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Preliminary Assessment of Radiological Doses in Alternative Waste Management Systems Without an MRS Facility

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June 1986

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PRELIMINARY ASSESSMENT OF RADIOLOGICAL DOSES IN ALTERNATIVE WASTE MANAGEMENT SYSTEMS WITHOUT AN MRS FACILITY

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ABSTRACT

This report presents generic analyses of radiological dose impacts of nine hypothetical changes in the operation of a waste management system without a monitored retrievable storage (MRS) facility. The waste management activities examined in this study include those for handling commercial spent fuel at nuclear power reactors and at the surface facilities of a deep geologic repository, and the transportation of spent fuel by rail and truck between the reactors and the repository.

In the reference study system, the radiological doses to the public and to the occupational workers are low, about 170 person-rem/1000 metric ton of uranium (MTU) handled with 70% of the fuel transported by rail and 30% by truck. The radiological doses to the public are almost entirely from transportation, whereas the doses to the occupational workers are highest at the reactors and the repository.

Operating alternatives examined included using larger transportation casks, marshaling rail cars into multicar dedicated trains, consolidating spent fuel at the reactors, and wet or dry transfer options of spent fuel from dry storage casks. The largest contribution to radiological doses per unit of spent fuel for both the public and occupational workers would result from use of truck transportation casks, which are smaller than rail casks. Thus, reducing the number of shipments by increasing cask sizes and capacities (which also would reduce the number of casks to be handled at the terminals) would reduce the radiological doses in all cases. Consolidating spent fuel at the reactors would reduce the radiological doses to the public but would increase the doses to the occupational workers at the reactors.

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TABLES

1.0 INTRODUCTION

In the commercial high-level waste management system, potential changes are being considered that will augment the benefits of an integral monitored retrievable storage (MRS) facility (DOE 1985). The U.S. Department of Energy (DOE) has recognized that alternative options could be implemented in the authorized waste management system (i.e., without an integral MRS facility) to potentially achieve some of the same beneficial effects of the integral MRS system. The review copy of the MRS Proposal to Congress (DOE 1985) summarized the analyses of such options that were conducted to support the need and feasibility analyses of an MRS facility. This report provides the details of the analyses related to radiation doses resulting from changes in the waste management system.

In this report, the generic analyses of radiological dose impacts of nine hypothetical operating alternatives are presented. Included are changes in the transportation system or in the location of an operation's performance.

The analyses in this study are limited to the spent-fuel-handling activities at the reactors and at the surface facilities of a deep geologic repository, and during the transportation of spent fuel between the reactors and repository. The results presented here are based on preliminary analyses of generic systems using available generic data. Where directly applicable generic data are not available for occupational exposures, analyses results are aimed at realistically low dose rates believed to be achievable through repetitive experience. The results are useful for overall comparisons of system alternatives, but are not intended as absolute values for specific sites, routes and designs, or for specific affected public or occupational workers.

The radiological doses examined in this study are those to the affected public and to the workers in the waste management system. The dose estimates include the radiological doses from routine activities and in some cases the expected doses (i.e., probabilities multiplied by consequences) from accidents. This study does not analyze the cost, feasibility, or other considerations of implementing the potential changes in the waste management system. It should be noted that operation of all facilities and equipment in the waste management system must meet stringent federal regulations that have been promulgated to assure adequate protection of the health and safety of the public, the environment, and the workers. These regulations set maximum radiological dose limits to individual workers or members of the public. The basic federal regulation for public environmental radiation protection for operations in the uranium nuclear fuel cycle is in the Environmental Protection Agency's (EPA's) regulation 40 CFR 190. The basic NRC regulation that carries out the EPA's regulation is 10 CFR 20. The NRC regulations for operating the various facilities are 10 CFR 50 for reactors, 10 CFR 72 for an independent spent-fuel storage facility, 10 CFR 60 for the repository, and 10 CFR 71 and 10 CFR 20 for the transportation system.

This report is comprised of 6 sections and 4 appendices. Section 2 presents the summary and conclusions of the study. Section 3 presents the approach, the alternative system configurations investigated, and overall study bases. Section 4 presents the occupational exposure analyses for routine operations at the reactors and at a repository, and Section 5 gives the public risks at the same facilities. Section 6 presents the occupational and public risks during transportation of spent fuel between the reactors and the repository.

Appendices A, B and C present occupational exposure analysis tables for the reference and alternative truck and rail casks at the reactor, for reactor operations, and for repository operations, respectively. Appendix D presents a detailed table on the radiation doses of all the possible changes in the waste management system that were evaluated in this study.

1.1 REFERENCES

U.S. Code of Federal Regulations, Title 10, Part 20 (10 CFR 20). "Standards for Protection Against Radiation."

U.S. Code of Federal Regulations, Title 10, Part 50 (10 CFR 50). "Quality Assurance Criteria."

U.S. Code of Federal Regulations, Title 10, Part 60 (10 CFR 60). "Disposal of High-Level Radioactive Wastes in Geologic Repositories."

U.S. Code of Federal Regulations, Title 10, Part 71 (10 CFR 71). "Packaging and Transportation of Radioactive Material."

U.S. Code of Federal Regulations, Title 10, Part 72 (10 CFR 72). "Licensing Requirements for the Independent Storage of Spent Fuel and High-Level Radioactive Waste."

U.S. Code of Federal Regulations, Title 40, Part 190 (40 CFR 190). "Environmental Radiation Protection Standards for Nuclear Power Operations."

U.S. Department of Energy. 1985. Environmental Assessment for a Monitored Retrievable Storage Facility. Volume 2 of Monitored Retrievable Storage Submission to Congress. Review Copy, DOE/RW-0035, U.S. Department of Energy, Washington, D.C.

2.0 SUMMARY AND CONCLUSIONS

The Pacific Northwest Laboratory (PNL) has estimated the generic radiation doses of a reference spent-fuel waste management system without an MRS facility and with potential changes in the system. The dose estimates may be low but are believed to be achievable, based on benefits of repetitive experience. The potential alternatives evaluated were considered for the review copy of the MRS Submission to Congress (DOE 1985).

The commercial radioactive waste management system in this analysis includes the spent-fuel-handling activities at the nuclear power reactors and at the surface facility of a deep geologic repository, and the transportation of spent fuel by rail and truck between the reactors and the repository. The spent-fuel-handling activities at the reactors are not within the federal portion of the waste management system. However, changes in the federal part of the system would impact the radiological doses at the reactors, so at-reactor spent-fuel cask-loading operations were included in the study. The analyses of the system risks are based on preliminary assessments using available generic data. The results are considered to be useful for overall comparisons of waste management system alternatives, but are not intended as absolute values for specific sites, routes, or designs.

2.1 OVERALL DOSES OF REFERENCE SYSTEM

The overall radiation doses developed in this study of the waste management system for spent fuel are listed in Table 2.1. Table 2.1 shows that the radiation doses would be low and about the same to the public and to the occupational workers for the reference waste management system. These doses can be compared to those from background radiation that about 1 million people within a 50-mile radius of the DOE preferred site of the proposed MRS facility (DOE 1985) would receive, or about 150,000 person-rem/year. The doses to the public would be dominated by those from transportation. The doses to the occupational workers would be highest at the source or terminal and would be almost exclusively from the transportation preparations at the reactor and from the cask-receiving

TABLE 2.1. Radiation Doses of the Reference High-Level Waste Management System

Activities	Radiation Doses (person-rem/1000 MTU) Public	Occupational
Spent-fuel handling at reactor	<1	77[a]
Transportation[b]	164	34
Spent-fuel handling at surface facilities at repository[c]	6	63[a]
Total	170	174

(a) Excludes accident risks.
(b) For 3000 km between reactor and repository, using 30% of spent-fuel by weight by truck and 70% by rail.
(c) Spent-fuel consolidation would be performed at the repository.

steps at the repository. Remote operations within hot cells at the repository would result in low occupational doses.

2.2 DOSE COMPARISONS OF POTENTIAL SYSTEM ALTERNATIVES

Although the radiation doses to the public and occupational workers would be low for the reference waste management system, alternative system configurations could further reduce the doses. The following potential changes to the reference waste management system were evaluated:

1. All reactors that cannot ship by rail (i.e., rail-limited reactors) are modified to ship by rail.
2. All truck shipments from rail-limited reactors are made in overweight trucks.
3. Rail-limited reactors wet load (in-pool loading) into rail casks that are heavy-hauled by truck to the nearest practical rail head, transferred to a rail car, and transported by rail the remaining distance to the repository.

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

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

6. Rail shipments from reactors are sent to offsite marshaling points, where they are combined into multicar dedicated trains to the repository.

7. Reactors consolidate spent fuel and place fuel rods in canisters before shipment.

8. All at-reactor dry storage is in nontransportable rail-size casks, and transfer to transportation casks is by dry transfer.

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

Each alternative's radiation dose impact on the reference waste management system is examined separately. Some of the hypothetical changes could be combined (e.g., at-reactor consolidation plus use of larger transportation casks), but the impacts of such combinations were not evaluated. Except for Alternatives 1 and 3, spent-fuel transportation to the repository was assumed to be the same as the reference case (70% by rail and 30% by truck).

The impacts of the nine alternatives on the radiation doses to the public and the occupational workers are given in Table 2.2. A more detailed table summarizing these results is provided in Appendix D. As Table 2.2 shows, most of the alternatives considered would tend to reduce the unit radiation doses to the public and to occupational personnel because the amount of spent-fuel handling would be reduced. A notable exception to this is the occupational doses of the alternative of at-reactor consolidation. However, in examining Table 2.2, it should be recognized that the doses from the reference system activities already would be low.

The preliminary dose values given in Table 2.2 are composed of 3 components: doses at the reactors, at the repository, and in transit during transportation. The changes in doses for the system could occur in all three

TABLE 2.2. Radiological Doses of Reference High-Level Waste Management System and Hypothetical Alternatives

Alternative	Radiological Doses (person-rem/1000 MTU)[(a)] and Location of Risk Change[(b)]			
	Public		Occupational	
	Dose	Δ Dose Location	Dose	Δ Dose Location
Reference System (w/o MRS facility)	170	--	174	--
System with MRS[(c)]	80	--	184	--
Hypothetical Alternatives				
1. All fuel is shipped by rail in 100-T casks.	14	Tr	75	Rea, Rep, Tr
2. All trucks are overweight.	125	Tr	121	Rea, Rep, Tr
3. Rail-sized casks are heavy-hauled to rail head and transferred to rail.	14	Tr	80	Rea, Rep, Tr
4. Extra large rail casks (150T) are used.	167	Tr	145	Rea, Rep, Tr
5. Rail shipments are marshaled at reactors and shipped by dedicated train.	168	Tr	172	Tr, Rea+
6. Rail shipments are marshaled offsite and shipped by dedicated train.	169	Tr	171	Tr
7. Fuel is consolidated at reactor.	95	Tr	269	Rea+, Rep, Tr
8. Reactors with dry storage[(d)] use dry transfer.	170	--	172	Rea
9. Reactors with dry storage[(d)] use transportable rail casks.	170	--	171	Rea

(a) Assumes 30% by weight shipped by truck and 70% by rail unless identified otherwise in the alternatives.
(b) Locations given in decreasing order of dose changes. Unless indicated otherwise, doses are reduced by the hypothetical alternative.
Rea = reactor; rep = repository; tr = in transit; + equals dose increase.
(c) Taken from DOE (1985), Table E.1.
(d) The reference system assumes no dry storage at the reactors except in alternatives 8 and 9. For these alternatives, the reference system assumes 10% of fuel at reactors is in dry storage and that all transferred wet fuel is shipped by rail. Adjusted reference system has public and occupational doses of 170 and 176 person-rem/1000 metric ton of uranium (MTU), respectively.

components or in only one. Also shown for comparison are the estimated doses of a system with an MRS facility (DOE 1985). Doses to the public generally would be affected by the in-transit component, whereas doses to the occupational worker would be generally more affected at the reactor or at the repository.

Some overall conclusions reached from these analyses are as follows:

1. The largest contribution to unit radiological doses in the reference system in this study would be from transportation in trucks. Therefore, the largest potential for dose reduction would result from using larger casks where possible rather than reference legal-weight truck casks. Public doses would be affected the most by the use of this alternative, and occupational doses also would be significantly affected. Public doses would be reduced because of the nearby public's exposure to the modest radiation levels from fewer shipments in larger capacity casks. Occupational doses would be reduced because the occupational manpower per shipment would not change significantly with cask capacity, so fewer workers would be exposed during the fewer shipments with high-capacity casks. Using larger casks rather than reference truck casks would decrease doses throughout the system.

2. Reducing the number of transportation cask loads (i.e., increasing the cask cargo capacity) of spent fuel would reduce the public and occupational doses in all cases. Reducing the number of cask loads would involve changing from legal-weight to overweight truck, from truck to rail, or from reference rail to large rail casks. Changing from truck to rail casks would yield the most significant change; changing from reference rail casks to large rail casks would yield a smaller dose reduction because the doses from using the reference rail cask already would be quite low.

3. Marshaling rail cars at the reactors and away from the reactors to form multicar dedicated trains would have only small effects on unit doses. The effects would be small, largely because the doses from using rail transport would be quite low without marshaling. Doses would increase only slightly at the marshaling location.

4. At-reactor consolidation of spent fuel would increase the radiological occupational doses compared with at-repository consolidation. At-reactor consolidation doses would be greater because the repository would be designed to perform this function efficiently using heavily shielded hot cells, whereas the function would be an add-on capability in the reactor storage pool. At-reactor consolidation would reduce occupational doses from transportation and at-repository fuel-shipping activities because of the resulting fewer number of shipments. Public radiological doses also would be reduced from at-reactor consolidation.

5. Dry transfer of spent fuel at reactors from dry storage casks to transportation casks would slightly reduce the occupational doses compared with the conventional wet transfer because dry transfer would require less handling operations than wet transfer.

6. Using transportable dry storage casks at the reactors would slightly reduce the occupational doses that would otherwise result from transferring spent fuel from dry storage casks for shipment offsite. This assumes the casks are recertifiable for transportation without unloading prior to transport.

2.3 REFERENCES

U.S. Department of Energy. 1985. Environmental Assessment for a Monitored Retrievable Storage Facility. Volume 2 of Monitored Retrievable Storage Submission to Congress. Review Copy, DOE/RW-0035, U.S. Department of Energy, Washington, D.C.

3.0 APPROACH AND OVERALL BASES

The overall approach, bases, and assumptions used in the study are presented in this section. The bases are used for the generic analyses in this study and may not necessarily reflect the currently preferred system configuration or bases. This section also includes a list of the alternatives evaluated.

3.1 APPROACH

The overall approach for this study was to perform the following activities:

- Identify a reference waste management system for evaluation.
- Identify the alternatives to the reference system for analysis.
- Estimate generic unit radiation doses for the reference system and for the alternatives.

The results of the study, presented in Section 2, are given in units of person-rem/1000 metric ton of initial uranium in fresh fuel (MTU). These units allow the results to be used in approximating total system doses for various scenarios.

The reference waste management system used in this study is broadly defined below:

- No MRS facility is in the system.
- Loading of spent fuel into transportation casks and preparations for shipment are included in the overall system.
- Consolidation of spent fuel occurs at the repository; no spent-fuel consolidation or canisterization occurs at reactors.
- Reactors that can ship spent fuel to the repository by rail will do so; reactors without rail shipment capability will ship by truck.
- The repository is in the western part of the U.S.

- All spent fuel transported to the repository is 10 years old since discharge from the reactor.

3.2 OVERALL BASES AND ASSUMPTIONS

From the broad reference system definition, the following additional major bases and assumptions were applied to the analyses:

- Generic, average data are used throughout.
- Spent fuel is from pressurized water reactors (PWRs), and each assembly contains 0.462 MTU (based on initial fuel content); boiling water reactor (BWR) fuel is addressed briefly in various parts of the document, but analyses for BWRs are not included.
- The radiation dose rates from loaded transportation casks are 2- to 4-fold below the regulatory maximum.
- Cask-handling operations at the terminals are aimed at achievably low occupational doses, believed to be obtainable through repetitive experience.
- Shipments from reactors are 30%/70% by general commerce truck/general freight rail, respectively, on the basis of weight of the fuel material.
- The reference truck cask has the capacity to carry 2 intact PWR fuel assemblies.
- The reference rail cask (loaded weight, approximately 100 tons) has the capacity to carry 14 intact PWR fuel assemblies.
- The average transport distance between the reactors and the western repository is 3000 kilometers (km).
- Reference storage casks and storage-transportation casks have the capacity to hold 14 intact PWR fuel assemblies.

- An overweight truck cask has the capacity to carry 4 intact PWR fuel assemblies.[a]
- A large, 150-ton rail cask has the capacity to carry 36 intact PWR fuel assemblies.[a]
- Consolidation increases the cask capacity for spent fuel by a factor of 2.[a]
- Consolidation results in nonfuel component hardware that is transported in canisters in spent-fuel casks at the equivalent of 9.24 MTU/reference truck cask and 46.2 MTU/reference rail cask. (This is equivalent to 1 volume of nonfuel component hardware to each 10 volumes of intact PWR fuel.)[a]
- Marshaling of rail cars from reactors results in dedicated trains with 5 casks.[a]

Further details of the specific bases used in particular analyses are given in Sections 4, 5 and 6.

3.3 ALTERNATIVES EVALUATED

For the reference system, the radiological doses to the public and the waste management system worker would be low (DOE 1985). Alternative system configurations, however, may be possible that could further reduce the dose. Some hypothetical changes in system configuration were identified for evaluation to obtain a perspective on the potential for reducing radiological doses. However, analyzing the feasibility and costs of implementing these alternatives in the system configurations is beyond the scope of this study.

In a waste management system without an MRS facility, the hypothetical changes that were identified and evaluated on a preliminary basis in this report are as follows:

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

(a) These apply to nonreference alternatives, discussed later in this section.

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

3. Rail-limited reactors wet load (in-pool loading) into rail casks that are heavy-hauled by truck to the nearest practical rail head, transferred to a rail car, and transported by rail the remaining distance to the repository.

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

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

6. Rail shipments from reactors are sent to offsite marshaling points, where they are combined into multicar dedicated trains to the repository.

7. Reactors consolidate spent fuel and place fuel rods in canisters before shipment.

8. All at-reactor dry storage is in nontransportable rail-size casks, and transfer to transportation casks is by dry transfer.

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

Most of these hypothetical changes would not be applicable to all reactors. Therefore, before these preliminary unit dose factors could be applied to specific changes in the system, the unit dose factors would have to be normalized to account for the applicable portion of the waste management system. A first-order approximation of this normalization is given in Appendix D. Also, some of the potential changes could be combined (e.g., at-reactor consolidation plus use of larger transportation casks), but the impacts of such combinations were not evaluated in this study.

From the above bases, the preliminary analyses given in the subsequent sections were performed. These analyses used data where available (i.e., for public doses from the fixed facilities, and for public and occupational doses during transportation). Where data were not available (i.e., some occupational doses at the fixed facilities), simplifying assumptions were made and calculations were done using microcomputer spreadsheets. The results are generic, and while they may not be highly accurate for absolute or individual dose comparisons, they are useful for overall comparisons of potential alternative generic systems.

3.4 REFERENCES

U.S. Department of Energy. 1985. Environmental Assessment for a Monitored Retrievable Storage Facility. Volume 2 of Monitored Retrievable Storage Submission to Congress. Review Copy, DOE/RW-0035, U.S. Department of Energy, Washington, D.C.

4.0 OCCUPATIONAL DOSES AT REACTORS AND REPOSITORIES

Occupational doses for the workers at the reactors and at the repository may be affected by potential changes to the waste management system. This section evaluates potential changes in occupational doses from alternatives concerning 1) spent-fuel handling at the reactors in preparation for transporting the fuel to the repository, and 2) spent-fuel receipt and handling at the repository's surface facilities. These occupational doses are a function of the time the workers are near the spent-fuel radiation sources, the number of workers affected, and the dose rates at those locations.

The potential changes to the waste management system evaluated in this study were identified in Section 3. Many of those potential changes may affect the occupational doses at the reactors and at the repository. Generic analyses of such effects are presented in the following subsections. These evaluations are for routine occupational exposures and do not consider accidents.

The analyses of occupational exposures are based on use of available data, which were adapted to the conditions of this study as necessary. The analyses are aimed at achievably low occupational doses believed to be obtainable through repetitive experience. Each major operation examined in the analyses is identified, then subdivided into smaller steps. For each of these smaller steps, average radiation field intensity, time, and manpower to perform the work at a "typical" reactor and repository are analyzed. The occupational doses from each step are calculated, then aggregated into doses for all steps, and normalized to the units used in this report. The numerical results of the calculations are preserved for information for the reader and to allow better traceability of the results. In general, however, the individual calculational results are believed to be accurate at the first significant figure and in the range of ±50% at the second significant figure.

4.1 OCCUPATIONAL DOSES FOR AT-REACTOR ACTIVITIES

This subsection estimates at-reactor routine occupational radiological doses during spent-fuel handling in preparing it for transportation to the repository.

Because most operating data were available for handling PWR fuel, all analyses are based on handling PWR spent-fuel assemblies. Because of the smaller size of BWR assemblies and the greater number of assemblies per MTU, the handling requirements per MTU of BWR assemblies are expected to be somewhat greater than for PWR assemblies.

The basic data source for the manpower and time requirements in these analyses is Lambert, King and Tehan (1981). From operating experience, Lambert provides step-by-step analyses of PWR spent-fuel handling in NAC-1 truck transportation casks (1 PWR assembly/cask load) and in IF-300 rail transportation casks (7 PWR assemblies/cask load). Tables 4.1 and 4.2 summarize these data for handling the NAC-1 and IF-300 shipping casks, respectively. These basic data are used in developing the analyses for at-reactor cask-handling activities. Detailed information on the basic data are given in Appendix A, Tables A.1 (NAC-1 cask) and A.2 (IF-300 cask), for receiving empty casks and for conventional wet-loading of spent fuel into casks at reactors.

Throughout these at-reactor analyses, the exposure rates to operating personnel are based on the measured exposure rates experienced at Oconee Nuclear Power Plant No. 1 during a spent-fuel consolidation demonstration in 1982 (Duke Power Company 1983). These exposure rates are assumed to be generic and are as follows:

- 0.5 mrem/hr for handling empty casks away from the spent-fuel pool
- 2.5 mrem/hr for all cask-handling operations (including fuel loading) at the spent-fuel storage pool but away from a loaded cask
- 10.0 mrem/hr for all hands-on or nearby operations with loaded casks. (A regulatory limit is 10 mrem/hr at 2 m from the cask surface).

The reference truck shipping cask, identified in Section 3, is a legal-weight truck (LWT) cask that can carry 2 PWR unconsolidated spent-fuel assemblies. The reference truck cask is also assumed to be capable of carrying consolidated fuel rods in 2 canisters, each containing rods from 2 PWR spent-fuel assemblies, or the nonfuel-bearing components (NFBC) from 20 PWR assemblies.

TABLE 4.1. Summary of Basic Handling and Occupational Exposure Data for Wet Loading of NAC-1 (truck) Spent-Fuel Cask (Lambert, King, and Tehan 1981)

Operation	Elapsed Time (hr)	Person-hr/ Cask Load	Person-mrem/ Cask Load	Person-rem/ 1000 MTU
Cask received at reactor	1.0	1.9	1.0	2.1
Cask washed and sampled	2.4	3.4	8.5	18.4
Cask transferred to setdown pad	0.7	2.1	5.3	11.4
Cask transferred into pool and loaded	1.6	3.5	8.0	17.3
Cask removed from pool, decontaminated and surveyed	6.0	11.1	102.0	220.8
Cask transferred to vehicle and exits facility	1.3	2.5	25.0	54.1
Total	13	25	150	324

The reference rail shipping cask weighs about 100 tons when loaded, and can carry 14 PWR unconsolidated fuel assemblies. The reference rail cask is also capable of carrying 14 canisters of consolidated fuel rods, each containing rods from 2 PWR spent-fuel assemblies, or 10 drums each containing the NFBC from 10 PWR assemblies.

Based on the NAC-1 truck and IF-300 rail cask-handling operations given in Tables 4.1, 4.2, A.1, and A.2, similar evaluations of operations with the reference truck and rail casks were derived in this study. This information is summarized in Tables 4.3 and 4.4, and is presented in detail in Appendix A, Tables A.3 and A.4. All activities in the Tables A.3 and A.4 are assumed to have the same operational requirements as the NAC-1 and IF-300 casks, respectively, except those activities for the different fuel-loading capacities of the reference casks. The data in Tables 4.3 and 4.4 are used in deriving the information on at-reactor cask-handling activities for the various system options evaluated in the following subsections.

TABLE 4.2. Summary of Basic Handling and Occupational Exposure Data for Wet Loading of IF-300 (rail) Spent-Fuel Cask (Lambert, King, and Tehan 1981)

Operation	Elapsed Time (hr)	Person-hr/ Cask Load	Person-mrem/ Cask Load	Person-rem/ 1000 MTU
Cask received at reactor	1.8	3.2	1.6	0.5
Cask washed and sampled	4.5	8.5	21.3	6.6
Cask transferred to setdown pad	1.0	3.0	7.5	2.3
Cask transferred into pool and loaded	3.9	8.2	20.5	6.4
Cask removed from pool, decontaminated and surveyed	9.9	18.1	167.5	51.9
Cask transferred to vehicle and exits facility	1.8	3.4	34.0	10.5
Total	23	44	252	78

TABLE 4.3. Summary of Basic Handling and Occupational Exposure Data for Wet Loading of Reference Legal-Weight Truck Cask

Operation	Elapsed Time (hr)	Person-hr/ Cask Load	Person-mrem/ Cask Load	Person-rem/ 1000 MTU
Cask received at reactor	1.0	1.9	1.0	1.0
Cask washed and sampled	2.4	3.4	8.5	9.2
Cask transferred to setdown pad	0.7	2.1	5.3	5.7
Cask transferred into pool and loaded	1.6	3.5	9.3	10.0
Cask removed from pool, decontaminated and surveyed	6.0	11.1	102.0	110.4
Cask transferred to vehicle and exits facility	1.3	2.5	25.0	27.1
Total	13	25	151	163

TABLE 4.4. Summary of Basic Handling and Occupational Exposure Data for Wet Loading of Reference Rail Cask

Operation	Elapsed Time (hr)	Person-hr/ Cask Load	Person-mrem/ Cask Load	Person-rem/ 1000 MTU
Cask received at reactor	1.8	3.2	1.6	0.3
Cask washed and sampled	4.5	8.5	21.3	3.3
Cask transferred to setdown pad	1.0	3.0	7.5	1.2
Cask transferred into pool and loaded	5.6	8.2	20.5	4.5
Cask removed from pool, decontaminated and surveyed	9.9	18.1	167.5	25.9
Cask transferred to vehicle and exits facility	1.8	3.4	34.0	5.3
Total	25	44	252	40

4.1.1 Legal-Weight Truck Versus Rail Shipments

Approximately 70% of the U.S. reactors could ship spent fuel by rail. Currently, the remainder could ship only by truck for various reasons. The rail-limited reactors possibly could be modified to be capable of shipping by rail. Shipment by rail instead of by truck would reduce the number of shipments and the resulting public and occupational doses. Using information taken from Tables 4.3 and 4.4, Table 4.5 summarizes the unit routine occupational radiological dose factors for reference truck and rail casks at a reactor. As the table shows, if rail-limited reactors were modified to receive and handle the reference rail cask, the expected at-reactor routine occupational doses for loading spent fuel in transportation casks would be reduced from 163 to 40 person-rem/1000 MTU.

4.1.2 Legal-Weight Truck Versus Overweight Truck Shipments

In this alternative, overweight truck (OWT) casks are assumed to replace LWT casks for transporting spent fuel from rail-limited reactors. The OWT cask is assumed to have double the capacity of the LWT cask in this study. The OWT

TABLE 4.5. Occupational Doses for At-Reactor Loading of Spent Fuel in the Reference Truck and Rail Casks

Operation	Unit Occupational Doses (person-rem/1000 MTU) Truck	Rail
Cask received at reactor	1.0	0.3
Cask washed and sampled	9.2	3.3
Cask transferred to setdown pad	5.7	1.2
Cask transferred into pool and loaded	10.0	4.5
Cask removed from pool, decontaminated and surveyed	110.4	25.9
Cask transferred to vehicle and exits facility	27.1	5.3
Total	163	40

cask would require approximately twice the time to insert the fuel in the LWT truck cask. The increased time would double the occupational exposure per cask load during this fuel-handling step, but the exposure per unit of fuel would be proportional to the amount of fuel loaded. The other operations involved in preparing the cask for use, loading the cask for shipment, and exiting the facility are assumed to be the same for both casks. The calculated routine occupational doses using the two casks are given in Table 4.6. Details of the analysis for handling the OWT cask are presented in Appendix B, Table B.1. Table 4.6 shows that the increased OWT cask capacity would reduce the at-reactor routine occupational doses from 163 to 83 person-rem/1000 MTU.

4.1.3 Legal-Weight Truck Versus Heavy-Haul Truck and Rail Shipments

In this alternative, reactors that cannot ship by rail would use an intermodal shipment in which a rail cask would be moved to and from the reactor in heavy-haul trucks. At the nearest rail siding, the cask would be transferred to a rail car and would complete the shipment by rail.

TABLE 4.6. Occupational Doses for At-Reactor Loading of Spent Fuel in the Reference Truck and Alternative Overweight Truck Casks

Operation	Unit Occupational Doses (person-rem/1000 MTU) LWT Cask	OWT Cask
Cask received at reactor	1.0	0.5
Cask washed and sampled	9.2	4.6
Cask transferred to setdown pad	5.7	2.8
Cask transferred into pool and loaded	10.0	6.4
Cask removed from pool, decontaminated and surveyed	110.4	55.2
Cask transferred to vehicle and exits facility	27.1	13.5
Total	163	83

A heavy-haul truck shipment is a special type of overweight and overdimension highway shipment that can travel only short distances and that requires special equipment and state and local permits. This type of shipment has not been used for spent fuel in the past but has been used for major pieces of reactor-related equipment, such as steam generators and reactor vessels. This option could potentially be implemented by reactors having the capability to wet load a rail cask but not having rail service to the repository. The use of a heavy-haul truck/rail would reduce the number of shipments and the public and occupational doses.

With this alternative, the reactor operations with the cask and fuel loading would be the same as with a conventional rail shipment. The rate of travel and moving time and manpower requirements for the loaded heavy-haul truck within the reactor site are expected to be the same as for a rail shipment. Therefore, at-reactor occupational doses from heavy-haul truck shipments from the facility are expected to be about the same as for conventional onsite rail shipment, or 40 person-rem/1000 MTU (see Section 4.4.1). The exposures can be compared to those from LWT shipments of 163 person-rem/1000 MTU, as given in Section 4.1.1. Doses resulting from the offsite movement of the truck and cask to the rail siding and the transfer of the cask from the heavy-haul truck to the rail car are discussed in Section 6.

4.1.4 100-Ton Versus 150-Ton Rail-Cask Shipments

With this alternative, it is assumed that reactors could be modified to handle large, 150-ton rail casks that could hold 36 PWR or 90 BWR unconsolidated spent-fuel assemblies. The use of the larger rail cask would result in fewer but larger shipments of spent fuel, with less cask handling and reduced public and occupational radiation doses.

It is assumed that the increase in size of the 150-ton rail cask would not increase the handling and monitoring manpower requirements involved when shipping with larger casks. The fuel-handling requirements would be unchanged and would be proportional to the amount of fuel handled. The unit occupational exposures for handling the larger casks are expected to be reduced because of the reduced cask handling required by the reduced number of shipments. The resultant routine occupational doses for using the large rail cask and the reference rail cask (taken from Section 4.1.1) are shown in Table 4.7. Details of the analysis for the large rail cask are given in Appendix B, Table B.2. Table 4.7 shows that using larger rail casks rather than the reference rail cask would reduce the at-reactor exposures from 40 to 17 person-rem/1000 MTU (a factor of about two).

4.1.5 No Marshaling Versus Marshaling Rail Cars at the Reactor

In this potential alternative, 5 loaded rail casks on their cars would be accumulated at the reactor. The 5 cask cars would then be combined, with a caboose and some buffer cars between the cask cars, to create a five-car dedicated train for shipping the spent fuel to the repository. Occupational doses at the reactor for this alternative would increase, primarily because of the increased time the loaded casks are at the facility site. The magnitude of the increase would depend on the length of time the rail cars would be marshaled, the dose rate from the casks, and the number of workers near the casks.

TABLE 4.7. Occupational Doses for At-Reactor Loading of Spent Fuel in 100- and 150-Ton Rail-Cask Shipments

Operation	Unit Occupational Doses (person-rem/1000 MTU) 100-T Rail Cask	150-T Rail Cask
Cask received at reactor	0.3	0.1
Cask washed and sampled	3.3	1.3
Cask transferred to setdown pad	1.2	0.5
Cask transferred into pool and loaded	4.5	3.4
Cask removed from pool, decontaminated and surveyed	25.9	10.1
Cask transferred to vehicle and exits facility	5.3	2.0
Total	40	17

Approximately 26 hours would be required to receive and load each of the 5 reference rail casks at the reactor (see Table A.4). Assuming the cask-loading operations are continuous and the marshaled cars leave the reactor immediately after the fifth cask has completed loading operations, the first cask would be stored for approximately 4.3 days. The second cask would be stored for about 26 hours less, etc. It is assumed that cursory monitoring of these loaded casks would require 1 hour per day for a total monitoring time of 4 hours. For the average radiation field in this study of 10 mrem/hr for the monitoring staff, the increase in routine occupational exposures from at-reactor marshaling would be 0.043 person-rem per 5-car shipment, or 1.3 person-rem/1000 MTU. Adding this to the unrounded doses for conventional handling of reference rail cars would bring the at-reactor doses for this alternative to 42 person-rem/1000 MTU.

4.1.6 No Marshaling Versus Marshaling Rail Cars Away from the Reactor

In this potential alternative, the loaded rail spent-fuel casks from one or more reactors would be accumulated at a nearby rail siding, along with a caboose and some buffer cars, to create a five-car dedicated train for the shipment to the repository. Because the at-reactor operations for this alternative would be the same as with the single-car shipments with the reference rail cask, occupational doses would not be affected by the cask-handling operations at the reactor. The routine occupational doses for this alternative would be the same as for handling a single reference rail cask at the reactor--40 person-rem/1000 MTU.

4.1.7 Consolidation at the Repository Versus at the Reactor

In this potential alternative, the spent fuel would be disassembled in the reactor pool. The fuel-bearing rods from two assemblies would be placed in canisters having the same volume as one original spent-fuel assembly. The NFBC would be compacted into separate canisters and are also loaded out for shipment to a repository. This alternative would reduce handling requirements for spent-fuel load-out and the number of shipments after consolidation, but would add to the consolidation operations. Total occupational doses at the reactor for this alternative would consist of those from consolidating and canisterizing the spent-fuel rods; compacting and canisterizing the resultant NFBC; setting up and checking out the equipment; removing and decontaminating the equipment; and loading out the consolidated spent-fuel rods and NFBC.

The evaluation of this alternative is based largely on the results of a wet spent-fuel consolidation demonstration at the Oconee Nuclear Power Station in 1982 (Bailey 1985; Duke Power Co. 1983; and E. R. Johnson 1984). This demonstration resulted in a 2:1 volumetric consolidation ratio of fuel rods from 4 nonradioactive PWR assemblies in 4 campaigns. The equipment used in this demonstration consisted of a spent-fuel-rod consolidation machine and an NFBC compactor.

A wet consolidation demonstration was also performed at the Barnwell Nuclear Fuel Plant in 1981. The consolidation and compaction equipment setups in the latter demonstration were positioned and operated at the same time in the spent-fuel pool (E. R. Johnson 1984). Because of limited space in the storage pool for the Oconee demonstration, only one of the two pieces of equipment could be in place at one time (Duke Power Co. 1983). At the end of each operating campaign of rod consolidation or compaction, the equipment had to be decontaminated and removed from the pool and the other piece of equipment installed. Not included in this analysis are the potential increased occupational exposures as a result of crud removal from the waste treatment system.

It is assumed in this analysis that the fuel-rod consolidation and NFBC compaction equipment could be placed in the spent-fuel pool at the same time. It is also assumed that at-reactor consolidation would be done in campaigns that consolidate the equivalent of 1 annual discharge, or about 30 MTU for a 1000 MWe reactor. It is also assumed that Oconee's best time for their 4 consolidation campaigns (1 shift per PWR assembly) would be improved with each subsequent operation to an average of 6 hours per assembly. The time required to compact the NFBC from each PWR assembly into canisters is also assumed to be improved relative to the Oconee's best time, or to 95 minutes. From these bases, detailed estimates were made of manpower and occupational doses from in-pool consolidation and NFBC compaction, and are given in Table B.3 and summarized in Table 4.8. From this analysis, the estimated total occupational doses for spent-fuel consolidation and NFBC compaction for a campaign of 30 MTU

TABLE 4.8. Routine Occupational Doses for At-Reactor Consolidation of Spent Fuel, Compaction of NFBC, and Setup and Decontamination of the Equipment

Operation	Total Man-hours/Campaign[a]	Person-mrem/Campaign[a]	Person-rem/1000 MTU
Consolidation	1344.0	3360.0	113.6
Compaction of NFBC	343.0	857.6	29.0
Equipment			
Setup/Checkout	77.0	192.5	6.5
Removal	28.0	70.0	2.4
Decontamination	36.8	308.4	10.4
Total	1829	4789	162

(a) For a campaign of 29.6 MTU (64 PWR assemblies).

(64 PWR assemblies) would be about 3.4 and 0.86 person-rem, respectively. For 1000 MTU, the routine occupational exposures would be 114 and 29 person-rem, respectively.

At the beginning of each campaign, the consolidation and compaction equipment would have to be installed in the pool and its operability confirmed. At the completion of each campaign, the equipment is assumed to be removed and decontaminated, thereby making the cask pool area available for shipping the consolidated fuel and NFBC and for receiving freshly discharged fuel. Detailed estimates have been made of manpower and occupational dose for setup and checkout at the beginning of each campaign, and for removal and decontamination of the consolidation and compaction equipment after each campaign. The estimated doses in this activity are summarized in Table 4.8 and given in detail in Table B.4. The occupational doses for these activities would total 0.57 person-rem for each 30 MTU campaign, or 19 person-rem/1000 MTU. Adding this equipment manipulation dose to those for spent-fuel consolidation and NFBC compaction gives a total at-reactor occupational dose of 162 person rem/1000 MTU for these operations.

Occupational exposures for load-out of the consolidated spent fuel and NFBC were estimated based on requirements for load-out of intact spent fuel, and reflect the volumes of these materials and the number of canisters. Tables 4.9 and 4.10 summarize the analysis for at-reactor loading of the canisters of consolidated spent-fuel rods and the separate canisters of NFBC into reference truck and rail casks, respectively.

The unit occupational doses accumulated in loading the consolidated fuel and compacted NFBC for transport in the reference truck and rail casks would be 115-rem/1000 MTU and 27 person-rem/1000 MTU, respectively. Adding to these values the doses for consolidation/compaction/equipment setup, removal, and decontamination would make the total routine occupational doses at the reactor 277 person-rem/1000 MTU for truck shipments and 189 person-rem/1000 MTU for rail shipments. These at-reactor doses are considerably higher than those for handling intact spent fuel: 163 and 40 person-rem/1000 MTU for truck and rail shipments, respectively.

TABLE 4.9. Occupational Doses for At-Reactor Loading of Consolidated Spent Fuel and NFBC in the Reference Truck Cask

Operation	Unit Occupational Doses for Reference Truck Cask (person-rem/1000 MTU)[a] Intact Fuel	Consolidated Spent Fuel	Compacted NFBC
Cask received at reactor	1.0	0.5	0.2
Cask washed and sampled	9.2	4.6	1.8
Cask transferred to set-down pad	5.7	2.8	1.1
Cask transferred into pool and loaded	10.0	5.0	2.0
Cask removed from pool, decontaminated and surveyed	110.4	55.2	22.1
Cask transferred to vehicle and exits facility	27.1	13.5	5.4
Total	163	82	33

(a) These calculations are based on 4 consolidated assemblies in 2 canisters per truck cask (1.85 MTU) and 20 compacted NFBC in each of 2 canisters (4.62 MTU/canister) per truck cask.

4.1.8 At-Reactor Wet Transfer from At-Reactor Dry Storage to Transportation Cask Versus Dry Transfer

Reactors that store spent fuel in dry storage casks typically would transfer the dry-stored spent fuel to a transportation cask by bringing the dry storage cask into their storage pool and by transferring the spent fuel under water in the pool. However, with the alternative, spent fuel in a dry storage cask at the reactor would be transferred to a rail cask through a dry transfer system. This alternative would apply only to at-reactor spent fuel that is in dry cask storage. The estimated occupational exposures from this alternative are based on available data for general dry transfer principles used in the NUTECH Horizontal Modular Storage (NUHOMS) dry transfer concept (NUTECH 1984). Other dry transfer concepts could be used, such as transfer and transport casks that have integral shield doors.

TABLE 4.10. Occupational Doses for At-Reactor Loading of Consolidated Spent Fuel and NFBC in the Reference Rail Cask

Operation	Unit Occupational Dose (person-rem/1000 MTU)[a] Intact Fuel	Consolidated Spent Fuel	Compacted NFBC
Cask received at reactor	0.3	0.1	0.1
Cask washed and sampled	3.3	1.6	1.2
Cask transferred to set-down pad	1.2	0.6	0.4
Cask transferred into pool and loaded	4.5	2.3	0.6
Cask removed from pool, decontaminated and surveyed	25.9	13.0	3.6
Cask transferred to vehicle and exits facility	5.3	2.6	0.7
Total	40	20	7

(a) Calculated based on 28 consolidated assemblies in 14 canisters per rail cask (12.94 MTU) and 10 compacted NFBC (4.62 MTU/canister) per rail cask in each of 10 canisters.

The analysis of this alternative assumes that there would be only one crew per shift and no parallel operations. Not included in this analysis are the operations associated with receiving the dry storage casks, wet loading the storage cask with the spent fuel in baskets, and drying and placing the storage casks in their storage location. A summary of the analysis of reference wet and the alternative dry transfer is given in Table 4.11. Details are given in Appendix B, Table B.5. The routine occupational doses would be an estimated 66 person-rem/1000 MTU for the reference condition and 22 person-rem/1000 MTU for the potential change.

4.1.9 At-Reactor Dry Storage in Nontransportable Rail-Sized Casks Versus in Transportable Rail Casks

In this alternative, spent fuel beyond the storage-pool capacity would be stored dry in casks that would be suitable for both storage and transportation,

TABLE 4.11. Occupational Doses for At-Reactor Wet and Dry Loading of Spent Fuel in Dry Rail-Storage Casks to the Reference Rail Cask

Operation	Unit Occupational Doses (person-rem/1000 MTU) Conventional Wet Transfer	Dry Transfer
Transport cask received at reactor, washed and sampled	3.6	3.2
Transport cask transferred to pool (wet), or mated to storage cask (dry)	3.2	11.3
Storage cask moved, washed and transferred into pool	20.6	0.0
Spent fuel loaded into the cask	0.2	3.1
Transport cask removed, sealed, decontaminated and surveyed	27.5	3.9
Transport cask transferred to vehicle and exits facility	5.3	0.8
Storage cask decontaminated, surveyed and stored	5.4	0.1
Total	66	22

compared with the reference case where dry storage is in storage-only casks that require wet transfer of the spent fuel. Initial in-pool loading and transfer to a storage pad onsite is not included in this analysis. Preparations for transportation with the transportable storage cask would be minimal. The casks are assumed to be handled as conventional transportation casks. This option would eliminate the transfer of the spent fuel to a separate transportation cask (either wet or dry) at the reactor.

Three operations would be required at reactors to prepare a transportable rail storage cask for transportation: 1) survey and decontaminate the transportation cask, 2) recertify the transportation cask, and 3) transfer transportation cask and cask exits facility. The occupational exposure estimates for these operations would be 2.3, 12.4, and 0.8 person-rem/1000 MTU, respectively (based on the evaluation in Table B.5). Thus, the total routine occupational doses for this option would be 16 person-rem/1000 MTU, compared with the reference wet transfer case (discussed in Section 4.1.8) of 66 person-rem/1000 MTU.

4.2 OCCUPATIONAL DOSES FOR AT-REPOSITORY SURFACE ACTIVITIES

This subsection evaluates the routine occupational radiological doses during spent-fuel handling in a reference repository's above-ground operations. The doses are estimated for the reference system and for each of the nine potential waste management system alternatives. The design and operation of the above-ground reference repository are assumed to be identical to comparable elements of the conceptual design of the proposed MRS facility (Parsons 1985; DOE 1985). The conceptual design of the MRS facility was used because it is further developed than potential designs for a repository.

In the reference case in this study, the repository would receive spent fuel by truck or rail, consolidate and package the fuel rods in a dry hot cell, and place the waste package in a transfer cask for transfer to the underground disposal area. The operating times involved and the exposures received for each option would be related to the transportation cask capacity, the time and personnel requirements for each operation, and the radiation exposure rates for each operation.

The exposure rates to operating personnel used in this analysis for at-repository operations correspond to those in the MRS facility conceptual design report (Parsons 1985), to those in simulation modeling of the proposed MRS facility (Chockie, Hostick and Winter 1986), and where comparable, to those defined in Section 4.1. The exposure rates are:

- 0.125 mrem/h for all remote operations in hot cells
- 0.5 mrem/h for handling empty casks not associated with the hot cells
- 0.5 mrem/h for positioning loaded casks while the casks are attached to their respective vehicles
- 0.75 mrem/h for handling drums of NFBC

- 2.5 mrem/h for operations within the receiving and handling building not requiring direct contact with the cask and welding operations
- 10.0 mrem/h for all other loaded cask-handling operations.

With these bases, detailed calculations were made to estimate the routine occupational doses for repository surface facility operations using the conceptual design of the proposed MRS facility, and reference truck and rail casks. As with the at-reactor analyses, the at-repository analyses are directed toward achievably low occupational doses believed to be obtainable through repetitive experience. These calculations are summarized in the following subsections, and are given in detail in Appendix C, Table C.1. Elapsed time and occupational exposures for each truck cask load would be 12 hours and 125 person-mrem, and for each rail cask load would be 18 hours and 160 person-mrem, respectively. These detailed calculations were used as the primary basis for subsequent calculations of the other potential system alternatives. The following subsections discuss the routine occupational dose estimates and results for the reference and potential system changes.

4.2.1 Legal-Weight Truck Versus Rail Shipments

In this option, the approximately 30% of reactors that currently cannot ship spent fuel by rail are considered as the reference case. For the potential system alternative, it is assumed that these reactors can be modified to have the capability of shipping unconsolidated spent fuel in the reference rail cask instead of the reference truck cask. As at the reactor, the occupational exposures for handling each rail shipment would be higher than for each truck shipment because of the increased time required to handle the larger rail cask and to unload its contents. However, this increased exposure per cask would be more than offset by the reduced number of rail casks to ship the same amount of fuel. The analysis of these alternatives uses directly the results of estimated cask-handling occupational exposures for the reference truck and rail shipments developed in Table C.1 in Appendix C. The resulting calculated routine radiological doses for at-repository handling with the reference truck and rail shipments are summarized in Table 4.12. As shown, the estimated

TABLE 4.12. Occupational Doses for At-Repository Unloading of Spent Fuel from the Reference Truck and Rail Casks

Operation	Occupational Doses (person-rem/1000 MTU) Reference LWT Cask	Reference Rail Cask
Cask inspected and transferred to wash	5.6	1.0
Cask washed and transferred to unloading	10.6	1.8
Cask off-loaded from vehicle	48.3	9.1
Cask sampled, bolts untorqued	51.4	9.3
Cask mated to cell	17.2	3.1
Cask unloaded	0.1	0.1
Cask transferred to vehicle and exits facility	2.5	0.4
Total	136	25

routine occupational doses would decrease from 136 person-rem to 25 person-rem for each 1000 MTU shipped by rail that was originally planned to be shipped by truck.

The doses during the consolidation and handling of spent fuel in the repository's hot cell would have to be added to these routine occupational doses. The consolidation and handling doses would be an estimated 5 person-rem/1000 MTU (see Section 4.2.7). Therefore, the total routine occupational doses for at-repository handling of reference LWT shipments would be 141 person-rem/1000 MTU, and for reference rail shipments would be 30 person-rem/1000 MTU.

4.2.2 Legal-Weight Truck Versus Overweight Truck Shipments

In this alternative, OWT casks would replace the reference truck casks that would be used for shipments from the reactors. The OWT casks hold twice as many spent-fuel assemblies as the LWT casks, but only the unloading time for the spent-fuel assemblies is proportional to the number of assemblies. The gross size of the OWT cask is sufficiently similar to that of the LWT cask that general handling requirements at the repository are expected to be about the same for the two casks. They are assumed to be the same in this study.

The analysis of the LWT and OWT casks is summarized in Table 4.13 (and details are given in Table C.2). As the table shows, the unit routine occupational doses for the reference LWT system would be 136 person-rem/1000 MTU, and 68 person-rem/1000 MTU for the OWT system.

The dose from consolidating and handling the spent fuel in the repository's hot cells must be added to the routine doses of unloading the spent fuel from transport cases. These doses would be an estimated 5 person-rem/1000 MTU (see later Section 4.2.7). Thus, the total routine occupational doses for at-repository handling of reference truck shipments would be 141 person-rem/1000 MTU, and for OWT shipments would be 73 person-rem/1000 MTU.

TABLE 4.13. Occupational Doses for At-Repository Unloading of Spent Fuel from the Reference and Overweight Truck Casks

Operation	Occupational Doses (person-rem/1000 MTU) LWT Cask	Occupational Doses (person-rem/1000 MTU) OWT Cask
Cask inspected and transferred to wash	5.6	2.8
Cask washed and transferred to unloading	10.6	5.3
Cask off-loaded from vehicle	48.3	24.1
Cask sampled, bolts untorqued	51.4	25.7
Cask mated to cell	17.2	8.6
Cask unloaded	0.1	0.1
Cask transferred to vehicle and exits facility	2.5	1.2
Total	136	68

4.2.3 Legal-Weight Truck Versus Heavy-Haul Truck and Rail Shipments

In this potential alternative, a heavy-haul truck/rail intermodal shipment would replace the LWT casks at reactors that do not have rail service. The alternative's effects on occupational doses at the repository are identical to the alternative in which rail casks are substituted for LWT casks (see Section 4.2.1). Routine occupational doses at the repository would change from 141 person-rem/1000 MTU for LWT shipments to 30 person-rem/1000 MTU for heavy-haul truck-plus-rail shipments.

4.2.4 100-Ton Versus 150-Ton Rail-Cask Shipments

In this potential alternative, the reference rail cask (loaded weight about 100 tons) would be replaced with a larger rail cask (loaded weight about 150 tons) that can haul 36/90 PWR/BWR assemblies (about 2.5 times the capacity of the reference rail cask).

At the repository, the principal benefit of using the 150-ton rail cask rather than the 100-ton cask would be a reduction in the number of casks to be handled. In this study, the handling requirements of the 150-ton cask are assumed to be the same as for the 100-ton rail casks at equivalent surface dose rates. Only the unloading time for the spent-fuel assemblies would be proportional to the number of assemblies. The results of the routine occupational dose analyses for this alternative are summarized in Table 4.14 and are given in detail in Table C.2. As Table 4.14 shows, the unit routine occupational doses for handling the reference 100-ton rail casks would be 25 person-rem/1000 MTU, and for the 150-ton cask would be 10 person-rem/1000 MTU.

The doses from consolidating and handling the spent fuel in the repository surface hot cells must be added to the doses for unloading the spent fuel. These doses would be an estimated 5 person-rem/1000 MTU (see later Section 4.2.7). Thus, the total routine occupational doses for at-repository handling of reference rail-cask shipments would be 30 person-rem/1000 MTU and 15 person-rem/1000 MTU for 150-ton rail-cask shipments.

4.2.5 No Marshaling Versus Marshaling Rail Cars at the Reactor

In this potential alternative, rail casks on their cars would be accumulated at the reactor until five loaded casks are present. The five cask cars

TABLE 4.14. Occupational Doses for At-Repository Unloading of Spent Fuel in 100- and 150-Ton Rail Casks

Operation	Occupational Doses (person-rem/1000 MTU)	
	Reference Rail Cask	150-Ton Rail Cask
Cask inspected and transferred to wash	1.0	0.4
Cask washed and transferred to unloading	1.8	0.7
Cask off-loaded from vehicle	9.1	3.5
Cask sampled, bolts untorqued	9.3	3.6
Cask mated to cell	3.1	1.2
Cask unloaded	0.1	0.1
Cask transferred to vehicle and exits facility	0.4	0.2
Total	25	10

would then be combined, with a caboose and buffer cars between each cask car, to create a five-car dedicated train for shipment to the repository.

At the repository receiving and handling facility, each of the two cask handling rooms would have the capacity to receive two casks at once. Each room would be used to prepare one cask for transfer into and out of the nearby cask unloading room and to hold the second cask until it could be transferred to the cask unloading room. Thus, the reference repository would be able to handle four casks simultaneously. It is assumed here that when the five-car dedicated train would arrive at the facility, the reference repository would have been operating continuously and that the cask handling and unloading rooms would have just been filled with four rail casks ready for unloading with no additional queue of casks waiting. Full cask-handling rooms with no queue are assumed to be the typical condition. At-repository occupational doses for this alternative are assumed to be from the exposures resulting from the outside queuing required for the five cars of the dedicated train. The increased exposures from marshaling versus no marshaling are assumed to be from daily cursory monitoring of each cask.

About 18 hours are estimated to be required to receive, unload and discharge the reference rail cask (Chockie, Hostick and Winter 1986). Approximately 16 hours of this time would be required for operations while each cask and/or its vehicle would be in the cask-handling/unloading rooms. From these bases, the approximate queuing time for each of the five casks waiting outside the repository receiving and handling area would be as follows:

- Two casks would be stored 16 hours.
- Two casks would be stored 32 hours.
- One cask would be stored 48 hours.

This queuing time would be equivalent to 1 cask in queue for 144 hours, or an average of about 29 hours/cask for the 5 casks. In the reference case, it is assumed that 1 cask at a time would be received and would be in queue for 16 hours. Each cask that is not in the cask-handling or unloading rooms is assumed to be given a cursory monitoring and inspection every 24 hours. The time required for cursory monitoring is estimated to be approximately 0.2 hours per cask. Using the average exposure rate of 10 mrem/hr in this study for monitoring and inspecting, the occupational exposures due to this alternative would be approximately 0.4 person-rem/1000 MTU, compared with approximately 0.2 person-rem/1000 MTU (see Table C.2) for the reference case. Because the values for each alternative are nearly the same, they are considered identical in this study at less than 1 person-rem/1000 MTU.

Adding the doses of cask handling and spent-fuel consolidation would result in the same total routine occupational doses at the reactor of 30 person-rem/1000 MTU for the reference single rail shipment and the five-car dedicated train shipments.

4.2.6 No Marshaling Versus Marshaling Rail Cars Away from the Reactor

In this potential alternative, rail cars would be marshaled at a railyard near the reactors to create a five-car dedicated train. The occupational doses at the repository for this option would be identical to those for the prior alternative in Section 4.2.5. That is, the total routine occupational doses at the repository for the reference single-rail shipments and the five-car dedicated train shipments would be the same at 30 person-rem/1000 MTU.

4.2.7 Consolidation at the Repository Versus at the Reactor

In this potential alternative, the spent fuel would be consolidated at the reactor, and the consolidated spent fuel and NFBC would be shipped in a reference truck or rail cask to the repository. The consolidated spent fuel would be in canisters that would not be emplacement-ready; that is, the canisters would need to be overpacked (placed in the final container in which geologic disposal occurs) and placed in a transfer cask for emplacement in the repository.

The routine occupational doses at the repository are separated into two categories for this analysis. One category includes receiving and unloading the transportation cask full of consolidated fuel rods or NFBC in canisters and discharging the empty cask; the other category includes overpacking the canisters and placing the overpacked canisters in a transfer cask for repository emplacement. Each of these categories is compared with the reference repository operations in this study. These reference operations are receiving unconsolidated spent fuel by truck or rail, consolidating the spent fuel into a repository package, compacting and placing the NFBC into a repository package, and placing the repository packages in a transfer cask.

In this potential alternative, each reference rail cask is assumed to carry 14 canisters of consolidated spent-fuel rods (equivalent to 28 intact PWR assemblies) or 10 drums of NFBC (from 100 intact PWR assemblies). Each reference truck cask would carry two canisters of consolidated spent-fuel rods (equivalent to 4 intact PWR assemblies) or 2 canisters of NFBC (from 20 intact PWR assemblies). The operations involved in receiving and unloading shipping casks containing consolidated spent fuel or NFBC are assumed to be the same as the operations for receiving and unloading intact spent-fuel assemblies, described in Section 4.2.1. The analysis of these receiving operations is summarized in Table 4.15 and detailed in Tables C.3 and C.4 in Appendix C.

Table 4.16 summarizes the estimates of occupational exposures for at-repository overpacking of consolidated spent fuel and NFBC received from reactors, and compares it with the reference case of consolidating spent fuel at the repository (see Tables C.5 and C.6 for details of the analysis).

TABLE 4.15. Occupational Doses for At-Repository Receiving of Intact and Consolidated Spent Fuel and NFBC from the Reference Truck and Rail Casks

Operation	Receiving Intact Spent Fuel — Truck	Receiving Intact Spent Fuel — Rail	Receiving Consolidated Spent Fuel and NFBC — Truck	Receiving Consolidated Spent Fuel and NFBC — Rail
	Occupational Doses (person-rem/1000 MTU)			
Cask inspected and transferred to wash	5.6	1.0	3.3	0.6
Cask washed and transferred to unloading	10.6	1.8	6.4	1.1
Cask off-loaded from vehicle	48.3	9.1	29.0	5.8
Cask sampled, bolts untorqued	51.4	9.3	30.8	6.0
Cask mated to cell	17.2	3.1	10.3	2.0
Cask unloaded	0.1	0.1	0.1	0.1
Cask transferred to vehicle and exits facility	2.5	0.4	0.9	0.3
Total	136	25	81	16

Thus, the analysis estimates that if the spent fuel were consolidated at the reactor, the total routine occupational doses for spent fuel and NFBC receiving and processing at the repository would be approximately 82 (81 + 1) and 17 (16 + 1) person-rem/1000 MTU for receipts by reference truck and rail casks, respectively. For the reference case, in which intact spent fuel would be received and consolidated at the repository, the total routine occupational doses for receiving and handling would be approximately 141 person-rem/1000 MTU and 30 person-rem/1000 MTU for receipts by the reference truck and rail casks, respectively.

TABLE 4.16. Occupational Doses for At-Repository Consolidation and Handling of Intact Spent Fuel and Overpacking of Consolidated Spent Fuel and NFBC

Operation	Occupational Doses (person-mrem/1000 MTU) Consolidate Fuel at Repository	Occupational Doses (person-mrem/1000 MTU) Overpack Consolidated Fuel and NFBC from Reactor
Spent fuel consolidated and packaged	3.6	0.0
NFBC consolidated and packaged	1.1	0.0
Overpack inspected and transferred	0.0	0.2
Overpack[(a)] prepared for loading	0.0	0.2
Overpack mated to cell	0.0	<0.1
Overpack loaded and sealed	0.0	0.4
Overpack lifted into transfer cask and exits surface facility	0.1	<0.1
Total	5	1

(a) The overpack is the final container in which geologic disposal occurs.

4.2.8 At-Reactor Wet Transfer from At-Reactor Dry Storage to Transportation Cask Versus Dry Transfer

In this potential alternative, reactors would ship spent fuel in transportable rail storage casks after dry cask storage, compared with the reference case of shipping in transportation-only rail casks. The capacity of the transportable storage cask was previously established in Section 3 to be the same as that of the reference rail transportation cask. At-repository handling of transportable storage casks of the same capacity as the transportation-only casks is assumed to be the same as for the transportation-only casks. Therefore, the routine occupational radiological doses for this alternative would be identical to those for receiving and handling reference rail casks (see Section 4.2.1), or 30 person-rem/1000 MTU for either case.

4.2.9 At-Reactor Dry Storage in Nontransportable Rail-Sized Casks Versus in Transportable Rail Casks

In this potential alternative, reactors would ship spent fuel that has been in dry storage in casks and dry transferred from storage to the reference rail transportation cask. In the reference case, spent fuel would be transferred to the transportation casks in the reactor's pool. In either case, the same amount of spent fuel would be shipped to the repository in the same reference rail cask. Therefore, the routine occupational radiological doses for these two cases would be identical to those for receiving and handling reference rail casks (see Section 4.2.1), or 30 person-rem/1000 MTU (including at-repository consolidation).

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5.0 PUBLIC RISKS AT REACTORS AND REPOSITORIES

This section evaluates potential changes in public radiological risks for routine and accident conditions at the reactor and at the repository as a result of implementing potential alternatives in the no-MRS waste management system identified in this study. Doses from routine operations and expected doses from potential accidents (risks or consequences of accidents times their respective frequency of occurrence) are evaluated in this section.

The alternatives that were identified as potential improvements to the waste management system and that may affect public radiological risks in some manner have been identified in Section 3. With the exception of marshaling rail cars to form a 5-car dedicated train shipment at some offsite location, all of the potential alternatives could affect radiological risks to the public from at-reactor operational changes. All potential alternatives affect at-repository public risk to some degree with the exception of those alternatives that deal with cask transfers made at the reactor site. Generic analysis of the effects of the potential waste management system on public radiological exposures are presented in the subsections that follow.

5.1 PUBLIC RISKS FOR AT-REACTOR OPERATIONS

To estimate potential changes in public radiological risks at the reactor, the affected system operating steps were identified and assumptions necessary to estimate changes in public risk were made. When information was not available, changes in public risk are presented qualitatively. The estimates derived are useful primarily for comparative purposes but also give insight into the absolute risks. The assumptions made and resulting estimates are included in the following discussions for each of the nine potential alternatives.

5.1.1 Legal-Weight Truck Versus Rail Shipments

In this case all rail-limited reactors are assumed to be modified to ship by rail with a cask capacity of 14/36 PWR/BWR fuel assemblies. This potential change would affect only reactors that currently do not have capabilities for receiving/handling rail casks (about 30% of the total reactors) and would involve implementing appropriate modifications to the facility/site. It is assumed that reactor facilities with rail capability would always ship by rail.

Routine public risks are not expected to change significantly with the handling of the larger capacity casks. The total number of fuel assemblies handled would remain the same even though shipment size would increase and the number of shipments would decrease. The routine public dose commitments from commercial nuclear reactors are typically less than 1 person-rem/year (Baker and Peloquin 1981). These doses are primarily from effluents from power-generating operations at the reactors. The doses to the public that are associated with only the handling of spent fuel in preparing it for transport are a small fraction of this value. The DOE (1978) estimates that the total body dose commitment to the public from an independent spent-fuel storage basin would be 1.4 person-rem. The facility analyzed in the DOE (1978) document has a receiving capacity of 2000 MTU per year, resulting in an estimate of 0.7 person-rem/1000 MTU. Because of the similarity in operations at a reactor, this value is assumed to apply to at-reactor spent-fuel-handling operations.

The potential drop of a fuel assembly is the typical credible offnormal event used to predict the upper-bound public radiological risk for accident conditions during handling prior to transporting fuel assemblies. The fuel-assembly drop accident is assumed to occur at the reactor pool during loading of the fuel into a transportation cask. Erdmann et al. (1979) analyzed accident risks for a fuel storage pool, along with other fuel-cycle facilities. The frequency of a fuel assembly drop and rupture was estimated to occur 0.012 per year for a facility handling 2000 MTU per year. A radiological risk estimate of 0.001 person-rem per plant year was reported, which is equivalent to 0.0005 person-rem/1000 MTU (Erdmann et al. 1979). Because of similarity in operations, this value is assumed to apply to at-reactor spent-fuel storage operations. The fuel-assembly drop accident frequency should not change significantly when the same amount of spent fuel is transferred to rail casks or to truck casks. Therefore, the associated public accident risks would not vary significantly.

Routine and accident public radiological risks at the reactor and associated with loading shipping casks for either rail or truck shipment are therefore estimated to be less than 1 person-rem/1000 MTU. The difference between truck and rail shipping options would not result in any significant difference in radiological risks to the public for at-reactor operations.

5.1.2 Legal-Weight Truck Versus Overweight Truck Shipments

In this case, reactors that cannot ship by rail are assumed to ship their spent fuel in overweight trucks instead of the reference legal-weight trucks. This potential alternative would provide a higher-capacity truck cask shipment with somewhat reduced average transit speeds and reduced total numbers of shipments. As with the prior alternative, public risks due to exposure from handling and loading spent fuel in preparation for transport would not be significantly affected by loading higher-capacity casks. Because the same number of fuel assemblies would be handled and because accidents associated with the number of fuel assemblies handled (e.g., fuel-assembly drops) typically would dominate handling and loading risk, the public risk base-case values related to the fuel-assembly drop accident analysis in alternative 1 (rail shipment) are applicable. Thus, the change from LWT to OWT would not result in any significant difference in radiological risks to the public. Either case would result in less than 1 person-rem/1000 MTU.

5.1.3 Legal-Weight Truck Versus Heavy-Haul Truck and Rail Shipments

In this alternative, a heavy-haul truck transports a rail cask to a nearby offsite rail access location where the cask is transferred to a rail car for the bulk of the trip. This alternative could potentially benefit reactor facilities that do not currently have direct rail accessibility but that can handle the larger-sized cask. Again, the public risks associated with handling and loading casks at the reactor would not be significantly different when loading rail casks on heavy-haul trucks rather than LWT. Routine and accident public radiological risks from LWT (less than 1 person-rem/1000 MTU) are also applicable to use of overweight trucks.

5.1.4 100-Ton Versus 150-Ton Rail Cask Shipments

This alternative would use larger rail casks weighing about 150 tons for reactors with rail shipment access (up to about 70% of total reactors). These casks are assumed to carry 36/90 PWR/BWR fuel assemblies, or about 2.5 times the load of the reference 100-ton casks. The basis and rationale governing the public risks obtained for the reference rail cask (see Section 5.1.1) are applicable for the larger rail cask (less than 1 person-rem/1000 MTU in either case). Therefore, the public routine and accident risks for the at-reactor operations are not expected to change.

5.1.5 No Marshaling Versus Marshaling Rail Cars at the Reactor

In this alternative, rail shipment casks that contain spent fuel previously in the reactor basin or in dry storage would be held at the reactor site until a dedicated train makeup is complete (assumed here to be 5 cars). Routine public exposure would increase slightly due to the external radiation exposure to the surrounding population from rail cars sitting in place.

The following conservative assumptions were made in estimating the public radiological risks associated with marshaling rail cars at the reactor:

- Loading and preparing each rail cask for shipment requires 1.5 days.
- The first rail car sits for 6 days and the shipment leaves the site when the last car is loaded.
- The 4 cars sitting various lengths of time provide external radiation equivalent to 1 car sitting 360 hours.
- The exposure rate equals approximately 10 mrem/hr at 2 meters from the loaded cask surfaces.
- The exposure rate varies inversely as the square of the distance from the dose source.
- The exclusion zone around the reactor is a circular area one-half mile in radius from the location of the loaded casks.
- The external radiation dose rates beyond 1 mile from the rail cars are exceedingly low and are ignored.
- A uniform population density of 340 people/square mile is assumed for the 2.36 square mile annulus between the exclusion zone and 1 mile away from the loaded casks.

The calculated average exposure rate within the annulus is approximately 2.8E-8[a] rem/hr for marshaling rail cars at the reactor. For the approximately 800 people within the annulus considered, a radiation dose of 0.0081 person-rem/marshaled shipment is estimated. This is equivalent to 0.25 person-rem/1000 MTU.

The probability of cask failure while the cask is sitting at the reactor site is considered negligibly small, and the change in this failure probability would not increase significantly due to marshaling. The accident risks due to at-reactor marshaling would not be substantially higher than that of alternative 1. Therefore, at-reactor marshaling would increase public routine and accident risks only minutely (less than 1 person-rem/1000 MTU) because of the increased time that rail cars sit at the reactor site. These risks are essentially the same as for single-car rail shipments.

5.1.6 No Marshaling Versus Marshaling Rail Cars Away from the Reactor

Compared with no marshaling of rail cars, marshaling rail cars away from reactors would affect the public risks during transportation (discussed in Section 6), but would not affect the risks to the public at the reactors. Therefore, the public risks would remain the same at less than 1 person-rem/1000 MTU for either case.

5.1.7 Consolidation at the Repository Versus at the Reactor

Consolidation (handling, disassembly and packaging) would require extra operations wherever they are done, and would increase the routine public exposure. The primary public exposure would be from very small releases of airborne fission products. The DOE (1985) estimates the routine releases from normal cask venting and consolidation operations at the proposed MRS facility would result in routine doses of 20 person-rem for a 50-year total body dose commitment from an annual release. This estimate assumes the handling of 3600 MTU of spent fuel per year. On a 1000-MTU basis, this dose commitment would be approximately 6 person-rem/1000 MTU. Consolidation operations at the proposed MRS facility would be performed in a hot cell, whereas consolidation operations

(a) 2.8E-8 = 2.8×10^{-8}, or 0.000000028.

at a reactor would most likely be performed under water in the spent-fuel storage pool. Because the routine effluents from consolidation operations would be primarily airborne fission products (tritium, krypton and iodine), the removal efficiencies of the hot cell ventilation system and the spent-fuel storage pool would be low, and the releases are assumed to be similar. For these reasons, the radiological exposures to the public from MRS consolidation operations are assumed to apply to at-reactor consolidation operations. Thus, dose commitments of 6 person-rem/1000 MTU are estimated for routine releases from at-reactor consolidation operations.

The extra operations associated with consolidation would also increase the risks due to potential accidents. It is assumed that consolidation operations would increase the spent-fuel-handling accident frequency (with similar consequences) by less than a factor of 10 when compared with normal spent-fuel handling (see Section 5.1.1). This results in a bounding radiological accident risk estimate of about 0.005 person-rem/1000 MTU.

Thus, total public radiological risks in the area around the reactor from at-reactor consolidation of spent fuel are estimated to be approximately 6 person-rem/1000 MTU, compared to less than 1 person-rem/1000 MTU for at-repository consolidation.

5.1.8 At-Reactor Wet Transfer from At-Reactor Dry Storage to Transportation Cask Versus Dry Transfer

At the reactor, spent fuel in dry storage but not in transportable casks would have to be transferred to transportation casks before shipment. The alternative is assumed to use a dry transfer method as discussed in Section 4.1.8, where the spent fuel would be directly transferred from the storage cask to the shipping cask rather than using conventional in-pool transfer. This alternative would apply only to reactors that use dry storage in nontransportable casks to extend their onsite storage capabilities. The spent fuel is assumed to be placed into a canister for dry storage, and no routine effluents are expected during the dry-handling operations. Wet-handling operations may result in small routine releases, but these are expected to result in a small fraction of the 0.7 person-rem/1000 MTU for at-reactor routine public dose commitments estimated for alternative 1 (rail versus truck shipment in Section 5.1.1).

The potential lift heights and accident forces associated with a handling accident would be smaller for dry transfer than for conventional in-pool transfer of the spent-fuel canisters. The potential accident risks are expected to be less than the 0.0005 person-rem/1000 MTU estimated for alternative 1 (truck versus rail shipment). Thus, routine and accident public radiological risks associated with at-reactor wet or dry transfer from dry storage of spent fuel are estimated to be less than 1 person-rem/1000 MTU.

5.1.9 At-Reactor Dry Storage in Nontransportable Rail-Sized Casks Versus in Transportable Rail Casks

In this alternative, spent fuel would be dry in casks that would be suitable for both storage and transportation. This option would apply only to those reactors that use dry storage in transportable casks to extend their onsite storage capabilities. The risk impacts to the public of loading the dry storage casks are approximately the same as those of alternative 1. Storage in a transportable cask would eliminate the need to unload the storage cask and would result in even lower risks than storage in nontransportable casks. Therefore, the routine and accident radiological risks are expected to be less than 1 person-rem/1000 MTU for either case.

5.2 PUBLIC RISKS FOR AT-REPOSITORY OPERATIONS

In estimating potential changes in public radiological risks at the repository, the affected system operating steps were identified and assumptions necessary to estimate changes in public risk were made. When information was not available, changes in public risks are presented qualitatively. The estimates derived are useful primarily for comparative purposes but also give insight into the absolute risks. The assumptions made and resulting estimates are included in the following discussions for each of the potential alternatives.

5.2.1 Legal-Weight Trucks Versus Rail Shipments

With this alternative, rail-limited reactors would transport spent fuel by train rather than by truck. At the repository, spent fuel would be received in transportation casks, unloaded, handled and repackaged before emplacement. The public risk differences between LWT and rail shipments would result from the differences in handling and unloading rail versus truck shipping casks. Under normal operating conditions at the repository, the primary source of routine effluents would be airborne releases from venting spent-fuel casks and consolidating spent fuel. These releases are expected to be similar to those of the proposed and conceptual MRS facility. For cask venting and consolidation operations, preliminary studies for the MRS facility, operating at 3600 MTU per year, estimate a 50-year dose commitment from an annual release of 20 person-rem to the surrounding population (DOE 1985). On a 1000-MTU basis, this radiological dose commitment would be approximately 6 person-rem per 1000 MTU. Because the repository would likely have a lower surrounding population density than the MRS facility, this estimate represents an upper bound of the public radiation exposure from routine releases resulting from repository preclosure operations.

Public radiological risk differences due to at-repository accidents during the handling of rail versus truck casks are not considered to be significant. The rail casks are larger and carry a higher number of fuel elements, which potentially would increase the consequences to the public of potential accidents. However, fewer casks would be received, with proportionally lower accident frequency. These tradeoffs in risks are expected to essentially nullify one another, resulting in an insignificant change in public risks.

Studies performed in support of the review copy of the MRS Environmental Assessment (DOE 1985) assumed two major potential accident scenarios at the reference proposed MRS facility. The risks from the similar surface operations at a repository can be assumed to be similar to these. These accidents and their resultant radiological dose commitments would be:

Accident	Radiological Doses (total body population dose) (person-rem)
Fuel-Assembly Drop	0.03
Shipping-Cask Drop	0.006

The frequency of the spent-fuel drop with a release is estimated to be no more than once per year with the MRS facility operating at 3600 MTU/yr. The frequencies of the accidents are estimated to be very low in the review copy of the MRS Environmental Assessment (DOE 1985). The total doses from these postulated operations would be less than 1 person-rem/1000 MTU, even if the frequencies of these accidents are assumed to be as high as one per year. Because the frequency of the shipping-cask drop accident would be much smaller than the frequency of a fuel-assembly drop, the doses from a fuel-assembly drop are used to estimate the public doses from these accidents. The frequency of a fuel-assembly drop and rupture, multiplied by the consequence of a fuel-assembly drop, results in an estimate of effective public risks of about 0.008 person-rem/1000 MTU, or much less than 1 person-rem/1000 MTU.

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

Thus, the total public radiological risks at the repository for receipt of intact spent fuel in either truck or rail casks would be approximately 6 person-rem/1000 MTU.

5.2.2 Legal-Weight Truck Versus Overweight Truck Shipments

As described in Section 5.2, this potential alternative would use higher-capacity casks for shipping spent fuel with somewhat reduced average transit speeds and reduced total numbers of shipments. The impact of this change on public risk at the repository would be insignificant. As discussed in alternative 1, radiological risks to the public are not significantly affected by handling larger casks. Because the public risks at the repository would be a function of the number of fuel assemblies handled and because this number would not change, the change in routine and accident radiological risks is expected to be negligible, and the risks would remain at about 6 person-rem/1000 MTU for either case.

5.2.3 Legal-Weight Truck Versus Heavy-Haul Truck and Rail Shipments

In this alternative, a rail cask carried by heavy-haul truck from the reactor to a rail access location where it is loaded onto a rail car would have the same impact on the repository as would a conventional rail shipment. As in alternative 1 (i.e., LWT versus rail shipments), this option would allow for fewer and larger shipments of spent fuel, which would not significantly affect routine and accident radiological risk to the public from repository operations. Thus, the resultant total radiological risks to the public would remain at about 6 person-rem/1000 MTU for either case.

5.2.4 100-Ton Versus 150-Ton Rail-Cask Shipments

This alternative would use larger rail casks (150-ton) from reactors with rail shipment access. As discussed in alternative 1, the change in routine and accident risks to the public would not be significant if the total number of fuel assemblies handled remained the same. Thus, the resultant total radiological risks to the public for this alternative would remain at about 6 person-rem/1000 MTU for either case.

5.2.5 No Marshaling Versus Marshaling Rail Cars at the Reactor

With this alternative, spent fuel would be stored in rail casks at the reactor site until a dedicated train makeup is completed (assumed here to be 5 cars/shipment). The effect that this alternative would have on public radiological risks from routine operations at the repository depends on the repository receiving facilities. The risks to the public would be less if all casks can be handled concurrently. If it is assumed that loading and unloading casks require identical periods of holding time and that casks must be unloaded one at a time, then the public risks associated with demarshaling rail casks at the repository would approximate those for marshaling at the reactor. Therefore, the results produced for alternative 5 in the at-reactor assessment (Section 5.1.5) can be used as an upper bound because the exclusion area and population density would likely be smaller for the repository than the reactor. Those results predicted approximately 0.25 person-rem/1000 MTU.

Public radiological risks for accident conditions associated with cask handling and movement at the repository are expected to be similar to those for single rail-car shipments. The spent-fuel-handling operations would also be similar to those for single rail-car shipments. The probability of cask failure while the casks are sitting at the repository site is considered negligible, and the change in this failure probability would not increase significantly due to marshaling.

Therefore, the total at-repository radiological risks for this option would remain at approximately 6 person-rem/1000 MTU for either case.

5.2.6 No Marshaling Versus Marshaling Rail Cars Away from the Reactor

The accumulation of spent-fuel rail casks at the repository would be the same for marshaling at the reactor or at some other location, as discussed in Section 5.2.5. Rationale discussed in that section for marshaling rail cars at reactor sites is applicable here, and public radiological risks remain the same at about 6 person-rem/1000 MTU for either case.

5.2.7 Consolidation at the Repository Versus at the Reactor

Waite (1984) estimated public radiological exposures from normal preclosure operations for a repository at various salt sites. The largest annual value reported for operations without consolidation is 0.0028 person-rem for a 70-year total body dose commitment. Assuming the repository is designed to received 3000 MTU per year, public radiological exposure from routine releases would be approximately 0.001 person-rem/1000 MTU.

The radiological risks from potential accidents during repository preclosure operations for this alternative are conservatively assumed to be similar to those discussed in alternative 1 (Section 5.2.1), 0.008 person-rem/1000 MTU.

Therefore, spent-fuel consolidation at the reactor would result in public radiological risks from repository surface operations of less than 1 person-rem/1000 MTU, compared with about 6 person-rem/1000 MTU for spent-fuel consolidation at the repository (see Section 5.2.1).

5.2.8 At-Reactor Wet Transfer from At-Reactor Dry Storage to Transportation Cask Versus Dry Transfer

This alternative would not affect the public risk from at-repository operations. The public radiological risks for this alternative would be approximately 6 person-rem/1000 MTU for either case.

5.2.9 At-Reactor Dry Storage in Nontransportable Rail-Sized Casks Versus in Transportable Rail Casks

The radiological risk impacts to the public at the repository for this alternative would be the same as those established for the reference rail transportation cask discussed in alternative 1 (Section 5.2.1). The risks are estimated to be approximately 6 person-rem/1000 MTU for either case.

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6.0 PUBLIC AND OCCUPATIONAL DOSES DURING TRANSPORTATION

Transportation in this study denotes the shipment of spent fuel between the site fences at the nuclear reactors and the repository. The transportation activities evaluated include moving the spent-fuel casks from the point of origination to the destination; changing trains or prime-mover vehicles; inspecting, monitoring, safeguarding, and marshaling more than one vehicle (for some alternatives); and stopping for traffic considerations. The radiological risks resulting from spent-fuel transportation would include 1) exposure of the public and the transportation occupational workers along the transportation route to the very low levels of radiation emitted from the shipping container, and 2) the potential exposures of the public to radioactive materials that might be released from the shipping container as a result of an accident in transit.

The analyses in this section are based primarily on the transportation unit dose factors developed at Sandia National Laboratories (Cashwell, Neuhauser and Reardon 1986).[a] Transportation unit dose factors are usually expressed as the expected person-rem per unit distance. Unit dose factors are a function of the population distribution along the route, the radiation dose rate emitted from the shipping cask, average transit speed, cargo capacity, exposure distance, and other parameters. The unit dose factors would be different for truck and rail shipments. Separate dose factors were developed by Sandia for travel through three population zones: urban, suburban, and rural. Additional information on the derivation of the unit dose factors can be found in Neuhauser et al. (1985) and Wilmot et al. (1983). The units of the dose factors provided by Sandia are converted from health effects to person-rem per unit-distance in this analysis.

The alternatives that were identified as potential improvements to the reference waste management system and that may affect public or occupational

(a) Cashwell, J., K. S. Neuhauser and P. C. Reardon. 1986 (Draft). Transportation Impacts of the Commercial Radioactive Waste Management Program. SAND85-2715, TTC-00633, Sandia National Laboratories, Albuquerque, NM.

radiological doses during spent-fuel transportation were identified in Section 3. Analyses of the effects of these potential system changes on radiological transportation risks are presented in the following subsections.

6.1 LEGAL-WEIGHT TRUCK VERSUS RAIL SHIPMENTS

This alternative would involve upgrading the spent-fuel cask-loading facilities at rail-limited reactors. This alternative would allow rail casks to be used at the approximately 30% of the reactors that are currently limited to using the smaller LWT casks.

For the reference case, spent fuel is assumed to be transported from the reactors to the repository by general-commerce shipping in the reference LWT cask. The alternative case would use general-freight rail (in the reference 100-ton rail cask). Transportation unit dose factors developed at Sandia National Laboratories (Cashwell, Neuhauser and Reardon 1986)[a] are summarized for these cases (for occupational and public radiological risks) in Table 6.1. It is assumed that the shipping route would traverse 75% rural, 24% suburban, and 1% urban areas for truck transport and 75%, 23% and 2% for rail transport, respectively [generalized values from DOE (1985) Appendix F]. Shipping 1000 MTU of spent fuel to the repository (averaging about 3000 km distance) would result in about 3 million MTU-km.

Using the above data and assumptions, the occupational radiation doses for shipping 1000 MTU of spent fuel to the repository by truck and rail are estimated to be 100 person-rem and 5 person-rem, respectively, as shown in Table 6.1. The public doses (sum of the routine and accident dose) for truck and rail shipment are estimated to be 528 and 8 person-rem, respectively. As the table shows, the accident risks would be significantly lower than the routine doses for both truck and rail shipments. Also, the occupational doses for the rail mode for this comparison would be a factor of 20 lower than for the truck mode, and for public doses more than a factor of 60 lower.

(a) Draft, see (a) on p. 6.1.

TABLE 6.1. Unit Radiological Risk Factors for General-Freight Rail and General-Commerce Legal-Weight Truck Shipments of Intact Spent Fuel from Reactors[a]

Type of Shipment	Hazard Group	Population Zone	Percent of Travel In Population Zone	Unit Risk Factor[b] Person-rem/ 3E6 MTU-km[c]	Weighted Person-rem/ 3E6 MTU-km[c,d]
Reference Legal-Weight Truck by General Commerce	Routine Occupational	Rural	75	76.30	
		Suburban	24	167.21	100.2
		Urban	1	279.22	
	Routine Public	Rural	75	461.03	
		Suburban	24	707.79	525.3
		Urban	1	967.52	
	Accident Public	Rural	75	0.006	
		Suburban	24	12.11	3.1
		Urban	1	19.81	
	Total Public	All	--	--	528.4
Reference Single Rail Cask (100-T) General Freight	Routine Occupational	Rural	75	4.96	
		Suburban	23	4.96	5.0
		Urban	2	4.96	
	Routine Public	Rural	75	2.67	
		Suburban	23	17.85	6.3
		Urban	2	5.98	
	Accident Public	Rural	75	0.002	
		Suburban	23	0.45	1.8
		Urban	2	15.58	
	Total Public	All	--	--	8.1

(a) The risk factors are from Cashwell, Neuhauser and Reardon 1986 (draft, see (a) on p. 6.1) using the population zone assumptions shown.
(b) Accuracy of some numbers is less than indicated by the number of significant figures shown, but numbers are retained for consistency in subsequent calculations.
(c) Cask capacities are 6.47 MTU/rail shipment and 0.924 MTU/truck shipment, based on 14 PWR assemblies/rail cask and 2 PWR assemblies/truck cask. 3.0E6 MTU-km (or 3 million MTU-km) is for 1000 MTU transported 3000 km.
(d) Overall value weighted for the percentage of travel in each population zone.

6.2 LEGAL-WEIGHT TRUCK VERSUS OVERWEIGHT TRUCK SHIPMENTS

In this alternative, the larger and higher-capacity OWT shipments would be used in place of the smaller LWT shipments for the rail-limited reactors. OWT shipments would have operational constraints that would not be imposed on LWT shipments. Two principal effects of these constraints would be to increase shipment costs and to reduce the average transit speed. The average transit speed is an important parameter in calculating routine radiological exposures. The effects on the unit risk factors of reducing average transit speed and of increasing the cask capacities are evaluated in this section.

In calculating unit risk factors, Sandia estimated that the average transit speed for a LWT shipment would be about 35 miles/hr (840 miles/day) (Cashwell, Neuhauser and Reardon 1986).[a] Daling (1984) estimated that OWT shipments would travel an average speed of about 25 mph (600 miles/day). This would represent approximately a 40% reduction in average transit speed for OWT shipments (which would include an allowance for the more frequent stops experienced by OWT shipments). Assuming that the routine radiological exposures, including both the general population surrounding a route and the persons exposed during stops, are linear with respect to average transit speed and frequency of stops, respectively, a 40% increase in routine exposures for both occupational and nonoccupational groups is estimated for each OWT shipment versus each LWT shipment.

The 40% increase in routine radiological exposures for OWT shipments can be translated to a 40% increase over the LWT unit dose factors per shipment. However, correcting the doses for the 100% increase in OWT spent-fuel capacity would reduce the net unit doses by a factor of 2/1.4, or about 1.4, for transporting a given quantity of spent fuel on OWT. The resultant unit radiological doses from OWT shipping are given in Table 6.2, and can be compared with those for LWT shipping given earlier in Table 6.1.

Accident risk assessments have not been performed for OWT shipping. However, OWT shipments are expected to have similar risks per shipment to the public from accidents as those from LWT shipments. More likely, the unit risks

(a) Draft, see (a) on pg. 6.1.

TABLE 6.2. Unit Radiological Risk Factors for Overweight Truck Shipments of Intact Spent Fuel by General Commerce[a]

Hazard Group	Population Zone	Percent of Travel in Population Zone	Unit Risk Factor[b] Person-rem/ 3E6 MTU-km[c]	Weighted Person-rem/ 3E6 MTU-km[c,d]
Routine Occupational	Rural	75	54.50	
	Suburban	24	119.44	71.5
	Urban	1	199.44	
Routine Public	Rural	75	329.31	
	Suburban	24	505.56	375.1
	Urban	1	691.09	
Accident Public	Rural	75	0.006	
	Suburban	24	12.11	3.1
	Urban	1	19.81	
Total Public	All	--	--	378.2

(a) The unit risk factors are from Cashwell, Neuhauser and Reardon (1986), draft, see (a) on p. 6.1.
(b) Accuracy of some numbers is less than indicated by the number of significant figures shown, but numbers are retained for consistency in subsequent calculations.
(c) Cask capacity is 1.848 MTU/OWT shipment, based on 4 PWR assemblies/OWT cask; 3.0E6 MTU km is for 1000 MTU transported 3000 km.
(d) Overall value weighted for the percentage of travel in each population zone.

for OWT shipments would fall between the unit risk values for LWT and general freight rail. However, because the inventory of radioactive material within an OWT cask would be double the inventory in a LWT cask, it may be conservatively assumed that the potential unit accident consequences would also double, but those per MTU would remain unchanged. This effect is also shown in Table 6.2. Also shown is that accident risks would be significantly lower than routine risks for both OWT and LWT shipments.

A comparison of the radiological risk factors in Table 6.1 and in Table 6.2 shows that substituting OWT shipments for LWT shipments from reactors would reduce occupational exposures from about 100 to 72 person-rem/1000 MTU, and would reduce public exposures from about 528 to 378 person-rem/1000 MTU.

6.3 LEGAL-WEIGHT TRUCK VERSUS HEAVY-HAUL TRUCK AND RAIL SHIPMENTS

In this alternative, reactors that cannot ship by rail would use an intermodal shipment in which a rail cask would be moved to and from the reactor in heavy-haul trucks. Relative to in-transit activities, rail transport is different from heavy-haul truck plus rail transport in two principal ways: the transport of a rail cask by highway and the additional cask-handling operation needed at the rail siding to transfer the rail cask from the heavy-haul truck rig to the railcar.

In this option, three components of risk must be added: 1) heavy-haul truck component, 2) the truck-to-rail transfer component, and 3) the general-freight rail component, as shown in the following formula:

Risks of a Heavy-Haul Truck Rail Intermodal Shipment	=	Risks from Reactor-to-Rail Head Heavy-Haul Truck Transport	+	Risks from Cask Transfer at Rail Head	+	Risks from Rail Shipment for the Balance of the Trip

The general-freight rail component would be identical to the reference option except that the one-way transit distance would be shortened slightly to account for the heavy-haul truck portion of the trip. The average distance from rail-limited reactors to the nearest rail point, that is, the heavy-haul truck shipping distance, is estimated to be approximately 20 km/reactor site (Daling et al. 1985). This average distance is used here to reduce the general-freight rail shipping distance, as well as to calculate the risks of the heavy-haul truck portion of the shipment. As discussed above, the unit risks from the heavy-haul truck segment are represented by the unit risks from the general-freight rail transport through urban areas (given in Table 6.1).

Heavy-haul trucks travel at about the same speed as does rail in an urban area and would have roughly equivalent radiation dose rates. Therefore, the public routine radiological exposures for the transport segment using heavy-haul truck can be estimated using the unit risk factors for rail shipments in an urban area. The resulting estimates (Table 6.3) are believed to be conservative for three reasons: 1) these unit risk factors account for the average transit speed factor; 2) the population density is overestimated for most

TABLE 6.3. Unit Risk Factors for Heavy-Haul Truck and General-Commerce-Freight Rail Shipments of Intact Spent Fuel from Reactors[a]

Type of Shipment	Hazard Group	Population Zone	Percent of Travel in Population Zone	Unit Risk Factor[b] Person-rem/ 2E4 MTU-km	Weighted Person-rem/ 2E4 MTU-km[c,d]	Person-rem/ 3E6 MTU-km[c]	Weighted Person-rem/ 3E6 MTU-km[c,d]
Heavy-Haul Truck (100-T cask) to Rail Head	Routine Occupational	Urban	100	0.033	0.03	NA	NA
	Routine Public	Urban	100	0.040	0.04	NA	NA
	Accident Public	Urban	100	0.104	0.10	NA	NA
	Total Public	Urban	100	--	0.14	--	NA
Cask Transfer at Rail Head	Routine Occupational			14.5 person-rem/1000 MTU[e]			
	Routine Public			0.17 person-rem/1000 MTU[e]			
Reference Rail	Routine Occupational	Rural	75	NA	NA	4.96	
		Suburban	23	NA	NA	4.96	5.0
		Urban	2	NA	NA	4.96	
	Routine Public	Rural	75	NA	NA	2.67	
		Suburban	23	NA	NA	17.85	6.3
		Urban	2	NA	NA	5.98	
	Accident Public	Rural	75	NA	NA	0.002	
		Suburban	23	NA	NA	6.45	1.8
		Urban	2	NA	NA	15.58	
	Total Public	All	--	--	--	--	8.1

(a) The risk factors shown are preliminary and are continuing to be updated. Total risk = sum of heavy haul + cask transfer + rail risks.
(b) Accuracy of some numbers is less than indicated by the number of significant figures shown, but numbers are retained for consistency in subsequent calculations.
(c) Cask capacity is 6.47 MTU/shipment based on 14 PWR assemblies/cask. 1E4 MTU-km is for 1000 MTU transported 20 km; 3.0E6 MTU-km is for 1000 MTU transported 3000 km.
(d) Overall value weighted for the percentage of travel in each population zone.
(e) Cask transfer doses need to be added to the respective in-transit doses to obtain the total doses for this alternative.

shipments; and 3) the rail unit risk factor accounts for stops, whereas the heavy-haul truck shipment is not expected to stop between the reactor and the rail siding.

Routine public radiological exposures would increase slightly because of the additional cask-handling operations performed at the nearest rail point. It is assumed here that a seven-person crew is required during the cask transfer operation: two drivers, a load supervisor, a crane operator, two crane riggers, and a radiation monitor. Three additional persons, who may be NRC inspectors, state inspectors, and rail inspectors, are assumed to be present, for a total of ten persons. This operation is estimated to take four hours to complete. The ten occupational personnel listed above are estimated to spend the following amounts of time at the specified distances from the cask (the estimated radiation dose rates are shown in parentheses):

- crane riggers: 2 hr at 2 m and 2 hr at 8 m from the cask surface (0.01 rem/hr and 0.0006 rem/hr, respectively)
- crane operator: 0.5 hr at 2 m and 3.5 hr at 8 m from the cask surface (0.01 rem/hr and 0.0006 rem/hr, respectively)
- truck drivers: 4 hr at 8 m from the cask surface (0.0006 rem/hr)
- radiation monitor: 1 hr at 2 m and 2 hr at 8 m from the cask surface (0.01 rem/hr and 0.0006 rem/hr, respectively)
- others: 0.5 hr at 2 m and 3.5 hr at 8 m from the cask surface (0.01 and 0.0006 rem/hr, respectively)

The resulting routine occupational exposures for this transfer operation would be approximately 0.094 person-rem/transfer or 14.5 person-rem/1000 MTU.

For estimating the public dose contribution of the cask transfer at the rail siding, it is assumed that the 4-hour transfer time would be added to the travel time of the rail portion of the trip. For a train that travels 3000 km at an average of 20 km/hr, the travel time would be 150 hours. Thus, the public routine radiological exposure would increase from 150 to 154 hours, or an increase of about 2.7%. This is 2.7% of the 6.3 person-rem/1000 MTU for the routine public risk for the rail portion of the trip (given in Table 6.3) or 0.17 person-rem/1000 MTU.

The shipping casks are designed to withstand severe puncture and impact or free-drop accident conditions. These conditions are not expected to be encountered during the transfer operation; for example, a 30-ft free drop is extremely unlikely because the casks would never need to be lifted to this height. As a result, accident risks during the cask transfer operation are expected to be significantly lower than the accident risks during transport, so they are assumed to be negligible.

Accident risks for the heavy-haul portion of this intermodal shipment are expected to be somewhat lower than for a general-freight rail shipment. Heavy-haul truck shipments travel relatively slowly, are normally accompanied by escort vehicles, and are subject to special traffic controls. As a result, the probability of an accident occurring would be extremely low and the probability of encountering accident conditions that exceed the regulatory accident conditions would be practically zero. The magnitude of the accident risk reduction is not evaluated here because the routine risks would be much greater than the overall accident risk. Any reduction in accident risks that would result from this aspect of this alternative would not significantly change the overall transportation risks.

The principal difference in risks between LWT, and heavy-haul truck and rail shipments is due to the offsite transfer of the loaded cask from a heavy-haul truck rig to the rail car. All other components of the risk of heavy-haul truck shipments can be estimated using the general-freight rail unit risk factors. The unit risk factors derived for this alternative are shown in Table 6.3. The total exposure for occupational workers in this alternative, from Table 6.3, would be the sum of 0.03 + 14.5 + 5.0, or about 20 person-rem/1000 MTU. The total risks to the public would be the sum of 0.14 + 0.17 + 8.1, or 8.4 person-rem/1000 MTU. These totals can be compared to 100 and 528 person-rem, respectively, for LWT shipments given earlier in Table 6.1.

6.4 100-TON VERSUS 150-TON RAIL-CASK SHIPMENTS

In this alternative, the reference 100-ton rail cask would be replaced, where possible, by a higher-capacity 150-ton rail cask for shipments from reactors to the repository. Most reactors would require modifications to their cask-handling facilities (for example, upgraded crane capabilities, upgraded floor structural reinforcement) in order to handle such a heavy cask. If these upgrades could be made, the number of rail-cask loads from reactors would be reduced by approximately a factor of 2.5 (based on the assumed capacities of the 100-ton and 150-ton casks in this study of 14/36 and 36/90 PWR/BWR assemblies, respectively).

The change in rail-cask size would affect the unit radiological risk factors primarily from the increased capacity of the 150-ton cask. Increasing the cask capacity is assumed to have no effect on the radiation dose rate emanating from the cask; that is, the 150-ton cask is designed to limit the dose rates to the same level as for the 100-ton cask. Therefore, the radiation dose rates of the 100-ton casks and the 150-ton casks would be the same. The principal effect would be an approximately 2.5-fold reduction in the number of shipments. This would reduce the unit public routine doses per MTU by the same factor, while the unit risk per km traveled would be unchanged. These risk estimates assume that there would be no operational differences, such as slower average transit speeds, additional enroute handling requirements, or increased stop time between the two types of shipping casks.

It is assumed that the 100-ton and 150-ton casks would be designed to provide equivalent protection from radioactivity releases caused by potential accidents during transport. Therefore, the principal effect on accident risks would result from an increase of approximately 2.5-fold higher consequences/km traveled from a potential accident (due to the 2.5 fold increase in spent fuel in each cask), with a comparable reduction in the expected frequency of such accidents because of the fewer km traveled. The net result would be no change in the expected accident risks/MTU-km (frequency times consequences).

The resulting unit radiological risk factors for this alternative are shown in Table 6.4. The total occupational and public risks would be 2 and

TABLE 6.4. Unit Risk Factors for Transport of Intact Spent Fuel in 150-Ton Rail-Cask Shipments from Reactors[a]

Hazard Group	Population Zone	Percent of Travel in Population Zone	Unit Risk Factor[b] Person-rem/ 3E6 MTU-km[c]	Weighted Person-rem/ 3E6 MTU-km[c,d]
Routine Occupational	Rural	75	2.15	
	Suburban	23	2.15	2.2
	Urban	2	2.15	
Routine Public	Rural	75	1.04	
	Suburban	23	6.94	2.4
	Urban	2	2.33	
Accident Public	Rural	75	0.002	
	Suburban	23	6.45	1.8
	Urban	2	15.58	
Total Public	All	--	--	4.2

(a) The unit risk factors are based on those in Cashwell, Neuhauser and Reardon (1986), draft, see (a) on p. 6.1.
(b) Accuracy of some numbers is less than indicated by the number of significant figures shown, but numbers are retained for consistency in subsequent calculations.
(c) Cask capacity is 16.63 MTU/150-ton rail shipment; based on 36 PWR assemblies/150-ton rail cask; 3.0E6 MTU km is for 1000 MTU transported 3000 km.
(d) Overall value weighted for the percentage of travel in each population zone.

4 person-rem/1000 MTU, respectively. These can be compared with those for 100-ton casks of 5 and 8 person-rem/1000 MTU, respectively, as given earlier in Table 6.1.

6.5 NO MARSHALING VERSUS MARSHALING RAIL CARS AT THE REACTOR

In this alternative, rail shipments of unconsolidated spent fuel would be marshaled at each reactor into 5-car dedicated trains. Each dedicated train would include a locomotive, caboose, and buffer cars between each cask car, between the locomotive and first cask car, and between the last cask car and the caboose. From the reactor, the dedicated train would transport the fuel to the repository. This contrasts with the reference case, in which single-car shipments would be made using general-freight rail service.

The use of dedicated trains would change the operational details of the transportation system as follows:

- provide short-term waiting times for loaded casks at reactors
- reduce the amount of time the trains spend in rail yards waiting for train make-up and classification.

The latter item is addressed in this subsection, while the former is addressed under at-reactor marshaling (Sections 4 and 5).

It has been assumed in this study that use of dedicated trains would not significantly increase or reduce the average speed of the trains in transit because the actual operating conditions, such as maximum speeds, procedures for passing other trains, etc., have not been defined for a dedicated spent-fuel train. However, a recent study of dedicated train service (Cashwell, Neuhauser and Reardon)[a] indicated that only 2 hours would be required at railyards for dedicated train makeup and classification, whereas an average of 60 hours per trip was measured for general-freight rail service. This would apply to the first and last stops made by the trains. Stop times between the first and last would not be significantly different for dedicated and regular trains. These stop times were factored into the calculations of unit risk factors by Cashwell, Neuhauser and Reardon (1986).[a] Use of the dedicated trains would result in a greater than 10-fold reduction in the unit risk factors for occupational groups and a small reduction to the public risk factors compared with general-freight rail shipments transporting the same amount of spent fuel.

The increase in radiation dose to the public from combining 5 cars into a single shipment is estimated to be negligible; that is, it does not matter whether 5 trains pass by individually or one 5-car train passes by. However,

(a) Draft, see (a) on p. 6.1.

the exposure time to the same number of casks would be about the same as for shipments with single casks. As a result, the general-freight rail routine exposures to the public can be multiplied by a factor of five to estimate their exposures from a single 5-car dedicated rail shipment. This factor of five increase would be canceled by a factor of five reduction in the number of shipments. Therefore, the differences between routine public unit radiological risk factors for dedicated and single-car shipments are estimated to be small.

The resultant total radiological risks to the public and to the occupational workers from spent-fuel shipment in 5-car dedicated trains (marshaled at the reactor) are given in Table 6.5. The risks are 5 and 0.3 person-rem/1000 MTU, respectively, and can be compared to 8 and 5 person-rem/1000 MTU, respectively, for single rail-car shipments as general freight, given earlier in Table 6.1.

6.6 NO MARSHALING VERSUS MARSHALING RAIL CARS AWAY FROM THE REACTOR

In this alternative, 5 loaded rail casks would be transported on a dedicated train that consists of only spent-fuel cask-bearing railcars, a locomotive, a caboose, and buffer cars as described in Section 6.5; that is, spent fuel is the only commodity in the train. The cask shipments would be "marshaled" at some location away from reactors until a sufficient number of rail cars is available for the shipment to proceed to its destination.

The transportation risks for dedicated trains made up at the reactors were presented in Section 6.5. The transportation risks imposed by away-from-reactor marshaling should be added to these risks. Marshaling away-from-reactors compared with marshaling at reactors would transfer some of the risks from the reactor workers to the in-transit workers. Also, small amounts of risks would be transferred from the public near the reactor site to the public near the away-from reactor marshaling site.

The incremental risks due to accidents in marshaling yards are assumed to be negligible relative to those for the other portions of the trip because rail traffic would be tightly controlled and rail speeds would be generally slow in the areas surrounding a rail head. Thus, severe accident conditions that could result in a release from a cask are not expected at a rail center. The routine

TABLE 6.5. Unit Risk Factors for Five-Car Dedicated Train Shipments of Intact Spent Fuel from Reactors[a]

Hazard Group	Population Zone	Percent of Travel in Population Zone	Unit Risk Factor[b] Person-rem/ 3E6 MTU-km[c]	Unit Risk Factor[b] Weighted Person-rem/ 3E6 MTU-km[c,d]
Routine Occupational	Rural	75	0.310	
	Suburban	23	0.310	0.31
	Urban	2	0.310	
Routine Public	Rural	75	0.386	
	Suburban	23	15.58	3.9
	Urban	2	3.70	
Accident Public	Rural	75	0.003	
	Suburban	23	4.58	1.3
	Urban	2	11.04	
Total Public	All	--	--	5.2

(a) The risk factors shown are derived from Cashwell, Neuhauser and Reardon (1986), draft, using the population zone assumptions shown. (See (a) on p. 6.1).
(b) Accuracy of some numbers is less than indicated by the number of significant figures shown, but numbers are retained for consistency in subsequent calculations.
(c) Cask capacities are 6.47 MTU/rail shipment and 0.924/truck shipment; based on 14 PWR assemblies/rail cask and 2 PWR assemblies/truck cask. 3.0E6 MTU km (or 3 million MTU-km) is for 1000 MTU transported 3000 km.
(d) Overall value weighted for the percentage of travel in each population zone.

exposures received by the population surrounding a rail marshaling yard would be slightly higher than for the other portions of the trip because of the increased time spent awaiting train makeup.

In this analysis, the single-cask shipments are assumed to arrive at the marshaling yard at a rate of 1 per day, resulting in an average marshaling time per shipment of 5 days or 120 hours. This can be compared to the 60 hr/trip average stop time for train classification that was estimated for general-freight rail transport of single casks. As a result, the routine public exposures received from rail-shipment marshaling are estimated to be approximately twice the exposures calculated for train classification in the unit risk factors for general-freight rail.

The exposures received during stops have been estimated to be approximately 10% of the total routine exposures (doses during storage in-transit were removed from the data) for general-freight rail (U.S. Nuclear Regulatory Commission 1977, Table 4.18). Thus, 10% of the public risks for general-freight rail shipments given on Table 6.1 (6.3 person-rem/1000 MTU), or 0.63 person-rem/1000 MTU, is estimated to be from stops enroute. The occupational exposures for security and monitoring are assumed to be the same fraction of these total doses for general-freight rail shipments (5.0 person-rem/1000 MTU), or 0.5 person-rem/1000 MTU.

The incremental public exposures due to marshaling were estimated above to be approximately twice those during stops (and also assumed here to be the same for occupational exposures) and must be added to the risks during travel time. The public and occupational risks/km during the assumed average 100-km travel to the rail head would be the same as for general-freight rail shipments in urban areas (given in Table 6.1), and the risks/km after marshaling (2900 km) would be the same as after at-reactor marshaling (given in Table 6.5).

The resultant risks for this alternative are given in Table 6.6. The total public and occupational risks would be the sum of the 3 components, and would be 7 and 1 person-rem/1000 MTU, respectively. These can be compared to 8 and 5 person-rem/1000 MTU, respectively, using single-rail car shipments as general freight, given earlier in Table 6.1.

6.7 CONSOLIDATION AT THE REPOSITORY VERSUS AT THE REACTOR

In this alternative, spent fuel would be consolidated at reactors in nonrepository-ready canisters or baskets and shipped directly to the repository. Both legal-weight truck and single-car, general-freight rail shipments of consolidated fuel canisters would be used for shipping spent fuel. Thus, the principal transportation-related difference between shipping unconsolidated

TABLE 6.6. Unit Risk Factors for Away-from-Reactor Marshaling of Rail Shipments of Intact Spent Fuel into Five-Car Dedicated Trains[a]

Type of Shipment	Hazard Group	Population Zone	Percent of Travel in Population Zone	Unit Risk Factor[b]: Person-rem/ 1E5 MTU-km	Unit Risk Factor[b]: Weighted Person-rem/ 1E5 MTU-km[c,d]	Unit Risk Factor[b]: Person-rem/ 2.9E6 MTU-km[c]	Unit Risk Factor[b]: Weighted Person-rem/ 2.9E6 MTU-km[c,d]
Single Cask as General-Freight Rail	Routine Occupational	Urban	100	0.171	0.17	NA	NA
	Routine Public	Urban	100	0.206	0.21	NA	NA
	Accident Public	Urban	100	0.537	0.54	NA	NA
	Total Public	Urban	100	--	0.75	NA	NA
Dedicated Train Makeup at Rail Head	Routine Occupational	Urban	100		1.0[e]		
	Routine Public	Urban	100		1.26[e]		
5-Car Dedicated Train	Routine Occupational	Rural	75	NA	NA	0.300	
		Suburban	23	NA	NA	0.300	0.3
		Urban	2	NA	NA	0.300	
	Routine Public	Rural	75	NA	NA	0.373	
		Suburban	23	NA	NA	15.06	3.8
		Urban	2	NA	NA	3.58	
	Accident Public	Rural	75	NA	NA	0.003	
		Suburban	23	NA	NA	4.43	1.2
		Urban	2	NA	NA	10.67	
	Total Public	All	--	NA	NA	--	5.1

(a) The risk factors shown are preliminary and are continuing to be updated. Total risk = sum of single-cask travel + dedicated train makeup + dedicated train travel.
(b) Accuracy of some numbers is less than indicated by the number of significant figures shown, but numbers are retained for consistency in subsequent calculations.
(c) Cask capacity is 6.47 MTU/shipment based on 14 PWR assemblies/cask. 1E5 MTU-km is for 1000 MTU transported 100 km; 2.9E6 MTU-km is for 1000 MTU transported 2900 km.
(d) Overall value weighted for the percentage of travel in each population zone.
(e) Train makeup doses need to be added to the respective in-transit doses to obtain the total doses for this alternative.

and consolidated fuel would be the higher shipping-cask capacities for consolidated fuel shipments, thereby reducing the number of shipments. Also, an additional level of containment during accident conditions may be provided by the canister versus shipping intact, uncanistered fuel assemblies, depending on the canister design.

The canister's additional level of containment may provide additional structural protection for the contained fuel rods and may reduce the amount of radioactive material released from a shipping cask that is damaged during a severe accident. The release fractions would be significantly reduced if the canister also were designed to withstand the regulatory severe accident conditions (that is, puncture, free drop, fire, and water immersion) that the shipping cask is designed to withstand. Release fractions would be reduced because the shipping cask would absorb a large fraction of the energy present in a transportation accident. Therefore, an extremely severe accident would be needed to cause the cask and a sealed canister to become breached. If the canister were not specifically designed to withstand the severe regulatory criteria, a smaller reduction in release fractions (and consequences) would result from severe transportation accidents.

The unit risk factors used here (Cashwell, Neuhauser and Reardon 1986)[a] assume no credit for containment provided by the canister. Most of the risk reduction would result from the decrease in routine risks when fewer spent-fuel shipments were made because accidents only account for a small fraction of the total radiological risks due to transportation.

A parameter that could be affected in this alternative is the radiation level emitted from the cask's external surface. It is assumed that casks for consolidated and unconsolidated fuel would be designed to the same surface dose rate at the regulatory limit. As a result, shipping consolidated fuel from reactors should not change the unit public and occupational routine exposure factors per unit distance traveled from those of intact fuel assemblies. However, because consolidation would result in a net decrease in the number of shipments by a factor of two (and therefore the shipment miles) relative to

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(a) Draft, see (a) on p. 6.1.

intact fuel shipments, the transportation routine radiological exposures would be reduced by a factor of two, as shown in Table 6.7.

Unit risk factors for consolidated fuel truck shipments were not developed in Cashwell, Neuhauser and Reardon (1986),[a] but are estimated here because some reactors are not capable of handling rail casks. The ratio of truck-to-rail consolidated fuel transport exposures is assumed to be identical to the ratio of truck-to-rail intact fuel transport risks. Therefore, the consolidated fuel truck transport exposure factors for transporting consolidated and intact fuel in trucks were assumed to be equivalent per unit distance traveled. The resulting routine radiological dose factors for truck transport were then converted to an equivalent MTU-km basis, as given in Table 6.7.

The radiological consequences from accidents with consolidated spent fuel are assumed to be twice those with intact fuel because the radionuclide inventory within the cask would be double. However, the frequency of such accidents should be half those with intact spent fuel because the number of shipment miles would be half. The resultant accident risk factors for consolidated spent fuel would be the same as for intact fuel, shown in Table 6.7.

The total radiological risks to the public from transporting consolidated spent fuel by the reference truck and rail modes, shown in Table 6.7, would be 266 and 5 person-rem/1000 MTU, respectively. The occupational risks would be 50 and 3 person-rem/1000 MTU, respectively.

When fuel assemblies are consolidated and the fuel rods are removed, the remaining NFBC would become waste material that must be managed. The added risks of transporting the NFBC wastes to disposal facilities must be accounted for. This material is assumed to be transported by truck and train to disposal facilities in casks similar to those for spent fuel. Unit risk factors were developed in Caldwell, Neuhauser and Reardon (1986)[a] for shipments of NFBC and are given in Table 6.7. The total radiological risks to the public from transporting the NFBC by the reference truck and rail modes would be 20 and 0.6 person-rem/1000 MTU, respectively. For occupational workers these values would be 0.8 and 0.04 person-rem/1000 MTU, respectively.

(a) Draft, see (a) on p. 6.1.

TABLE 6.7. Unit Risk Factors for General-Freight Rail and General-Commerce Legal-Weight Truck Shipments of Consolidated Spent Fuel and Nonfuel-Bearing Components[a]

				Unit Risk Factor[b]			
			Percent of	Consolidated Spent Fuel		Nonfuel-Bearing Components	
Type of Shipment	Hazard Group	Population Zone	Travel in Population Zone	Person-rem/ 3.0E6 MTU-km	Weighted Person-rem/ 3.0E6 MTU-km[c,d]	Person-rem/ 3.0E6 MTU-km[c,e]	Weighted Person-rem/ 3.0E6 MTU-km[d,e]
Reference Legal Weight Truck by General Commerce	Routine Occupational	Rural	75	38.15		0.471	
		Suburban	24	83.61	50.1	1.04	0.78
		Urban	1	139.61		17.85	
	Routine Public	Rural	75	230.52		6.66	
		Suburban	24	353.90	262.7	61.69	20.4
		Urban	1	483.76		60.06	
	Accident Public	Rural	75	0.006		<0.001	
		Suburban	24	12.11	3.1	<0.001	<0.001
		Urban	1	19.81		<0.001	
	Total Public	All			265.8		20.4
Reference Rail (100-T) by General Freight	Routine Occupational	Rural	75	2.48		0.042	
		Suburban	23	2.48	2.5	0.042	0.042
		Urban	2	2.48		0.042	
	Routine Public	Rural	75	1.34		0.055	
		Suburban	23	8.93	3.1	2.17	0.55
		Urban	2	2.99		0.520	
	Accident Public	Rural	75	0.002		<0.001	
		Suburban	23	0.45	1.8	<0.001	<0.001
		Urban	2	15.58		<0.001	
	Total Public	All			4.9		0.55

(a) The risk factors shown are preliminary and are continuing to be updated.
(b) Accuracy of some numbers is less than indicated by the number of significant figures shown, but numbers are retained for consistency in subsequent calculations.
(c) For consolidated spent fuel, cask capacities are 12.94 MTU/rail shipment and 1.848 MTU/truck shipment, based on 28 PWR assemblies/rail cask and 4 PWR assemblies/truck cask. 3.0E6 MTU-km is for 1000 MTU transported 3000 km.
(d) Overall value weighted for the percentage of travel in each population zone.
(e) For nonfuel-bearing components, cask capacities are components from 46.2 MTU/rail cask and 9.24 MTU/truck cask.

The unit risk factors for transporting spent fuel that has been consolidated at reactors are obtained from Table 6.7 by adding the risks for spent fuel and NFBC. These risks would be 286 and 5 person-rem/1000 MTU to the public from truck and rail transport, respectively, and 51 and 3 person-rem/1000 MTU to the occupational workers by truck and rail, respectively. These values would be a factor of nearly two lower than those for the reference truck and rail transport of intact spent fuel, given in Table 6.1.

6.8 AT-REACTOR WET TRANSFER FROM AT-REACTOR DRY STORAGE TO TRANSPORTATION CASK VERSUS DRY TRANSFER

In this alternative, the transportation conditions would be the same as for the reference rail transportation cask system in this study, discussed in Section 6.1. Differences in radiation exposures would occur in at-reactor operations, discussed in Section 4. The transportation radiation exposures would be the same as for the reference rail transportation system. For occupational risks, exposures would be 5 person-rem/1000 MTU, and 8 person-rem/1000 MTU for public risks.

6.9 AT-REACTOR DRY STORAGE IN NONTRANSPORTABLE RAIL-SIZED CASKS VERSUS IN TRANSPORTABLE RAIL CASKS

In this alternative, the transportable storage cask used at the reactor is assumed to have the same characteristics relative to transportation radiological risks of the reference rail-cask system in this study, discussed in Section 6.1. Differences in radiological exposures would occur at the repository, discussed in Section 4. The unit transportation radiological risks would be the same as for the reference rail transportation system. These exposures would be 5 and 8 person-rem/1000 MTU for occupational and public risks, respectively.

6.10 REFERENCES

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U.S. Department of Energy. 1985. Monitored Retrievable Storage Submission to Congress, Volume 2, Environmental Assessment for a Monitored Retrievable Storage Facility. Review Copy, DOE/RW-0035, U.S. Department of Energy, Washington, D.C.

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APPENDIX A

OCCUPATIONAL EXPOSURE ANALYSIS TABLES FOR THE NAC-1, IF-300 AND REFERENCE TRUCK AND RAIL CASKS AT THE REACTOR

APPENDIX A

OCCUPATIONAL EXPOSURE ANALYSIS TABLES FOR THE NAC-1, IF-300 AND REFERENCE TRUCK AND RAIL CASKS AT THE REACTOR

Appendix A presents the basic exposure analyses for handling the NAC-1 truck and IF-300 rail casks in Tables A.1 and A.2, respectively. These analyses were used in developing the detailed exposure analyses for the reference truck and rail casks, given in Tables A.3 and A.4, respectively. Results from the latter two tables were summarized in Section 4.

TABLE A.1. Detailed Analysis of Occupational Exposures During Handling of the NAC-1 Truck Cask at the Reactor

Description of Operation Sub-operation	No. of Staff	Elapsed Hours/ Operation	Man-hrs/ Cask	Exposure Rate mrem/hr	Man-mrem Cask Load(a)	Man-mrem/ MT
Cask received at reactor						
Open carrier vehicle	2	0.1	0.2	0.5	0.10	0.22
Radiation survey	1	0.3	0.3	0.5	0.15	0.32
Remove valve box covers	2	0.2	0.4	0.5	0.20	0.43
Install trunnions	2	0.2	0.4	0.5	0.20	0.43
Engage yoke and transfer	3	0.2	0.6	0.5	0.30	0.65
Total		1.0	1.9		0.95	2.06
Cask wash and sample						
Cask wash	2	0.7	1.4	2.5	3.50	7.58
Cask transfer	2	0.2	0.4	2.5	1.00	2.16
Pressure check cask cavity	2	0.1	0.2	2.5	0.50	1.08
Hook-up hoses	2	0.1	0.2	2.5	0.50	1.08
Cask filled with inert gas	1	0.7	0.2	2.5	0.50	1.08
Flush and sample gas	1	0.3	0.3	2.5	0.75	1.62
Remove head nuts	2	0.1	0.2	2.5	0.50	1.08
Attach yoke	3	0.1	0.3	2.5	0.75	1.62
Remove hoses	2	0.1	0.2	2.5	0.50	1.08
Total		2.4	3.4		8.50	18.40
Cask transferred to set-down pad						
Move cask	3	0.4	1.2	2.5	3.00	6.49
Remove head	3	0.3	0.9	2.5	2.25	4.87
Total		0.7	2.1		5.25	11.36
Cask transferred into fuel pool and loaded (a)						
Install skirt and lower cask	2	0.3	0.6	2.5	1.50	3.25
Load fuel (15 min/assy)	2	0.3	0.5	2.5	1.25	2.71
Raise cask and remove skirt	3	0.3	0.6	2.5	1.50	3.25
Replace head	3	0.2	0.6	2.5	1.50	3.25
	3	0.3	0.9	2.5	2.25	4.87
Total		1.4	3.2		8.00	17.32
Cask decon'd and surveyed						
Move cask	3	0.4	1.2	2.5	3.00	6.49
Dry cask	2	0.5	1.0	10.0	10.00	21.65
Move cask	3	0.1	0.3	10.0	3.00	6.49
Remove yoke	3	0.1	0.3	10.0	3.00	6.49
Survey cask	1	0.5	0.5	10.0	5.00	10.82
Hook-up flush and drain hose	2	0.1	0.2	10.0	2.00	4.33
Drain cask	2	0.5	1.0	10.0	10.00	21.65
Tighten head	2	0.5	1.0	10.0	10.00	21.65
Pressure test	2	0.5	1.0	10.0	10.00	21.65
Spot decon	2	1.5	3.0	10.0	30.00	64.94
Survey for release	1	1.0	1.0	10.0	10.00	21.65
Replace valve port covers	2	0.3	0.6	10.0	6.00	12.99
Total		6.0	11.1		102.00	220.78
Cask transferred to vehicle						
Engage yoke	3	0.1	0.3	10.0	3.00	6.49
Transfer cask	3	0.2	0.6	10.0	6.00	12.99
Remove trunnions	2	0.3	0.6	10.0	6.00	12.99
Replace shield cover	2	0.3	0.6	10.0	6.00	12.99
Secure cask	1	0.2	0.2	10.0	2.00	4.33
Move vehicle	1	0.2	0.2	10.0	2.00	4.33
Total		1.3	2.5		25.00	54.11
Grand Total		12.8	24.2		149.70	324.03

(a) Each cask load is 1 PWR assembly (Lambert, et al. 1981).

TABLE A.2. Detailed Analysis of Occupational Exposures During Handling of the IF-300 Rail Cask at the Reactor

Description of Operation Sub-operation	No. of Staff	Elapsed Hours/ Operation	Man-hrs/ Cask	Exposure Rate mrem/hr	Man-mrem/ Load Cask(a)	Man-mrem/ MT
Cask received at reactor						
Open carrier vehicle	2	0.2	0.4	0.5	0.20	0.06
Radiation survey	1	0.6	0.6	0.5	0.30	0.09
Remove valve box covers	2	0.5	1.0	0.5	0.50	0.15
Install trunnions	2	0.3	0.6	0.5	0.30	0.09
Engage yoke and transfer	3	0.2	0.6	0.5	0.30	0.09
Total		1.8	3.2		1.60	0.50
Cask wash and sample						
Cask wash	2	0.7	1.4	2.5	3.50	1.08
Cask transfer	2	0.2	0.4	2.5	1.00	0.31
Pressure check cask cavity	2	0.1	0.2	2.5	0.50	0.15
Hook-up hoses	2	0.1	0.2	2.5	0.50	0.15
Cask filled with inert gas	1	0.7	0.7	2.5	1.75	0.54
Flush and sample gas	2	1.4	2.8	2.5	7.00	2.17
Remove head nuts	2	1.0	2.0	2.5	5.00	1.55
Attach yoke	3	0.2	0.6	2.5	1.50	0.46
Remove hoses	2	0.1	0.2	2.5	0.50	0.15
Total		4.5	8.5		21.25	6.58
Cask transferred to set-down pad						
Move cask	3	0.6	1.8	2.5	4.50	1.39
Remove head	3	0.4	1.2	2.5	3.00	0.93
Total		1.0	3.0		7.50	2.32
Cask transferred into fuel pool and loaded (a)						
Install skirt and lower cask	2	0.3	0.6	2.5	1.50	0.46
Load fuel (15 min/assy)	2	1.8	3.5	2.5	8.75	2.71
Raise cask and remove skirt	2	0.3	0.6	2.5	1.50	0.46
Replace head	3	0.5	1.5	2.5	3.75	1.16
	2	1.0	2.0	2.5	5.00	1.55
Total		3.9	8.2		20.50	6.35
Cask decon'd and surveyed						
Move cask	3	0.6	1.8	2.5	4.50	1.39
Dry cask	2	0.5	1.0	10.0	10.00	3.10
Move cask	3	0.1	0.3	10.0	3.00	0.93
Remove yoke	3	0.1	0.3	10.0	3.00	0.93
Survey cask	1	1.0	1.0	10.0	10.00	3.10
Hook-up flush and drain hose	2	0.1	0.2	10.0	2.00	0.62
Drain cask	2	1.0	2.0	10.0	20.00	6.19
Tighten head	2	1.5	3.0	10.0	30.00	9.29
Pressure test	2	1.0	2.0	10.0	20.00	6.19
Spot decon	2	2.0	4.0	10.0	40.00	12.38
Survey for release	1	1.5	1.5	10.0	15.00	4.64
Replace valve port covers	2	0.5	1.0	10.0	10.00	3.10
Total		9.9	18.1		167.50	51.86
Cask transferred to vehicle						
Engage yoke	3	0.1	0.3	10.0	3.00	0.93
Transfer cask	3	0.2	0.6	10.0	6.00	1.86
Remove trunnions	2	0.4	0.8	10.0	8.00	2.48
Replace shield cover	2	0.6	1.2	10.0	12.00	3.72
Secure cask	1	0.3	0.3	10.0	3.00	0.93
Move vehicle	1	0.2	0.2	10.0	2.00	0.62
Total		1.8	3.4		34.00	10.53
Grand Total		22.9	44.4		252.35	78.13

(a) Each cask load is 7 PWR assemblies (Lambert, et al. 1981).

TABLE A.3. Detailed Analysis of Occupational Exposures During Handling of the Reference Legal-Weight Truck Cask at the Reactor

Description of Operation Sub-operation	No. of Staff	Elapsed Hours/ Operation	Man-hrs/ Cask	Exposure Rate mrem/hr	Man-mrem/ Cask Load(a)	Man-mrem/ MT
Cask received at reactor						
Open carrier vehicle	2	0.1	0.2	0.5	0.1	0.11
Radiation survey	1	0.3	0.3	0.5	0.2	0.16
Remove valve box covers	2	0.2	0.4	0.5	0.2	0.22
Install trunnions	2	0.2	0.4	0.5	0.2	0.22
Engage yoke and transfer	3	0.2	0.6	0.5	0.3	0.32
Total		1.0	1.9		1.0	1.03
Cask wash and sample						
Cask wash	2	0.7	1.4	2.5	3.5	3.79
Cask transfer	2	0.2	0.4	2.5	1.0	1.08
Pressure check cask cavity	2	0.1	0.2	2.5	0.5	0.54
Hook-up hoses	2	0.1	0.2	2.5	0.5	0.54
Cask filled with inert gas	1	0.7	0.2	2.5	0.5	0.54
Flush and sample gas	1	0.3	0.3	2.5	0.8	0.81
Remove head nuts	2	0.1	0.2	2.5	0.5	0.54
Attach yoke	3	0.1	0.3	2.5	0.8	0.81
Remove hoses	2	0.1	0.2	2.5	0.5	0.54
Total		2.4	3.4		8.5	9.20
Cask transferred to set-down pad						
Move cask	3	0.4	1.2	2.5	3.0	3.25
Remove head	3	0.3	0.9	2.5	2.3	2.44
Total		0.7	2.1		5.3	5.68
Cask transferred into fuel pool and loaded						
Install skirt and lower cask	2	0.3	0.6	2.5	1.5	1.62
Load fuel (15 min/assy)	2	0.5	1.0	2.5	2.5	2.71
Raise cask and remove skirt	2	0.3	0.6	2.5	1.5	1.62
Replace head	3	0.2	0.6	2.5	1.5	1.62
	3	0.3	0.9	2.5	2.3	2.44
Total		1.6	3.7		9.3	10.01
Cask decon'd and surveyed						
Move cask	3	0.4	1.2	2.5	3.0	3.25
Dry cask	2	0.5	1.0	10.0	10.0	10.82
Move cask	3	0.1	0.3	10.0	3.0	3.25
Remove yoke	3	0.1	0.3	10.0	3.0	3.25
Survey cask	1	0.5	0.5	10.0	5.0	5.41
Hook-up flush and drain hose	2	0.1	0.2	10.0	2.0	2.16
Drain cask	2	0.5	1.0	10.0	10.0	10.82
Tighten head	2	0.5	1.0	10.0	10.0	10.82
Pressure test	2	0.5	1.0	10.0	10.0	10.82
Spot decon	2	1.5	3.0	10.0	30.0	32.47
Survey for release	1	1.0	1.0	10.0	10.0	10.82
Replace valve port covers	2	0.3	0.6	10.0	6.0	6.49
Total		6.0	11.1		102.0	110.39
Cask transferred to vehicle						
Engage yoke	3	0.1	0.3	10.0	3.0	3.25
Transfer cask	3	0.2	0.6	10.0	6.0	6.49
Remove trunnions	2	0.3	0.6	10.0	6.0	6.49
Replace shield cover	2	0.3	0.6	10.0	6.0	6.49
Secure cask	1	0.2	0.2	10.0	2.0	2.16
Move vehicle	1	0.2	0.2	10.0	2.0	2.16
Total		1.30	2.50		25.0	27.06
Grand Total		13.00	24.70		150.95	163.37

(a) Each cask load is 2 PWR assemblies

TABLE A.4. Detailed Analysis of Occupational Exposures During Handling of the Reference Rail Cask at the Reactor

Description of Operation Sub-operation	No. of Staff	Elapsed Hours/ Operation	Man-hrs/ Cask	Exposure Rate mrem/hr	Man-mrem/ Cask Load(a)	Man-mrem/ MT
Cask received at reactor						
Open carrier vehicle	2	0.2	0.4	0.5	0.20	0.03
Radiation survey	1	0.6	0.6	0.5	0.30	0.05
Remove valve box covers	2	0.5	1.0	0.5	0.50	0.08
Install trunnions	2	0.3	0.6	0.5	0.30	0.05
Engage yoke and transfer	3	0.2	0.6	0.5	0.30	0.05
Total		1.8	3.2		1.60	0.25
Cask wash and sample						
Cask wash	2	0.7	1.4	2.5	3.50	0.54
Cask transfer	2	0.2	0.4	2.5	1.00	0.15
Pressure check cask cavity	2	0.1	0.2	2.5	0.50	0.08
Hook-up hoses	2	0.1	0.2	2.5	0.50	0.08
Cask filled with inert gas	1	0.7	0.7	2.5	1.75	0.27
Flush and sample gas	2	1.4	2.8	2.5	7.00	1.08
Remove head nuts	2	1.0	2.0	2.5	5.00	0.77
Attach yoke	3	0.2	0.6	2.5	1.50	0.23
Remove hoses	2	0.1	0.2	2.5	0.50	0.08
Total		4.5	8.5		21.25	3.29
Cask transferred to set-down pad						
Move cask	3	0.6	1.8	2.5	4.50	0.70
Remove head	3	0.4	1.2	2.5	3.00	0.46
Total		1.0	3.0		7.50	1.16
Cask transferred into fuel pool and loaded						
Install skirt and lower cask	2	0.3	0.6	2.5	1.50	0.23
Load fuel (15 min assy)	2	3.5	7.0	2.5	17.50	2.71
Raise cask and remove skirt	2	0.3	0.6	2.5	1.50	0.23
Replace head	3	0.5	1.5	2.5	3.75	0.58
	2	1.0	2.0	2.5	5.00	0.77
Total		5.6	11.7		29.25	4.52
Cask decon'd and surveyed						
Move cask	3	0.6	1.8	2.5	4.50	0.70
Dry cask	2	0.5	1.0	10.0	10.00	1.55
Move cask	3	0.1	0.3	10.0	3.00	0.46
Remove yoke	3	0.1	0.3	10.0	3.00	0.46
Survey cask	1	1.0	1.0	10.0	10.00	1.55
Hook-up flush and drain hose	2	0.1	0.2	10.0	2.00	0.31
Drain cask	2	1.0	2.0	10.0	20.00	3.09
Tighten head	2	1.5	3.0	10.0	30.00	4.64
Pressure test	2	1.0	2.0	10.0	20.00	3.09
Spot decon	2	2.0	4.0	10.0	40.00	6.18
Survey for release	1	1.5	1.5	10.0	15.00	2.32
Replace valve port covers	2	0.5	1.0	10.0	10.00	1.55
Total		9.9	18.1		167.50	25.90
Cask transferred to vehicle						
Engage yoke	3	0.1	0.3	10.0	3.00	0.46
Transfer cask	3	0.2	0.6	10.0	6.00	0.93
Remove trunnions	2	0.4	0.8	10.0	8.00	1.24
Replace shield cover	2	0.6	1.2	10.0	12.00	1.86
Secure cask	1	0.3	0.3	10.0	3.00	0.46
Move vehicle	1	0.2	0.2	10.0	2.00	0.31
Total		1.8	3.4		34.00	5.26
Grand Total		24.6	47.9		261.10	40.37

(a) Each cask load is 14 PWR assemblies.

REFERENCE FOR APPENDIX A

Lambert, R. W., C. E. King and T. E. Tehan. 1981. Comparative Evaluation of Wet and Dry Unloading of Spent Fuel Shipping Casks. TTC-0203, General Electric Company, Nuclear Fuels Division, San Jose, California.

APPENDIX B

OCCUPATIONAL EXPOSURE ANALYSIS TABLES FOR OPERATIONS AT THE REACTOR

APPENDIX B

OCCUPATIONAL EXPOSURE ANALYSIS TABLES FOR OPERATIONS AT THE REACTOR

Appendix B presents in Tables B.1 through B.5 the operational-exposure analyses of at-reactor cask-handling operations for the reference and alternative cases in this study. Results from Appendix B are summarized in Section 4.

TABLE B.1. Detailed Analysis of Occupational Exposures During Handling of the Overweight (OWT) Truck Cask at the Reactor

Description of Operation Sub-operation	No. of Staff	Elapsed Hrs/ Operation	Man-Hrs/ Cask	Exposure Rate mrem/Hr	Man-mrem/ Cask Load(a)	Man-mrem/ MT
Cask received at reactor						
Open carrier vehicle	2	0.1	0.2	0.5	0.10	0.05
Radiation survey	1	0.3	0.3	0.5	0.15	0.08
Remove valve box covers	2	0.2	0.4	0.5	0.20	0.11
Install trunnions	2	0.2	0.4	0.5	0.20	0.11
Engage yoke and transfer	3	0.2	0.6	0.5	0.30	0.16
Total		1.0	1.9		0.95	0.51
Cask wash and sample						
Cask wash	2	0.7	1.4	2.5	3.50	1.89
Cask transfer	2	0.2	0.4	2.5	1.00	0.54
Pressure check cask cavity	2	0.1	0.2	2.5	0.50	0.27
Hook-up hoses	2	0.1	0.2	2.5	0.50	0.27
Cask filled with inert gas	1	0.7	0.2	2.5	0.50	0.27
Flush and sample gas	1	0.3	0.3	2.5	0.75	0.41
Remove head nuts	2	0.1	0.2	2.5	0.50	0.27
Attach yoke	3	0.1	0.3	2.5	0.75	0.41
Remove hoses	2	0.1	0.2	2.5	0.50	0.27
Total		2.4	3.4		8.50	4.60
Cask transferred to set-down pad						
Move cask	3	0.4	1.2	2.5	3.00	1.62
Remove head	3	0.3	0.9	2.5	2.25	1.22
Total		0.7	2.1		5.25	2.84
Cask transferred into fuel pool and loaded						
Install skirt and lower cask	2	0.3	0.6	2.5	1.50	0.81
Load fuel (15 min/assy)	2	1.0	2.0	2.5	5.00	2.71
Raise cask and remove skirt	2	0.3	0.6	2.5	1.50	0.81
Replace head	3	0.2	0.6	2.5	1.50	0.81
	3	0.3	0.9	2.5	2.25	1.22
Total		2.1	4.7		11.75	6.36
Cask decon'd and surveyed						
Move cask	3	0.4	1.2	2.5	3.00	1.62
Dry cask	2	0.5	1.0	10.0	10.00	5.41
Move cask	3	0.1	0.3	10.0	3.00	1.62
Remove yoke	3	0.1	0.3	10.0	3.00	1.62
Survey cask	1	0.5	0.5	10.0	5.00	2.71
Hook-up flush and drain hose	2	0.1	0.2	10.0	2.00	1.08
Drain cask	2	0.5	1.0	10.0	10.00	5.41
Tighten head	2	0.5	1.0	10.0	10.00	5.41
Pressure test	2	0.5	1.0	10.0	10.00	5.41
Spot decon	2	1.5	3.0	10.0	30.00	16.23
Survey for release	1	1.0	1.0	10.0	10.00	5.41
Replace valve port covers	2	0.3	0.6	10.0	6.00	3.25
Total		6.0	11.1		102.00	55.19
Cask transferred to vehicle						
Engage yoke	3	0.1	0.3	10.0	3.00	1.62
Transfer cask	3	0.2	0.6	10.0	6.00	3.25
Remove trunnions	2	0.3	0.6	10.0	6.00	3.25
Replace shield cover	2	0.3	0.6	10.0	6.00	3.25
Secure cask	1	0.2	0.2	10.0	2.00	1.08
Move vehicle	1	0.2	0.2	10.0	2.00	1.08
Total		1.30	2.50		25.00	13.53
Grand Total		13.5	25.7		153.45	83.04

(a) Each cask load is 4 PWR assemblies.

TABLE B.2. Detailed Analysis of Occupational Exposures During Handling of the 150-T Rail Cask at the Repository

Description of Operation Sub-operation	No. of Staff	Elapsed Hours/ Operation	Man-hrs/ Cask	Exposure Rate mrem/hr	Man-mrem/ Cask Load(a)	Man-mrem/ MT
Cask received at reactor						
Open carrier vehicle	2	0.2	0.4	0.5	0.20	0.01
Radiation survey	1	0.6	0.6	0.5	0.30	0.02
Remove valve box covers	2	0.5	1.0	0.5	0.50	0.03
Install trunnions	2	0.3	0.6	0.5	0.30	0.02
Engage yoke and transfer	3	0.2	0.6	0.5	0.30	0.02
Total		1.8	3.2		1.60	0.10
Cask wash and sample						
Cask wash	2	0.7	1.4	2.5	3.50	0.21
Cask transfer	2	0.2	0.4	2.5	1.00	0.06
Pressure check cask cavity	2	0.1	0.2	2.5	0.50	0.03
Hook-up hoses	2	0.1	0.2	2.5	0.50	0.03
Cask filled with inert gas	1	0.7	0.7	2.5	1.75	0.11
Flush and sample gas	2	1.4	2.8	2.5	7.00	0.42
Remove head nuts	2	1.0	2.0	2.5	5.00	0.30
Attach yoke	3	0.2	0.6	2.5	1.50	0.09
Remove hoses	2	0.1	0.2	2.5	0.50	0.03
Total		4.5	8.5		21.25	1.28
Cask transferred to set-down pad						
Move cask	3	0.6	1.8	2.5	4.50	0.27
Remove head	3	0.4	1.2	2.5	3.00	0.18
Total		1.0	3.0		7.50	0.45
Cask transferred into fuel pool and loaded						
Install skirt and lower cask	2	0.3	0.6	2.5	1.50	0.09
Load fuel (15 min/assy)	2	9.0	18.0	2.5	45.00	2.71
Raise cask and remove skirt	2	0.3	0.6	2.5	1.50	0.09
Replace head	3	0.5	1.5	2.5	3.75	0.23
	2	1.0	2.0	2.5	5.00	0.30
Total		11.1	22.7		56.75	3.41
Cask decon'd and surveyed						
Move cask	3	0.6	1.8	2.5	4.50	0.27
Dry cask	2	0.5	1.0	10.0	10.00	0.60
Move cask	3	0.1	0.3	10.0	3.00	0.18
Remove yoke	3	0.1	0.3	10.0	3.00	0.18
Survey cask	1	1.0	1.0	10.0	10.00	0.60
Hook-up flush and drain hose	2	0.1	0.2	10.0	2.00	0.12
Drain cask	2	1.0	2.0	10.0	20.00	1.20
Tighten head	2	1.5	3.0	10.0	30.00	1.80
Pressure test	2	1.0	2.0	10.0	20.00	1.20
Spot decon	2	2.0	4.0	10.0	40.00	2.41
Survey for release	1	1.5	1.5	10.0	15.00	0.90
Replace valve port covers	2	0.5	1.0	10.0	10.00	0.60
Total		9.9	18.1		167.50	10.07
Cask transferred to vehicle						
Engage yoke	3	0.1	0.3	10.0	3.00	0.18
Transfer cask	3	0.2	0.6	10.0	6.00	0.36
Remove trunnions	2	0.4	0.8	10.0	8.00	0.48
Replace shield cover	2	0.6	1.2	10.0	12.00	0.72
Secure cask	1	0.3	0.3	10.0	3.00	0.18
Move vehicle	1	0.2	0.2	10.0	2.00	0.12
Total		1.8	3.4		34.00	2.04
Grand Total		30.1	58.9		288.60	17.35

(a) Each cask load is 36 PWR assemblies.

TABLE B.3. Detailed Analysis of Occupational Exposures During Consolidation of Spent Fuel and Compacting NFBC at the Reactor

Description of Personnel Required	Spent Fuel Consolidation: No. of Staff	% of Shift	Shifts Req'd.	Total Man-hrs.	Exposure Rate mrem/hr	Man-mrem/ Campaign	NFBC Compaction: No. of Staff	% of Shift	Shifts Req'd.	Total Man-hrs.	Exposure Rate mrem/hr	Man-mrem/ Campaign	Summary of Consolidation/Compaction: Shifts Req'd.	Shifts Req'd.	Total Man-hrs.	Exposure Rate mrem/hr	Man-mrem/ Campaign(b)
Health Physicist	1	100.0	48.0	384.0	2.5	960.0	1	100.0	12.8	102.4	2.5	256.0	1	60.8	486.4	2.5	1216.0
Fuel Handler	1	20.0	48.0	76.8	2.5	192.0	1	5.0	12.8	5.1	2.5	12.8	1	60.8	81.9	2.5	204.8
Consolidation Technician	2	100.0	48.0	768.0	2.5	1920.0	2	100.0	12.8	204.8	2.5	512.0	4	60.8	972.8	2.5	2432.0
Tooling Engineer	1	5.0	48.0	19.2	2.5	48.0	1	5.0	12.8	5.1	2.5	12.8	1	60.8	24.3	2.5	60.8
Supervisor	1	12.5	48.0	48.0	2.5	120.0	1	12.5	12.8	12.8	2.5	32.0	1	60.8	60.8	2.5	152.0
QA Engineer	1	12.5	48.0	48.0	2.5	120.0	1	12.5	12.8	12.8	2.5	32.0	1	60.8	60.8	2.5	152.0
Sub-Total				1344.0		3360.0				343.6		857.6			1687.6		4217.6

(a) Man-power and exposure rates are based on the Oconee demonstration (Duke Power 1983).
(b) Each campaign is for 29.57 MTU (64 PWR assemblies).

TABLE B.4. Detailed Analysis of Occupational Exposures During Set-Up, Testing, Removing, and Decontaminating Consolidation and Compaction Equipment at the Reactor

Description of Personnel Required	Equipment Set-Up: No. of Staff	% of Shift	Shifts Req'd.	Total Man-hrs.	Exposure Rate mrem/hr	Man-mrem/ Campaign	Equipment Removal: No. of Staff	% of Shift	Shifts Req'd.	Total Man-hrs.	Exposure Rate mrem/hr	Man-mrem/ Campaign	Equipment Decontamination: No. of Staff	% of Shift	Shifts Req'd.	Total Man-hrs.	Exposure Rate mrem/hr	Man-mrem/ Campaign(c)
Health Physicist	1	100.0	2.8	22.0	2.5	55.0	1	100.0	1.0	8.0	2.5	20.0	1	75.0	1.3	7.9	10.0	78.8
Fuel Handler	1	25.0	2.8	5.5	2.5	13.8	1	25.0	1.0	2.0	2.5	5.0	(b)	25.0	0.4	0.9	2.5	2.2
Consolidation Technician	2	75.0	2.8	33.0	2.5	82.5	2	75.0	1.0	12.0	2.5	30.0	4	50.0	1.8	21.0	10.0	210.0
Tooling Engineer	1	25.0	2.8	5.5	2.5	13.8	1	25.0	1.0	2.0	2.5	5.0	N/A(d)					N/A
Supervisor	1	25.0	2.8	5.5	2.5	13.8	1	25.0	1.0	2.0	2.5	5.0	1	25.0	1.8	3.5	2.5	8.8
QA Engineer	1	25.0	2.8	5.5	2.5	13.8	1	25.0	1.0	2.0	2.5	5.0	1	25.0	1.8	3.5	2.5	8.8
Sub-Total				77.0		192.5				28.0		70.0				36.8		308.4

(a) Man-power and exposure rates are based on the Oconee Demonstration (Duke Power 1983).
(b) The health physicist is exposed to 10 mrem/hr for 75% of the total time and 2.5 mrem/hr for 25% of the required time.
(c) Each campaign is for 29.57 MTU (64 PWR assemblies).
(d) Tooling engineer notrequired during decontamination.

TABLE B.5. Detailed Analysis of Occupational Exposures During At-Reactor Wet and Dry Transfer of Spent Fuel from Dry Storage Casks to Rail Transportation Casks

Wet Transfer

Description of Operation Sub-operation	Man-Hrs/ Cask (a)	Exposure Rate m-rem/hr	Man-mRem/ MT Transport Cask	Exposure Rate m-rem/hr	Man-mRem/ MT Storage Cask (d)
Cask received at reactor					
Open carrier vehicle	0.4	0.5	0.03		
Radiation survey	0.6	0.5	0.05	10.0	0.93
Remove valve box covers	1.0	0.5	0.08		
Install trunnions	0.6	0.5	0.05	10.0	
Engage yoke and transfer	0.6	0.5	0.05	10.0	0.93
Total	3.20		0.25		1.86
Cask wash and sample					
Cask wash	1.4	2.5	0.54	10.0	2.16
Cask transfer	0.4	2.5	0.15	10.0	0.62
Pressure check cask cavity	0.2	2.5	0.08	10.0	0.31
Hook-up hoses	0.2	2.5	0.08	10.0	0.31
Cask filled with inert gas	0.7	2.5	0.27	10.0	1.08
Flush and sample gas	2.8	2.5	1.08	10.0	4.33
Remove head nuts	2.0	2.5	0.77	10.0	3.09
Attach yoke	0.6	2.5	0.23	10.0	0.93
Remove hoses	0.2	2.5	0.08	10.0	0.31
Total	8.50		3.29		13.14
Cask transferred into fuel pool					
Move cask	1.8	2.5	0.70	10.0	2.78
Remove head	1.2	2.5	0.46	10.0	1.86
Install skirt and lower cask	0.6	2.5	0.23	10.0	0.93
Total	3.60		1.39		5.57
Spent fuel transferred					
Load fuel	0.5	2.5	0.19	2.5	0.19
Total	0.5		0.19		0.19
Cask removed from fuel pool					
Raise cask and remove skirt	0.5	2.5	0.23	2.5	0.23
Replace head	1.5	2.5	0.58	2.5	0.58
	2.0	2.5	0.77	2.5	0.77
Total	4.10		1.58		1.58
Cask decon'd and surveyed					
Move cask	1.8	2.5	0.70	2.5	0.70
Dry cask	1.0	10.0	1.55	2.5	0.39
Move cask	0.3	10.0	0.46	2.5	0.12
Remove yoke	0.3	10.0	0.46	2.5	0.12
Survey cask	1.0	10.0	1.55	2.5	0.39
Hook-up flush and drain hose	0.2	10.0	0.31	2.5	0.08
Drain cask	2.0	10.0	3.09	2.5	0.77
Tighten head	3.0	10.0	4.64	2.5	1.16
Pressure test	2.0	10.0	3.09	2.5	
Spot decon	4.0	10.0	6.19	2.5	1.55
Survey for release	1.5	10.0	2.32	0.5	0.06
Replace valve port covers	1.0	10.0	1.55	0.5	
Total	13.10		25.98		5.31
Cask transferred to vehicle					
Engage yoke	0.3	10.0	0.46	0.5	0.02
Transfer cask	0.6	10.0	0.93	0.5	0.05
Remove trunnions	0.8	10.0	1.24	0.5	
Replace shield cover	1.2	10.0	1.86	0.5	
Secure cask	0.3	10.0	0.46	0.5	0.02
Move vehicle	0.2	10.0	0.31	0.5	0.02
Total	3.40		5.26		0.11
Grand Total	41.40		37.85		27.76

Dry Transfer

Description of Operation Sub-operation	Man-Hrs/ Cask(a)(b)	Exposure Rate mrem/hr	Man-mrem/ MT (d)
Transport cask received at reactor			
Open carrier vehicle	0.40	0.50	0.03
Radiation survey	0.60	0.50	0.05
Remove valve box covers	1.00	0.50	0.08
Install trunnions	0.60	0.50	
Engage yoke and transfer	0.60	0.50	0.05
Total	3.20		0.20
Transport cask wash and sample			
Cask wash	0.70	2.50	0.27
Cask transfer	0.40	2.50	0.15
Pressure check cask cavity	0.20	2.50	0.08
Hook-up hoses	0.20	2.50	0.08
Cask filled with inert gas	0.70	2.50	0.27
Flush and sample gas	2.80	2.50	1.08
Remove head nuts	2.00	2.50	0.77
Attach yoke	0.60	2.50	0.23
Remove hoses	0.20	2.50	0.08
Total	7.80		3.01
Transport cask positioned at dry storage cask			
Storage cask opened	0.50	10.00	0.77
Transportation cask mated to storage cask	6.80	10.00	10.51
Total	7.30		11.23
Spent fuel transferred			
Basket pulled into transportation cask	2.00	10.00	3.09
Total	2.00		3.09
Transport cask prepared for release			
Cask removed and sealed	1.00	10.00	1.55
Cask decon'd and surveyed	1.50	10.00	2.32
Total	2.50		3.87
Transport cask released from facility			
Cask transferred to vehicle and exits facility	0.50	10.00	0.77
Total	0.50		0.77
Storage cask closed and stored			
Storage cask surveyed, closed and stored	0.30	2.50	0.12
Total	0.30		0.12
Grand Total	23.60		22.35

(a) The man-hrs and the exposure rates were developed in Table A.2
(b) The man-hrs are based on the NUHOMS concept (NUTECH 1984), using the exposure rates in Table A.2.
(c) The spent fuel basket has the capacity to hold 14 PWR or 36 BWR assemblies
(d) No values have been calculated for the operations that are not required based on the cask type. Denoted with N/A.

B.1 REFERENCES

Duke Power Company. 1983. Spent Fuel Consolidation Demonstration. Duke Power Company, Charlotte, North Carolina.

NUTECH. 1984. NUTECH Horizontal Modular Storage System for Irradiated Nuclear Fuel. NUH-001, NUTECH Incorporated, San Jose, California.

APPENDIX C

OCCUPATIONAL EXPOSURE ANALYSIS TABLES FOR OPERATIONS AT THE REPOSITORY

APPENDIX C

OCCUPATIONAL EXPOSURE ANALYSIS TABLES FOR OPERATIONS AT THE REPOSITORY

Appendix C presents in Tables C.1 through C.6 detailed tables of occupational analysis for handling the reference and alternative truck and rail casks at the repository, and for other alternatives at the repository. Results from these tables are summarized in Section 4.

TABLE C.1. Detailed Analysis of Occupational Exposures During Receiving and Unloading Unconsolidated Spent Fuel at the Repository

Description of Operation	No. of Staff	Hours/ Truck Cask	Hours/ Rail Cask	Man-hrs/ Truck Cask	Man-hrs/ Rail Cask	Exposure Rate mrem/hr	Man-mrem/ Truck Cask (a)	Man-mrem/ Rail Cask (b)
Inspect cask and transfer to wash								
Positioning of vehicle	3.0	0.1	0.1	0.3	0.3	0.5	0.13	0.13
Portable monitoring	2.0	0.0	0.1	0.1	0.1	10.0	0.67	1.00
Visual inspection, bottom	1.0	0.1	0.2	0.1	0.2	10.0	0.83	1.67
Visual Inspection, top	1.0	0.1	0.1	0.1	0.1	10.0	0.83	0.83
Transfer to washdown	2.0	0.1	0.1	0.3	0.3	10.0	2.67	2.67
Sub-Total		0.4	0.5	0.8	0.9		5.13	6.29
Wash and transfer cask to unloading								
Hook-up to puller units	2.0	0.1	0.1	0.2	0.2	10.0	1.67	1.67
Washdown (double pass)	2.0	0.1	0.1	0.1	0.2	10.0	1.00	2.00
Drying	1.0	1.0	1.0	1.0	1.0	2.5	2.50	2.50
Transfer to cask handling	2.0	0.2	0.3	0.5	0.5	10.0	4.67	5.33
Sub-Total		1.4	1.5	1.7	1.9		9.83	11.50
Off-load cask								
Position vehicle	2.0	0.2	0.3	0.3	0.5	10.0	3.33	5.00
Remove tiedowns, etc.	3.0	0.8	1.0	2.3	3.0	10.0	22.50	30.00
Complete preperations	3.0	0.3	0.5	1.0	1.5	10.0	10.00	15.00
Position cask on cart	3.0	0.6	0.6	1.8	1.8	10.0	8.75	8.75
Sub-Total		1.8	2.3	5.3	6.8		44.58	58.75
Sample cask, untorque bolts								
Sample gas, vent cask, install barrier adapter, untorque inner bolts	3.0	1.6	2.0	4.8	6.0	10.0	47.50	60.00
Sub-Total		1.6	2.0	4.8	6.0		47.50	60.00
Mate cask to cell								
Engage barrier, close door	1.0	1.6	2.0	1.6	2.0	10.0	15.83	20.00
Remove entry port plugs, and cask inner closure	1.0	0.5	0.7	0.5	0.7	0.1250	0.06	0.08
Sub-Total		2.1	2.7	2.1	2.7		15.90	20.08
Unload cask								
PWR operations only	1.0	0.7	4.7	0.7	4.7	0.1250	0.08	0.58
Sub-Total		0.7	4.7	0.7	4.7		0.08	0.58
Cask transferred to vehicle								
Replace inner closure, port plugs	1.0	0.8	1.3	0.8	1.3	0.1250	0.09	0.16
Move cask into decon area	2.0	0.3	0.3	0.7	0.7	0.5	0.33	0.33
Complete closure	1.0	2.0	2.5	2.0	2.5	0.5	1.00	1.25
Position cask on vehicle	3.0	0.6	0.6	1.8	1.8	0.5	0.88	0.88
Sub-Total		3.7	4.7	5.2	6.2		2.3	2.6
Total		11.7	18.3	20.6	29.0		125.32	159.82

(a) Each cask load is 2 intact PWR assemblies.
(b) Each cask load is 14 intact PWR assemblies.

TABLE C.2. Detailed Analysis of Occupational Exposures During Receiving and Unloading Spent Fuel from the Reference and Alternative Shipping Casks at the Repository

Description of Operation	No. of Staff	Hours/ Truck	Hours/ Rail	Man-hrs/ Truck Cask	Man-hrs/ Rail Cask	Exposure Rate mrem/hr	Man-mrem/ Truck Cask	Man-mrem/ Rail Cask	Man-mrem/MT Ref. LWT Cask (a)	Man-mrem/MT Ref. Rail Cask (b)	Man-mrem/MT OWT Cask (c)(e)	Man-mrem/MT 150-T Rail Cask (d)(e)
Inspect cask and transfer to wash												
Positioning of vehicle	3.0	0.1	0.1	0.3	0.3	0.5	0.13	0.13	0.14	0.02	0.07	0.01
Portable monitoring	2.0	0.0	0.1	0.1	0.1	10.0	0.67	1.00	0.72	0.15	0.36	0.06
Visual inspection, bottom	1.0	0.1	0.2	0.1	0.2	10.0	0.83	1.67	0.90	0.26	0.45	0.10
Visual Inspection, top	1.0	0.1	0.1	0.1	0.1	10.0	0.83	0.83	0.90	0.13	0.45	0.05
Transfer to washdown	2.0	0.1	0.1	0.3	0.3	10.0	2.67	2.67	2.89	0.41	1.44	0.16
Sub-Total		0.4	0.5	0.8	0.9		5.13	6.29	5.55	0.97	2.77	0.38
Wash and transfer cask to unloading												
Hook-up to puller units	2.0	0.1	0.1	0.2	0.2	10.0	1.67	1.67	1.80	0.26	0.90	0.10
Washdown (double pass)	2.0	0.1	0.1	0.1	0.2	10.0	1.00	2.00	1.08	0.31	0.54	0.12
Drying	1.0	1.0	1.0	1.0	1.0	2.5	2.50	2.50	2.71	0.39	1.35	0.15
Transfer to cask handling	2.0	0.2	0.3	0.5	0.5	10.0	4.67	5.33	5.05	0.82	2.53	0.32
Sub-Total		1.4	1.5	1.7	1.9		9.83	11.50	10.64	1.78	5.32	0.69
Off-load cask												
Position vehicle	2.0	0.2	0.3	0.3	0.5	10.0	3.33	5.00	3.61	0.77	1.80	0.30
Remove tiedowns, etc.	3.0	0.8	1.0	2.3	3.0	10.0	22.50	30.00	24.35	4.64	12.18	1.80
Complete preperations	3.0	0.3	0.5	1.0	1.5	10.0	10.00	15.00	10.82	2.32	5.41	0.90
Position cask on cart	3.0	0.6	0.6	1.8	1.8	10.0	8.75	8.75	9.47	1.35	4.73	0.53
Sub-Total		1.8	2.3	5.3	6.8		44.58	58.75	48.25	9.08	24.13	3.53
Sample cask, untorque bolts												
Sample gas, vent cask, install barrier adapter, untorque inner bolts	3.0	1.6	2.0	4.8	6.0	10.0	47.50	60.00	51.41	9.28	25.70	3.61
Sub-Total		1.6	2.0	4.8	6.0		47.50	60.00	51.41	9.28	25.70	3.61
Mate cask to cell												
Engage barrier, close door	1.0	1.6	2.0	1.6	2.0	10.0	15.83	20.00	17.14	3.09	8.57	1.20
Remove entry port plugs, and cask inner closure	1.0	0.5	0.7	0.5	0.7	0.1250	0.06	0.08	0.07	0.01	0.03	0.01
Sub-Total		2.1	2.7	2.1	2.7		15.90	20.08	17.20	3.11	8.60	1.21
Unload cask												
PWR operations only	1.0	0.7	4.7	0.7	4.7	0.1250	0.08	0.58	0.09	0.09	0.09	0.09
Sub-Total		0.7	4.7	0.7	4.7		0.08	0.58	0.09	0.09	0.09	0.09
Cask transferred to vehicle												
Replace inner closure, port plugs	1.0	0.8	1.3	0.8	1.3	0.1250	0.09	0.16	0.10	0.02	0.05	0.01
Move cask into decon area	2.0	0.3	0.3	0.7	0.7	0.5	0.33	0.33	0.36	0.05	0.18	0.02
Complete closure	1.0	2.0	2.5	2.0	2.5	0.5	1.00	1.25	1.08	0.19	0.54	0.08
Position cask on vehicle	3.0	0.6	0.6	1.8	1.8	0.5	0.88	0.88	0.95	0.14	0.47	0.05
Sub-Total		3.7	4.7	5.2	6.2		2.30	2.61	2.49	0.40	1.25	0.16
Total		11.7	18.3	20.6	29.0		125.32	159.82	135.63	24.71	67.86	9.66

(a) Based on each cask load of 2 intact PWR assemblies.
(b) Based on each cask load of 14 intact PWR assemblies.
(c) Based on each cask load of 4 intact PWR assemblies.
(d) Based on each cask load of 36 intact PWR assemblies.
(e) The exposure rates and man-hrs/cask are based on the reference cases, the MTU/cask and the time required to unload are increased for this case to reflect the increased cask capacities.

TABLE C.3. Detailed Analysis of Occupational Exposures During Receiving and Unloading Consolidated Spent Fuel and NFBC from the Reference Truck Cask at the Repository

Receipt of Consolidated Fuel and Discharge of Empty Cask

Description of Operation	No of Staff	Hours/ Truck Cask	Man-hrs/ Truck Cask	Exposure Rate mrem/hr	Man-mrem/ Truck Cask	Man-mrem/MT Truck Cask	Man-mrem/MT Consol. SF Truck Cask (a)	Man-mrem/MT NFBC Truck Cask (b)
Inspect cask and transfer to wash								
Positioning of vehicle	3.0	0.1	0.3	0.5	0.13	0.14	0.07	0.01
Portable monitoring	2.0	0.0	0.1	10.0	0.67	0.72	0.36	0.07
Visual inspection, bottom	1.0	0.1	0.1	10.0	0.83	0.90	0.45	0.09
Visual Inspection, top	1.0	0.1	0.1	10.0	0.83	0.90	0.45	0.09
Transfer to washdown	2.0	0.1	0.3	10.0	2.67	2.89	1.44	0.29
Sub-Total		0.4	0.8		5.13	5.55	2.77	0.55
Wash and transfer cask to unloading								
Hook-up to puller units	2.0	0.1	0.2	10.0	1.67	1.80	0.90	0.18
Washdown (double pass)	2.0	0.1	0.1	10.0	1.00	1.08	0.54	0.11
Drying	1.0	1.0	1.0	2.5	2.50	2.71	1.35	0.27
Transfer to cask handling	2.0	0.2	0.5	10.0	4.67	5.05	2.53	0.51
Sub-Total		1.4	1.7		9.83	10.64	5.32	1.06
Off-load cask								
Position vehicle	2.0	0.2	0.3	10.0	3.33	3.61	1.80	0.36
Remove tiedowns, etc.	3.0	0.8	2.3	10.0	22.50	24.35	12.18	2.44
Complete preperations	3.0	0.3	1.0	10.0	10.00	10.82	5.41	1.08
Position cask on cart	3.0	0.6	1.8	10.0	8.75	9.47	4.73	0.95
Sub-Total		1.8	5.3		44.58	48.25	24.13	4.83
Sample cask, untorque bolts								
Sample gas, vent cask, install barrier adapter, untorque inner bolts	3.0	1.6	4.8	10.0	47.50	51.41	25.70	5.14
Sub-Total		1.6	4.8		47.50	51.41	25.70	5.14
Mate cask to cell								
Engage barrier, close door	1.0	1.6	1.6	10.0	15.83	17.14	8.57	1.71
Remove entry port plugs, and cask inner closure	1.0	0.5	0.5	0.1250	0.06	0.07	0.03	0.01
Sub-Total		2.1	2.1		15.90	17.20	8.60	1.72
Unload cask								
PWR operations only	1.0	0.7	0.7	0.1250	0.08	0.09	0.05	0.01
Sub-Total		0.7	0.7		0.08	0.09	0.05	0.01
Cask transferred to vehicle								
Replace inner closure, port plugs	1.0	0.8	0.8	0.1250	0.09	0.10	0.05	0.01
Move cask into decon area	2.0	0.3	0.7	0.5	0.33	0.36	0.18	0.04
Complete closure	1.0	2.0	2.0	0.5	1.00	1.08	0.54	0.11
Position cask on vehicle	3.0	0.6	1.8	0.5	0.88	0.95	0.47	0.09
Sub-Total		3.1	3.4		1.43	1.54	0.77	0.15
Total		11.1	18.8		124.45	134.68	67.34	13.47

(a) Based on 1.85 MT consolidated PWR spent fuel.
(b) Based on 9.24 MT consolidated PWR NFBC's.

TABLE C.4. Detailed Analysis of Occupational Exposures During Receiving and Unloading Consolidated Spent Fuel and NFBC from Reference Rail Cask at the Repository

Receipt of Consolidated Fuel and Discharge of Empty Cask

Description of Operation	No. of Staff	Hours/ Rail Cask	Man-hrs/ Rail Cask	Exposure Rate mrem/Hr	Man-mrem/ Rail Cask	Man-mrem/MT Rail Cask	Man-mrem/MT Consol. SF Rail Cask (a)	Man-mrem/MT NFBC Rail Cask (b)
Inspect cask and transfer to wash								
Positioning of vehicle	3.0	0.1	0.3	0.5	0.13	0.02	0.01	0.00
Portable monitoring	2.0	0.1	0.1	10.0	1.00	0.15	0.08	0.02
Visual inspection, bottom	1.0	0.2	0.2	10.0	1.67	0.26	0.13	0.04
Visual Inspection, top	1.0	0.1	0.1	10.0	0.83	0.13	0.06	0.02
Transfer to washdown	2.0	0.1	0.3	10.0	2.67	0.41	0.21	0.06
Sub-Total		0.5	0.9		6.29	0.97	0.49	0.14
Wash and transfer cask to unloading								
Hook-up to puller units	2.0	0.1	0.2	10.0	1.67	0.26	0.13	0.04
Washdown (double pass)	2.0	0.1	0.2	10.0	2.00	0.31	0.15	0.04
Drying	1.0	1.0	1.0	2.5	2.50	0.39	0.19	0.05
Transfer to cask handling	2.0	0.3	0.5	10.0	5.33	0.82	0.41	0.12
Sub-Total		1.5	1.9		11.50	1.78	0.89	0.25
Off-load cask								
Position vehicle	2.0	0.3	0.5	10.0	5.00	0.77	0.39	0.11
Remove tiedowns, etc.	3.0	1.0	3.0	10.0	30.00	4.64	2.32	0.65
Complete preperations	3.0	0.5	1.5	10.0	15.00	2.32	1.16	0.32
Position cask on cart	3.0	0.6	1.8	10.0	8.75	1.35	0.68	0.19
Sub-Total		2.3	6.8		58.75	9.08	4.54	1.27
Sample cask, untorque bolts								
Sample gas, vent cask, install barrier adapter, untorque inner bolts	3.0	2.0	6.0	10.0	60.00	9.28	4.64	1.30
Sub-Total		2.0	6.0		60.00	9.28	4.64	1.30
Mate cask to cell								
Engage barrier, close door	1.0	2.0	2.0	10.0	20.00	3.09	1.55	0.43
Remove entry port plugs, and cask inner closure	1.0	0.7	0.7	0.125	0.08	0.01	0.01	0.00
Sub-Total		2.7	2.7		20.08	3.11	1.55	0.43
Unload cask								
PWR operations only	1.0	4.7	4.7	0.125	0.58	0.09	0.05	0.01
Sub-Total		4.7	4.7		0.58	0.09	0.05	0.01
Cask transferred to vehicle								
Replace inner closure, port plugs	1.0	1.3	1.3	0.125	0.16	0.02	0.01	0.00
Move cask into decon area	2.0	0.3	0.7	0.5	0.33	0.05	0.03	0.01
Complete closure	1.0	2.5	2.5	0.5	1.25	0.19	0.10	0.03
Position cask on cart	3.0	0.6	1.8	0.5	0.88	0.14	0.07	0.02
Sub-Total		4.7	6.2		2.61	0.40	0.20	0.06
Total		18.3	29.1		159.82	24.71	12.35	3.46

(a) Based on 12.9 MT consolidated PWR spent fuel.
(b) Based on 46.2 MT consolidated PWR NFBCs.

TABLE C.5. Detailed Analysis of Occupational Exposures During Spent Fuel Consolidation and NFBC Shredding and Their Canistering Operations at the Reference Repository

Description of Operation (a)	No. of Staff	Hours/ Operation	Man-hrs/ Operation	Exposure Rate mrem/hr	Man-mrem/ Operation (b)(c)	Man-mrem/ MT
	Consolidate and package Spent Fuel					
Load fuel assemblies into disassembler	3	0.8	2.3	0.125	0.28	0.20
Disassemble fuel	3	2.5	7.5	0.125	0.94	0.68
Consolidate fuel rods	3	1.2	3.5	0.125	0.44	0.32
Load fuel rods in canister	3	0.3	0.8	0.125	0.09	0.07
Rotate canister	3	0.1	0.3	0.125	0.03	0.02
Evacuate canister and weld lid	3	0.3	1.0	2.500	2.50	1.80
Decontaminate, inspect weld	3	1.6	4.8	0.125	0.59	0.43
Survey and move	3	0.4	1.3	0.125	0.16	0.11
		7.1			5.03	3.63
	Consolidate and package NFBC					
Sever Nozzles						
Sever bottom nozzles	2.0	0.6	1.2	0.125	0.15	0.20
Place in chute	1.0	0.2	0.2	0.125	0.03	0.02
Sub-Total		0.8			0.18	0.22
Position drum						
Place drum on elevator	1.0	0.1	0.1	0.125	0.01	0.00
Operate elevator	1.0	0.1	0.1	0.125	0.01	0.00
Place drum on cart	1.0	0.0	0.0	0.125	0.00	0.00
Prepare and position drum	2.0	0.1	0.1	0.125	0.01	0.00
Sub-Total		0.3			0.04	0.01
Fill drum						
Empty shredder and chute	2.0	0.7	1.3	2.500	3.33	0.72
Sub-Total		0.7			3.33	0.72
Prepare and decon drum						
Transfer drum	1.0	0.0	0.0	0.125	0.00	0.00
Crimp lid and position	1.0	0.2	0.2	2.500	0.42	0.09
Decon cell floor	1.0	0.1	0.1	0.125	0.01	0.00
Decon drum	1.0	0.4	0.4	0.125	0.05	0.01
Survey drum	2.0	0.2	0.4	0.125	0.05	0.01
Position for removal	1.0	0.1	0.1	0.750	0.04	0.01
Sub-Total		0.9			0.57	0.12
Total		2.4			4.09	1.07
Total for all consolidation operations (Spent Fuel+NFBC)		9.5			9.12	4.70

(a) Based on Parsons 1985.
(b) Consolidated spent fuel from 3 PWR assemblies.
(c) Shred the NFBCs from 10 PWR assemblies.

TABLE C.6. Detailed Analysis of Occupational Exposures During Overpacking Consolidated Spent Fuel and NFBC at the Reference Repository

Description of Operation	No. of Staff	Hours/ RO (a)	mrem/hr	Man-mrem/RO	Man-mrem/MT Spent Fuel (b)	Man-mrem/MT NFBC (c)
Inspection and transfer of RO						
Inspection at gate	2.0	0.1	0.5	0.08	0.01	0.00
Move vehicle to prot. area	3.0	0.3	0.5	0.38	0.03	0.01
Survey vehicle	1.0	0.0	0.5	0.00	0.00	0.00
Move to washdown area	2.0	0.3	0.5	0.25	0.02	0.01
Washdown	2.0	0.8	0.5	0.75	0.06	0.02
Move to cask handling area	2.0	0.3	0.5	0.33	0.03	0.01
Sub-Total		1.7		1.79	0.14	0.04
Prepare RO for loading						
Remove impact limiters	3.0	0.5	0.5	0.75	0.06	0.02
Modify cask cart	1.0	0.3	0.5	0.17	0.01	0.00
Remove RO from vehicle	2.0	0.3	0.5	0.25	0.02	0.01
Place RO on cask cart	2.0	0.5	0.5	0.50	0.04	0.01
Move to RO handling area	3.0	0.2	0.5	0.25	0.02	0.01
Install barrier	1.0	0.2	0.5	0.08	0.01	0.00
Sub-Total		1.9		2.00	0.15	0.04
Mate cask to cell						
Engage barrier, close door	1.0	0.3	0.5	0.17	0.01	0.00
Remove entry port plugs, and RO inner closure	1.0	0.3	0.125	0.04	0.00	0.00
Place RO in weld/decon area	1.0	0.3	0.125	0.04	0.00	0.00
Remove lid	1.0	0.2	0.125	0.02	0.00	0.00
Replace entry port plug	1.0	0.4	0.125	0.05	0.00	0.00
Sub-Total		1.6		0.3	0.0	0.0
Load RO						
Load canisters of repo. waste	1.0	1.3	0.125	0.17	0.01	0.00
Sub-Total		1.3		0.17	0.01	0.00
Place RO in emplacement cask						
Prepare RO for weld	1.0	0.3	2.500	0.83	0.06	0.02
Weld RO lid	1.0	1.0	2.500	2.50	0.19	0.05
Inspect weld	1.0	0.2	2.500	0.42	0.03	0.01
Lift RO into emplacement cask	1.0	0.4	0.125	0.05	0.00	0.00
Sub-Total		1.9		3.80	0.29	0.08
Total		8.4		8.08	0.62	0.17

(a) RO = repository overpack
(b) Based on 12.9 MT consolidated PWR spent fuel.
(c) Based on 46.2 MT consolidated NFBCs.

REFERENCE FOR APPENDIX C

Parsons Company. 1985. Integral Monitored Retrievable Storage (MRS) Facility Conceptually Design Report. Volume I, Book II, Design Description. Ralph M. Parson Company, Pasadena, California.

APPENDIX D

DETAILED TABULATION OF RADIOLOGICAL DOSES FOR POSSIBLE CHANGES IN THE WASTE MANAGEMENT SYSTEM

APPENDIX D

DETAILED TABULATION OF RADIOLOGICAL DOSES FOR POSSIBLE CHANGES IN THE WASTE MANAGEMENT SYSTEM

Table D.1 presents all the results of the public and occupational doses developed in this study. Reference and alternative cases are compared individually. The reference case is given in the first column, with the individually compared alternative shown indented. In subsequent columns, the values for the reference and alternative cases are given for each of the 3 steps of the waste management system. Following the doses from the 3 components of the waste management system is a column giving the subtotal for the system. The differences in subtotals for the system are given below the reference and alternative values.

Although public and occupational doses are of different concerns, they are added together in the column "Total System." The last column gives the change in this "total system" dose multiplied times the approximate percentage of spent fuel affected (given in the second column).

TABLE D.1. Preliminary Unit Radiological Doses for Reference and Possible Changes in Waste Management System[(a)]

Reference System Feature to Potential Alternative Feature	Approx. % of Spent Fuel Affected	Unit Risk (person-rem/1000 MTU) Public: At Reactor	Public: At Reposit	Public: Transp.[(b)]	Public: Subtotal	Occupational: At Reactor	Occupational: At Reposit	Occupational: Transp.[(b)]	Occupational: Subtotal	Total System	Change in Total System	Change Times Fraction Applicable
1. Legal-weight truck cask	30	<1	6	528	534	163	141	100	404	938		
Standard rail cask	30	<1	6	8	14	40	30	5	75	89		
Difference					-520				-329		-849	-255
2. Legal-weight truck cask	30	<1	6	528	534	163	141	100	404	938		
Overweight truck cask	30	<1	6	378	384	83	73	72	228			
Difference					-150				-176		-326	-98
3. Legal-weight truck cask	30	<1	6	528	534	163	141	100	404	938		
Heavy-haul truck + reference rail cask[(c)]	30	<1	6	8	14	40	30	20	90	104		
Difference					-520				-314		-834	-250
4. Reference rail cask	70[(d)]	<1	6	8	14	40	30	5	75	89		
150-ton rail cask	70[(d)]	<1	6	4	10	17	15	2	34	44		
Difference					-4				-41		-45	-32
5. Reference rail cask, single-cask shipment	70[(d)]	<1	6	8	14	40	30	5	75	89		
Marshal 5-car dedicated trains AFR	70[(d)]	<1	6	5	11	42	30	<1	72	83		
Difference					-13				-3		-6	-4
6. Reference rail cask, single-cask shipment	70[(d)]	<1	6	8	14	40	30	5	75	89		
Marshal 5-car dedicated trains AFR[(e)]	70[(d)]	<1	6	7	13	40	30*	1	71	84		
Difference					-1				-4		-5	-4
7A. Consolidate fuel at repository[(f)]	30	<1	6	528	534	163	141	100	404	938		
Consolidate fuel at reactor[(f)]	30	6	<1	286	292	277	82	51	410	702		
Difference					-242				+6		-236	-71
7B. Consolidate fuel at repository[(f)]	70	<1	6	8	14	40	30	5	75	91		
Consolidate fuel at reactor[(f)]	70	6	<1	5	11	189	17	3	209	220		
Difference					-3				+134		+131	+92
8. Wet transfer from dry storage at reactors[(g)]	10	<1	6	8	14	66	30	5	101	115		
Dry transfer from dry storage at reactors[(g)]	10	<1	6	8	14	22	30	5	57	71		
Difference					-0				-44		-44	-4
9. Dry storage in nontransportable casks at reactors[(g,h)]	10	<1	6	8	14	66	30	5	101	115		
Dry storage in transportable casks at reactors[(g)]	10	<1	6	8	14	16	30	5	51	65		
Difference					-0				-50		-50	-5

(a) Based on no-MRS in the system.
(b) Equivalent to 1000 MTU shipped an average of 3000 km.
(c) Heavy-haul distance is assumed to be 20 km.
(d) Assumes applicability to all reactors with rail capability.
(e) Assumes 100 km to marshaling yard.
(f) Case 7A is for truck shipments; case 7B is for rail shipments.
(g) Assumes shipment by rail.
(h) Assumes wet transfer from dry storage at reactors.

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