OCRWM	DESIGN CALCULATION OR ANALYSIS COVER SHEET	1. QA: QA 2. Page 1						
3. System SNF Aging System		4. Document Identifier 170-00C-HA00-00200-000-00A						
5. Title Aging Facility Worker Dose Assessment								
6. Group Environmental & Nuclear Engineering/Radiological Engineering								
7. Document Status Designation ☒ Preliminary ☐ Final ☐ Cancelled								
8. Notes/Comments <p>Original author (E.R. Faillace) left the employ of BSC prior to the approval of revision 00A. The responsibility was re-assigned to R.L. Thacker on 01/04/05.</p> <p style="text-align: center; font-size: 1.2em;">An LP-2.14Q-BSC Review was completed on 03/16/05</p>								
Attachments		Total Number of Pages						
N/A								
RECORD OF REVISIONS								
9. No.	10. Reason For Revision	11. Total # of Pgs.	12. Last Pg. #	13. Originator (Print/Sign/Date)	14. Checker (Print/Sign/Date)	15. QEP (Print/Sign/Date)	16. Approved/Accepted (Print/Sign)	17. Date
00A	Initial issue. This document supercedes Migliore, R. 2004. Aging-Related Dose Assessment. COGEMA-C0115-EN-CLC-0015, Rev. 1. Las Vegas, Nevada: Cogema. (DIRS 169500).	35	35	R.L. Thacker 3-24-05	V. Arakali 3/24/05	D.J. Tunney 3/24/2005	A.G. Ogurek	3/24/05

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ACRONYMS AND ABBREVIATIONS

ALARA	as low as is reasonably achievable
BSC	Bechtel SAIC Company, LLC
CEDE	committed effective dose equivalent
CFR	Code of Federal Regulations
CHF	Canister Handling Facility
DOE	U.S. Department of Energy
DTF	Dry Transfer Facility
EDE	effective dose equivalent
HP	Health Physics
MSC	monitored geologic repository site-specific cask
NRC	U.S Nuclear Regulatory Commission
PWR	Pressurized Water Reactor
SNF	spent nuclear fuel
TEDE	total effective dose equivalent

UNITS OF MEASURE

Bq	becquerel
Ci	curie
cm	centimeter
hr	hour
m	meter
min	minute
mL	milliliter
mrem	millirem
MTHM	metric tons heavy metal
s	second
Sv	sievert
yr	year

1 PURPOSE

The purpose of this calculation is to estimate radiation doses received by personnel working in the Aging Facility performing operations to transfer aging casks to the aging pads for thermal and logistical management, stage empty aging casks, and retrieve aging casks from the aging pads for further processing in other site facilities. Doses received by workers due to aging cask surveillance and maintenance operations are also included. The specific scope of work contained in this calculation covers both collective doses and individual worker group doses on an annual basis, and includes the contributions due to external and internal radiation from normal operation. There are no Category 1 event sequences associated with the Aging Facility (BSC 2004 [DIRS 167268], Section 7.2.1). The results of this calculation will be used to support the design of the Aging Facility and to provide occupational dose estimates for the License Application.

The calculations contained in this document were developed by Environmental and Nuclear Engineering of the Design and Engineering Organization and are intended solely for the use of the Design and Engineering Organization in its work regarding facility operation. Yucca Mountain Project personnel from the Environmental and Nuclear Engineering should be consulted before use of the calculations for purposes other than those stated herein or use by individuals other than authorized personnel in Environmental and Nuclear Engineering.

2 QUALITY ASSURANCE

This document was prepared in accordance with AP-3.12Q, *Design Calculations and Analyses* [DIRS 168413]. The results of this calculation will be used to support Preclosure Safety Analysis relative to radiological safety of the repository, and elements of the Aging System (Cask Transfer, Aging Pad, and Aging Cask or Site-Specific Cask) are classified as "Safety Category" in the *Q-List* (BSC [Bechtel SAIC Company] 2005 [DIRS 171190], p. A-8), with the exception of Aging Pad support structures. Therefore, this calculation is subject to the requirements of the *Quality Assurance Requirements and Description* (DOE [U.S. Department of Energy] 2004 [DIRS 171539]).

3 METHODOLOGY

Dose assessment involves the calculation of annual individual worker group doses and annual collective worker doses due to normal cask transfer, handling and surveillance operations in the Aging Facility. The calculated doses include the contributions from external radiation and from inhalation of and submersion in airborne radioactivity. The methodology for calculating direct external radiation doses is described in section 3.1. The methodology for calculating inhalation and submersion doses is described in section 3.2 and Appendix A. The total effective dose equivalent (TEDE) is calculated by summing the component doses from inhalation, submersion and direct external radiation dose.

The dose assessments are performed by worker group, using time-motion information and dose rates calculated for worker locations. Dose calculations are made on per unit operation, i.e., per

cask transferred to or from the Aging Pads, and then multiplied by the annual number of cask transfers to determine the total worker group dose.

Each worker group consists of a number of crews (i.e., teams of operators) that provide support for operations. The average individual dose in a worker group is determined by dividing the total worker dose by the product of the number of crews and crewmembers per crew. The calculated total individual dose is compared with the “as low as is reasonably achievable” (ALARA) design goal specified in the *Project Design Criteria* (PDC) document (BSC 2004 [DIRS 171599], Section 4.9.3.3).

Different worker groups are involved in the following Aging Facility operations: aging cask transfer, inspection, and maintenance/repair. Crewmembers in the aging cask transfer group are accompanied by a health physics technician, which is considered as a separate support worker group. The worker group categories, number of worker crews, number of workers per crew, and worker functions are described in Section 5.

3.1 EXTERNAL DOSE CALCULATION

The direct external dose, ED_k , received by a worker in group g per operation task, k , is calculated as follows. The dose rates at the locations of each operation task due to external radiation from the contained radiation sources are obtained from shielding calculations.

$$ED_k = \frac{t_k}{60} \times (EDR_{dist} + EDR_{area}) \quad \text{Equation 1}$$

where

ED_k	=	External dose to a worker in group g per operation task k (mrem/task)
t_k	=	Duration of exposure per operation task k (minutes)
EDR_{dist}	=	Dose rate at the worker's distance $dist$ from the cask being handled (mrem/hr)
EDR_{area}	=	Area dose rate at the worker's location from all other sources of external radiation (mrem/hr)
60	=	Units conversion (minutes/hr)

The dose rates at various distances from a cask or array of casks are scaled from a dose rate of 60 mrem/hr at one meter from a vertically orientated TN-32 cask surface (Assumptions 5.2.1 and 5.1.2). These scaling factors will depend on the operation being performed. For emplacement operations, the peak year (year in which casks with the highest dose rate will be processed) is used to scale the TN-32 dose rates. This scaling factor will bound all other years in which emplacement or retrieval operations are conducted. For cask inspections, monitoring, or repair activities, the average dose rate for all emplaced casks is used to scale the TN-32 dose rate.

For tasks where individual aging casks are not being handled, maintained, or repaired (e.g., routine inspection of multiple casks on a pad, or returning an empty transfer vehicle), only the area dose rate is used in the calculation. As with single-cask operations, area dose rates are derived using TN-32 dose rates that are modified by the appropriate scaling factor(s).

The collective external dose, CED_o , to workers in group g for a series of N different tasks per operation (e.g., per aging cask transfer operation or inspection operation) performed at the Aging Facility is calculated as follows:

$$CED_o = \sum_{k=1}^N \left(\frac{N_{wg} \times ED_k}{1000} \right) \quad \text{Equation 2}$$

where

- CED_o = Collective external dose to workers in group g per operation consisting of N different tasks (person-rem/operation)
- N_{wg} = Number of workers in group g required to perform operation task k (persons)
- 1000 = Units conversion (mrem/rem)

The annual collective external dose, CED_g , to all workers within group g following N_o operations during a year is calculated as:

$$CED_g = CED_o \times N_o \quad \text{Equation 3}$$

where

- CED_g = Annual collective external dose to workers in group g (person-rem/year)
- N_o = Frequency of activity or number of operations (operations/year)

The average annual external dose, ED_{wg} , to an individual worker in a group g is calculated as:

$$ED_{wg} = \frac{1000 \times CED_g}{N_{wg} \times WC} \quad \text{Equation 4}$$

where

- ED_{wg} = Annual average external dose to an individual worker in group g (mrem/year)
- N_{wg} = Number of workers in group g per worker crew (persons/crew)
- WC = Number of worker crews required to perform annual operations (crews)
- 1000 = Units conversion (mrem/rem)

3.2 INHALATION AND SUBMERSION DOSE CALCULATION

All operations conducted within the Aging Facility will involve sealed casks with very low levels of surface contamination. The annual maximum internal and external doses to an aging cask worker due to re-suspension of surface contamination on an aging cask are much lower than the contribution from the direct external dose (Appendix A).

3.3 TEDE DOSE CALCULATION

The annual TEDE for a worker in group g is calculated by summing the component doses from inhalation, submersion and direct external radiation doses. Since only the latter contribute significantly to worker doses (see section 7.3), the TEDE to a worker in group g is estimated by using Equation 4.

3.4 ANNUAL AGING CASK AND CANISTER OPERATIONS

3.4.1 Annual Number of Aging Casks and Canisters Emplaced

The number of aging casks and canisters emplaced per year, SC , is determined from the highest nominal (hereinafter referred to as peak) annual throughput and converted to a number of aging casks or canisters that require aging as:

$$SC = \frac{TP \times f_a}{f_c} \quad \text{Equation 5}$$

where

- SC = Peak aging cask or canister emplacement rate (casks-canisters/year)
- TP = Peak annual throughput of spent nuclear fuel (metric tons heavy metal [MTHM]/year)
- f_a = Fraction of spent nuclear fuel requiring aging (unitless)
- f_c = Conversion factor (MTHM/cask-canister)

3.4.2 Annual Number of Aging Casks and Canisters Retrieved

Since all aging casks and canisters will eventually be emplaced in the repository, the same number of casks requiring placement at the aging facility will also have to be removed from the aging pad. The specific aging times can only be established once a cask or canister is ready for emplacement in the aging facility. Thus, the timing or specific number of casks that require removal from the aging facility in any given year is not known. However, the rate at which casks and canisters will eventually be removed from the aging facility can be approximated by the emplacement rate using Equation 5 above.

3.5 CONSTANTS

The following constants are used in this calculation:

- 1 Sv = 100 rem (10 CFR [Code of Federal Regulations] 20.1004(a) [DIRS 167538])
- 1 Ci = 3.7×10^{10} Bq (10 CFR 20.1005(b) [DIRS 167538])

4 DESIGN INPUTS

4.1 DOSE RATES NEAR SINGLE AGING CASKS

Per Assumption 5.2.1, the dose rates at various distances from a vertical aging cask (Assumption 5.1.2) are based on 60 mrem/hr at one meter from the TN-32 cask surface and the radial dose distance factors for a TN-32 cask (Assumption 5.2.1). Per Assumptions 5.2.1 and 5.2.4, workers are modeled to be at 1, 2, 5, and 10 m from the exterior surfaces of an aging cask. Table 4-1 summarizes the worker dose rates versus distance for a TN-32 cask. Dose rates at 1, 2, 5, and 10 m are estimated and described in Assumption 5.2.1. The average dose rates at the four distances are 60, 36, 12, and 4 mrem/hr, respectively. These dose rates are used in worker dose assessment

when a single cask is being handled. During retrieval operations, the dose rates are assumed to be a factor of 3 times lower (Assumption 5.2.3).

Table 4-1. Radial Dose Distance Factor for a Single TN-32 Cask and Estimated Dose Rates

Distance from Cask Surface [A]	Distance Factor ^a [B]	TN-32 Cask Dose Rate (mrem/hr) [C]
1 m	1.66	60
2 m	1.00	36
5 m	0.32	12
10 m	0.10	4

^a Distance Factor relates dose at various distances to dose at 2m

Columns [A] and [B]: Assumption 5.2.1

Column [C] = $(60 / 1.66) \times \text{Column [B]}$

4.2 DOSE RATES NEAR MULTIPLE AGING CASKS

For aging pad cask transfer operations, the dose rates at various distances from a series of vertical aging casks already on the pad are also based on the 60 mrem/hr dose rate at one meter from the cask surface. For work activities involving a cask on an active aging pad, dose contributions consist of those from the single cask as well as the other nearby aging casks on the active pad. These work activities are modeled to occur at distances of 1, 2 and 5 m from the exterior surface of the single cask (Assumption 5.2.4). Dose rates at 1, 2, and 5 m are estimated for the geometries described in Assumption 5.1.1.

To estimate the dose rate at 1 m from an active cask, the dose rates at five locations (BSC 2004 [DIRS 172499], Table 12) are considered. These dose rates are 247.7, 183.7, 170.5, 149.2, and 113.3 mrem/hr and are averaged numerically to obtain a representative dose rate of 173 mrem/hr, as described in Assumption 5.2.2.

For the 2 m location from an active cask, two dose points are considered (121.6 and 91.7 mrem/hr) and averaged (107 mrem/hr), as described in Assumption 5.2.2.

Similarly, for the 5 m location, two dose points are considered (60.0 and 52.8 mrem/hr) and averaged (56 mrem/hr), as described in Assumption 5.2.2.

A dose rate reduction factor of 3 is assumed to apply for retrieval, maintenance and repair activities which are performed during an average year (Assumption 5.2.3).

Table 4-2 summarizes the worker dose rates versus distance, accounting for the presence of multiple aging casks in the aging facility. These dose rates are used in the worker dose assessment when a single cask is being handled in the vicinity of other aging casks on an active pad, or for cask maintenance and repair operations.

Table 4-2. Estimated Dose Rates in the Vicinity of an Active Pad

Distance from Cask Surface [A]	TN-32 Cask Dose Rate (mrem/hr) [B]	Average Year Dose Rate (mrem/hr) [C]
1 m	173	58
2 m	107	36
5 m	56	19

Column [A]: Assumption 5.2.1

Column [B]: Assumption 5.2.2 and BSC (2004 [DIRS 172499], Table 12)

Column [C] = Column [B] / 3 (Assumption 5.2.3)

During inspections, the dose rates are modeled assuming an individual inspector is moving at a constant speed along one side of a double column of vertical aging casks (Assumption 5.2.2). For the TN-32 casks, the dose rate at 2 m from the outer surfaces of the row of casks is estimated to be 103 mrem/hr (BSC 2004 [DIRS 172499], Table 12). Using the average year scaling factor of 3, this dose rate becomes 34 mrem/hr (Assumption 5.2.3).

4.3 ANNUAL NUMBER OF CASK TRANSFER OPERATIONS

Based on the design capacity of the aging facility and expected throughput of spent nuclear fuel (SNF) that will require aging, the number of cask transfers to the aging facility at maximum throughput is 100 casks per year (Assumption 5.1.3). The same number of casks will eventually be removed from the aging facility, at approximately the same throughput rate.

4.4 PROCESS TASKS AND DURATIONS

Process task definitions for aging facility operations and their corresponding task durations are presented in Assumptions 5.2.4, 5.2.6, 5.2.7, and Table 5-1.

4.5 STAFFING AND WORKER GROUP CATEGORIES

The staffing requirements and worker group categories are presented in Assumptions 5.2.5, 5.2.6, and 5.2.7.

4.6 INHALATION AND SUBMERSION DOSES DUE TO CASK SURFACE CONTAMINATION

The annual maximum internal and external doses to a worker due to re-suspension of contamination on aging casks in the aging facility is given in Appendix A. This dose rate is well below 1 mrem/yr, and is based on 2000 hr/yr occupancy for workers. Since any individual's occupancy in the vicinity of the aging facility will be considerably less than 2000 hr/yr, doses incurred this way are inconsequential to the TEDE, which is dominated by direct radiation from the aging cask contents.

4.7 REGULATIONS

The regulation applicable to worker doses is contained in 10 CFR 20.1201 [DIRS 167538], *Occupational Dose Limits for Adults*:

The licensee shall control the occupational dose to individual adults to the following dose limits:

- (1) An annual limit, which is the more limiting of:
 - (i) The total effective dose equivalent being equal to 5 rems; or
 - (ii) The sum of the deep-dose equivalent and the committed dose equivalent to any individual organ or tissue other than the lens of the eye being equal to 50 rems.
- (2) The annual limits to the lens of the eye, to the skin, and to the extremities, which are:
 - (i) A lens dose equivalent of 15 rems, and
 - (ii) A shallow-dose equivalent of 50 rems to the skin or to any extremity.

4.8 ALARA DESIGN GOALS

ALARA design goals (BSC 2004 [DIRS 171599], Section 4.9.3.3) for occupational workers ensure that individual annual doses are maintained at ALARA levels during normal operations and as a result of Category 1 event sequences. The following ALARA design goal is established for the design process.

(1) Individual Dose:

“The ALARA design goal for individual radiation worker doses is to minimize the number of individuals that have the potential of receiving more than 500 mrem/yr total effective dose equivalent (TEDE). That goal is 10 percent of the annual TEDE limit in 10 CFR 20.1201 [DIRS 167538], and includes both internal and external exposures.”

5 ASSUMPTIONS

5.1 BOUNDING ASSUMPTIONS

5.1.1 Location of Cask Transfer Activities

Emplacement operations on an aging pad are assumed to progress from one end of a pad to the other end, alternating between two rows of casks. The maximum dose rates are expected to occur once a pad has been filled to half of its capacity, when taking into account contributions from neighboring pads that have already been filled to capacity. There are two possible configurations for this geometry: one with an even number of casks and one with an odd number of casks on the active pad, each cask spaced 13 ft apart, center-to-center (BSC 2004 [DIRS 172499], Sections 5.2.1 and 5.3.3). The average dose rates for these two configurations are used when estimating doses to workers transferring casks to an aging pad (BSC 2004 [DIRS 172499], Table 12).

Rationale: Dose rates for transfers that occur at either end of an aging pad will be somewhat lower than the doses at mid-pad. Since the pads are arranged parallel to one another, simple geometrical considerations indicate that the radiation dose contributed

from a full neighboring pad will be at a maximum at the midpoint of an active pad. Dose rates at pads located at the perimeter of the aging facility (i.e., those with neighboring pads only on one side) will be lower than at pads located towards the middle of the aging facility. Therefore, dose rates at the midpoint of aging pads that are located closer to the middle of the aging facility will bound the dose rate for locations closer to the perimeter of the aging facility.

Usage: This assumption is used in Sections 4.2 and 5.2.2.

5.1.2 Cask Design for Aging Facility

All SNF transferred to, stored in, or retrieved from the aging facility is assumed to be stored in vertical casks represented by the TN-32 design.

Rationale: The current design for the aging facility includes provisions for storing both SNF in vertical and horizontal storage configurations (BSC 2004 [DIRS 171161], Section 3.1.2.1.1). Approximately 80% of the storage locations are allocated for vertical storage casks. Horizontal storage locations would account for the remaining 20%. As discussed in BSC 2004 (DIRS 172499), Section 5.2.1, a vertical cask such as the TN-32 will have higher surface dose rates and thus dominate the overall dose rates at any distance from an aging area. Therefore, assuming that all SNF is stored in vertical casks will bound the dose rates from SNF that may be stored horizontally.

Usage: This assumption is used in Sections 3.1, 4.1 and 7.1.

5.1.3 Annual Throughput of Casks Placed and Removed

The estimated peak annual commercial SNF throughput is 3000 MTHM (Curry 2004 [DIRS 170557], Table A-2). Of this amount, one third is assumed to require aging. Therefore, an aging pad designed to accommodate 1000 MTHM will be filled to capacity each year in which the peak throughput occurs. Since each aging pad is designed to accommodate 100 casks (BSC 2004 [DIRS 171161], Section 4.1.1.1), the number of casks transferred to the aging facility in one year is assumed to be 100. The same number of casks is assumed to be retrieved during the peak year. Emplacement and retrieval operations (performed on different casks in different aging pads) are assumed to occur concurrently once operations achieve steady state. Additionally, the conversion factor, f_c , utilized in Equation 5 can therefore be nominally estimated to be 10 MTHM/cask (1000 MTHM/pad divided by 100 casks/pad).

Rationale: Since the total design capacity of the repository is 63,000 MTHM for commercial SNF (Curry 2004 [DIRS 170557] Table A-1), and the total design capacity for the aging facility is 21,000 MTHM (BSC 2004 [DIRS 171161], Section 3.1.1.3.1), this represents one third of the total inventory. All casks that are transferred to the aging facility will eventually require removal. Assuming that emplacement and removal can occur during the same year (albeit at different areas of the aging facility) will conservatively bound the annual doses to workers.

Usage: This assumption is used in Sections 4.3, 5.2.8, 7.2, and Appendix A

5.2 OTHER ASSUMPTIONS

5.2.1 Dose Rates for Individual Casks

A TN-32 cask, similar in design to a site-specific cask, is used to estimate dose rates and distance factors for workers while transferring an aging cask to or from the aging facility. A dose rate of 60 mR/hr at 1 meter from the cask surface is utilized to perform the worker dose calculations. Radial dose distance factors relating dose rates at various distances to the dose rate at 2 meters have been computed for the TN-32 cask (BSC 2004 [DIRS 171772], Table I-5). These can be used to estimate dose rates received by workers at various distances from the exterior surfaces of an aging cask, overpack or module by multiplying the 2 meter dose rate by the distance factor. The distance scaling factors for 1, 2, 5, and 10 meters are 1.66, 1.00, 0.32, and 0.10, respectively (BSC 2004 [DIRS 171772], Table I-5). Table 4-1 summarizes the determination of the worker dose rates versus distance described in this assumption.

Rationale: As discussed in BSC 2004 (DIRS 172499), Section 3.1, the site-specific cask that produces the maximum dose rates is similar in design to the TN-32. The design dose rate for a site-specific cask has been established to be 60 mR/hr at 1 meter (BSC 2004 [DIRS 172520], p. 6). Since a design similar to the TN-32 produces the maximum dose rates, the dose rates associated with the TN-32 cask are considered to be conservative for purposes of representing an appropriate Aging Facility source term (BSC 2004 [DIRS 172499], Section 3.1).

Usage: This assumption is used in Sections 3.1, 4.1, 4.2, and 7.1.

5.2.2 Dose Rates at Location of Cask Transfer Activities

The dose rate at 1 m from the TN-32 cask is the average for locations B, C, and D described in BSC (2004 [DIRS 172499], Section 5.3.3) under the even cask configuration described in Assumption 5.1.1 and locations B and C for the odd cask configuration. The dose rate at 2 m is the average for the even/odd configuration at locations E and D, respectively, described in BSC (2004 [DIRS 172499], Section 5.3.3). The dose rate at 5 m is the average for the even/odd configuration at locations F and E, respectively, described in BSC (2004 [DIRS 172499], Section 5.3.3). The dose rate location for inspection workers is assumed to be at 2 m from a continuous row of casks along a pad.

Rationale: Dose rates at locations B, C, and D in the even configuration and locations B and C in the odd configuration (BSC 2004 [DIRS 172499], Section 5.3.3) range from a high of 248 mrem/hr (even configuration, location B) to a low of 113 mrem/hr (odd configuration, location C) (BSC 2004 [DIRS 172499], Table 12). Similar considerations are made for 2 m (average of locations E and D for even/odd configurations, respectively) and 5 m (average of locations D and F for even/odd configurations, respectively) dose points (BSC 2004 [DIRS 172499], Table 12). For inspection workers, a single dose rate is used (BSC 2004 [DIRS 172499], Table 12).

These locations are representative of various distances of interest from a cask which is located in the proximity of neighboring casks on the pad. Use of the average dose rates at each of these distances is reasonable for estimating the dose rates the workers would be exposed to since there is a natural averaging of dose rates as a worker moves through various orientations relative to the casks.

Usage: This assumption is used in Sections 4.2, 5.2.6, and 7.1.

5.2.3 Dose Rates for Retrieval, Inspection, and Repair Activities

Average dose rates received by workers conducting cask retrieval, inspection, maintenance and repair operations are assumed to be a factor of 3 times lower than the dose rates outside the TN-32 cask. Average dose rates are considered appropriate for estimating doses.

Rationale: The main purpose of the aging facility is to reduce the thermal output of the spent fuel contained in the aging casks prior to emplacement in the repository. Therefore, any operations that involve a large number of aged casks (retrieval and inspection), or a random selection of casks (maintenance and repair) will emit radiation below levels outside the TN-32 casks. Furthermore, since the dose rates of the TN-32 cask loaded with the average PWR SNF are a factor of 5 times lower than those of the TN-32 cask loaded with design basis PWR SNF (BSC 2004 [DIRS 171772], Table I-5), a factor of 3 reduction for the average dose rates around the aging casks represents a reasonable estimate for this preliminary calculation.

Usage: This assumption is used in Sections 4.1, 4.2, 5.2.6, 5.2.7, 7.1, and 7.2.

5.2.4 Cask Transfer Task Parameters

The tasks involved in the transfer of a single aging cask (i.e., monitored geologic repository site-specific cask [MSC]) to the aging facility, the duration of these tasks (in both minutes and hours), and distances (in meters from the cask surface) of different worker groups from a single aging cask or row of multiple aging casks is given in Table 5-1.

Table 5-1. Tasks, Durations, and Distances from Cask Surface for Cask Transfer Activities

Task [A]	Duration		Distance (m)		
	Time (min) [B]	Time (hr) [C]	Cask Transporter Operator [D]	Spotting / Installation Operator [E]	HP Technician [F]
Prepare to transfer MSC					
Retrieve cask transporter - Engage cask within facility (within cask prep system)	20	0.33	2	5	5
Move to 17B-E perimeter wall	60	1.00	2	10	10
Transfer MSC to aging pad					
Move to designated aging location	15	0.25	2	5	5
Retract cask transporter	5	0.08	2	5	5
Bolt MSC to tie-down system	30	0.50	N/A	1	5
Connect overpressure system					
Install overpressure system	15	0.25	N/A	1	5
Position mobile equipment	15	0.25	N/A	1	5
Connect overpressure system	10	0.17	N/A	1	5
Return transfer crawler to Dry Transfer Facility (DTF)/Canister Handling Facility (CHF)					
Move to 17B-E perimeter wall	7.5	0.13	2	5	N/A
Move to cask loading facility	30	0.50	2	5	N/A
Total Duration	208	3.46			

Notes:

Column [C] = Column [B] / 60 min/hr

N/A = not applicable, worker not required for these tasks.

Rationale: The identification of tasks, associated time durations and distances are provided in Table 5-1. These are preliminary estimates, since a protocol for such operations has not yet been developed. These figures are based on professional judgement and operational experience.

The cask transporter operator is assumed to be located at approximately two meters from the surface of the aging cask while this cask is being transferred. This distance is based on a review of existing vertical cask transporter designs used at other storage facilities. It is common practice for two spotters (one on each side) to accompany the loaded and unloaded transporter along the path from the loading facility to and from the aging facility, relaying any deviations from the prescribed path to the transporter operator. The spotting operators will be able to maintain an appropriate distance from the loaded transport to help minimize their dose, and still provide pertinent information to the transporter operator. During the inbound trip to the aging facility with a loaded cask, an HP Tech will be required to escort the transporter to provide positive control over the radioactive material in transit. The loaded transporter is assumed to make the uphill

inbound trip to 17B through 17E (approximately 1 mile from the loading dock to the aging facility perimeter) at a speed of 1 mph, resulting in a duration of 1 hour for this task. The downhill return trip of the empty transporter is assumed to take half the time (at a speed of 2 mph). Once inside the aging facility perimeter, the transporter is assumed to travel a quarter mile to the designated location (on average; it may be more or less depending on the designated storage location). After delivering the aging cask to the designated location on the pad, the transporter will be moved to the edges of the aging pad (approximately 5 m from a line of casks) to allow space for the cask installation operators to secure the cask and install monitoring equipment, which must occur at a short distance from the cask surface. Two installation operators are assumed to be required for these operations. The transporter operator is not required for securing the cask or for installation of the monitoring equipment and therefore will relocate to a no-dose area. A health physics technician (HPT) is present to provide job coverage for the evolution as well. The HPT will not be required to escort the transporter on its return trip since the path dose rates will have already been established and it is no longer transporting radioactive material. The total duration of the cask transfer tasks (3.5 hr) allows for a single cask transfer operation to be performed in a single eight-hour shift.

Usage: This assumption is used in Sections 4.1, 4.2, 4.4, and 7.1.

5.2.5 Cask Transfer Staffing

The anticipated staffing level required to perform cask transfer operations at the aging facility is as follows:

- 15 Cask Transporter Operators (1 per team, 3 teams per crew, 5 crews)
- 30 Spotting/Installation Operators (2 per team, 3 teams per crew, 5 crews)
- 15 Health Physics Technicians (1 per team, 3 teams per crew, 5 crews)

Rationale: The required number of workers per crew and the number of crews are preliminary estimates since a formal protocol for such operations has not yet been developed. These figures are based on professional judgement and operational experience.

To support each placement/retrieval evolution, a crew needs to consist of a transporter operator and 2 spotting/installation operators at any one time. In an effort to equalize dose distribution, the transporter operators and spotting/installation operators will be cross-trained to perform each other's job functions. To further minimize individual doses, it is expected to utilize 3 teams of operators on each crew. Each team of operators will consist of one transporter operator and 2 spotting/installation operators. One HPT can provide the necessary coverage, but in an effort to minimize individual dose, one HPT will be provided with each team of operations personnel, for a total of 3 HPTs on a crew. It is further assumed that 5 cask transfer crews (consisting of 9 workers – 3 teams of 3 operators) are required to handle the annual throughput of casks destined for the aging facility in order minimize doses to individual workers and maintain the ALARA concept.

Usage: This assumption is used in Sections 4.5, 7.1, and 7.2

5.2.6 Inspection Task Parameters and Staffing

The inspection activities associated with casks on the aging pad are assumed to take an average of 30 seconds per cask and performed at a distance of 2 meters from the row of casks on the pad (Assumption 5.2.2). It is assumed that the required observations can be made from this distance and entering between the rows of casks on a pad will not be required. The average dose rate utilized for inspection activities is taken at a distance of 2 meters from a continuous row of casks along a pad and is 34 mrem/hr (BSC 2004 [DIRS 172499], Section 5.3.3 and Table 12). Inspections are assumed to be performed once each quarter. In an effort to minimize individual dose, it is assumed that a separate individual performs each quarterly inspection (i.e., four inspectors per year).

Rationale: The values for frequency, duration and distance associated with inspection activities are preliminary estimates since a protocol for these operations have not yet been developed. The frequency, duration and distance estimates are made utilizing professional judgements. The dose rate calculation is based on a full pad with the individual casks loaded with average PWR SNF (Assumption 5.2.3). This is appropriate due to the inherent averaging of dose rates that will occur as an inspector passes through various dose rate fields while proceeding along the row of casks 2 meters from a pad.

Usage: This assumption is used in Sections 4.4, 4.5, 7.1, and 7.2.

5.2.7 Maintenance Task Parameters and Staffing

The maintenance/repair activities associated with the aging pad are assumed to take 1 hour for each evolution at varying distances from the cask. It is expected that 2 maintenance workers will be required for each of the maintenance events. Two teams of 2 maintenance workers each will be assumed to be able to perform all the maintenance activities over the course of a year. It is estimated that there will be 20 maintenance/repair events each year. The average dose rate in the area surrounding a cask where the maintenance/repair activities are expected to occur is 67 mrem/hr.

Rationale: The values for frequency, duration and distance associated with maintenance/repair activities are preliminary estimates since a protocol for these operations have not yet been developed. The frequency, duration and distance estimates are made utilizing professional judgements. The dose rate calculation is based on a full pad with the individual casks loaded with average PWR SNF (Assumption 5.2.3). The dose rate value of 67 mrem/hr is based on the average dose rate within a volume of air surrounding a cask which is located in the middle of an aging pad (BSC 2004 [DIRS 172499], Section 5.3.3 and Table 12). Maintenance/repair work is performed at various distances from a cask during the course of the activity, and this results in an inherent averaging of the various dose rate fields. Utilizing an average the dose rate of the air volume in the vicinity of a cask is therefore the best representation of the effective dose

rate the individuals are likely to receive. Based on professional judgement, the annual quantity of maintenance/repair events is estimated to be 1% of the maximum capacity of aging pads 17B through 17 E, which is 100 casks/pad x 20 pads = 2,000 casks (BSC 2004 [DIRS 171161], Section 1.1 and Figure B-4). Therefore the number of maintenance/repair events is 20 events annually.

Usage: This assumption is used in Sections 4.4, 4.5, 7.1, and 7.2.

5.2.8 Cask Contamination Parameters

For purposes of evaluating the occupational doses from the release of surface contamination from the aging casks, appropriate cask parameters must be established. The maximum surface contamination levels present on the aging casks is conservatively assumed to be equivalent to that which is allowed on the waste packages, which is $9.5\text{E-}07\text{ Ci/m}^2$ beta-gamma and $8.0\text{E-}09\text{ Ci/m}^2$ alpha (BSC 2004 [DIRS 171710], Table II-1). These maximum levels are considered to be present on the entire surface area of each aging cask placed on an aging pad. The maximum cask placement rate is 100 casks per year (Assumption 5.1.3) The outer surface area of a typical cask is approximately 50 m^2 (rounded) as described in BSC 2004 [DIRS 171710], Section 4.3.13.

Rationale: BSC 2004 [DIRS 171710], Table II-1 provides the average concentration of waste package contamination available for release to the environment. This calculation is based on the maximum contamination values anticipated to be allowed for waste package emplacement (BSC 2004 [DIRS 171710], Section 4.2.7). Since the aging cask will be exposed to the outside environment, good health physics practice would suggest that the contamination levels on the aging casks be maintained as low as is practicable to limit radioactive releases to the environment. Considering the level of contamination on the aging cask to be consistent with that of the waste package for emplacement would therefore be appropriate for limiting releases.

Usage: This assumption is used in Appendix A.

5.2.9 Ambient Area Dose Rates for Transport

Ambient area dose rates are considered as a source of radiation exposure during the retrieval and movement of the cask transporter to and from the Aging Facility. The dose rate assumed for this is 2.5 mrem/hr.

Rationale: BSC 2004 [DIRS 171535] classifies areas as radiation zones which identify the radiation dose rates expected in an area. The area surrounding the aging facility and in the load out areas of the CHF and FHF are all zoned as R-2 (BSC 2004 [DIRS 171535], Figures I-4.1, I-2.1 and I-6.1 respectively) and therefore have a dose rate range of 0.05 mrem/hr to 5.0 mrem/hr. While traversing these zones, dose rates will drop off as distance from the source increases, and therefore it is appropriate to use an average dose rate of the zone which equates to 2.5 mrem/hr. The majority of the path from the package facility to the aging facility is in zone R-1 (BSC 2004[DIRS 171535], Figure I-

4.1), with dose rates of up to 0.05 mrem/hr. Therefore an ambient dose rate field of 0.05 mrem/hr will be used for all cask transporter tasks to and from the aging facility.

Usage: This assumption is used in Section 7.1.

6 USE OF COMPUTER SOFTWARE

6.1 COMMERCIAL OFF-THE-SHELF SOFTWARE

Microsoft® Excel 97 SR-2, a spreadsheet program, is used in this calculation. Excel was used to generate tables listing the receipt, processing and loading tasks for each operation, the dose rates at the worker locations, and the time spent by the workers in the radiation field at each location. User-defined formulas (derived in Section 3), design inputs and assumptions (discussed in Sections 4 and 5), and results are documented in sufficient detail in Section 7 and Appendix A to allow for independent duplication of the various computations without recourse to the originator. Per Sections 2.1.2 and 2.1.6 of LP-SI.IIQ-BSC [DIRS 171923], *Software Management*, this software is considered exempt.

7 CALCULATIONS

Dose assessment calculations are performed using time-motion inputs and dose rates calculated at aging facility worker locations for cask transfer, inspection and maintenance operations. Dose calculations are made per unit operation, i.e., per aging cask transferred or per inspection, and then multiplied by the annual number of casks transferred or inspections performed. Doses are determined for sub-tasks that require hands-on activities or local observations identified in Assumption 5.2.4. The dose assessment calculates annual individual worker doses including contributions from external (i.e., direct) radiation and from inhalation of airborne radioactivity.

External radiation doses are calculated in Sections 7.1 and 7.2. Section 7.1 covers the calculation of external doses to aging facility workers by task of the operation process. Section 7.2 determines the annual dose of each work crew.

7.1 EXTERNAL RADIATION DOSE BY TASK

This section discusses the calculation of doses to aging facility workers due to external radiation exposures incurred during operations (i.e., transfer, inspection and maintenance operations) to process aging casks.

7.1.1 Dose Incurred During Transfer of a Single Aging Cask

Per Assumptions 5.2.1 and 5.1.2, the radiation dose rate distribution around a TN-32 cask is assumed to be representative of that for other aging casks. Per Section 4.1, workers are modeled at 1 m, 2 m, 5 m, or 10 m from the exterior surfaces of a loaded aging cask. As described in Sections 4.1 and 4.2, the dose rates at the four distances (1 m, 2 m, 5 m, and 10 m) from the cask surface are used to estimate the radiation dose in the vicinity of single (1 m, 2 m, 5 m, and 10 m) or multiple casks (1 m, 2 m, and 5 m). Tables 7-1, 7-2, and 7-3 show distances and dose rates for

each worker group based on Assumptions 5.2.1 and 5.2.2. These dose rates are multiplied by the task duration (Assumption 5.2.4) to obtain a dose for each task to each worker group. Utilizing the staffing information in Assumption 5.2.5 will provide the individual worker dose for each cask transfer operation.

When retrieving casks from the aging facility, the average dose rates are assumed to be one third of the TN-32 cask dose rates (Assumption 5.2.3). Therefore, the doses listed in Tables 7-1 to 7-3 will be a factor of 3 times lower for each cask that is retrieved from the aging pad.

Table 7-1. Dose to Cask Transporter Operator During Cask Placement Operation

Task [A]	Time (hr) [B]	Distance (m) [C]	Cask Dose Rate (mrem/hr) [D]	Ambient Area Dose Rate (mrem/hr) [E]	Total Dose Rate (mrem/hr) [F]	Single Worker Dose (mrem) [G]
Prepare to transfer MSC						
Retrieve cask transporter - Engage cask within facility (within cask prep system)	0.33	2	36	0.05	36	12
Move to 17B-E perimeter	1.00	2	36	2.5	39	39
Transfer MSC to aging pad						
Move to designated aging location	0.25	2	^a	107	107	27
Retract cask transporter	0.08	2	^a	107	107	9
Bolt MSC to tie-down system	0.50	N/A	^a	0	0	0
Connect overpressure system						
Install overpressure system	0.25	N/A	^a	0	0	0
Position mobile equipment	0.25	N/A	^a	0	0	0
Connect overpressure system	0.17	N/A	^a	0	0	0
Return transfer crawler to DTF/CHF						
Move to 17B-E perimeter wall	0.13	2	0	107	107	13
Move to cask loading facility	0.50	2	0	2.5	2.5	1
Total	3.46					101

^a For these operations, the dose rate for a single cask is included in the ambient dose rate.

Columns [A], [B], and [C]: Columns [A], [C], and [D], respectively, in Table 5-1

Column [D]: Table 4-1

Column [E]: Table 4-2 and Assumption 5.2.9

Column [F]: Columns [D]+ [E]

Column [G]: Column [B] x Column [F]

Table 7-2. Dose to Cask Spotting/Installation Operators During Cask Placement Operation

Task [A]	Time (hr) [B]	Distance (m) [C]	Cask Dose Rate (mrem/hr) [D]	Ambient Area Dose Rate (mrem/hr) [E]	Total Dose Rate (mrem/hr) [F]	Single Worker Dose (mrem) [G]
Prepare to transfer MSC						
Retrieve cask transporter - Engage cask within facility (within cask prep system)	0.33	5	12	0.05	12	4
Move to 17B-E perimeter	1.00	10	4	2.5	7	7
Transfer MSC to aging pad						
Move to designated aging location	0.25	5	^a	56	56	14
Retract cask transporter	0.08	5	^a	56	68	6
Bolt MSC to tie-down system	0.50	1	^a	173	184	92
Connect overpressure system						
Install overpressure system	0.25	1	^a	173	173	43
Position mobile equipment	0.25	1	^a	173	173	43
Connect overpressure system	0.17	1	^a	173	173	29
Return transfer crawler to DTF/CHF						
Move to 17B-E perimeter wall	0.13	5	0	56	56	7
Move to cask loading facility	0.50	10	0	2.5	2.5	1
Total	3.46					245

^a For these operations, the dose rate for a single cask is included in the ambient dose rate.

Columns [A], [B], and [C]: Columns [A], [C], and [E], respectively, in Table 5-1

Column [D]: Table 4-1

Column [E]: Table 4-2 and Assumption 5.2.9

Column [F]: Columns [D]+ [E]

Column [G]: Column [B] x Column [F]

Table 7-3. Dose to Health Physics Technician During Cask Placement Operation

Task [A]	Time (hr) [B]	Distance (m) [C]	Cask Dose Rate (mrem/hr) [D]	Ambient Area Dose Rate (mrem/hr) [E]	Total Dose Rate (mrem/hr) [F]	Single Worker Dose (mrem) [G]
Prepare to transfer MSC						
Retrieve cask transporter - Engage cask within facility (within cask prep system)	0.33	5	12	0.05	12	4
Move to 17B-E perimeter	1.00	10	4	2.5	7	7
Transfer MSC to aging pad						
Move to designated aging location	0.25	5	^a	56	56	14
Retract cask transporter	0.08	5	^a	56	56	5
Bolt MSC to tie-down system	0.50	5	^a	56	56	28
Connect overpressure system						
Install overpressure system	0.25	5	^a	56	56	14
Position mobile equipment	0.25	5	^a	56	56	14
Connect overpressure system	0.17	5	^a	56	56	9
Return transfer crawler to DTF/CHF						
Move to 17B-E perimeter wall	0.13	N/A	0	0	0	0
Move to cask loading facility	0.50	N/A	0	0	0	0
Total	3.46					95

^a For these operations, the dose rate for a single cask is included in the ambient dose rate.

Column [A], [B], and [C]: Columns [A], [C], and [F], respectively, in Table 5-1

Column [D]: Table 4-1

Column [E]: Table 4-2 and Assumption 5.2.9

Column [F]: Columns [D] + [E]

Column [G]: Column [B] x Column [F]

7.1.2 Dose Incurred During Inspections

Inspection activities are expected to be visual observations of each cask. It is estimated that the time spent inspecting each cask is approximately 30 seconds (Assumption 5.2.6). The number of casks being inspected is the maximum capacity of aging pads 17B through 17 E, which is 100 casks/pad x 20 pads = 2,000 casks (BSC 2004 [DIRS 171161], Section 1.1 and Figure B-4). Therefore the total time needed to perform each inspection campaign is 30 sec/cask x 2000 casks ÷ 3600 seconds/hour = 17 hours (rounded). The dose rate associated with the inspection activity is 34 mrem/hr which is the projected dose rate at 2 meters from a row of casks (Assumption 5.2.6). This results in an integrated dose for each inspection campaign of 34 mrem/hr x 17 hours/inspection = 578 mrem/inspection.

7.1.3 Dose Incurred During Maintenance and Repair Operations

Occasional on-pad maintenance/repair to a cask is expected to require 2 individuals working in the vicinity of the affected cask (Assumption 5.2.7). There are 20 maintenance/repair activities

projected annually, each of which is expected to have a duration of 1 hour (Assumption 5.2.7). The average dose rate in the work area is 67 mrem/hr (Assumption 5.2.7). This results in a dose of 0.067 rem/operation/worker or 0.134 person-rem/operation total for both involved individuals.

7.2 ANNUAL EXTERNAL RADIATION DOSES

The doses incurred by the various worker groups involved in operations at the aging facility – Cask Transfer Operations workers, Health Physics Technicians, Cask Inspectors, and Maintenance/Repair personnel – are calculated below.

The total annual external dose, ED_g , to a worker in a work-crew within group g for all cask transfer operations is given by taking the individual doses to each worker for each set of tasks developed in Section 7.1 and multiplying them by the frequency of operations and number of workers involved.

For a frequency of 100 cask transfers to the aging facility per year (Assumption 5.1.3), the collective dose rate for the various work groups are determined as follows:

Placement Operations

Cask Transporter Operators

Dose to a single Cask Transport Operator for each placement operation was calculated and presented in Table 7-1. Multiplying the individual worker dose per operation (101 mrem) by the number of functional area workers per team involved (1) (Assumption 5.2.5) and by the number of operations per year (100) (Assumption 5.1.3) results in the integrated dose for the work group (10.1 person-rem/year).

Spotting/Installation Operators

Dose to a single Spotting/Installation Operator for each placement operation was calculated and presented in Table 7-2. Multiplying the individual worker dose per operation (245 mrem) by the number of functional area workers per team involved (2) (Assumption 5.2.5) and by the number of operations per year (100) (Assumption 5.1.3) results in the integrated dose for the work group (49.0 person-rem/year).

Health Physics Technicians

Dose to a single Health Physics Technician for each placement operation was calculated and presented in Table 7-3. Multiplying the individual worker dose per operation (95 mrem) by the number of functional area workers per team involved (1) (Assumption 5.2.5) and by the number of operations per year (100) (Assumption 5.1.3) results in the integrated dose for the work group (9.5 person-rem/year).

Retrieval Operations

As discussed in Assumption 5.2.3, the average dose rates workers are exposed to during retrieval operations is a factor of 3 times less than those during placement operations. Therefore integrated dose for each work group for retrieval operations is the integrated dose for placement operations divided by 3.

Cask Transporter Operators

Integrated dose for Cask Transporter Operators is 10.1 person-rem/year divided by 3 or 3.4 person-rem/year.

Spotting/Installation Operators

Integrated dose for Spotting/Installation Operators is 49.0 person-rem/year divided by 3 or 16.4 person-rem/year.

Health Physics Technicians

Integrated dose for Health Physics Technicians is 9.5 person-rem/year divided by 3 or 3.2 person-rem/year.

Overall Cask Transfer Operations

The total annual dose for all Cask Transfer Operations is the sum of the placement doses and the retrieval doses (HPT considered separately). This results in 78.9 person-rem/year. It is expected that 5 crews will be utilized to handle the annual throughput (Assumption 5.2.5). Therefore the total dose for a crew is anticipated to be 15.8 person-rem/year/crew. Each Cask Transfer Operations crew consists of 3 teams resulting in 9 operators – 3 Transporter Operators and 6 Spotting/Installation Operators (Assumption 5.2.5). Therefore, the average dose to an operator on each crew is 1.75 rem/year/worker.

Health Physics Technicians

The total annual dose for Health Physics Technicians is the sum of the placement dose and the retrieval dose. This results in 12.7 person-rem/year. It is expected that 5 crews will be utilized to handle the annual throughput (Assumption 5.2.5). Each crew consists of 3 teams resulting in 3 HPTs on each crew for a total of 15 HPTs (Assumption 5.2.5). Therefore, the average dose to an HPT on a crew is 0.85 rem/year/worker.

Inspection Operations

Inspections of the casks on the aging pad are assumed to be performed on a quarterly basis (Assumption 5.2.6). Dose for a single inspection campaign was calculated and presented in Section 7.1.2. The calculation resulted in an integrated dose for each inspection campaign of 0.578 rem/inspection. Since the inspections will be performed on a quarterly basis, this will result in 2.3 person-rem/year. This is based on one single individual performing all of the inspection activities for the year. The inspection duties are assumed to be subdivided such

that a separate individual will perform each quarterly inspection (Assumption 5.2.6). Therefore, the average dose to an inspector is 0.58 rem/year/worker.

Maintenance/Repair Operations

Occasional on-pad maintenance/repair to a cask is expected to be required. There are 20 maintenance/repair activities projected annually (Assumption 5.2.7). Dose for a single maintenance/repair operation was calculated and presented in Section 7.1.3. The calculation resulted in an integrated dose for each maintenance/repair operation of 0.067 rem/operation/worker or 0.134 person-rem/operation for the 2 workers (Assumption 5.2.7) assumed to be required for each maintenance/repair operation. For the projected 20 maintenance/repair operations annually, the total annual integrated dose is projected to be 2.68 person-rem/year. Two teams of 2 workers each have been assumed to perform the maintenance/repair operations (Assumption 5.2.7). Therefore, the average dose to a maintenance/repair worker is 0.67 rem/year/worker.

7.3 ANNUAL INHALATION AND SUBMERSION DOSES

The annual maximum internal and external doses to a worker due to re-suspension of cask surface contamination are estimated in Appendix A. These doses are much lower than the external doses for all worker categories and are therefore considered to be an insignificant contributor to the totals presented in Section 7.2.

7.4 TEDE DOSE CALCULATION

The annual TEDE for each worker category is calculated by summing the component doses from inhalation, submersion, and direct external radiation exposure over all sources. As indicated in Section 7.3, only external dose is considered a significant contributor in the dose calculation. Therefore, the TEDE is equivalent to the doses presented in Section 7.2.

8 RESULTS AND CONCLUSIONS

The results of this dose assessment calculation are summarized in Section 7. The parameters used in the dose calculations are supported by appropriate and conservative input data and assumptions. The calculated worker doses in Section 7 represent reasonable maximum results compared with the input used to derive them. The results are therefore suitable for the intended use. The uncertainties in the results are identified primarily by the worker locations and the dose rates they will receive, and by the duration of operations, which are currently not easily quantifiable. However, the selected inputs are judged to be representative of conservative conditions.

8.1 COMPARISON TO REGULATIONS AND DESIGN GOALS

The average estimated doses to an individual Cask Transfer Operation worker is **1.75 rem per year** and to an individual Health Physics Technician is **0.85 rem per year**. The annual dose to individual Inspection personnel is estimated to be **0.58 rem per year**, and to an individual Maintenance/Repair worker is **0.67 rem per year**.

These doses are in compliance with the requirements of 10 CFR 20.1201(a)(1)(i) [DIRS 167538] limit of 5 rem per year for occupational workers in Section 4.7. The estimated annual doses trigger the ALARA design goal of minimizing the number of workers exposed to more than 0.5 rem per year.

8.2 DISCUSSION

This estimate is based on best available estimates or projections of annual aging cask processing rates with the current throughput model. Dose rates are based on a representative aging cask based on the design basis thermal loading for placement operations and average thermal loading for retrieval, inspection, maintenance, and repair operations.

One of the secondary uses of the dose assessment is to identify and prioritize aging facility design areas that should consider additional ALARA design features to reduce individual worker doses in order to achieve the ALARA goals. In this respect, attention should be focused on means by which doses to all staff involved with aging facility operations can be reduced.

8.3 RECOMMENDATIONS

The results of the dose assessment presented in this document lead to the following conclusions and recommendations:

1. The principal contributor to the worker dose is from the contained source in the aging cask and nearby casks on the pad. The contribution from the airborne source is negligible. The cask transfer operations and health physics technician work groups will receive the highest dose, because of their proximity to the cask during cask transfers to and from the aging pads and the duration and frequency of these procedures. The doses to the aging facility workers trigger the ALARA design goal of minimizing the number of workers exposed to more than 0.5 rem per year. Individual doses could be further reduced by the addition of more crews, however it is recommended that further ALARA design considerations be included in the final design to achieve the ALARA design goal. Opportunities for dose reduction could include the possibility of shielding, use of more automation and use of remote monitoring/surveillance techniques.
2. A sensitivity analysis was performed in BSC (2004 [DIRS 172499], Section 6) to determine how a change in cask spacing would affect the results at the reference dose point. The current nominal spacing is set at a 13 ft pitch (center-to-center). This pitch was increased to 18 ft, a spacing that still allows 100 casks to be placed on a single pad.

The increased spacing had the impact of reducing the dose rates, within a range of 5% to 33%, depending on the distance from the array of casks (BSC 2004 [DIRS 172499], Table 13). Therefore, the doses to workers on the pad would not be significantly reduced by increasing the casks spacing, even for those operations performed in close proximity to the casks where the greatest reduction in the dose rate might be expected. In fact, in the case of cask inspection operations, a decrease in the dose rate of approximately 15% may be more than offset by the increased inspection time, since the inspectors would have to travel a greater distance between casks (roughly the ratio of 13 ft to 18 ft, or 38% greater distance). There may be other reasons for increasing the spacing calculations, such as improved access

between casks, which may reduce operation times and/or allow the use of temporary shielding.

9 REFERENCES

9.1 DOCUMENTS CITED

167268 BSC (Bechtel SAIC Company) 2004. *Categorization of Event Sequences for License Application*. 000-00C-MGR0-00800-000-00A. Las Vegas, Nevada: Bechtel SAIC Company. ACC: ENG.20040722.0001.

172499 BSC (Bechtel SAIC Company) 2004. *Dose Rate Evaluations for Spent Nuclear Fuel Aging Areas*. 170-00C-HAP0-00400-000-00A. Las Vegas, Nevada: Bechtel SAIC Company. ACC: ENG.20041217.0001.

171772 BSC (Bechtel SAIC Company) 2004. *Dry Transfer Facility Worker Dose Assessment*. 110-00C-CD00-00100-000-00B. Las Vegas, Nevada: Bechtel SAIC Company. ACC: ENG.20040923.0001.

171710 BSC (Bechtel SAIC Company) 2004. *Normal Operation Airborne Release Calculation*. 000-HSC-WHS0-00200-000-00B. Las Vegas, Nevada: Bechtel SAIC Company. ACC: ENG.20040920.0005.

171599 BSC (Bechtel SAIC Company) 2004. *Project Design Criteria Document*. 000-3DR-MGR0-00100-000-003. Las Vegas, Nevada: Bechtel SAIC Company. ACC: ENG.20041124.0001.

171161 BSC (Bechtel SAIC Company) 2004. *SNF Aging System Description Document*. 170-3YD-HA00-00100-000-003. Las Vegas, Nevada: Bechtel SAIC Company. ACC: ENG.20040916.0001.

172520 BSC (Bechtel SAIC Company) 2004. *Technical Management Review Board (TMRB) Decision Proposal*. TMRB-2004-092. Las Vegas, Nevada: Bechtel SAIC Company. ACC: MOL.20041117.0130.

172941 BSC (Bechtel SAIC Company) 2005. *GROA Airborne Release Dispersion Factor Calculation*. 000-HYC-MGR0-00100-000-00B. Las Vegas, Nevada: Bechtel SAIC Company. ACC: ENG.20050321.0001.

171190 BSC (Bechtel SAIC Company) 2005. *Q-List*. 000-30R-MGR0-00500-000-001. Las Vegas, Nevada: Bechtel SAIC Company. ACC: ENG.20050217.0010.

170557 Curry, P.M. 2004. *Project Functional and Operational Requirements*. TDR-MGR-ME-000003 REV 02. Las Vegas, Nevada: Bechtel SAIC Company. ACC: DOC.20040714.0003.

171539 DOE (U.S. Department of Energy) 2004. *Quality Assurance Requirements and Description*. DOE/RW-0333P, Rev. 16. Washington, D.C.: U.S. Department of Energy, Office of Civilian Radioactive Waste Management. ACC: DOC.20040907.0002.

107684 Eckerman, K.F. and Ryman, J.C. 1993. *External Exposure to Radionuclides in Air, Water, and Soil, Exposure-to-Dose Coefficients for General Application, Based on the 1987 Federal Radiation Protection Guidance*. EPA 402-R-93-081. Federal Guidance Report No. 12. Washington, D.C.: U.S. Environmental Protection Agency, Office of Radiation and Indoor Air. TIC: 225472.

164177 Edwards, T.A. and Yuan, Y. 2003. *Recommended Surface Contamination Levels for Waste Packages Prior to Placement in the Repository*. 000-30R-OSS0-00100-000-000. Las Vegas, Nevada: Bechtel SAIC Company. ACC: ENG.20030903.0001.

172721 ICRP (International Commission on Radiological Protection) 1995. *Dose Coefficients for Intakes of Radionuclides by Workers, Replacement of ICRP Publication 61*. Volume 24, No. 4 of *Annals of the ICRP*. ICRP Publication 68. Tarrytown, New York: Pergamon. TIC: 235867.

169500 Migliore, R. 2004. Aging-Related Dose Assessment. COGEMA-C0115-EN-CLC-0015, Rev. 1. Las Vegas, Nevada: Cogema. ACC: ENG.20040519.0018.

9.2 REGULATIONS AND PROCEDURES CITED

167538 10 CFR 20. 2001 Energy: Standards for Protection Against Radiation. Readily available.

168413 AP-3.12Q, Rev. 2, ICN 2. *Design Calculations and Analyses*. Washington, D.C.: U.S. Department of Energy, Office of Civilian Radioactive Waste Management. ACC: DOC.20040318.0002.

171923 LP-SI.11Q-BSC, Rev. 0, ICN 1. *Software Management*. Washington, D.C.: U.S. Department of Energy, Office of Civilian Radioactive Waste Management. ACC: DOC.20041005.0008.

10 APPENDICES

There is one appendix in this calculation: Appendix A – Inhalation and Air Submersion Doses.

APPENDIX A

INHALATION AND AIR SUBMERSION DOSES

In order to evaluate the resultant occupational dose rates produced through the release of surface contamination from aging casks, it is important to establish the worst-case release of material from the aging casks. In Edwards and Yuan (2003 [DIRS 164177], Section 3.1), it is determined that the worst-case steady state release of surface contamination from waste packages in the repository is produced by setting the release rate from the packages equal to the rate of waste package contamination entering into the repository. In this way, it can be related that surface contamination is released from the surface of each waste package such that the entire quantity of contamination is released from the surface of each package within the first year of emplacement. This basis is sufficient for the purpose of determining the releasable quantity of material at the aging facility as well.

In order to evaluate the dispersion of radionuclides from the release point to the exposure point, the dispersion calculations presented in BSC (2005 [DIRS 172941], Tables 6 through 11) are used. The worst-case dispersion value for the aging facility is $2.4\text{E-}05 \text{ s/m}^3$ for releases from 17A to a receptor in 17A, while it is $5.0\text{E-}06 \text{ s/m}^3$ for releases from 17E to a receptor in 17BCDE. The most limiting of these two values is used in this calculation (i.e., $2.4\text{E-}5 \text{ s/m}^3$). It should be noted that it is unrealistic to expect that a worker would be present at an aging pad for a full 2000-hr work year. However, this value is bounding for all workers at the aging facility and will be utilized in the calculation.

For purposes of this calculation, the two contributors to occupational dose are considered to be inhalation of and submersion in the radioactive material released from the surface of the spent fuel canisters/casks placed at the aging facility pads.

The dose conversion factors for inhalation are taken from International Commission on Radiological Protection (ICRP) Publication 68 (ICRP 1995 [DIRS 172721], Tables B.1 and C.1), and can be used to determine dose incurred to various organs as a result of inhalation of a specific quantity of each radionuclide. The most limiting dose conversion factor (i.e., that which provides the highest dose per unit activity) from ICRP 68 was used.

The dose factors for submersion are taken from Federal Guidance Report 12 (Eckerman and Ryman 1993 [DIRS 107684], Table III.1). These values present the dose conversion factors for various organs resulting from external exposure to radionuclides in air.

Since the dose calculations must be performed using individual radionuclide concentrations, for which dose factors have been established, the beta-gamma and alpha surface contamination levels must include a distribution of those important radionuclides. These radiologically significant radionuclides are presented in BSC (2004 [DIRS 171710], Table II-2), along with the relative abundances present in the surface contamination of waste packages. These values are used to represent the distribution of radionuclides potentially present on the surface of casks to be stored at the aging facility. These radionuclides are listed in Table A-1, along with the source term provided for these radionuclides from BSC (2004 [DIRS 171710], Table II-2). The relative abundance (percent) of each radionuclide is then used to scale the surface contamination levels

on the casks. This is done by first multiplying the maximum surface contamination levels present on the aging casks ($9.6\text{E-}07\text{ Ci/m}^2$ beta-gamma plus alpha) (Assumption 5.2.8) by the relative activity of each radionuclide. These values are then multiplied by the total cask area (50 m^2) (Assumption 5.2.8) and the number of casks (100) placed in one year (Assumption 5.1.3) to obtain the source term available for release from the aging facility in one year.

The source term is converted to a release rate by dividing this activity by the number of seconds in one year ($3.15\text{E+}07\text{ s/yr}$). The concentration of each radionuclide at the receptor location is then obtained by multiplying the release rate in Ci/s by the dispersion factor for this location ($2.4\text{E-}05\text{ s/m}^3$). These calculated release rates and concentrations are presented in Table A-1 for each radionuclide.

The dose calculations presented in Table A-2 are based on the concentrations derived in Table A-1. The inhalation dose is calculated by multiplying the airborne concentration by the worker inhalation rate in 10 CFR 20 Appendix B [DIRS 167538] of $2\text{E+}04\text{ mL/min}$ (converted to $3.3\text{E-}04\text{ m}^3/\text{s}$) for a 2000-hr work year and the committed effective dose equivalent (CEDE) inhalation dose conversion factor (DCF) for each radionuclide in ICRP 68 (ICRP 1995 [DIRS 172721], Tables B.1 and C.1). Similarly, the submersion dose is calculated using the same airborne concentration multiplied by the exposure duration of 2000 hr/yr, then multiplied by the submersion effective dose equivalent (EDE) DCF in FGR 12 (Eckerman and Ryman 1993 [DIRS 107684], Table III.1). The total EDE (TEDE) from the inhalation and submersion exposures is calculated as the sum of the inhalation CEDE and the submersion EDE. The dose to the skin is calculated using the same airborne concentration multiplied by the exposure duration of 2000 hr/yr, then multiplied by the submersion EDE DCF for the skin in FGR 12 (Eckerman and Ryman 1993 [DIRS 107684], Table III.1). The dose to the lens of the eye is calculated as the sum of the TEDE and the skin EDE.

Based on the results presented in Table A-2, the dose from airborne material released from casks stored on the aging pad is only 0.012 mrem/yr , even for a worker that spends a full work year at the point of highest airborne concentrations. This dose is insignificant compared to the regulatory limits and ALARA guidelines presented in Section 4, and is significantly lower than any of the direct external doses calculated in Section 7. Therefore, any doses incurred by workers from airborne releases are effectively included in the calculation of direct external doses.

Table A-1. Air Concentrations of Radionuclides Released from Surface of Aging Casks

Nuclide [A]	From Surface Release to Off- gas (Ci/yr) [B]	Contamination Activity Distribution % [C]	Aging Pad Contamination Activity (Ci) [D]	Release Rate (Ci/s) [E]	Total Air Concentration (Ci/m ³) [F]
Part beta-gamma					
Cs-137	2.6E+02	37.24%	1.8E-03	5.65E-11	1.36E-15
Ba-137m	2.4E+02	35.01%	1.7E-03	5.31E-11	1.27E-15
Crud Co-60	1.1E+02	15.95%	7.6E-04	2.42E-11	5.81E-16
Co-60	3.0E-01	0.04%	2.0E-06	6.45E-14	1.55E-18
Ni-63	2.4E-01	0.03%	1.6E-06	5.20E-14	1.25E-18
Sr-90	2.6E+01	3.70%	1.8E-04	5.61E-12	1.35E-16
Y-90	2.6E+01	3.70%	1.8E-04	5.61E-12	1.35E-16
Pm-147	1.1E-01	0.02%	7.7E-07	2.45E-14	5.89E-19
Sm-151	2.0E-01	0.03%	1.4E-06	4.35E-14	1.04E-18
Eu-154	6.4E-01	0.09%	4.4E-06	1.38E-13	3.32E-18
Pu-241	2.3E+01	3.36%	1.6E-04	5.09E-12	1.22E-16
Total Part beta-gamma	6.9E+02	99.16%	4.7E-03		
Pu-238	2.2E+00	0.31%	1.5E-05	4.72E-13	1.13E-17
Pu-239	1.7E-01	0.02%	1.2E-06	3.65E-14	8.76E-19
Pu-240	3.0E-01	0.04%	2.1E-06	6.56E-14	1.57E-18
Am-241	1.9E+00	0.27%	1.3E-05	4.08E-13	9.80E-18
Am-243	2.1E-02	0.00%	1.4E-07	4.54E-15	1.09E-19
Cm-243	9.8E-03	0.00%	6.7E-08	2.12E-15	5.10E-20
Cm-244	1.3E+00	0.18%	8.8E-06	2.80E-13	6.73E-18
Total Part Alpha	5.8E+00	0.84%	4.0E-05		
Total Activity	7.0E+02	100.00%	4.8E-03		

Sources/calculations

Columns [A], [B] and [C]: BSC 2004 [DIRS 171710], Table II-2

Column [D] = Column [C] x 9.6E-07 Ci/m² (BSC 2004 [DIRS 171710], Table II-1) x 50 m²/cask x 100 casks

Column [E] = Column [D] / 3.15E+07 s

Column [F] = Column [E] x 2.4E-05 s/m³

Table A-2. Dose to Aging Facility Workers from Radionuclides Released from Surface of Aging Casks

Nuclide [A]	Air Concentration (Ci/m ³) [B]	Effective Inhalation DCF (rem/Gi) [C]	Inhalation Dose (CEDE) (mrem/yr) [D]	Submersion Effective DCF (rem/s/Ci/m ³) [E]	Submersion Dose (EDE) (mrem/year) [F]	Dose (TEDE) (mrem/year) [G]	Submersion Skin DCF (rem/s/Ci/m ³) [H]	Skin Dose (EDE) (mrem/year) [J]	Lens Dose (LDE) (mrem/year) [K]
Cs-137	1.36E-15	2.5E+04	8.1E-05	1.0E-01	9.8E-07	8.2E-05	1.6E-01	1.6E-06	8.3E-05
Ba-137m	1.27E-15					Included in Cs-137 calculation			
Crud Co-60	5.81E-16	1.1E+05	1.5E-04	4.7E-01	1.9E-06	1.5E-04	5.4E-01	2.2E-06	1.5E-04
Co-60	1.55E-18	1.1E+05	4.0E-07	4.7E-01	5.2E-09	4.0E-07	5.4E-01	6.0E-09	4.1E-07
Ni-63	1.25E-18	7.4E+03	2.2E-08	0.0E+00	0.0E+00	2.2E-08	0.0E+00	0.0E+00	2.2E-08
Sr-90	1.35E-16	5.6E+05	1.8E-04	7.3E-04	7.1E-10	1.8E-04	2.6E-01	2.6E-07	1.8E-04
Y-90	1.35E-16					Included in Sr-90 calculation			
Pm-147	5.89E-19	1.7E+04	2.5E-08	2.6E-06	1.1E-14	2.5E-08	3.0E-03	1.3E-11	2.5E-08
Sm-151	1.04E-18	1.4E+04	3.4E-08	1.3E-07	1.0E-15	3.4E-08	7.0E-07	5.3E-15	3.4E-08
Eu-154	3.32E-18	1.9E+05	1.5E-06	2.3E-01	5.4E-09	1.5E-06	3.1E-01	7.3E-09	1.5E-06
Pu-241	1.22E-16	3.1E+06	9.2E-04	2.7E-07	2.4E-13	9.2E-04	4.3E-07	3.8E-13	9.2E-04
Pu-238	1.13E-17	1.6E+08	4.3E-03	1.8E-05	1.5E-12	4.3E-03	1.5E-04	1.2E-11	4.3E-03
Pu-239	8.76E-19	1.7E+08	3.7E-04	1.6E-05	9.9E-14	3.7E-04	6.9E-05	4.3E-13	3.7E-04
Pu-240	1.57E-18	1.7E+08	6.6E-04	1.8E-05	2.0E-13	6.6E-04	1.5E-04	1.6E-12	6.6E-04
Am-241	9.80E-18	1.4E+08	3.4E-03	3.0E-03	2.1E-10	3.4E-03	4.7E-03	3.3E-10	3.4E-03
Am-243	1.09E-19	1.4E+08	3.8E-05	8.1E-03	6.3E-12	3.8E-05	1.0E-02	8.0E-12	3.8E-05
Cm-243	5.10E-20	1.1E+08	1.3E-05	2.2E-02	8.0E-12	1.3E-05	3.6E-02	1.3E-11	1.3E-05
Cm-244	6.73E-18	9.3E+07	1.5E-03	1.8E-05	8.8E-13	1.5E-03	1.4E-04	7.0E-12	1.5E-03
Total			1.2E-02		2.9E-06	1.2E-02		4.1E-06	1.2E-02

Sources/calculations

Column [A]: Column [A], Table A-1

Column [B]: Column [F], Table A-1

Column [C] = ICRP 68 (ICRP 1995 [DIRS 172721], Tables B.1 and C.1)

Column [D] = Column [B] x Column [C] x 3.3 E-04 m³/s x 2000 hr/yr x 3600 s/hr x 1000 mrem/rem

Column [E] = FGR 12 (Eckerman and Ryman 1993 [DIRS 107684], Table III.1)

Column [F] = Column [B] x Column [E] x 2000 hr/yr x 3600 s/hr x 1000 mrem/rem

Column [G] = Column [D] + Column [F]

Column [H] = FGR 12 (Eckerman and Ryman 1993 [DIRS 107684], Table III.1)

Column [J] = Column [B] x Column [H] x 2000 hr/yr x 3600 s/hr x 1000 mrem/rem

Column [K] = Column [G] + Column [J]