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Design Calculation or Analysis Cover Sheet

Complete only applicable items.

1. QA: QA
2. Page 1

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1) CACN-001, DATED 05/23/2007
2) CACN-002, DATED 02/12/2009

Attachments	Total Number of Pages
Attachment 1: Annual inhalation and Submersion Doses	4
Attachment 2: Sensitivity Study	5

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)
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DISCLAIMER

CONTENTS

Page

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TABLES

Page

ACRONYMS AND ABBREVIATIONS

ACRONYMS

ALARA	as low as is reasonably achievable
AO	aging overpack
CRCF	Canister Receipt and Closure Facility
DCF	dose conversion factor
DOE	U.S. Department of Energy
FGR	Federal Guidance Report
HPT	health physics technician
HVAC	heating, ventilation, and air-conditioning
ICRP	International Commission on Radiation Protection
MTU	Metric Tons of Uranium
TAD	transportation, aging, and disposal (canister)
TEDE	total effective dose equivalent
SNF	spent nuclear fuel

ABBREVIATIONS

Bq	Becquerel
Ci	curie
cm	centimeter
hr	hour
m	meter
min	minute
mL	milliliter
mrem	millirem
s	second
Sv	sievert
yr	year

1. PURPOSE

The purpose of this calculation is to estimate radiation doses received by personnel working in the Canister Receipt and Closure Facility (CRCF) who perform operations to transfer spent nuclear fuel (SNF) to waste packages for emplacement in the repository, or to transfer SNF into aging overpacks (AOs) for aging on aging pads. 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 CRCF (Ref. 2.1.1, Section 7.2). Radiation dose contribution, if any, from contaminated air outside the CRCF is not considered in this calculation. The results of this calculation will be used to support the design of the CRCF 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 operation. Yucca Mountain Project personnel from the Radiological and Nuclear 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.

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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 CRCF cask preparation room (Room 1026) 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 13,947 m^3.

Rationale: A typical nuclear 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 room 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 the door vestibules thus resulting in a smaller room volume which will effectively increase the airborne concentration in the room. Measurements are taken from wall centerline so the wall portion of the total length is subtracted from each measurement. This volume is derived from (Ref. 2.2.1, 2.2.2 and 2.2.3) as follows:

Room 1026 east section.

Width = 74 ft – 2 ft west wall = 72 ft
Length = 94 ft – 2 ft north wal – 2 ft south wall = 90 ft
Height = 72 ft – 1.5 ft floor thickness = 70.5 ft
72 ft x 90 ft x 70.5 ft = 456,840 ft^3
Room 1026 west section.
Width = 15 ft – 2 ft west wall = 13 ft
Length = 94 ft – 2ft north wall – 2 ft south wall = 90 ft
Height = 32 ft – 1.5 ft floor thickness = 30.5 ft
13 ft x 90 ft x 30.5 ft = 35,685 ft^3
456,840 ft^3 + 35,685 ft^3 = 492,525 $ft^3/35.315m^3/ft^3$ = 13,947m^3

Usage: This assumption is used in Section 6.7.

3.2 ASSUMPTIONS NOT REQUIRING VERIFICATION

3.2.1 Dose Rates

Assumption: The radiation dose rate distribution around a TS125 cask (Table 3) Ref 2.2.4 Figure 6.2-2 is used to estimate dose rates received by workers while processing a transportation cask in the CRCF. It is assumed that this calculated data is representative of the conditions of the cask process in the CRCF and can be used to estimate dose rates received by workers at various distances from the exterior surfaces of a transportation cask.

Rationale: Per Ref. 2.2.5 Section 1.0, the CRCF will handle only sealed canistered waste, i.e., U.S. Department of Energy (DOE) spent nuclear fuel (SNF), high level radioactive waste (HLW), and Commercial SNF for transfer to waste packages or aging overpacks (AOs). Dose rates from AOs and shielded transfer casks will be lower than incoming transportation, aging, and disposal canister (TAD) on a rail cask. The dose rates from the TS125 are considered representative of all SNF casks and bounding because they will have a higher dose rate than other cask configurations. Dose rates in the vicinity of a TS125 rail cask have been determined in Ref. 2.2.4 Figure 6.2-2. All transportation casks received at the CRCF are required to meet the requirements in Ref 2.3.1 for packaging, preparation for shipment, and transportation of licensed materials. For the purpose of these dose calculations it is expected that the transportation cask 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 consistant with the radiation dose rates of the TS125 (Ref 2.2.4). Because this dose estimate is on an annual average basis, it is reasonable to expect most casks will meet the limits of Ref 2.3.1 Section 47(a) limits. For the dose rate calculations in Ref 2.2.4, the TS125 cask is situated 10 ft above a 2 ft thick concrete floor (Ref 2.2.4 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 2.2.4 Section 5.1.7) which corresponds to 60 GWd/MTU burnup, 4.0 wt% initial ^{235}U enrichment, and 18 year cooling time. This configuration is considered representative of what typically will be handled in the CRCF.

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

3.2.2 Time and Motion Study

Assumption: Process task definitions for transportation canister operations within the CRCF, and their corresponding task durations, average worker distance, and times, are based on Reference 2.2.6 which have a conservatively 37.5% longer amount of time per cask operation than those described in Ref. 2.2.5[MSOffice1].

Rationale: The operation process steps, durations, average worker distance, and times are necessary information for the determination of external and internal doses in the CRCF. The total time from Reference 2.2.6 , Table 1, Tasks 1, 4, and 15 is 825 minutes which is 37.5% longer per cask process than Reference 2.2.5 Figure B-1 of 600 minutes (600 x 1.375 = 825). The use of the longer durations for operations will bound any changes in Ref. 2.2.5. 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 CRCF.

The following worker average distance locations for axial work are defined as:
1 m = 1 m away from the center plane and 2 m away vertical
2 m = 2 m away from the center plane and 2 m away vertical
5 m = 2 m away from the center plane and 5 m away vertical

The radial doses used are from the mid-plane and are 7.5 mrem/hr at 2 m, 3 mrem/hr at 5 m and 1.1 mrem/hr at 10 m (Ref 2.2.4 Figure 6.2-2).

The top axial dose rates are 7.7 mrem/hr at 1m average distance, 5.6 mrem/hr at 2 m average distance and 2.8 mrem/hr at 5 m average distance (Ref 2.2.4 Figure 6.2-2).

The bottom axial dose rates are 4.3 mrem/hr at 1m average distance, 2.8 mrem/hr at 2 m average distance and 1.7 mrem/hr at 5 m average distance (Ref 2.2.4 Figure 6.2-2).

Usage: This assumption is used in Sections 4.3, 6.2, and 6.7.

3.2.3 Average Distances

Assumption: Worker locations for cask preparation operations in the CRCF are defined in terms of distances from the transportation cask. The distances are estimated from averaged worker locations to perform the specific tasks for cask preparation operations. 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 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 as low as is reasonably achievable (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 operations in the CRCF are selected from Ref. 2.2.6. Appropriate length tools will be used to facilitate the distances used.

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

3.2.4 Staffing

Assumption: It is assumed that there will need to be 5 work crews to support the CRCF 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. 2.2.5).

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

3.2.5 HPTs

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

Rationale: The Ref. 2.2.6 has an HPT listed during material handling activities to support personnel on the day-to-day operation and processing activities. HPT's 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 CRCF personnel are performing operations involving exposure to radiation. The HPT support perrsonnel will use remote monitoring whenever possible to support cask operations to maintain ALARA.

Usage: This assumption is used in Sections 6.2 and 6.7.

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 CRCF 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 CRCF.

3.2.7 Throughput

Assumption: The total number of transportation casks that will be handled annually in the CRCF is taken as the <u>higher</u> of the following:

(a) The annual receipt of casks from rail or crawler containing DOE SNF, HLW, or commercial SNF is obtained from Ref. 2.2.5 Table 5. The CRCF can receive 214 casks annually.

(b) The total number of casks that could be processed annually in the CRCF is based on the "expected" task durations obtained from Ref. 2.2.5 Table 3. The CRCF can process 211 casks in terms of waste packages.

Rationale: The CRCF has the ability to receive more casks than can be process[MSOffice2]ed in a year and also to stage up to two TADs and 10 DOE casks. This assumption uses the CRCF maximum annual receipt capability of 214 total casks.

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

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 Reference 2.3.2, Section 443(a), as set forth in Table 9 of that regulation. Transportation casks accepted at the CRCF are expected to meet the external contamination limits of Reference 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.

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. 2.2.7 Section 5, p. 5-7, and Section 5.2.4, p. 5-21).

Usage: This assumption is used in Section 6.7.

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 Department of Energy (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. 2.2.14, Section 4.3.7).

Usage: This assumption is used in Section 6.7.

3.2.11 Nuclides

Assumption: The radioactive surface contamination on the transportation cask 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 because any contamination on the exterior surface of the transportation cask 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 particulates in the pool are the long half-life corrosion products from SNF surfaces that might dislodge during SNF movement. The most prominent particulates are ^{60}Co, ^{58}Co, ^{55}Fe, ^{59}Fe, ^{54}Mn, ^{51}Cr, and ^{65}Zn (Ref. 2.2.8, p. 4-51). Of these products, ^{60}Co has the highest inhalation dose conversion factor (Ref. 2.2.9, Table 2.1) and half-life (5.27 years) (Ref. 2.2.10, 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 [MSOffice3]2.

Table 2. Half-Lives and DCFs for Selected Isotopes

Table 2		FGR 11	FGR 12	ICRP 68	FGR 13
Isotope	Half-Life (yr)	DCF^{inh} (Sv/Bq)	DCF^{sub} (Sv-m^3/Bq-s)	DCF^{inh} (Sv/Bq)	DCF^{sub} (Sv-m^3/Bq-s)
^{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: References 2.2.8 Isotopes; 2.2.9 Table 2.1 FGR11; 2.2.10 Half Lives; 2.2.11, Table III.1 FGR12; 2.2.12 ICRP68, Table B.1; 2.2.13 FGR13.

NOTES: Half-lives are from Reference 2.2.10, pp. 78, 99, 209, and 211.[MSOffice4]

As shown in Reference 2.2.10, pp. 78, 99, 209, and 211, ^{60}Co and ^{90}Sr are beta-gamma emitters, and ^{239}Pu and ^{214}Am are primarily alpha emitters.

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. 2.2.14 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 CRCF. 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 contamination under normal and off-normal conditions would be significantly less than the amount assumed. This is expected to be the case whether portions of a transportation cask 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.

3.2.13 Worker Breathing Rate

Assumption: The CRCF 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 Reference 2.2.15, p. 8.34-10, Equation A-1).

Usage: This assumption is used in Section 6.7.

3.2.14 Not Hands on Work

Assumption: It is assumed that all CRCF 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, CRCF 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. 2.2.16, 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 and 6.5.

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 CRCF divided by the number of work crews supporting those operations.

Rationale: A single work crew will not be present 24/7 to process casks. Crews will be rotated as necessary to levelize 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 will be designed to be lesser than or equal to 100 mrem/hr at 30 cm, per Ref. 2.2.17, 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.

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 CRCF. 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 EG-PRO-3DP-G04B-00037, *Calculations and Analyses* (Ref. 2.1.2). The CRCF 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. 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 001859). 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 2.2.6) and dose rates calculated for worker locations from Table 1. Dose calculations are made on a per unit operation, i.e., per TAD processed, 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 "as low as is reasonably achievable" (ALARA) design goal specified in the (Ref. 2.1.5). Different worker tasks are involved in the CRCF operations from receiving the loaded canister through the Waste Package (WP) exiting the facility. (Assumption 3.2.2).

4.3.1 Exposure rates for specific CRCF 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 2.2.4, 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.

(Ref 2.2.4 Figure 6.2-2)

4.3.2 Annual Number of Cask Operations

Based on the design capacity of the CRCF the expected TADs that will require processing is 214 (Assumption 3.2.7) per year. Since the primary purpose of the CRCF is to receive TADs and to place them into waste packages, the number of TADs needing to go into AOs and the number of

AO/shielded transfer casks being recovered from other facilities are not included in this calculation. (Assumption 3.2.1)

4.3.3 Process Tasks and Durations

Process tasks, durations, number of personnel and distances are obtained from (Ref. 2.2.6) 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.

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

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:

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

where

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

When not performing manual operations on a canister, the individual in a work-crew is assumed to remain inside the CRCF 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 x 50 week/year = 2000 hrs, minus the time performing canister operations, T_o.

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

and Equation 3

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

where

T_o = Time performing cask or canister operations 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 canister operations including support-only time is calculated as:

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

where

ED_g = external dose to a worker (mrem/year)
ED_C = external dose to a worker per cask during cask processing operations (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 CRCF 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 Equation 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 due to the ventilation system cleanup operation. Therefore, the maximum airborne activity concentration occurs at the time of cask removal *t* and is determined by:

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

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 is given by:

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

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 CRCF in the presence of airborne activity is calculated as follows:

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

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:

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

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 a CRCF 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 total annual effective dose equivalent (TEDE), $TEDE_g$, to a worker in a work-crew is calculated by summing the component doses from inhalation, submersion and direct external radiation doses.

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

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	5

6. BODY OF CALCULATION

6.1 PROCESSING TASK PER WORKER

The average number of transportation casks processed annually by each work crew is the total number of transportation casks that will be handled annually in the CRCF divided by the number of work crews performing those operations. Per Assumption 3.2.7, the CRCF throughput is 214 TADs. The annual number of transportation casks 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 42.8 casks (i.e., 214/5). 42.8 casks/year is conservatively rounded up to 43. The total time expected to process a single transportation cask in the cask preparation room is equal to 765 min (Ref. 2.2.6, Table 1, Task 1 and 4). 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. 2.2.6, Table 1, Task 15a and 15b). This results in a total process time of 825 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 CRCF (HPTs or operators), and the CRCF total annual exposure for all workers, are calculated and listed in Table 4, using:

$$ED_k = \frac{t_k}{60} \times EDR_{dist}$$ Equation 11

where

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

$$ED_o = \sum_{k=1}^{N} ED_k$$ Equation 12

where

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

The total annual dose, ED_{anl}, to a worker to process 43 casks/yr (per section 6.1) divided by 1000 rem/mrem and is calculated as follows:

$$ED_{anl} = ED_o \times 43 \frac{casks}{yr} / 1000 \frac{rem}{mrem}$$ Equation 13

where

ED_{anl} = total annual external dose to a worker to process 43 casks (person-rem/yr)
ED_o = external dose to a worker per operation (processing 1 casks) consisting of N different tasks (mrem/operation, processing 1 casks)

The total annual dose, ED_{crew}, to a work crew to process 43 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 CRCF, as follows:

$$ED_{crew} = (ED_{anl}\ (Operator) \times 5 + ED_{anl}(HPT)) \times 5$$ Equation 14

where

ED_{crew} = total annual external dose to a work crew to process 43 casks (person-rem/yr)
HPT = HPT total exposure

B T.L.K. 4-25-07

Table 4 CRCF #1 Worker Dose Table

CRCF			Operator			HPT		
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]	Worker Dose Rate (mrem/hr) [H]	Single Worker Dose (mrem) [I]
Receive and Process TAD								
Open Exterior CRCF Entrance Vestibule	5	**0.08**	0	0.05	**0.00**	0	0.05	**0.00**
Move Loaded Cask into Entrance Vestibule	10	**0.17**	2	7.5	**1.25**	5	3.0	**0.50**
Close Exterior CRCF Entrance Vestibule Doors	5	**0.08**	0	0.05	**0.00**	0	0.05	**0.00**
Move Loaded Cask into Prep Area	10	**0.17**	2	7.5	**1.25**	5	3.0	**0.50**
Perform inspection and survey	60	**1.00**	2	7.5	**7.50**	2	7.5	**7.50**
Prepare cask for removal from rail car	40	**0.67**	2	7.5	**5.00**	0	0.05	**0.03**
Remove Personnel Barrier	45	**0.75**	2	7.5	**5.63**	5	2.8	**2.10**
Partially Unbolt First Impact Limiter	20	**0.33**	1	7.70	**2.57**	5	2.8	**0.93**
200/20 Ton Crane moves to impact limiter lifting	5	**0.08**	0	0.05	**0.00**	0	0.05	**0.00**
Attach lifting device to crane	15	**0.25**	0	0.05	**0.01**	0	0.05	**0.01**
Move the crane to Impact Limiter	5	**0.08**	0	0.05	**0.00**	0	0.05	**0.00**
Attach lifting device to the Impact Limiter	5	**0.08**	1	7.70	**0.64**	5	2.8	**0.23**
Finish unbolting the impact limiter	10	**0.17**	1	7.70	**1.28**	5	2.8	**0.47**
Lift Impact Limiter and move to storage	10	**0.17**	0	0.05	**0.01**	0	0.05	**0.01**
Detach lifting device from Impact Limiter	5	**0.08**	0	0.05	**0.00**	0	0.05	**0.00**
Move crane back to get Second Impact Limiter	5	**0.08**	0	0.05	**0.00**	0	0.05	**0.00**
Partially unbolt Second Impact Limiter	20	**0.33**	1	4.30	**1.43**	5	1.7	**0.57**
Attach lifting device to Impact Limiter	5	**0.08**	1	4.30	**0.36**	5	1.7	**0.14**
Finish unbolting the impact limiter	10	**0.17**	1	4.30	**0.72**	5	1.7	**0.28**
Lift Impact Limiter and move to storage	10	**0.17**	0	0.05	**0.01**	0	0.05	**0.01**
Move crane to lifting device storage area	5	**0.08**	0	0.05	**0.00**	0	0.05	**0.00**
Detach the lifting device from the crane	15	**0.25**	0	0.05	**0.01**	0	0.05	**0.01**
Move the 200/20 Ton crane to its secure location	5	**0.08**	0	0.05	**0.00**	0	0.05	**0.00**
Perform radiological survey impact limiters	30	**0.50**	0	0.05	**0.03**	0	0.05	**0.03**
Perform radiological survey of transportation cask	30	**0.50**	0	0.05	**0.03**	2	7.5	**3.75**
Move the 200/20 Ton crane to the Cask Lifting Yoke	5	**0.08**	0	0.05	**0.00**	0	0.05	**0.00**
Attach the Cask Lifting Yoke to the Crane	15	**0.25**	0	0.05	**0.01**	0	0.05	**0.01**
Move the Crane to the CASK Upper Lifting Trunnions ~~of the~~	5	**0.08**	5	3.0	**0.25**	0	0.05	**0.00**
Engage Cask Lifting Yoke with Cask Upper	10	**0.17**	2	7.50	**1.25**	0	0.05	**0.01**
Remove Cask Tie Downs and Stabilizers	10	**0.17**	2	7.50	**1.25**	5	3.0	**0.50**
Tilt the Cask to vertical position	15	**0.25**	0	0.05	**0.01**	0	0.05	**0.01**
Lift the Cask from the rail car	5	**0.08**	0	0.05	**0.00**	0	0.05	**0.00**
Move Cask to trolley position	15	**0.25**	0	0.05	**0.01**	0	0.05	**0.01**
Lower cask on trolley	5	**0.08**	0	0.05	**0.00**	0	0.05	**0.00**
Cask Trolley engage the cask	30	**0.50**	2	7.50	**3.75**	2	7.5	**3.75**
Disengage Lifting Yoke with Cask Upper Trunnions	5	**0.08**	2	7.50	**0.63**	2	7.5	**0.63**
Move the 200/20 Ton crane to the Cask Lifting Yoke	5	**0.08**	0	0.05	**0.00**	0	0.05	**0.00**
Detach the Cask Lifting Yoke from the Crane	15	**0.25**	0	0.05	**0.01**	0	0.05	**0.01**
Move Loaded casks to transfer room	90	**1.50**	5	3.0	**4.50**	5	3.0	**4.50**
Perform gas sampling	60	**1.00**	3	5.6	**5.60**	2	7.5	**7.50**
Remove lid bolts from cask	60	**1.00**	2	5.60	**5.60**	0	0.05	**0.05**
Attach lid lifting fixture to crane**	10	**0.17**	0	0.05	**0.01**	0	0.05	**0.01**
Move the 200/20 Ton crane to the transfer trolley**	5	**0.08**	0	0.05	**0.00**	0	0.05	**0.00**
Attach lid lifting fixture to cask, remove crane**	10	**0.17**	2	5.60	**0.95**	0	0.05	**0.01**
Move the 200/20 Ton crane to its secure location**	5	**0.08**	0	0.05	**0.00**	0	0.05	**0.00**
Attach rigging for removal of shield ring from trolley	30	**0.50**	2	7.50	**3.75**	5	3.00	**1.50**
Survey the loaded TEV Assumption 3.2.16	30	**0.50**	0	0.05	**0.03**	2	7.5	**3.75**
Total	825	**13.75**		Total	**55.39**		Total	**39.39**

B T.L.K. 04-25-07

Individual dose (Equation 13)	Operator(1)	**2.382**	person-rem/yr	HPT	**1.694**	person-rem/yr
5 Operators and 1 HPT (Equation 14)	Per Crew	**13.602**	person-rem/yr			

Column [A] : From Ref 2.2.6 Table 1

Column [B] : From Ref 2.2.6 Table 1

Column [C] : Column [B]/60

Column [D] : From Ref 2.2.6 Table 1

Column [E] : From Table 3 (Assumption 3.2.2) and Assumption 3.2.14.

Column [F] : [C] x [E]

Column [G] : From Ref 2.2.6 Table 1

Column [H] : From Table 3 (Assumption 3.2.2) and Assumption 3.2.14.

Column [I] : [C] x [H]

Equation 11 used for [F] and [I]

$$ED_k = \frac{t_k}{60} \times EDR_{k,d}$$

Equation 12 used for the total of [F] and [I]

$$ED_o = \sum_{k=1}^{N} ED_k$$

NOTE*: 0 in this column corresponds to a remote operation in 0.05mrem/hr background. See Assumption 3.2.14.

NOTE**: These tasks are equivalent in time to the last task in task 1 from Ref.2.2.6. This breakdown was done because of the different dose rates for each part of this task.

Table 4 estimates a total external exposure for one CRCF operator to be 55.4 mrem for processing one cask.

Table 4 estimates a total external exposure for one HPT to be 39.4 mrem for processing one cask.

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 steps to process one cask and multiplying them by the frequency of operations.

Taking the total worker type exposure from Table 4 and multiplying it by 43 casks processed per work crew gives the total annual external dose to a specific worker type for all the cask transfer operations in which the worker will be involved. The HPT and CRCF 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):

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

$$T_o = \frac{825\left(\frac{\text{min}}{cask}\right)}{60\left(\frac{\text{min}}{hr}\right)} \times 43\left(\frac{cask}{crew - yr}\right)$$

$$= 591\left(\frac{hrs}{yr}\right)$$

and

$$T_n = 2000\left(\frac{hrs}{yr}\right) - T_o = 2000\left(\frac{hrs}{yr}\right) - 591\left(\frac{hrs}{yr}\right) = 1409\left(\frac{hrs}{yr}\right)$$

6.5 ANNUAL EXTERNAL DOSE PER WORK CREW WORKER

The total annual external dose, ED_g, to a worker in a work crew for cask operations including support-only time (Assumption 3.2.14) is calculated from Equation 4:

For an operator:

$$ED_g = (55.4\ \frac{\text{mrem}}{\text{cask}} \times 43\ \frac{\text{cask}}{\text{yr}} + 0.05\ \frac{\text{mrem}}{\text{hr}} \times 1409\ \frac{\text{hrs}}{\text{yr}}) / 1000\ \frac{\text{mrem}}{\text{rem}} =$$
$$2.453\ person - rem$$

For an HPT:

$$ED_g = (39.4 \frac{mrem}{cask} \times 43 \frac{cask}{yr} + 0.05 \frac{mrem}{hr} \times 1409 \frac{hrs}{yr}) / 1000 \frac{mrem}{rem} = 1.765\, person - rem$$

6.6 ANNUAL EXTERNAL RADIATION DOSES

The average estimated doses to an individual CRCF operator is 2.453 rem per year and to an individual HPT is 1.765 rem per year.

The total annual facility external radiation dose to all workers is equal to the annual dose to a single work crew (2.453 rem/operator/yr x 5 operators/crew) plus the dose to 1 HPT (1.765 rem/yr), which results in (14.030 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 70.15 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 CRCF will involve sealed casks with very low levels of surface contamination. The annual maximum internal and external doses to a CRCF 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 total effective dose equivalent (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 Equation 10. All operations conducted within the CRCF will involve sealed casks with very low levels of surface contamination. The annual maximum internal and external doses to a CRCF 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 calculated in Table 5 below:

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

Doses from CRCF Operations	**Symbol**	**Units**	**Operator**	**Health Physics**
External Dose	ED_g	rem/yr	2.453	1.765
Inhalation Dose (CEDE) + Submersion (DDE)	ID_g	rem/yr	0.00152	0.00152
Total Annual Doses by Worker Group		rem/yr	**2.455**	**1.767**

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 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 operations. However, the selected inputs are judged to be representative of the operating conditions. From Section 6.8, the average estimated doses to an individual CRCF worker is 2.455 rem/yr and to an individual HPT is 1.767 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 CRCF 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 Reference 2.2.17 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. 2.1.5) 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 total effective dose equivalent (TEDE). That goal is 10 percent of the annual TEDE limit in 10 CFR 20.1201, and includes both internal and external exposures."

7.3 DISCUSSION

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

One of the secondary uses of the dose assessment is to identify and prioritize CRCF 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 CRCF 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 CRCF. The contribution from the airborne source is negligible. The CRCF operators and HPTs will receive the highest dose during processing canister with TADs resulting from the high frequency of this process in the facility. The doses to the CRCF workers does not contribute to the ALARA design goal[MSOffice6] 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 Concentration Buildup while Cask in CRCF

Radioactive contamination resuspended off the transportation cask surface would be dispersed within the free air volume of the cask preparation room 1026. The maximum time the cask could be present would be equal to the total cask processing time 765 min.

The CRCF 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 CRCF cask handling area is determined from Equation 6 with t_B equal to infinity and λ_R, the surface contamination resuspension rate, equal to $4 \times 10^{-5}\ \mathrm{hr}^{-1}$ per Assumption 3.2.9. The volume of the cask preparation room is 13,947 m^3 per Assumption 3.1.1.

The calculation for airborne concentration at equilibrium is:

$$C_i(\infty) = \frac{\lambda_R S_i}{\lambda_H V_B}\left(1 - e^{-\lambda_H \infty}\right) = \frac{\lambda_R S_i}{\lambda_H V_B} = \frac{4\times10^{-5}\left(hr^{-1}\right) S_i\left(\mu Ci\right)}{0.1\left(hr^{-1}\right) \times 13{,}947\left(m^3\right)} = 2.868\times10^{-8}\left(m^{-3}\right) \times S_i\left(\mu Ci\right)$$

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:

$$C_{\beta\gamma}(\infty) = 2.868\times10^{-8}\left(m^{-3}\right)\times S_{\beta\gamma}\left(\mu Ci\right) = 2.868\times10^{-8}\left(m^{-3}\right)\times 51\ \mu Ci = 1.46\times10^{-6}\left(\mu Ci / m^3\right)$$

and

$$C_{\alpha}(\infty) = 2.868\times10^{-8}\left(m^{-3}\right)\times S_{\alpha}\left(\mu Ci\right) = 2.868\times10^{-8}\left(m^{-3}\right)\times 5.1\ \mu Ci = 1.46\times10^{-7}\left(\mu Ci / m^3\right)$$

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 is 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 765 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 $3.33 \times 10^{-4}\ m^3/s$ 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 the 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/m³)	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	1.46E-06	5.91E-08	8.77E-05	1.26E-13	5.62E-07	8.83E-05
^{90}Sr-90	1.46E-06	3.51E-07	5.21E-04	7.53E-18	3.36E-11	5.21E-04
^{239}Pu	1.46E-07	1.16E-04	1.72E-02	4.24E-18	1.89E-12	1.72E-02
^{241}Am	1.46E-07	1.20E-04	1.78E-02	8.18E-16	3.65E-10	1.78E-02
					Max ID_o $(\beta-\gamma)$ +Max ID_o (α) =	3.56E-02

Sources: References 2.2.9 and 2.2.11

Inhalation and Submersion Doses ICRP-68 and FGR 13.

Isotope	$C_{\beta-\gamma}$ or C_α (µCi/m³)	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	1.46E-06	2.90E-08	4.30E-05	1.19E-13	5.30E-07	4.36E-05
^{90}Sr	1.46E-06	1.50E-07	2.23E-04	9.83E-17	4.38E-10	2.23E-04
^{239}Pu	1.46E-07	4.70E-05	6.98E-03	3.49E-18	1.56E-12	6.98E-03
^{241}Am	1.46E-07	3.90E-05	5.79E-03	6.77E-16	3.02E-10	5.79E-03
					Max ID_o $(\beta-\gamma)$ +Max ID_o (α) =	1.30E-02

Sources: References 2.2.11 and 2.2.13

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 effect 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. 2.2.13) supplement CD Table F12TIII1 using Microsoft notepad.

Using FGR 11 (Ref. 2.2.9) and FGR 12 (Ref. 2.2.11), values result in a higher and more conservative exposure estimate of 3.56E-02 mrem/cask 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 operations is determined from Equation 9 with the total number of operations, *OP*, equal to the number of casks processed per year of 214 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).

$$ID_g = \sum_o ID_o \times \frac{OP}{crews_g} = 3.56\times10^{-2}\left(\frac{mrem}{cask}\right)\times\frac{214\left(\frac{casks}{yr}\right)}{5} = 1.52\left(\frac{mrem}{yr}\right)$$

This dose of 1.52 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 0.476 person-rem/yr, while a decrease of 20% per task time results in a decrease of 0.477 person-rem/yr from the base case dose presented in Section 6.2 Table 4 of 2.382 person-rem/yr. Based on Assumption 3.2.2 the task times presented for the base case shown in Section 6.2 Table 4 have a 37.5% longer total duration than Reference 2.2.5. The sensitivity study shows that even with a 20% per task time reduction from the base case, the dose only changes by 0.477 person-rem/yr. Thus, the results presented in the base case are conservative even if the total task duration in reference 2.2.5 increases by 37.5% since it would take another 225 minutes (600 x .375 = 225) to obtain the total task duration of 825 minutes in Reference 2.2.6.

Sensitivity Study

CRCF			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]**	**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 TAD												
Open Exterior CRCF Entrance Vestibule	5	**0.08**	0	0.05	**0.00**	0	0.05	**0.00**	0.067	0.003	0.10	0.01
Move Loaded Cask into Entrance Vestibule	10	**0.17**	2	7.5	**1.25**	5	3.0	**0.50**	0.133	1.000	0.20	1.50
Close Exterior CRCF Entrance Vestibule Doors	5	**0.08**	0	0.05	**0.00**	0	0.05	**0.00**	0.067	0.003	0.10	0.01
Move Loaded Cask into Prep Area	10	**0.17**	2	7.5	**1.25**	5	3.0	**0.50**	0.133	1.000	0.20	1.50
Perform inspection and survey	60	**1.00**	2	7.5	**7.50**	2	7.5	**7.50**	0.800	6.000	1.20	9.00
Prepare cask for removal from rail car	40	**0.67**	2	7.5	**5.00**	0	0.05	**0.03**	0.533	4.000	0.80	6.00
Remove Personnel Barrier	45	**0.75**	2	7.5	**5.63**	5	2.8	**2.10**	0.600	4.500	0.90	6.75
Partially Unbolt First Impact Limiter	20	**0.33**	1	7.70	**2.57**	5	2.8	**0.93**	0.267	2.053	0.40	3.08
200/20 Ton Crane moves to impact limiter lifting device	5	**0.08**	0	0.05	**0.00**	0	0.05	**0.00**	0.067	0.003	0.10	0.01
Attach lifting device to crane	15	**0.25**	0	0.05	**0.01**	0	0.05	**0.01**	0.200	0.010	0.30	0.02
Move the crane to Impact Limiter	5	**0.08**	0	0.05	**0.00**	0	0.05	**0.00**	0.067	0.003	0.10	0.01
Attach lifting device to the Impact Limiter	5	**0.08**	1	7.70	**0.64**	5	2.8	**0.23**	0.067	0.513	0.10	0.77
Finish unbolting the impact limiter	10	**0.17**	1	7.70	**1.28**	5	2.8	**0.47**	0.133	1.027	0.20	1.54
Lift Impact Limiter and move to storage	10	**0.17**	0	0.05	**0.01**	0	0.05	**0.01**	0.133	0.007	0.20	0.01
Detach lifting device from Impact Limiter	5	**0.08**	0	0.05	**0.00**	0	0.05	**0.00**	0.067	0.003	0.10	0.01
Move crane back to get Second Impact Limiter	5	**0.08**	0	0.05	**0.00**	0	0.05	**0.00**	0.067	0.003	0.10	0.01
Partially unbolt Second Impact Limiter	20	**0.33**	1	4.30	**1.43**	5	1.7	**0.57**	0.267	1.147	0.40	1.72

CRCF			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]**	**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]**
Attach lifting device to Impact Limiter	5	**0.08**	1	4.30	**0.36**	5	1.7	**0.14**	0.067	0.287	0.10	0.43
Finish unbolting the impact limiter	10	**0.17**	1	4.30	**0.72**	5	1.7	**0.28**	0.133	0.573	0.20	0.86
Lift Impact Limiter and move to storage	10	**0.17**	0	0.05	**0.01**	0	0.05	**0.01**	0.133	0.007	0.20	0.01
Move crane to lifting device storage area	5	**0.08**	0	0.05	**0.00**	0	0.05	**0.00**	0.067	0.003	0.10	0.01
Detach the lifting device from the crane	15	**0.25**	0	0.05	**0.01**	0	0.05	**0.01**	0.200	0.010	0.30	0.02
Move the 200/20 Ton crane to its secure location	5	**0.08**	0	0.05	**0.00**	0	0.05	**0.00**	0.067	0.003	0.10	0.01
Perform radiological survey impact limiters	30	**0.50**	0	0.05	**0.03**	0	0.05	**0.03**	0.400	0.020	0.60	0.03
Perform radiological survey of transportation cask	30	**0.50**	0	0.05	**0.03**	2	7.5	**3.75**	0.400	0.020	0.60	0.03
Move the 200/20 Ton crane to the Cask Lifting Yoke	5	**0.08**	0	0.05	**0.00**	0	0.05	**0.00**	0.067	0.003	0.10	0.01
Attach the Cask Lifting Yoke to the Crane	15	**0.25**	0	0.05	**0.01**	0	0.05	**0.01**	0.200	0.010	0.30	0.02
Move the Crane to the Upper Lifting Trunnions of the Cask	5	**0.08**	5	3.0	**0.25**	0	0.05	**0.00**	0.067	0.200	0.10	0.30
Engage Cask Lifting Yoke with Cask Upper Trunnions	10	**0.17**	2	7.50	**1.25**	0	0.05	**0.01**	0.133	1.000	0.20	1.50
Remove Cask Tie Downs and Stabilizers	10	**0.17**	2	7.50	**1.25**	5	3.0	**0.50**	0.133	1.000	0.20	1.50
Tilt the Cask to vertical position	15	**0.25**	0	0.05	**0.01**	0	0.05	**0.01**	0.200	0.010	0.30	0.02
Lift the Cask from the rail car	5	**0.08**	0	0.05	**0.00**	0	0.05	**0.00**	0.067	0.003	0.10	0.01
Move Cask to trolley position	15	**0.25**	0	0.05	**0.01**	0	0.05	**0.01**	0.200	0.010	0.30	0.02
Lower cask on trolley	5	**0.08**	0	0.05	**0.00**	0	0.05	**0.00**	0.067	0.003	0.10	0.01
Cask Trolley engage the	30	**0.50**	2	7.50	**3.75**	2	7.5	**3.75**	0.400	3.000	0.60	4.50

CRCF			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]**	**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]**
cask												
Disengage Lifting Yoke with Cask Upper Trunnions	5	**0.08**	2	7.50	**0.63**	2	7.5	**0.63**	0.067	0.500	0.10	0.75
Move the 200/20 Ton crane to the Cask Lifting Yoke Stand	5	**0.08**	0	0.05	**0.00**	0	0.05	**0.00**	0.067	0.003	0.10	0.01
Detach the Cask Lifting Yoke from the Crane	15	**0.25**	0	0.05	**0.01**	0	0.05	**0.01**	0.200	0.010	0.30	0.02
Move Loaded casks to transfer room	90	**1.50**	5	3.0	**4.50**	5	3.0	**4.50**	1.200	3.600	1.80	5.40
Perform gas sampling	60	**1.00**	3	5.6	**5.60**	2	7.5	**7.50**	0.800	4.480	1.20	6.72
Remove lid bolts from cask	60	**1.00**	2	5.60	**5.60**	0	0.05	**0.05**	0.800	4.480	1.20	6.72
Attach lid lifting fixture to crane **	10	**0.17**	0	0.05	**0.01**	0	0.05	**0.01**	0.133	0.007	0.20	0.01
Move the 200/20 Ton crane to the transfer trolley**	5	**0.08**	0	0.05	**0.00**	0	0.05	**0.00**	0.067	0.003	0.10	0.01
Attach lid lifting fixture to cask/removing from crane**	10	**0.17**	2	5.60	**0.95**	0	0.05	**0.01**	0.133	0.747	0.20	1.12
Move the 200/20 Ton crane to its secure location**	5	**0.08**	0	0.05	**0.00**	0	0.05	**0.00**	0.067	0.003	0.10	0.01
Attach rigging for removal of shield ring from trolley	30	**0.50**	2	7.50	**3.75**	5	3.00	**1.50**	0.400	3.000	0.60	4.50
Survey the TEV before leaving the facility Assumption 3.2.16	30	**0.50**	0	0.05	**0.03**	2	7.5	**3.75**	0.400	0.020	0.60	0.03
Total	825	**13.75**		Total	**55.39**		Total	**39.39**	Total	**44.293**	Total	**66.44**

5 Operators (2.382 x 5)	Operators (5)	**11.908**	person-rem/yr
Annual 1 Crew (Equation 14)	Per Crew	**13.602**	person-rem/yr

Column [A] : From Ref 2.2.6 Table 1
Column [B] : From Ref 2.2.6 Table 1
Column [C] : Column [B]/60
Column [D] : From Ref 2.2.6 Table 1
Column [E] : From Table 3 (Assumption 3.2.2) and Assumption 3.2.14.
Column [F] : [C] x [E]
Column [G] : From Ref 2.2.6 Table 1
Column [H] : From Table 3 (Assumption 3.2.2) and Assumption 3.2.14.
Column [I] : [C] x [H]
Column [J] : [C] x 0.8
Column [K] : [E] x [J]
Column [L] : [C] x 1.2
Column [M] : [E] x [L]

NOTE*: 0 in this column corresponds to a remote operation in 0.05mrem/hr background. See Assumption 3.2.14.

NOTE**: These tasks are equivalent in time to the last task in task 1 from Ref.2.2.6. This breakdown was done because of the different dose rates for each part of this task.

Equation 11 used for [F] and [I]

$$ED_k = \frac{t_k}{60} \times EDR_{dist}$$

Equation 12 used for the total of [F] and [I]

$$ED_o = \sum_{k=1}^{N} ED_k$$

Sensitivity Numbers per cask step				
Operator(1)	-20%	**1.905**	person-rem/yr	Equals 44.293 x 43/1000
Operator(1)	20%	**2.857**	person-rem/yr	Equals 66.44 x 43/1000

% DELTA is 1 - (1.905/2.382) = 20% low
% DELTA is 1 - (2.382/2.858) = 20% high

BSC	**Calculation/Analysis Change Notice** *Complete only applicable items.*	1. QA: QA 2. Page 1 of 1

3. Document Identifier:	4. Rev.:	5. CACN:
060-00C-CR00-00100-000	00B	001

6. Title:
Canister Receipt and Closure Facility #1 Worker Dose Assessment

7. Reason for Change:
Editorial with additional text clarification. Change number in text (765) in 2 places to reflect the number (825) used throughout calculation. 825 min was used in calculations to be conservative when estimating the worker doses.

8. Supersedes Change Notice: ☐ Yes If, Yes, CACN No.: NA X No

9. Change Impact:

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

10. Description of Change:
Attachment 1, page 30, 2nd to last paragraph. Change "**765 min**" to "**825 min which includes cask import and export times to process one cask as described in section 6.1.**"

Attachment 1, page 31, 3rd to last paragraph. Change "**765 min**" to "**825 min.**"

11. REVIEWS AND APPROVAL

Printed Name	Signature	Date
11a. Originator: Tom Karl	[signature]	5-22-07
11b. Checker: Scott Newsom	Scott A. Newsom	05/22/07
11c. EGS: Norman Kahler	N. Kahler	5/22/07
11d. DEM: David Darling	DRB Darling	5/22/07
11e. Design Authority: Barbara Rusinko	B Rusinko	5/23/07

BSC

Calculation/Analysis Change Notice

Complete only applicable items.

1. QA: QA

3. Document Identifier:	4. Rev.:	5. CACN:
060-00C-CR00-00100-000	00B	002

6. Title:
Canister Receipt and Closure Facility #1 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.

$$H_k^{inh} = \sum C_i\left(\frac{\mu Ci}{m^3}\right)\times DCF_i\left(\frac{Sv}{Bq}\right)\times 3.7\times 10^9\left(\frac{mrem-Bq}{Sv-\mu Ci}\right)\times 1\times 3.33\times 10^{-4}\left(\frac{m^3}{\text{sec}}\right)\times t_k\times\left(\frac{60\,\text{sec}}{\text{min}}\right)$$

$$H_k^{sub} = \sum C_i\left(\frac{\mu Ci}{m^3}\right)\times DCF_i\left(\frac{Sv-m^3}{Bq-\text{sec}}\right)\times 3.7\times 10^9\left(\frac{mrem-Bq}{Sv-\mu Ci}\right)\times t_k\times\left(\frac{60\,\text{sec}}{\text{min}}\right)$$

  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.
- 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 CRCF.

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:

Pages 8 and 9
- Changed Assumption 3.1.1 and the first two sentences of the rationale to read :

  3.1.1 Instantaneous Fraction Removed (λ_H)

  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.

Page 21

- Changed definition of $crews_g$ in Equation 9 to read "number of work crews performing this operation, 5 crews"
  Note: This definition was used correctly in the body of the calculation.
- Change first paragraph to read "The airborne activity will decrease after the cask is removed from the area due to the ventilation system cleanup. The maximum airborne activity concentration is calculated using equation 6:"

Page 27

- In Table 5, Revised:
  - The sum of the inhalation and submersion dose values to 0.005 rem/yr.
  - Total annual doses by worker group to 2.5 rem/yr for operator, and 1.8 rem/yr for health physics.
- Revised last sentence of first paragraph in Section 7 to read " From Section 6.8, the average estimated maximum doses to an individual CRCF worker is 2.5 rem/yr and to an individual HPT is 1.8 rem/yr."

Page 30

- Changed first paragraph 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 sentence in next to the last paragraph to read "The maximum time the cask could be present would be equal to the total cask processing time 825 min.
- Revised last paragraph on page to read: "The RF 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: "
- Changed the instantaneous fraction removed (λ_H) from 0.1 to 1.

Page 31

- Due to the change in λ_H to 1, the airborne concentration at equilibrium (C_i) was revised to 2.9×10^{-9} (m^{-3}) × S_i (μCi) resulting in an equilibrium concentration for $C_{\beta\gamma}$ equal to 1.5×10^{-7} ($\mu Ci/m^3$) and C_α equal to 1.5×10^{-8} ($\mu Ci/m^3$).
- Revised cask processing time to read 825 min. in the third paragraph from the bottom.

Page 32

- Revised last sentence of first 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 (μCi/m³)	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	1.5E-07	5.91E-08	5.41E-04	1.26E-13	3.46E-06	5.44E-04
^{90}Sr	1.5E-07	3.51E-07	3.21E-03	7.53E-18	2.07E-10	3.21E-03
^{239}Pu	1.5E-08	1.16E-04	1.06E-01	4.24E-18	1.16E-11	1.06E-01
^{241}Am	1.5E-08	1.20E-04	1.10E-01	8.18E-16	2.25E-09	1.10E-01
					Max ID_o (β-γ) +Max ID_o (α) =	1.1E-01

- 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 (μCi/m³)	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	1.5E-07	2.90E-08	2.65E-04	1.19E-13	3.27E-06	2.69E-04
^{90}Sr	1.5E-07	1.50E-07	1.37E-03	9.83E-17	2.70E-09	1.37E-03
^{239}Pu	1.5E-08	4.70E-05	4.30E-02	3.49E-18	9.59E-12	4.30E-02
^{241}Am	1.5E-08	3.90E-05	3.57E-02	6.77E-16	1.86E-09	3.57E-02
					Max ID_o (β-γ) +Max ID_o (α) =	4.4E-02

- Deleted last paragraph.

Page 33

- Replaced everything following first paragraph with:

Annual Inhalation and Submersion Dose FGR 11 & FGR 12

$$ID_g = \sum_o ID_o \times \frac{OP}{crews_g} = 0.11\left(\frac{mrem}{cask}\right) \times \frac{214\left(\frac{casks}{yr}\right)}{5} = 5\left(\frac{mrem}{yr}\right)$$

Annual Inhalation and Submersion Dose ICRP 68 & FGR 13

$$ID_g = \sum_o ID_o \times \frac{OP}{crews_g} = 0.044\left(\frac{mrem}{cask}\right) \times \frac{214\left(\frac{casks}{yr}\right)}{5} = 2\left(\frac{mrem}{yr}\right)$$

Using FGR 11 (Ref. 2.2.9) and FGR 12 (Ref. 2.2.11), values shown above, result in a higher and more conservative exposure estimate of 5 mrem/yr. This result will be used in Table 5 to calculate the annual TEDE doses by worker category.

The dose of 5 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	[signature]	12/12/08
11b. Checker: Scott Manley	[signature]	12/12/08
11c. EGS: Norman Kahler	[signature]	12/12/08
11d. DEM: Dave Darling	[signature]	2/2/09
11e. Design Authority: Barbara Rusinko	[signature]	2/12/09

2.2.12 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)

2.2.13 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).

2.2.14 BSC 2004, Normal Operation Airborne Release Calculation. 000-HSC-WHS0-00200-000-00C. Las Vegas, Nevada: Bechtel SAIC. ACC: ENG.20050615.0018.

2.2.15 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)

2.2.16 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.

2.2.17 BSC 2006. *Project Design Criteria Document*. 000-3DR-MGR0-00100-000-006. Las Vegas, Nevada: Bechtel SAIC Company. ACC: ENG. 20061201.0005.

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 Instantaneous Fraction Removed (λ_H)

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 room 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 the door vestibules thus resulting in a smaller room volume which will effectively increase the airborne concentration in the room. Measurements are taken from wall centerline so the wall portion of the total length is subtracted from each measurement. This volume is derived from (Ref. 2.2.1, 2.2.2 and 2.2.3) as follows:

Room 1026 east section.
Width = 74 ft – 2 ft west wall = 72 ft
Length = 94 ft – 2 ft north wal – 2 ft south wall = 90 ft
Height = 72 ft – 1.5 ft floor thickness = 70.5 ft
72 ft x 90 ft x 70.5 ft = 456,840 ft^3

Room 1026 west section.
Width = 15 ft – 2 ft west wall = 13 ft
Length = 94 ft – 2ft north wall – 2 ft south wall = 90 ft
Height = 32 ft – 1.5 ft floor thickness = 30.5 ft
13 ft x 90 ft x 30.5 ft = 35,685 ft^3
456,840 ft^3 + 35,685 ft^3 = 492,525 ft^3/35.315m^3/ ft^3 = 13,947m^3

Usage: This assumption is used in Section 6.7.

3.2 ASSUMPTIONS NOT REQUIRING VERIFICATION

3.2.1 Dose Rates

Assumption: The radiation dose rate distribution around a TS125 cask (Table 3) Ref 2.2.4 Figure 6.2-2 is used to estimate dose rates received by workers while processing a transportation cask in the CRCF. It is assumed that this calculated data is representative of the conditions of the cask process in the CRCF and can be used to estimate dose rates received by workers at various distances from the exterior surfaces of a transportation cask.

Rationale: Per Ref. 2.2.5 Section 1.0, the CRCF will handle only sealed canistered waste, i.e., U.S. Department of Energy (DOE) spent nuclear fuel (SNF), high level radioactive waste (HLW), and Commercial SNF for transfer to waste packages or aging overpacks (AOs). Dose rates from AOs and shielded transfer casks will be lower than incoming transportation, aging, and disposal canister (TAD) on a rail cask. The dose rates from the TS125 are considered representative of all SNF casks and bounding because they will have a higher dose rate than other cask configurations. Dose rates in the vicinity of a TS125 rail cask have been determined in Ref. 2.2.4 Figure 6.2-2. All transportation casks received at the CRCF are required to meet the requirements in Ref 2.3.1 for packaging, preparation for shipment, and transportation of licensed materials. For the purpose of these dose calculations it is expected that the transportation cask 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 2.2.4). Because this dose estimate is on an annual average basis, it is reasonable to

The airborne activity will decrease after the cask is removed from the area due to the ventilation system cleanup. The maximum airborne activity concentration is calculated using equation 6:

$$C_i(t) = \frac{\lambda_R S_i}{\lambda_H V_B}\left(1 - e^{-\lambda_H t_B}\right)$$ **Equation 6**

where:

C_i = airborne concentration of isotope i at time t (μCi/m³)
V_B = room air volume (m³)

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

$$H_k^{inh} = \sum_i C_i(t) \times DCF_i^{inh} \times 3.7 \times 10^9 \times RF \times BR \times t_k \times 60$$

$$H_k^{sub} = \sum_i C_i(t) \times DCF_i^{sub} \times 3.7 \times 10^9 \times t_k \times 60$$ **Equation 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(m³/s)
DCF_i^{sub} = submersion DCF for isotope i (Sv-m³/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 CRCF in the presence of airborne activity is calculated as follows:

$$ID_o = \sum_{k=1}^{N}\left(H_k^{inh} + H_k^{sub}\right)$$ **Equation 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:

$$ID_g = \sum_o ID_o \times \frac{OP}{crews_g}$$ **Equation 9**

where

ID_g = inhalation and submersion dose to a worker (mrem/year)
$crews_g$ = number of work crews performing this operation, 5 crews

totals presented in Table 5 below. The annual TEDE doses by worker category are calculated in Table 5 below:

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

Doses from CRCF Operations	Symbol	Units	Operator	Health Physics
External Dose	ED_g	rem/yr	2.453	1.765
Inhalation Dose (CEDE) + Submersion (DDE)	ID_g	rem/yr	0.005	0.005
Total Annual Doses by Worker Group		rem/yr	**2.5**	**1.8**

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 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 operations. However, the selected inputs are judged to be representative of the operating conditions. From Section 6.8, the average estimated maximum doses to an individual CRCF worker is 2.5 rem/yr and to an individual HPT is 1.8 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 CRCF 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 Reference 2.2.17 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.

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:

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

and

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

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 Concentration Buildup while Cask in CRCF

Radioactive contamination resuspended off the transportation cask surface would be dispersed within the free air volume of the cask preparation room 1026. The maximum time the cask could be present would be equal to the total cask processing time 825 min.

The RF 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 CRCF 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 13,947 m^3 per Assumption 3.1.1.

The calculation for airborne concentration at equilibrium is:

$$C_i(\infty) = \frac{\lambda_R S_i}{\lambda_H V_B}\left(1 - e^{-\lambda_H \infty}\right) = \frac{\lambda_R S_i}{\lambda_H V_B} = \frac{4\times10^{-5}\left(hr^{-1}\right) S_i\left(\mu Ci\right)}{1\left(hr^{-1}\right) \times 13{,}947\left(m^3\right)} = 2.9\times10^{-9}\left(m^{-3}\right) \times S_i\left(\mu Ci\right)$$

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:

$$C_{\beta\gamma}(\infty) = 2.9\times10^{-9}\left(m^{-3}\right)\times S_{\beta\gamma}\left(\mu Ci\right) = 2.9\times10^{-9}\left(m^{-3}\right)\times 51\,\mu Ci = 1.5\times10^{-7}\left(\mu Ci/m^3\right)$$

and

$$C_{\alpha}(\infty) = 2.9\times10^{-9}\left(m^{-3}\right)\times S_{\alpha}\left(\mu Ci\right) = 2.9\times10^{-9}\left(m^{-3}\right)\times 5.1\,\mu Ci = 1.5\times10^{-8}\left(\mu Ci/m^3\right)$$

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 is 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 825 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 the 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	1.5E-07	5.91E-08	5.41E-04	1.26E-13	3.46E-06	5.44E-04
^{90}Sr	1.5E-07	3.51E-07	3.21E-03	7.53E-18	2.07E-10	3.21E-03
^{239}Pu	1.5E-08	1.16E-04	1.06E-01	4.24E-18	1.16E-11	1.06E-01
^{241}Am	1.5E-08	1.20E-04	1.10E-01	8.18E-16	2.25E-09	1.10E-01
					Max ID_o $(\beta-\gamma)$ +Max ID_o (α) =	1.1E-01

References 2.2.9 and 2.2.11

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	1.5E-07	2.90E-08	2.65E-04	1.19E-13	3.27E-06	2.69E-04
^{90}Sr	1.5E-07	1.50E-07	1.37E-03	9.83E-17	2.70E-09	1.37E-03
^{239}Pu	1.5E-08	4.70E-05	4.30E-02	3.49E-18	9.59E-12	4.30E-02
^{241}Am	1.5E-08	3.90E-05	3.57E-02	6.77E-16	1.86E-09	3.57E-02
					Max ID_o $(\beta-\gamma)$ +Max ID_o (α) =	4.4E-02

Sources: References 2.2.12 and 2.2.13

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 effect 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. 2.2.13) supplement CD Table F12TIII1 using Microsoft notepad.(Version 5.1)

The total annual inhalation and submersion dose, ID_g, to a worker in a work crew for all operations is determined from Equation 9 with the total number of operations, *OP*, equal to the number of casks processed per year of 214 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

$$ID_g = \sum_o ID_o \times \frac{OP}{crews_g} = 0.11\left(\frac{mrem}{cask}\right) \times \frac{214\left(\frac{casks}{yr}\right)}{5} = 5\left(\frac{mrem}{yr}\right)$$

Annual Inhalation and Submersion Dose ICRP 68 & FGR 13

$$ID_g = \sum_o ID_o \times \frac{OP}{crews_g} = 0.044\left(\frac{mrem}{cask}\right) \times \frac{214\left(\frac{casks}{yr}\right)}{5} = 2\left(\frac{mrem}{yr}\right)$$

Using FGR 11 (Ref. 2.2.9) and FGR 12 (Ref. 2.2.11), values result in a higher and more conservative exposure estimate of 5 mrem/yr. This result will be used in Table 5 to calculate the annual TEDE doses by worker category.

The dose of 5 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.