BSC

Design Calculation or Analysis Cover Sheet

Complete only applicable items.

1. QA: QA
2. Page 1

3. System	4. Document Identifier
Initial Handling	51A-00C-IH00-00100-000-00A

5. Title
Initial Handling Facility Worker Dose Assessment

6. Group
Nuclear and Radiological Engineering

7. Document Status Designation
☐ Preliminary ☒ Committed ☐ Confirmed ☐ Cancelled/Superseded

8. Notes/Comments

NOTICE OF OPEN CHANGE DOCUMENTS - THIS DOCUMENT IS IMPACTED BY THE LISTED CHANGE DOCUMENTS AND CANNOT BE USED WITHOUT THEM.
----
1) CACN-001, DATED 02/12/2009

Attachments	Total Number of Pages
Attachment 1: Annual Inhalation and Submersion Doses	4
Attachment 2: Sensitivity Study	4
Attachment 3: Listing of Files Contained on Compact Disk	1
Attachment 4: Compact Disc containing the Electronic Files Generated by this Calculation	1 CD

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. EGS (Print/Sign/Date)	16. Approved/Accepted (Print/Sign/Date)
00A	Initial issue	39	39	Scott Newsom 05/24/07	Tom Karl 05-24-07	Norman Kahler 5/24/07	David Darling 5/24/07

DISCLAIMER

The calculations contained in this document were developed by Bechtel SAIC Company, LLC, and are intended solely for the use of Bechtel SAIC Company, LLC, in its work for the Yucca Mountain Project.

CONTENTS

Page

ACRONYMS 6

ABBREVIATIONS 6

1. PURPOSE 8

2. REFERENCES 8
   2.1 PROCEDURES/DIRECTIVES 8
   2.2 DESIGN INPUTS 9
   2.3 DESIGN CONSTRAINTS 10
   2.4 DESIGN OUTPUTS 11

3. ASSUMPTIONS 11
   3.1 ASSUMPTIONS REQUIRING VERIFICATION 11
   3.2 ASSUMPTIONS NOT REQUIRING VERIFICATION 11

4. METHODOLOGY 18
   4.1 QUALITY ASSURANCE 18
   4.2 USE OF SOFTWARE 18
   4.3 EXTERNAL DOSE CALCULATION 19
   4.4 INHALATION AND SUBMERSION DOSE CALCULATION 22
   4.5 TEDE DOSE CALCULATION 24

5. LIST OF ATTACHMENTS 24

6. BODY OF CALCULATION 24
   6.1 PROCESSING TASK PER WORKER 24
   6.2 EXTERNAL RADIATION DOSES BY TASK PER WORKER TYPE 25
   6.3 ANNUAL EXTERNAL EXPOSURE PER ALL CASKS PER WORKER TYPE 27
   6.4 WORKER TIME IN CONTINUOUS-ACCESS AREAS OF LOW RADIATION 27
   6.5 ANNUAL EXTERNAL DOSE PER WORK CREW WORKER 27
   6.6 ANNUAL EXTERNAL RADIATION DOSES 28
   6.7 ANNUAL INHALATION AND SUBMERSION DOSES 28
   6.8 TEDE DOSE CALCULATION 28

7. RESULTS AND CONCLUSIONS 29
   7.1 REGULATIONS 29
   7.2 ALARA DESIGN GOALS 30
   7.3 DISCUSSION 30
   7.4 RECOMMENDATIONS 30

ATTACHMENT 1 ANNUAL INHALATION AND SUBMERSION DOSES 31

ATTACHMENT 2 SENSITIVITY STUDY 35

ATTACHMENT 3 LISTING OF FILES CONTAINED ON COMPACT DISC 39

ATTACHMENT 4 COMPACT DISC CONTAINING THE ELECTRONIC FILES GENERATED BY THIS CALCULATION

TABLES

Page

1. Non-fixed External Radioactive Contamination Limits for Packages.....15
2. Half-Lives and DCFs for Selected Isotopes.....16
3. Dose Map for One Horizontal Cask (without Impact Limiters).....20
4. IHF Worker Dose Table.....26
5. Annual TEDE Doses by Worker Category (rem/yr).....29

ACRONYMS AND ABBREVIATIONS

ACRONYMS

ALARA	as low as is reasonably achievable
BSC	Bechtel SAIC Company, LLC
CEDE	committed effective dose equivalent
CTM	canister transfer machine
DCF	dose conversion factor
DDE	deep dose equivalent
DOE	U.S. Department of Energy
FGR	Federal Guidance Report
GWd	gigawatt day
HLW	high level radioactive waste
HPT	Health Physics Technician
HVAC	heating, ventilation, and air-conditioning
ICRP	International Commission on Radiation Protection
IHF	Initial Handling Facility
MTU	Metric Tons of Uranium
TC	transportation cask
TEDE	total effective dose equivalent
TEV	transport emplacement vehicle
SNF	spent nuclear fuel
WP	waste package

ABBREVIATIONS

Bq	Becquerel
Cal	calendar
Ci	Curie
cm	centimeter
dpm	disintegrations per minute
Eq.	equation

ft	feet
hr	hour
m	meter
min	minute
mL	milliliter
mrem	millirem
s	second
Sv	sievert
µ	micro
wt%	percent weight (weight fraction)
yr	year

1. PURPOSE

The purpose of this calculation is to estimate radiation doses received by personnel working in the Initial Handling Facility (IHF) who perform operations to transfer Navy Canisters and high-level radioactive waste (HLW) canisters to waste packages (WPs) for emplacement in the repository. The specific scope of work contained in this calculation covers both collective doses and individual worker doses on an annual basis, and includes contributions from external and internal radiation from normal operations, since there are no Category 1 event sequences associated with the IHF (Ref. 2.1.1, Section 7.2). Radiation dose contribution, if any, from contaminated air outside the IHF is not considered in this calculation. The results of this calculation will be used to support the design of the IHF and to provide occupational dose estimates for the license application.

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

2. REFERENCES

2.1 PROCEDURES/DIRECTIVES

2.1.1 BSC (Bechtel SAIC Company) 2005. *Categorization of Event Sequences for License Application.* 000-00C-MGR0-00800-000-00C. Las Vegas, Nevada: Bechtel SAIC Company. ACC: ENG.20050808.0003; ENG.20050929.0003.

2.1.2 EG-PRO-3DP-G04B-00037 Rev. 8, *Calculations and Analyses*. Las Vegas, Nevada: Bechtel SAIC Company. ACC: ENG.20070420.0002

2.1.3 BSC 2005. *Q-list*. 000-30R-MGR0-00500-000, Rev. 3. Las Vegas, Nevada: Bechtel SAIC Company. ACC: ENG.20050929.0008.

2.1.4 IT-PRO-0011-004. ICN 0 *Software Management.* Las Vegas, Nevada: Bechtel SAIC Company. ACC: DOC.20070319.0016.

2.1.5 BSC 2006. *Basis of Design for the TAD Canister-Based Repository Design Concept*. 000-3DR-MGR0-00300-000-000. Las Vegas, Nevada: Bechtel SAIC Company. ACC: ENG.20061023.0002.

2.1.6 BSC 2007. Application of ALARA in the YMP Design Process. EG-DSK-3701-Rev.1. Las Vegas, Nevada: Bechtel SAIC Company. ACC: ENG.20070312.0021.

2.2 DESIGN INPUTS

2.2.1 BSC 2007. *Initial Handling Facility General Arrangement Ground Floor Plan.* 51A-P10-IH00-00102-000. Las Vegas, Nevada: Bechtel SAIC Company. ACC: ENG.20070523.0028

2.2.2 BSC 2007. *Initial Handling Facility General Arrangement Second Floor Plan.* 51A-P10-IH00-00103-000. Las Vegas, Nevada: Bechtel SAIC Company. ACC:ENG.20070523.0029

2.2.3 BSC 2007. *Initial Handling Facility General Arrangement Sections A and B.* 51A-P10-IH00-00106-000. Las Vegas, Nevada: Bechtel SAIC Company. ACC:ENG.20070523.0032

2.2.4 BSC 2006. *Preliminary Throughput Study for the Initial Handling Facility.* 51A-30R-IH00-00100-000-000. Las Vegas, Nevada: Bechtel SAIC Company. ACC: ENG.20060814.0019.

2.2.5 BSC 2006. *Initial Handling Facility Layout Study.* 51A-30R-MGR0-00100-000-001. Las Vegas, Nevada: Bechtel SAIC Company. ACC: ENG.20061005.0005.

2.2.6 BSC 2004. *Shielding Calculation for Transportation Rail Cask Receipt.* 140-00C-HCR0-00200-000-00A. Las Vegas, Nevada: Bechtel SAIC. ACC: ENG.20041217.0002.

2.2.7 BSC 2007. *Initial Handling Facility Time and Motion Study*. 51A-30R-IH00-00200-000-000. Las Vegas, Nevada: Bechtel SAIC. ACC: ENG.20070502.0004.

2.2.8 DOE (U.S. Department of Energy) 1994. *Analysis of Experimental Data.* Volume 1 of *Airborne Release Fractions/Rates and Respirable Fractions for Nonreactor Nuclear Facilities.* DOE-HDBK-3010-94. Washington, D.C.: U.S. Department of Energy. TIC: 233366. (DIRS 103756)

2.2.9 NRC (U.S. Nuclear Regulatory Commission) 2001. *Final Environmental Impact Statement for the Construction and Operation of an Independent Spent Fuel Storage Installation on the Reservation of the Skull Valley Band of Goshute Indians and the Related Transportation Facility in Tooele County, Utah.* NUREG-1714. Two volumes. Washington, D.C.: U.S. Nuclear Regulatory Commission, Office of Nuclear Material Safety and Safeguards. TIC: 253836. (DIRS 157761)

2.2.10 Eckerman, K.F.; Wolbarst, A.B.; and Richardson, A.C.B. 1988. *Limiting Values of Radionuclide Intake and Air Concentration and Dose Conversion Factors for Inhalation, Submersion, and Ingestion.* EPA 520/1-88-020. Federal Guidance Report No. 11. Washington, D.C.: U.S. Environmental Protection Agency. ACC: MOL.20010726.0072. (DIRS 101069)

2.2.11 Kocher, D.C. 1981. *Radioactive Decay Data Tables, A Handbook of Decay Data for Application to Radiation Dosimetry and Radiological Assessments.* DOE/TIC-11026. Washington, D.C.: U.S. Department of Energy. TIC: 228074. (DIRS 105622)

2.2.12 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. (DIRS 107684)

2.2.13 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. (DIRS 172721)

2.2.14 EPA (U.S. Environmental Protection Agency) 2002. *Federal Guidance Report 13, CD Supplement, Cancer Risk Coefficients for Environmental Exposure to Radionuclides, EPA.* EPA-402-C-99-001, Rev. 1. [Washington, D.C.]: U.S. Environmental Protection Agency. ACC: MOL.20051013.0016. (DIRS 175544).

2.2.15 BSC 2005, *Normal Operation Airborne Release Calculation*. 000-HSC-WHS0-00200-000-00C. Las Vegas, Nevada: Bechtel SAIC. ACC: ENG.20050615.0018; ENG.20050801.0007.

2.2.16 Regulatory Guide 8.34, Rev. 0. 1992. *Monitoring Criteria and Methods to Calculate Occupational Radiation Doses.* Washington, D.C.: U.S. Nuclear Regulatory Commission. TIC: 8912. (DIRS 103658)

2.2.17 BSC 2007. *Classification of Radiation and Contamination Zones of Geologic Repository Operations Areas*. 000-00C-WHS0-01600-000-00A. Las Vegas, Nevada: Bechtel SAIC. ACC: ENG.20070130.0011.

2.2.18 BSC 2006. *Project Design Criteria Document.* 000-3DR-MGR0-00100-000-006. Las Vegas, Nevada: Bechtel SAIC Company. ACC: ENG. 20061201.0005; ENG.20070111.0025; ENG.20070111.0026; ENG.20070111.0027; ENG.20070111.0028; ENG.20070112.0001; ENG.20070201.0021; ENG.20070222.0011; ENG.20070222.0012; ENG.20070226.0030; ENG.20070308.0028; ENG.20070412.0001; ENG.20070501.0008; ENG.20070510.0002.

2.3 DESIGN CONSTRAINTS

2.3.1 10 CFR 71. 2006 Energy*: Packaging and Transportation of Radioactive Material*. Internet Accessible. (DIRS 176575)

2.3.2 49 CFR 173. 2005 Transportation: *Shippers-- General Requirements for Shipments and Packagings*. ACC: MOL.20060116.0146. (DIRS 176026)

2.3.3 10 CFR 20. 2006 Energy: *Standards for Protection Against Radiation*. Internet Accessible. (DIRS 176618)

2.4 DESIGN OUTPUTS

This calculation is performed to support information in the license application.

3. ASSUMPTIONS

3.1 ASSUMPTIONS REQUIRING VERIFICATION

3.1.1 Air Changes

Assumption: The air change rate in the IHF cask preparation area (Room 1012) during normal operations is assumed to be one air change per hour, with 10% of the air exchange comprised of outside air makeup, and the volume of the cask preparation room is 39,960 m^3.

Rationale: A typical nuclear heating, ventilation, and air-conditioning (HVAC) system for a nuclear facility has a room air turn over rate greater than 1 air change per hour and make up from outside air of 10% or more. Using one air change per hour with 10% of the air exchange comprised of outside air makeup is conservative. The volume of the cask preparation area (Room 1012) is estimated from Ref. 2.2.1, 2.2.2, and 2.2.3, and is considered conservative because it only considers the open volume of the room and not other open spaces such as the canister transfer machine (CTM) maintenance area (Room 1009), thus resulting in a smaller room volume which will effectively increase the airborne concentration in the room. When measurements are taken from the wall centerline, the wall portion of the total length is subtracted from the measurement. This volume is derived from Ref. 2.2.1, 2.2.2, and 2.2.3 as follows:
Room 1012.

Width = 86 ft – 2 ft north wall = 84 ft
Length = 160 ft
Height = 105 ft room height ceiling to floor
84 ft × 160 ft ×105 ft = 1,411,200 ft^3
1,411,200 ft^3/35.315 ft^3/m^3 = 39,960 m^3

Usage: This assumption is used in Attachment 1.

3.2 ASSUMPTIONS NOT REQUIRING VERIFICATION

3.2.1 Dose Rates

Assumption: The radiation dose rate distribution around a TS125 cask, Ref. 2.2.6, Figure 6.2-2, (Table 3) is used to estimate dose rates received by workers while processing a transportation cask (TC) in the IHF. It is assumed that this calculated data is representative of the conditions of the cask process in the IHF and can be used to estimate dose rates received by workers at various distances from the exterior surfaces of a TC.

Rationale: Per Ref. 2.2.4, Section 1.0 and Ref. 2.2.5 Section 3.1, the IHF will handle only sealed canistered waste, i.e., U.S. Department of Energy (DOE) HLW and Naval spent nuclear fuel (SNF) canisters for transfer to waste packages. The dose rates from the TS125 are considered representative of a loaded transportation cask. Dose rates in the vicinity of a TS125 rail cask have been determined in Ref. 2.2.6, Figure 6.2-2. All TCs received at the IHF are required to meet the requirements in Ref. 2.3.1 § 71.5 for packaging, preparation for shipment, and transportation of licensed materials. For the purpose of these dose calculations, it is expected that the TC will not exceed 200 mrem/hr at any point on the package external surface and 10 mrem/hr at 2 meters from the surface of the package which is consistent with the radiation dose rates of the TS125 (Ref. 2.2.6). Because this dose estimate is on an annual average basis, it is expected that all casks will meet the limits of Ref. 2.3.1 Section 47(a) limits. For the dose rate calculations in Ref. 2.2.6, the TS125 cask is situated 10 ft above a 2 ft thick concrete floor (Ref. 2.2.6 Section 5.2.1) in a void, no air density reduction. The gamma and neutron source terms for the fuel region were taken from Ref. 2.2.6 Section 5.1.7 which corresponds to 60 GWd/MTU burnup, 4.0 wt% initial ^{235}U enrichment, and 18 year cooling time. The use of this dose rate profile is representative of a typical rail cask containing spent fuel handled in the IHF.

Usage: This assumption is used in Sections 4.3 and 6.2.

3.2.2 Time and Motion Study

Assumption: Process task definitions for TC operations within the IHF, and their corresponding task durations, average worker distance, and times, are based on Reference 2.2.7 which have a conservatively 31.7 % longer amount of time per DOE HLW cask operation and 49.1% longer amount of time per Naval SNF cask operation than those described in Ref. 2.2.4.

Rationale: The operation process task steps, time durations, and average worker distance are necessary information for the determination of external and internal doses in the IHF. The number of Naval casks processed in the IHF per year is considered the bounding case scenario for this worker dose assessment, and therefore the task steps associated with the processing of a Naval cask are addressed in this calculation. The bounding theoretical number of 90 Naval casks processed on an annual basis is used in the calculation. Therefore, the Naval cask processing steps 2, 3B, and 6 are considered the bounding process steps for this calculation. The total time from Ref. 2.2.7, Table 1, Tasks 2, 3B, and 6 is 1215 minutes which is 49.1% longer per cask process than Ref. 2.2.4 Appendix B of 815 minutes (815 × 1.491 = 1215 minutes). The use of the longer durations for operations will encompass any changes in Ref. 2.2.4. To further illustrate this, a sensitivity study was performed and is provided as Attachment 2. This information represents reasonable estimates and is suitable for performing a worker dose estimate for this calculation at this stage of design of the IHF.

The following worker average distance locations for axial work are defined as:

1 m = 1 m away from the center axial plane of the cask surface and 2 m away vertical (radial)
2 m = 2 m away from the center axial plane of the cask surface and 2 m away vertical (radial)
5 m = 2 m away from the center axial plane of the cask surface and 5 m away vertical (radial)

The radial doses used are from the mid-plane and are 7.495 (rounded to 7.5) mrem/hr at 2 m, 2.912 (rounded to 2.9) mrem/hr at 5 m and 1.071 (rounded to 1.1) mrem/hr at 10 m (Ref. 2.2.6, Figure 6.2-2).

The top axial dose rates are 7.631 (rounded to 7.6) mrem/hr at 1 m average distance, 5.577 (rounded to 5.6) mrem/hr at 2 m average distance and 2.747 (rounded to 2.7) mrem/hr at 5 m average distance (Ref. 2.2.6, Figure 6.2-2).

Usage: This assumption is used in Sections 4.3, 6.2, Table 4, 6.7, and Attachment 2.

3.2.3 Average Distances

Assumption: Worker locations for cask preparation task steps in the IHF are defined in terms of distances from the TC. The distances are estimated from averaged worker locations to perform the specific tasks for cask preparation. In general, for hands-on activities (e.g., smears for surface contamination sampling), the worker is assumed to be 1 m from the cask. For processing tasks that are not hands-on but require the worker's presence in the area, the worker is assumed to be standing a reasonable distance from the cask. In addition to the general as low as is reasonably achievable (ALARA) concept of workers minimizing their time and maximizing their distance from sources, permanent engineered controls (shielding) would be expected to be designed/installed to protect personnel not required to perform tasks that are in the immediate proximity of the cask (ALARA-time, distance, shielding).

Rationale: Based on ALARA principles it is expected that workers will use distance as much as possible to reduce their radiation doses. They are expected to move to a reasonably distant location when not specifically required by a job function to be proximate to the cask. The approximate worker locations for the required cask preparation task steps in the IHF are selected from Ref. 2.2.7. Appropriate length tools will be used to facilitate the distances used.

Usage: This assumption is used in Sections 4.3, 6.2, and Attachment 2.

3.2.4 Staffing

Assumption: It is assumed that there will need to be 5 work crews to support the IHF operating 24/7. Staffing requirements and worker group categories include the following to support 24/7 operations:

- Operators
- Health Physics Technicians (HPTs)

The following make up a complete work crew:

- Five operators
- One HPT

Total work crews for facility:

- Five complete crews

Rationale: At least three crews are needed to support 24/7 operations. However, three crews would not allow for days off, holidays, vacation or sick leave. Five crews, each working 2,000 hours per year, would provide 10,000 hours per year coverage, which covers the number of hours per year required (8,760 hours in a year). This assumption is also consistent with shift coverage practices at facilities operating under 24/7 schedules. 5 operators and 1 HPT meet the minimum amount of personnel per crew to support cask operations (Ref. 2.2.7).

Usage: This assumption is used in Sections 6.1, 6.2, 6.7, and Attachment 1.

3.2.5 HPTs

Assumption: An HPT is assumed to be present whenever IHF workers are performing tasks involving exposure to radiation.

Rationale: The Ref. 2.2.7 has an HPT listed during material handling activities to support personnel on the day-to-day operation and processing activities. HPTs are within close proximity to operators with whom they work side-by-side. Every activity is surveyed and analyzed for radiological conditions. Radiation protection personnel are in a support role and do not perform hands-on activities. An HPT is assumed to be present whenever IHF personnel are performing tasks involving exposure to radiation. The HPT support personnel will use remote monitoring whenever possible to support cask processing operations to maintain ALARA.

Usage: This assumption is used in Sections 6.2 and Attachment 1.

3.2.6 Operation Support Personnel

Assumption: It is assumed that doses to operations support personnel will not be calculated because the calculation is bounded by the doses received by operations personnel and HPTs.

Rationale: The IHF will have support personnel that are "Not Hands-On." These personnel will generally be located in continuously accessible areas of low radiation that are well shielded from major radiation sources.

Usage: This is a general assumption for the IHF.

3.2.7 Throughput

Assumption: The total number of TCs and waste packages (WPs) that will be handled annually in the IHF is taken from Ref. 2.2.4, Table 1, and is 90 Naval HLW TCs and 90 WPs.

Rationale: While it is not expected that more than 24 Naval casks would arrive per year, the IHF throughput model (Ref. 2.2.4, Table 1) processed as many casks in one year to determine the maximum theoretical throughput. All of the Naval TCs are rail-based, and the bounding theoretical throughput number of 90 Naval casks processed on an annual basis is used in the calculation, thus the total number of TCs and WPs that will be handled annually in the IHF is 90. Per Ref. 2.2.4, Table 1, the annual number of Naval HLW casks processed is 90, and the annual number of waste packages generated is 90 WPs. The processing of a TC will result in higher

exposures to workers and longer evolutions, so using the higher number of 90 TCs is conservative and bounding.

Usage: This assumption is used in Sections 4.3.2, 6.1, 6.2 and Attachment 1.

3.2.8 Contamination Levels

Assumption: It is assumed that the non-fixed (removable) radioactive contamination on the external surface of a transportation cask is 10^{-4} μCi/cm^2 for beta and gamma emitters and low-toxicity alpha emitters, and 10^{-5} μCi/cm^2 for all other alpha emitters.

Rationale: The surface contamination levels used in this assumption are the regulatory limits for packages offered for transportation, per Ref. 2.3.2, Section 443(a), as set forth in Table 9 of that regulation. TCs accepted at the IHF are expected to meet the external contamination limits of Ref. 2.3.2, Section 443(a), which states, in part:

> "The level of non-fixed (removable) radioactive contamination on the external surfaces of each package offered for transport must be kept as low as reasonably achievable. The level of non-fixed radioactive contamination may not exceed the limits set forth in table 9…"

Therefore, this assumption is conservative for the purpose of calculating inhalation and submersion doses to workers due to resuspension from the cask surface. Table 9 of Ref. 2.3.2, Section 443(a), is reproduced in Table 1.

Table 1. Non-fixed External Radioactive Contamination Limits for packages.

Contaminant	Maximum permissible limits		
	Bq/cm^2	μCi/cm^2	dpm/cm^2
Beta and gamma emitters and low toxicity alpha emitters	4	10^{-4}	220
All other alpha emitting radionuclides	0.4	10^{-5}	22

Ref. 2.3.2 Table 9

Usage: This assumption is used in Section 6.7 and Attachment 1.

3.2.9 Resuspension

Assumption: It is assumed that the resuspension rate of surface contamination from the transportation cask is 4×10^{-5}/hr.

Rationale: This resuspension factor is the bounding value recommended for aerodynamic entrainment of powder lying on a heterogeneous surface (indoors or outdoors) exposed to ambient conditions following an event (Ref. 2.2.8, Section 5, p. 5-7, and Section 5.2.4, p. 5-21).

Usage: This assumption is used in Section 6.7 and Attachment 1.

3.2.10 Respirability

Assumption: It is assumed that all released or suspended radioactive particles are respirable.

Rationale: This assumption is appropriate because it yields the most conservative dose values. Furthermore, the DOE handbook for estimating airborne release fractions/rates and respirable fractions recommends a respirable fraction of 1 for aerodynamic entrainment of powder lying on a heterogeneous surface (indoors or outdoors) exposed to ambient conditions following an event (Ref. 2.2.15, Section 4.3.7).

Usage: This assumption is used in Section 6.7 and Attachment 1.

Nuclides

Assumption: The radioactive surface contamination on the TC is assumed to be cobalt-60 (^{60}Co), strontium-90 (^{90}Sr), plutonium-239 (^{239}Pu), and americium-241 (^{241}Am).

Rationale: ^{60}Co is assumed to be the chief isotope of concern because any contamination on the exterior surface of the TC containing SNF is likely to come from radioactive particulates suspended in the spent fuel pool water at the originating facility. At the time of loading, most of the dislodge occurs during SNF movement. The most prominent particulates are ^{60}Co, ^{58}Co, ^{55}Fe, ^{59}Fe, ^{54}Mn, ^{51}Cr, and ^{65}Zn (Ref. 2.2.9, p. 4-51). Of these products, ^{60}Co has the highest inhalation dose conversion factor (Ref. 2.2.10, Table 2.1) and half-life (5.27 years) (Ref. 2.2.11, p. 78).

The remaining isotopes are chosen because they are the most dose-significant, long-lived isotopes likely to be present in the HLW glass product. Table 2 lists the half-lives, effective inhalation dose conversion factors (DCFs) and submersion DCFs for the isotopes considered. A comparison of DCFs is also shown in Table 2.

Table 2. Half-Lives and DCFs for Selected Isotopes

		FGR 11	FGR 12	ICRP 68	FGR 13
Isotope [A]	**Half-Life (yr) [B]**	***DCF^{inh}* (Sv/Bq) [C]**	***DCF^{sub}* (Sv-m^3/Bq-s) [D]**	***DCF^{inh}* (Sv/Bq) [E]**	***DCF^{sub}* (Sv-m^3/Bq-s) [F]**
^{60}Co	5.271	5.91E-08	1.26E-13	2.90E-08	1.19E-13
^{90}Sr	28.6	3.51E-07	7.53E-18	1.50E-07	9.83E-17
^{239}Pu	24,131	1.16E-04	4.24E-18	4.70E-05	3.49E-18
^{241}Am	432.2	1.20E-04	8.18E-16	3.90E-05	6.77E-16

Sources: [A] Isotopes, Ref. 2.2.9

[B] Half Lives, Ref. 2.2.11, pp. 78, 99, 209, and 211.

[C] FGR11, Ref. 2.2.10 Table 2.1.

[D] FGR12, 2.2.12, Table III.1.

[E] ICRP68, Ref. 2.2.13.

[F] FGR13, Ref. 2.2.14, Table B.1.

Usage: This assumption is used in Section 6.7.

3.2.12 Surface Contamination Area

Assumption: Surface contamination is assumed to cover the entire external surface of a rail cask 51 m^2 (Ref. 2.2.15, Section 4.3.13) and all of it is assumed to be removable and releasable to the atmosphere.

Rationale: The amount of surface contamination assumed to be available for release to the atmosphere is 100%, significantly higher than is anticipated for the transportation casks handled at the IHF. This is because only a small portion, if any, of the cask's exterior would have any removable contamination due to preventive decontamination measures used during loading at the originating facility. Therefore, the amount of removable contamination hypothetically available to become airborne under normal and off-normal conditions would be significantly less than the amount assumed. Also, the amount of removable contamination available to go airborne contributes just a small fraction to the estimated dose of the worker, regardless of the cask size, or the isotopes used to represent α and $\beta\gamma$ emitters (Table 2). This is expected to be the case whether portions of a TC exceed the removable surface contamination limits upon arrival at the Yucca Mountain Repository. The use of this assumed value will yield conservative dose values.

Usage: This assumption is used in Section 6.7 and Attachment 1.

3.2.13 Worker Breathing Rate

Assumption: The IHF worker is assumed to be breathing at a rate of 20,000 mL/min, which is equivalent to 3.33×10^{-4} m^3/s.

Rationale: This is the breathing rate recommended to be used in calculating occupational doses due to inhalation intake by Ref. 2.2.16, p. 8.34-10, Equation A-1.

Usage: This assumption is used in Section 6.7 and Attachment 1.

3.2.14 Not Hands On Work

Assumption: It is assumed that all IHF worker-crew will be in an environment with an average external dose rate of 0.05 mrem/hr for non-cask processing times.

Rationale: When not performing work involved with processing canisters that will be loaded into waste packages, IHF work crews will be in either an unlimited occupancy possible area, (R1), or a routine occupancy possible area less than 2000 hrs/yr, (R2) (Ref. 2.2.17, Figure I-1-1). It is considered reasonable based on the area classification that the workers are on average residing in an environment where the dose rate is 0.05 mrem/hr when not involved in an operation.

Usage: This assumption is used in Sections 6.2, Table 4, 6.5 and Attachment 2.

3.2.15 Annual Number of Canisters Processed per Work Crew

Assumption: It is assumed that the average number of casks processed annually by each work crew is the total number of casks that will be handled annually in the IHF divided by the number of work crews supporting those cask processing tasks..

Rationale: A single work crew will not be present 24/7 to process casks. Crews will be rotated as necessary to level accumulated doses.

Usage: This assumption is used in Sections 6.1 and 6.7.

3.2.16 Loaded Transport Emplacement Vehicle Dose Rate

Assumption: It is assumed that the dose rates from Table 3 are representative of a loaded transport emplacement vehicle.

Rationale: Transport emplacement vehicles (TEV) will be designed to be less than or equal to 100 mrem/hr at 30 cm, per Ref. 2.2.18, p. 149, when loaded with any waste type. The TS125 cask can have up to 200 mrem/hr at any point on the package external surface and 10 mrem/hr at 2 meters from the surface of the package. Using the exposure rates from this configuration is more conservative than using the allowed TEV design criteria for exposure when loaded.

Usage: This assumption is used in Section 6.2 Table 4.

4. METHODOLOGY

This dose assessment involves the calculation of annual individual worker exposures and annual collective worker exposures resulting from the processing of loaded canisters in the IHF. 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 4.3. The methodology for calculating inhalation and submersion doses is described in Section 6.7. The total effective dose equivalent (TEDE) is calculated by summing the component doses from inhalation, submersion, and direct external radiation dose.

4.1 QUALITY ASSURANCE

This calculation was prepared in accordance with Ref. 2.1.2. The IHF has not yet been classified on *Q-List* (Ref. 2.1.3). Results of this calculation provide worker dose assessments that identify radiological hazards for facilities important to safety or important to waste isolation. Per the *Basis* of Design for the TAD Canister-Based Repository Design Concept (Ref. 2.1.5), the IHF structure is ITS. Therefore, the approved version is designated as QA: QA.

4.2 USE OF SOFTWARE

Microsoft® Excel® 2003 SR-2, a spreadsheet program, is used in this calculation. This software is installed on a personnel computer running Microsoft® XP Professional (Central Processing number 004619). 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 4.3), design inputs and assumptions (discussed in Sections 2.2 and 3.2), and results are documented in sufficient detail in Section 6 to allow hand checking for independent duplication of the various computations without recourse to the originator per Ref. 2.1.2. Microsoft® Excel® 2003 is listed on the Controlled Software Report and is identified in the Repository Project Management automation plan and the use of Excel constitutes level 2 software usage per Ref. 2.1.4 and does not require qualification. All calculation results generated from Excel were verified by hand calculation.

4.3 EXTERNAL DOSE CALCULATION

This dose assessment uses data from a time-motion study (Ref. 2.2.7) and dose rates calculated for worker locations from Table 1. Dose calculations are made on a per unit cask operation, and then multiplied by the annual number of loaded canister transfers to determine the total worker dose. The calculated total individual dose is compared with the ALARA design goal specified in Ref. 2.1.6. Different worker tasks are involved in the IHF operations from receiving the loaded canister through the WP exiting the facility. (Assumption 3.2.2).

4.3.1 Exposure rates for specific IHF canister operations

Per Assumptions 3.2.1, 3.2.2 and 3.2.3 the dose rates at various distances from a loaded TS125 cask are from the calculations in Ref. 2.2.6, Figure 6.2-2 as shown in Table 3.

Table 3. Dose Map for One Horizontal Cask (without Impact Limiters)

	center	2 m	5 m	10 m	15 m	20 m	30 m	40 m	50 m
40 m	0.091	0.130	0.108	0.103	0.092	0.081	0.062	0.046	0.033
30 m	0.150	0.217	0.205	0.179	0.151	0.128	0.092	0.064	0.043
20 m	0.317	0.396	0.370	0.295	0.235	0.187	0.121	0.081	0.053
15 m	0.513	0.713	0.594	0.430	0.324	0.244	0.148	0.093	0.058
10 m	1.115	1.541	1.092	0.679	0.452	0.320	0.174	0.104	0.063
5 m	3.397	3.370	1.967	1.000	0.591	0.381	0.191	0.109	0.065
2 m	11.192	5.577	2.747	1.192	0.639	0.406	0.194	0.112	0.066
1 m	19.641	7.631	3.159	1.256	0.680	0.413	0.197	0.111	0.066
Top axial	**cask**	9.097	3.435	1.313	0.677	0.412	0.200	0.113	0.067
	cask	7.015	2.801	1.112	0.597	0.375	0.183	0.104	0.062
mid-plane radial	**cask**	7.495	2.912	1.071	0.566	0.351	0.173	0.100	0.060
	cask	6.723	2.763	1.067	0.557	0.342	0.166	0.095	0.057
Bottom axial	**cask**	5.622	2.408	1.011	0.534	0.331	0.164	0.093	0.056
-1m	2.943	4.225	2.054	0.944	0.529	0.326	0.162	0.093	0.055
-2 m	1.611	2.761	1.669	0.830	0.495	0.318	0.157	0.092	0.055
-5 m	0.669	1.459	1.095	0.667	0.421	0.291	0.152	0.088	0.053
-10 m	0.269	0.483	0.520	0.401	0.304	0.226	0.131	0.082	0.049
-15 m	0.164	0.208	0.235	0.136	0.194	0.161	0.108	0.070	0.045
-20 m	0.104	0.128	0.140	0.141	0.135	0.115	0.084	0.059	0.039
-30 m	0.064	0.111	0.081	0.080	0.079	0.076	0.059	0.044	0.031
-40 m	0.034	0.040	0.044	0.046	0.045	0.043	0.038	0.030	0.022

The dose rates are given in mrem/hr. The displayed distances are from the surface of the cask to the dose points. See legend below for distance coordinates.

(Ref. 2.2.6 Figure 6.2-2)

LEGEND:

4.3.2 Annual Number of Cask Operations

Based on the design capacity of the IHF, the expected number of TCs that will be processed is 90 (Assumption 3.2.7) per year.

4.3.3 Process Tasks and Durations

Process tasks, durations, number of personnel and distances are obtained from Ref. 2.2.7. See Assumption 3.2.2.

4.3.4 Staffing

The staffing requirements and worker group categories are presented in (Assumption 3.2.4). The staffing requirements and worker group categories support 24 hr 7 day (24/7) operations.

4.3.5 Calculation of External Dose

For an operation such as canister processing, the external dose, ED_k, received by a worker for a task k is calculated as follows. The dose rates are at the locations of each operation task due to external radiation from the contained radiation sources.

$$ED_k = \frac{t_k}{60} \times EDR_{dist} \qquad \text{Eq. 1}$$

where

ED_k = external dose to a worker per task k (mrem/task)
t_k = duration of exposure per task k (minutes)
EDR_{dist} = external dose rate at the worker's distance (*dist*) from the source (mrem/hr)
60 = units conversion (minutes/hr)

The total external dose, ED_o, to a worker for a series of N different tasks per operation (e.g., canister handling) is calculated as follows:

$$ED_o = \sum_{k=1}^{N} ED_k \qquad \text{Eq. 2}$$

where

ED_o = external dose to a worker consisting of N different tasks (mrem/operation)

When not performing manual hands-on work on a canister, the individual in a work-crew is assumed to remain inside the IHF doing support activities in intermittent access lower radiation areas. This support-only time, T_n, is determined from the time available, i.e. 40 hrs/week × 50 week/year = 2000 hrs, minus the time performing canister tasks, T_o.

$$T_o = \sum_{k=1}^{N_C} \frac{t_k}{60} \times NP_C$$

$$\textit{and} \qquad \text{Eq. 3}$$

$$T_n = 2000\left(\frac{hrs}{yr}\right) - T_o$$

where

T_o	=	Time performing cask or canister tasks for worker (hrs/year)
T_n	=	Support-only time for worker (hrs/year)
NP_C	=	Annual number of casks processed per crew (casks/crew-year) = $OP_C / crews_g$
OP_C	=	Number of casks processed per year (casks/year)
$crews_g$	=	Number of work-crews
60	=	Units conversion (minutes/hr)

The total annual external dose, ED_g, to a worker for all transportation cask operations is calculated as:

$$ED_g = ED_C \times OP_C + T_n \times DR \qquad \text{Eq. 4}$$

where

ED_g	=	External dose to a worker (mrem/year)
ED_C	=	External dose to a worker per cask during cask processing tasks (mrem/cask)
OP_C	=	Number of casks processed per year (casks/year)
DR	=	Dose rate in areas of lower radiation (mrem/hr)

4.4 INHALATION AND SUBMERSION DOSE CALCULATION

All operations conducted within the IHF will involve sealed casks with very low levels of surface contamination.

The following methodology is used to calculate the airborne concentrations and resultant doses from potential resuspension of surface contamination on a transportation cask.

Without taking credit for radioactive decay, the airborne activity buildup in a room while the cask is present is given by:

$$\frac{dA_i}{dt} = \lambda_R S_i - \lambda_H A_i$$

and solving Eq. 5

$$A_i(t) = \frac{\lambda_R S_i}{\lambda_H}\left(1 - e^{-\lambda_H t}\right)$$

where:

A_i	=	airborne activity of isotope i at time t (μCi)
S_i	=	cask surface contamination activity of isotope i (μCi)
λ_R	=	surface contamination resuspension rate (hr^{-1})
λ_H	=	room HVAC turn over rate (hr^{-1})
t	=	duration of cask presence in the room (hr)

The airborne activity will decrease after the cask is removed from the area, and also due to the ventilation system normal operation. Therefore, the maximum airborne activity concentration occurs at the time of cask removal *t* and is determined by:

$$C_i(t) = \frac{\lambda_R S_i}{\lambda_H V_B}\left(1 - e^{-\lambda_H t_B}\right) \qquad \text{Eq. 6}$$

where:

C_i = airborne concentration of isotope *i* at time *t* (μCi/m^3)
V_B = room air volume (m^3)

The inhalation and submersion doses to a worker for task, *k*, due to resuspension are given by:

$$H_k^{inh} = \sum_i C_i(t) \times DCF_i^{inh} \times 3.7 \times 10^9 \times RF \times BR \times t_k \times 60$$
$$H_k^{sub} = \sum_i C_i(t) \times DCF_i^{sub} \times 3.7 \times 10^9 \times t_k \times 60 \qquad \text{Eq. 7}$$

where:

H_k^{inh} = inhalation dose (mrem)
H_k^{sub} = submersion dose (mrem)
DCF_i^{inh} = inhalation dose conversion factor for isotope *i* (Sv/Bq)
RF = respirable fraction (= 1 per Assumption 3.2.10)
BR = occupational breathing rate (m^3/s)
DCF_i^{sub} = submersion DCF for isotope *i* (Sv-m^3/Bq-s)
t_k = duration of exposure per operation task *k* (minutes) (i.e., residence time in airborne activity)
60 = units conversion (s/min)
3.7×10^9 = units conversion (mrem Bq/Sv μCi)

The total inhalation and submersion dose, ID_o, to a worker for a series of *N* different tasks per cask handling operation in the IHF in the presence of airborne activity is calculated as follows:

$$ID_o = \sum_{k=1}^{N}\left(H_k^{inh} + H_k^{sub}\right) \qquad \text{Eq. 8}$$

where

ID_o = inhalation and submersion dose to a worker per operation consisting of *N* different tasks (mrem/operation)

The total annual inhalation and submersion dose, ID_g, to a worker in a work-crew for all operations is calculated as:

$$ID_g = \sum_o ID_o \times \frac{OP}{crews_g} \qquad \text{Eq. 9}$$

where

ID_g = inhalation and submersion dose to a worker (mrem/year)

$crews_g$ = number of workers in a work crew performing this operation
OP = total number of these operations, o, per year

The annual maximum internal and external doses to an IHF worker due to re-suspension of surface contamination on a canister are much lower than the contribution from the direct external dose for all worker categories and are therefore considered to be an insignificant contributor to the totals presented in Section 6.8. See Attachment 1.

4.5 TEDE DOSE CALCULATION

The annual TEDE to a worker, $TEDE_g$, in a work-crew is calculated by summing the component doses from inhalation, submersion and direct external radiation doses.

$$TEDE_g = ID_g + ED_g \qquad \text{Eq. 10}$$

where
$TEDE_g$ = annual TEDE to a worker (mrem/year)

5. LIST OF ATTACHMENTS

	Number of Pages
Attachment 1: Annual Inhalation and Submersion Doses	4
Attachment 2: Sensitivity Study	4
Attachment 3: Listing of Files Contained on Compact Disc	1
Attachment 4: Compact Disc Containing the Electronic Files Generated by this Calculation	1 CD

6. BODY OF CALCULATION

6.1 PROCESSING TASK PER WORKER

The average number of TCs processed annually by each work crew is the total number of TCs that will be handled annually in the IHF divided by the number of work crews performing those operations. Per Assumption 3.2.7, the IHF throughput is 90 TCs and 90 WPs. The annual number of TCs processed per work crew is OP_c divided by the number of work crews (five crews per Assumptions 3.2.4, 3.2.15). Thus, a work crew will process an estimated annual average of 18 TCs (i.e., 90/5). The annual number of WPs processed per work crew is OP_c divided by the number of crews (5 crews per assembly). Thus a work crew will process an estimated annual average of 18 WPs (90/5). The total time expected to process a single transportation cask in the cask preparation room is equal to 810 min (Ref. 2.2.7, Table 1, Tasks 2 and 3B). These specific tasks are shown in Table 4. Table 4 also includes the tasks for waste package load out into a TEV that involve personnel (Ref. 2.2.7, Table 1, Task 6) (405 minutes).

Process time for 1 TC into the facility is 810 min.

Process time for 1 WP out of the facility is 405 min.

810 min. + 405 min. = 1215 min.

This results in a total process time of 1215 minutes that involves personnel.

6.2 EXTERNAL RADIATION DOSES PER CASK PER WORKER TYPE

The total dose incurred per cask by workers involved in cask processing operations at the IHF (HPTs or operators), and the IHF total annual exposure for all workers, are calculated and listed in Table 4, using Eq. 1.

The total external dose, ED_o, to a worker for a series of N different tasks per operation (e.g., canister handling) is calculated and listed in Table 4, using Eq.2.

The total annual dose, ED_{anl}, to a worker to process 18 casks/yr (per section 6.1) divided by 1000 mrem/rem and is calculated as follows:

$$ED_{anl} = ED_o \times 18 \frac{casks}{yr} / 1000 \frac{mrem}{rem} \qquad \text{Eq. 11}$$

where

ED_{anl} = total annual external dose to a worker to process 18 casks (person-rem/yr)

ED_o = external dose to a worker per operation (processing 1 cask) consisting of N different tasks (mrem/task, processing 1 casks)

The total annual dose, ED_{crew}, to a work crew to process 18 casks/yr (per section 6.1) is calculated, using Assumption 3.2.5, 5 operators and 1 HPT per work crew and Assumption 3.2.4, 5 crews working annually in the IHF, as follows:

$$ED_{crew} = (ED_{anl}\ (Operator) \times 5 + ED_{anl}(HPT)) \times 5 \qquad \text{Eq. 12}$$

where

ED_{crew} = total annual external dose to a work crew to process 18 casks (person-rem/yr)

HPT = HPT total exposure

Table 4. IHF Worker Dose Table****

IHF								
Process Step [A]	Time (min) [B]	Time (hr) [C]	Distance (m) [D] See NOTE *	Worker Dose Rate (mrem/hr) [E] See NOTE **	Single Worker Dose (mrem) [F]	Distance (m) [G] See NOTE *	Worker Dose Rate (mrem/hr) [H] See NOTE **	Single Worker Dose (mrem) [I]
Receive and Process Naval SNF canister								
Open IHF exterior door	5	**0.08**	0	0.05	**0.0**	0	0.05	**0.0**
Park/secure loaded TC conveyance in cask prep. area	10	**0.17**	2	7.5	**1.3**	5	2.9	**0.5**
Close IHF entrance door	5	**0.08**	0	0.05	**0.0**	0	0.05	**0.0**
Perform inspection and radiological survey	60	**1.00**	2	7.5	**7.5**	2	7.5	**7.5**
Secure conveyance and prepare TC for removal	60	**1.00**	2	7.5	**7.5**	0	0.05	**0.1**
Remove and store personnel barriers	45	**0.75**	2	7.5	**5.6**	5	2.7	**2.0**
Install pivot adapter	45	**0.75**	1	7.6	**5.7**	0	0.05	**0.0**
Install cask lifting plate	45	**0.75**	1	7.6	**5.7**	0	0.05	**0.0**
Remove clamps and tie downs	30	**0.50**	1	7.6	**3.8**	2	5.6	**2.8**
Upend the loaded TC on the transportation conveyance	10	**0.17**	0	0.05	**0.0**	0	0.05	**0.0**
Move the loaded TC to cask transfer trolley	5	**0.08**	0	0.05	**0.0**	0	0.05	**0.0**
Secure the TC to cask transfer trolley	30	**0.50**	1	7.6	**3.8**	2	5.6	**2.8**
Install floor accesss platform around cask transfer trolley	10	**0.17**	1	7.6	**1.3**	2	5.6	**0.9**
Remove upper impact limiter bolts	60	**1.00**	1	7.6	**7.6**	2	5.6	**5.6**
Remove upper impact limiter	5	**0.08**	0	0.05	**0.0**	0	0.05	**0.0**
Place upper impact limiter in storage	5	**0.08**	0	0.05	**0.0**	0	0.05	**0.0**
Remove TC lid bolts and lid	60	**1.00**	1	7.6	**7.6**	2	5.6	**5.6**
Place TC lid on cask lid stand	5	**0.08**	0	0.05	**0.0**	0	0.05	**0.0**
Remove cask shear and backing ring segments	120	**2.00**	1	7.6	**15.2**	2	5.6	**11.2**
Remove and stage cask shield plug (cask restraint plate)	60	**1.00**	1	7.6	**7.6**	2	5.6	**5.6**
Attach naval canister lifting device	15	**0.25**	1	7.6	**1.9**	0	0.05	**0.0**
Remove and store naval canister shield ring	15	**0.25**	0	0.05	**0.0**	0	0.05	**0.0**
Remove floor access platform	15	**0.25**	1	7.6	**1.9**	2	5.6	**1.4**
Move loaded TC on cask transfer trolley to cask unloading room	90	**1.50**	5	2.9	**4.4**	5	2.9	**4.4**
Export loaded WP from IHF in a TEV	375	**6.25**	0	0.05	**0.3**	0	0.05	**0.3**
Survey TEV	30	**0.50**	0	0.05	**0.0**	1	7.6	**3.8**
Survey TEV***						2	5.6	**2.8**
Total	1215	**20.25**		Total	**88.7**		Total	**57.4**

Individual dose (Equation 11)	Operator (1)	**1.6** person-rem/yr				
5 Operators and 1 HPT	Per crew	**9.0** person-rem/yr		HPT (1)	**1.0**	person-rem/yr
External Dose to Work Crews (Equation 12)	Crews (5)	**45.1** person-rem/yr				

Column [A]: From Ref. 2.2.7 Table 1
Column [B]: From Ref. 2.2.7 Table 1
Column [C]: Column [B]/60
Column [D]: From Ref. 2.2.7 Table 1
Column [E]: From Table 3 (Assumption 3.2.2) and Assumption 3.2.14
Column [F]: [C] ×[E]
Column [G]: From Ref. 2.2.7 Table 1

LEGEND:
TOP AXIAL
MID-PLANE RADIAL

Column [H]: From Table 3 (Assumption 3.2.2) and Assumption 3.2.14
Column [I]: [C] × [H]
Equation 1 used for [F] and [I]
—
Equation 2 used for the total of [F] and [I]

NOTE*: 0 in this column corresponds to a remote operation in 0.05mrem/hr background. See Assumption 3.2.14
NOTE**: Dose rate values are rounded to the nearest tenth.
NOTE***: Denotes second HPT dose while supporting the first HPT.This dose applies only to the survey of the TEV task step.
NOTE****: Values have been rounded in the table. See Attachment 4 for exact values used in calculation.

Table 4 (Attachment 4, IHFexternal.xls) estimates a total external exposure for one IHF operator to be 88.7 mrem for processing one WP. Table 4 estimates a total external exposure for one HPT to be 57.4 mrem for processing one WP.

6.3 ANNUAL EXTERNAL EXPOSURE PER ALL CASKS PER WORKER TYPE

The total annual external dose to a worker for all cask transfer operations is given by taking the individual doses to each worker for each set of task steps to process one cask and to process one waste package, and multiplying them by the frequency of operations.

To obtain the worker type total annual external exposure for all cask and WP operations, the total worker type exposure to process one cask from Table 4 is multiplied by 18, which gives the total annual external dose to a specific worker type for all cask transfer operations in which the worker will be involved. The HPT and IHF operator are calculated separately.

A sensitivity study of task times is included in Attachment 2. The sensitivity study takes plus or minus 20% per task time for the times to process one cask. This is done by multiplying each step time by 0.80 and 1.20 with the results totaled at the bottom. This sensitivity test shows the effect of reducing or increasing the time to perform each step or the overall time to process one cask.

6.4 WORKER TIME IN CONTINUOUS-ACCESS AREAS OF LOW RADIATION

The time in continuous-access low radiation areas, T_n, with Equation 3 from the annual time available (i.e., 40 hr/week × 50 weeks/year = 2,000 hr) minus the time performing manual cask operations, T_o (from table 4):

Eq.3

$$T_O = \sum_{k=1}^{N_c} \frac{t_k}{60} \times NP_c$$

$$T_O = \frac{1215\left(\frac{\min}{cask}\right)}{60\left(\frac{\min}{hr}\right)} \times 18\left(\frac{cask}{crew-yr}\right)$$

$$= 364.5\left(\frac{hrs}{yr}\right)$$

and

$$T_n = 2000\left(\frac{hrs}{cal.yr}\right) - T_O = 2000\left(\frac{hrs}{cal.yr}\right) - 364.5\left(\frac{hrs}{yr}\right) = 1635.5\left(\frac{hrs}{yr}\right)$$

6.5 ANNUAL EXTERNAL DOSE PER WORK CREW WORKER

The total annual external dose, ED_g, to a worker in a work crew for performing cask operation tasks including support-only time (Assumption 3.2.14) is calculated by using Equation 4 for each worker type:

For an operator:

$$ED_g = (88.7\frac{\text{mrem}}{\text{WP}} \times 18\ \frac{\text{WP}}{\text{yr}} + (\ 0.05\ \frac{\text{mrem}}{\text{hr}} \times 1635.5\ \frac{\text{hrs}}{\text{yr}}\ ))/1000\ \frac{\text{mrem}}{\text{rem}} = 1.7\,person - rem \qquad \text{Eq. 4}$$

For an HPT:

$$ED_g = (57.4\frac{mrem}{WP} \times 18\frac{WP}{yr} + (\ 0.05\frac{mrem}{hr} \times 1635.5\frac{hrs}{yr}\ ))/1000\frac{mrem}{rem} = 1.1\,person - rem \qquad \text{Eq. 4}$$

6.6 ANNUAL EXTERNAL RADIATION DOSES

The average estimated doses to an individual IHF operator is 1.7 rem per year and to an individual HPT is 1.1 rem per year.

The total annual facility external radiation dose to all workers is equal to the annual dose to a single work crew (1.7 rem/operator/yr x 5 operators/crew) plus the dose to 1 HPT (1.1 rem/yr), which results in (9.6 rem/crew) and then multiplied by the total number of work crews expected to be working throughout a year in the facility, 5, to obtain 48.0 person-rem.

6.7 ANNUAL INHALATION AND SUBMERSION DOSES

Airborne concentrations, and inhalation and submersion doses, are determined based on the methodology in Section 4.4. The airborne concentration of radioactive contamination from a release of surface contamination from a transportation cask is determined as a time-dependent buildup. The concentration builds up while the cask is present in the facility resulting from resuspension off the cask surface and eventually decreases after the cask leaves the facility because of the air exchange provided by the HVAC system.

All operations conducted within the IHF will involve sealed casks with very low levels of surface contamination. The annual maximum internal and external doses to an IHF worker due to re-suspension of surface contamination on a canister are much lower than the contribution from the direct external dose for all worker categories and are therefore considered to be an insignificant contributor to the totals presented in Section 6.8. See Attachment 1.

6.8 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 isotopes considered, using Eq. 10. All operations conducted within the IHF will involve sealed casks with very low levels of surface contamination. The annual maximum internal and external doses to an IHF worker due to re-suspension of surface contamination on a canister are much lower than the contribution from the direct external dose for all worker categories and are therefore considered to be an insignificant contributor to the totals presented in Table 5 below. The annual TEDE doses by worker category are also calculated in Table 5 below.

Table 5. Annual TEDE Doses by Worker Category (rem/yr)

Doses from IHF Operations	Symbol	Units	Operator	Health Physics
External Dose	ED_g	rem/yr	1.7	1.1
Inhalation Dose (CEDE) + Submersion (DDE)	ID_g	rem/yr	3.30E-04	3.30E-04
Total Annual Doses by Worker Group		rem/yr	**1.7**	**1.1**

CEDE = committed effective dose equivalent; DDE = deep dose equivalent.

7. RESULTS AND CONCLUSIONS

The results of this dose assessment calculation are summarized in Section 6.6. The parameters used in the dose calculations are supported by appropriate and conservative input data and assumptions. The calculated worker doses in Section 6.8 represent reasonable, bounding 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 that workers will receive, and by the duration of cask processing operations. However, the selected inputs are judged to be representative of the operating conditions. From Section 6.8, the average estimated dose to an individual IHF worker is 1.7 rem/yr and to an individual HPT is 1.1 rem/yr.

These doses are in compliance with the requirements of Ref. 2.3.3, Section 1201(a) (1) (i), limit of 5 rem per year for occupational workers. The IHF estimated annual doses do not contribute to the ALARA design goal of minimizing the number of workers exposed to more than 0.5 rem per year.

7.1 REGULATIONS

The regulation applicable to worker doses is provided in Ref. 2.3.3 Section 1201 as specified in Ref. 2.2.18, Section 4.10.1.

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: A lens dose equivalent of 15 rems, and a shallow-dose equivalent of 50 rems to the skin or to any extremity.

7.2 ALARA DESIGN GOALS

ALARA design goals (Ref. 2.2.18, Section 4.10.3.3.1) for occupational workers ensure that individual annual doses are maintained at ALARA levels during normal operations or during a potential 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 TEDE. That goal is 10 percent of the annual TEDE limit in 10 CFR 20.1201 (Ref 2.2.3), and includes both internal and external exposures."

7.3 DISCUSSION

This estimate is based on best available estimates or projections of annual IHF processing rates with the current throughput model. Dose rates are based on representative cask configurations based on the IHF time and motion studies.

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

7.4 RECOMMENDATIONS

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

The principal contributor to the worker dose is external radiation from cask handling operations in the IHF. The contribution from the airborne source is negligible. The IHF operators and HPTs will receive the highest dose during the processing of loaded canisters resulting from the high frequency of this process in the facility. The doses to the IHF workers does not contribute to the ALARA design goal of minimizing the number of workers exposed to more than 0.5 rem per year. 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 additional shielding for higher dose operations, use of more automation, and use of remote monitoring/surveillance techniques.

In addition to the general ALARA concept of workers minimizing their time and maximizing their distance from sources, permanent engineered controls (shielding) would be expected to be designed/installed to protect personnel not required to perform tasks that are in the immediate proximity of the cask (ALARA-time, distance, shielding).

ATTACHMENT 1

ANNUAL INHALATION AND SUBMERSION DOSES

Airborne concentrations, and inhalation and submersion doses, are determined based on the methodology in Section 4.4. The airborne concentration of radioactive contamination from a release of surface contamination from a transportation cask is determined as a time-dependent buildup. The concentration builds up while the cask is present in the facility resulting from resuspension off the cask surface and eventually decreases after the cask leaves the facility because of the air exchange provided by the HVAC system.

Surface Contamination Available for Resuspension

The amount of radioactive contamination on the surface of a cask is a function of the assumed contamination level, the radioisotopes present, and the surface area covered by contamination.

Per Assumption 3.2.12, surface contamination is assumed to cover the entire external surface of the transportation casks and it is assumed to be removable and releasable to the atmosphere.

The external surface area of a cask is 51 m^2 per Assumption 3.2.12.

Per Assumption 3.2.8, the non-fixed (removable) radioactive contamination on the external surface of a transportation cask is 10^{-4} μCi/cm^2 for beta and gamma emitters, and low-toxicity alpha emitters, and 10^{-5} μCi/cm^2 for all other alpha emitters. Therefore, the amount of activity available to be released from the cask surface is:

$$S_{\beta\gamma} = 10^{-4}\left(\mu Ci / cm^2\right) \times 5.1\times10^5\left(cm^2\right) = 51\ \mu Ci$$

and

$$S_{\alpha} = 10^{-5}\left(\mu Ci / cm^2\right) \times 5.1\times10^5\left(cm^2\right) = 5.1\ \mu Ci$$

Per Assumption 3.2.11, four radioisotopes are considered to dominate the doses resulting from airborne contamination: ^{60}Co, ^{90}Sr, ^{239}Pu, and ^{241}Am. ^{60}Co and ^{90}Sr are beta/gamma emitters, and ^{239}Pu and ^{241}Am are primarily alpha emitters.

Airborne Radioactivity Buildup While Cask is in IHF

Radioactive contamination resuspended off the transportation cask surface would be dispersed within the free air volume of the cask preparation area (Room 1012). The maximum time the cask could be present would be equal to the total cask processing time 1215 min, which includes cask import and export times to process one cask as described in Section 6.1.

The IHF ventilation fresh air intake rate, λ_H, is the product of the HVAC air exchange rate, 1 hr^{-1}, and the outside air fraction, 10%, per Assumption 3.1.1. Thus,

$$\lambda_H = 1\ hr^{-1} \times 10\% = 0.1\ hr^{-1}$$

The buildup of airborne radioactivity concentration in the IHF cask handling area is determined from Equation 6 with t_B equal to infinity and λ_R, the surface contamination resuspension rate, equal to 4×10^{-5} hr^{-1} per Assumption 3.2.9. The volume of the cask preparation room is 39,960 m^3 per Assumption 3.1.1.

The calculation for airborne concentration at equilibrium is:

$$C_i(\infty) = \frac{\lambda_R S_i}{\lambda_H V_B}\left(1 - e^{-\lambda_H \infty}\right) = \frac{\lambda_R S_i}{\lambda_H V_B} = \frac{4\times10^{-5}\left(hr^{-1}\right) S_i(\mu Ci)}{0.1\left(hr^{-1}\right) \times 39{,}960\left(m^3\right)} = 1.001\times10^{-8}\left(m^{-3}\right) \times S_i(\mu Ci)$$

Therefore, airborne concentration at equilibrium for beta and gamma emitters and low-toxicity alpha emitters and for all other alpha emitters based on the surface activity is:

$$C_{\beta\gamma}(\infty) = 1.001\times10^{-8}\left(m^{-3}\right)\times S_{\beta\gamma}(\mu Ci) = 1.001\times10^{-8}\left(m^{-3}\right)\times 51\,\mu Ci = 5.11\times10^{-7}\left(\mu Ci/m^3\right)$$

and

$$C_{\alpha}(\infty) = 1.001\times10^{-8}\left(m^{-3}\right)\times S_{\alpha}(\mu Ci) = 1.001\times10^{-8}\left(m^{-3}\right)\times 5.1\,\mu Ci = 5.11\times10^{-8}\left(\mu Ci/m^3\right)$$

Worker Inhalation and Submersion Doses per Cask

The inhalation and submersion doses to a worker resulting from resuspension of contamination from a single cask for a duration of t_k minutes are determined from Equation 7:

$$H_k^{inh} = \sum_i C_i(t) \times DCF_i^{inh} \times 3.7\times10^9 \times RF \times BR \times t_k \times 60$$

$$H_k^{sub} = \sum_i C_i(t) \times DCF_i^{sub} \times 3.7\times10^9 \times t_k \times 60$$

The exposure duration t_k is conservatively taken as the total cask processing time 1215 min from Section 6.1 and accounts for all different tasks in the cask processing operation. Per Assumption 3.2.10, the respirable fraction, RF, is 1. The breathing rate, BR, is 3.33×10^{-4} m^3/s per Assumption 3.2.13.

The total inhalation and submersion dose, ID_o, to a worker for all cask processing tasks resulting from the presence of airborne activity is determined from Equation 8 with $N = 1$ because the exposure duration t_k is conservatively taken as total cask processing time and includes all tasks:

$$ID_o = \left(H_k^{inh} + H_k^{sub}\right)$$

The results of applying equations 7 and 8 to determine *IDo* (mrem/cask) are given in the following tables below. Per Assumption 3.2.11, the dominant beta/gamma-emitting isotopes are

^{60}Co and ^{90}Sr, and the dominant alpha-emitting isotopes are ^{239}Pu and ^{241}Am. The effective inhalation and submersion DCFs for these isotopes are given in Assumption 3.2.11.

The dose per cask due to inhalation and submersion is conservatively taken as the sum of the calculated ^{60}Co, ^{90}Sr, ^{239}Pu, and ^{241}Am doses. The doses are then summed to estimate the total inhalation and submersion dose, ID_o, to a worker in group g for all the cask processing tasks.

Inhalation and Submersion Doses FGR 11 and FGR 12

Isotope	$C_{\beta-\gamma}$ or C_α (µCi/m^3)	DCF^{inh} (Sv/Bq)	H^{inh} (mrem/cask)	DCF^{sub} (Sv/Bq-s-m^{-3})	H^{sub} (mrem/cask)	ID_o (mrem/cask)
^{60}Co	5.11E-07	5.91E-08	4.52E-05	1.26E-13	2.89E-07	4.55E-05
^{90}Sr-90	5.11E-07	3.51E-07	2.69E-04	7.53E-18	1.73E-11	2.69E-04
^{239}Pu	5.11E-08	1.16E-04	8.87E-03	4.24E-18	9.74E-13	8.87E-03
^{241}Am	5.11E-08	1.20E-04	9.18E-03	8.18E-16	1.88E-10	9.18E-03
					Max ID_o (β–γ) +Max ID_o (α) =	1.84E-02

Sources: Ref. 2.2.10, Table 2.1 and 2.2.12, Table III.1

Inhalation and Submersion Doses ICRP-68 and FGR 13.

Isotope	$C_{\beta-\gamma}$ or C_α (µCi/m^3)	DCF^{inh} (Sv/Bq)	H^{inh} (mrem/cask)	DCF^{sub} (Sv/Bq-s-m^{-3})	H^{sub} (mrem/cask)	ID_o (mrem/cask)
^{60}Co	5.11E-07	2.90E-08	2.22E-05	1.19E-13	2.73E-07	2.25E-05
^{90}Sr	5.11E-07	1.50E-07	1.15E-04	9.83E-17	2.26E-10	1.15E-04
^{239}Pu	5.11E-08	4.70E-05	3.60E-03	3.49E-18	8.02E-13	3.60E-03
^{241}Am	5.11E-08	3.90E-05	2.98E-03	6.77E-16	1.56E-10	2.98E-03
					Max ID_o (β–γ) +Max ID_o (α) =	6.72E-03

Sources: Ref. 2.2.13, Table B.1 and 2.2.14, Table F12TIII1

Although many of the biokinetic and dosimetric models used in FGR 13 are updates of models used in FGR 11, the present report does not replace either that document or FGR 12 or affect their use for radiation protection purposes. The dose coefficients given in FGR 11 and FGR 12 continue to be recommended for determining conformance with radiation protection guidance to Federal agencies. The values cited for submersion from FGR 13 are the submersion values from FGR 12 with the ICRP 60 weighting factors applied to them and can be found in the FGR 13 (Ref. 2.2.14) supplement CD Table F12TIII1 using Microsoft notepad.

Using FGR 11 (Ref. 2.2.10) and FGR 12 (Ref. 2.2.12), values result in a higher and more conservative exposure estimate of 1.84E-02 mrem/cask (Attachment 4, IHFexternal.xls) and will be used to calculate the total annual inhalation and submersion doses.

The total annual inhalation and submersion dose, ID_g, to a worker in a work crew for all cask processing task steps is determined from Equation 9 with the total number of operations, *OP*, equal to the number of casks processed per year of 90 casks (Assumption 3.2.7) and the number of work crews, $crews_g$, in the cask operations group of five work crews (Assumption 3.2.4).

$$ID_g = \sum_o ID_o \times \frac{OP}{crews_g} = 1.84\times10^{-2}\left(\frac{mrem}{cask}\right) \times \frac{90\left(\frac{casks}{yr}\right)}{5} = 0.33\left(\frac{mrem}{yr}\right)$$

This dose of 0.33 mrem/yr is applied to both the operator and the HPT because they are present in the cask preparation room and is shown to be insignificant to the overall TEDE in Table 5 of section 6.8.

ATTACHMENT 2

SENSITIVITY STUDY

This sensitivity study table takes plus or minus 20% per task time for the durations to process one cask. This is done by multiplying each step time by 0.80 and 1.20 with the results totaled at the bottom. This sensitivity test shows the effect of reducing or increasing the task time to perform each step and the overall duration to process one cask. An increase of 20% per task time results in an increase of 0.318 person-rem/yr, while a decrease of 20% per task time results in a decrease of 0.318 person-rem/yr from the base case dose presented in Section 6.2, Table 4 of 1.596 person-rem/yr (Attachment 4, IHFexternalSensitivity.xls). The sensitivity study shows that the result of the worker dose assessment is directly proportional to the task time. Based on Assumption 3.2.2 the task times presented for the base case shown in Section 6.2, Table 4 have a 49.1% longer total duration than Ref. 2.2.4. The sensitivity study shows that even with a 20% per task time reduction from the base case, the dose only changes by 0.318 person-rem/yr. Thus, the results presented in the base case are conservative even if the total task duration in Ref. 2.2.4 increases by 49.1% since it would take another 400 minutes (815 × .491 = 400) to obtain the total task duration of 1215 minutes in Reference 2.2.7.

Sensitivity Study

Attachment 2

IHF			Operator			HPT			Sensitivity Check			
Process Step [A]	**Time (min) [B]**	**Time (hr) [C]**	**Distance (m) [D] See NOTE ***	**Worker Dose Rate (mrem/hr) [E]**	**Single Worker Dose (mrem) [F]**	**Distance (m) [G] See NOTE ***	**Worker Dose Rate (mrem/hr) [H]**	**Single Worker Dose (mrem) [I]**	**-20% Time [J]**	**Single Worker Dose (mrem) [K]**	**+20% Time [L]**	**Single Worker Dose (mrem) [M]**
Receive and Process DOE HLW Canister												
Open IHF Exterior Door	5	**0.08**	0	0.05	**0.0**	0	0.05	**0.0**	0.07	0.003	0.1	0.01
Park and Secure Loaded TC Conveyance in Cask Preparation Area	10	**0.17**	2	7.5	**1.3**	5	2.9	**0.5**	0.1	1.0	0.2	1.5
Close IHF Entrance Door	5	**0.08**	0	0.05	**0.0**	0	0.05	**0.0**	0.07	0.003	0.1	0.01
Perform Inspection and Radiological Survey	60	**1.00**	2	7.5	**7.5**	2	7.5	**7.5**	0.8	6.0	1.2	9.0
Secure Conveyance and Prepare TC for Removal	60	**1.00**	2	7.5	**7.5**	0	0.05	**0.05**	0.8	6.0	1.2	9.0
Remove and Store Personnel Barriers	45	**0.75**	2	7.5	**5.6**	5	2.7	**2.0**	0.6	4.5	0.9	6.8
Install pivot adapter	45	**0.75**	1	7.6	**5.7**	0	0.05	**0.04**	0.6	4.6	0.9	6.8
Install cask lifting plate	45	**0.75**	1	7.6	**5.7**	0	0.05	**0.04**	0.6	4.6	0.9	6.8
Remove clamps and tie downs	30	**0.50**	1	7.5	**3.8**	2	5.6	**2.8**	0.4	3.0	0.6	4.6
Upend the loaded TC on the transportation conveyance	10	**0.17**	0	0.05	**0.01**	0	0.05	**0.01**	0.1	0.007	0.2	0.01
Move the loaded TC to cask transfer trolley	5	**0.08**	0	0.05	**0.0**	0	0.05	**0.0**	0.07	0.003	0.1	0.01
Secure the TC to cask transfer trolley	30	**0.50**	1	7.5	**3.8**	2	5.6	**2.8**	0.4	3.0	0.6	4.6
Install floor access platform around cask transfer	10	**0.17**	1	7.6	**1.3**	2	5.6	**0.9**	0.1	1.0	0.2	1.5
Remove upper impact limiter bolts	60	**1.00**	1	7.6	**7.6**	2	5.6	**5.6**	0.8	6.1	1.2	9.1

IHF			Operator			HPT			Sensitivity Check			
Process Step [A]	**Time (min) [B]**	**Time (hr) [C]**	**Distance (m) [D] See NOTE ***	**Worker Dose Rate (mrem/hr) [E]**	**Single Worker Dose (mrem) [F]**	**Distance (m) [G] See NOTE ***	**Worker Dose Rate (mrem/hr) [H]**	**Single Worker Dose (mrem) [I]**	**-20% Time [J]**	**Single Worker Dose (mrem) [K]**	**+20% Time [L]**	**Single Worker Dose (mrem) [M]**
Remove upper impact limiter	5	**0.08**	0	0.05	**0.0**	0	0.05	**0.0**	0.07	0.003	0.1	0.01
Place upper impact limiter in storage	5	**0.08**	0	0.05	**0.0**	0	0.0	**0.0**	0.07	0.003	0.1	0.01
Remove TC lid bolts and lid	60	**1.00**	1	7.6	**7.6**	2	5.6	**5.6**	0.8	6.1	1.2	9.1
Place TC lid on cask lid stand	5	**0.08**	0	0.05	**0.0**	0	0.05	**0.0**	0.07	0.003	0.1	0.01
Remove cask shear and backing ring segments	120	**2.00**	1	7.6	**15.2**	2	5.6	**11.2**	1.6	12.2	2.4	18.2
Remove and stage cask shield plug (cask restraint)	60	**1.00**	1	7.6	**7.6**	2	5.6	**5.6**	0.8	6.1	1.2	9.1
Attach naval canister lifting device	15	**0.25**	1	7.6	**1.9**	0	0.05	**0.01**	0.2	1.5	0.3	2.3
Remove and store naval canister shield ring	15	**0.25**	0	0.05	**0.01**	0	0.05	**0.01**	0.2	0.01	0.3	0.02
Remove floor access platform	15	**0.25**	1	7.6	**1.9**	2	5.6	**1.4**	0.2	1.5	0.3	2.3
Move loaded TC on cask transfer trolley to cask unloading room	90	**1.50**	5	2.9	**4.4**	5	2.9	**4.4**	1.2	3.6	1.8	5.2
Export loaded WP from IHF in a TEV	375	**6.25**	0	0.05	**0.3**	0	0.05	**0.3**	5.0	0.2	7.5	0.4
Survey TEV	30	**0.50**	0	0.05	**0.03**	1	7.5	**3.8**	0.4	0.02	0.6	0.03
Survey TEV***						2	5.6	**2.8**	0.0		0.000	
Total	1215	**20.3**		Total	**88.7**		Total	**57.4**	Total	**70.9**	Total	**106.4**

Individual dose (Equation 11)	Operator (1)	1.6 person-rem/yr
5 Operators and 1 HPT	Per Crew	9.0 person-rem/yr
External Dose to Work Crews (Equation 12)	Crews (5)	45.1 person-rem/yr

Equation 1 used for [F] and [I]

Equation 2 used for total of [F] and [I]

Column [A]: From Ref. 2.2.7 Table 1
Column [B]: From Ref. 2.2.7 Table 1
Column [C]: Column [B]/60
Column [D]: From Ref. 2.2.7 Table 1
Column [E]: From Table 3 (Assumption 3.2.2) and Assumption 3.2.14
Column [F]: [C] ×[E]
Column [G]: From Ref. 2.2.7 Table 1
Column [H]: From Table 3 (Assumption 3.2.2) and Assumption 3.2.14
Column [I]: [C] × [H]
Column [J]: [C] × 0.8
Column [K]: [E] × [J]
Column [L]: [C] × 1.2
Column [M]: [E] × [L]

Sensitivity Numbers per task step				
Operator (1)	-20%	1.3	person-rem/yr	Equals 70.9 x 18/1000
Operator (1)	20%	1.9	person-rem/yr	Equals 106.4 x 18/1000

% DELTA is 1 - (1.278/1.597)=20% low
% DELTA is 1 - (1.597/1.916)=20% high

NOTE*: 0 in this column corresponds to a remote operation in 0.05mrem/hr background.
See Assumption 3.2.14
NOTE**: Dose rate values are rounded to the nearest tenth.
NOTE***: Denotes second HPT dose while supporting the first HPT. This dose applies only to the survey of the TEV task step.
NOTE****: Values have been rounded in the table. See Attachment 4 for exact values used in calculation.

ATTACHMENT 3

Listing of Files Contained on Compact Disc (Attachment 4)

This attachment lists the Excel files including file name, file size, and date and time of last access. All files are stored on an electronic medium (compact disc).

Directory: CD\Excel, Attachment 4

Date	Time	File Size (bytes)	File Name
05/24/2007	1:56 pm	31,000	IHFexternal.xls
05/24/2007	1:55 pm	30,000	IHFexternalSensitivity.xls

BSC

Calculation/Analysis Change Notice

Complete only applicable items.

3. Document Identifier:	4. Rev.:	5. CACN:
51A-00C-IH00-00100-000	00A	001

6. Title:
Initial Handling Facility Worker Dose Assessment

7. Reason for Change:
This CACN is being issued to resolve CR# 13047

- As shown in the following unit analysis, in order for the units of t_k to cancel out they have to be in minutes.

$$H_k^{inh} = \sum C_i\left(\frac{\mu Ci}{m^3}\right) \times DCF_i\left(\frac{Sv}{Bq}\right) \times 3.7\times10^9\left(\frac{mrem-Bq}{Sv-\mu Ci}\right) \times 1\times3.33\times10^{-4}\left(\frac{m^3}{\sec}\right) \times t_k \times \left(\frac{60\sec}{\min}\right)$$

$$H_k^{sub} = \sum C_i\left(\frac{\mu Ci}{m^3}\right) \times DCF_i\left(\frac{Sv-m^3}{Bq-\sec}\right) \times 3.7\times10^9\left(\frac{mrem-Bq}{Sv-\mu Ci}\right) \times t_k \times \left(\frac{60\sec}{\min}\right)$$

  In the worker inhalation and submersion dose calculation the cask process time (t_k) was calculated in hours which resulted in inhalation and submersion dose values being reported a factor of 60 lower.

- In the Max ID_o calculation, the dose contribution for all isotopes was included in the summation of the individual isotopic dose contributors. By definition, Max ID_o refers to the largest single dose contributor for the isotopes of concern in each group (i.e., beta or alpha emitters). Summing all the individual dose contributors results in an over estimation of the inhalation and submersion dose.

- Eliminated the process time for a TEV from the overall cask process time (t_k). Canister transfers into TEVs will be performed remotely. Therefore, work crews will not be exposed to any inhalation or submersion doses from these processes.

- The instantaneous fraction removed (λ_H) was revised from 0.1 to 1. This value is still conservative, and more consistent with nuclear facility HVAC designs. The previous value only took into account a 10% infiltration of outside air with no consideration of total air exhausted from the cask preparation room resulting in infiltration of air from other spaces. Adjusting λ_H from 0.1 to 1 results in a peak airborne activity concentration a factor of 10 lower.

- An additional calculation was added to show the facility dose consequence of the inhalation and submersion dose for ICRP68 and FGR 13 on an annual basis so it could be used for comparative purposes when summing internal and external doses. The previous calculation only calculated this dose on a per cask basis.

There was no impact from these changes on the previously reported individual or collective facility doses for the IHF.

8. Supersedes Change Notice: ☐ Yes If, Yes, CACN No.: _____ ☒ No

9. Change Impact:

Inputs Changed:	☐ Yes	☒ No	Results Impacted:	☐ Yes	☒ No
Assumptions Changed:	☒ Yes	☐ No	Design Impacted:	☐ Yes	☒ No

10. Description of Change:
Replacement pages for the affected calculation are provided with this CACN in order to more clearly show the changes made by this CACN. Changes were made on the following pages:
Page 11

- Changed Assumption 3.1.1 and the first four sentences of the rationale to read :

  3.1.1 Instantaneous Fraction Removed (λ_H) and Airborne Activity Volume

  Assumption: λ_H is assumed to be equal to 1.

  Rationale: λ_H is calculated by taking the sum of all infiltration sources into the space and dividing by the space volume which is defined as the instantaneous room turn over rate. A typical nuclear heating, ventilation and air-conditioning (HVAC) system for a nuclear facility has a room turnover rate greater than 1. Therefore, using a value of 1 for λ_H is conservative and appropriate for this level of design.

  The volume of the cask preparation area alone (Room 1012) is conservatively used to calculate airborne concentration and is

Page 11 (cont.)

estimated from Ref. 2.2.1, 2.2.2, and 2.2.3. This volume is considered conservative because it only considers the open volume of the room and not other open spaces such as the canister transfer machine (CTM) maintenance area (Room 1009), thus resulting in a smaller room volume which will effectively increase the airborne concentration in the room.

Page 24

- Changed definition of $crews_g$ in Equation 9 from "number of workers in a work crew performing this operation" to "number of work crews performing this operation, 5 crews"
  Note: This definition was used correctly in the body of the calculation.

Page 29

- Revised the sum of the inhalation and submersion dose values in Table 5 to 0.001 rem/yr.

Page 31

- Changed paragraph at the top of page to read: "Airborne concentrations, and inhalation and submersion doses, are determined based on the methodology in Section 4.4. The airborne concentration of radioactive contamination from a release of surface contamination from a cask is determined using a constant release which is proportional to the resuspension factor and the surface contamination available for resuspension. The peak activity concentration is arrived at by setting the airborne release rate equal to the airborne removal rate. This peak activity concentration is present during all cask dismantling operations and hence is a worst case scenario."
- Revised last paragraph on page to read: "The IHF ventilation instantaneous fraction removal rate, λ_H, is the sum of all infiltration sources into the cask preparation room divided by the space volume and is conservatively chosen as: "

Page 32

- Changed the instantaneous fraction removed (λ_H) from 0.1 to 1.
- Due to the change in λ_H to 1, the airborne concentration at equilibrium (C_i) is revised to 1.0×10^{-9} (m^{-3}) × S_i (μCi) resulting in an equilibrium concentration for $C_{\beta\gamma}$ equal to 5.1×10^{-8} ($\mu Ci/m^3$) and C_α equal to 5.1×10^{-9} ($\mu Ci/m^3$).
- Revised the exposure duration t_k in the third paragraph from the bottom to read 810 min.

Page 33

- Changed last sentence of first full paragraph to read "The Max ID_o is then calculated by summing the largest single dose contributor for the isotopes of concern in each group (i.e., beta or alpha emitters) as highlighted below."
- The values in the FGR 11 and FGR 12 table that have been changed are highlighted as shown below:
  - Revised values for $C_{\beta\text{-}\gamma}$ *or* C_α, H^{inh}, H^{sub}, ID_o, and Max ID_o (β-γ) + Max ID_o (α).
  - Revised "^{90}Sr-90" to read "^{90}Sr"

Isotope	$C_{\beta\text{-}\gamma}$ or C_α ($\mu Ci/m^3$)	DCF^{inh} (Sv/Bq)	H^{inh} (mrem/cask)	DCF^{sub} (Sv/Bq-s-m^{-3})	H^{sub} (mrem/cask)	ID_o (mrem/cask)
^{60}Co	5.1E-08	5.91E-08	1.80E-04	1.26E-13	1.16E-06	1.82E-04
^{90}Sr	5.1E-08	3.51E-07	1.07E-03	7.53E-18	6.91E-11	1.07E-03
^{239}Pu	5.1E-09	1.16E-04	3.54E-02	4.24E-18	3.89E-12	3.54E-02
^{241}Am	5.1E-09	1.20E-04	3.66E-02	8.18E-16	7.50E-10	3.66E-02
					Max ID_o (β-γ) +Max ID_o (α) =	3.8E-02

- The values in the ICRP 68 and FGR 13 table that have been changed are highlighted as shown below:
  - revised values for $C_{\beta\text{-}\gamma}$ *or* C_α, H^{inh}, H^{sub}, ID_o, and Max ID_o (β-γ) + Max ID_o (α).

Isotope	$C_{\beta\text{-}\gamma}$ or C_α ($\mu Ci/m^3$)	DCF^{inh} (Sv/Bq)	H^{inh} (mrem/cask)	DCF^{sub} (Sv/Bq-s-m^{-3})	H^{sub} (mrem/cask)	ID_o (mrem/cask)
^{60}Co	5.1E-08	2.90E-08	8.86E-05	1.19E-13	1.09E-06	8.97E-05
^{90}Sr	5.1E-08	1.50E-07	4.58E-04	9.83E-17	9.01E-10	4.58E-04
^{239}Pu	5.1E-09	4.70E-05	1.44E-02	3.49E-18	3.20E-12	1.44E-02
^{241}Am	5.1E-09	3.90E-05	1.19E-02	6.77E-16	6.21E-10	1.19E-02
					Max ID_o (β-γ) +Max ID_o (α) =	1.5E-02

- Deleted last paragraph.

Page 34

Replaced everything following first paragraph with:

Annual Inhalation and Submersion Dose FGR 11 & FGR 12

$$ID_g = \sum_o ID_o \times \frac{OP}{crews_g} = 0.038\left(\frac{mrem}{cask}\right) \times \frac{90\left(\frac{casks}{yr}\right)}{5} = 0.7\left(\frac{mrem}{yr}\right)$$

Annual Inhalation and Submersion Dose ICRP 68 & FGR 13

$$ID_g = \sum_o ID_o \times \frac{OP}{crews_g} = 0.015\left(\frac{mrem}{cask}\right) \times \frac{90\left(\frac{casks}{yr}\right)}{5} = 0.3\left(\frac{mrem}{yr}\right)$$

Using FGR 11 (Ref. 2.2.10) and FGR 12 (Ref. 2.2.12), values shown above, result in a higher and more conservative exposure estimate of 0.7 mrem/year. This result, rounded to 1 mrem/yr, will be used in Table 5 to calculate the annual TEDE doses by worker category.

The dose of 1 mrem/yr is applied to both the operator and the HPT because they are present in the cask preparation room during cask processing and as shown in Table 5 is an insignificant contributor to the total individual doses.

11.	REVIEWS AND APPROVAL	
Printed Name	**Signature**	**Date**
11a. Originator: Ed Salisbury		12/12/08
11b. Checker: Scott Manley		12/12/08
11c. EGS: Norman Kahler		12/12/08
11d. DEM: Dave Darling		2/2/09
11e. Design Authority: Barbara Rusinko		2/12/09

2.3.3 10 CFR 20. 2006 Energy: *Standards for Protection Against Radiation*. Internet Accessible. (DIRS 176618)

2.4 DESIGN OUTPUTS

This calculation is performed to support information in the license application.

3. ASSUMPTIONS

3.1 ASSUMPTIONS REQUIRING VERIFICATION

3.1.1 Instantaneous Fraction Removed (λ_H) and Airborne Activity Volume

Assumption: λ_H is assumed to be equal to 1.

Rationale: λ_H is calculated by taking the sum of all infiltration sources into the space and dividing by the space volume which is defined as the instantaneous room turn over rate. A typical nuclear heating, ventilation and air-conditioning (HVAC) system for a nuclear facility has a room turnover rate greater than 1. Therefore, using a value of 1 for λ_H is conservative and appropriate for this level of design.

The volume of the cask preparation area alone (Room 1012) is conservatively used to calculate airborne concentration and is estimated from Ref. 2.2.1, 2.2.2, and 2.2.3. This volume is considered conservative because it only considers the open volume of the room and not other open spaces such as the canister transfer machine (CTM) maintenance area (Room 1009), thus resulting in a smaller room volume which will effectively increase the airborne concentration in the room. When measurements are taken from the wall centerline, the wall portion of the total length is subtracted from the measurement. This volume is derived from Ref. 2.2.1, 2.2.2, and 2.2.3 as follows:

Room 1012.

Width = 86 ft – 2 ft north wall = 84 ft
Length = 160 ft
Height = 105 ft room height ceiling to floor
84 ft × 160 ft ×105 ft = 1,411,200 ft^3
1,411,200 ft^3/35.315 ft^3/m^3 = 39,960 m^3

Usage: This assumption is used in Attachment 1.

3.2 ASSUMPTIONS NOT REQUIRING VERIFICATION

3.2.1 Dose Rates

Assumption: The radiation dose rate distribution around a TS125 cask, Ref. 2.2.6, Figure 6.2-2, (Table 3) is used to estimate dose rates received by workers while processing a transportation cask (TC) in the IHF. It is assumed that this calculated data is representative of the conditions of the cask process in the IHF and can be used to estimate dose rates received by workers at various distances from the exterior surfaces of a TC.

$crews_g$ = number of work crews performing this operation, 5 crews
OP = total number of these operations, o, per year

The annual maximum internal and external doses to an IHF worker due to re-suspension of surface contamination on a canister are much lower than the contribution from the direct external dose for all worker categories and are therefore considered to be an insignificant contributor to the totals presented in Section 6.8. See Attachment 1.

4.5 TEDE DOSE CALCULATION

The annual TEDE to a worker, $TEDE_g$, in a work-crew is calculated by summing the component doses from inhalation, submersion and direct external radiation doses.

$$TEDE_g = ID_g + ED_g \qquad \text{Eq. 10}$$

where

$TEDE_g$ = annual TEDE to a worker (mrem/year)

5. LIST OF ATTACHMENTS

	Number of Pages
Attachment 1: Annual Inhalation and Submersion Doses	4
Attachment 2: Sensitivity Study	4
Attachment 3: Listing of Files Contained on Compact Disc	1
Attachment 4: Compact Disc Containing the Electronic Files Generated by this Calculation	1 CD

6. BODY OF CALCULATION

6.1 PROCESSING TASK PER WORKER

The average number of TCs processed annually by each work crew is the total number of TCs that will be handled annually in the IHF divided by the number of work crews performing those operations. Per Assumption 3.2.7, the IHF throughput is 90 TCs and 90 WPs. The annual number of TCs processed per work crew is OP_c divided by the number of work crews (five crews per Assumptions 3.2.4, 3.2.15). Thus, a work crew will process an estimated annual average of 18 TCs (i.e., 90/5). The annual number of WPs processed per work crew is OP_c divided by the number of crews (5 crews per assembly). Thus a work crew will process an estimated annual average of 18 WPs (90/5). The total time expected to process a single transportation cask in the cask preparation room is equal to 810 min (Ref. 2.2.7, Table 1, Tasks 2 and 3B). These specific tasks are shown in Table 4. Table 4 also includes the tasks for waste package load out into a TEV that involve personnel (Ref. 2.2.7, Table 1, Task 6) (405 minutes).

Process time for 1 TC into the facility is 810 min.

Process time for 1 WP out of the facility is 405 min.

Table 5. Annual TEDE Doses by Worker Category (rem/yr)

Doses from IHF Operations	Symbol	Units	Operator	Health Physics
External Dose	ED_g	rem/yr	1.7	1.1
Inhalation Dose (CEDE) + Submersion (DDE)	ID_g	rem/yr	0.001	0.001
Total Annual Doses by Worker Group		rem/yr	**1.7**	**1.1**

CEDE = committed effective dose equivalent; DDE = deep dose equivalent.

7. RESULTS AND CONCLUSIONS

The results of this dose assessment calculation are summarized in Section 6.6. The parameters used in the dose calculations are supported by appropriate and conservative input data and assumptions. The calculated worker doses in Section 6.8 represent reasonable, bounding 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 that workers will receive, and by the duration of cask processing operations. However, the selected inputs are judged to be representative of the operating conditions. From Section 6.8, the average estimated dose to an individual IHF worker is 1.7 rem/yr and to an individual HPT is 1.1 rem/yr.

These doses are in compliance with the requirements of Ref. 2.3.3, Section 1201(a) (1) (i), limit of 5 rem per year for occupational workers. The IHF estimated annual doses do not contribute to the ALARA design goal of minimizing the number of workers exposed to more than 0.5 rem per year.

7.1 REGULATIONS

The regulation applicable to worker doses is provided in Ref. 2.3.3 Section 1201 as specified in Ref. 2.2.18, Section 4.10.1.

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: A lens dose equivalent of 15 rems, and a shallow-dose equivalent of 50 rems to the skin or to any extremity.

ATTACHMENT 1

ANNUAL INHALATION AND SUBMERSION DOSES

Airborne concentrations, and inhalation and submersion doses, are determined based on the methodology in Section 4.4. The airborne concentration of radioactive contamination from a release of surface contamination from a cask is determined using a constant release which is proportional to the resuspension factor and the surface contamination available for resuspension. The peak activity concentration is arrived at by setting the airborne release rate equal to the airborne removal rate. This peak activity concentration is present during all cask dismantling operations and hence is a worst case scenario.

Surface Contamination Available for Resuspension

The amount of radioactive contamination on the surface of a cask is a function of the assumed contamination level, the radioisotopes present, and the surface area covered by contamination.

Per Assumption 3.2.12, surface contamination is assumed to cover the entire external surface of the transportation casks and it is assumed to be removable and releasable to the atmosphere.

The external surface area of a cask is 51 m^2 per Assumption 3.2.12.

Per Assumption 3.2.8, the non-fixed (removable) radioactive contamination on the external surface of a transportation cask is 10^{-4} μCi/cm^2 for beta and gamma emitters, and low-toxicity alpha emitters, and 10^{-5} μCi/cm^2 for all other alpha emitters. Therefore, the amount of activity available to be released from the cask surface is:

$$S_{\beta\gamma} = 10^{-4}\left(\mu Ci/cm^2\right) \times 5.1\times10^5\left(cm^2\right) = 51\ \mu Ci$$

and

$$S_{\alpha} = 10^{-5}\left(\mu Ci/cm^2\right) \times\ 5.1\times10^5\left(cm^2\right) = 5.1\ \mu Ci$$

Per Assumption 3.2.11, four radioisotopes are considered to dominate the doses resulting from airborne contamination: ^{60}Co, ^{90}Sr, ^{239}Pu, and ^{241}Am. ^{60}Co and ^{90}Sr are beta/gamma emitters, and ^{239}Pu and ^{241}Am are primarily alpha emitters.

Airborne Radioactivity Buildup While Cask is in IHF

Radioactive contamination resuspended off the transportation cask surface would be dispersed within the free air volume of the cask preparation area (Room 1012). The maximum time the cask could be present would be equal to the total cask processing time 1215 min, which includes cask import and export times to process one cask as described in Section 6.1.

The IHF ventilation instantaneous fraction removal rate, λ_H, is the sum of all infiltration sources into the cask preparation room divided by the space volume and is conservatively chosen as:

$$\lambda_H = 1\ hr^{-1}$$

The buildup of airborne radioactivity concentration in the IHF cask handling area is determined from Equation 6 with t_B equal to infinity and λ_R, the surface contamination resuspension rate, equal to 4×10^{-5} hr^{-1} per Assumption 3.2.9. The volume of the cask preparation room is 39,960 m^3 per Assumption 3.1.1.

The calculation for airborne concentration at equilibrium is:

$$C_i(\infty) = \frac{\lambda_R S_i}{\lambda_H V_B}\left(1 - e^{-\lambda_H \infty}\right) = \frac{\lambda_R S_i}{\lambda_H V_B} = \frac{4\times10^{-5}\left(hr^{-1}\right) S_i\ (\mu Ci)}{1\left(hr^{-1}\right) \times 39{,}960\left(m^3\right)} = 1.0\times10^{-9}\left(m^{-3}\right) \times S_i\ (\mu Ci)$$

Therefore, airborne concentration at equilibrium for beta and gamma emitters and low-toxicity alpha emitters and for all other alpha emitters based on the surface activity is:

$$C_{\beta\gamma}(\infty) = 1.0\times10^{-9}\left(m^{-3}\right)\times S_{\beta\gamma}\ (\mu Ci) = 1.0\times10^{-9}\left(m^{-3}\right)\times 51\ \mu Ci = 5.1\times10^{-8}\left(\mu Ci/m^3\right)$$

and

$$C_{\alpha}(\infty) = 1.0\times10^{-9}\left(m^{-3}\right)\times S_{\alpha}\ (\mu Ci) = 1.0\times10^{-9}\left(m^{-3}\right)\times 5.1\ \mu Ci = 5.1\times10^{-9}\left(\mu Ci/m^3\right)$$

Worker Inhalation and Submersion Doses per Cask

The inhalation and submersion doses to a worker resulting from resuspension of contamination from a single cask for a duration of t_k minutes are determined from Equation 7:

$$H_k^{inh} = \sum_i C_i\left(t\right) \times DCF_i^{inh} \times 3.7\times10^9 \times RF \times BR \times t_k \times 60$$

$$H_k^{sub} = \sum_i C_i\left(t\right) \times DCF_i^{sub} \times 3.7\times10^9 \times t_k \times 60$$

The exposure duration t_k is conservatively taken as the total cask processing time 810 min from Section 6.1 and accounts for all different tasks in the cask processing operation. Per Assumption 3.2.10, the respirable fraction, RF, is 1. The breathing rate, BR, is 3.33×10^{-4} m^3/s per Assumption 3.2.13.

The total inhalation and submersion dose, ID_o, to a worker for all cask processing tasks resulting from the presence of airborne activity is determined from Equation 8 with $N = 1$ because the exposure duration t_k is conservatively taken as total cask processing time and includes all tasks:

$$ID_o = \left(H_k^{inh} + H_k^{sub}\right)$$

The results of applying equations 7 and 8 to determine *IDo* (mrem/cask) are given in the following tables below. Per Assumption 3.2.11, the dominant beta/gamma-emitting isotopes are

^{60}Co and ^{90}Sr, and the dominant alpha-emitting isotopes are ^{239}Pu and ^{241}Am. The effective inhalation and submersion DCFs for these isotopes are given in Assumption 3.2.11.

The dose per cask due to inhalation and submersion is conservatively taken as the sum of the calculated ^{60}Co, ^{90}Sr, ^{239}Pu, and ^{241}Am doses. The Max ID_o is then calculated by summing the largest single dose contributor for the isotopes of concern in each group (i.e., beta or alpha emitters) as highlighted below.

Inhalation and Submersion Doses FGR 11 and FGR 12

Isotope	$C_{\beta-\gamma}$ or C_α (µCi/m^3)	DCF^{inh} (Sv/Bq)	H^{inh} (mrem/cask)	DCF^{sub} (Sv/Bq-s-m^{-3})	H^{sub} (mrem/cask)	ID_o (mrem/cask)
^{60}Co	5.1E-08	5.91E-08	1.80E-04	1.26E-13	1.16E-06	1.82E-04
^{90}Sr	5.1E-08	3.51E-07	1.07E-03	7.53E-18	6.91E-11	1.07E-03
^{239}Pu	5.1E-09	1.16E-04	3.54E-02	4.24E-18	3.89E-12	3.54E-02
^{241}Am	5.1E-09	1.20E-04	3.66E-02	8.18E-16	7.50E-10	3.66E-02
					Max ID_o (β–γ) +Max ID_o (α) =	3.8E-02

Sources: Ref. 2.2.10, Table 2.1 and 2.2.12, Table III.1

Inhalation and Submersion Doses ICRP-68 and FGR 13.

Isotope	$C_{\beta-\gamma}$ or C_α (µCi/m^3)	DCF^{inh} (Sv/Bq)	H^{inh} (mrem/cask)	DCF^{sub} (Sv/Bq-s-m^{-3})	H^{sub} (mrem/cask)	ID_o (mrem/cask)
^{60}Co	5.1E-08	2.90E-08	8.86E-05	1.19E-13	1.09E-06	8.97E-05
^{90}Sr	5.1E-08	1.50E-07	4.58E-04	9.83E-17	9.01E-10	4.58E-04
^{239}Pu	5.1E-09	4.70E-05	1.44E-02	3.49E-18	3.20E-12	1.44E-02
^{241}Am	5.1E-09	3.90E-05	1.19E-02	6.77E-16	6.21E-10	1.19E-02
					Max ID_o (β–γ) +Max ID_o (α) =	1.5E-02

Sources: Ref. 2.2.13, Table B.1 and 2.2.14, Table F12TIII1

Although many of the biokinetic and dosimetric models used in FGR 13 are updates of models used in FGR 11, the present report does not replace either that document or FGR 12 or affect their use for radiation protection purposes. The dose coefficients given in FGR 11 and FGR 12 continue to be recommended for determining conformance with radiation protection guidance to Federal agencies. The values cited for submersion from FGR 13 are the submersion values from FGR 12 with the ICRP 60 weighting factors applied to them and can be found in the FGR 13 (Ref. 2.2.14) supplement CD Table F12TIII1 using Microsoft notepad.

The total annual inhalation and submersion dose, ID_g, to a worker in a work crew for all cask processing task steps is determined from Equation 9 with the total number of operations, OP, equal to the number of casks processed per year of 90 casks (Assumption 3.2.7) and the number of work crews, $crews_g$, in the cask operations group of five work crews (Assumption 3.2.4).

Annual Inhalation and Submersion Dose FGR 11 & FGR 12

$$ID_g = \sum_o ID_o \times \frac{OP}{crews_g} = 0.038\left(\frac{mrem}{cask}\right) \times \frac{90\left(\frac{casks}{yr}\right)}{5} = 0.7\left(\frac{mrem}{yr}\right)$$

Annual Inhalation and Submersion Dose ICRP 68 & FGR 13

$$ID_g = \sum_o ID_o \times \frac{OP}{crews_g} = 0.015\left(\frac{mrem}{cask}\right) \times \frac{90\left(\frac{casks}{yr}\right)}{5} = 0.3\left(\frac{mrem}{yr}\right)$$

Using FGR 11 (Ref. 2.2.10) and FGR 12 (Ref. 2.2.12), values shown above, result in a higher and more conservative exposure estimate of 0.7 mrem/yr. This result, rounded to 1 mrem/yr, will be used in Table 5 to calculate the annual TEDE doses by worker category.

The dose of 1 mrem/yr is applied to both the operator and the HPT because they are present in the cask preparation room during cask processing and as shown in Table 5 is an insignificant contributor to the total individual doses.