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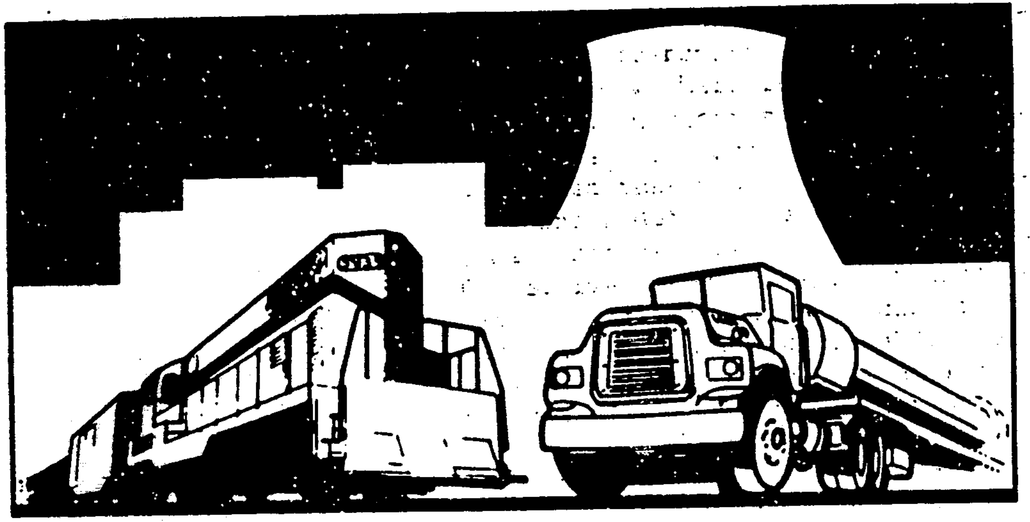
Analysis of Radiation Doses from Operation of Postulated Commercial Spent Fuel Transportation Systems

Main Report



November 1987

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SUBJECT: DISTRIBUTION OF ALARA REPORT

The enclosed report entitled "Analysis of Radiation Doses from Operation of Postulated Commercial Spent Fuel Transportation Systems" documents the results of a 2-year effort to define and describe a postulated reference transportation system and to estimate radiation doses to the public and workers resulting from the transport of spent fuel from commercial nuclear power reactors to a geologic repository. A postulated reference rail/legal weight truck transportation system is developed that would use current transport technology. The report contains a detailed breakdown of activities and a description of time/distance/dose-rate estimates for each activity within the system. Collective doses are estimated for each of the major activities at the reactor site, in transit, and at the repository receiving and handling facility. Annual individual doses to the maximally exposed individuals or groups of individuals are also estimated. A total of 17 alternatives and sub-alternatives to the postulated reference transportation system are identified, conceptualized, and their dose-reduction potentials and costs estimated. Resulting ratios of cost/collective system dose for each alternative relative to the postulated reference transportation system are given. Most of the alternatives evaluated are estimated to provide both cost and dose reductions.

The results of the study can be used to provide input to the Department of Energy in its development and optimization of the Federal waste management transportation system for spent fuel, including shipping and receiving facility designs.

As the design of the waste management system matures and as further developments are made to assure a safe and efficient system, the results and analyses provided by this report will be updated. These updates will assure timely documentation of system changes and continue to provide a detailed and complete description of the most current reference transportation system. The special loose-leaf edition of this report is provided for your ease in incorporating the updated analyses and descriptions of the transportation system, as they occur.

Cindy Boggs-Mayes
Cynthia Boggs-Mayes
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Enclosure:
As Stated

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ANALYSIS OF RADIATION DOSES FROM OPERATION OF POSTULATED COMMERCIAL SPENT FUEL TRANSPORTATION SYSTEMS

Main Report

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ABSTRACT

This report contains a system study of estimated radiation doses to the public and workers resulting from the transport of spent fuel from commercial nuclear power reactors to a geologic repository. A postulated reference rail/legalweight truck transportation system is defined that would use current transport technology. The report contains a detailed breakdown of activities and a description of time/distance/dose-rate estimates for each activity within the system. Collective doses are estimated for each of the major activities at the reactor site, in transit, and at the repository receiving facility. Annual individual doses to the maximally exposed individuals or groups of individuals are also estimated. A total of 17 alternatives and subalternatives to the postulated reference transportation system are identified, conceptualized, and their dose-reduction potentials and costs estimated. Resulting ratios of Δcost/Δcollective system dose for each alternative relative to the postulated reference transportation system are given. Most of the alternatives evaluated are estimated to provide both cost and dose reductions.

Major reductions in transportation system dose and cost are estimated to result from using higher-capacity rail and truck casks, and particularly when replacing legalweight truck casks with "advanced design" overweight truck casks. The study of the postulated reference transportation system indicates that individuals who work close to the loaded casks on a daily basis throughout the year (such as those at the repository receiving facility) could receive an annual radiation dose in excess of that permitted in current regulations. Such doses will not be permitted by DOE. The greatest annual dose reduction to the highest exposed individual workers (i.e., at the repository) is estimated to be achieved by using remote handling equipment for the cask handling operations at the repository. Additional shielding on the postulated reference legalweight truck cask, particularly on the cask ends, is also effective in reducing doses to both occupational radiation workers at the reactor and repository and to transport workers. Truck operations with shorter stop times at truck stops are found to reduce the collective radiation dose to the public.

A transportation system incorporating a combination of alternatives is also defined and evaluated as an example to show the potential effects and interactions of combining compatible alternatives.

The results of the study can be used to provide input to the Department of Energy in its development and optimization of the federal waste management transportation system for spent fuel, including shipping and receiving facility designs.

ACKNOWLEDGMENTS

The authors would like to thank E. L. Wilmot, C. W. Connor and H. J. Hale of the U.S. Department of Energy's Office of Civilian Radioactive Waste Management for their technical guidance and sponsorship of this work. C. Boggs-Mayes of DOE's Chicago Operations Office and R. B. Goranson and D. E. Kenyon of DOE's Richland Operations Office are also acknowledged for their support and help on this project.

A number of individuals in industry and government contributed to the quality of this final report through their in-depth peer review of the draft. They are: R. L. Chapman, EG&G Idaho, Inc.; K. H. Henry, Westinghouse Hanford Company; R. H. Jones, private consultant; W. Pardue, R. C. Tucker, R. L. Fisher, D. R. Doman and S. Maheras, Battelle Project Management Division; C. Forsberg, C. V. Parks, R. Rawl, Oak Ridge National Laboratory; G. Allen and T. L. Sanders, Sandia National Laboratory; M. L. Smith and B. H. Wakeman, Virginia Power Co.; P. D. Steneck and S. H. Woolfolk, Science Applications International Corporation; E. Pearson, MACTEC; and R. F. Williams and R. W. Lambert, Electric Power Research Institute. To these individuals and their sponsoring organizations, we extend our appreciation.

The following Pacific Northwest Laboratory staff members deserve recognition for their contributions to this study: J. C. McKay for his consultations regarding cask handling procedures and requirements and for conceptualizing the special tool alternative; G. H. Beeman, A. J. Boegel, D. F. Newman, and M. K. White for their efforts in the overall management of this work under the Systems Integration Program at PNL; D. L. Brenchley for moderating the October 1986 and May 1987 peer review meetings; M. R. Anderson for providing computer support for the time/distance/dose calculations; D. R. Payson for editing and producing the final report; and T. R. Lorenzo for typing the final manuscript.

The design and evaluation of the remote handling alternative was performed at Westinghouse Hanford Company under the direction of D. H. Nyman and at Sandia National Laboratories by P. J. Eicker. Their edited report is contained in Appendix K.

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1.0 INTRODUCTION

The federal system for management of spent fuel and high-level radioactive waste includes the acceptance by the Department of Energy (DOE) of the spent fuel or waste loaded in casks at the reactor or other waste generators, its transportation to a repository, and its handling and final emplacement in the repository. The DOE plans to implement a transportation system that is safe, secure, efficient and cost-effective (DOE 1985; DOE 1986a,b; DOE 1987). This system will be designed and operated to meet applicable safety and security requirements of the Department of Transportation (DOT) and the Nuclear Regulatory Commission (NRC) as well as those of the DOE.

In planning for implementation of a safe and cost-effective transportation system, DOE commissioned the Pacific Northwest Laboratory (PNL) to develop estimates of the radiation doses, both public and occupational, that would result from operation of a system postulated using current designs and practices. From that evaluation, PNL identified activities/operations that result in relatively high doses, proposed conceptual alternatives that would effectively reduce such exposures, and evaluated the cost-effectiveness of such alternatives.

This study is one of a series of system studies to be carried out within the DOE's Office of Storage and Transportation Systems' (OSTS) overall Transportation System Study Plan (TSSP) now being developed. The TSSP is designed to identify, schedule and integrate the results of numerous system studies needed to support informed system design and operational decisions at the DOE-OSTS responsibility level. This dose analysis and alternatives study in itself is not intended to specify the reference DOE transportation system, nor form the basis for final system design characteristics or operational procedures. While both public and occupational radiation exposures are very important in system design, regulatory limits must be met. Control of doses within (below) regulatory limits requires consideration of various other overall system impacts that may result from decisions/actions directed toward reducing exposures. The results of this study will be considered, along with results of other system studies, in making overall system design and operational decisions leading to specifications describing an optimal system for deployment in the late 1990s.

While radiation doses to the public and to workers in the transportation-related[a] part of the waste management system will be within regulatory limits, ALARA[b] principles will be considered in identifying cost-effective changes in the system that could reduce exposures below regulatory limits. The purpose of this study is to assess cost versus radiation dose reduction trade-offs associated with potential alternatives for transportation system design and operations. These results are expected to provide technical bases (when combined with numerous other factors) for the DOE's value judgments and decisions for the spent fuel shipping cask development process, as well as input to both DOE's cask system design and planning and to the transportation system operational planning.

This report contains an analysis of routine operations and estimates of the public and worker radiation doses that would occur in a postulated

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(a) The term "transportation-related" includes cask handling and spent fuel loading and unloading at reactors and at the postulated reference repository. For the remainder of this report, the term is shortened to the "transportation system."

(b) The term ALARA is defined in the proposed 10 CFR 20.3 (<u>Fed. Reg.</u>, January 9, 1986):
"'ALARA' (acronym for "as low as is reasonably achievable") means making every reasonable effort to maintain exposures to radiation as far below the dose limits in this part as is practical:
   (i) consistent with the purpose for which the licensed activity is undertaken
   (ii) taking into account the state of technology, the economics of improvements in relation to benefits to the public health and safety, and other societal and socioeconomic considerations
   (iii) in relation to utilization of nuclear energy in the public interest."
Guidance on the application of the ALARA principles is found in DOE's Order 5480.1B (DOE 1986c) and in NRC's Regulatory Guide 8.10.

generic reference spent fuel transportation system(a,b,c) using both truck and rail modes. Total risks are not estimated (i.e., consideration of nonradiological or accident risks that will be the subject of future studies in the TSSP are not included). The analysis encompasses spent fuel loading at the reactor (not part of the DOE-OCRWM waste management system), transportation of the fuel to a repository, and unloading of the fuel at a repository, and provides cost/dose trade-off analyses of selected potential alternatives to the transportation system. The postulated reference transportation system described is one that is envisioned for service in the late 1990s and is based on using current technology. It is defined only for use in this analysis. In overall system development and optimization, many design-performance assessment iterations will be necessary, and it is likely that the certain system components in the actual system deployed in the late 1990s will be different from the system described here.

An analysis of the routine radiation doses to the public and to transportation workers for each operation in the postulated reference system is presented. The design features/operations that produce the largest collective and individual radiation doses are then identified and provide the basis for identification and analysis of dose-reduction alternatives. In some cases, the estimated annual individual worker doses exceed the present regulatory limits. Final designs of the system and components will require that regulatory limits are not exceeded and that ALARA alternatives are considered.

(a) The postulated reference system is defined for use in this study only. No officially designated reference reactor, transportation system, or repository exists at this time. The study has been based on a single set of spent fuel characteristics and a single split (30/70% by weight) between truck and rail mode. The impact of other bases would require additional analysis.

(b) The postulated reference system defined in this study involves using shipping casks that just meet DOT regulatory limits for external radiation levels from the casks (see Appendix E, Sections E.2.1-3). Most spent fuel shipped in the U.S. to date is less radioactive than that for which the casks were designed, which results in low external radiation levels from the casks. Thus, the bases used in this analysis result in higher doses than generally experienced in recent shipments in casks designed in the 1970s.

(c) High-level waste is not included in this study because its final volume is uncertain. HLW transport would result in trends similar to those for spent fuel (see Appendix E, Section E.1).

The main report is comprised of six chapters. Following this introduction, the report is summarized in Chapter 2. A review of the overall study bases and approach is given in Chapter 3. Chapter 4 provides a detailed description of the postulated reference transportation system. This description covers the overall system, the casks and their vehicles, the spent fuel handling system at the reactors (under utility control) and at the repository, and the in-transit operations (encompassing all activities in the public domain while the vehicles are moving or stopped). Included in Chapter 4 are estimates of radiation doses that would result from implementing the postulated reference transportation system due to at-reactor transportation activities, in-transit operations, and at-repository transportation activities. Next, in Chapter 5, evaluations of individual alternatives for reducing dose in the postulated reference transportation system are identified and discussed. In Chapter 6, an example alternative transportation system incorporating a combination of alternatives is presented to illustrate total dose-reduction potentials.

Fourteen appendices provide additional information on the various assessments in the main report. In Appendix A, calculations of dose rate fields around the postulated reference casks are presented. Time/distance/dose calculations for at-reactor and at-repository operations for the postulated reference system are given in Appendices B and C, respectively. In Appendix D, additional information on the in-transit dose calculations is provided. Assumptions and related bases/rationale used in this study for the postulated reference system are given in Appendix E. Detailed operational impacts and radiation dose summary tables for the dose reduction alternatives are presented in Appendices F through I, while calculations of cost impacts for the alternatives are presented in Appendix J. Additional information on a system for remotely handling casks at a receiving facility is provided in Appendix K. Appendix L contains time/distance/dose spreadsheets for the example combination of alternatives that is analyzed for reducing system dose. The rationale and data for the selection of the alternatives for analysis in the report are provided in Appendix M. Finally, the calculations of selected average annual individual radiation doses are contained in Appendix N.

1.1 REFERENCES

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2.0 SUMMARY

Estimates were developed for routine radiation doses resulting from operation of a postulated system for transporting spent fuel from commercial nuclear power reactors to a DOE repository for packaging and geologic emplacement. A postulated reference transportation system(a) is first defined and time/distance/dose studies are performed to determine potential radiation exposures to the workers and the public.(b,c) With the identification of the high dose-producing activities in the postulated reference study, alternatives to that system are identified and evaluated on a conceptual basis. The analyses of these alternatives will provide input to the development of a cost-effective transportation system, including the design and operation of the casks and interfacing facilities.

The results of this study are summarized in this chapter. A summary of the postulated reference system description is given in Section 2.1, including its estimated radiation doses from the total system, to population groups, and to maximally exposed groups or individual workers. A summary of the evaluation of individual transportation system alternatives to the postulated reference system is given in Section 2.2, along with the associated dose reductions and costs of the individual alternatives. The estimated doses and costs for an example alternative system incorporating a combination of alternatives are summarized in Section 2.3.

(a) This is a postulated reference system for use in this study only. No officially designated reference reactor, transportation system, or repository exists at the current time, nor is one defined in DOE (1986a).

(b) Analysis of nonradiological risks and other risk factors from the transportation system are not included in this study.

(c) The postulated reference system defined in this study involves using shipping casks that just meet DOT regulatory limits for external radiation levels from the casks. As a result, it is assumed that the postulated reference casks will have a dose rate of 10 mrem/hr at 2 meters from the edge of the transport vehicle. Most spent fuel shipped in the U.S. to date is less radioactive than that for which the casks were designed, which results in low radiation levels external to the casks. Thus, the bases used in this analysis result in higher estimated doses than have generally been experienced in recent shipments using casks designed in the 1970s.

2.1 POSTULATED REFERENCE TRANSPORTATION SYSTEM

The operational activities evaluated in this study of the postulated reference transportation system include those in the following three major functional steps in the system: a) receiving empty transport casks at a typical commercial nuclear power reactor and in-pool loading of the casks with spent fuel, b) transporting the spent fuel (dry) in the casks to a repository, and c) receiving the loaded transport casks at a repository, dry unloading of the spent fuel and placing it into lag storage, and preparing and returning the empty casks to the reactors.(a) A description of the postulated reference system is shown schematically in Figure 2.1 and summarized in Table 2.1.

It should be noted that the actual system for transporting spent fuel from commercial nuclear power reactors to a geologic repository does not yet exist. The system postulated in this study is a "snapshot" of a system representative

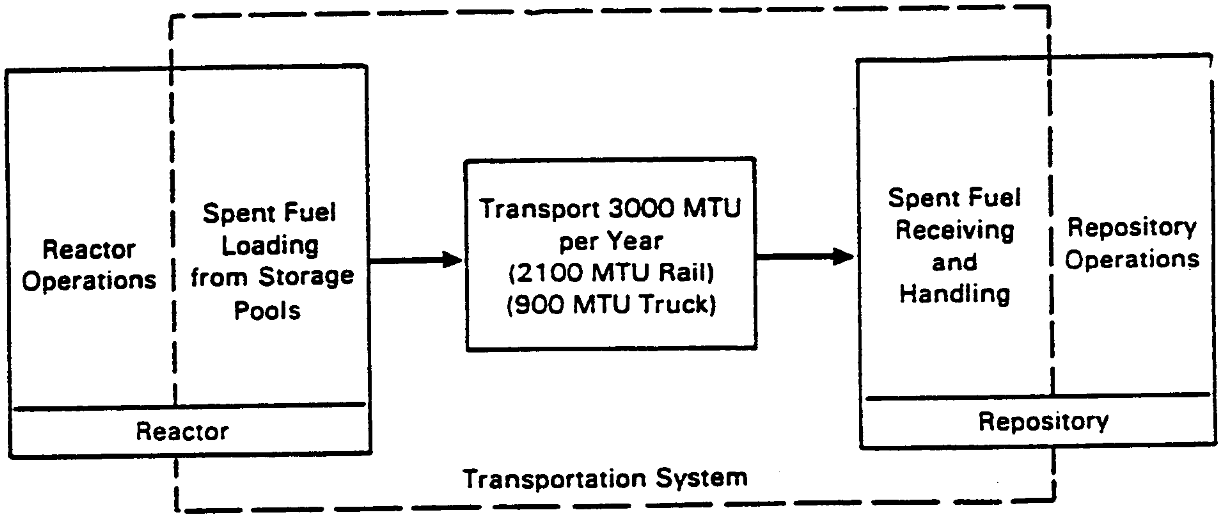

FIGURE 2.1. Postulated Reference Transportation System

(a) The DOE has proposed to include a monitored retrievable storage (MRS) facility in the waste management system (DOE 1987a). The MRS facility would receive spent fuel from reactors, package it, and eventually load it out for shipment by rail to a repository. The results from this study would be applicable to the shipments to an MRS facility, with in-transit radiation doses changing because of different shipping distances to the proposed MRS facility. Radiation doses resulting from shipments from the proposed MRS facility to the repository could be evaluated using the same methodology used in this report.

TABLE 2.1. Summary Description of Postulated Reference Transportation System[(a)]

Reactor[(b)]	- Contemporary large LWR,[(c)] pool storage and in-pool cask loading
Repository	- Spent fuel dry receiving and handling facility similar to the advanced conceptual design of the MRS facility (DOE 1987a)
Transport Casks	- Legalweight (25 tons) truck and 100-ton rail, including spent fuel - Description similar to DOE fact sheets (DOE 1986b); handling features similar to existing casks - Capacity 14/36 PWR/BWR assemblies by rail; 2/5 PWR/BWR assemblies by truck - Shielding to meet DOT regulations
In-Transit Conditions	- 3,000 MTU/yr shipped; 60 wt% PWR/40 wt% BWR - 70 wt% rail/30 wt% truck transport of spent fuel - Rail/truck route distances 3070/2860 km (1910/1780 mi) - Rail by general freight; truck by general commerce
Spent Fuel Radiation Source	- Standard PWR, 10 years old, 35,000 MWD/MT burnup

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(a) See Chapter 3 and Appendix E for rationale for selection of this system; see Chapter 4 for details of the system.

(b) Spent fuel cask loading and shipping operations at the reactor are part of the spent fuel management system. Although these operations are not part of the federal system, they are included in this study because design features and operations in the federal part of the system can impact them.

(c) Certain differences related to cask handling among PWRs and for BWRs are discussed in Appendix E, Section E.3.

of current technology, its applications and operating practices. It contains all the functions needed in any transportation system. Design and operation of the new-generation transportation system will apply the principle of ALARA to control radiation doses within regulatory limits.

Operations with this postulated reference transportation system were analyzed to develop estimates of public and worker radiation doses if such a system were implemented.

The overall logistics and shipment information for the postulated reference transportation system, based on this study's system definitions and analysis results, is summarized in Table 2.2. The number of truck shipments would be three times the number of rail shipments, but truck shipments require significantly shorter in-transit time than rail shipments because of the higher average speed. The average daily receipt rate of casks at the repository would be about 3.6 casks/day. The estimated turnaround times for the casks include an allowance for normal operations and times in queues while awaiting handling in the receiving and handling building at the repository.

2.1.1 Estimated Radiation Doses in the Total System

Shielding analyses were performed to provide information for developing the conceptual configuration of the postulated reference truck and rail casks (e.g., cavity size, weight, shield thickness and materials). These analyses confirmed that the DOT external dose-rate criteria were just met, and that the payload capacity requirements and gross vehicle weight restrictions were satisfied. Radiation dose-rate maps were then developed for the areas around the casks.

Operations within the postulated reference system were evaluated to estimate times and locations for affected members of the public and workers for each activity within the system. Time estimates were based largely on review of available information, with consensus judgment of the authors used where information was unavailable or conflicting.

The time/distance analyses were combined with the dose-rate field information around the casks and general-area background radiation dose rates from other facility sources to estimate radiation doses to people in three

TABLE 2.2. Estimate of Overall Logistics and Shipment Information

Parameter	Rail	Truck	Total
Bases for This Study			
MTU/Yr Shipped	2100	900	3000
MTU/Cask, PWR/BWR	6.47/6.70	0.92/0.93	--
Shipments/Yr	320	971	1291
Average Casks/Day Received at Repository[(a)]	0.9	2.7	3.6
Overall Logistics Results from This Study			
Avg. Reactor Turnaround Days, PWR/BWR[(b)]	2.3/2.5	1.3/1.4	--
Avg. Round-Trip Transit Days (to and from repository)	21.6	5.1	--
Avg. Repository Turnaround[(c,d)] Days, PWR/BWR	1.7/2.0	1.3/1.4	--
Avg. Total Round-Trip Days/[(d)] Shipment, PWR/BWR	25.6/26.1	7.7/7.9	--

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(a) Repository receiving 365 days/yr, 24 hr/day (DOE 1987a).

(b) Reactor fuel loading and shipping operations are nominally one shift/day. Carrier drop-off and pick-up delays are not included.

(c) Includes approximation of typical queuing time at the repository.

(d) Wet decontamination of every tenth cask, assumed in this study, is not included here but is estimated to add approximately 8 hr and 7 hr to the rail/truck cask turnaround times for each tenth shipment, respectively.

categories that are defined specifically for this study. These categories are: 1) the affected public,[a] 2) occupational radiation workers[b] at the reactor and at the repository receiving and handling facility; and 3) transport workers[c] while the shipments are in transit.

A summary of the estimated overall collective radiation doses for the postulated reference transportation system is given in Table 2.3. The table shows that the collective doses (person-mrem/MTU)[d] to the workers are higher than to the public for either shipment mode. It should be noted that the collective doses to the public are spread over millions of public members, while doses to the workers are spread over a few hundred. Thus, individual doses to the average affected members of the public are at least one-thousand-fold lower than those to the average worker. There is essentially no dose to the public from transportation activities at the reactor or repository (DOE 1987a); all the dose to the public is received during the in-transit activities.[e] Public doses per unit of spent fuel shipped by rail are estimated to be more than 10-fold lower than for truck shipments, primarily

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(a) In this analysis, the affected members of the public are those that are near enough to a loaded transport cask that they can receive a measurable radiation dose. These public members do not include any of the reactor or repository workers (see footnote b) or the transport workers (see footnote c).

(b) In this analysis, the radiation workers at the reactor and the repository are those workers at those facilities that participate in the handling and loading or unloading of the transport casks/vehicles.

(c) In this analysis, the transport worker category includes all who play an occupational role in completing the shipments. Transport workers include truck drivers, service station attendants, state highway and railroad inspectors, train crews, railroad train handling and service crafts, and escorts.

(d) Person-mrem/MTU is the sum of all the mrem/MTU accumulated by all affected persons, regardless of the total number of persons involved. For example, 100 person-mrem/MTU may result from one person exposed to 100 mrem/MTU, from 100 persons exposed at an average of 1 mrem/MTU, from 1,000,000 persons exposed at an average of 0.0001 mrem/MTU, or from any equivalent combinations thereof.

(e) The in-transit activities all occur outside the fences of the reactors and the repository. They occur in the "public domain" where members of the public "see" the shipments at various distances and under varying circumstances.

TABLE 2.3. Summary of Estimated Collective Radiation Doses from Postulated Reference Transportation System Activities(a)

Location of Activity	Doses, Person-mrem/MTU by Shipment Mode(b,c,d)			
	To Public		To Worker(e)	
	Rail(f)	Truck(g)	Rail(f)	Truck(g)
Reactor	(h)	(h)	62/77	293/314
In-Transit	6/6	495/495	10/10	231/231
Repository	(h)	(h)	72/70	300/299
Total	6/6	495/495	144/157	824/844

(a) The number of significant figures given in this and subsequent tables in this report are greater than warranted by the accuracy of the analysis, but they are retained to assure consistency of the results within the report.
(b) These unit doses are independent of the time period of concern; for annual doses, multiply by 3,000 MTU/yr (the nominal acceptance rate for a repository per DOE 1986a).
(c) Assumes shipment either by all truck or all rail. For the postulated reference system doses, multiply rail values by 0.7 (shipment fraction), truck values by 0.3, and sum the two results.
(d) Excludes doses resulting from maintenance of casks/vehicles, not evaluated in this study.
(e) Reported for PWR and BWR fuel types as PWR/BWR.
(f) 14/36 PWR/BWR spent fuel assemblies/rail cask.
(g) 2/5 PWR/BWR spent fuel assemblies/truck cask.
(h) Previously shown to be insignificant, and therefore not developed in this study (DOE 1987a).

because of the fewer but larger(a) shipments made by rail and the fewer public members near enough to the rail shipments to be affected by them.

Worker radiation doses occur during each of the three major steps in the transportation activities (i.e., during at-reactor, in-transit, and at-repository operations). Collective worker doses associated with the smaller-capacity casks shipped by truck are estimated to be nearly 5-fold higher than the doses associated with the larger casks shipped by rail. Collective transport worker doses per unit of spent fuel shipped are estimated to be lower than for the workers at the reactor or repository. Doses are much

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(a) Rail cask payload in MTU of spent fuel is 6 to 7 times greater than for truck casks in the postulated reference system.

higher for shipments by truck than by rail. Truck shipment doses are higher because of the proximity of the truck transport workers for significant time periods compared to the rail transport system. Collective worker doses per shipment are estimated to be about the same at the reactors and at the repository per unit of spent fuel shipped.

2.1.2 Estimated Collective Radiation Doses Associated with Specific Transportation Activities

The activities within the three steps in the postulated reference transportation system that would produce the highest collective unit radiation doses, i.e., person-mrem/MTU, are given in Table 2.4, along with the estimated doses from those activities. All of the activities considered are listed.

Transportation activities at reactors include receiving the empty transport cask at the site fence, preparing and moving the cask into the facility loading area, removing the cask from the vehicle, preparing it for loading and placing it into the water-filled loading pit, filling it with spent fuel from the storage pool, removing the cask from the pool and preparing it for shipment, placing the cask on the vehicle, and moving it to the site gate where it is connected to the transport carrier's prime mover for shipment to the repository.

Transportation activities in transit include those associated with the normal movement of the load over highways or railroads, and those that occur while the vehicle is stopped. Activities at stops include refueling, inspections, driver resting/eating, train make-up, and crew changes. Radiation doses are received by the transport workers, and by members of the public who may be bystanders at stops, who are traveling along or nearby the route, and who live or work within the radiation field of the cask.

Transportation activities at the repository include receiving the loaded transportation cask at the site gate, inspecting, monitoring, and washing of the cask, moving the cask into the facility receiving and handling area, removing the cask from the vehicle, preparing it for unloading, mating it to the hot cell unloading port, removing the spent fuel from the cask and placing it in lag storage in the hot cell, removing the cask from its hot cell port connection and preparing it for return shipment, placing the cask on the vehicle, and

TABLE 2.4. Estimated Collective Radiation Doses from Major Activities in the Postulated Reference Transportation System

	Workers				Public			
	Rail[a]		Truck		Rail[a]		Truck	
Activity	Person-mrem/MTU[b]	% of Dose[b,c]	Person-mrem/MTU[b]	% of Dose[b,c]	Person-mrem/MTU[b]	% of Dose[b,c]	Person-mrem/MTU[b]	% of Dose[b,c]
AT-REACTOR								
- Install lids, flush cask interior, drain, dry and seal cask	25/24	40/31	126/126	43/40	0/0	--	0/0	--
- Install TD, IL, PB[d]	10/9	15/12	56/55	19/18	0/0	--	0/0	--
- Load spent fuel into cask	11/27	17/35	11/27	4/9	0/0	--	0/0	--
- On-vehicle cask decon and survey	3/3	5/4	18/18	6/6	0/0	--	0/0	--
- Final inspection and contamination/radiation survey	2/2	4/3	16/15	5/5	0/0	--	0/0	--
- All others	11/12	19/16	66/73	23/23	0/0	--	0/0	--
Totals	62/77	100/100	293/314	100/100	0/0	--	0/0	--
IN-TRANSIT								
- Moving enroute	2.2/2.2	20/20	194/194	86/86	3/3	48/48	62/62	13/13
- Activities at stops	7.8/7.8	80/80	37/37	14/14	3/3	52/52	433/433	87/87
Totals	10/10	100/100	231/231	100/100	6/6	100/100	495/495	100/100
AT-REPOSITORY								
- Remove cask lids, prepare for unloading	54/52	75/75	202/201	68/68	0/0	--	0/0	--
- Remove IL, TD[d]	12/12	17/17	58/58	19/19	0/0	--	0/0	--
- Wash cask/vehicle, retract PB, monitor, inspect loaded cask	2/2	3/3	17/17	6/6	0/0	--	0/0	--
- Receive cask at gate, monitor, inspect, unhook	1/1	1/1	6/6	2/2	0/0	--	0/0	--
- Remove cask from vehicle, place on cask cart	0.7/0.6	1/1	4/4	1/1	0/0	--	0/0	--
- All others	2/2	3/3	13/13	4/4	0/0	--	0/0	--
Totals[e]	72/70	100/100	300/299	100/100	0/0	--	0/0	--

(a) Rail cask capacity = 14/36 PWR/BWR assemblies; truck cask capacity = 2/5 PWR/BWR assemblies.
(b) Reported for PWR and BWR fuel types as PWR/BWR.
(c) % of collective dose at the reactor, in-transit, or at the repository.
(d) IL = impact limiters, TD = tie-downs, PB = personnel barriers.
(e) Excludes wet decontamination of the internals and seal replacement of each cask after every tenth shipment.

moving the vehicle with its cask to the site gate where it is connected to the carrier's prime mover. In addition, wet decontamination of the cask internals is assumed to be done at the repository on each cask after every tenth trip. This activity has essentially no effect on the collective doses at the repository (because it is done remotely in a shielded hot cell), but it adds an estimated 7 to 8 hours turnaround time each time it is done on every cask.

As shown in Table 2.4, workers' collective radiation doses at the reactor and repository are dominated by activities where the workers are near the cask, particularly when they are working around the cask lid area. These activities would result in at least 40% of the total collective worker doses at the reactor, and about 70% at the repository. Doses to the workers at the reactor and the repository from the next largest dose-producing activity, working on the cask tiedowns, impact limiters, and personnel barriers, would account for 15 to 20% of the total collective doses at those facilities. Doses to reactor workers resulting from in-pool loading of spent fuel into the casks would account for 4 to 30% of the reactor workers' total collective doses. The last three major dose-producing activities at the reactor and repository, cask/vehicle decontamination, inspection and monitoring, and placing the cask on the vehicle, would account for only 1 to 6% each of the total collective worker doses. Estimated radiation doses to the workers resulting from all of the remaining 19 activities would account for about 20% of the total collective worker doses at the reactor, and 3 to 4% at the repository.

Radiation doses to the public result from activities where the people are near the cask while the shipments are in transit. In this case, the majority of public doses result primarily from the activities while the vehicles are stopped, especially in truck shipments. (Doses to the public that are a direct result of spent fuel loading and unloading are very low [DOE 1987a] and are not developed in this study.)

2.1.3 Estimated Radiation Doses to Maximally Exposed Groups or Individuals Associated with Transportation Activities

The estimated radiation doses resulting from transportation activities that could occur to maximally exposed groups or individuals are given in

Table 2.5. For worker exposures at the reactor and repository, and for transport workers, the doses are based on using crews on each operation that are assumed to be dedicated solely to performing the cask handling work. Thus, the estimated annual doses(a) for the workers, given in Table 2.5, are averages for the dedicated crews. Staff rotation for dose distribution is not included in the evaluations in this study. For members of the uninvolved public, the maximum individual doses(a) are for unique persons who may be exposed under rare situations, and are believed to be conservative.

In all cases, annual average radiation doses to worker groups or to maximally exposed individuals resulting from truck shipments are significantly higher than for rail shipments.

At the reactor, average individual worker doses to the maximally exposed worker groups, i.e., maintenance-craftsmen and operators,(b) are estimated to be about 1000 mrem/year from truck shipments or about 220 mrem/year from rail shipments (330 mrem/year for operators at BWRs). These doses, particularly from truck shipments, could be a significant fraction of the workers' total annual dose from all activities. These doses would be approximately proportional to the MTU/year shipped from each reactor (30 MTU/year assumed in this study).

In-transit annual radiation doses resulting from truck shipments are also much higher than for rail shipments. Individual doses to truck drivers could reach an estimated 3,000 mrem/year if the drivers spend all their working year on transporting spent fuel. It is estimated that state escorts for truck shipments could receive up to about 140 mrem/year if all shipments were escorted in the repository state by 4 shifts of escorts as is assumed in this study. Similarly, it is estimated that each service station attendant (who works one of four shifts) at a truck stop near the repository (that services one-half of all truck shipments) could receive as much as about 100 mrem/year

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(a) Individual annual doses are expressed in mrem/yr. These doses are the average mrem/yr for each member of the maximally exposed worker groups, or for a potential maximally exposed individual member of the public.

(b) The maintenance-craftsmen are responsible for routine operations such as removing bolts from impact limiters and lids. This function should not be confused with building maintenance activities.

TABLE 2.5. Estimated Annual Doses to Maximally Exposed Groups or Individuals in the Postulated Reference Transportation System

Worker or Public Category	Number of Persons in Category	Individual mrem/yr(a,b)			Related Section in Chap. 4
		Rail(c)	Truck(d)	Total Rail and Truck(e)	
AT-REACTOR(f)					
Maintenance-Craftsmen	4	220/220	1010/1010	NA(g)	4.2
Operators	4	220/330	900/1040	NA	4.2
Radiation Monitors	1	84/84	460/460	NA	4.2
Quality Control Inspectors	1	120/230	340/440	NA	4.2
Total Workers	13				
IN-TRANSIT					
Transport Crew	NAv(h)	2	3030	NAv	4.3
State Inspectors(i)	NAv	32	770	NAv	4.3
Escorts(j)	NAv	115	140	NAv	4.3
Train Handlers	NAv	16(k)	NA	NAv	4.3
Service Attendants(l)	NAv	16	100	NAv	4.3
Public Resident	NAv	2(m)	3(m)	NAv	4.3
Public Passersby	NAv	<1	2	NAv	4.3
AT-REPOSITORY					
Maintenance-Craftsmen	26	4,960	8,250(n)	13,200(n)	4.4
Security Guard	8	224	777	1,000	4.4
Operators	47	256	777	1,030	4.4
Radiation Monitors	10	224	583	807	4.4
All Other Workers	22	192(o)	486(o)	614(o)	4.4
Total Workers	113				

TABLE 2.5. (contd)

Footnote Definitions:

(a) Given for PWR and BWR spent fuel at-reactor. In-transit values are based on PWR (worst case) analysis. Repository values are based on a 60% PWR/40% BWR split, by weight.
(b) Average annual doses for individual craft workers; annual doses for hypothetical, maximally exposed, selected, unusual potential cases for individual public members.
(c) Rail cask capacity is 14/36 PWR/BWR assemblies.
(d) Truck cask capacity is 2/5 PWR/BWR assemblies.
(e) Total dose from 30 wt% of spent fuel shipped by truck and 70 wt% by rail.
(f) Assumes 30 MTU/yr shipped from each reactor; each reactor ships either all by truck or all by rail. Reported for PWR and BWR fuel types as PWR/BWR.
(g) NA = not applicable, since each reactor will use truck or rail.
(h) NAv = not available; insufficient information is available to estimate these values.
(i) Assumes state inspections for truck and/or rail in the originating and destination state. Each individual inspector inspects 1/4 of all truck or all rail shipments at the state border where the repository is located.
(j) Maximally exposed rail escorts are assumed to accompany all rail shipments from the last railyard to the repository gate. Maximally exposed state truck escorts are assumed to follow 1/4 of all truck shipments from the border of the final state to the repository. Other state escorts for truck shipments are only in urban areas.
(k) Assumes a train handler that services 1/4 of all rail shipments at the last railyard near the repository.
(l) Assumes a truck service station attendant at the last stop near the repository that services 1/4 of 1/2 of all truck shipments, 121 truck shipments/yr. Assumes a train servicing/maintenance crewman that services 8 train shipments/yr.
(m) For a resident living near the railroad or highway and exposed to all rail or to all truck shipments. For a hypothetical nontransport worker at the truck stop nearest to the repository where one-half of all truck shipments are assumed to stop, the maximally exposed individual could receive 55 mrem/yr.
(n) Note that this dose exceeds the regulatory limit of 5 rem/yr. This is unacceptable, and will be brought into compliance with the regulations before the facility is built and operated.
(o) The highest rail dose is to crane operators; the highest truck dose and total dose are to the security guards.

if he services one-eighth of all the truck shipments.(a) A public "resident" (e.g., a cook) who works at this same hypothetical truck stop could receive an estimated 55 mrem/year, which is about one-half of the dose from natural background. No public passerby for truck shipments should receive more than about 2 mrem/year, and most would receive annual doses that are orders of magnitude lower.

It is estimated that individual train crew members would receive only about 2 mrem/year. Individual state inspectors, where inspection is done on each shipment in the repository state by 4 shifts of inspectors, can receive about 770 mrem/year from truck shipments and about 30 mrem/year from rail shipments. Maximally exposed train handlers, rail yard crewmen, and rail escorts could receive about 16, 1.3, and 115 mrem/year, respectively. The maximally exposed member of the public who resides near the final train stop enroute to the repository could receive about 2 mrem/year. All other persons affected by rail shipments are estimated to receive less than about 1 mrem/year from the rail shipments.

At the repository, average annual radiation doses to individuals in the maximally exposed worker group (13,000 mrem/year to each maintenance-craftsman) are estimated to be more than 2.5 times the annual doses allowed by NRC for such workers. DOE guidelines (DOE 1986c) state that new facilities should have a design objective such that maximum individual doses are less than 1000 mrem/year. The maintenance-craftsman dose will be reduced by DOE to conform to regulations. The annual doses to other individual cask handling workers at the repository (400 to 1,000 mrem/year) are well within NRC regulations but present opportunities for dose reduction. More than 60% of these annual doses to individual repository workers would result from handling truck casks, and less than 40% would result from handling rail casks.

(a) The truck drivers are expected to do essentially all of their own refueling and the driver doses include those from all refuelings. However, this maximally exposed service attendant is assumed to perform the refueling at the last truck stop enroute to the repository, at which one-half of the trucks stop and at which 4 shifts of workers are used.

2.2 ALTERNATIVES TO THE POSTULATED REFERENCE TRANSPORTATION SYSTEM

The analysis of the postulated reference system identified the significant dose-generating activities and individuals receiving those doses. With these activities determined, a large number of alternatives was conceived that may reduce the dose from these activities. These alternatives were screened to the following 17 that were evaluated:

- overweight truck cask (replaces legalweight truck cask)
- uranium-shielded rail cask
- increased end shielding for truck and rail casks
- increased side shielding for truck casks
- increased side shielding for rail casks
- advanced design(a) legalweight truck cask
- advanced design(a) overweight truck cask (replaces legalweight truck cask)
- advanced design(a) rail cask
- special impact-wrench tool
- single-action cask lid fasteners
- built-in cask lid-lifting fixture
- integral cask impact limiters
- quick-release cask impact limiters
- quick-release cask tiedowns
- total remote handling at the repository
- remote cask lid operations at the repository (cask handling area only)
- improved truck operations.

Each of these alternatives was evaluated individually for operational times, radiation exposures, and cost impacts. These evaluations are described and discussed in Chapter 5, and the details of the analyses are given in Appendices F through K. This section describes the alternatives in general terms and summarizes the results of evaluations of impacts on doses and costs.

(a) "Advanced design" casks in this study are casks that use uranium shielding, thinner-walled separators, and closer spacing between the assemblies, taking advantage of the burnup of fissile materials in the spent fuel. These features result in significant potential increases in cask capacities.

2.2.1 Dose-Reduction Principles for the Selected Alternatives

The selected alternatives utilize the three general methods for reducing radiation doses: shielding, time, and distance. The first general method is to increase the shielding around the radioactive material. The alternatives using increased shielding include increased cask end shielding and increased cask side shielding.

The second general method for reducing dose is to decrease the time that an individual is exposed to the radiation. This can result from increasing the speed of the activity or reducing the number of times that the activity must be repeated. An example of this is an improved truck operations that reduces scheduled stop times and travels at higher average speeds. Alternatives for reducing work time around the cask are using single-action fasteners for removing cask tiedowns, impact limiters, and cask lids. Several activities could also be eliminated by designs such as including the lid-lifting adaptor as a part of the inner lid and by building the impact limiters as part of the casks so that they do not have to be individually installed or removed for each shipment. Reducing the number of times that an activity must be performed (primarily through reducing the number of shipments) also can significantly reduce doses. Alternatives that can reduce the number of shipments include the use of higher-capacity casks through use of overweight truck shipments, use of uranium rather than steel shielding in rail casks, and allowing credit for burnup of the spent fuel to reduce neutron poison requirements and allow for closer spent fuel spacing in the design of the cask basket.

The third general way to reduce radiation dose is to keep the casks and people farther apart (radiation dose rates decrease rapidly with distance) without increasing the exposure times to perform the activities. Alternatives utilizing this principle include: parking truck casks farther away from service facilities at truck stops to reduce the public exposure during the stops for crew eating, rest, and truck refueling; performing activities in high dose-rate areas with special tools to enable workers to perform work in lower dose fields; and performing activities with remote-automated equipment (e.g., robots), which removes workers from radiation fields. The repository receiving facility is the prime candidate for application of remote-automated handling technology because of the large number of casks that must be handled. Two remote-handling alternatives have been included in the study. In the first alternative, nearly all cask handling operations at the repository receiving facility are assumed to be done by robots. In the second alternative, remote handling is done only for the work around the cask lids in the repository cask handling rooms.

Some alternatives evaluated (e.g., the use of a special impact wrench tool) actually incorporate two of the ALARA principles (time and distance), because the envisioned tools may accomplish the activity faster than conventional manual methods, and also keep the individuals out of the higher-dose fields.

2.2.2 Reductions in Total System Annual Radiation Dose from Implementation of Individual Alternatives

Time/distance studies and radiation dose-rate maps from the postulated reference system were modified to account for the conditions in the various alternatives identified for evaluation. These modifications were made to the spreadsheet models used in the evaluation of the postulated reference system to allow calculation of the new dose estimates and of the dose reductions possible to workers and to the public from implementation of the alternatives.

A summary of the estimated collective radiation doses that would result from the use of each major alternative is given in Table 2.6. The table contains the estimated total annual collective doses from the combination of truck and rail transportation of 3000 MTU of spent fuel from loading at the reactor, during in-transit, and unloading at the repository. The information in Table 2.6 is developed using the postulated reference system, except for the individual changes noted to implement that individual alternative.

Figure 2.2 illustrates graphically the estimates of annual collective dose reduction for each of the alternatives compared to the postulated system. The total dose reduction for each of the alternatives can be noted by the total length of the bars in Figure 2.2 and can be compared to the final column in Table 2.6. The segments of the bars represent the dose reduction within various modes, locations and groups. For example, with the overweight truck

TABLE 2.6. Summary of Estimated Collective Annual Radiation Doses Resulting from Use of Each Major Alternative (person-rem)[a]

	Truck				Rail				Total System Dose	Annual System Dose Reduction
	Worker			Public	Worker			Public		
Identification	Reactor	In-Transit	Repository	In-Transit	Reactor	In-Transit	Repository	In-Transit		
Postulated reference system	271	200	269	444	144	21	149	12	1510	0
Overweight truck cask	143	103	135	256	144	21	149	12	964	546
Uranium-shielded rail cask[b]	271	200	269	444	97	11	83	7	1382	128
Increased cask end shielding	166	23	91	444	95	10	38	10	877	633
Increased cask side shielding - truck only	246	197	246	311	144	21	149	12	1326	184
Increased cask side shielding - rail only	271	200	269	444	135	18	141	9	1487	23
Advanced design[c] - LWT[d] cask	149	104	141	231	144	21	149	12	951	559
Advanced design - OWT[e] cask	93	62	82	155	144	21	149	12	718	792
Advanced design - uranium rail cask[f]	271	200	269	444	90	10	75	6	1365	145
Special impact wrench tool	246	200	162	444	125	21	62	12	1272	238
Single-action cask lid fasteners	253	200	158	444	130	21	62	12	1280	230
Built-in cask lid fixtures	264	200	234	444	142	21	139	12	1456	54
Integral cask impact limiters	253	200	246	444	135	21	139	12	1450	60
Quick-release cask impact limiters	266	200	258	444	137	21	143	12	1481	29
Quick-release cask tiedowns	259	200	248	444	140	21	138	12	1462	48
Total remote handling at repository	271	200	3	444	144	21	2	12	1097	413
Remote cask lid handling at repository	271	200	83	444	144	21	36	12	1211	299
Improved truck operations	271	155	269	110	144	21	149	12	1131	379

(a) Table based on 900 MTU of spent fuel shipped by truck and 2100 MTU shipped by rail with 60% PWR and 40% BWR by each mode.
(b) Standard design uranium rail cask has capacity of 27/58 PWR/BWR assemblies.
(c) Advanced design includes burnup credit.
(d) Legalweight truck cask with capacity of 4/9 PWR/BWR assemblies.
(e) Overweight truck cask with capacity of 7/15 PWR/BWR assemblies.
(f) Uranium-shielded rail cask with capacity of 30/66 PWR/BWR assemblies.

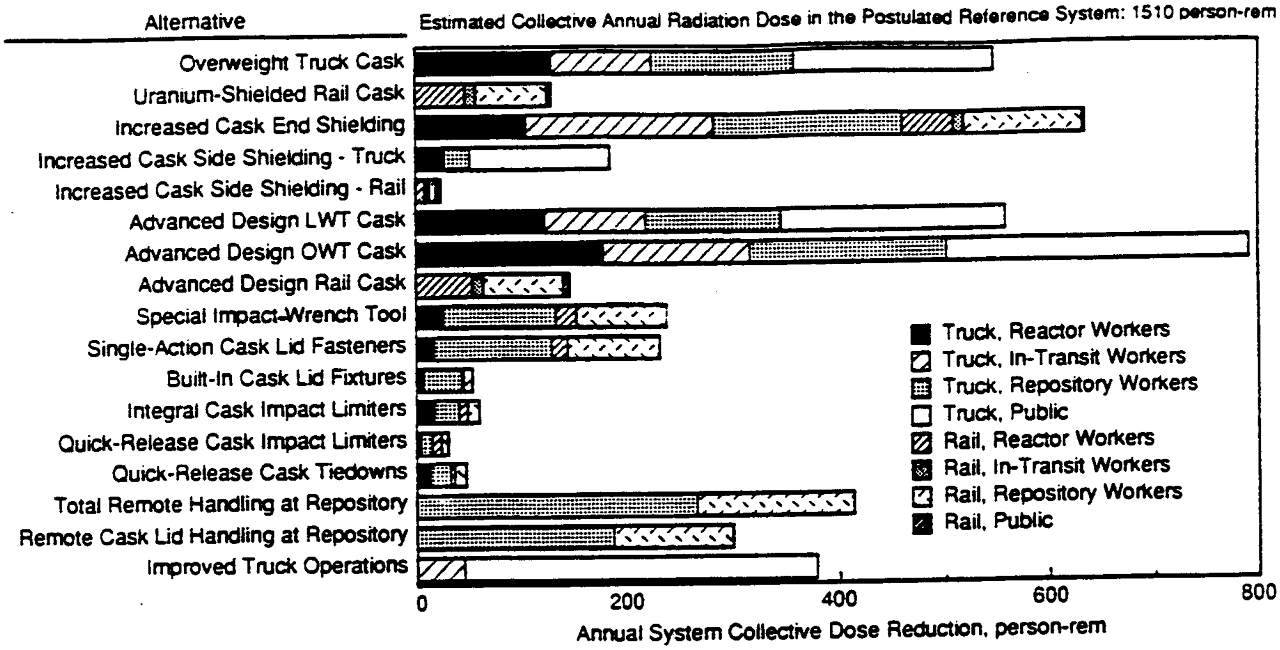

FIGURE 2.2. Estimated System Dose Reductions from Alternatives Relative to the Postulated Reference System

cask alternative, significant reductions can be noted for all four categories of truck dose, at-reactor, in-transit, and at-repository for the workers and for the public in-transit doses, but no dose reductions are noted from the rail part of the system, because it is not changed in this alternative. The total estimated dose reduction is 546 person-rem/year. Additional details can be determined by comparing the collective annual doses in Table 2.6 for individual alternatives to the postulated reference system. As shown in Figure 2.2, the alternatives with the highest system dose reduction are: 1) those with increased cask capacity (i.e., use of OWT casks and "advanced design" casks), 2) increased end shielding on casks, and 3) use of remote handling at the repository.

Increased cask capacity reduces doses throughout the system because of the reduced number of cask shipments. The truck cask capacity is significantly increased by use of both overweight truck or "advanced design" casks. Likewise, the uranium-shielded rail casks and/or "advanced design" rail casks significantly reduce the dose due to rail transport. However, doses from rail transport are relatively low, even for the postulated reference case. Increased cask end shielding is effective in reducing the operational doses at both the reactor and at the repository receiving facility. Remote handling at the repository receiving facility is very effective in reducing doses at that location but has no effect on other parts of the system. Reduced stop times and parking farther away from service facilities are effective in reducing the dose at truck stops, which cause the major dose to the public from truck operations.

Other alternatives that can result in significant dose reduction in the system are special impact wrench tools, single-action fasteners on cask lids, and increased side shielding on truck casks. The remaining alternatives evaluated are estimated to have only small impacts on the overall system dose, but could still be cost-effective.

The most effective alternative for reducing system doses, use of "advanced design" overweight truck casks, reduces the total system dose by about an estimated 800 person-rem/year, or over one-half of the estimated collective dose in the postulated reference system. No single alternative reduces the doses by both truck and rail for each worker category as well as to the public. This suggests that selected alternatives should be combined to minimize the system doses. This possibility is discussed further in Section 2.3.

2.2.3 Reductions in Individual Annual Radiation Doses from Implementation of Individual Alternatives

As noted in Section 2.1, several groups of workers in the postulated reference system would receive doses at or above the 1 rem/year level, which is the DOE design objective for a new facility (DOE 1986c). The maintenance-craftsmen(a) at the repository receiving facility are estimated to receive the highest annual individual doses of any group. As shown in Figure 2.3, several of the alternatives can reduce the anticipated annual individual doses to this worker group. The increased cask end shielding alternative would reduce the annual individual dose to the repository maintenance-craftsmen by an estimated 78%, to 2.9 rem/year, which is still not within the DOE's design objectives

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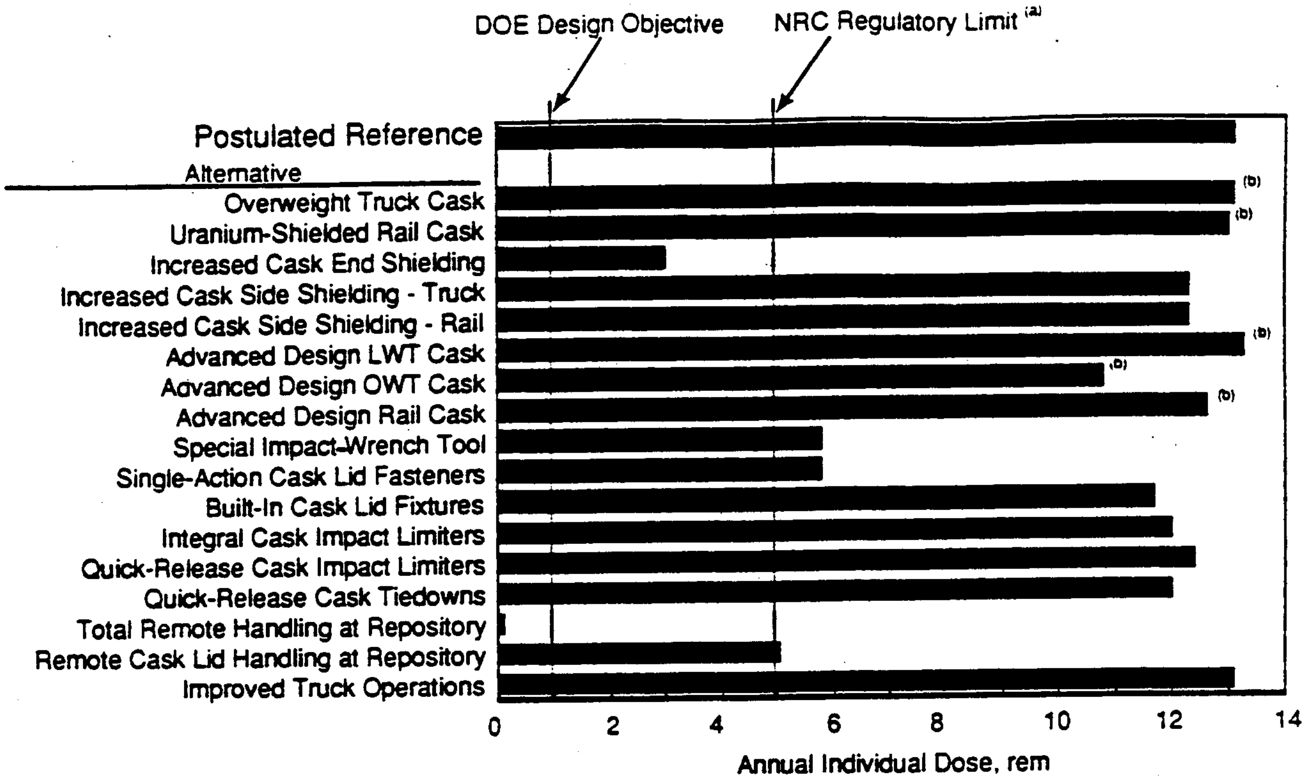
(a) The maintenance-craftsmen remove and install bolts and perform other mechanical work on the cask in high dose-rate areas.



(a) Doses beyond the NRC regulatory limit will not be permitted by DOE.

(b) The number of workers is assumed to be reduced from the postulated reference system because of the reduced labor requirements

FIGURE 2.3. Comparison of Estimated Annual Average Dose to Individual Maintenance-Craftsmen at the Repository for Selected Alternatives

(DOE 1986c), but is a major improvement. The use of special tools and single-action fasteners would also reduce the annual individual dose to the maintenance-craftsmen by over 50%. The other alternatives that increase the speed of operations (e.g., quick-release cask impact limiters and tiedowns) would also reduce the annual dose to the maintenance-craftsmen, but the amount of dose reduction for each alternative is relatively small. Increasing the capacity of the casks would decrease the collective dose to the maintenance-craftsmen, but because this would also allow a reduction in the total staff, the individual doses would not decrease to the same degree (as indicated by the footnoted alternatives in Figure 2.3). The remote-handling alternative is the only single alternative studied that would bring the maximum annual individual worker dose at the repository into compliance with facility design objectives. (However, it may be possible to bring these doses to within facility design objectives by combining alternatives in an optimal system.) This alternative requires fewer operating workers at the repository, and they do not normally need to work directly on the casks. Annual individual doses to the maintenance-craftsmen at the reactors are not expected to change with remote handling at the repository unless this alternative is implemented at reactors.

As noted in Section 2.1, the individual dose to a dedicated truck driver is estimated to be relatively high, at about 3 rem/year. The alternative that reduces this dose most significantly is the increased cask end shielding. This alternative reduces the dose to about 0.23 rem/year. The improved truck operations alternative reduces the estimated driver dose per shipment, but each driver could move additional shipments per year, resulting in an increase in the driver's annual dose to about 3.3 rem/year.

2.2.4 Cost Impacts of Selected Alternatives

Costs were estimated on a life-cycle basis with a total operating time of 21 years (62,000 MTU handled at the rate of 3,000 MTU/year [DOE 1987b]). The estimated costs (capital and operating) of the postulated reference system were first derived, followed by estimates of the changes to those costs from implementing each of the alternatives. Each of the alternatives affects system costs in different ways. The number of casks, the complexity of special features of the casks, the operational times, and the equipment to handle the casks are all affected by the alternatives.

The present worth of the cost differences was calculated using 0% and 3% discount rates. Table 2.7 provides a summary of these estimated differential life-cycle costs for each of the alternatives. Cost savings (shown in parenthesis in Table 2.7) are estimated to occur in most of the alternatives evaluated. The alternatives where savings are estimated are generally those for which the number of casks is reduced and those where labor hours are reduced by faster operations. The alternatives with estimated cost savings deserve careful consideration even without ALARA considerations. Cask lifetimes in excess of the 21 years are expected (DOE 1986d), and use of longer cask lifetimes would decrease the effective annual and the total life-cycle costs. It is significant that an estimated life-cycle cost savings of about $200 million (at 0% discount rate) out of an estimated $900 million may

TABLE 2.7. Summary of Estimated System Life-Cycle Cost Differences for Each Alternative Relative to the Postulated Reference System

	Cost Difference, $ Thousands			
Alternative	Capital Costs	Operating Costs/yr	Present Value(a) at 0%	Present Value(a) at 3%
Overweight truck cask	(11,000)	(4,600)	(107,600)	(81,900)
Uranium-shielded rail cask	(9,000)	(9,830)	(215,000)	(160,000)
Increased cask end shielding(b)	1,670	1,580	34,900	26,100
Increased cask side shielding - truck only	1,000	190	5,070	3,990
Increased cask side shielding - rail only	800	580	12,900	9,700
Advanced design - LWT(c) cask	(18,100)	(7,000)	(166,000)	(127,000)
Advanced design - OWT(c) cask	(21,000)	(8,300)	(195,000)	(149,000)
Advanced design - Rail(d) cask	(13,000)	(11,200)	(249,000)	(186,000)
Special impact wrench tool	(110)	(53)	(580)	(472)
Single-action cask lid fasteners	440	(115)	(1,980)	(1,340)
Built-in cask lid fixtures	2,800	(18)	2,430	2,530
Integral cask impact limiters	62	(132)	(2,710)	(1,970)
Quick-release cask impact limiters	(4)	(67)	(1,400)	(1,030)
Quick-release cask tiedowns	0	(48)	(1,000)	(734)
Total remote handling at repository	18,500	(1,330)	(9,360)	(1,940)
Remote cask lid handling at repository	5,200	(690)	(9,290)	(5,440)
Improved truck operations	(6,000)	(300)	(12,300)	(10,600)

Parenthesis denote a cost savings.

(a) Capital costs are assumed to occur at year 1 and have a useful life of 21 years, except for special tools, which have a 5-year lifetime.

(b) Includes both truck and rail casks.

(c) In combination with steel rail cask.

(d) In combination with reference LWT cask.

result from 3 individual alternatives with increased cask capacities and fewer number of casks and cask shipments. Combinations of some alternatives could save even more money.

2.2.5 Cost Effectiveness of the Alternatives in Reducing Radiation Doses

The estimated dose information in Section 2.2.2 and the estimated cost information in Section 2.2.3 have been combined to determine the Δcost/Δdose ratios (on cost effectiveness) of the alternatives. Table 2.8 presents a

TABLE 2.8. Overview Comparison of Alternatives Based on Estimated ΔCost/ΔDose Ratio and Total Dose Reduction

Alternative	Present Value at 3% ($1000)	Annual Dose Reduction (person-rem)	ΔCost/ΔDose(a) ($/person-rem)
Advanced design OWT cask	(149,000)(b)	792	(c)
Advanced design LWT cask	(127,000)	559	(c)
Overweight truck cask	(81,000)	546	(c)
Total remote handling at repository	(1,940)	413	(c)
Improved truck operations	(10,620)	379	(c)
Remote cask lid handling at repository	(5,436)	299	(c)
Special impact wrench tool	(472)	238	(c)
Single-action cask lid fasteners	(1,340)	230	(c)
Advanced design rail cask	(186,000)	145	(c)
Uranium-shielded rail cask	(160,000)	128	(c)
Integral cask impact limiters	(1,970)	60	(c)
Quick-release cask tiedowns	(734)	48	(c)
Quick-release cask impact limiters	(1,030)	29	(c)
Increased cask side shielding - truck	3,990	184	1,030
Increased cask end shielding	26,000	633	1,960
Built-in cask lid fixtures	2,530	54	2,230
Increased cask side shielding - rail	9,700	23	20,100

(a) Present value divided by 21 times the annual dose reduction.
(b) Parenthesis denote a cost savings.
(c) Negative Δcost/Δdose ratio is not meaningful.

listing of the alternatives in decreasing order of cost-effectiveness; however, the ratio of cost to dose is not meaningful for those alternatives that result in a cost savings, so those alternatives are listed in decreasing order of dose reduction. The listing in Table 2.8 shows that most of the alternatives considered individually are estimated to be cost-effective.

The estimated Δcost/Δdose for most of the individual alternatives are in the range where alternatives are usually considered for further study and implementation.(a) No specific guidelines exist for selection of cost-effective or non-cost-effective alternatives for transportation activities. An early

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(a) The cost effectiveness of the alternatives may be affected by the conservative postulated reference system utilized in the study.

guideline for public doses from nuclear power reactor operations suggested adopting alternatives with a cost-dose ratio of less than $1000/person-rem (NRC 1987). DOE has also published similar general guidance (Kathryn 1980). For highly trained workers that receive high individual doses, the value of a unit of dose averted may be higher than for less-skilled workers. For example, if additional at-repository maintenance-craftsmen could be used (which is against DOE practice) to reduce individual dose to less than 5 rem/year (NRC regulation) or to 1 rem/year (DOE design objective), the additional annual labor cost would place the value of dose averted at about $8,000/person-rem or $40,000/person-rem, respectively.

2.2.6 Additional Considerations of Alternatives

In considering the alternatives, it is important that factors other than just the Δcost/Δdose ratio need to be considered before implementation of any concept. Some alternatives may need to be considered to reduce the maximum individual doses identified in Section 2.2.2 to be in compliance with regulations or policy.

In the selection of alternatives, it is also important to consider the potential problems in licensing of the alternative, the amount of R&D or testing that will be needed to gain acceptance of the alternative, the impacts on other parts of the operational system (e.g., facility capabilities, highways, and railroads), and the effects on nonradiological risks due to accidents or other factors. Each candidate alternative should be evaluated with respect to these other considerations before implementation.

2.3 EXAMPLE ALTERNATIVE SYSTEM INCORPORATING A COMBINATION OF ALTERNATIVES

While each of the alternatives in this report has been analyzed as though it was were implemented separately, it is recognized that several of the alternatives could be combined together to more effectively reduce dose than any single alternative. Although it is not the purpose of this report to select the alternatives for optimizing the transportation system, to illustrate the potential of combining alternatives into a system, an example alternative system has been analyzed in Chapter 6. The example alternative system that was evaluated included:

- the use of advanced design overweight truck casks (with a capacity of 7 PWR or 15 BWR assemblies) for all truck shipments and advanced design rail (30 PWR/66 BWR) casks, but with increased end shielding for both truck and rail casks
- the use of a special impact wrench tool for cask lid work
- the use of built-in cask lid-lifting fixtures
- the use of quick-release cask impact limiters and quick-release cask tiedowns
- improvements in operations for truck shipments that eliminate conservatism and reflect current experience.

These alternatives would each reduce system doses in different ways and to different population groups, so that their combined effects would be much greater than from any single alternative. In the example alternative system analyzed in this study, radiation dose reductions at the reactor would result from increased capacity in the casks, by having improved end shielding on the casks, and by faster operations. The reductions in dose from in-transit activities would result from improved truck operations, increased cask end shielding, elimination of LWT shipments, and use of increased-capacity OWT shipments. The reductions in dose from repository activities would result from the increased-capacity casks, increased cask end shielding, use of special tools, and use of quick-release cask impact limiters and tiedowns. The estimated annual collective doses from the example alternative system are compared to the postulated reference system in Table 2.9.

As shown in Table 2.9, using this alternative system, the annual collective radiation dose to the reactor workers is estimated to be reduced by about 73%, to transport workers and the public from in-transit operations by about 92%, and to the repository workers by about 93%. The overall system collective dose is reduced by about 87% compared to the postulated reference system. With the high-capacity OWT casks, only 10 or 11 truck shipments would be needed for transporting 30 MTU/year of spent fuel from each reactor, and only 296 truck shipments would be needed for transporting the 900 MTU/year of spent fuel

TABLE 2.9. Comparison of Estimated Annual Collective Doses for the Postulated Reference and Example Alternative System Using a Combination of Alternatives

	person-rem/year	
	Postulated Reference System	Example Alternative System
At-Reactors	415	112
In-transit	677	53
At-Repository	418	30
Total	1510	195

shipped by truck. The high-capacity rail casks would only require three shipments/year for 30 MTU of spent fuel from each reactor, and 160 shipments/year for the 2100 MTU of spent fuel transported annually by rail. The reduced number of shipments (averaging 1.1/day for truck plus rail) is the primary cause of the reduced system doses.

At the reactor, the reduced number of shipments plays the major role in reducing doses to the workers.

The reduced number of shipments, improved cask end shielding, and improved truck operations in the alternative system all contribute significantly to reducing the in-transit worker and public doses.

At the repository, the fewer number of shipments and the increased cask end shielding in the alternative system would reduce the dose to the individual worker as well as reduce the number of workers needed.

The reduction in total system dose in the alternative system would also result in the reduction of individual annual doses. At the reactor, it is estimated that the annual individual dose of about 1 rem/year to the operators and maintenance-craftsmen in the postulated reference system would be reduced to about 0.2 rem/year for the operators and about 0.1 rem/year to the maintenance-craftsmen in the system with the example combination of alternatives. For in-transit operations, the annual dose to individual drivers is estimated to be reduced from about 3 rem/year in the postulated reference system to about 0.2 rem/year for the combination alternative system. At the repository, it is estimated that the annual dose to individual maintenance-craftsman would be reduced from over 13 rem/year in the postulated reference system to about 0.9 rem/year in the combination alternative system, which is within the DOE design objective for new facilities.

The reduced size of the cask fleet with the example system with a combination of alternatives would provide major savings in both capital costs (estimated at about \$28 million) and in annual operating costs (estimated at \$19 million/year). The total life-cycle cost savings for the alternative system is estimated at \$314 million, using a 3% annual discount rate. The value of the ratio of Δcost/Δdose would be negative.

There are obviously numerous additional combinations of alternatives and evaluation factors that need to be considered in the implementation of a safe, cost-effective, and timely transportation system for commercial spent fuel. These will be the subject of future studies.

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3.0 STUDY APPROACH AND BASES

The analyses contained in this report are an important step in the evolution of the spent fuel transportation subsystem in DOE's civilian radioactive waste management system. They provide input to DOE decisions that are expected to result in improvements in the transportation system relative to the postulated reference system.

The study approach and bases are presented in this chapter. In Section 3.1, the overall ALARA analysis approach is described. The approach to the analysis of the postulated reference system is given in Section 3.2, while the alternatives analysis approach is outlined in Section 3.3. The major study bases and assumptions are given in Section 3.4.

3.1 OVERALL ALARA ANALYSIS APPROACH

The overall ALARA study has investigated the effects of conceptual transportation system design and operating changes and the cost effectiveness of those changes for reducing the routine public and worker radiation doses. In addition, the study has evaluated the effects of the postulated changes on the total transportation-related aspects of the waste management system: at-reactor handling,(a) in-transit operations, and at-repository handling.

The approach to the ALARA study is summarized in Figure 3.1. First, the overall study bases are developed, including definition of the scope of the study, definition of a generic postulated reference transportation system and its associated interfaces that are used for comparison of potential alternatives, and identification of the parameters to be considered. Work done in other areas of the DOE-OCRWM program (e.g., repository interface and engineering, waste system characterization, systems integration, transportation systems analyses) also provides important inputs to the analyses in this study.

(a) Although operations at the reactors are not part of the federal system, radiation doses there can be significant, and can be impacted by the design and operation of the federal part of the system. They, and the operations at the repository, are considered as part of the transportation system in this study.

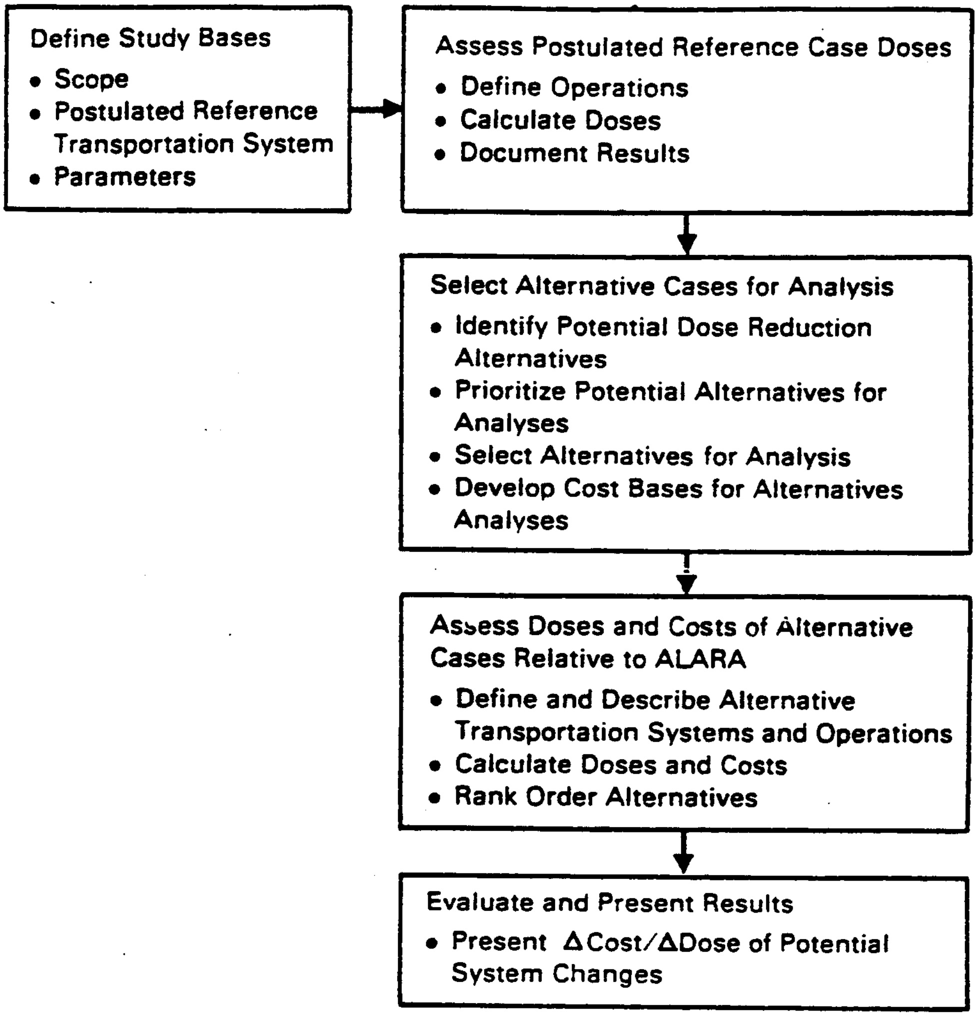

FIGURE 3.1. ALARA Study Approach

Next, analyses of the radiation doses in the postulated reference transportation system are performed and documented in Chapter 4 of this report.

Based on the dose analysis of the postulated reference transportation system, the alternatives having the most potential for dose reduction were identified for analysis in the third study phase. System characteristics relative to expected cost-effectiveness for radiation dose reduction to collective populations and to maximally exposed groups or individuals were used as the primary basis for selecting the alternatives studied. Other factors (such as status of technology, licensability, R&D needs, etc.) were also considered in the screening of the alternatives to be studied, but on a qualitative basis. (See Appendix M for additional detail.)

The alternative concepts have been defined sufficiently to allow for development of operating procedures and cost estimates. It should be noted that the study does not evaluate specific designs, but investigates concepts only. The revised operating procedures were developed for the alternative concepts, and radiation doses and costs throughout the total system were calculated and compared with those in the postulated reference case. This information is being developed in concert with information developed in the repository projects, in other DOE transportation and system studies, and by the electric utilities.

The alternatives, after being individually evaluated for cost and dose-reduction potential, were combined with other alternatives into logical groups for further evaluation. Many of the alternatives can impact the dose reduction of the other alternatives when they are combined. An example combination of alternatives was also selected and evaluated to indicate some general effects of combining compatible alternatives.

3.2 APPROACH TO ANALYSIS OF THE POSTULATED REFERENCE TRANSPORTATION SYSTEM

The approach to the analysis of the postulated reference transportation system, summarized in the prior section, is expanded in Figure 3.2. The postulated reference transportation system was defined in broad terms based on current transportation system requirements (DOE 1986a), and on configurations, operations, and some characteristics of the waste management system when implemented. No actual system currently exists. The postulated reference system is a "snapshot" of current technology as it might be applied to functions of the waste management system. It is a basis for evaluating potential system alternatives. (The actual system implemented in the late 1990s is expected to be improved from the postulated reference system analyzed here.) The overall parameters to be considered were defined based on available information on contributions to radiation doses in the system. A graphic illustration of the postulated reference transportation system postulated for this study is given in Figure 3.3.

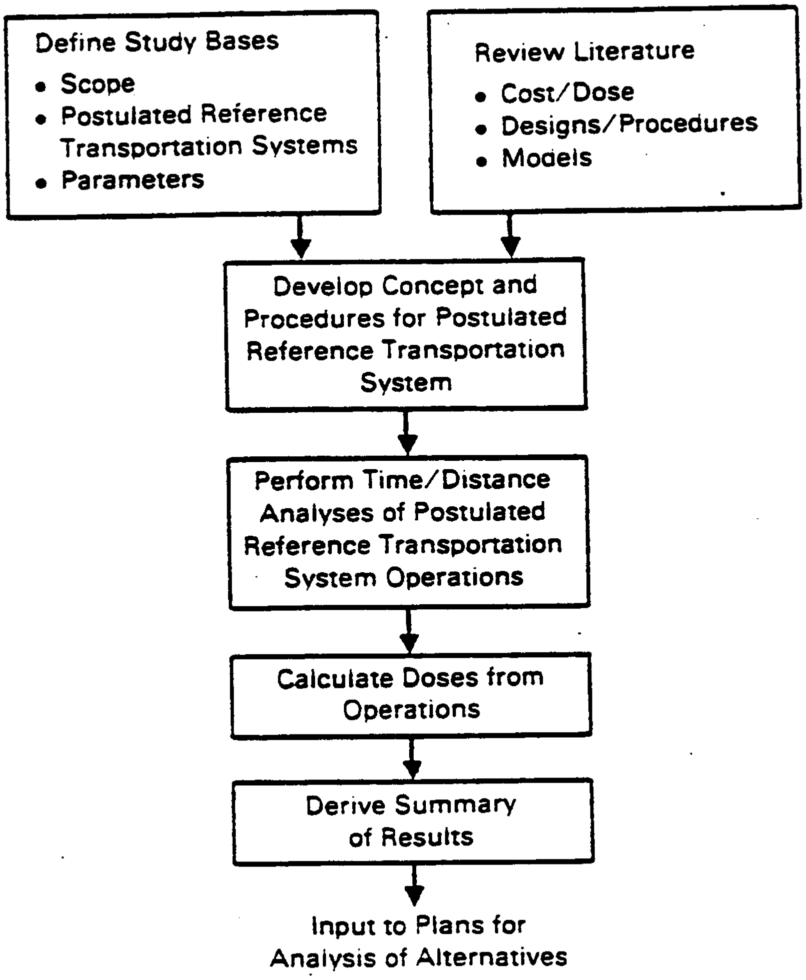

FIGURE 3.2. Approach to Analysis of Postulated Reference Transportation System

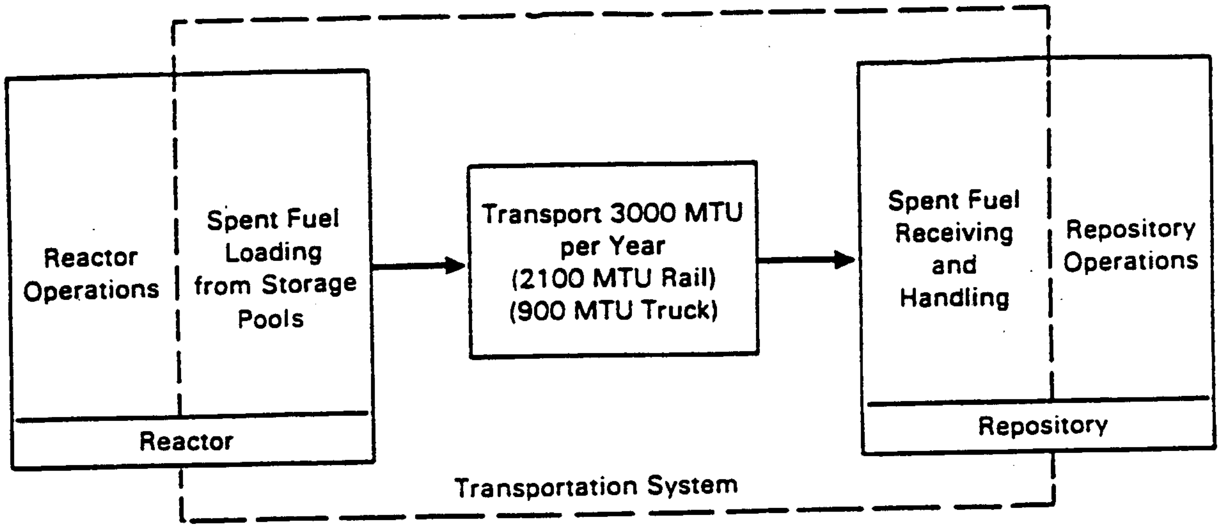

FIGURE 3.3. Postulated Reference Transportation System

In parallel with the definition of study bases, available information of potential use and application to this study was sought, reviewed and summarized. This information included time/distance/dose studies, cost and radiation dose analyses, system requirements and designs and associated operating procedures, and models for analysis of components of the system.

Additional details of the postulated reference transportation system were defined to the extent necessary for carrying out the subsequent dose analyses. These included development of a postulated reference map of the radiation dose rates around the outside of the postulated reference transport casks.

The physical and operational characteristics of the transportation system components (i.e., the cask and vehicles, the reactor and its handling system, the in-transit operations, and the repository and its handling system) were defined.(a)

Time/distance/dose analyses were performed for operations in the postulated reference transportation system. These operations include loading of

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(a) This is a postulated reference system for this study only. No officially designated reference reactor, transportation system, or repository exists at the current time.

spent fuel casks at reactors, transporting the spent fuel in the postulated reference casks in the public domain of highways and railroads, and unloading the spent fuel casks at the repository.

From the time/distance/dose analysis and the definition of the postulated reference transportation system, radiation doses due to routine transportation activities were estimated. These doses were estimated for the public and for individual occupational and transport workers, and for each activity within each element of the system. Individual occupational and transport worker doses were also aggregated to give total collective occupational and transport worker doses. These doses were then summarized and documented in this report.

3.3 APPROACH TO ANALYSIS OF ALTERNATIVES TO THE POSTULATED REFERENCE TRANSPORTATION SYSTEM

The approach to the analysis of the alternatives to the postulated reference transportation system, summarized in Section 3.1, is expanded in Figure 3.4. From the postulated reference study, the most promising concepts and operations for dose reduction were identified and documented. With these as a guide, a "brainstorming" session was held and 24 alternatives were identified. The 24 potential alternatives were given a preliminary evaluation from both cost and dose perspectives and the better alternatives were selected for detailed evaluation. The selection of the alternatives for detailed analysis was reviewed by a peer group to avoid individual bias in the selection process and to identify alternatives not previously considered.

With the selection of the alternatives, the detailed evaluation was started. An ALARA alternative was conceptually designed to provide the needed function. The design was not detailed nor optimized for the subsequent analysis. Selected alternatives should be optimized before they are designed and implemented in future systems. The same methodology as developed for the postulated reference study was used to evaluate the alternatives. When changes in the shielding were part of the alternative, new dose rates were prepared. The spreadsheets developed for the postulated reference study were modified with the revised procedure and with the new values of exposure distances, dose

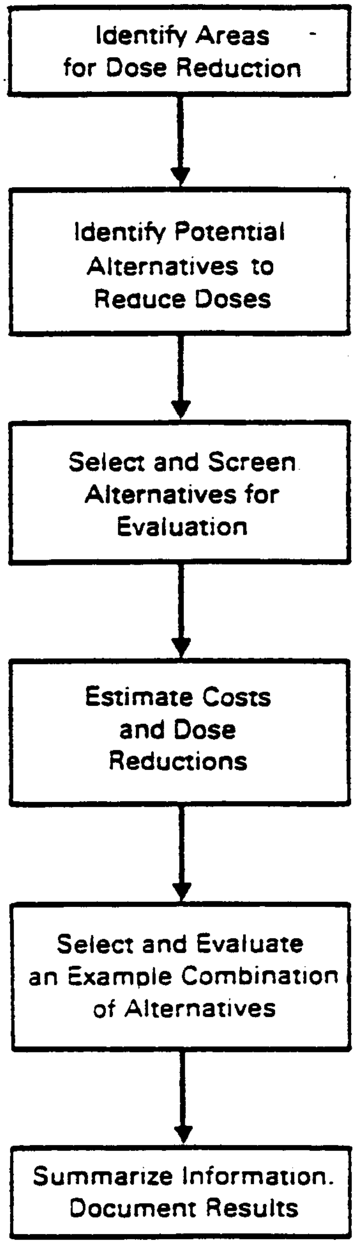

FIGURE 3.4. Approach to Analysis of Alternatives to Postulated Reference Transportation System

rates, and activity times to calculate the reduced doses from each of the alternatives. Each of the alternatives was evaluated as if it were the only alternative, thus maximizing its potential dose reductions.

With the perspective of cost and dose-reduction of the individual alternatives, an example combination of the alternatives was prepared and evaluated. The evaluation of numerous combinations will eventually be necessary before developing an optimized transportation system, because of the interactions of the various alternatives. For example, an increase in the end shielding reduces the dose rates from the casks and reduces the benefit from the use of special tools or remote or robotic operations. The example combination evaluated in this study was selected to use many of the individually justifiable and compatible alternatives.

Following the evaluation of the example combination of alternatives, the results of the study have been summarized and documented in this report.

3.4 MAJOR BASES FOR ANALYSIS OF THE POSTULATED REFERENCE TRANSPORTATION SYSTEM

The major bases and assumptions used for this analysis are given in the following subsections. Supplementary rationale for the bases are given in the postulated references cited and/or in Appendix E.

3.4.1 Overall Study Scope and Approach Bases

The major bases and assumptions that relate to the scope of and approach to the dose analyses are:

- Collective radiation doses to the public, to the occupational radiation workers (i.e., at the reactor and repository), and to in-transit transport workers from typical activities are evaluated and presented in units of person-mrem/MTU. Radiation doses and nonradiological injuries or fatalities due to potential accidents are not considered in these analyses but will need to be considered in later studies. Radiation doses to the public resulting from spent fuel loading at the reactor and spent fuel unloading at the repository are small (DOE 1987) and are not included in the analyses in this study.

- Annual radiation doses to individual worker categories and to hypothetical maximally exposed individual members of the public are evaluated.

- Radiation doses are calculated based on current procedures, regulations, and related available data. The time/distance/dose analyses allow for minor perturbations to operations and are believed to represent values that are sustainable over long time periods, with the exception that there are no allowances for major breakdowns. The dose calculations are based on the estimated staffing required to perform the work using reasonable numbers of workers, with activities being done in parallel where practicable. The estimates do not allow for nonessential extra persons such as onlookers. (It should be noted that results from prior analyses generally vary by a factor of about 4 from minimum to maximum collective doses at reactors and repositories [see Tables 4.4 and 4.15 in Chapter 4], for a number of reasons. The dose values from the postulated reference analysis are generally at the upper end of the range of the values from prior studies, primarily because of the basis of the dose rate from the loaded cask being at the regulatory limit and because designs and operations have not been optimized with respect to occupational exposure factors.

- Average annual radiation doses for individuals in various worker groups (or crafts) are estimated based on routinely using the same staff for given similar activities. Rotation of workers to other activities in the facilities to reduce individual doses is not considered in this analysis.

- Time/distance/dose analyses are done separately for truck and rail cask systems to account for differences in these activities.

- Radiation doses to workers at the origin and destination facilities are the sum of those received directly from the transport cask and those from general area background radiation from other sources (excluding natural background) expected to exist at the facilities.

These background dose rates are based on those existing at a typical reactor (Section 4.2) and those estimated for a repository (Section 4.4).

- Dose calculations assume an unobstructed path between the source and the receiver. This makes the calculated exposures higher than will occur in many cases because of the presence of obstructions between the individuals and the source.

3.4.2 Overall System Bases

The major bases and assumptions that relate to the overall postulated reference system are given below. (See also Chapter 4 for a description of the postulated reference system, including operations, and Appendix E for supplementary rationale for many bases.) Those that relate to the specific elements of casks/vehicles, reactor facilities, and repository facilities are given in later subsections.

- The system under consideration consists of spent fuel(a) loading at a typical but hypothetical reactor; transport off-site through the public domain in a generic truck and rail system; and unloading at a hypothetical deep geologic repository. This system is referred to in this report as the "transportation system."
- The at-reactor activities include receipt of the empty transport cask at the site gate and processing the cask until it is ready to receive spent fuel, removing previously-identified spent fuel from in-pool storage and loading it into the cask, preparing the loaded cask for shipment, and moving the cask to the reactor site gate for DOE acceptance and transport.
- The in-transit activities include all operations while the loaded transport cask is traveling or stopped outside the gates of the origin and destination facilities.

(a) High-level waste is not included in this study because its final volume is uncertain. HLW transport would result in similar trends to those for spent fuel (see Appendix E).

- The at-repository activities include receipt of the loaded transport cask at the repository gate, preparing the cask for unloading, unloading the spent fuel into lag storage,[a] preparing the empty cask for shipment, and moving the cask to the repository site gate for its return journey to a reactor. Decontamination of the internals and seal replacement of each cask are also assumed to be performed here after every tenth shipment with that cask.

- Total system handling and transport capacity is 3,000 MTU/year of spent fuel, based on the amount of initial uranium in the fresh fuel. This is the nominal capacity for a waste management system with one repository (DOE 1986a).

- The postulated reference spent fuel source term for dose-rate calculations is PWR fuel that has been irradiated to 35,000 MWd/MTU and that is 10 years out-of-reactor. (Note: this is consistent with the basis in the cask procurement RFP [DOE 1986b].) Note that in a real system a range of conditions would occur, which would result in a range of results for individual shipments. (See Appendix E for additional discussion.)

- Each postulated reference PWR and BWR spent fuel assembly is assumed to contain 0.462 and 0.186 MT of initial uranium before irradiation, respectively (DOE 1987). The postulated reference PWR fuel source term is conservatively assumed to be applicable to BWR fuel. Only handling of standard spent fuel is considered (see Appendix E for discussion on handling of non-standard fuel).

- Shipments are approximately 2860 km (1780 miles) long (one-way) by truck and 3070 km (1910 miles) by rail on generic routes based on typical distance between reactors and the three final repository sites in the western part of the U.S. The population distributions

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(a) Neither lag storage operations nor impact of lag storage capacity on queuing time at repository are considered in this study.

enroute are taken from typical distributions given in the Environmental Assessments (EAs) for the three final repository sites (DOE 1986c).

- 70% of the spent fuel (i.e., 2100 MTU/year by weight of original fuel material) is transported by the postulated reference rail casks and 30% (900 MTU/year) is transported by the postulated reference truck casks (DOE 1986a).
- Truck shipments are carried out by general commerce; rail shipments are by general freight (DOE 1986d).
- Truck and rail shipments are assumed to be inspected by state officials at the originating and destination states upon entry into the public environment in the respective states. Truck shipments are assumed to be escorted by state patrol only in urban areas.(a) Rail shipments are accompanied by escorts in a separate railcar on the train.
- Casks are loaded in reactor pools and dried before shipping. Casks are unloaded dry at the receiving facility by mating to a hot cell port. Dry transport is required and current experience and safety studies indicate that dry unloading is preferred (DOE 1986b).
- Empty casks being returned to the reactors are assumed to be sufficiently free of radioactive contamination that these return shipments are considered to be "empty" in accordance with DOT regulations. Thus, dose analysis is not included in this study for the transport of empty shipping casks. However, the time required for the empty return trip is accounted for in estimating total round-trip times and cask/vehicle fleet requirements. (See Appendix E.5 for additional discussion.)

(a) Inspecting and escorting of shipments in each state (except escorts in high population areas) are at the prerogative of each state. In current practice, many states elect not to exercise this prerogative to avoid unnecessary exposure. This comment should not be viewed as DOE policy.

3.4.3 Cask/Vehicle Bases

The overall bases and assumptions related primarily to the shipping casks and vehicles in the postulated reference case are itemized below.

- Shipment is by postulated reference legalweight truck casks (loaded weight approximately 25 tons with a gross vehicle weight of no more than 40 tons) or by postulated reference conventional-sized rail casks (loaded weight approximately 100 tons with a gross vehicle weight of no more than 263,000 pounds, or 131.5 tons). These weights allow for unrestricted travel of the loaded casks/vehicles (DOE 1986a). Each cask is transported on its respective dedicated trailer or railcar.

- The postulated reference transport casks are similar to those described in the Systems Requirements and Description Document (DOE 1986a) and in the DOE reference fact sheets, with handling characteristics similar to present-generation lower-capacity casks (primarily the NLI 1/2 truck cask and the NLI 10/24 rail cask). Handling procedures for these casks have been verified and documented and are available. The rail cask has steel-only for gamma shielding[a] and the truck cask has steel plus depleted uranium for gamma shielding. Both have solid material for neutron shielding. The casks have no cooling fins (surface temperatures are expected to be low enough to allow routine contact operations), they each have a relatively thin structural outer lid and a heavy shielding inner lid, they have removable impact limiters and fuel baskets, and redundant lifting trunnions.

- The spent fuel capacities of the postulated reference transport casks are 2 PWR or 5 BWR fuel assemblies in the truck cask and 14 PWR or 36 BWR assemblies in the postulated rail cask (DOE 1986a). These

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(a) Use of steel-only for rail cask shielding tends to increase doses to the public and workers. This is because use of more dense shielding materials (such as lead or depleted uranium) will allow for greater payloads and fewer shipments with the same shielding effectiveness. (This option was evaluated in the study on alternatives.)

capacities are estimated, using the reference spent fuel, to allow for complying with DOT cask external dose rate regulations[a] and with highway and railroad limitations for unlimited transport.

- Each cask can transport PWR or BWR spent fuel assemblies, using appropriate removable baskets and longitudinal spacers.
- An inert gas atmosphere is provided in the cask cavity for shipping spent fuel.
- Shielding on the casks is based on the maximum radiation levels set by the DOT. The controlling limits are 10 mrem/hour at 2 meters away from the edges of the vehicle, and 2 mrem/hour in the nearest routinely occupied position (i.e., the truck cab) (49 CFR 173.441 1985).
- The shielding effect of the impact limiters on the external dose rates from the casks is not considered in this study.
- Casks are equipped with connections for temperature, pressure and gas activity measurements. These connections are considered to be necessary to facilitate satisfying shipping and receiving requirements.
- Casks and contents require no pre-cooling before unloading. (This remains to be confirmed for contact operations.)
- Criticality control features of the casks and their components require only infrequent verification of effectiveness. Thus, doses from such verification need not be incurred in routine operations and are not included in the postulated reference system study.

(a) The postulated reference system defined in this study involves using shipping casks that just meet DOT regulatory limits for external radiation levels from the casks. Most spent fuel shipped in the U.S. to date is less radioactive than that for which the casks were designed, which results in low external radiation levels from the casks. Thus, the bases used in this analysis result in higher doses than generally experienced in recent shipments using casks designed in the 1970s. The external radiation dose rates from the casks largely control all routine radiation doses received by the public and by workers from operation of the system.

- Doses resulting from major cask and vehicle servicing and maintenance at either the origin, destination, or separate facilities are excluded from consideration in the study. Replacement of cask closure seals is assumed to occur at the repository as part of the cask and basket decontamination activity every tenth shipment.

- Casks/vehicles are assumed to be in the operating circuit for 300 days/year (DOE 1986b). The rest of the time the casks are not operating for a variety of reasons, including major maintenance and servicing and compliance inspection/testing. Doses resulting from these operations are not considered in this study.

3.4.4 Bases for At-Reactor Fuel Loading

The overall bases and assumptions related primarily to at-reactor fuel loading activities in the postulated reference system are given below.

- Cask handling activities at the reactor are typical of those at a contemporary large PWR or BWR power station. A generic facility arrangement and procedures are used that are functionally representative of those at LWRs.(a) Where significant time/distance/dose differences occur at PWRs and BWRs, they are analyzed and reported individually. (See Appendix E.3 for additional discussion.)

- At-reactor procedures allow immersion of crane hooks/blocks into the pools during lowering and raising of the casks in the pools.

- Staffing for fuel loading into casks is based on performing the work in a reasonably short time period, utilizing parallel activities where practicable. Staffing and time requirements are based on performing the work on a routine and sustainable rate, assuming minor perturbations but no major breakdowns. It is recognized that cask handling activities at each reactor are expected to be infrequent and will require relearning of skills for each shipping campaign.

(a) It is recognized that each facility and its operating practices are different from others. Those selected in this study are intended to be functionally representative of most facilities.

- Spent fuel is assumed to be loaded in campaigns of 30 MTU/year from the typical reactor. Loading activities will be with one shift that works nominally 8 hours/day, but could extend to as long as 12 hours/day. No work is done on cask handling during the remaining two shifts. Resultant average cask waiting times are estimated based on deterministic time/location analysis.
- Internal surfaces of empty casks received at the reactor are sufficiently clean that transfer of contamination from the casks to the reactor pools is insignificant.
- Spent fuel classification and identification for loading (as required in 10 CFR 961) are performed before arrival of the empty transport cask. Doses resulting from these activities are not considered in this analysis.
- Exposures are not assessed to personnel doing other work in the locations affected by fuel loading work at the reactors.
- Only one cask at a time is processed within the site of the reactor.

3.4.5 Bases for At-Repository Cask Handling

The overall bases and assumptions related primarily to at-repository cask handling in the postulated reference system are given below.

- Cask handling activities and facility arrangements at the repository are postulated to be generally typical of those in the advanced conceptual design of the monitored retrievable storage (MRS) facility as defined in the MRS proposal to Congress (DOE 1987). This conceptual design uses primarily hands-on operations except for the actual dry unloading of spent fuel into a hot cell. The concept differs from the evolving repository receiving facility designs, but it embodies the functional capabilities required at a repository.
- Neither lag storage operations downstream from hot cell nor impact of lag storage capacity on receiving operations are considered in this study.

- The receiving of shipments from carriers and discharge of spent fuel casks/vehicles to the carriers at the facility gate is done 24 hours/day, 7 days/week. The operations within the unloading facility are generally carried out 24 hours/day, 5 days/week (DOE 1987). These bases are consistent with the estimates for the MRS facility operating capacity for handling 3,000 MTU/year (DOE 1987).
- Staffing is based on the number of people estimated to perform the work on a routine and sustainable basis, assuming typical minor perturbations but no major breakdowns, and has not been adjusted to reduce individual doses.
- The analysis includes placing the incoming casks in a queue after entry into the site. The queuing time results in increased fleet size, but in very low radiation doses to the workers, which are assumed to be zero in this study. However, future MRS/repository operational studies will need to include such considerations.
- Average queuing times are estimated for awaiting handling at the repository, based on deterministic time/location estimates on-site and random arrival of casks at the site.
- Because several casks are being processed in the facility at one time, doses to workers from area background include direct radiation from other casks and scattering from ceilings, walls, and floors that is expected to be in all areas where work on a specific cask is being carried out. Background analysis including scattering is facility design-dependent and should be considered on a facility-specific basis in the future. This includes areas outside and inside the cask handling building.
- Each cask is routinely vacuum-cleaned internally and spot-decontaminated externally after each unloading (DOE 1987). After every ten shipments, each cask is taken off the cask-handling line for wet internal decontamination and replacement of closure seals. During wet decontamination, the fuel basket is removed and is replaced with

a decontaminated basket. This work is done in a remotely operated hot cell. All other cask maintenance/repair is assumed to be done elsewhere (which could be in another facility at or away from the repository site). Doses that result from this maintenance and from management of wastes from maintenance and decontamination are not estimated in this study. Doses resulting from queuing of empty casks awaiting wet decontamination will be low, and are not considered in this study. Similarly, cask unavailability while awaiting in queue for decontamination should be low, and is not considered in this study.

- Cask handling cranes are assumed to have a usable capacity of 150 tons. These cranes will handle both truck and rail casks (DOE 1987).

3.5 MAJOR BASES FOR ALTERNATIVE EVALUATIONS

In addition to the bases given previously for the postulated reference study, the overall bases and assumptions related to the study of alternatives are given below.

- Alternatives are based on concepts that have not been designed or optimized.
- For overweight truck shipments, one overnight stop is included for each one-way trip to account for some state limitations on the travel of overweight vehicles during non-daylight hours or due to other restrictions. This longer stop replaces one of the food and rest stops included in the postulated reference study. Increased time has been allowed at state inspection stops to account for increased permitting and inspection time.
- Activity times are not increased for larger-capacity casks except for spent fuel handling. The times for removing bolts and handling are considered to be independent of capacity for a specific class of casks (i.e., truck or rail).

- Additional end and side shielding can be added to the postulated reference casks and the casks will remain within the nominal weight limits. This assumes that the postulated reference cask shielding thicknesses are limited by dose-rate and not weight (an assumption supported by preliminary calculations).
- It is assumed that the alternatives can be implemented with either no effect on, or with improvements in the resultant risks due to accidents or abnormal events. Such effects will obviously need to be evaluated in detail for any concepts that are considered for implementation.
- For some alternatives there is a need for special tools for loading and unloading. It is assumed that the tools are procured for each reactor and for the repository, and that the trucks or trains would not carry the tools for use at all locations. This assumption tends to yield somewhat inflated costs for applicable alternatives.
- Δ Dose is calculated for both public and worker doses.
- Cost analyses consider all potential reductions in time at the reactor as having monetary value; however, at the repository receiving facility, monetary values change only when the number of workers can be reduced by one full crew or shift.
- Cost analyses consider all components of the postulated reference system.
- Cost analyses estimate the differences between the postulated reference system and the alternatives.
- Costs are in 1987 dollars.
- Capital costs include the cost of procuring the cask fleet.
- In combining the capital costs and the annual costs, real discount rates of 0% and 3% are considered. No inflation in annual costs is considered. In calculating costs and doses, it is assumed that the system operates for 21 years, which results from considering a total of 62,000 MTU with an annual processing rate of 3000 MTU/year.

More detailed bases and assumptions for the specific analyses in this study are presented in the respective chapters where the analyses are discussed. Additional details and rationale for the major bases in this study are given in Appendix E.

3.6 REFERENCES

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4.0 DEFINITION AND ANALYSIS OF THE POSTULATED REFERENCE TRANSPORTATION SYSTEM

The postulated reference transportation system is described and analyzed in this chapter. Section 4.1 provides a general description of the postulated reference system. Following this description, estimated radiation doses resulting from at-reactor, in-transit, and at-repository operations are presented and analyzed in Sections 4.2, 4.3, and 4.4, respectively.

4.1 GENERAL DESCRIPTION OF THE POSTULATED REFERENCE TRANSPORTATION SYSTEM

In this section, the postulated reference system is described. The system is defined in terms of five elements: 1) system characteristics and parameters, 2) casks and transport vehicles, 3) reactor facility and operations, 4) in-transit operations, and 5) repository facility and operations.

4.1.1 System Characteristics and Parameters

The postulated reference system analyzed in this study includes the materials, equipment, facilities, operations, and personnel involved with the movement of spent fuel from individual reactor sites to a geologic repository, as shown previously in Figure 3.3. The system transfers 3000 MTU of spent fuel per year (which is 60 wt% PWR and 40 wt% BWR fuels) from reactor sites to the repository and is assumed to ship 30% (by weight) of the spent fuel by truck and 70% by rail. The average one-way distance between all reactors and the three repository sites is approximately 2860 kilometers (1780 miles) by road and 3070 kilometers (1910 miles) by rail.

The number of shipments per year is given in Table 4.1. Both the rail and truck casks are designed to accommodate 10-year-old PWR spent fuel with a burnup of 35,000 MWd/MTU. The truck cask will transport 2 PWR or 5 BWR spent fuel assemblies while the rail cask will transport 14 PWR or 36 BWR spent fuel assemblies.

Details of the postulated reference casks and transport vehicles are given in Section 4.1.2. The facilities and operations at individual reactor sites are chosen to simulate currently available equipment and procedures being

TABLE 4.1. Annual Spent Fuel Shipments in the Postulated Reference System

Spent Fuel Type	Shipments/year		
	Rail	Truck	Total
PWR	195	584	779
BWR	125	387	512
Total	320	971	1291

utilized at operating reactors.(a) A detailed description of these facilities and operations is given in Section 4.1.3. The in-transit portion of the system, including truck and rail operations, is described in Section 4.1.4. The postulated reference repository receiving facility and operations are similar to the conceptual design of the proposed MRS receiving and handling facility (Parsons 1985).(b) A description of this facility is given in Section 4.1.5. Additional information on the rationale for selection of the postulated reference transportation system is given in Section 3.4 and in Appendix E.

4.1.2. Cask and Transport Vehicle Descriptions

This section contains descriptions of the postulated reference truck and railroad spent fuel transport casks used in this dose analysis, the related features of the transport vehicles, and the radiation dose rates around the loaded and empty casks.

These postulated reference cask and vehicle concepts are based on experience with casks currently used for spent fuel shipments. They incorporate typical handling features identified by that experience with modifications to accommodate 10-year-cooled standard PWR spent fuel with 35,000 MWd/MTU

(a) Although each nuclear power station is different from the others and their cask handling operations differ somewhat, the functions that must be performed are similar and are utilized in this study. The facility and procedures used in this study typify those at most LWRs in the U.S.

(b) In addition, the MRS concept represents one that uses proven manual operations; repository receiving and handling concepts, which are functionally similar to the MRS receiving and handling concept, are still evolving.

exposure. The casks are based on the "fact sheet" casks presented in DOE (1986a). Specifically, the cask concepts were adjusted to have the following features:

- radiation dose rates at the regulatory maxima (for the postulated reference spent fuel source)
- smooth external surfaces without fins
- smooth internal surfaces
- bolted-on inner shielding lid with double seals
- bolted-on outer protective lid with double seals
- sampling, drain, and seal-testing connections through inner lid
- bolted-on removable tiedowns
- bolted-on removable impact limiters
- retractable louvered metal personnel barriers.

A single generic design concept with regard to handling features is presented for both the truck and railroad casks. The primary differences between these two types of casks are differences in dimensions, weights, and fuel assembly capacities.

This section is divided into four additional parts. The first part contains a general description of both types of transport casks. The second contains a list of the specific characteristics that differ between the truck and railroad casks. In the third part, those features of the casks that influence the time, costs, and radiation doses associated with spent fuel shipments are described. Descriptions of the related cask tiedowns and personnel barrier characteristics of the transport vehicle are included. The fourth part contains the calculated radiation dose rates around the casks.

The descriptive information provided here is developed only to the extent needed for the ALARA analysis. No attempt is made to provide sufficient information for cask design or construction.

4.1.2.1 General Description of the Transport Casks

The shipping casks are hollow, smooth-surface, right cylinders with a closed bottom end and two closure lids on the upper end. The truck cask wall contains a layer of depleted uranium shield material. The rail cask walls are solid austenitic stainless steel. Both casks have an outer neutron shield of solid organic material.

The casks contain removable baskets for supporting the spent fuel assemblies and waste containers. The baskets are designed to provide criticality control and to aid heat rejection. Baskets of various designs are assumed to be interchangable to permit transportation of spent fuel assemblies and high-level waste canisters of various designs and heat generation rates.

The cask closure lids are circular steel plates that bolt to the upper end. The outer lid provides protection for the inner lid and its penetrations. A spacer is bolted to the inner face of the inner lid to hold the fuel assemblies in position during shipment and to allow for accommodations of spent fuel from different reactors having different lengths. The inner lid contains lid seals, penetrations for pressure testing, gas testing, and flushing and draining of the inner cavity.

The casks have four external trunnions at 90° intervals at the upper end for lifting, using the redundant yoke equipment required at many reactor facilities.

4.1.2.2 Characteristics of the Postulated Reference Truck and Railroad Casks

The postulated reference truck and railroad casks differ primarily in dimensions, weights and payloads. The truck cask uses steel and depleted uranium for gamma shielding, whereas only steel is used in the rail cask. The physical characteristics of the two cask types are given in Table 4.2.

4.1.2.3 Descriptions of Specific Cask and Transport Vehicle Features

Descriptions of the cask features and related support mechanisms that influence the handling times, costs and radiation doses associated with spent fuel and waste shipments follow. General rationale for each feature is included.

TABLE 4.2. Typical Characteristics of Postulated Reference Truck and Railroad Casks and Their Vehicles

Characteristics	Truck Cask	Railroad Cask
Length (in.)	215	235
Outside Diameter (in.)	44	85
Nominal Empty Weight (tons)	24[a]	87[a]
Nominal Loaded Weight (tons)	26[a]	98[a]
Payload		
BWR Assemblies	5	36
PWR Assemblies	2	14
Inner Cavity Length (in.)	180	180
Inner Cavity Diameter (in.)	22.7	57.0
Neutron Shields		
Material	Solid Boron-Silicone	Solid Boron-Silicone
Thickness (in.)	3.0	3.0
Cask Wall		
Material	Stainless Steel	Stainless Steel
Thickness (in.)	2.9	10.0
Cavity Liner		
Material	Clad Uranium	None
Thickness (in.)	2.1	None
Cask Bottom		
Material	Stainless Steel	Stainless Steel
Thickness (in.)	9.5	10.5
Inner Lid (gamma & neutron shield)		
Diameter (in.)	38	79
Thickness (in.)	6.5 + 3.0	7.5 + 3.0
Weight (lb)	2,000	11,000
Outer Lid		
Diameter (in.)	44	85
Thickness (in.)	1.5	1.5
Weight (in.)	600	2,500
Tiedown, Impact Limiter, and Personnel Barrier Weight (lb)	3,000	6,000
Vehicle Weight Without Cask (lb)[b]	25,000	60,000
Vehicle Weight Loaded (lb) (including all hardware)	80,000	263,000

(a) Total cask weight including lids, tiedowns and impact limiter (given separately near the bottom of the table).

(b) Total vehicle weight including personnel barrier.

- General Configuration (Figure 4.1)

  The general cask configuration is a right cylinder. This design was selected because it is the most common design for casks, the easiest to fabricate and the easiest to analyze for both structural strength and radiation doses.

- Surfaces

  The cask surfaces are smooth with a minimum of crevices. Heat transfer studies have shown that casks for shipping spent fuel that has been cooled for over 3 years after discharge from a reactor have adequate heat dissipation with a smooth external surface (Bucholz 1983). Because the radioactive contamination of objects placed in spent fuel pools is generally proportional to the surface area of the object, the surface area of the cask should be as small as possible. In addition, a smooth surface is easier to decontaminate than an irregular surface.

- Lid Design (Figure 4.2)

  The cask has two lids on the upper end. The inner lid provides the primary seal and shielding for the inner cavity, and contains the upper neutron shield. It has three penetrations, each with valves and quick-connect, shut-off couplings.

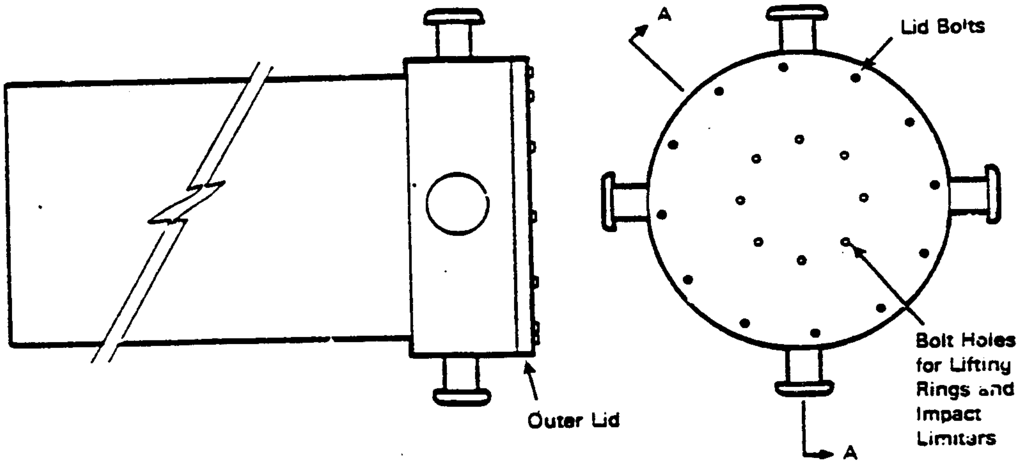


FIGURE 4.1. Postulated Reference Spent Fuel Transport Cask

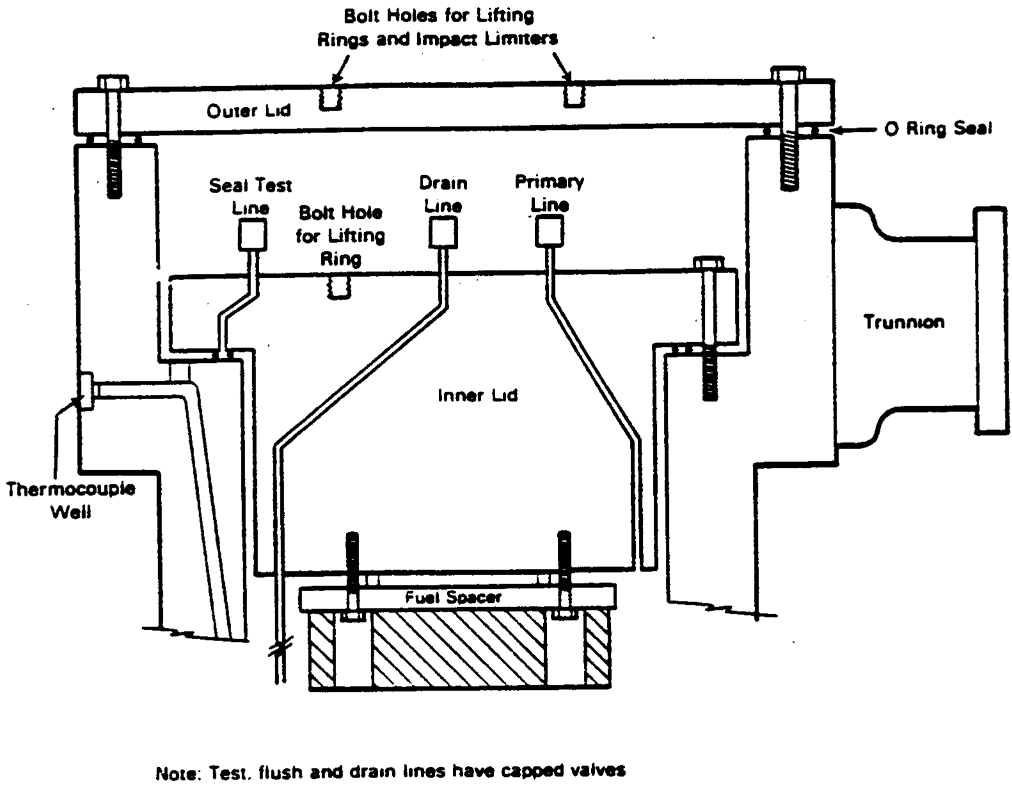


FIGURE 4.2. Postulated Reference Spent Fuel Transport Cask Lid Design (Section A-A of Figure 4.1).

The primary penetration permits pressure testing and flushing of the inner cavity. The other two penetrations are a drain connection for sampling, flushing and drying the cavity, and a small-diameter tube for testing the integrity of the inner lid seal. The inner lid is held in place by 36 bolts for rail casks and 12 bolts for truck casks.

The outer lid is a circular steel plate 1 1/2 inches thick that provides protection against impact damage to the connectors on the inner lid. The outer lid is held in place by 12 bolts for rail casks and 8 bolts for truck casks.

All connections into the cask inner cavity are through the inner lid. A minimum number of cask penetrations is desirable to reduce the potential for release of contamination to the environment and to minimize the amount of crevices in the cask surface that can become contaminated when the cask is in a spent fuel storage pool. Placing the pressure test and gas sample penetrations in the lids makes those penetrations available for decontamination while the lids are removed from the casks.

Thermocouples are installed in the cask wall for temperature measurements. The external thermocouple connections are made through the top edge of the cask.

- Lid Seals (Figure 4.2)

  Each cask lid has two elastomer o-ring seals. Using double seals reduces significantly the potential for leakage and also permits testing the integrity of the seals by pressurizing or evacuating the space between the seals.

- Lid-Lifting Attachments (Figure 4.2)

  The inner lid has shallow threaded holes for four eye bolts for attaching the lid-lifting device. The inner lid on a loaded cask must not be removed until the cask is in a pool or coupled to a hot cell and must be installed before the cask is removed from the pool or hot cell. Connecting a lifting device to the inner lid before it is placed in a pool expedites the lid removal and replacement.

  The outer lid has shallow threaded holes for three ring supports for lifting the lid and additional shallow threaded holes for attaching the impact limiters.

- Fuel Spacers (Figure 4.2)

  The fuel placement spacers are bolted to the inner surface of the inner lid. Installation of the fuel spacers on the lid must occur before the inner lid is installed on the cask.

- Cask Rotation (Figure 4.3)

  A tilting cradle is used for cask rotation on the transport vehicle. During removal of the cask from the transport vehicle and

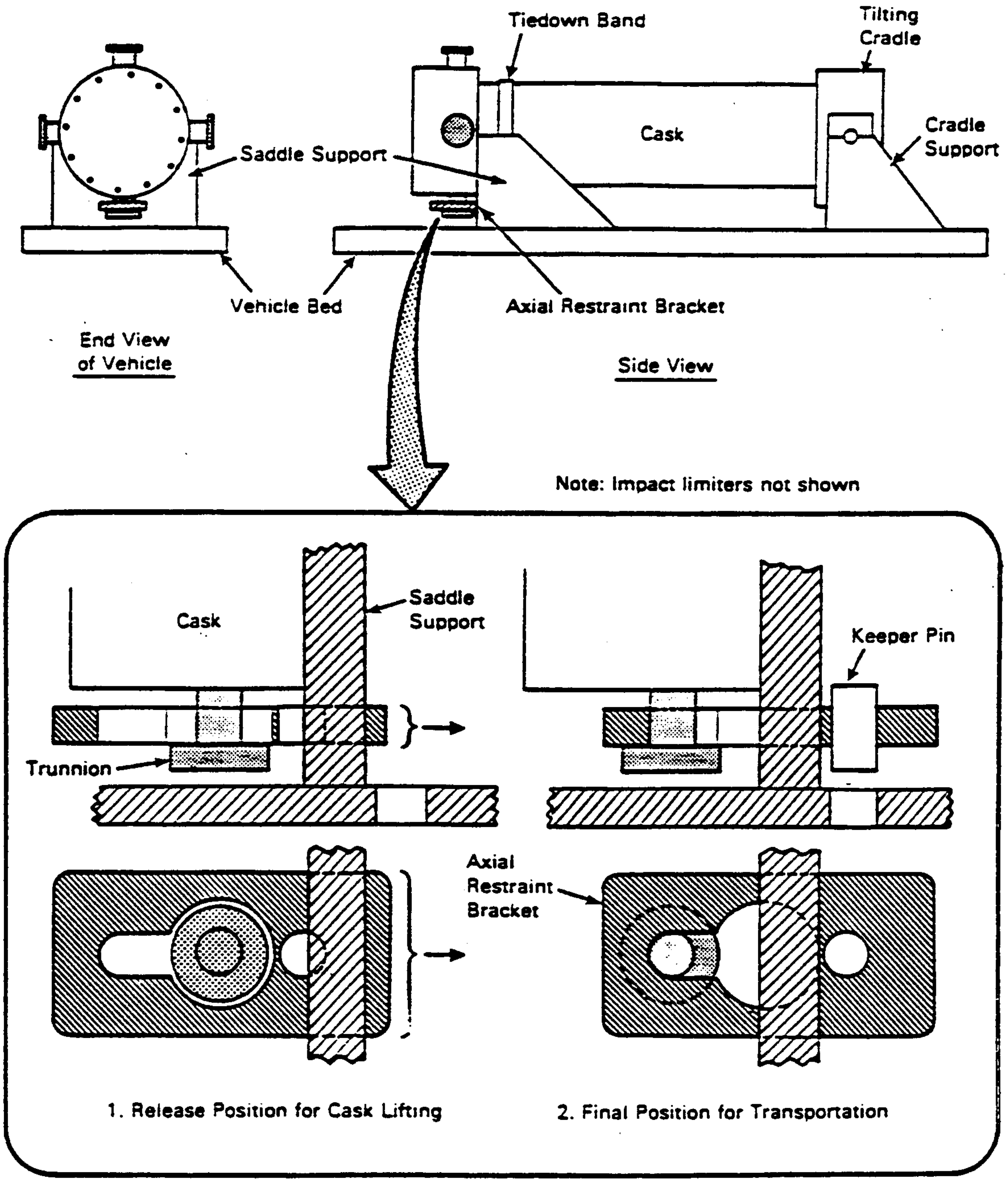


FIGURE 4.3. Vehicle Supports for Postulated Reference Spent Fuel Transport Cask

loading of the cask onto the vehicle, the cask must be rotated 90° between the horizontal and vertical positions.

- Cask Support on Transport Vehicle (Figure 4.3)

  The ends of the cask are supported on the transport vehicle by a saddle at the closure end and within a hollow cylindrical tilting cradle at the bottom end. These are designed so that about one-quarter of the cask circumference is in contact with these supports during transport. This arrangement distributes the support over much of the cask surface and avoids placing concentrated loads on the trunnions during transportation. The saddle support is designed to resist axial movement of the cask relative to the transport vehicle during a rapid vehicle deceleration.

- Cask Tiedowns (Figure 4.4)

  The cask tiedowns are designed for rapid installation and removal. The cask tiedowns consist of a band placed over the cask and then pinned in place. They are designed such that all operations can be performed rapidly without the use of overhead cranes. Small keeper bolts are used to hold the pins in place.

- Impact Limiters (Figure 4.5)

  Impact limiters are bolted to each end of the cask. The impact limiters are large cylindrical structures designed to protect the cask body and closure against impacts.

- Personnel Barrier (Figure 4.6)

  The personnel barrier is a telescoping barrier that encloses the cask, supports, and impact limiters and protects against inadvertent intrusion and road grime. The general design consists of a metal frame supporting a solid sheet-metal top and louvered sheet-metal sides. The barrier consists of movable sections that can be retracted toward each respective end of the vehicle. It is designed so that it can be easily retracted manually by pulling, without the use of overhead cranes, or other power-operated equipment and can be rapidly pinned and locked into place.

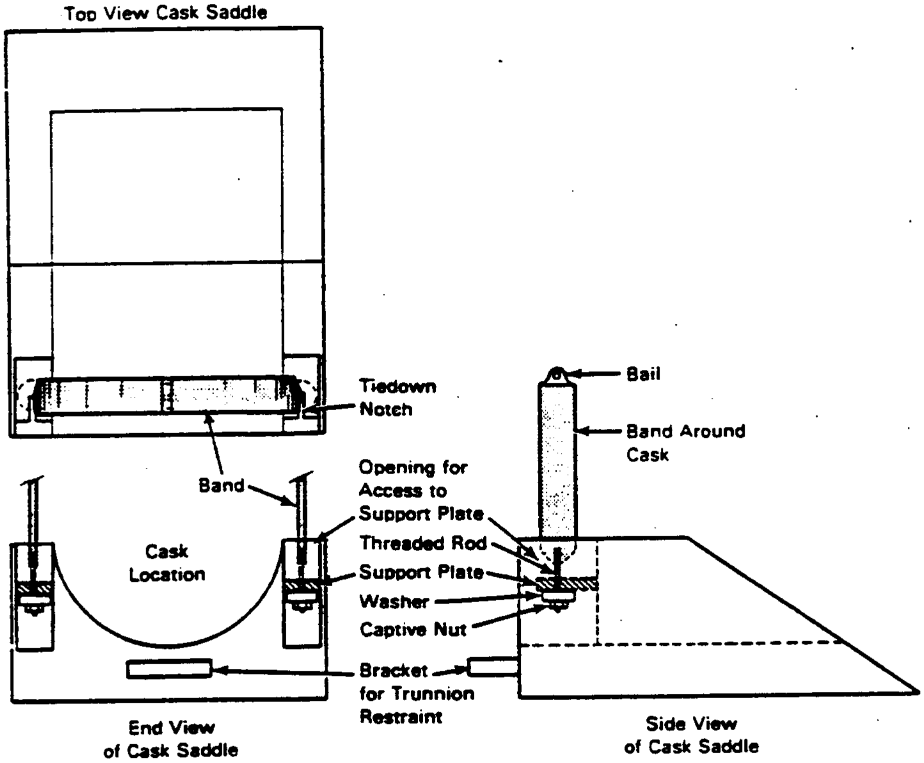


FIGURE 4.4. Cask Tiedowns for Postulated Reference Spent Fuel Transport Cask

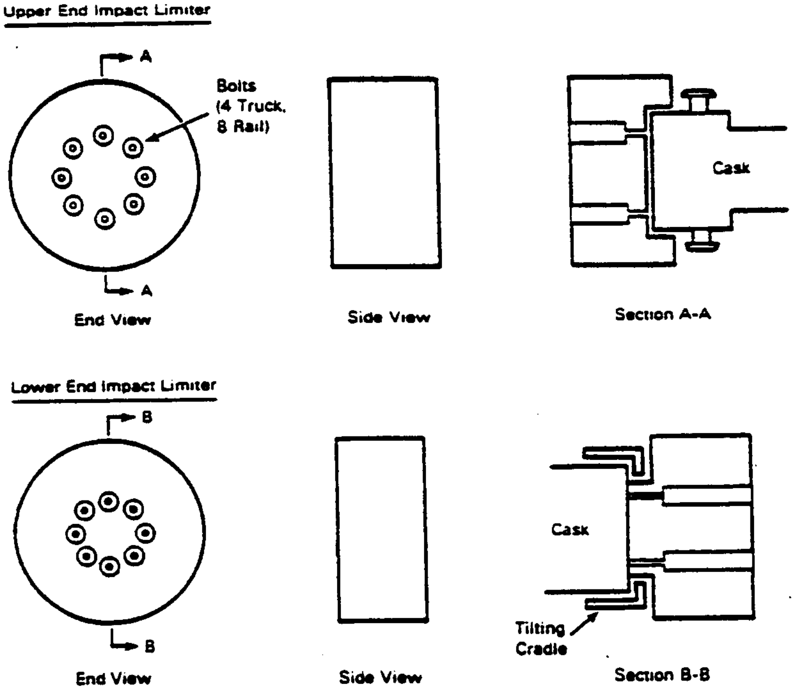


FIGURE 4.5. Impact Limiters for Postulated Reference Spent Fuel Transport Cask

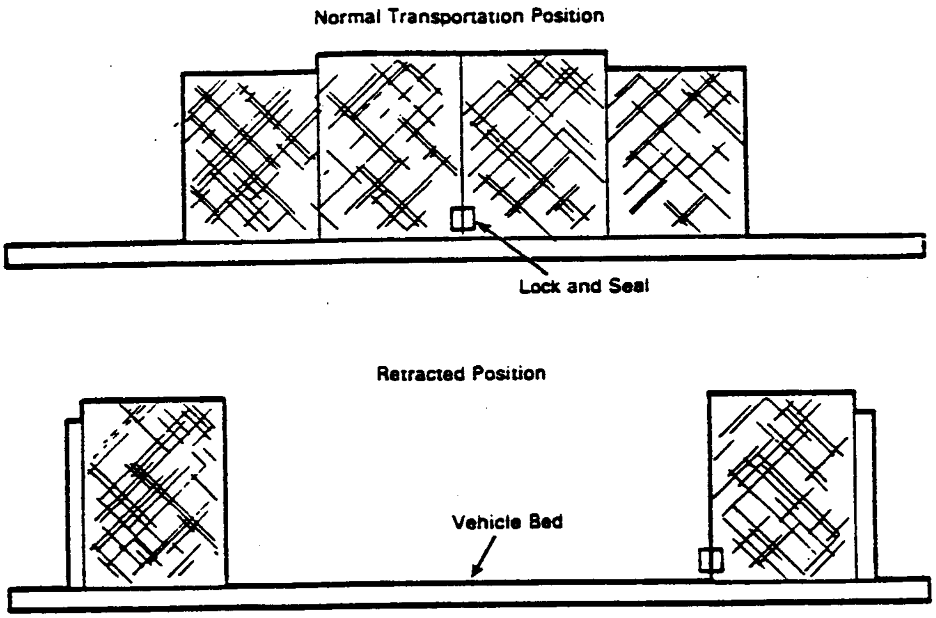


FIGURE 4.6. Personnel Barriers for Postulated Reference Spent Fuel Transport Vehicle

- Fuel Assembly Baskets

  The fuel assembly baskets are right-circular cylinders containing an arrangement of square longitudinal channels sized to contain irradiated fuel assemblies. The primary structure is stainless steel. Other materials to provide shielding, heat transfer, and neutron absorption may be included.

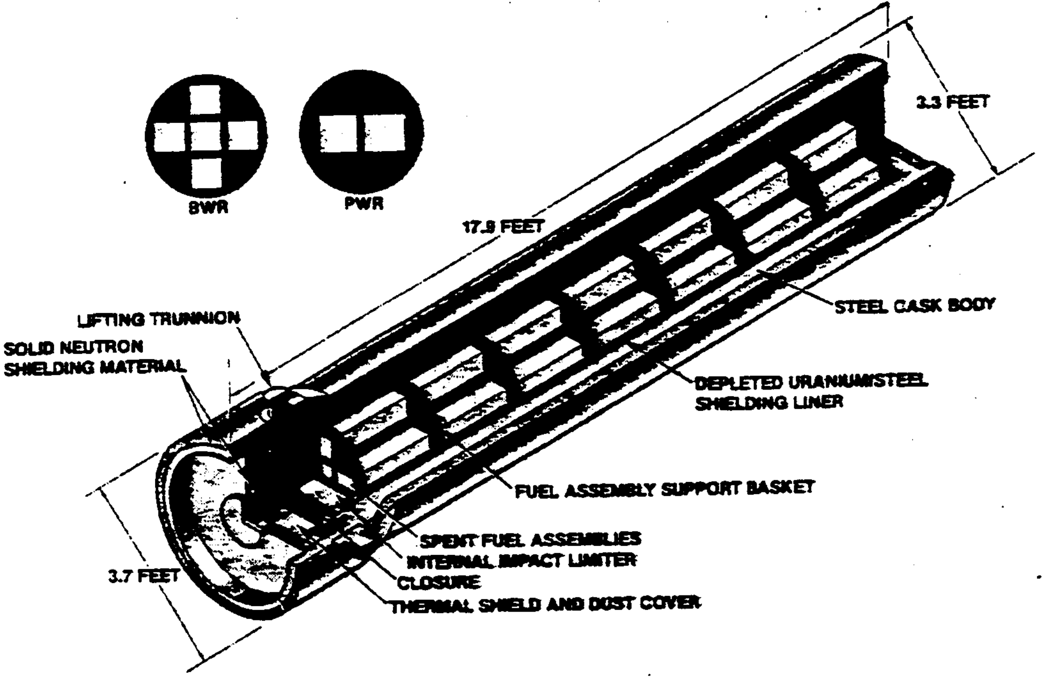
- Transport Vehicles

  The transport vehicles are dedicated to carrying one type of cask. They are standard truck trailers or railroad flatbed cars designed to carry the maximum design weight loads for unrestricted travel. The vehicle beds are permanently modified as appropriate for the cask and personnel barrier support mechanisms.

4.1.2.4 Cask Dose Rate Maps

The general configurations of a legalweight truck cask and a large rail cask, as shown on the DOE fact sheets (Figure 4.7)(DOE 1986a), were used as the postulated reference casks for the analysis of the postulated reference

Truck Cask for Spent Fuel



Rail Cask for Spent Fuel

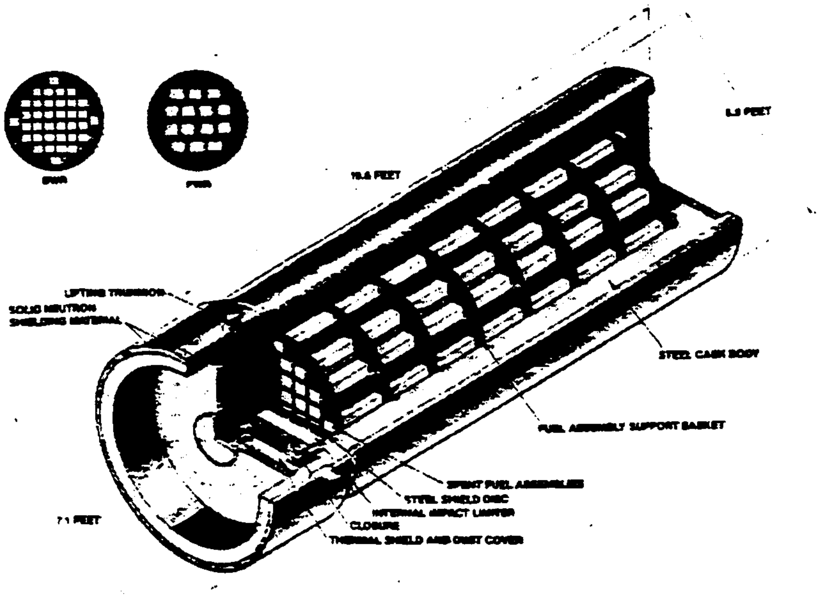


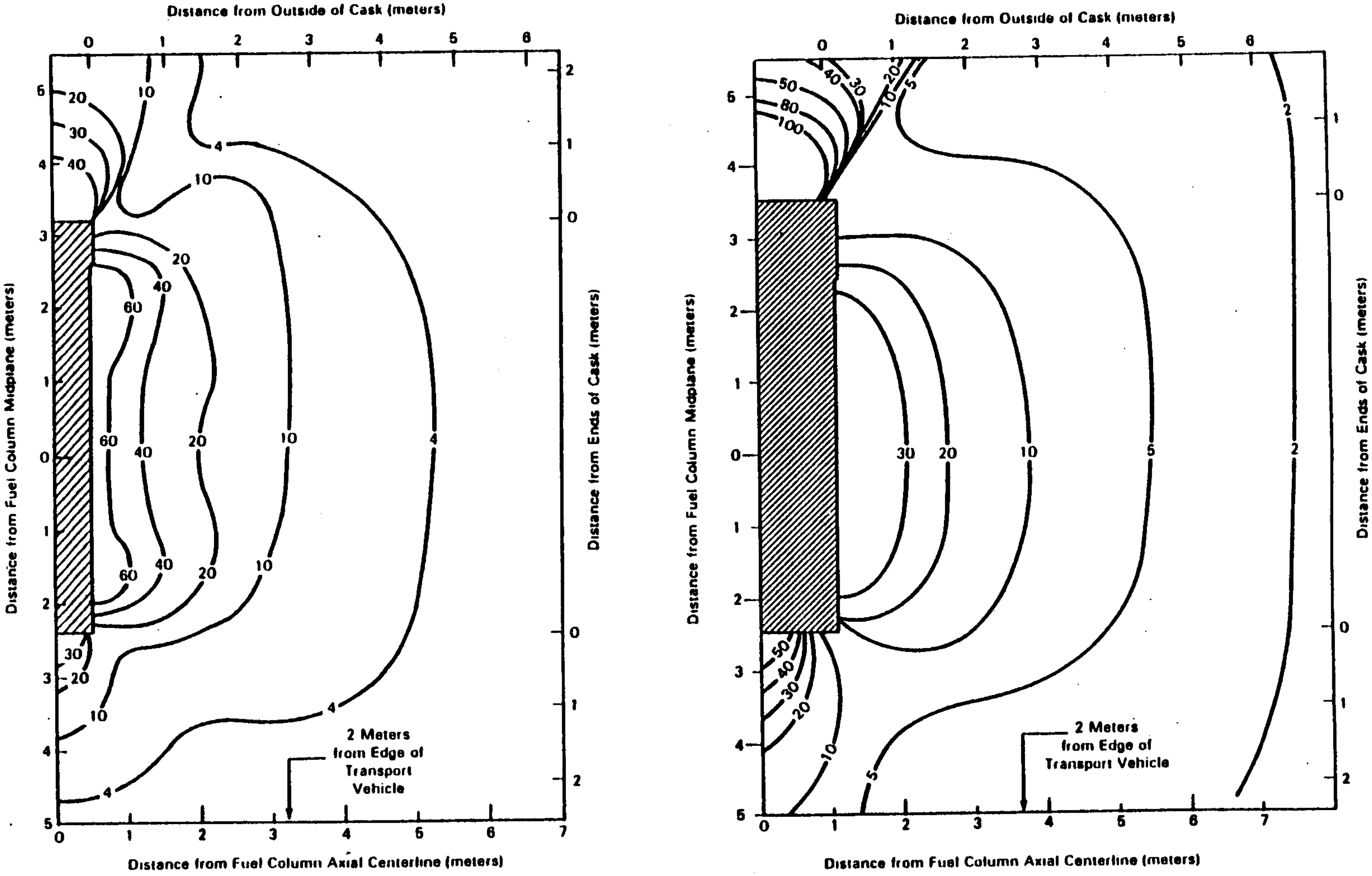
FIGURE 4.7. DOE Fact Sheet Cask Illustrations

transportation system. The shielding in the casks was adjusted to yield dose rates at the regulatory limits at 2 meters radially from the side of the transport vehicle and at the nearest occupied location axially from the ends of the casks.

The two-dimensional transport theory code DOT-4 (Rhoades 1982) was used to calculate the directional (R-Z) dose rates. The source material for these dose calculations was assumed to be two Westinghouse 17 x 17 PWR fuel assemblies in the truck cask and 14 fuel assemblies in the rail cask. The fuel assemblies were assumed to have a cylindrical geometry that had the same volume as the sum of the volumes of the square assemblies. The radionuclide inventories contained within the fuel assemblies were calculated using the computer code ORIGEN2 (Croff 1980) for exposures of 35,000 MWd/MTU and 10 years cooling. The axial shape of the fission product and structural activation product source was based on actual profiles from spent fuel assemblies.

The gamma and neutron flux-to-dose-rate conversion factors used in this analysis were taken from ANS/ANSI 6.1.1 (ANSI 1977). Recent reviews of the data supporting these factors have suggested that the neutron conversion factors should be increased by about a factor of 2, which would increase the aggregate dose rate at the cask surface by about 30%. However, these revised neutron factors have not yet been universally accepted and were not used in this analysis. A more complete discussion of the cask dose rate calculations is presented in Appendix A.

The results of the calculations for dry casks are illustrated in Figure 4.8 in the form of iso-dose rate maps. It can be seen from the maps that workers engaged in activities close to the sides of the cask body (such as manual decontamination) would be working in fields averaging 30-40 mrem/hour over most of the length of the cask. Workers engaged in operations at the top of the cask would be in relatively high dose rate fields while the outer lid is in place, averaging as much as 80 mrem/hour. Once the outer lid is removed, average dose rates to the workers are as high as 200 mrem/hour. However, when a cask is removed from the spent fuel pool following loading, the normally void space in the cask cavity is filled with water, and the shielding and neutron-moderating properties of the water reduces the external dose rates. For PWR



Truck Cask

Rail Cask

FIGURE 4.8. Iso-Dose Rate Maps, in mrem/hr, for the Postulated Reference Truck and Rail Casks (dry)

spent fuels this is about a factor of 120 in the closure region and about a factor of 40 along the sides of the cask. The dose-rate reduction factor is lower for BWR spent fuels. Thus, until the water is removed from the cavity, the external dose rates around a loaded cask are very low (see Appendix A). These dose rate profiles, calculated for the postulated reference casks, were used as the basis for estimating the personnel exposures (public and occupational) received during transportation activities.

Line- and disk-source calculations using the formula given by Rockwell (1956) were employed to estimate the dose rates at locations at larger distances from the cask than are shown in the iso-dose rate maps, using the dose rates at 2.7 meters (side, 10 mrem/hour) and 2.3 meters (bottom end, 4 mrem/hour; top end, 12 mrem/hour) from the cask surfaces as the normalization points for the truck cask. The calculated dose rates are given in Table 4.3 for selected distances from the cask surfaces. Dose rates from the ends of the rail cask are somewhat higher but are still within regulatory limits, since the nearest occupied location for a rail shipment is at a greater distance from the cask ends.

TABLE 4.3. Dose Rates at Selected Distances from Cask Surfaces

	Dose Rates, mrem/hr, at Distance Shown						
Distance (m)	5	10	20	30	50	100	400
Side (Truck & Rail)	3.2	0.76	0.18	0.07	0.02	0.005	0.00005
Bottom End (Truck)	0.8	0.2	0.05	0.02	0.006	0.001	-------
Top End (Truck)	2.5	0.60	0.15	0.06	0.019	0.004	-------
Bottom End (Rail)	8.1	2.0	0.46	0.19	0.06	0.01	-------
Top End (Rail)	2.8	0.69	0.16	0.07	0.02	0.004	-------

4.1.3 Reactor Plant Fuel Shipment Facilities

This section contains a description of the postulated reference concept for the spent fuel shipment facilities at the reactor plants where spent fuel is loaded into transport casks and the casks are prepared for cross-country shipment.

Most of the reactor plant spent fuel shipment facilities expected to be used during the next 15-20 years already have been designed and constructed. Review of those designs shows a wide variation in facility characteristics and dimensions such that a typical design cannot be selected that is representative of all reactor plants. As a result, the postulated reference concept described herein was selected to represent the typical facilities expected to be available at large reactor plants. This description should not be interpreted as being representative of any specific plant, although it is conceptually correct for a majority of reactor plants and functionally correct for all reactor plants. For additional rationale on selection of the postulated reference facility, see Appendix E.

One postulated reference concept is presented for the shipment facilities-separate designs are not presented for BWR and PWR facilities. The cask handling facilities for BWRs are located on the refueling floor far above the ground level, whereas they are generally near ground level for PWRs. This difference results primarily in a somewhat longer time for moving a cask between the transport vehicle and the cask service pad at BWRs. Because of the structural shielding and isolation of the transport path within BWR plants, and because of operational and procedural controls, the longer times associated with internal transport at BWRs do not result in a significant increase in radiation dose to the plant workers nor in a significant increase in cask turnaround times.

This facility description is presented in two parts. The first part contains a description of the postulated reference plant facilities related to movements of the cask transport vehicles from the plant outer gatehouse to the vehicle loading area within the fuel handling building. The second contains a description of the facilities inside the process building for moving the cask between the transport vehicle and the spent fuel loading pit in or near the spent fuel pool. Each part leads off with a general narrative describing the vehicle and cask activities related to the facilities being described.

4.1.3.1 Transportation Vehicle Facilities Outside the Buildings

The transport vehicle carrying an empty cask arrives at the plant outer guardhouse at the plant perimeter fence, is disconnected from the commercial carrier, monitored for radioactivity, inspected for foreign objects, connected to an onsite drive unit and pulled through the outer gate to an inspection and washdown area between the perimeter fence and the inner security fence. The onsite drive unit is a standard yard truck designed for either road or railroad use.

The trailer or railroad car and cask personnel barrier are washed using hand-held hoses and inspected for foreign objects. The personnel barrier is retracted and the equipment and vehicle that was under the cover is washed and inspected, as appropriate. The trailer or railroad car is then pulled through the inner security fence, moved to and parked inside the process building in the vehicle loading area underneath the process crane.

After the cask is loaded with spent fuel assemblies and placed back on the transport vehicle, the onsite drive unit pulls the vehicle to the plant outer guardhouse where it is transferred to the commercial carrier.

A general diagram of the plant facilities related to the transportation vehicle activities is presented in Figure 4.9. The washdown area can be essentially anywhere between the perimeter fence and inside the process

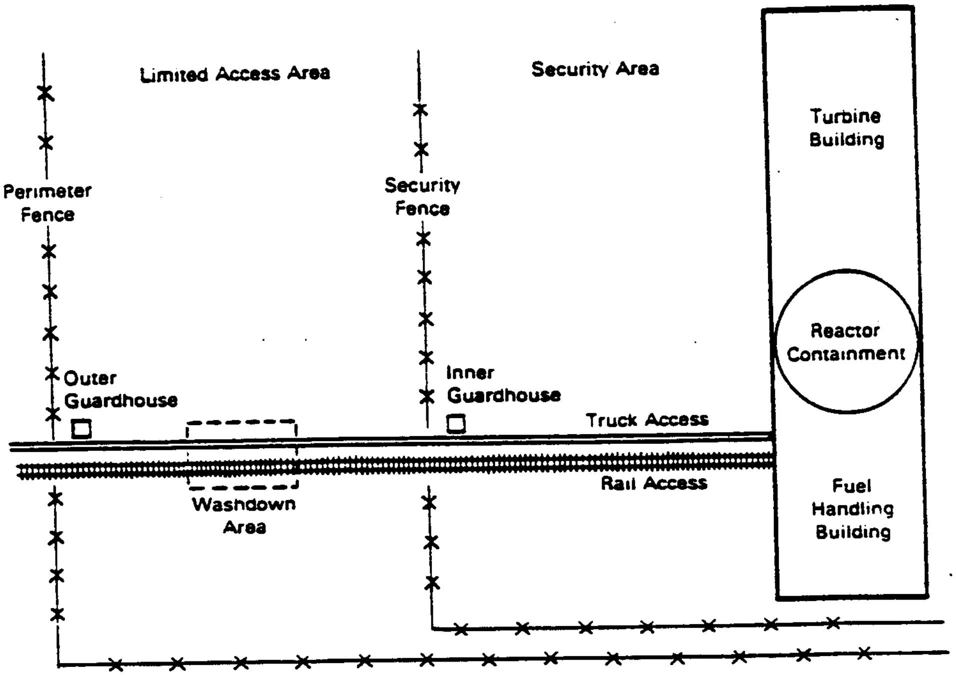


FIGURE 4.9. Cask Receiving and Shipping Facilities for the Postulated Reference Nuclear Power Plant

buildings. It consists of a concrete pad where the vehicle can be washed and the wash water will flow into a monitored collection system. Since only road dirt is being washed off the vehicle, special treatment of the effluent normally is not necessary. If, however, radiation monitoring reveals abnormal conditions, special handling will be necessary.

4.1.3.2 Cask and Spent Fuel Movement Facilities Inside the Buildings

A brief description of cask handling and fuel loading operations within the spent fuel loading area at the nuclear power station is given below. Detailed step-by-step descriptions are given in Section 4.2.2 and in Appendix B. With the cask resting on the transportation vehicle in the loading area in the fuel handling building, the impact limiters are detached and tiedowns are removed, releasing the cask from the vehicle. The cask is then lifted from the vehicle and placed on a service pad where it is prepared for loading, and is then placed in the underwater loading pit where it is loaded with spent fuel assemblies. It is lifted back to a service pad, prepared for shipment, decontaminated, and placed back on the transport vehicle. It is then connected to the vehicle, the impact limiters are installed and a thorough inspection is made.

A plan view of the postulated reference facilities for cask handling is presented in Figure 4.10 and a cross section of these facilities is presented in Figure 4.11. These illustrations best represent PWR facilities. At BWRs, the vehicle loading area is at ground level and the other handling areas are on the elevated refueling floor.

The generic cask handling facilities consist of a vehicle loading area, a cask service pad, and a cask loading pit.

The vehicle loading area is a large bay in the fuel handling building in which a truck trailer or a railroad car containing a cask is parked. It is serviced by an overhead crane of sufficient capacity to handle the casks. The crane also has auxiliary hooks for lighter loads and is operated by pendant controls from the operating floor.

The cask service pad is a reinforced concrete structure surrounded by a shallow curbing upon which the cask is prepared for placement in the loading

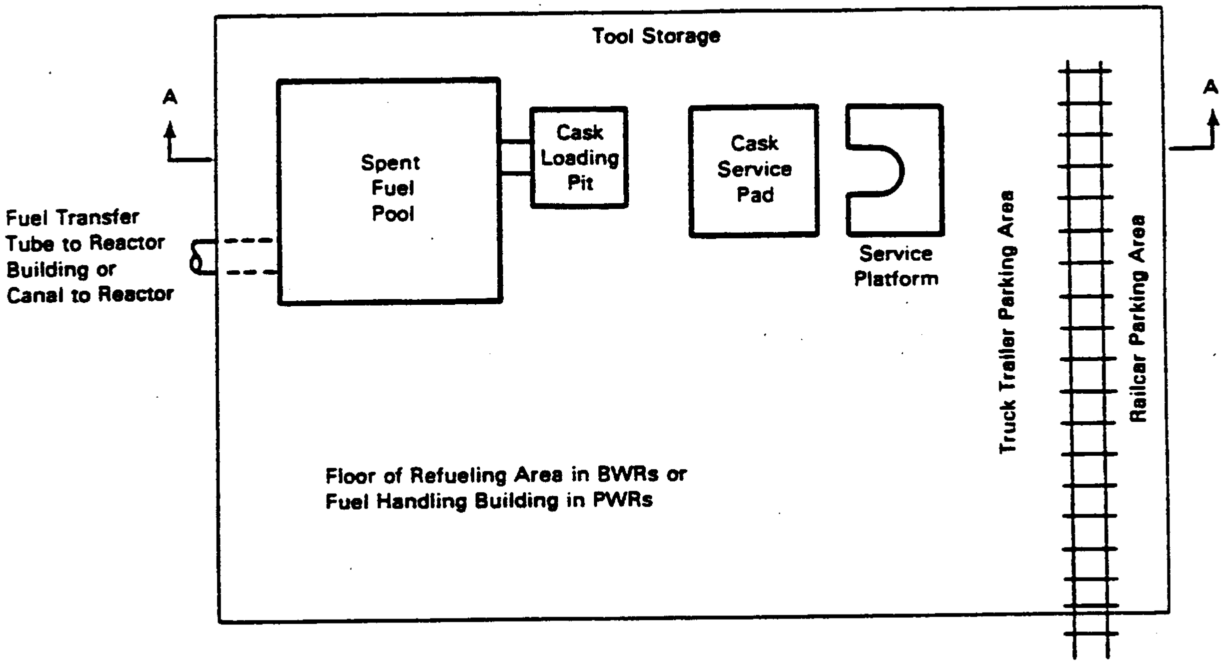


FIGURE 4.10. Plan View of Postulated Reference Cask Handling Facilities at Reactor Plants

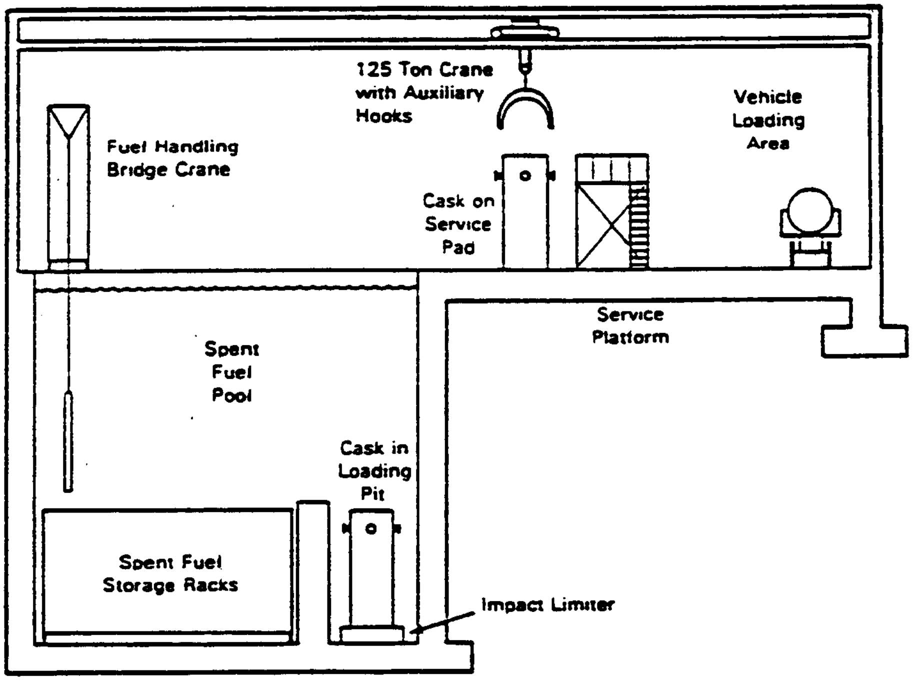


FIGURE 4.11. Elevation View of Postulated Reference Cask Handling Facilities at Reactor Plants

pit or prepared for placement on the transport vehicle. It is designed to permit decontamination of the cask and has a movable service platform to provide an elevated working level for personnel working on the head of the cask. The pad is designed such that wash waters from cask decontamination flow into drains connected to the plant radioactive liquid waste treatment system.

The cask loading pit is connected to the spent fuel pool, and is serviced by the fuel pool bridge crane. At some locations, it also contains an impact limiter at the bottom to reduce the impact on the pit structure in the event of a dropped cask.

4.1.4 In-transit Transportation Operations

The operations that occur while the shipment is in transit between the origin and destination terminals are discussed in this subsection. During these operations, the casks and vehicles are in locations that are accessible to the general public. Truck operations are described in the first subsection and rail operations in the second. These descriptions establish the bases for the detailed assessment of in-transit operations presented in Section 4.3. Additional rationale for the bases is given in Section 3.4 and in Appendix E.

4.1.4.1 Truck Operations

Truck shipments are assumed to be made by commercial carriers in general commerce using legalweight trucks (total gross vehicle weight less than 80,000 lbs). Tractors are equipped with two-way radios, telecommunication capabilities, shipment disabling equipment used in case of an attempted hijacking or diversion, and a sleeper cab for one person sleeping. The shipment is placarded in accordance with DOT regulations (49 CFR 172.500 1986). The cask and vehicle are described more fully in Subsection 4.2.1.

The transport route is 2,860 km (1,780 miles) one-way and passes through rural, suburban, and urban areas for 79, 20 and 1% of the route, respectively. These fractions were determined by calculating average fractions of travel in each population zone for spent fuel truck shipments from five representative reactors to three potential repository locations, given in the repository Environmental Assessments, Appendix A (DOE 1986b). In accordance with DOT routing regulations (49 CFR 177.825), transport is entirely on interstate highways, except when going from the origin to an interstate highway and from an interstate highway to the destination. Bypass routes around major cities are also assumed to be taken, where available.

Truck shipments can be divided into activities that occur when moving and those that occur at stops. Activities at truck stops include refueling and eating. Stops are also assumed to be made at the initial vehicle exit from the nuclear power station and upon entrance into the host repository state. These stops are for vehicle safety inspections, cask radiation inspections, and to be weighed. These inspections are currently not performed by each state but could potentially be required by the states in the future. The State of Washington, for example, has extensive inspection requirements on some types of radioactive material shipments. The entire procedure, according to the Washington State Patrol, includes a vehicle undercarriage inspection for structural defects, brake and tire inspections, checking the shipment manifest and driver's credentials, and a radiation inspection of the cask. In addition, drivers are required to notify each Port of Entry at least 4 hours in advance of arrival at the Port, which reduces waiting time.

It is also assumed in this study that each state will provide two armed escorts in a following vehicle throughout travel in urban areas within the state. Such escorts are required only for high-population zones, but states may provide escorts if they desire. The requirement for armed escorts in cities has been proposed by the NRC to be eliminated (49 FR 112 1984) for shipments of fuel that has cooled for more than 150 days but is retained in this study. (Note that this requirement is in addition to the second driver who also serves as an escort when he is not driving.)

Drivers are required to rest for at least 8 hours after driving for a 10-hour period. Therefore, two drivers are needed in order for the shipment to travel around-the-clock. One driver sleeps while the other drives for ten hours (including stops) and then the second driver drives while the first sleeps. This reduces the amount of stop-time because there is no need for overnight stops for driver's rest.

More details of in-transit operations are provided in Section 4.3.2.

4.1.4.2 Rail Operations

Rail shipments are assumed to be made by commercial carrier companies using general freight rail service. Special precautions are made for the shipping cask because it is carrying radioactive material. These precautions include not placing the cask/railcar next to the locomotive or caboose (one or more cars is placed between the cask car and these rail cars), and disallowing "humping" or "kicking" the railcar at rail terminals. Humping or kicking are the processes used to sort railcars and assemble trains according to their next destination. Thus, spent fuel rail shipments are assumed to be "shoved to rest" at rail terminals. Each train with a spent fuel cask is provided with a two-way voice communication system (e.g., radiotelephone) but is not required by regulation to have shipment-disabling capabilities.

The rail transport route is assumed to be 3,070 km (1,910 miles) one-way and travels through rural, suburban, and urban areas for 81, 18 and 1% of the route, respectively. As with truck shipments, these fractions were determined by averaging the fractions of travel in each population zone for a set of representative rail shipments to a repository that are described in DOE (1986b). The transport vehicle is placarded in accordance with DOT regulations (49 CFR 172.403 1986).

Rail operations are somewhat more complex than truck operations but can also be divided into activities while moving and activities while at stops. Rail shipments stop for a number of reasons, such as for classification, train makeup, refueling, and crew change. The basic operating sequence was extracted from Wooden (1986), which was also the basis for similar information on the repository EAs, and is discussed below.

The first operation in a rail shipment is to pick up the railcar and cask at the origin facility. This is typically done by a local train or industrial "switcher," depending on the location of the origin facility. After the rail crew ascertains that the car is ready and safe to be moved, the local train or switcher will proceed to a classification terminal, often stopping to pick up or set off other cars along the way.

Upon arrival at the classification terminal, the car is inspected and, if necessary, repaired. Classification, or marshaling, is the process of sorting cars according to the next handling and routing they are to receive. In essence, the railcar/cask is moved through the terminal so it can be joined to a "block" or group of cars having the same destination, which are being assembled to make up an outbound train. After the outbound train is assembled, it is moved to a "departure yard" where air hoses are connected, car inspections are performed, brakes are checked, and the locomotive and caboose are attached. The completed train then departs for the next terminal. A similar operation, only in reverse, occurs at the final classification terminal prior to delivery to the destination facility.

Intermediate stops between the origin and destination terminals are typically not as complex. However, when the railcar/cask is to be turned over to a different carrier enroute (carrier exchange), a procedure similar to classification is performed. At intermediate stops, the railcar/cask usually undergoes a "block exchange" in which the block of cars having the same destination are held as a block to be picked up by another train. Block exchanges may occur at classification terminals or even at stations or sidings along the rail line.

Normally, the cars receive no special attention during the time when the shipment is moving between terminals. There is a requirement to inspect the cars in a train every 1,000 miles, but the distance between classification terminals, where inspections are almost always performed, is usually less than this distance, so this requirement is not usually a constraint.

The number of crewmen on a shipment, until recently, was either four or five. A five-man crew is assumed here, which is consistent with the assumptions used in the EAs (DOE 1986b). Wooden (1986) indicates that the crew size will eventually be no more than three crew members, and may become as little as two. In addition to the crewmen, two escorts are assumed to accompany the train throughout the shipment.

Detailed time/distance/dose estimates for a representative 3,070-km one-way rail shipment are presented in Section 4.3.3.

4.1.5 Repository Receiving and Handling System

This section contains a description of the postulated reference spent fuel receiving facilities at the repository where transport casks are unloaded and the empty casks are prepared for return shipment.

The cask handling characteristics of the advanced conceptual design of the MRS receiving and handling building were selected to represent the postulated repository cask handling facility design. The MRS conceptual design (Parsons 1985, DOE 1987) was selected to represent the postulated repository system, because 1) it is representative of current technology for dry unloading facilities, and 2) the MRS design provides more detail in describing cask handling facilities than other conceptual cask handling facility designs, including evolving repository designs. Additional rationale for selection of this facility is given in Section 3.4 and in Appendix E.

The cask handling facilities consist of four hot cells, each hot cell containing two spent fuel unloading ports to which the casks are mated for spent fuel loading. Each port is served by one cart to transfer the cask from the transport vehicle to the port. Two additional hot cells are assumed to be provided for periodic cask decontamination.

The general plan of the postulated reference repository site and its receiving and handling facility is shown in Figure 4.12. The facilities of interest in this study are an inspection gatehouse, protected area gate, and a receiving and handling building that contains two washdown areas and two cask receiving and handling areas.

Spent fuel arrives at the repository facility in transport casks carried by either truck or rail. Following initial inspection and checking of documents at the inspection gatehouse, the transport vehicle and cask are transported to the protected area gate. At the protected-area gate, the over-the-road transport prime mover is released, a yard tractor is hooked up, and a thorough security search and radiation monitoring is performed of the cask and its vehicle. The cask is then transported through the protected-area gate into the protected area where it waits in queue for unloading.

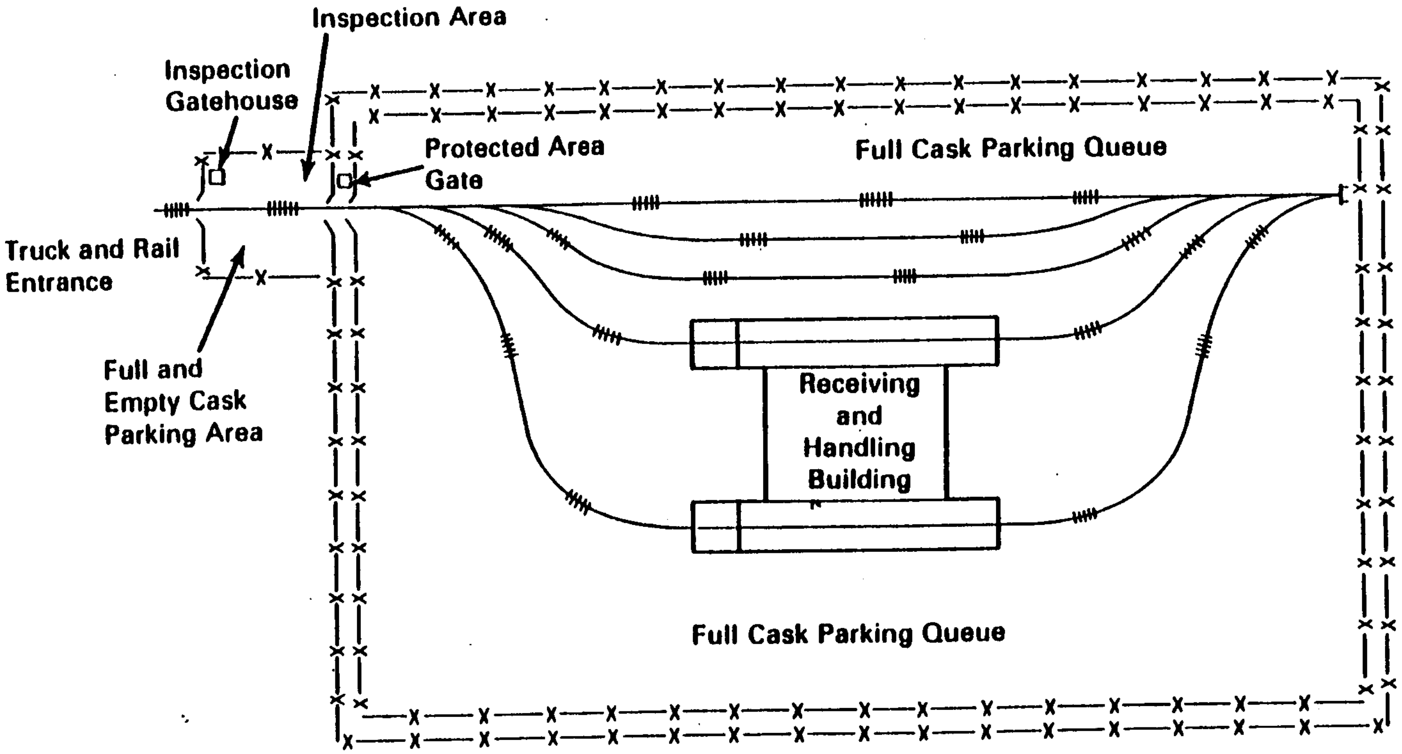


FIGURE 4.12. General Plan of the Postulated Reference Repository Facility

When the receiving and handling building is ready to accept the cask, the cask is transported from the queue in the the protected area to one of the two washdown stations inside the receiving and handling building. Each washdown station services two receiving hot cells, as shown in the receiving and handling building layout in Figure 4.13.

Each cask vehicle is washed at the washdown station. The tamper-indicating seals are removed, the personnel barrier is retracted, and the cask is manually spot-washed (if necessary), and allowed to drip-dry. The cask is then transported to the adjacent cask receiving and handling area, shown in Figure 4.14. Both the washdown area and receiving and handling area are enclosed with doorways serving as ventilation control barriers.

Each receiving and handling area is served by a 150-ton crane for cask handling and a 40-ton crane for handling smaller items. Each of the four receiving hot cells is served with two electrically-driven cask carts on their own rails, one cask cart for each of the two ports per hot cell.

At the receiving and handling area, the cask impact limiters and tiedowns are removed using manual tools. Then a cask lifting yoke is attached and the 150-ton crane upends and transports the cask to the cask cart.

A roll-up, ventilation-control door is then opened and the cart and cask are moved into their respective cask handling and unloading rooms, shown in Figure 4.15. The roll-up door is closed and a movable working platform is moved into position around the top of the cask. Gas sampling and pressure relieving, outer lid removal, inner lid bolt removal, contamination barrier adapter installation and inner lid lifting adapter installation are all completed in the cask handling room. The contamination barrier adapter consists of a large ring that fits around the top of the cask to assist in proper cask mating with the vertical telescoping contamination barrier built into the hot cell port. The inner lid lifting adapter is a lifting frame that bolts onto the inner lid to facilitate lid removal by the hot cell crane.

A shielding door is then opened, and the cask is moved into the unloading room beneath the hot cell port. The telescoping contamination barrier is extended downward from the cell port and mated with the contamination barrier

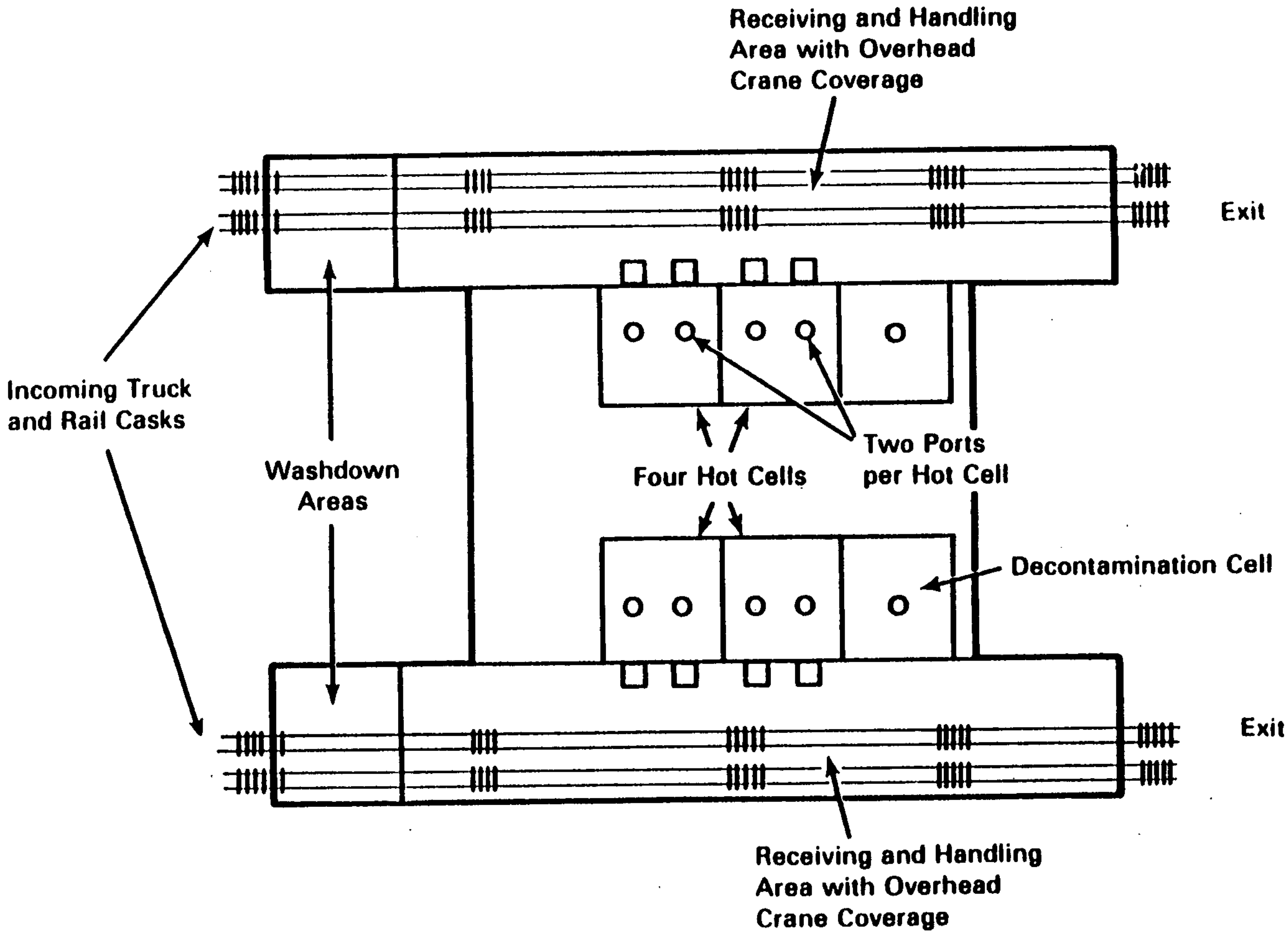


FIGURE 4.13. Receiving and Handling Building Layout at the Postulated Reference Repository

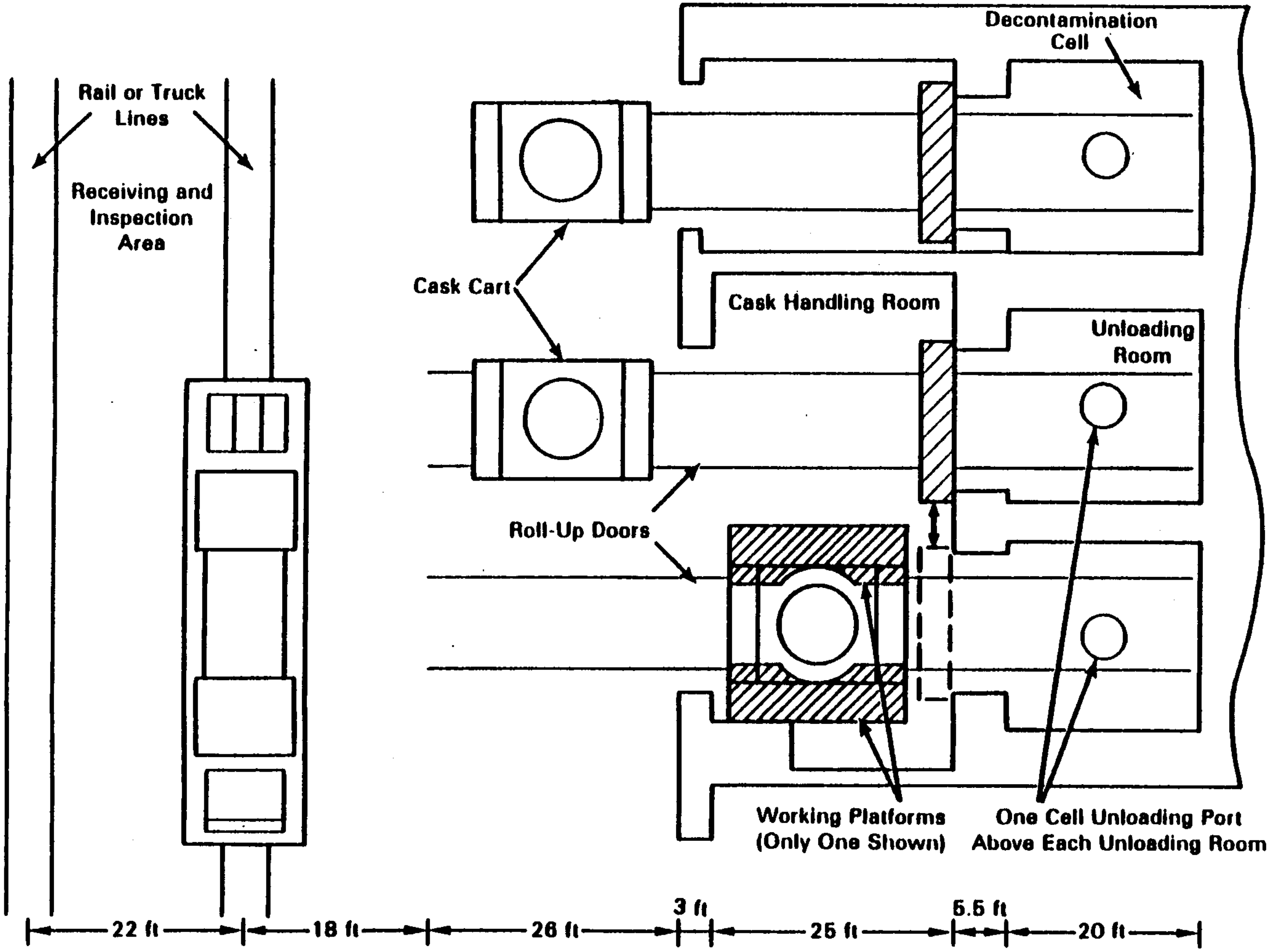


FIGURE 4.14. Plan View of Receiving and Handling Area and Adjacent Hot Cell at the Postulated Reference Repository

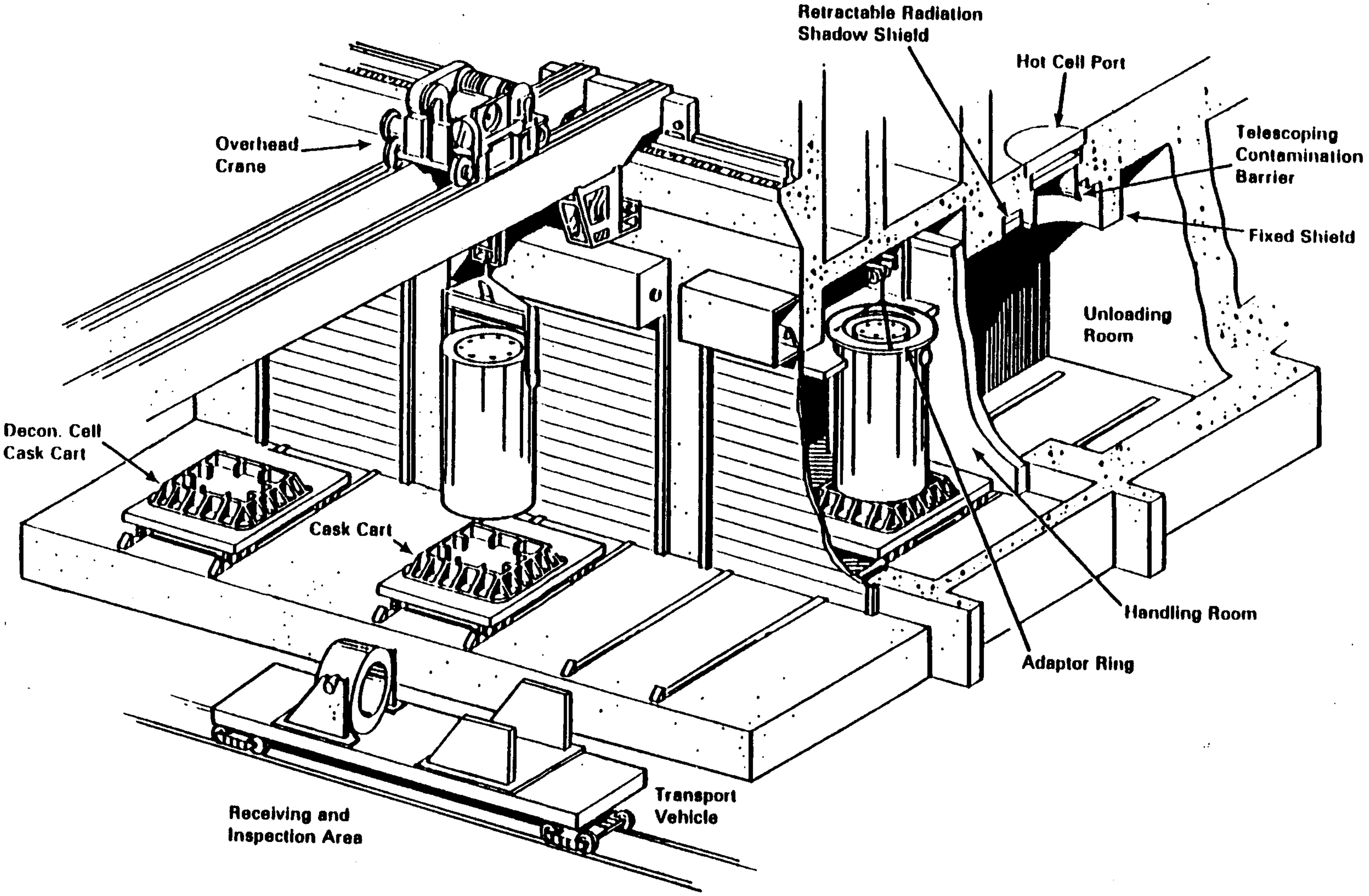


FIGURE 4.15. Cask Handling and Unloading Rooms at the Postulated Reference Repository

adapter on the cask. A shadow shield near the top of the cask is remotely extended from the roof of the unloading room, the personnel leave the unloading room, and the shielding door is closed.

The remotely operated 20-ton overhead crane within the hot cell is used to remove the port plugs in the floor of the hot cell, then to remove the inner cask lid and fuel spacer. Spent fuel assemblies are then grappled and removed one at a time and placed into hot cell lag storage. After removal of all spent fuel, the cask cavity and fuel basket are decontaminated by vacuuming, and the fuel spacer, inner cask lid, and hot cell port plugs are reinstalled.

The telescoping contamination barrier in the cask unloading room is retracted, the shadow shield is retracted, and the shielding door is opened to allow the empty cask to be moved back into the handling room for manual lid reinstallation and external decontamination. The roll-up hand ing room door is then opened and the empty cask is moved out to the receiving and handling area. If the in-cell inspection of the cask interior shows that an interior decontamination is required, the cask is moved to the cask decontamination hot cell where the basket is removed, the cavity, lids, and fuel spacers are decontaminated, a clean basket is installed, and the cask lid seals are refurbished as needed. Following this effort, the cask is placed back on the transport vehicle, is prepared for shipment (i.e., impact limiters, tiedowns, and personnel barrier are reinstalled), and is moved to the protected area gatehouse for release to the over-the-road carrier and release from the facility.

4.2 ANALYSIS OF DOSES FROM AT-REACTOR OPERATIONS

Estimated worker radiation doses resulting from routine at-reactor operations are presented in this section. These estimates are based on the overall study bases and rationale given in Section 3.4 and Appendix E, and on the description of the postulated reference reactor plant provided in Section 4.1. The bases for the dose estimates for transport cask handling and the approach used are presented in Section 4.2.1. At-reactor cask handling activities are summarized in Section 4.2.2, and presented in detail in Appendix B. A summary of the dose analysis is presented in Section 4.2.3.

4.2.1 Approach, Bases, and Methodology

Radiation doses resulting from cask handling operations at the postulated reference reactor plants were estimated by a standard process analysis of the postulated plant facilities. A flow chart of the approach is presented in Figure 4.16. The general steps in that process analysis are listed below:

- Obtain operating procedures and descriptions of related equipment and facilities for spent fuel assembly shipments at several reactor plants that have shipped assemblies, and from engineering analyses in the literature. (General Electric Co. 1986; Scott 1986; Northern States Power Co. 1985; Rafferty 1986; Bray 1986; NLI 1979; Lambert 1981a; McCreery 1979, 1980 and 1981.)
- Review available time/distance/dose studies, dose analyses and related information.
- Obtain the description and characteristics of the postulated reference system transport casks and reactor plant facilities (see Section 4.1).
- Develop a process flow activity list for reactor plant cask handling operations. This listing shows a major process activity for each of the process steps that occur as the cask is moved through the shipment process.
- Complete a detailed activity analysis for each process step. The activity analysis includes estimating personnel requirements, performing a time/distance/dose analysis, determining working distances from the cask, and estimating radiation dose rates for each cask handling operation.
- Compare these activity analyses and personnel and time estimates with information from previous analysis and cask handling experience. If these estimates seem unrealistic, based on prior information, review and reconcile the detailed activity analysis.
- Calculate radiation exposure for each staff member for each type of cask load.

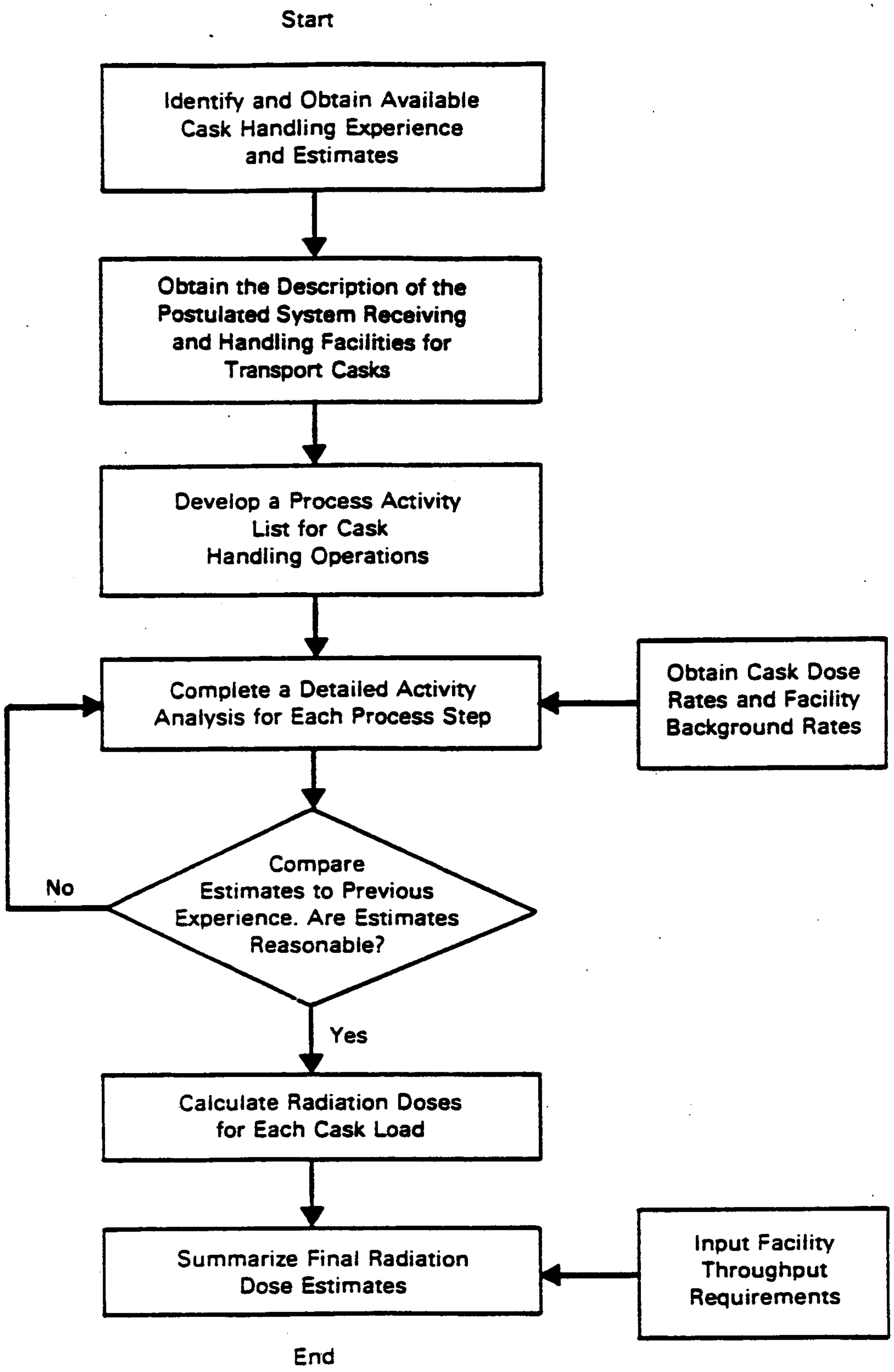


FIGURE 4.16. General Analysis Procedure for Spent Fuel Handling Activities at the Reactor Plants

- Summarize final radiation exposure estimates using annual facility throughput requirements.

Current contact handling techniques were assumed in estimating personnel needs, personnel locations, and time requirements. Personnel requirements for each operation were based on typical crew sizes representative of current cask handling experience. Distance estimates between the cask surface and operating crew members during handling activities were also based on current cask handling practices. For example, all bolt removal was assumed to be completed by air-driven torque-limited impact wrenches without extension handles. Estimates of similar activities by others were found to vary significantly. The estimates in this study are based on working procedures and times that are believed to be sustainable for long time periods, barring major breakdowns. The estimates are neither minimum nor maximum, but are believed to be realistic for the bases used. The detailed results of the activity analysis are given in Appendix B.

The time/distance/dose estimates and their respective bases developed for the system postulated for this study result from several internal workshops with senior staff where each cask activity was reviewed in detail.

Specific bases and assumptions, in addition to those in Chapter 3 and Appendix E, for the analysis of doses from at-reactor operations are as follows:

- The personnel are well-trained and experienced in the activities as provided for in utility/DOE contracts.
- The casks are well-maintained.
- Personnel with the appropriate skills are available when needed.
- The activities proceed in an orderly manner without major interruptions.
- Equipment and supplies are available as needed.

- In estimating doses from other sources in the general work area, crew members identified as participating in an activity are assumed to be in the general area for the complete duration of the activity, even when they are not working on the cask.
- Doses received by workers when they are neither near the cask nor in the area where the cask activities are being performed are not included in this study.
- Work on shipments during a campaign is on one shift/day basis with all work accomplished by one dedicated crew that is part of the normal plant operating crew. The shifts are nominally 8 hours long, but can be extended to up to 12 hours to complete a shipment within a shift.
- Only one cask is at the facility and being processed at one time.
- Time and staffing requirements are based on performing certain activities in parallel where practicable. Only the times that are additive (i.e., critical path times) are included in the turnaround times for casks.
- Personnel radiation dose for each activity is calculated by the expression:

$$\begin{matrix}\text{Radiation Dose}\\ \text{from Activity}\end{matrix} = \begin{matrix}\text{Radiation Dose}\\ \text{from Cask}\end{matrix} + \begin{matrix}\text{Radiation Dose}\\ \text{from General Area}\end{matrix}$$

Where

$$\begin{matrix}\text{Radiation Dose}\\ \text{from Cask}\end{matrix} = \left(\begin{matrix}\text{Dose Rate}\\ \text{from Cask}\end{matrix}\right) \times \left(\begin{matrix}\text{Time to Complete}\\ \text{Activity}\end{matrix}\right) \times \left(\begin{matrix}\text{No. People}\\ \text{Performing}\\ \text{Activity}\end{matrix}\right)$$

$$\begin{matrix}\text{Radiation Dose}\\ \text{From General Area}\end{matrix} = \left(\begin{matrix}\text{General Area}\\ \text{Dose Rate}\end{matrix}\right) \times \left(\begin{matrix}\text{Time}\\ \text{in Area}\end{matrix}\right) \times \left(\begin{matrix}\text{No. People}\\ \text{in Area}\end{matrix}\right)$$

- The normal (general area) dose rates used in this study for the reactor areas identified in Subsection 4.1.3 (excluding natural background) are as follows:

Location	General Area Dose Rate[a] (mrem/hr)	Related Figure No.
Outside process buildings	0	4.9
In vehicle loading area	0.5	4.10
Around service pad	2.0	4.10
Near spent fuel pool	4.0	4.10

(a) Based on dose measurements taken at Surry nuclear station during cask handling operations.

- The work times include an allowance to cover normal delays due to minor equipment malfunctions, routine personnel errors and personnel entry/departure from the work area. This allowance is in the order of 10-20% of the work time. Therefore, all time estimates are not minimum or maximum expected times, but are estimated to be sustainable handling times.
- Spent fuel shipments will be done in campaigns of 30 MTU during each year of shipments. (See Appendix E.3 for additional discussion.)
- An empty, decontaminated cask has a surface dose rate of less than 0.5 mrem/hour as required by DOT regulations. The dose rate at 2 feet from the surface is estimated to be 0.2 mrem/hour and at 5 feet is 0.1 mrem/hour. (See Appendix E.3 for additional discussion.)
- The activities were assumed to be accomplished by use of equipment normally expected to be available at the reactor plants (e.g., single-head torque-limited impact wrenches). No consideration was given to use of improved equipment (e.g., multiple-head impact wrenches).

The activity time/distance/dose estimates for other reactor cask handling facilities and cask handling experience were reviewed. Information from General Electric Co. (Lambert 1981), Allied-General Nuclear Services (Anderson 1978a, b, c), and past estimates by staff at PNL, were included in the reviews. In addition, time/distance/dose activities were observed for truck cask loading at a PWR reactor (Surry nuclear station) and for dry cask unloading at the Test Area North (TAN) hot cell at the Idaho National Engineering Laboratory (INEL).[a] A summary of some of the relevant time estimates from prior studies is given in Table 4.4. Time/distance/dose estimates for the postulated reference system in this study are generally higher than previous estimates, primarily because some of the previous estimates were stated as minimum times and because the systems analyzed were sometimes different.

4.2.2 Summary of Reactor Plant Operating Procedures

Cask handling activities at the reactor plants are represented by 24 major activities, shown in Table 4.5. The major activities are briefly summarized below.

Cask handling activities 1 through 4 (Table 4.5) cover the movements of the cask from the time of arrival at the reactor plant perimeter fence until the transport vehicle is parked in the process building vehicle loading area under the process crane.

The transport vehicle carrying an empty cask arrives at the guardhouse at the plant perimeter fence, is disconnected from the commercial drive unit, monitored for radioactivity, and inspected for foreign objects. It is then connected to an onsite drive unit and pulled through the outer gates to an inspection and washdown area between the perimeter fence and the inner security fence. At the washdown area the trailer or railcar and cask personnel barrier are washed. The personnel barrier is retracted and the equipment and vehicle that was under the cover is washed and inspected as appropriate. The trailer or railcar is then pulled through the inner security fence and parked inside the process building in the vehicle loading area underneath the process crane.

Activities 5 to 9 cover the movement of the cask from the transport vehicle to the cask loading pit. The impact limiters are removed and the cask

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(a) The results of these observations are to be published in a document titled "Time/Motion Observations and Dose Analysis of Reactor Loading, Transportation and Dry Unloading of an Overweight Truck Spent Fuel Shipment," by C. J. Hostick, J. C. Lavender, and B. H. Wakeman, Pacific Northwest Laboratory, Richland, Washington.

TABLE 4.4. Comparison of Some Prior Analyses of Cask and Spent Fuel Handling Estimates at Wet Handling Facilities

Cask Type	No. and Type of SFAs(a) Carried	Source	Total Time for Cask Turnaround (hr)	Total Person-mrem for Cask Turnaround
Truck TN-8	3 PWR	Anderson 1978b	15.8	100
Truck TN-9	7 BWR	Anderson 1978b	15.8	100
Truck TN-9	7 BWR	McCreery 1981	14.8	98
Truck TN-9	7 BWR	Lambert 1981a	21.2	(b)
Truck TN-8	3 PWR	Lambert 1981a	20.1	(b)
Truck NLI-1	1 PWR	Lambert 1981a	16.4	(b)
Truck NLI-2	2 BWR	Lambert 1981a	16.6	(b)
Truck NAC-1	1 PWR	Lambert 1981a	14.4	(b)
Truck NAC-1	2 BWR	Lambert 1981a	14.6	(b)
Truck NAC-1	1 PWR	Schneider 1986	12.8	150
Truck	2 PWR	Schneider 1986	13.0	151
Truck (OWT)	4 PWR	Schneider 1986	13.5	153
Rail IF-300	7 PWR	Anderson 1978c	35.5(c)	247(d)
Rail IF-300	18 BWR	Anderson 1978c	35.5(c)	247(d)
Rail NLI-10/24	10 PWR	Anderson 1978a	27.7(e)	244(d)
Rail NLI-10/24	24 BWR	Anderson 1978a	27.7(e)	244(d)
Rail IF-300	7 PWR	Lambert 1981a	25.8	(b)
Rail IF-300	18 BWR	Lambert 1981a	28.5	(b)
Rail NLI-10/24	10 PWR	Lambert 1981a	35.9	(b)
Rail NLI-10/24	24 BWR	Lambert 1981a	39.4	(b)
Rail IF-300	7 PWR	Schneider 1986	22.9	252
Rail	14 PWR	Schneider 1986	24.6	261

(a) SFAs = Spent Fuel Assemblies.
(b) Not given or not available.
(c) A contamination barrier was not used when placing the cask into a spent fuel pool.
(d) Design basis fuel approximately 5 months cooling time prior to shipment.
(e) Assuming the availability of a contamination barrier on the cask while immersed in the pool.

TABLE 4.5. Major Cask and Spent Fuel Handling Activities at the Postulated Reference Reactor Plant

	Activity	Location
1.	Receive transport vehicle and empty cask, monitor, inspect, unhook over-the-road carrier's drive unit and attach utility drive unit	Outer guardhouse
2.	Move transport vehicle and cask to inspection and washdown area	Facility grounds
3.	Wash transport vehicle and cask, monitor and inspect	Washdown pad
4.	Move transport vehicle and cask to vehicle loading area	Facility grounds
5.	Prepare cask for removal from transport vehicle, remove impact limiters and tiedowns	Loading area
6.	Remove cask from vehicle and place on cask service pad	Loading area
7.	Remove transport vehicle from loading area	Facility grounds
8.	Prepare cask for placement in loading pit, remove outer lid and remove all but 4 inner lid bolts	Service pad
9.	Move cask to loading pit, remove remaining inner lid bolts, and place cask in loading pit	Service pad to loading pit
10.	Prepare cask for loading, remove inner lid, inspect and remove any foreign objects in inner cavity	Loading pit
11.	Move spent fuel assemblies from storage pool to the loading pit, place spent fuel assemblies in cask	Spent fuel pool and loading pit
12.	Install fuel spacers and inner lid on the cask	Loading pit
13.	Lift cask from loading pit, install 4 inner lid bolts and place on service pad	Loading pit to service pad
14.	Decontaminate cask exterior	Service pad
15.	Prepare cask for shipment, install lids, flush, drain, dry cask, and seal cask	Service pad
16.	Move cask to vehicle loading area	Service pad to loading area
17.	Move transport vehicle to loading area	Facility grounds
18.	Place cask on the transport vehicle	Loading area
19.	Perform contamination survey and decontaminate cask exterior	Loading area
20.	Prepare loaded vehicle for shipment, install cask tiedowns, impact limiters and personnel barrier	Loading area
21.	Final inspection and contamination/radiation survey, monitor, inspect and document	Loading area
22.	Move transport vehicle out of security area	Facility grounds
23.	Release cask and transport vehicle to carrier for OCRWM acceptance and transportation	Outer guardhouse
24.	Notify appropriate organizations of the shipment departure.	Supervisor's office

is disconnected from the transport vehicle, lifted from the vehicle and placed on a service pad, where the outer lid is removed and the cask is prepared for placement in the cask loading pit. From there it is moved to the loading pit.

Activities 10 to 12 cover the activities in and around the loading pit, namely, removal of the cask inner lid, inspection and preparation of the cask internals, loading of fuel assemblies, and replacement of the cask inner lid.

Activities 13 to 18 cover movement of the cask from the loading pit to the transport vehicle and include installation of cask lids, draining, drying and decontamination of the cask, and placement of the cask on the vehicle.

The final activities, 19 to 24, cover final cask decontamination, plus installation of impact limiters, tiedowns, and personnel barrier. The cask is moved from the loading area to the plant perimeter fence, transferred to the over-the-road carrier, and appropriate organizations notified.

4.2.3 Dose Analysis

Worker dose estimates for reactor plant cask handling activities are based on a) cask dose rates presented in Section 4.1, b) background dose rates (i.e., from other nearby sources) for working areas where casks are handled, c) manpower and time estimates, and d) location of workers relative to the radiation source. Detailed manpower, time, motion, and dose estimates for specific handling activities are presented in Appendix B.

A summary of the estimates of the number of personnel needed for each of the major process activities is presented in Table 4.6. These data are given in more detail in the analysis worksheets in Appendix B.

The personnel for the cask handling activities are expected to be part of the normal reactor plant operating personnel in accordance with the availability of personnel with adequate training for those activities. For this report, the average doses to workers in each craft were obtained by assuming that a single dedicated crew is available for these activities.(a) The

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(a) The dedicated crew consists of 1 crane operator, 4 operators, 1 quality control inspector, 1 radiation monitor, 1 yard driver, 1 security guard, and 4 maintenance craftsmen. In addition, a supervisor is needed. The supervisor receives no doses and is not included in the dedicated crew.

TABLE 4.6. Estimated Cask Handling Personnel Requirements at the Postulated Reference Reactor Plant, by Activity

Activity	Facility Location	Task Title	Personnel[(a)] CO	OP	RM	I(QC)	TD[(b)]	YD	SG	M-C	S
1	Outer Guardhouse	Receive transport vehicle and empty cask, monitor, inspect		1	1	1	2	1	1		1
2	Facility Grounds	Move transport vehicle and cask to inspection and washdown area		1				1	1		
3	Washdown Pad	Wash transport vehicle and cask, monitor, inspect		2	1				1		
4	Facility Grounds	Move transport vehicle and cask to loading area						1			
5	Loading Area	Prepare cask for removal from transport vehicle	1	2	1					2	
6	Loading Area	Remove cask from vehicle and place on cask service pad	1	2							
7	Facility Grounds	Remove transport vehicle from loading area						1			
8	Service Pad	Prepare cask for placing in loading pit	1	2	1					2	
9	Service Pad	Place cask in loading pit	1	1	1					1	
10	Loading Pit	Prepare cask for loading	1	1	1	1				2	
11	Loading Pit	Place spent fuel assemblies in cask		4		1					
12	Loading Pit	Install fuel spacers and inner lid on the shipping cask	1	1		1					
13	Loading Pit	Lift cask from loading pit and place on service pad	1	2	1					1	
14	Service Pad	Decontaminate cask		2	1						
15	Service Pad	Prepare cask for shipment	1	2	1	1				3	
16	Service Pad	Move cask to loading area	1	2							
17	Facility Grounds	Move vehicle to loading area						1			
18	Loading Area	Place cask on the transport vehicle	1	1							
19	Loading Area	Perform contamination survey		1	1						
20	Loading Area	Prepare loaded vehicle for shipment	1	1						4	
21	Loading Area	Final inspection and contamination survey		1	1	1				1	
22	Facility Grounds	Move transport vehicle out of security area						1			
23	Outer Guardhouse	Release cask and transport vehicle to carrier		1		1	2	1	1		1
24	Supervisor's Office	Notify appropriate organizations of the shipment departure.									1
	Totals Maximum per shift		1	4	1	1		1	1	4	1

(a) Personnel Legend:

CO = Crane Operator
OP = Reactor Site Operator
RM = Radiation Monitor
I(QC) = Inspector
TD = Offsite Truck Driver/Rail Crew
YD = Site Yard Driver
SG = Security Guard
M-C = Maintenance Craft
S = Supervisor

Not all personnel are in the radiation zones for the full time of the listed activity.

(b) Doses to these workers are not included in reactor personnel requirements.

personnel requirements for each major process activity are summarized in Table 4.6. Note that many of these workers are not needed full time. It is assumed that the workers are working on other reactor activities when not used full time on cask loading activities.

Detailed staff assignments and dose estimates for individual crew members for each activity were developed and are presented in Appendix B. Estimated collective occupational radiation doses and critical path times (i.e., total clock times) by major activity for each cask load are shown in Table 4.7.

The estimated radiation doses for activities at reactor plants (in Table 4.7) show that handling a truck cask results in approximately 270 and 290 person-mrem of collective exposure for PWR and BWR facilities, respectively. The equivalent values for handling a rail cask are approximately 400 and 520 person-mrem, respectively. Because of the larger capacity of the rail cask, however, the total dose associated with rail cask handling is about 65 person-mrem per MTU of spent fuel, while that for truck casks is about 300 person-rem per MTU. Twenty-five to 50% of these total doses result from background radiation (i.e., from other non-natural radiation sources) in the work area, and not from the cask.

The critical path times during actual work times on the casks were estimated to be about 15 and 17 hours for a truck cask being loaded with PWR and BWR fuel, respectively, and 23 and 29 hours for a rail cask for PWR and BWR fuel, respectively. (It should be noted that these are reasonably good performance time estimates that are believed to be sustainable for long time periods. An allowance is included for minor perturbations, but not for major delays due to major equipment failures or lack of sufficient personnel.) The difference in turnaround times for the two types of casks results primarily from the longer time necessary for loading fuel assemblies into the rail casks. (See Activity 11 in Table 4.7.) The total cask turnaround times are significantly longer, however, because there is only one crew doing all of the work. Based on the one-shift operations, the total turnaround times increase to 31 and 33 hours for truck casks and 55 and 61 hours for rail casks, not including lost time for carrier drop-off of empty casks and pick-up of loaded casks.

TABLE 4.7. Estimated Collective Radiation Doses for Loading Spent Fuel into Transport Casks at the Postulated Reference Reactor Plant

		Radiation Doses - Person-mrem Per Cask Load						Critical Path Time (minutes)	
		Rail Shipments			Truck Shipments				
Activity Number	Major Activity	Cask Work	Area	Total	Cask Work	Area	Total	Truck	Rail
1	Receive transport vehicle, empty cask, monitor, inspect	0.02	0	0.02	0.02	0	0.02	35	40
2	Move transport vehicle and cask to inspection and washdown area	0	0	0	0	0	0	20	20
3	Wash transport vehicle and cask, monitor, and inspect	0.15	0	0.15	0.15	0	0.15	45	50
4	Move transport vehicle and cask to loading area	0	0.17	0.17	0	0.17	0.17	10	10
5	Prepare cask for removal from transport vehicle	0.49	3.38	3.87	0.45	2.88	3.33	60	75
6	Remove cask from vehicle and place on cask service pad(a)	0.07/0.10	3.38/3.88	3.44/3.98	0.07/0.10	3.12/3.62	3.19/3.72	60/90(a)	75/105(a)
7	Remove transport vehicle from loading Area(b)	0	0.25	0.25	0	0.17	0.17	0(b)	0(b)
8	Prepare cask for placing in loading pit	0.91	14.00	14.91	0.68	9.33	10.02	110	165
9	Place cask in loading pit	0.15	5.00	5.15	0.15	4.17	4.32	35	45
10	Prepare cask for loading	0.30	9.92	10.22	0.30	6.83	7.13	40	55
11	Place spent fuel assemblies in cask(a)	0	70/180	70/180	0	10/25	10/25	30/75(a)	210/540(a)
12	Install fuel spacers and inner lid on the shipping cask	0.02	4.66	4.68	0.02	3.67	3.69	20	25
13	Lift cask from loading pit and place on service pad	1.17	8.00	9.17	1.17	7.67	8.83	55	60
14	Decontaminate cask exterior	3.67	3.33	7.00	3.25	2.33	5.58	25	35
15	Prepare cask for shipment	139.92	22.33	162.25	102.92	14.00	116.92	155	250
16	Move cask to loading area	5.68	3.33	9.02	5.52	3.00	8.52	35	45
17	Move vehicle to loading area(b)	0	0.17	0.17	0	0.17	0.17	0(b)	0(b)
18	Place cask on the transport vehicle(a)	4.00/9.00	0.46/0.96	4.46/9.96	3.83/8.84	0.42/0.92	4.25/9.75	30/60(a)	35/65(a)
19	Perform contamination survey	18.33	0.67	19.00	15.83	0.62	16.46	10	15
20	Prepare loaded vehicle for shipment	58.42	3.42	61.84	48.42	3.17	51.58	70	85
21	Final inspection and contamination/ radiation survey	15.00	1.00	16.00	13.33	1.00	14.33	30	30
22	Move transport vehicle out of security area	0.33	0.08	0.42	0.33	0.08	0.42	10	10
23	Release cask and transport vehicle to carrier	1.42	0	1.42	1.33	0	1.33	30	35
24	Notify appropriate organizations of the shipment departure.	0	0	0	0	0	0	0	0
	Totals PWR	250	154	404	198	73	271	915 (15.2)(c)	1370 (22.8)(c)
	BWR	255	265	520	203	89	292	1020 (17.0)(c)	1760 (29.3)(c)
	Person-mrem/MTU								
	PWR			62			293		
	BWR			77			314		

(a) PWR/BWR.
(b) Parallel Operation.
(c) In hours.

The five primary dose-producing activities at the postulated reference reactor plant are listed in Table 4.8. They cause 75 to 85% of the collective personnel radiation exposures. The rest of the exposures result from a multitude of activities, none of which results in more than 4% of the total exposure for truck shipments and 4% for rail shipments.

The top three dose-producing activities account for about 70% of the total collective dose. These activities are: Activity No. 15, preparing cask for shipment, i.e., install cask lids, flush and drain cask, and seal cask (about 31% to 43%); Activity No. 20, preparing loaded vehicle for shipment, i.e., install cask tiedowns, impact limiters and personnel barrier (about 12% to 19%) and Activity No. 11, placing spent fuel assemblies in casks (about 4% to 35%).

The five major dose-producing activities were analyzed to determine the resultant average annual doses to the workers, assuming that a dedicated crew was used on each shift to perform these activities. The results are presented in Table 4.9, which lists the number of dedicated workers receiving most of the total dose for each of the activities, the locations of the activities, and the average individual worker doses for performing the activities. If an individual in the dedicated crew were assigned to each of the five major dose-producing activities, the total dose that that person would receive each year just for performing these activities is shown at the bottom of Table 4.9. If that person were an operator or a maintenance-craftsmen, the total annual individual dose from these five activities would be larger than the average annual dose for persons in that craft for all cask handling activities. (Compare the total doses at the bottom of Table 4.9 to the annual average doses in Table 4.10.)

The total annual collective dose to the dedicated cask handling crew would be about 9 person-rem/year when using truck casks and about 2 person-rem/year when using rail casks.

The estimates of the average annual individual doses to all worker crafts in the cask handling crews at the postulated reference reactor plant are presented in Table 4.10. They were calculated by dividing the personnel radiation exposures for each craft by the assumed dedicated crew sizes for the respective craft (defined in Table 4.6) and multiplying by the annual number or shipments. The workers with the highest collective annual exposures would be the

TABLE 4.8. Primary Radiation Dose-Producing Activities and Collective Doses from Spent Fuel Shipments at the Postulated Reference Reactor Plant

			Rail Shipments						Truck Shipments					
			Person-mrem/cask		Person-(a) mrem/MTU		Percent of Cask/Fuel Handling Doses		Person-mrem/cask		Person-(a) mrem/MTU		Percent of Cask/Fuel Handling Doses	
No.	Activity Description	Facility Location	PWR	BWR	PWR	BWR	PWR	BWR	PWR	BWR	PWR	BWR	PWR	BWR
15	Prepare cask for shipment, install lids, flush, drain, dry cask and seal cask	Service Pad	162	162	25	24	40	31	117	117	126	126	43	40
20	Prepare loaded vehicle for shipment, install cask tiedowns, impact limiters and personnel barrier	Loading Area	62	62	10	9	15	12	52	52	56	55	19	18
11	Move spent fuel assemblies from storage pool to the loading pit, place spent fuel assemblies in cask	Loading Pit	70	180	11	27	17	35	10	25	11	27	4	9
19	Perform contamination survey and decontaminate cask exterior	Loading Area	19	19	3	3	5	4	16	16	18	18	6	6
21	Final inspection and contamination/radiation survey, monitor, inspect and document	Loading Area	16	16	2	2	4	3	14	14	16	15	5	5
	All other activities		73	79	11	12	19	16	62	68	66	73	23	22
	Totals		402	518	62	77	100	100	271	292	293	314	100	100

(a) Rail casks contain 6.468 MTU PWR fuel, or 6.696 MTU BWR fuel. Truck casks contain 0.924 MTU PWR fuel, or 0.930 MTU BWR fuel. These calculations assume PWR MTU cask capacities.

TABLE 4.9. Estimated Average Annual Individual Radiation Doses to the Reactor Plant Workers from the Highest Dose-Producing Activities

No.	Major Dose-Causing Activities	Worker Category Receiving Most of Total Dose	Number of Workers	Work Location	Average Individual Worker Doses, person-mrem per year(a)			
					Rail		Truck	
					PWR	BWR	PWR	BWR
15	Prepare cask for shipment, install lids, flush, drain, dry cask and seal cask	Maintenance-Craftsmen;	3	Service Pad	156	148	700	692
		Operators	21		135	130	790	785
20	Prepare loaded vehicle for shipment, install cask tiedowns, inspect limiters and personnel barrier	Maintenance-Craftsmen	4	Loading Area	64	60	352	348
11	Move spent fuel assemblies from storage pool to the loading pit, place spent fuel assemblies in cask	Operators	4	Loading Pit	65	65	165	165
19	Perform contamination survey and decontaminate cask exterior	Radiation Monitors;	1	Loading Area	36	36	256	252
		Operators	1		50	50	280	280
21	Final inspection and contamination survey, monitor, inspect and document	Maintenance-Craftsmen	1	Loading Area	24	24	172	168
		Operators	1		25	25	170	170
	Total doses for persons assigned to all of these activities.	Maintenance-Craftsmen;	1		244	232	1224	1208
		Operators	1		275	340	1305	1395
		Radiation Monitors	1		36	36	256	252

(a) 30 MTU/year

TABLE 4.10. Estimated Average Annual Radiation Doses Received by Individual Workers in Each Craft at the Postulated Reference Reactor Plant[a]

Craft	No. Persons	Rail Shipments[b] One Shipment[c] (mrem/person)	Rail Shipments[b] Annual[d] Average (mrem)	Truck Shipments[b] One Shipment[c] (mrem/person)	Truck Shipments[b] Annual[d] Average (mrem)
Crane Operators	1	15.2/16.7	76/83.5	13.0/14.5	429/479
Operators	4	43.4/66.5	217/333	27.2/31.4	898/1036
Radiation Monitors	1	16.7/16.7	83.5/83.5	14/14	462/462
Quality Control Inspectors	1	24.2/46.2	121/231	10.4/13.4	342/442
Yard Drivers	1	1.4/1.4	7.0/7.0	1.3/1.3	43/43
Security Guards	1	0.3/0.3	1.5/1.5	0.3/0.3	10/10
Maintenance-Craftsmen	4	43/43	215/215	30.7/30.7	1013/1013
Total[e]	13		1870/2330[f]		8780/9410[f]

(a) Considered to be maximally exposed individual doses assuming that the doses are distributed uniformly among each worker in each craft in the dedicated work crews.

(b) Assumes all shipments from a given reactor are either 100% by rail or 100% by truck.

(c) Data shown are for PWR/BWR. Either 14 PWR (6.47 MTU) or 36 BWR (6.70 MTU) assemblies in a rail cask or 2 PWR (0.924 MTU) or 5 BWR (0.930 MTU) in a truck cask.

(d) Assumed to be for 30 MTU per year.

(e) Supervisors not included because they perform no work in radiation zones.

(f) Collective annual dose for all crafts and individuals.

maintenance-craftsmen (0.2 rem when handling rail casks and about 1.0 rem when handling truck casks), and the operators (0.2 to 0.3 rem when handling rail casks and about 1.0 rem when handling truck casks). The average annual exposure for all workers in the total dedicated cask handling crew is estimated to be about 160 mrem when handling rail casks and about 700 mrem when handling truck casks.

The major source of individual worker doses is work around the cask lids after the fuel is loaded into the cask (Activity 15). The total annual doses resulting from work around the lids is about 380 person-mrem for using truck casks (about 40% of total doses) and about 750 person-mrem for using rail casks (about 30% to 40% of total doses).

In summary, the smaller-capacity truck shipments result in about a 4- to 5-fold higher collective worker dose per MTU than the larger-capacity rail shipments. The same cask handling activities are needed for handling either size cask. However, the major dose-producing activities must be carried out more times for the smaller-capacity truck casks for the same amount of fuel. The results are higher aggregate and individual doses per MTU shipped in truck casks.

4.3 ANALYSIS OF DOSES FROM IN-TRANSIT OPERATIONS

Estimated public and worker radiation doses resulting from routine in-transit operations are presented in this section. These estimates are based on the overall study bases and rationale given in Section 3.4 and Appendix E, and on the description of in-transit operations provided in Section 4.1. Section 4.3.1 discusses the population groups exposed during in-transit operations, and the specific approach, bases and methods used to calculate the radiation doses to these groups. The postulated reference shipment characteristics, operating times, and estimated doses for a representative truck shipment are described in Section 4.3.2. In Section 4.3.3, the same information is presented for a representative rail shipment. Additional details on the in-transit evaluations are given in Appendix D.

4.3.1 Approach, Bases, and Methodology

This analysis defines typical operational activities during transportation of spent fuel and estimates the resultant radiation doses for each activity for the population groups exposed. This analysis estimates public and worker radiation exposures at stops individually and uses the RADTRAN III computer code (Madsen et al. 1986) to estimate public exposures while the transport vehicle is moving.

One population group receiving a radiation dose is the transport workers that are exposed as a result of their occupation, including those exposed on a random basis. Persons such as crew members of trains, truck drivers, state inspectors, rail inspectors, railyard employees, shipment escorts, and service station attendants are considered in this analysis to be transport workers. The general public is the nonoccupationally exposed group, which includes bystanders at truck stops and rail sidings, persons living or working along a route or near a truck stop or railyard, and nearby travelers (moving in the same and opposite directions). The RADTRAN III computer code (Madsen et al. 1986) calculates doses while the vehicles are in motion and was used to check the calculated doses. The models in RADTRAN III are briefly discussed here. The RADTRAN III normal population exposures models are illustrated in Figure 4.17.

In the population exposure model, the assessment of population dose assumes the packaging or transport cask is a point source of external, penetrating radiation. The point source approximation is generally acceptable for distances between the receptor and source of more than two source-characteristic lengths, or about 30 feet away from the side of the cask. From the point source approximation, the dose rate is given by:

$$DR(r) = \frac{(K)\ B(r)\ \exp\ (-\mu r)}{r^2}$$

where $DR(r)$ = dose rate at distance r

$B(r)$ = dose buildup factor for an isotopic source

K = dose rate factor for a unit source strength

μ = linear attenuation coefficient, m^{-1}

r = distance from the source, m.

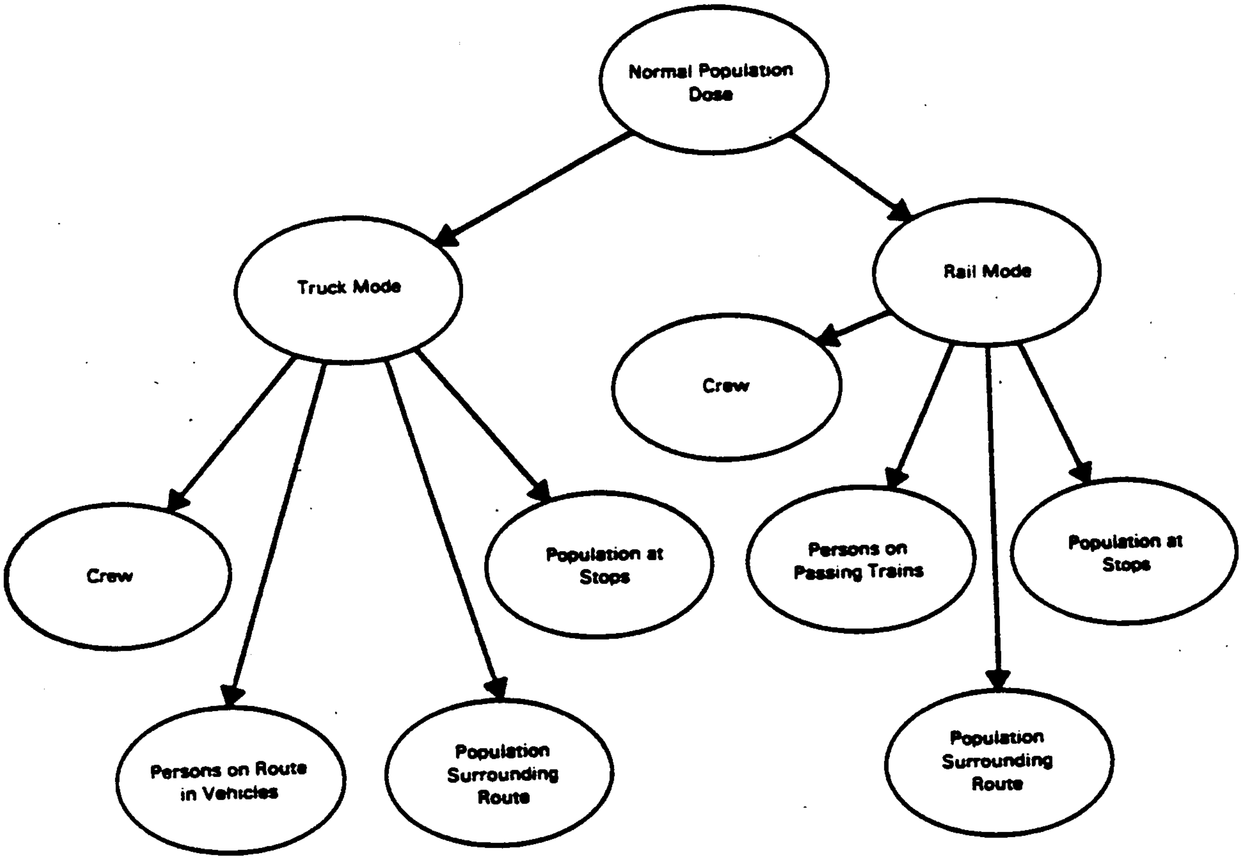

FIGURE 4.17. Population Dose Models for Normal Transport Included in RADTRAN III

At shorter distances, the dose rate is proportional to 1/r, rather than $1/r^2$. RADTRAN III applies a line source approximation to estimate dose rates at these shorter distances.

The equations used to calculate exposures differ for the different population groups and transport modes (i.e., truck and rail), but their basis in the point-source and line-source assumptions is the same. Derivations of the various equations are discussed in detail by Taylor and Daniel (1982) and Madsen et al. (1986).

The RADTRAN III computer code was used to calculate "unit dose factors" for routine transport conditions while the vehicles are moving. Unit dose factors define the radiation dose received by the nearby affected population for each unit of distance traveled for each of three population density zones: urban, suburban, and rural. The average speed of the shipment and the time required to complete a shipment, including stop times, are factored into the unit dose factors. Total routine exposures for a particular shipment are calculated by multiplying the unit dose factor for a specific population density zone times the distance traveled per shipment in that zone and summing the doses over all the population zones, as shown in the equation below:

$$\begin{array}{l}\text{Exposure per shipment} \\ \text{(person-rem)}\end{array} \quad \sum_{i=r,s,u} R_i D \cdot F_i$$

where i = summation index denoting rural (r), suburban (s), and urban (u) population zones

R_i = unit dose factor (person-rem/km) for rural, suburban, and urban zones

D = one-way shipping distance (km)

F_i = fraction of travel in each population zone.

The values for R_i used in this study were obtained from Appendix A of the repository EAs (DOE 1986b). These unit dose factors were used to calculate per-shipment exposures for one-way truck and rail shipping distances of approximately 2,860 km (1,780 miles) and 3,070 km (1,910 miles), respectively. These shipping distances were obtained by averaging the distances given in the repository EAs between representative reactors and the three potential repository sites. A similar procedure was used to estimate fractions of travel in each population zone for shipments from representative reactors to the three repository sites. These fractions for truck shipments are estimated to be 0.79, 0.20, and 0.01 and for rail shipments are 0.81, 0.18, and 0.01 for rural, suburban, and urban zones respectively. Additional information on route characteristics is presented in Sections 6.2 and 6.3. Separate unit dose factors are presented in the repository EAs for worker and nonworker population groups.

Detailed RADTRAN III-calculated results that were provided by Sandia National Laboratories to support the repository EAs were obtained and used for this study. These results formed the basis for the time/distance/dose and radiation dose estimates that are provided here. However, a more detailed breakdown of transportation exposures than is provided by RADTRAN III is required for this analysis. These exposures were calculated by identifying population groups exposed to the shipment and estimating the amount of time each group is exposed, the number of persons exposed, and the external radiation dose rate at the distance from the cask where the exposure occurs. These three parameters are multiplied together to calculate exposures per-shipment for each population group. Where appropriate, the radiation dose submodels and input parameters used in RADTRAN III to estimate population group doses are used in this study. In some cases, the RADTRAN III unit dose factors are used as the basis to derive the more detailed doses using fractions of total shipment doses. These fractions were developed from other studies of routine spent fuel shipment doses.

The population groups considered here are listed below.

I. Transport workers[a]
- At stops
    - Service station attendants
    - State inspectors
    - Train handlers
    - Rail yard crews
    - Escorts
- On Road
    - Truck drivers
    - Rail crew
    - Escorts

II. Nonoccupational (Public)
- At Stops
    - Residents
    - Passersby
- On Road
    - On-link (persons along routes in passing vehicles)
    - Off-link (persons residing along routes).

(a) In this analysis, the transport worker category includes all who play an occupational role in completing the shipments. Transport workers include truck drivers, service station attendants, state highway and railroad inspectors, train crews, railroad train handling and service crafts, and escorts.

The radiation dose rates, population data, and operating times used to calculate per-shipment exposures for each population group shown above are discussed in the next two subsections. Additional details are given in Appendix D.

A typical shipment origin-destination pair was selected from the repository EAs and used to define representative truck and rail routes for further examination. Truck and rail operating sequences from the origin to the destination were then constructed to estimate approximate locations of refueling and rest stops, state inspections of the cask and vehicle, train changes, train classifications, and travel times and distances between stops. Shipments are by general commerce legalweight truck (LWT) and by general freight rail.

As given in Section 3.4.2, the radiation dose rates from empty casks are negligible. Thus, doses from return of the empty casks are assumed to be zero and are not calculated.

4.3.2 Analysis of Truck Operating Procedures and In-transit Doses

This section presents detailed time/distance/dose estimates, operating characteristics, and radiation dose estimates for in-transit truck operations.

4.3.2.1 Truck Operations

Based on RADTRAN III, the truck shipment operating sequence for the representative route was determined using an average speed while moving of 80 km/hour (50 mph) in rural areas, 40 km/hour (25 mph) in suburban areas, and 24 km/hour (15 mph) in urban areas (see Appendix D). Each shipment is assumed to be provided with two drivers to allow the shipment to travel around-the-clock. Another important parameter that was taken from the RADTRAN III calculations is the amount of stop-time per shipment. The value used in the repository EAs was based on a conservative average value of 0.011 hours of stop-time per km of travel. Thus, for a 2,860-km shipment, the total stop-time is 31 hours.

The representative route was traced on a map from origin to destination to identify potential stops. Refueling stops are assumed to occur approximately every 800 km (500 miles) based on a 150-gallon fuel load and an average fuel consumption rate of about 8 km/gallon (5 miles/gallon). Thus, the truck is assumed to stop three times enroute for refueling. Food and rest stops are assumed to occur every 6 to 7 hours and an additional short stop for rest and NRC-required communication is provided between food/rest stops. (The remaining communications, required every 2 hours, are assumed to take place by telephone while the vehicle is stopped.) Stops for refueling plus food/rest are assumed to last approximately 3 hours. These stop times are believed to be conservatively long to account for waiting times and the NRC safeguards requirement to have the shipment constantly under direct visual surveillance (in many cases this requirement causes the drivers to eat separately so that one driver can remain with the shipment while the other driver eats). Rest-only and communications stops are assumed to last 30 minutes.

Recent experience with the shipment of spent fuel from Surry to INEL (Ruska and Schoonen 1986) has indicated that the stop times in actual practice may be much shorter. Should this occur the calculated doses for the public at stops would be reduced accordingly.

States have the right to stop the shipments for vehicle safety inspections, radiological inspections, and to be weighed. The first state inspection is assumed to occur at the origin facility and need not be done again at the border of that state. The second and final inspection is assumed to occur at the border of the state in which the final destination is located. Based on telephone discussions with the Washington State Patrol, who performs these activities for the State of Washington, the entire inspection procedure takes about 30 to 45 minutes, including an undercarriage inspection, brake and tire inspection, radiation monitoring, and checking the shipping manifest and driver's credentials. The total average stop time for state inspections is increased to 1 hour in this analysis to account for waiting times at the inspection station.

The detailed operating sequence for the representative truck shipment is presented in Appendix D. A summary of operating characteristics for a representative truck shipment is shown in Table 4.11.

TABLE 4.11. Summary of Representative Postulated Reference Truck Shipment Operational Characteristics

AGGREGATED

Total Distance: 1780 miles
Moving Time: 43.75 hours
Stop Time: 30.0 hours
Total Time: 73.75 hours

Number in crew: 2
Average speed: 24.1 mph
Average speed while moving: 50 mph - rural
25 mph - suburban
15 mph - urban

DETAILS

Fractions of Travel: Rural - 79%; Suburban - 20%; Urban - 1%

Stops:(a)
8 for food/rest = 24 hours
3 for refueling (included above) --
2 for state inspections x 1 hour = 2 hours
8 for communications x 30 minutes = 4.0(b)
TOTAL 30.0 hours

Refueling Times: 40 minutes/stop(c) x 3 refueling stops
= 2.0 hours for refueling per trip

State Inspections: 2 x 1 hour/inspection(d) = 2 hours
2 persons/stop plus drivers

(a) Food, rest stops are based on stop times estimated by RADTRAN III (Madsen et al. 1986).
(b) Three additional communications during other stops.
(c) Source: Sandquist et al. 1985 Represents amount of time spent by drivers (or service station attendants) in the vicinity of the shipment to pump fuel.
(d) Based on 30-45 minute estimate for inspection time provided by the Washington State Patrol and increased to 1 hour per stop to account for waiting or time spent in queue.

The estimated time to return an empty cask to its originating facility is faster than the loaded part of the trip because there is no need for communications stops and state inspections. Thus, the estimated time to return the truck cask is 47 hours.

4.3.2.2 Doses Received from Representative Truck Shipments

This section presents estimates of routine doses for representative truck shipments. These doses are received by the truck drivers and other transport workers such as service station attendants, state inspectors, and escorts, as well as the uninvolved general public. Estimates are also presented for the maximally exposed individuals or groups. The calculations are illustrated in Appendix D.

Doses to Transport Workers While Moving. Normal doses to truck drivers are the sum of the exposures received while the shipment is moving and those received at stops. As shown in Table 4.11, the representative truck shipment is moving for 43.75 hours and stopped for about 30 hours. The dose rate in the truck cab is 2 mrem/hour, based on the maximum permissible dose rate given in DOT regulations (see 49 CFR 173). Thus, the total collective exposures to truck crews (two drivers/shipment) while moving are approximately 175 person-mrem/shipment.

The other category of transport worker doses while moving are the doses received by escorts that precede and follow the shipment. This is a requirement only in densely populated urban areas, or for about 30 km (18.6 miles) of the representative shipping distance. The NRC is currently considering an amendment to 10 CFR 73 that would eliminate the requirement for armed guards within the cities (49 CFR 112). These doses are included here. Doses to escorts are not included in RADTRAN III. To estimate doses to escorts, it is assumed that two escorts precede and two escorts follow the shipment at an average distance of 50 meters. The dose rate at 50 meters away from the bottom of the cask is approximately 0.006 mrem/hour and from the top of the cask is 0.019 mrem/hour. Multiplying these dose rates by 2 persons and by 1.25 hours of travel time in urban areas results in a collective dose for escorts of about 0.06 person-mrem/shipment while the shipment is moving.

Doses to the Public While Moving. Exposures to the public are received while the shipment is moving. These doses are comprised of those received by the population surrounding the route (off-link) and those received by persons on the road in passing vehicles (on-link). These doses were taken from the results of the RADTRAN III analyses in the repository EAs. These particular doses are explicitly given in the RADTRAN III output. Separate unit-dose values (person-rem/km) were given in RADTRAN III output for travel in rural, suburban, and urban areas. These unit-dose values were multiplied in this study by the distances traveled in rural, suburban, and urban areas

(2,260, 570, and 30 km, respectively) to compute the per-trip exposures for this population group. The total collective doses are estimated to be 23 person-mrem/shipment for off-link groups and 34 person-mrem/shipment for on-link groups.

Doses at Stops. Truck driver exposures at stops were calculated for two conditions: one for doses while one driver eats (or telephones or observes at a distance) and the other for doses while one driver maintains visual surveillance. The average exposure distance for activities away from the truck is assumed to be 20 meters from the side of the cask, which is the same as the average distance used for public exposures at stops. The driver that maintains surveillance is assumed to be exposed to the dose rate at 10 meters from the top of the cask. The latter exposure distance is also used to estimate the doses for refueling operations. This is believed to be reasonable because even though the distance to the fuel tanks is somewhat lower (approximately 5 meters), the driver also spends part of this time performing activities farther away, such as washing the windshield and checking in the engine compartment. The dose rates at 20 meters and 10 meters from the cask are 0.18 and 0.6 mrem/hour, respectively. Assuming the drivers spend equal amounts of the total stop-time per shipment in both areas, or about 15 hours in each area per shipment, the total collective radiation dose to truck drivers at stops is estimated to be 23.4 person-mrem/shipment.

Total collective exposures to the public at stops are calculated by RADTRAN III assuming the average truck stop (food, refueling) includes 50 persons at an average exposure distance of 20 meters. Unit-dose factors (person-rem/km) were obtained from the RADTRAN III results and then multiplied by the shipping distance (2860 km) to estimate these doses. The unit-dose factor is 1.4E-4 person-rem/km in all three population zones. These factors result in an estimated collective dose to the public at stops of 400 person-mrem/shipment.

Total collective exposures to other transport workers are the sum of those for service station attendants, state radiological and vehicle inspectors at state borders, and escorts. Pumping of fuel into the truck may be performed by service station attendants in some cases, but is assumed to be done by truck drivers in this study.[a] Exposures for this activity were calculated using the dose rate at 10 meters from the top of the cask for the refueling activity and at 20 meters from the cask side for activities other than refueling for the rest of the duration of a stop. According to Sandquist et al. (1985), refueling activities last about 40 minutes. Thus the attendant receives a close-proximity (10 meters) exposure for 40 minutes and a longer-distance (20 meters) exposure for 2 hours and 20 minutes. The total dose to the attendant for each refueling stop is thus estimated to be about 0.8 mrem/refueling activity. Total doses to these persons from three refueling activities per shipment is thus 2.5 person-mrem/shipment.

When the shipment is escorted, the escorts will also receive radiation doses while the shipment is at a stop. Doses to escorts are calculated assuming they are exposed at an average distance of 20 meters from the side of the cask. The dose rate at this distance, 0.18 mrem/hour, was multiplied by 4 persons and by 3 stop-hours in urban zones to estimate total collective radiation doses to escorts at about 2.2 person-mrem/shipment. These doses are not included in the RADTRAN III calculations.

The last category of transport worker radiation doses at stops are the doses received during inspections of the shipment at the originating facility and after the shipment crosses the border of the destination state. Activities at state borders may include radiation inspections of the cask and vehicle, brake and tire inspections, and shipment weighing. These doses were estimated assuming one inspector is exposed for 1 hour per inspection (total of 2 hours per shipment) at an average distance of 5 meters from the side at the centerline of the cask. The dose rate at 5 meters was estimated at 3.2 mrem/hour (see Table 4.3). Using this dose rate, total collective doses to inspectors were estimated at 3.2 mrem/inspection, or 6.4 mrem/shipment.

Doses to Maximally Exposed Individuals or Groups. The maximally exposed workers are the truck drivers. These doses amount to approximately 100 mrem/driver (87.5 mrem while moving, 11.5 mrem at stops) for the representative 2,860-km one-way truck shipment. Based on the 74-hour one-way transit time and

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[a] The doses for refueling are included in the driver doses estimated above. These doses are discussed here for information only.

32 hours at-reactor, the total duration of each shipment is about 180 hours. Assuming each driver is available for 5,400 hours/year (225 days/year at 24 hours/day), a two-person driving team can move approximately 30 shipments per year. Thus, their total annual individual doses are approximately 30 shipments/year times 99 mrem/shipment, or 2,970 mrem/year.

An attendant at a service station where refueling is performed by an attendant (not by the drivers) would receive an estimated dose of 0.83 person-mrem/shipment. Assuming the maximally exposed attendants are at the last truck stop enroute before the repository, and this truck stop is used by 486 truck shipments/year (1/2 of total), and there are a total of four attendants that work at the truck stop (i.e., 4 shifts), each attendant could be exposed to 121 shipments/year. The maximum annual individual dose for each of these 4 attendants would be 100 mrem/year.

Doses to state inspectors were estimated earlier to be approximately 3.2 mrem/inspector for each inspection. Assuming the maximally exposed inspectors are at the entrance to the last state enroute to the repository (i.e., the state where the repository is located), and this station is used for all of the 971 truck shipments/year and there are a total of 4 inspectors that share the inspections equally, each inspector is exposed to 242 shipments. The annual dose to each inspector would be 774 mrem.

The maximum individual annual doses to escorts are estimated assuming the escort is present for a single entire stop at a distance of 20 meters from the cask and precedes the cask by 50 meters through an urban area. The dose per stop for each escort is 0.18 mrem/hour times 3 hours, or 0.54 mrem/stop. Individual doses while moving are 0.019 mrem/hour times 1.25 hours, or 0.02 mrem/shipment. Assuming the urban area is located near the repository and each of the 971 shipments/year is escorted by one of four escort teams, each escort could be exposed to 242 shipments/year. The annual dose then becomes 136 mrem/year.

The maximum annual individual dose to a member of the public who is at a truck stop was estimated assuming the person is present for an entire single stop. Using the dose rate at 20 meters from the side of the cask (0.18 mrem/hour) and an exposure time of 2.5 hours, this individual receives a dose of 0.45 mrem.

The maximum annual individual dose for a nontransport worker who works at the truck stop was calculated using the dose rate at 20 meters from the side of the cask. Assuming four shifts/day at a truck stop that services 1/2 the truck shipments, this individual could be exposed to 486/4, or 121 shipments/year. The maximum annual individual dose becomes 121 shipments/year times 0.45 person-mrem/shipment (see escort doses, above), or about 55 mrem/year.

The maximum annual individual dose to a member of the public residing near a truck route was estimated using data given in DOE (1986b, p. A-19). This document indicates that a person 30 meters from the highway that sees a truck shipment receives approximately 0.00283 mrem per shipment. Assuming this individual is present while all 971 shipments per year pass by, the maximum annual dose to this individual is estimated to be 2.8 mrem per year.

The final category of maximum individual exposures to a member of the public occurs if the cask/vehicle becomes stuck in traffic. If it is assumed that vehicles are stopped adjacent to the shipment (approximately 5 meters away) for 30 minutes, the maximum individual exposure will be 1.6 mrem, based on the dose rate of 3.2 mrem/hour at 5 meters from the side of the cask. This value should not be multiplied by the expected number of shipments to calculate total individual exposures; the same person will probably be exposed to only one shipment in this situation.

Estimated radiation doses for the representative truck shipment are summarized in Table 4.12.

4.3.3 Analysis of Rail Operating Procedures and In-transit Doses

This section presents detailed time/distance/dose estimates, operating characteristics, and radiation dose estimates for in-transit rail operations.

4.3.3.1 Rail Operations

A similar approach to that used for truck operations was used to develop a detailed in-transit operating sequence for the representative rail shipment. A

TABLE 4.12 Summary of Estimated Doses for the Postulated Reference Truck Shipment

	Collective Doses			Doses to Maximum Individual (mrem/yr)
Exposure Category	Person-mrem/shipment	Person-(a) mrem/MTU	Person-(b) rem/yr	
Transport Workers				
• Truck Crew				
- while moving	175	189	170	2625
- at stops	23	25	22	345
• State Inspectors	6.4	7	6	770
• Service Attendants	2.5(c)	2.7(c)	2.4(c)	100
• State Escorts	2.2	2.4	2.1	136
Total Transport Worker Dose	206	223	201	NA
Public				
• While Moving				
- on-link	23	25	22	1.6(d)
- off-link	34	37	33	2.8
• At Stops	400	433	389	55(e)
Total Public Dose	457	495	444	NA

NA = Not applicable.
(a) Based on 0.926 MTU/shipment.
(b) Based on 900 MTU/year.
(c) Not included in totals. Truck refueling is typically performed by the drivers. If done by the service attendant, the doses to drivers would be reduced.
(d) Assumes person becomes stuck in traffic next to a shipment one time per year.
(e) Assumes nontransport worker at the final truck stop where 1/2 of all 971 truck shipments/year stop and he works on 1/4 of these for 1/8 of total (121 shipments/year).

3,070-km (1,910-mile) one-way shipping distance is used in this section, based on the typical distances taken from the repository EAs of the three final candidate repositories (DOE 1986b). The basis for stop times, and their associated activities, average distance between stops, and average speed while moving was extracted from Wooden (1986) and Ostmeyer (1986). Wooden (1986) indicates an average train speed while moving of approximately 32 km/hour (20 mph) in all three population zones, although there is evidence to indicate speeds are somewhat lower than this in urban areas and higher in rural areas. Wooden (1986) generated relationships that were used here to calculate the number of stops and stop times per shipment. The results of these calculations for a 3,070-km shipment were 7 stops for classification and inspection and a total of about 160 hours at stops per 3,070-km shipment. The average times at stops are discussed in Appendix D.

Classification is the process in railyards whereby railcars are sorted according to their next destination. This process typically includes an inspection of the railcar to ensure brakes, undercarriage, etc., are not damaged. Classification stops, on average, require approximately 20 hours (Wooden 1986). Stops where rail carriers are changed require significantly more time to complete because time is needed to move the railcar from one carrier's railyard to the other. A safety inspection by the carriers is also performed when carriers are exchanged. Wooden (1986) reported that these activities, which also include classification operations (and primarily waiting time), require about 25 hours per stop. Another type of stop is a "block exchange" in which blocks of several railcars together are released by one train and subsequently picked up in one group by a second train. According to Wooden (1986) the average time required for a block exchange is 3.5 hours.

Inspections of the cask and railcar are typically included with classification activities. This includes inspections performed by state inspectors as well as those performed by the rail carriers. In general, these inspections require much less time than the classifications and can occur at any time prior to departure of the train. Thus, they are assumed to not add any additional time to the train shipment.

Wooden (1986) also indicated that the average time required by a local switch engine to pick up the railcar at the origin facility (in this case, the reactor site) and travel to the first railyard is approximately 12 hours (this time also allows the switch engine to pick up railcars from other industrial shippers). The time required for the equivalent delivery to the destination facility (i.e., the repository) from the last stop averages about 6 hours. These operating times, average speeds, and stop frequencies were used to develop the rail operating sequence that is given in Appendix D. A summary of the major characteristics of the representative rail shipment is shown in Table 4.13. The average speed over the entire trip is estimated to be slightly over 11 km/hour (7.3 mph). Total stop time is approximately 150 hours, and time while moving is approximately 110 hours.

TABLE 4.13. Summary of Representative Rail Shipment Operational Characteristics

AGGREGATED

Total Distance: 1910 miles
Moving Time: 108 hours
Stop Time: 152 hours
Total Time: 260 hours

Number in crew: 5
Average speed: 7.3 mph
Average speed while moving: 20 mph(a)

DETAILS

Fractions of Travel: Rural - 81%; Suburban - 18%; Urban - 1%

Stops: 152 hours in yards

- inspection time: 2 hours/trip (includes state and railroad inspections)
- time for marshaling/classification/carrier change activities: 24 + 20 + 20 + 20 + 20 + 20 + 24 = 148 hours (includes inspection time shown above)
- time for block exchanges: 1 x 3.5 hours = 3.5 hours

(a) Does not include speed during pickup from originating facility and during delivery to destination facility.

Because these same activities are generally applicable to all rail shipments, empty or loaded, it is assumed that return of the empty cask to the origin facility requires the same amount of time. Inspection activities generally occur during classifications and do not delay the train from leaving the railroad.

4.3.3.2 Doses Received from Representative Rail Shipments

A similar approach to that used for estimating truck shipment doses was used to estimate the detailed breakdown of radiation doses for the representative rail shipment. The RADTRAN III calculations that were used in the repository EAs (DOE 1986b) form the basis for the detailed dose calculations here. Estimated doses are presented in this section for the train crew, employees at railyards, state inspectors, and the general public surrounding the route and intermediate railyards. These calculations are given in Appendix D.

Doses at Stops. Doses at stops consist of those received by the in-transit train crew, train handlers, other railroad employees in the railyard, state inspectors, escorts, and the general population surrounding railyards.

The in-transit train crew, consisting of 5 persons, is assumed to be present for the entire stop-time at a distance of 150 meters from the cask. This distance is also used to calculate train crew doses while moving and is based on the same distance used in the repository EAs. The dose rate at this distance was obtained by applying the $1/r^2$ approximation(a) to the 50-m dose rate given in Table 4.3. This dose rate is estimated to be 0.0021 mrem/hour. The dose to train crewmen at stops is thus estimated to be 1.6 person-mrem/shipment (5 persons x 152 hour x 0.0021 mrem/hour).

State inspections of the cask/railcar are assumed to occur during the first classification stop after departing from the reactor and at the last classification yard prior to delivery to the repository. It is assumed here that the state inspection crews consists of two persons. Each inspection requires about 30 minutes and the average exposure distance during the state inspections is 10 meters (where the average dose rate is 0.76 mrem/hour). Therefore, state-inspector collective radiation doses are estimated to be about 1.5 person-mrem/shipment (2 persons x 60 minutes x 0.76 mrem/hour). Note that this exposure is somewhat less than for a typical truck shipment where the inspectors are closer to the cask and the inspection takes longer than for a rail shipment.

(a) Note that this approximation is conservative because it does not allow for additional attenuation of radiation by the air between the radiation source and the persons being exposed.

Other railroad employees will also receive radiation exposures during stops. The total average effective exposed population at stops is taken to be 340 persons (Wooden 1986), which includes both railroad employees and the general population surrounding railyards. One-hundred employees, typical of an intermediate-sized railyard, are assumed to be present in the railyard, although not directly associated with the spent fuel shipment. The average exposure distance is assumed to be 200 meters. This is the approximate weighted average distance (i.e., weighted by the ratio of employees at specific locations to total railyard employees) given on p. 81 of Wooden (1986). The dose rate at this distance, obtained by interpolating the dose rates given earlier in this chapter in Section 4.1, is about 0.0013 mrem/hour. The collective exposures to rail employees not directly involved in the shipment are thus estimated at about 19.8 person-mrem/shipment.

A number of train handling workers will also be directly involved with handling the spent fuel shipment. These include carmen and the yard switch crews. Based on information provided by Wooden (1986), approximately 10 persons are directly involved with a typical shipment at a railyard. This includes 2 carmen at the arrival area, 2 carmen at the departure area, and 3 intermediate yard switch crews consisting of 2 persons each. These persons must come in close proximity to the shipping cask and vehicle. As a result, the average exposure distance is assumed to be 10 meters. Although these persons will be closer than 10 meters away from the cask for a short time, their efforts focus on the front and rear parts of the railcar. As a result, 10 meters is believed to be a reasonable weighted average distance. The total time spent in close proximity to the casks is assumed to be 12 minutes per stop, or a total of 72 minutes per shipment (for the six stops shown). Based on a dose rate of 0.76 mrem/hour at 10 meters from the side of the cask, the collective radiation dose to yard crewmembers directly involved with the shipment is about 9.1 person-mrem/shipment.

The general population that resides or are passersby in the vicinity of the railyards will also receive a small radiation dose. As discussed above, the total effective exposed population at railstops is assumed to be 340 persons (Wooden 1986), of which 240 are assumed here to be members of the uninvolved general public. The average exposure distance is assumed to be

300 meters, which is about half of the smallest dimension of typical railyards illustrated by Wooden (1986). The dose rate at this distance is estimated to be 0.00055 mrem/hour, based on application of the $1/r^2$ approximation to the dose rate at 100 meters that was given in Section 4.1. After combining the number of exposed persons (240), the dose rate (0.00055 mrem/hour), and the exposure time (152 hours), the collective general population radiation dose at all stops is estimated at 20.1 person-mrem/shipment.

Escorts are assumed to accompany the rail shipment over its entire length. The escort crew consists of two-person teams that are located in a railcar 50 meters from the cask. From Table 4.3, the dose rate at this distance is approximately 0.06 mrem/hour. Thus, the collective radiation doses to all escorts at stops are estimated to be 18.2 person-mrem/shipment (2 persons x 152 hour x 0.19 mrem/hour).

Doses While Moving. The dose while the shipment is moving is comprised of the dose to the train crew, to escorts, and to the uninvolved general public surrounding the rail route. The dose to the crew is estimated by assuming the average distance from the cask to the crew is 150 meters. The dose rate at this distance is 0.0021 mrem/hour (see above). Using the estimated exposure time of 108 hours for the 5-man crew gives a total collective exposure of about 1.1 person-mrem/shipment.

The radiation dose while moving to the 2-man escort team was calculated assuming the escort crew is 50 meters away and the same time that was used for the rail crew dose calculations. The resulting collective radiation doses to the escorts are estimated to be 13.0 person-mrem/shipment (0.06 mrem/hour x 2 persons x 108 hours).

The general population radiation doses while moving include doses to persons on passing trains (on-link) and to persons residing in the vicinity of the rail line (off-link). These doses were estimated here using the results of the RADTRAN III analysis that was performed for the repository EAs (DOE 1986b). Unit dose factors (person-mrem/km) for these population groups were given in the RADTRAN III calculational output. These dose factors, given in (Appendix D), are multiplied by the distance traveled in each population zone and then summed over all three zones to estimate the on-link and off-link doses.

The results are that the collective on-link dose is estimated to be 0.4 person-mrem/shipment and the off-link dose is estimated to be 18.3 person-mrem/shipment.

Estimated radiation doses for the representative rail shipment are summarized in Table 4.14.

Doses to Maximally Exposed Individuals or Groups. Annual radiation doses to a maximally exposed individual while the train is moving were calculated for railcrew members assuming that the longest run for a single crew is approximately 12 hours, including stops. Assuming the crew is exposed at an average distance of 150 meters, the exposure to an individual crewman for the representative rail shipment is about 0.025 mrem. This value was multiplied by the number of shipments/year an individual crewman could deliver. If a single railyard handles all 320 rail shipments/year (because the rail shipments will converge on to one or two railyards near the repository) and assuming four shifts, each crewman is estimated to deliver approximately 80 shipments/year. The maximum individual annual doses would then be about 2 mrem/year.

Radiation doses received by individual state inspectors were previously estimated at 0.4 mrem/inspection. Assuming 80 shipments/year (one-fourth of the total) for each inspector as above, the annual dose is estimated to be 32 mrem/year.

According to Sandquist et al. (1985) maximum individual radiation exposures received during each train servicing (engine refueling, train maintenance, etc.) are 2 mrem/activity, assuming an average exposure distance of 10 meters and exposure duration of 2 hours. Assuming as above that this person is exposed to 8 shipments/year (one-tenth of the trains were assumed to require these operations at the final railyard), the annual dose becomes 16 mrem/year.

The radiation dose to train handlers from each shipment (0.15 mrem/shipment) was estimated previously using an average exposure distance of 10 meters and exposure time of 12 minutes. The maximum dose to train handlers would occur at the final railyard prior to the repository, which is assumed to handle all 320 rail shipments/year. Assuming the railyard is operated on a 4-shift

TABLE 4.14. Summary of Estimated Doses for the Postulated Reference Rail Shipment

	Collective Doses			Doses to Maximum Individual (mrem/yr)
Exposure Category	Person-mrem/shipment	Person-mrem/MTU(a)	Person-rem/yr(b)	
Transport Workers				
• Stops				
- State Inspectors	1.5	0.2	0.48	32
- Train Handlers/ Serviceman	9.1	1.4	2.9	16(c)
- Rail Yard Crew	19.8	3.0	6.3	1.3
- Crew	1.6	0.2	0.51	2.0(d)
- Escorts	18.2	2.8	5.8	115(d)
• While Moving				
- Crew	1.1	0.2	.35	2.0(d)
- Escorts	13.0	2.0	4.2	115(d)
Total Transport Worker Dose	64	9.8	20.6	NA
Public				
• While moving				
- On-Link	0.4	0.1	.13	NA
- Off-Link	18.3	2.8	5.9	1.6
• At Stops	20.1	3.1	6.4	3.5
Total Public Dose	39	6.0	12.4	NA

NA = Not applicable.

(a) Based on 6.56 MTU/shipment.

(b) Based on 2100 MTU/year.

(c) Dose for maximum individual train servicing/maintenance crewman that is exposed to 8 shipments/year.

(d) Individual present during both stops and while moving. Maximum dose considers both activities. Doses are not additive.

schedule, the maximum individual would be exposed to 80 shipments/year. Thus, the maximally exposed train handler is estimated to receive an annual dose of about 12.2 mrem/year.

The maximum annual individual dose to a member of the public residing near a rail route was estimated using data given in DOE (1986b, p. A-19). This document indicates that a person 30 meters from the railroad that sees a rail shipment receives approximately 0.00504 mrem per shipment. Assuming this individual is present while all 320 shipments per year pass by, the maximum annual dose to this individual is estimated to be 1.6 mrem per year.

The maximum annual radiation dose to an individual member of the public who resides near a train stop is estimated assuming an exposure distance of 300 meters from the cask. The dose rate at 300 meters is approximately 0.00055 mrem/hour. Assuming the maximally exposed individual is present for the entire 20 hours/stop at the destination railyard, and is exposed to 320 shipments/year, the annual dose is estimated to be 3.5 mrem/year to this maximally exposed individual.

The maximum annual dose to train escorts was estimated assuming the maximally exposed escort accompanies the shipment on the final leg of the trip; i.e., from the last railyard to the repository. This trip is 6 hours long and the average exposure distance is assumed to be 50 meters. The dose rate at this distance is about 0.06 mrem/hour. Assuming this person is exposed to all 320 shipments/year,(a) the maximally exposed escort receives an annual dose of about 115 mrem/year.

The maximally exposed railyard workers that are not directly involved with handling shipments (e.g., dispatchers, shopworkers) were estimated assuming they are also exposed to 80 shipments/year. Their average exposure distance is assumed to be 200 meters (dose rate = 0.0013 mrem/hour) and exposure time is assumed to be 12 hours/shipment. The resulting maximally exposed individuals would receive about 1.3 mrem/year.

Public passersby in areas where the train is stopped or moving slowly are estimated to receive a maximum individual dose of approximately 0.2 mrem/shipment, assuming an average exposure distance of 8 meters and exposure time of

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(a) This was arrived at by considering that this final delivery of the rail shipments to the repository could occur once per day. Conceivably, this could be performed by a single escort team.

10 minutes. This value should not be multiplied by the expected number of shipments to calculate total individual exposures; the same person will probably be exposed to only one shipment in this situation.

The estimates of the calculated annual doses to the maximally exposed individuals or groups were presented in the last column of Table 4.14.

4.4 ANALYSIS OF DOSES FROM AT-REPOSITORY OPERATIONS

Estimated worker radiation doses resulting from routine at-repository operations are presented in this section. These estimates are based on the overall study bases and rationale given in Section 3.4 and Appendix E, and on the description of the postulated reference repository provided in Section 4.1. The basis of the dose estimates for transport cask handling and the approach used are presented in Section 4.4.1. At-repository cask handling activities are summarized in Section 4.4.2, and presented in detail in Appendix C . A summary of the dose analysis is presented in Section 4.4.3.

4.4.1 Approach, Bases, and Methodology

Radiation doses resulting from cask handling operations at the postulated reference repository were estimated by a standard process analysis of the postulated receiving and handling (R&H) facilities. The flow chart of this analysis procedure is identical to that shown in Figure 4.16 for the reactor plants, and is not repeated here for the postulated reference repository. The general steps in the repository process analysis are listed below:

- Obtain operating procedures and descriptions of related equipment and facilities for spent fuel assembly shipments at several reactor plants that have shipped assemblies, and from engineering analyses in the literature, as postulated referenced in Section 4.2.
- Review available time/distance/dose studies, dose analyses and related information.
- Obtain the description and characteristics of the postulated reference system transport casks and repository R&H facilities (see Section 4.1).

- Develop a process activity list for repository cask handling operations.
- Complete a detailed activity analysis for each process step. The activity analysis includes estimating personnel requirements, performing a time/distance/dose analysis, determining working distances from the cask, and estimating radiation dose rates for each cask handling operation.
- Compare these activity analyses and personnel and time estimates with information from previous analysis and cask handling experience. If these estimates seem unrealistic, based on prior information, review and reconcile the detailed activity analysis.
- Calculate radiation exposure for each staff member for each type of cask load.
- Summarize final radiation exposure estimates using annual facility throughput requirements.

Current handling techniques were assumed in estimating personnel needs, personnel locations, and time requirements. Personnel requirements for each operation were based on typical crew sizes representative of current cask handling experience. Distance estimates between the cask surface and operating crew members during handling activities were also based on current cask handling practices. For example, all bolt removal was assumed to be completed by air-driven torque-limited impact wrenches without extension handles. Estimates of similar activities by others were found to vary significantly. The estimates in this study are based on working procedures and times that are believed to be sustainable for long time periods, barring major breakdowns. The estimates are neither minimum nor maximum, but are believed to be realistic for the bases used. The detailed results of the activity analysis are given in Appendix C.

The time/distance/dose estimates and their respective bases developed for the system postulated for this study result from several internal workshops with senior staff where each activity was reviewed in detail.

Specific bases and assumptions, in addition to those in Chapter 3 and Appendix E, for the analysis of doses from at-repository operations are as follows:

- The personnel are well-trained and experienced in the activities.
- The casks are well-maintained.
- Personnel with the appropriate skills are available when needed.
- The activities proceed in an orderly manner without major interruptions.
- Equipment and supplies are available as needed.
- In estimating doses from other sources in the general work area, crew members identified as participating in an activity are assumed to be in the general area for the complete duration of the activity, even when they are not working on the cask.
- Doses received by workers when they are neither near the cask nor in the area where the cask activities are being performed are not included in this study.
- Each receiving cell and cask handling area is in use at all times, and background doses for each cask handling station include those from loaded casks at nearby stations. This includes doses during cask queuing operations.
- Time and staffing requirements are based on performing certain activities in parallel where practicable. Only the times that are additive (i.e., critical path times) are included in the turnaround times for casks.
- Personnel radiation dose for each activity is calculated by the expression:

$$\text{Radiation Dose from Activity} = \text{Radiation Dose from Cask} + \text{Radiation Dose from General Area}$$

Where

$$\begin{array}{l}\text{Radiation Dose}\\ \text{from Cask}\end{array} = \left(\begin{array}{l}\text{Dose Rate}\\ \text{from Cask}\end{array}\right) \times \left(\begin{array}{l}\text{Time to Complete}\\ \text{Activity}\end{array}\right) \times \left(\begin{array}{l}\text{No. People}\\ \text{Performing}\\ \text{Activity}\end{array}\right)$$

$$\begin{array}{l}\text{Radiation Dose}\\ \text{from General Area}\end{array} = \left(\begin{array}{l}\text{General Area}\\ \text{Dose Rate}\end{array}\right) \times \left(\begin{array}{l}\text{Time}\\ \text{in Area}\end{array}\right) \times \left(\begin{array}{l}\text{No. People}\\ \text{in Area}\end{array}\right)$$

- The normal (general area) dose rates used in this study for the repository areas identified in Subsection 4.1.5 (excluding natural background) are given as follows:

Location	General Area Dose Rate[a,b] (mrem/hr)	Related Figure No.
Gatehouse	0.0	4.12
Cask parking area outside the buildings	2.0	4.12
Cask washdown area	0.1	4.13
Receiving and handling area	0.1	4.13
Handling room	0.1	4.14
Unloading room	0.1	4.14
Hot cell operating galleries	0.1	4.14
Wet decontamination	0.1	4.14

(a) Where other loaded casks are assumed to be in the work area at all times (e.g., in the receiving and inspection area) doses from those casks are added to those of general background.
(b) Parsons 1985.

- The work times include an allowance to cover normal delays due to minor equipment malfunctions and routine personnel errors, and personnel entry/departure from the work area. This allowance is in the order of 10-20% of the work time. Therefore, all time estimates are not minimum or maximum expected times, but are estimated to be sustainable handling times.

- Repository crew requirements are based on the number of personnel estimated by the authors to be needed to receive and handle 3,000 MTU per year of spent fuel. Operation of the cask receiving and dispatching activities is around-the-clock for 7 days/week, which requires 4 shifts of workers. Cask and fuel handling operations are around-the-clock for 5 days/week, which requires 3 shifts of workers.

- An empty decontaminated cask has a surface dose rate of less than 0.5 mrem/hour, as required by DOT regulations. The dose rate at 2 feet from the cask surface is estimated to be 0.2 mrem/hour and at 5 feet is 0.1 mrem/hour. (See Appendix E.5 for additional discussion.)
- The activities were assumed to be accomplished by use of conventional equipment (e.g., single-head torque-limited impact wrenches). No consideration was given to use of improved equipment (e.g., multiple-head impact wrenches).
- Wet decontamination of the interior of each cask is carried out on each cask every tenth trip to the repository.
- The wet decontamination cell is conceptually added to the MRS advanced conceptual design (Parsons 1985, DOE 1987) by the authors.

The activity time/distance/dose estimates for other postulated repository R&H facilities and/or other cask handling experience were reviewed. Information from General Electric Co. (Lambert 1981b), Allied-General Nuclear Services (Anderson 1978d), past estimates by staff at PNL, Oak Ridge National Laboratory (ORNL), Sandia National Laboratory (SNL), and handling estimates for the conceptual MRS facility and preconceptual repository designs were included in the reviews. In addition, time/distance/dose activities were observed for truck cask loading at a PWR reactor and for dry cask unloading at The Test Area North (TAN) hot cell at the Idaho National Engineering Laboratory (INEL).(a) A summary of some of the relevant time estimates from prior studies is given in Table 4.15. Time/distance/dose estimates for the postulated system in this

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(a) The results of these observations are to be published in a document titled "Time/Motion Observations and Dose Analysis of Reactor Loading, Transportation and Dry Unloading of an Overweight Truck Spent Fuel Shipment," by C. J. Hostick, J. C. Lavender, and B. H. Wakeman, Pacific Northwest Laboratory, Richland, Washington.

TABLE 4.15. Comparison of Some Prior Analyses of Cask and Spent Fuel Estimates at Dry Unloading Facilities

Cask Type	No. and Type of SFAs(a) Carried	Source	Total Time for Cask Turnaround (hr)	Total Person-mrem for Cask Turnaround
Rail	14 PWR	Raymond Kaiser 1985	13.1	(b)
Rail	36 BWR	Raymond Kaiser 1985	20.4	(b)
Rail IF-300	7 PWR	Raymond Kaiser 1985	10.8	(b)
Rail IF-300	18 BWR	Raymond Kaiser 1985	14.8	(b)
Truck	2 PWR	Raymond Kaiser 1985	7.5	(b)
Truck	5 BWR	Raymond Kaiser 1985	8.5	(b)
Truck NLI-1	1 PWR	Bechtel 1985	8.3	(b)
Truck NLI-2	2 BWR	Bechtel 1985	8.8	(b)
Rail IF-300	7 PWR	Bechtel 1985	11.3	(b)
Rail IF-300	18 BWR	Bechtel 1985	17.3	(b)
Truck	2 PWR	Bechtel 1985	8.8	(b)
Truck	5 BWR	Bechtel 1985	10.3	(b)
Rail	2 PWR	Bechtel 1985	14.5	(b)
Rail	5 BWR	Bechtel 1985	25.8	(b)
Truck	2 PWR	Schneider 1986	11.7	126
Rail	14 PWR	Schneider 1986	18.3	162
Truck DHLW(c)	(1 canister)	Yount 1984	13.6	(b)
Truck DHLW	(1 canister)	Dennis 1984	8.7	(b)
Rail IF-300	7 PWR	Lambert 1981b	23.1	86
Rail IF-300	18 BWR	Lambert 1981b	25.8	(b)
Rail NLI-10/24	10 PWR	Lambert 1981b	32.9	(b)
Rail NLI-10/24	24 BWR	Lambert 1981b	36.4	(b)
Truck TN-8L	3 PWR	Lambert 1981b	16.9	(b)
Truck TN-9L	3 PWR	Lambert 1981b	18.0	(b)
Truck NLI-1	1 PWR	Lambert 1981b	16.4	(b)
Truck NLI-2	2 BWR	Lambert 1981b	16.6	(b)
Truck NAC-1	1 PWR	Lambert 1981b	13.6	59
Truck NAC-4	2 BWR	Lambert 1981b	13.8	(b)
Truck	2 PWR	Parsons 1985	11.4	(b)
Truck	5 BWR	Parsons 1985	12.0	(b)
Rail	12 PWR	Parsons 1985	15.6	(b)
Rail	32 BWR	Parsons 1985	19.6	(b)
Truck TN-8L	3 PWR	TAN Data 1986(d)	10.0	(b)

(a) SFAs = Spent Fuel Assemblies.
(b) Not given or not available.
(c) DHLW = Defense High-Level Waste.
(d) Based on dry unloading operations observed at Test Area North (TAN), Idaho National Engineering Laboratory (INEL). To be published in a document titled "Time/Motion Observations and Dose Analysis of Reactor Loading, Transportation and Dry Unloading of an Overweignt Truck Spent Fuel Shipment," by C. J. Hostick, J. L. Lavender and B. Wakeman, Pacific Northwest Laboratory, Richland, Washington.

study are generally higher than previous estimates, primarily because some of the previous estimates were stated as minimum times and because the systems analyzed were sometimes different.

4.4.2 Summary of Repository Operating Procedures

Cask handling activities at the repository are represented by 24 major activities, shown in Table 4.16. These major activities are briefly summarized below.

Cask handling activities 1 through 4 include receiving and inspecting the cask and transport vehicle at the outside security gate, transporting the cask and vehicle by yard tractor to and from the queuing area, then the washdown area, and washing and drying the cask and vehicle prior to moving them into the receiving and handling area.

Activities 5 through 7 cover the removal of the cask from the transport vehicle and placement of the cask on the cask cart, and movement of the cask and cart into the cask handling room.

Activities 8 through 10 cover pressure and gas testing, outer lid removal, and mating to the hot cell port. An inner lid lifting adapter and a contamination barrier adapter are also installed at this time.

Activities 11 through 16 consist of remote cask unloading, internal cavity vacuuming, and unmating the cask from the cell port. Spent fuel assemblies are placed into lag storage within the hot cell upon removal from the cask.

Activities 17 through 20 include reinstallation of the cask lids, decontamination of the cask exterior, and placement of the cask on the vehicle.

Activities 21 through 24 include installing the cask tiedowns and impact limiters, closing the personnel barrier, preparing the vehicle for departure, and releasing the vehicle to the over-the-road carrier.

It is assumed that each cask will be routed to the wet decontamination cell after every tenth shipment. Wet decontamination activities are listed in Table 4.17.

TABLE 4.16. Major Cask and Spent Fuel Handling Activities at the Postulated Reference Repository

	Activity	Location
1.	Receiving transport vehicle and loaded cask at the repository site. Monitor, inspect, unhook over-the-road carrier's drive unit and attach repository drive unit	Receiving Gatehouse
2.	Move the transport vehicle and cask to parking area and wait for washdown station, hook up to car puller when ready.	Parking Area
3.	Wash transport vehicle and cask, open personnel barrier, monitor, inspect and dry	Washdown Area
4.	Move transport vehicle and cask to receiving and handling area	Receiving and Handling Area
5.	Prepare cask for removal from transport vehicle	Receiving and Handling Area
6.	Remove cask from transport vehicle and place on cask cart	Receiving and Handling Area.
7.	Move cart and cask to cask handling room and close roll-up door to handling room	Handling Room
8.	Prepare cask for unloading, position platform, install contamination barrier adapter, remove outer lid, pressure/gas sample cask cavity, remove inner lid bolts and install lid lifting adapter	Handling Room
9.	Open sliding shielding door to unloading room (if necessary), retract platform, move cart and cask to unloading room	Unloading Room
10.	Mate the cask to the hot cell entry port and close shielding door	Unloading Room
11.	Using 20-ton hot cell crane, remove hot cell port plugs	Hot Cell
12.	Remove remaining inner lid bolts and remove inner lid and spent fuel assembly spacer	Unloading Room/ Hot Cell
13.	Unload spent fuel assemblies and place into in-cell lag storage	Unloading Room/ Hot Cell
14.	Monitor and vacuum cask cavity and fuel basket	Unloading Room/ Hot Cell
15.	Replace spent fuel assembly spacer and replace inner lid and hot cell port plugs	Unloading Room/ Hot Cell
16.	Unmate cask from hot cell port and open unloading room shielding door	Unloading Room
17.	Move cart and cask to handling room	Handling Room
18.	(If wet decontamination is to be performed, refer to wet decontamination steps in Table 7.3). Install platform, remove contamination barrier adapter and lifting adapter, install inner and outer lids, secure all openings to the cask, monitor and decontaminate exterior of cask, open roll-up door and retract platform	Handling Room
19.	Move cask and cart to receiving and handling area	Receiving and Handling Area
20.	Place cask on the transport vehicle	Receiving and Handling Area
21.	Prepare cask for shipment, install cask tiedowns and impact limiters and close personnel barrier	Receiving and Handling Area
22.	Move transport vehicle and cask to inspection area, disconnect repository drive unit	Inspection Area
23.	Hook up over-the-road carrier, move to gatehouse, perform final monitoring and inspection of empty cask	Gatehouse Receiving and Dispatching
24.	Notify appropriate organizations of the shipment departure	Supervisor's Office

TABLE 4.17. Alternative Activities for Wet Decontamination of Cask Interiors at the Postulated Reference Repository

Activity	Location
Activities 1-17 are identical with steps 1-17 in Table 4.16	
18. Install platform, remove contamination adapter and lifting adapter, secure outer lid for move to decontamination cell and retract platform	Handling Room
19. Move cart and cask to receiving and handling area	Receiving and Handling Area
20. Lift cask and place on the cask cart for the wet decontamination cell	Receiving and Handling Area
21. Move cart and cask into decon prep. room, close door	Decon. Prep. Room
22. Install platform, remove outer lid, install inner lid lifting adapter and install contamination barrier adapter	Decon. Prep. Room
23. Retract platform and move cart and cask to decon. room	Decon. Prep. Room
24. Mate cask to decon. cell entry port, close door	Decon. Room
25. Using 20-ton decon. cell crane, remove hot cell port plugs	Decon. Cell
26. Place lid into lid decontamination station, place fuel spacer cell fuel basket into decontamination station, wet decontaminate and dry cask cavity, install replacement fuel basket and spacer into cask, install inner lid and replace port plugs	Decon. Room/ Decon. Cell
27. Unmate cask from decon. cell entry port and open decon. room door	Decon. Room
28. Move cart and cask to decon. prep. room	Decon. Prep. Room
29. Install platform, monitor and decontaminate exterior of cask, remove inner lid, replace seals, replace lid bolts, remove contamination barrier adapter and lifting adapter, secure all openings to the cask, install outer lid and retract platform	Decon. Prep. Room
Subsequent activities are identical with activities 19-24 in Table 4.16.	

A detailed breakdown of each of these major cask handling activities is presented in the worksheets in Appendix C, together with time estimates, personnel requirements and working distances, and dose calculations.

4.4.3 Dose Analysis

Worker dose estimates for repository cask handling are based on a) cask dose rates presented in Section 4.1, b) background dose rates (i.e., from other nearby sources) for working areas where casks are handled, c) manpower and time estimates, and d) location of workers relative to the radiation sources. Detailed manpower, time, motion, and dose estimates for specific handling activities are presented in Appendix C in the individual analysis sheets for each major activity.

It is assumed that the facility will receive shipments around-the-clock, seven days per week. Shipments arriving on weekends are placed into the parking area outside the receiving and handling area. This area serves as the queue for the subsequent cask receiving and handling operations. Doses associated with placing casks into the queue and removing them from the queue are included in this analysis. Doses from cask waiting times within the queues are expected to be minimal, and are not considered in this analysis. However, typical waiting times for casks in queues are estimated.

The operating hours require four crew shifts for gatehouse and inspection areas. Performance assessments using stochastic simulation models of the postulated reference receiving facility indicate that a 3,000 MTU/year receiving rate can be met by operating the washdown areas and four hot cells three shifts/day and five days/week (Lotz 1986).

Wet decontamination requirements are estimated to require operating each of the two decontamination cells less than one shift/day and five days/week. The resulting personnel requirements on which this dose analysis is based are shown in Table 4.18. All of the 113 staff shown are assumed in this analysis to be working full time at their activities. Staff requirements for each cask handling activity are shown in Table 4.19.

TABLE 4.18. Estimated Cask Handling Personnel Requirements at the Postulated Reference Repository

Facility Location	Personnel Per Shift	Number of Shifts	Total Personnel Required
Receiving and Dispatching Gatehouse	1 security guard	4	4
	1 operator	4	4
	1 radiation monitor	4	4
Inspection Area	1 security guard	4	4
	1 yard driver	4	4
Washdown Areas	1 operator	3	3
Receiving and Handling Side A	1 crane operator	3	3
	1 radiation monitor	3	3
	1 quality control/ inspector	3	3
	1 hot cell quality/ control/inspector	3	3
Crew for Hot Cell 1	2 maintenance-craftsmen	3	6
	1 handling room operator	3	3
	2 hot cell operators	3	6
Crew for Hot Cell 2	2 maintenance-craftsmen	3	6
	1 handling room operator	3	3
	2 hot cell operators	3	6
Receiving and Handling Side B	1 crane operator	3	3
	1 radiation monitor	3	3
	1 quality control/ inspector	3	3
	1 hot cell quality control/inspector	3	3
Crew for Hot Cell 3	2 maintenance-craftsmen	3	6
	1 handling room operator	3	3
	2 hot cell operators	3	6
Crew for Hot Cell 4	2 maintenance-craftsmen	3	6
	1 handling room operator	3	3
	2 hot cell operators	3	6
Decontamination Cells	2 maintenance-craftsmen	1	2
	2 side A operators	1	2
	2 side B operators	1	2
Total			113

TABLE 4.19. Estimated Cask Handling Personnel Requirements at the Postulated Reference Repository, by Activity

			Personnel[a]								
Activity	Facility Location	Task Title	CD	OP	RM	I(QC)	TD[b]	YD	SG	M-C	S
1	Receiving Gatehouse	Receive transport vehicle		1	1		2		1		
2	Packing Area	Move to washdown stations						1		2	
3	Washdown Area	Washdown		1	1				1	2	
4	Receiving and Handling Area	Move to receiving area	1								
5	Receiving and Handling Area	Remove impact limiters, tiedowns	1		1					2	
6	Receiving and Handling Area	Lift cask, place on cart	1	1						2	
7	Handling Room	Move to handling room		1							
8	Handling Room	Remove outer lid, test, remove inner lid bolts		1	1	1				2	
9	Unloading Room	Move to unloading room		1							
10	Unloading Room	Mate to hot cell		1							
11	Hot Cell	Remove port plugs		2							
12	Unloading Room/Hot Cell	Remove inner lid		2		1					
13	Unloading Room/Hot Cell	Unload cask		2		1					
14	Unloading Room/Hot Cell	Vacuum and inspect		2		1					
15	Unloading Room/Hot Cell	Replace inner lid, port plugs		2		1					
16	Unloading Room	Disengage from Port		1							
17	Handling Room	Move to Handling Room		1							
18	Handling Room	External decontamination, install lids		1	1	1				2	
19	Receiving and Handling Area	Move to receiving and handling area		1							
20	Receiving and Handling Area	Place cask on transport vehicle	1	1							
21	Receiving and Handling Area	Install tiedowns, impact limiters, etc.	1		1	1				2	
22	Inspection Area	Move to gatehouse						1			
23	Receiving Gatehouse	Final inspection		1	1			1	1		
24	Supervisor's Office	Notification of shipment release									
	Totals										
	Maximum per shift		2	18	3	4		1	2	10	
	Needed for all shifts		6	47	10	12		4	8	26	

(a) Personnel Legend:
CD = Crane Operator
OP = Reactor Site Operator
RW = Radiation Monitor
I(QC) = Inspector
TD = Offsite Truck Driver/Rail Crew
YD = Site Yard Driver
SG = Security Guard
M-C = Maintenance Craft
S = Supervisor

Not all personnel are in the radiation zone for the full time of the listed activity.

(b) Doses to these workers are not included in repository personnel requirements.

The receiving and dispatching gatehouse security guard, operator, and radiation monitor inspect all arriving and departing shipments, and they remain at that location while receiving or dispatching vehicles. The yard driver indicated for the inspection area in Table 4.18 services the entire repository area. One crane operator, radiation monitor, quality control/inspector, and hot cell quality control/inspector are assigned to each half of the facility. (The hot cell quality control/inspector is located in the operating galleries for the hot cell remote operations.) Each hot cell is staffed by two hot cell operators. The handling room for each cell requires one operator and two maintenance-craftsmen. The handling room operator and maintenance-craftsmen perform hands-on cask handling activities and the hot cell operators carry out the remote handling activities while the cask is mated to the cell port. The two decontamination cells for the repository are staffed by two maintenance-craftsmen that rotate from operating cells, and by two operators for Side A and two operators for Side B.

Detailed staff assignments and dose estimates for individual crew members for each activity were developed and are presented in detail in Appendix C. Estimated collective occupational doses and critical path times (i.e., total clock time) by activity for each cask load are shown in Table 4.20. (It should be noted that these are reasonably good performance time estimates that are believed to be sustainable for long time periods. An allowance is included for minor perturbations, but not for major delays due to major equipment failures or lack of sufficient personnel.)

Total collective dose per cask load, as shown in Table 4.20, is approximately 280 person-mrem per truck cask load for either PWR or BWR spent fuel (approximately 300 person-mrem/MTU) and approximately 465 person-mrem per rail cask load for either PWR or BWR spent fuel (approximately 70 person-mrem/MTU). One to 2% of these total doses result from background radiation doses (i.e., from other nonnatural radiation sources) in the work area, not from the cask being worked on.

Cask turnaround time estimates for transport casks at the repository, assuming zero queue time, range from 14.6 (PWR) to 16.3 (BWR) hours for truck casks and 21.6 (PWR) to 30.1 (BWR) hours for rail casks. In addition, average

TABLE 4.20. Estimated Collective Radiation Doses for Unloading Spent Fuel from Transport Casks at the Postulated Reference Repository

Activity Number	Major Activity	Radiation Doses - person-mrem per cask Load						Critical Path(a) Time (minutes)	
		Rail Shipments			Truck Shipments				
		Cask Work	Area	Total	Cask Work	Area	Total	Truck	Rail
1	Receive transport vehicle	6.3	0.0	6.3	5.5	0.0	5.5	30	40
2	Move to washdown station	1.3	0.5	1.8	1.2	0.5	1.7	30	40
3	Washdown	11.7	0.2	11.9	15.8	0.2	16.0	45	55
4	Move to receiving area	0.1	0.0	0.1	0.1	0.0	0.1	5	5
5	Remove impact limiters, tiedowns	78.4	0.6	79.0	53.1	0.4	53.5	80	110
6	Lift cask, place on cart	4.1	0.2	4.3	3.5	0.2	3.7	50	55
7	Move to handling room	0.4	0.0	0.4	0.7	0.0	0.7	5	5
8	Remove outer lid, test, remove inner lid bolts	349.5	0.5	350.0	186.3	0.4	186.7	60	90
9	Move to unloading room	1.7	0.0	1.7	2.7	0.0	2.7	10	10
10	Mate to hot cell	1.0	0.0	1.0	1.5	0.0	1.5	15	15
11	Remove port plugs	0.0	0.0	0.0	0.0	0.0	0.0	25	25
12	Remove inner lid	0.0	0.2	0.2	0.0	0.2	0.2	50	50
13	Unload cask	0.0	1.1/2.7(b)	1.1/2.7(b)	0.0	0.2/0.4(b)	0.2/0.4(b)	30/75(b)	210/540(b)
14	Vacuum and inspect	0.0	0.6/1.5(b)	0.5/1.5(b)	0.0	0.4/0.7(b)	0.4/0.7(b)	70/130(b)	120/300(b)
15	Replace inner lid, port plugs	0.0	0.4	0.4	0.0	0.4	0.4	80	80
16	Disengage from port	0.0	0.0	0.0	0.0	0.0	0.0	15	15
17	Move to handling room	0.0	0.0	0.0	0.0	0.0	0.0	5	5
18	External decontamination, install lids	0.8	0.9	1.7	0.6	0.7	1.3	110	135
19	Move to receiving and handling area	0.0	0.0	0.0	0.0	0.0	0.0	5	5
20	Place cask on transport vehicle	0.0	0.1	0.1	0.0	0.2	0.2	45	50
21	Install tiedowns, impact limiters, etc.	1.3	0.9	2.2	0.9	0.6	1.5	70	115
22	Move to gatehouse	0.0	0.0	0.0	0.0	0.0	0.0	10	20
23	Final inspection and release cask and transport vehicle to carrier	0.3	0.0	0.3	0.2	0.0	0.2	25	35
24	Notification of shipment release								
	Totals PWR	457	7	464	272	5	277	875	1295
	BWR	457	9	466	272	6	278	(14.6)(c)	(21.6)(c)
	Person-mrem/MTU								
	PWR			71.7			299.8	980	1805
	BWR			69.6			298.9	(16.3)(c)	(30.1)(c)

(a) Exclusive of queue time; estimated to be about 14 hours for each truck cask and 20 hours for each rail cask.
(b) PWR/BWR fuel and cask type.
(c) In hours.

times that casks are waiting in queues outside the receiving and handling building are estimated to be 14 hours for each truck cask and 20 hours for each rail cask.

Times and doses for wet decontamination of cask internals are shown in Table 4.21. The impact of wet decontamination on total dose per cask load is minimal (i.e., approximately one to two additional person-mrem per load). This results from minimal increases in general area dose received during hot cell decontamination and preparatory activities, and small decreases in doses from handling slightly contaminated casks when returning the empty casks to the transport vehicles for shipment out. However, wet decontamination activities have a significant impact on cask turnaround time, increasing truck cask turnaround times by an estimated 6.9 hours and rail cask turnaround times by an estimated 7.8 hours.

The five primary dose-producing activities are shown in Table 4.22. Step number 8, consisting of lid work, gas/pressure testing, contamination barrier and lifting system installation performed in the handling room, accounts for 67 to 75% of all the collective dose received by cask handling workers at the repository. Removing inner lid bolts is the largest dose-producing subactivity, contributing 36% of total collective dose to repository cask workers in all places per truck cask load (100 person-mrem) and 43% of total collective dose to repository cask handling workers in all places per rail cask load (200 person-mrem). Note that lid work on loaded casks results in about twice the occupational collective dose as the comparable activity at the reactor (see Table 4.7). This is because the lid work at the reactor is done while the cask is full of water, which reduces the dose rates to the workers. Step number 5, consisting of removing impact limiters and tiedowns, contributes 17 to 19% of all collective dose to repository cask handling workers (79 person-mrem for each rail cask and 54 person-mrem for each truck cask). Those two steps alone account for 86 to 92% of all dose. The five major dose-producing steps result in 95 to 97% of the collective dose to the cask handling workers at the repository for truck and rail cask handling, respectively. Each of the other 19 major activities contributes less than 1% of the total collective doses.

TABLE 4.21. Estimated Collective Radiation Doses for Unloading Spent Fuel at the Postulated Reference Repository with Wet Decontamination of Cask Internals

Activity Number	Major Activity	Radiation Doses - Person-mrem per Cask Load						Critical Path(a) Time (minutes)	
		Rail Shipments			Truck Shipments				
		Cask Work	Area	Total	Cask Work	Area	Total	Truck	Rail
1	Receive transport vehicle	6.3	0.0	6.3	5.5	0.0	5.5	30	40
2	Move to washdown station	1.3	0.5	1.8	1.2	0.5	1.7	30	40
3	Washdown	11.7	0.2	11.9	15.8	0.2	16.0	45	55
4	Move to receiving area	0.1	0.0	0.1	0.1	0.0	0.1	5	5
5	Remove impact limiters, tiedowns	78.4	0.6	79.0	53.1	0.4	53.5	80	110
6	Lift cask, place on cart	4.1	0.2	4.3	3.5	0.2	3.7	50	55
7	Move to handling room	0.4	0.0	0.4	0.7	0.0	0.7	5	5
8	Remove outer lid, test, remove inner lid bolts	349.5	0.5	350.0	186.3	0.4	186.7	60	90
9	Move to unloading room	1.7	0.0	1.7	2.7	0.0	2.7	10	10
10	Mate to hot cell	1.0	0.0	1.0	1.5	0.0	1.5	15	15
11	Remove port plugs	0.0	0.0	0.0	0.0	0.0	0.0	25	25
12	Remove inner lid	0.0	0.2	0.2	0.0	0.2	0.2	50	50
13	Unload cask	0.0	1.1/2.7(b)	1.1/2.7(b)	0.0	0.2/0.4(b)	0.2/0.4(b)	30/75(b)	210/540(b)
14	Vacuum and inspect	0.0	0.6/1.5(b)	0.6/1.5(b)	0.0	0.4/0.7(b)	0.4/0.7(b)	70/130(b)	120/300(b)
15	Replace inner lid, port plugs	0.0	0.4	0.4	0.0	0.4	0.4	80	80
16	Disengage from port	0.0	0.0	0.0	0.0	0.0	0.0	15	15
17	Move to handling Room	0.0	0.0	0.0	0.0	0.0	0.0	5	5
18	Prepare to move to decon. cell	0.1	0.1	0.2	0.1	0.2	0.3	35	35
19	Move to receiving and handling area	0.0	0.0	0.0	0.0	0.0	0.0	5	5
20	Place cask on decon. cell cask cart	0.0	0.1	0.1	0.0	0.1	0.1	35	35
21	Move into decon. prep. room	0.0	0.0	0.0	0.0	0.0	0.0	5	5
22	Remove outer lid, prepare cask	0.2	0.2	0.4	0.2	0.2	0.4	35	35
23	Move to decon. room	0.0	0.0	0.0	0.0	0.0	0.0	10	10
24	Mate to decon. cell port	0.0	0.0	0.0	0.0	0.0	0.0	15	15
25	Remove port plugs	0.0	0.0	0.0	0.0	0.0	0.0	25	25
26	Replace basket, decon. lid	0.0	0.7	0.7	0.0	0.6	0.6	190	220
27	Unmate from port	0.0	0.0	0.0	0.0	0.0	0.0	15	15
28	Move to decon. port room	0.0	0.1	0.1	0.0	0.0	0.0	5	5
29	Replace seals, install lids	0.0	1.1	1.1	0.0	0.8	0.8	150	190
30	Move to receiving and handling area	0.0	0.0	0.0	0.0	0.0	0.0	5	5
31	Place cask on transport vehicle	0.0	0.2	0.2	0.0	0.1	0.1	45	50
32	Install tiedowns, impact limiters	0.0	1.0	1.0	0.0	0.6	0.6	70	125
33	Move to inspection area	0.0	0.0	0.0	0.0	0.0	0.0	10	20
34	Hook-up over-the-road carrier	0.0	0.0	0.0	0.0	0.0	0.0	25	35
35	Notification of shipment release	0.0	0.0	0.0	0.0	0.0	0.0	5	5
	Totals PWR	455	8	463	271	6	277	1290 (21.5)(c)	1765 (29.4)(c)
	BWR	455	10	465	271	7	278	1395 (23.3)(c)	2275 (37.9)(c)
	Person-mrem/MTU								
	PWR			71.6			299.8		
	BWR			69.4			298.9		

(a) Exclusive of queue time.
(b) PWR/BWR fuel and cask type.
(c) In hours.

TABLE 4.22. Primary Radiation Dose-Producing Activities and Collective Doses from Receiving Spent Fuel Shipments at the Postulated Reference Repository

			Rail Shipments[(a)]				Truck Shipments[(a)]			
					Percent of Cask/Fuel Handling Doses				Percent of Cask/Fuel Handling Doses	
No.	Activity Description	Facility Location	Person-mrem per Cask	Person-mrem per MTU	PWR	BWR	Person-mrem per Cask	Person-mrem per MTU	PWR	BWR
8	Prepare cask for unloading, position platform, install contamination barrier adapter, remove outer lid, pressure/gas sample cask cavity, remove inner lid bolts, install lid lifting adapter.	Handling Room	350.0	54.1	75	75	186.7	202.1	67	67
5	Prepare cask for removal from transport vehicle	Receiving and Handling Area	79.0	12.2	17	17	53.5	57.9	19	19
3	Wash transport vehicle and cask, open personnel barrier, monitor, inspect, and dry	Washdown Area	11.9	1.8	3	3	16.0	17.2	6	6
1	Receive transport vehicle and loaded cask at the repository site. Monitor, inspect, unhook over-the road carrier's drive unit and attach repository drive unit.	Receiving Gatehouse	6.3	1.0	1	1	5.5	6.0	2	2
6	Remove cask from transport vehicle, place on cask cart	Receiving and Handling Area	4.3	0.7	1	1	3.7	4.0	1	1
	All Other Activities		13.0/15.0[(b)]	2.0/2.2[(b)]	3	3	11.6/12.6[(b)]	12.6/13.5[(b)]	5	5
	Totals		464/466[(b)]	71.7/69.6[(b)]	100	100	277/278[(b)]	299.8/298.9[(b)]	100	100

(a) Rail casks contain 6.468 MTU PWR fuel, or 6.696 MTU BWR fuel. Truck casks contain 0.924 MTU PWR fuel, or 0.930 MTU BWR fuel. These calculations assume PWR MTU cask capacities.

(b) PWR/BWR fuel and cask type.

Estimated average annual doses for individuals in the various groups of repository cask handling workers for the highest dose-producing activities are shown in Table 4.23. These doses would be accrued if the same members of each respective craft always performed the respective steps shown. Step 8 (i.e., lid work, gas/pressure testing, etc.), as shown in Table 4.23, could result in maintenance-craftsmen(a) personnel exposures averaging 10,700 mrem/year(b) and operator exposures averaging 2,500 mrem/year. Maintenance-craftsmen could receive an average additional 3,150 mrem/year from Step 5, which consists primarily of impact limiter and tiedown removal operations. The manual washdown could result in an average of 2,600 mrem/year per operator, and the security inspection following washdown operations in Step 3 results in an average of over 1,000 mrem/year for each security guard assigned to that duty. The last two activities shown in Table 4.23 would contribute 500 mrem or less average annual exposure to any worker.

Estimated average annual individual exposures by workers in each craft are shown in Table 4.24. The analysis presented in the table assumes that individuals assigned to cask handling rotate within their craft in each cask handling position, but they do not rotate within their craft for other facility operations. For example, maintenance craft personnel may complete lid work activities for both cask handling room activities and applicable decontamination cell maintenance craft duties. This analysis estimates that individual maintenance workers assigned to cask handling at the repository would receive an average dose of 13,200 mrem/year.(b) The workers with the next highest annual doses are security guards and operators, who would average approximately 1,000 mrem/year. All other crafts would receive less than 1,000 mrem/year.

(a) Maintenance-craftsmen are involved in the removal and replacement of bolts and other mechanical components on the casks. It should be recognized that they are not receiving the doses from facility maintenance work.

(b) This is a calculated dose which exceeds regulatory limits. Final designs will be modified to reduce this dose before the facility is built.

TABLE 4.23. Estimated Average Annual Individual Radiation Doses to the Repository Workers if They Worked Only on the Individual Highest Dose-Producing Cask Handling Activities

No.	Major Dose-Causing Activities	Worker Category Receiving Most of Total Dose	Number of Workers	Work Location	Average Individual Worker Doses, person-mrem per year[a]				
					Rail		Truck		Total
					PWR	BWR	PWR	BWR	Per Year
8	Prepare cask for unloading, position platform, install contamination barrier adapter, remove outer lid, pressure/gas sample cask cavity, remove inner lid bolts, install lid lifting adapter.	Maintenance-Craftsmen	24	Handling Area	2,609	1,672	3,835	2,541	10,657[b]
		Operator	12	Handling Area	382	245	1,139	755	2,523
5	Prepare cask for removal from transport vehicle	Maintenance-Craftsmen	24	Receiving and Handling Area	623	399	1,280	848	3,150
3	Wash transport vehicle and cask, open personnel barrier, monitor, inspect, and dry	Operator	3	Washdown Area	437	280	1,149	761	2,627
		Security Guard	4		166	106	496	329	1,097
1	Receive transport vehicle and loaded cask at the repository site. Monitor, inspect, unhook over-the-road carrier's drive unit and attach repository drive unit.	Radiation Monitor	4	Receiving and Inspection Gatehouse	114	73	219	145	551
		Security Guard	8		57	36	201	133	427
6	Remove cask from transport vehicle, place on cask cart	Operator	12	Receiving and Handling Area	35	22	107	71	235

(a) Assumes 3,000 MTU/year, 70% received by rail and 30% by truck.
(b) Doses in excess of regulatory limits will not be permitted by DOE.

TABLE 4.24. Estimated Average Annual Radiation Doses Received by Individual Workers in Each Craft at the Postulated Reference Repository[(a)]

		Rail Shipments[(b)]		Truck Shipments[(b)]		
Craft	No. Persons	One Shipment (mrem/person)	Annual Average (mrem)	One Shipment (mrem/person)	Annual Average (mrem)	Total Annual Average (mrem)
Crane Operator	6	0.6	192	0.3	291	483
Operators	47	0.8	256	0.8	777	1,033
Radiation Monitors	10	0.7	224	0.6	583	807
Quality Control Inspectors	12	0.4	128	0.3	291	419
Yard Drivers	4	0.4	128	0.5	486	614
Security Guards	8	0.7	224	0.8	777	1,001
Maintenance-Craftsmen	26	15.5	4,960	8.5	8,254[(c)]	13,214[(c)]
Totals	113	19.1	148,224[(d)]	11.8	270,351[(d)]	3,704

(a) For 3,000 MTU/yr.
(b) For 70%/30% spent fuel shipped by rail/truck. Dose differences between PWR/BWR fuel types are negligible for this analysis.
(c) Doses in excess of regulatory limits will not be permitted by DOE.
(d) Collective annual dose for all crafts and individuals.

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5.0 EVALUATIONS OF DOSE AND COST IMPACTS FOR INDIVIDUAL ALTERNATIVES TO THE POSTULATED REFERENCE TRANSPORTATION SYSTEM

The analysis in Chapter 4 developed the estimated doses in the postulated reference transportation system and identified the significant dose-generating activities. With these major dose-producing activities identified, a large number of alternatives was conceived that may reduce the dose from these activities. After a preliminary screening of the potential alternatives, those that appeared most promising were further defined and analyzed, and are described in this chapter. The alternatives considered but not analyzed are identified in Section 5.15. A description of the selection process for the alternatives was summarized in Section 3.3 and is given in more detail in Appendix M. Each of the selected alternatives was evaluated for operational times, radiation exposures, and cost impacts relative to the postulated reference system. In this chapter, each of the alternatives is described and analyzed as if it were the only alternative implemented. However, many combinations of alternatives are possible, which could have different cost and dose impacts. In Chapter 6, an example alternative system incorporating a combination of alternatives is considered.

It should be recognized that the alternatives are described and evaluated as concepts. Much additional work would be required to design, optimize and implement any of the concepts. Other concepts that could accomplish similar improvements may also be considered in the final designs (see Section 5.15).

The alternatives presented illustrate the three general methods of dose reduction. The first general method is to increase the shielding around the spent fuel. Increased cask shielding is the major example of this method. The second general method of dose reduction is to reduce the time that an individual is exposed to the dose. This includes both doing the job faster (e.g., use of single-action fasteners for removing tiedowns or impact-limiters and reducing the time at stops for truck shipments) and also reducing the number of shipments through the use of larger-capacity casks. The third general method of reducing dose is to increase the distance between the source and the worker. The parking of the trucks farther from the service facilities is one example. The most notable example of this type, however, is the use of remote-automated operations, which removes workers from direct, hands-on handling operations. Some of the alternatives can accomplish two of the objectives at the same time. Examples are: improved truck operations may be done in such a way to reduce the time at the truck service facilities and increase the distance from the cask to individuals at the service facility; or use of special impact-wrench tools or remote-automated operations can increase the worker distance from the cask and may decrease the time needed to complete the activity.

Evaluations were done in this study for transportation casks having seven different capacities. As described in Section 4.1.2, the postulated reference cask capacities of 2 PWR/5 BWR assemblies in a legalweight truck cask and 14 PWR/36 BWR assemblies in the 100-ton rail cask were based on the DOE fact-sheet designs given in Figure 4.7. The alternative cask capacities are 4/9 for an advanced design legalweight truck cask; 4/10 for the conventional overweight truck cask; 7/15 for an advanced design overweight truck cask; 27/58 for a uranium-shielded rail cask; and 30/66 for an advanced design uranium-shielded rail cask. Again, it must be recognized that the cask capacities are based on conceptual definitions only, not detailed designs. As an example, preliminary analysis indicates that the targeted cask capacities may be achievable, but have not been confirmed. Thus, the alternative casks may exceed the weight limitations specified in the current cask development RFP (DOE 1986a), but serve to illustrate the potential for dose reductions.

The capacities of the uranium-shielded rail casks and of the advanced design rail and truck casks were estimated by use of the Oak Ridge National Laboratory (ORNL) CAPSIZE computer code (Bucholz 1986) and information from Sandia National Laboratories (SNL) on the relationships between basket-divider designs and cask reactivity control (Sanders et al. 1987). These analyses result in cask capacities that are believed to be representative of the capacities for those designs, but it should be realized that detailed cask designs may result in slight variations in capacity from those assumed here.

Costs for implementing the alternatives are estimated for differences in features and characteristics with the estimated life-cycle costs of the postulated reference system. Capital and annual operating costs are estimated.

Present worth of the costs is based on an assumed 21 years of operations, or 62,000 MTU of spent fuel shipped to the first repository, as given in the Mission Plan Amendment (DOE 1987). In general, capital costs were charged at the start of year 1 and annual operating costs were charged over each of 21 years, except for special impact-wrench tools, which have a 5-year lifetime. Other bases for cost calculations can be found in Section 3.4.6 and Appendix J.

Detailed operational impact and radiation dose summary tables for the alternatives examined in this chapter are presented in Appendices F through I. Details of the calculations of cost impacts for the alternatives are presented in Appendix J. Additional information on the alternatives for the remote handling of casks at a repository receiving facility is provided in Appendix K.

Overall bases for the evaluations of alternatives were summarized in Section 3.4.6. Additional rationale is given in Appendix E. Assumptions specific to a given alternative are given in the discussion of that alternative.

In the discussions of the radiation dose impacts for workers, the average annual dose received per person in each worker group is based on the crew size given in the analysis of the postulated reference transportation system (described in Chapter 4) unless otherwise stated.

The alternatives are compared based on collective annual system doses (to the public and workers), based on life-cycle costs, and based on Δcost/Δdose relative to the postulated reference transportation system. The smaller the ratio of Δcost/Δdose the better the alternative, since it would cost less to achieve a given dose reduction. However, the ratio is meaningful only when it is a positive value. If the costs for the alternatives are lower, then the ratio is negative and the alternative should generally be implemented for both economic and dose benefits (unless there are other controlling factors, such as institutional issues). With negative Δcost/Δdose ratios (i.e., cost savings), the magnitude of the ratio is not particularly meaningful as a comparison measure because an increase in dose (smaller Δdose) yields a more negative ratio. Because of this, negative values of the Δcost/Δdose ratio are not reported.

In the late 1970s, as a guide to reactor operators, the NRC provided a guideline for reactor operations of $1000/person-rem below which an action was recommended to be taken to reduce public dose. The applicability of this guide to the workers and public of concern in this study is unknown. With inflation of the dollar and with increased concerns about radiation doses, particularly to highly skilled workers, much higher values are often considered.

The ratios of Δcost/Δdose are given for discount rates of 0% and 3% for the costs. The doses are not discounted.

5.1 OVERWEIGHT TRUCK CASKS

In this alternative, it is assumed that all truck shipments would be made in overweight trucks, with no change in the rail system. In the postulated reference system, legalweight truck casks are assumed to be used. With the assumption that casks are designed to just meet regulatory limits for dose rates at the sides of the vehicles and in the truck cab, the doses received per shipment are assumed to be the same for the same operations regardless of the cask capacity. Therefore, significant system dose reductions appear to be possible if overweight truck casks, which are estimated to have about twice the capacity of legalweight truck casks, are used. This would reduce the number of truck shipments by about 50%.

5.1.1 Description of Overweight Truck Casks

The legalweight truck cask, assumed for the postulated reference system, has a loaded weight of approximately 50,000 pounds. The cask capacity is 2 PWR or 5 BWR spent fuel assemblies. Overweight truck (OWT) casks (with an estimated loaded weight of 74,500 pounds) could have capacities of 4 PWR/10 BWR spent fuel assemblies (DOE 1986b). It is assumed that cask shielding is such that cask external dose rates at the regulatory limit points are unchanged from the postulated reference system; that is, they are at the regulatory limits. Therefore, the number of truck shipments required per year is reduced from 971 to 486. Potential drawbacks to the use of overweight truck casks are additional in-transit restrictions apply, special permits are required, possible increased wear may result on the highways, and a small number of reactors could not handle the larger casks without modifications.

5.1.2 Operational and Dose Impacts of Overweight Truck Casks

This section discusses the estimated transportation system effects resulting from the use of overweight truck casks. Table 5.1 presents the estimated annual collective dose reductions for at-reactor, in-transit, and at-repository truck operations. For this alternative, worker doses received for truck operations at reactors decrease by 47%, while at-repository worker doses are reduced by 50%. These dose reductions would be realized because many of the processing times and activities are the same for legalweight and overweight trucks. Thus, the handling time per MTU of fuel is cut nearly in half when using overweight trucks. In-transit worker doses are estimated to decrease by 48% because the number of shipments is halved, and public in-transit doses decrease by 42%. Each overweight shipment would result in a slightly higher system dose than

TABLE 5.1. Summary Comparison of Estimated Annual Collective Radiation Doses in the Postulated Reference Truck Transport System With and Without Overweight Truck Casks

	person-rem/year[a,b]		
	Postulated Reference	Overweight Truck Alternative	Dose Change
At-Reactor	271	143	-128
In-Transit			
Worker	200	103	-97
Public	444	256	-188
At-Repository	269	135	-134
Totals	1184	641	-553

(a) Based on 540 MTU/year of PWR and 360 MTU/year of BWR spent fuel.

(b) Cask capacity is 4/10 PWR/BWR assemblies for the overweight truck alternative.

each legalweight shipment because of increased restrictions on travel that increase slightly the transport times and the associated doses.

At-Reactor Impacts

As shown in Appendix B, the cask handling activities at the reactors that are affected by the use of overweight truck casks are step 11.1 (identify spent fuel assemblies to be loaded, perform accountability) and step 11.2 (move spent fuel assemblies to loading area, place in cask). For all the analyses in this document, 15 minutes is estimated to be needed per spent fuel assembly for each of these activities. With twice the amount of spent fuel to be loaded into a shipping cask, the activity times for both steps 11.1 and 11.2 would double (from 30 minutes to 60 minutes for a PWR cask, and from 75 minutes to 150 minutes for a BWR cask). All other activities at the reactor are assumed to be the same for legalweight and overweight trucks. These at-reactor turnaround times (excluding cask/vehicle waiting times) would increase from 915 minutes to 945 minutes for a PWR cask, and from 1020 minutes to 1095 minutes for a BWR cask.

Estimated annual collective radiation doses received at the reactor are shown in Table 5.2. Small additional doses are noted on a per-cask basis, but the increased capacity reduces the dose on a per-MTU basis by about 46 to 48% for the overweight truck alternative.

TABLE 5.2. Summary Comparison of Estimated Annual Collective Radiation Doses at the Postulated Reference Reactor With and Without Overweight Truck Casks

	Postulated Reference			Overweight Truck Alternative		
	Person-mrem/ Shipment	Person-mrem/ MTU	Person-rem/ year	Person-mrem/ Shipment	Person-mrem/ MTU[(a)]	Person-rem/ year[(b)]
PWR	271	293	158	281	152	82
BWR	292	314	113	317	170	61
Total			271			143

(a) Based on 1.85 MTU/shipment.
(b) Based on 540 MTU/year of PWR spent fuel and 306 MTU/year of BWR spent fuel.

The average annual doses to individual operators during at-reactor truck cask handling operations in the postulated reference system are reduced from

898 mrem/year to 497 mrem/year when using overweight truck casks for PWR operations, and from 1035 mrem/year to 618 mrem/year for BWR operations. For maintenance-craftsmen, the equivalent doses are the same for both PWR and BWR operations and would be reduced from 1011 mrem/year in the postulated reference system to 521 mrem/year when using overweight truck casks. Details of these dose calculations are contained in Appendix N.

In-Transit Impacts

A reanalysis of in-transit operations and routine doses was performed for a representative OWT shipment to estimate the change in doses that would result from implementing this alternative. Most of the bases and assumptions used to develop time/distance/dose estimates for LWT shipments are again used in the analysis of OWT shipments. These include the average speed while moving (rural - 50 mph; suburban - 25 mph; urban - 15 mph), number of refueling stops (3), number of drivers (2), dose rates, and number of state inspections (2). The only difference in in-transit operations was assumed to be related to possible delays caused by state restrictions on OWT shipments. States impose travel restrictions on OWT shipments, such as time-of-day, day-of-week, seasonal, routes, bridges, and speed (OTSP 1986). About 80% of the states restrict OWT movement to daylight hours and/or prohibit travel on weekends and holidays.

For this analysis, it was assumed that the representative OWT shipment will stop overnight one night (8 hours) for each one-way trip. This can be done through careful route planning and traffic management, e.g., selecting departure times to ensure the shipment passes through states with night travel restrictions during the day.(a) Similarly, other state restrictions, including route, bridge, weekend travel, etc., could potentially be minimized through careful route and shipment planning. It should be noted, however, that the assumption used in this study that the restrictions can be overcome with detailed route planning may tend to understate the doses resulting from OWT

(a) Recent experience confirms the validity of this assumption; to be reported in "Time/Motion Observations and Dose Analysis of Reactor Loading, Transportation, and Dry Unloading of an Overweight Truck Spent Fuel Shipment," by C. J. Hostick, J. C. Lavender, and B. H. Wakeman, Pacific Northwest Laboratory, Richland, Washington.

shipment and may therefore tend to overestimate the dose reduction resulting from OWT shipments relative to legalweight truck (LWT) shipments.

The 8-hour overnight stop for the OWT shipment is assumed to occur one time during the OWT shipment and will replace a 3-hour food/rest stop. Other stops are assumed to occur at the same frequency and require the same amount of time as for LWT shipments, except for state inspections, as discussed below. The resulting operational characteristics for a representative OWT shipment are summarized in Table 5.3.

TABLE 5.3. Summary of Estimated Operational Characteristics for the Representative Overweight Truck Shipment[a]

Aggregated

Total distance: 1,780 miles

Moving Time: 43.75 hours
Stop Time: 35.17 hours

Total Time: 78.92 hours

Number in crew: 2

Average speed: 22.7 mph
Average speed while moving:
50 mph - rural
25 mph - suburban
15 mph - urban

Details

Fractions of Travel: Rural - 79%; Suburban - 20%; Urban - 1%
Stops: 1 for overnight = 8 hours
7 for food/rest = 21 hours
3 for refueling (included above)
2 for state inspections = 2.17 hours
8 for communications = 4 hours

Total 35.17 hours

Refueling Times: 40 minutes/stop x 3 refueling stops
= 2.0 hours for refueling/trip

State Inspections: 2 x 1.09 hour/inspection = 2.17 hours/shipment
2 persons/stop plus drivers

(a) See Table 4.11 for bases for travel.

The per-shipment radiation doses to the public and workers while moving are unchanged from the doses estimated for LWT shipments. These include the on-link and off-link public doses and the doses to drivers and escorts while moving. Thus, the changes in per-shipment doses for the representative OWT shipment arise primarily from the increased stop-times relative to LWT shipments.

Doses to drivers at stops were adjusted to account for the increased times at stops. According to Table 5.3, the representative OWT shipment required approximately 35 hours at stops. As for the LWT shipments, it is assumed that the drivers each spend half of the stop-time at 10 meters from the top of the cask and half at 20 meters from the side. This assumption allows the cask to be under constant visual surveillance. Assuming the same dose rates at these distances that were calculated for the LWT cask (0.6 and 0.18 mrem/hour, respectively) and multiplying by 35.17 stop-hours/shipment, the total dose to the two drivers is estimated to be 27.4 person-mrem/shipment.

Doses to the public at stops will also increase because of the increased stop times. To account for an increase in OWT public doses at stops, on a per-shipment basis, the doses at stops estimated for LWT shipments were multiplied by the ratio of OWT stop time to LWT stop time (35.2/30.0 or 1.17). The resulting public doses at stops for the OWT alternative are estimated to be 470 person-mrem/shipment.

The final category of doses that are different for OWT shipments and LWT shipments are the doses received by state inspectors. The number of inspections (2) and inspectors (2 per inspection) are assumed to be the same, as is the exposure distance (5 meters from the site of the cask) and dose rate (3.2 mrem/hour). The inspection time is assumed to be increased by 5 minutes per inspection to account for additional activities that must occur (e.g., checking permits). This results in an estimated average inspection time of 1.09 hours/inspection, rather than 1.0 hours/inspection that was assumed for LWT shipments. The resulting state inspection doses were estimated to be 7.0 person-mrem/shipment.

The maximum individual truck driver dose is estimated to be 3.4 rem/year, assuming that he works full time on shipments of spent fuel and completes 30 trips per year. This compares to 3.0 rem/year for the postulated reference system. While the maximum individual dose is higher in this alternative, the number of persons receiving that dose is one-half that in the reference system.

The estimates of in-transit collective radiation doses for the OWT shipment are summarized in Table 5.4. Note that the total doses per shipment are slightly higher for OWT shipments than for LWT shipments. However, the doses per MTU shipped are lower for OWT shipments.

At-Repository Impacts

Activity steps at the repository that are affected by the use of overweight truck casks are those which involve unloading the spent fuel assemblies from the cask and inspecting and vacuuming the cask cavities. These are activity steps 13.1 (unload spent fuel assemblies), 14.2 (vacuum cavities, lid, fuel spacer), 14.4 (radiation survey of cask cavities), 14.5 (inspect cask cavities), and 14.6 (additional vacuum, survey, and inspection time for BWR casks). The operational times for these activities are directly related to the capacity of the cask and are therefore double those for LWT. All other activity steps at the repository receiving facility are taken to be the same for OWT and LWT. From these bases, turnaround time for a PWR cask (excluding cask queue time) is estimated to increase by 90 minutes, from 875 minutes to 965 minutes. (BWR turnaround time is estimated to increase from 980 minutes to 1175 minutes.) Because each overweight cask carries twice the amount of fuel as the legal-weight cask, however, average turnaround time per MTU of spent fuel would decrease (from 947 minutes to 522 minutes per PWR MTU, and from 1054 minutes to 632 minutes per BWR MTU).

Estimated collective worker radiation doses received at the repository receiving facility are shown in Table 5.5. Only small differences are noted for each cask load, but the increased capacity reduces the dose per MTU by 50%.

No significant reductions in average annual individual doses to receiving facility personnel would result from OWT shipments, because of the reduction in staffing requirements. For example, it is estimated that 18 maintenance-craftsmen would be needed, and their estimated average annual individual dose would be 5.9 rem/year from the OWT shipments and 7.2 rem/year from the rail shipments, for a total dose of 13.1 rem/year. This compares to the

TABLE 5.4. Summary of Estimated In-Transit Collective Radiation Doses for the Representative Overweight Truck Shipments

Exposure Category	Collective Dose Person-mrem/ Shipment	Person-mrem/ MTU[a]	Annual Truck System Doses, Person-rem/yr[b]
Transport Workers			
Truck Crew			
- While moving	175[c]	95	85.0
- At stops	27.4	14.8	13.3
State Inspectors	7.0	3.8	3.4
Service Attendants[d]	2.5[c]	1.4	1.2
State Escorts	2.2[c]	1.2	1.1
Total Transport Workers	218	114	103
	(206)[e]	(223)	(200)
Public			
While moving			
- on-link	34.0[c]	18.4	16.5
- off-link	23.2[c]	12.5	11.3
At stops	470	254	229
Total Public	527	285	256
	(457)	(495)	(444)

(a) Based on an average cask capacity of 1.85 MTU/shipment (4/10 PWR/BWR assemblies).

(b) Based on 900 MTU/year.

(c) These values are unchanged from the analysis of doses for the postulated reference LWT shipment.

(d) Not included in totals. Truck refueling is typically performed by the drivers and the dose is included in the driver dose. If done by a service attendant, the doses to drivers would be reduced.

(e) Numbers in parentheses are the dose estimates for the postulated reference LWT (2/5 PWR/BWR assemblies) shipment for comparison.

TABLE 5.5. Summary Comparison of Estimated Collective Radiation Doses at the Postulated Reference Repository With and Without Overweight Truck Casks

	Postulated Reference			Overweight Truck Alternative		
	Person-mrem/ Shipment	Person-mrem/ MTU	Person-rem/ year	Person-mrem/ Shipment	Person-mrem/ MTU[(a)]	Person-rem/ year[(b)]
PWR	276	299	162	277	150	81
BWR	277	298	107	278	149	54
Total			269			135

(a) Based on 1.85 MTU/shipment.
(b) Based on 540 MTU/year of PWR spent fuel and 360 MTU/year of BWR spent fuel.

13.2 rem/year to 26 maintenance-craftsmen in the postulated reference system. Details of these dose calculations are contained in Appendix N.

5.1.3 Cost Consequences of Overweight Truck Casks

The increase in cask capacity by a factor of two reduces the number of OWT shipments to one-half of those for the LWT. This is estimated to result in savings for both capital costs for the cask fleet as well as annual cost savings for cask maintenance, transport, and labor costs of loading and unloading. The minimum truck cask fleet needed for the overweight alternative is estimated to be 14 casks, while the postulated reference system needed 26 truck casks. The cost per cask and vehicle is estimated to be $500,000 more for the overweight cask ($2 million versus $1.5 million) but the capital cost savings, as shown in Table 5.6, is estimated to be $11 million due to the reduction in fleet size. Similarly, though the maintenance cost per cask is estimated to increase by $25,000/year, to $75,000/year, a savings is maintenance cost of $550,000/year would result from the smaller fleet size. Details of the cost estimates are given in Appendix J.

The cost for an overweight truck shipment is estimated to be $15,000, which is $4,800 more than for a legalweight truck shipment. But a savings of $2.6 million per year in operating costs results from reducing the number of shipments by one-half. The time, and thus the labor cost, needed to load one overweight cask at the reactor is higher than for the postulated reference system cask. But again, because only half as many cask loadings are needed, the at-reactor labor costs are estimated to be reduced by about $300,000 per year.

TABLE 5.6. Comparison of Estimated Life-Cycle Costs for the Postulated Reference Truck Transport System With and Without Overweight Truck Casks[a]

Cost Category	Postulated Reference Cost ($)	Overweight Truck Alternative Cost ($)	Change in Cost ($)
Capital Costs:			
Cask Fleet	39,000,000	28,000,000	-11,000,000[b]
Annual Costs:			
Shipping	9,900,000	7,290,000	-2,610,000
Cask Maintenance	1,950,000	1,400,000	-550,000
At-Reactor Labor	1,060,000	744,000	-316,000
Repository Labor	4,640,000	3,510,000	-1,120,000
Total Annual Cost Difference			-4,600,000
Present Worth of Cost Difference:			
3% Discount Rate			-81,900,000
0% Discount Rate			-107,000,000

(a) Costs are shown to more significant figures than justified, to provide for consistency in the calculations. See Appendix J for cost estimating details.

(b) Negative values indicate a cost savings.

At the repository, the labor cost savings result from the elimination of the third shift of receiving and unloading personnel at all of the hot cells for the 5 days/week, because of the reduced manpower requirements. This results in a total estimated cost savings of approximately $1.1 million per year compared to the postulated reference system. Again, this is a consequence of reducing the number of truck casks to be unloaded to half those with the postulated reference LWT. All of the annual cost savings resulting from the use of overweight trucks are shown in Table 5.6 and total approximately $4.6 million/year.

The present worth of the life-cycle cost savings for the overweight truck alternative has been calculated with discount rates of 0% and 3% using a 21-year lifetime and 1987 dollars. The respective values, shown in Table 5.6, are $107 million and $82 million.

5.1.4 Overview Evaluation of Overweight Truck Casks

It was estimated that the overweight truck casks would significantly reduce the overall costs of truck transport for spent fuel and would also reduce the collective doses to workers and public. Individual doses are not expected to decrease with the lower staffing-level requirements. Because the ratio of Δcost/Δdose is negative, its magnitude is not significant. Based on the consideration of cost and dose, the alternative is attractive.

However, it should be remembered that overweight trucks will require greater planning as to shipment routes and times, and permits may not always be available. There is also continuing concern about road damage from the use of overweight trucks, although spent fuel shipments would only be a small part of all OWT shipments. A recent study indicated that road damage would be similar for one overweight truck or two legalweight trucks (OTSP 1986). There are also a small number of reactors that currently do not have the capability to handle OWT casks. The reduced system costs and doses would be accompanied by somewhat reduced flexibility in the truck transportation system.

5.2 URANIUM-SHIELDED RAIL CASKS

The postulated reference rail cask has only stainless steel shielding. It has a capacity of 14 PWR or 36 BWR spent fuel assemblies. Depleted uranium is a more effective shielding material (1 inch of uranium provides approximately the same shielding as 2.8 inches of stainless steel). Thus, the use of uranium shielding allows for thinner cask walls that result in a larger cask cavity and an increase in cask capacity without an increase in cask weight or cask external dose rates. As with the OWT alternative in Section 5.1, many cask operations at reactors and the repository are independent of the capacities of various rail casks, and significant dose reductions can be realized by an increase in cask capacity and fewer shipments.

5.2.1 Description of Uranium-Shielded Rail Casks

If the shielding on the rail cask is composed of 2 inches of depleted uranium and 3.5 inches of stainless steel (the stainless steel is in the inner and outer shells), it is estimated that the cask capacity can be increased to 27 PWR or 58 BWR spent fuel assemblies. It is estimated that this can be done with the same external dose rates from a loaded cask as in the postulated reference system. The total weight of the shielding material is estimated to decrease from 106,500 pounds for the all-stainless steel cask to 94,300 pounds for the uranium-plus stainless steel cask. At the same time, the diameter of the cask internal cavity would be increased by 9 inches, to 63 inches, for increased capacity. The increased cask capacity implies a 48% reduction in the number of PWR rail shipments and a 38% decrease in the number of BWR rail shipments.

5.2.2 Operational and Dose Impacts of Uranium-Shielded Rail Casks

The estimated transportation system effects resulting from the use of uranium-shielded rail casks are discussed in this section. Table 5.7 presents a summary comparison of the estimated annual collective dose reductions for at-reactor, in-transit, and at-repository rail operations. For this alternative, doses received for rail cask handling operations at reactors are

TABLE 5.7. Summary Comparison of Estimated Annual Collective Radiation Doses in the Postulated Reference Rail Transport System With and Without Uranium-Shielded Rail Casks

	Annual person-rem/year[a]		
	Postulated Reference	Uranium Rail Alternative	Dose Change
At-Reactor	144	97	-47
In-Transit			
- Worker	21	11	-10
- Public	12	7	-5
At-Repository	149	83	-66
Totals	326	198	-128

(a) Based on 12.5 MTU/PWR shipment and 10.8 MTU/BWR shipment.

estimated to decrease by 33%, while at-repository doses are reduced by 44%. These dose reductions would be realized because all of the activities and many of the processing times are the same for the uranium-shielded rail cask as for the postulated reference rail cask, but the number of shipments is reduced. Thus, the handling time per MTU of fuel is reduced. In-transit rail doses are estimated to be reduced by approximately 50% as a result of fewer shipments.

At-Reactor Impacts

The cask handling activity steps at the reactor that are affected by the use of uranium-shielded rail casks are 11.1 (identify spent fuel assemblies to be loaded, perform accountability) and 11.2 (move spent fuel assemblies to loading area, place in cask). For all the analyses in this document, 15 minutes is estimated to be needed per spent fuel assembly for each of these activities. With the increased amount of spent fuel to be loaded into a transport cask, the activity times for steps 11.1 and 11.2 would increase accordingly (from 210 minutes to 405 minutes for a PWR cask, and from 540 minutes to 870 minutes for a BWR cask). All other activities at the reactor are assumed to be the same for the uranium-shielded rail cask as for the postulated reference rail cask. Thus, total turnaround time (excluding cask waiting time) would increase from 1370 minutes to 1565 minutes for a PWR cask, and 1760 minutes to 2090 minutes for a BWR cask. However, the increased capacity of uranium-shielded rail casks would reduce the average turnaround time per-MTU (from 212 minutes to 125 minutes per PWR MTU, and from 263 minutes to 194 minutes per BWR MTU).

The average annual doses to individual operators during at-reactor rail cask handling operations in the postulated reference system are reduced from 217 mrem/year to 169 mrem/year when using uranium-shielded rail casks for PWR operations, and from 333 mrem/year to 266 mrem/year for BWR operations. For maintenance-craftsmen, the equivalent doses are the same for both PWR and BWR operations and would be reduced from 215 mrem/year in the postulated reference system to 129 mrem/year when using uranium-shielded rail casks. Details of these dose calculations are contained in Appendix N.

Estimated collective radiation doses received at the reactor are shown in Table 5.8. Small additional doses are noted on a per-cask load basis (which

TABLE 5.8. Summary Comparison of Estimated Collective Radiation Doses at the Postulated Reference Reactor With and Without Uranium-Shielded Rail Casks

	Postulated Reference			Uranium Rail Alternative		
	Person-mrem/ Shipment	Person-mrem/ MTU	Person-rem/ year	Person-mrem/ Shipment	Person-mrem/ MTU[a]	Person-rem/ year[b]
PWR	404	62	78	469	38	48
BWR	520	78	66	630	58	49
Total			144			97

(a) Based on 12.5 MTU/PWR shipment and 10.8 MTU/BWR shipment.
(b) Based on 1260 MTU/year of PWR spent fuel and 840 MTU/year of BWR spent fuel.

result from additional times for loading the casks), but the increased cask capacity would reduce the dose on a per-MTU basis by 25% to 40% for the uranium-shielded rail cask alternative.

In-Transit Impacts

A detailed re-evaluation was not needed to estimate the in-transit effects of this alternative. Because the dose rate maps are assumed to be the same for both the postulated reference rail cask and the alternative, increased capacity cask, the in-transit collective radiation doses received per shipment would be the same for each system. The dose received per MTU would be reduced because each alternative cask shipment would carry more fuel. Table 5.9 presents the estimated doses received during in-transit activities.

At-Repository Impacts

Activity steps at the repository that are affected by the use of uranium-shielded rail casks are those that involve unloading the spent fuel assemblies from the cask and inspecting and vacuuming the cask cavities. These are activity steps 13.1 (unload spent fuel assemblies) 14.2 (vacuum cavities, lid, fuel spacer), 14.4 (radiation survey of cask cavities), 14.5 (inspect cavities), and 14.6 (additional allowance for BWR casks for 14.2, 14.4, and 14.5). The operational times for these activities are directly related to the capacity of the cask. All other activity steps at the repository are capacity-independent. Turnaround time for a PWR cask increases 305 minutes, from 1295 minutes to 1600 minutes (BWR turn-around increases from 1805 minutes to 2325 minutes). Since each alternative rail cask carries an increased amount of fuel, however,

TABLE 5.9. Summary of Dose Estimates for the Uranium-Shielded Rail Cask Alternative

	Collective Doses		
Exposure Category	Person-mrem/ Shipment	Person-mrem/ MTU[a]	Person-rem/ year[b]
Transport Workers			
Stops			
- State Inspectors	1.5	0.1	0.3
- Train Handlers	9.1	0.7	1.5
- Rail Yard Crew	19.8	1.6	3.3
- Crew	1.6	0.1	0.3
- Escorts	18.2	1.5	3.1
While Moving			
- Crew	1.1	0.1	0.2
- Escorts	13.0	1.0	2.2
Total Transport Workers	64 (64)[c]	5.1 (9.8)	10.8 (20.6)
Public			
Stops	20.1	1.6	3.4
While-moving			
- on-link	0.4	0.0	0.1
- off-link	18.3	1.5	3.1
Total Public	39 (39)	3.1 (6.0)	6.5 (12.4)

(a) Based on a cask capacity of 12.5 MTU (27/58 PWR/BWR assemblies).
(b) Based on 2100 MTU/year.
(c) Numbers in parentheses are the dose estimates for the postulated reference rail (14/36 PWR/BWR assemblies) shipment for comparison.

average turnaround time per MTU of spent fuel decreases (from 200 minutes to 128 minutes per PWR MTU, and from 270 minutes to 216 minutes per BWR MTU).

Estimated annual collective worker doses received at the repository are summarized in Table 5.10. Only small differences are noted on a per-cask basis, but the increased capacity reduces the dose on a per-MTU and per-year basis by about 45%.

TABLE 5.10. Summary Comparison of Estimated Collective Radiation Doses at the Postulated Reference Repository With and Without Uranium-Shielded Rail Casks

	Postulated Reference			Uranium Rail Alternative		
	Person-mrem/ Shipment	Person-mrem/ MTU	Person-rem/ year	Person-mrem/ Shipment	Person-mrem/ MTU[a]	Person-rem/ year[b]
PWR	463	72	91	465	37	47
BWR	466	70	59	469	43	36
Total			149[c]			83

(a) Based on 12.5 MTU/PWR shipment and 10.8 MTU/BWR shipment.
(b) Based on 1260 MTU/year of PWR spent fuel and 840 MTU/year of BWR spent fuel.
(c) Because of roundoffs, the total is 149, not 150.

Only modest reductions in average annual doses to individual receiving facility personnel would result from shipments using uranium-shielded rail casks because of the reduction in staffing requirements. It is estimated that 22 maintenance-craftsmen would be needed, and their estimated average annual individual dose would be 9.7 rem/year from the truck shipments and 3.3 rem/year from uranium-shielded rail shipments, for a total dose of 13.0 rem/year. This compares to the 13.2 rem/year in the postulated reference system with 26 maintenance-craftsmen. Details of these dose calculations are contained in Appendix N.

5.2.3 Cost Consequences of Uranium-Shielded Rail Casks

In this alternative, the increased cask capacity would require fewer shipments, thereby saving transport costs, labor costs at the repository and reactors, cask/vehicle maintenance costs, and the capital cost of the smaller fleet of rail casks.

The capacities of the rail casks in this alternative are estimated to increase by 93% for PWR shipments and by 61% for BWR shipments. This results in a minimum rail cask fleet needed for rail shipments of 16 casks versus 28 for the postulated reference system. The use of depleted uranium in the cask body is estimated to increase the cost per cask by $1.3 million, to a total of $3.8 million. The savings in capital cost for the rail cask fleet from this alternative is $8.8 million, as shown in Table 5.11. Also, the smaller fleet size would reduce the annual cask maintenance costs by $1.5 million.

TABLE 5.11. Comparison of Estimated Life-Cycle Costs for the Postulated Reference System With and Without Uranium-Shielded Rail Casks[(a)]

Cost Category	Postulated Reference Cost ($)	Uranium Rail Alternative Cost ($)	Change in Cost ($)
Capital Costs:			
Cask Fleet	70,000,000	61,200,000	-8,800,000[(b)]
Annual Costs:			
Transport	17,060,000	9,490,000	-7,570,000
Cask Maintenance	3,500,000	2,000,000	-1,500,000
At-Reactor Labor	590,000	415,000	-175,000
Repository Labor	4,640,000	4,050,000	-590,000
Total Annual Cost Difference			-9,800,000
Present Worth of Cost Difference:			
3% Discount Rate			-160,000,000
0% Discount Rate			-215,000,000

(a) Costs are shown to more significant figures than justified, to provide for consistency in the calculations. See Appendix J for cost estimating details.

(b) Negative values indicate a cost savings.

Primarily due to the decrease in the number of rail shipments from 320 per year in the postulated reference case to 180 per year for this alternative, the cost of transport would decrease by $7.6 million per year. The increase in the number of spent fuel assemblies that each uranium shielded cask holds leads to an increase in the labor cost per cask for loading at the reactors. But due to the decrease in the total number of casks being loaded per year, the at-reactor labor costs would be reduced by $175,000 per year. At the repository, the labor cost savings would result from a reduction of one shift of receiving and unloading personnel per day, five days per week, in one of the four hot cells. This results in a cost savings of $590,000 per year. Again, this is a consequence of reducing the number of rail shipments unloaded per year. The total annual cost savings resulting from this alternative are estimated at $9.8 million per year, as shown in Table 5.11.

The present worth of the life-cycle cost savings for the uranium-shielded rail cask alternative has been calculated with discount rates of 0% and 3% using a 21-year lifetime and 1987 dollars. The respective values, shown in Table 5.11, are $215 million and $160 million.

5.2.4 Overview Evaluation of Uranium-Shielded Rail Casks

It was estimated that the uranium-shielded rail casks would significantly reduce the overall costs of the rail transportation of spent fuel and would also reduce the collective doses to workers and public. Because the ratio of Δcost/Δdose is negative, its magnitude is not significant. Based on the consideration of cost and dose, this alternative is attractive. A potential negative aspect of this alternative may be some additional design and licensing concerns.

5.3 INCREASED END SHIELDING ON TRUCK AND RAIL CASKS

The casks in the postulated reference system are conceived to just meet federal regulations for dose rates around the transport vehicles. This basis results in a dose rate of 200 mrem/hour at a distance of 1 meter from the cask inner lid when the outer lid is removed. The activities that are performed near the ends of the cask contribute a major portion of the total doses received by workers at the reactor and repository. Significant dose reductions for each shipment could be achieved if the cask had additional shielding material on its ends. The system dose estimates for this alternative are based on a preliminary estimate that enough shielding material can be added to reduce dose rates around the ends of the cask by 95% (i.e., dose rates at the cask ends are 1/20 of the postulated reference dose rates) without reducing cask capacity within the reference weights for loaded casks plus their vehicles. This preliminary estimate remains to be confirmed during detailed cask design and may not be valid for casks in which capacity has already been maximized with respect to gross vehicle weight.

5.3.1 Description of Increased End Shielding on Truck and Rail Casks

The addition of about 4 inches of stainless steel in both the cask lid and bottom is estimated to reduce the radiation dose rates around the ends of the cask by approximately 95%. The alternative truck cask would thus have 10.5 inches of stainless steel shielding on the inner lid and 13.5 inches of stainless steel on the cask bottom. The additional amount of stainless steel is estimated to increase the weight of the truck cask by approximately 3,040 pounds. Similarly, the alternative rail cask would have 11.5 inches of stainless steel shielding on the inner lid and 14.5 inches of stainless steel shielding on the cask bottom. The additional stainless steel is estimated to add about 12,090 pounds to the rail cask. It is estimated that the alternative truck vehicle (tractor and trailer) plus loaded cask would weigh no more than 80,000 pounds and the alternative rail vehicle (rail car) plus loaded cask would weigh no more than 263,000 pounds.

5.3.2 Operational and Dose Impacts of Increased End Shielding

The estimated transportation system effects resulting from using truck and rail casks with additional end shielding are discussed in this section. Table 5.12 summarizes the estimated annual collective dose reductions for at-reactor, in-transit, and at-repository operations. Collective doses received by the cask handling workers at reactors decrease by 37%, and at-repository worker doses decrease by 70%. Reactor worker doses do not decrease as much as repository worker doses because the cask is either in the spent fuel pool or is filled with water when most lid work is done on a loaded cask at a reactor. Also, background radiation dose rates are higher at reactors than at the repository and cause a larger fraction of the worker radiation doses. Thus, improved cask end shielding will affect reactor worker doses less

TABLE 5.12. Summary Comparison of Estimated Annual Collective Radiation Doses in the Postulated Reference Rail/Truck Transport System With and Without Increased Cask End Shielding

	person-rem/year								
	Truck			Rail			Total System[a,b]		
	Postulated Reference	End Shield Alternative	Dose Change	Postulated Reference	End Shield Alternative	Dose Change	Postulated Reference	End Shield Alternative	Dose Change
At-Reactor	271	166	-105	144	95	-49	415	261	-154
In-Transit									
- Worker	200	23	-177	21	10	-11	221	33	-188
- Public	444	444	0	12	12	-0	456	456	-0
At-Repository	269	91	-178	149	38	-111	418	129	-289
Totals	1184	724	-460	326	155	-171	1510	879	-631

(a) Based on 0.924 MTU/PWR truck shipment, 0.930 MTU/BWR truck shipment, 6.47 MTU/PWR rail shipment, and 6.70 MTU/BWR rail shipment.

(b) Cask capacity is 2/5 PWR/BWR assemblies for truck shipments and 14/36 PWR/BWR assemblies for rail shipments.

than repository worker doses. Additional end shielding is estimated to reduce in-transit worker doses by about 89%, but would have no significant impact on public doses, which are principally from the sides of the cask.

At-Reactor Impacts

All cask dose rates in activity steps at the reactor sites that require workers to be near the ends of the cask are affected by increased end shielding. The effects are most pronounced for activities after the water is removed from the loaded cask. Several examples of these activities are impact limiter installation, outer lid bolt installation, measurement of cask cavity pressure, and radiation survey of the inner lid. The activities in which the cask dose rates do not change in this alternative are those where the work is being done near the sides of the cask. In this alternative, all activity times remain the same as for the postulated reference system.

Estimated collective radiation doses received by the reactor cask handling workers are shown in Table 5.13. About 37% reduction in doses are estimated to result from this alternative compared to the postulated reference case. The worker doses for activity 15.0 (prepare cask for shipment: installation of lids, flushing, draining, and drying cask, and sealing cask) are affected the most by improving the cask end shielding. Doses resulting from this activity

TABLE 5.13. Summary Comparison of Estimated Collective Radiation Doses at the Postulated Reference Reactor With and Without Increased Cask End Shielding

	Postulated Reference			End Shield Alternative		
	Person-mrem/ Shipment	Person-mrem/ MTU(a)	Person-rem/ year(b)	Person-mrem/ Shipment	Person-mrem/ MTU(a)	Person-rem/ year(b)
Truck						
PWR	271	293	158	163	176	95
BWR	292	314	113	184	198	71
Total			271			166
Rail						
PWR	404	62	78	251	39	49
BWR	520	78	66	367	55	46
Total			144			95

(a) Based on 0.924 MTU/PWR truck shipment, 0.930 MTU/BWR truck shipment, 6.47 MTU/PWR rail shipment, and 6.70 MTU/BWR rail shipment.

(b) Based on 540 MTU of PWR and 360 MTU of BWR spent fuel by truck and 1200 MTU of PWR and 840 MTU of BWR spent fuel by rail.

would be reduced by 77% (from 117 to 27 person-mrem for each truck shipment and from 162 to 37 person-mrem for each rail shipment). (See Appendices F and G.)

The average annual doses to individual operators during at-reactor truck cask handling operations in the postulated reference system are reduced from 898 mrem/year to 587 mrem/year when using increased cask end shielding for PWR operations, and from 1035 mrem/year to 724 mrem/year for BWR operations. For maintenance-craftsmen, the equivalent doses are the same for both PWR and BWR operations and would be reduced from 1011 mrem/year in the postulated reference system to 438 mrem/year when using increased cask end shielding. Details of these dose calculations are contained in Appendix N.

In-Transit Impacts

Increasing the shielding on the ends of the truck and rail casks would affect the public and worker radiation doses during in-transit activities where exposures result from the ends of the cask. Those activities where doses result from the sides of the cask are assumed to be unaffected in this alternative. The unaffected exposure activities for the representative LWT shipment include a portion of the driver and service attendant doses at stops (when they are away from the cask), escorts observations at stops, the general public activities (both at stops and while the shipment is moving), and inspections by state inspectors. The rail activities where the doses are unaffected by this alternative include train handling, yard crew work, and inspections by state inspectors at stops, as well as the general public activities (both at stops and while moving). The rest of this section describes the analyses that were performed to estimate the effects of increased end shielding on the radiation doses from the representative LWT and rail shipments.

Effect on Truck Shipment Doses. The radiation exposures for the representative LWT shipment that would be affected by increased cask end shielding include those to truck drivers (both while moving and during portions of the stop time), escorts while the shipment is moving, and a portion of the service attendant doses. Truck driver doses while moving are reduced by 95% (or by a factor of 20). Thus, the doses to drivers while moving are estimated at 9.0 person-mrem/shipment. The truck driver doses at stops are derived from two activities: in the first, one-half of the stop time is estimated to be spent near the cask (10 meters from the top end of the cask); and in the second, the remaining time is spent farther away from the cask (50 meters from the side of the cask). The latter activities are assumed to have no effect on truck driver doses in this alternative. The resultant reduced collective dose to the drivers during the close-distance portion of all the stops becomes 0.9 person-mrem/shipment. The total dose to both truck drivers at all stops is thus estimated to be 5.4 (unaffected portion from the postulated reference case) plus 0.9, or 6.3 person-mrem/shipment. With two drivers for each truck and each driver making 30 trips per year, the individual driver dose is reduced from 3 rem/year to one-half of (a + 6.3) x 30, or 0.23 rem/year.

Escort doses while moving would also be reduced by increasing the truck cask end shielding, but their doses at stops are assumed to be unaffected. Doses while moving were estimated in the postulated reference system by using the assumption that four escorts accompanied the shipment in urban areas; 2 escorts precede the shipment; and 2 escorts follow the shipment. The exposure distance was assumed to be 50 meters for both the preceding and following escorts. Reducing the dose rate from the ends of the cask by 95% results in a total collective dose to the escorts while moving of 0.009 person-mrem/shipment. The total escort dose (while moving plus stops) is thus 1.8 (unaffected from the postulated reference case) plus 0.009, or 1.81 person-mrem/shipment.

A portion of the dose to service attendants is also affected by this alternative. The affected portion of this dose consists of the amount of time the attendant is near the cask (10 meters from the top) for refueling. This activity is assumed to be unchanged from that in the postulated reference case. Thus, the total dose for the 3 refueling activities is estimated at 0.06 person-mrem/shipment (0.02 person-mrem/refueling). Addition of this dose to the unaffected portion of the service attendant dose (1.3 person-mrem/shipment) that is unaffected by this alternative, results in a total dose to service attendants of 1.31 person-mrem/shipment.

A summary of the collective doses for the representative LWT shipment for this alternative is presented in Table 5.14.

Effect on Rail Transport Doses. The radiation exposures for the representative rail shipment that would be affected by increased cask end shielding include those to the train crew and escorts. Train crew doses at stops were estimated in the postulated reference system analysis using the dose rate at 150 meters from the end of the cask, assuming a crew size of 5 persons and an estimated total stop time of 152 hours. For the train crew doses while moving, the conditions were assumed to be the same as at stops, except exposure time while moving was estimated at 108 hours. Reducing the dose rate from the end of the cask by 95% results in an estimated total collective dose to the train crew at stops for this alternative of 0.08 person-mrem/shipment. Similarly, train crew doses while moving are estimated to be 0.06 person-mrem/shipment. Total collective doses to the train crew for the representative rail shipment are thus estimated to be 0.14 person-mrem/shipment.

Similar to the train crew, escorts will also receive lower doses if the dose rates from the cask ends are decreased. As a result, the estimate of total collective dose to escorts while moving becomes 0.7 person-mrem/shipment and the dose at stops becomes 0.9 person-mrem/shipment (5% of those in the

TABLE 5.14. Summary of Estimated In-Transit Collective Radiation Doses for the Representative Truck Shipment - Increased Cask End Shielding Alternative

	Collective Doses		
Exposure Category	Person-mrem/ Shipment	Person-mrem/ MTU(a)	Person-rem/ year
Transport Workers			
Truck Crew			
- while moving	9.0	9.7	8.8
- at stops	6.3	6.8	6.1
State Inspectors	6(b)	6.5(b)	5.8
Service Attendants(c)	1.4	1.5	1.4
State Escorts	1.8	2.0	1.8
	24.5	24.9	22.5
Total	(206)(d)	(223)	(200)
Public			
While Moving			
- on-link	23(b)	25(b)	22
- off-link	34(b)	37(b)	33
At Stops	400(b)	433(b)	389
Total	457(b)	495(b)	444
	(457)	(495)	(444)

(a) Based on an average cask capacity of 0.926 MTU/shipment (2/5 PWR/BWR assemblies).

(b) These values are unchanged from the postulated reference system analysis.

(c) Not included in totals. Refueling is typically performed by truck drivers, and dose for this activity is included in that for the truck drivers. If done by the service station attendant, the dose to the drivers would be reduced.

(d) Numbers in parentheses are the dose estimates from the postulated reference system analysis for comparison.

postulated reference shipment). These estimates were based on assuming that a 2-person escort crew is present for the entire shipment and is located 50 meters from the end of the cask.

A summary of the estimated collective doses for the representative rail shipment for this alternative is presented Table 5.15.

TABLE 5.15. Summary of Estimated In-Transit Collective Radiation Doses for the Representative Rail Shipment - Increased Cask End Shielding Alternative

	Collective Doses		
Exposure Category	Person-mrem/ Shipment	Person-mrem/ MTU[(a)]	Person-rem/ year
Transport Workers			
● Stops			
- State Inspectors	1.5[(b)]	0.2	0.5
- Train Handlers	9.1[(b)]	1.4	29.0
- Rail Yard Crew	19.8[(b)]	3.0	6.3
- Crew	0.08	0.01	0.03
- Escorts	0.9	0.1	0.3
● While Moving			
- Crew	0.06	0.01	0.02
- Escorts	0.7	0.1	0.2
Total Transport Workers	32.1 (64)[(c)]	5.0 (9.8)	10.3 (21)
Public			
● Stops	20.1[(b)]	3.1	6.4
● While-moving			
- on-link	0.4[(b)]	0.1	0.1
- off-link	18.3[(b)]	2.8	5.9
Total Public	39[(b)] (39)	6.0 (6.0)	12.4 (12.4)

(a) Based on an average cask capacity of 6.56 MTU/shipment (14/36 PWR/BWR assemblies).

(b) These values are unchanged from the postulated reference system analysis.

(c) Numbers in parentheses are the dose estimates from the postulated reference system analysis for comparison.

At-Repository Impacts

As in the reactor case, all doses to repository cask handling workers for activity steps in which work is being done near the cask ends are reduced when additional cask end shielding is used. Doses that do not change are those that result from activities that are performed near the sides of the cask. All activity times and worker locations are assumed to remain the same, but dose rates near the ends of the cask in this alternative are 1/20 of those for the postulated reference system.

Collective doses received by the repository cask handling workers are summarized in Table 5.16. Worker dose reductions of 66% for truck and 78% for rail shipments are estimated on a per-cask and per-MTU basis, respectively. Activity 8 (removal of outer lid, removal of inner lid bolts, and installation of lid-lifting fixture) is the major contributer to at-repository worker doses in the postulated reference system. With the additional end shielding, however, a reduction of 162 person-mrem/shipment (86% reduction) is estimated for this activity for workers handling truck casks. Similarly, workers doses from handling rail casks are reduced by an estimated 318 person-mrem/shipment (91% reduction) for this activity.

TABLE 5.16. Summary Comparison of Estimated Collective Radiation Doses at the Postulated Reference Repository With and Without Cask End Shielding

	Postulated Reference			End Shield Alternative		
	Person-mrem/ Shipment	Person-mrem/ MTU(a)	Person-rem/ year(b)	Person-mrem/ Shipment	Person-mrem/ MTU(a)	Person-rem/ year(b)
Truck						
PWR	276	299	162	93	101	55
BWR	277	298	107	94	101	36
Total			269			91
Rail						
PWR	463	72	91	115	18	23
BWR	466	70	59	117	18	15
Total			149			38

(a) Based on 0.924 MTU/PWR truck shipment, 0.930 MTU/BWR truck shipment, 6.47 MTU/PWR rail shipment, and 6.70 MTU/BWR rail shipment.

(b) Based on 540 MTU of PWR and 360 MTU of BWR spent fuel by truck and 1200 MTU of PWR and 840 MTU of BWR spent fuel by rail.

The personnel performing most of the lid work, maintenance-craftsmen, would realize the majority of the dose reductions with this increased end shielding alternative. The average annual dose to individual maintenance-craftsmen is estimated to be reduced from 13.2 rem/year to 2.9 rem/year, which is within the 5 rem/year regulatory limit for occupational exposure (but not within the 1 rem/year design objective of DOE). The number of maintenance-craftsmen for this alternative remains at 26, as in the postulated reference case. These dose calculations are contained in Appendix N.

5.3.3 Cost Consequences of Increased End Shielding

This alternative involves adding 4 inches of stainless steel to both the inner lid and the cask bottom of the truck and rail casks in the postulated reference case. The diameter and length of the cask cavity are not changed as a result of this modification. Thus, the capacities of both the truck and rail casks, the cask fleet size, and the repository loading and unloading times are all unchanged from those in the postulated reference case.

The added stainless steel material on both ends of the cask is estimated to increase the capital cost of the alternative truck cask by $12,160 per cask. With a fleet of 26 truck casks, this results in a total estimated increase in capital cost of $320,000 for the total truck cask fleet. Similarly, the capital cost of the alternative rail cask is estimated to increase by $48,400 per cask, or $1.35 million for the total rail cask fleet of 28 casks.

Due to the increased weight of the end shielding, both the truck and rail transport costs will increase. The additional 3040 pounds of weight to the truck cask increases the transport cost by an estimated $600 per round-trip, or $583,000/year for the 971 truck shipments. The rail cask weight increase of 12,090 pounds results in an increase in the transport cost of $3126 per round-trip, or $1.0 million/year for the 320 annual rail shipments. Thus, the total annual operating cost increase is about $1.6 million. Details of the cost estimates are given in Appendix J.

Table 5.17 summarizes the estimated capital and annual costs associated with this alternative. The present worth of the additional costs for the increased end shielding alternative has been calculated with discount rates of

TABLE 5.17. Comparison of Estimated Life-Cycle System Costs for the Postulated Reference System With and Without Increased Cask End Shielding(a)

Cost Category	Postulated Reference Cost ($)	End Shield Alternative Cost ($)	Change in Cost ($)
Capital Costs:			
Truck Cask Fleet	39,000,000	39,320,000	320,000
Rail Cask Fleet	70,000,000	71,350,000	1,330,000
Total Capital Costs			1,670,000
Annual Costs:			
Truck Transport	9,904,000	10,487,000	583,000
Rail Transport	17,100,000	18,100,000	1,000,000
Total Annual Cost Difference			1,583,000
Present Worth of Cost Difference:			
3% Discount Rate			26,000,000
0% Discount Rate			34,800,000

(a) Costs are shown to more significant figures than justified, to provide for consistency in the calculations. See Appendix J for cost estimating details.

0% and 3% using a 21-year lifetime and 1987 dollars. The respective values, shown in Table 5.17, are estimated to be $35 million and $26 million.

5.3.4 Overview Evaluation of Increased Cask End Shielding

It was estimated that the increased cask end shielding alternative would significantly reduce the overall collective doses from truck and rail transportation, with primary dose benefits to the workers. The alternative is estimated to increase the costs of the system. The ratio of Δcost/Δdose based on the 3% discount rate is $1,960/person-rem avoided. The ratio is in the range often considered for implementation. This alternative also appears to be attractive for reducing the individual doses to the maintenance-craftsmen.

5.4 INCREASED SIDE SHIELDING ON TRUCK AND RAIL CASKS

The casks in the postulated reference system are conceived to just meet federal regulations for dose rates around transport vehicles. This basis results in an estimated dose rate of 30 mrem/hour at a distance of 1 meter from the cask side. Dose reductions to the public and workers for each shipment could be achieved if the cask had additional shielding material on the cask sides. The system dose estimates for this alternative are based on a preliminary estimate that enough shielding material could be added to reduce dose rates from the sides of the cask by 30% (Smith 1987) without reducing cask capacity within the reference weights for loaded casks plus their vehicles. This preliminary estimate remains to be confirmed during detailed cask design.

5.4.1 Description of Increased Side Shielding on Truck and Rail Casks

The addition of 1/8 inch of depleted uranium to the sides of the postulated reference truck cask, and 1/2 inch of stainless steel to the sides of the postulated reference rail cask, are estimated to reduce the dose rates to the sides of the cask by approximately 30% without loss of cask capacity or exceeding legal weights. The alternative truck cask would thus have 2.9 inches of stainless steel plus 2.23 inches of depleted uranium on the cask walls. The alternative rail cask would have a total of 10.5 inches of stainless steel on the cask walls. The additional shielding is estimated to increase the weight of the truck cask by approximately 1,275 pounds and increase the weight of the rail cask by 11,600 pounds. The additional weight will not affect cask handling times at reactors or the repository or affect in-transit operations. It is estimated that the alternative truck vehicle (tractor and trailer) plus loaded cask would weigh no more than 80,000 pounds, and the alternative rail vehicle (rail car) plus loaded cask would weigh no more than 263,000 pounds.

5.4.2 Operational and Dose Impacts of Increased Cask Side Shielding

The estimated transportation system effects resulting from using truck and rail casks with additional side shielding are discussed in this section. Table 5.18 presents a summary of the estimated annual collective dose

TABLE 5.18. Summary Comparison of Estimated Annual Collective Radiation Doses in the Postulated Reference Rail/Truck Transport System With and Without Increased Cask Side Shielding

	person-rem/year								
	Truck			Rail			Total System[a,b]		
	Postulated Reference	Side Shield Alternative	Dose Change	Postulated Reference	Side Shield Alternative	Dose Change	Postulated Reference	Side Shield Alternative	Dose Change
At-Reactor	271	246	-25	144	135	-9	415	381	-34
In-Transit									
- Worker	200	197	-3	21	18	-3	221	215	-6
- Public	444	311	-133	12	9	-3	456	320	-136
At-Repository	269	246	-23	149	141	-8	418	387	-31
Totals	1184	1000	-184	326	303	-23	1510	1303	-207

(a) Based on 0.924 MTU/PWR truck shipment, 0.930 MTU/BWR truck shipment, 6.47 MTU/PWR rail shipment, and 6.70 MTU/BWR rail shipment.

(b) Cask capacity is 2/5 PWR/BWR assemblies for truck shipments and 14/36 PWR/BWR assemblies for rail shipments.

reductions for at-reactor, in-transit, and at-repository operations. Collective doses received by the cask handling workers at the reactors and the repository decrease by 8%. The increased side shielding has no effect on the high dose-producing activities performed on the ends of the cask. The major benefit gained by using additional side shielding is the reduction of in-transit doses, mostly to the public. Total in-transit doses are reduced by about 26%.

At-Reactor Impacts

All cask dose rates in activity steps at the reactor sites that require workers to be at the sides of the cask are affected by increased side shielding. The activities in which dose rates do not change in this alternative are those where the work is being done on either the top or bottom end of the cask (e.g., closure head and impact limiter installation/removal, gas/ pressure testing, etc.). All activity times remain the same as for the postulated reference case, but dose rates for affected activities decrease by 30%.

Estimated collective radiation doses received by the reactor cask handling workers are shown in Table 5.19. About 9% reduction of doses for truck shipments and 6% to 7% reduction of doses for rail shipments are estimated to result from this alternative compared to the postulated reference case.

The average annual doses to individual operators during at-reactor truck cask handling operations in the postulated reference system are reduced from

TABLE 5.19. Summary Comparison of Estimated Collective Radiation Doses at the Reactor With and Without Increased Cask Side Shielding

	Postulated Reference			Side Shield Alternative		
	Person-mrem/ Shipment	Person-mrem/ MTU[a]	Person-rem/ year[b]	Person-mrem/ Shipment	Person-mrem/ MTU[a]	Person-rem/ year[b]
Truck						
PWR	271	293	158	245	265	143
BWR	292	314	113	265	285	103
Total			271			246
Rail						
PWR	404	62	78	377	59	73
BWR	520	78	66	491	74	62
Total			144			135

(a) Based on 0.924 MTU/PWR truck shipment, 0.930 MTU/BWR truck shipment, 6.47 MTU/PWR rail shipment, and 6.70 MTU/BWR rail shipment.

(b) Based on 540 MTU of PWR and 360 MTU of BWR spent fuel by truck and 1200 MTU of PWR and 840 MTU of BWR spent fuel by rail.

898 mrem/year to 818 mrem/year when using increased cask side shielding for PWR operations, and from 1035 mrem/year to 944 mrem/year for BWR operations. For maintenance-craftsmen, the equivalent doses are the same for both PWR and BWR operations and would be reduced from 1011 mrem/year in the postulated reference system to 926 mrem/year when using increased cask side shielding. Details of these dose calculations are contained in Appendix N.

In-Transit Impacts

Increasing the shielding on the sides of the truck and rail casks would reduce the public and worker radiation doses during in-transit activities where exposures would result from the sides of the casks. It is assumed that doses during those activities that are functions of the dose rates at the top and bottom to the cask are unaffected. For the representative LWT shipment, the latter exposure categories include those to truck drivers and state escorts while moving, and to state escorts and service attendants during the time the truck is being refueled. For the representative rail shipment, the doses to the train crew and escorts (while moving and at stops) are unaffected. The rest of this section describes the analyses that were performed to estimate the effects of increased side shielding on the truck and rail shipment doses.

Effect on Truck Shipment Doses. The radiation exposures that would be affected by the reduced dose rate from the side of the LWT cask include those to truck drivers and state escorts while the shipment is stopped, to state inspectors and service attendants during their respective servicing, and to the general population (both at stops and while moving). Driver doses at stops were estimated assuming that each driver spends one-half of the stop-time near the cask (assumed to be 10 meters from the end of the cask) and one-half of the stop-time away from the cask (assumed to be 20 meters from the side of the cask). The dose rate for the time near the cask is unchanged from the postulated reference case, and the dose rate for the latter portion is reduced by 30%. The resulting driver doses at stops are thus 18.0 person-mrem/shipment for activities at close distances (unchanged from the postulated reference case), plus 2 persons x 15 hours x (0.7 x 0.18 mrem/hour), or 3.8 person-mrem/shipment for the activities at longer distances. The total dose to drivers at stops is estimated at 21.8 person-mrem/shipment. The individual annual dose to the truck driver remains at about 3 rem/year.

Escort doses at stops would also be reduced when the cask side shielding is increased. It was assumed in the postulated reference system analysis that 4 escorts would be exposed for 3 hours/shipment at a distance of 20 meters from the side of the cask. The reduced dose rate at 20 meters due to the increased side shielding becomes 0.13 mrem/hour and the estimated escort doses at stops become 1.6 person-mrem/shipment. The total escort dose is thus 1.6 person-mrem/shipment at stops plus 0.06 person-mrem/shipment while moving, or 1.7 person-mrem/shipment.

A portion of the dose to service attendants is also assumed to be affected by this alternative. As with the escorts, the affected portion of the dose is that received from activities at longer distances (i.e., not during the time when the truck is being refueled). The activities at longer distances were estimated in the postulated reference case by assuming that the equivalent of 1 attendant at each of 3 refueling stops was exposed at a distance of 20 meters from the side of the cask for 2.3 hours/shipment. Reducing the dose rate by 30%, results in the estimated dose from the exposure portion of the refueling stops at longer distance from the cask at 0.9 person-mrem/shipment. The total dose to service attendants is the sum of the unchanged close-distance dose (1.2 person-mrem/shipment) plus the longer-distance dose (0.9 person-mrem/shipment), or 2.1 person-mrem/shipment.

Increased shielding on the cask sides will also reduce the dose to state inspectors. The dose was estimated for the postulated reference system by assuming that 1 person at each of 2 inspection stops was exposed to the dose rate at 10 meters from the side of the cask for 1 hour. Using the reduced dose rate, the total estimated dose to state inspectors becomes 4.5 person-mrem/shipment.

The maximum individual doses to the state inspectors, service attendants and state escorts are also reduced about 30% from the postulated reference truck case to 542, 68, and 100 mrem/year, respectively.

The estimated collective doses for the representative LWT shipment for this alternative are summarized in Table 5.20. The summary estimates of the analysis of the postulated reference system doses are shown for comparison.

<u>Effect on Rail Transport Doses</u>. The exposures for rail shipments that are affected by increased cask side shielding include those to train handlers, yard crews, and the general population and state inspectors at stops. In the postulated reference system analysis, a total of 10 train handlers was assumed to be exposed at a distance of 10 meters from the side of the cask, for a total of 1.2 hours/shipment. Using the reduced dose rate resulting from the increased cask side shielding, the total dose to train handlers is estimated to be 6.4 person-mrem/shipment. Similarly, yard crew collective doses would also be reduced by 30%, and are estimated at 13.8 person-mrem/shipment for this alternative.

State inspector doses were estimated in the postulated reference system by assuming that 4 inspectors were each exposed to the dose rate at 10 meters from the side of the rail cask for each shipment. The reduced dose rate in this alternative results in an estimated collective dose to the state inspectors of 1.1 person-mrem/shipment.

Doses to the general public, both while moving and at stops, would be decreased by 30% in this alternative. The resulting collective dose estimates

TABLE 5.20. Summary of Estimated In-Transit Collective Radiation Doses for the Representative Truck Shipment - Increased Cask Side Shielding Alternative

Exposure Category	Collective Doses Person-mrem/ Shipment	 Person-mrem/ MTU[a]	 Person-rem/ year[b]
Transport Workers			
Truck Crew			
- While Moving	175[c]	188[c]	170
- At Stops	21.8	23.5	21
State Inspectors	4.5	4.9	4
Service Attendants[d]	2.1	2.3	2
State Escorts	1.4	1.5	1
Total Transport Workers	209 (206)[e]	219 (223)	197 (200)
Public			
While Moving			
- on-link	16.2	17.5	16
- off-link	23.8	25.7	23
At Stops	280	302	272
Total Public	320 (457)	346 (495)	311 (444)

(a) Based on an average cask capacity of 0.926 MTU/shipment (2/5 PWR/BWR assemblies).

(b) Based on 900 MTU/year shipped by truck.

(c) These values are unchanged from the postulated reference system analysis.

(d) Not included in totals. Refueling is typically performed by truck drivers and dose for this activity is included in that for the truck drivers. If done by the service station attendant, the doses to the drivers would be reduced.

(e) Numbers in parentheses are the dose estimates from the postulated reference system analysis for comparison.

are as follows: for the public at stops, 0.7 x 20 = 14.0 person-mrem/shipment; for on-link doses while moving, 0.7 x 0.4 = 0.28 person-mrem/shipment; and for off-link doses while moving, 0.7 x 18.3 = 12.8 person-mrem/shipment.

The estimates of the in-transit collective doses for the representative rail shipment with increased cask side shielding are summarized in Table 5.21.

TABLE 5.21. Summary of Estimated In-Transit Collective Radiation Doses for the Representative Rail Shipment - Increased Cask Side Shielding Alternative

	Collective Doses		
Exposure Category	Person-mrem/ Shipment	Person-mrem/ MTU[a]	Person-rem/ Year[b]
Transport Workers			
• Stops			
State inspectors	1.1	0.2	0.4
Train handlers	6.4	1.0	2.1
Rail Yard Crew	13.8	2.1	4.4
Crew	1.6[c]	0.2	0.5
Escorts	18.2[c]	2.8	5.8
• While Moving			
Crew	1.1[c]	0.2	0.4
Escorts	13.0[c]	2.0	4.2
Total Transport Workers	55.2 (64)[d]	8.5 (9.8)	18.0 (21)
Public			
• Stops	14.0	2.1	4.5
• While Moving			
- on-link	0.3	0.05	0.1
- off-link	12.8	2.0	4.1
Total Public	27.1 (39)	4.1 (6.0)	8.7 (12.4)

(a) Based on an average cask capacity of 6.55 MTU/shipment (14/36 PWR/BWR assemblies).
(b) Based on 2100 MTU/year shipped by rail.
(c) These values are unchanged from the postulated reference system analysis.
(d) Numbers in parentheses are the dose estimates from the postulated reference system analysis for comparison.

At-Repository Impacts

As for reactor operations, all doses to cask handling workers for activity steps in which work is being done to the sides of the cask are reduced when additional cask side shielding is used. Doses that do not change are those that result from activities that are performed on the ends of the cask. All activity times and worker locations would remain the same, but dose rates to the sides of the cask in this alternative are 30% less than those for the postulated reference system.

Estimated collective radiation doses received by the repository cask handling workers are summarized in Table 5.22. Dose reductions of about 9% for truck and 6% for rail shipments are estimated on a per-cask and per-MTU basis, respectively. The collective dose reductions are dispersed widely among the various crafts, because almost all of the cask handling worker categories perform tasks at the sides of the cask at one time or another. For the increased side shielding alternative, the average annual individual dose to the 26 maintenance-craftsmen is estimated to decrease to 12.5 rem/year, or about a 5% reduction from that for the postulated reference case. Details of these dose calculations are contained in Appendix N.

TABLE 5.22. Summary Comparison of Estimated Collective Radiation Doses at the Postulated Reference Repository With and Without Increased Cask Side Shielding

	Postulated Reference			Side Shield Alternative		
	Person-mrem/ Shipment	Person-mrem/ MTU(a)	Person-rem/ year(b)	Person-mrem/ Shipment	Person-mrem/ MTU(a)	Person-rem/ year(b)
Truck						
PWR	276	299	162	253	274	148
BWR	277	298	107	253	272	98
Total			269			246
Rail						
PWR	463	72	91	436	68	86
BWR	466	70	59	438	66	55
Total			149			141

(a) Based on 0.924 MTU/PWR truck shipment, 0.930 MTU/BWR truck shipment, 6.47 MTU/PWR rail shipment, and 6.70 MTU/BWR rail shipment.

(b) Based on 540 MTU of PWR and 360 MTU of BWR spent fuel by truck and 1200 MTU of PWR and 840 MTU of BWR spent fuel by rail.

5.4.3 Cost Consequences of Increased Cask Side Shielding

This alternative involves adding 1/8 inch of depleted uranium to the side shielding of all truck casks and 1/2 inch of stainless steel to the side shielding of all rail casks in the postulated reference case. The size of the inner cask cavities would not change as a result of this modification. Thus, the capacities of both the truck and rail casks, the cask fleet size, and the repository loading and unloading times are all unchanged from those in the postulated reference case.

The added shielding on the truck cask is estimated to increase the capital cost by $38,000 per cask. With a fleet of 26 truck casks, a total estimated increase in capital cost of about $1 million results for the total truck cask fleet. Similarly, the capital cost of the alternative rail cask is estimated to increase by $27,200 per cask, or a total increase of $800,000 for the rail cask fleet of 28 casks.

Due to the increased weight of both the alternative casks, the annual transport costs will also increase. The addition of 1275 pounds of depleted uranium to the truck cask increases the transport cost by an estimated $200 per round-trip, or a total increase of $194,200 per year for the 971 truck shipments. The rail cask weight increase of 6800 pounds would result in an estimated increase in the transport cost of $1800 per round-trip, or a total increase for the 320 rail shipments in a year of $576,000.

The estimated capital and annual costs associated with this alternative are summarized in Table 5.23. The present worth of the additional life-cycle costs for the increased cask side shielding alternative has been calculated with discount rates of 0% and 3% using a 21-year lifetime and 1987 dollars. The respective values, shown in Table 5.23, are estimated to be $12.9 million to $9.7 million.

5.4.4 Overview Evaluation of Increased Cask Side Shielding

It was estimated that the increased cask side shielding would increase the overall costs of the truck and rail transportation of spent fuel but would reduce the collective doses to workers and public. The magnitude of the estimated reduction in collective dose for using the rail cask system is much

TABLE 5.23. Comparison of Estimated Life-Cycle Costs for the Postulated Reference System With and Without Increased Cask Side Shielding[a]

Cost Category	Postulated Reference Cost ($)	Side Shield Alternative Cost ($)	Change in Cost ($)
Capital Costs:			
Truck Cask Fleet	39,000,000	40,000,000	1,000,000
Rail Cask Fleet	70,000,000	70,800,000	800,000
Total Capital Cost Increase			1,800,000
Annual Costs:			
Truck Transport	9,904,000	10,098,000	194,000
Rail Transport	17,056,000	17,632,000	576,000
Total Annual Cost Difference			770,000
Present Worth of Cost Difference (Truck):			
3% Discount Rate			3,990,000
0% Discount Rate			5,070,000
Present Worth of Cost Difference (Rail):			
3% Discount Rate			9,680,000
0% Discount Rate			12,900,000

(a) Costs are shown to more significant figures than justified, to provide for consistency in the calculations. See Appendix J for detailed cost calculations.

smaller than from the truck system. The ratio of Δcost/Δdose for the truck system based on the 3% discount rate is $1030/person-rem avoided. The ratio of Δcost/Δdose for the rail system based on the 3% discount rate is $20,100/person-rem avoided. With these ratios, the increased cask side shielding alternative may be attractive for truck casks, but may not be attractive for rail casks. It must be remembered that the additional shielding was estimated to be added to the casks without affecting cask capacity, based on preliminary analyses. This would have to be confirmed by further calculations. It should also be noted that this alternative appears to be reasonably effective in reducing the public doses from truck shipments.

5.5 ADVANCED DESIGN INCLUDING URANIUM SHIELDING AND BURNUP CREDIT

In the postulated reference system, the casks were assumed to be designed as cylindrical casks with all neutron and gamma shielding materials in the cask walls and neutron poison materials in the baskets. The basket dividers were assumed to be relatively thick in order to maintain the effective neutron multiplication factor (k_{eff}) below 0.95 when the cask was filled with water and unirradiated fresh fuel. Fuel with no or very low burnup is not expected to be shipped to the repository on a routine basis. By taking credit for the burnup of the fissile materials in the spent fuel, the baskets within the casks can be made with thinner separators, which allows more space for spent fuel, thereby allowing the cask capacity to be increased significantly. Because many cask operations at reactors and the repository are independent of the amount of spent fuel within a given-size cask, substantial dose reductions are possible if burnup is taken into account during the design of the casks and baskets, thereby increasing cask capacity and reducing the number of individual shipments required.

Within the advanced design alternative, three casks are considered and are evaluated separately: a legalweight truck cask, an overweight truck cask, and a rail cask. Each of these three cask types can be considered as a separate alternative for analysis.

5.5.1 Description of Advanced Design Casks

The basket dividers in the postulated reference system fuel basket are assumed to be 1.5 inches thick and to contain a substantial quantity of stainless steel, boron, and space for water (as neutron absorbers), as is the standard practice in current casks. However, much of the fuel separation is not needed to prevent nuclear criticality when fuel with significant burnup is shipped in the casks. The divider thickness can be reduced to about 3/4 inch, allowing more room for fuel assemblies in a cask of the same weight (Sanders et al. 1987).

With utilization of burnup credit and uranium shielding, preliminary analyses indicate that the capacities of transport casks could be increased to 4 PWR/9 BWR assemblies (legalweight truck), to 7 PWR/15 BWR assemblies (overweight truck), and to 30 PWR/66 BWR assemblies (uranium-shielded rail). These increased capacities are assumed to result in external radiation dose rates within regulatory limits. The number of legalweight truck shipments would be reduced by 50% (PWR) and by 44% (BWR) compared to the postulated reference system legalweight casks. Similarly, overweight truck shipments would be reduced by 71% (PWR) and by 67% (BWR). Rail cask shipments would be reduced by 53% (PWR) and by 46% (BWR) compared to the postulated reference system rail cask.

5.5.2 Operational and Dose Impacts of Advanced Design Casks

The system effects resulting from the use of advanced design truck and rail casks are discussed in this section. A summary of the estimated annual collective radiation dose reductions for at-reactor, in-transit, and at-repository operations for the three different casks is presented in Table 5.24. Each of the different casks is treated as a separate alternative and is compared directly to either the legalweight truck or steel rail casks in the postulated reference system. Overall dose reductions are substantial because many of the processing times are independent of the capacity of casks in a given size range. Thus, handling time per MTU of fuel is reduced, and consequently, radiation doses are reduced. Estimated collective doses received by cask handling workers at reactors on an annual basis for legalweight truck operations would decrease by 45%, while at-repository doses would be reduced by 48%. The corresponding annual collective worker doses for overweight truck cask handling operations and rail cask handling operations at reactors and at the repository would be reduced by an estimated 66% (PWR) and 69% (BWR) for overweight truck shipments, and 38% (PWR) and 50% (BWR) for rail shipments, respectively. In-transit doses would decrease by an estimated 50% for legalweight truck shipments, 67% for overweight truck shipments, and 55% for rail shipments.

TABLE 5.24. Summary Comparison of Estimated Collective Radiation Doses (person-rem/yr) for the Three Advanced Design Cask Alternatives

Legalweight Truck Cask Alternative (4/9 capacity)[a]

	Postulated Reference	Truck Alternative[a]	Dose Change
At-Reactor	271	149	-122
In-Transit			
- Worker	200	104	-96
- Public	444	231	-213
At-Repository	269	141	-128
Totals	1184	625	-559

Overweight Truck Cask Alternative (7/15 capacity)[a]

	Postulated Reference (LWT)	Truck Alternative[c]	Dose Change
At-Reactor	271	93	-178
In-Transit			
- Worker	200	62	-138
- Public	444	155	-289
At-Repository	269	82	-187
Totals	1184	392	-792

Uranium-Shielded Rail Cask Alternative (30/66 capacity)[a]

	Postulated Reference	Truck Alternative[d]	Dose Change
At-Reactor	144	90	-54
In-Transit			
- Worker	21	10	-11
- Public	12	6	-6
At-Repository	149	75	-74
Totals	326	181	-145

(a) PWR/BWR assemblies.
(b) Based on 1.85 MTU/PWR shipment and 1.67 MTU/BWR shipments.
(c) Based on 3.23 MTU/PWR shipment and 2.79 MTU/BWR shipments.
(d) Based on 13.2 MTU/PWR shipment and 12.4 MTU/BWR shipments.

At-Reactor Impacts

The cask handling activity steps at the reactor that are affected by cask capacity changes are 11.1 (identify spent fuel assemblies to be loaded, perform accountability) and 11.2 (move spent fuel assemblies to loading area, place in cask). In the postulated reference system, 15 minutes is estimated per spent fuel assembly for each of these activities. Thus, times for these activities increase in direct proportion to increased cask capacities. All other activities and time requirements at the reactor are assumed to be independent of the capacity of the casks within a given size range. Estimated at-reactor turnaround times for this alternative are shown in Table 5.25.

TABLE 5.25. Comparison of Estimated At-Reactor Turnaround Times for the Postulated Reference System With and Without Advanced Design Casks

	Turnaround Time (min/shipment)	
	Postulated Reference (PWR/BWR)	Advanced Design Alternative (PWR/BWR)
Legalweight Truck Cask (4/9)	915/1020	945/1080
Overweight Truck Cask (7/15)	915/1020	990/1170
Uranium-Shielded Rail Cask (30/66)	1370/1760	1610/2210

Cask handling worker radiation doses received at the reactor on a per-shipment basis increase due to the additional time required to load the cask. However, because the alternative casks carry significantly more fuel than the postulated reference system casks, doses received per MTU of fuel shipped decrease. Table 5.26 displays the estimated annual collective dose impacts to the reactor cask handling workers of implementing this alternative. As the table shows, implementation of advanced cask designs is estimated to reduce the radiation doses substantially to the workers at reactors from cask handling operations. Because nearly all activities at reactors are assumed to be independent among truck and rail casks, increasing cask capacities (which reduces the number of shipments) is one of the most direct methods to reduce doses.

The average annual doses to individual operators during at-reactor legalweight truck cask handling operations are reduced from 898 mrem/year when using the postulated reference legalweight cask to 497 mrem/year when using the advanced design legalweight cask for PWR operations, and from 1035 mrem/year to 636 mrem/year for BWR operations. For maintenance-craftsmen, the equivalent

TABLE 5.26. Summary Comparison of Estimated At-Reactor Doses for the Postulated Reference System With and Without Advanced Design Casks

	Postulated Reference			Advanced Design Alternative		
	Person-mrem/ Shipment	Person-mrem/ MTU	Person-rem/ year[a]	Person-mrem/ Shipment	Person-mrem/ MTU	Person-rem/ year[a]
Legalweight Truck Cask Alternative						
PWR	271	293	158	281	152[b]	82
BWR	292	314	113	312	186[b]	67
Total			271			149
Overweight Truck Cask Alternative						
PWR	271	293	158	296	92[c]	50
BWR	292	314	113	342	122[c]	44
Total			271			94
Uranium-Shielded Rail Cask Alternative						
PWR	404	62	78	484	35[d]	44
BWR	520	78	66	670	55[d]	46
Total			144			90

(a) Based on 540 MTU of PWR and 360 MTU of BWR spent fuel by truck and 1200 MTU of PWR and 840 MTU of BWR spent fuel by rail.
(b) Based on 1.85 MTU/PWR shipment was 1.67 MTU/BWR shipment.
(c) Based on 3.23 MTU/PWR shipment and 2.79 MTU/BWR shipment.
(d) Based on 13.2 MTU/PWR shipment and 12.4 MTU/BWR shipment.

doses for both PWR and BWR operations are 1011 mrem/year when using the postulated reference legalweight cask and would be reduced to 521 mrem/year (PWR) and to 552 mrem/year (BWR) when using the advanced design cask.

The average annual doses to individual operators during at-reactor overweight truck cask handling operations are reduced from 898 mrem/year when using the postulated reference overweight cask to 322 mrem/year when using the advanced design overweight cask for PWR operations, and from 1035 mrem/year to 455 mrem/year for BWR operations. For maintenance-craftsmen, the equivalent doses for both PWR and BWR operations are 1011 mrem/year when using the postulated reference overweight cask and would be reduced to 307 mrem/year (PWR) and to 337 mrem/year (BWR) when using the advanced design cask.

The average annual doses to individual operators during at-reactor uranium-shielded rail cask handling operations are reduced from 217 mrem/year when using the postulated reference uranium-shielded rail cask to 178 mrem/year when using the advanced design uranium-shielded rail cask for PWR operations, and from 333 mrem/year to 290 mrem/year for BWR operations. For maintenance-craftsmen, the equivalent doses are the same for PWR and BWR operations and would be reduced from 215 mrem/year when using the postulated reference uranium-shielded cask to 129 mrem/year when using the advanced design cask.

Details of the dose calculations for the legalweight, overweight, and rail cask handling operations are provided in Appendix N.

In-Transit Impacts

A detailed re-evaluation was not needed to estimate the in-transit effects of this alternative. Because the dose rate maps and time/distance/dose rates are assumed to be the same for both the postulated reference truck and rail casks and the alternative legalweight truck and rail casks, the doses received per shipment would be the same. The bases for the advanced design overweight truck cask (7/15 spent fuel assemblies) and the "nominal" overweight truck cask (4/10 spent fuel assemblies, discussed in Section 5.1) are also the same. The doses received per MTU in these alternatives are reduced because each alternative cask would carry more fuel than the postulated reference cask. Tables 5.27 through 5.29 present the estimated doses received during in-transit activities.

The annual dose to individual truck drivers would remain the same as in the postulated reference case because the dose per shipment remains the same and the drivers would transport the same number of shipments. Because of the fewer shipments, however, fewer truck drivers would be needed.

At-Repository Impacts

Cask handling activity steps at the repository that are affected by spent fuel capacity of the casks are those that involve unloading the spent fuel assemblies from the cask and inspecting and vacuuming the cask cavities. These are activity steps 13.1 (unload spent fuel assemblies), 14.2 (vacuum cavities, lid, fuel spacer), 14.4 (radiation survey of cask cavities), 14.5 (inspect cavities), and 14.6 (additional allowance for BWR casks for activity steps 14.2, 14.4, and 14.5). The operational times for these activities are directly

TABLE 5.27. Summary of In-Transit Collective Radiation Dose Estimates for the Advanced Design LWT Cask (4/9) Alternative

Exposure Category	Collective Dose Person-mrem/ Shipment[a]	 Person-mrem/ MTU[b]	 Person-rem/ year[c]
Transport Workers			
Truck Crew			
- while moving	175	98	88
- at stops	23	13	12
State Inspectors	6.4	4	3
Service Attendants[d]	2.5	1	1
State Escorts	2.2	1	1
Total Transport Worker Dose	207	116	104
	(206)[e]	(223)	(200)
Public			
While Moving			
- on-link	23	13	12
- off-link	34	19	17
At Stops	400	225	202
Total Public Dose	457	257	231
	(457)	(495)	(444)

(a) These values are unchanged from the analysis of doses for the postulated reference legalweight truck cask shipments.

(b) Based on an average cask capacity of 1.78 MTU/shipment (4/9 PWR/BWR assemblies).

(c) Based on 900 MTU/year.

(d) Not included in totals. Truck refueling is typically performed by the drivers and the dose is also included with the driver dose. If done by the service attendant, the doses to drivers would be reduced.

(e) Numbers in parentheses are dose estimates for the postulated reference LWT (2/5 PWR/BWR assemblies) shipment for comparison.

TABLE 5.28. Summary of In-Transit Collective Radiation Dose Estimates for the Advanced Design OWT Cask (7/15) Alternative

Exposure Category	Collective Dose Person-mrem/Shipment(a)	Person-mrem/MTU(b)	Person-rem/year(c)
Transport Workers			
Truck Crew			
- while moving	175(b)	57	51
- at stops	27	9	8
State Inspectors	7.0	2	2
Service Attendants(d)	2.5(c)	1	1
State Escorts	2.2(c)	1	1
Total Transport Worker Dose	217	69	62
	(206)(e)	(223)	(200)
Public			
While Moving			
- on-link	34.0	11	10
- off-link	23.2	8	7
At Stops	470	154	138
Total Public	527	172	155
	(457)	(495)	(444)

(a) These values are unchanged from the analysis of doses for the postulated reference overweight truck cask shipments.

(b) Based on an average cask capacity of 3.06 MTU/shipment (7/15 PWR/BWR assemblies).

(c) Based on 540 MTU/year of PWR and 360 MTU/year of BWR spent fuel.

(d) Not included in totals. Truck refueling is typically performed by the drivers and the dose is also included with the driver dose. If done by a service attendant, the doses to drivers would be reduced.

(e) Numbers in parentheses are the dose estimates for the postulated reference LWT (2/5 PWR/BWR assemblies) shipment for comparison.

TABLE 5.29. Summary of In-Transit Collective Radiation Dose Estimates for the Advanced Design Rail Cask (30/66) Alternative

	Collective Dose		
Exposure Category	Person-mrem/ Shipment[a]	Person-mrem/ MTU[b]	Person-rem/ year[c]
Transport Workers			
Stops			
- State Inspectors	1.5	0.1	0.2
- Train Handlers	9.1	0.7	1.5
- Rail Yard Crew	19.8	1.5	3.2
- Crew	1.6	0.1	0.2
- Escorts	18.2	1.4	2.9
While Moving			
- Crew	1.1	0.1	0.2
- Escorts	13.0	1.0	2.1
	64	4.9	10.2
Total Transport Worker Dose	(64)[d]	(9.9)	(20.6)
Public			
Stops	20.1	1.5	3.2
While Moving			
- on-Link	0.4	0.03	0.06
- off-Link	18.3	1.4	2.9
Total Public Dose	39	2.9	6.2
	(39)	(6.0)	(12.4)

(a) These values are unchanged from the analysis of doses for the postulated reference rail cask shipments.

(b) Based on an average cask capacity of 13.2 MTU/shipment (30/66 PWR/BWR assemblies).

(c) Based on shipment of 2100 MTU/year.

(d) Numbers in parentheses are the dose estimates for the postulated reference rail (14/36 PWR/BWR assemblies) shipment for comparison.

related to the capacity of the cask. All other activity steps at the repository are taken to be the same for all rail and truck casks. Estimated turnaround times for using the alternative casks are presented in Table 5.30.

TABLE 5.30. Comparison of Estimated At-Repository Turnaround Times for the Postulated Reference System With and Without Advanced Design Casks

	Turnaround Time (min/shipment)	
	Postulated Reference (PWR/BWR)	Advanced Design Alternative (PWR/BWR)
Legalweight Truck Cask (4/9)	875/980	965/1150
Overweight Truck Cask (7/15)	875/980	1105/1405
Uranium-Shielded Rail Cask (30/66)	1295/1805	1665/2495

Estimated doses received by the cask handling workers at the repository for each shipment increase only slightly for this alternative. This factor, combined with the increased capacity of the alternative casks, results in significant reductions in collective doses to the cask handling workers at the repository. The estimated collective radiation doses to the repository cask handling workers using these increased capacity casks are given in Table 5.31. Dose reductions of 44% to 53% per MTU result from the use of this rail or LWT alternative compared to the postulated reference system; and dose reductions of 67% to 71% per MTU result from the use of the OWT alternative compared to the postulated reference system.

Reductions of annual doses to individual repository cask handling workers would also result from using this alternative. Individual maintenance-craftsmen receive an estimated average of 8.2 rem/year from handling truck casks and 5.0 rem/year from handling rail casks in the postulated reference system. If the advanced design concepts are implemented to increase cask capacity and the corresponding reductions in staff are considered, the maintenance-craftsmen dose would be reduced only slightly. Specifically, the average annual individual dose to a maintenance-craftsman for handling advanced design LWT casks and reference rail casks would be 6.2 rem and 7.2 rem, respectively, for a total of 13.4 rem/year with a crew of 18. The average annual dose to an

TABLE 5.31. Summary Comparison of Estimated Doses at the Postulated Reference Repository With and Without Advanced Design Casks

	Postulated Reference			Advanced Design Alternative		
	Person-mrem/ Shipment	Person-mrem/ MTU	Person-rem/ year(a)	Person-mrem/ Shipment	Person-mrem/ MTU	Person-rem/ year(a)
Legalweight Truck Cask Alternative						
PWR	276	299	162	277	150(b)	81
BWR	277	298	107	278	166(b)	60
Total			269			141
Overweight Truck Cask Alternative						
PWR	276	299	162	278	86(c)	46
BWR	277	298	107	279	100(c)	36
Total			269			82
Uranium-Shielded Rail Cask Alternative						
PWR	463	72	91	465	34(d)	43
BWR	466	70	59	469	38(d)	32
			149			75

(a) Based on 540 MTU of PWR and 360 MTU of BWR spent fuel by truck and 1200 MTU of PWR and 840 MTU of BWR spent fuel by rail.
(b) Based on 1.85 MTU/PWR shipment and 1.67 MTU/BWR shipment.
(c) Based on 3.23 MTU/PWR shipment and 2.79 MTU/BWR shipment.
(d) Based on 13.2 MTU/PWR shipment and 12.4 MTU/BWR shipment.

individual maintenance-craftsman when handling advanced design OWT casks and reference rail casks would be 3.6 rem and 7.2 rem, respectively, for a total of 10.8 rem/year. For the reference truck with advanced rail, the average annual dose would be 9.7 rem and 2.9 rem, respectively, for a total of 12.6 rem/year with a crew of 22 maintenance-craftsmen. Thus, the reduction in collective dose is accompanied by only modest reductions in annual doses to individual workers. Details of these dose calculations are contained in Appendix N.

5.5.3 Cost Consequences of Advanced Design Casks

Costs for the three cases using the three advanced design casks discussed in the prior section are developed in this section. In this study, the cask fleet size needed for the advanced design LWT cask would be reduced from 26 casks (in the postulated reference system) to 14 casks, the overweight truck cask fleet would be 9 casks to handle the 900 MTU of spent fuel/year, and the rail cask fleet size would be reduced from 28 casks to 15 casks.

LWT Cask Costs

The only change in the capital cost estimate for each advanced design LWT cask is to reduce the amount of stainless steel in the basket dividers. This results in an estimated cost savings of $5000 per cask. With the reduction in truck cask fleet size by 12 casks, the total capital cost savings due to the advanced design LWT cask is estimated to be about $18 million, and the total annual cost savings is estimated to be about $7 million, as shown in Table 5.32.

TABLE 5.32. Comparison of Estimated Life-Cycle Costs for the Postulated Reference System With and Without Advanced Design LWT Casks(a)

Cost Category	Postulated Reference Cost ($)	Advanced Design Alternative Cost ($)	Change in Cost ($)
Capital Costs:			
Truck Cask Fleet	39,000,000	20,900,000	-18,100,000(b)
Annual Costs:			
Cask Maintenance	1,950,000	1,050,000	-900,000
Truck Transport	9,900,000	5,310,000	-4,590,000
At-Reactor Labor	1,060,000	593,000	-467,000
Repository Labor	4,640,000	3,550,000	-1,080,000
Total Annual Cost Difference			-7,040,000
Present Worth of Cost Difference:			
3% Discount Rate			-127,000,000
0% Discount Rate			-166,000,000

(a) Costs are shown to more significant figures than justified, to provide for consistency in the calculations. See Appendix J for detailed cost calculations.
(b) A negative cost denotes a cost savings.

The lighter basket would reduce the advanced design LWT cask weight by an estimated 1260 pounds, but this weight is offset by the weight of the additional spent fuel assemblies carried in the cask. The estimated transport cost per round-trip shipment for the advanced design LWT cask becomes $10,475, which is $275 more than for the postulated reference truck. The decrease in the number of annual truck shipments by 464 would reduce the total annual transport cost for truck shipments by approximately $4.6 million.

The increase in the number of spent fuel assemblies that each advanced design LWT cask holds would lead to a slight increase in the labor cost per cask for loading each cask at the reactors. But the reduced number of casks being loaded per year would reduce the at-reactor cask handling labor costs by an estimated $470,000 per year. At the repository, cost savings for cask handling labor would result from the elimination of the third shift of receiving and unloading personnel in all four of the hot cells. This would result in a decrease in the number of personnel required by 28, at an estimated savings of approximately $1.1 million per year. As a result of the smaller fleet sizes, the annual cask maintenance costs decrease by $900,000. All of the annual cost savings resulting from this alternative total an estimated $7.0 million per year, as shown in Table 5.32.

The present worth of the estimated life-cycle cost savings for using the advanced design LWT casks relative to the postulated reference LWT casks has been calculated for discount rates of 0% and 3% using a 21-year lifetime and 1987 dollars. The respective values, shown in Table 5.32, are $166 million and $127 million.

OWT Cask Costs

The total number of truck shipments needed for the advanced design OWT cask is 296 per year. The truck cask fleet size could then be reduced from 26 postulated reference LWT casks to 9 advanced design OWT casks.

The prior OWT cask evaluated in Section 5.1 was estimated to cost $2 million. The primary change from the prior OWT cask is an increase in the stainless steel in the basket due to the increased number of assemblies (although the basket web thickness is decreased). This increased stainless steel results in an estimated increase in cost of about $5,000 per cask. With the reduction in truck cask fleet size by 17 casks, the total capital cost of the truck fleet would be reduced by an estimated $21 million, as shown in Table 5.33.

TABLE 5.33. Comparison of Estimated Life-Cycle Costs for the Postulated Reference System With and Without Advanced Design OWT Casks(a)

Cost Category	Postulated Reference Cost ($)	Advanced Design Alternative Cost ($)	Change in Cost ($)
Capital Costs:			
Truck Cask Fleet	39,000,000	18,000,000	-21,000,000(b)
Annual Costs:			
Cask Maintenance	1,950,000	900,000	-1,050,000
Truck Transport	9,900,000	4,420,000	-5,480,000
At-Reactor Labor	1,060,000	380,000	-680,000
Repository Labor	4,640,000	3,550,000	-1,080,000
Total Annual Cost Difference			-8,290,000
Present Worth of Cost Difference:			
3% Discount Rate			-149,000,000
0% Discount Rate			-195,000,000

(a) Costs are shown to more significant figures than justified, to provide for consistency in the calculations. See Appendix J for details of cost estimates.

(b) A negative sign indicates a cost savings.

The advanced design changes to the OWT cask increase the weight of the empty cask by 185 pounds. The loaded weight also increases due to the loading of more spent fuel assemblies into the cask. The cost per round-trip shipment is $14,930 for this case as compared to the postulated reference cost of $10,200/round-trip shipment. However, the reduced number of shipments would result in reduced annual total transport costs for truck casks by about

$5.5 million per year. Also, as a result of the smaller fleet sizes, the annual cask maintenance costs decrease by an estimated $1.1 million for truck casks.

The increase in the number of spent fuel assemblies that each advanced design OWT cask holds would lead to a slight increase in the labor cost for loading each cask at the reactors. But the reduced number of casks being loaded per year would reduce the at-reactor cask handling labor costs by an estimated $680,000 per year. At the repository, the cost savings for cask handling labor would result from the elimination of the third shift of receiving and unloading personnel from all four of the hot cells. This would result in a decrease in the number of personnel required by 28, at an estimated savings of about $1.1 million per year. All of the annual cost savings resulting from this alternative would total an estimated $8.3 million per year.

The present worth of the estimated life-cycle cost savings for using the advanced design OWT casks relative to the postulated reference LWT casks has been calculated for discount rates of 0% and 3% using a 21-year lifetime and 1987 dollars. The respective values, shown in Table 5.33, are $195 million and $149 million.

Uranium-Shielded Advanced Design Rail Cask Costs

The capital cost of the uranium-shielded rail cask, evaluated in Section 5.2, was estimated to be $3.82 million. The primary change from the prior uranium-shielded rail cask is a reduction of stainless steel in the basket dividers. This reduced material would result in a cost savings of $22,000 per cask, thereby reducing the capital cost of the uranium-shielded advanced design rail cask to $3.8 million. This is higher than the cost of each postulated reference system rail cask of $2.5 million (28 required), but with a reduction in the rail cask fleet size to 15 casks, the total capital cost for the rail cask fleet in this alternative would be reduced by about $13 million, as shown in Table 5.34.

The loaded weight of the rail cask in this alternative increases by 1900 pounds compared to the postulated reference case. The weight of the empty advanced design uranium-shielded rail cask is reduced by 17,000 pounds compared

TABLE 5.34. Comparison of Estimated Life-Cycle Costs for the Postulated Reference System With and Without Advanced Design Uranium-Shielded Rail Casks[a]

Cost Category	Postulated Reference Cost ($)	Advanced Design Alternative Cost ($)	Change in Cost ($)
Capital Costs:			
Rail Cask Fleet	70,000,000	57,000,000	-13,000,000[b]
Annual Costs:			
Cask Maintenance	3,500,000	1,880,000	-1,620,000
Rail Transport	17,050,000	8,220,000	-8,830,000
At-Reactor Labor	590,000	390,000	-200,000
Repository Labor	4,640,000	4,090,000	-550,000
Total Annual Cost Difference			-11,200,000
Present Worth of Cost Difference:			
3% Discount Rate			-186,000,000
0% Discount Rate			-249,000,000

(a) Costs are shown to more significant figures than justified, to provide for consistency in the calculations. See Appendix J for details of cost savings.
(b) A negative sign indicates a cost savings.

to the empty postulated reference cask weight, which results in a slight reduction of cost on the return leg of each shipment. The total round-trip transport cost is $51,400 for the advanced design uranium-shielded rail cask compared to $53,300 per round-trip shipment for the postulated reference case. As a result of the reduced fleet size, the annual maintenance costs also decrease by $1,620,000, as shown in Table 5.34. The reduction in rail shipments of 160 per/year for this alternative results in a rail transport cost decrease of about $8.8 million/year.

The increased cask capacity would increase the cask handling labor cost per shipment at the reactor, but with the reduced number of shipments, the at-reactor labor costs would be reduced by about $200,000/year. The increased capacity also allows for reduction of 14 cask handling workers at the repository receiving facility, resulting in a net reduction in repository labor costs of $550,000/year. Total annual rail operating costs are estimated to be reduced by about $11.2 million for this alternative.

The present worth of the estimated total life-cycle cost savings when using the advanced design uranium-shielded rail casks at discount rates of 0% and 3% are $249 million and $186 million, respectively, using 1987 dollars.

5.5.4 Overview Evaluation of Advanced Design Casks

The use of advanced design casks is estimated to markedly decrease the overall costs of the truck and rail transport of spent fuel, and to reduce the collective doses to workers and public. Because the ratios of Δcost/Δdose for the alternatives are negative, the relative value is not significant, but shows improvements in both cost and radiation doses.

It is expected that the advanced design cask concepts would require additional licensing effort to assure safety from nuclear criticality events. Such a cask system may also require new technology such as burnup meters or additional administrative procedures to verify the burnup of the spent fuel before the fuel is loaded into the casks. The benefits, however, appear sufficient to give strong consideration to this concept.

5.6 SPECIAL IMPACT-WRENCH TOOL FOR CASK LID WORK

In the postulated reference system, standard hand-held impact wrenches are assumed to be used for cask lid work. Thus, two people would typically work 2 to 3 feet from the cask during work activities at the lid end of the cask. These activities contribute a major portion of the total doses received by the workers at the reactor and repository. Worker dose reductions could be achieved if special impact-wrench tools that are faster-acting and are on longer handles were used. With such tools, workers could stand an estimated 3 feet farther from the cask in lower radiation dose-rate fields and complete the operation in less time. This alternative estimates impacts on radiation doses and costs for one example of numerous types of special impact-wrench tools, when applied to the truck and rail casks in the postulated reference system. This concept would have no effects on in-transit doses and costs.

5.6.1 Description of Special Impact-Wrench Tools

The wrenches used for working on the outer and inner cask lids in the postulated reference system were assumed to be standard hand-held impact wrenches. This work is assumed to be done primarily by two maintenance-craftsmen standing close to the cask when lid bolts are removed or tightened. Furthermore, in the postulated reference system it is assumed that one person is needed to operate the wrench while another worker is assisting.

One example of a special tool is a pair of specially-mounted impact wrenches. Two impact wrenches, mounted on a long bar/handle, conceptualized in Figure 5.1, would allow workers to remove two bolts at one time and to stand farther away from the cask where the dose rates are lower, and complete the work more quickly. It is envisioned that these tools would be supported by an overhead framework, and the entire assembly could be moved up and down and rotated through 360 degrees. The relative positions of the impact wrenches would be variable, to accommodate different cask sizes. One worker would be positioned at each end of the "strong-back" (or support bar) at the control handles. In unison, the workers would lower the strong-back and the two impact wrenches to connect the drive sockets to lid bolts located directly across from one another. Once the sockets were engaged to the bolts, the workers would power the impact wrenches to remove or loosen the bolts. The workers would then lift the strong-back, rotate the assembly, and proceed to the next two bolts. In contrast to the postulated reference system, two workers would be able to remove two bolts simultaneously, decreasing the time needed to complete bolt removal. Thus, in addition to reducing worker doses, operation times would decrease for the affected activities.

5.6.2 Operational and Dose Impacts of Special Impact-Wrench Tools

The radiation dose effects to workers from using special impact-wrench tools for cask lid work are discussed in this section. A summary of the annual collective radiation dose reductions for at-reactor and at-repository workers using this alternative is presented in Table 5.35. (This alternative has no

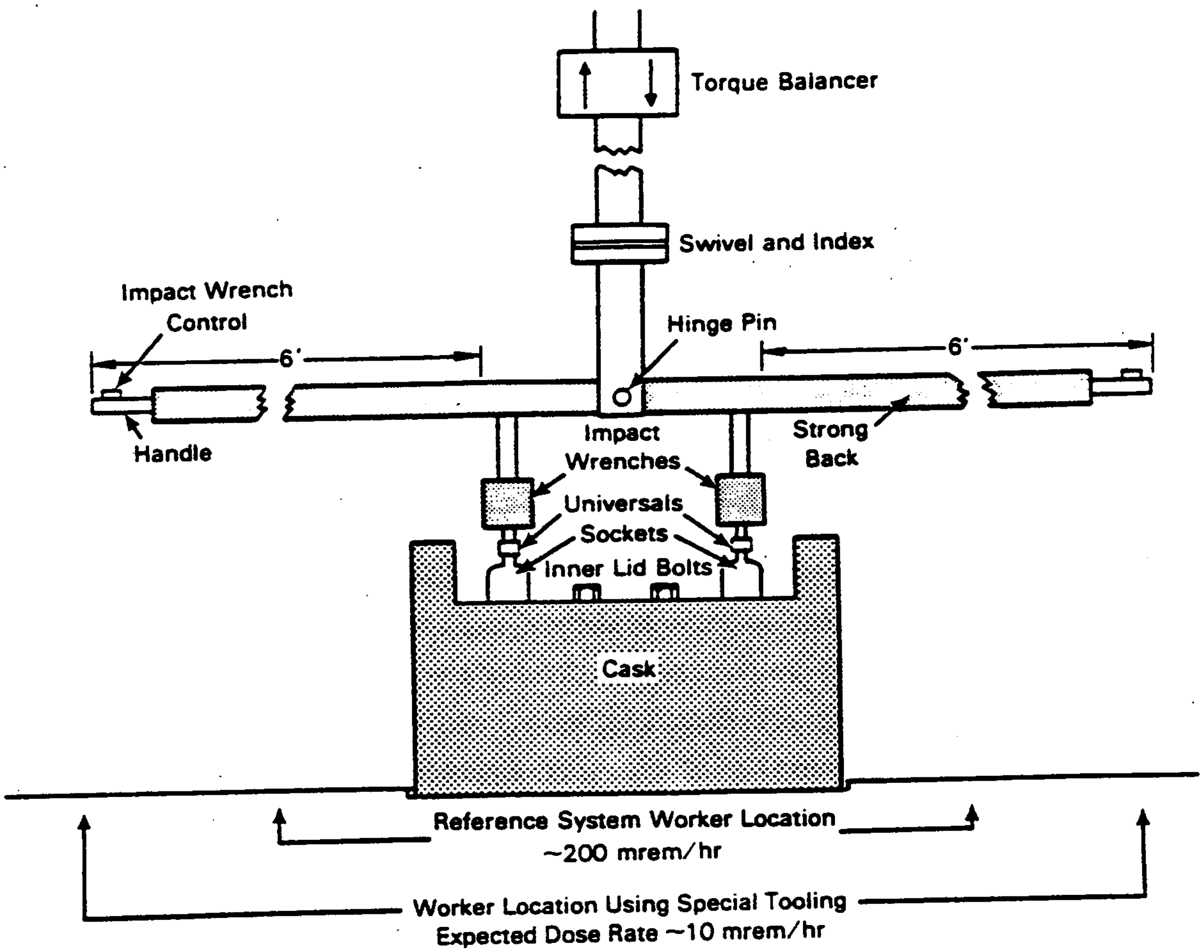


FIGURE 5.1. Special Impact-Wrench Tooling and Power Equipment

TABLE 5.35. Summary Comparison of Estimated Annual Collective Radiation Doses for the Postulated Reference System With and Without Special Impact-Wrench Tools

	person-rem/year								
	Truck			Rail			Total System[a,b]		
	Postulated Reference	Special Tools Alternative	Dose Change	Postulated Reference	Special Tools Alternative	Dose Change	Postulated Reference	Special Tools Alternative	Dose Change
At-Reactor	271	246	-25	144	125	-19	415	371	-44
At-Repository	269	162	-107	149	62	-87	418	224	-194
Totals	540	408	-132	293	187	-106	833	595	-238

(a) Based on 0.924 MTU/PWR truck shipment, 0.930 MTU/BWR truck shipment, 6.47 MTU/PWR rail shipment, and 6.70 MTU/BWR rail shipment.

(b) Cask capacity is 2/5 PWR/BWR assemblies for truck shipments, and 14/36 PWR/BWR assemblies for rail shipments.

effect on in-transit doses.) Collective doses received by reactor cask handling workers would decrease by an estimated 10%, and doses received by repository cask handling workers would decrease by about 46%. Radiation doses to reactor cask handling workers would not decrease as much as to repository workers because the cask is in the spent fuel pool and filled with water when much of the lid work is done on a loaded cask at a reactor.

At-Reactor Impacts

The cask handling activity steps at the reactor that are affected by the use of the special impact-wrench tool are 8.1 (remove outer lid bolts and store), 8.10 (loosen inner lid bolts), 15.1 (install inner lid bolts, remove lid-lifting fixture), and 15.10 (install outer lid). The distances for maintenance-craftsmen working on cask lids increase for this alternative, which reduces the dose rate they are exposed to. In addition, removal of two bolts simultaneously with the special impact-wrench tool results in reduced work times. The dose rate during this work is reduced from 20 mrem/hour in the postulated reference system to an estimated 2 mrem/hour for this alternative. As before, the cask is still filled with water at this point. It is estimated that turnaround time for truck and rail shipments decreases by 25 and 50 minutes, respectively, as a result of the more efficient tool.

Estimated collective radiation doses received by the reactor cask handling workers are shown in Table 5.36. Doses are reduced by about 9% for truck shipments and by about 11% to 14% for rail shipments, compared to the postulated reference system. For both truck and rail shipments, about 94% of the reduction in collective worker dose results from the effects during activity 15. Maintenance-craftsmen benefit from the majority of the dose reductions (90% of the total worker collective dose for truck, 95% for rail), because they remove all lid bolts.

The average annual doses to individual operators during at-reactor truck cask handling operations in the postulated reference system are reduced from 898 mrem/year to 883 mrem/year when using special impact-wrench tools for PWR operations, and from 1035 mrem/year to 1019 mrem/year for BWR operations. For maintenance-craftsmen, the equivalent doses are the same for both PWR and BWR operations and would be reduced from 1011 mrem/year in the postulated

TABLE 5.36. Summary Comparison of Estimated Collective Radiation Doses at the Postulated Reference Reactor With and Without Special Impact-Wrench Tools

	Postulated Reference			Special Tools Alternative		
	Person-mrem/ Shipment	Person-mrem/ MTU[(a)]	Person-rem/ year[(b)]	Person-mrem/ Shipment	Person-mrem/ MTU[(a)]	Person-rem/ year[(b)]
Truck						
PWR	271	293	158	245	265	143
BWR	292	314	113	266	286	103
Total			271			246
Rail						
PWR	404	62	78	346	53	67
BWR	520	78	66	462	69	58
Total			144			125

(a) Based on 0.924 MTU/PWR truck shipment, 0.930 MTU/BWR truck shipment, 6.47 MTU/PWR rail shipment, and 6.70 MTU/BWR rail shipment.

(b) Based on 540 MTU of PWR and 360 MTU of BWR spent fuel by truck and 1200 MTU of PWR and 840 MTU of BWR spent fuel by rail.

reference system to 824 mrem/year when using special impact-wrench tools. Details of these dose calculations are contained in Appendix N.

At-Repository Impacts

Cask handling activity steps at the repository that are affected by the use of special impact-wrench tools for lid work are steps 8.3 (remove outer lid and place on platform), 8.5 (remove all but 4 bolts on inner lid), 18.4 (install inner lid bolts), and 18.6 (install outer lid). The dose rate for inner cask lid work with a loaded cask in this alternative is performed in a 10 mrem/hour dose field, rather than in a 200 mrem/hour field as in the postulated reference system.

It is estimated that cask turnaround time at the repository is reduced by 25 minutes for a truck shipment and 40 minutes for a rail shipment for this alternative. Estimated collective radiation doses received by cask handling workers at the repository are shown in Table 5.37. Collective dose reductions of about 40% for handling truck casks and about 58% for handling rail casks are noted. The collective dose from activity 8, which is the greatest contributor to occupational doses at the repository in the postulated reference system, is

TABLE 5.37. Summary Comparison of Estimated Collective Radiation Doses at the Postulated Reference Repository With and Without Special Impact-Wrench Tools

	Postulated Reference			Special Tools Alternative		
	Person-mrem/ Shipment	Person-mrem/ MTU(a)	Person-rem/ year(b)	Person-mrem/ Shipment	Person-mrem/ MTU(a)	Person-rem/ year(b)
Truck						
PWR	276	299	162	166	180	97
BWR	277	298	107	167	180	65
Total			209			162
Rail						
PWR	463	72	91	195	30	38
BWR	466	70	59	197	29	24
Total			149			62

(a) Based on 0.924 MTU/PWR truck shipment, 0.930 MTU/BWR truck shipment, 6.47 MTU/PWR rail shipment, and 6.70 MTU/BWR rail shipment.

(b) Based on 540 MTU of PWR and 360 MTU of BWR spent fuel by truck and 1200 MTU of PWR and 840 MTU of BWR spent fuel by rail.

reduced by an estimated 110 person-mrem (59% reduction) for a truck shipment and an estimated 268 person-mrem (77% reduction) for a rail shipment.

As in the reactor operations, maintenance-craftsmen benefit most from the dose reductions. The individual maintenance-craftsman's average annual dose is estimated to decrease from 8.2 rem/year from truck shipments and 5.0 rem/year from rail shipments in the postulated reference system, to 4.2 rem/year and 1.7 rem/year, respectively, for this alternative. Details of these dose calculations are contained in Appendix N.

5.6.3 Cost Consequences of Special Impact-Wrench Tools

As described above, operational times would decrease slightly at both the reactors and the repository by using the special impact-wrench tools. The labor at the repository is not reduced enough to eliminate one shift of workers, so no labor cost savings are assumed to result from this alternative at the repository. At the reactors, though, any time saved is assumed to reduce the labor costs charged to the cask loading activities. Thus, the special impact-wrench tool alternative results in labor savings at the reactor of about $52,600 per year, as shown in Table 5.38.

TABLE 5.38. Comparison of Estimated Life-Cycle Costs for the Postulated Reference System With and Without Special Impact-Wrench Tools[a]

Cost Category	Postulated Reference Cost ($)	Special Tools Alternative Cost ($)	Change in Cost ($)
Capital Costs:			
Tool Cost	0	105,000	105,000
Annual Costs:			
At-Reactor Labor	1,649,600	1,597,000	-52,600[b]
Present Worth of Cost Difference:			
3% Discount Rate			-472,000
0% Discount Rate			-580,000

(a) Costs are shown to more significant figures than justified, to provide for consistency in the calculations. See Appendix J for cost estimating details.
(b) A negative cost denotes a cost savings.

The capital cost of the special impact-wrench tool is composed of four separate components: adjustable tool support bar, torque balancer, swivel, and remote controls. The total cost of the four components is estimated to be $825. Assuming that the 117 operating, and soon-to-be operating, reactors in the United States will need one of these tools and that the repository will need ten of them, the total capital cost is estimated to be $104,800 (127 x $825).

The present worth of the estimated life-cycle cost savings for the special impact-wrench tool alternative has been calculated for discount rates of 0% and 3% using a 5-year tool lifetime and 1987 dollars. The respective values, shown in Table 5.38, are $580,000 and $472,000.

5.6.4 Overview Evaluation of Special Impact-Wrench Tools

The use of a special impact-wrench tool would decrease both the overall costs of the truck and rail transportation of spent fuel, and the collective doses to reactor and repository cask handling workers. The resultant ratio of

Δcost/Δdose is negative, and the concept appears to be attractive for future consideration. Special impact-wrench tools also may be an attractive alternative for other applications and could be considered for such uses as for impact limiter and tiedown removal. There should be little or no concerns about licensing issues for this alternative, but nonradiological occupational risks should be evaluated before implementation.

The costs of this alternative might be reduced by the hauling of such special tooling in a separate truck along with all other accessories needed to prepare for each campaign, rather than purchasing a set of tools for each reactor. This possibility has not been evaluated, however.

5.7 SINGLE-ACTION FASTENERS FOR CASK LIDS

The cask inner lid provides the primary seal and shielding for the spent fuel in the cask cavity. In the postulated reference system, the inner cask lid is secured by 12 bolts for a truck cask and by 36 bolts for a rail cask. Eight and twelve bolts, respectively, secure the outer cask lids. These bolts are installed and removed with conventional hand-held impact wrenches by maintenance-craftsmen working in radiation zones with dose rates of 200 mrem/hour (inner lid) and 30 mrem/hour (outer lid) for a loaded cask. This operation is one of the major contributors to the repository and reactor worker radiation doses. The use of single-action fastener mechanisms on the inner and outer lids could result in considerable dose reductions to these workers. This concept, however, would have no effects on in-transit costs or doses.

5.7.1 Description of Single-Action Fasteners

An alternative to the multiple bolts required for cask closure could be to modify the inner and outer cask lids and their associated cask feature to allow the use of single-action fasteners for cask closure. An illustrative concept for doing this is shown in Figure 5.2. The 12 bolts on the truck cask inner lid and the 36 bolts on the rail cask inner lid would be replaced by a single massive stud bolt located at the top center of the inner cask lid. A nearly identical system would also replace the bolt fasteners on top of the outer lid. The stud bolt would accommodate a castle nut, a thrust bearing washer assembly, and three or more pie-shaped sectors (lever arms) that engage a

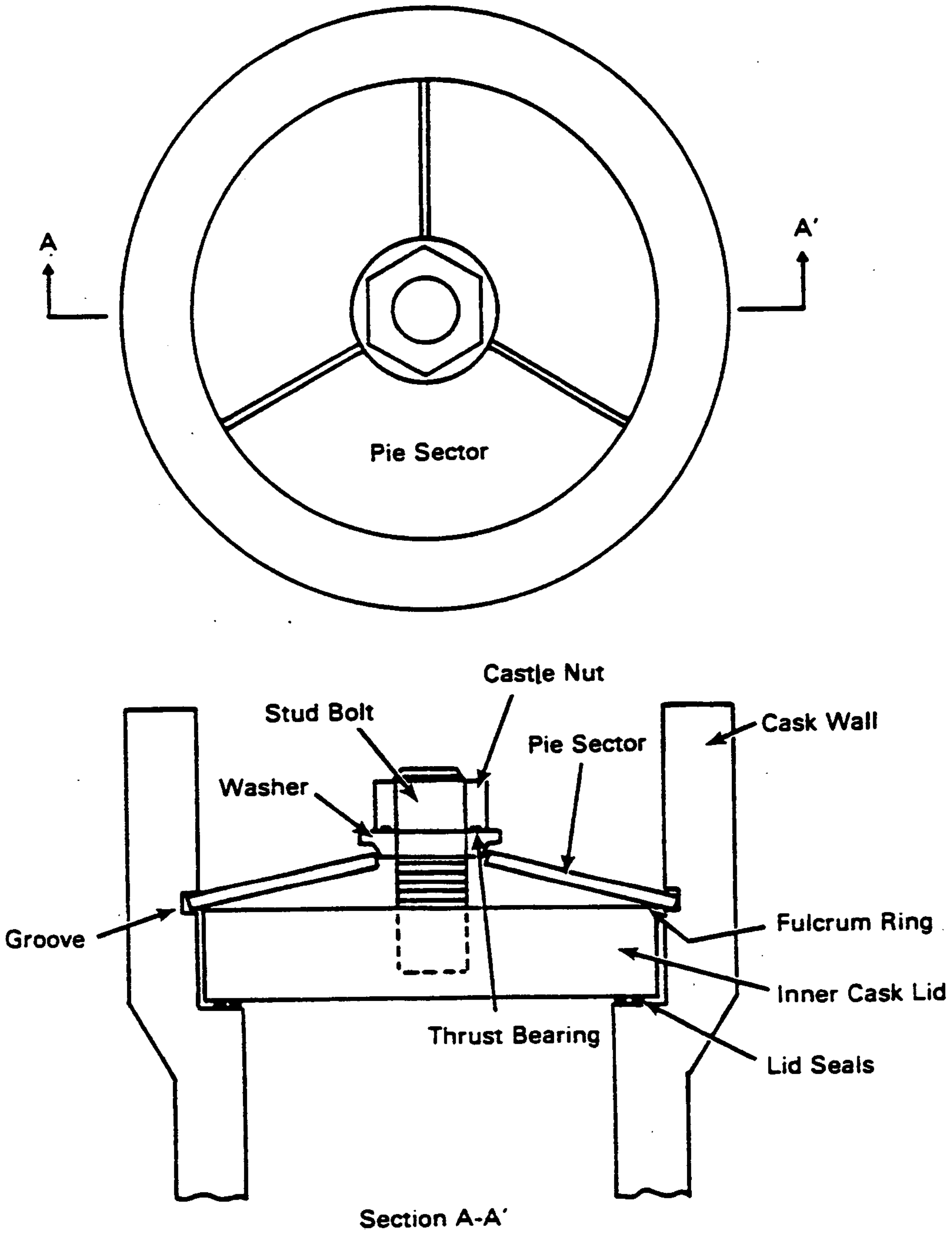


FIGURE 5.2. Single-Action Fastener for Cask Lids

machined groove in the cask body. As the single nut and washer assembly is screwed down onto the stud bolt, the pie-shaped sectors would be inserted into machined grooves in the cask body. When fully inserted, the sectors would compress the cask lid seals and hold the lid securely in place. A snap ring key would be inserted through the castle nut and the stud bolt to prevent inadvertent loosening of the lid. The pie-shaped sector concept used on the single-fastener cask closure would allow full use of the lid penetrations and lid-lifting device.

5.7.2 Operational and Dose Impacts of Single-Action Fasteners

The effects of using single-action fasteners for cask lid closure are discussed in this section. The single-action lid closure in this alternative is assumed to be applied to postulated reference truck and rail casks with capacities of 2/5 PWR/BWR and 14/36 PWR/BWR assemblies, respectively. A summary of estimated collective annual dose reductions for cask handling workers at the reactor and at the repository is presented in Table 5.39. Total doses received by reactor cask handling workers are estimated to decrease by 8%, and by repository workers by 48%. Reactor worker doses would not decrease as much as repository doses because the cask is in the spent fuel pool and filled with water when most lid work is done on a loaded cask at a reactor.

TABLE 5.39. Summary Comparison of Estimated Annual Collective Radiation Doses for the Postulated Reference System With and Without Single-Action Fasteners for Cask Lids

	person rem/year								
	Truck			Rail			Total System[a,b]		
	Postulated Reference	Single-Action Alternative	Dose Change	Postulated Reference	Single-Action Alternative	Dose Change	Postulated Reference	Single-Action Alternative	Dose Change
At-Reactor	271	253	-18	144	130	-13	415	384	-31
At-Repository	269	158	-111	149	62	-87	418	219	-198
Totals	540	411	-129	293	192	-100	833	603	-229

(a) Based on 0.924 MTU/PWR truck shipment, 0.930 MTU/BWR truck shipment, 6.47 MTU/PWR rail shipment, and 6.70 MTU/BWR rail shipment.

(b) Cask capacity is 2/5 PWR/BWR assemblies for truck shipments, and 14/36 PWR/BWR assemblies for rail shipments.

At-Reactor Impacts

The cask handling activity steps at the reactor that are affected by the use of single-action fasteners are 8.1 (remove outer lid bolts and store), 8.3 (seal bolt and pin holes), 8.10 (loosen inner lid bolts), 8.11 (remove and store inner lid bolts), 15.1 (install inner lid bolts, remove lid-lifting fixture), and 15.10 (install outer lid). Maintenance-craftsmen distances from the cask would be unaffected when the single-action fasteners are used, but times to complete the activity would be substantially reduced, thereby reducing the doses they receive. Turnaround time is estimated to decrease by 60 minutes for a truck shipment and by 120 minutes for a rail shipment as a result of this alternative.

Estimated collective radiation doses received by cask handling workers at the reactor are shown in Table 5.40. Doses would be reduced by about 6% to 7% for truck shipments and by 8% to 10% for rail shipments compared to the postulated reference system. For both truck and rail shipments, activity 15 is responsible for 75% to 80% of the reduction in collective worker dose. Maintenance-craftsmen would benefit from the majority of the dose reductions (77% of the total worker collective dose for truck, 82% for rail), because they perform all bolt removal activities in the postulated reference system.

TABLE 5.40. Summary Comparison of Estimated Collective Radiation Doses at the Postulated Reference Reactor With and Without Single-Action Fasteners for Cask Lids

	Postulated Reference			Single-Action Alternative		
	Person-mrem/ Shipment	Person-mrem/ MTU[(a)]	Person-rem/ year[(b)]	Person-mrem/ Shipment	Person-mrem/ MTU[(a)]	Person-rem/ year[(b)]
Truck						
PWR	271	293	158	252	272	147
BWR	292	314	113	273	294	106
Total			271			253
Rail						
PWR	404	62	78	362	56	70
BWR	520	78	66	478	72	60
Total			144			130

(a) Based on 0.924 MTU/PWR truck shipment, 0.930 MTU/BWR truck shipment, 6.47 MTU/PWR rail shipment, and 6.70 MTU/BWR rail shipment.

(b) Based on 540 MTU of PWR and 360 MTU of BWR spent fuel by truck and 1200 MTU of PWR and 840 MTU of BWR spent fuel by rail.

The average annual doses to individual operators during at-reactor truck cask handling operations in the postulated reference system are reduced from 898 mrem/year to 872 mrem/year when using single-action fasteners for PWR operations, and from 1035 mrem/year to 1008 mrem/year for BWR operations. For maintenance-craftsmen, the equivalent doses are the same for both PWR and BWR operations and would be reduced from 1011 mrem/year in the postulated reference system to 893 mrem/year when using single-action fasteners. Details of these dose calculations are contained in Appendix N.

At-Repository Impacts

Cask handling activity steps at the repository that are affected by the use of single-action fasteners for cask lids are steps 8.3 (remove outer lid and place on platform), 8.5 (remove all but 4 bolts on inner lid), 12.2 (remove 4 bolts), 15.4 (install 4 bolts), 18.4 (install inner lid bolts), and 18.6 (install outer lid). Activities 8.5 and 18.4 are essentially eliminated in this alternative (the single-action fastener on the inner lid is assumed to be loosened in the hot cell).

In this alternative, turnaround time is estimated to be reduced by 85 minutes for a truck shipment and by 130 minutes for a rail shipment. Dose reductions at the repository for this alternative would be substantial because, unlike the reactor situation, the cask is not filled with water when lid work is done. The reduction in activity times would result in lower doses to personnel. Estimated collective radiation doses received by cask handling workers at the repository are shown in Table 5.41. Collective dose reductions of about 41% for truck casks and about 59% for rail casks are noted. The collective dose from activity 8, which is the greatest contributor to occupational doses at the repository, is reduced 113 person-mrem (61% reduction) for a truck shipment and 272 person-mrem (78% reduction) for a rail shipment.

As in the reactor case, maintenance-craftsmen at the repository benefit most from the dose reductions. The individual maintenance-craftsman's average annual dose is estimated to decrease from 8.2 rem/year from truck shipments and 5.0 rem/year from rail shipments in the postulated reference system to 4.1 rem/year and 1.7 rem/year, respectively, for this alternative, using the same 26 maintenance-craftsmen. Details of these dose calculations are contained in Appendix N.

TABLE 5.41. Summary Comparison of Estimated Collective Radiation Doses at the Postulated Reference Repository With and Without Single-Action Fasteners for Cask Lids

	Postulated Reference			Single-Action Alternative		
	Person-mrem/ Shipment	Person-mrem/ MTU[a]	Person-rem/ year[b]	Person-mrem/ Shipment	Person-mrem/ MTU[a]	Person-rem/ year[b]
Truck						
PWR	276	299	162	162	175	95
BWR	277	298	107	163	175	63
Total			269			158
Rail						
PWR	463	72	91	191	30	38
BWR	466	70	59	194	29	24
Total			149			62

(a) Based on 0.924 MTU/PWR truck shipment, 0.930 MTU/BWR truck shipment, 6.47 MTU/PWR rail shipment, and 6.70 MTU/BWR rail shipment.

(b) Based on 540 MTU of PWR and 360 MTU of BWR spent fuel by truck and 1200 MTU of PWR and 840 MTU of BWR spent fuel by rail.

5.7.3 Cost Consequences of Single-Action Fasteners

It was estimated that operational times would decrease at both the reactors and the repository by the use of single-action fasteners on both closures on the truck and rail casks. The cask handling labor at the repository is not reduced enough to eliminate one shift of workers. Therefore, labor cost savings at the repository are taken to be zero for this alternative. At the reactors, though, any operational time is assumed to reduce the labor costs charged to the cask handling activities. Thus, the single-action fastener closure alternative results in labor cost savings at the reactors. These labor savings, as shown in Table 5.42, are estimated to be $115,000 per year.

The capital cost for the single-action fastener closures for each cask is made up of two components: the two locking disk lids for both the inner and outer lids, and the cost of milling the grooves in the cask. This capital cost is partially offset by the savings resulting from eliminating 20 bolts per truck cask and 48 bolts per rail cask, and the cost to drill and tap the holes for these bolts. The net increased capital costs for the single-action fastener closure alternative are estimated to be $7870 per truck cask and $8460

TABLE 5.42. Comparison of Estimated Life-Cycle Costs for the Postulated Reference System With and Without Single-Action Fasteners[a]

Cost Category	Postulated Reference Cost ($)	Single-Action Alternative Cost ($)	Change in Cost ($)
Capital Costs:			
Truck Cask Fleet	39,000,000	39,205,000	205,000
Rail Cask Fleet	70,000,000	70,235,000	235,000
Total Capital Costs			440,000
Annual Costs:			
At-Reactor Labor	1,649,000	1,534,000	-115,000[b]
Present Worth of Cost Difference:			
3% Discount Rate			-1,340,000
0% Discount Rate			-1,980,000

(a) Costs are shown to more significant figures than justified, to provide for consistency in the calculations. See Appendix J for details of cost savings.

(b) A negative cost denotes a cost savings.

per rail cask, or $205,000 ($7870 x 26 casks) for the truck cask fleet and $235,000 ($8460 x 28 casks) for the rail cask fleet.

The weight of the casks in this alternative is estimated to be the same as for the postulated reference casks. Thus, there would be no effect on in-transit costs for using this alternative.

The present worth of the estimated total life-cycle cost savings for this alternative, using a 21-year lifetime and 1987 dollars, is $2.0 million and $1.3 million, for discount rates of 0% and 3%, respectively.

5.7.4 Overview Evaluation of Single-Action Fasteners

The use of single-action fasteners is estimated to decrease slightly the overall system costs and decrease reactor and repository worker doses. Because the ratio of Δcost/Δdose is negative, its magnitude is not meaningful. With both a cost reduction and a dose reduction this alternative is attractive.

However, it should be noted that it may be difficult to license such a concept and that the additional testing and licensing cost may overcome the small potential cost savings.

5.8 BUILT-IN LID-LIFTING FIXTURES

In the postulated reference system, a lid-lifting fixture must be installed on the inner cask lid prior to lid removal. Similarly, the fixture must be removed after the inner lid is replaced. Although the time to install or remove the lid-lifting fixture is short (estimated at 5 minutes each), the work is done in a radiation dose field of up to 200 mrem/hour. Dose reductions are achievable with the use of a built-in lid-lifting fixture, thus eliminating the activities for installation/removal of the lifting adapter. Use of this concept would have no effects on in-transit doses or costs.

5.8.1 Description of Built-in Lid-Lifting Fixtures

A three-point lid-lifting appendage that is a part of the inner lid is an example of an alternative to the requirement for installing a lid-lifting device each time a cask is opened/closed. This concept is illustrated in Figure 5.3. This device would consist of three pintles that are an integral part of the inner lid. These pintles would be located on the lid to provide a balanced lift and to not interfere with the service pipes currently proposed for the inner lid. A special yoke that contains the grapples for connection to the pintles would be provided as a part of the handling equipment package used at the reactor and repository sites. This yoke and its grapples would be designed for either contact or remote operation. With the outer lid removed, the yoke would be moved into position by the appropriate crane, hoist, or power mast and the grapples would be engaged with the pintles. At this point the inner lid could be removed or replaced. A three-point lift on the circular lid is felt to provide a more stable lift/return compared to a single- or four-point lift design.

5.8.2 Operational and Dose Impacts of Built-in Lid-Lifting Fixtures

This section discusses the effects of using built-in lid-lifting fixtures, rather than installing an adapter every time the inner lid requires removal, as

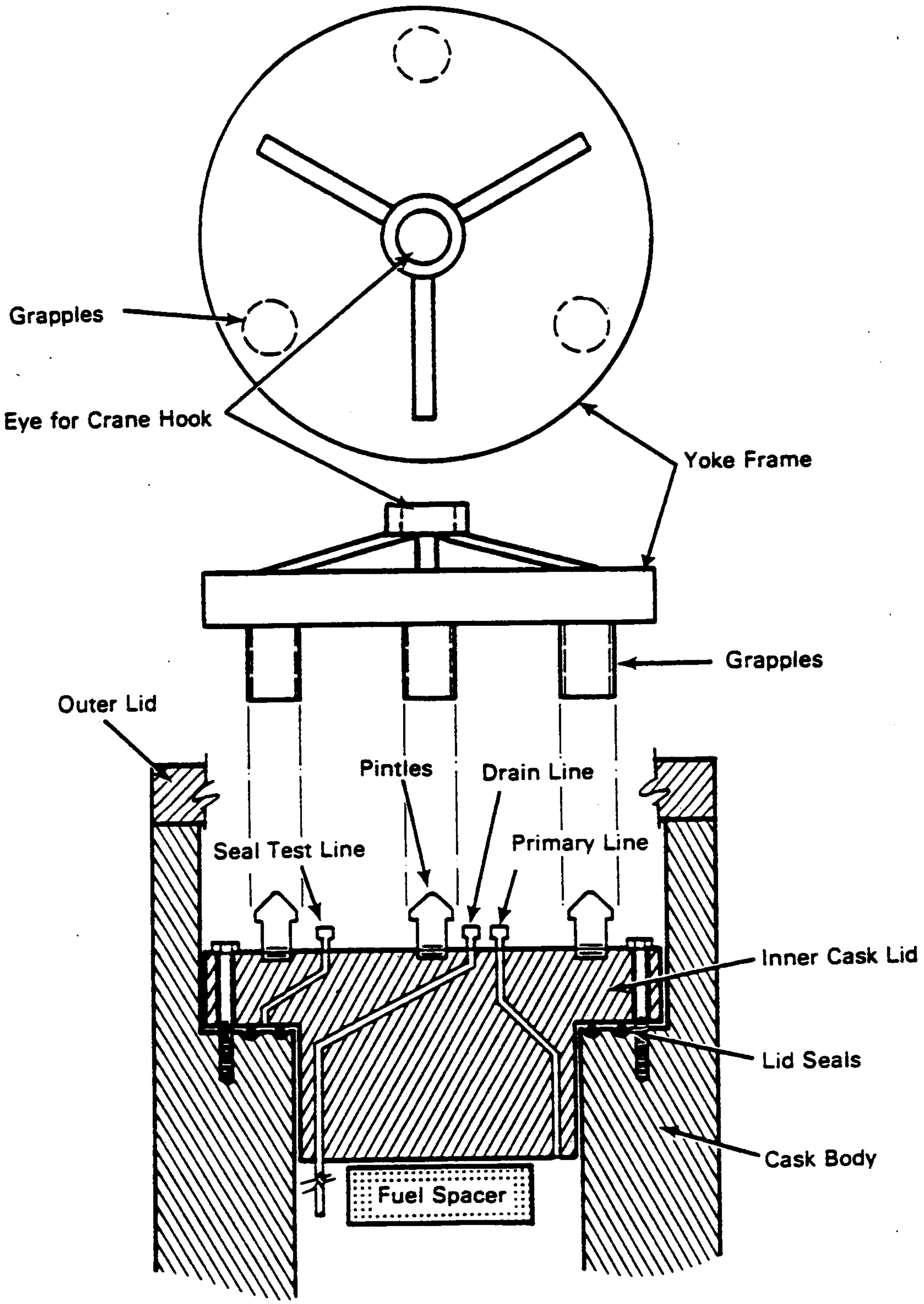


FIGURE 5.3. Built-in Lid-Lifting Fixture and Yoke/Grapple Hardware

in the postulated reference system. Table 5.43 presents a summary of the estimated annual collective doses for cask handling operations at the reactor and at the repository. Total collective doses received by cask handling workers at the reactors are estimated to be reduced by 2%, and at the repository by 11%. Worker doses at the reactor are not reduced as much as at the repository because the cask is full of water at the reactor when the removal operation is performed.

TABLE 5.43. Summary Comparison of Estimated Annual Collective Radiation Doses for the Postulated Reference System With and Without Built-in Lid-Lifting Fixtures

	person-rem/year								
	Truck			Rail			Total System[a,b]		
	Postulated Reference	Lid Fixture Alternative	Dose Change	Postulated Reference	Lid Fixture Alternative	Dose Change	Postulated Reference	Lid Fixture Alternative	Dose Change
At-Reactor	271	264	-7	144	142	-2	415	406	-9
At-Repository	269	234	-35	149	139	-10	418	373	-45
Totals	540	498	-42	293	281	-12	833	779	-54

(a) Based on 0.924 MTU/PWR truck shipment, 0.930 MTU/BWR truck shipment, 6.47 MTU/PWR rail shipment, and 6.70 MTU/BWR rail shipment.

(b) Cask capacity is 2/5 PWR/BWR assemblies for truck shipments, and 14/36 PWR/BWR assemblies for rail shipments.

At-Reactor Impacts

The cask handling activity steps at the reactor that are affected by the use of built-in lid-lifting fixtures are 8.11 (remove and store inner lid bolts, install lid-lifting fixture) and 15.1 (install inner lid bolts, remove lid-lifting fixture). The times to perform these activities are reduced because a fixture does not need to be installed or removed. Turnaround time for both truck and rail shipments decreases by an estimated 10 minutes.

Doses received by the cask handling workers at the reactor are shown in Table 5.44. About a 2% reduction in dose for truck shipments and about a 1% to 2% reduction for rail shipments are estimated in comparison with those for the postulated reference case. For both truck and rail shipments, activity 15 is responsible for about 90% of the reduction in dose. Maintenance-craftsmen would benefit from the majority of the dose reductions.

TABLE 5.44. Summary Comparison of Estimated Collective Radiation Doses at the Postulated Reference Reactor With and Without Built-in Lid-Lifting Fixtures

	Postulated Reference			Lid Fixture Alternative		
	Person-mrem/ Shipment	Person-mrem/ MTU[a]	Person-rem/ year[b]	Person-mrem/ Shipment	Person-mrem/ MTU[a]	Person-rem/ year[b]
Truck						
PWR	271	293	158	264	285	154
BWR	292	314	113	285	306	110
Total			271			264
Rail						
PWR	404	62	78	397	61	77
BWR	520	78	66	513	77	65
Total			144			142

(a) Based on 0.924 MTU/PWR truck shipment, 0.930 MTU/BWR truck shipment, 6.47 MTU/PWR rail shipment, and 6.70 MTU/BWR rail shipment.

(b) Based on 540 MTU of PWR and 360 MTU of BWR spent fuel by truck and 1200 MTU of PWR and 840 MTU of BWR spent fuel by rail.

The average annual doses to individual operators during at-reactor truck cask handling operations in the postulated reference system are reduced from 898 mrem/year to 895 mrem/year when using built-in-lid-lifting fixtures for PWR operations, and from 1035 mrem/year to 1032 mrem/year for BWR operations. For maintenance-craftsmen, the equivalent doses are the same for both PWR and BWR operations and would be reduced from 1011 mrem/year in the postulated reference system to 963 mrem/year when using built-in lid-lifting fixtures. Details of these dose calculations are contained in Appendix N.

At-Repository Impacts

Cask handling activity steps at the repository that are affected by the use of built-in lid-lifting fixtures are steps 8.6 (install lid-lifting fixture) and 18.3 (remove lid-lifting fixture). The cask is full of fuel in step 8.6, and is empty in step 18.3. These activities are eliminated in this alternative. Cask turnaround time is reduced by an estimated 10 minutes for both truck and rail shipments.

Radiation doses to the cask handling workers are reduced at the repository as a result of the reduced cask contact time in this alternative. Collective cask handling worker doses received at the repository are shown in Table 5.45.

TABLE 5.45. Summary Comparison of Estimated Collective Radiation Doses at the Postulated Reference Repository With and Without Built-in Lid-Lifting Fixtures

	Postulated Reference			Lid Fixture Alternative		
	Person-mrem/ Shipment	Person-mrem/ MTU(a)	Person-rem/ year(b)	Person-mrem/ Shipment	Person-mrem/ MTU(a)	Person-rem/ year(b)
Truck						
PWR	276	299	162	241	261	141
BWR	277	298	107	241	259	93
Total			269			234
Rail						
PWR	463	72	91	428	67	84
BWR	466	70	59	431	65	55
Total			149			139

(a) Based on 0.924 MTU/PWR truck shipment, 0.930 MTU/BWR truck shipment, 6.47 MTU/PWR rail shipment, and 6.70 MTU/BWR rail shipment.

(b) Based on 540 MTU of PWR and 360 MTU of BWR spent fuel by truck and 1200 MTU of PWR and 840 MTU of BWR spent fuel by rail.

Estimated reductions in collective worker doses of about 13% for handling truck casks and about 8% for handling rail casks are noted. The collective worker dose from activity 8 is estimated to be reduced by 36 person-mrem (19% reduction) for a truck shipment and 35 person-mrem (10% reduction) for a rail shipment.

Maintenance-craftsmen would benefit from nearly all of the dose reductions. The average annual dose to individual maintenance-craftsmen is estimated to be reduced from 13.2 rem/year in the postulated reference system to 11.6 rem/yr with this alternative (using the same 26 maintenance-craftsmen as in the postulated reference system). Details of these dose calculations are contained in Appendix N.

5.8.3 Cost Consequences of Built-in Lid-Lifting Fixtures

The estimated dose reductions described above result from reduced activity times both at the reactors and at the repository from using the built-in lid-lifting fixture. The estimated decrease in labor needs at the repository is not enough to eliminate one shift of workers, so no labor cost savings are assumed to result from using this alternative at the repository. At the reactors, though, any time saved is assumed to reduce the labor costs charged to the cask loading activities. Thus, the use of built-in lid-lifting fixtures results in small labor cost savings at the reactors. These labor savings, as shown in Table 5.46, are estimated at $17,600 per year.

TABLE 5.46. Comparison of Estimated Life-Cycle Costs for Built-in Lid-Lifting Fixtures[a]

Cost Category	Postulated Reference Cost ($)	Lid Fixture Alternative Cost ($)	Change in Cost ($)
Capital Costs:			
Fixture Cost	0	2,800,000	2,800,000
Annual Costs:			
At-Reactor Labor	1,649,700	1,632,100	-17,600[b]
Present Worth of Cost Difference:			
3% Discount Rate			2,530,000
0% Discount Rate			2,430,000

(a) Costs are shown to more significant figures than justified, to provide for consistency in the calculations. See Appendix J for details of cost savings.

(b) A negative cost denotes a cost savings.

The built-in lid-lifting fixture and yoke are already manufactured by and available from a vendor in the United States. The cost for one of these units is conservatively estimated at $22,000. Assuming that the 117 operating, and soon-to-be operating, reactors in the United States will each need one of these adapters and that the repository will need ten of them, the total capital cost for fixtures is estimated to be $2.8 million (127 x $22,000).

The weight of the casks in this alternative is estimated to be the same as for the postulated reference casks. Thus, there would be no effect on in-transit costs for using this alternative.

As shown in Table 5.46, the present worth of the estimated total life-cycle cost savings for this alternative, using a 21-year lifetime and 1987 dollars, is \$2.4 million and \$2.5 million, for discount rates of 0% and 3%, respectively.

5.8.4 Overview Evaluation of Built-in Lid-Lifting Fixtures

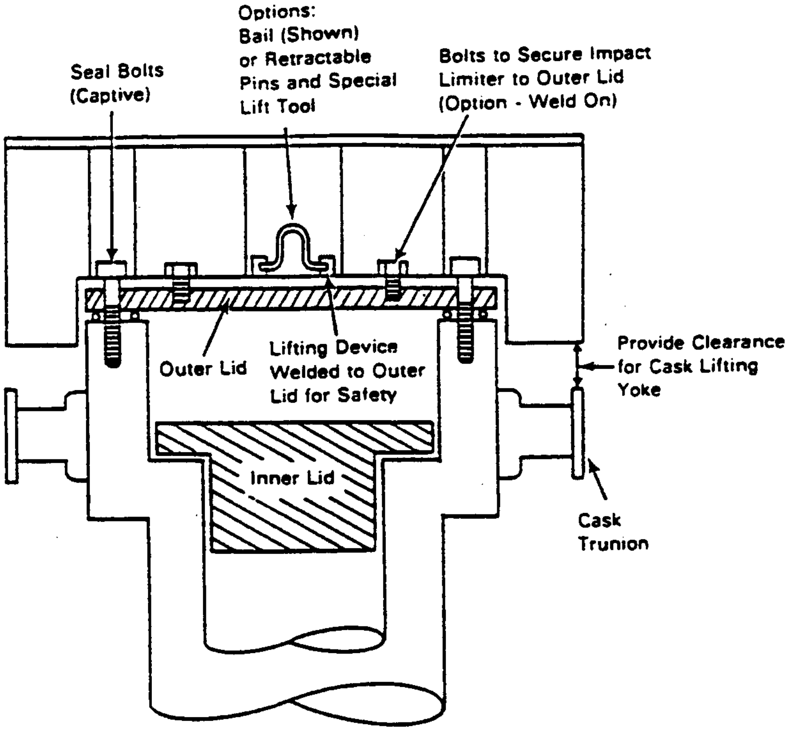
The use of built-in lid-lifting fixtures on the cask inner lids is estimated to slightly increase overall system costs and to decrease cask handling worker doses at the reactor and repository. The ratios of Δcost/Δdose for the system using 0% and 3% discount rates are \$2140 and \$2190 per person-rem avoided, respectively. The ratio is in the range where the alternative warrants further detailed consideration. One concern in using this alternative could be a slight increase in difficulty in the making and breaking of connections on the inner lid. A possible improvement in costs might be realized by the hauling of the handling yoke with the cask rather than purchasing one set for each reactor.

5.9 INTEGRAL CASK IMPACT LIMITERS

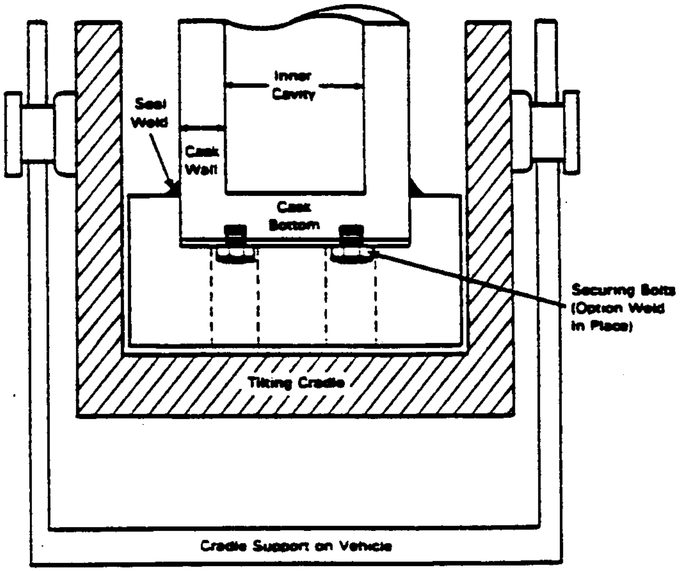
In the postulated reference system, the impact limiters are large balsa wood, polyurethane, or foam structures that are separate from the cask. They are bolted to the ends of the cask and must be removed before the cask is removed from the transport vehicle. Dose reductions to workers are possible with the use of integral impact limiters, which are part of the casks.

5.9.1 Description of Integral Cask Impact Limiters

The impact limiters used in the postulated reference system must be bolted onto the cask after the cask is placed on the transport vehicle (see Figure 4.5). When the cask contains spent fuel, the doses received from these activities are significant. Elimination of these activities is possible with the use of integral impact limiters. Figure 5.4 illustrates an example of this concept. The bottom limiter must be strong enough to support the cask, and both top and bottom limiters are designed to absorb the shock if a cask were dropped in accordance with the NRC cask tests (10 CFR 71). The top limiter is integral with the cask outer lid in this alternative, and is assumed to require



a. Top Impact Limiter

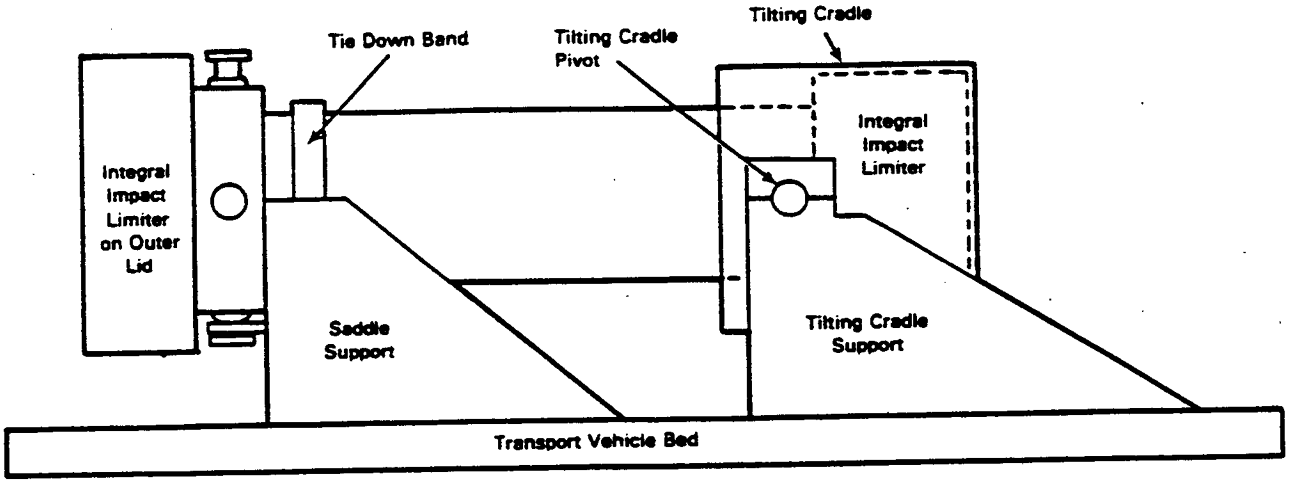


Note:

1. Integral limiter must be able to support cask weight at all points of contact with tilting cradle during the up-end and down-end operation
2. Integral limiter (bottom end of cask) must be cased and water tight to prevent crud traps when cask is placed into loading pool at reactor site

b. Bottom Impact Limiter

FIGURE 5.4. Integral Cask Impact Limiters



c. Side View with Impact Limiters in Place

FIGURE 5.4. (contd)

no additional time for removal/installation during the normal outer lid removal procedures. The bottom limiter is not removed. It is assumed that the impact limiters are designed with smooth surfaces to facilitate decontamination, and no increase is required in the amount of decontamination. It is also assumed that the integral impact limiters do not affect the capacity of the casks and cranes; however, it is recognized that the lifting yoke will be more complicated and be heavier than in the postulated reference system.

5.9.2 Operational and Dose Impacts of Integral Cask Impact Limiters

The effects of using integral cask impact limiters, rather than separate impact limiters as in the postulated reference system, are discussed in this section. The estimated annual collective dose reductions for at-reactor and at-repository operations are given in Table 5.47. Total cask handling worker doses received at reactors decrease by 7%, while at-repository doses are reduced by 8%.

It should be remembered that there are several disadvantages to the use of integral impact limiters. The overall length of the cask is increased and, hence, the hook height of the receiving area crane and the clear height of the receiving area must be increased by the length of the bottom impact limiter. The clear height of the cask handling room and the height of the shield door

TABLE 5.47. Summary Comparison of Estimated Annual Collective Radiation Doses for the Postulated Reference System With and Without Integral Cask Impact Limiters

	person-rem/year								
	Truck			Rail			Total System[a,b]		
	Postulated Reference	Integral Limiter Alternative	Dose Change	Postulated Reference	Integral Limiter Alternative	Dose Change	Postulated Reference	Integral Limiter Alternative	Dose Change
At-Reactor	271	253	-18	144	135	-9	415	388	-27
At-Repository	269	246	-23	149	139	-10	418	385	-33
Totals	540	499	-41	293	274	-19	833	773	-60

(a) Based on 0.924 MTU/PWR truck shipment, 0.930 MTU/BWR truck shipment, 6.47 MTU/PWR rail shipment, and 6.70 MTU/BWR rail shipment.

(b) Cask capacity is 2/5 PWR/BWR assemblies for truck shipments, and 14/36 PWR/BWR assemblies for rail shipments.

must also be increased. The height of the loadout cell may also need to be increased by the height of the bottom impact limiter. The additional cask length will also reduce the water shielding depth during cask loading in the reactor fuel basins and could increase dose rates. Such changes may increase the capital costs of the receiving facility and may also add costs to the reactor facility, which are not currently considered.

At-Reactor Impacts

Activity steps at the reactor that are affected by the use of integral impact limiters are steps 5.3 (crane retrieves hooks and grapples), 5.4 (impact limiter removal), and 20.3 (install impact limiters). These activities are all eliminated in this alternative, because the bottom impact limiter is not removed and the top impact limiter is removed with the outer lid of the cask. Turnaround time for a truck shipment is estimated to decrease by 60 minutes, and rail shipment turnaround time is estimated to be reduced by 90 minutes.

The greatest dose reduction occurs in activity step 20.3, when the cask is loaded with fuel and is being prepared for shipment. Collective radiation doses received by cask handling workers at the reactor are shown in Table 5.48. A dose reduction of 6% to 7% for handling either truck or rail casks is noted for this alternative compared to the postulated reference case. For both truck and rail shipments, activity 20 is responsible for about 92% of the reduction in dose. Maintenance-craftsmen benefit from the majority of the dose reductions (78% for truck, 86% for rail).

TABLE 5.48. Summary Comparison of Estimated Collective Radiation Doses at the Postulated Reference Reactor With and Without Integral Cask Impact Limiters

	Postulated Reference			Integral Limiter Alternative		
	Person-mrem/ Shipment	Person-mrem/ MTU[(a)]	Person-rem/ year[(b)]	Person-mrem/ Shipment	Person-mrem/ MTU[(a)]	Person-rem/ year[(b)]
Truck						
PWR	271	293	158	252	272	147
BWR	292	314	113	273	294	106
Total			271			253
Rail						
PWR	404	62	78	374	58	73
BWR	520	78	66	490	74	62
Total			144			135

(a) Based on 0.924 MTU/PWR truck shipment, 0.930 MTU/BWR truck shipment, 6.47 MTU/PWR rail shipment, and 6.70 MTU/BWR rail shipment.

(b) Based on 540 MTU of PWR and 360 MTU of BWR spent fuel by truck and 1200 MTU of PWR and 840 MTU of BWR spent fuel by rail.

The average annual doses to individual operators during at-reactor truck cask handling operations in the postulated reference system are reduced from 898 mrem/year to 873 mrem/year when using integral cask impact limiters for PWR operations, and from 1035 mrem/year to 1009 mrem/year for BWR operations. For maintenance-craftsmen, the equivalent doses are the same for both PWR and BWR operations and would be reduced from 1011 mrem/year in the postulated reference system to 889 mrem/year when using integral cask impact limiters. Details of these dose calculations are contained in Appendix N.

At-Repository Impacts

Activity steps at the repository that are affected by the use of integral cask impact limiters are steps 5.2 (crane retrieves hook and grapples), 5.3 (remove impact limiters), and 21.2 (install impact limiters). The cask is loaded with fuel in steps 5.2 and 5.3, and is empty in step 21.2. All of these activities are eliminated as a result of implementing this alternative. Turnaround time is estimated to be reduced 70 minutes for a truck shipment and 100 minutes for a rail shipment.

The collective radiation dose to cask handling workers at the repository is reduced as a result of the elimination of the above contact operations.

Estimated doses received at the repository receiving facility are shown in Table 5.49. Dose reductions to workers of about 8% for truck casks and 7% for rail casks are estimated on a per-cask and per-MTU basis. The dose from activity 5 is reduced by 22 person-mrem (42% reduction) for a truck shipment and by 32 person-mrem (41% reduction) for a rail shipment. Maintenance-craftsmen receive nearly all of the dose reduction benefits.

TABLE 5.49. Summary Comparison of Estimated Collective Radiation Doses at the Postulated Reference Repository With and Without Integral Cask Impact Limiters

	Postulated Reference			Integral Limiter Alternative		
	Person-mrem/ Shipment	Person-mrem/ MTU[(a)]	Person-rem/ year[(b)]	Person-mrem/ Shipment	Person-mrem/ MTU[(a)]	Person-rem/ year[(b)]
Truck						
PWR	276	299	162	253	274	148
BWR	277	298	107	254	273	98
Total			269			246
Rail						
PWR	463	72	91	430	67	84
BWR	466	70	57	433	65	55
Total			149			139

(a) Based on 0.924 MTU/PWR truck shipment, 0.930 MTU/BWR truck shipment, 6.47 MTU/PWR rail shipment, and 6.70 MTU/BWR rail shipment.

(b) Based on 540 MTU of PWR and 360 MTU of BWR spent fuel by truck and 1200 MTU of PWR and 840 MTU of BWR spent fuel by rail.

The total average annual dose to the maintenance-craftsmen decreases from 13.2 rem/year in the postulated reference system to 12.0 rem/year with the incorporation of integral cask impact limiters (assuming 26 maintenance-craftsmen). Details of these dose calculations are contained in Appendix N.

5.9.3 Cost Consequences of Integral Cask Impact Limiters

At the reactors, any time saved reduces the labor costs charged to the cask loading activities. Thus, the use of integral impact limiters would result in labor cost savings at the reactors. These savings, as shown in Table 5.50, are estimated at $132,000 per year. The decrease in labor requirements at the repository is not enough to eliminate one shift of workers for one

TABLE 5.50. Comparison of Estimated Life-Cycle Costs for the Postulated Reference System With and Without Integral Cask Impact Limiters[a]

Cost Category	Postulated Reference Cost ($)	Integral Limiter Alternative Cost ($)	Change in Cost ($)
Capital Costs:			
Truck Cast Fleet	39,000,000	38,986,500	-13,500[b]
Rail Cask Fleet	70,000,000	70,075,600	75,600
Total Capital Cost Increase			62,100
Annual Costs:			
At-Reactor Labor	1,650,000	1,518,000	-132,000
Present Worth of Cost Difference:			
3% Discount Rate			-1,970,000
0% Discount Rate			-2,710,000

(a) Costs are shown to more significant figures than justified, to provide for consistency in the calculations. See Appendix J for cost estimating details.

(b) A negative cost denotes a cost savings.

hot cell. Therefore, no labor cost savings are included from using the integral cask impact limiter at the repository.

The integral cask impact limiters are part of the cask. The top impact limiter is a steel cylinder attached to the outer lid. The bottom limiter has six steel fins. The addition of the alternative limiters adds 1035 pounds of stainless steel to the truck cask, at an estimated cost of $3880 per cask. For the rail casks, the net additional weight of 2220 pounds of stainless steel increases the cost by $8325 per cask. Adding the integral impact limiters eliminates the removable balsa wood limiters that are bolted on the postulated reference cask. The cost of these are estimated to be $4400 per truck cask and $5600 per rail cask. Thus, the integral cask impact limiter results in a capital cost savings of $520 per truck cask and a cost increase of $2725 per rail cask. The capital cost of the truck cask fleet is reduced by $13,500, while the capital cost of the rail cask fleet is increased by $75,600, for a total increase in capital costs of $62,100 for this alternative.

The present worth of the estimated total life-cycle cost savings for the integral cask impact limiters alternative has been calculated with discount rates of 0% and 3% using a 21-year lifetime and 1987 dollars. The respective values, shown in Table 5.50, are $2.7 million and $2.0 million.

5.9.4 Overview Evaluation of Integral Cask Impact Limiters

The use of integral impact limiters for the truck and rail casks would slightly decrease overall system costs and would also slightly decrease worker doses. The ratio of Δcost/Δdose for the system is negative and thus the magnitude of the ratio is not meaningful.

The major concerns about this alternative include potential changes at the reactor and at the repository to accommodate the longer and heavier casks, additional regulatory issues because of a change in technology, assuring the design is prepared to avoid difficulties with decontamination after removal from the reactor pool, the avoidance of damage to the impact limiters during cask handling operations, and the potential need for a more complicated and heavier lifting yoke.

5.10 QUICK-RELEASE CASK IMPACT LIMITERS

In the postulated reference system, the cask impact limiters (one for each end of the cask) are secured to the cask by four bolts for a truck cask and by eight bolts for a rail cask (see Figure 4.5). The alternative of using an integral impact limiter was described in Section 5.9. Another alternative would be to redesign the impact limiter to be attached to the cask with a single bolt, thus reducing installation/removal times and the radiation doses received by cask handling workers.

5.10.1 Description of Quick-Release Cask Impact Limiters

The impact limiters used in the postulated reference system are large cylindrical structures designed to protect the cask body and closure against impacts. They are held in place by four bolts on a truck cask and by eight bolts on a rail cask. These bolts are not load-bearing bolts for cask support.

It is assumed that a conventional impact limiter constructed of stainless-steel-sheathed balsa wood or similar material would be acceptable. To remove or install the impact limiter requires the use of a crane to lift and position the impact limiter to the alignment required for the installation of the four or eight bolts using conventional hand or power tools.

An alternative would be to modify the impact limiter design to allow securing it in place with a single bolt. Figure 5.5 shows a diagram of a concept for this alternative. The four/eight bolts used in the postulated reference system would be replaced by alignment bars on the cask side walls. The alignment bars would mate with slots in the impact limiter, thus indexing the single securing bolt located in the center of the impact limiter. Appropriate hoisting equipment would be used to manually orient the impact limiter to its mating position, and the captive fastener would then be tightened to the designed torque. These operations would essentially be reversed for removal of the impact limiter.

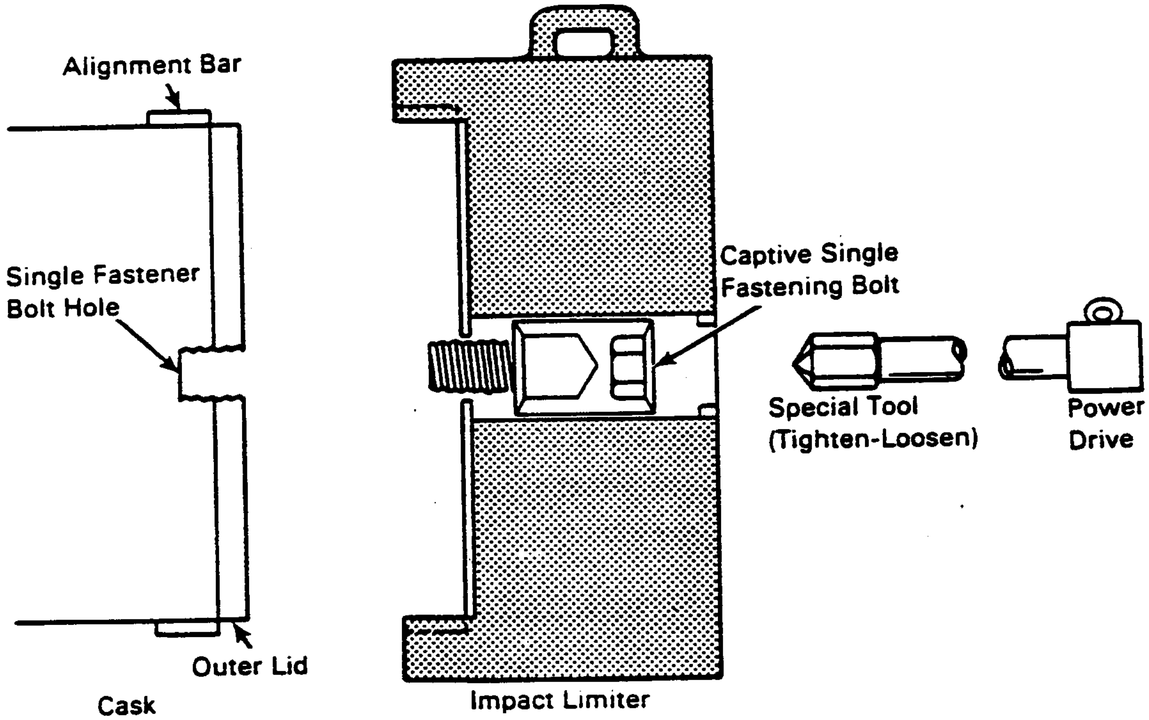


FIGURE 5.5. Quick-Release Cask Impact Limiter

5.10.2 Operational and Dose Impacts of Quick-Release Cask Impact Limiters

The effects of using quick-release cask impact limiters are discussed in this section. The estimates of annual dose reductions for at-reactor and at-repository operations are given in Table 5.51. Total doses received by the cask handling workers at reactors would decrease by 3%, and at-repository, by 4%.

TABLE 5.51. Summary Comparison of Estimated Annual Collective Radiation Doses in the Postulated Reference Truck/Rail Transport System With and Without Quick-Release Cask Impact Limiters

	person-rem/year								
	Truck			Rail			Total System[(a,b)]		
	Postulated Reference	Quick-Release Alternative	Dose Change	Postulated Reference	Quick-Release Alternative	Dose Change	Postulated Reference	Quick-Release Alternative	Dose Change
At-Reactor	271	266	-5	144	137	-7	415	403	-12
At-Repository	269	258	-11	149	143	-6	418	401	-17
Totals	540	524	-16	293	280	-13	833	804	-29

(a) Based on 0.924 MTU/PWR truck shipment, 0.930 MTU/BWR truck shipment, 6.47 MTU/PWR rail shipment, and 5.70 MTU/BWR rail shipment.

(b) Cask capacity is 2/5 PWR/BWR assemblies for truck shipments, and 14/36 PWR/BWR assemblies for rail shipments.

At-Reactor Impacts

The activity steps at the reactor that are affected by the use of quick-release impact limiters are steps 5.4 (impact limiter removal) and 20.3 (install impact limiters). Activity times are reduced because only one bolt secures the quick-release impact limiter. Turnaround time for a truck shipment would be decreased by 30 minutes, and rail shipment turnaround time would be reduced by 60 minutes as a result of this alternative.

Doses received by the cask handling workers at the reactor are shown in Table 5.52. About 2% dose reduction would result from handling truck casks, and 3% to 4% reduction from handling rail casks compared to the postulated reference system. Activity step 20.3, when the cask is loaded with fuel and is being prepared for shipment, is responsible for about 88% to 92% of the reduction in dose for this alternative. Maintenance-craftsmen benefit from the majority of the dose reductions.

TABLE 5.52. Summary Comparison of Estimated Collective Radiation Doses at the Postulated Reference Reactor With and Without Quick-Release Cask Impact Limiters

	Postulated Reference			Quick-Release Alternative		
	Person-mrem/ Shipment	Person-mrem/ MTU(a)	Person-rem/ year(b)	Person-mrem/ Shipment	Person-mrem/ MTU(a)	Person-rem/ year(b)
Truck						
PWR	271	293	158	265	287	155
BWR	292	314	113	286	308	311
Total			271			266
Rail						
PWR	404	62	78	387	59	74
BWR	520	78	66	503	75	63
Total			144			137

(a) Based on 0.924 MTU/PWR truck shipment, 0.930 MTU/BWR truck shipment, 6.47 MTU/PWR rail shipment, and 6.70 MTU/BWR rail shipment.
(b) Based on 540 MTU of PWR and 360 MTU of BWR spent fuel by truck and 1200 MTU of PWR and 840 MTU of BWR spent fuel by rail.

The average annual doses to individual operators during at-reactor truck cask handling operations in the postulated reference system are reduced from 898 mrem/year to 886 mrem/year when using quick-release cask impact limiters for PWR operations, and from 1035 mrem/year to 1022 mrem/year for BWR operations. For maintenance-craftsmen, the equivalent doses are the same for both PWR and BWR operations and would be reduced from 1011 mrem/year in the postulated reference system to 977 mrem/year when using quick-release cask impact limiters. Details of these dose calculations are contained in Appendix N.

At-Repository Impacts

Activity steps at the repository that are affected by the use of quick-release impact limiters are step 5.3 (remove impact limiters) and 21.2 (install impact limiters). The cask is loaded with fuel in step 5.3, and is empty in step 21.2. Activity times are reduced as a result of implementing this alternative. Turnaround time is reduced 30 minutes for a truck shipment and 60 minutes for a rail shipment.

Total radiation exposure is reduced to cask handling workers at the repository as a result of the reduction in cask contact time. Estimated doses received at the repository receiving facility from this alternative are shown in Table 5.53.

TABLE 5.53. Summary Comparison of Estimated Collective Radiation Doses at the Postulated Reference Repository With and Without Quick-Release Cask Impact Limiters

	Postulated Reference			Quick-Release Alternative		
	Person-mrem/ Shipment	Person-mrem/ MTU(a)	Person-rem/ year(b)	Person-mrem/ Shipment	Person-mrem/ MTU(a)	Person-rem/ year(b)
Truck						
PWR	276	299	162	266	288	155
BWR	277	298	107	266	286	103
Total			269			258
Rail						
PWR	463	72	91	442	69	87
BWR	466	70	59	445	67	56
Total			149			143

(a) Based on 0.924 MTU/PWR truck shipment, 0.930 MTU/BWR truck shipment, 6.47 MTU/PWR rail shipment, and 6.70 MTU/BWR rail shipment.

(b) Based on 540 MTU of PWR and 360 MTU of BWR spent fuel by truck and 1200 MTU of PWR and 840 MTU of BWR spent fuel by rail.

Dose reductions of about 4% for handling truck casks and 5% for handling rail casks are noted for this alternative. The dose from activity 5 is reduced by 10 person-mrem (19% reduction) for a truck shipment and by 21 person-mrem (26% reduction) for a rail shipment.

Maintenance-craftsmen benefit from nearly all of the dose reductions. The average annual dose to an individual maintenance-craftsman decreases from 13.2 rem/year in the postulated reference system to 12.6 rem/year with the incorporation of quick-release cask impact limiters (assuming 26 maintenance-craftsmen). Details of these dose calculations are contained in Appendix N.

5.10.3 Cost Consequences of Quick-Release Cask Impact Limiters

The dose reductions in this alternative result from reduced activity times both at the reactor and at the repository from using quick-release cask impact limiters. The reduced labor requirements at the repository is not enough to eliminate one shift of workers from any hot cell. Therefore, no labor cost savings are included from using the quick-release cask impact limiters at the repository. At the reactors, the use of quick-release cask impact limiters results in labor cost savings of $66,600 per year, as shown in Table 5.54.

TABLE 5.54. Comparison of Estimated Life-Cycle Costs for the Postulated Reference System With and Without Quick-Release Cask Impact Limiters[a]

Cost Category	Postulated Reference Cost ($)	Quick-Release Alternative Cost ($)	Change in Cost ($)
Capital Costs:			
Cask Fleet	98,000,000	97,996,000	-4,000[b]
Annual Costs:			
At-Reactor Labor	1,649,700	1,583,100	-66,600
Present Worth of Cost Difference:			
3% Discount Rate			-1,030,000
0% Discount Rate			-1,400,000

(a) Costs are shown to more significant figures than justified, to provide for consistency in the calculations. See Appendix J for cost estimating details.

(b) A negative value indicates a cost savings.

The quick-release cask impact limiter is a simpler design than the postulated reference system cask impact limiter. The elimination of bolts, and the associated threading cost, and their replacement with simpler alignment bars results in an estimated capital cost savings of $32 per truck cask and $108 per rail cask. The total capital cost savings for the minimum cask fleet is estimated to be $4000.

The present worth of the estimated total life-cycle cost savings for the quick-release cask impact limiters alternative has been calculated with discount rates of 0% and 3% using a 21-year lifetime and 1987 dollars. The respective values, shown in Table 5.54, are $1.4 million and $1.0 million.

5.10.4 Overview Evaluation of Quick-Release Cask Impact Limiters

The use of quick-release cask impact limiters is estimated to result in decreased overall system costs and also decreased worker doses. The ratio of Δcost/Δdose is negative and the magnitude of the ratio is not meaningful. The combination of both cost reduction and dose reduction implies that the alternative is attractive. It should be noted, however, that cost increases for testing, demonstration, and licensing of quick-release impact limiters have not been considered and could significantly alter the estimated cost in this evaluation.

5.11 QUICK-RELEASE CASK TIEDOWNS

In the postulated reference system design, cask tiedown bands are made secure by one captive nut at each end of the band. Furthermore, the tiedown band is stored separately from the transport vehicle when it is removed. The efficiency of installation and removal of cask tiedowns could potentially be improved by using a quick-release tiedown concept, and making the tiedown an integral part of the transport vehicle. The time saved by these changes would translate into dose reductions for those workers that install or remove tiedowns.

5.11.1 Description of Quick-Release Cask Tiedowns

In the postulated reference system, the cask tiedown band is placed over the cask and secured to the band-anchor structure by captive nuts. Each end of the band is bolted to the band-anchor structure. For cask removal, the two captive nuts are removed and the band is lifted and removed from the transport cask. The tiedown band is stored away from the transport vehicle. These operations are essentially done by direct contact of the workers, so the dose rates to the workers from these activities are moderately high.

An example of a quick-release tiedown, shown in Figure 5.6, would be an integral part of the transport vehicle. It would be simpler and quicker to install and release than in the postulated reference system. With the tiedown in the open position, the cask would be placed in its saddle. Then, by use of an auxiliary hoist, the tiedown would be hinged over the cask and the securing

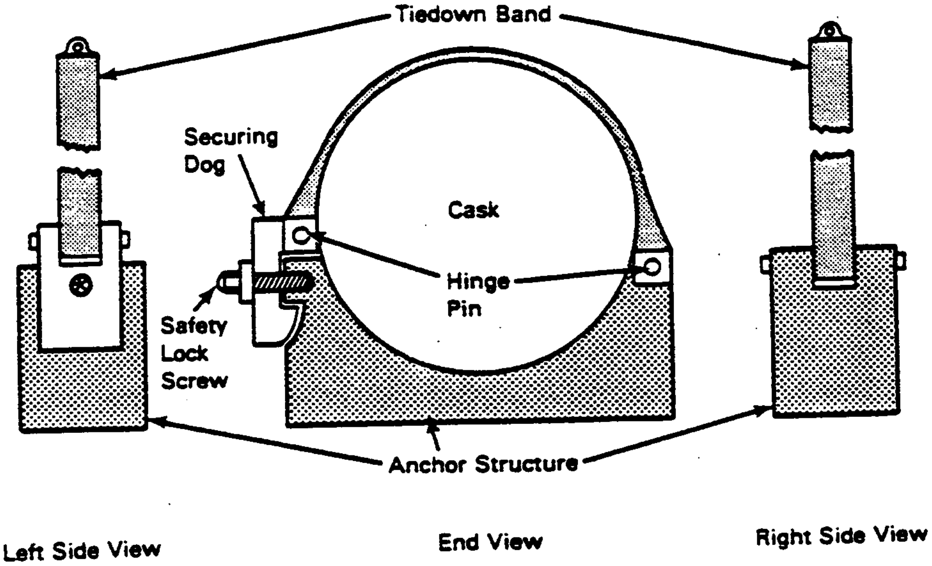


FIGURE 5.6. Quick-Release Cask Tiedown

dog would be set into place. The locking safety screw would be tightened to prevent inadvertent release of the securing dog. The tension of the tiedown band would then be adjusted to the designed torque using tension levers that are part of the cask saddle. These operations would be reversed for tiedown removal. The removal and installation of the axial cask restraint bracket is unaffected by this alternative.

5.11.2 Operational and Dose Impacts of Quick-Release Cask Tiedowns

The effects of using quick-release cask tiedowns are discussed in this section. The estimates of annual collective dose reductions for at-reactor and at-repository cask handling operations are given in Table 5.55. Total doses received by cask handling workers at reactors decrease by 4%, and at-repository, by 8%.

At-Reactor Impacts

The reactor activity steps affected by the use of quick-release cask tiedowns are step 5.5 (tiedown removal, storage) and 20.2 (install cask tiedowns). Times to perform these activities would decrease, which would reduce the dose to cask handling workers. Turnaround times for truck and rail shipments would decrease by an estimated 30 minutes as a result of this alternative.

TABLE 5.55. Summary Comparison of Estimated Annual Collective Radiation Doses in the Postulated Reference Truck/Rail Transport System With and Without Quick-Release Cask Tiedowns

	person-rem/year								
	Truck			Rail			Total System[a,b]		
	Postulated Reference	Quick-Release Alternative	Dose Change	Postulated Reference	Quick-Release Alternative	Dose Change	Postulated Reference	Quick-Release Alternative	Dose Change
At-Reactor	271	259	-12	144	140	-4	415	399	-16
At-Repository	269	248	-21	149	138	-11	418	386	-32
Totals	540	507	-33	293	278	-15	833	785	-48

(a) Based on 0.924 MTU/PWR truck shipment, 0.930 MTU/BWR truck shipment, 6.47 MTU/PWR rail shipment, and 6.70 MTU/BWR rail shipment.

(b) Cask capacity is 2/5 PWR/BWR assemblies for truck shipments and 14/36 PWR/BWR assemblies for rail shipments.

The greatest dose reduction would occur in activity step 20.2, when the cask is loaded with fuel and being prepared for shipment. The dose rate for this activity is the same as in the postulated reference system, but because tiedown installation time is decreased, the total dose to the workers is reduced. Doses received by cask handling workers at the reactor are shown in Table 5.56. Dose reductions of about 4% for handling truck casks and 3% for handling rail casks are noted compared to the postulated reference case.

TABLE 5.56. Summary Comparison of Estimated Collective Radiation Doses at the Postulated Reference Reactor With and Without Quick-Release Cask Tiedowns

	Postulated Reference			Quick-Release Alternative		
	Person-mrem/Shipment	Person-mrem/MTU[a]	Person-rem/year[b]	Person-mrem/Shipment	Person-mrem/MTU[a]	Person-rem/year[b]
Truck						
PWR	271	293	158	259	280	151
BWR	292	314	113	280	301	108
Total			271			259
Rail						
PWR	404	62	78	392	60	76
BWR	520	78	66	508	76	64
Total			144			140

(a) Based on 0.924 MTU/PWR truck shipment, 0.930 MTU/BWR truck shipment, 6.47 MTU/PWR rail shipment, and 6.70 MTU/BWR rail shipment.

(b) Based on 540 MTU of PWR and 360 MTU of BWR spent fuel by truck and 1200 MTU of PWR and 840 MTU of BWR spent fuel by rail.

Maintenance-craftsmen benefit from the majority of the dose reductions, because they perform all tiedown installation/removal activities.

The average annual doses to individual operators during at-reactor truck cask handling operations in the postulated reference system are reduced from 898 mrem/year to 889 mrem/year when using quick-release cask tiedowns for PWR operations, and from 1035 mrem/year to 1025 mrem/year for BWR operations. For maintenance-craftsmen, the equivalent doses are the same for both PWR and BWR operations and would be reduced from 1011 mrem/year in the postulated reference system to 922 mrem/year when using quick-release cask tiedowns. Details of these dose calculations are contained in Appendix N.

At-Repository Impacts

Activity steps at the repository that are affected by the use of quick-release tiedowns are steps 5.4 (remove cask tiedowns, prepare tilting cradle, lubricate trunnions) and 21.1 (install tiedowns). Turnaround times for truck and rail shipments are estimated to decrease by 30 minutes and 50 minutes, respectively.

The greatest dose reduction would occur in activity step 5.4. The cask would be prepared for removal from the transport vehicle at this point. Doses received by the cask handling workers at the repository are shown in Table 5.57. Dose reductions would be about 8% for handling both truck and rail casks.

Maintenance-craftsmen benefit from the majority of the dose reductions. The average annual exposure for individual maintenance-craftsmen is reduced from 13.2 rem/year to 12.0 rem/year (7.5 rem/year from truck shipments, 4.5 rem/year from rail shipments) with this alternative. Details of these dose calculations are contained in Appendix N.

5.11.3 Cost Consequences of Quick-Release Cask Tiedowns

The dose reductions in this alternative result from reduced activity times both at the reactors and at the repository. The decrease in labor needs at the repository is not enough to eliminate one shift of workers from any hot cell. Therefore, no labor cost savings at the repository are included from using quick-release tiedowns. At the reactors, though, any time saved reduces the

TABLE 5.57. Summary Comparison of Estimated Collective Radiation Doses at the Postulated Reference Repository With and Without Quick-Release Cask Tiedowns

	Postulated Reference			Quick-Release Alternative		
	Person-mrem/ Shipment	Person-mrem/ MTU[a]	Person-rem/ year[b]	Person-mrem/ Shipment	Person-mrem/ MTU[a]	Person-rem/ year[b]
Truck						
PWR	276	299	162	255	276	149
BWR	277	298	107	256	275	99
Total			269			248
Rail						
PWR	463	72	91	427	66	83
BWR	466	70	59	430	65	55
Total			149			138

(a) Based on 0.924 MTU/PWR truck shipment, 0.930 MTU/BWR truck shipment, 6.47 MTU/PWR rail shipment, and 6.70 MTU/BWR rail shipment.

(b) Based on 540 MTU of PWR and 360 MTU of BWR spent fuel by truck and 1200 MTU of PWR and 840 MTU of BWR spent fuel by rail.

labor costs charged to the cask loading activities. Thus, the use of quick-release cask tiedowns would result in labor cost savings at the reactors. These labor savings, as shown in Table 5.58, are estimated at $47,600 per year.

TABLE 5.58. Comparison of Estimated Life-Cycle Costs for the Postulated Reference System With and Without Quick-Release Cask Tiedowns[a]

Cost Category	Postulated Reference Cost ($)	Quick-Release Alternative Cost ($)	Change in Cost ($)
Annual Costs:			
At-Reactor Labor	1,649,700	1,602,100	-47,600[b]
Present Worth of Cost Difference:			
3% Discount Rate			-734,000
0% Discount Rate			-1,000,000

(a) Costs are shown to more significant figures than justified, to provide for consistency in the calculations. See Appendix J for cost estimating details.

(b) Negative values indicate a cost savings.

Tiedowns similar to the concept in this alternative are commercially available for about $25 each, regardless of the bracket design. This cost is sufficiently low to be considered as zero in this study. In addition, the change in the bracket design should have no capital cost effect.

The present worth of the life-cycle cost savings for the quick-release cask tiedown alternative has been calculated with discount rates of 0% and 3% using a 21-year lifetime and 1987 dollars. The respective cost savings, shown in Table 5.58, are $1.0 million and $734,000.

5.11.4 Overview Evaluation of Quick-Release Cask Tiedowns

The use of quick-release cask tiedowns is estimated to decrease overall system costs and to decrease cask handling worker doses at the reactor and repository. The ratio of Δcost/Δdose for the system is negative and thus the magnitude of the ratio is not meaningful. The combination of both cost and dose reductions makes this an attractive alternative for consideration. Some additional testing and demonstration may be needed for licensing.

5.12 REMOTE-AUTOMATED HANDLING OF CASKS AT THE RECEIVING FACILITY

Cask handling workers at the repository receiving facility accrue most of their radiation exposure from being in close proximity to the cask. One way to nearly eliminate their doses is to use remote handling methods so that workers are not routinely required to be near the casks. This is particularly important for workers at the repository receiving facility who must handle all of the casks in the waste management system (in comparison to the workers at the over 100 reactors who individually only handle a small fraction of the total). In Chapter 4, for the postulated reference system, it was estimated that some categories of repository workers would receive doses higher than the maximum individual annual dose allowed by NRC regulations.

Conceptual details of a potential remote handling system at the postulated reference repository were developed by Westinghouse Hanford Company (WHC) and Sandia National Laboratory (SNL) personnel. These are presented in detail in Appendix K. The concepts used here are envisioned for use at the repository only in this study, but are compatible with operations of the postulated reference system at the reactor and in-transit. As such, the concepts would only affect doses and costs at the repository.

5.12.1 Description of Remote-Automated Handling Systems

Remote-automated techniques were conceptualized for all cask handling activities at the repository receiving facility including: receiving inspection, cask washdown and survey, removal of the casks from the vehicle, preparation of the casks for unloading, unloading of spent fuel assemblies from the casks, and reloading of the casks onto the vehicle. These activities are noted in Figure 5.7, which identifies the activities and their respective locations at the repository receiving facility. These systems could replace the conventional, hands-on systems used in the postulated reference repository. This is the only alternative investigated in this study that would require major changes in the cask handling systems at the repository.

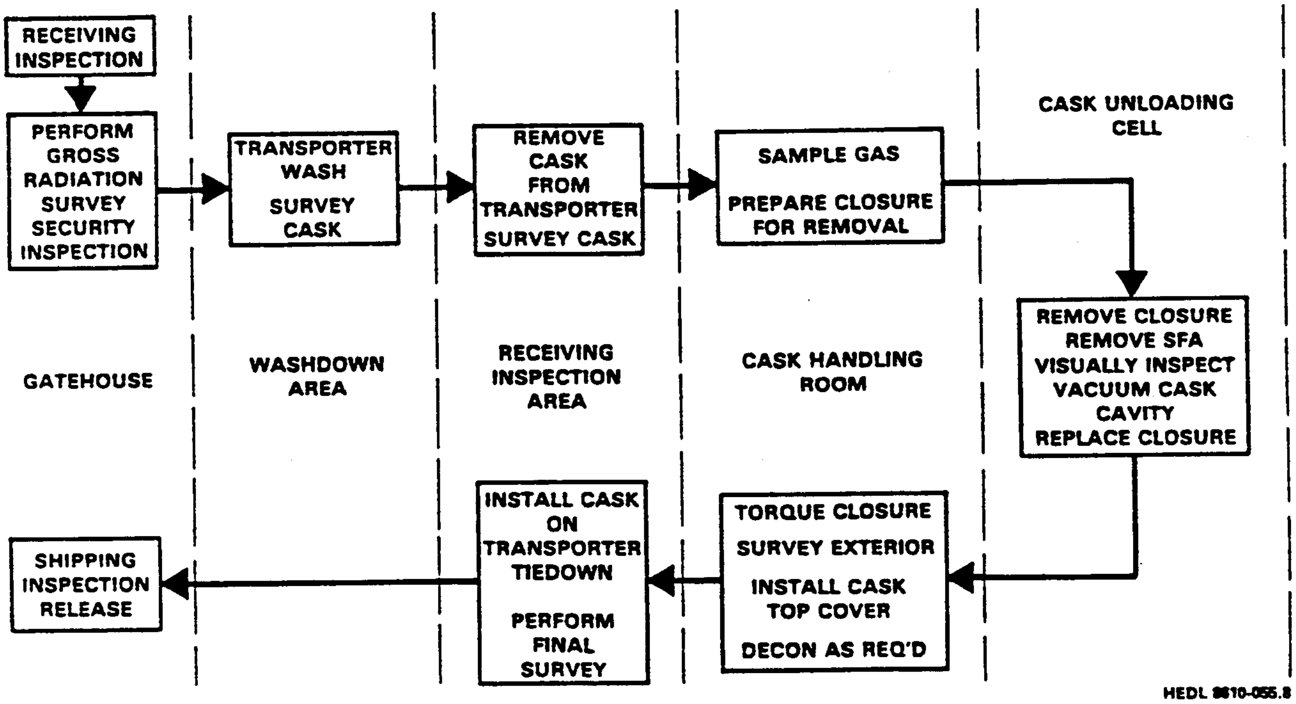


FIGURE 5.7. Location and Activities in the Repository Receiving Facility for Remote Handling Systems

Two cases are considered in this report. The first is a totally remote system as described in detail in Appendix K and summarized in the rest of this subsection. The second system limits the remote operations to the cask handling rooms as described in the fourth remote-automated handling system, below, and automates activities 8 and 18 (see Table 4.16). Neither system has been optimized for remote operations. They are simply replacements of contact operations by people with robotic operations. The robots could be normally operated automatically through pre-programming as assumed here, or they could be manually controlled.

A series of four remote handling subsystems is envisioned to complete all of the cask handling functions identified. The first system, shown at the left in Figure 5.7 and illustrated in Figure 5.8, is in the gatehouse area. It performs the function of inspection of the cask and vehicle immediately after arrival. It utilizes a remote television system and a fixed set of radiation detectors. An overhead rail-mounted robot and a robot in a pit below the

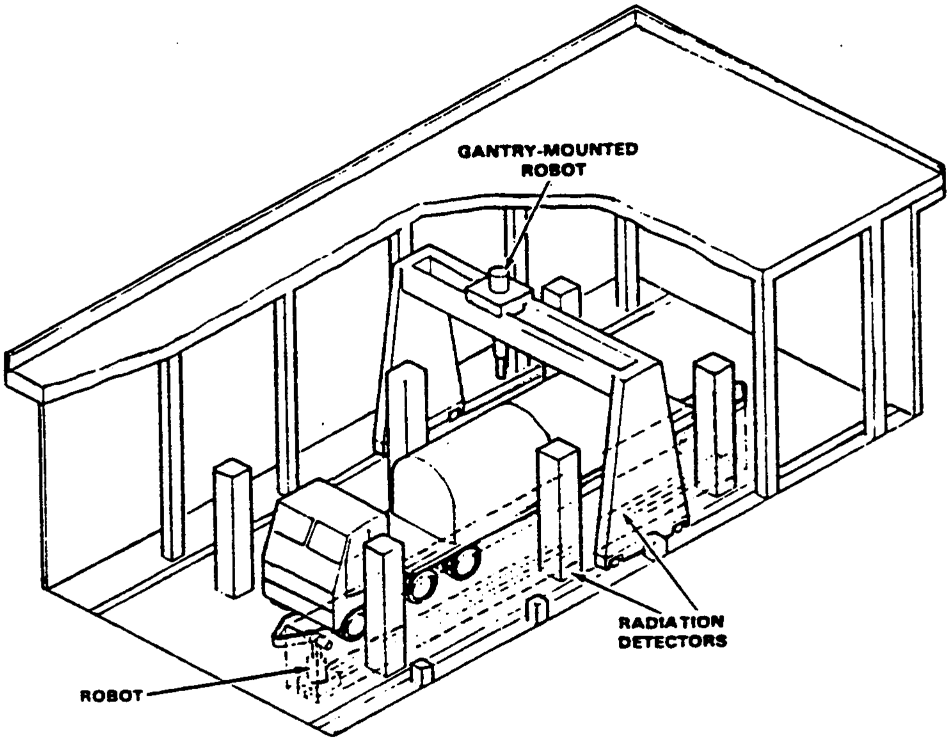


FIGURE 5.8. Robotic System for the Repository Inspection Gatehouse

cask/vehicle allow for full coverage of the vehicle. Various tools could be operated by the robot. Automatic radiation detection is also employed here for release of a cask for return to the reactor after the spent fuel has been removed.

In the washdown and inspection area, a second remote-automated system, shown second from the left in Figure 5.7 and illustrated in Figure 5.9, is provided to wash the vehicle and cask, and to provide for additional detailed inspection of the cask. It is composed of a remote-controlled washdown unit and a gantry and a track-mounted robot with various tools needed to perform the functions here. It is not normally used on a cask after removal of the spent fuel.

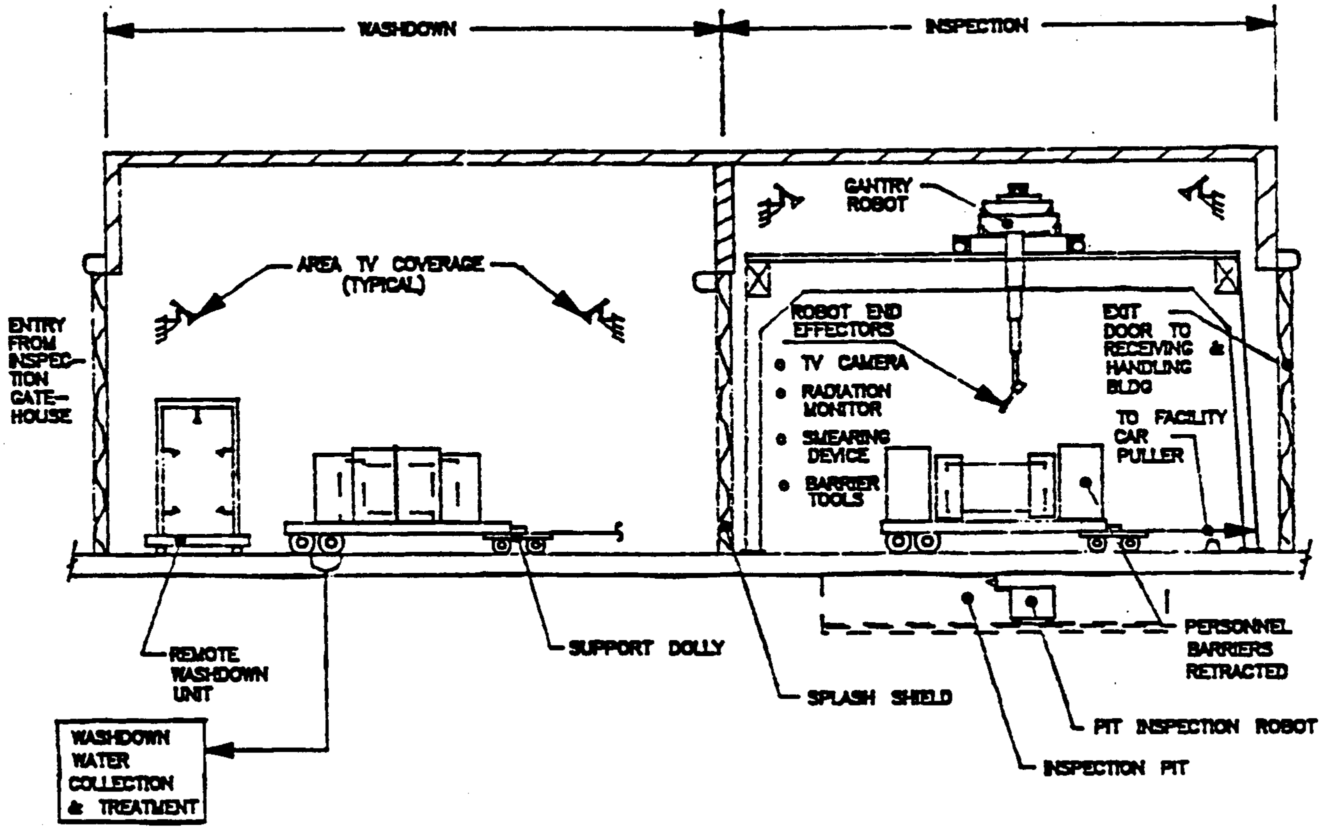


FIGURE 5.9. Robotic System for Repository Washdown/Inspection Area

The third remote-automated handling system, shown third from the left in Figure 5.7 and illustrated in Figure 5.10, is in the receiving and handling

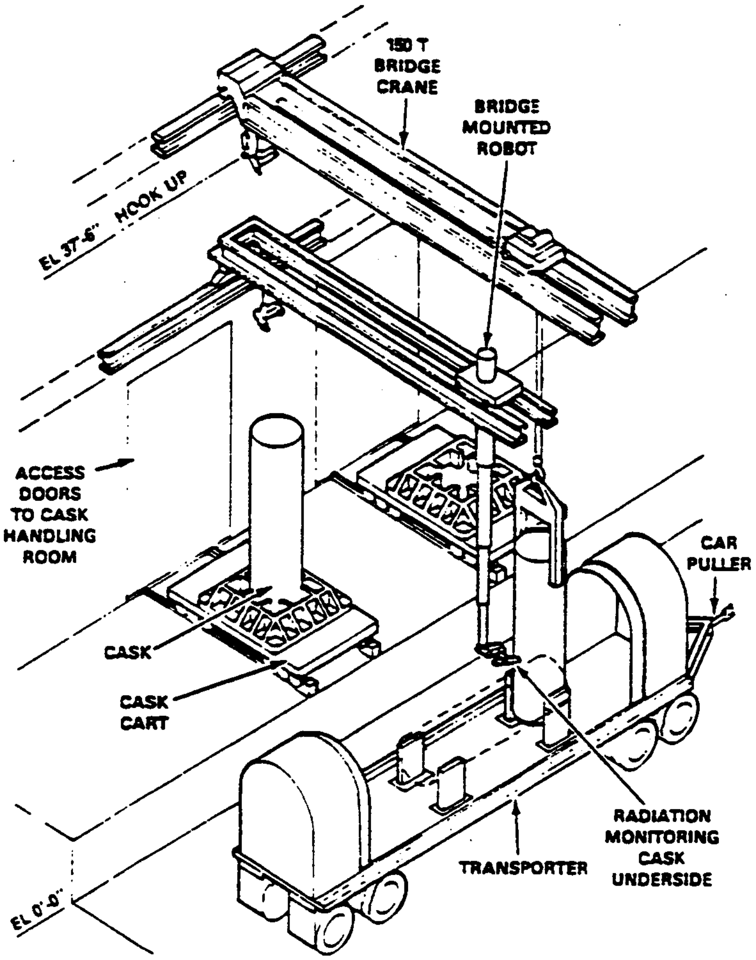


FIGURE 5.10. Robotic System for Cask Removal from and Mounting on Vehicles at the Repository

building where all of the major operations are handled by a bridge-mounted robot in conjunction with the overhead crane in each of the two wings of the building. The robot would perform the same functions as done manually in this part of the repository in the postulated reference system. These operations would be performed on both full and empty casks.

The fourth remote-automated handling system, shown fourth from the left in Figure 5.7 and illustrated in Figure 5.11, is an overhead robot operating from a ceiling-suspended bridge in each of the four cask handling rooms. These robots would perform the functions done manually in the postulated reference system, including cask lid work, using special tools. The system would also

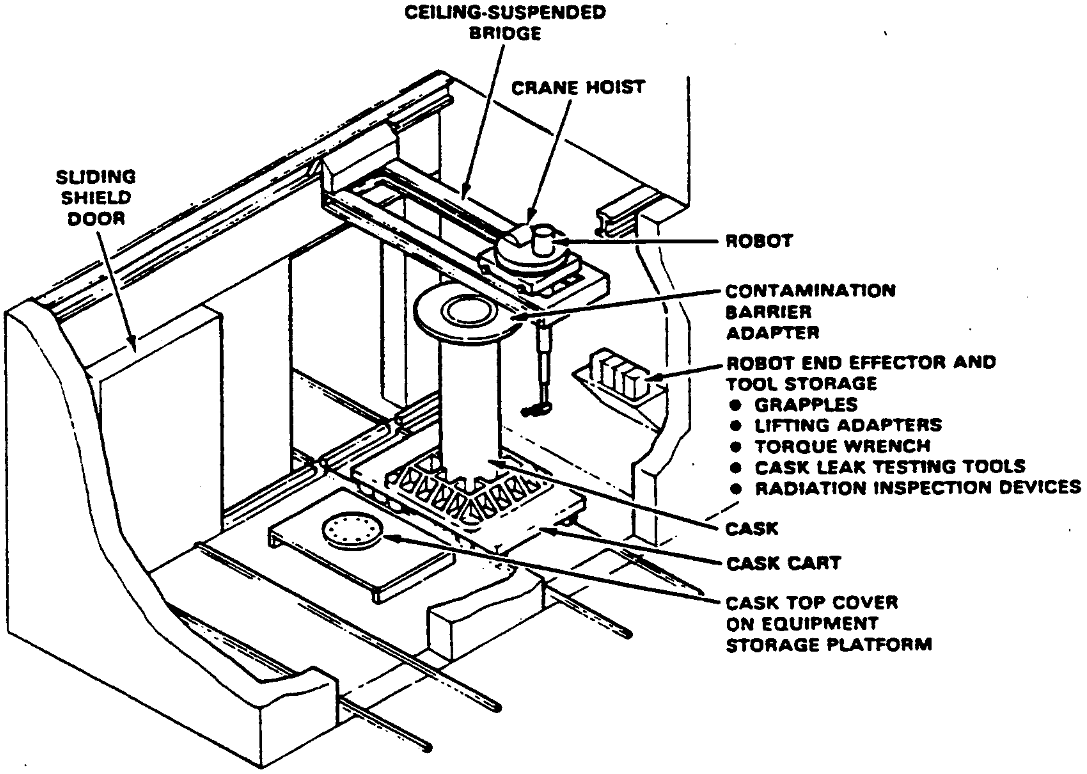


FIGURE 5.11. Robotic System for Operations at the Cask Lid Area in the Cask Handling Room at the Repository

perform radiation surveys, minimum decontamination, and lid closure for empty casks. This system comprises the second subalternative of remote handling, as identified above.

The right-most section of Figure 5.7 shows the activities and facilities that are unchanged from the postulated reference system. In all cases in this study, this work is done remotely from the control room of the hot cell.

Each of the four remote-automated systems would be controlled from a central control room. In total, the four systems would provide for the handling operations for the cask for all activities except for the movement around the receiving facility yard and for when the cask is mated to the port in the floor of the facility hot cell. Periodic maintenance of the remote-automated equipment would be provided by maintenance-craftsmen on the staff at the receiving facility.

5.12.2 Operational and Dose Impacts of Remote-Automated Handling Systems

With the elimination of most contact operations near the casks, most of the doses from the cask and particularly from the cask lid work would be eliminated in both subalternatives. Because the remote systems are only located at the repository, they would not affect the postulated reference case doses at the reactor or during transit. A summary of the estimated annual collective radiation doses for the cask handling workers at the repository is shown in Table 5.59. As can be noted, nearly all of the radiation dose is eliminated by limited use of all four remote handling systems. Limiting the remote handling to the operations in the cask handling rooms also reduces worker doses by a significant amount. This limited automated system will also significantly reduce the annual radiation doses to individual operating personnel.

TABLE 5.59. Summary Comparison of Estimated Annual Collective Radiation Doses for the Postulated Reference Repository With and Without Total Remote or Remote Cask Handling

	person-rem/year								
	Truck			Rail			Total System(a,b)		
	Postulated Reference	Remote Alternative	Dose Change	Postulated Reference	Remote Alternative	Dose Change	Postulated Reference	Remote Alternative	Dose Change
Total Remote	269	3	-266	149	2	-147	418	5	-413
Remote Cask Handling	269	83	-186	149	36	-113	418	119	-299

(a) Based on 0.924 MTU/PWR truck shipment, 0.930 MTU/BWR truck shipment, 6.47 MTU/PWR rail shipment, and 6.70 MTU/BWR rail shipment.

(b) Cask capacity is 2/5 PWR/BWR assemblies for truck shipments, and 14/36 PWR/BWR assemblies for rail shipments.

Estimates of the operational times for this alternative indicate that remote operations should not take longer than manual operations. With future improvements, some activities may require less time than contact operations. In this study, the operational and turnaround times are estimated to be the same as for the postulated reference case. Changes in operational times, however, would impact only slightly the dose to workers because workers would not be near the casks, but they would be located in control rooms with low background dose rates. Therefore, operational times for remote handling are not of major importance in doses received by workers. It is recognized, however, that changes in operational times could have important effects on system costs.

As noted in Table 5.59, the estimated collective dose to cask handling workers at the repository is estimated to be reduced from 418 person-rem/year for the postulated reference system to 5 person-rem/year for the totally remote system. With an estimated total crew of about 80 people, the average dose to individual workers would be about 60 mrem/year and should be well within the 1 rem/year DOE guideline. Limiting the remote operations to the cask handling rooms reduces the estimated collective worker dose from 418 person-rem/year to about 119 person-rem/year. With a staff estimated at 96, the average dose to individual workers is estimated to exceed the 1 rem/year guideline.

For the maintenance-craftsmen, the normal operational dose would be near zero for cask handling in the totally remote system. For the system with remote handling in the cask handling room only, the annual collective dose would be reduced to an estimated 87 person-rem for the maintenance-craftsmen. With a reduced staff of 17, the estimated average annual dose to individual maintenance-craftsmen would be 5.1 rem.

5.12.3 Cost Consequences of Remote-Automated Handling Systems

Totally Remote-Automated System

The costs of using robotics in the total repository cask handling system were estimated by personnel at WHC and SNL. Details of these estimates are given in Appendix K. The two major elements of the costs are the initial capital costs (including development and demonstration costs) and labor costs. The incremental capital cost estimates for the totally remote system are summarized in Table 5.60 and are estimated to be nearly \$19 million.

The use of a totally remote-automated system at the receiving and handling facility would result in an estimated reduction in staff of 31 persons compared to the postulated reference case, as shown in Table 5.61, which compares the staffing requirements in the various areas of the repository cask receiving and handling facilities. Additional details on staffing requirements are contained in Table 4.18 and in Table K.2. The totally remote-automated system reduces

TABLE 5.60. Summary of Estimated Increased Capital Costs Due to Totally Remote-Automated Handling Alternative

Cost Element	Increased Cost ($)
Gatehouse (1)[a]	2,680,000
Receiving & Handling Areas (2)	2,310,000
Cask Handling Rooms (4)	2,075,000
Control Room (1)	1,140,000
Development & Verification	6,520,000
Installation & Startup	3,795,000
Total	18,520,000

(a) Numbers in parentheses indicate the number of remote-automated systems needed.

TABLE 5.61. Estimated Personnel Requirements for All Shifts with Remote-Handling at the Repository

Facility Location	Number of Staff		
	Postulated Reference System	Totally Remote System	Remote Cask Handling Only
Receiving and Dispatching Gatehouse	12	8	12
Inspection Area	8	--	8
Washdown Area	3	4	3
Receiving and Handling Area	24	--	24
Hot Cell Crews	60	36	36
Decontamination Cell Crews	6	6	6
Automated Area Maintenance	--	12	3
Control Room	--	12	4
Total	113	82	96

the requirements for operators, maintenance-craftsmen, quality control persons, crane operators, and radiation monitors. Additional staff for operation of the control room and a maintenance-craftsmen crew for robotic maintenance would be needed. Reducing the repository labor force by the above amount results in an estimated decrease in labor costs of $1.3 million per year, as shown in Table 5.62.

TABLE 5.62. Comparison of Estimated Life-Cycle Costs for the Postulated Reference System With and Without Totally Remote-Automated Handling[a]

Cost Category	Postulated Reference Cost ($)	Remote Alternative Cost ($)	Change in Cost ($)
Capital Cost:			
Robotics Equipment	0	18,520,000	18,520,000
Annual Cost:			
Repository Labor	4,640,000	3,310,000	-1,330,000[b]
Present Worth of Cost Difference:			
3% Discount Rate			-1,940,000
0% Discount Rate			-9,360,000

(a) Costs are shown in more significant figures than justified, to provide for consistency in the calculations. See Appendix K for details of cost savings.

(b) A negative cost denotes a cost savings.

Remote-Automation in the Cask Handling Rooms Only

The increased capital costs associated with the remote-handling in the four cask handling rooms are estimated to be $5.2 million based on Table K.13 in Appendix K. This includes the costs for the development and verification ($1.9 million), installation and startup ($0.9 million), control room ($0.3 million), and robotic systems ($2.1 million) for the cask handling rooms. Limiting the remote handling to the cask handling rooms would result in an estimated reduction in staff of 17 people compared to the postulated reference case, as shown in Table 5.61. These changes in labor requirements would reduce the costs of the repository cask handling labor force by $690,000 per year, as shown in Table 5.63.

TABLE 5.63. Comparison of Estimated Life-Cycle Costs for the Postulated Reference System With and Without Remote-Automated Cask Handling Rooms[(a)]

Cost Category	Postulated Reference Cost ($)	Remote Room Alternative Cost ($)	Change in Cost ($)
Capital Costs:			
Robotics Equipment	0	5,200,000	5,200,000
Annual Costs:			
Repository Labor	4,640,000	3,950,000	-690,000[(b)]
Present Worth of Cost Difference:			
3% Discount Rate			-5,400,000
0% Discount Rate			-9,300,000

(a) Costs are shown in more significant figures than justified, to provide for consistency in the calculations. See Appendix K for details of cost savings.
(b) A negative cost denotes a cost savings.

The present worth of the estimated life-cycle cost changes for these alternatives has been calculated with discount rates of 0% and 3% using a 21-year lifetime and 1987 dollars. The respective values, shown in Table 5.62, show an estimated cost savings of $9.4 million and $1.9 million for the totally remote-automated system. The equivalent respective values for the remote-automated system in the cask handling rooms only, shown in Table 5.63, are estimated at $9.3 million and $5.4 million.

5.12.4 Overview Evaluation of Remote-Automated Handling Systems

The use of remote-automated handling systems at the repository is estimated to decrease both costs and collective worker doses. The ratios of Δcost/Δdose for these alternatives are negative and both appear attractive.

The totally remote alternative is the only single alternative (i.e., not in combination with other alternatives) that has been estimated to decrease the annual doses to individual workers at the repository receiving facility so that they would be in conformance with DOE design objectives for new facilities. However, these alternatives involve the use of high technology with its associated concern on reliability and maintenance requirements. The use of remote technology may also be expected to introduce new issues, such as robotic system malfunctions, into regulatory considerations and the licensing process.

Comparison of the two remote-automated alternatives indicates that the more limited system may save up to about an estimated $3.5 million more over the 21-year operational period than the totally remote system; however, the annual collective dose to repository workers would increase by about 114 person-rem/year, or about 2400 person-rem over the assumed 21-year facility life. This would result in a Δcost/Δdose ratio of about $1500/person-rem for the totally remote system compared to the partially remote system. The ratio is in the range where serious consideration should be given to the totally remote alternative. Other factors should also be considered in any decision process.

5.13 IMPROVED TRUCK OPERATIONS ALTERNATIVE

In the postulated reference system, conservative parameter values for in-transit truck stop times and distances to the cask, based on parameters in the RADTRAN-III computer model (DOE 1986b), were used for the truck operational characteristics. The alternative presented here uses some recent spent fuel transport experience to define some less conservative assumptions about trucking operations. In this alternative, postulated reference case trucks are assumed to maintain somewhat higher average speeds, made possible by the recent increase in the national speed limit and shorter stops for food, fuel, and communications. The trucks are also assumed to be administratively directed to only use truck stops that allow for parking farther from facilities occupied by the public. Improved truck operations would not affect at-reactor or at-repository operations or doses. A summary of the estimated collective annual radiation doses for the improved truck operations alternative is given in Table 5.64.

TABLE 5.64. Summary Comparison of Estimated Annual Collective Radiation Doses During In-Transit for the Postulated Reference System With and Without Improved Truck Operations

	person-rem/year		
	Postulated Reference	Improved Truck Alternative	Dose Change(a,b)
In-transit			
Worker	200	155	-55
Public	444	110	-334
Totals	644	205	-389

(a) Based on 540 MTU of PWR and 360 MTU of BWR spent fuel.
(b) Cask capacity is assumed to be 2/5 PWR/BWR assemblies per shipment.

5.13.1 Description of Improved Truck Operations

Based on recent experience with spent fuel truck shipping campaigns (Ruska and Schoonen 1986; Aerospace Corp. 1987; Gertz 1987), it is recognized that the truck stop and travel times that were assumed for the postulated reference system analysis are very conservative. This alternative represents improved truck operations relative to the postulated reference system that are consistent with the truck stop times and average speeds experienced in recent LWT and OWT shipping campaigns. This alternative would reduce the round-trip time requirements, which would affect the cask fleet requirements and transportation costs. The effects on in-transit radiation doses and transportation costs are discussed in this section.

5.13.2 Operational and Dose Impacts of Improved Truck Operations

A complete re-analysis of in-transit operations and doses was performed for the improved truck operations alternative. This re-analysis includes a time/distance study as well as dose estimates.

Some of the fundamental bases for deriving the estimates for this alternative are the same as those used for the postulated reference system analysis. These include the shipping distance (1,780 miles), number of refueling stops (3), number of drivers (2), number of state inspections (2), and the dose rates from the casks.

Key assumptions that were revised in the improved truck operations analysis include the average speeds while moving in rural, suburban, and urban areas, as well as the durations of stops enroute. Average truck speeds while moving were increased to reflect a higher average trip speed than was assumed in the postulated reference system analysis. The average speeds while moving that are used in this alternative are: rural - 55 mph; suburban - 35 mph; and urban - 25 mph. These speeds more accurately reflect the average speeds in urban and suburban zones because most trucks travel on interstate highways and beltways in these zones. The average speed in rural zones was increased because relatively infrequent delays have been experienced in these areas. Stop durations were reduced to reflect the shipping experience described in Ruska and Schoonen (1986). The assumed stop durations are: 1) state inspections - 30 minutes; 2) food/rest/refueling stops - 60 minutes; and 3) communication stops - 15 minutes. These values were used to develop the operating sequence for the improved truck operations shipment that is shown in Table 5.65. The important characteristics of the improved truck operations shipment are summarized in Table 5.66. Doses to uninvolved persons at truck stops are also reduced by assuming the truck and cask is parked 50 meters from the occupied buildings, rather than 20 meters, as in the postulated reference system.

The estimated radiation doses to the public and workers, both while the trucks are moving and at stops, would be lower for the improved truck operations alternative than those estimated for the postulated reference truck operations because travel and stop times are reduced. Times while moving are

TABLE 5.65. Detailed Operating Sequence for the Improved Truck Operations Alternative

Activity	Hrs/Activity	Miles Traveled	Elapsed hr:min	Elapsed Miles
State inspection/depart site	:30	0	0:30	0
Drive to interstate	:45	40	1:15	40
Drive 2 hours on interstate	2:00	110	3:15	150
Communications stop	:15	---	3:30	150
Drive 2 hours	2:00	100	5:30	250
Food/rest stop	1:00	---	6:30	250
Drive 2 hours	2:00	100	8:30	350
Communications stop	:15	---	8:45	350
Drive 2 hours	2:00	110	10:45	460
Food/rest/refuel stop	1:00	---	11:45	460
Drive 3 hours	3:00	140	14:45	600
Communications stop	:15	--	15:00	600
Drive 2 hours	2:00	80	17:00	680
Food/rest stop	1:00	---	18:00	680
Drive 2 hours	2:00	100	20:00	780
Communications stop	:15	---	20:15	780
Drive 2 hours	2:00	100	22:15	880
Communications stop	:15	---	22:30	880
Drive 2 hours	2:00	90	24:30	970
Food/rest/refuel stop	1:00	---	25:30	970
Drive 2 hours	2:00	100	27:30	1070
Communications stop	:15	---	27:45	1070
Drive 3 hours	3:00	140	30:45	1210
Food/rest stop	1:00	---	31:45	1210
Drive 2 hours	2:00	100	33:45	1310
Communications stop	:15	---	34:00	1310
Drive 2 hours	2:00	90	36:00	1400
Food/rest/refuel stop	1:00	---	37:00	1400
Drive 3 hours	3:00	140	40:00	1540
Communications stop	:15	---	40:15	1540
Drive 2 hours	2:00	100	42:15	1640
Food/rest stop	1:00	---	43:15	1640
Drive 2 hours	2:00	75	45:15	1715
State inspection stop	:30	---	45:45	1715
Drive 2 hours to destination	1:30	75	47:15	1780

TABLE 5.66. Summary of Estimated Operational Characteristics for the Improved Truck Operations Alternative

AGGREGATED

Total distance:	1,780 miles	Number in crew: 2
Moving Time:	37.25 hours	Average speed: 37.7 mph
Stop Time:	10.00 hours	Average speed while moving:
Total Time:	47.25 hours	55 mph - rural
		35 mph - suburban
		25 mph - urban

DETAILS

Fractions of Travel: Rural - 79%; Suburban - 20%; Urban - 1%

Stops: 7 for food/rest/refueling = 7 hours
2 for state inspections[(a)] = 1 hour
8 for communications = 2 hours
Total 10.00 hours

(a) For the originating and final states only.

reduced somewhat (from 44.75 hours to 37.25 hours), but stop times are reduced significantly (from 30 hours to 10 hours) for the improved truck operations shipment. Thus, the estimated doses received at truck stops will be significantly lower than those while moving, compared to the postulated reference operations.

Doses to drivers were recalculated to account for reduced stop and travel times. The same method that was used to estimate driver doses for the postulated reference system was used for the improved truck operations alternative. Assuming the dose rate in the truck cab is 2 mrem/hour, the collective radiation dose to the two drivers while moving is 149 person-mrem for each shipment.

The stop times for each improved truck operations shipment total 10 hours. As for the postulated reference case, it is assumed that the drivers each spend about half of the stop time at 10 meters from the top of the cask and half at 50 meters from the side of the cask. Assuming the same dose rates at these distances that were calculated for the postulated reference truck cask (0.6 mrem/hour and 0.02 mrem/hour, respectively) and multiplying by 10 stop-hours/shipment, the total collective radiation dose to the two drivers at stops is estimated at about 6.2 person-mrem/shipment. Thus, the total collective dose to the drivers for this alternative is estimated at about (149 + 6) = 155 person-mrem/shipment compared to 198 person-mrem in the postulated reference system analysis.

The maximum individual dose to the truck driver is the product of the dose per shipment and the number of trips per year. With the improved truck operations, the travel times are reduced by about 26.5 hours each way so that the total cycle time is reduced from 180 hours in the postulated reference system to 127 hours in the improved operations system. Assuming the drivers are available the same number of hours for both the postulated reference system and the alternative system, the drivers would complete about 42 trips per year compared to the 30 trips in the postulated reference system. This would result in an estimated average annual dose to each driver of 3.3 rem compared to 3.0 rem/year annual dose in the postulated reference system.

Radiation doses to the public in this alternative at stops would also change because of the reduced stop time and an increase in the average exposure distance from 20 meters to 50 meters. This longer average distance can be achieved by selecting specific suitable stop locations that have large parking areas during per-shipment planning activities. Doses at stops to members of the public were estimated for the postulated reference system based on the results of the RADTRAN III analyses for LWT that were described in the repository EAs (DOE 1986b). This dose category includes two subcategories: doses to bystanders and passersby at the stop, and doses to the public that reside near the stop. The collective public dose at stops was estimated for the postulated reference truck shipment at about 400 person-mrem per-shipment (see Section 4.3.2.1). Doses to bystanders for the postulated reference system were estimated assuming that 50 persons are exposed at an average distance of 20 meters from the shipping cask. This resulted in an estimated dose to bystanders of about 216 person-mrem per shipment. Thus, the dose to residents for the postulated reference truck shipment was estimated to be 400 - 216 = 184 person-mrem per shipment.

For this alternative where the average exposure distance between bystanders and a cask at truck stops is increased to 50 meters and the total stop time is reduced to 10 hours/shipment, the estimated per-shipment collective dose to this group would be 10 person-mrem/shipment. The collective dose to residents near the truck stop would also be reduced as a result of the reduced total stop time for the improved truck operations shipment. The population dose is assumed to be approximately linear with respect to total stop time. Because the stop time for the improved truck operations shipment is estimated to be 10 hours versus 30 hours for the postulated reference truck shipment, the dose to residents was reduced to 10/30 of the postulated reference dose. Thus, the dose to residents near the truck stop is reduced to an estimated (10/30)(184) = 61 person-mrem/ shipment. The total collective public dose at stops is thus estimated to be 61 + 10 = 71 person-mrem/shipment.

Radiation doses to escorts for the improved truck operations shipment are lower than for the postulated reference shipment because of the increased travel speed and reduced stop times in the alternative. As indicated in Section 4.3.2.1, escorts are assumed to be required in urban areas only. It was also shown that approximately 1% (about 18 miles) of the truck shipment route is through urban areas where escorts are used. At an average speed of 25 mph, a total of 0.7 hours is estimated to be in urban areas with escorts. Assuming that each shipment is preceded and followed by two-person escort teams (total of 4 escorts) at an average exposure distance of 50 meters, the collective dose to escorts while moving is estimated at about 0.04 person-mrem/ shipment. It was assumed in the postulated reference case that the escorts would also be present for an entire stop. Assuming the stop duration is 1 hour and the average exposure distance is 20 meters, the collective radiation dose to the four escorts at stops is estimated at about 0.7 person-mrem/shipment.

Radiation doses to the public while the truck shipment is moving will be lower for the improved truck operations shipment than for the postulated reference truck shipment because the average speeds are slightly higher and thus the exposure times will be lower in the former case. The collective doses that were estimated in the postulated reference analysis were recalculated for the improved truck operations analysis by assuming the doses are approximately linear but inversely proportional with respect to the average speed while moving. Thus, the unit dose factors for on-link and off-link population groups in the postulated reference system analysis were multiplied by the ratio of the average travel speeds that were assumed for the postulated reference truck shipment to the average speeds assumed for the improved truck operations shipment. The revised unit dose factors were then multiplied by the transport distance to estimate the on-link and off-link doses. The resulting collective dose to the public while the truck is moving for the improved truck operations alternative were estimated at about 25 and 17 person-mrem per shipment, respectively, for on-link and off-link doses.

The final category of transport worker radiation doses at stops is the doses received during inspections of the shipment at the originating facility and after the shipment crosses the border of the destination state. These doses were estimated in this alternative by assuming one inspector is exposed for 0.5 hour (1.0 hour was used for the postulated reference truck shipment) per inspection. An average exposure distance of 5 meters from the side of the cask was used to estimate these doses. Thus, the per-shipment dose to state inspectors was estimated to be about (3.2 mrem/hour) (0.5 hour/inspection) (1 person/inspection) (2 inspections/shipment), or 3.2 person-mrem/shipment.

The estimated radiation doses for the improved truck operations alternative are summarized in Table 5.67.

5.13.3 Cost Consequence of Improved Truck Operations

The major cost changes from this alternative result from the reduced round-trip transit times and the resultant reduced cask fleet size. Compared to the postulated reference LWT cask operations, the improved truck operations would reduce the total turnaround time from 7.7 to about 6.6 days for PWR fuel and from 7.9 to about 6.8 days for BWR fuel, respectively. This would allow for an estimated reduction in the cask fleet to 13 casks for PWR fuel and 9 casks for BWR fuel, for a total cask fleet of 22 versus 26 for the postulated reference system. This smaller fleet size would reduce the estimated capital costs for casks by $6 million and the maintenance costs by $300,000/year, as shown in Table 5.68. All other costs should remain the same as for the postulated reference case.

TABLE 5.67. Summary of Estimated In-Transit Collective Radiation Doses for the Postulated Reference System With and Without Improved Truck Operations

Exposure Category	Person-mrem/ Shipment	Person-mrem/ MTU[a]	Person-rem/ year[b]
Transport Workers			
Truck Crew			
- While moving	149	161	145
- At stops	6.2	6.7	6.0
State Inspectors	3.2	3.5	3.1
Service Attendants[c]	2.5[d]	2.7	2.4
State Escorts	0.7	0.8	0.7
Total Transport Workers	162 (206)[e]	175 (223)	155 (200)
Public			
While moving			
- on-link	25	27	24
- off-link	17	18	17
At stops	71	77	89
Total Public	113 (457)	122 (495)	110 (444)

(a) Based on an average cask capacity of 0.924 MTU/shipment.
(b) Based on 900 MTU/year.
(c) Not included in totals. Truck refueling is typically performed by the drivers and the dose is included with the driver doses. If done by a service station attendant, the dose to the drivers would be reduced.
(d) This value is unchanged from the postulated reference system analysis.
(e) Numbers in parentheses are dose estimates for the postulated reference LWT (2/5) shipment.

The present worth of the estimated cost savings of the improved truck operations alternative, with discount rates of 0% and 3% and using a 21-year lifetime and 1987 dollars, is $12.3 million and $10.6 million, respectively.

TABLE 5.68. Comparison of Estimated Life-Cycle Costs for the Postulated Reference System With and Without Improved Truck Operations[(a)]

Cost Category	Postulated Reference Cost ($)	Improved Truck Alternative Cost	Change in Cost ($)
Capital Cost:	39,000,000	33,000,000	-6,000,000[(b)]
Annual Cost:			
Maintenance	5,450,000	5,150,000	-300,000
Present Worth of Cost Difference:			
3% Discount Rate			-10,600,000
0% Discount Rate			-12,300,000

(a) Costs are shown to more significant figures than justified, to provide for consistency in the calculations. See Appendix J for details of cost savings.

(b) Negative values indicate a cost savings.

5.13.4 Overview Evaluation of Improved Truck Operations

The potential improvements indicated in this alternative appear to be very beneficial. Significant reduction in collective doses to the public and to the transport workers, as well as a reduction in costs, are anticipated. However, the maximum individual dose to the truck drivers does not decrease. The alternative appears attractive for implementation. Calculation of the Δcost/Δdose ratio is not meaningful since the ratio is negative. The analysis of this alternative also indicates that actions that tend to retard the truck shipments will tend to increase public dose and transport worker doses.

5.14 OTHER CONSIDERATIONS NOT EVALUATED

It must be remembered that while the ratio of Δcost/Δdose is a useful figure of merit for evaluation of system alternatives, other factors also need to be considered when making any final selection of system alternatives for implementation. These additional factors are: 1) the potential R&D costs associated with bringing a given concept to a fully functional status; 2) the ease or difficulty (time and/or cost) of obtaining an NRC license for a cask or facility that incorporates the alternative concept; 3) the increase or decrease in system nonradiological risk associated with implementation of a given concept; 4) effects on radiological accident risks; 5) acceptance of concepts by the public or by institutions; 6) impacts on interfacing parts of the system (e.g. highways, railroads); and 7) logistics and scheduling.

One example of the impact of these considerations may be illustrated for the concept of the single-action fastener on the cask lids. It is expected that a significant engineering design, analysis and demonstration effort would be required to assure that the concept would be acceptable from the standpoint of accident risks and licensing requirements. Thus, the projected reductions in capital and operational costs could be offset by the developmental and other costs and by time delays due to licensing.

Another example of the impact of other considerations would apply to all of those concepts that increase the capacity of the transport casks. In these cases, especially for truck shipments, the increased capacities result in large reductions in doses and in the number of shipment-miles required to transport a given quantity of spent fuel. These reductions would also be expected to reduce the nonradiological risk to the public and to transport workers, principally from reduction in traffic accidents and exhaust emissions. As an illustration of the relative impacts, consider the unit risk factors for fatality from truck transport, given in Cashwell (1986); the risk of fatality per kilometer traveled for spent fuel shipments by truck is about 3.5×10^{-8} from both routine and accident radiation exposure and about 6.4×10^{-8} from nonradiological hazards. On a given shipment, the radiation exposure would occur only on the loaded segment of the round trip, whereas the nonradiological hazards would be present on both segments of the trip. Using the risk factors given, the chances of fatality per round-trip from nonradiological hazards would be nearly a factor of 4 times that from the radiation exposure. Thus, the reduced number of shipments would have an even greater benefit for reducing total risks than for reducing routine radiation risks.

5.15 OTHER ALTERNATIVES

Numerous other alternatives with the potential for reducing routine radiation doses in the transportation system were identified during this study (see Appendix M). This study is not intended to be exhaustive, and other alternatives could be evaluated. These other alternatives, considered early in this study, have not been evaluated and described individually because they were considered beyond the scope of this study or their benefits appeared to be marginal relative to those evaluated. They are listed here, without detailed descriptions, as potential additional improvements to be considered during development of the transportation system or other future system optimization studies.

1. Tailor the design of the combined casks and their transport vehicles to minimize the vehicle weight and maximize the cask payload, while remaining within weight and dimensional restrictions.
2. Use rail casks of larger sizes and higher weights.
3. Design casks for fuel cooled more than 10 years. Add incremental shielding to cask cavities or baskets as fuel-cooling period decreases.
4. Design transport vehicles so that the structural members also enhance cask shielding and accident protection.
5. Design cask top and bottom "corners" to provide the same shielding as the cask wall.
6. Electropolish cask surfaces.
7. Use captive bolts in cask lids.
8. Use multiple bolt-removal tools.
9. Use self-erecting cask mechanisms on vehicles.
10. Use local or shadow-shielding plates for inner and outer lid work at reactors and at the repository.
11. Use dedicated trains to reduce shipment times and doses during rail transit.

12. Use specially designed tools for rapid impact limiter removal, etc.

13. Transport more spent fuel by rail and less by truck.

14. Ship loaded casks with water in cavity. (This is contrary to currently allowed practice and would lead to licensing difficulties.)

5.16 REFERENCES

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6.0 EVALUATION OF DOSE AND COST OF AN EXAMPLE ALTERNATIVE TRANSPORTATION SYSTEM INCORPORATING A COMBINATION OF ALTERNATIVES

As demonstrated in Chapter 5, radiation doses in the postulated reference transportation system can be reduced through the implementation of cost-effective dose-reduction alternatives. This chapter provides an example of system dose reductions that can be achieved through the use of a combination of the alternatives analyzed in Chapter 5.(a)

While the alternatives assembled in the example alternative system evaluated in this chapter were selected to illustrate the potential for dose reduction and related incremental cost changes, it is recognized that many other factors (e.g., technical and institutional feasibility, operational reliability and maintainability) would necessarily be considered in selecting and implementing alternatives to optimize the overall transportation system. Numerous other combinations are possible that would warrant further evaluations.

The dose-reduction alternatives selected for the example alternative system are:

- An overweight truck subsystem transporting 900 MTU of spent fuel annually(b)
    - A cask capacity of 7 PWR or 15 BWR fuel assemblies using "advanced design" casks incorporating burnup credit and increased end shielding (see Sections 5.1, 5.3, and 5.5).
    - Improved trucking operations (see Section 5.13).
- A rail subsystem transporting 2100 MTU of spent fuel annually

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(a) This combination of alternatives is hereinafter referred to as the "example alternative system" in this report.

(b) This not intended to imply that no legalweight trucking would be utilized; only that overweight trucking would be utilized to the maximum extent possible, depending on success in obtaining highway permits and resolution of a few reactor facility interface constraints.

  - A cask capacity of 30 PWR or 66 BWR fuel assemblies using "advanced design" casks incorporating burnup credit and increased end shielding (see Sections 5.2, 5.3, and 5.5).

- Handling alternatives applicable to both rail and truck subsystems
  - special impact wrench tool (see Section 5.6).
  - cask lid-lifting fixtures (see Section 5.8).
  - quick-release impact limiters on casks (see Section 5.10).
  - quick-release tiedowns on casks (see Section 5.11).

The above example alternative system represents a formidable challenge to cask-vehicle designers, operations and traffic management personnel, and those responsible for resolution of institutional issues. Achieving the 7/15 and 30/66 cask capacities with additional end shielding, improved handling features and dependence on burnup credit will require innovative design and testing approaches in both casks and vehicles. Likewise, achievement of improved control of stop time and proximity of shipments to people in trucking operations will require careful planning and procedure development.

In addition, reduction of legalweight trucking in favor of overweight trucking will necessitate more uniform highway transportation permitting in many states and careful scheduling to minimize time-of-travel restrictions (e.g., nights, weekends, holidays) that may be included in some permits. However, even if only limited success is achieved in the permitting effort, the 40-ton (nominal) 7/15 cask concept has attractive dose-reduction potential and may provide operational flexibility in intermodel (truck-rail) service with reasonable overall system economics.

Notwithstanding the above challenges, the example alternative system chosen serves to illustrate the potential for system dose reduction and approximate the incremental cost changes for use in planning and conduct of ongoing system optimization studies.

A summary comparison of annual collective transportation system radiation doses for the postulated reference system and for the example alternative system is shown in Table 6.1. As shown in Table 6.1, total annual collective

TABLE 6.1. Summary Comparison of Estimated Annual Collective Radiation Doses for the Postulated Reference and Example Alternative Systems

	person-rem		
	Postulated Reference System	Alternative System	Dose Change
At-Reactors	415	112	-303
In-transit	677	53	-624
At-Repository	418	30	-388
Total	1510	195	-1315

dose for the system is reduced from 1,510 person-rem for the postulated reference system to 195 person-rem for the example alternative system analyzed here.

The analysis of the dose from cask loading operations at the reactor site is presented in Section 6.1. The in-transit dose analysis is described in Section 6.2, and the analysis of the dose from transport cask unloading operations at the repository is provided in Section 6.3. The estimated cost impact of incorporating the example alternative system is presented in Section 6.4.

6.1 AT-REACTOR DOSES

The radiation doses from cask loading operations at the reactor site were calculated using the same methodology as in Chapters 4 and 5. The times and dose rates were selected as appropriate and used in the spreadsheet models. Detailed values are contained in Appendix L.

The example alternative system selected for the at-reactor analysis is estimated to reduce the collective dose to reactor cask handling workers from 415 person-rem/year for the postulated reference system to 112 person-rem for the example alternative system handling 3,000 MTU/year.

Estimated collective doses for the example alternative truck cask handling are 155 person-mrem/shipment or 186 person-mrem/shipment for PWR or BWR spent fuel, respectively. The estimated dose for each activity is compared to that in the postulated reference system in Table 6.2. Collective dose is estimated to be reduced by 106 to 116 mrem/shipment, primarily due to increased cask end shielding.

A summary of the estimates of average annual doses to individual reactor workers for handling truck shipments is shown in Table 6.3. Operators are estimated to receive the highest annual dose, at an average of about 0.2 rem/individual. The resulting estimated collective annual dose for all truck cask handling workers at a single reactor that ships 30 MTU/year ranges from 1.5 to 2.0 person-rem/year (18% to 22% of the postulated reference system dose), depending on reactor type.

Estimated collective doses for the example alternative rail cask handling subsystem are 309 person-mrem/shipment or 495 person-mrem/shipment for PWR or BWR spent fuel, respectively. Estimated dose for each activity is shown in Table 6.4. Collective dose is estimated to be reduced by 25 to 95 mrem/shipment.

A comparison of the estimates of average annual doses to individual reactor cask workers for handling rail shipments is shown in Table 6.5. The resulting estimated collective annual dose for rail cask handling workers at a single reactor that ships 30 MTU/year ranges from 0.93 to 1.5 person-rem/year (50% to 64% of the postulated reference system dose), depending on reactor type. Operators, the maximally exposed craft, are estimated to receive an annual average dose of 0.2 to 0.3 rem/individual.

TABLE 6.2. Comparison of Estimated Collective Radiation Dose by Activity at the Reactor for the Postulated Reference Truck and the Example Alternative OWT Subsystems

			person-mrem/shipment		
Activity No.	Activity	Facility Location	Postulated Reference System[(a)]	Example Alternative System[(b)]	Dose Change
1	Receive transport vehicle and empty cask, monitor, inspect	Outer Guardhouse	0.017	0.017	0
2	Move transport vehicle and cask to inspection and washdown area	Facility Grounds	0	0	0
3	Wash transport vehicle and cask, monitor, inspect	Washdown Pad	0.150	0.150	0
4	Move transport vehicle and cask to loading area	Facility Grounds	0.167	0.167	0
5	Prepare cask for removal from transport vehicle	Loading Area	3.33	2.02	-1.31
6	Remove cask from vehicle and place on cask service pad	Loading Area	3.19 PWR 3.73 BWR	3.19 PWR 3.73 BWR	0 PWR 0 BWR
7	Remove transport vehicle from loading area	Facility Grounds	0.167	0.167	0
8	Prepare cask for placing in loading pit	Service Pad	10.00	7.64	-2.36
9	Place cask in loading pit	Service Pad	4.32	4.25	-0.07
10	Prepare cask for loading	Loading Pit	7.13	6.87	-0.27
11	Place spent fuel assemblies in cask	Loading Pit	10.0 PWR 25.0 BWR	20.0 PWR 45.0 BWR	10.0 PWR 20.0 AWR
12	Install fuel spacers and inner lid on the shipping cask	Loading Pit	3.68	3.68	0
13	Lift cask from loading pit and place on service pad	Loading Pit	8.83	8.04	-0.79
14	Decontaminate cask exterior	Service Pad	5.58	5.58	0
15	Prepare cask for shipment	Service Pad	117.0	23.8	-93.2
16	Move cask to loading area	Service Pad	8.52	8.52	0
17	Move vehicle to loading area	Facility Grounds	0.167	0.167	0
18	Place cask on transport vehicle	Loading Area	4.25 PWR 9.75 BWR	3.46 PWR 8.96 BWR	-0.79 PWR -0.79 BWR
19	Perform contamination survey	Loading Area	16.5	16.5	0
20	Prepare loaded vehicle for shipment	Loading Area	51.6	24.5	-27.1
21	Final inspection and contamination survey	Loading Area	14.3	14.3	0
22	Move transport vehicle out of security area	Facility Grounds	0.417	0.417	0
23	Release cask and transport vehicle to carrier	Outer Guardhouse	1.33	1.33	0
24	Notify appropriate organizations of shipment departure	Supervisor's Office	0	0	0
	Totals PWR		271	155	-116
	BWR		292	186	-106

(a) Reference truck cask capacity is 2 PWR or 5 BWR assemblies.
(b) Alternative truck cask capacity is 7 PWR or 15 BWR assemblies.

TABLE 6.3. Comparison of Estimated Average Annual Radiation Doses(a) Received by Individual Workers in Each Craft at the Reactor for the Postulated Reference Truck and Example Alternative OWT Subsystems

		Postulated Reference System Truck Shipments(b,c,d)		Example Alternative System Truck Shipments(b,d,e)	
Craft	Number of Workers	mrem/Shipment	mrem/year	mrem/Shipment	mrem/year
Crane Operators	1	13.0/14.5	429/479	12.8/14.4	128/157
Operators	4	27.2/31.4	898/1036	19/25	190/276
Radiation Monitors	1	14.0/14.0	462/462	14/14	135/149
Quality Control Inspectors	1	10.4/13.4	342/442	12/17	117/184
Yard Drivers	1	1.3/1.3	43/43	1.3/1.3	13/15
Security Guards	1	0.3/0.3	10/10	0.26/0.26	3/3
Maintenance-Craftsmen	4	30.7/30.7	1013/1013	10/10	98/107
Totals	13(f)		8780/9410(g)		1545/2043(g)

(a) The average annual individual doses assume that the doses are distributed uniformly among each worker in each craft in the dedicated work crews.
(b) Assumes all shipments from a given reactor are by truck.
(c) Postulated reference system can ship 30 MTU in 33 truck casks of either fuel type.
(d) Data shown are for the average of each worker from either PWR or BWR shipments.
(e) Example alternative system can ship 30 MTU in 10 PWR or 11 BWR truck cask shipments.
(f) Supervisors are not included because they are assumed to perform no work in radiation zones.
(g) Collective annual dose for all cask handling workers.

TABLE 6.4. Comparison of Estimated Collective Radiation Dose by Activity at the Reactor for the Postulated Reference and the Example Alternative Rail Subsystems

			person-mrem/shipment		
Activity No.	Activity	Facility Location	Postulated Reference System[a]	Example Alternative System[b]	Dose Change
1	Receive transport vehicle and empty cask, monitor, inspect	Outer Guardhouse	0.017	0.017	0
2	Move transport vehicle and cask to inspection and washdown area	Facility Grounds	0	0	0
3	Wash transport vehicle and cask, monitor, inspect	Washdown Pad	0.150	0.150	0
4	Move transport vehicle and cask to loading area	Facility Grounds	0.167	0.167	0
5	Prepare cask for removal from transport vehicle	Loading Area	3.87	1.85	-2.02
6	Remove cask from vehicle and place on cask service pad	Loading Area	3.44 PWR 3.98 BWR	3.44 PWR 3.98 BWR	0 PWR 0 BWR
7	Remove transport vehicle from loading area	Facility Grounds	0.250	0.250	0
8	Prepare cask for placing in loading pit	Service Pad	14.90	11.12	-3.78
9	Place cask in loading pit	Service Pad	5.15	5.08	-0.07
10	Prepare cask for loading	Loading Pit	10.20	9.92	-0.30
11	Place spent fuel assemblies in cask	Loading Pit	70.0 PWR 180.0 BWR	150.0 PWR 330.0 BWR	80.0 PWR 150.0 BWR
12	Install fuel spacers and inner lid on the shipping cask	Loading Pit	4.68	4.68	-0
13	Lift cask from loading pit and place on service pad	Loading Pit	9.17	8.37	-0.80
14	Decontaminate cask	Service Pad	7.00	7.00	0
15	Prepare cask for shipment	Service Pad	162.0	31.8	-130.2
16	Move cask to loading area	Service Pad	9.02	9.02	0.00
17	Move vehicle to loading area	Facility Grounds	0.167	0.167	0.000
18	Place cask on the transport vehicle	Loading Area	4.46 PWR 9.96 BWR	3.67 PWR 9.17 BWR	-0.78 PWR -0.79 BWR
19	Perform contamination survey	Loading Area	19.0	19.0	0
20	Prepare loaded vehicle for shipment	Loading Area	61.8	25.7	-36.1
21	Final inspection and contamination survey	Loading Area	16.0	16.0	0
22	Move transport vehicle out of security area	Facility Grounds	0.417	0.417	0
23	Release cask and transport vehicle to carrier	Outer Guardhouse	1.42	1.42	0
24	Notify appropriate organizations of shipment departure	Supervisor's Office	0	0	0
	Totals PWR BWR		404 520	309 495	-95 -25

(a) Reference rail cask capacity is 14 PWR or 36 BWR assemblies.
(b) Alternative rail cask capacity is 30 PWR or 66 BWR assemblies.

TABLE 6.5. Comparison of Estimated Average Annual Radiation Dose(a) Received by Individual Workers in Each Craft at the Reactor for the Postulated Reference and Example Alternative Rail Subsystems

		Postulated Reference System Truck Shipments(b,c,d)		Example Alternative System Truck Shipments(b,d,e)	
Craft	Number of Workers	mrem/Shipment	mrem/year	mrem/Shipment	mrem/year
Crane Operators	1	15.2/16.7	76/83.5	15/16.5	45/50
Operators	4	43.4/66.5	217/333	48/85	144/256
Radiation Monitors	1	16.7/16.7	83.5/83.5	16/16	48/48
Quality Control Inspectors	1	24.2/46.2	121/231	39/75	117/225
Yard Drivers	1	1.4/1.4	7.0/7.0	1.4/1.4	4/4
Security Guards	1	0.3/6.3	1.5/1.5	.3/.3	1/1
Maintenance-Craftsmen	4	43/43	215/215	11/11	33/33
Totals	13(f)		1870/2330(g)		926/1485(g)

(a) The average annual individual doses assume that the doses are distributed uniformally among each worker in each craft in the dedicated work crews.
(b) Assumes all shipments from a given reactor are 100% by rail.
(c) Postulated reference system can ship 30 MTU in 5 rail cask shipments.
(d) Data shown are for the average of each worker from either PWR or BWR shipments.
(e) Example alternative system can ship 30 MTU in 3 rail cask shipments.
(f) Supervisors are not included because they are assumed to perform no work in radiation zones.
(g) Collective annual dose for all cask handling workers.

6.2 IN-TRANSIT DOSES

The approach to estimating the annual system in-transit doses for the example alternative system was to modify the postulated reference system doses using the fractional change in doses for each single alternative. These fractions were multiplied sequentially by the postulated reference system doses to estimate the total revised dose for the example alternative system.

For the truck subsystem, the per-shipment doses estimated in Section 5.1 for the overweight truck cask were used as the starting point. The starting point for the rail subsystem was the rail cask doses from the increased cask end shielding alternative, discussed in Section 5.3. The changes in doses due to advanced design (burnup credit) were based only on differences of cask capacities because this alternative does not change the dose rate field surrounding the cask, nor does it change the time spent in a radiation field. Advanced design was assumed to affect only spent fuel transport cask capacities. To account for change in transport cask capacities, the revised per-shipment doses (calculated using the fractions discussed above) were divided by the cask capacities, in MTU per shipment, for the advanced design alternatives (7 PWR/15 BWR assemblies or 3.23/2.79 MTU/shipment for the advanced design OWT cask and 30 PWR/66 BWR assemblies or 13.8/12.3 MTU/shipment for the advanced design rail cask). The resulting values represent the revised unit in-transit doses for the example alternative system.

The factors used to adjust the OWT shipment doses were derived as follows. The postulated reference system LWT shipment doses were estimated to be 457 person-mrem/shipment to the public and 210 person-mrem/shipment for workers. The analysis of improved trucking operations alternative (see Section 5.13) indicated these doses would be reduced to 113 and 162 person-mrem/shipment, respectively. This represents about 23% and 76% of the public and worker doses, respectively, that were calculated for the reference LWT shipment. As a result, the per-shipment public and worker dose estimates for the OWT shipment alternative only were multiplied by these fractions to estimate the per-shipment dose for the OWT/improved-operations combination.

The increased cask end shielding alternative was incorporated into this example alternative system in a similar manner. For the increased cask end shielding alternative, the fractional dose reductions amounted to 1.0 for public doses (i.e., this alternative does not affect public doses) and 0.11 for worker doses. The resulting per-shipment doses for the OWT/improved-operations/increased-end-shielding subsystem are thus the estimated OWT shipment doses (527 person-mrem/shipment for the public and 215 person-mrem/shipment for workers) times the appropriate fractions listed above. The resulting doses for the subsystem are 132 person-mrem/shipment for the public and 18 person-mrem/shipment for workers, for a total collective dose of 150 person-mrem/shipment.

The final step in calculating the unit dose for this subsystem was to convert the per-shipment doses to per-MTU doses using the cask capacity estimated for the advanced design truck cask alternative (3.23/2.79 MTU/shipment). The resulting unit public and worker doses are 41 person-mrem/MTU and 5.6 person-mrem/MTU, respectively. Assuming that 900 MTU is hauled by truck annually, the total annual dose for this subsystem is estimated at 42.4 person-rem/year (which consists of 37 person-rem/year to the public and 5.4 person-rem/year to workers). Using a similar method, the average annual dose to individual truck drivers is estimated to be 0.17 rem/year.

The unit doses for the rail cask subsystem shipment were estimated in a manner similar to the truck cask subsystem shipment discussed above. However, no fractional dose reductions were applied because only the increased cask end shielding alternative changes the dose rate from the shipping cask. There were no changes to the amounts of time spent by workers or the public in the cask's radiation field. Therefore, the results of the increased cask end shielding alternative analysis were used as the starting point. These doses were estimated to be 39 person-mrem/shipment and 32 person-mrem/shipment to the public and workers, respectively (see Table 5.15). These per-shipment doses were divided by the increased cask capacity in this alternative (i.e., 13.8/12.3 MTU/shipment) that results from advanced cask designs to estimate the revised unit dose for the rail cask subsystem. The resulting unit doses are 2.8 person-mrem/MTU for the public and 2.3 person-mrem/MTU for workers. The total annual dose for shipping 2,100 MTU/year by rail is thus estimated to be 10.7 person-rem/year (which consists of 5.9 person-rem/year for the public and 4.8 person-rem/year for workers).

The results of the analysis of in-transit doses for the example alternative system are compared with the in-transit doses for the postulated reference system in Table 6.6. The 624 person-rem/year dose reduction shown in Table 6.6 represents a 92% decrease in in-transit dose for the example alternative system compared to the postulated reference system. The most significant decrease occurs in the public dose from truck shipments. This decrease amounts to about 407 person-rem/year, or about a 92% reduction in public dose from truck shipments. Worker doses are reduced by 195 person-rem/year in the example alternative system. The total public plus worker doses are decreased by about 94% for the example alternative system.

The total annual doses from rail shipments are also decreased significantly. Public doses from rail shipments are reduced by 6 person-rem/year (50%) and worker doses are decreased by about 16 person-rem/year (77%) compared to the public and worker doses, respectively, for the postulated reference

TABLE 6.6. Comparison of Estimated Collective Annual In-Transit Radiation Dose for the Postulated Reference and the Example Alternative Subsystems

		person-rem/year(a)		
		Postulated Reference System	Alternative System	Dose Change
Truck:	In-transit			
	- worker	200	5	-195
	- public	444	37	-407
Rail:	In-transit			
	- worker	21	5	-16
	- public	12	6	-6
	Totals	677	96	-624

(a) For shipping 900 MTU/year by truck and 2100 MTU/year by rail; spent fuel is 60% from PWRs and 40% from BWRs.

system rail shipments. This amounts to a total annual dose reduction for rail shipments of about 22 person-rem/year, or about 67% of the dose estimate for the postulated reference system rail shipments.

6.3 AT-REPOSITORY DOSES

The radiation doses from transport cask unloading operations at the repository were calculated using the same methodology as in Chapters 4 and 5. The times and dose rates were selected as appropriate and used in the spreadsheet models. Detailed values are contained in Appendix L.

Significant reductions in collective worker radiation doses from transport cask unloading operations at the repository are estimated to result from the implementation of the example alternative system. As shown in Table 6.1, annual collective dose is estimated to be reduced from 418 to 30 person-rem/year for receiving 3000 MTU/year at the repository.

Estimated collective doses by at-repository activity for overweight truck unloading operations are shown in Table 6.7. Collective repository worker doses are estimated to be reduced by 211 person-mrem/truck shipment relative to the postulated reference system, for a total dose of approximately 65 person-mrem/truck shipment.

A summary of the estimates of average annual doses to individual repository workers from handling truck shipments is provided in Table 6.8. The maximally exposed craft from overweight truck cask handling is maintenance-craftsmen. Each individual craftsman is estimated to receive an average annual dose of about 0.6 rem. The estimated 296 shipments would result in an estimated 19.1 person-rem/year of collective dose to the cask handling workers (7% of the postulated reference system dose).

Estimated collective at-repository worker doses by activity for rail cask handling in the example alternative system are shown in Table 6.9. It is estimated that the collective dose is reduced by about 395 person-mrem/shipment relative to the postulated reference system, for a total collective dose of about 70 person-mrem/shipment.

The estimated average annual doses to individual repository workers from handling the 160 rail shipments/year required for 2,100 MTU/year of spent fuel are shown in Table 6.10. The maximally exposed craft from rail cask handling is maintenance craftsmen. Each individual craftsman is estimated to receive an average annual dose of 0.32 rem. The collective repository dose resulting from rail cask unloading at the repository is estimated to be 11.1 person-rem/year (7% of the postulated reference system dose).

Total annual radiation doses to individual repository cask receiving and unloading workers are the sum of those from handling 900 MTU/year shipped by truck and 2100 MTU/year shipped by rail. The sums of these estimates are presented graphically in Figure 6.1. The maintenance-craftsmen are estimated to receive the highest average annual dose (0.92 rem/individual), followed by security guards (0.34 rem/individual). These doses are based on the number of workers shown in Tables 6.8 and 6.9.

The estimated collective radiation doses in the total system for this example alternative system are lower than for any of the alternatives by themselves. In addition, the estimated annual doses to individual repository workers would all meet the DOE design objectives for individual facility worker doses. Optimization of selected alternatives and other combinations of these alternatives should result in further reductions in system radiation doses.

TABLE 6.7. Comparison of Estimated Collective Radiation Dose by Activity at the Repository for the Postulated Reference Truck and the Example Alternative OWT Subsystems

Activity No.	Activity	Facility Location	person-mrem/shipment Postulated Reference System[(a)]	 Example Alternative System[(b)]	 Dose Change
1	Receive transport vehicle and loaded cask at the repository site. Monitor, inspect, unhook over-the-road carrier's drive unit and attach repository drive unit	Receiving Gatehouse	5.50	5.50	0
2	Move the transport vehicle and cask to parking area and wait for washdown station, hook up to car puller when ready	Parking Area	1.53	1.53	0
3	Wash transport vehicle and cask, open personnel barrier, monitor, inspect and dry	Washdown Area	16.0	16.0	0
4	Move transport vehicle and cask to receiving and handling area	Receiving and Handling Area	0.092	0.092	0
5	Prepare cask for removal from transport vehicle	Receiving and Handling Area	53.5	11.8	-41.7
6	Remove cask from transport vehicle and place on cask cart	Receiving and Handling Area	3.73	3.73	0
7	Move cart and cask to cask handling room and close roll-up door to handling room	Handling Room	0.675	0.675	0
8	Prepare cask for unloading, position platform, install contamination barrier adapter, remove outer lid, pressure/gas sample cask cavity, remove inner lid bolts and install lid lifting adapter	Handling Room	187	18	-169
9	Open sliding shielding door to unloading room (if necessary), retract platform, move cart and cask to unloading room	Unloading Room	2.70	2.70	0
10	Mate the cask to the hot cell entry port and close shielding door	Unloading Room	1.53	1.53	0
11	Using 20-ton hot cell crane, remove hot cell port plugs	Hot Cell	0.083	0.083	0
12	Remove remaining inner lid bolts and remove inner lid and spent fuel assembly spacer	Unloading Room/Hot Cell	0.217	0.217	0
13	Unload spent fuel assemblies and place into in-cell lag storage	Unloading Room/Hot Cell	0.150 PWR 0.375 BWR	0.300 PWR 0.675 BWR	0.150 PWR 0.300 BWR
14	Monitor and vacuum cask cavity and fuel basket	Unloading Room/Hot Cell	0.350 PWR 0.650 BWR	0.650 PWR 1.200 BWR	0.300 PWR 0.550 BWR

TABLE 6.7. (contd)

			person-mrem/shipment		
Activity No.	Activity	Facility Location	Postulated Reference System[a]	Example Alternative System[b]	Dose Change
15	Replace spent fuel assembly spacer and replace inner lid and hot cell port plugs	Unloading Room/Hot Cell	0.400	0.4	0
16	Unmate cask from hot cell port and open unloading room shielding door	Unloading Room	0.025	0.025	0
17	Move cart and cask to handling room	Handling Room	0.008	0.008	0
18	(If wet decontamination is to be performed, refer to wet decontamination steps in Table 7.3). Install platform, remove contamination barrier adapter and lifting adapter, install inner and outer lids, secure all openings to the cask, monitor and decontaminate exterior of cask, open roll-up door and retract platform	Handling Room	1.267	0.775	-0.492
19	Move cask and cart to receiving and handling area	Receiving and Handling Area	0.008	0.008	0
20	Place cask on the transport vehicle	Receiving and Handling Area	0.150	0.150	0
21	Prepare cask for shipment, install cask tiedowns and impact limiters and close personnel barrier	Receiving and Handling Area	1.53	0.62	-0.91
22	Move transport vehicle and cask to inspection area, disconnect repository drive unit	Inspection Area	0.017	0.017	0
23	Hook up over-the-road carrier, move to gatehouse, perform final monitoring and inspection of empty cask	Gatehouse Receiving and Dispatching	0.150	0.150	0
24	Notify appropriate organizations of the shipment departure	Supervisor's Office	0	0	0
	Totals PWR		276	65	-211
	BWR		277	66	-211

(a) Reference truck cask capacity is 2 PWR or 5 BWR assemblies.
(b) Alternative truck cask capacity is 7 PWR or 15 BWR assemblies.

TABLE 6.8. Comparison of Estimated Average Annual Radiation Doses(a) Received by Individual Workers in Each Craft at the Repository for the Postulated Reference Truck and the Example Alternative OWT Subsystems(b,c)

	Postulated Reference system Truck Shipments(d)			Example Alternative System Truck Shipments(e)		
Craft	Number of Workers	mrem/shipment	mrem/year	Number of Workers	mrem/shipment	mrem/year
Crane Operators	6	0.3	291	3	0.5	155
Operators	47	0.8	777	29	0.7	196
Radiation Monitors	10	0.6	583	7	0.6	181
Quality Control Inspectors	12	0.3	291	6	0.4	123
Yard Drivers	4	0.5	486	4	0.5	139
Security Guards	8	0.8	777	8	0.8	228
Maintenance-Craftsmen	26	8.5	8,250	14	2.1	613
Totals	113(f)		270,000(g)	71(f)		19,100(g)

(a) The average annual individual doses assume that the doses are distributed uniformly among each worker in each craft in the dedicated work crews.
(b) For shipment of 900 MTU/year by truck.
(c) Dose differences between PWR/BWR fuel types are negligible for this analysis. Data shown are for the average of each worker from either PWR or BWR shipments.
(d) 971 LWT shipments per/year required.
(e) 296 OWT shipments per/year required.
(f) Supervisors are not included because they are assumed to perform no work in radiation zones.
(g) Collective annual dose for all cask handling workers.

TABLE 6.9. Comparison of Estimated Collective Radiation Dose by Activity at the Repository for the Postulated Reference and the Example Alternative Rail Subsystems

			person-mrem/shipment		
Activity No.	Activity	Facility Location	Postulated Reference System(a)	Example Alternative System(b)	Dose Change
1	Receive transport vehicle and loaded cask at the repository site. Monitor, inspect, unhook over-the-road carrier's drive unit and attach repository drive unit	Receiving Gatehouse	6.25	6.25	0
2	Move the transport vehicle and cask to parking area and wait for washdown station, hook up to car puller when ready	Parking Area	1.88	1.88	0
3	Wash transport vehicle and cask, open personnel barrier, monitor, inspect and dry	Washdown Area	11.9	11.9	0
4	Move transport vehicle and cask to receiving and handling area	Receiving and Handling Area	0.092	0.092	0
5	Prepare cask for removal from transport vehicle	Receiving and Handling Area	79.0	12.1	-66.9
6	Remove cask from transport vehicle and place on cask cart	Receiving and Handling Area	4.33	4.33	0
7	Move cart and cask to cask handling room and close roll-up door to handling room	Handling Room	0.425	0.425	0
8	Prepare cask for unloading, position platform, install contamination barrier adapter, remove outer lid, pressure/gas sample cask cavity, remove inner lid bolts and install lid lifting adapter	Handling Room	350	22	-328
9	Open sliding shielding door to unloading room (if necessary), retract platform, move cart and cask to unloading room	Unloading Room	1.70	1.70	0
10	Mate the cask to the hot cell entry port and close shielding door	Unloading Room	1.020	1.030	0
11	Using 20-ton hot cell crane, remove hot cell port plugs	Hot Cell	0.083	0.083	0
12	Remove remaining inner lid bolts and remove inner lid and spent fuel assembly spacer	Unloading Room/Hot Cell	0.242	0.242	0
13	Unload spent fuel assemblies and place into in-cell lag storage	Unloading Room/Hot Cell	1.05 PWR 2.70 BWR	2.25 PWR 4.95 BWR	1.20 PWR 2.25 BWR
14	Monitor and vacuum cask cavity and fuel basket	Unloading Room/Hot Cell	0.60 PWR 1.50 BWR	1.25 PWR 2.70 BWR	0.65 PWR 1.20 BWR

TABLE 6.9. (contd)

			person-mrem/shipment		
Activity No.	Activity	Facility Location	Postulated Reference System[a]	Example Alternative System[b]	Dose Change
15	Replace spent fuel assembly spacer and replace inner lid and hot cell port plugs	Unloading Room/Hot Cell	0.400	0.400	0
16	Unmate cask from hot cell port and open unloading room shielding door	Unloading Room	0.025	0.025	0
17	Move cart and cask to handling room	Handling Room	0.008	0.008	0
18	(If wet decontamination is to be performed, refer to wet decontamination steps in Table 4.17). Install platform, remove contamination barrier adapter and lifting adapter, install inner and outer lids, secure all openings to the cask, monitor and decontaminate exterior of cask, open roll-up door and retract platform	Handling Room	1.65	1.01	-0.64
19	Move cask and cart to receiving and handling area	Receiving and Handling Area	0.008	0.008	0
20	Place cask on the transport vehicle	Receiving and Handling Area	0.175	0.175	0
21	Prepare cask for shipment, install cask tiedowns and impact limiters and close personnel barrier	Receiving and Handling Area	2.190	0.625	-1.57
22	Move transport vehicle and cask to inspection area, disconnect repository drive unit	Inspection Area	0.033	0.033	0
23	Hook up over-the-road carrier, move to gatehouse, perform final monitoring and inspection of empty cask	Gatehouse Receiving and Dispatching	0.250	0.250	0
24	Notify appropriate organizations of the shipment departure	Supervisor's Office	0	0	0
	Totals PWR		463	67.6	-395
	BWR		466	71.8	-394

(a) Reference rail cask capacity is 14 PWR or 36 BWR assemblies.
(b) Alternative rail cask capacity is 30 PWR or 66 BWR assemblies.

TABLE 6.10. Comparison of Estimated Average Annual Radiation Doses(a) Received by the Individual Workers in Each Craft at the Repository for the Postulated Reference and the Example Alternative Rail Subsystems(b,c)

	Postulated Reference System Rail Shipments(d)			Example Alternative System Rail Shipments(e)		
Craft	Number of Workers	mrem/shipment	mrem/year	Number of Workers	mrem/shipment	mrem/year
Crane Operator	6	0.6	192	3	0.8	127
Operators	47	0.8	256	29	0.7	117
Radiation Monitors	10	0.7	224	7	0.7	114
Quality Control Inspectors	12	0.4	128	6	0.6	103
Yard Drivers	4	0.4	128	4	0.6	90
Security Guards	8	0.7	224	8	0.7	116
Maintenance-Craftsmen	26	15.5	4,960	14	2.0	315
Totals	113(f)		148,000(g)	71(f)		11,100(g)

(a) The average annual individual doses assume that the doses are distributed uniformly among each worker in each craft in the dedicated work crews.
(b) For shipment of 2100 MTU/year by rail.
(c) Dose differences between PWR/BWR fuel types are negligible for this analysis. Data are shown for the average of each worker from either PWR or BWR shipments.
(d) 320 shipments per year required.
(e) 160 shipments per year required.
(f) Supervisors not included because they perform no work in radiation zones.
(g) Collective annual dose for all cask handling workers.

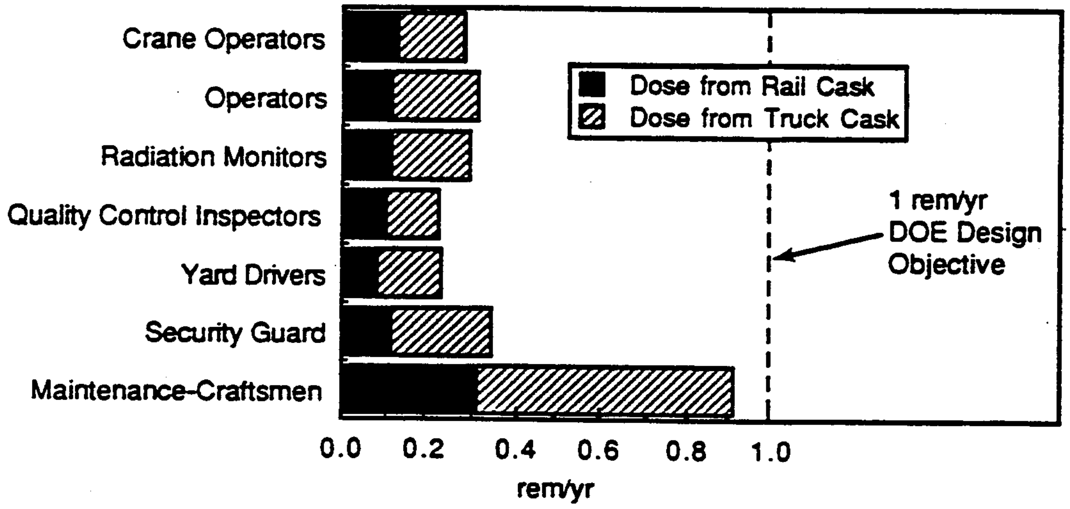

FIGURE 6.1. Estimated Annual Radiation Dose for Individual Cask Handling Workers at the Repository for the Example Alternative System

6.4 COST IMPACTS OF THE EXAMPLE ALTERNATIVE SYSTEM

Using the capital and operating costs presented for the individual alternatives in Chapter 5, the total cost impact of implementing the example alternative system was estimated. The cost differences are summarized in Table 6.11 and are given in more detail in Appendix J. The implementation of the example alternative system is estimated to result in savings in both capital and operating costs, primarily due to reduced cask fleet size and reduced labor requirements. Total transportation system capital costs are reduced by an estimated \$27.6 million, and annual operating costs are reduced by an estimated \$18.6 million. Total life-cycle costs for the example alternative system are estimated to be reduced by about \$418 million and \$314 million, for present worth discount rates of 0% and 3%, respectively.

Because both the radiation doses and costs are estimated to be reduced in the example alternative system, the combination looks attractive for detailed consideration. Because the ratio of Δcost/Δdose is negative, the value of the ratio is not significant. As stated earlier, however, a wide variety of other alternative systems is possible, and other systems will be evaluated before the final transportation system is implemented.

TABLE 6.11. Comparison of Estimated Life-Cycle Costs for the Postulated Reference and the Example Alternative Systems[a]

Cost Category	Postulated Reference Cost ($)	Example Alternative System Cost ($)	Change in Cost ($)
Capital Costs:			
Truck Cask Fleet	39,000,000	20,700,000	18,300,000
Rail Cask Fleet	70,000,000	57,800,000	12,200,000
Other Costs[b]		2,900,000	-2,900,000[c]
Net Change in Capital Costs			27,600,000
Annual Costs:			
At-Reactor Labor	1,649,700	1,637,300	12,400
At-Repository Labor	4,636,000	2,346,000	2,290,000
Fleet Maintenance Charges	5,450,000	2,775,000	2,675,000
Transport Charges	26,960,200	13,327,800	13,633,000
Net Change in Annual Costs			18,600,000
Total Change in System Life-Cycle Cost[d]			418,000,000
Present Worth:			
3% Discount Rate			314,000,000
0% Discount Rate			418,000,000

(a) Costs are shown to more significant figures than justified, to provide for consistency in the calculations.
(b) Total costs of special tools, lid-lifting fixtures, and quick-release impact limiters.
(c) Negative value indicates an additional cost.
(d) Assumes 21 years of system operation.