quantities in MTU and MTU-weighted average distances were calculated for specific categories of reactors designated by mode of transport and by pool/cask handling capabilities. This information is summarized in Table 2-2.

As noted in Table 2-2, a total of 86,779 MTU shipments of SNF are encompassed in the NNO-1986 case. In terms of MTU shipped, the actual PWR/BWR split is 65/35. This compares with a 60/40 split assumed in the PNL ALARA Study (8). The actual life-cycle levelized rail/truck split is 56/44, which compares to the 70/30 used in the 1987 PNL study. This comparison is noted to acknowledge the difference between current data and past assumptions.

The percentage cask handling capabilities for all facilities are as follows:

25-ton handling	100% of all nuclear plants
40-ton handling	92.5% of all nuclear plants
100-ton handling	58.7% of all nuclear plants
125-ton handling	41.3% of all nuclear plants.

The 25-ton truck cask can be handled at all reactor facilities. The 125-ton casks can be handled at 41.3% of all nuclear plants.

Table 2-1. Detailed Reactor/Storage Pool Data for the Transport Modal Option Study

Facility Name	State	Type of Fuel	MTU Discharged Thru Life	Distance to Yucca Mtn. Site (mi)		Nominal Handling Capability (tons)	Transport Mode
				Highway	Rail		
Arkansas Nuclear 1	AR	PWR	645.151	1744	2066.60	100	R
Arkansas Nuclear 2	AR	PWR	633.809	1744	2066.60	100	R
Beaver Valley 1	PA	PWR	671.020	2347	2572.40	125	R
Beaver Valley 2	PA	PWR	728.380	2347	2572.40	125	R
Bellefonte 1	AL	PWR	804.769	2302	2602.40	125	R
Big Rock 1	MI	BWR	73.226	2391	2481.00	25	T
Braidwood 1	IL	PWR	822.735	1902	2060.80	125	R
Braidwood 2	IL	PWR	813.006	1902	2060.80	125	R
Browns Ferry 1	AL	BWR	1005.685	2279	2365.40	40	T*
Browns Ferry 2	AL	BWR	1040.852	2279	2365.40	40	T*
Browns Ferry 3	AL	BWR	994.018	2279	2365.40	40	T*
Brunswick 1	NC	BWR	810.307	2836	3032.90	40	T
Brunswick 1 Pool	NC	PWR	71.342	2836	3032.90	40	T
Brunswick 2	NC	BWR	774.827	2836	3032.90	40	T
Brunswick 2 Pool	NC	PWR	65.534	2836	3032.90	40	T
Byron 1	IL	PWR	815.121	1862	2095.30	125	R
Byron 2	IL	PWR	810.468	1862	2095.30	125	R
Callaway 1	MO	PWR	834.714	1807	1834.40	40	T
Calvert Cliffs 1	MD	PWR	696.244	2714	2966.50	25	T
Calvert Cliffs 2	MD	PWR	712.914	2714	2966.50	25	T
Catawba 1	SC	PWR	835.106	2628	2819.00	125	R
Catawba 2	SC	PWR	854.120	2628	2819.00	125	R
Clinton 1	IL	BWR	783.595	1927	2077.30	100	R
Comanche Peak 1	TX	PWR	923.801	1747	1693.50	25	T
Comanche Peak 2	TX	PWR	913.499	1747	1693.50	25	T
Cook 1	MI	PWR	876.887	1985	2077.90	100	R

Table 2-1. Detailed Reactor/Storage Pool Data for the Transport Modal Option Study (Cont.)

Facility Name	State	Type of Fuel	MTU Discharged Thru Life	Distance to Yucca Mtn. Site (mi)		Nominal Handling Capability (tons)	Transport Mode
				Highway	Rail		
Cook 2	MI	PWR	796.613	1985	2077.90	100	R
Cooper Stn	NE	BWR	667.008	1516	1620.30	40	T
Crystal River 3	FL	PWR	668.419	2837	3009.10	40	T
Davis-Besse 1	OH	PWR	653.482	2186	2386.80	125	R
Diablo Canyon 1	CA	PWR	663.559	546	686.50	40	T*
Diablo Canyon 2	CA	PWR	660.293	546	686.50	40	T*
Dresden 1	IL	BWR	69.525	1900	2003.20	40	T
Dresden 2	IL	BWR	748.421	1900	2003.20	100	R
Dresden 3	IL	BWR	723.321	1900	2003.20	100	R
Duane Arnold	IA	BWR	540.209	1721	1793.60	40	T
Enrico Fermi 2	MI	BWR	1019.794	2179	2363.30	125	R
Farley 1	AL	PWR	778.500	2533	2956.10	125	R
Farley 2	AL	PWR	727.170	2533	2956.10	125	R
Fitzpatrick	NY	BWR	789.705	2622	2805.10	125	R
Fort Calhoun 1	NE	PWR	410.754	1458	1530.60	40	T
Ginna	NY	PWR	443.867	2533	2751.50	25	T
Grand Gulf 1	MS	BWR	1163.114	2080	2418.60	40	T
Haddam Neck	CT	PWR	535.127	2809	3104.30	40	T
Harris 1	NC	PWR	582.645	2732	2962.20	40	T
Harris 1 Pool	NC	BWR	0.000	2732	2962.20	40	T
Hatch 1	GA	BWR	864.507	2619	2898.60	125	R
Hatch 2	GA	BWR	844.062	2619	2898.60	125	R
Hope Creek 1	NJ	BWR	1066.180	2755	2946.50	40	T*
Humboldt Bay	CA	BWR	28.942	1003	1157.80	40	T
Indian Point 1	NY	PWR	30.584	2728	3021.80	40	T

Table 2-1. Detailed Reactor/Storage Pool Data for the Transport Modal Option Study (Cont.)

Facility Name	State	Type of Fuel	MTU Discharged Thru Life	Distance to Yucca Mtn. Site (mi)		Nominal Handling Capability (tons)	Transport Mode
				Highway	Rail		
Indian Point 2	NY	PWR	736.010	2728	3021.80	40	T
Indian Point 3	NY	PWR	720.268	2728	3021.80	40	T
Kewaunee	WI	PWR	515.215	2098	2213.50	40	T*
Lacrosse	WI	BWR	37.951	1944	2094.00	40	T
LaSalle City 1	IL	BWR	931.494	1875	2046.20	100	R
LaSalle City 2	IL	BWR	961.581	1875	2046.20	100	R
Limerick 1	PA	BWR	937.784	2755	2880.60	100	R
Maine Yankee	ME	PWR	767.259	3029	3242.90	100	R
McGuire 1	NC	PWR	833.875	2597	2881.50	125	R
McGuire 2	NC	PWR	862.737	2597	2881.50	125	R
Millstone 1	CT	BWR	707.584	2813	3115.00	40	T
Millstone 2	CT	PWR	650.149	2813	3115.00	100	R
Millstone 3	CT	PWR	883.642	2813	3115.00	125	R
Monticello	MN	BWR	376.738	1863	1932.70	40	T
Morris-B Pool	IL	BWR	432.020	1902	2001.20	125	R
Morris-P Pool	IL	PWR	132.062	1902	2001.20	125	R
Nine Mile Point 1	NY	BWR	648.411	2623	2804.30	100	R
Nine Mile Point 2	NY	BWR	882.165	2623	2804.30	125	R
North Anna 1	VA	PWR	701.833	2741	2788.60	125	R
North Anna 2	VA	PWR	700.328	2741	2788.60	125	R
Oconee 1	SC	PWR	795.869	2536	2768.50	40	T*
Oconee 2	SC	PWR	671.682	2536	2768.50	40	T*
Oconee 3	SC	PWR	761.666	2536	2768.50	40	T*
Oyster Creek 1	NJ	BWR	644.192	2791	3030.40	40	T*
Palisades	MI	PWR	579.234	2014	2107.90	40	T

Table 2-1. Detailed Reactor/Storage Pool Data for the Transport Modal Option Study (Cont.)

Facility Name	State	Type of Fuel	MTU Discharged Thru Life	Distance to Yucca Mtn. Site (mi)		Nominal Handling Capability (tons)	Transport Mode
				Highway	Rail		
Palo Verde 1	AZ	PWR	807.628	607	695.50	125	R
Palo Verde 2	AZ	PWR	826.693	607	695.50	125	R
Palo Verde 3	AZ	PWR	823.657	607	695.50	125	R
Peachbottom 2	PA	BWR	1010.950	2713	2859.60	40	T*
Peachbottom 3	PA	BWR	975.533	2713	2859.60	40	T*
Perry 1	OH	BWR	980.577	2290	2453.10	125	R
Pilgrim 1	MA	BWR	645.724	2922	3203.00	25	T
Point Beach 1	WI	PWR	446.767	2094	2145.50	40	T*
Point Beach 2	WI	PWR	436.602	2094	2145.50	40	T*
Prairie Island 1	MN	PWR	478.996	1858	1893.50	125	R
Prairie Island 2	MN	PWR	488.947	1858	1893.50	125	R
Quad Cities 1	IL	BWR	790.904	1770	2012.00	100	R
Quad Cities 2	IL	BWR	799.823	1770	2012.00	100	R
Rancho Seco 1	CA	PWR	617.827	680	821.00	40	T
River Bend 1	LA	BWR	872.937	2134	2676.10	125	R
Robinson 2	SC	PWR	503.986	2681	2865.00	40	T
Salem 1	NJ	PWR	881.505	2755	2953.00	40	T*
Salem 2	NJ	PWR	887.176	2755	2953.00	40	T*
San Onofre 1	CA	PWR	271.284	415	455.00	25	T
San Onofre 2	CA	PWR	802.402	415	455.00	125	R
San Onofre 3	CA	PWR	815.707	415	455.00	125	R
Sequoyah 1	TN	PWR	821.451	2318	2537.00	40	T*
Sequoyah 2	TN	PWR	825.486	2318	2537.00	40	T*
South Texas 1	TX	PWR	979.757	1862	2613.20	125	R
South Texas 2	TX	PWR	974.680	1862	2613.20	125	R

Table 2-1. Detailed Reactor/Storage Pool Data for the Transport Modal Option Study (Cont.)

Facility Name	State	Type of Fuel	MTU Discharged Thru Life	Distance to Yucca Mtn. Site (mi)		Nominal Handling Capability (tons)	Transport Mode
				Highway	Rail		
St. Lucie 1	FL	PWR	731.755	2957	3116.10	25	T
St. Lucie 2	FL	PWR	703.902	2957	3116.10	40	T*
Summer 1	SC	PWR	768.960	2600	2779.00	125	R
Surry 1	VA	PWR	640.287	2843	2890.50	40	T*
Surry 2	VA	PWR	597.208	2843	2890.50	40	T*
Susquehanna 1	PA	BWR	987.985	2565	2879.60	125	R
Susquehanna 2	PA	BWR	995.304	2565	2879.60	125	R
Three Mile Island 1	PA	PWR	691.850	2666	2814.60	100	R
Trojan	OR	PWR	792.295	1328	1475.70	125	R
Turkey Point 3	FL	PWR	588.917	3103	3340.10	25	T
Turkey Point 4	FL	PWR	559.131	3103	3340.10	25	T
Vermont Yankee	VT	BWR	652.385	2848	3088.90	100	R
Vogtle 1	GA	PWR	912.559	2606	2933.70	125	R
Vogtle 2	GA	PWR	921.370	2606	2933.70	125	R
Wash Nuclear 2	WA	BWR	984.099	1166	1309.70	40	T*
Waterford 3	LA	PWR	858.317	2200	2610.70	125	R
Watts Bar 1	TN	PWR	797.298	2368	2502.00	40	T*
Watts Bar 2	TN	PWR	785.767	2368	2502.00	40	T*
West Valley-B Pool	NY	BWR	11.497	2452	2651.90	100	R
West Valley-P Pool	NY	PWR	15.287	2452	2651.90	100	R
Wolf Creek	KS	PWR	851.220	1669	1765.60	125	R
Yankee-Rowe 1	MA	PWR	165.707	2885	2967.50	40	T
Zion 1	IL	PWR	821.997	1955	2023.10	125	R
Zion 2	IL	PWR	817.841	1955	2023.10	125	R

*Truck-serviced reactor plants that have potential crane capacity to handle rail casks > 100 tons.

Table 2-2. Aggregated Reactor/Storage Pool Data for the
Transport Modal Options Study

Service Reactor/Pool Class	Number of Facilities	SNF PWR/BWR	MTU Discharges Through Life	Distance to Yucca Mountain (Miles)		Initial Transportation Mode T/R
				Highway	Rail	
LWT, 25 tons	9	PWR	5841	2396	2525	T
	2	BWR	719	2868	3129	T
	<u>11</u>	PWR/BWR	<u>6560</u>	2448	2592	T
OWI, 40 tons	31	PWR	18414	2297	2464	T
	19	BWR	12898	2325	2490	T
	<u>50</u>	PWR/BWR	<u>31312</u>	2309	2475	T
Trucks	40	PWR	24255	2321		T
	21	BWR	13617	2379		T
	<u>61</u>	PWR/BWR	<u>37872</u>	2333		T
R, 100 tons	8	PWR	5077		2486	R
	<u>11</u>	BWR	<u>7989</u>		2280	R
	<u>19</u>	PWR/BWR	<u>13066</u>		2360	R
R, HRC, 125 tons	35	PWR	27171		2215	R
	<u>10</u>	BWR	<u>8669</u>		2696	R
	<u>45</u>	PWR/BWR	<u>35840</u>		2331	R
Rail	43	PWR	32248		2258	R
	21	BWR	16658		2473	R
	<u>64</u>	PWR/BWR	<u>48906</u>		2339	R
All Facilities (All Truck Case)	83	PWR	56504	2155		T
	42	BWR	30275	2312		T
	<u>125</u>	PWR/BWR	<u>86779</u>	2210		T

Table 2-2 (Cont.) Aggregated Reactor/Storage Pool Data
for the Transport Modal Options Study

Service Reactor/Pool Class	Number of Facilities	SNF PWR/BWR	MTU Discharges Through Life	Distance to Yucca Mountain (Miles)		Initial Transportation Mode T/R
				Highway	Rail	
HHT - Serviced	17	PWR	11892		2460	T
	8	BWR	7722		2494	T
	<u>25</u>	PWR/BWR	<u>19614</u>		2473	T
Remaining OWT	14	PWR	6522	2294	2473	T
	11	BWR	5176	2276	2483	T
	<u>25</u>	PWR/BWR	<u>11698</u>	2286	2478	T
Remaining LWT	9	PWR	5841	2396	2525	T
	2	BWR	719	2868	3129	T
	<u>11</u>	PWR/BWR	<u>6560</u>	2448	2592	T

3.0 STUDY BASES AND ASSUMPTIONS

3.1 CASK DATA

A set of reference cask designs have been adopted for this study. The cask specifications in terms of loaded weight and PWR/BWR spent fuel assembly capacity are summarized in Table 3-1.

Table 3-1. Reference Cask Designs for the Transport Modal Option Study

Type of Cask	Weight (tons)	Capacity
LWTC	28	3/7
OWTC	40	5/12
Rail Cask, RC	100	21/48
Hefty Rail Cask, HRC	125	24/60

3.2 COST DATA AND METHODS

The LCC analyses for this study are being carried out via the computer model CASKCOM (9). Using CASKCOM, component costs are calculated and then summed to obtain a total LCC. A description of the model assumptions and the model logic is given in the appendix. Key cost data used in estimating LCCs are summarized in Table 3-2.

Table 3-2. Key Cost Data

	LWTC	OWTC	RC	HRC
Cask Unit Costs (Mill 1987 \$)	.80	1.0	2.0	2.5
Development, Certification Costs (Mill 1987 \$)	6.0	7.0	8.0	9.0
Annual Unit Maintenance Costs (Mill 1987 \$)	.075	.085	.125	.150
Crew Wages at Reactor and Repository (1987 \$/hr)	63.0	63.0	63.0	63.0

In current practice, only single-mode transport of SNF has been seriously considered. However, because many nuclear power plants are not directly accessible by rail but have rail cask handling capability, truck/rail IMT systems are now receiving more serious consideration. Cases V to VII of this study specifically deal with IMT.

The cost calculations for IMT are done exogenously to CASKCOM. Two situations have been considered; so-called lift-off/lift-on (LO/LO) operations which pertain specifically to cases V and VI; and roll-off/roll-on (RO/RO) operations which pertain to the HHT/rail transfers in Case VII.

For the LO/LO operations, it is assumed that truck casks (either LWTCs or OWTCs) are hauled by truck to the nearest railhead and then transferred and shipped. The cask shipments would be part of a reactor annual shipping campaign, involving about 35 MTU. The number of casks per campaign would be about 25 LWTC loads or 15 OWTC loads, respectively.

It was further assumed that utility crew schedules and riggers' schedules are adequately optimized so that neither organization has to unreasonably wait for the other. Truck casks are shipped, one per truck, and loaded two per railcar.

For the LWTC cask, the cost of the IMT is estimated to be ~ 3.5 \$/kg. For the OWTC cask, the transfer costs are estimated to be ~ 2.2 \$/kg. The details of these cost estimates are shown in Table 3-3.

For the RO/RO operations, 100-ton rail casks are hauled by a HHT to the nearest railhead and then transferred to a railcar. There would be about 3 railcars per campaign. The casks would be shipped one per HHT and loaded one per railcar. The cost of the RO/RO operation was estimated to be ~ 2.4 \$/kg. Details of this estimate are shown in Table 3-4.

3.3 DOSE DATA AND METHODS

To estimate collective occupational and public doses, use has been made of the methodology and data developed in the recent PNL ALARA study, published in November 1987 (8). In this method, doses in person-mrem are calculated for direct exposure from "cask work" as well as for exposure from "general area work" (background radiation). Different dose estimates are made for truck and rail casks and for PWR and BWR casks. The public incurs doses only from actual transit operations off site. Public doses resulting from reactor plant and repository operations are assumed to be negligible. The PNL in-transit doses are based on RADTRAN III (10) calculations for typical truck distances (i.e., 1,780 miles) and rail distances (i.e., 1,910 miles). In the calculations for this report, a simple distance correction has been made for the in-transit doses, i.e., the in-transit doses have been assumed to be simply proportional to distance.

The dose data derived from the PNL report are summarized in Table 3-5. OWT shipments are expected to proceed differently than regular LWT shipments. There are more restrictions on OWT than on LWT. Increased stop-times compared to LWT shipments occur. The net result is an increase in overall public and occupational in-transit doses. The numbers in parentheses in Table 3-5 refer to OWT.

Table 3-3. Estimated Costs for Truck/Rail
LO/LO Cask Transfer

LWTC

Crew size	5
Total working time, days (1 day/cask)	25
Total man-hours worked (5 men) (25 days) (10 hrs/day)	1,250
	<u>Costs (\$K)</u>
Labor costs (1250) (63 \$/hr)	~ 79
Per diem (5) (25 days) (60 \$/day)	~ 8
Mobilization and Return (2 trips) [(5 men) (12 hrs/trip) (63 \$/hr) + (5) (60)]	~ 8
Crane rental (27 days) (1000 \$/day)	~ 27
Truck rental (27 days) (75 \$/day)	~ 2
Total	~ 124

\$/kg ~ 124/35 ~ 3.5

OWTC

Crew size	5
Total working time, days (1 day/cask)	15
Total man-hours (5 men) (15 days) (10 hrs/day)	750
	<u>Costs (\$K)</u>
Labor costs (750) (63 \$/hr)	~ 47
Per diem (5) (15 days) (60 \$/day)	~ 5
Mobilization and Return (2 trips) [(5 men) (12 hrs/trip) (63 \$/hr) + (5) (60)]	~ 8
Crane rental (17 days) (1000 \$/day)	~ 17
Truck rental (17 days) (75 \$/day)	~ 1
Total	~ 78

\$/kg ~ 78/35 ~ 2.2

Table 3-4. Estimated Costs for HHT/Rail
RO/RO Cask Transfer

RR/HRC

Crew size	5
Total working time, days	6
Total man-hours (5 men) (6 days) (8 hrs/day)	240
	<u>Costs (\$K)</u>
Labor costs (240) (63 \$/hr)	~ 15
Per diem (5 men) (6 days) (60 \$/day)	~ 2
Mobilization and return	~ 8
Rig, tractor trailer, mobile ramp rental (8) (4000 \$/day)	~ 32
Facility preparation (4 days)	~ 25
Service truck rental (8 + 4) (50 \$/day)	~ <u>1</u>
Total	~ 83

\$/kg ~ 83/35 ~ 2.4

Table 3-5. Population Dose Summaries for
Spent Fuel Transportation System

	PWR	BWR
<u>Truck Doses (pers-mrem/cask)</u>		
Reactor Plant	$261 + 5 P_T$	$268 + 5 B_T$
Transit - Worker	206 (218)	206 (218)
Transit - Public*	457 (527)	457 (527)
Repository	$276 + .175 P_T$	$276 + .175 B_T$
<u>Rail Doses (pers-mrem/cask)</u>		
Reactor Plant	$334 + 5 P_R$	$340 + 5 B_R$
Transit - Worker	64	64
Transit - Public	39	39
Repository	$462 + .116 P_R$	$462 + .116 B_R$

where P_T = number of PWR spent fuel assemblies (SFAs) per truck cask,
 B_T = number of BWR SFAs per truck cask,
 P_R = number of PWR SFAs per rail cask, and
 B_R = number of BWR SFAs per rail cask.

*Numbers in parentheses refer to OWT.

The dose rates for the HRC are assumed to be the same as for regular rail casks.

For the IMT cases, a special set of dose data had to be developed. As in the cost section, separate dose estimates were developed for the LO/LO and the RO/RO transfer operations.

For the LO/LO operations, a flow sheet for the truck to rail IMT is shown in Figure 3-1. It consists of 9 basic steps, starting with trucks hauling LWT/OWT casks to the nearest railhead (from nearby, up to 40 miles away) and ending with the return of the trucks to the reactor.

The casks are expected to be mounted on skids at the reactor, with the personnel barriers in place. Lifting of casks from the trucks to the railcars would be accomplished via 50-ton mobile cranes.

For each of the steps, dose rates and number of workers doing actual "cask work" or being in the "general area" have been estimated. Elapsed time for each operation was also estimated and used to calculate total collective dose in person-mrem for the transfer operations. This is summarized in Table 3-6.

Table 3-6. Collective Dose Data - Truck/Rail LO/LO Transfer

Operation	Time Hours	Cask Work		Area Work		Dose Pers-mrem
		Mrem/hr	# of Workers	Mrem/hr	# of Workers	
1	1	1-2	2	-	-	3
2	1	-	-	2	5	10
3	1	5	2	2	3	16
4	1	5	2	2	3	16
5	1	3	3	2	2	13
6	1	5	2	2	3	16
7	1	5	2	2	3	16
8						0
9	1	3	2	-	-	6
						<u>96</u>

As shown in Table 3-6, the total dose for the truck/rail transfer operation is ~ 96 person-mrem per cask.

Because the RO/RO operations are somewhat complex, some explanations and illustrations are in order. To start the RO/RO operations, a suitable heavy-haul transporter and accessory equipment are needed. These items are illustrated in Figure 3-2 [based on Reference (11)]. The cask mounted on a skid is sitting on a cart outside of the reactor bay. When the HHT is ready on site, the front and rear goosenecks are engaged to the equipment skid and the skid is raised to operating height. This is shown on Figure 3-3a. The cart is removed and the HHT hauls the cask/skid assembly to the railhead. At the railhead, the railcar is positioned adjacent to the loading ramp, the temporary ramps are installed, and the HHT is driven up the ramp (see Figure 3-3b).

Figure 3-1. Truck-to-Rail Cask Transfer Operations (LOLO)

- 1 Tractor
- 2 Jeep Dolly
- 3 Front Hydraulic Gooseneck
- 4 Rear Hydraulic Gooseneck
- 5 Rear Steering Dolly
- 6 Trailer (Temporary Ramp)

Figure 3-2. HHT Transporter and Auxiliary Equipment
[Based on Reference (11)]

To complete the operation, the cask/skid assembly is lowered onto the railcar (Figure 3-3c). The front and rear goosenecks are then disengaged, the cask/skid assembly is tied down, and after final inspections, the railcar can be moved to make room for the next cask operation. Finally, the tractor and goosenecks are returned to the reactor site.

For the RO/RO operation (Case VII) a suitable flow sheet was developed (Figure 3-4). It is assumed that at the start of the operation, the cask with personnel barriers in place has been mounted on a skid and is sitting on a transfer cart in the reactor loading bay.

The transfer operation has been subdivided into 12 steps, starting with the pull-out of the cart into a clear area outside of the reactor bay. In the last step of the operation, the tractor and goosenecks are returned to the reactor site.

For each of the 12 steps, dose rates, number of workers doing actual "cask work" or being in the "general area" have been estimated and used to calculate collective dose in person-mrem for the transloading operation. The dose data are summarized in Table 3-7.

The total dose for this operation is estimated to be ~ 94.5 person-mrem. Public dose is considered to be negligible. A similar analysis was made in 1978 for a rail/barge transfer of a rail cask (12). For this case, the dose per cask was estimated to be ~ 120 person-mrem.

(a) HHT and Cask/Skid Assembly Ready for Transport

(b) Equipment Skid Ready to Be Lowered Onto the Railcar

(c) Equipment Skid in Place on Railcar; Goosenecks Ready to Be Disengaged at Transfer Site

Figure 3-3. RO/RO Operations [Based on Reference (11)]

* Most reactor loading bays are not long enough to accommodate the HHT.

Figure 3-4. HHT-to-Rail Cask Transfer Operations (R0/R0)

Table 3-7. Collective Dose Data - HHT/Rail RO/RO Transfer

Operation	Time (Hours)	Cask Work		Area Work		Dose Pers-mrem
		Mrem/hr	# of Workers	Mrem/hr	# of Workers	
1	1/2	-	-	1	1	.5
2	1	5	2	1	1	11
3	1	-	-	1	4	4
4	2	1	3	-	-	6
5	1	-	-	2	5	10
6	1	5	2	1	3	13
7	1	5	2	1	3	13
8	1	5	3	1	2	17
9	1	-	-	1	4	4
10	1	5	2	2	3	16
11	1	-	-	0	3	0
12	1	-	-	0	4	0
						<u>94.5</u>

4.0 LIFE-CYCLE COST (LCC) ANALYSES

As described in Chapter 3, life-cycle cost (LCC) analyses were performed using the CASKCOM computer program. Results of the analyses for each of the seven cases and three subcases of this program are presented in Tables 4-1 to 4-9. All estimates are total life-cycle costs in million of 1987 dollars. Detailed input data and cost formulas are compiled in the appendix.

A first examination of the results shows that, for single-mode transport (Cases I to IV), the costs drop as the casks get larger and as fewer trips are needed to transport a given amount of fuel from the nuclear power plants to the repository. This trend is not completely followed as use is made of the hefty rail cask. In this case, the cost figures actually increase from ~ 14 \$/kg (Case III) to ~ 16 \$/kg for Case IV. At first, this seems counter-intuitive, because the HRC has a capacity of 24/60, which is larger than the capacity of 21/48 for the regular rail cask. Thus, fewer trips and lower costs are expected. However, unlike the situation with regular rail casks, hefty rail casks are assumed to use dedicated train transportation for the entire round trip. Regular rail casks would travel by dedicated train only in the loaded condition.

When returning the empty casks, regular casks would be returned via regular trains at lower average speeds. The dedicated train charge is taken as \$48/train-mile and this adds considerably to the hauling cost. In fact, for Case IV, this cost differential has been calculated to be ~ \$109 million. If the hefty rail casks were assumed to return by regular train, the cost for Case IV would only be \$1,360 minus \$109 ~ \$1,251 million, which is just slightly below the quoted Case III cost of \$1,254 million (Table 4-3).

It is interesting to compare the 1987 dollar costs quoted in Tables 4-1 to 4-4 with "typical" transport costs quoted about 10 years ago (actually 1976) of 25 \$/kg (13). If we take this 25 \$/kg cost as an "average" number, then it is to be compared with the 17 \$/kg for the current "base case." The 25 \$/kg number needs to be adjusted for inflation. If we assume an inflation factor of ~ 1.8, then cask shipping costs have dropped by about a factor of (1.8) (25)/17 ~ 2.6 over the past decade. The most likely cause for this reduction in costs is the fact that the fuel to be shipped now is cooler, the cask capacities much larger (cask capacities used to be about 1/2 for truck casks and 7/17 to 10/24 for rail casks), and hence the number of trips less than half of what was expected in the mid-1970s.

The next set of cases, V, VI, and Cases VIIa, VIIb, and VIIc, all represent versions of intermodal transport (IMT). These cases were constructed to remain within the limits of existing site constraints. As one might expect, the cost trends here all tend to be up as more and more operations get to be involved. One reason why one might want to proceed with the IMT, nevertheless, is to reduce population dose, particularly the collective public radiation dose. This can be done by shifting progressively more to rail transport (see Chapter 5).

There are several nuances in the cost tabulations for IMT (Tables 4-4 to 4-9) that need to be pointed out. The general assumption has been made that transport campaigns cover a single large reactor discharge cycle of ~ 35 MTU. In IMT, where truck and rail transport are involved, an important variable is

the number of casks loaded onto a single train. A sensitivity study was done to examine this situation for Case V, OWT[R] transport. If casks are kept idle at the railhead as more and more casks are loaded from truck to rail, the average cask utilization goes down and the average round-trip time will increase, hence a larger cask fleet will be needed. Thus, fleet capital costs will go up as will cask maintenance costs. However, more casks per train also imply fewer train trips. Fewer train trips mean lower hauling and security charges. The other costs, cask handling and development and certification costs, are essentially independent of the cask per train variable. In the case of IMT using OWT casks, the maximum number of casks shipped per train would be ~ 15. Figure 4-1 shows the variation of the OWT(R) cost component as a function of the number of casks/train. For this case, the net cost trend is down over the range of casks/train shown. (Similar trends could be expected for the LWT(R) IMT operation.)

For Cases V and VI, we have assumed for purposes of our cost estimates that the casks loaded on a single train would be the maximum number of casks available per campaign. (This is about 25 LWT casks, 15 OWT casks, or 3 RR casks.) This results in a minimum cost case. In actuality, utility crews may only be available for about 10 days of single-shift operation (8). Such a crew could handle about 5 OWT casks, and thus the net costs for IMT transport would rise, as the number of casks per train are reduced (see Figure 4-1).

Another problem concerns the return of empty casks from the repository. In our calculations (and estimated costs) we have assumed that casks are returned via train, passing through the railhead as in forward transport. Another scheme would be to return all LWT truck casks directly by truck, bypassing the transfer operation at the railhead. For this case, the costs would be somewhat lower than the quoted costs. For Case VI, this cost differential is about \$33 million.

For IMT Cases VIIa to VIIc, there are fewer variations to be explored. In each case only three rail casks are transloaded, and the expectation is that three casks would indeed be handled in each operation. Also, these rail casks would all be returned by rail and thus regular truck transport is not involved. There is, however, still the option open to return the empty LWT casks considered in Case VIIc by truck.

Figure 4-1. Cost Dependence on Casks/Train

Table 4-1. Case I. All Casks Shipped by LWT

	LWT Cask 3/7 Ship by Truck
PWR/BWR MTU	56503/30275
Total MTU	86,779
One-Way Distance (mi)	2,210
Average Speed Front Haul (mph)	37.5
Average Speed Back Haul (mph)	37.5
Development/Certification Cost	6
Cask Capital Cost	98
Hauling Cost	722
Maintenance Cost	133
Security Cost	519
Handling Cost	575
At Reactor	325
At Repository	250
Total LCC (mill \$)	\$2,052
LCC per kgU	\$24
PWR/BWR Cask Fleet	39/22
Turnaround Time (days)	8.4
At Reactor	2.0
In-Transit	4.9
At Repository	1.5
Cask Availability (days)	310
Cask Round-Trips per Year	36.9

Table 4-2. Case II. Reference Case: LWT/RR

	LWT Cask 3/7 Ship by Truck	Regular Rail Cask 21/48	Total
PWR/BWR MTU	24255/13617	32248/16658	
Total MTU	37,872	48,906	86,778
One-Way Distance (mi)	2,333	2,339	
Average Speed Front Haul (mph)	37.5	11.85	
Average Speed Back Haul (mph)	37.5	7.9	
Development/Certification Cost	6	8	14
Cask Capital Cost	43	76	119
Hauling Cost	331	258	590
Maintenance Cost	59	69	128
Security Cost	239	23	263
Handling Cost	251	79	331
At Reactor	142	44	187
At Repository	109	35	144
Total (mill \$)	930	514	1,444
LCC per KgU	25	11	17
PWR/BWR Cask Fleet	17/10	12/7	--
Turnaround Time (days)	8.7	28.7	--
At Reactor	2.0	5.9	--
In-Transit	5.2	20.6	--
At Repository	1.5	2.2	--
Cask Availability (days)	310	280	--
Cask Round-Trips per Year	35.7	9.8	--

Table 4-3. Case III. LWT, OWT, RR

	LWT Cask 3/7 Ship by Truck	OWT Cask 5/12 Ship by Truck	Regular Rail Cask 21/48	Total
PWR/BWR MTU	5841/719	18414/12899	32248/16658	
Total MTU	6,560	31,313	48,906	86,779
One-Way Distance (mi)	2,449	2,309	2,339	--
Average Speed Front Haul (mph)	37.5	22.7	11.85	--
Average Speed Back Haul (mph)	37.5	22.7	7.9	--
Development/Certification Cost	6	7	8	21
Cask Capital Cost	10	38	76	124
Hauling Cost	59	229	258	547
Maintenance Cost	13	47	69	129
Security Cost	43	116	23	182
Handling Cost	42	130	79	252
At Reactor	24	74	44	142
At Repository	18	57	35	110
Total (mill \$)	173	567	514	1,254
LCC per KgU	26	18	11	14
PWR/BWR Cask Fleet	5/1	11/8	12/7	
Turnaround Time (days)	8.9	12.0	28.7	
At Reactor	2.0	2.0	5.9	
In-Transit	5.4	8.5	20.6	
At Repository	1.5	1.5	2.2	
Cask Availability (days)	310	310	280	
Cask Round-Trips per Year	34.7	25.9	9.8	

Table 4-4. Case IV. LWT/OWT/RR/HRC

	LWT Cask 3/7 Ship by Truck	OWT Cask 5/12 Ship by Truck	Regular Rail Cask 21/48	Hefty Rail 24/60 Cask	Total
PWR/BWR MTU	5841/719	18414/12899	5077/7989	27171/8669	56503/30275
Total MTU	6,560	31,313	13,066	35,840	86,779
One-Way Distance (mi)	2,449	2,309	2,360	2,331	--
Average Speed Front Haul (mph)	37.5	22.7	11.93	11.86	--
Average Speed Back Haul (mph)	37.5	22.7	7.96	11.86	--
Development/Certification Cost	6	7	8	9	30
Cask Capital Cost	10	38	24	55	127
Hauling Cost	59	229	71	291	650
Maintenance Cost	13	47	22	48	129
Security Cost	43	116	6	12	178
Handling Cost	42	130	23	50	246
At Reactor	24	74	13	28	138
At Repository	18	57	10	22	107
Total (mill \$)	\$173	\$567	\$154	\$466	\$1,360
LCC per KgU	\$26	\$18	\$12	\$13	\$16
PWR/BWR Cask Fleet	5/1	11/8	2/4	8/3	--
Turnaround Time (days)	8.9	12.0	28.7	25.5	--
At Reactor	2.0	2.0	5.9	6.9	--
In-Transit	5.4	8.5	20.6	16.4	--
At Repository	1.5	1.5	2.2	2.2	--
Cask Availability (days)	310	310	280	280	--
Cask Round-Trips per Year	34.7	25.9	9.7	11.0	--

Table 4-5. Case V. LWT/OWT[R]/RR/HRC - Intermodal Transport

	LWT Cask 3/7 Ship by Truck	OWT Cask 5/12 Ship by Rail	Regular Rail Cask 21/48	Hefty Rail 24/60 Cask	Total
PWR/BWR MTU	5841/719	18414/12899	5077/7989	27171/8669	56503/30275
Total MTU	6,560	31,313	13,066	35,840	86,779
One-Way Distance (mi)	2,449	2,475	2,360	2,331	--
Average Speed Front Haul (mph)	37.5	12.25	11.93	11.86	--
Average Speed Back Haul (mph)	37.5	8.17	7.96	11.86	--
Development/Certification Cost	6	7	8	9	30
Cask Capital Cost	10	126	24	55	215
Hauling Cost	59	182	71	291	604
Maintenance Cost	13	155	22	48	238
Security Cost	43	13	6	12	75
Handling Cost	42	130	23	50	246
At Reactor	24	74	13	28	138
At Repository	18	57	10	22	107
Intermodal Transfer Cost	0	138	0	0	138
Total (mill \$)	\$173	\$751	\$154	\$466	\$1,544
LCC per KgU	\$26	\$24	\$12	\$13	\$18
PWR/BWR Cask Fleet	5/1	37/26	2/4	8/3	--
Turnaround Time (days)	8.9	40.5	28.7	25.5	--
At Reactor	2.0	16.0	5.9	6.9	--
In-Transit	5.4	21.0	20.6	16.4	--
Intermodal Transfer	--	2.0	--	--	--
At Repository	1.5	1.5	2.2	2.2	--
Cask Availability (days)	310	310	280	280	--
Cask Round-Trips per Year	34.7	7.6	9.7	11.0	--

Table 4-6. Case VI. LWT[R]/OWT[R]/RR/HRC - Intermodal Transport

	LWT Cask 3/7 Ship by Rail	OWT Cask 5/12 Ship by Rail	Regular Rail Cask 21/48	Hefty Rail 24/60 Cask	Total
PWR/BWR MTU	5841/719	18414/12899	5077/7989	27171/8669	56503/30275
Total MTU	6,560	31,313	13,066	35,840	86,779
One-Way Distance (mi)	2,592	2,475	2,360	2,331	--
Average Speed Front Haul (mph)	12.56	12.25	11.93	11.86	--
Average Speed Back Haul (mph)	8.37	8.17	7.96	11.86	--
Development/Certification Cost	6	7	8	9	30
Cask Capital Cost	46	126	24	55	251
Hauling Cost	42	182	71	291	587
Maintenance Cost	63	155	22	48	288
Security Cost	3	13	6	12	34
Handling Cost	42	130	23	50	246
At Reactor	24	74	13	28	138
At Repository	18	57	10	22	107
Intermodal Transfer Cost	46	138	0	0	184
Total (mill \$)	\$248	\$751	\$154	\$466	\$1,619
LCC per KgU	\$38	\$24	\$12	\$13	\$19
PWR/BWR Cask Fleet	25/4	37/26	2/4	8/3	--
Turnaround Time (days)	51.0	40.5	28.7	25.5	--
At Reactor	26.0	16.0	5.9	6.9	--
In-Transit	21.5	21.0	20.6	16.4	--
Intermodal Transfer	2.0	2.0	--	--	--
At Repository	1.5	1.5	2.2	2.2	--
Cask Availability (days)	310	310	280	280	--
Cask Round-Trips per Year	6.1	7.6	9.7	11.0	--

Table 4-7. Case VIIa. LWT/RES. OWT/HHT[R]/RR/HRC - Intermodal Transport

	LWT Cask 3/7 Ship by Truck	HHT by Rail 21/48	Residual OWT by 5/12 Truck	Hefty Rail 24/60 Cask	Regular Rail Cask 21/48	Total
PWR/BWR MTU	5841/719	11892/7722	6522/5176	27171/8669	5077/7989	56503/30275
Total MTU	6,560	19,614	11,698	35,840	13,066	86,778
One-Way Distance (mi)	2,449	2,473	2,286	2,331	2,360	--
Average Speed Front Haul (mph)	37.5	12.24	22.7	11.86	11.93	--
Average Speed Back Haul (mph)	37.5	8.16	22.7	11.86	7.96	--
Development/Certification Cost	6	8	7	9	8	38
Cask Capital Cost	10	36	16	55	24	141
Hauling Cost	59	109	85	291	71	615
Maintenance Cost	13	33	20	48	22	135
Security Cost	43	10	43	12	6	137
Handling Cost	42	32	49	50	23	197
At Reactor	24	18	28	28	13	111
At Repository	18	14	21	22	10	86
Intermodal Transfer Cost	0	94	0	0	0	94
Total LCC (mill \$)	\$173	\$323	\$219	\$466	\$154	\$1,356
LCC per KgU	\$26	\$16	\$19	\$13	\$12	\$16
PWR/BWR Cask Fleet	5/1	5/4	4/4	8/3	2/4	--
Turnaround Time (days)	8.9	33.2	11.9	25.5	28.7	--
At Reactor	2.0	5.9	2	6.9	5.9	--
Intermodal Transfer	0.0	4.0	0.0	0.0	0.0	--
In-Transit	5.4	21.0	8	16.4	20.6	--
At Repository	1.5	2.2	2	2.2	2.2	--
Cask Availability (days)	310	280	310	280	280	--
Cask Round-Trips per Year	34.7	8.4	26.1	11.0	9.7	--

Table 4-8. Case VIIb. LWT/RES. OWT[R]/HHT[R]/RR/HRC - Intermodal Transport

	LWT Cask 3/7 Ship by Truck	HHT by Rail 21/48	Residual OWT by 5/12 Rail	Hefty Rail 24/60 Cask	Regular Rail Cask 21/48	Total
PWR/BWR MTU	5841/719	11892/7721	6522/5176	27171/8669	5077/7989	56503/30275
Total MTU	6,560	19,613	11,698	35,840	13,066	86,777
One-Way Distance (mi)	2,449	2,473	2,478	2,331	2,360	--
Average Speed Front Haul (mph)	37.5	12.24	12.26	11.86	11.93	--
Average Speed Back Haul (mph)	37.5	8.16	8.17	11.86	7.96	--
Development/Certification Cost	6	8	7	9	8	38
Cask Capital Cost	10	36	48	55	24	173
Hauling Cost	59	109	68	291	71	599
Maintenance Cost	13	33	59	48	22	174
Security Cost	43	10	5	12	6	77
Handling Cost	42	32	49	50	23	197
At Reactor	24	18	28	28	13	111
At Repository	18	14	21	22	10	86
Intermodal Transfer Cost	0	94	51	0	0	146
Total LCC (mill \$)	\$173	\$323	\$287	\$466	\$154	\$1,403
LCC per KgU	\$26	\$16	\$25	\$13	\$12	\$16
PWR/BWR Cask Fleet	5/1	5/4	13/11	8/3	2/4	--
Turnaround Time (days)	8.9	33.2	40.6	25.5	28.7	--
At Reactor	2.0	5.9	16.0	6.9	5.9	--
Intermodal Transfer	--	4.0	2.0	--	--	--
In-Transit	5.4	21.0	21.1	16.4	20.6	--
At Repository	1.5	2.2	1.5	2.2	2.2	--
Cask Availability (days)	310	280	310	280	280	--
Cask Round-Trips per Year	34.7	8.4	7.6	11.0	9.7	--

Table 4-9. Case VIIc. LWT[R]/RES. OWT[R]/HHT[R]/RR/HRC - Intermodal Transport

	LWT Cask 3/7 Ship by Rail	HHT by Rail 21/48	Residual OWT by 5/12 Rail	Hefty Rail 24/60 Cask	Regular Rail Cask 21/48	Total
PWR/BWR MTU	5841/719	11892/7721	6522/5176	27171/8669	5077/7989	56503/30275
Total MTU	6,560	19,613	11,698	35,840	13,066	86,777
One-Way Distance (mi)	2,449	2,473	2,478	2,331	2,360	--
Average Speed Front Haul (mph)	37.5	12.24	12.26	11.86	11.93	--
Average Speed Back Haul (mph)	37.5	8.16	8.17	11.86	7.96	--
Development/Certification Cost	6	8	7	9	8	38
Cask Capital Cost	46	36	48	55	24	209
Hauling Cost	42	109	68	291	71	582
Maintenance Cost	63	33	59	48	22	224
Security Cost	3	10	5	12	6	37
Handling Cost	42	32	49	50	23	197
At Reactor	24	18	28	28	13	111
At Repository	18	14	21	22	10	86
Intermodal Transfer Cost	46	94	51	0	0	192
Total LCC (mill \$)	\$248	\$323	\$287	\$466	\$154	\$1,478
LCC per KgU	\$38	\$16	\$25	\$13	\$12	\$17
PWR/BWR Cask Fleet	25/4	5/4	13/11	8/3	2/4	--
Turnaround Time (days)	51.0	33.2	40.6	25.5	28.7	--
At Reactor	26.0	5.9	16.0	6.9	5.9	--
Intermodal Transfer	2.0	4.0	2.0	--	--	--
In-Transit	21.5	21.0	21.1	16.4	20.6	--
At Repository	1.5	2.2	1.5	2.2	2.2	--
Cask Availability (days)	310	280	310	280	280	--
Cask Round-Trips per Year	6.1	8.4	7.6	11.0	9.7	--

5.0 LIFE-CYCLE DOSE (LCD) ANALYSES

The life-cycle dose (LCD) analyses were carried out as described in Section 3.3 of this report. The results for the nine cases and subcases are presented in Tables 5-1 to 5-9.

The information presented in the tables does not only include the LCD results, but also some basic input data for each case, i.e., life-time metric tons of uranium (MTU) discharged, number of reactor plants involved, and weighted-average distances from the plants to the repository.

The results are given in terms of total and public person-rem for each case, as well as in person-rem/MTU. Several points are worth noting about these results. As to be expected, the truck doses are considerably higher than the rail doses, by about a factor of 10(!). For instance, in Case II we find the truck dose to be 1.1 person-rem/MTU, compared to a rail dose of about 0.12 person-rem/MTU. When both truck and rail shipments are used together, the combined dose for Case II is about 0.53 person-rem/MTU. (A similar calculation made in the PNL ALARA report for 30/70 truck/rail and 60/40 PWR/BWR split assumptions gives a combined dose of 0.50 person-rem/MTU.)

If all spent nuclear fuel (SNF) casks were shipped by legal-weight truck (LWT) (Case I)--a rather contrived bounding case--the total dose would be about 1.0 person-rem/MTU* and the public dose would be 0.42 person-rem/MTU. For this extreme case, the total population dose is close to 100,000 person-rem. Assuming 200 latent cancer fatalities (LCFs) per 10^6 person-rem (14), this 100,000 person-rem dose would result in about 20 LCFs related to radioactive exposure from normal transport operations. For the base case, which involves a substantial rail shipment fraction, the fatality rate would be about half of that figure.

In Cases III and IV, the effect of using large-capacity casks, i.e., overweight truck casks (OWTCs) and hefty rail casks (HRCs), wherever possible, is examined. For example, using OWTCs (Case III) in truck transport whenever feasible within reactor crane limitations, reduces the total population dose from 0.53 (Case II) to 0.39 person-rem/MTU (Case III). The public dose is reduced from 0.20 (Case II) to 0.15 person-rem/MTU.

The remaining Cases V through VII represent intermodal transport (IMT). Transshipping the OWTCs by rail results in a fairly large dose reduction percentage-wise, i.e., the population dose drops from 0.39 person-rem/MTU (for Case IV [OWTCs shipped by rail]), to 0.27 person-rem/MTU (for Case V, ~ 30% decrease). The public dose drops to 0.045 person-rem/MTU from 0.15 person-rem/MTU.

If all fuel is shipped by rail (Case VI), such that both OWTCs and LWTCs are transferred onto railcars, this "all rail" dose is 0.23 person-rem/MTU with a corresponding public dose of 0.013 person-rem/MTU.

*The reason that the truck dose is 1.0 for this case and 1.1 for Case II is traceable to the different reactors involved in Case I and Case II.

Finally, Cases VIIa, b, and c represent another set of long-distance rail shipments. In Case VII, heavy-haul trucks are used to haul 100-ton casks to the nearest railhead from truck-designated reactors with crane capacities of 100 tons or more but no direct rail access. Case VIIC, which is the final "all rail" transport version, ends up with a total dose of 0.18 person-rem/MTU and a public dose of 0.010 person-rem/MTU.

A public dose level of 0.010 person-rem/MTU is quite small. For a shipment of ~ 100,000 MTU, this amounts to 1,000 person-rem corresponding to a public LCF rate ascribable to nuclear waste transport of 0.2. It is clear that from this public risk point of view, rail transport may be a preferred waste transport mode.

Table 5-1. LCD Summary - Case I
Cask Transport Via LWT

	HHT (R)	OWT	OWT (R)	LWT	LWT (R)	R	HRC	ELL
Number of Reactors, Total (PWR/BWR)				125 (83/42)				125 (83/42)
MTU (PWR)				56503				56503
MTU (BWR)				30275				30275
MTU (Total)				86773				86773
Distance to Repository (miles)								
via T (PWR Reactors)				2155				
via T (BWR Reactors)				2312				
via R (PWR Reactors)								
via R (BWR Reactors)								
Total Dose (pers-rem)				39748				39748
Total Dose (pers-rem MTU)				1.0				1.0
Public Dose (pers-rem)				36357				36357
Public Dose (pers-rem MTU)				.42				.42

Table 5-2. LCD Summary - Case II
Cask Transport Via LWT/R

	HHT(R)	DWT	DWT(R)	LWT	LWT(R)	R	HRC	ALL
Number of Reactors, Total (PWR/SWR)				61(40/21)		64(43/21)		125((33/42)
MTU (PWR)				24255		32248		56503
MTU (SWR)				13616		16653		30274
MTU (Total)				37871		48906		86777
Distance to Repository (miles)								
Via T (PWR Reactors)				2321				
Via T (SWR Reactors)				2353				
Via R (PWR Reactors)						2258		
Via R (SWR Reactors)						2496		
Total Dose (pers-rem)				40033		5614		45647
Total Dose (pers-rem/MTU)				1.1		.12		.53
Public Dose (pers-rem)				16747		248		16995
Public Dose (pers-rem/MTU)				.44		.0051		.20

Table 5-3. LCD Summary - Case III
Cask Transport Via OWT/LWT/R

	HHT(R)	OWT	OWT(R)	LWT	LWT(R)	R	HRC	ALL
Number of Reactors, Total (PWR/BWR)		50(31/19)		11(9/2)		64(43/21)		125(83/42)
MTU (PWR)		13414		5841		32248		56503
MTU (BWR)		12893		719		16658		30275
MTU (Total)		31312		6560		48906		66778
Distance to Repository (miles)								
Via T (PWR Reactors)		2297		2396				
Via T (BWR Reactors)		2325		2369				
Via R (PWR Reactors)						2253		
Via R (BWR Reactors)						2496		
Total Dose (pers-rem)		21268		6993		5614		33880
Total Dose (pers-rem/MTU)		.68		1.1		.12		.39
Public Dose (pers-rem)		9396		2998		243		12642
Public Dose (pers-rem/MTU)		.30		.46		.0051		.15

Table 5-4. LCD Summary - Case IV
Cask Transport Via OWT/LWT/R/HRC

	HHT(R)	OWT	OWT(R)	LWT	LWT(R)	R	HRC	ALL
Number of Reactors, Total (PWR/BWR)		50(31/19)		11(9/2)		19(8/11)	45(35/10)	125(83/42)
MTU (PWR)		13414		5341		5077	27171	56503
MTU (BWR)		12393		719		7939	3669	30275
MTU (Total)		31312		6560		13066	35840	86773
Distance to Repository (miles)								
Via T (PWR Reactors)		2297		2396				
Via T (BWR Reactors)		2325		2368				
Via R (PWR Reactors)						2436	2215	
Via R (BWR Reactors)						2230	2696	
Total Dose (pers-rem)		21263		6993		1591	3515	33372
Total Dose (pers-rem/MTU)		.68		1.1		.12	.093	.395
Public Dose (pers-rem)		9396		2993		69	153	12616
Public Dose (pers-rem/MTU)		.30		.46		.0053	.0043	.15

Table 5-5. LCD Summary - Case V
Cask Transport Via OWT(R)/LWT/R/HRC

	OWT(R)	OWT	OWT(R)	LWT	LWT(R)	R	HRC	ALL
Number of Reactors, Total (PWR/BWR)			50(31/19)	11/9/2)		19(8/11)	45(35/10)	125(83/42)
MTU (PWR)			18414	5841		5077	27171	56503
MTU (BWR)			12898	719		7989	8669	30275
MTU (Total)			31312	6560		13066	35840	86778
Distance to Repository (miles)								
Via T (PWR Reactors)				2396				
Via T (BWR Reactors)				2868				
Via R (PWR Reactors)			2464			2486	2215	
Via R (BWR Reactors)			2490			2280	2696	
Total Dose (pers-rem)			11141	6998		1591	3515	23245
Total Dose (pers-rem/MTU)			.36	1.1		.12	.098	.27
Public Dose (pers-rem)			694	2998		69	153	3914
Public Dose (pers-rem/MTU)			.022	.46		.0053	.0043	.045

Table 5-6. LCD Summary - Case VI
Cask Transport Via OWT(R)/LWT(R)/R/HRC

	HHT(R)	OWT	OWT(R)	LWT	LWT(R)	R	HRC	ALL
Number of Reactors, Total (PWR/BWR)			50(31/19)		11(9/2)	19(8/11)	45(35/10)	125(83/42)
MTU (PWR)			13414		5841	5077	27171	56503
MTU (BWR)			12898		719	7989	8669	30275
MTU (Total)			31312		6560	13066	35840	36778
44 Distance to Repository (miles)								
Via T (PWR Reactors)								
Via T (BWR Reactors)								
Via R (PWR Reactors)			2464		2525	2436	2215	
Via R (BWR Reactors)			2490		3129	2280	2696	
Total Dose (pers-rem)			11141		3778	1591	3515	20025
Total Dose (pers-rem/MTU)			.36		.58	.12	.098	.23
Public Dose (pers-rem)			694		254	69	153	1170
Public Dose (pers-rem/MTU)			.022		.039	.0053	.0043	.013

Table 5-7. LCD Summary - Case VIIa
Cask Transport Via HHT(R)/OWT/LWT/R/HRC

	HHT(R)	OWT	OWT(R)	LWT	LWT(R)	R	HRC	ALL
Number of Reactors, Total (PWR/BWR)	25(17/8)	25(14/11)		11(9/2)		19(8/11)	45(35/10)	125(83/42)
MTU (PWR)	11392	6522		5841		5077	27171	56053
MTU (BWR)	7722	5176		719		7989	8669	30275
MTU (Total)	19614	11698		6560		13066	35840	86778
Distance to Repository (miles)								
Via T (PWR Reactors)		2294		2336				
Via T (BWR Reactors)		2276		2363				
Via R (PWR Reactors)	2460					2436	2215	
Via R (BWR Reactors)	2494					2280	2695	
Total Dose (pers-rem)	2491	7912		6993		1591	3515	22507
Total Dose (pers-rem/MTU)	.13	.58		1.1		.12	.098	.26
Public Dose (pers-rem)	105	3480		2993		59	153	6805
Public Dose (pers-rem/MTU)	.0054	.30		.46		.0053	.0043	.073

Table 5-8. LCD Summary - Case VIIb
Cask Transport Via HHT(R)/OWT(R)/LWT/R/HRC

	HHT(R)	OWT	OWT(R)	LWT	LWT(R)	R	HRC	ALL
Number of Reactors, Total (PWR/BWR)	25(17/8)		25(14/11)	11(9/2)		19(2/11)	45(35/10)	125(83/42)
MTU (PWR)	11392		6522	5841		5077	27171	56503
MTU (BWR)	7722		5176	719		7989	8669	30275
MTU (Total)	19614		11698	6560		13866	35840	86778
46 Distance to Repository (miles)								
Via T (PWR Reactors)				2396				
Via T (BWR Reactors)				2368				
Via R (PWR Reactors)	2460		2473			2486	2215	
Via R (BWR Reactors)	2494		2433			2280	2696	
Total Dose (pers-rem)	2491		4174	6998		1591	3515	12769
Total Dose (pers-rem/MTU)	.13		.36	1.1		.12	.093	.22
Public Dose (pers-rem)	105		262	2993		69	153	3587
Public Dose (pers-rem/MTU)	.0054		.022	.46		.0053	.0043	.041

Table 5-9. LCD Summary - Case VIIc
Cask Transport Via HRT(R)/OWT(R)/LWT(R)/R/HRC

	HRT(R)	OWT	OWT(R)	LWT	LWT(R)	R	HRC	ALL
Number of Reactors, Total (PWR/BWR)	25(17/8)		25(14/11)		11(9/2)	19(8/11)	45(35/10)	125(83/42)
MTU (PWR)	11392		6522		5841	5077	27171	56503
MTU (BWR)	7722		5176		719	7989	8569	30275
MTU (Total)	19614		11698		6560	13066	35640	86778
Distance to Repository (miles)								
Via T (PWR Reactors)								
Via T (BWR Reactors)								
Via R (PWR Reactors)	2460		2473		2525	2436	2215	
Via R (BWR Reactors)	2494		2483		3129	2230	2596	
Total Dose (pers-rem)	2491		4174		3773	1591	3515	13549
Total Dose (pers-rem/MTU)	.13		.36		.63	.12	.098	.18
Public Dose (pers-rem)	195		262		254	69	153	543
Public Dose (pers-rem/MTU)	.0054		.022		.029	.0053	.0043	.019

6.0 SUMMARY AND CONCLUSIONS

Life-cycle cost (LCC) and life-cycle dose (LCD) estimates have been made for seven transport modal options and three subcases pertaining to the "No-New Orders-'86" nuclear waste scenario. The NNO-'86 scenario encompasses 125 reactor plants and waste pools. The results of these estimates are summarized in Table 6-1 and shown graphically in Figure 6-1.

Table 6-1. Summary LCC/LCD Estimates

Case*	Total Cost \$(Bill)	Unit Cost (\$/kg)	Unit Dose Pers-Rem/MTU	
			Total	Pub.
I. LWT	2.1	24	1.0	.42
II. LWT/RR	1.4	17	.53	.20
III. LWT/OWT/RR	1.3	14	.39	.15
IV. LWT/OWT/RR/HRC	1.4	16	.39	.15
V. LWT/OWT(R)/RR/HRC	1.5	18	.27	.045
VI. LWT(R)/OWT(R)/RR/HRC	1.6	19	.23	.013
VIIa. LWT/OWT/HHT(R)/RR/HRC	1.4	16	.26	.078
VIIb. LWT/OWT(R)/HHT(R)/RR/HRC	1.4	16	.22	.041
VIIc. LWT(R)/OWT(R)/HHT(R)/RR/HRC	1.5	17	.18	.010

*LWT - Legal-weight truck transport
 OWT - Overweight truck transport
 RR - Rail transport
 HRC - Hefty rail cask transport
 LWT(R) - Intermodal transport, LWT casks via rail
 OWT(R) - Intermodal transport, OWT casks via rail
 HHT(R) - Intermodal transport, casks handled by heavy haul truck and then shipped by rail

As more transport is by rail, the collective LCDs, both occupational and public, generally drop. In fact, over the range of cases examined, the total dose drops by more than a factor of 5 ($1/.18 \sim 5.6$) and the public dose component declines by about a factor of 40 ($.42/.010 \sim 42$). The reduction in occupational dose is by about a factor of 3 ($.58/.17 \sim 3.4$) over the range of cases examined.

For single-mode transport (Cases I to IV) the cost trends are down at first. The lowest cost of $\sim 14\$/kg$ occurs for Case III which makes maximum use of OWT casks, to the extent that crane capacity at the nuclear plants is sufficient. However, until the OWT permit issue is resolved, the results of Case III must be considered as a hypothetical construct only. Based on current

cost data, truck transport is considerably more expensive than rail transport. Hefty railcar transport tends to be more expensive, mostly because dedicated rail charges on the empty cask return trip are collected, which is not the case for regular rail cask transport. If hefty rail casks were assumed to be returned by regular freight, then the use of hefty rail casks would result in costs essentially the same as for regular rail casks.

The intermodal transport schemes (Cases V to VII) all involve more handling and transport time than single-mode transport and the corresponding shipping costs increase.

Figure 6-1. LCC/LCD Summary

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APPENDIX A

LCC MODEL DESCRIPTION

The life-cycle costs (LCCs) corresponding to the legal-weight truck (LWT) transport of the 3/7 and 4/9 cask designs were calculated using the computer code CASKCOM, modified to include current transportation assumptions.

The objective of the cask LCC model is to estimate the total costs of handling and transporting a fleet of shipping cask designed to move some given quantity of PWR and BWR spent nuclear fuel. The following cost components of spent fuel transportation are estimated:

- Development and certification cost
- Cask acquisition cost
- Reactor handling cost
- Cask maintenance cost
- Hauling cost
- Security cost
- Repository handling cost.

A.1 MODEL ASSUMPTIONS

Certain simplifying assumptions are incorporated into the LCC model. The major assumptions include:

- Spent fuel is shipped between one origin and one destination which is linked by a fixed distance. This distance represents the weighted-average distance from each reactor, in a specified set of reactors, to the Nevada Yucca Mountain site, where the MTU discharges of spent fuel serve as weighting factors in calculating the distance.
- Average speed of the shipment while en route is fixed. In the case of truck transport, the average speed is based on the origin-destination distance and the cask size being utilized.
- Cask fleet size is calculated as a function of the total cask turnaround time and cask utilization, where turnaround time is a composite of turnaround time at the reactor and at the repository plus the round-trip in-transit time.
- Cask life is estimated to be 20 years.
- Annual quantity of waste shipped is fixed and is based on the specified set of reactors with their corresponding MTU spent fuel discharges through life.
- Costs are tabulated in constant 1987 dollars, and it is assumed that there is no cost escalation.

A.2 MODEL LOGIC

What follows is a description of the individual cost calculations that are pertinent to legal weight truck transport and are contained in the current CASKCOM code.

A.2.1 Development and Certification Costs

The cask development and certification costs depend upon the nature of the cask design and the degree to which it departs from traditional concepts. An estimate of the total development and certification costs is distributed over time using whatever distribution is deemed appropriate.

$$DCERT(IYEAR) = DAC * DCDIST(IYEAR)$$

where DAC is the total development and certification cost, and
DCDIST(IYEAR) is the percentage of DAC accruing to year IYEAR.

A.2.2 Acquisition Cost

Acquisition cost is not simply the cost of purchasing one cask. Because such cask design features as utilization rate and turnaround time affect the effective capacity of a cask, it is necessary to base acquisition cost on the fleet size required to transport a fixed quantity of spent fuel between a given origin and destination within a given time period. The time required for a cask to complete a round trip is estimated as

$$TTIME(WT) = DIST(1/SPEEDL/24) + DIST(1/SPEEDE/24) + \\ TURN(WT,R) + TURN(WT,REP) + TRANSF(WT)$$

where DIST is the one-way distance between origin and destination,
SPEEDL is the average speed on the loaded front haul,
SPEEDE is the average speed on the empty back haul,
TURN(WT,R) is the average number of days required to handle cask of type WT at the reactor (calculated as a function of shipment size),
TURN(WT,REP) is the number of days required to handle a cask of type WT at the repository,
TRANS(WT) is the number of days required to transfer a cask of type WT from one transport mode to another, and
WT is an index referring to either PWR or BWR.

If the transport mode is rail, then the average turnaround time per cask at the reactor is calculated as a function of shipment size to be

$$TURN(WT,R) = [((N*2 + N)/2) * CASTURN(WT,R)]/N$$

where N is the number of casks per train shipment, and
CASTURN(WT,R) is the number of days required to
handle a cask of type WT.

If the transport mode is truck, then average turnaround time at reactor per cask TURN(WT) is assumed equal to the estimated turnaround time per cask CASTURN(WT) because it is assumed that truck casks are dispatched singly from the reactor.

The annual number of trips that each PWR/BWR cask is able to make is

$$ATRIP(WT) = DAYS * UTIL(WT) / TTIME(WT)$$

where DAYS are the number of days per year, and
UTIL(WT) is the percentage of time that the cask
of type WT is operational.

The amount of spent fuel that each type of cask is able to carry annually is a product of the annual trips per cask and the capacity of the cask, such that

$$AWPC(WT) = ATRIP(WT) * CASKCAP(WT) * RMTUPAS(WT)$$

where CASKCAP(WT) is the capacity of the cask in PWR or BWR
assemblies, and
RMTUPAS(WT) is the MTU per PWR/BWR assembly.

The cask fleet needed to transport the total amount of PWR and BWR spent fuel from the origin to the destination is

$$ICASKF(WT) = INT(RMTU(WR) / AWPC(WT))$$

where RMTU(WT) is the MTU of PWR/BWR assemblies shipped
per year, and
INT indicates that ICASK has an integer value, rounded up.

The total cask fleet needed to transport both the PWR and BWR spent fuel is the sum of the two cask fleets.

$$FLEETTOT = ICASKF(PWR) + ICASKF(BWR)$$

Because the possibility exists that there are scale effects associated with the cost of fabricating the cask fleet, the cost per cask is a function of the size of the total cask fleet (PWR plus BWR). In order to capture this scale effect, the total cask fleet acquisition cost is interpolated from data provided on the cost of fabricating cask fleets of 10, 20, and 70 casks, respectively. The cost of acquiring a cask fleet of size FLEETTOT is then interpolated from these design data.

CCOST = INTERPOLATION [FLEETTOT, CASK DESIGNERS' COST DATA]

where INTERPOLATION indicates that the value of CCOST is interpolated using FLEETTOT and cask design data from the cask designers.

The number of years required to fabricate the cask fleet is interpolated from data previously provided by various cask designers and is then used to distribute the acquisition costs uniformly over that time period such that

$$\text{CAPCOST}(\text{YEAR}) = \text{CCOST} / \text{NYR}$$

A.2.3 Operating Costs

The annual fleet operating costs include the annual hauling costs, security costs, maintenance costs, and handling costs. The annual handling costs for the PWR/BWR casks are

$$\text{HAULC}(\text{WT}) = (\text{WTE}(\text{WT}) * \text{EMPTYC} + \text{WTL}(\text{WT}) * \text{LOADC}) * \text{ICASKF}(\text{WT}) * \text{ATRIP}(\text{WT})$$

where WTE(WT) is the empty weight (in hundredweight CWT) of the PWR/BWR cask, and
WTL(WT) is the loaded weight (CWT) of the cask.

The unit hauling costs for an empty and loaded cask, EMPTYC and LOADC, depend upon the mode of cask shipment. For truck transport the unit hauling costs are

$$\text{EMPTYC} = .00402 * \text{DIST} + .3954$$

$$\text{LOADC} = .004764 * \text{DIST} + 1.1614$$

For rail transport the unit hauling costs are estimated by

$$\text{EMPTYC} = .03636 * \text{DIST} ** .586$$

$$\text{LOADC} = .03636 * \text{DIST} ** .586$$

When a dedicated train is assumed, then an additional per train-mile charge of \$48 is used.

The average annual cask security cost for truck transport is calculated as a function of distance to be

$$\text{SECCOST}(\text{WT}) = \text{DIST} * 3.688$$

For rail transport, the cask security cost is calculated as

$$\text{SECCOST}(\text{WT}) = (.76 * \text{DIST}) + 500 (\text{DIST}/\text{SPEEDL} + \text{DIST}/\text{SPEEDR}) + 500 * \text{CASTURN}(\text{WT}, \text{R})$$

Annual fleet maintenance costs depend upon whether the cask is a PWR or BWR cask.

$$\text{CMAINT}(\text{WT}) = \text{ICASKF}(\text{WT}) * \text{UCM}(\text{WT})$$

where $\text{UCM}(\text{WT})$ is the annual cost of maintaining a PWR/BWR cask.

The annual cost of handling the PWR/BWR cask fleet at the reactor and the repository is

$$\text{HANDC}(\text{WT}) = (\text{PROC}(\text{WT}, \text{R}) * \text{RCOST}(\text{WT}) * \text{CREW}(\text{R}) + \text{PROC}(\text{WT}, \text{REP}) * \text{REPCOST}(\text{WT}) * \text{CREW}(\text{REP})) * \text{ATRIP}(\text{WT}) * \text{ICASKF}(\text{WT})$$

where $\text{PROC}(\text{WT}, \text{R})$ is the time required to process the PWR/BWR cask at the reactor,
 $\text{PROC}(\text{WT}, \text{REP})$ is the time required to process the PWR/BWR cask at the repository,
 $\text{RCOST}(\text{WT})$ is the hourly cost of handling the PWR/BWR cask at the reactor,
 $\text{REPCOST}(\text{WT})$ is the hourly cost of handling the PWR/BWR at the repository, and
 $\text{CREW}(\text{R})$ and $\text{CREW}(\text{REP})$ are the crew sizes at the reactor and repository, respectively.

The total annual fleet operating cost is, therefore, the sum of annual hauling, security, maintenance, and handling costs for both the PWR and BWR casks.

$$\text{TOTOPER} = \text{SUM}(\text{WT}) [\text{HAULC}(\text{WT}) + \text{SECCOST}(\text{WT}) + \text{MAINTC}(\text{WT}) + \text{HANDC}(\text{WT})]$$

where $\text{SUM}(\text{WT})$ indicates that the variables in the brackets are summed for both PWR and BWR.