BSC**Design Calculation or Analysis Cover Sheet**

1. QA: QA

2. Page 1

3. System Monitored Geologic Repository			4. Document Identifier 000-00C-MGR0-00900-000-00C			
5. Title Preclosure Consequence Analyses for License Application						
6. Group Preclosure Safety Analysis						
7. Document Status Designation ☐ Preliminary ☒ Committed ☐ Final ☐ Cancelled						
8. Notes/Comments Checker Responsibilities : Kathryn L. Ashley: Overall document Jorge Schulz: MACCS2 runs and dose results						
Attachments						Total Number of Pages
A – Surface Facility Airborne Release Evaluation						4
B – Preclosure Radiation Dose Limits						4
C – MACCS2 FGR-11 Input and Output File Listing						2 pages and 1 CD
D – COMIDA2 ICRP-72 Food Chain File <i>YUCICRPD.BIN</i>						1
E – ICRP Worker and General Public Dose Results						19
F – MACCS2 ICRP-72 Input and Output File Listing						2 page and 1 CD
G – Comparison of ICRP-72 and FGR-11 Dose Conversion Factors						28
H – Comparison of ICRP-68 and FGR-11 Dose Conversion Factors						3
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. Approved/Accepted (Print/Sign/Date)
00A	Initial issue.	108	C-2	Sen-Sung Tsai	R.P. McDonnell J.A. Ziegler	Dennis C. Richardson
00B	Complete revision. Updated source terms and dose calculations for naval spent nuclear fuel and Hanford high-level radioactive waste. Deleted failed fuel oxidation from the Category 1 event sequence list. Included worker dose calculations for the Fuel Handling Facility and the spent nuclear fuel aging system. Updated references and revised to incorporate CR 3207 comments.	112 pages and 1 CD	C-2 of C-2	Sen-Sung Tsai	Kathryn L. Ashley	Dennis C. Richardson
00C	Major revision to include bounding source terms for Category 1 event sequences, direct radiation doses for Category 1 and Category 2 event sequences. Added dose evaluation with dose conversion factors from ICRP Publications 68 and 72. Revised to include updated event sequences involving other source terms. Incorporates CR 4920 comments.	171 pages and 2 CDs	H-3 of H-3	Dale T. Dexheimer R.P. McDonnell Sen-Sung Tsai <i>for R.P. McDonnell</i> 8/5/05	Kathryn L. Ashley Jorge Schulz <i>for Kathryn L. Ashley</i> 8/5/2005	Mark Wisenburger <i>for Mark Wisenburger</i> 8/5/2005

The calculations contained in this document were developed by Preclosure Safety Analysis (PCSA) and are intended solely for the use of the PCSA in its work regarding design calculations related to preclosure safety analysis. Yucca Mountain Project personnel from the PCSA should be consulted before use of the calculations for purposes other than those stated herein or use by individuals other than authorized personnel in the PCSA.

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ACRONYMS

ALARA	as low as is reasonably achievable
ARF	airborne release fraction
BWR	boiling water reactor
CDE	committed dose equivalent
CEDE	committed effective dose equivalent
CHF	Canister Handling Facility
CSNF	commercial spent nuclear fuel
DCF	dose conversion factor
DDE	deep dose equivalent
DOE	U.S. Department of Energy
DPC	dual-purpose canister
DR	damage ratio; for example, fuel rod breakage fraction
DTF	dry transfer facility [DTF 1 or DTF 2]
DTN	data tracking number
EDE	effective dose equivalent
FA	fuel assembly
FHF	Fuel Handling Facility
GET	generalized event tree
HEPA	high-efficiency particulate air [filter]
HLW	high-level radioactive waste
HVAC	heating, ventilation, and air-conditioning
LDE	lens dose equivalent
LLW	low-level radioactive waste
LPF	leak path factor
MAR	material at risk
NRC	U.S. Nuclear Regulatory Commission
PULF	release fraction pulverized into respirable sizes ($< 10 \mu\text{m}$) from a drop event
PWR	pressurized water reactor
RF	respirable fraction
SDE	shallow dose equivalent
SFA	spent fuel assembly
SNF	spent nuclear fuel
SSCs	structures, systems, and components
TCRRF	Transportation Cask Receipt/Return Facility
TEDE	total effective dose equivalent
TODE	total organ dose equivalent

UNITS OF MEASURE

Ci	curie
cm	centimeter
cm ²	square centimeter
cm ³	cubic centimeter
ft	feet
g	gram
GWd	gigawatt days
hr	hour
in.	inch
kB	kilobyte
kW	kilowatt
km	kilometer
m	meter
m ²	square meter
m ³	cubic meter
min	minute
mph	miles per hour
mrem	millirem
MTHM	metric tons of heavy metal
MTU	metric ton uranium
rem	roentgen equivalent man
s	second
Sv	Sievert
μCi	microcurie
μm	micrometer

1. PURPOSE

The purpose of this calculation is to demonstrate that the preclosure performance objectives, specified in 10 CFR 63.111(a) and 10 CFR 63.111(b) [DIRS 173273], have been met for the proposed design and operations in the geologic repository operations area. Radiological consequence analyses are performed for potential releases and direct radiation from normal operations in surface and subsurface facilities and from Category 1 and Category 2 event sequences during the preclosure period. Surface releases from normal repository operations are primarily from radionuclides released from opening a transportation cask during dry transfer operations of spent nuclear fuel (SNF) in Dry Transfer Facility 1 (DTF 1), Dry Transfer Facility 2 (DTF 2), or the Fuel Handling Facility (FHF). Subsurface releases from normal repository operations are from resuspension of waste package surface contamination and neutron activation of ventilated air and silica dust from host rock in the emplacement drifts. Preclosure performance objectives are discussed in Section 6.2.3 and are summarized in Table 1 and Table 2.

Table 1. Performance Objectives for Normal Operations and Category 1 Event Sequences

Event Sequence Type	Dose Type	Performance Objectives		
		Worker ^a	Onsite Member of the Public ^c	Offsite Member of the Public ^{b,c}
Normal operations and Category 1	TEDE	5 rem/year ^b	100 mrem/year ^c	15 mrem/year ^d 100 mrem/year ^{b,c}
Normal operations and Category 1	Highest TODE	50 rem/year	NA	NA
Normal operations and Category 1	LDE	15 rem/year	NA	NA
Normal operations and Category 1	SDE	50 rem/year	NA	NA
Normal operations and Category 1	External dose: Highest of DDE, LDE, or SDE for the unrestricted area	NA	NA	2 mrem in any 1 hour ^e

NOTES: Radiation exposures and releases from Category 1 event sequences are aggregated per 10 CFR 63.111(a)(2) and 10 CFR 63.111(b)(1) [DIRS 173273].

^a10 CFR 20.1201 [DIRS 173165]

^b10 CFR 63.111(a)(1) [DIRS 173273] requires that 10 CFR 20 be met. 10 CFR 20 [DIRS 173165] provides for establishment for ALARA goals

^c10 CFR 20.1301(a)(1) [DIRS 173165]

^d10 CFR 63.204 [DIRS 173273]

^e10 CFR 20.1301(a)(2) [DIRS 173165]

DDE = deep dose equivalent; LDE = lens dose equivalent; mrem = one thousandth of a rem; NA = not applicable; rem = roentgen equivalent man; SDE = shallow dose equivalent to skin; TEDE = total effective dose equivalent; TODE = total organ dose equivalent.

Table 2. Performance Objectives for Category 2 Event Sequences

Event Sequence Type	Dose Type	Performance Objectives		
		Worker	Onsite Member of the Public	Offsite Member of the Public
Category 2	TEDE	NA	NA	5 rem/event
Category 2	Highest TODE	NA	NA	50 rem/event
Category 2	LDE	NA	NA	15 rem/event
Category 2	SDE	NA	NA	50 rem/event

Source: 10 CFR 63.111(b)(2) [DIRS 173273].

LDE = lens dose equivalent; NA = not applicable; rem = roentgen equivalent man; SDE = shallow dose equivalent to skin; TEDE = total effective dose equivalent; TODE = total organ dose equivalent.

Category 1 event sequences are those natural events and human-induced event sequences that are expected to occur one or more times before permanent closure of the repository. Category 2 event sequences are other event sequences that have at least one chance in 10,000 of occurring before permanent closure of the repository. Event sequences that have less than one chance in 10,000 of occurring before permanent closure of the repository are designated as beyond Category 2 event sequences.

Public dose calculations are performed in Section 6.0. To support the license application, the results from public dose calculations are integrated with the results of worker dose calculations from *Geologic Repository Operations Area Worker Dose Assessment* (BSC 2005c [DIRS 172488]). The results of the worker dose calculation are used, as required by 10 CFR 63.111, to perform worker dose aggregation in Section 6.4.3. Aggregated doses are reported in Section 7.0.

Potential surface and subsurface releases from normal operations are discussed in Section 6.1.1. Event sequence frequency and categorization are discussed in Section 6.1.2. Listings of Category 1 and Category 2 event sequences and the types of waste forms and material at risk (MAR) involved in these event sequences are identified in Sections 6.1.3 and 6.1.4.

Results of public and worker dose calculations for normal operational releases and Category 1 event sequences, as well as bounding Category 2 event sequences, are summarized in Sections 6.3 and 6.4, which include:

- Total effective dose equivalent (TEDE)
- The highest total organ dose equivalent (TODE)
- Shallow dose equivalent to skin (SDE)
- Lens dose equivalent (LDE).

Direct radiation exposures during normal operations and Category 1 and Category 2 event sequences are discussed in Sections 6.3.5 and 6.4.2.1.

Doses in the body of this calculation are determined using ingestion and inhalation dose conversion factors from Federal Guidance Report No. 11 (Eckerman et al. 1988 [DIRS 101069]) and using cloud shine and ground shine dose conversion factors from Federal Guidance Report

No. 12 (Eckerman and Ryman 1993 [DIRS 107684]). For comparison purposes, similar doses are determined in Attachment E of this calculation using Federal Guidance Report No. 12 dose conversion factors for cloud shine and ground shine, but using inhalation dose conversion factors from ICRP-68 (ICRP 1995 [DIRS 172721]) for workers and ingestion and inhalation dose conversion factors from ICRP-72 (ICRP 1996 [DIRS 152446]) for the general public.

2. QUALITY ASSURANCE

This analysis is subject to *Quality Assurance Requirements and Description* (DOE 2004a [DIRS 171539], Section 2.2.2), because it pertains to preclosure safety analysis. This analysis was performed in accordance with LP-3.12Q-BSC, *Design Calculations and Analyses*, and is subject to the requirements of LP-3.13Q-BSC, *Design Control*. Design inputs are identified and tracked in accordance with LP-3.15Q-BSC, *Managing Technical Product Inputs*.

3. METHOD

The methodology used for evaluating radiological consequences from normal operations and Category 1 event sequences is presented in Section 3.1. The methodology used for evaluating radiological consequences from Category 2 event sequences is presented in Section 3.2. Potential releases from normal operations in surface and subsurface facilities are discussed in Section 6.1.1. Potential Category 1 and Category 2 event sequences and the types of waste forms, and quantities of the waste forms, involved in the event sequences are identified in *Categorization of Event Sequences for License Application* (BSC 2005i [DIRS 174467]). The categorization analysis identifies Category 1 and Category 2 event sequences.

Calculations performed in this document use the MACCS2 V.1.12 computer code (MELCOR Accident Consequence Code System for the Calculation of the Health and Economic Consequences of Accidental Atmospheric Radiological Releases) (ORNL 1998 [DIRS 164761]). MACCS2 (ORNL 1998 [DIRS 164761]) calculates doses to onsite and offsite members of the public resulting from surface and subsurface releases during normal operations and Category 1 and Category 2 event sequences. MACCS2 considers potential exposure pathways, including inhalation, resuspension inhalation, ingestion, air submersion, and groundshine. A description of the MACCS2 computer program is given in Section 5.1.

Four dose measures, as follows, are applicable to normal operations and to Category 1 and Category 2 event sequences:

- **Total Effective Dose Equivalent (TEDE)**—For purposes of assess in dose to workers, TEDE is defined in 10 CFR 63.2 [DIRS 173273] as the sum of the deep dose equivalent (DDE) for external exposures and the committed effective dose equivalent (CEDE) for internal exposures. For the purposes of assessing the doses to members of the public, TEDE is defined in 10 CFR 63.2 as the sum of the EDE plus the CEDE. *Use of the Effective Dose Equivalent in Place of the Deep Dose Equivalent in Dose Assessments* (NRC 2003c [DIRS 163018], p. 2) states that the EDE should be used instead of the DDE in situations that do not involve dose measurements using personnel dosimetry, such as in dose assessments based on calculations. Thus, for assessing doses for both

the workers and the members of the public prior to operation, the TEDE is equal to the sum of the EDE for external exposures plus the CEDE for internal exposures.

- **The Highest of the Total Organ Dose Equivalent (TODE)**–The highest TODE is equal to the sum of the highest CDE plus the DDE. The organs evaluated to determine the highest CDE are the lungs, breasts, gonads, red marrow, bone surface, thyroid, and remainder. The remainder is not an organ, but rather a weighted combination of five remaining organs or tissues receiving the highest doses, such as the liver, kidneys, spleen, brain, small intestine, upper large intestine, lower large intestine, or other organs, excluding the skin, lens of the eye, and extremities, as stated in Federal Guidance Report No. 11 (Eckerman et al. 1988 [DIRS 101069], p. 6). The DDE, which is added to the highest CDE, is equal to that used to calculate the TEDE. In dose assessments based on calculations, the DDE is replaced by the EDE as recommended in NRC guidance on the use of the DDE and EDE for external exposure (NRC 2003c [DIRS 163018], p. 2).
- **Lens Dose Equivalent (LDE)**– Only one lens of the eye dose DCF of ^{83m}Kr can be found in Federal Guidance Report No. 11 (Eckerman et al. 1988 [DIRS 101069], Table 2.1). The LDEs are not calculated using the lens of the eye DCFs, because the lens of the eye DCFs given in Federal Guidance Report No. 11 are incomplete. NUREG-1567 (NRC 2000 [DIRS 149756], p. 9-14) states that compliance with the lens of the eye dose limit is achieved if the sum of the SDE plus the TEDE does not exceed 15 rem.
- **Shallow Dose Equivalent to Skin (SDE)** –SDE is from the air submersion and groundshine pathways. The SDE is defined in 10 CFR 20 for occupational exposures as applying to “the skin of the whole body or the skin to any extremity” (10 CFR 20.1201(a)(2)(ii) [DIRS 173165]). The SDE is cited in 10 CFR 63 as “the shallow dose equivalent to skin” (10 CFR 63.111(b)(2) [DIRS 173273]). SDEs are calculated using MACCS2 (ORNL 1998 [DIRS 164761]), which is based on the DCFs for air submersion and for exposure to contaminated ground surfaces in Federal Guidance Report No. 12 (Eckerman and Ryman 1993 [DIRS 107684], Tables III.1 and III.3).

3.1 METHODOLOGY FOR NORMAL OPERATIONS AND CATEGORY 1 EVENT SEQUENCES

This section discusses the methodology used for evaluating radiological consequences from normal operations in the surface and subsurface facilities and Category 1 event sequences. Summary of methodologies and pertinent inputs for release categories is provided in Table 8.

3.1.1 Normal Operations and Category 1 Event Sequence Performance Objectives

Performance objectives for normal operations and Category 1 event sequences are provided in 10 CFR Part 20 [DIRS 173165] and 10 CFR Part 63 [DIRS 173273], are summarized in Table 1 and are discussed in Section 6.2.3.

3.1.2 Normal Operations and Category 1 Event Sequence Public Dose Methodology

This section discusses the method for calculating doses from normal operations and from Category 1 event sequences, including dose aggregation as required by 10 CFR 63.111 [DIRS 173273].

The χ/Q values are calculated internally in MACCS2 (ORNL 1998 [DIRS 164761]) using hourly meteorological data gathered at the Yucca Mountain site from 1998 through 2002 (Section 6.2.1.1.2). MACCS2 [DIRS 164761] uses 8,760 sets of hourly data on wind speed, wind direction, atmospheric stability class, and rain intensity collected over a period of 1 year to calculate χ/Q values. This process generates 8,760 χ/Q values, which includes the 16 directional sectors, wind speeds, and atmospheric stability classes collected in the annual data for 1999. The χ/Q values output from MACCS2 [DIRS 164761] are the mean, 50th percentile (median), 95th percentile, and 99.5th percentile values evaluated at a 11 km distance from the release point for a surface release, or at a 8 km distance for a subsurface release (Section 6.2.1.5 and Attachment B, Figure B-1).

The χ/Q values are determined regardless of wind direction or sector for the distance of interest. The χ/Q values are overall site χ/Q values and are not tied to any particular sector, such as the sector to the west site boundary. Because all sector meteorological data are used in χ/Q calculations and the receptor location (i.e., 11 km from a DTF to the west site boundary) is the shortest distance from the release point, the resultant χ/Q values are the most conservative and bound all site boundary locations.

The sector-independent MACCS2 (ORNL 1998 [DIRS 164761]) calculated mean χ/Q value of 2.69×10^{-6} s/m³ at a distance of 11 km (Attachment A, Table A-1) is at least one order of magnitude higher than the annual average χ/Q value of 2.1×10^{-7} s/m³ at a distance of 10 km, using Regulatory Guide 1.111 [DIRS 103765], Equation 3, as calculated in *Calculations of Acute and Chronic "Chi/Q" Dispersion Estimates for a Surface Release* (CRWMS M&O 1999a [DIRS 136424], Table 6c).

3.1.2.1 Normal Operations Public Dose Methodology

During normal operations, radioactive materials could be released from a waste transfer cell during the opening of a transportation cask (Assumption 4.2.6). There may be additional releases that could result from the potential events discussed in Section 6.1.6. However, the release from these potential events would be inconsequential compared to those from normal operation. The heating, ventilation, and air-conditioning (HVAC) system is operating during normal operation with credit for HEPA filters (Assumption 4.2.2) and airborne radioactive material is vented through the exhaust stack (Assumption 4.1.6) and released as a radioactive plume that is dispersed en route to the site boundary (Assumption 4.2.4). This results in an acute individual exposure during plume passage and a chronic individual exposure to ground contamination and contaminated food after plume passage (Assumption 4.2.4). To ensure that the χ/Q value is conservative at the site boundary, no credit is taken for plume meandering or for plume rise from initial thermal energy (Assumption 4.2.15). For normal operations, credit is taken for atmospheric dispersion of radionuclides released via the exhaust stack (Assumption 4.1.6). Therefore, the release is modeled as a release from a vent above the facility roof with no plume rise (Assumption 4.2.11). The building wake effect on the plume is considered for surface facility releases (Assumption 4.2.11).

For public doses using MACCS2 (ORNL 1998 [DIRS 164761]), a release duration of 24 hour is used for surface and subsurface annual releases from normal operations (Assumption 4.2.4). MACCS2 [DIRS 164761] is designed to simulate accidents with a release duration of 24 hour or less, however, it is used to simulate normal operations for which the release duration is 1 year. The use of a 24-hr release duration is conservative because: (1) a 24-hr release duration has a shorter time for radionuclide decay than a 1-year release duration, and (2) a 24-hr release duration results in a longer duration at higher ground concentrations of radionuclides and, therefore, higher resuspension inhalation, groundshine, and ingestion doses. This is confirmed by sensitivity analysis (Section 6.3.4.1), which shows that modeling annual releases from normal operations with a 24-hr duration instead of a 1-year duration is conservative because the shorter duration MACCS2 [DIRS 164761] run shows higher doses (Section 6.3.4.1).

For normal operations, the MACCS2 (ORNL 1998 [DIRS 164761]) calculated mean or median χ/Q value is used, depending on which value is higher.

3.1.2.2 Category 1 Event Sequence Public Dose Methodology

For Category 1 event sequences involving drops or collisions, or both, of SNF, radioactive materials are released during transfer (BSC 2005i [DIRS 174467], Section 6.3.1.3) inside a waste transfer cell (Assumption 4.2.6). The HVAC system is operating with credit for HEPA filters (Assumption 4.2.2) and that radioactive material is vented through the exhaust stack (Assumption 4.2.11) as a radioactive plume. For Category 1 event sequences, no credit is taken for the stack height and the release is modeled as a ground-level release (Assumption 4.2.12), and the building wake effect is considered. A release duration of 1 hour is used (Assumption 4.2.3). The plume is dispersed en route to the site boundary, resulting in an acute individual exposure during plume passage and in a chronic individual exposure to ground contamination and contaminated food for 1 year after plume passage (Assumption 4.2.4). To ensure that the χ/Q value is maximized at the site boundary, no credit is taken for plume

meandering or for plume rise from initial thermal energy (Assumption 4.2.15). Category 1 event sequences use the 95th percentile with a 5% exceedance of the χ/Q value evaluated at the closest site boundary of 11 km for the maximally exposed individual without regard to sectors.

Source terms for spent fuel assemblies (SFAs) from pressurized water reactors (PWRs) and boiling water reactors (BWRs), with the four different combinations of initial enrichment, burnup, and decay time in Table 3, are presented in Table 4.

Table 3. Boiling Water Reactor and Pressurized Water Reactor Spent Fuel Assemblies

Spent Fuel Assembly	Initial Enrichment (Percent)	Burnup (GWd/MTU)	Decay Time (Years)
Average PWR ^a	4.0	48	25
Maximum PWR ^a	5.0	80	5
Average BWR ^b	3.5	40	25
Maximum BWR ^b	5.0	75	5

Sources: ^a BSC 2004f [DIRS 169061], p. 27

^b BSC 2003a [DIRS 164364], p. 46.

BWR = boiling water reactor; GWd = gigawatt days; MTU = metric ton uranium;
PWR = pressurized water reactor.

Radionuclide inventories in curies per fuel assembly (Ci/FA) for the average and maximum PWR and the average and maximum BWR SFAs are presented in Table 4. The average PWR SFAs are used to calculate the mean dose for normal operations. Both the maximum PWR and the maximum BWR SFAs are used to calculate bounding doses for Category 1 and Category 2 event sequences (Assumption 4.1.8).

Table 4. Boiling Water Reactor and Pressurized Water Reactor Radionuclide Inventories

Radionuclide	Average PWR (Ci/FA) ^a	Maximum PWR (Ci/FA) ^a	Average BWR (Ci/FA) ^b	Maximum BWR (Ci/FA) ^b
²²⁷ Ac	1.61×10^{-5}	0.00×10^0	0.00×10^0	0.00×10^0
²⁴¹ Am	$1.98 \times 10^{+3}$	$8.79 \times 10^{+2}$	$5.58 \times 10^{+2}$	$2.66 \times 10^{+2}$
²⁴² Am	6.36×10^0	$1.01 \times 10^{+1}$	2.16×10^0	3.39×10^0
^{242m} Am	6.39×10^0	$1.02 \times 10^{+1}$	2.17×10^0	3.41×10^0
²⁴³ Am	$2.20 \times 10^{+1}$	$6.00 \times 10^{+1}$	5.34×10^0	$1.93 \times 10^{+1}$
^{137m} Ba	$3.88 \times 10^{+4}$	$9.89 \times 10^{+4}$	$1.31 \times 10^{+4}$	$3.65 \times 10^{+4}$
¹⁴ C	3.32×10^{-1}	5.35×10^{-1}	1.76×10^{-1}	3.16×10^{-1}
^{113m} Cd	7.66×10^0	$4.31 \times 10^{+1}$	2.26×10^0	$1.39 \times 10^{+1}$
³⁶ Cl	6.80×10^{-3}	1.05×10^{-2}	2.93×10^{-3}	4.99×10^{-3}
²⁴² Cm	5.26×10^0	$3.56 \times 10^{+1}$	1.78×10^0	$1.13 \times 10^{+1}$
²⁴³ Cm	$1.03 \times 10^{+1}$	$4.19 \times 10^{+1}$	2.47×10^0	$1.12 \times 10^{+1}$
²⁴⁴ Cm	$1.36 \times 10^{+3}$	$1.40 \times 10^{+4}$	$2.55 \times 10^{+2}$	$3.94 \times 10^{+3}$
²⁴⁵ Cm	3.07×10^{-1}	1.79×10^0	4.03×10^{-2}	3.53×10^{-1}
²⁴⁶ Cm	1.04×10^{-1}	1.21×10^0	1.45×10^{-2}	2.96×10^{-1}
⁶⁰ Co	$3.13 \times 10^{+2}$	$5.99 \times 10^{+3}$	$4.39 \times 10^{+1}$	$8.53 \times 10^{+2}$
¹³⁴ Cs	$2.52 \times 10^{+1}$	$4.05 \times 10^{+4}$	6.32×10^0	$1.15 \times 10^{+4}$

Table 4. Boiling Water Reactor and Pressurized Water Reactor Radionuclide Inventories (Continued)

Radionuclide	Average PWR (Ci/FA) ^a	Maximum PWR (Ci/FA) ^a	Average BWR (Ci/FA) ^b	Maximum BWR (Ci/FA) ^b
¹³⁵ Cs	3.50×10^{-1}	6.34×10^{-1}	1.39×10^{-1}	2.82×10^{-1}
¹³⁷ Cs	$4.11 \times 10^{+4}$	$1.05 \times 10^{+5}$	$1.39 \times 10^{+4}$	$3.87 \times 10^{+4}$
¹⁵⁴ Eu	$6.71 \times 10^{+2}$	$6.15 \times 10^{+3}$	$1.75 \times 10^{+2}$	$1.80 \times 10^{+3}$
¹⁵⁵ Eu	$5.15 \times 10^{+1}$	$1.80 \times 10^{+3}$	$1.60 \times 10^{+1}$	$6.28 \times 10^{+2}$
⁵⁵ Fe	3.46×10^0	$7.27 \times 10^{+2}$	1.09×10^0	$2.34 \times 10^{+2}$
³ H	$1.14 \times 10^{+2}$	$4.95 \times 10^{+2}$	$3.95 \times 10^{+1}$	$1.76 \times 10^{+2}$
¹²⁹ I	2.19×10^{-2}	3.60×10^{-2}	7.42×10^{-3}	1.35×10^{-2}
⁸⁵ Kr	$1.13 \times 10^{+3}$	$5.79 \times 10^{+3}$	$3.81 \times 10^{+2}$	$2.03 \times 10^{+3}$
^{93m} Nb	$1.30 \times 10^{+1}$	$4.87 \times 10^{+1}$	4.73×10^{-1}	1.22×10^0
⁹⁴ Nb	8.39×10^{-1}	1.37×10^0	1.87×10^{-2}	3.38×10^{-2}
⁵⁹ Ni	2.09×10^0	2.96×10^0	5.02×10^{-1}	7.78×10^{-1}
⁶³ Ni	$2.52 \times 10^{+2}$	$4.52 \times 10^{+2}$	$5.86 \times 10^{+1}$	$1.16 \times 10^{+2}$
²³⁷ Np	2.47×10^{-1}	4.01×10^{-1}	6.89×10^{-2}	1.33×10^{-1}
²³¹ Pa	2.97×10^{-5}	4.18×10^{-5}	1.39×10^{-5}	2.94×10^{-5}
¹⁰⁷ Pd	8.41×10^{-2}	1.60×10^{-1}	2.65×10^{-2}	5.69×10^{-2}
¹⁴⁷ Pm	$1.19 \times 10^{+2}$	$2.29 \times 10^{+4}$	$3.98 \times 10^{+1}$	$7.46 \times 10^{+3}$
²³⁸ Pu	$2.29 \times 10^{+3}$	$6.80 \times 10^{+3}$	$5.85 \times 10^{+2}$	$2.11 \times 10^{+3}$
²³⁹ Pu	$1.77 \times 10^{+2}$	$1.83 \times 10^{+2}$	$5.35 \times 10^{+1}$	$5.36 \times 10^{+1}$
²⁴⁰ Pu	$3.18 \times 10^{+2}$	$4.01 \times 10^{+2}$	$1.14 \times 10^{+2}$	$1.48 \times 10^{+2}$
²⁴¹ Pu	$2.46 \times 10^{+4}$	$8.00 \times 10^{+4}$	$6.78 \times 10^{+3}$	$2.25 \times 10^{+4}$
²⁴² Pu	1.64×10^0	3.34×10^0	5.08×10^{-1}	1.26×10^0
¹⁰⁶ Ru	1.23×10^{-2}	$1.33 \times 10^{+4}$	3.00×10^{-3}	$3.29 \times 10^{+3}$
¹²⁵ Sb	9.71×10^0	$2.14 \times 10^{+3}$	2.89×10^0	$6.21 \times 10^{+2}$
⁷⁹ Se	4.57×10^{-2}	7.35×10^{-2}	1.59×10^{-2}	2.88×10^{-2}
¹⁵¹ Sm	$2.11 \times 10^{+2}$	$3.19 \times 10^{+2}$	$5.39 \times 10^{+1}$	$8.22 \times 10^{+1}$
¹²⁶ Sn	3.85×10^{-1}	6.83×10^{-1}	1.27×10^{-1}	2.52×10^{-1}
⁹⁰ Sr	$2.72 \times 10^{+4}$	$6.52 \times 10^{+4}$	$9.54 \times 10^{+3}$	$2.52 \times 10^{+4}$
⁹⁹ Tc	8.98×10^0	$1.34 \times 10^{+1}$	3.20×10^0	5.35×10^0
²³⁰ Th	1.48×10^{-4}	3.33×10^{-5}	6.09×10^{-5}	2.05×10^{-5}
²³² U	2.04×10^{-2}	5.97×10^{-2}	4.63×10^{-3}	2.00×10^{-2}
²³³ U	3.79×10^{-5}	2.42×10^{-5}	1.06×10^{-5}	0.00×10^0
²³⁴ U	6.77×10^{-1}	5.21×10^{-1}	2.50×10^{-1}	2.26×10^{-1}
²³⁵ U	7.37×10^{-3}	3.28×10^{-3}	2.62×10^{-3}	9.43×10^{-4}
²³⁶ U	1.72×10^{-1}	2.23×10^{-1}	6.26×10^{-2}	9.55×10^{-2}
²³⁸ U	1.48×10^{-1}	1.42×10^{-1}	6.32×10^{-2}	6.07×10^{-2}
⁹⁰ Y	$2.72 \times 10^{+4}$	$6.53 \times 10^{+4}$	$9.54 \times 10^{+3}$	$2.52 \times 10^{+4}$
⁹³ Zr	8.94×10^{-1}	1.41×10^0	3.39×10^{-1}	6.03×10^{-1}

Sources: ^a BSC 2004f [DIRS 169061], Attachment IX^b BSC 2003a [DIRS 164364], Attachment XIII.

BWR = boiling water reactor; Ci/FA = curies per fuel assembly; PWR = pressurized water reactor.

Airborne release fractions (ARFs) and respirable fractions (RFs) for intact and damaged commercial SNF and naval SNF are shown in Table 5. Fuel rods with hairline cracks and pinhole leaks are treated as intact fuel rods as stated in Interim Staff Guidance-1 (NRC 2002 [DIRS 164018]). ARFs and RFs for intact commercial SNF assemblies (Table 5) are used for normal operations and Category 1 event sequences. Because Category 2 event sequences with drops or collisions of transportation casks or waste packages could involve intact and/or damaged SNF fuel rods or assemblies, bounding value ARFs and RFs in Table 5 are used.

Table 5. Spent Nuclear Fuel Airborne Release Fractions and Respirable Fractions

Nuclide	Airborne Release Fraction (ARF)	Respirable Fraction (RF)	Effective Release Fraction (ARF × RF)
Breach of Intact SNF Assemblies^{a, b} (Used in Normal Operations and Category 1 Event Sequences)			
³ H	3×10^{-1}	1.0	3×10^{-1}
⁸⁵ Kr	3×10^{-1}	1.0	3×10^{-1}
¹²⁹ I	3×10^{-1}	1.0	3×10^{-1}
Cs	2.0×10^{-4}	1.0	2.0×10^{-4}
Sr ^c	3.0×10^{-5}	$1.0/5.0 \times 10^{-3 e}$	$3.0 \times 10^{-5}/1.5 \times 10^{-7 e}$
Ru	2.0×10^{-4}	1.0	2.0×10^{-4}
Crud	$1.5 \times 10^{-2 d}$	1.0	1.5×10^{-2}
Fuel Fines other than Sr	3.0×10^{-5}	$1.0/5.0 \times 10^{-3 e}$	$3.0 \times 10^{-5}/1.5 \times 10^{-7 e}$
Bounding Values for Breach of Intact or Failed SNF Rods or Assemblies^{b, f} (Used in Category 2 Event Sequences)			
³ H	3×10^{-1}	1.0	3×10^{-1}
⁸⁵ Kr	3×10^{-1}	1.0	3×10^{-1}
¹²⁹ I	3×10^{-1}	1.0	3×10^{-1}
Cs	2.0×10^{-4}	1.0	2.0×10^{-4}
Sr ^c	5.9×10^{-7}	1.0	5.9×10^{-7}
Ru	2.0×10^{-4}	1.0	2.0×10^{-4}
Crud	$1.5 \times 10^{-2 d}$	1.0	1.5×10^{-2}
Fuel Fines other than Sr	5.9×10^{-7}	1.0	5.9×10^{-7}

NOTES: ^a ARFs and RFs are for intact assemblies and Category 2 event sequences involving naval SNF.

^b Source: BSC 2004g [DIRS 172371], Section 6.2.1.3 and Table 11

^c Sr is treated as fuel fines

^d For crud, the value shown is the "effective ARF," the product of a crud spallation fraction of 0.15 and an ARF of 0.1 (BSC 2004g [DIRS 172371], Section 6.2.1.3)

^e Fuel fines and Sr RF values of 5×10^{-3} and 1.0 are used for unfiltered and filtered releases, respectively, that is all particles released through the HEPA filters are assumed to be of respirable size (Assumption 4.2.16). These values are also used for Category 2 event sequences involving naval SNF.

^f Bounding ARF × RF values for both intact single fuel rods and failed fuel assemblies and rods and fuel pieces and debris; fuel rods with hairline cracks and pinhole leaks are treated as intact fuel rods.

ARF = airborne release fraction; RF = respirable fraction; SNF = spent nuclear fuel.

Potential radiation doses to members of the public that come from inhalation, resuspension inhalation, ingestion, air submersion, and groundshine pathways are considered for normal

operations and for Category 1 event sequences. Whole body and organ doses to a member of the public at the site boundary by inhalation, resuspension inhalation, ingestion, air submersion, and groundshine pathways are calculated using MACCS2 (ORNL 1998 [DIRS 164761], Section 5).

Dose Aggregation—Total annual public dose is based on contributions from four sources:

- Category 1 event sequences (aggregated)
- Normal operational releases from surface facilities
- Normal operational releases from the subsurface repository
- Direct radiation dose from contained radiation sources.

The direct radiation dose to offsite members of the public from the repository is very low because radiation sources, such as transportation casks, waste packages, and aging casks are processed at locations far away from the site boundary. For onsite members of the public the direct radiation dose from aging casks is significant and is included because of the shorter distances to onsite locations. The Category 1 annual dose, normal operational release annual dose, and direct radiation dose from aging casks are included in the dose aggregation calculation as described by:

$$D_{TOT} = D_{Cat.1} + D_{NO}^{SF} + D_{NO}^{Sub} + D_{NO}^{Dir} \quad (\text{Eq. 1})$$

where,

$D_{Cat.1}$	=	Annual dose from Category 1 event releases (mrem/year)
D_{NO}^{SF}	=	Annual dose from normal operational releases from surface facilities (mrem/year)
D_{NO}^{Sub}	=	Annual dose from normal operational releases from the subsurface repository (mrem/year).
D_{NO}^{Dir}	=	Annual dose from normal operation direct radiation from contained sources (mrem/year).

The annual dose from Category 1 event sequences is calculated using:

$$D_{Cat.1} = \sum_{i=1}^n D_i \cdot f_i \quad (\text{Eq. 2})$$

where,

i	=	Index for a given Category 1 event sequence; $i = 1, 2, \dots, n$
n	=	Total number of Category 1 event sequences
D_i	=	Dose from event sequence i (mrem/event)
f_i	=	Frequency of event sequence i (events/year).

Doses from annual releases from normal operations in surface facilities, D_{NO}^{SF} , normal operations in the subsurface repository, D_{NO}^{Sub} , and from each Category 1 event sequence i , D_i , are

calculated using MACCS2 (ORNL 1998 [DIRS 164761]) and results are summarized in Section 6.3.1.

To show compliance with 10 CFR 63.111 [DIRS 173273], the calculated annualized dose, D_{TOT} , is compared with the regulatory dose limit of 15 mrem/year at the site boundary. In addition, the calculated TEDE from each Category 1 event sequence and any combination of Category 1 event sequences that can occur in 1 year are also compared with the regulatory dose limit of 15 mrem/year at the site boundary.

3.1.3 Worker Dose Methodology

As Low As is Reasonably Achievable (ALARA) design goals, as described in *Project Design Criteria Document* (BSC 2005f [DIRS 173614], Section 4.9.3.3), for occupational workers ensure that both individual and collective annual doses are maintained at ALARA levels during normal operations and as a result of Category 1 event sequences. Category 1 event sequences are included in ALARA dose assessments. The ALARA goal is to minimize the number of individuals that have the potential of receiving more than 500 mrem/year TEDE (BSC 2005f [DIRS 173614], Section 4.9.3.3).

For the purpose of demonstrating compliance with the normal operations and Category 1 event sequence performance objectives for workers in Table 1, the results from worker dose calculation BSC 2005c (DIRS 172488) are reported in this calculation and are used in Section 6.4.3 to perform worker dose aggregation. This section describes the methods used to calculate worker dose during normal operations and Category 1 event sequences. Regulation 10 CFR 63.111(a)(1) [DIRS 173273] requires that the geologic repository operations area must meet the requirements of 10 CFR Part 20 [DIRS 173165] for radiation protection.

Shielding must take normal operations and Category 1 event sequences into consideration. The primary objective of shielding is to maintain occupational radiation exposures ALARA, and within the exposure dose limits specified in 10 CFR 20.1201. The controlling dose limit for workers (Table 1) is a TEDE of 5 rem/year in 10 CFR 20.1201(a)(1). The general approach used to estimate worker doses is to estimate radiation levels in occupied areas, to determine the personnel requirements and duration of activities in these areas, and to combine the dose rates, times, and personnel estimates to generate the worker dose estimates.

Sections 3.1.3.1 and 3.1.3.2 present the methodologies for calculating worker dose and the potential dose consequences from surface and subsurface releases during normal operations. Among the surface facilities, only DTF 1, DTF 2, and the FHF have a potential for airborne releases of radionuclides during normal operations or following a Category 1 event sequence. Sections 3.1.3.3 thru 3.1.3.5 present the source terms, shielding calculation methodologies and worker doses from direct radiation.

3.1.3.1 Worker Dose From Airborne Releases

For normal operation and Category 1 event sequences, radionuclides are primarily released in a waste transfer cell within a surface facility. The HVAC system, including HEPA filters, is operating and the airborne radionuclides are vented through the building exhaust stack, then

disperse into the atmosphere and reenter the building through the building ventilation system air intakes (Assumption 4.2.11). For radionuclides released from the subsurface facility, it is assumed that the airborne radionuclides are dispersed into the atmosphere and reenter the subsurface facility through the subsurface ventilation system air intakes (Assumption 4.2.11).

The TEDE dose measure for airborne releases, described in Interim Staff Guidance-5 (NRC 2003a [DIRS 160582], p. 10) with EDE used in place of DDE (NRC 2003c [DIRS 163018], p. 2). The TEDE measure is thus expressed as:

$$TEDE = CEDE + EDE = \sum_j D_{j, effective}^{inh} + \sum_j D_{j, effective}^{ext} \quad (\text{Eq. 3})$$

where,

$TEDE$	=	Total effective dose equivalent (rem)
$CEDE$	=	Committed effective dose equivalent (rem)
EDE	=	Effective dose equivalent (rem)
$D_{j, effective}^{inh}$	=	Whole body effective inhalation dose from the j^{th} nuclide (rem)
$D_{j, effective}^{ext}$	=	Whole body effective external dose from the j^{th} nuclide (rem)

The TODE (= CDE + EDE) measure is described in NRC 2003a ([DIRS 160582], p. 10) with EDE used in place of DDE (NRC 2003c [DIRS 163018], p. 2):

$$TODE_k = CDE_k + EDE_k = \sum_j D_{j,k}^{inh} + \sum_j D_{j,k}^{ext} \quad \text{where } k \neq \text{effective or skin} \quad (\text{Eq. 4})$$

where,

CDE_k	=	Committed dose equivalent to the k^{th} organ (rem)
$D_{j,k}^{inh}$	=	Radiation dose from the j^{th} nuclide to the k^{th} organ from inhalation (rem)
$D_{j,k}^{ext}$	=	Radiation dose from the j^{th} nuclide to the k^{th} organ from external exposure (rem)
k	=	Organ index, where organs are gonads, breast, lungs, red marrow, bone surface, thyroid, and remainder.

The external dose is the sum of the groundshine dose and the air submersion dose. The groundshine dose is a small contribution to the total dose and therefore for worker doses the external dose is approximated by the air submersion dose. For example, MACCS2 Output LAPWR01.OUT for Run 4 (Table 20) shows that the groundshine dose at 100 m is about 2.1×10^{-2} mrem, which is less than 0.2% of the inhalation dose.

The ingestion dose is not calculated for workers because no ingestion of contaminated food, water, or soil is expected.

For airborne releases of radionuclides through building vents, the previous inhalation and external doses can be further expressed as (NRC 2003a [DIRS 160582], pp. 9 and 10):

$$\begin{aligned} D_{j,k}^{inh} &= Q_j \times duration \times \frac{\chi}{Q} \times BR \times conv \times DCF_{j,k}^{inh} \\ &= ST_j \times FA \times \frac{\chi}{Q} \times BR \times conv \times DCF_{j,k}^{inh} \end{aligned} \quad (\text{Eq. 5})$$

$$\begin{aligned} D_{j,k}^{ext} &= Q_j \times duration \times \frac{\chi}{Q} \times conv \times DCF_{j,k}^{sub} \\ &= ST_j \times FA \times \frac{\chi}{Q} \times conv \times DCF_{j,k}^{sub} \end{aligned} \quad (\text{Eq. 6})$$

where,

Q_j	=	Release rate for source term for the j^{th} nuclide (Ci/sec)
$duration$	=	Release duration (sec)
<i>For an integrated release from fuel assemblies, $Q_j \times duration = ST_j \times FA$</i>		
ST_j	=	Release source term per fuel assembly for the j^{th} nuclide (Ci/FA)
FA	=	Number of SFAs involved in the release per year or per event; $FA = 7,579$ PWR SFAs for normal operations per year (Assumption 4.2.1) and $FA = 2$ or 1 PWR SFAs per event for Category 1 event sequences (Table 11)
χ/Q	=	Atmospheric dispersion factor (s/m^3)
BR	=	Breathing rate = $3.33 \times 10^{-4} \text{ m}^3/\text{s}$ (NRC 2000 [DIRS 149756], p. 9-13)
$DCF_{j,k}^{inh}$	=	Inhalation DCF of the j^{th} nuclide for the k^{th} organ in Sv/Bq (Eckerman et al. 1988 [DIRS 101069], Table 2.1)
$DCF_{j,k}^{ext}$	=	Air submersion DCF of the j^{th} nuclide for the k^{th} organ [$(\text{Sv}\cdot\text{m}^3)/(\text{Bq}\cdot\text{s})$] (Eckerman and Ryman 1993 [DIRS 107684], Table III.1)
$conv$	=	DCF unit conversion factor: $3.7 \times 10^{12} \text{ (rem}\cdot\text{Bq)} / (\text{Ci}\cdot\text{Sv})$

The SDE is equal to (NRC 2003a [DIRS 160582], p. 10):

$$SDE = \sum_j D_{j,skin}^{sub} \quad (\text{Eq. 8})$$

where,

SDE	=	Shallow dose equivalent to skin (rem)
$D_{j,skin}^{sub}$	=	Radiation dose from the j^{th} nuclide to the skin from air submersion (rem).

NUREG-1567 (NRC 2000 [DIRS 149756], p. 9-14) states that compliance with the LDE limit is achieved when the sum of the SDE and the TEDE does not exceed 15 rem; the LDE may be expressed as:

$$LDE = TEDE + SDE \quad (\text{Eq. 9})$$

where,

$$LDE = \text{Lens dose equivalent (rem).}$$

The receipt rate of 3,600 MTHM/year equals 7,579 PWR SFAs/year based on 0.475 MTU/SFA (Assumption 4.2.1). For calculation of normal operation doses, 1% (Assumption 4.1.3) of fuel rods in these SFAs are assumed damaged. For Category 1 event sequences, an SFA is dropped back into a transportation cask and damages another SFA inside the cask during the dry transfer of SNF from a transportation cask to a waste package (see Sections 6.1.3.1 and 6.1.3.2).

For worker doses χ/Q values are required at short distances from release point, and therefore, the χ/Q values are generated using the NRC-sponsored computer code, *Software Code: ARCON*. V.96 [ARCON96], (BSC 2003b [DIRS 164784]), as described in NUREG/CR-6331 (Ramsdell and Simonen 1997 [DIRS 164547]). ARCON96 (BSC 2003b [DIRS 164784]) was developed by Pacific Northwest National Laboratory for the NRC to calculate χ/Q values in plumes for nuclear power plants at control room air intakes in the vicinity of the release point. ARCON96 (BSC 2003b [DIRS 164784]) implements a straight-line Gaussian dispersion model with dispersion coefficients modified to account for low wind meander and building wake effects. ARCON96 (BSC 2003b [DIRS 164784]) also accounts for variations in the location of release points.

The χ/Q values used for normal operational releases and Category 1 event sequences are predicted using ARCON96 (BSC 2003b [DIRS 164784]). For each receptor of interest, a cumulative probability distribution of χ/Q is constructed by the code for various release time periods. The 8,760-hr probabilistic χ/Q distribution is used to determine the annual average and the 50% median χ/Q values for the receptor of interest. The larger of the annual average or median χ/Q value is used to calculate the annual average dose to workers from airborne radionuclides during normal operations. The maximum 2 hour 95th percentile χ/Q value is used to calculate the dose to workers from airborne radionuclides for Category 1 event sequences.

The χ/Q values represent the dilution of an airborne contamination from atmospheric mixing and turbulence based on the site-specific atmospheric conditions, the relative configuration of the release point and the receptor, and the distance from the release point to the receptor of interest. It is the ratio of the contaminant air concentration at the receptor to the contaminant release rate at the release point, and it is used to determine the dose consequences for a receptor based on the quantity released, the atmospheric conditions, and the distance to the receptor.

The χ/Q values at various onsite receptor locations for airborne releases from surface and subsurface facilities were calculated using ARCON96 (BSC 2003b [DIRS 164784]) and the results of the calculations are reported in *GROA Airborne Release Dispersion Factor Calculations* (BSC 2005d [DIRS 172941], Section 6.3). The maximum of the χ/Q values at receptors for each of the release sources were used to calculate the maximum worker doses for

releases from the surface and subsurface facilities from normal operations and Category 1 event sequences. These χ/Q values represent the dispersion factors estimated at the air intake point of the surface and subsurface facilities.

The airborne source term is the amount of radioactive material in Ci that is released to the air per assembly under normal operating conditions or following a Category 1 event sequence. The airborne source term, ST_j , is calculated by the following, from DOE-HDBK-3010-94 (DOE 1994 [DIRS 103756], p. 1-2):

$$\text{Source Term (Ci/FA) } ST_j = MAR_j \times DR \times ARF \times RF \times LPF \quad (\text{Eq. 7})$$

where,

MAR_j	=	Material at risk; commercial SNF radionuclide inventory per fuel assembly (Ci/FA)
DR	=	Damage ratio; rod breakage fraction ($DR = 1.0$)
ARF	=	Airborne release fraction; the fraction of processed commercial SNF that is suspended or released from the SFAs
RF	=	Respirable fraction (for inhalation doses)
LPF	=	Leak path factor; the fraction of airborne released material that discharges into the atmosphere from the HVAC exhaust systems; $LPF = 1.0 \times 10^{-4}$ for normal operations and Category 1 event sequences.

The assumptions in the following paragraph are consistent with the release fractions shown in NUREG-1567 (NRC 2000 [DIRS 149756], p. 9-12) and Interim Staff Guidance-5 (NRC 2003a [DIRS 160582], Attachment, Table 7.1).

For normal operations, 1% (Assumption 4.1.3) of the fuel rods received are modeled to have cladding breaches that could result in the release of fission product gases, volatile species, and particulates. It is assumed that for Category 1 event sequences involving drops and collisions, 100% of the fuel rods have failed because of the event (Assumption 4.2.7). Of the total SFA radioactive inventory, the ARFs given in Table 5 are used for Category 1 event sequences involving drops and collisions.

Strontium isotopes including ^{90}Sr are considered as nonvolatile materials and are, therefore, treated as fuel particles according to *Commercial SNF Accident Release Fractions* (BSC 2004g [DIRS 172371], Section 6.2.1.2 and Table 11).

For crud, a crud spallation fraction of 0.15 (BSC 2004g [DIRS 172371], Section 6.2.1.3) is used, which means that 15% of the crud becomes loose from the fuel rod surfaces under normal conditions and Category 1 event sequences. Of the loose crud, 10% (BSC 2004g [DIRS 172371], Section 6.2.1.3) becomes airborne and released during normal operations and Category 1 event sequences. An ARF of 10% represents the bounding release fraction for the case when venting gases pressurize the volume in which there exists loose powdering surface contamination (DOE 1994 [DIRS 103756], p. 5-22). An ARF of 10% also bounds ARFs for other potential release mechanisms, such as venting of pressurized powders or pressurized gases through a powder (DOE 1994 [DIRS 103756], Section 4.4.2.3) and suspension of surface contamination

from solid material by impact and vibration shock (DOE 1994 [DIRS 103756], pp. 5-7 and 5-24). The effective crud ARF is defined as the product of the crud spallation fraction of 0.15 and the crud ARF of 0.1, hence, an effective crud ARF of 0.015 (Table 5).

For calculating inhalation dose, the RFs in Equation 7 are used to calculate respirable release source terms. The RF is the respirable fraction of airborne radionuclide particles having an aerodynamic equivalent diameter of 10 μm or less. For estimating respirable release source terms, the appropriate RFs from Table 5 are used. For calculating doses other than inhalation, a bounding value of 1.0 is used for the RF.

In Equation 7, the release source term per PWR assembly for radionuclide j , ST_j , is calculated by multiplying the average PWR (normal operation) or the maximum PWR (Category 1 event sequences) radionuclide inventory per assembly (MAR_j) for that radionuclide (Table 4) by the damage ratio (DR), the ARF (Table 5), and the leak path factor (LPF).

Added to the fuel release source term for normal operation are 25-year ^{60}Co and ^{55}Fe activities of 2.35 Ci and 4.64 Ci (Section 6.2.1.2) per PWR assembly in crud on the surface of commercial SNF assemblies. The use of 25-year old crud is consistent with the use of the average PWR radionuclide inventory, which has a cooling time of 25 years. Again, the crud release source term is calculated by multiplying the activities Ci/FA by the ARF for intact commercial SNF assemblies (Table 5). For a Category 1 event sequence, 5-year ^{60}Co and ^{55}Fe activities of 32.6 Ci and 745.0 Ci (Section 6.2.1.2) per PWR assembly are added to the release source term.

The source term includes a list of radionuclides selected from the output of a point depletion and decay calculation using a computer code, such as the SAS2H sequence in SCALE V4.4, (CRWMS M&O 2000 [DIRS 153872]). Source term radionuclides are based on selection criteria in NUREG-1567 (NRC 2000 [DIRS 149756], p. 9-11) and Interim Staff Guidance-5 (NRC 2003a [DIRS 160582], Attachment, Section 3). For confinement analysis, the source term, as a minimum, includes activity from ^{60}Co in crud, activity from iodine, other fission products that contribute greater than 0.1% of design basis fuel activity, and actinide activity that contributes greater than 0.01% of the design basis activity. Individual radionuclide activity and its contribution in percent for PWR source term nuclides are presented in *Category 1 Event Sequences Release Worker Dose Calculation* (BSC 2005a [DIRS 173590], Tables I-1, I-2, I-3a and I-3b). The nuclides ^{14}C and ^{36}Cl are included in the tables because of a potential release into the atmosphere as gaseous nuclides.

For normal operations and Category 1 event sequences, a two-stage HEPA filtration system with a particulate removal efficiency of 99% per stage with a HEPA LPF of 0.01 per stage is used (see Section 4.1.1). This gives a combined efficiency of 99.99% for the two stages; a HEPA LPF of 10^{-4} (see Section 4.1.1). The HVAC system removes particulates and cesium in air through two stages of HEPA filters in series, which are protected by prefilters, sprinklers, and demisters. Test data from NUREG/CR-0722 (Lorenz et al. 1980 [DIRS 100990], Table 19) show that two-stage HEPA filters capture almost 100% of incoming airborne cesium.

3.1.3.2 Worker Dose From Resuspension of Waste Package Surface Contamination, Activated Air, or Activated Silica Dust

Equations 3, 4, 8, and 9 are applicable to the subsurface worker dose from resuspension of surface contamination from emplaced waste packages, or from exposure to neutron-activated air or silica dust from emplacement drifts.

Equation 7 is not used and the term $ST_j \times FA$ in Equations 5 and 6 is replaced with ST_j , where ST_j is the total release source term from waste package surface contamination and activated air and activated silica dust from the emplacement drifts. The ST_j is calculated in *Normal Operation Airborne Release Calculation* (BSC 2005b [DIRS 172487], Table 13) and is summarized in Section 6.1.1.2.

3.1.3.3 Shielding Source Term Description

3.1.3.3.1 Shielding Source Term Criteria

The following shielding source term criteria are used for the shielding design for the surface and subsurface facilities (BSC 2005f [DIRS 173614], Section 4.9.1.4) to provide reasonable conservatism in the shielding design:

- Shielding source terms for the surface and subsurface facility design are based on the limiting waste form, as well as the limiting waste package type.
- Design basis and maximum source terms are established to provide sufficient and bounding coverage, respectively (BSC 2005f [DIRS 173614], Section 4.9.1.4), of the historical and projected fuel inventory for normal operations and Category 1 event sequences. The design basis source term covers a minimum of 95% of the total inventory, with provisions made to accommodate the remaining 5%. The maximum source term represents the bounding SFA in the inventory at the repository.
- Interim Staff Guidance-6 (NRC 2001 [DIRS 160595]) establishes the use of minimum initial enrichment for the selected SFA to determine the source term, because lower enriched fuel irradiated to the same burnup as higher enriched fuel produces a higher source term (BSC 2005f [DIRS 173614], Section 4.9.1.4).

3.1.3.3.2 Limiting Canistered Waste Form

The repository receives, handles, processes, packages, and emplaces a variety of canistered waste forms including commercial SNF from PWR and BWR power plants, high-level radioactive waste (HLW), U.S. Department of Energy (DOE) SNF, and naval SNF. A source comparison study determined that, for the sources evaluated in that study, a single PWR SNF assembly with a 75-GWd/MTU burnup, a 5-wt% initial enrichment, and a 5-year cooling time is a limiting radiation source for canistered SNF and HLW glass canisters as described in *Shielding Calculation for Dry Transfer Facility, Remediation Facility, and Canister Handling Facility* (BSC 2004h [DIRS 171405], p. 19). Therefore, PWR SNF represents the limiting waste form and is selected for specification of shielding source terms for repository design.

3.1.3.3.3 Limiting Waste Package

Several dose rate calculations have been performed for different capacity waste packages, including:

- 21 PWR uncanistered fuel waste package
- 44 BWR uncanistered fuel waste package
- HLW or DOE SNF codisposal waste package, or both
- Naval SNF waste package.

Other waste package types, such as the 12 PWR and 24 BWR small waste packages, are less radiation limiting than the corresponding large waste packages as described in *Subsurface Shielding Source Term Specification Calculation* (BSC 2002 [DIRS 161120], p. 21).

Comparison of the dose rate calculations for the different waste packages shows that the 21 PWR waste package has the highest dose rate on the surface of the waste package and, thus, the 21 PWR is the limiting waste package for shielding analysis (BSC 2002 [DIRS 161120], p. 22).

3.1.3.3.4 Maximum Fuel Specification

With PWR SNF as the limiting waste form, the limiting SFA is a PWR SFA with the following characteristics, as described in *PWR Source Term Generation and Evaluation* (BSC 2004f [DIRS 169061], p. 27):

- 5% initial ^{235}U enrichment
- 80 GWd/MTU burnup
- 5 years cooling time.

Shielding calculations use the maximum source terms for operations involving a single assembly; examples include fuel transfer from the transportation cask through the transfer cell to the waste package, fuel transfer to the staging area, and fuel transfer in the remediation pool.

3.1.3.3.5 Design Basis Fuel Specification

The design basis source terms shall cover a minimum of 95% of the total historical and projected fuel inventory (BSC 2005f [DIRS 173614], Section 4.9.1.4). The design basis fuel specification provides the shielding source terms for a loaded waste package.

The waste package source specification uses the following parameters as a design basis (BSC 2002 [DIRS 161120], Section 5.5.2), because the waste package thermal output is limited to 11.8 kW:

- 4% initial ^{235}U enrichment
- 60 GWd/MTU
- 10 years cooling.

These characteristics result in a heat generation rate of 1.2 kW/SFA, which is more than twice the average heat output per assembly allowed in the 21 PWR waste package.

3.1.3.3.6 Axial Power Peaking Factor

Source terms in Table 6 and Table 7 represent the values for uniform fuel burnup; a relative power factor of 1 for the entire length of the SFA. Shielding source terms account for the power peaking factor to obtain the peak dose rate, because fuel burnup varies axially along the length of the SFA.

For PWR fuel, shielding calculations use a conservative peaking factor of 1.25, based on the predicted heat profile for a PWR assembly provided in *The TN-24P PWR Spent-Fuel Storage Cask: Testing and Analyses* (Creer et al. 1987 [DIRS 136937], p. 3-29). This factor is directly applied to the calculated gamma dose rate as a multiplier; the gamma source strength is reasonably proportional to fuel burnup. The multiplier for the neutron dose rate is determined to be the ratio of the neutron source strength at the peak burnup to that for uniform burnup, as described in *Dose Rate Calculation for 21-PWR Waste Package* (BSC 2004i [DIRS 172227], Section 5.2.1).

Table 6. Maximum and Design Basis Pressurized Water Reactor Spent Fuel Neutron Source Term

Neutron Energy Range (MeV)		Neutron Source (n/s per assembly)	
Upper Bound	Lower Bound	Maximum ^a	Design Basis ^b
$2.00 \times 10^{+1}$	6.43×10^0	$3.93 \times 10^{+7}$	$1.54 \times 10^{+7}$
6.43×10^0	3.00×10^0	$4.43 \times 10^{+8}$	$1.74 \times 10^{+8}$
3.00×10^0	1.85×10^0	$4.85 \times 10^{+8}$	$1.91 \times 10^{+8}$
1.85×10^0	1.40×10^0	$2.76 \times 10^{+8}$	$1.09 \times 10^{+8}$
1.40×10^0	9.00×10^{-1}	$3.76 \times 10^{+8}$	$1.48 \times 10^{+8}$
9.00×10^{-1}	4.00×10^{-1}	$4.11 \times 10^{+8}$	$1.61 \times 10^{+8}$
4.00×10^{-1}	1.00×10^{-1}	$8.05 \times 10^{+7}$	$3.16 \times 10^{+7}$
1.00×10^{-1}	1.70×10^{-2}	0.00	0.00
1.70×10^{-2}	3.00×10^{-3}	0.00	0.00
3.00×10^{-3}	5.50×10^{-4}	0.00	0.00
5.50×10^{-4}	1.00×10^{-4}	0.00	0.00
1.00×10^{-4}	3.00×10^{-5}	0.00	0.00
3.00×10^{-5}	1.00×10^{-5}	0.00	0.00
1.00×10^{-5}	3.05×10^{-6}	0.00	0.00
3.05×10^{-6}	1.77×10^{-6}	0.00	0.00
1.77×10^{-6}	1.30×10^{-6}	0.00	0.00
1.30×10^{-6}	1.13×10^{-6}	0.00	0.00
1.13×10^{-6}	1.00×10^{-6}	0.00	0.00
1.00×10^{-6}	8.00×10^{-7}	0.00	0.00
8.00×10^{-7}	4.00×10^{-7}	0.00	0.00
4.00×10^{-7}	3.25×10^{-7}	0.00	0.00
3.25×10^{-7}	2.25×10^{-7}	0.00	0.00
2.25×10^{-7}	1.00×10^{-7}	0.00	0.00
1.00×10^{-7}	5.00×10^{-8}	0.00	0.00
5.00×10^{-8}	3.00×10^{-8}	0.00	0.00
3.00×10^{-8}	1.00×10^{-8}	0.00	0.00
1.00×10^{-8}	1.00×10^{-11}	0.00	0.00

NOTES: ^a BSC 2004f [DIRS 169061], Attachment X; PWR fuel with 5% enrichment, 80 GWd/MTU burnup and 5-year cooling

^b BSC 2004f [DIRS 169061], Attachment X; PWR fuel with 4% enrichment, 60 GWd/MTU burnup and 10-year cooling.

MeV = million electron volt; n/s = neutrons per second.

Table 7. Maximum and Design Basis Pressurized Water Reactor Spent Nuclear Fuel Gamma Source Terms

Gamma Energy Range (MeV) Upper – Lower		Maximum Source (γ/s per assembly) ^a				Design Basis Source (γ/s per assembly) ^b			
		Fuel Region	Bottom Region	Plenum Region	Top Region	Fuel Region	Bottom Region	Plenum Region	Top Region
5.00×10^{-2}	1.00×10^{-2}	$2.33 \times 10^{+15}$	$5.94 \times 10^{+11}$	$5.28 \times 10^{+11}$	$3.79 \times 10^{+11}$	$1.21 \times 10^{+15}$	$2.73 \times 10^{+11}$	$1.88 \times 10^{+11}$	$1.75 \times 10^{+11}$
1.00×10^{-1}	5.00×10^{-2}	$6.44 \times 10^{+14}$	$1.16 \times 10^{+11}$	$6.09 \times 10^{+10}$	$7.43 \times 10^{+10}$	$3.29 \times 10^{+14}$	$5.28 \times 10^{+10}$	$2.77 \times 10^{+10}$	$3.39 \times 10^{+10}$
2.00×10^{-1}	1.00×10^{-1}	$5.22 \times 10^{+14}$	$2.83 \times 10^{+10}$	$3.52 \times 10^{+10}$	$1.79 \times 10^{+10}$	$2.45 \times 10^{+14}$	$1.28 \times 10^{+10}$	$1.17 \times 10^{+10}$	$8.19 \times 10^{+9}$
3.00×10^{-1}	2.00×10^{-1}	$1.48 \times 10^{+14}$	$1.41 \times 10^{+9}$	$1.96 \times 10^{+9}$	$8.91 \times 10^{+8}$	$7.13 \times 10^{+13}$	$6.39 \times 10^{+8}$	$6.33 \times 10^{+8}$	$4.07 \times 10^{+8}$
4.00×10^{-1}	3.00×10^{-1}	$9.85 \times 10^{+13}$	$1.90 \times 10^{+9}$	$5.86 \times 10^{+9}$	$1.17 \times 10^{+9}$	$4.55 \times 10^{+13}$	$8.50 \times 10^{+8}$	$1.64 \times 10^{+9}$	$5.33 \times 10^{+8}$
6.00×10^{-1}	4.00×10^{-1}	$1.53 \times 10^{+15}$	$1.91 \times 10^{+9}$	$1.10 \times 10^{+11}$	$7.41 \times 10^{+7}$	$2.26 \times 10^{+14}$	$4.92 \times 10^{+8}$	$2.69 \times 10^{+10}$	$3.37 \times 10^{+7}$
8.00×10^{-1}	6.00×10^{-1}	$4.70 \times 10^{+15}$	$4.35 \times 10^{+9}$	$5.95 \times 10^{+10}$	$2.37 \times 10^{+9}$	$2.37 \times 10^{+15}$	$2.91 \times 10^{+9}$	$1.60 \times 10^{+10}$	$1.86 \times 10^{+9}$
1.00×10^0	8.00×10^{-1}	$7.08 \times 10^{+14}$	$1.37 \times 10^{+11}$	$8.03 \times 10^{+9}$	$7.66 \times 10^{+10}$	$1.22 \times 10^{+14}$	$5.40 \times 10^{+9}$	$2.48 \times 10^{+9}$	$3.41 \times 10^{+9}$
1.33×10^0	1.00×10^0	$4.55 \times 10^{+14}$	$3.38 \times 10^{+13}$	$1.74 \times 10^{+13}$	$2.17 \times 10^{+13}$	$1.95 \times 10^{+14}$	$1.54 \times 10^{+13}$	$7.97 \times 10^{+12}$	$9.90 \times 10^{+12}$
1.66×10^0	1.33×10^0	$1.30 \times 10^{+14}$	$9.53 \times 10^{+12}$	$4.91 \times 10^{+12}$	$6.12 \times 10^{+12}$	$4.50 \times 10^{+13}$	$4.35 \times 10^{+12}$	$2.25 \times 10^{+12}$	$2.80 \times 10^{+12}$
2.00×10^0	1.66×10^0	$1.44 \times 10^{+12}$	$1.87 \times 10^{+3}$	$9.19 \times 10^{+2}$	$1.13 \times 10^{+3}$	$1.52 \times 10^{+11}$	2.35E+00	$1.49 \times 10^{+2}$	2.15×10^{-2}
2.50×10^0	2.00×10^0	$2.49 \times 10^{+12}$	$2.26 \times 10^{+8}$	$1.16 \times 10^{+8}$	$1.45 \times 10^{+8}$	$5.17 \times 10^{+10}$	$1.03 \times 10^{+8}$	$5.34 \times 10^{+7}$	$6.64 \times 10^{+7}$
3.00×10^0	2.50×10^0	$1.10 \times 10^{+11}$	$3.51 \times 10^{+5}$	$1.81 \times 10^{+5}$	$2.25 \times 10^{+5}$	$3.79 \times 10^{+9}$	$1.60 \times 10^{+5}$	$8.29 \times 10^{+4}$	$1.03 \times 10^{+5}$
4.00×10^0	3.00×10^0	$1.39 \times 10^{+10}$	7.66×10^{-8}	1.00×10^{-8}	4.16×10^{-8}	$4.97 \times 10^{+8}$	9.43×10^{-10}	1.55×10^{-10}	5.19×10^{-10}
5.00×10^0	4.00×10^0	$7.09 \times 10^{+7}$	0.00×10^0	0.00×10^0	0.00×10^0	$2.82 \times 10^{+7}$	0.00×10^0	0.00×10^0	0.00×10^0
6.50×10^0	5.00×10^0	$2.85 \times 10^{+7}$	0.00×10^0	0.00×10^0	0.00×10^0	$1.13 \times 10^{+7}$	0.00×10^0	0.00×10^0	0.00×10^0
8.00×10^0	6.50×10^0	$5.58 \times 10^{+6}$	0.00×10^0	0.00×10^0	0.00×10^0	$2.22 \times 10^{+6}$	0.00×10^0	0.00×10^0	0.00×10^0
$1.00 \times 10^{+1}$	8.00×10^0	$1.19 \times 10^{+6}$	0.00×10^0	0.00×10^0	0.00×10^0	$4.71 \times 10^{+5}$	0.00×10^0	0.00×10^0	0.00×10^0

NOTES: ^a BSC 2004f [DIRS 169061], Attachment X; PWR fuel with 5% enrichment, 80 GWd/MTU burnup and 5-year cooling^b BSC 2004f [DIRS 169061], Table 10; PWR fuel with 4% enrichment, 60 GWd/MTU burnup and 10-year cooling.MeV = million electron volt; γ/s = photons per second.

3.1.3.4 Shielding Methodologies

3.1.3.4.1 Shielding Computer Codes

The shielding analysis to support the repository facility design uses methods and codes that are consistent with those of commonly accepted shielding calculations and that are appropriate for radiation types, geometry, and materials. The analytical tools include codes that use Monte Carlo, deterministic transport, and point-kernel integration techniques for the various shielding problems encountered in the repository design.

Simple and scoping-type gamma shielding problems are handled with the efficient point-kernel integration codes.

Complex or deep-penetration shielding problems require the use of Monte Carlo or deterministic transport codes, especially for problems involving neutron and secondary gamma dose contributions.

The following shielding codes have been benchmarked, validated, qualified, and baselined in accordance with LP-SI.11Q-BSC, *Software Management* to support the repository design:

- MCNP from *MCNP-A General Monte Carlo N-Particle Transport Code* (Briesmeister 1997 [DIRS 103897])
- SCALE V4.4 from *Users Manual for SCALE-4.4A*. 10129-UM-4.4A-00 (CRWMS M&O 2000 [DIRS 153872])
- QAD-CGGP from *Final Version Description Document for the QAD-CGGP Computer Code, Version 1.0* (CRWMS M&O 1995 [DIRS 160397]); a three-dimensional point-kernel gamma transport shielding computer code
- PATH from *PATH Gamma Shielding Code User's Manual* (Su et al. 1987 [DIRS 105603]); a three-dimensional point-kernel gamma shielding computer code.

Except for PATH (Su et al. 1987 [DIRS 105603]), the NRC recognizes these codes for analysis of SNF storage facilities in NUREG-1567 (NRC 2000 [DIRS 149756], pp. 7-12 and 7-13). PATH is similar to the accepted QAD-CGGP code (CRWMS M&O 1995 [DIRS 160397]) and is accepted by the NRC in the GA-4 cask certification, *GA-4 Legal Weight Truck Spent Fuel Shipping Cask, Safety Analysis Report for Packaging (SARP)* (General Atomics 1998 [DIRS 103042], p. 5.4-2).

MCNP (Briesmeister 1997 [DIRS 103897]) is a general purpose Monte Carlo code for neutron, photon, or coupled neutron-photon transport problems, suitable for complex three-dimensional geometry and a variety of radiation source types. MCNP represents the best choice for Monte Carlo shielding analysis, because it is widely used in the nuclear industry for various applications.

SCALE V4.4 (CRWMS M&O 2000 [DIRS 153872]) contains the modules for performing source term and shielding calculations. For Yucca Mountain Project applications, SCALE can be used for both source term and shielding calculations. The ability of updating burnup-dependent cross section library in SCALE provides a more accurate determination of the source

terms than does the ORIGEN code from *RSIC Computer Code Collection, ORIGEN 2.1, Isotope Generation and Depletion Code, Matrix Exponential Method* (ORNL 1991 [DIRS 147923]).

QAD-CGGP (CRWMS M&O 1995 [DIRS 160397]) and PATH (Su et al. 1987 [DIRS 105603]) are both point-kernel integration codes for gamma shielding problems, capable of explicitly treating three-dimensional source shield configurations. These two codes are similar in capabilities and produce results in satisfactory agreement. PATH provides additional features to treat multiple sources and various source types in a single run.

Flux-to-DCFs (BSC 2002 [DIRS 161120], Section 5.6.1) used in the shielding analyses are consistent with ANSI/ANS-6.1.1-1977, *Neutron and Gamma-Ray Flux-to-Dose-Rate Factors*, pp. 4 and 5 [DIRS 107016]. No degradation or loss of shielding materials from an event sequence has been identified.

The computer codes listed in this section are not used to produce results in this calculation.

3.1.3.5 Worker Dose From Direct Radiation

During the preclosure period, some surface and subsurface facility workers could be exposed to direct radiation when work requires them to be in close proximity to contained sources, such as transportation casks, storage casks, or waste packages. Fixed or portable shielding materials are used to reduce the doses to workers. The dose rate at a distance from the contained source was calculated using the MCNP computer program (Briesmeister 1997 [DIRS 103897]). The dose assessment involves calculations of annual individual doses to workers. The dose contributions from contained radiation sources, such as SFAs in a transportation cask or waste package, are obtained from the shielding calculations using NRC accepted computer codes, such as MCNP. These shielding calculations generate dose maps around functional areas within the facilities for determining dose rates at worker locations.

Dose assessments are performed by job function or worker group using time-motion inputs and dose rates calculated at worker locations. The time-and-motion inputs define the process step, location, number of workers, and duration of worker occupancy. The individual doses are calculated for each process step and summed over the process steps to obtain cumulative external exposures to workers on an annual basis. Outputs of the assessment consist of a matrix of operations, locations, source, frequency, dose rates, stay times, and doses. In addition, to demonstrate regulatory compliance, calculated annual individual doses are used for comparison with the ALARA design goal to minimize the number of individuals who have the potential of receiving more than 500 mrem/year TEDE (BSC 2005f [DIRS 173614], Section 4.9.3.3).

The annual external dose per individual worker is generally calculated as:

$$ED_g = \frac{\sum_{k,i} DR_{g,k,i} \times T_{g,k,i} \times N_{g,k,i}}{crews_g} \quad (\text{Eq. 12})$$

where

ED_g = Annual external dose to an individual worker in worker group g (mrem/year)

$DR_{g,k,i}$ = Dose rate for an individual worker in worker group g for operation or support task k at location i (mrem/hour)

$T_{g,k,i}$ = Duration of exposure for workers in worker group g for operation or support task k at location i (hours/operation task)

$N_{g,k,i}$ = Number of operation or support tasks of type k performed by workers in worker group g at location i per year (operation tasks/year)

$crews_g$ = Number of work shifts or work crews in worker group g (unitless)

Although the dose assessment for each facility uses equations that reflect the specific operations for that facility, these equations all use the general approach above. Groups, operation and support tasks, and locations are defined as needed for each facility dose assessment. Specific methodologies may be found in the dose assessment calculations (BSC 2005e [DIRS 172931], Equation 1; BSC 2004a [DIRS 171388], Equations 1, 2, and 3; BSC 2004b [DIRS 167881], Equations 1, 2, 3, and 4; BSC 2004c [DIRS 171772], Equations 1, 2, 3, and 4; BSC 2004d [DIRS 167878], Equations 1, 2, 3, and 4; BSC 2004e [DIRS 167763], Equations 1 and 2; BSC 2005k [DIRS 173167], Equations 1, 2, 3, and 4).

Worker locations for cask preparation operations are categorized in terms of distances from the transportation cask surface. The distances are estimated from the most likely worker locations to perform the specific tasks for the cask preparation operations. For hands-on activities, such as swipes for surface contamination sampling, the worker is 1 m from the cask. For processing tasks that are not hands-on, but require worker presence in the area, the worker is standing at a reasonable distance from the cask. For processing transportation casks, workers are at one of three distances from the exterior surfaces of a transportation cask: 1 m, 5 m, or 10 m. Dose rates in the vicinity of a transportation cask are estimated using the 2-m dose rates of the Universal Transport Cask and the radial dose distance factors derived from the TN-32 cask (BSC 2004c [DIRS 171772], p. 11). Average dose rates from the cask surface are: 9.10 mrem/hr at 1 m, 1.66 mrem/hr at 5 m, and 0.51 mrem/hr at 10 m (BSC 2004c [DIRS 171772], p. 11).

3.1.3.6 Annual Worker Dose

Dose Aggregation—Total annual worker dose is based on contributions from four sources:

- Category 1 event sequences (aggregated)
- Normal operational releases from surface facilities

- Normal operational releases from the subsurface repository
- Direct radiation dose from contained radiation sources during normal operation.

Equation 1 is slightly modified to yield the total annual worker dose, D_{TOT} :

$$D_{TOT} = D_{Cat.1} + D_{NO}^{SF} + D_{NO}^{Sub} + D_{NO}^{Dir} \quad (\text{Eq. 13})$$

where,

$D_{Cat.1}$	=	Annual dose from Category 1 event releases and direct radiation (mrem/year) (using Eq. 2)
D_{NO}^{SF}	=	Annual dose from normal operational releases from surface facilities (mrem/year)
D_{NO}^{Sub}	=	Annual dose from normal operational releases from the subsurface repository (mrem/year)
D_{NO}^{Dir}	=	Annual dose from normal operation direct radiation from contained sources (mrem/year) (i.e., ED_g + direct radiation from aging cask).

Worker dose assessment includes individual doses for both normal operations and Category 1 event sequences. Total dose, including internal and external exposures, is calculated on an annual basis by summing the contributions from normal operations and frequency-weighted doses from Category 1 event sequences for demonstration of regulatory compliance. Equation 2 is used to calculate annualized worker dose from Category 1 event sequences.

Worker dose assessment includes contributions from both surface and subsurface facilities on a building-by-building basis; the assessment of subsurface facilities also includes contributions from operations and activities performed underground.

3.2 METHODOLOGY FOR CATEGORY 2 EVENT SEQUENCES

This section discusses the methodology used for evaluating radiological consequences from Category 2 event sequences. Summary of methodologies and pertinent inputs for release categories is provided in Table 8.

3.2.1 Category 2 Event Sequence Performance Objectives

The four dose measures of LDE, SDE, TEDE, and TODE used to evaluate normal operations and Category 1 event sequences are also used to evaluate Category 2 event sequences. Performance objectives for Category 2 event sequences are summarized in Table 2.

3.2.2 Category 2 Event Sequence Public Dose Methodology

In Category 2 event sequences, radioactive materials are assumed to be released as a ground-level radioactive plume (Assumption 4.2.12) and the building wake effect is considered. The plume is dispersed en route to the site boundary, resulting in an acute individual exposure during plume passage and a chronic individual exposure to ground contamination and

contaminated food after plume passage (Assumption 4.2.3). To further ensure that the χ/Q value is conservative at the site boundary, no credit is taken for plume meandering or for plume rise caused by initial thermal energy (Assumption 4.2.15). Potential radiation doses from inhalation, resuspension inhalation, ingestion, air submersion, and groundshine pathways are considered for Category 2 event sequences. Inhalation, resuspension inhalation, ingestion, air submersion, and groundshine doses are calculated using MACCS2 (ORNL 1998 [DIRS 164761]). Doses to members of the public from direct radiation after a Category 2 event sequence is inconsequential based on dose rate versus distance analyses in BSC 20051 ([DIRS 173483], Section 8).

The χ/Q values are calculated internally by MACCS2 (ORNL 1998 [DIRS 164761]) using hourly meteorological data gathered at Yucca Mountain from 1998 through 2002. The 1999 meteorological data are used after a sensitivity analysis showed that any of the five year's data produced similar χ/Q values (Section 6.2.1.1.2). The χ/Q values output from MACCS2 (ORNL 1998 [DIRS 164761]) for surface releases are the mean, 50th percentile, 95th percentile, and 99.5th percentile values evaluated at 11 km for surface releases (Section 6.2.1.5 and Attachment B, Figure B-1).

MACCS2 (ORNL 1998 [DIRS 164761]) randomly samples the Yucca Mountain site-specific hourly data over a 1-year period, producing 8,760 sets of wind speed, wind direction, stability class, and precipitation to calculate χ/Q values.

Each set of weather data calculates one value of χ/Q . Depending of the number of sampling chosen, thousands of χ/Q values could be generated in one MACCS2 (ORNL 1998 [DIRS 164761]) run. Statistical analysis is performed internally in MACCS2 on these χ/Q values. Values for the mean, 50th percentile, 95th percentile, and 99.5th percentile are generated and printed on the MACCS2 (ORNL 1998 [DIRS 164761]) output file.

Category 2 event sequences use the 95th percentile with a 5% exceedance of the χ/Q value evaluated at the closest site boundary of 11 km for the maximally exposed individual without regard to sectors. MACCS2 results are used to determine compliance with regulations.

Commercial SNF Source Term—Only maximum source terms for PWR and BWR SFAs for the initial enrichment, burnup, and decay time presented in Table 3 are considered for Category 2 event sequences. Radionuclide inventories in Ci/FA for the maximum PWR and BWR SFAs are presented in Table 4. For Category 2 event sequences, both maximum PWR and maximum BWR SFAs are used to calculate maximum doses.

The bounding ARFs and RFs for breach intact or failed SNF assemblies and rods (Table 5) are used for Category 2 event sequences.

Naval SNF Source Term—A bounding radionuclide release source term was provided (Gisch 2004 [DIRS 171579]) which covers all naval SNF canister inventories and internal hardware designs. Conservative estimates of SNF inventory, crud inventory, fuel damage ratio, and release fractions were used to develop a bounding radionuclide release source term which will result in estimated doses that are larger than those expected should an actual Category 2 event sequence occur.

For naval SNF assemblies, a conservative radionuclide inventory for a canister of naval SNF at five years after shutdown is developed using Naval Nuclear Propulsion Program depletion codes in conjunction with ORIGEN-S, which have been qualified for use with naval SNF in repository applications. The type of SNF assembly that is used in the analysis is the one that represents a majority of the naval SNF assemblies that will be emplaced (Griffith 2003 ([DIRS 168871], page 3).

The crud contribution to the source term for naval SNF is calculated using the standard naval program shielding procedure. This value is increased by a factor of 2.5 to provide a conservative crud concentration at core shutdown for use in developing the source term.

The fuel and crud damage ratios used to develop the source term were conservatively selected to ensure that all canister radionuclide inventories and internal hardware designs are bounded. The ARFs and RFs for intact commercial SNF assemblies (Table 5) are used for Category 2 event sequences involving naval SNF.

HLW Source Term—Bounding per-canister HLW radionuclide data were obtained from four different DOE sites, including the Savannah River Site, Hanford Site, West Valley, and Idaho National Laboratory. Projected bounding per-canister radionuclide inventory data for nuclides were set equal to the maximum values from sludge batches of wastes, vitrified between October 10, 1994 and March 17, 2003, as presented in *Projected Glass Composition and Curie Content of Canisters from the Savannah River Site (U)* (Fowler 2003 [DIRS 164361], Section 5.0). The methodology used for Category 2 event sequences involving HLW is to demonstrate that the Savannah River Site HLW bounds HLW from the other DOE sites.

In summary, the methodology for Category 2 event sequence public dose calculations is to maximize the public dose to account for the variability or uncertainty, or both, in MAR, source terms, release fractions, and varying weather conditions. Weather conditions relevant to dose calculations include wind speed, wind direction, stability class, and precipitation.

Table 8. Summary of Methodologies for Normal Operation, Category 1 and Category 2 Event Sequences

Parameters	Normal Operations		Category 1	Category 2
	Subsurface Facilities	Surface Facilities		
HVAC/HEPA Filters	No HEPA filter	HEPA filter	HEPA filtered	No HEPA filters
Release Height	Ground-level	Elevated	Ground-level	Ground-level
Duration of Release	24 hour (1 yr)	24 hours (1 yr)	1 hour	1 hour
	Onsite χ / Q and Doses			
Worker inside RA	ARCON96			N/A
Receptor Distance	At relative distances between release points and facility worker locations			N/A
Plume Meander Credit	When applicable, internally determined by ARCON96			N/A
Building Wake Effect	No	Yes		N/A
Plume Rise Credit	By exit velocity, not thermal		No	N/A
Onsite Exposure Duration	2000 hour			N/A
Onsite Dose Pathways	Direct radiation, inhalation, and submersion			N/A
General Public outside RA	MACCS2			N/A
Receptor Distance	3 km	100 m	100 m	N/A
Plume Meander Credit	No			N/A
Building Wake Effect	No	Yes		N/A
Onsite Dose Pathways	Direct radiation, inhalation, resuspension inhalation, air submersion, and groundshine			N/A
	Offsite χ / Q and Doses			
General Public Code	MACCS2			
Receptor Distance	8 km	11 km	11 km	11 km
Offsite Exposure Duration	8760 hour		1 hr plume exposure and 8760 resuspension inhalation, groundshine and ingestion	
Offsite Dose Pathways	Inhalation, resuspension inhalation, air submersion, groundshine and ingestion			
Plume Meander Credit	No			
Building Wake Effect	No	Yes		
Plume Rise Credit	No			
Source Terms Evaluated	WP surface contamination	1% of 3,600 MTHM/yr PWR Ave. SFA	Drop with 2 Max. PWR SFA.	Seismic – accumulated HEPA filter and duct activity. 1% of non-volatiles from 63,000 MTHM
	Neutron activated air		Collision with 1 Max. PWR SFA	Cask drop with 5 HLW- Savannah River Plant
	Neutron activated dust		Drop with 2 Max. BWR SFA	Cask drop with 5 HLW – Hanford Site canisters
			Collision with 1 Max. BWR SFA	Cask drop with 5 HLW – West Valley canisters
				Cask drop with 5 HLW – INEEL canisters
				Cask drop with 1 HLW – Naval canister
				Cask drop with 36 Max. PWR SFAs
				Cask drop with 74 Max. BWR SFAs

BWR = boiling water reactor; PWR = pressurized water reactor; SFA = spent fuel assembly; nuclear fuel; HLW = high level waste; INEEL = Idaho national environmental engineering laboratory; HVAC = heating ventilating and air conditioning; HEPA = high efficiency particulate air [filter]; MTHM = metric tons heavy metal; N/A = not applicable; RA = restricted area.

4. TECHNICAL INPUT AND ASSUMPTIONS

4.1 TECHNICAL INPUT

- 4.1.1 For normal operations and Category 1 event sequences, a two-stage HEPA filtration system with a particulate and cesium removal efficiency of 99% per stage (i.e., a HEPA leak path factor (LPF)_{HEPA} of 0.01 per stage) is used. This gives a combined efficiency of 99.99% for two stages and a HEPA LPF of 10^{-4} when the series of HEPA filters is protected by pre-filters, sprinklers, and demisters.

Basis: A HEPA filter removal efficiency of 99% per stage is acceptable to the NRC for dose evaluations as presented in Regulatory Guide 1.52 (Section 6.3). A HEPA filter removal efficiency of greater than 99% is recommended in NUREG/CR-6410 (SAIC, 1998, [DIRS 103695]), Appendix F, Section F 2.1.3. Additionally, ASME N509-1989 (DIRS 115139] Section 3) defines a HEPA filter as a filter that has a particle removal efficiency of no less than 99.97% for 0.3 μm particles.

This input is used in Sections 3.1.3.1 and 6.2.1.3.

- 4.1.2 Waste forms involved in normal operations and in Category 1 and Category 2 event sequences include PWR or BWR SFAs, HLW, and naval SNF.

Basis: The only waste form not included in airborne releases and dose calculations is DOE SNF, because a drop and breach of a DOE SNF canister, including the 18 in. or 24 in. standardized canister or the multiccanister overpack is a beyond Category 2 event sequence (BSC 2005i [DIRS 174467], Tables 18 and 19). DOE SNF is included in the dose calculations for external exposures to direct radiation for normal operation and Category 1 event sequences.

This input is used in Section 6.1.

- 4.1.3 Releases from 1% of the highest nominal throughput of 7,579 SFAs (see Assumption 4.2.1) are used as the source term for the calculation of normal operations doses. One percent (i.e., DR of 0.01) of the fuel rods received at the repository is used as the DR to consider defect sizes equal to pinhole leaks or hairline cracks and the fission product gases, volatile species, and fuel fines are released.

Basis: The 1% fuel rod breakage percentage is from Interim Safety Guide-5 (NRC 2003a [DIRS 160582], Attachment, p. 7) for normal operations.

This input is used in Sections 3.1.3.1, 6.1.1.1, and 6.2.1.

- 4.1.4 For the purposes of this calculation to 1) evaluate normal operations and Category 1 event sequences for “any real member of the public beyond the boundary of the site” (10 CFR 63.111(a)(2) [DIRS 173273]) and 2) evaluate Category 2 events sequences for an “individual located on, or beyond, any point on the boundary of the site” (10 CFR 63.111(b)(2) [DIRS 173273]), a maximally exposed offsite individual member of the public is defined as an individual located at a distance that corresponds to the

approximate distance between the surface facility or the subsurface repository and the nearest point of public access on the repository site boundary, which lies to the west (Attachment B, Figure B-1). The proposed land withdrawal area boundary is used as the site boundary (i.e., preclosure controlled area boundary). A site boundary distance of 11 km is used to determine χ/Q values from radiological releases from the surface facility and a site boundary distance of 8 km is used to determine χ/Q values from radiological releases from the subsurface repository as measured on the *Nevada Test and Training Range Chart* (NIMA 2001).

Basis: Attachment B, Figure B-1 is an illustration that used DTN: MO0001YMP00001.00 as a base for creation of areas of interest for this document. Distances using *Nevada Test and Training Range Chart* (NIMA 2001) were measured from the southern exhaust shaft and from the approximate east-west midplane to the proposed land withdrawal boundary as shown on Figure B-1. These distances are suitable for use in this calculation because they are rounded down to the nearest kilometer to account for uncertainty of map measurements.

This input is used in Sections 6.1.1.1, 6.2.1.5, 6.3.3, and 6.3.5.

- 4.1.5 During construction of surface facilities, the locations of maximally exposed individual members of the public onsite are assumed to be at construction worker locations adjacent to facilities already in operation.

Basis: During construction, the closest members of the public will be those construction workers close to any operating facilities. Potential construction worker locations are listed in Table 5a of BSC 2005c [DIRS 172488] and shown on Figure 1 of BSC 2005c [DIRS 172488].

This input is used in Section 6.2.1.5.2.

- 4.1.6 For evaluating doses to the public using MACCS2 during normal operations, radionuclides are released from surface facilities via a vent with an assumed height of 30 m.

Basis: This release height is used to calculate χ/Q values for use in dose calculations for surface facility normal operations. This is a conservative usage because a release height of 30 m is shorter than the stack heights of 40 m for DTF 1, of 40 m for DTF 2, or of 36 m for the FHF (BSC 2005d [DIRS 172941], Tables I-1, I-2, and Table I-14). A higher release height would result in a lower radiation dose for onsite locations and insignificant differences for offsite locations by comparing results of MACCS2 runs 1 and 17 (Table 20).

This assumption is used in Sections 3.1.2 and 6.2.1.1.

- 4.1.7 During a Category 2 seismic event sequence, accumulated activity on HEPA filters and ducting is conservatively treated as a bulk-powder and released in two stages: 1) shock vibration of bulk powder, for which the ARF and RF are 1E-3 and 0.1 (DOE 1994 [DIRS

103756], Section 4.4.3.3.1), and 2) free-fall spill if the ducting collapses, for which the ARF and RF are $2\text{E-}3$ and 0.3 (DOE 1994 [DIRS 103756], Section 4.4.3.1.3). The combined $\text{ARF} \times \text{RF}$ value is $7\text{E-}4$ (i.e., $1\text{E-}3 \times 0.1 + 2\text{E-}3 \times 0.3$).

Basis: These airborne release fractions and respirable fractions are conservative for use in assessing releases from HEPA filters and ducting because the release scenario assumes all activity is in the form of a bulk powder on the ducting surfaces rather than attached to HEPA surfaces or agglomerated on ducting surfaces. Release values include both shock-vibration and free fall conditions consistent with assuming two stage release following a seismic event with complete collapse of all the ducting.

This assumption is used in Section 6.1.4.4.

- 4.1.8 The average PWR SFAs are used to calculate the mean dose for normal operations. Both the maximum PWR and the maximum BWR SFAs are used to calculate bounding doses for Category 1 and Category 2 event sequences.

Basis: Doses for normal operations are to be based on annual average source terms while doses for Category 1 and Category 2 event sequences are to be based on bounding source terms.

This assumption is used in Section 3.1.2.

- 4.1.9 The maximally exposed onsite individual member of the public is assumed to be located outside the restricted area and within the site boundary at a distance that corresponds to the approximate distance between the surface facility or the subsurface repository and the nearest point on the restricted area boundary. For surface facility releases that distance is assumed to be 100 m. For subsurface releases that distance assumed to be 100 m for restricted areas surrounding the subsurface exhaust vents and 3 km for the restricted area surrounding the surface facilities. The restricted area boundaries are shown in Figure B-1.

Basis: Following completion of construction of the surface facilities, members of the general public could be outside the restricted area and within the site boundary. The surface facilities' restricted area boundary is shown in Figure B-1 and is further identified by the security fence as shown on Figure A-1. For releases from the surface or subsurface facilities, the locations of maximally exposed individual members of the public onsite are at the shortest distance from the release points.

For surface facilities, the shortest distance identified on Figure A-1 is north-east of DTF 1 at the security fence (i.e. restricted area boundary). It is scaled as more than 100m from the DTF 1 stack release identified on Figure 1 of BSC 2005c [DIRS 172488]. Other facility release locations on Figure 1 of BSC 2005c [DIRS 172488] are further than DTF 1 from the restricted area boundary. The dose to members of the public from each surface facility is conservatively calculated at 100 m.

For subsurface releases, the maximum dose occurs at the shortest distance from the subsurface facility exhaust shafts to the restricted area boundary. Individual restricted areas are provided around each subsurface exhaust shaft as shown on Figure B-1. A

minimum distance of 100m is used for the distance from an exhaust vent to its individual area boundary. The shortest distance from an exhaust vent to the surface facilities is 3,560 m from Exhaust Shaft #1 to the Emplacement Ramp (BSC 2005c [DIRS 172488], Table I-18). Because the Emplacement Ramp is inside the surface facilities' restricted area, a shorter distance of 3 km is used in analyses. Thus doses to members of the public are determined at 100 m and 3 km for releases from a subsurface exhaust

This assumption is used in Section 6.2.1.5.2.

4.2 BOUNDING ASSUMPTIONS

- 4.2.1 For evaluation of releases, it is assumed that the maximum annual receipt rate of 3,600 MTHM of commercial SNF for the MGR passes through the CHF, DTF 1, DTF 2, and the FHF. It is also assumed that for the purposes of calculating worker and public doses, the SNF received is PWR SFAs. Using an average PWR assembly weight of 0.475 MTHM/SFA (BSC 2004f [DIRS 169061], p. 8), the resulting throughput is 7,579 SFAs/year.

Basis: The receipt rate for commercial SNF in any year may not exceed 3,600 MTHM as determined from the monthly receipt rate shown in the *Yucca Mountain Site Characterization Project Requirements Document (YMP-RD)* (YMP 2001 [DIRS 156713], Requirement 1.3.2.E). The use of 3,600 MTHM allows for a 20% margin above the 3,000 MTHM requirement for annual receipt capability given by *Civilian Radioactive Waste Management System Requirement Document* (DOE 2004b [DIRS 171945], Table 1). It is also a bounding assumption that the 3,600 MTHM is PWR SFAs, because PWR SFAs typically have higher enrichment and burnup than BWR SFAs (Table 3). SNF with a higher enrichment and a higher burnup, in general, has a higher total radionuclide inventory. Even though the BWR assembly crud source is higher than the PWR assembly crud source (Table 15), the contribution of the crud source to the total dose from releases is not significant for either PWR or BWR fuel. Even the maximum crud inventories per SFA in Table 15 are orders of magnitude below the fuel inventories per SFA in Table 4.

This assumption is used in Sections 3.1.3, 4.1.3, and 6.1.1.1.

- 4.2.2 The HEPA filters of the surface facility HVAC systems are assumed to be unavailable to remove radionuclides for Category 2 event sequences. HEPA filters are assumed to be functioning for surface facility normal operations and Category 1 event sequence dose calculations.

Basis: It is conservative to not take credit for the HEPA filters to mitigate Category 2 event sequences. HVAC systems are required to be operational in facilities which handle radioactive materials. Therefore, for normal operations and Category 1 event sequences it is appropriate to take credit for the HEPA filters installed in the HVAC systems. The assumption that the HVAC system is operating during the entire Category 1 event sequence release period is also consistent with use of a short-term release for a drop or collision event.

This assumption is used in Sections 3.1.2, 6.1.3, 6.1.4, and 6.2.1.3.

- 4.2.3 For evaluating public doses for Category 1 and Category 2 event sequences using MACCS2, radioactive materials are assumed to be released in a 1-hr duration. The period of long-term exposure to ground contamination and intake of contaminated food is 1 year.

Basis: The use of a short-term release is consistent with a drop or collision event. A release duration longer than 1-hr would provide more time for atmospheric dispersion and result in lower χ/Q values and lower doses. The use of 1-hr χ/Q values for accident releases is conservative and consistent with Regulatory Guide 1.145 [DIRS 103651], Section 1.3. Using 1 year as the value for long-term exposure to ground contamination and intake of contaminated food will also result in a higher dose rate than the exposure period of 30 days recommended in Interim Safety Guide-5 (NRC 2003a, p. 9-15).

This assumption is used in Sections 3.1.2, 3.2.2, 6.1.3, and 6.1.4.

- 4.2.4 For calculating annual public doses from normal operations using MACCS2 (ORNL 1998) [DIRS 164761]), the release duration is assumed to be 24 hour. All releases are assumed to result in an acute individual exposure during plume passage and a chronic individual exposure to ground contamination and contaminated food after plume passage. Annual doses include long-term exposure to ground contamination and intake of contaminated food for a 1 year period.

Basis: The sensitivity run discussed in Section 6.3.4.1 showed that the use of the release duration of 24 hour, which is the longest duration allowed by MACCS2, instead of 1 year, for normal operations is conservative.

This assumption is used in Sections 3.1.2, 3.2.2, 6.1.1.1, 6.1.3, 6.1.4, 6.2.1.5, and 6.3.4.

- 4.2.5 For evaluating seismic event doses, it is assumed that the maximum total receipt at the repository is 63,000 MTHM of commercial SNF. It is also assumed that for the purposes of calculating buildup of activity on the DTF 1, DTF 2 and FHF HEPA filters and ducting surfaces from SNF releases, the SNF received is PWR SFAs. Using an average PWR assembly weight of 0.475 MTHM/SFA (BSC 2004f [DIRS 169061], p. 8), the total throughput is 132,632 SFAs. It is further assumed that the entire released particulate activity from the SFAs using normal operations ARFs accumulates on HVAC surfaces without credit for decay or HEPA filter change out.

Basis: The total acceptance of commercial SNF may not exceed 63,000 MTHM as determined from *Civilian Radioactive Waste Management System Requirements Document* (DOE 2004b [DIRS 171945], Table 2). It is a bounding assumption that the 63,000 MTHM is PWR SFAs, because PWR SFAs typically have higher enrichment and burnup than BWR SFAs (Table 3). SNF with a combined higher enrichment and a higher burnup, in general, has a higher total initial radionuclide inventory. Thus, this assumption is bounding with respect to the total curie inventory which is used in dose calculations.

This assumption is used in Sections 6.1.4.4.

- 4.2.6 For normal operations and Category 1 event sequences, it is assumed that radionuclides are released from the primary confinement areas (transfer cells and DPC cutting areas, etc.) within a surface facility.

Basis: For Category 1 event sequences involving drops or collisions, or both, of SNF, release of radioactive materials would occur during transfer (BSC 2005i [DIRS 174467], Section 6.3.1.3) and would only occur inside a waste transfer cell. During normal operations, radioactive materials could be released during the opening of a transportation cask and that also occurs inside waste transfer cell. There may be some other small releases that could result from the potential events discussed in Section 6.1.6 **Error! Reference source not found.** However, the releases from those events would involve 1) only minor surface contamination, 2) involve only small fractions of the assumed 1% normal operations release and/or 3) be so infrequent that their dose contribution to aggregated doses would be inconsequential compared to those from normal operation.

This assumption is used in 3.1.2.1 and 3.1.2.2.

- 4.2.7 For Category 1 and Category 2 event sequences, the DR is assumed to be 1.0 for commercial SNF. For Category 2 event sequences, the DR is assumed to be 1.0 for HLW in a canister. The DR is the fraction of fuel rods that is assumed to fail by cladding breach during an event sequence or the fraction of HLW that is damaged by crush or impact, or both. Bounding source terms for Category 2 event sequences involving naval SNF already include a DR, as documented in Gisch 2004 ([DIRS 171579], p. 1) and Griffith 2003 ([DIRS 168871, Enclosure pages 3 and 4).

Basis: These are bounding assumptions for commercial SNF, HLW, and naval SNF because the use of a DR of 1 assumes 100% of the fuel is damaged and naval SNF source terms already include a DR that provides bounding source terms.

This assumption is used in Sections 3.1.3.1, 6.1.3, 6.1.4, 6.2.1, 6.3.4 and Appendix E.

- 4.2.8 For Category 2 event sequences, the cask leak path factor $(LPF)_{cask}$ is assumed to be 0.1 for SNF in a transportation cask and 0.01 for HLW in a canister in a transportation cask, and 1.0 for naval SNF in a transportation cask or in a canister. The $(LPF)_{cask}$ is the fraction of the ARF that reaches the ventilation system after local deposition, consisting of plate-out and gravitational settling, within a transportation cask.

Basis: This is a conservative assumption. For rail casks involved in end, corner, or side impacts, at an impact speed of 60 mph, NUREG/CR-6672 (Sprung et al. 2000 [DIRS 152476], Table 7.19) calculated an $(LPF)_{cask}$ of 0.02 for particles and 0.0008 for cesium, which are smaller than the conservatively assumed $(LPF)_{cask}$ of 0.1. Both the canister and the cask are assumed to have an LPF of 0.1 because HLW is shipped inside a canister within a transportation cask. The combined LPF for HLW is equal to 0.01 (i.e., $0.1 \times 0.1 = 0.01$). An $(LPF)_{cask}$ of 1.0 for naval SNF is a bounding value because it assumes a 100% release.

This assumption is used in Section 6.2.1.

- 4.2.9 For normal operations and Category 1 event sequences, the facility leak path factor $(LPF)_{fac}$ is assumed to be 1.0 inside a waste transfer cell. The $(LPF)_{fac}$ is the fraction of the ARF that reaches the ventilation system after local deposition, consisting of plate-out and gravitational settling.

Basis: This is a bounding assumption because no credit is taken for local deposition of particulates within a surface facility or deposition on HVAC ducting.

This assumption is used in Section 6.2.1.

- 4.2.10 The HVAC system is assumed to be operating and no airborne material released from Category 1 event sequences leaks into space occupied by workers in rooms adjacent to a waste transfer cell in a DTF or the FHF.

Basis: This assumption is reasonable because the transfer cell confinement and the HVAC system are designed to prevent any leakage to rooms adjacent to the transfer cell in the event of a Category 1 event sequence.

This assumption is used in Sections 6.1.1.1 and 6.1.3.

- 4.2.11 For normal operations and Category 1 event sequences, it is assumed that for radionuclides released from the Primary confinement areas (Transfer Cells and DPC cutting areas) within a surface facility, the HVAC system is operating and airborne radionuclides are vented through the building exhaust stack and dispersed into the atmosphere. The airborne release may then transport to onsite or offsite general public locations or may reenter the building through the building ventilation system air intakes. It is assumed that for radionuclides released from the subsurface facility, airborne radionuclides are dispersed into the atmosphere and similarly may transport or reenter the subsurface facility through the subsurface ventilation system air intakes. The building wake effect is considered for surface facility releases.

Basis: The calculation of general public doses outside facilities considers the air concentrations at that onsite or offsite location. The calculation of worker doses considers that the concentrations within the facility are at equilibrium with the concentration at the air intake, which is the major source of air into the facility. The subsurface ventilation system air intakes are the only places that airborne radionuclides could enter the subsurface facility. Including the wake effect is appropriate for release from surface facilities, but subsurface facilities do not have building structures adjacent to the release locations.

This assumption is used in Sections 3.1.2 and 3.1.3.

- 4.2.12 The releases from the subsurface exhaust shafts during normal operations and the releases from the surface facilities from Category 1 and Category 2 event sequences are assumed to be at ground level. The building wake effect on the plume is considered for Category 1 and Category 2 event sequences.

Basis: Assuming a ground-level release of radioactive material, instead of an elevated release from the subsurface exhaust shafts, reduces the relative dispersion and increases exposure concentration. Releases from Category 1 event sequences are expected to exit surface facilities through a stack but are conservatively modeled as ground level releases. Releases from Category 2 event sequences are also modeled as ground level releases. Assuming radioactive releases occur at ground level rather than an elevated level such as from an exhaust stack results in slightly higher dose rates and are therefore more conservative. Including the building wake effect on the plume is appropriate for Category 1 and Category 2 event sequences releases from the surface facilities.

This assumption is used in Sections 3.1.2, 3.2.2, 6.1.1.2, 6.1.3, 6.1.4, and 6.2.1.

- 4.2.13 For normal operations, the maximally exposed individual at the site boundary is assumed to receive doses from the inhalation, resuspension inhalation, air submersion, groundshine, and ingestion pathways for a period of 8,760 hour. The onsite individual member of the public, following completion of construction, at 100 m from a DTF and FHF and 3 km from a subsurface exhaust shaft is assumed to receive doses from inhalation, resuspension inhalation, air submersion, and groundshine pathways for a period of 2,000 hour.

Basis: The dose to the onsite public is calculated at the surface facilities where the public is expected to be located following completion of construction. It is expected that onsite ground contamination after event sequences will be detected and removed prior to restart of the repository operation. Unlike facility workers who work 2,000 hour a year, an individual member of the public is expected to visit the Yucca Mountain site for only a few days in a year. Therefore, the assumption of a 2,000-hr exposure period is conservative.

This assumption is used in Sections 6.2.1.5, 6.3.1, 6.3.2, and Attachment E.

- 4.2.14 Significant oxidation of CSNF does not occur during normal operations or following a Category 1 or Category 2 event sequence.

Basis: To prevent significant oxidation of CSNF, an operational requirement will ensure that CSNF accepted by the repository is “old and cold” (BSC 2005i [DIRS 174467], Section 5.1.1.70).

This assumption is used in Section 6.1.1.1.

- 4.2.15 No credit is taken for plume meandering or for plume rise from initial thermal energy to ensure that the χ/Q value is conservative at the site boundary.

Basis: Not taking credit for plume meander or for plume rise results in conservatively higher χ/Q value.

This assumption is used in MACCS2 runs in Section 6.2 and discussed in Sections 3.1.2 and 3.2.2.

4.2.16 Following HEPA filtration, the respirable fraction for fuel fines and Sr is assumed to be 1.0.

Basis: This conservatively accounts for reduction in average particle size following HEPA filtration. All particles released through the HEPA filters are assumed to be of respirable size.

This assumption is used in Table 5.

4.3 ASSUMPTIONS REQUIRING VERIFICATION

None.

5. USE OF COMPUTER SOFTWARE

5.1 SOFTWARE APPROVED FOR QUALITY-AFFECTING WORK

MACCS2 (ORNL 1998 [DIRS 164761]) and its preprocessor module COMIDA2 are the only computer programs used in this calculation, except for the exempt Microsoft Excel 97 spreadsheet program.

MACCS2 V.1.12 (ORNL 1998 [DIRS 164761])

MACCS2 (ORNL 1998 [DIRS 164761]) is baselined in accordance with LP-SI.11Q-BSC, *Software Management*. The code validation and verification results are documented in *Users Manual: MACCS2 Version 1.12, STN: 11000-1.12-00* (Tsai 2003 [DIRS 170201]). The code is used within its validated range.

- Program Name: MACCS2
- Version/Revision Number: Version 1.12
- Software Tracking Number (STN): 11000-1.12-00
- Computer Type: Dell OPTIPLEX GX240
- Platform/Operating System: PC/Windows 2000
- Computer Processing Unit Tag Number: CRWMS M&O Tag 152128.

MACCS2 (ORNL 1998 [DIRS 164761]) calculates doses resulting from radionuclide releases from nuclear facilities to onsite and offsite members of the public. The code considers: atmospheric transport; short- and long-term mitigation actions; and potential exposure pathways, such as inhalation, resuspension inhalation, ingestion, air submersion, and groundshine.

MACCS2 (ORNL 1998 [DIRS 164761]) also simulates the impact of atmospheric releases of radiological materials on the surrounding environment. The principal phenomena considered in MACCS2 [DIRS 164761] are atmospheric transport, mitigative actions based on dose projection, dose accumulation by a number of pathways including food and water ingestion, and acute and chronic exposures. MACCS2 [DIRS 164761] contains simple models with analytical solutions. A MACCS2 [DIRS 164761] calculation consists of three phases: input processing and validation, phenomenological modeling, and output processing. The phenomenological models are based on empirical data and the solutions are analytical in nature and computationally straightforward.

The phenomenological modeling phase is divided into three modules: ATMOS, EARLY, and CHRONC. The ATMOS module treats atmospheric transport and dispersion of material and its deposition from the air using a Gaussian plume model with Pasquill-Gifford dispersion parameters. The EARLY module models consequences of the accident to the surrounding area during an emergency action period. The CHRONC module considers the long-term impact in the period subsequent to the emergency action period.

The applicability of MACCS2 (ORNL 1998 [DIRS 164761]) to normal operations is discussed in Section 3.1.2. The MACCS2 [DIRS 164761] calculated χ/Q values (Attachment A) are more

conservative than the χ/Q values calculated based on Regulatory Guide 1.111 [DIRS 103765] for normal operations (Section 3.1.2).

COMIDA2 V.1.11 (ORNL 1998 [DIRS 164761])

COMIDA2 (ORNL 1998 [DIRS 164761] Volume 2, Section 2) is run to generate the food chain dose-to-source output data file *YUCICRPD.BIN* (Attachment D) based on dose conversion factors from ICRP Publication 72 (ICRP-72) (ICRP 1996 [DIRS 152446]). The COMIDA2 module is distributed with the already baselined MACCS2 program from ORNL (STN: 11000-1.12-00). Although the sample problems had been provided with MACCS2, the COMIDA2 module was not incorporated into the original baseline documentation with MACCS2. COMIDA2 will be baselined in accordance with LP-SI.11Q-BSC, *Software Management*.

- Program Name: COMIDA2
- Version/Revision Number: Version 1.11
- Computer Type: Dell OPTIPLEX GX240
- Platform/Operating System: PC/Windows 2000
- Computer Processing Unit Tag Number: CRWMS M&O Tag 152128.

5.2 EXEMPT SOFTWARE

The Microsoft Excel 97 spreadsheet program is used to perform simple calculations as documented in Section 6. User-defined formulas, input, and results are documented in sufficient detail in Section 6 to allow for independent duplication of various computations without recourse to the originator. This software is considered exempt from the requirements of LP-SI.11Q-BSC, *Software Management*.

6. ANALYSIS

6.1 RADIONUCLIDE RELEASES FROM NORMAL OPERATIONS AND EVENT SEQUENCES

This section discusses radionuclide releases from normal operations and Category 1 and Category 2 event sequences, as well as event sequence frequency calculation. Waste forms involved in normal operations and in Category 1 and Category 2 event sequences include PWR or BWR SFAs, HLW, and naval SNF (see Section 4.1.2).

6.1.1 Radionuclide Releases from Normal Operations

This section discusses normal operations in surface and subsurface facilities and the potential release of radionuclides from these facilities.

6.1.1.1 Potential Releases from Surface Facilities

The repository surface facilities are located near the North Portal entrance to the repository. Waste handling operations are carried out in the geologic repository operations area. The facilities necessary to receive, package, age, and emplace waste in the repository are located in this area.

Waste transfer operations are performed in several waste handling facilities, including the CHF, DTF 1, DTF 2, and the FHF, as described in *Internal Hazards Analysis for License Application* (BSC 2005j [DIRS 174059], Section 6.4).

The SNF and vitrified HLW are transported to the repository in NRC-certified transportation casks in accordance with applicable federal regulations. When an SNF or HLW transportation cask is received, personnel verify the shipping manifests and inspect and survey the cask and its trailer or railcar. The cask is then moved to a restricted area for staging (BSC 2005j [DIRS 174059], Section 6.4).

From the staging area, casks are delivered to TCRRF for transfer to a site rail transfer cart and the transportation cask buffer area, as applicable. Casks delivered to the FHF are delivered directly to the facility on public conveyance (truck trailer or railcar) from the staging area; there is no FHF interface with a site rail transfer cart or transportation cask buffer area (BSC 2005j [DIRS 174059], Section 6.4).

When an empty waste package is scheduled for processing, it is moved into the appropriate waste handling facility. The waste handling facility operators prepare and configure the empty waste package for SNF/HLW transfer. The steps for waste package preparation include positioning the waste package for transfer, inserting the inner shell lid and transferring the waste package to the appropriate SNF/HLW transfer area (BSC 2005j [DIRS 174059], Section 6.4).

When a waste shipment is scheduled for processing, the transportation cask containing the SNF/HLW is moved into an appropriate waste handling facility. Cask preparation consists of (BSC 2005j [DIRS 174059], Section 6.4):

- Surveying the cask for radiation and surface contamination
- Decontamination, if required
- Removal of impact limiters
- Upending the cask
- Positioning the cask for transfer
- Sampling gases inside the cask
- Venting the cask cavity to atmospheric pressure
- Removing the cask lid(s)
- Transferring the cask to the SNF/HLW transfer area
- Establishing radiological confinement between the cask and the waste handling facility, as required.

Radiological confinement is attained using the cask unload port sealing device, if required. If the cask shipment contains a dual-purpose canister (DPC) of commercial SNF, then the DPC undergoes a series of preparation steps prior to commercial SNF transfer. These preparation steps include the rigging of the DPC for transfer, removing the DPC to the SNF/HLW transfer area, sampling gases inside the DPC, cutting the DPC lid off, and removing the DPC lid to allow for commercial SNF transfer. The empty DPC and lid are packaged as low-level radioactive waste and transported to a low-level radioactive waste disposal site (BSC 2005j [DIRS 174059], Section 6.4).

Preparation of an aging cask consists of positioning the cask for transfer, removing the cask lid(s), transferring the cask to the SNF/HLW transfer area, and establishing radiological confinement between the empty cask and the waste handling facility, if required. The SNF/HLW is remotely transferred from the transportation casks to the aging cask. Once loaded, the aging cask is closed, inerted (if required), and sealed prior to being transported to the SNF aging system for cooling. In addition, if staging is required, then SNF/HLW may be placed in an aging cask and transported to the SNF aging system (BSC 2005j [DIRS 174059], Section 6.4). No significant normal operational releases are expected from the SNF aging system as reported in *Aging-Facility Worker Dose Assessment* (BSC 2005k [DIRS 173167], Appendix A).

After waste package loading is completed, the inner lid is placed on the waste package. Then the waste package is transferred to the waste package closure cell where the inner lid is welded first and then the middle and outer lids are placed on the waste package and welded, the welds are inspected, and the weld stresses are mitigated. Waste packages may be staged (DTF 1 and DTF 2 only) or transferred to the waste package loadout area where the waste package is surveyed for contamination, down-ended onto the emplacement pallet, positioned for lifting collar removal, and transferred into the waste package transporter. The waste package transporter is moved into the subsurface facilities to an emplacement drift, where the waste package is remotely transferred to an emplacement gantry for final positioning in the emplacement drift (BSC 2005j [DIRS 174059], Section 6.4).

Significant oxidation of CSNF does not occur during normal operations or following a Category 1 or Category 2 event sequence (Assumption 4.2.14). The repository receipt rate of 3,600 MTHM/year equals 7,579 PWR SFAs/year based on 0.475 MTU/SFA (Assumption 4.2.1).

One percent of the fuel rods in the maximum annual throughput are assumed to have cladding breaches that allow fission product gases, volatile species, and fuel fines to be released (see Assumption 4.1.3). Therefore, releases from 1% of fuel rods in the 7,579 PWR SFAs are used as the source term for the calculation of normal operations doses. During normal waste handling at the process facilities, there are releases from the exhaust stacks of DTF 1, DTF 2, and the FHF (Assumption 4.2.5). There are no releases expected from the CHF during normal operations, because the CHF handles only sealed canisters with insignificant levels of surface contamination.

Failed fuel is defined in 10 CFR Part 961, [DIRS 171309], p. 607, as the fuel that has significant failed cladding. Failed fuel has already released its radionuclide inventory in the gap region between the cladding and the fuel pellets, while at a nuclear power plant. Historical fuel discharge data show that the fuel rod failure is about 0.01%, versus the range of 0.02 to 0.07% in the first 20 years of commercial nuclear power (BSC 2003c [DIRS 165990], p. G-6).

Failed commercial SNF will be shipped to the repository in screen-end or closed-end canisters in a transportation cask. Failed commercial SNF canisters will be transferred from the cask to a waste package inside a waste transfer cell in a DTF or the FHF, during normal operations.

For evaluating public doses for normal operations using MACCS2, radioactive materials are continuously released over 24 hour (Assumption 4.2.4) via the building exhaust stack (Assumption 4.2.5) as a radioactive plume that is dispersed en route to the site boundary. The release can result in an acute individual exposure during plume passage and a chronic individual exposure to ground contamination and contaminated food after plume passage (Assumption 4.2.4). The period of long-term exposure to ground contamination and intake of contaminated food is 1 year (Assumption 4.2.4).

For public and worker dose calculations, the HVAC system is operating and no unfiltered material leaks into space occupied by workers in rooms adjacent to a waste transfer cell in a DTF or the FHF (Assumption 4.2.10). The waste transfer cell confinement and the HVAC system are designed to prevent unfiltered leakage out of the transfer cell in the event of a Category 1 event sequence.

Credit is taken for HEPA filters to remove radionuclides as they are exhausted by the HVAC system.

6.1.1.2 Potential Releases from Subsurface Facility

Under normal operations of the subsurface repository, there are three potential mechanisms that generate airborne releases of radioactive materials, which are:

- Resuspension of radioactive contamination from the external surfaces of the emplaced waste packages
- Neutron activation of ventilating air inside the emplacement drifts
- Neutron activation of silica dust generated from host rock in the emplacement drifts.

Contamination on the surface of waste packages in emplacement drifts may become entrained in the ventilated airflow and be released to the environment through the ventilation shaft. Neutrons that penetrate the emplaced waste packages during normal operations, can activate the ventilated airflow through subsurface emplacement drifts and the host rock surrounding the emplaced waste packages. Activated air and dust are released to the environment through the ventilation shaft. Total estimated annual releases from the subsurface facility from normal operations are shown in Table 9 (BSC 2005b [DIRS 172487], Table 13).

Annual releases (Table 9) are based on the postulated activation of air and silica dust in the subsurface facilities during normal operations as summarized in BSC (2005b [DIRS 172487], Table 13). Subsurface releases include waste package surface contamination and radionuclides generated by the activation of air (^{41}Ar and ^{16}N) and dust (^{16}N , ^{24}Na , ^{28}Al , ^{31}Si , ^{42}K and ^{55}Fe). Nitrogen-16 (^{16}N) is not considered in the dose assessment because of its short half-life and the associated long travel time from the release point to the site boundary. The assumptions, parameters, and methodology used to calculate subsurface releases are presented in BSC 2005b [DIRS 172487].

The releases from the subsurface exhaust shafts during normal operations are at ground level (Assumption 4.2.12).

Table 9. Annual Releases from Subsurface Facility Normal Operation

Normal Operations Release (Ci/year)	
Waste Package Surface Contamination	
^{137}Cs	6.8×10^{-3}
Crud ^{60}Co	2.9×10^{-3}
^{60}Co	7.8×10^{-6}
^{63}Ni	6.3×10^{-6}
^{90}Sr	6.8×10^{-4}
^{90}Y	6.8×10^{-4}
^{147}Pm	3.0×10^{-6}
^{151}Sm	5.3×10^{-6}
^{154}Eu	1.7×10^{-5}
^{241}Pu	6.2×10^{-4}

Table 9. Annual Releases from Subsurface Facility
Normal Operation (Continued)

Waste Package Surface Contamination (Continued)	
²³⁸ Pu	5.7×10^{-5}
²³⁹ Pu	4.4×10^{-6}
²⁴⁰ Pu	7.9×10^{-6}
²⁴¹ Am	4.9×10^{-5}
²⁴³ Am	5.5×10^{-7}
²⁴³ Cm	2.6×10^{-7}
²⁴⁴ Cm	3.4×10^{-5}
Activated Air	
¹⁶ N	3.4×10^{-2}
⁴¹ Ar	2.0×10^{-1}
Activated Dust	
¹⁶ N	9.5×10^{-13}
²⁴ Na	3.7×10^{-3}
²⁸ Al	1.6×10^{-3}
³¹ Si	5.2×10^{-4}
⁴² K	8.0×10^{-4}
⁵⁵ Fe	8.2×10^{-5}

Source: BSC 2005b [DIRS 172487], Table 13

6.1.1.3 Potential Releases from Retrieval Operations

The geologic repository operations area must be designed to preserve the option of waste retrieval throughout the period during which wastes are emplaced and thereafter, until NRC review of the information obtained from a performance confirmation program is completed (10 CFR 63.111(e)(1) [DIRS 173273]). Permanent retrieval of any or all waste would require a separate license and possibly new facilities.

6.1.2 Event Sequence Frequency Calculation and Categorization

Categorization of event sequences based on frequency calculations and design bases are presented in BSC (2005i [DIRS 174467], Section 7). Design bases are a set of requirements to be implemented by design to prevent releases or to mitigate radiological consequences. Bounding Category 1 and Category 2 event sequences are identified in BSC (2005i [DIRS 174467], Section 7).

6.1.2.1 External Event Sequences

The following hazards are applicable to the repository (BSC 2005i [DIRS 174467], Section 6.2):

- Aircraft crash
- Ash fall due to volcanism
- Drift degradation
- Extreme weather (temperature) fluctuation
- Lightning
- Loss of offsite or onsite power
- Nearby industrial and military activities
- Rainstorm and flooding
- Range fire
- Sandstorm
- Seismic activity
- Tornado and extreme wind.

If there is some chance that an external hazard could initiate an event sequence, then the hazard is considered applicable (BSC 2005i [DIRS 174467], Section 6.2). In some cases, event sequences initiated by applicable hazards were shown to be beyond Category 2 by separate calculations.

Potential event sequences initiated by external hazards (BSC 2005i [DIRS 174467], Section 6.2) can be prevented by designing SSCs important to safety or engineered features to withstand external hazards or by showing that the event frequency is beyond Category 2 (BSC 2005i [DIRS 174467], Section 6.2). Implementation of seismic design requirements for SSCs that are important to safety ensures that surface facilities are designed such that seismic events will not initiate Category 1 or Category 2 event sequences that exceed the dose limits specified in 10 CFR Part 63 (BSC 2005i [DIRS 174467], Section 4.1.14).

There is only one Category 2 external event sequences SSC-1 (involving the earthquake-induced failure of SSCs) (BSC 2005i [DIRS 174467], Section 7.1). The seismically initiated Category 2 external event sequence of concern is described in Table 10 and specific SSC failures associated with that seismic event are identified as SSC-1a and SSC-1b.

Table 10. Description of the Category 2 Seismic Event Sequences

Seismic Event Identifier	SSC ^a	Description of SSC Failure a	Bounding Material at Risk ^a
SSC-1a	HEPA filters (Primary Surface Nuclear HVAC, accumulate radioactive material)	Failure of HEPA filters leading to discharge of accumulated radioactive material	HEPA filter activity
SSC-1b	Exhaust ducting and dampers (Primary Surface Nuclear HVAC, accumulate radioactive material)	Failure of ducting and dampers leading to discharge of accumulated radioactive material.	Exhaust duct plateout activity

NOTE: ^a Reference *Categorization of Event Sequences for License Application* (BSC 2005i [DIRS 174467], Table 7)

6.1.2.2 Internal Event Sequences

Internal fire-induced event sequences involving other than uncanistered commercial SNF are screened out by design and operational requirements that limit the quantities of combustible or flammable materials. For CSNF, fire-induced event sequences releases would not be more severe than releases that occur during normal handling operations (BSC 2005i [DIRS 174467], Section 4.1.9). Fire event sequences involving low level radwaste (LLW) are Category 2 and the bounding event involves 100 drums of LLW in transit to the storage yard (BSC 2005i [DIRS 174467], Section 5.1.1.6).

Internal events involving criticality are prevented by design requirements that control the amounts of moderators in the CHF, DTF 1, DTF 2, and the FHF. In addition, geometry control is used in the design of SNF staging racks and the remediation pool (BSC 2005i [DIRS 174467], Sections 5.1.1.2 and 5.1.5.9).

Certain internal events involving drops or collisions of commercial SNF assemblies are Category 1 events. The frequencies of drops or collisions and the numbers of SFAs affected at the maximum rate of receipt are presented in Table 11.

Table 11. Category 1 Event Sequences

Event Sequence Identifier	Description	Expected Number of Event Sequences Before Permanent Closure	Annual Event Frequency for Consequence Analysis	Bounding Material at Risk
GET-03B	Collision involving a commercial SNF assembly	9.7 collisions	0.5 collisions/y	1 PWR or 1 BWR assembly
GET-03D	Drop of a commercial SNF assembly	9.7 drops	0.5 drops/y	2 PWR or 2 BWR assemblies

Source: *Categorization of Event Sequences for License Application* (BSC 2005i [DIRS 174467], Table 51)

BWR = boiling water reactor; GET = generalized event tree; MAR = material at risk; PWR = pressurized water reactor; SNF = spent nuclear fuel.

Drops or collisions involving uncanistered commercial SFAs during transfer are determined to be Category 1 event sequences (BSC 2005i [DIRS 174467], Section 6.3.1.3), because of the large number of commercial SFAs to be handled inside a waste transfer cell of a DTF in 1 year. The frequency of drops or collisions of uncanistered commercial SNF during dry transfer depends on the handling frequency and the drop or collision rate per movement.

6.1.3 Radionuclide Releases from Category 1 Event Sequences

6.1.3.1 Event Sequence GET-03B (Table 11)

During the transfer of individual commercial SFAs from a transportation cask to a waste package in a transfer cell, an SFA could collide with heavy equipment or structures. It is assumed that the cladding of 100% of the fuel rods in the one affected SFA is damaged and that radionuclides are released to the environment (Assumption 4.2.7).

This event sequence results in a release of fission product gases, volatile species, fuel fines, and crud immediately following a cladding breach. The release fractions are given in Table 5.

It is assumed that for this event sequence, radioactive materials are released in 1 hour (Assumption 4.2.3) as a ground-level plume (Assumption 4.2.12) that is dispersed en route to the site boundary, resulting in an acute individual exposure during plume passage and a chronic individual exposure to ground contamination and contaminated food after plume passage (Assumption 4.2.4).

It is assumed that for worker dose calculations, the HVAC system is operating and no airborne material released from Category 1 event sequences leaks into space occupied by workers in rooms adjacent to the waste transfer cell in a DTF or the FHF (Assumption 4.2.10), because the transfer cell confinement and the HVAC system are designed to prevent any unfiltered leakage to rooms adjacent to the transfer cell in the event of a Category 1 event sequence.

Credit is taken for HEPA filters to remove radionuclides (Assumption 4.2.2).

6.1.3.2 Event Sequence GET-03D (Table 11)

During the transfer of an individual commercial SFA, an SFA could drop (for example):

- Into an empty cask, waste package, or transfer cell staging rack
- Onto another SFA in the cask
- Into a waste package
- Onto the transfer cell floor.

It is assumed that the cladding of 100% of the fuel rods in the two affected SFAs is damaged and that radionuclides are released to the environment (Assumption 4.2.7). The release of radionuclides involves a release of fission product gases, volatile species, fuel fines, and crud immediately following a cladding breach. The release fractions are given in Table 5.

It is assumed that for this event sequence, radioactive materials are released in a duration of 1 hour (Assumption 4.2.3) as a ground-level plume (Assumption 4.2.12) that is dispersed en route to the site boundary, resulting in an acute individual exposure during plume passage and a chronic individual exposure to ground contamination and contaminated food after plume passage (Assumption 4.2.4).

It is assumed that for worker dose calculations, the HVAC system is operating and no airborne material released from Category 1 event sequences leaks into space occupied by workers in rooms adjacent to the waste transfer cell of a DTF or the FHF (Assumption 4.2.10), because the

transfer cell confinement and the HVAC system are designed to prevent any leakage to rooms adjacent to the transfer cell in the event of a Category 1 event sequence.

Credit is taken for HEPA filters to remove radionuclides (Assumption 4.2.2).

6.1.4 Radionuclide Releases from Category 2 Event Sequences

Drops or collisions of commercial SFAs, HLW, and naval SNF in canisters, transportation casks, or waste packages are determined to be Category 2 event sequences (BSC 2005i [DIRS 174467], Table 53). For these Category 2 event sequences, radioactive materials are modeled as released in a duration of 1 hour (Assumption 4.2.3) as a ground-level radioactive plume (Assumption 4.2.12) that is dispersed en route to the site boundary, resulting in an acute individual exposure during plume passage and a chronic individual exposure to ground contamination and contaminated food after plume passage (Assumption 4.2.3). The period of long-term exposure to ground contamination and intake of contaminated food is 1 year (Assumption 4.2.4).

No credit is taken for HEPA filters to remove radionuclides (Assumption 4.2.2).

Three Category 2 event sequences, that bound other Category 2 event sequences (BSC 2005i [DIRS 174467], Table 53) with respect to frequency and MAR, are identified in Table 12.

Table 12. Bounding Category 2 Event Sequences

Event Sequence Identifier	Description	Expected Number of Occurrences Over the Life of the Repository	Bounding Material at Risk
SEISMIC	Failure of HEPA filters and exhaust ducting and dampers leading to discharge of accumulated radioactive material during a seismic event	1.0×10^{-4}	Accumulated radioactive material in HEPA filters, exhaust ducting, and dampers (Section 6.1.4.4)
GET-01A	Drop of a transportation cask, without impact limiters, in the CHF, DTF, FHF, or TCRRF	5.7×10^{-1}	74 BWR or 36 PWR SFAs, 5 DOE HLW canisters, or 1 naval SNF canister
GET-02B	Drop of the inner lid of a transportation cask, site specific cask, or waste package into a transportation cask, site specific cask, or waste package in the CHF, DTF, or FHF	5.7×10^{-1}	74 BWR or 36 PWR SFAs, 5 DOE HLW canisters or 1 naval SNF canister

Note: The event 'SEISMIC' includes the combined releases from SSC-1a and SSC-1b in Table 10.

Source: BSC 2005i [DIRS 174467], Table 53 and Section 6.2.6

BWR = boiling water reactor; CHF = Canister Handling Facility; DOE = U.S. Department of Energy; DTF = Dry Transfer Facility (DTF 1 or DTF 2); FHF = Fuel Handling Facility; HEPA = high efficiency particulate air [filter]; HLW = high-level radioactive waste; PWR = pressurized water reactor; SFA = spent fuel assembly; TCRRF = Transportation Cask Receipt and Return Facility.

6.1.4.1 Bounding Category 2 Event Sequence Involving Boiling Water Reactor and Pressurized Water Reactor Spent Nuclear Fuel Assemblies

Event sequences GET-01A and GET-02B (Table 12) bound other Category 2 event sequences involving PWR and BWR SFAs. Event sequence GET-01A involves a drop of a transportation cask and breach of PWR or BWR SFAs. It is assumed that the event sequence results in

breaches of 36 PWR SFAs or 74 BWR SFAs and releases of radionuclides to the environment (Table 12).

6.1.4.2 Bounding Category 2 Event Sequence Involving Naval Spent Nuclear Fuel

Event sequences GET-01A and GET-02B (Table 12) bound other event sequences involving naval SNF. Event sequence GET-01A (Table 12) involves a drop of a transportation cask and breach of a naval SNF canister. It is assumed that the event sequence results in damage to naval SNF assemblies and releases of radionuclides to the environment.

6.1.4.3 Bounding Category 2 Event Sequence Involving Vitrified HLW

Event sequences GET-01A and GET-02B (Table 12) bound other event sequences involving vitrified HLW. Event sequence GET-01A (Table 12) involves a drop of a transportation cask and breach of five vitrified HLW canisters. It is assumed that the event sequence results in breaches of five HLW canisters and releases of radionuclides to the environment.

6.1.4.4 Bounding Category 2 Seismic Event Sequence

SEISMIC is a bounding Category 2 seismic event sequence that includes the combined releases from events designated as SSC-1a and SSC-1b in Table 10. The seismic event sequence was identified in BSC 2005i ([DIRS 174467], Section 6.2.6). The bounding material at risk for the Category 2 seismic event sequence is the accumulated radioactive material in HEPA filters, exhaust ducting, and dampers in dry transfer cells in DTF-1, DTF-2 and FHF.

The seismic event is postulated to include failure of HEPA filters, ducting and dampers leading to discharge of accumulated radioactive material. A conservative bounding source term is determined by accumulating 100% of the normal operating release from 1% of the total fuel rods received at the repository onto the HEPA filter and ducting surfaces. The normal operating release is based on release fractions from Table 5 for intact spent fuel assemblies. Spent fuel activities are based on average PWR source terms from Table 4. The total number of fuel assemblies received at the repository is determined as 132,632 SFA for 63,000 MTHM (Assumption 4.2.5). Conservatively, no credit is taken for the routine replacement of HEPA filters and removal of their accumulated activity during the emplacement period (Assumption 4.2.5).

During a seismic event, the accumulated activity is conservatively treated as a bulk-powder and released in two stages: 1) shock-vibration of bulk-powder, and 2) free-fall spill as the ducting collapse. The combined ARF x RF values is $7E-4$ (Assumption 4.1.7).

6.1.4.5 Fire Event Involving LLW Drums

A Category 2 event sequence involving dry active waste (DAW) has been identified in BSC 2005i ([174467], Table 53). DAW is a type of LLW and contains a mixture of materials, with the non-compactible portion being comprised of equipment and small tools and the compactible portion being comprised of paper, plastic, and cloth. DAW has a bounding specific activity of 0.025 curie/cubic meter (i.e., 0.7 millicurie/cubic foot) (McFeely 1998 [DIRS 104701], p. 2). Compacted and non-compacted DAW will be placed in 0.21 m^3 (55-gallon) drums.

This event sequence assumes that 100 DAW drums (BSC 2005i [174467], Table 53) are involved in a fire. Because of intense heat, the contents of the DAW catch fire, releasing radionuclides inside the drums. The bounding release fraction for burning combustible packaged contaminated waste is 5×10^{-4} (DOE 1994, p. 5-12). No credit is taken for HEPA filters for removing airborne radionuclides. The release source term, meaning the amount of radionuclides released to the environment, is calculated below:

$$\begin{aligned}\text{DAW release source term} &= 100 \text{ drums} \times 0.21 \text{ m}^3/\text{drum} \times 0.025 \text{ Ci/m}^3 \times 5 \times 10^{-4} \\ &= 2.6 \times 10^{-4} \text{ Ci}\end{aligned}$$

This DAW fire event sequence is bounded by the bounding seismic event sequence described in Section 6.1.2.1. This seismic event sequence assumes that accumulated fuel fine and crud activity on HEPA filters and ducting as a result of handling all 63,000 MTHM of commercial SNF, equivalent to 132,632 SFAs (Assumption 4.2.5), received over the lifetime of the repository is released to the environment during a seismic event sequence. The total activity in each average PWR assembly is 1.7×10^5 Ci/FA, including 1.67×10^5 Ci/FA from fuel matrix (Table 4, excluding H-3, Kr-85 and C-14) and 7 Ci/FA from crud (Table 15). It is assumed that 1% of the fuel rods received has breached cladding, with a particulate release fraction of 3×10^{-5} (Table 5). The combined ARF $\times$ RF for the seismic event sequence is 7×10^{-4} (Assumption 4.1.7). The seismic event release source term is calculated below:

$$\begin{aligned}\text{Seismic event release source term} &= 132,632 \text{ FAs} \times 1.7 \times 10^5 \text{ Ci/FA} \times 1\% \times 3 \times 10^{-5} \times 7 \times 10^{-4} \\ &= 4.7 \text{ Ci}\end{aligned}$$

This calculation shows that the seismic event release source term is at least 10,000 times larger than the fire event DAW release source term. Thus the dose consequence from a fire event sequence involving DAW is bounded by the seismic event sequence and not addressed further in this calculation.

6.1.5 Interactions of Hazards and Controls

Much of the equipment used for handling and moving SNF and HLW is remotely operated. To prevent the initiation of a Category 1 or Category 2 event sequence upon a loss of power, the instrumentation and control systems for remotely operated equipment are designed to be “fail safe” so that CSNF do not experience adverse events such as a load drop, collision, etc. (BSC 2005i [DIRS 174467], Section 5.1.2.1).

Procedural safety controls are needed to prevent or mitigate certain event sequences (BSC 2005i [DIRS 174467], Tables III-2 through III-37).

The surface nuclear HVAC systems are required to mitigate potential releases of radionuclides from surface facilities during normal operations and Category 1 event sequences. These systems are required to be operable when waste handling operations are conducted in the Primary confinement areas (e.g. transfer cells and DPC cutting areas, etc.) (Assumption 4.2.11). Neither the HVAC fans nor the HEPA filters are credited to be operable following a Category 2 event sequence.

6.1.6 Potential Events Accounted for in Normal Operations Dose Estimates

The list of potential events accounted for in normal operations dose estimates are identified in *Categorization of Event Sequences for License Application* (BSC 2005i [DIRS 174467], Table 54). These potential events are accounted for in the normal operations dose estimate because they do not lead to further degradation or failure of SNF cladding. The potential event involving release of activated air and dust to the environment from subsurface facilities is discussed in Section 6.1.1.2.

6.2 INPUTS

This section discusses the input parameters used in public and worker dose calculations.

6.2.1 Public Dose Calculation Design Inputs

This section discusses input files, output files, and input parameters used in MACCS2 (ORNL 1998 [DIRS 164761]) analyses of radionuclide releases from normal operations and Category 1 and Category 2 event sequences.

6.2.1.1 MACCS2 Input Files

Seven input files are necessary to run MACCS2 (ORNL 1998 [DIRS 164761]) for event sequences. The first file, ATMOS, provides radionuclide inventory and release information. The second file, EARLY, provides information related to the early phase of the event sequence. The third file, CHRONC, provides information on the long-term chronic exposure phase. A fourth file provides hourly meteorological data, YMP1999, and a fifth file, YMPSIT or YSITE8, provides site-specific data including population data, land use data, and grid spacing information. Because neither population doses nor economic costs are calculated, the only input data used on the YMPSIT or YSITE8 file are the spatial distances that must be consistent with those in the ATMOS file. For subsurface releases the site data file is YMPSIT8 with a spatial distance interval corresponding to the 8 km distance from the subsurface releases (Section 4.1.4).

The remaining two input files, those being the dosimetry file and the food pathway file, are identified in the first five input files. The dosimetry file, current applications use YMPD825.INP, is defined in the EARLY input file YMPEA1.INP. The food pathway file, current applications use YUCCALA.BIN, is defined in the CHRONC input file YMPCH1.INP. These file names are not changed; if the dosimetry file is changed, then it is necessary to rerun the COMIDA2 module (Section 5.1) with the same dosimetry file because MACCS2 checks the two files to ensure that they are based on the same dosimetry file used in the current MACCS2 run.

MACCS2 (ORNL 1998 [DIRS 164761]) is run using a batch command file called RUNMAX2. Use of this file requires specification of additional file names that identify the files' source of input information required by MACCS2.

The command line for running the PWR base case is:

RUNMAX2 LAPWR01 YMPEA1 YMPCH1 YMP1999 YMPSIT LAPWR01

This command line directs MACCS2 (ORNL 1998 [DIRS 164761]) to read the ATMOS data set from file LAPWR01.INP, the EARLY data set from YMPEA1, the CHRONC data set from YMPCH1, the meteorology data set from YMP1999, and the site data set from file YMPSIT. The output results are written to file LAPWR01.OUT. The dosimetry file YMPD825.INP and the food pathway file YUCCALA.BIN are used as previously described.

The command line for running the HLW base case is:

RUNMAX2 LAHLW01 YMPEA YMPCH1 YMP1999 YMPSIT LAHLW01

This command line directs MACCS2 (ORNL 1998 [DIRS 164761]) to read the ATMOS data set from file YMHLW01.INP, the EARLY data set from YMPEA, the CHRONC data set from YMPCH1, the meteorology data set from YMP1999, and the site data set from file YMPSIT. The output results are written to file LAHLW01.OUT.

The command line for running the naval SNF base case is:

RUNMAX2 LANAV01 YMPEA YMPCH1 YMP1999 YMPSIT LANAV01

This command line directs MACCS2 (ORNL 1998 [DIRS 164761]) to read the ATMOS data set from file LANAV01.INP, the EARLY data set from YMPEA, the CHRONC data set from YMPCH1, the meteorology data set from YMP1999, and the site data set from file YMPSIT. The output results are written to file LANAV01.OUT.

To modify one of the base cases for a different event sequence, the following parameters are defined and entered into the ATMOS file. The new file is prepared by first copying the appropriate existing file, for example LAPWR01.INP, to a file with a representative name, such as changing the “01” to a “02” to represent a new event sequence and then editing the file to represent the new event sequence.

Five sets of ATMOS input files are prepared based on different fuel types: a maximum PWR SFA of 5 years decay, an average PWR SFA of 25 years decay, a maximum BWR SFA of 5 years decay, a HLW canister, and a naval fuel canister. These files are used to describe additional event sequences by modifying specific parameters in the input files.

The parameters likely to need modification for a new event sequence are listed in Table 13.

Each parameter listed in Table 13 is entered in the ATMOS type file using a keyword. Table 13 also provides the keyword and section in the MACCS2 user manual (ORNL 1998 [DIRS 164761]) that describe the parameter. Base case files are set up for Category 1 and Category 2 events to release the activity over a 1-hr period. For normal surface and subsurface releases, a different release period, 24 hours, is entered. When using a different value, the value for parameter PMTIMBAS is also changed to the same value. This inhibits special plume meander corrections (Assumption 4.2.15). The maximum value allowed for the release duration is 24 hour.

The values for the initial sigma-y and sigma-z values should not be changed unless the building height or width (not an input) is changed. An initial sigma-y of 10.3 m and an initial sigma-z of 12 m (Table 13) are used to approximate the FHF building (used a 25.9-m high building that is 44.5 m wide) (BSC 2005d [DIRS 172941], Table 2) and a release height of 0 m (ground level) (Assumption 4.2.12) or 30 m (see Section 4.1.6). These values are used for each MACCS2 run except for Run 3 (Section 6.3) in which no building structures are present at the subsurface exhaust shafts. An initial sigma-y of 0.1 m and an initial sigma-z of 0.1 m (Table 13) are used for MACCS2 Run 3 (Section 6.3).

If a different size building were involved, then both of the following would apply (ORNL 1998 [DIRS 164761], p. 5-21):

- The initial sigma-y value is evaluated as: building width divided by 4.3 m
- The initial value of sigma-z is evaluated as: building height divided by 2.15 m.

The lookup-table option of MACCS2 is used for interpolating sigma-y and sigma-z values based on the Tadmor-Gur parameterization scheme as discussed in the MACCS2 manual (ORNL 1998 [DIRS 164761], pp. 3-5 and 5-12). The Tadmor-Gur formulation has been shown to give results that are nearly the same for the same ranges and stability classes as other formulations. The Tadmor-Gur formulation is used in the original version of MACCS2 and used in the validation package (Tsai 2003 [DIRS 170201]).

The resuspension of material deposited on the ground from the release plume during the MACCS2 short-term “emergency” phase is determined from an initial resuspension factor, SERESCON, value of 1.0×10^{-4} appropriate for mechanical resuspension by vehicles. A weathering half-life of 2.11 days causes that resuspension factor to decay in one week to 1.0×10^{-5} , the first term for MACCS2 “long term” resuspension (ORNL 1998 [DIRS 164761], pp. C-22). For inhalation doses, the breathing rate is set to $3.33 \times 10^{-4} \text{ m}^3/\text{s}$ for all activities (NRC 2000 [DIRS 149756], p. 9-13).

Release fractions are entered on one line in the order indicated in Table 13. Release fractions are multiplied by the radionuclide inventory of one assembly or one canister to determine the total activity of each radionuclide released to the atmosphere in the event sequence. Release fractions are defined based on the core inventory, which represents the total activity in one SFA. If more than one SFA is involved in the event sequence, then the number of SFAs may be included in the definition of the release fractions; if two SFAs are involved, then the release fractions are doubled. Alternatively, dose results for one SFA may be multiplied by the total number involved in the event.

Table 13. MACCS2 Key Input Parameters

Parameter Description	Keyword	ORNL 1998 Section	Base Case Value
Release height (m)	RDPLHITE	5-26	0, 30
Building height (m)	WEBUILDH	5-22	25.9
Release duration (s)	RDPLUDUR	5-26	3600, 86400
Heat of release (watts)	RDPLHEAT	5-25	0.
Initial sigma-y value (m)	SIGYINIT	5-22	0.1, 10.3
Initial sigma-z value (m)	SIGZINIT	5-23	0.1, 12.0
Release fraction for H-3	RDRELFRC	5-28, 5-29	Table 5
Release fraction for Kr-85	RDRELFRC	5-28, 5-29	Table 5
Release fraction for Cs	RDRELFRC	5-28, 5-29	Table 5
Release fraction for Ru	RDRELFRC	5-28, 5-29	Table 5
Release fraction for Co	RDRELFRC	5-28, 5-29	Table 5
Release fraction for I	RDRELFRC	5-28, 5-29	Table 5
Release fraction for others	RDRELFRC	5-28, 5-29	Table 5
Breathing Rate (m ³ /s)	SEBRAT001	6-13	3.33×10^{-4}
Resuspension coefficient (s/m)	SERESCON	6-14, C-22	1.0×10^{-4}
Resuspension half-life (s)	SERESHAF	6-14, C-22	1.82×10^5

Sources: ORNL 1998 [DIRS 164761], Section 5, pp. 5-22, 5-23, 5-25, 5-26, 5-28, 5-29; 6-5 and C-22. Assumption 4.2.12 and Section 4.1.6.

6.2.1.1.1 MACCS2 EARLY and CHRONC Files

The MACCS2 (ORNL 1998 [DIRS 164761]) EARLY component file, YMPEA.INP, and the CHRONC component file, YMPCH1.INP, are not changed for consequence analysis. These files define the parameters for describing exposures during the early and late phases of an event sequence. The analyses are set up to eliminate evacuation so that people do not move, and to eliminate interdiction activities, such as impounding contaminated food, in the late phase, which results in an analysis that maximizes the exposure to the pathways. These files also allow the user to select the output results desired.

6.2.1.1.2 MACCS2 Meteorological Data File

Meteorology data from the Yucca Mountain site is available for the 5-year period of 1998 through 2002. The meteorological data used for χ/Q value calculations using the MACCS2 code are based on site-specific measurements made at air quality and meteorology monitoring Site 1, which is a 60-m tower located approximately 1-km south-southwest of the North Portal.

The data consists of hourly data collected under quality assurance procedures that are submitted to the Technical Data Management System under the following data tracking numbers (DTNs):

DTN: MO0306WPMM9802.000 [DIRS 164763]. Wind Direction Sector, Wind Speed, Stability Class and Precipitation Data for MACCS2 98-02 Model.

DTN: MO0304MACCS280.000 [DIRS 164766]. Wind Direction Sector, Wind Speed, Stability Class and Precipitation Data for MACCS2 98-00 Model.

DTN: MO0210MXHT8491.000 [DIRS 164768]. Mean Seasonal Mixing Height Data (0400 and 1600 PST) for Desert Rock, Nevada from 1984 through 1991.

MACCS2 (ORNL 1998 [DIRS 164761]) requires one full year of hourly observation data. Five one-full-year hourly data files, 1998 through 2002, are located in DTN: MO0306WPMM9802.00 [DIRS 164763]. The remaining two DTNs [DIRS 164766 and DIRS 164768] were used as input sources to DTN: MO0306WPMM9802.00 [DIRS 164763]. Blanks in the files, indicating data gaps, are filled by directly inserting data or adjusting the data before it is inserted, from nearby Yucca Mountain Project meteorological stations, or by directly inserting data from different time periods having similar meteorological conditions at the primary station, Site 1.

Details on data replacement are documented in the data replacement methodologies accompanying the data input files in DTNs: MO0306WPMM9802.000 [DIRS 164763] and MO0304MACCS280.000 [DIRS 164766]. Such data replacement was accomplished using professional judgement and specific knowledge of the meteorological conditions at Yucca Mountain.

The resulting meteorological data files are named:

- YMP1998.INP data for calendar year 1998
- YMP1999.INP data for calendar year 1999
- YMP2000.INP data for calendar year 2000
- YMP2001.INP data for calendar year 2001
- YMP2002.INP data for calendar year 2002.

The YMP1999.INP was selected for this calculation after a previous sensitivity analysis, “Met Data” (McDonnell 2003 [DIRS 172503]), showed that any of the five files produced similar results.

6.2.1.1.3 MACCS2 Output File

MACCS2 (ORNL 1998 [DIRS 164761]) output results are printed to the last named file on the command line; extension OUT. The first part of the file is a record of the parameter values used in the analysis and provides a record of the analysis. Results are provided as mean values and for 50th, 90th, 95th, 99th, and 99.5th percentiles. Three sets of results are provided: χ/Q values, whole body effective dose, and organ doses. Information on dose contributions from specific pathways is also contained in the output file.

A descriptive title is entered for the event sequence in the ATMOS file, near the start; keyword name RIATNAM1. The title is enclosed in single quote marks. The title appears on the output file as a check that the correct file was used in the analysis. A convention in the input files is that lines starting with an asterisk (*) are comment lines and are not read by the program. Only those lines recognized as containing data are given a number in the left column.

In the MACCS2 output file, the values of the parameter "Ground-Level Dilution, χ/Q (s/m³)" at 100 m, 8 km, or 11 km for mean values and for 50th, 90th, 95th, 99th, and 99.5th percentiles are

provided. Immediately following the χ/Q value outputs, the centerline doses at various distances away from the release point are provided for mean values and for 50th, 90th, 95th, 99th, and 99.5th percentiles. The centerline doses include the parameter "L-EFFECTIVE TOT LIF," for whole body dose excluding ingestion dose, and the parameter "L-BONE SUR TOT LIF," which is the highest TODE excluding ingestion dose. Among the internal organs, bone surface is the organ that receives the highest radiation dose for commercial SNF according to *Significant Radionuclides Determination* (BSC 2001 [DIRS 156955], p. VI-8, VI-16 and VI-24) and for HLW according to *DOE High-Level Vitrified Waste Dose Calculation* (CRWMS M&O 1999b [DIRS 105652], Attachment VII). The ingestion dose is printed on the last page of the output file under the heading "MAXIMUM ANNUAL FOOD DOSE (EFFECTIVE)."

The offsite public TEDE, at 11 km or 8 km away from the release point for normal operations is determined by summing up the mean value of the parameter "L-EFFECTIVE TOT LIF" and the ingestion dose. The TEDE at 11 km or 8 km from the release point for Category 1 and Category 2 event sequences is determined by summing up the 95th percentile value of the parameter "L-EFFECTIVE TOT LIF" and the ingestion dose. The TODE at 11 km or 8 km from the release point for Category 2 event sequences is the 95th percentile value of the parameter "L-BONE SUR TOT LIF".

The onsite public TEDE at 100 m from the release point for normal operations and Category 1 event sequences do not include ingestion dose and are calculated based on an exposure period of 2,000 hours (Assumption 4.2.13). Therefore, the annual TEDE needs to be adjusted to reflect an exposure period of 2,000 hours instead of 8,760 hours.

The onsite public TEDE, at 100 m from the release point for normal operations, is the mean value of the parameter "L-EFFECTIVE TOT LIF" in cohorts 1 and 2 those being the combined EARLY and CHRONC outputs multiplied by a factor of 0.228, which is equal to 2,000 hours divided by 8,760 hours.

The onsite public TEDE, at 100 m from the release point for Category 1 event sequences, is determined by summing up the 95th percentile value of the parameter "L-EFFECTIVE TOT LIF" in cohort 1 (the EARLY phase) and the parameter "L-EFFECTIVE TOT LIF" in cohort 2 (the CHRONC phase) multiplied by a factor of 0.228.

6.2.1.2 Source Terms

Source term input parameters are needed in the ATMOS file. Source term is defined as concentrations or inventories of radionuclides in SNFs or waste forms to be received and handled at the repository. The concentration or inventory of each radionuclide in a waste form is expressed as curies per SFA, curies per unit weight of waste form, or curies per canister. A curie is a unit quantity of any radioactive nuclide in which 3.7×10^{10} disintegrations occur per second. Source terms for waste forms to be received and handled at the repository are needed for consequence analyses. Source terms are a function of the initial fuel enrichment, fuel compound, cladding type, moderator type, and reactor operating history. Source terms are calculated using a computer program that performs a point depletion and decay calculation.

Commercial SNF—Average and maximum source terms for PWR and BWR commercial SNF are from BSC (2004f [DIRS 169061], Attachment IX) and BSC (2003a [DIRS 164364], Attachment XIII).

The SAS2H sequence in SCALE V4.4 (CRWMS M&O 2000 [DIRS 153872]) is used to calculate the PWR and BWR source terms for selected SFAs as a function of assembly average burnup and cooling time. The prime functional module of the SAS2H code sequence used is the ORIGEN-S module. This module performs a point depletion and decay calculation of a selected fuel type with user-specified irradiation conditions and decay times. The resulting source terms are then extracted from the SAS2H output and are used as input to consequence analyses. Source terms for PWR and BWR SFAs in Table 4 with four different combinations of initial enrichment, burnup, and decay time are considered in these consequence analyses and combinations are presented in Table 3.

For normal operations, average PWR SFAs are used to calculate both mean doses and 50th percentile doses using MACCS2. The calculated mean doses in the MACCS2 outputs (LASUR01.out and LASUB01.out) are used because they are higher than the calculated 50th percentile dose. For Category 1 and Category 2 event sequences, both maximum PWR SFAs and maximum BWR SFAs are used to calculate doses under 95th percentile weather conditions. Radionuclide inventories in Ci/FA for each nuclide and fuel type evaluated are presented in Table 4.

Crud (Commercial SNF)—Crud is activated corrosion products found on the exterior surface of SFAs, primarily caused by the irradiation of reactor internals and imperfect water chemistry control in a reactor coolant system. Crud can be released to the environment during an accident involving commercial SNF. After decaying for 5 years, the nuclide species that have significant activity in the crud are ⁵⁵Fe and ⁶⁰Co. Commercial SNF assemblies have initial crud activities at the time of discharge from the reactor as shown in Table 14.

Table 14. Commercial Spent Nuclear Fuel Assembly Initial Crud Activities

Radionuclide	PWR (μCi/cm ²)	BWR (μCi/cm ²)
⁶⁰ Co	140	1,254
⁵⁵ Fe	5,902	7,415

NOTE: Crud activities are bounding estimates based on analysis of measured crud activity data (BSC 2004g [DIRS 172371], Table 4).

BWR = boiling water reactor; PWR = pressurized water reactor

The crud surface activity for a given assembly is a function of time after discharge from the reactor. The time-dependent crud surface activity is based on the following radioactive decay equation (BSC 2004f [DIRS 169061], p. 27):

$$N(t) = N(0) \exp\left(\frac{-t \times \ln 2}{t_{1/2}}\right) \quad (\text{Eq. 14})$$

where,

$N(t)$	=	crud activity at time t ,
$N(0)$	=	crud activity at time 0,
$t_{1/2}$	=	radionuclide half-life in years
	=	5.271 years for ^{60}Co (Eckerman and Ryman 1993 [DIRS 107684], Table A.1), and
	=	2.73 years for ^{55}Fe (BSC 2004f [DIRS 169061], Table 6)
t	=	the decay time in years.

The crud source term, in Ci/FA released to the environment, on a per assembly basis, is calculated as:

$$ST_{crud} = SA_{crud} \times A_{SFA} \times conv \quad (\text{Eq. 15})$$

where,

ST_{crud}	=	crud source term; Ci/FA
SA_{crud}	=	crud surface activity; $\mu\text{Ci}/\text{cm}^2$
A_{SFA}	=	surface area per assembly; cm^2/FA
$conv$	=	conversion factor; $10^{-6} \text{ Ci}/\mu\text{Ci}$.

Commercial SNF fuel assemblies have the following surface areas, A_{SFA} :

- PWR = 449,003 $\text{cm}^2/\text{assembly}$ (BSC 2004f [DIRS 169061], p. 27)
- BWR = 168,148 $\text{cm}^2/\text{assembly}$ (BSC 2003a [DIRS 164364], Table 45).

These surface areas are bounding estimates based on SFAs with the highest known surface areas, which are a South Texas PWR SFA (BSC 2004f [DIRS 169061], p. 27) and an ANF 9 × 9 JP-4 BWR SFA (BSC 2003a [DIRS 164364], Table 45). The crud source term for normal operations is based on a decay time of 25 years, which is consistent with the decay time of the average PWR or BWR SFA (Table 3). The crud source term for Category 1 and Category 2 event sequences is based on a decay time of 5 years, which is consistent with the decay time of the maximum PWR or BWR SFA (Table 3). Using Equations 14 and 15, the 5-year crud and 25-year source term is given in Table 15..

Table 15. Five-year and 25-year Crud Source Terms

Radionuclide In Crud	5-year Crud Source (Ci/FA)	25-year Crud Source (Ci/FA)
^{55}Fe PWR	$7.45 \times 10^{+2}$	4.64×10^0
^{55}Fe BWR	$3.50 \times 10^{+2}$	2.18×10^0
^{60}Co PWR	$3.26 \times 10^{+1}$	2.35×10^0
^{60}Co BWR	$1.09 \times 10^{+2}$	7.87×10^0

BWR = boiling water reactor; Ci/FA = curies per fuel assembly;
PWR = pressurized water reactor.

The cobalt and iron inventories used in this calculation are comprised of two different sources. One source is from the SFA crud surface deposit. The other source is from the fuel fines that may be dispersed from the gap inventory or failed fuel rods. MACCS2 does not allow for entry of separate release fractions for the same isotope in the program RECORD, "RDRELFRACT001."

In the case of the cobalt and iron inventories, the airborne release fraction (ARF) is 1.5×10^{-2} for surface crud, but 3.0×10^{-5} for fuel fines for intact assemblies or 5.9×10^{-7} for fuel fines for intact rods (Table 5). To account for the ARF differences, an adjusted inventory is entered into MACCS2 for cobalt and iron. The fuel fines inventory is weighted by the ratio of proper fuel fines ARF, for example 3.0×10^{-5} or 5.9×10^{-7} , divided by the crud ARF, for example 1.5×10^{-2} , that will be entered in the MACCS2 RECORD, "RDRELFRACT001". The weighted fuel fine inventory is added to the crud inventory and entered as the total inventory in the MACCS2 RECORD, "RDCORINVxxx". For example: For 32.6 curies of Co-60 as crud and 5,990 curies of Co-60 as fuel fines, the Co-60 entry in RDCORINVxxx for Co-60 would be: $3.26 \times 10^{+1} \text{ Ci} + (5.99 \times 10^{+3} \text{ Ci}) (3.0 \times 10^{-5}) / (1.5 \times 10^{-2}) = 32.6 \text{ Ci} + 11.98 \text{ Ci} = 4.46 \times 10^{+1} \text{ Ci}$ of Co-60.

DOE SNF–, A drop and breach of DOE canisters or multicanister overpacks is a beyond Category 2 (BSC 2005i [DIRS 174467], Table 19) and detailed dose consequence analyses are not necessary.

Naval SNF–Some drops or collisions involving a naval canister may result in a breach of the canister but no fuel damage. These events do not correspond to any bounding Category 2 event sequences listed in Table 12, because they do not cause fuel damage. For this category of events, a release source term based on radionuclides involving only crud was developed (Gisch 2004 [DIRS 171579], p. 1). A table of radionuclides, for crud and total activity, for a representative naval SNF canister 5 years after shutdown is provided in Gisch (2004 [DIRS 171579], Table 1). The crud inventory for naval SNF is calculated using the standard naval program shielding procedure. This value was increased by a factor of 2.5 to provide a conservative crud concentration for use in developing the source term. Table 16 identifies a radionuclide release source term for Category 2 event sequences in which a naval SNF canister is breached and fuel is not damaged. The values in Table 16 are taken directly from Gisch (2004 [DIRS 171579], Table 1) and not adjusted to add additional conservatism.

A conservative damage ratio, along with the crud ARF and RF (Table 5) were applied to the naval crud inventory, using a conservative leak path factor of 1.0 (Assumption 4.2.8). The release source terms in Table 16 takes no credit for HEPA filtration, plateout, or deposition of radionuclides.

Table 16. Crud Release From a Naval Spent Nuclear Fuel Canister

Radionuclide	Activity (Ci)
^{241m} Am	2.7×10^{-6}
^{242m} Am	1.5×10^{-8}
²⁴³ Am	2.3×10^{-8}
¹⁴ C	7.8×10^{-3}
²⁴² Cm	2.1×10^{-8}
²⁴³ Cm	1.7×10^{-8}
²⁴⁴ Cm	2.3×10^{-6}
²⁴⁵ Cm	2.0×10^{-10}
²⁴⁶ Cm	7.8×10^{-11}
²⁴⁷ Cm	2.3×10^{-16}
²⁴⁸ Cm	7.4×10^{-16}
⁶⁰ Co	4.1×10^{-1}
¹³⁷ Cs	2.8×10^{-4}
⁵⁵ Fe	4.4×10^{-1}
¹²⁹ I	3.1×10^{-8}
^{93m} Nb	9.5×10^{-3}
⁹⁴ Nb	1.6×10^{-4}
⁵⁹ Ni	2.3×10^{-3}
⁶³ Ni	2.3×10^{-1}
²³⁷ Np	2.3×10^{-11}
²³⁸ Pu	1.9×10^{-6}
²³⁹ Pu	3.1×10^{-7}
²⁴⁰ Pu	2.0×10^{-7}
²⁴¹ Pu	6.1×10^{-5}
²⁴² Pu	2.3×10^{-9}
⁷⁹ Se	1.2×10^{-9}
¹²⁶ Sn	3.5×10^{-9}
⁹⁰ Sr	2.8×10^{-4}
⁹⁹ Tc	7.8×10^{-6}
²³² Th	7.4×10^{-13}
²³² U	1.1×10^{-8}
⁹³ Zr	1.6×10^{-6}

Source: Gisch 2004 [DIRS 171579], Table 1

Table 17 identifies a source term, based on radionuclide inventories involving releases from crud and fuel-bearing regions for bounding Category 2 event sequences (Table 12) that could result in a canister breach with fuel damage. These Category 2 event sequences involve slapdowns onto unyielding surfaces resulting in the highest canister strain levels and the highest potential for fuel damage, because of contact between the SFAs and the canister basket support plates.

The fuel and crud damage ratios, used to develop the source term, were conservatively selected to ensure that canister radionuclide inventories and internal hardware designs are bounded. ARFs and RFs for intact commercial SNF (Table 5) are used for Category 2 event sequences involving naval SNF. A conservative leak path factor of 1.0 was used (Assumption 4.2.8). Separate activity columns are listed: one for dose calculations for all pathways except inhalation, and one for dose calculations in the inhalation pathway. The release source term in Table 17 takes no credit for HEPA filtration, plateout, or deposition of radionuclides. For conservatism in dose analyses, only the releases from Column 2 of Table 17 are used in the MACCS2 runs, including inhalation dose analyses. Column 3 of Table 17 is not used.

Table 17. Fuel and Crud Release From a Naval Spent Nuclear Fuel Canister

Nuclide	Activity – All Pathways Except Inhalation (Ci)	Activity – Inhalation Pathway Only (Ci)
²²⁷ Ac	2.9×10^{-11}	1.5×10^{-13}
²⁴¹ Am	1.8×10^{-5}	2.8×10^{-6}
^{242m} Am	1.5×10^{-7}	1.6×10^{-8}
²⁴³ Am	2.2×10^{-7}	2.4×10^{-8}
^{137m} Ba	1.3×10^{-1}	6.4×10^{-4}
¹⁴ C	7.8×10^{-3}	7.8×10^{-3}
^{113m} Cd	1.1×10^{-5}	5.6×10^{-8}
²⁵² Cf	3.5×10^{-13}	1.7×10^{-15}
²⁴² Cm	4.5×10^{-7}	2.4×10^{-8}
²⁴³ Cm	2.5×10^{-7}	1.9×10^{-8}
²⁴⁴ Cm	2.1×10^{-5}	2.4×10^{-6}
²⁴⁵ Cm	2.3×10^{-9}	2.1×10^{-10}
²⁴⁶ Cm	4.8×10^{-10}	8.0×10^{-11}
²⁴⁷ Cm	3.0×10^{-15}	2.5×10^{-16}
²⁴⁸ Cm	8.5×10^{-15}	7.8×10^{-16}
⁶⁰ Co	4.1×10^{-1}	4.1×10^{-1}
¹³⁴ Cs	1.7×10^{-1}	1.7×10^{-1}
¹³⁵ Cs	9.3×10^{-6}	9.3×10^{-6}
¹³⁷ Cs	9.0×10^{-1}	9.0×10^{-1}
¹⁵⁴ Eu	3.4×10^{-3}	1.7×10^{-5}
¹⁵⁵ Eu	5.6×10^{-4}	2.8×10^{-6}
⁵⁵ Fe	4.4×10^{-1}	4.4×10^{-1}
³ H	4.2×10^0	4.2×10^0
¹²⁹ I	3.7×10^{-4}	3.7×10^{-4}
⁸⁵ Kr	$1.1 \times 10^{+2}$	$1.1 \times 10^{+2}$
^{93m} Nb	9.5×10^{-3}	9.5×10^{-3}
⁹⁴ Nb	2.1×10^{-4}	1.6×10^{-4}
⁵⁹ Ni	2.3×10^{-3}	2.3×10^{-3}
⁶³ Ni	2.3×10^{-1}	2.3×10^{-1}

Table 17. Fuel and Crud Release From a Naval Spent Nuclear Fuel Canister (Continued)

Nuclide	Activity – All Pathways Except Inhalation (Ci)	Activity – Inhalation Pathway Only (Ci)
²³⁷ Np	4.7×10^{-7}	2.4×10^{-9}
²³¹ Pa	1.5×10^{-10}	7.7×10^{-13}
²¹⁰ Pb	2.7×10^{-13}	1.3×10^{-15}
¹⁰⁷ Pd	1.8×10^{-8}	9.0×10^{-11}
¹⁴⁷ Pm	4.8×10^{-2}	2.4×10^{-4}
²³⁸ Pu	3.5×10^{-3}	1.9×10^{-5}
²³⁹ Pu	3.9×10^{-6}	3.3×10^{-7}
²⁴⁰ Pu	4.2×10^{-6}	2.2×10^{-7}
²⁴¹ Pu	1.3×10^{-3}	6.7×10^{-5}
²⁴² Pu	2.6×10^{-8}	2.5×10^{-9}
²²⁶ Ra	1.6×10^{-12}	8.2×10^{-15}
²²⁸ Ra	1.5×10^{-16}	7.5×10^{-19}
¹⁰² Rh	8.3×10^{-9}	4.2×10^{-11}
¹⁰⁶ Ru	1.2×10^{-2}	1.2×10^{-2}
¹²⁵ Sb	9.8×10^{-4}	4.9×10^{-6}
⁷⁹ Se	1.0×10^{-7}	1.7×10^{-9}
¹⁴⁷ Sm	9.6×10^{-12}	4.8×10^{-14}
¹⁵¹ Sm	4.3×10^{-4}	2.1×10^{-6}
¹²⁶ Sn	3.6×10^{-7}	5.3×10^{-9}
⁹⁰ Sr	1.3×10^{-1}	9.4×10^{-4}
⁹⁹ Tc	2.9×10^{-5}	7.9×10^{-6}
²²⁹ Th	2.7×10^{-12}	1.3×10^{-14}
²³⁰ Th	5.5×10^{-10}	2.7×10^{-12}
²³² Th	7.4×10^{-13}	7.4×10^{-13}
²³² U	1.8×10^{-7}	1.2×10^{-8}
²³³ U	7.1×10^{-10}	3.6×10^{-12}
²³⁴ U	4.5×10^{-6}	2.2×10^{-8}
²³⁵ U	8.6×10^{-8}	4.3×10^{-10}
²³⁶ U	7.5×10^{-7}	3.7×10^{-9}
²³⁸ U	3.6×10^{-10}	1.8×10^{-12}
⁹⁰ Y	1.3×10^{-1}	6.7×10^{-4}
⁹³ Zr	3.8×10^{-6}	1.6×10^{-6}

Source: Gisch 2004 [DIRS 171579], Table 2

Vitrified HLW—Vitrified HLW forms from the Savannah River Site, Hanford Site, West Valley, and Idaho National Laboratory are received at the repository in sealed canisters inside transportation casks. The per canister source terms for vitrified HLW from the four sites are provided in Table 18.

The per canister source term for vitrified HLW shipped from Savannah River Site (Table 18) is from Fowler (2003 [DIRS 164361], Table 2, column 3); this source term is the projected maximum radionuclide inventory per canister based on waste tank sludge batches collected as of March 17, 2003.

Table 18. Radionuclide Inventory Per Vitrified High-level Radioactive Waste Canister

Nuclide	SRS (Ci) ^a	Hanford (Ci) ^b	West Valley (Ci) ^c	INL (Ci) ^d
²⁴¹ Am	$2.28 \times 10^{+2}$	$4.65 \times 10^{+2}$	$5.07 \times 10^{+2}$	2.61×10^0
^{242m} Am	1.30×10^{-1}	-	2.74×10^0	-
²⁴³ Am	3.68×10^{-1}	9.99×10^{-2}	3.28×10^0	-
^{137m} Ba ^e	$6.24 \times 10^{+4}$	$6.62 \times 10^{+4}$	$3.00 \times 10^{+4}$	$1.40 \times 10^{+4}$
¹⁴ C	-	1.06×10^{-7}	1.30×10^0	-
^{113m} Cd	-	$2.69 \times 10^{+1}$	-	-
¹⁴⁴ Ce	1.80×10^0	-	-	$1.23 \times 10^{+2}$
²⁴² Cm	-	3.46×10^{-1}	-	-
²⁴³ Cm	4.14×10^{-1}	4.42×10^{-2}	-	-
²⁴⁴ Cm	$1.86 \times 10^{+3}$	4.27×10^{-1}	$5.75 \times 10^{+1}$	5.48×10^{-1}
²⁴⁵ Cm	1.49×10^{-1}	-	-	-
²⁴⁶ Cm	4.34×10^{-2}	-	-	-
⁶⁰ Co	$7.15 \times 10^{+2}$	1.04×10^0	-	-
¹³⁴ Cs	$2.40 \times 10^{+2}$	$2.23 \times 10^{+2}$	-	$7.85 \times 10^{+2}$
¹³⁵ Cs	2.62×10^{-1}	-	1.09×10^0	-
¹³⁷ Cs	$6.67 \times 10^{+4}$	$7.00 \times 10^{+4}$	$3.17 \times 10^{+4}$	$1.48 \times 10^{+4}$
¹⁵² Eu	-	4.96×10^0	-	-
¹⁵⁴ Eu	$1.68 \times 10^{+3}$	7.92×10^0	-	$1.54 \times 10^{+2}$
¹⁵⁵ Eu	6.70×10^{-1}	$3.28 \times 10^{+2}$	-	-
¹²⁹ I	7.35×10^{-5}	-	-	-
^{93m} Nb	1.47×10^{-1}	2.44×10^0	1.96×10^0	-
⁵⁹ Ni	2.16×10^{-1}	4.96×10^{-1}	1.00×10^0	-
⁶³ Ni	$1.41 \times 10^{+1}$	$5.13 \times 10^{+1}$	$7.74 \times 10^{+1}$	-
²³⁷ Np	3.39×10^{-2}	2.50×10^{-1}	1.50×10^{-1}	-
²³¹ Pa	-	4.24×10^{-4}	1.44×10^{-1}	-
¹⁴⁷ Pm	$4.86 \times 10^{+3}$	-	-	$4.09 \times 10^{+3}$
²³⁸ Pu	$5.93 \times 10^{+3}$	2.29×10^0	$3.92 \times 10^{+1}$	$8.60 \times 10^{+1}$
²³⁹ Pu	$4.90 \times 10^{+1}$	$2.13 \times 10^{+1}$	8.75×10^0	8.92×10^{-1}
²⁴⁰ Pu	$3.34 \times 10^{+1}$	6.42×10^0	6.28×10^0	8.27×10^{-1}
²⁴¹ Pu	$3.49 \times 10^{+3}$	$1.22 \times 10^{+2}$	$3.11 \times 10^{+2}$	$1.61 \times 10^{+2}$
²⁴² Pu	1.11×10^{-1}	9.91×10^{-4}	8.15×10^{-3}	-
¹⁰⁶ Ru	4.70×10^0	1.61×10^{-2}	-	$4.07 \times 10^{+1}$
¹²⁵ Sb	-	$1.87 \times 10^{+1}$	-	-
⁷⁹ Se	5.91×10^{-2}	9.15×10^{-2}	5.70×10^{-1}	-
¹⁵¹ Sm	$1.22 \times 10^{+2}$	$3.62 \times 10^{+3}$	$7.63 \times 10^{+2}$	-
¹²⁶ Sn	3.09×10^{-2}	5.74×10^{-1}	9.85×10^{-1}	-
⁹⁰ Sr	$7.62 \times 10^{+4}$	$7.38 \times 10^{+4}$	$2.80 \times 10^{+4}$	$1.52 \times 10^{+4}$
⁹⁹ Tc	$1.56 \times 10^{+1}$	$2.31 \times 10^{+1}$	8.72×10^0	-
²³² U	3.68×10^{-4}	4.72×10^{-4}	-	-
²³³ U	2.75×10^{-2}	2.09×10^{-3}	9.03×10^{-2}	-
²³⁴ U	8.10×10^{-2}	1.46×10^{-2}	2.40×10^{-2}	-
²³⁵ U	6.00×10^{-4}	5.56×10^{-4}	-	-
²³⁶ U	7.54×10^{-3}	1.18×10^{-3}	-	-

Table 18. Radionuclide Inventory Per Vitrified High-level Radioactive Waste Canister (Continued)

Nuclide	SRS (Ci) ^a	Hanford (Ci) ^b	West Valley (Ci) ^c	INL (Ci) ^d
²³⁸ U	5.17×10^{-2}	1.01×10^{-2}	-	-
⁹⁰ Y	$7.62 \times 10^{+4}$	$7.38 \times 10^{+4}$	$2.80 \times 10^{+4}$	$1.52 \times 10^{+4}$
⁹³ Zr	1.88×10^{-1}	5.76×10^0	2.58×10^0	-

NOTES: ^a Fowler 2003 [DIRS 164361], Table 2, column 3

^b DOE 2004c [DIRS 172092], Table 5, column 4

^c WVNS 2001 [DIRS 157559], Table 5, column 4 (high estimate case for 1996)

^d CRWMS M&O 1999b [DIRS 105652], p. III-1

^e Ba-137m = $0.946 \times$ Cs-137 (Eckerman and Ryman 1993 [DIRS 107684], p. 203).

INL = Idaho National Laboratory; SRS = Savannah River Site.

The per canister source term for vitrified HLW shipped from the Hanford Site (Table 18) is from *Waste Treatment and Immobilization Plant (WTP) High-Level Waste (HLW) Canister Production Estimates to Support Analyses by the Yucca Mountain Project* (DOE 2004c [DIRS 172092], Table 5, column 4); this source term is the estimated bounding radionuclide inventory per canister based on HLW canisters produced from the 241-AZ-101 waste tank decayed to January 1, 2010. Among the waste tanks in the Hanford tank farm, the 241-AZ-101 waste tank has been determined to be the waste tank that will contain the maximum concentration of radionuclides for the Hanford HLW canisters (DOE 2004c [DIRS 172092], p. 6).

The per canister source term for vitrified HLW (Table 18), shipped from West Valley, is the estimated highest radionuclide inventory per canister, based on a 100% fill canister with radionuclides decayed to the year 1996, from *WVDP Waste Form Qualification Report - Canistered Waste Form Specifications, Chemical Specification*, Chapter 1 of *Waste Form Qualification Report (WQR)* (WVNS 2001 [DIRS 157559], Table 5, column 4).

The per canister source term for vitrified HLW shipped from Idaho National Laboratory (Table 18) is from CRWMS M&O 1999b ([DIRS 105652], p. III-1). Dose calculations show that Savannah River Site HLW has the highest dose consequence of HLW from the four DOE sites, those being Hanford, Idaho National Laboratory, Savannah River Site, and West Valley (CRWMS M&O 1999b [DIRS 105652], p. III-1).

6.2.1.3 Release Fractions

Radionuclide release fractions are needed in the ATMOS file. The Category 1 and Category 2 event sequence total release fraction is defined as the fraction of total inventory of a given radionuclide that is released to the environment from a commercial SNF element following an event sequence; for example, drop of a fuel element. The release fraction for commercial SNF is primarily a measure of the inventory of fuel particulates, gases, and volatile species present in a breached fuel element.

The source term released from Category 1 and Category 2 event sequences are a function of the MAR, DR, ARF, RF, (LPF)_{cask}, (LPF)_{fac}, and (LPF)_{HEPA}:

Release Source Term $ST_j = MAR_j \times DR \times ARF \times RF \times (LPF)_{cask} \times (LPF)_{fac} \times (LPF)_{HEPA}$ (Eq. 16)

The MAR_j is the material at risk for radionuclide j . The DR is the damage ratio or the fraction of fuel rods that are assumed to fail by cladding breach during an event sequence. The ARF is the fraction of the total radionuclide inventory in damaged fuel rods that is released from breached cladding and is suspended in air as an aerosol following an event sequence. The RF can be transported through air, inhaled into the human respiratory system, and contribute to the inhalation dose.

The $(LPF)_{cask}$ is the fraction of the ARF that reaches the ventilation system after local deposition from plate-out and gravitational settling inside a cask. The $(LPF)_{fac}$ is the fraction of the ARF that reaches the ventilation system after local deposition from plate-out and gravitational settling inside a facility. The $(LPF)_{HEPA}$ is the fraction of radionuclides that is released to the environment after passing through the HEPA filters in a surface nuclear ventilation system.

For Category 1 and Category 2 event sequences, the DR is assumed to be 1.0 for commercial SNF and for HLW in a canister (Assumption 4.2.7). For Category 2 event sequences, the $(LPF)_{cask}$ is assumed to be 0.1 for SNF in a transportation cask and 0.01 for HLW in a canister in a transportation cask (Assumption 4.2.8). For normal operations and Category 1 event sequences, the $(LPF)_{fac}$ is assumed to be 1.0 (i.e., no plate-out is assumed) for a waste transfer cell (Assumption 4.2.9).

Commercial SNF Release Fractions—For commercial SNF releases in air, ARF and RF parameters for Category 1 and Category 2 dose assessments are shown in Table 5.

An intact commercial SNF assembly has intact cladding and structural integrity before a Category 1 or Category 2 event occurs. There are four types of canistered commercial SNF with a loss of its original assembly structure, with damaged cladding, or with both, as follows (BSC 2003c [DIRS 165990], pp. G-1 and G-2):

- Type 1: Mechanically and cladding-penetration damaged commercial SNF
- Type 2: Consolidated or reconstituted SFAs, or both
- Type 3: Fuel rods, pieces, and debris
- Type 4: Non-fuel components.

Type 3 is further divided into (3a) fuel rods with intact cladding and (3b) other fuel rods, pieces, and debris.

Type 1 and Type 3b contain commercial SNF that are classified as failed commercial SNF by waste generators. Known or suspected failed fuel is segregated from intact fuel at nuclear power plants. Failed SFAs and fuel debris are placed into either unsealed screen-end canisters or sealed solid-end canisters (BSC 2003c [DIRS 165990], p. G-2). In Table 5, the ARF and RF values for Type 3a (fuel rods with intact cladding) are presented because these values bound the ARF and RF values for fuel types 1, 2, 3b, and 4 (BSC 2004g [DIRS 172371], Table 11).

The $ARFs$ and RFs for intact commercial SNF assemblies shown in Table 5 are used for normal operations and Category 1 event sequences. The $ARFs$ and RFs for Type 3a (fuel rods with

intact cladding) are used for Category 2 event sequences because the combined $ARF \times RF$ values for Type 3a are larger or equal to the values for intact commercial SNF assemblies. Because drops or collisions of Type 3a in transportation casks and waste packages are assumed to be Category 2 event sequences (Assumption 4.2.6), the ARFs and RFs for Type 3a are not applicable to normal operations and Category 1 event sequences.

Damaged commercial SNF in damaged fuel cans are shipped to the repository inside a transportation cask as stated in Interim Safety Guide-1 (NRC 2002 [DIRS 164018]). Interim Safety Guide-1 allows utilities to ship fuel with pinhole leaks or hairline cracks as intact fuel (NRC 2002 [DIRS 164018]). Intact fuel, damaged fuel in canisters, and fuel with pinhole leaks or hairline cracks will be transferred, from a transportation cask to a waste package, inside a waste transfer cell during normal operations in a DTF or the FHF.

For the purposes of calculating normal operation doses, 1% of the total fuel rods received at the repository have developed cladding failures with pinhole or hairline crack or larger (Assumption 4.1.3).

HLW Release Fractions—The formation of particulates from an impact breach of a HLW canister is based on ANSI/ANS-5.10-1998, *Airborne Release Fractions at Non-Reactor Nuclear Facilities*, p. 15 [DIRS 103755]. The results are based on empirical measurements of impact tests on UO_2 , ceramic, and glass-simulated waste forms. Small-scale laboratory tests establish each correlation for the percentage of respirable size release fractions created during impacts.

This method uses the available results to develop a method to estimate the ARFs of HLW canister glass that could be released as airborne particulates. Based on these methods, the release fraction of respirable airborne particulates or the release fraction pulverized into respirable sizes ($< 10 \mu m$) from a drop event (PULF) formed following an impact is estimated as:

$$PULF = 2 \times 10^{-4} \text{ cm}^3/\text{joule} * E/V \quad (\text{Eq. 17})$$

where,

PULF	=	release fraction pulverized into respirable sizes ($< 10 \mu m$) from a drop event (units = dimensionless)
E/V	=	impact energy density in impacted HLW
	=	$1.0 \times 10^{-7} \text{ joule-s}^2/\text{g-cm}^2 * \rho * g * h$ (CRWMS M&O 1999b [DIRS 105652], Attachment V)
ρ	=	density of the HLW dropped
	=	2.75 g/cm^3 (CRWMS M&O 1999b [DIRS 105652], Section 5.2.5)
g	=	gravitational constant
	=	980.7 cm/s^2 (CRWMS M&O 1999b [DIRS 105652]; Attachment V)
h	=	drop height in cm.

PULF for HLW Canister Drop

From Equation 17:

$$\text{PULF} = \frac{2 \times 10^{-4} \text{ cm}^3/\text{joule} * 1.0 \times 10^{-7} \text{ joule-s}^2/\text{g-cm}^2 * 2.75 \text{ g/cm}^3 * 980.7 \text{ cm/s}^2}{(\text{drop height}) \text{ cm}}$$

Calculated PULF for selected drop heights (CRWMS M&O 1999b [DIRS 105652]; Attachment V) are:

<u>Drop Height</u>	<u>PULF</u>
80 in. (203 cm)	1.10×10^{-5}
264 in. (671 cm)	3.62×10^{-5}
330 in. (838 cm)	4.52×10^{-5}
448 in. (1138 cm)	6.14×10^{-5}

The drop height of 448 in. (1138 cm) represents the worst case with a PULF of 6.14×10^{-5} , which is used in the public dose calculations for HLW canisters because it bounds the other values. It is assumed that the canister handling system is designed so that a drop of an HLW canister, inside a surface facility, will not exceed a drop height of 276 in. (710 cm) (BSC 2005i [DIRS 174467], Section 5.1.1.52) and, therefore, the use of a 448-in. (1138 cm) drop height is conservative.

Naval SNF Release Fractions—ARFs and RFs used for Category 2 event sequences involving naval SNF are presented in Section 6.2.1.2.

HEPA Filter Leak Path Factor—The HEPA filter (LPF)_{HEPA} refers to the removal of particulates provided by HEPA filters present in the surface facility ventilation system. For normal operations and Category 1 event sequences, a two-stage HEPA filtration system with a particulate removal efficiency of 99% per stage, meaning a HEPA LPF of 0.01 per stage, is used (see Assumption 4.1.1), for a combined efficiency of 99.99% for two stages; a HEPA LPF of 10^{-4} .

The HVAC system removes particulates and cesium in air through two stages of HEPA filters in series, which are protected by prefilters, sprinklers, and demisters (Assumption 4.1.1).

No credit is taken for HEPA filters in mitigating radiological consequences from Category 2 event sequences. Credit is taken for HEPA filters in mitigating radiological consequences from normal operations and Category 1 event sequences (Assumption 4.2.2).

6.2.1.4 Dose Conversion Factors

DCFs for inhalation, cloudshine, groundshine, and ingestion pathways are generated by the FGRDCF module in MACCS2 (ORNL 1998 [DIRS 164761]).

The output filename generated by the FGRDCF module is *YMPD825.INP* (Attachment C, Table C-1). This file is called by the EARLY file and the CHRONC file during MACCS2 (ORNL 1998 [DIRS 164761]) execution. The *YMPD825.INP* file contains DCF data from Federal

Guidance Reports Nos. 11 (Eckerman et al. 1988 [DIRS 101069]) and 12 (Eckerman and Ryman 1993 [DIRS 107684]) for inhalation, cloudshine, groundshine, and ingestion pathways, in accordance with NUREG-1804 (NRC 2003b [DIRS 163274], Section 2.1.1.5).

DCFs for inhalation are dependent on the chemical form of the radionuclide, which is represented by the lung clearance class of D = daily, W = weekly, Y = yearly, and the fractional uptake from the small intestine to blood (f_l). Some nuclides have only one lung clearance class, for example, ³H, whereas others have multiple lung clearance classes, for example, ²³⁹Pu.

Inhalation DCFs used by *YMPD825.INP* are from Federal Guidance Report No. 11 (Eckerman et al. 1988 [DIRS 101069], Table 2.1). The air submersion DCFs for gonads, breast, lungs, red marrow, bone surface, thyroid, remainder, effective-whole body, and skin used by *YMPD825.INP* are from Federal Guidance Report No. 12 (Eckerman and Ryman 1993 [DIRS 107684], Table III.1). The remainder is a weighted combination of five remaining organs or tissues receiving the highest doses, such as the liver, kidneys, spleen, brain, small intestine, upper large intestine, lower large intestine, or other organs, excluding the skin, lens of the eye, and extremities (Eckerman et al. 1988 [DIRS 101069], p. 6).

6.2.1.5 General Public Location of Potentially Exposed Individual

6.2.1.5.1 Offsite Locations

For this dose evaluation, the maximally exposed individual is defined as an individual located at a distance that corresponds to the approximate distance between the surface facility or the subsurface repository and the nearest point of public access on the repository site boundary, which lies to the west (Assumption 4.1.4).

A site boundary distance of 11 km (Attachment B, Figure B-1) is used to calculate χ/Q values from radiological releases from the surface facility. This distance corresponds to the approximate distance from the surface waste handling facilities to the nearest point on the site boundary that is the closest point where any member of the public could be standing, or living, at the time of a postulated radiological release (Assumption 4.1.4).

A site boundary distance of 8 km (Attachment B, Figure B-1) is used to calculate χ/Q values from radiological releases from the subsurface repository exhaust shafts. This distance corresponds to the approximate distance between the subsurface repository emplacement exhaust shafts and the nearest point of public access on the site boundary, which lies to the west (Assumption 4.1.4).

The maximally exposed individual at the site boundary of 11 km is assumed to receive doses from the inhalation, resuspension inhalation, air submersion, groundshine, and ingestion pathways for a period of 8,760 hours (Assumption 4.2.13). This individual is present at the site boundary and exposed to ground contamination and intake of contaminated food for 1 year (Assumption 4.2.4).

6.2.1.5.2 Onsite Locations

Attachment B (Figures B-1 and B-2) is an illustration of the locations of the site boundaries, restricted areas, and preclosure dose limits. Doses to members of public onsite were calculated using MACCS2 at various distances from the release points.

1) During Surface Facility Construction

Per Assumption 4.1.5, during construction of surface facilities, the locations of potentially exposed individual members of the public onsite are at construction worker locations adjacent to facilities already in operation. Doses from airborne releases and direct radiations are evaluated at each construction location based on their relative locations to operating facilities. Potential construction worker locations are listed in Table 5a of BSC 2005c [DIRS 172488] and shown on Figure 1 of BSC 2005c [DIRS 172488].

2) After Surface Facility Construction

Per Assumption 4.1.8, potentially exposed onsite individual members of the public are assumed to be located outside the restricted area and within the site boundary at a distance that corresponds to the approximate distance between the surface facility or the subsurface repository and the nearest point on the restricted area boundary. For surface facility releases that distance is assumed to be 100 m. For subsurface releases that distance assumed to be 100 m for restricted areas surrounding the subsurface exhaust vents and 3 km for the restricted area surrounding the surface facilities. The restricted area boundaries are shown in Figure B-1.

The dose to members of the public at 3 km from subsurface facility releases is used in dose aggregation with the dose to members of the public at 100 m from surface facility releases in Section 6.3.2. The onsite individual member of the public, at 100 m away from a DTF, the FHF, or 3 km away a subsurface exhaust shaft, is assumed to receive doses from inhalation, resuspension inhalation, air submersion, and groundshine pathways for a period of 2,000 hour (Assumption 4.2.13).

6.2.1.6 Food Consumption and Production Rates

The consequence analysis using MACCS2 (ORNL 1998 [DIRS 164761]) requires that any farmland used in the 50-mi radius from the point of a radioactive release be defined. Annual consumption rates of foods are from a 1997 regional survey of the population in the vicinity of Amargosa Valley, as described in *Characteristics of the Receptor for the Biosphere Model* (BSC 2005g [DIRS 172827], Section 7).

This analysis is conducted using the 1997 survey of food consumption rates for each food type, as shown in Table 19. These values are entered into input files for the COMIDA2 module.

The COMIDA2 module uses the food consumption rates in Table 19 to generate the food pathway factor data file *YUCCALA.BIN*. This file provides the best estimates of the individual dose from food and the total population dose from foods. The food pathway file name is specified in the CHRONC input file by keyword BIN_FILE.

Table 19. Food Consumption Rates Used as Input to COMIDA2

Food Product	Intake (kg/year)	COMIDA2 Category
Cereal and Bread	0.23	Grains
Eggs; eggs and fish	5.53	Other
Fruit	12.68	Fruits
Leafy Vegetables	3.78	Leafy vegetables
Meat; beef, pork and wild game	2.85	Beef
Milk	4.66	Milk
Other Vegetables	4.73	50% split to Roots and Legumes
Poultry	0.42	Poultry

Source: BSC 2005g [DIRS 172827], Table 7-5

6.2.2 Worker Dose Calculation Design Inputs

This section discusses input parameters used in worker dose calculations for normal operations and Category 1 event sequences.

The source terms, release fractions, and DCFs used as input to worker dose calculations are the same as those used in public dose calculations (Sections 6.2.1.2 to 6.2.1.4).

Other input parameters, such as surface and subsurface facility dimensions, and locations, such as receptors, exhaust stacks, and exhaust shafts, are discussed in the worker dose calculation BSC 2005c [DIRS 172488] and its references.

6.2.3 Regulations

Regulation 10 CFR 63.111(a) [DIRS 173273] states that the repository operations area must meet the requirements of 10 CFR Part 20 [DIRS 173165], and that the annual TEDE resulting from normal operations and Category 1 event sequences to any real member of the public located beyond the site boundary must meet the preclosure standard specified in 10 CFR 63.204.

The regulations specify: (1) dose limits for workers and members of the public during normal operations and for Category 1 event sequences, which are summarized in Table 1, and (2) public dose limits for Category 2 event sequences, which are summarized in Table 2. In Table 1 and Table 2, the dose receptors are divided into three groups, namely, workers, onsite members of the public, and offsite members of the public. For dose compliance purposes, the people who work or visit at the Yucca Mountain site or work near the site are assigned to one of these three groups. The preclosure dose limits for workers in the restricted area; onsite members of the public in the preclosure controlled area, and offsite members of the public in the unrestricted area are shown in Attachment B (Figures B-1 and B-2).

6.3 PUBLIC DOSE RESULTS

This section discusses the results of MACCS2 (ORNL 1998 [DIRS 164761]) calculations of doses to members of the public from airborne radionuclides as a result of normal operations and Category 1 and Category 2 event sequences.

Twelve base cases (Table 20, Runs 1, 3 to 12 and 18) and five sensitivity cases (Table 20, Runs 13 to 17) are run using MACCS2 (ORNL 1998 [DIRS 164761]) for normal operations, and for Category 1 and Category 2 event sequences involving PWR and BWR SFAs, HLW, and naval SNF. The output file names from the 12 principal runs with five sensitivity runs are listed in Table 20.

Table 20. MACCS2 Computer Runs

Run No.	ATMOS File	Output File	Remarks
1	LASUR01.INP	LASUR01.OUT	Surface releases from 1% of an annual throughput of 3,600 MTHM, average PWR inventory with HEPA filters, elevated release, 30 m vent height
2			Not used.
3	LASUB01.INP	LASUB01.OUT	Subsurface releases from waste package surface contamination, neutron-activated air and dust without HEPA filters, ground-level release
4	LAPWR01.INP	LAPWR01.OUT	1 assembly, maximum PWR inventory with HEPA filters, ground-level release
5	LAPWR02.INP	LAPWR02.OUT	1 assembly, maximum PWR inventory without HEPA filters, ground-level release, cask leak path factor
6	LABWR01.INP	LABWR01.OUT	1 assembly, maximum BWR inventory with HEPA filters, ground-level release
7	LABWR02.INP	LABWR02.OUT	1 assembly, maximum BWR inventory without HEPA filters, ground-level release, cask leak path factor
8	LAHLW01.INP	LAHLW01.OUT	1 SRS HLW canister inventory without HEPA filters, ground-level release
9	LAHLW02.INP	LAHLW02.OUT	1 Hanford Site HLW canister inventory without HEPA filters, ground-level release
10	LAHLW03.INP	LAHLW03.OUT	1 West Valley HLW canister inventory without HEPA filters, ground-level release
11	LAHLW04.INP	LAHLW04.OUT	1 INL HLW canister inventory without HEPA filters, ground-level release
12	LANAV01.INP	LANAV01.OUT	1 naval SNF canister inventory without HEPA filters, ground-level release
13	LASEN01.INP	LASEN01.OUT	Sensitivity analysis of Run 1: surface releases from 1% of an annual throughput of 3,600 MTHM, average PWR inventory with HEPA filters, elevated release. The release duration is changed from 24 hour to 1 hour
14	LASEN02.INP	LASEN02.OUT	Sensitivity analysis of Run 4: 1 assembly, maximum PWR inventory with HEPA filters, ground-level release. The deposition velocity is changed from 0.01 m/s to 0.001 m/s
15	LASEN03.INP	LASEN03.OUT	Sensitivity analysis of Run 4: 1 assembly, average PWR inventory with HEPA filters, ground-level release.
16	LASEN04.INP	LASEN04.OUT	Sensitivity analysis of Run 4: 1 assembly, maximum PWR inventory without HEPA filters, ground-level release.
17	LASEN05.INP	LASEN05.OUT	Surface releases from 1% of an annual throughput of 3,600 MTHM, average PWR inventory with HEPA filters, elevated release, 40 m vent height
18	LAHEPA01.INP	LAHEPA01.OUT	Seismic event release of accumulated normal releases from 63,000 MTHM average PWR inventory, without HEPA filters, ground-level release, no leak path factor

BWR = boiling water reactor; HEPA = high-efficiency particulate air; HLW = high-level radioactive waste; INL = Idaho National Laboratory; PWR = pressurized water reactor; SNF = spent nuclear fuel; SRS = Savannah River Site.

The ATMOS file in MACCS2 (ORNL 1998 [DIRS 164761]) provides the radiological inventory, defines the radial distances of 16 sector wind rose, establishes the dry or wet deposition factors, provides the release fractions for the predefined isotopic groups, and integrates the site-specific weather data with a selected frequency distribution. Only the ATMOS file is changed when a different case is run. The input parameters used in ATMOS, EARLY, and CHRONC output files for each of the seventeen cases are given in Attachment C.

Normal operations dose results are selected from the MACCS2 (ORNL 1998 [DIRS 164761]) output files (LASUR01.OUT and LASUB01.OUT) as the higher of the mean and 50th percentile probability level doses.

Category 1 and Category 2 event sequence dose results are from the MACCS2 (ORNL 1998 [DIRS 164761]) output file at the 95th percentile probability level. Calculated doses are converted from Sv to mrem using a conversion factor of 1 Sv equal to 1.0×10^5 mrem. The majority of the dose is received during the initial plume passage.

Public dose includes contributions from inhalation and cloudshine during plume passage plus resuspension inhalation, ingestion, and groundshine pathways during the long-term exposure period.

Values of DR, ARF, RF, (LPF)_{cask}, and (LPF)_{fac} used in these MACCS2 (ORNL 1998 [DIRS 164761]) computer runs are summarized in Table 21.

Table 21. Values of DR, ARF, RF, (LPF)_{cask}, (LPF)_{fac}, and (LPF)_{HEPA} Used in MACCS2

Run No.	DR	ARF	RF	(LPF) _{cask}	(LPF) _{fac}	(LPF) _{HEPA}
1	0.01 ^a	0.3 (t) 0.3 (g) 2.0×10^{-4} (c) 3.0×10^{-5} (p) 1.5×10^{-2} (crud) ^b	1.0	1.0	1.0	1.0(t) 1.0(g) 1.0×10^{-4} (c) 1.0×10^{-4} (p) 1.0×10^{-4} (crud)
2 Not used						
3	1.0	1.0	1.0	1.0	1.0	1.0
4	1.0	0.3(t) 0.3 (g) 2.0×10^{-4} (c) 3.0×10^{-5} (p) 1.5×10^{-2} (crud) ^b	1.0	1.0	1.0	1.0(t) 1.0(g) 1.0×10^{-4} (c) 1.0×10^{-4} (p) 1.0×10^{-4} (crud)
5	1.0	0.3(t) 0.3 (g) 2.0×10^{-4} (c) 5.9×10^{-7} (p) 1.5×10^{-2} (crud) ^b	1.0	1.0(t) 1.0 (g) 0.1 (c) 0.1 (p) 0.1 (crud)	1.0	1.0
6	1.0	0.3(t) 0.3(g) 2.0×10^{-4} (c) 3.0×10^{-5} (p) 1.5×10^{-2} (crud) ^b	1.0	1.0	1.0	1.0(t) 1.0(g) 1.0×10^{-4} (c) 1.0×10^{-4} (p) 1.0×10^{-4} (crud)
7	1.0	0.3(t) 0.3 (g) 2.0×10^{-4} (c) 5.9×10^{-7} (p) 1.5×10^{-2} (crud) ^b	1.0	1.0(t) 1.0 (g) 0.1 (c) 0.1 (p) 0.1 (crud)	1.0	1.0
8	1.0	6.14×10^{-5}	1.0	0.01	1.0	1.0
9	1.0	6.14×10^{-5}	1.0	0.01	1.0	1.0

Table 21. Values of DR, ARF, RF, (LPF)_{cask}, (LPF)_{fac}, and (LPF)_{HEPA} Used in MACCS2 (Continued)

Run No.	DR	ARF	RF	(LPF) _{cask}	(LPF) _{fac}	(LPF) _{HEPA}
10	1.0	6.14×10^{-5}	1.0	0.01	1.0	1.0
11	1.0	6.14×10^{-5}	1.0	0.01	1.0	1.0
12	Footnote c	0.3 (t) 0.3 (g) 2.0×10^{-4} (c) 3.0×10^{-5} (p) 1.5×10^{-2} (crud) ^b	Footnote d	1.0	1.0	1.0
13	0.01 ^a	0.3(t) 0.3 (g) 2.0×10^{-4} (c) 3.0×10^{-5} (p) 1.5×10^{-2} (crud) ^b	1.0	1.0	1.0	1.0(t) 1.0(g) 1.0×10^{-4} (c) 1.0×10^{-4} (p) 1.0×10^{-4} (crud)
14	1.0	0.3(t) 0.3 (g) 2.0×10^{-4} (c) 3.0×10^{-5} (p) 1.5×10^{-2} (crud) ^b	1.0	1.0	1.0	1.0(t) 1.0(g) 1.0×10^{-4} (c) 1.0×10^{-4} (p) 1.0×10^{-4} (crud)
15	1.0	0.3(t) 0.3 (g) 2.0×10^{-4} (c) 3.0×10^{-5} (p) 1.5×10^{-2} (crud) ^b	1.0	1.0	1.0	1.0(t) 1.0(g) 1.0×10^{-4} (c) 1.0×10^{-4} (p) 1.0×10^{-4} (crud)
16	1.0	0.3(t) 0.3 (g) 2.0×10^{-4} (c) 5.9×10^{-7} (p) 1.5×10^{-2} (crud) ^b	1.0	1.0	1.0	1.0
17	0.01 ^a	0.3(t) 0.3 (g) 2.0×10^{-4} (c) 3.0×10^{-5} (p) 1.5×10^{-2} (crud) ^b	1.0	1.0	1.0	1.0(t) 1.0(g) 1.0×10^{-4} (c) 1.0×10^{-4} (p) 1.0×10^{-4} (crud)
18	0.01 ^a	0.0(t) 0.0 (g) 2.0×10^{-4} (c) 3.0×10^{-5} (p) 1.5×10^{-2} (crud) ^b	1.0	1.0	7.0×10^{-4} ^e	1.0

NOTES: ^a DR=0.01 is used in calculating the release fraction input to MACCS2 (ORNL 1998 [DIRS 164761])

^b For crud, the value shown is the "effective ARF," which is the product of a crud spallation fraction of 0.15 and an ARF of 0.1 (BSC 2004g [DIRS 172371], Section 6.2.1.3)

^c Radionuclide releases for Category 2 event sequences involving naval SNF were developed by the Naval Nuclear Propulsion Program (Gisch 2004)

^d RFs for radionuclide releases for Category 2 event sequences involving naval SNF are identified in Table 5.

^e For seismic release of accumulated activity due to 1) shock-vibration and 2) free-fall spill.

(c) = cesium and rubidium; (g) = fission product gases; (p) = particulate and strontium; (t) = tritium; ARF = airborne release fraction; DR = damage ratio; LPF = leak path factor; RF = respirable fraction.

Run 1 involves a HEPA-filtered release from an annual throughput of 3,600 MTHM of PWR SFAs in a DTF, or the FHF.

Run 3 simulates an unfiltered subsurface release of waste package surface contamination, neutron-activated air, and silica dust during normal operations.

Run 4 involves a HEPA-filtered release from a drop or collision of a maximum PWR assembly while Run 5 simulates an unfiltered release from a drop or collision of a maximum PWR assembly with a cask leak path factor.

Run 6 involves a HEPA-filtered release from a drop or collision of a maximum BWR assembly while Run 7 simulates an unfiltered release from a drop or collision of a maximum BWR assembly with a cask leak path factor. Run 18 simulates an unfiltered release from a drop or collision of a maximum BWR assembly without a cask leak path factor.

Runs 8, 9, 10, and 11 involve unfiltered releases from a drop or collision of a Savannah River Site HLW canister, a Hanford Site HLW canister, a West Valley HLW canister, and an Idaho National Laboratory HLW canister.

Run 12 simulates an unfiltered release from a drop or collision of a naval SNF canister.

Run 13 is a variation of Run 1; the radionuclide release duration input parameter used in Run 1 was changed from 24 hour used in Run 1 to 1 hour used in Run 13.

Run 14 is a variation of Run 4; Run 14 changes the particle deposition velocity input parameter used in Run 4 from 0.01 m/s to 0.001 m/s.

Run 15 is a variation of Run 4; Run 15 changes the source term used in Run 4 from one maximum PWR assembly to one average PWR assembly.

Run 16 is a variation of Run 4; Run 4 takes credit for HEPA filters while Run 16 does not.

Run 17 is a variation of Run 1; Run 1 uses a 30 m vent height while Run 17 use a 40 m vent height.

Run 18 simulates the unfiltered ground-level release following a seismic event, of accumulated normal releases from 63,000 MTHM average PWR inventory, without HEPA filters.

MACCS2 (ORNL 1998 [DIRS 164761]) analyses results are summarized in Table 22, Table 23, Table 26 and Table 27.

6.3.1 Doses to Members of the Public from Normal Operations and Category 1 Event Sequences

MACCS2 (ORNL 1998 [DIRS 164761]) was used to calculate public TEDE to members of the public onsite at 100 m and at the site boundary of 11 km from normal operations (Table 22) and Category 1 event sequences (Table 24). In Table 22, the doses at 11 km are larger than the doses at 3 km, because: (1) 11 km doses include ingestion, 3 km doses do not, and (2) 11 km doses use an exposure period of 8,760 hour, 3 km doses use an exposure period of only 2,000 hour (Assumption 4.2.13).

The maximally exposed individual at the site boundary of 11 km is assumed to receive doses from the inhalation, resuspension inhalation, air submersion, groundshine, and ingestion pathways for a period of 8,760 hour (Assumption 4.2.13). The onsite individual member of the

public, at 100 m or 3 km away from a DTF, the FHF, or a subsurface exhaust shaft, is assumed to receive doses from inhalation, resuspension inhalation, air submersion, and groundshine pathways for a period of 2,000 hour (Assumption 4.2.13). Only HEPA-filtered public TEDEs for Category 1 event sequences are reported in Table 24.

Table 22. Public Doses from Normal Operations (FGR-11)

Releases From:	Public TEDE at 100m	Public TEDE at 3 km	Public TEDE at 11 km	Reference
Surface Releases from 1% of 3,600 MTHM SNF per Year	(Sv/year)		(Sv/year)	LASUR01.out ^a
Merged L-EFFECTIVE TOT LIF 10.9-11.1km MEAN	-		5.27×10^{-6}	p. 1
MAXIMUM ANNUAL FOOD DOSE (EFFECTIVE) MEAN	-		1.85×10^{-6}	p. 6
Merged - L-EFFECTIVE TOT LIF 0.1-0.2 km MEAN	3.79×10^{-4}		-	p. 1
Occupancy Factor (unitless)	0.228		1.0	
	(mrem/year)		(mrem/year)	
Total x Occupancy Factor x 1E5 (mrem/Sv)	8.7×10^0		7.1×10^{-1}	
Subsurface Releases from Activation and WP Contamination		(Sv/year)	(Sv/year)	LASUB01.out ^b
Merged L-EFFECTIVE TOT LIF 7.9-8.1km MEAN		-	4.03×10^{-7}	p. 1
MAXIMUM ANNUAL FOOD DOSE (EFFECTIVE) MEAN		-	3.68×10^{-9}	p. 6
Merged - L-EFFECTIVE TOT LIF 3.2-6.0 km MEAN		1.27×10^{-6}	-	p. 1
Occupancy Factor (unitless)		0.228	1.0	
		(mrem/year)	(mrem/year)	
Total x Occupancy Factor x 1E5 (mrem/Sv)		2.9×10^{-2}	4.1×10^{-2}	

NOTES: ^a Table 20, MACCS2 Run 1 ^b Table 20, MACCS2 Run 3.

HEPA = high-efficiency particulate air; mrem = one thousandth of a rem; MTHM = metric tons of heavy metal; PWR = pressurized water reactor; rem = roentgen equivalent man; TEDE = total effective dose equivalent.

Table 23. Public Doses from HEPA Filtered Release from One Maximum Spent Fuel Assembly (FGR-11)

Releases From:	Public TEDE at 100m	Public TEDE at 11 km	Reference
HEPA-filtered Release from 1 Maximum PWR SFA ^a	(Sv/event)	(Sv/event)	LAPWR01.out
Merged L-EFFECTIVE TOT LIF 10.9-11.1km 95%	-	4.36×10^{-7}	p. 1
MAXIMUM ANNUAL FOOD DOSE (EFFECTIVE) 95%	-	1.38×10^{-7}	p. 6
Cohort 1 - L-EFFECTIVE TOT LIF 0.1-0.2 km 95%	1.20×10^{-4}	-	p. 3
Cohort 2 - L-EFFECTIVE TOT LIF 0.1-0.2 km 95%	1.77×10^{-4}	-	p. 5
Occupancy Factors (unitless) [except 1.0 for Cohort 1]	0.228	1.0	
	(mrem/event)	(mrem/event)	
Total x Occupancy Factor x 1E5 (mrem/Sv)	$1.6 \times 10^{+1}$	5.7×10^{-2}	
HEPA-filtered Release from 1 Maximum BWR SFA ^b	(Sv/event)	(Sv/event)	LABWR01.out
Merged L-EFFECTIVE TOT LIF 10.9-11.1km 95%	-	1.36×10^{-7}	p. 1
MAXIMUM ANNUAL FOOD DOSE (EFFECTIVE) 95%	-	5.25×10^{-8}	p. 6
Cohort 1 - L-EFFECTIVE TOT LIF 0.1-0.2 km 95%	3.83×10^{-5}	-	p. 3
Cohort 2 - L-EFFECTIVE TOT LIF 0.1-0.2 km 95%	6.01×10^{-5}	-	p. 5
Occupancy Factors (unitless) [except 1.0 for Cohort 1]	0.228	1.0	
	(mrem/event)	(mrem/event)	
Total x Occupancy Factor x 1E5 (mrem/Sv)	5.2×10^0	1.9×10^{-2}	

NOTES: ^a Table 20, MACCS2 Run 4 ^b Table 20, MACCS2 Run 6

HEPA = high-efficiency particulate air; mrem = one thousandth of a rem; MTHM = metric tons of heavy metal; PWR = pressurized water reactor; BWR = boiling water reactor; rem = roentgen equivalent man; TEDE = total effective dose equivalent.

Table 24. HEPA-Filtered Public TEDE for Category 1 Event Sequences (FGR-11)

Event Sequence Identifier	Category 1 Events	Location	MAR (No. SFAs)		HEPA-Filtered Public TEDE at 100 m (mrem/event)		HEPA-Filtered Public TEDE at 11 km (mrem/event)	
			PWR ^a	BWR ^a	Max PWR ^b	Max BWR ^c	Max PWR ^b	Max BWR ^c
GET-03B	Collision involving a commercial SNF assembly	DTF and FHF Waste Transfer Cells	1	1	$1.6 \times 10^{+1}$	5.2×10^0	5.7×10^{-2}	1.9×10^{-2}
GET-03D	Drop of a commercial SNF assembly onto another assembly in a transportation cask	DTF and FHF Waste Transfer Cells	2	2	$3.2 \times 10^{+1}$	$1.0 \times 10^{+1}$	1.1×10^{-1}	3.8×10^{-2}

NOTES: Max PWR Fuel: Enrichment = 5.0%; Burnup = 80 GWd/MTU; Decay Time = 5 years.
 Max BWR Fuel: Enrichment = 5.0%; Burnup = 75 GWd/MTU; Decay Time = 5 years.

^a Table 11, Column 5.

^b Table 23, PWR SFA x No. SFAs.

^c Table 23, BWR SFA x No. SFAs.

Max = maximum; BWR = boiling water reactor; DTF = Dry Transfer Facility (DTF 1 or DTF 2); FHF = Fuel Handling Facility; GWd = gigawatt day; HEPA = high-efficiency particulate air; MAR = material at risk; max. = maximum; mrem = one thousandth of a rem; MTU = metric tons uranium; PWR = pressurized water reactor; rem = roentgen equivalent man; SFA = spent fuel assembly; SNF = spent nuclear fuel; TEDE = total effective dose equivalent.

6.3.2 Sum of Doses from Normal Operations and Category 1 Event Sequences

6.3.2.1 Sum of Doses Using Frequency-Weighted Category 1 Event Sequences Dose

The maximum PWR dose per SFA with HEPA filters is used in the calculation of the sum of frequency-weighted Category 1 event sequence doses using:

$$\text{Category 1 event sequence doses} = (FA_{\text{drop}} \times N_{\text{drop}} + FA_{\text{coll}} \times N_{\text{coll}}) \times D_{\text{pwr}} \quad (\text{Eq. 18})$$

where,

FA_{drop}	=	Maximum number of SFAs affected in a drop event
N_{drop}	=	Number of drops per year
FA_{coll}	=	Maximum number of SFAs affected in a collision event
N_{coll}	=	Number of collisions per year
D_{pwr}	=	Maximum PWR drop or collision dose per SFA.

The results of the dose aggregation calculation using Equation 18 are shown in Table 25.

Table 25. Sum of Public Doses From Normal Operations and Category 1 Event Sequences (FGR-11)

Event Sequence Identifier	Releases from:	MAR (1)	Number of events/year (2)	Public TEDE at 100 m (mrem/event) ^a (3)	Public TEDE at 11 km (mrem/event) ^b (4)	Public TEDE at 100 m (mrem/year) ^a (5)=(2)×(3)	Public TEDE at 11 km (mrem/year) ^b (6)=(2)×(4)
N.O	Surface releases from 1% of 3,600 MTHM of Average PWR SFAs per year, HEPA-filtered	NA	NA	NA	NA	Annual Dose 8.7×10^0 (Note c)	Annual Dose 7.1×10^{-1} (Note c)
N.O.	Subsurface releases of waste package surface contamination, activated air and silica dust, unfiltered	NA	NA	NA	NA	Annual Dose 2.9×10^{-2} (Note c)	Annual Dose 4.1×10^{-2} (Note c)
N.O.	Direct radiations from stored casks ^f	NA	NA	NA	NA	Annual Dose 3.1×10^0	Annual Dose NA
GET-03B	Collision involving a Maximum PWR commercial SNF assembly	1 ^d	0.5 ^e	$1.6 \times 10^{+1}$ (Note d)	5.7×10^{-2} (Note d)	Frequency Weighted Dose 8.0×10^0	Frequency Weighted Dose 2.9×10^{-2}
GET-03D	Drop of a Maximum PWR commercial SNF assembly onto another assembly	2 ^d	0.5 ^e	$3.2 \times 10^{+1}$ (Note d)	1.1×10^{-1} (Note d)	Frequency Weighted Dose $1.6 \times 10^{+1}$	Frequency Weighted Dose 5.7×10^{-2}
Total:						$3.6 \times 10^{+1}$	8.4×10^{-1}

NOTES: ^a Onsite member of the public is located at 100 m away from a DTF or the FHF and at 3 km away from the subsurface exhaust shafts and is exposed to radiation for a period of 2,000 hour (Assumption 4.2.13)

^b Offsite member of the public is located at 11 km away from a DTF or the FHF, and at 8 km away from the subsurface exhaust shafts and is exposed to radiation for a period of 8,760 hour (Assumption 4.2.13)

^c Table 22, columns 1, 2, and 3

^d Table 24

^e Table 11, column 3.

^f Direct radiations from stored casks to North Perimeter Security Station (30C) from BSC 2005c ([DIRS 172488], Table 7b) corresponding to the maximum onsite public dose location for releases in Assumption 4.1.13.

DTF = Dry Transfer Facility (DTF 1 or DTF 2); FHF = Fuel Handling Facility; HEPA = high-efficiency particulate air [filter]; NA = not applicable; PWR = pressurized water reactor; SNF = spent nuclear fuel.

6.3.2.2 Sum of Doses Using Combinations of Category 1 Event Sequences Dose

The dose impact of combinations of Category 1 event sequences is evaluated. Three combinations of Category 1 event sequences were identified for consideration in the consequence analysis (BSC 2005i [DIRS 174467], Section 7.2.2):

- Two commercial SNF assembly drops within 1 year
- Two commercial SNF assembly collisions within 1 year
- One drop and one collision of commercial SNF assemblies within 1 year.

The collision event involves one PWR or BWR SFA; the drop event potentially affects two PWR or BWR SFAs.

The case of the two commercial SNF assembly drops has the highest MAR (i.e., four SFAs) and, hence, has the highest radiation dose among the three cases.

The radiation doses resulting from two commercial SNF assembly drops and normal operations from Table 25 results are $8.7 + 0.029 + 3.1 + 2 \times 32$ mrem/year = $7.6 \times 10^{+1}$ mrem/year for public exposure at 100 m and $0.71 + 0.041 + 2 \times 0.11$ mrem/year = 9.7×10^{-1} mrem/year for public exposure at the site boundary.

6.3.3 Doses to Members of the Public From Category 2 Event Sequences

The outputs from MACCS2 (ORNL 1998 [DIRS 164761]) dose calculations for members of the public from Category 2 event sequences are inhalation, resuspension inhalation, ingestion, cloudshine, and groundshine doses at 11 km (see Section 4.1.4). Table 12 shows that the bounding Category 2 event sequences are:

- Event GET-01A(a) for a drop and breach of 36 PWR SFAs
- Event GET-01A(b) for a drop and breach of 74 BWR SFAs
- Event GET-02B(n) for a drop and breach of one naval SNF canister
- Event GET-02B(a) for a drop and breach of five HLW canisters from Savannah River Site
- Event GET-02B(b) for a drop and breach of five HLW canisters from the Hanford Site
- Event GET-02B(c) for a drop and breach of five HLW canisters from West Valley
- Event GET-02B(d) for a drop and breach of five HLW canisters from Idaho National Laboratory.
- Event SEISMIC for bounding release of accumulated HEPA and duct activity.

Doses to members of the public from these bounding Category 2 event sequences are summarized in Table 26, Table 27 and Table 28.

Unfiltered doses from dropping a waste package or a transportation cask containing maximum PWR or maximum BWR SFAs and from dropping commercial spent nuclear fuel assemblies are shown in Table 26. Public doses from the drop of an SNF canister, an HLW canister, or a DPC are bounded by the doses from dropping a waste package or a transportation cask containing maximum PWR or maximum BWR SFAs.

The results of public dose calculations for HLW and naval SNF show that breached Savannah River Site HLW canisters have the highest dose consequences (Table 27). Table 28 summarizes doses to members of the public from each of these bounding Category 2 event sequences.

Table 26. Unfiltered Public Doses from Breached Transportation Cask and Dropped Commercial Spent Nuclear Fuel Assemblies (FGR-11)

Releases From:	TEDE at 11 km	TODE ^a at 11 km	SDE at 11 km	LDE at 11 km	Reference
Drop and Breach of Cask with 1 Maximum PWR no HEPA	(Sv/event)	(Sv/event)	(Sv/event)	(Sv/event)	LAPWR02.out ^b
Merged L-EFFECTIVE TOT LIF 10.9-11.1km 95%	2.47×10^{-5}				p. 1
MAXIMUM ANNUAL FOOD DOSE (EFFECTIVE) 95%	4.36×10^{-6}				p. 6
Merged L-BONE SUR TOT LIF 10.9-11.1km 95%		9.49×10^{-5}			p. 1
Cohort 1 A-SKIN(FGR) TOT LIF 10.9-11.1 km 95%			6.08×10^{-6}		p. 4
sum TEDE + SDE				3.51×10^{-5}	Sum
	(mrem)	(mrem)	(mrem)	(mrem)	
Total x 1E5 (mrem/Sv)	2.9×10^0	9.5×10^0	6.1×10^{-1}	3.5×10^0	
Transportation Cask with 36 Maximum PWR SFAs	$1.0 \times 10^{+2}$	$3.4 \times 10^{+2}$	$2.2 \times 10^{+1}$	$1.3 \times 10^{+2}$	x 36
Drop and Breach of Cask with 1 Maximum BWR no HEPA	(Sv/event)	(Sv/event)	(Sv/event)	(Sv/event)	LABWR02.out ^c
Merged L-EFFECTIVE TOT LIF 10.9-11.1km 95%	1.03×10^{-5}				p. 1
MAXIMUM ANNUAL FOOD DOSE (EFFECTIVE) 95%	1.51×10^{-6}				p. 6
Merged L-BONE SUR TOT LIF 10.9-11.1km 95%		3.12×10^{-5}			p. 1
Cohort 1 A-SKIN(FGR) TOT LIF 10.9-11.1 km 95%			2.14×10^{-6}		p. 4
sum TEDE + SDE				1.40×10^{-5}	sum
	(mrem)	(mrem)	(mrem)	(mrem)	
Total x 1E5 (mrem/Sv)	1.2×10^0	3.1×10^0	2.1×10^{-1}	1.4×10^0	
Transportation Cask with 74 Maximum BWR SFAs	$8.7 \times 10^{+1}$	$2.3 \times 10^{+2}$	$1.6 \times 10^{+1}$	$1.0 \times 10^{+2}$	x 74
Seismic event HEPA and ducting release no HEPA	(Sv/event)	(Sv/event)	(Sv/event)	(Sv/event)	LAHEPA01.out ^d
Merged L-EFFECTIVE TOT LIF 10.9-11.1km 95%	8.04×10^{-4}				p. 1
MAXIMUM ANNUAL FOOD DOSE (EFFECTIVE) 95%	1.35×10^{-5}				p. 6
Merged L-BONE SUR TOT LIF 10.9-11.1km 95%		1.10×10^{-2}			p. 1
Cohort 1 A-SKIN(FGR) TOT LIF 10.9-11.1 km 95%			2.93×10^{-6}		p. 4
sum TEDE + SDE				8.20×10^{-4}	sum
	(mrem)	(mrem)	(mrem)	(mrem)	
Total x 1E5 (mrem/Sv)	$8.2 \times 10^{+1}$	$1.1 \times 10^{+3}$	2.9×10^{-1}	$8.2 \times 10^{+1}$	
<p>NOTES: Maximum PWR Fuel: enrichment = 5.0%; burnup = 80 GWd/MTU; decay time = 5 years. Maximum BWR Fuel: enrichment = 5.0%; burnup = 75 GWd/MTU; decay time = 5 years.</p> <p>^a The bone surface dose is the highest TODE; ^b Table 20, MACCS2 Run 5 ; ^c Table 20, MACCS2 Run 7; ^d Table 20, MACCS2 Run 18.</p> <p>BWR = boiling water reactor; CDE = committed dose equivalent; DDE = deep dose equivalent; HEPA = high-efficiency particulate air; LDE = lens dose equivalent; mrem = one thousandth of a rem; PWR = pressurized water reactor; rem = roentgen equivalent man; SDE = shallow dose equivalent to skin; TEDE = total effective dose equivalent; TODE = total organ dose equivalent.</p>					

Table 27. Unfiltered Public Doses From Breached Vitrified High-level Radioactive Waste Canisters and Naval Spent Nuclear Fuel Canisters (FGR-11)

	TEDE	TODE ^a	SDE	LDE	Reference
Releases From:	at 11 km	at 11 km	at 11 km	at 11 km	
Drop and Breach of 1 Naval SNF Canister no HEPA ^b	(Sv/event)	(Sv/event)	(Sv/event)	(Sv/event)	LANAV01.out
Merged L-EFFECTIVE TOT LIF 10.9-11.1km 95%	2.50×10^{-5}				p. 1
MAXIMUM ANNUAL FOOD DOSE (EFFECTIVE) 95%	1.73×10^{-6}				p. 6
Merged L-BONE SUR TOT LIF 10.9-11.1km 95%		1.33×10^{-4}			p. 1
Cohort 1 A-SKIN(FGR) TOT LIF 10.9-11.1 km 95%			8.20×10^{-7}		p. 4
sum TEDE + SDE				2.76×10^{-5}	Sum
	(mrem)	(mrem)	(mrem)	(mrem)	
Total x 1E5 (mrem/Sv)	2.7×10^0	$1.3 \times 10^{+1}$	8.2×10^{-2}	2.8×10^0	
Drop and Breach of 1 SRS HLW Canister no HEPA ^c	(Sv/event)	(Sv/event)	(Sv/event)	(Sv/event)	LAHLW01.out
Merged L-EFFECTIVE TOT LIF 10.9-11.1km 95%	1.72×10^{-5}				p. 1
MAXIMUM ANNUAL FOOD DOSE (EFFECTIVE) 95%	1.54×10^{-7}				p. 6
Merged L-BONE SUR TOT LIF 10.9-11.1km 95%		2.07×10^{-4}			p. 1
Cohort 1 A-SKIN(FGR) TOT LIF 10.9-11.1 km 95%			5.46×10^{-8}		p. 4
sum TEDE + SDE				1.74×10^{-5}	Sum
	(mrem)	(mrem)	(mrem)	(mrem)	
Total x 1E5 (mrem/Sv)	1.7×10^0	$2.1 \times 10^{+1}$	5.5×10^{-3}	1.7×10^0	
Cask with 5 SRS HLW Canisters	8.7×10^0	$1.0 \times 10^{+2}$	2.7×10^{-2}	8.7×10^0	x 5
Drop and Breach of 1 Hanford Site HLW Canister no HEPA ^d	(Sv/event)	(Sv/event)	(Sv/event)	(Sv/event)	LAHLW02.out
Merged L-EFFECTIVE TOT LIF 10.9-11.1km 95%	2.08×10^{-6}				p. 1
MAXIMUM ANNUAL FOOD DOSE (EFFECTIVE) 95%	1.33×10^{-7}				p. 6
Merged L-BONE SUR TOT LIF 10.9-11.1km 95%		3.18×10^{-5}			p. 1
Cohort 1 A-SKIN(FGR) TOT LIF 10.9-11.1 km 95%			5.36×10^{-8}		p. 4
sum TEDE + SDE				2.27×10^{-6}	Sum
	(mrem)	(mrem)	(mrem)	(mrem)	
Total x 1E5 (mrem/Sv)	2.2×10^{-1}	3.2×10^0	5.4×10^{-3}	2.3×10^{-1}	
Cask with 5 Hanford Site HLW Canisters	1.1×10^0	$1.6 \times 10^{+1}$	2.7×10^{-2}	1.1×10^0	x 5
Drop and Breach of 1 West Valley HLW Canister no HEPA ^e	(Sv/event)	(Sv/event)	(Sv/event)	(Sv/event)	LAHLW03.out
Merged L-EFFECTIVE TOT LIF 10.9-11.1km 95%	2.18×10^{-6}				p. 1
MAXIMUM ANNUAL FOOD DOSE (EFFECTIVE) 95%	5.85×10^{-8}				p. 6
Merged L-BONE SUR TOT LIF 10.9-11.1km 95%		3.53×10^{-5}			p. 1
Cohort 1 A-SKIN(FGR) TOT LIF 10.9-11.1 km 95%			2.12×10^{-8}		p.4
sum TEDE + SDE				2.26×10^{-6}	Sum
	(mrem)	(mrem)	(mrem)	(mrem)	
Total x 1E5 (mrem/Sv)	2.2×10^{-1}	3.5×10^0	2.1×10^{-3}	2.3×10^{-1}	
Cask with 5 West Valley HLW Canisters	1.1×10^0	$1.8 \times 10^{+1}$	1.1×10^{-2}	1.1×10^0	x 5

Table 27. Unfiltered Public Doses From Breached Vitrified High-level Radioactive Waste Canisters and Naval Spent Nuclear Fuel Canisters (Continued)

	TEDE	TODE ^a	SDE	LDE	
Releases From:	at 11 km	at 11 km	at 11 km	at 11 km	Reference
Drop and Breach of 1 INL HLW Canister no HEPA ^f	(Sv/event)	(Sv/event)	(Sv/event)	(Sv/event)	LAHLW04.out
Merged L-EFFECTIVE TOT LIF 10.9-11.1km 95%	3.03×10^{-7}				p. 1
MAXIMUM ANNUAL FOOD DOSE (EFFECTIVE) 95%	2.63×10^{-8}				p. 6
Merged L-BONE SUR TOT LIF 10.9-11.1km 95%		2.46×10^{-6}			p. 1
Cohort 1 A-SKIN(FGR) TOT LIF 10.9-11.1 km 95%			1.1×10^{-9}		p. 4
sum TEDE + SDE				3.4×10^{-7}	Sum
	(mrem)	(mrem)	(mrem)	(mrem)	
Total x 1E5 (mrem/Sv)	3.3×10^{-2}	2.5×10^{-1}	1.1×10^{-3}	3.4×10^{-2}	
Cask with 5 INL HLW Canisters	1.6×10^{-1}	1.2×10^0	5.5×10^{-3}	1.7×10^{-1}	x 5

NOTES: a The bone surface dose is the highest TODE for HLW canisters and naval SNF canisters

b Table 20, MACCS2 Run 12

c Table 20, MACCS2 Run 8

d Table 20, MACCS2 Run 9

e Table 20, MACCS2 Run 10

f Table 20, MACCS2 Run 11.

HEPA = high-efficiency particulate air; HLW = high-level radioactive waste; INL = Idaho National Laboratory; LDE = lens dose equivalent; mrem = one thousandth of a rem; rem = roentgen equivalent man; SDE = shallow dose equivalent to skin; SRS = Savannah River Site; TEDE = total effective dose equivalent; TODE = total organ dose equivalent.

Table 28. Summary of Category 2 Public Doses per Event (FGR-11)

		TEDE	TODE	SDE	LDE
Event	Event Description	at 11 km	at 11 km	at 11 km	at 11 km
		(mrem/event)	(mrem/event)	(mrem/event)	(mrem/event)
GET-01A(a)	Drop and Breach Transportation Cask with 36 Maximum PWR SFAs ^a	$1.0 \times 10^{+2}$	$3.4 \times 10^{+2}$	$2.2 \times 10^{+1}$	$1.3 \times 10^{+2}$
GET-01A(b)	Drop and Breach Transportation Cask with 74 Maximum BWR SFAs ^a	$8.7 \times 10^{+1}$	$2.3 \times 10^{+2}$	$1.6 \times 10^{+1}$	$1.0 \times 10^{+2}$
GET-02B(n)	Drop and Breach of 1 Naval SNF Canister ^b	2.7×10^0	$1.3 \times 10^{+1}$	8.2×10^{-2}	2.8×10^0
GET-02B(a)	Drop and Breach of Cask with 5 SRS HLW Canisters ^b	8.7×10^0	$1.0 \times 10^{+2}$	2.7×10^{-2}	8.7×10^0
GET-02B(b)	Drop and Breach of Cask with 5 Hanford Site HLW Canisters ^b	1.1×10^0	$1.6 \times 10^{+1}$	2.7×10^{-2}	1.1×10^0
GET-02B(c)	Drop and Breach of Cask with 5 West Valley HLW Canisters ^b	1.1×10^0	$1.8 \times 10^{+1}$	1.1×10^{-2}	1.1×10^0
GET-02B(d)	Drop and Breach of Cask with 5 INL HLW Canisters ^b	1.6×10^{-1}	1.2×10^0	5.5×10^{-3}	1.7×10^{-1}
SEISMIC	Release of Accumulated HEPA and Ducting Activity	$8.2 \times 10^{+1}$	$1.1 \times 10^{+3}$	2.9×10^{-1}	$8.2 \times 10^{+1}$

Notes: ^a From Table 26 ; ^b From Table 27.

BWR = boiling water reactor; GET = generalized event tree; HEPA = high-efficiency particulate air; HLW = high-level radioactive waste; INL = Idaho National Laboratory; LDE = lens dose equivalent; mrem = one thousandth of a rem; PWR = pressurized water reactor; rem = roentgen equivalent man; SDE = shallow dose equivalent to skin; SFA = spent fuel assembly; SNF = spent nuclear fuel; SRS = Savannah River Site; TEDE = total effective dose equivalent; TODE = total organ dose equivalent.

6.3.4 Sensitivity Analysis and Treatment of Uncertainty

This section discusses sensitivity analysis performed for and treatment of uncertainties in public doses. Results of individual MACCS2 runs are in outputs identified in Table 20. A discussion of uncertainties in worker doses is beyond the scope of this report because the calculated worker doses presented in this calculation were provided by various references.

6.3.4.1 Sensitivity Analysis

A maximum release duration of 24 hour allowed in MACCS2 (ORNL 1998 [DIRS 164761]) is used for annual releases for normal operations (Assumption 4.2.4). MACCS2 Run 1 and Run 13 (Table 20) were made with 24-hr and 1-hr release durations, respectively. The resulting doses from the shorter 1-hr release duration are higher than the longer 24-hr release duration. The result is considered reasonable because the radionuclides inhaled and ingested at an earlier time for the shorter release duration have a slightly longer time to decay and produce alpha and beta particles. Therefore, the use of a shorter release duration of 1 day instead of 1 year with the same amount of radionuclide releases for normal operations is conservative.

For the twelve MACCS2 base cases, a particle deposition velocity of 0.01 m/s is used. For sensitivity analysis, a particle deposition velocity of 0.001 m/s is used in MACCS2 Run 14 (Table 20) with results showing a dose decrease by a factor of about 2 at 100 m and increase by a factor of about 1.7 at 11 km. Because the 100m doses are the more limiting, i.e. closer to regulatory limits, a particle deposition velocity of 0.01 m/s provides more conservative results for compliance evaluations.

MACCS2 Run 15 (Table 20) has shown that the calculated doses decrease by approximately a factor of 3 by use of an average PWR assembly instead of a maximum PWR assembly. Thus the use of the maximum PWR radionuclide inventory is conservative.

MACCS2 Run 16 (Table 20) has shown that without HEPA filters the calculated doses at 100 m and 11 km away from the release point for a drop event involving two PWR SFAs could exceed the 100 mrem and 15 mrem dose limits for onsite and offsite members of the public, respectively.

MACCS2 Run 17 (Table 20) with a 40 m vent height has shown, by comparing to Run 1 with a 30 m vent height, that calculated doses decrease by a factor of about 3 at 100 m and increase by a factor of about 1.06 at 11 km. Because the 100m doses are the more limiting, i.e. close to regulatory limits, a 30 m vent height provides more conservative results for compliance evaluations.

6.3.4.2 Treatment of Uncertainty

Uncertainties in consequence analyses are addressed by using conservative inputs and assumptions. For calculating public and worker doses for Category 1 event sequences involving drops and collisions, it is conservatively assumed that 100% fuel rod cladding is breached (Assumption 4.2.7). This is at least a factor of five larger than the best estimate value.

A comparison between MACCS2 Run 15 and Run 4 (Table 20) has shown that using the average PWR assembly inventory instead of the maximum PWR assembly inventory, the calculated doses for Category 1 event sequences involving drops and collisions decrease by a factor of about 3.

Uncertainties in calculating public doses for Category 2 event sequences are addressed by using conservative inputs and bounding assumptions. The bounding assumptions include the use of the bounding MAR (i.e., the maximum possible number of SFAs allowed in a certified cask) for a

transportation cask, bounding source terms, 100% fuel rod cladding breach, and 95th percentile weather condition (i.e., χ/Q values). The bounding MAR (i.e., 36 PWR or 74 BWR SFAs in a transportation cask) is at least a factor of 1.5 higher than the average value of the MAR. A comparison between MACCS2 Run 4 and Run 15 (Table 20) has shown that the bounding PWR and BWR source terms are at least a factor of 3 higher than the average PWR and BWR source terms.

The assumption of a 100% fuel rod cladding breach (Assumption 4.2.7) is very conservative in view of the fact that historical SNF drop incidents at nuclear power plants showed only minimum damage to the cladding. Run 4 (Table 20) has shown that the use of the 95th percentile weather condition is about a factor of 3 higher than the mean value.

The information on conservatism provided in this section ensures that uncertainties in inputs are treated with a reasonable degree of conservatism.

6.3.5 Direct Radiation Exposures During Normal Operations, Category 1 Event Sequences, and Category 2 Event Sequences

Offsite direct exposures originate only from the surface facilities, because subsurface facilities, such as the emplacement drifts, are shielded by massive rock. Surface facilities with potential sources of contribution to offsite direct exposures include the transportation cask buffer/staging area and the SNF aging system.

Other facilities, such as the CHF, DTF 1, DTF 2, and the FHF, provide concrete shielding for the exterior walls except for the entrance vestibules. This shielding typically reduces the dose rate outside the building to 0.25 mrem/hour (BSC 2005f [DIRS 173614], Section 4.9.1.3) except during cask handling operations around the vestibule. These dose rates result in a negligible contribution to the public dose at the site boundary located at 11 km (see Section 4.1.4) from the surface facilities.

The transportation cask buffer/staging area provides space for staging of shielded truck and rail casks. The dose rate from an individual cask is regulated by the NRC (e.g., 10 mrem/hour at any point 2 m from the outer lateral surface of the transport vehicle specified in 10 CFR 71.47(b)(3) [DIRS 173375] for exclusive use shipment only). With multiple casks in the staging area, the dose rate will increase, depending on the cask staging configurations. This radiation level affects the worker dose, but poses no impact on the public dose at the site boundary because of the large distance factor.

In addition, 10 CFR 20.1301(a)(2) [DIRS 173165] requires that each licensee shall conduct operations so that the dose in any unrestricted area from external sources does not exceed 0.002 rem (2 mrem) in any 1 hour. This requirement applies to normal operations and Category 1 event sequences.

The dose requirements in 10 CFR Part 20 [DIRS 173165] include contributions from direct exposures. Direct exposures from the SNF aging system arise from the effects of neutron and gamma skyshine. These effects depend on site-specific fuel characteristics of initial enrichment,

burnup, and cooling time, along with facility layout, site layout, and site boundary characteristics.

Skyshine radiation dose calculations are typically performed with the MCNP code (Briesmeister 1997 [DIRS 103897]). Aging cask vendors have included the skyshine analysis in their safety analysis reports submitted to the NRC to demonstrate regulatory compliance, such as *Topical Safety Analysis Report for the HI-Storm 100 Cask System, HOLTEC Report HI-951312, Revision 2, NRC Docket No. 72-1014* (NRC 1997 [DIRS 152462], Section 5.4.3, p. 5.4-4).

NRC (1997 [DIRS 152462], Section 5.4.3, p. 5.4-4) shows that the skyshine dose at 200 m from an independent spent fuel storage facility is in the range of 11.6 to 19.3 mrem/year (NRC 1997 [DIRS 152462], Table 5.1.9, p. 5.1-15) for array configurations 2×3 , 2×4 , and 2×5 . This dose would be further reduced by permanent or temporary shielding. With this dose level, the public dose at the site boundary from skyshine radiation is negligible, based on the distance factor and attenuation by air.

Onsite and offsite doses from direct exposure following Category 1 and Category 2 event sequences were calculated in BSC 2005f [DIRS 173483]. The bounding source terms for commercial SNF, naval SNF, DOE SNF standardized and MCO canisters and HLW were used to calculate the dose rates at various distances from the source (BSC 2005f [DIRS 173483], Section 6.3). The dose rates are multiplied by exposure time to yield the onsite and offsite doses. The calculated doses to onsite workers in Table 33 do include those contributions from direct exposure during Category 1 event sequences. However, it was concluded that the dose to onsite and offsite members of the public from direct radiation following Category 1 and Category 2 events is not significant (BSC 2005f [DIRS 173483], Section 7).

6.3.6 Doses to Members of the Public Being As Low As is Reasonably Achievable

Regulation 10 CFR 20.1101(b) states that the licensee shall use to the extent practical both procedures and engineering controls based upon sound radiation protection principles to achieve occupational doses and doses to members of the public that are ALARA.

To implement the ALARA goals of 10 CFR 20.1101(d), the calculated offsite public TEDE is compared with the 10 mrem/year offsite ALARA dose constraint (Section 7) along with other project ALARA goals.

6.4 WORKER DOSE RESULTS

ALARA design goals, as described in *Project Design Criteria Document* (BSC 2005f [DIRS 173614], Section 4.9.3.3), for occupational workers ensure that both individual and collective annual doses are maintained at ALARA levels during normal operations and as a result of Category 1 event sequences. Category 1 event sequences are included in ALARA dose assessments. The ALARA goal is to minimize the number of individuals that have the potential of receiving more than 500 mrem/year TEDE (BSC 2005f [DIRS 173614], Section 4.9.3.3).

For the purpose of demonstrating compliance with the normal operations and Category 1 event sequence performance objectives for workers in Table 1, the results from worker dose

calculation BSC 2005c (DIRS 172488) are reported in this calculation and used in Section 6.4.3 to perform worker dose aggregation.

6.4.1 Normal Operations

6.4.1.1 Worker Dose From Airborne Releases

The annual doses to surface facility workers from potential surface facility normal operational releases are calculated and summarized in BSC 2005b ([DIRS 172487], Table 16) and BSC 2005c ([DIRS 172488], Table 5a) for a full time worker who works 2,000 hours (BSC 2005b [DIRS 172487], Section 4.3.7). Doses are determined using inhalation dose conversion factors from Federal Guidance Report No. 11 (Eckerman et al. 1988 [DIRS 101069]).

The estimated maximum annual surface facility worker dose from airborne releases is 2.0 mrem/year TEDE (Table 29) based on summing the maximums of releases to any worker location. Results for specific worker locations show that the highest total, among the 30 receptor locations, is at DTF 2 with a total of 1.8 mrem/year TEDE (BSC 2005c [DIRS 172488], Table 5a).

Table 29. Maximum Annual Surface Facility Worker Doses From Normal Operations Releases (FGR-11)

Released from	TEDE (mrem/year)	Highest TODE (mrem/year)	SDE (mrem/year)	LDE (mrem/year)
DTF 1 ^b	1.2×10^0	$1.1 \times 10^{+1}$	5.6×10^0	6.8×10^0
DTF 2 ^b	4.6×10^{-1}	4.2×10^0	2.1×10^0	2.6×10^0
FHF ^b	2.8×10^{-1}	2.6×10^0	1.3×10^0	1.6×10^0
Maximum of 17A and 17B ^a	1.9×10^{-2}	NC	NC	NC
Subsurface Exhaust Shafts ^b	8.0×10^{-2}	9.1×10^{-1}	2.6×10^{-2}	1.1×10^{-1}
Total ^c	2.0×10^0	1.9×10^1	9.0×10^0	1.1×10^1

NOTES: ^a BSC 2005c [DIRS 172488], (Table 5a) for the Canister Handling Facility

^b BSC 2005b [DIRS 172487], Table 16

^c Total is the sum of maximums from DTF 1, DTF 2, FHF, maximum of 17A and 17B, and subsurface exhaust shafts for any worker location.

DTF = Dry Transfer Facility; FHF = Fuel Handling Facility; LDE = lens dose equivalent; mrem = one thousandth of a rem; NC = not calculated; rem = roentgen equivalent man; SDE = shallow dose equivalent to skin; SNF = spent nuclear fuel; TEDE = total effective dose equivalent; TODE = total organ dose equivalent.

Three potential sources of airborne releases radioactive material were calculated for the subsurface repository under normal operations, which are (BSC 2005b [DIRS 172487], Section 6):

- Radioactive contamination suspended from the external surfaces of the emplaced waste packages
- Neutron activation products generated from irradiation of ventilation air inside the emplacement drifts
- Neutron activation products generated from irradiation of the host rocks inside the emplacement drifts.

Annual TEDEs to subsurface workers from potential normal operational releases are calculated and summarized in BSC (2005c [DIRS 172488], Table 5a). The estimated maximum annual subsurface facility worker dose from airborne releases is 1.6×10^{-1} mrem/year TEDE (Table 30).

The annual maximum dose to a repository worker was calculated for a full time worker who works 2,000 hour/year at the access main that is taking air from Intake Shaft 1, about 410 m from Exhaust Shaft 1 (BSC 2005b [DIRS 172487], Section 4.2.9). Airborne radioactive contamination in the access main may result from re-entry of the released material from the exhaust shafts.

Table 30. Maximum Annual Subsurface Facility Worker Doses From Normal Operations Releases (FGR-11)

Released from	TEDE (mrem/year)	Highest TODE (mrem/year)	SDE (mrem/year)	LDE (mrem/year)
DTF 1	2.5×10^{-2}	NC	NC	NC
DTF 2	1.8×10^{-2}	NC	NC	NC
FHF	2.8×10^{-2}	NC	NC	NC
Maximum of 17A and 17B	4.5×10^{-3}	NC	NC	NC
Subsurface Exhaust Shafts	8.0×10^{-2}	NC	NC	NC
Total	1.6×10^{-1}	NC	NC	NC

DTF = Dry Transfer Facility; FHF = Fuel Handling Facility; LDE = lens dose equivalent; mrem = one thousandth of a rem; NC = not calculated; rem = roentgen equivalent man; SDE = shallow dose equivalent to skin; TEDE = total effective dose equivalent; TODE = total organ dose equivalent.

Source: BSC 2005c [DIRS 172488], Table 5a

6.4.1.2 Worker Dose From Direct Radiation

Annual worker doses from direct radiation from contained sources, such as transportation casks and waste packages, during normal operations were calculated for the CHF, DTF 1, DTF 2, the FHF, the TCRRF, the Remediation Facility, the SNF aging system, and the subsurface facility (Table 31).

The highest annual doses from exposure to direct radiation are: 1) for subsurface facility workers 380 mrem/year for an individual in the emplacement/retrieval locomotive operator work group (Table 31), and 2) for surface facility workers 1,800 mrem/year for an individual in the cask/waste receipt operator work group in the DTFs and a cask transfer operator in the SNF Aging System (Table 31). These dose rates exceed the ALARA goal to minimize the number of individuals that have the potential of receiving more than 500 mrem/year TEDE (BSC 2005f [DIRS 173614], Section 4.9.3.3). Additional ALARA design features and refinements in dose analyses during design and operational practices including staffing optimization during operation may be used to achieve the ALARA goal.

Table 31. Annual Worker Doses From Direct Radiation From Facility Normal Operations

Facility	Worker Group	Individual Worker (mrem/yr) ^{a,b}
Transportation Cask Receipt and Return and Staging	Security Personnel	30
	Transportation Personnel	270
	Cask Operator	620
	Health Physics Technician	110
	Gantry Operator	130
Canister Handling Facility	Cask/Waste Receipt Operator	660
	Health Physics Technician	420
	Transfer Bay Operator	100
Dry Transfer Facility	Cask/Waste Receipt Operator	1800
	Health Physics Technician	800
	Transfer Bay Operator	100
	Electrical, Mechanical, HVAC, Utility Maintenance	32 (including 6 from remediation activities)
	General Facility Maintenance and Radiation Monitoring	120 (including 18 from remediation activities)
	Remediation Operator	170
Fuel Handling Facility	Cask/Waste Receipt Operator	770
	Health Physics Technician	260
	Transfer Bay Operator	100
Subsurface	Emplacement/ Retrieval Locomotive Operator	380
	Ventilation Maintenance	47
	Electrical Maintenance	85
	Mechanical Maintenance	20
	Ground Control Maintenance	3.2
SNF Aging System	Cask Transfer	1800
	Health Physics Technician	850
	Cask Inspection	580
	Cask Maintenance	670

NOTES: ^a Dose values are rounded to two significant values

^b BSC 2005c [DIRS 172488], Table 4

HVAC = heating, ventilation, and air-conditioning; mrem = one thousandth of a rem; rem = roentgen equivalent man; SNF = spent nuclear facility;

6.4.2 Category 1 Event Sequences

6.4.2.1 Surface Facility Worker Dose

Category 1 event sequence scenarios and estimated maximum worker dose consequences from airborne releases are shown in Table 32. Dose consequences in mrem received by the maximally exposed worker in a work group for releases from the Category 1 event sequences are calculated

in BSC 2005a ([DIRS 173590], Table 7b). In addition, the direct radiation dose from a single Category 1 event sequence in the DTF 1, DTF 2 or FHF is 10 mrem/event BSC 2005l ([DIRS 173483], Section 8).

Table 32. Maximum Worker Doses From Category 1 Event Sequence Releases (FGR-11)

Facility ^a	Category 1 Event Sequences ^a	χ/Q (s/m ³) ^a	TEDE ^a (mrem)	TODE ^a (mrem)	SDE ^a (mrem)	LDE ^a (mrem)
DTF 1	Drop	7.0×10^{-4}	$1.6 \times 10^{+1}$	$1.4 \times 10^{+2}$	$1.2 \times 10^{+2}$	$1.3 \times 10^{+2}$
	Collision	7.0×10^{-4}	7.8×10^0	$6.8 \times 10^{+1}$	$5.9 \times 10^{+1}$	$6.7 \times 10^{+1}$
DTF 2	Drop	3.8×10^{-4}	8.5×10^0	$7.4 \times 10^{+1}$	$6.4 \times 10^{+1}$	$7.3 \times 10^{+1}$
	Collision	3.8×10^{-4}	4.2×10^0	$3.7 \times 10^{+1}$	$3.2 \times 10^{+1}$	$3.6 \times 10^{+1}$
FHF	Drop	9.1×10^{-4}	$2.0 \times 10^{+1}$	$1.8 \times 10^{+2}$	$1.5 \times 10^{+2}$	$1.7 \times 10^{+2}$
	Collision	9.1×10^{-4}	$1.0 \times 10^{+1}$	$8.9 \times 10^{+1}$	$7.7 \times 10^{+1}$	$8.7 \times 10^{+1}$

NOTES: ^a BSC 2005a [DIRS 173590], Table 7b

DTF = Dry Transfer Facility; FHF = Fuel Handling Facility; LDE = lens dose equivalent; mrem = one thousandth of a rem; rem = roentgen equivalent man; SDE = shallow dose equivalent to skin; TEDE = total effective dose equivalent; TODE = total organ dose equivalent.

6.4.2.2 Subsurface Facility Worker Dose

There are no Category 1 event sequences associated with the subsurface facility (BSC 2005i [DIRS 174467], Section 6.3.6). Therefore, there is no subsurface worker dose from Category 1 event sequences.

6.4.3 Worker Dose TEDE Summary

The results of worker dose calculations from *Geologic Repository Operations Area Worker Dose Assessment* (BCS 2005c [DIRS 172488]) are provided in this section. The calculated annual doses to repository workers include contributions from external radiation and from exposure to airborne radioactivity potentially caused by indoor operations. The TEDE is calculated by summing the dose contributions from inhalation, submersion, and direct external radiation (BSC 2005c [DIRS 172488], Section 4.1). Potential repository worker TEDE doses from both normal operations and Category 1 events are summarized in Table 33 at the location of the highest worker doses: DTF 1 for facility workers and CHF for construction workers.

Table 33. Facility Worker and Construction Worker Dose Summary (FGR-11)

Maximally Exposed Facility Worker (Building DTF 1)	Contribution (Location)	TEDE (mrem/year)
	Normal operations airborne releases (DTF 1) ^a	0.81
	External radiation from routine operations (DTF 1) ^a	1,800
	External radiation from cask storage (DTF 1) ^a	72
	Total Normal Operations	1,873
	Including Category 1 Event Sequences	
	Frequency Weighted Category 1 event sequences (DTF 1) ^{b, c}	12
	Total Normal Operations (1,873 mrem) plus Weighted Category 1 Event Sequences	1,885
	Combination of 2 maximum Category 1 event sequences in 1 year (DTF 1) ^b	32
	Total Normal Operations (1,873 mrem) plus Combination of Category 1 Event Sequences	1,905
Maximally Exposed Construction Worker (Building CHF)	Contribution (Location)	TEDE (mrem/year)
	Normal operations airborne releases (CHF) ^a	0.21
	External radiation from cask storage at 17A (CHF) ^a	46
	Total Normal Operations	46.2
	Including Category 1 Event Sequences	
	Frequency Weighted Category 1 event sequences (CHF) ^{d, e}	9.8
	Total Normal Operations (46.2 mrem) plus Weighted Category 1 Event Sequences	56.0
	Combination of 2 maximum Category 1 event sequences in 1 year (CHF) ^d	26
	Total Normal Operations (46.2 mrem) plus Combination of Category 1 Event Sequences	72.2

NOTE: ^a Doses from (BSC 2005c [DIRS 172488], Tables 4, 5a, 7a and 11).

^b DTF 1 facility worker doses from maximum single Category 1 event sequence is 16 mrem/event from (BSC 2005c [DIRS 172488], Table 6a) based on drop event in DTF 1 involving 2 SFA/event (BSC 2005a [DIRS 173590], Tables 5a to 5d).

^c Frequency weighted dose is based on frequencies from BSC 2005a ([DIRS 173590], Table 1) of 0.5 drops with 2 SFA and 0.5 collisions with 1 SFA/year. Weighted dose is $0.5 \times 16 \text{ mrem} / 2 \text{ SFA} \times 2 \text{ SFA} + 0.5 \times 16 \text{ mrem} / 2 \text{ SFA} \times 1 \text{ SFA} = 12 \text{ mrem}$.

^d Construction worker doses from maximum single Category 1 event sequence is 13 mrem/event from (BSC 2005c [DIRS 172488], Table 11) based on drop event in FHF involving 2 SFA/event (BSC 2005a [DIRS 173590], Tables 5a to 5d).

^e Frequency weighted dose is based on frequencies from BSC 2005a ([DIRS 173590], Table 1) of 0.5 drops with 2 SFA and 0.5 collisions with 1 SFA/year. Weighted dose is $0.5 \times 13 \text{ mrem} / 2 \text{ SFA} \times 2 \text{ SFA} + 0.5 \times 13 \text{ mrem} / 2 \text{ SFA} \times 1 \text{ SFA} = 9.8 \text{ mrem}$.

CHF = canister handling facility; DTF = Dry Transfer Facility; FHF = Fuel Handling Facility; mrem = one thousandth of a rem; rem = roentgen equivalent man; TEDE = total effective dose equivalent.

7. CONCLUSIONS

MACCS2 (ORNL 1998 [DIRS 164761]) and ARCON96 (BSC 2003b [DIRS 164784]) are used to perform the public dose and worker dose calculations. Calculated doses are compared to the performance objectives shown in Table 34. Calculated public doses and worker doses show that 10 CFR 63.111(a) and 10 CFR 63.111(b) [DIRS 173273] performance objectives are met.

The outputs listed in Attachment C have been found reasonable as compared to the inputs, and the results have been found suitable for their intended use.

Table 34. Summary Preclosure Dose Performance Criteria and Evaluation Results (FGR-11)

Standard	Limits	Results
Public Exposures		
Preclosure standard: 10 CFR 63.204 [DIRS 173273]; Preclosure Performance Objective for normal operations and Category 1 event sequences per 10 CFR 63.111(a)(2)	15 mrem/year ^b	0.84 mrem/year ^{a, c} (Table 25) 0.11 mrem/year ^{a, d} (Table 24) 0.97 mrem/year ^{a, e} (Section 6.3.2)
Constraint specified for air emissions of radioactive material to the environment; not a dose limitation per 10 CFR 20.1101(d) [DIRS 173165] ^f	10 mrem/year ^b	0.84 mrem/year ^{a, c} (Table 25)
Dose Limits for Individual Members of the Public for normal operations and Category 1 event sequences per 10 CFR 20.1301 [DIRS 173165] ^f	100 mrem/year ^{b, g} (general public or construction workers)	56 mrem/year ^{j, c} (Table 33) 32 mrem/year ^{h, d} (Table 24) 73 mrem/year ^{h, e} (Section 6.3.2)
	2 mrem/hr in any unrestricted area from external sources	< 2 mrem/hr ⁱ
Preclosure Performance Objective for any Category 2 event sequence per 10 CFR 63.111 (b)(2) [DIRS 173273]	5 rem ^b	0.10 rem (Max. TEDE Table 26)
	50 rem organ or tissue dose other than the lens of the eye	1.1 rem (Max. TODE Table 26)
	15 rem lens of the eye dose	0.13 rem (Max. LDE Table 26)
	50 rem shallow dose to skin	0.022 rem (Max. SDE Table 26)
Facility Workers' Exposures		
Occupational Dose Limits for Adults from normal operations and Category 1 event sequences per 10 CFR 20.1201 [DIRS 173165] ⁱ	5 rem/year ^b	1.9 rem/year ^{k, c} (Table 33) 0.016 rem/year ^{k, d} (Table 33) 1.9 rem/year ^{k, e} (Table 33)
	50 rem organ or tissue dose other than the lens of the eye	0.38 rem ^m
	15 rem lens of the eye dose	0.35 rem ⁿ
	50 rem shallow dose to skin	0.31 rem ^o

NOTES: ^a Results for public exposures are calculated at the site boundary

^b TEDE

^c Sum of TEDEs from normal operations and frequency weighted Category 1 event sequences in 1 year

^d TEDE from a single maximum Category 1 event sequence in 1 year

^e Sum of TEDEs from normal operations and any combination of Category 1 event sequences in 1 year

^f 10 CFR 63.111(a)(1) [DIRS 173273] requires operations area to meet the requirements of 10 CFR Part 20 [DIRS 173165]

^g 10 CFR 20.1301(a)(1); dose limit to the extent applicable (maximum of general public and construction worker)

^h Onsite public dose at 100 m

ⁱ 10 CFR 63.111(b)(1) would require repository design objectives for Category 1 event sequences and normal operations to meet 10 CFR 63.111(a)(1) requirements (10 CFR Part 20)

^j Onsite construction worker maximum dose from operating facilities at CHF

^k The highest annual facility worker at DTF 1

^l Shielding design criterion limits dose rate to 0.05 mrem/hr at unrestricted area surface BSC 2005f [DIRS 173614], Section 4.9.1.4]

^m 0.019 rem (TODE Table 29)+ 2 events x 0.18 rem/event (TODE Table 32) = 0.38 rem

ⁿ 0.011 rem (LDE Table 29)+ 2 events x 0.17 rem/event (LDE Table 32) = 0.35 rem

^o 0.009 rem (SDE Table 29)+ 2 events x 0.15 rem/event (SDE Table 32) = 0.31 rem

EDE = effective dose equivalent; LDE = lens dose equivalent; mrem = one thousandth of a rem; rem = roentgen equivalent man; SDE = shallow dose equivalent to skin; TEDE = total effective dose equivalent; TODE = total organ dose equivalent.

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8.2 CODES, STANDARDS, AND REGULATIONS

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10 CFR 63. 2005. Energy: Disposal of High-Level Radioactive Wastes in a Geologic Repository at Yucca Mountain, Nevada. ACC: MOL.20050405.0118

[DIRS 173375]

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8.3 PROCEDURES

LP-3.12Q-BSC, Rev. 0, ICN 0. *Design Calculations and Analyses*.

LP-3.13Q-BSC, Rev. 0, ICN 0. *Design Control*.

LP-3.15Q-BSC, Rev. 0 ICN 2. *Managing Technical Product Inputs*.

LP-SI.11Q-BSC, Rev. 0, ICN 1. *Software Management*.

8.4 SOURCE DATA, LISTED BY DATA TRACKING NUMBER

[DIRS 143142]

MO0001YMP00001.000 Minimum Distances from Selected Yucca Mountain Project Sites to Public Lands. Submittal date: 01/26/2000.

[DIRS 164768]

MO0210MXHT8491.000. Mean Seasonal Mixing Height Data (0400 and 1600 PST) for Desert Rock, Nevada from 1984 through 1991. Submittal date: 10/30/02.

[DIRS 164763]

MO0306WPMM9802.000. Wind Direction Sector, Wind Speed, Stability Class and Precipitation Data for MACCS2 98-02 Model. Submittal date: 06/06/2003.

[DIRS 164766]

MO0304MACCS280.000. Wind Direction Sector, Wind Speed, Stability Class and Precipitation Data for MACCS2 98-00 Model. Submittal date: 04/30/03.

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ATTACHMENT A – SURFACE FACILITY AIRBORNE RELEASE EVALUATION

A.1 Location of Receptors and Releases

The waste handling facilities of the repository consist of multiple buildings constructed near the North Portal to the underground repository. These facilities will receive, handle, stage, prepare, transfer, age, package, seal, transport, and emplace SNF and HLW. The surface facility layout is shown in Figure A-1. The subsurface facility layout is shown in Figure A-2.

The releases from the following waste handling facilities during normal operations are considered:

- Stack of DTF 1 (110)
- Stack of DTF 2 (120)
- Stack of FHF (210)
- SNF Aging System 17A and 17 B
- Subsurface exhaust shafts.

The release locations are shown in Figures A-1 and A-2.

A.2 ARCON96-Generated Atmospheric Dispersion Factors

For worker doses χ/Q values are required at short distances from release point, and therefore, the χ/Q values are generated using the NRC-sponsored computer code, *Software Code: ARCON*. V.96 (Atmospheric Relative CONcentrations in Building Wakes [ARCON96]), (BSC 2003b [DIRS 164784]), as described in NUREG/CR-6331 (Ramsdell and Simonen 1997 [DIRS 164547]).

For each receptor of interest, a cumulative probability distribution of χ/Q is constructed by the code for various release time periods. The 8,760-hr probabilistic χ/Q distribution is used to determine the annual average and the 50% median χ/Q values for the receptor of interest. The larger of the annual average or median χ/Q value is used to calculate the annual average dose to workers from airborne radionuclides during normal operations. The maximum 2 hour 95th percentile χ/Q value is used to calculate the dose to workers from airborne radionuclides for Category 1 event sequences.

The χ/Q values for airborne releases, at 26 onsite receptor locations, from DTF 1, DTF 2, the FHF, the SNF aging system, and the subsurface exhaust shafts, were calculated using ARCON96 (BSC 2003b [DIRS 164784]) in BSC 2005d ([DIRS 172941], Section 6.3). Receptor and exhaust stack input information is based on drawings (Figures A-1 and A-2). The χ/Q values at receptors for each release source are used to calculate the worker doses for releases from the surface and subsurface facilities from normal operations and Category 1 event sequences. These χ/Q values represent the dispersion factors estimated at the air intake points of the surface and subsurface facilities.

Source: BSC 2005d [DIRS 172941] Figure II-1

Figure A-1. Stack and Intake Location of Repository Surface Facilities

Source: BSC 2003d [DIRS 165572], Figure 10

Figure A-2. Subsurface Air intake and Exhaust Locations

A.3 MACCS2-Generated Atmospheric Dispersion Factors

For general public doses the χ/Q values are calculated internally in MACCS2 (ORNL 1998 [DIRS 164761]) using hourly meteorological data gathered at the Yucca Mountain site from 1998 through 2002 (Section 6.2.1.1.2). MACCS2 [DIRS 164761] uses 8,760 sets of hourly data on wind speed, wind direction, atmospheric stability class, and rain intensity collected over a period of 1 year to calculate χ/Q values. This process generates 8,760 χ/Q values, which includes the 16 directional sectors, wind speeds, and atmospheric stability classes collected in the annual data for 1999. The χ/Q values output from MACCS2 [DIRS 164761] are the mean, 50th percentile (median), 95th percentile, and 99.5th percentile values evaluated at a 11 km distance

from the release point for a surface release, or at a 8 km distance for a subsurface release (Section 6.2.1.5 and Attachment B, Figure B-1).

For normal operations, the mean or median χ/Q value is used, depending on which value is higher. Category 1 event sequences use the 95th percentile with a 5% exceedance of the χ/Q value evaluated in accordance with Regulatory Guide 1.145 [DIRS 103651], Section 3, at the closest site boundary of 11 km for the maximally exposed individual regardless of sector.

The χ/Q values are determined regardless of wind direction or sector for the distance of interest. The χ/Q values are overall site χ/Q values and are not tied to any particular sector, such as the sector to the west site boundary. Because all sector meteorological data are used in χ/Q calculations and the receptor location (i.e., 11 km from a DTF to the west site boundary) is the shortest distance from the release point, the resultant χ/Q values are the most conservative and bound all site boundary locations.

The output file for each of the MACCS2 computer runs (Table 20) provides information on the calculated χ/Q values at various distances from the release point (Table A-1). For each distance, the χ/Q values are provided as mean, 50th (median), 90th, 95th, 99th, and 99.5th percentile values.

The χ/Q values in Table A-1 are used in Section 6.3 to calculate public doses in the MACCS2 runs.

Table A-1. χ/Q Values for Normal Operations and Event Sequences

Event	Releases from:	X/Q Values at Various Distances From Release Point		
		100 m (s/m ³)	8 km (s/m ³)	11 km (s/m ³)
Normal Operations Max of (mean or median)	Surface facilities: surface releases from 1% of 3,600 MTHM SNF per year, Average PWR SFAs, HEPA-filtered ^a	5.62×10^{-5}	NA	2.69×10^{-6}
Normal Operations Max of (mean or median)	Subsurface facility: subsurface releases of waste package surface contamination, activated air and silica dust, unfiltered ^b	4.66×10^{-3}	5.26×10^{-6}	NA
Category 1 Event Sequence (95%-tile)	DTF or FHF: (drops and collisions) ^c	1.12×10^{-3}	NA	9.68×10^{-6}
Category 2 Event Sequence (95%-tile)	CHF, DTF, or FHF ^d	NA	NA	9.68×10^{-6}

NOTES: ^a Table 20, MACCS2 Run 1

^b Table 20, MACCS2 Run 3

^c Table 20, MACCS2 Run 4

^d Table 20, MACCS2 Run 8.

CHF = Canister Handling Facility; DTF = Dry Transfer Facility (DTF 1 or DTF 2); FHF = Fuel Handling Facility; HEPA = high-efficiency particulate air; MTHM = metric tons of heavy metal; NA = not applicable; PWR = pressurized water reactor; SFA = spent fuel assembly; SNF = spent nuclear fuel.

ATTACHMENT B

PRECLOSURE RADIATION DOSE LIMITS

Dose limits, both outside and inside the preclosure restricted area, are illustrated in Figures B-1 and B-2. The extent of the geologic repository operations area is to be considered coincident with the restricted area, as illustrated in Figure B-2.

Sources: DTN: MO0001YMP00001.000 [DIRS 143142]

Figure B-1. Minimum Distances From Selected Yucca Mountain Project Sites to Public Lands and Radiation Dose Limits Outside of the Preclosure Controlled Area

Sources: Figures A-1 and A-2 (Attachment A); Table 1 (Section 1)

Figure B-2. Radiation Dose Limits Inside the Preclosure Controlled Area

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ATTACHMENT C – MACCS2 FGR-11 INPUT AND OUTPUT FILE LISTING

MACCS2 (ORNL 1998 [DIRS 164761]) input and output files are listed in Table C-1 for all cases (Table 20, Runs 1 and 3 to 18) on a compact disk submitted to Document Control.

Table C-1. Listing of MACCS2 Computer Input and Output Files

Run No.	MACCS2 Input and Output File Name	Date	Time	File Size (B)
1	lasur01.inp	7/6/2005	04:50p	44,863
1	LASUR01.OUT	7/12/2005	01:30p	736,306
2	Not used.	-	-	-
2	Not used.	-	-	-
3	lasub01.inp	10/27/2004	04:22p	44,396
3	LASUB01.OUT	7/12/2005	04:37p	734,982
4	lapwr01.inp	7/14/2005	09:19a	44,856
4	LAPWR01.OUT	7/14/2005	09:38a	735,738
5	lapwr02.inp	6/23/2004	08:35p	44,755
5	LAPWR02.OUT	7/12/2005	01:54p	729,661
6	labwr01.inp	7/12/2005	01:45p	44,844
6	LABWR01.OUT	7/12/2005	02:19p	735,717
7	labwr02.inp	6/23/2004	09:25p	44,752
7	LABWR02.OUT	7/12/2005	02:32p	729,619
8	lahlw01.inp	9/23/2004	02:15p	44,459
8	LAHLW01.OUT	7/12/2005	02:55p	726,598
9	lahlw02.inp	9/24/2004	12:32p	44,714
9	LAHLW02.OUT	7/12/2005	03:02p	727,332
10	lahlw03.inp	10/1/2004	02:50p	44,528
10	LAHLW03.OUT	7/12/2005	03:09p	726,561
11	lahlw04.inp	9/25/2004	10:24a	44,315
11	LAHLW04.OUT	7/12/2005	03:13p	725,328
12	lanav01.inp	8/30/2004	03:41p	46,129
12	LANAV01.OUT	7/12/2005	03:26p	734,117
13	lasen01.inp	7/6/2005	04:52p	44,847
13	LASEN01.OUT	7/12/2005	03:39p	735,822
14	lasen02.inp	7/12/2005	04:18p	44,831
14	LASEN02.OUT	7/12/2005	05:00p	735,738
15	lasen03.inp	3/30/2005	03:01p	44,742
15	LASEN03.OUT	7/12/2005	04:03p	735,670
16	lasen04.inp	7/12/2005	04:19p	44,815
16	LASEN04.OUT	7/12/2005	05:22p	735,759
17	Lasen05.inp	7/15/2005	03:46p	44,824
17	LASEN05.OUT	7/15/2005	04:00p	736,416
18	Lahepa01.inp	7/15/2005	02:09p	44,824
18	LAHEPA01.OUT	7/15/2005	02:24p	729,771
All	YMP1999.INP	07/31/2003	2:27 PM	166,602
All	YMPCH1.INP	05/17/2004	10:33 AM	11,081

Table C-1. Listing of MACCS2 Computer Input and Output Files (Continued)

Run No.	MACCS2 Input and Output File Name	Date	Time	File Size (B)
5, 7, and 8 to 12	YMPEA.INP	07/12/2005	12:53 PM	12,356
1, 2, 3, 4, 6, 13, and 14	YMPEA1.INP	07/12/2005	12:53 PM	12,056
1 and 4 to 14	YMPSIT.INP	07/17/2003	8:39 AM	7,564
3	YSITE8.INP	05/07/2001	8:27 AM	7,564
All	YUCCALA.BIN	03/10/2004	5:11 PM	1,337,623
All	YMPD825.INP	02/22/2000	8:38 AM	678,657

ATTACHMENT D – COMIDA2 ICRP-72 FOOD CHAIN FILE *YUCICRPD.BIN*

This Attachment D describes the COMIDA2 (ORNL 1998 [DIRS 164761] Volume 2, Section 2) run to generate the food chain dose-to-source output data file *YUCICRPD.BIN* that is based on ICRP-72 dose conversion factors for use in evaluating general public doses in Attachment E.

Input to COMIDA2 is read from the following four formatted files:

1. *YUCICRPD.INP* – contains accident times and food consumption rates
2. *YUCICRPD.VAR* – contains nuclide specific data for crops
3. *YUCICRPD.PAR* – contains non-nuclide specific data for crops
4. *YMPICRPD.INP* – contains ICRP-72 dose conversion factors

The input parameters in the first three files are identical to those used to create the Federal Guidance Report No. 11 (Eckerman et al. 1988 [DIRS 101069]) based file *YUCCALA.BIN* identified in Attachment C, Table C-1, except that *YUCICRPD.INP* specifies the ICRP-72 dose conversion factor file, *YMPICRPD.INP* from *ICRP-72 Dose Conversion Factor Input File for MACCS2* (BSC 2005h [DIRS 174424], Table 13) for conversion factors. The COMIDA2 file *YUCICRPD.BIN* includes implicit daughter contributions for the nuclides listed in BSC 2005h ([DIRS 174424], Table 2).

COMIDA2 is executed using a batch command file called RUNCOM2 (ORNL 1998 [DIRS 164761] Volume 2, Section 2.3.1).

RUNCOM2 *YUCICRPD*

The following files are the input and output files from the COMIDA2 run to create *YUCICRPD.BIN*. included a compact disk submitted to Document Control.

Table D-1. COMIDA2 Input and Output File Names

COMIDA2 Input and Output File Name		Date	Time	File Size (kB)
Input Files	<i>YUCICRPD.inp</i>	03/16/2005	09:48a	2,775
	<i>YUCICRPD.par</i>	03/10/2005	02:54p	1,574
	<i>YUCICRPD.var</i>	03/10/2005	02:54a	34,644
ICRP DCF File	<i>YMPICRPD.inp</i>	03/16/2005	09:40a	676,863
Output Files	<i>YUCICRPD.BIN</i>	03/16/2005	10:18a	1,337,623
	<i>YUCICRPD.CNC</i>	03/16/2005	10:18a	6,666,551
	<i>YUCICRPD.LST</i>	03/16/2005	10:18a	2,409,734

ATTACHMENT E – ICRP WORKER AND GENERAL PUBLIC DOSE RESULTS

Doses in the body of this calculation are determined using ingestion and inhalation dose conversion factors from Federal Guidance Report No. 11 (Eckerman et al. 1988 [DIRS 101069]) and using cloud shine and ground shine dose conversion factors from Federal Guidance Report No. 12 (Eckerman and Ryman 1993 [DIRS 107684]). For comparison purposes, similar doses are determined in Attachment E of this calculation using Federal Guidance Report No. 12 dose conversion factors for cloud shine and ground shine, but using inhalation dose conversion factors from ICRP-68 (ICRP 1995 [DIRS 172721]) for workers and ingestion and inhalation dose conversion factors from ICRP-72 (ICRP 1996 [DIRS 152446]) for the general public.

This Attachment E summarizes worker and general public dose results using dose conversion factors ICRP references. The methodology, technical inputs and assumptions, and analysis approaches are the same as those described in Sections 3, 4, and 6 of this analysis. The computer software used is the same as discussed in Section 5 of this calculation. General public doses are calculated using ICRP-72 (ICRP 1996 [DIRS 152446]) inhalation and ingestion dose conversion factors and worker doses are calculated using ICRP-68 (ICRP 1995 [DIRS 172721]) inhalation dose conversion factors. Worker doses do not include an ingestion contribution. Cloud immersion and ground shine doses are based on FGR-12 (Eckerman and Ryman 1993 [DIRS 107684]) dose conversion factors.

For public doses, ICRP-72 (ICRP 1996 [DIRS 152446]) and FGR-11 (Eckerman et al. 1988 [DIRS 101069]) dose conversion factors are compared in Attachment G. That attachment tabulates the ratios of both inhalation and ingestion dose conversion factors by organ for each of the nuclides used in the MACCS2 (ORNL 1998 [DIRS 164761]) runs in this calculation. For worker doses, ICRP-68 (ICRP 1995 [DIRS 172721]) and FGR-11 dose conversion factors are compared in Attachment H. That attachment also tabulates the ratios of both inhalation and ingestion dose conversion factors by organ for each of the nuclides used in worker dose calculations.

E.1 MACCS2 Runs with ICRP Dose Conversion Factors

Each of the MACCS2 (ORNL 1998 [DIRS 164761]) runs listed in Table 20 for public doses is re-run with ICRP-72 (ICRP 1996 [DIRS 152446]) dose conversion factors. MACCS2 input files are identical to those for the FGR-11 (Eckerman et al. 1988 [DIRS 101069]) runs discussed in Section 6.2 and 6.3, except that the dose conversion factor file is *YMPICRPD.INP* (BSC 2005h [DIRS 174424], Table 13) and the food chain input file is the COMIDA2 output file *YUCICRPD.BIN* from Attachment D. MACCS2 runs with ICRP-72 dose conversion factors are listed in Table E-1.

Table E-1 MACCS2 ICRP-72 Computer Runs

Run No.	ATMOS File	Output File	Remarks
1	LASUR01i.INP	LASUR01i.OUT	Surface releases from 1% of an annual throughput of 3,600 MTHM, average PWR inventory with HEPA filters, elevated release
2			Not used.
3	LASUB8i.INP	LASUB8i.OUT	Subsurface releases from waste package surface contamination, neutron-activated air and dust without HEPA filters, ground-level release
4	LAPWR01i.INP	LAPWR01i.OUT	1 assembly, maximum PWR inventory with HEPA filters, ground-level release
5	LAPWR02i.INP	LAPWR02i.OUT	1 assembly, maximum PWR inventory without HEPA filters, ground-level release, with cask leak path factor
6	LABWR01i.INP	LABWR01i.OUT	1 assembly, maximum BWR inventory with HEPA filters, ground-level release
7	LABWR02i.INP	LABWR02i.OUT	1 assembly, maximum BWR inventory without HEPA filters, ground-level release, with cask leak path factor
8	LAHLW01i.INP	LAHLW01i.OUT	1 SRS HLW canister inventory without HEPA filters, ground-level release
9	LAHLW02i.INP	LAHLW02i.OUT	1 Hanford Site HLW canister inventory without HEPA filters, ground-level release
10	LAHLW03i.INP	LAHLW03i.OUT	1 West Valley HLW canister inventory without HEPA filters, ground-level release
11	LAHLW04i.INP	LAHLW04i.OUT	1 INL HLW canister inventory without HEPA filters, ground-level release
12	LANAV01i.INP	LANAV01i.OUT	1 naval SNF canister inventory without HEPA filters, ground-level release
13	LASEN01i.INP	LASEN01i.OUT	Sensitivity analysis of Run 1i: surface releases from 1% of an annual throughput of 3,600 MTHM, average PWR inventory with HEPA filters, elevated release. The release duration is changed from 24 hour to 1 hour
14	LASEN02i.INP	LASEN02i.OUT	Sensitivity analysis of Run 4i: 1 assembly, maximum PWR inventory with HEPA filters, ground-level release. The deposition velocity is changed from 0.01 m/s to 0.001 m/s
15	LASEN03i.INP	LASEN03i.OUT	Sensitivity analysis of Run 4i: 1 assembly, average PWR inventory with HEPA filters, ground-level release.
16	LASEN04i.INP	LASEN04i.OUT	Sensitivity analysis of Run 4i: 1 assembly, maximum PWR inventory without HEPA filters, ground-level release.
17	LASEN05i.INP	LASEN05i.OUT	Surface releases from 1% of an annual throughput of 3,600 MTHM, average PWR inventory with HEPA filters, elevated release, 40 m vent height
18	LAHEPA1i.INP	LAHEPA1i.OUT	Seismic event release of accumulated normal releases from 63,000 MTHM average PWR inventory, without HEPA filters, ground-level release, no leak path factor

BWR = boiling water reactor; HEPA = high-efficiency particulate air; HLW = high-level radioactive waste; INL = Idaho National Laboratory; PWR = pressurized water reactor; SNF = spent nuclear fuel; SRS = Savannah River Site.

E.2 PUBLIC DOSE RESULTS

E.2.1 Doses to Members of the Public from Normal Operations and Category 1 Event Sequences

MACCS2 (ORNL 1998 [DIRS 164761]) was used to calculate public TEDE to members of the public onsite at 100 m and at the site boundary of 11 km from normal operations (Table E-2) and Category 1 event sequences (Table E-4). Airborne doses to members of the public are based on inhalation and ingestion dose conversion factors from ICRP-72 (ICRP 1996 [DIRS 152446]).

Table E-2. Public Doses from Normal Operations (ICRP-72)

	Public	Public	Public	
Releases From:	TEDE at 100m	TEDE at 3 km	TEDE at 11 km	Reference
Surface Releases from 1% of 3,600 MTHM SNF per Year	(Sv/year)		(Sv/year)	LASUR01i.out ^a
Merged L-EFFECTIVE TOT LIF 10.9-11.1km MEAN	-		3.48×10^{-6}	p. 1
MAXIMUM ANNUAL FOOD DOSE (EFFECTIVE) MEAN	-		2.70×10^{-6}	p. 6
Merged - L-EFFECTIVE TOT LIF 0.1-0.2 km MEAN	2.53×10^{-4}		-	p. 1
Occupancy Factor	0.228		1.0	
	(mrem/year)		(mrem/year)	
Total x Occupancy Factor x 1E5 (mrem/Sv)	5.8×10^0		6.2×10^{-1}	
Subsurface Releases from Activation and WP Contamination		(Sv/year)	(Sv/year)	LASUB01i.out ^b
Merged L-EFFECTIVE TOT LIF 7.9-8.1km MEAN		-	1.49×10^{-7}	p. 1
MAXIMUM ANNUAL FOOD DOSE (EFFECTIVE) MEAN		-	3.28×10^{-9}	p. 6
Merged - L-EFFECTIVE TOT LIF 3.2-6.0 km MEAN		4.69×10^{-7}	-	p. 1
Occupancy Factor		0.228	1.0	
		(mrem/year)	(mrem/year)	
Total x Occupancy Factor x 1E5 (mrem/Sv)		1.1×10^{-2}	1.5×10^{-2}	
NOTES: ^a Table E-1, MACCS2 Run 1i ^b Table E-1, MACCS2 Run 3i. HEPA = high-efficiency particulate air; mrem = one thousandth of a rem; MTHM = metric tons of heavy metal; PWR = pressurized water reactor; rem = roentgen equivalent man; TEDE = total effective dose equivalent.				

In Table E-2, the doses at 11 km are larger than the doses at 3 km, because: (1) the doses at 11 km include the ingestion pathway while the doses at 3 km do not, and (2) the doses at 11 km assumes an exposure period of 8,760 hours while the doses at 3 km assume an exposure period of only 2,000 hours (Assumption 4.2.13).

Table E-3. Public Doses from HEPA Filtered Release from One Maximum Spent Fuel Assembly (ICRP-72)

Releases From:	Public TEDE at 100m	Public TEDE at 11 km	Reference
HEPA-filtered Release from 1 Maximum PWR SFA ^a	(Sv/event)	(Sv/event)	LAPWR01i.out
Merged L-EFFECTIVE TOT LIF 10.9-11.1km 95%	-	3.41×10^{-7}	p. 1
MAXIMUM ANNUAL FOOD DOSE (EFFECTIVE) 95%	-	1.98×10^{-7}	p. 6
Cohort 1 - L-EFFECTIVE TOT LIF 0.1-0.2 km 95%	8.86×10^{-5}	-	p. 3
Cohort 2 - L-EFFECTIVE TOT LIF 0.1-0.2 km 95%	1.35×10^{-4}	-	p. 5
Occupancy Factors (except 1.0 for Cohort 1)	0.228	1.0	
	(mrem/event)	(mrem/event)	
Total x Occupancy Factor x 1E5 (mrem/Sv)	$1.2 \times 10^{+1}$	5.4×10^{-2}	
HEPA-filtered Release from 1 Maximum BWR SFA ^b	(Sv/event)	(Sv/event)	LABWR01i.out
Merged L-EFFECTIVE TOT LIF 10.9-11.1km 95%	-	1.16×10^{-7}	p. 1
MAXIMUM ANNUAL FOOD DOSE (EFFECTIVE) 95%	-	7.61×10^{-8}	p. 6
Cohort 1 - L-EFFECTIVE TOT LIF 0.1-0.2 km 95%	3.09×10^{-5}	-	p. 3
Cohort 2 - L-EFFECTIVE TOT LIF 0.1-0.2 km 95%	4.99×10^{-5}	-	p. 5
Occupancy Factors (except 1.0 for Cohort 1)	0.228	1.0	
	(mrem/event)	(mrem/event)	
Total x Occupancy Factor x 1E5 (mrem/Sv)	4.2×10^0	1.9×10^{-2}	
NOTES: ^a Table E-1, MACCS2 Run 4i ^b Table E-1, MACCS2 Run 6i HEPA = high-efficiency particulate air; mrem = one thousandth of a rem; MTHM = metric tons of heavy metal; PWR = pressurized water reactor; BWR = boiling water reactor; rem = roentgen equivalent man; TEDE = total effective dose equivalent.			

The maximally exposed individual at the site boundary of 11 km is assumed to receive doses from the inhalation, resuspension inhalation, air submersion, groundshine, and ingestion pathways for a period of 8,760 hours (Assumption 4.2.13). The onsite individual member of the public, at 100 m from a DTF or the FHF, or 3 km away a subsurface exhaust shaft, is assumed to receive doses from inhalation, resuspension inhalation, air submersion, and groundshine pathways for a period of 2,000 hours (Assumption 4.2.13). Only HEPA-filtered public TEDEs are reported in Table E-4.

Table E-4. HEPA-Filtered Public TEDE for Category 1 Event Sequences (ICRP-72)

Event Sequence Identifier	Category 1 Events	Location	MAR (No. SFAs)		HEPA-Filtered Public TEDE at 100 m (mrem/event)		HEPA-Filtered Public TEDE at 11 km (mrem/event)	
			PWR ^a	BWR ^a	Max PWR ^b	Max BWR ^c	Max PWR ^b	Max BWR ^c
GET-03B	Collision involving a commercial SNF assembly	DTF and FHF Waste Transfer Cells	1	1	$1.2 \times 10^{+1}$	4.2×10^0	5.4×10^{-2}	1.9×10^{-2}
GET-03D	Drop of a commercial SNF assembly onto another assembly in a transportation cask	DTF and FHF Waste Transfer Cells	2	2	$2.4 \times 10^{+1}$	8.5×10^0	1.1×10^{-1}	3.8×10^{-2}

NOTES: Max PWR Fuel: Enrichment = 5.0%; Burnup = 80 GWd/MTU; Decay Time = 5 years.
Max BWR Fuel: Enrichment = 5.0%; Burnup = 75 GWd/MTU; Decay Time = 5 years.

^a Table 11, Column 5.

^b Table E-3, PWR SFA x No. SFAs.

^c Table E-3, BWR SFA x No. SFAs.

Max = maximum; BWR = boiling water reactor; DTF = Dry Transfer Facility (DTF 1 or DTF 2); FHF = Fuel Handling Facility; GWd = gigawatt day; HEPA = high-efficiency particulate air; MAR = material at risk; mrem = one thousandth of a rem; MTU = metric tons uranium; PWR = pressurized water reactor; rem = roentgen equivalent man; SFA = spent fuel assembly; SNF = spent nuclear fuel; TEDE = total effective dose equivalent.

E.2.2 Sum of Doses from Normal Operations and Category 1 Event Sequences

E.2.2.1 Sum of Frequency-Weighted Category 1 Event Sequences Dose

The maximum PWR dose per SFA with HEPA filters is used in the calculation of the sum of frequency-weighted Category 1 event sequence doses using:

$$\text{Category 1 event sequence doses} = (FA_{\text{drop}} \times N_{\text{drop}} + FA_{\text{coll}} \times N_{\text{coll}}) \times D_{\text{pwr}} \quad (\text{Eq. E.1})$$

where,

FA_{drop}	=	Maximum number of SFAs affected in a drop event
N_{drop}	=	Number of drops per year
FA_{coll}	=	Maximum number of SFAs affected in a collision event
N_{coll}	=	Number of collisions per year
D_{pwr}	=	Maximum PWR drop or collision dose per SFA.

The results of the dose aggregation calculation using Equation E.1 are shown in Table E-5.

Table E-5. Sum of Public Doses From Normal Operations and Category 1 Event Sequences (ICRP-72)

Event Sequence Identifier	Releases from:	MAR (1)	Number of events/year (2)	Public TEDE at 100 m (mrem/event) ^a (3)	Public TEDE at 11 km (mrem/event) ^b (4)	Public TEDE at 100 m (mrem/year) ^a (5)=(2)×(3)	Public TEDE at 11 km (mrem/year) ^b (6)=(2)×(4)
N.O	Surface releases from 1% of 3,600 MTHM of Average PWR SFAs per year, HEPA-filtered	NA	NA	NA	NA	Annual Dose 5.8×10^{0c}	Annual Dose 6.2×10^{-1c}
N.O.	Subsurface releases of waste package surface contamination, activated air and silica dust, unfiltered	NA	NA	NA	NA	Annual Dose 1.1×10^{-2c}	Annual Dose 1.5×10^{-2c}
N.O.	Direct radiations from stored casks ^f	NA	NA	NA	NA	Annual Dose 3.1×10^0	Annual Dose NA
GET-03B	Drop of a Maximum PWR commercial SNF assembly onto another assembly	1 ^d	0.5 ^e	$1.2 \times 10^{+1}$ (Note d)	5.4×10^{-2} (Note d)	Frequency Weighted Dose 6.0×10^0	Frequency Weighted Dose 2.7×10^{-2}
GET-03D	Drop of a Maximum PWR commercial SNF assembly onto another assembly	2 ^d	0.5 ^e	$2.4 \times 10^{+1}$ (Note d) ^d	1.1×10^{-1} (Note d)	Frequency Weighted Dose $1.2 \times 10^{+1}$	Frequency Weighted Dose 5.4×10^{-2}
Total:						$2.7 \times 10^{+1}$	7.1×10^{-1}

NOTES: ^a Onsite member of the public is located at 100 m away from a DTF or the FHF and at 3 km away from the subsurface exhaust shafts and is exposed to radiation for a period of 2,000 hour (Assumption 4.2.13)

^b Offsite member of the public is located at 11 km away from a DTF or the FHF, and at 8 km away from the subsurface exhaust shafts and is exposed to radiation for a period of 8,760 hour (Assumption 4.2.13)

^c Table E-2, columns 1, 2, and 3

^d Table E-4

^e Table 9, column 3.

^f Direct radiations from stored casks to North Perimeter Security Station (30C) from BSC 2005c ([DIRS 172488], Table 7b) corresponding to the maximum onsite public dose location for releases in Assumption 4.1.13.

DTF = Dry Transfer Facility (DTF 1 or DTF 2); FHF = Fuel Handling Facility; HEPA = high-efficiency particulate air [filter]; NA = not applicable; PWR = pressurized water reactor; SNF = spent nuclear fuel.

E.2.2.2 Sum of Combinations of Category 1 Event Sequences Dose

The dose impact of combinations of Category 1 event sequences is evaluated. Three combinations of Category 1 event sequences were identified for consideration in the consequence analysis (BSC 2005i [DIRS 174467], Section 7.2.1):

- Two commercial SNF assembly drops within 1 year
- Two commercial SNF assembly collisions within 1 year
- One drop and one collision of commercial SNF assemblies within 1 year.

The collision event involves one PWR or BWR SFA; the drop event potentially affects two PWR or BWR SFAs.

The case of the two commercial SNF assembly drops has the highest MAR (i.e., four SFAs) and, hence, has the highest radiation dose among the three cases.

The radiation doses resulting from two commercial SNF assembly drops and normal operations from Table E-5 results are $5.8 + 0.011 + 3.1 + 2 \times 24$ mrem/year = $5.7 \times 10^{+1}$ mrem/year for

public exposure at 100 m and $0.62 + 0.015 + 2 \times 0.11$ mrem/year = 8.6×10^{-1} mrem/year for public exposure at the site boundary.

E.2.3 Doses to Members of the Public from Category 2 Event Sequences

The outputs from MACCS2 (ORNL 1998 [DIRS 164761]) dose calculations for members of the public from Category 2 event sequences are inhalation, resuspension inhalation, ingestion, cloudshine, and groundshine doses at 11 km (see Section 4.1.4). Table 12 shows that the bounding Category 2 event sequences are:

- Event GET-01A(a) for a drop and breach of 36 PWR SFAs
- Event GET-01A(b) for a drop and breach of 74 BWR SFAs
- Event GET-02B(n) for a drop and breach of one naval SNF canister
- Event GET-02B(a) for a drop and breach of five HLW canisters from Savannah River Site
- Event GET-02B(b) for a drop and breach of five HLW canisters from the Hanford Site
- Event GET-02B(c) for a drop and breach of five HLW canisters from West Valley
- Event GET-02B(d) for a drop and breach of five HLW canisters from Idaho National Laboratory.
- Event SEISMIC for bounding release of accumulated HEPA and duct activity.

Doses to members of the public from these bounding Category 2 event sequences are summarized in Table E-6, Table E-7 and Table E-8.

Unfiltered doses from dropping a waste package or a transportation cask containing maximum PWR or maximum BWR SFAs and from dropping commercial spent nuclear fuel assemblies are shown in Table E-6. Public doses from the drop of an SNF canister, an HLW canister, or a DPC are bounded by the doses from dropping a waste package or a transportation cask containing maximum PWR or maximum BWR SFAs.

The results of public dose calculations for HLW and naval SNF show that breached Savannah River Site HLW canisters have the highest dose consequences (Table E-7). Table E-8 summarizes doses to members of the public from each of these bounding Category 2 event sequences.

Table E-6. Unfiltered Public Doses from Breached Transportation Cask and Dropped Commercial Spent Nuclear Fuel Assemblies (ICRP-72)

	TEDE	TODE ^a	SDE	LDE	
Releases From:	at 11 km	at 11 km	at 11 km	at 11 km	Reference
Drop and Breach of Cask with 1 Maximum PWR no HEPA	(Sv/event)	(Sv/event)	(Sv/event)	(Sv/event)	LAPWR02i.out ^b
Merged L-EFFECTIVE TOT LIF 10.9-11.1km 95%	2.03×10^{-5}				p. 1
MAXIMUM ANNUAL FOOD DOSE (EFFECTIVE) 95%	4.29×10^{-6}				p. 6
Merged L-BONE SUR TOT LIF 10.9-11.1km 95%		7.01×10^{-5}			p. 1
Cohort 1 A-SKIN(FGR) TOT LIF 10.9-11.1 km 95%			6.65×10^{-6}		p. 4
sum TEDE + SDE				3.12×10^{-5}	Sum
	(mrem)	(mrem)	(mrem)	(mrem)	
Total x 1E5 (mrem/Sv)	2.5×10^0	7.0×10^0	6.7×10^{-1}	3.1×10^0	
Transportation Cask with 36 Maximum PWR SFAs	$8.9 \times 10^{+1}$	$2.5 \times 10^{+2}$	$2.4 \times 10^{+1}$	$1.1 \times 10^{+2}$	x 36
Drop and Breach of Cask with 1 Maximum BWR no HEPA	(Sv/event)	(Sv/event)	(Sv/event)	(Sv/event)	LABWR02i.out ^c
Merged L-EFFECTIVE TOT LIF 10.9-11.1km 95%	8.49×10^{-6}				p. 1
MAXIMUM ANNUAL FOOD DOSE (EFFECTIVE) 95%	1.46×10^{-6}				p. 6
Merged L-BONE SUR TOT LIF 10.9-11.1km 95%		2.32×10^{-5}			p. 1
Cohort 1 A-SKIN(FGR) TOT LIF 10.9-11.1 km 95%			2.35×10^{-6}		p. 4
sum TEDE + SDE				1.23×10^{-5}	Sum
	(mrem)	(mrem)	(mrem)	(mrem)	
Total x 1E5 (mrem/Sv)	1.0×10^0	2.3×10^0	2.4×10^{-1}	1.2×10^0	
Transportation Cask with 74 Maximum BWR SFAs	$7.4 \times 10^{+1}$	$1.7 \times 10^{+2}$	$1.7 \times 10^{+1}$	$9.1 \times 10^{+1}$	x 74
Seismic event HEPA and ducting release no HEPA	(Sv/event)	(Sv/event)	(Sv/event)	(Sv/event)	LAHEPA1i.out ^d
Merged L-EFFECTIVE TOT LIF 10.9-11.1km 95%	2.61×10^{-4}				p. 1
MAXIMUM ANNUAL FOOD DOSE (EFFECTIVE) 95%	1.11×10^{-5}				p. 6
Merged L-BONE SUR TOT LIF 10.9-11.1km 95%		6.97×10^{-3}			p. 1
Cohort 1 A-SKIN(FGR) TOT LIF 10.9-11.1 km 95%			1.20×10^{-5}		p. 4
sum TEDE + SDE				2.84×10^{-4}	Sum
	(mrem)	(mrem)	(mrem)	(mrem)	
Total x 1E5 (mrem/Sv)	$2.7 \times 10^{+1}$	$7.0 \times 10^{+2}$	1.2×10^0	$2.8 \times 10^{+1}$	
NOTES: Maximum PWR Fuel: enrichment = 5.0%; burnup = 80 GWd/MTU; decay time = 5 years. Maximum BWR Fuel: enrichment = 5.0%; burnup = 75 GWd/MTU; decay time = 5 years. ^a The bone surface dose is the highest TODE; ^b Table E-1, MACCS2 Run 5i; ^c Table E-1, MACCS2 Run 7i; ^d Table E-1, MACCS2 Run 18i.					
BWR = boiling water reactor; CDE = committed dose equivalent; DDE = deep dose equivalent; HEPA = high-efficiency particulate air; LDE = lens dose equivalent; mrem = one thousandth of a rem; PWR = pressurized water reactor; rem = roentgen equivalent man; SDE = shallow dose equivalent to skin; TODE = total organ dose equivalent.					

Table E-7. Unfiltered Public Doses From Breached Vitrified High-level Radioactive Waste Canisters and Naval Spent Nuclear Fuel Canisters (ICRP-72)

	TEDE	TODE ^a	SDE	LDE	
Releases From:	at 11 km	at 11 km	at 11 km	at 11 km	Reference
Drop and Breach of 1 Naval SNF Canister no HEPA ^b	(Sv/event)	(Sv/event)	(Sv/event)	(Sv/event)	LANAV01i.out
Merged L-EFFECTIVE TOT LIF 10.9-11.1km 95%	1.31×10^{-5}				p. 1
MAXIMUM ANNUAL FOOD DOSE (EFFECTIVE) 95%	1.68×10^{-6}				p. 6
Merged L-BONE SUR TOT LIF 10.9-11.1km 95%		4.31×10^{-5}			p. 1
Cohort 1 A-SKIN(FGR) TOT LIF 10.9-11.1 km 95%			1.08×10^{-6}		p. 4
sum TEDE + SDE				1.59×10^{-5}	Sum
	(mrem)	(mrem)	(mrem)	(mrem)	
Total x 1E5 (mrem/Sv)	1.5×10^0	4.3×10^0	1.1×10^{-1}	1.6×10^0	
Drop and Breach of 1 SRS HLW Canister no HEPA ^c	(Sv/event)	(Sv/event)	(Sv/event)	(Sv/event)	LAHLW01i.out
Merged L-EFFECTIVE TOT LIF 10.9-11.1km 95%	4.73×10^{-6}				p. 1
MAXIMUM ANNUAL FOOD DOSE (EFFECTIVE) 95%	1.31×10^{-7}				p. 6
Merged L-BONE SUR TOT LIF 10.9-11.1km 95%		8.79×10^{-5}			p. 1
Cohort 1 A-SKIN(FGR) TOT LIF 10.9-11.1 km 95%			1.50×10^{-7}		p. 4
sum TEDE + SDE				5.01×10^{-6}	Sum
	(mrem)	(mrem)	(mrem)	(mrem)	
Total x 1E5 (mrem/Sv)	4.9×10^{-1}	8.8×10^0	1.5×10^{-2}	5.0×10^{-1}	
Cask with 5 SRS HLW Canisters	2.4×10^0	$4.4 \times 10^{+1}$	7.5×10^{-2}	2.5×10^0	x 5
Drop and Breach of 1 Hanford Site HLW Canister no HEPA ^d	(Sv/event)	(Sv/event)	(Sv/event)	(Sv/event)	LAHLW02i.out
Merged L-EFFECTIVE TOT LIF 10.9-11.1km 95%	8.86×10^{-7}				p. 1
MAXIMUM ANNUAL FOOD DOSE (EFFECTIVE) 95%	9.96×10^{-8}				p. 6
Merged L-BONE SUR TOT LIF 10.9-11.1km 95%		2.34×10^{-5}			p. 1
Cohort 1 A-SKIN(FGR) TOT LIF 10.9-11.1 km 95%			8.79×10^{-8}		p. 4
sum TEDE + SDE				1.07×10^{-6}	Sum
	(mrem)	(mrem)	(mrem)	(mrem)	
Total x 1E5 (mrem/Sv)	9.9×10^{-2}	2.3×10^0	8.8×10^{-3}	1.1×10^{-1}	
Cask with 5 Hanford Site HLW Canisters	4.9×10^{-1}	$1.2 \times 10^{+1}$	4.4×10^{-2}	5.4×10^{-1}	x 5
Drop and Breach of 1 West Valley HLW Canister no HEPA ^e	(Sv/event)	(Sv/event)	(Sv/event)	(Sv/event)	LAHLW03i.out
Merged L-EFFECTIVE TOT LIF 10.9-11.1km 95%	8.22×10^{-7}				p. 1
MAXIMUM ANNUAL FOOD DOSE (EFFECTIVE) 95%	4.48×10^{-8}				p. 6
Merged L-BONE SUR TOT LIF 10.9-11.1km 95%		2.67×10^{-5}			p. 1
Cohort 1 A-SKIN(FGR) TOT LIF 10.9-11.1 km 95%			5.79×10^{-8}		p. 4
sum TEDE + SDE				9.25×10^{-7}	Sum
	(mrem)	(mrem)	(mrem)	(mrem)	
Total x 1E5 (mrem/Sv)	8.7×10^{-2}	2.7×10^0	5.8×10^{-3}	9.2×10^{-2}	
Cask with 5 West Valley HLW Canisters	4.3×10^{-1}	$1.3 \times 10^{+1}$	2.9×10^{-2}	4.6×10^{-1}	x 5

Table E-7. Unfiltered Public Doses From Breached Vitrified High-level Radioactive Waste Canisters and Naval Spent Nuclear Fuel Canisters (Continued)

	TEDE	TODE ^a	SDE	LDE	
Releases From:	at 11 km	at 11 km	at 11 km	at 11 km	Reference
Drop and Breach of 1 INL HLW Canister no HEPA ^f	(Sv/event)	(Sv/event)	(Sv/event)	(Sv/event)	LAHLW04i.out
Merged L-EFFECTIVE TOT LIF 10.9-11.1km 95%	1.13×10^{-7}				p. 1
MAXIMUM ANNUAL FOOD DOSE (EFFECTIVE) 95%	2.20×10^{-8}				p. 6
Merged L-BONE SUR TOT LIF 10.9-11.1km 95%		7.19×10^{-7}			p. 1
Cohort 1 A-SKIN(FGR) TOT LIF 10.9-11.1 km 95%			1.26×10^{-8}		p. 3
sum TEDE + SDE				1.48×10^{-7}	Sum
	(mrem)	(mrem)	(mrem)	(mrem)	
Total x 1E5 (mrem/Sv)	1.4×10^{-2}	7.2×10^{-2}	1.3×10^{-3}	1.5×10^{-2}	
Cask with 5 INL HLW Canisters	6.8×10^{-2}	3.6×10^{-1}	6.3×10^{-3}	7.4×10^{-2}	x 5
NOTES: a The bone surface dose is the highest TODE for HLW canisters and naval SNF canisters b Table E-1, MACCS2 Run 12i c Table E-1, MACCS2 Run 8i d Table E-1, MACCS2 Run 9i e Table E-1, MACCS2 Run 10i f Table E-1, MACCS2 Run 11i HEPA = high-efficiency particulate air; HLW = high-level radioactive waste; INL = Idaho National Laboratory; LDE = lens dose equivalent; mrem = one thousandth of a rem; rem = roentgen equivalent man; SDE = shallow dose equivalent to skin; SRS = Savannah River Site; TEDE = total effective dose equivalent; TODE = total organ dose equivalent.					

Table E-8. Summary of Category 2 Public Doses per Event (ICRP-72)

		TEDE	TODE	SDE	LDE
Event	Event Description	at 11 km	at 11 km	at 11 km	at 11 km
		(mrem/event)	(mrem/event)	(mrem/event)	(mrem/event)
GET-01A(a)	Drop and Breach Transportation Cask with 36 Maximum PWR SFAs ^a	$8.9 \times 10^{+1}$	$2.5 \times 10^{+2}$	$2.4 \times 10^{+1}$	$1.1 \times 10^{+2}$
GET-01A(b)	Drop and Breach Transportation Cask with 74 Maximum BWR SFAs ^a	$7.4 \times 10^{+1}$	$1.7 \times 10^{+2}$	$1.7 \times 10^{+1}$	$9.1 \times 10^{+1}$
GET-02B(n)	Drop and Breach of 1 Naval SNF Canister ^b	1.5×10^0	4.3×10^0	1.1×10^{-1}	1.6×10^0
GET-02B(a)	Drop and Breach of Cask with 5 SRS HLW Canisters ^b	2.4×10^0	$4.4 \times 10^{+1}$	7.5×10^{-2}	2.5×10^0
GET-02B(b)	Drop and Breach of Cask with 5 Hanford Site HLW Canisters ^b	4.9×10^{-1}	$1.2 \times 10^{+1}$	4.4×10^{-2}	5.4×10^{-1}
GET-02B(c)	Drop and Breach of Cask with 5 West Valley HLW Canisters ^b	4.3×10^{-1}	$1.3 \times 10^{+1}$	2.9×10^{-2}	4.6×10^{-1}
GET-02B(d)	Drop and Breach of Cask with 5 INL HLW Canisters ^b	6.8×10^{-2}	3.6×10^{-1}	6.3×10^{-3}	7.4×10^{-2}
SEISMIC	Release of Accumulated HEPA and Ducting Activity	$2.7 \times 10^{+1}$	$7.0 \times 10^{+2}$	1.2×10^0	$2.8 \times 10^{+1}$
Notes: ^a From Table E-6; ^b From Table E-7.					

E.2.4 Sensitivity Analysis and Treatment of Uncertainty

This section discusses sensitivity analysis performed for and treatment of uncertainties in public doses. A discussion of uncertainties in worker doses is beyond the scope of this report because the calculated worker doses presented in this calculation were provided by various references.

E.2.4.1 Sensitivity Analysis

A maximum release duration of 24 hour allowed in MACCS2 (ORNL 1998 [DIRS 164761]) is used for annual releases for normal operations (Assumption 4.2.4). MACCS2 Run 1i and Run 13i (Table E-1) were made with 24-hr and 1-hr release durations, respectively. The resulting doses from the shorter 1-hr release duration are higher than the longer 24-hr release duration. The result is considered reasonable because the radionuclides inhaled and ingested at an earlier time for the shorter release duration have a slightly longer time to decay and produce alpha and beta particles. Therefore, the use of a shorter release duration of 1 day instead of 1 year with the same amount of radionuclide releases for normal operations is conservative.

For the twelve MACCS2 base cases, a particle deposition velocity of 0.01 m/s is used. For sensitivity analysis, a particle deposition velocity of 0.001 m/s is used in MACCS2 Run 14i (Table E-1) with results showing a dose decrease by a factor of about 2 at 100 m and increase by a factor of about 1.7 at 11 km. Because the 100m doses are the more limiting, i.e. closer to regulatory limits, a particle deposition velocity of 0.01 m/s provides more conservative results for compliance evaluations.

MACCS2 Run 15i (Table E-1) has shown that the calculated doses decrease by approximately a factor of 3 by use of an average PWR assembly instead of a maximum PWR assembly. Showing the use of the maximum PWR radionuclide inventory is conservative.

MACCS2 Run 16i (Table E-1) has shown that without HEPA filters the calculated doses at 100 m and 11 km away from the release point for a drop event involving two PWR SFAs could exceed the 100 mrem and 15 mrem dose limits for onsite and offsite members of the public, respectively.

MACCS2 Run 17i (Table E-1) with a 40 m vent height has shown, by comparing to Run 1 with a 30 m vent height, that calculated doses decrease by a factor of about 3 at 100 m and increase by a factor of about 1.06 at 11 km. Because the 100m doses are the more limiting, i.e. close to regulatory limits, a 30 m vent height provides more conservative results for compliance evaluations.

E2.4.2 Treatment of Uncertainty

Uncertainties in consequence analyses are addressed by using conservative inputs and assumptions. For calculating public and worker doses for Category 1 event sequences involving drops and collisions, it is conservatively assumed that 100% fuel rod cladding is breached (Assumption 4.2.7). This is at least a factor of five larger than the best estimate value.

A comparison between MACCS2 Run 15i and Run 4i (Table E-1) has shown that using the average PWR assembly inventory instead of the maximum PWR assembly inventory, the calculated doses for Category 1 event sequences involving drops and collisions decrease by a factor of about 3.

Uncertainties in calculating public doses for Category 2 event sequences are addressed by using conservative inputs and bounding assumptions. The bounding assumptions include the use of the bounding MAR (i.e., the maximum possible number of SFAs allowed in a certified cask) for a

transportation cask, bounding source terms, 100% fuel rod cladding breach, and 95th percentile weather condition (i.e., χ/Q values). The bounding MAR (i.e., 36 PWR or 74 BWR SFAs in a transportation cask) is at least a factor of 1.5 higher than the average value of the MAR. A comparison between MACCS2 Run 4i and Run 15i (Table E-1) has shown that the bounding PWR source terms are at least a factor of 3 higher than the average PWR source terms.

The assumption of a 100% fuel rod cladding breach (Assumption 4.2.7) is very conservative in view of the fact that historical SNF drop incidents at nuclear power plants showed only minimum damage to the cladding. Run 4i (Table E-1) has shown that the use of the 95th percentile weather condition is about a factor of 3 higher than the mean value.

The information on conservatism provided in this section ensures that uncertainties in inputs are treated with a reasonable degree of conservatism.

E.2.5 Direct Radiation Exposures During Normal Operations, Category 1 Event Sequences, and Category 2 Event Sequences

Offsite direct exposures originate only from the surface facilities, because subsurface facilities, such as the emplacement drifts, are shielded by massive rock. Surface facilities with potential sources of contribution to offsite direct exposures include the transportation cask buffer/staging area and the SNF aging system.

Other facilities, such as the CHF, DTF 1, DTF 2, and the FHF, provide concrete shielding for the exterior walls except for the entrance vestibules. This shielding typically reduces the dose rate outside the building to 0.25 mrem/hour (BSC 2005f [DIRS 173614], Section 4.9.1.3) except during cask handling operations around the vestibule. These dose rates result in a negligible contribution to the public dose at the site boundary located at 11 km (see Section 4.1.4) from the surface facilities.

The transportation cask buffer/staging area provides space for staging of shielded truck and rail casks. The dose rate from an individual cask is regulated by the NRC (e.g., 10 mrem/hour at any point 2 m from the outer lateral surface of the transport vehicle specified in 10 CFR 71.47(b)(3) [DIRS 173375] for exclusive use shipment only). With multiple casks in the staging area, the dose rate will increase, depending on the cask staging configurations. This radiation level affects the worker dose, but poses no impact on the public dose at the site boundary because of the large distance factor.

In addition, 10 CFR 20.1301(a)(2) [DIRS 173165] requires that each licensee shall conduct operations so that the dose in any unrestricted area from external sources does not exceed 0.002 rem (2 mrem) in any 1 hour. This requirement applies to normal operations and Category 1 event sequences.

The dose requirements in 10 CFR Part 20 [DIRS 173165] include contributions from direct exposures. Direct exposures from the SNF aging system arise from the effects of neutron and gamma skyshine. These effects depend on site-specific fuel characteristics of initial enrichment, burnup, and cooling time, along with facility layout, site layout, and site boundary characteristics.

Skyshine radiation dose calculations are typically performed with the MCNP code (Briesmeister 1997 [DIRS 103897]). Aging cask vendors have included the skyshine analysis in their safety analysis reports submitted to the NRC to demonstrate regulatory compliance, such as *Topical Safety Analysis Report for the HI-Storm 100 Cask System, HOLTEC Report HI-951312, Revision 2, NRC Docket No. 72-1014* (NRC 1997 [DIRS 152462], Section 5.4.3, p. 5.4-4).

NRC (1997 [DIRS 152462], Section 5.4.3, p. 5.4-4) shows that the skyshine dose at 200 m from an independent spent fuel storage facility is in the range of 11.6 to 19.3 mrem/year (NRC 1997 [DIRS 152462], Table 5.1.9, p. 5.1-15) for array configurations 2×3 , 2×4 , and 2×5 . This dose would be further reduced by permanent or temporary shielding. With this dose level, the public dose at the site boundary from skyshine radiation is negligible, based on the distance factor and attenuation by air.

Onsite and offsite doses from direct exposure following Category 1 and Category 2 event sequences were calculated in BSC 2005c [DIRS 172488]. The bounding source terms for commercial SNF, naval SNF, DOE SNF standardized and MCO canisters and HLW were used to calculate the dose rates at various distances from the source BSC 2005c ([DIRS 172488], Section 6.3). The dose rates are multiplied by the exposure time to yield the onsite and offsite doses. The calculated doses (Table E-8) include contributions from direct exposure.

E.2.6 Doses to Members of the Public Being ALARA

Regulation 10 CFR 20.1101(b) states that the licensee shall use to the extent practical both procedures and engineering controls based upon sound radiation protection principles to achieve occupational doses and doses to members of the public that are ALARA.

To implement the ALARA goals of 10 CFR 20.1101(d), the calculated offsite public TEDE is compared with the 10 mrem/year offsite ALARA dose constraint (Section 7) along with other project ALARA goals.

E.3 WORKER DOSE RESULTS

The results of worker dose calculations are discussed in this section.

E.3.1 Normal Operations

E.3.1.1 Worker Dose From Airborne Releases

The annual doses to surface facility workers from potential surface facility normal operational releases are calculated and summarized in BSC 2005b ([DIRS 172487], Table 16) and BSC 2005c ([DIRS 172488], Table 5b) for a full time worker who works 2,000 hours (BSC 2005b [DIRS 172487], Section 4.3.7). Airborne doses to workers are based on inhalation dose conversion factors from ICRP-68 (ICRP 1995 [DIRS 172721]).

The estimated maximum annual surface facility worker dose from airborne releases is 1.3 mrem/year TEDE (Table E-9) based on summing the maximums of releases to any worker location. Results for specific worker locations show that the highest total, among the 30 receptor locations, is at DTF 2 with a total of 1.2 mrem/year TEDE (BSC 2005c [DIRS 172488], Table 5b).

Table E-9. Surface Facility Worker Maximum Annual Doses From Normal Operations Releases (ICRP-68)

Released from	TEDE (mrem/year)	Highest TODE (mrem/year)	SDE (mrem/year)	LDE (mrem/year)
DTF 1 ^b	7.9×10^{-1}	6.5×10^0	5.6×10^0	6.4×10^0
DTF 2 ^b	3.0×10^{-1}	2.5×10^0	2.1×10^0	2.5×10^0
FHF ^b	1.9×10^{-1}	1.5×10^0	1.3×10^0	1.5×10^0
Maximum of 17A and 17B ^a	8.3×10^{-3}	NC	NC	NC
Subsurface Exhaust Shafts ^b	3.4×10^{-2}	5.4×10^{-1}	2.6×10^{-2}	6.0×10^{-2}
Total ^c	1.3×10^0	$1.1 \times 10^{+1}$	9.0×10^0	$1.0 \times 10^{+1}$

NOTES: ^a BSC 2005c [DIRS 172488], (Table 5b) for CHF

^b BSC 2005b [DIRS 172487], Table 16

^c Total is the sum of maximums from DTF 1, DTF 2, FHF, Max. of 17A and 17B, and subsurface exhaust shafts for any worker location.

DTF = Dry Transfer Facility; FHF = Fuel Handling Facility; LDE = lens dose equivalent; mrem = one thousandth of a rem; NC = not calculated; rem = roentgen equivalent man; SDE = shallow dose equivalent to skin; SNF = spent nuclear fuel; TEDE = total effective dose equivalent; TODE = total organ dose equivalent.

Three potential sources of airborne radioactive material releases were calculated for the subsurface repository under normal operations, which are (BSC 2005b [DIRS 172487], Section 6):

- Radioactive contamination suspended from the external surfaces of the emplaced waste packages
- Neutron activation products generated from irradiation of ventilation air inside the emplacement drifts

- Neutron activation products generated from irradiation of the host rocks inside the emplacement drifts.

Annual TEDEs to subsurface workers from potential normal operational releases are calculated and summarized in BSC (2005c [DIRS 172488], Table 5b). The estimated maximum annual subsurface facility worker dose from airborne releases is 8.4×10^{-2} mrem/year TEDE (Table E-10).

The annual maximum dose to a repository worker was calculated for a full time worker who works 2,000 hours at the access main that is taking air from Intake Shaft 1, about 410 m from Exhaust Shaft 1 (BSC 2005b [DIRS 172487], Section 4.2.9). Airborne radioactive contamination in the access main may result from re-entry of the released material from the exhaust shafts.

Table E-10. Annual Subsurface Facility Worker Doses From Normal Operations Releases (ICRP-68)

Released from	TEDE (mrem/year)	Highest TODE (mrem/year)	SDE (mrem/year)	LDE (mrem/year)
DTF 1	1.7×10^{-2}	NC	NC	NC
DTF 2	1.2×10^{-2}	NC	NC	NC
FHF	1.9×10^{-2}	NC	NC	NC
Maximum of 17A and 17B	2.1×10^{-3}	NC	NC	NC
Subsurface Exhaust Shafts	3.4×10^{-2}	NC	NC	NC
Total	8.4×10^{-2}	NC	NC	NC

DTF = Dry Transfer Facility; FHF = Fuel Handling Facility; LDE = lens dose equivalent; mrem = one thousandth of a rem; NC = not calculated (negligible); rem = roentgen equivalent man; SDE = shallow dose equivalent to skin; TEDE = total effective dose equivalent; TODE = total organ dose equivalent.

Source: BSC 2005c [DIRS 172488], Table 5b

E.3.1.2 Worker Dose From Direct Radiation

Annual worker doses from direct radiation from contained sources, such as transportation casks and waste packages, during normal operations were calculated for the CHF, DTF 1, DTF 2, the FHF, the TCRRF, the Remediation Facility, the SNF aging system, and the subsurface facility (Table E-11).

The highest annual dose to subsurface facility workers from exposure to direct radiation is 380 mrem/year for an emplacement/retrieval locomotive operator (Table E-11), which does not exceed the ALARA goal to minimize the number of individuals that have the potential of receiving more than 500 mrem/year TEDE (BSC 2005f [DIRS 173614], Section 4.9.3.3).

The highest annual dose to surface facility workers from exposure to direct radiation is 1,800 mrem/year for a cask/waste receipt operator in the DTFs and a cask transfer operator in the SNF Aging System (Table E-11). This dose rate exceeds the ALARA goal to minimize the number of individuals that have the potential of receiving more than 500 mrem/year TEDE (BSC 2005f [DIRS 173614], Section 4.9.3.3). For the final design, ALARA design considerations will be included to achieve the ALARA goal.

Table E-11. Annual Worker Doses From Direct Radiation From Facility Normal Operations

Facility	Worker Group	Individual Worker (mrem/yr) ^a
Transportation Cask Receipt and Return and Staging	Security Personnel	30
	Transportation Personnel	270
	Cask Operator	620
	Health Physics Technician	110
	Gantry Operator	130
Canister Handling Facility	Cask/Waste Receipt Operator	660
	Health Physics Technician	420
	Transfer Bay Operator	100
Dry Transfer Facility	Cask/Waste Receipt Operator	1800
	Health Physics Technician	800
	Transfer Bay Operator	100
	Electrical, Mechanical, HVAC, Utility Maintenance	32 (including 6 from remediation activities)
	General Facility Maintenance and Radiation Monitoring	120 (including 18 from remediation activities)
	Remediation Operator	170
Fuel Handling Facility	Cask/Waste Receipt Operator	770
	Health Physics Technician	260
	Transfer Bay Operator	100
Subsurface	Emplacement/ Retrieval Locomotive Operator	380
	Ventilation Maintenance	47
	Electrical Maintenance	85
	Mechanical Maintenance	20
	Ground Control Maintenance	3.2
SNF Aging System	Cask Transfer	1800
	Health Physics Technician	850
	Cask Inspection	580
	Cask Maintenance	670

NOTES: ^a Dose values are rounded to two significant values^b BSC 2005c [DIRS 172488], Table 4

HVAC = heating, ventilation, and air-conditioning; mrem = one thousandth of a rem; rem = roentgen equivalent man; SNF = spent nuclear facility;

E.3.2 Category 1 Event Sequences

E.3.2.1 Surface Facility Worker Dose

Category 1 event sequence scenarios and estimated maximum worker dose consequences from releases are shown in Table E-12. Dose consequences in mrem received by the maximally exposed worker for the Category 1 event sequence releases are calculated in BSC (2005a [DIRS 173590], Table 7b). In addition, the direct radiation dose from a single Category 1 event sequence in the DTF 1, DTF 2 or FHF is 10 mrem/event BSC 2005l ([DIRS 173483], Section 8).

Table E-12. Maximum Worker Doses From Category 1 Event Sequence Releases (ICRP-68)

Facility ^a	Category 1 Event Sequences ^a	χ/Q (s/m ³) ^a	TEDE ^a (mrem)	TODE ^a (mrem)	SDE ^a (mrem)	LDE ^a (mrem)
DTF 1	Drop	7.0×10^{-4}	$1.6 \times 10^{+1}$	$1.4 \times 10^{+2}$	$1.2 \times 10^{+2}$	$1.3 \times 10^{+2}$
	Collision	7.0×10^{-4}	7.8×10^0	$6.8 \times 10^{+1}$	$5.9 \times 10^{+1}$	$6.7 \times 10^{+1}$
DTF 2	Drop	3.8×10^{-4}	8.5×10^0	$7.4 \times 10^{+1}$	$6.4 \times 10^{+1}$	$7.3 \times 10^{+1}$
	Collision	3.8×10^{-4}	4.2×10^0	$3.7 \times 10^{+1}$	$3.2 \times 10^{+1}$	$3.6 \times 10^{+1}$
FHF	Drop	9.1×10^{-4}	$2.0 \times 10^{+1}$	$1.8 \times 10^{+2}$	$1.5 \times 10^{+2}$	$1.7 \times 10^{+2}$
	Collision	9.1×10^{-4}	$1.0 \times 10^{+1}$	$8.9 \times 10^{+1}$	$7.7 \times 10^{+1}$	$8.7 \times 10^{+1}$

NOTES: ^a BSC 2005a [DIRS 173590], Table 7b

DTF = Dry Transfer Facility; FHF = Fuel Handling Facility; LDE = lens dose equivalent; mrem = one thousandth of a rem; rem = roentgen equivalent man; SDE = shallow dose equivalent to skin; TEDE = total effective dose equivalent; TODE = total organ dose equivalent.

E.3.2.1 Subsurface Facility Worker Dose

There are no Category 1 event sequences associated with the subsurface facility. Therefore, there is no subsurface worker dose from Category 1 event sequences.

E.3.3 Worker Dose TEDE Summary

The results of worker dose calculations from *Geologic Repository Operations Area Worker Dose Assessment* (BCS 2005c [DIRS 172488]) are provided in this section. The calculated annual doses to repository workers include contributions from external radiation and from exposure to airborne radioactivity potentially caused by indoor operations. The TEDE is calculated by summing the dose contributions from inhalation, submersion, and direct external radiation (BSC 2005c [DIRS 172488], Section 4.1). Potential repository worker TEDE doses from both normal operations and Category 1 events are summarized in Table E-13 at the location of the highest worker doses: DTF 1 for facility workers and CHF for construction workers..

Table E-13. Facility and Construction Worker Dose Summary (ICRP-68)

Maximally Exposed Facility Worker (Building DTF 1)	Contribution (Location)	TEDE (mrem/year)
	Normal operations airborne releases (DTF 1) ^a	0.53
	External radiation from routine operations (DTF 1) ^a	1,800
	External radiation from cask storage (DTF 1) ^a	72
	Total Normal Operations	1,873
	Including Category 1 Event Sequences	
	Frequency Weighted Category 1 event sequences (DTF 1) ^{b, c}	10.5
	Total Normal Operations (1,873 mrem) plus Weighted Category 1 Events	1,884
	Combination of 2 maximum Category 1 event sequences in 1 year (DTF 1) ^b	28
	Total Normal Operations (1,873 mrem) plus Combination of Category 1 Events	1,901
Maximally Exposed Construction Worker (Building CHF)	Contribution (Location)	TEDE (mrem/year)
	Normal operations airborne releases (CHF) ^a	0.13
	External radiation from cask storage at 17A (CHF) ^a	46
	Total Normal Operations	46.1
	Including Category 1 Event Sequences	
	Frequency Weighted Category 1 event sequences (CHF) ^{d, e}	6.4
	Total Normal Operations (46.1 mrem) plus Weighted Category 1 Events	52.5
	Combination of 2 maximum Category 1 event sequences in 1 year (CHF) ^d	17
	Total Normal Operations (46.1 mrem) plus Combination of Category 1 Events	63.1

NOTE: ^a Doses from (BSC 2005c [DIRS 172488], Tables 4, 5b, 7b, and 11).

^b DTF 1 facility worker doses from maximum single Category 1 event sequence is 14 mrem/event from (BSC 2005c [DIRS 172488], Table 6b) based on drop event in FHF involving 2 SFA/event (BSC 2005a [DIRS 173590], Tables 5a to 5d).

^c Frequency weighted dose is based on frequencies from BSC 2005a ([DIRS 173590], Table 1) of 0.5 drops with 2 SFA and 0.5 collisions with 1 SFA/year. Weighted dose is $0.5 \times 14 \text{ mrem} / 2 \text{ SFA} \times 2 \text{ SFA} + 0.5 \times 14 \text{ mrem} / 2 \text{ SFA} \times 1 \text{ SFA} = 10.5 \text{ mrem}$.

^d Construction worker doses from maximum single Category 1 event sequence is 8.5 mrem/event from (BSC 2005c [DIRS 172488], Table 11) based on drop event in FHF involving 2 SFA/event (BSC 2005a [DIRS 173590], Tables 5a to 5d).

^e Frequency weighted dose is based on frequencies from BSC 2005a ([DIRS 173590], Table 1) of 0.5 drops with 2 SFA and 0.5 collisions with 1 SFA/year. Weighted dose is $0.5 \times 8.5 \text{ mrem} / 2 \text{ SFA} \times 2 \text{ SFA} + 0.5 \times 8.5 \text{ mrem} / 2 \text{ SFA} \times 1 \text{ SFA} = 6.4 \text{ mrem}$.

CHF = canister handling facility; CSNF = commercial spent nuclear fuel; DTF = Dry Transfer Facility; FHF = Fuel Handling Facility; mrem = one thousandth of a rem; rem = roentgen equivalent man; SNF = spent nuclear fuel; TEDE = total effective dose equivalent.

E.4. CONCLUSIONS

MACCS2 (ORNL 1998 [DIRS 164761]) and ARCON96 (BSC 2003b [DIRS 164784]) are used to perform the public dose and worker dose calculations. Calculated doses are compared to the performance objectives shown in Table E-14. Calculated public doses and worker doses show that 10 CFR 63.111(a) and 10 CFR 63.111(b) [DIRS 173273] performance objectives are met by taking credit for the HVAC HEPA filters to mitigate the consequences of normal operations and Category 1 and Category 2 event sequences.

The outputs listed in Attachment C have been found reasonable as compared to the inputs, and the results have been found suitable for their intended use.

Table E-14. Summary Preclosure Dose Performance Criteria and Evaluation Results (ICRP-68 and ICRP-72)

Standard	Limits	Results
Public Exposures		
Preclosure standard: 10 CFR 63.204 [DIRS 173273]; Preclosure Performance Objective for normal operations and Category 1 event sequences per 10 CFR 63.111(a)(2)	15 mrem/year ^b	0.71 mrem/year ^{a, c} (Table E-5) 0.11 mrem/year ^{a, d} (Table E-4) 0.86 mrem/year ^{a, e} (Section E.2.2)
Constraint specified for air emissions of radioactive material to the environment; not a dose limitation per 10 CFR 20.1101(d) [DIRS 173165] ^f	10 mrem/year ^b	0.71 mrem/year ^{a, b} (Table E-5)
Dose Limits for Individual Members of the Public for normal operations and Category 1 event sequences per 10 CFR 20.1301 [DIRS 173165] ^f	100 mrem/year ^{b, g} (general public or construction workers)	71 mrem/year ^{h, b} (Table E-5) 24 mrem/year ^{h, d} (Table E-4) 63 mrem/year ^{j, e} (Table E-13)
	2 mrem/hr in any unrestricted area from external sources	< 2 mrem/hr ⁱ
Preclosure Performance Objective for any Category 2 event sequence per 10 CFR 63.111 (b)(2) [DIRS 173273]	5 rem ^b	0.089 rem ^b (Table E-6)
	50 rem organ or tissue dose other than the lens of the eye	0.70 rem (Table E-6)
	15 rem lens of the eye dose	0.11 rem (Table E-6)
	50 rem shallow dose to skin	0.024 rem (Table E-6)
Facility Workers' Exposures		
Occupational Dose Limits for Adults from normal operations and Category 1 event sequences per 10 CFR 20.1201 [DIRS 173165] ^f	5 rem/year ^b	1.9 rem/year ^{k, c} (Table E-13) 0.014 rem/year ^{k, d} (Table E-13) 1.9 rem/year ^{k, e} (Table E-13)
	50 rem organ or tissue dose other than the lens of the eye	0.37 rem ^m
	15 rem lens of the eye dose	0.35 rem ⁿ
	50 rem shallow dose to skin	0.31 rem ^o

NOTES: ^a Results for public exposures are calculated at the site boundary^b TEDE^c Sum of TEDEs from normal operations and frequency weighted Category 1 event sequences in 1 year^d TEDE from a single maximum Category 1 event sequence in 1 year^e Sum of TEDEs from normal operations and any combination of Category 1 event sequences in 1 year^f 10 CFR 63.111(a)(1) [DIRS 173273] requires operations area to meet the requirements of 10 CFR Part 20 [DIRS 173165]^g 10 CFR 20.1301(a)(1); dose limit to the extent applicable (maximum of general public and construction worker)^h Onsite public dose at 100 mⁱ 10 CFR 63.111(b)(1) would require repository design objectives for Category 1 event sequences and normal operations to meet 10 CFR 63.111(a)(1) requirements (10 CFR Part 20)^j Onsite construction worker maximum dose from operating facilities at CHF^k The highest annual facility worker at DTF 1^l Shielding design criterion limits dose rate to 0.05 mrem/hr at unrestricted area surface BSC 2005f [DIRS 173614], Section 4.9.1.4].^m 0.011 rem (TODE Table E-9)+ 2 events x 0.18 rem/event (TODE Table E-12) = 0.37 remⁿ 0.010 rem (LDE Table E-9)+ 2 events x 0.17 rem/event (LDE Table E-12) = 0.35 rem^o 0.009 rem (SDE Table E-9)+ 2 events x 0.15 rem/event (SDE Table E-12) = 0.31 rem

EDE = effective dose equivalent; LDE = lens dose equivalent; mrem = one thousandth of a rem; rem = roentgen equivalent man; SDE = shallow dose equivalent to skin; TEDE = total effective dose equivalent; TODE = total organ dose equivalent.

ATTACHMENT F – MACCS2 ICRP-72 INPUT AND OUTPUT FILE LISTING

MACCS2 (ORNL 1998 [DIRS 164761]) input and output files are listed in Table F-1 for the runs identified in Table E-1 and are provided on a compact disk submitted to Document Control. These runs utilized the ICRP-72 (ICRP 1996 [DIRS 152446]) dose conversion factors.

Table F-1. Listing of MACCS2 ICRP-72 Computer Input and Output Files

ICRP-72 Run No.	MACCS2 Input and Output File Name	Date	Time	File Size (B)
1i	lasub01i.inp	7/4/2005	03:49p	44,396
1i	LASUB01I.OUT	7/12/2005	05:12p	735,092
2i	Not used.			
2i	Not used.			
3i	lasur01i.inp	7/7/2005	07:51a	44,865
3i	LASUR01I.OUT	7/12/2005	01:28p	736,416
4i	lapwr01i.inp	7/6/2005	10:31a	44,909
4i	LAPWR01I.OUT	7/14/2005	01:36p	735,958
5i	lapwr02i.inp	6/26/2005	01:38p	44,808
5i	LAPWR02I.OUT	7/12/2005	01:50p	729,881
6i	labwr01i.inp	6/29/2005	05:24p	44,893
6i	LABWR01I.OUT	7/12/2005	02:12p	735,937
7i	labwr02i.inp	6/26/2005	01:40p	44,801
7i	LABWR02I.OUT	7/12/2005	02:23p	729,839
8i	lahlw01i.inp	6/26/2005	01:40p	44,460
8i	LAHLW01I.OUT	7/12/2005	02:44p	726,708
9i	lahlw02i.inp	6/26/2005	01:41p	44,715
9i	LAHLW02I.OUT	7/12/2005	02:51p	727,442
10i	lahlw03i.inp	6/26/2005	01:41p	44,529
10i	LAHLW03I.OUT	7/12/2005	02:58p	726,671
11i	lahlw04i.inp	6/26/2005	01:42p	44,316
11i	LAHLW04I.OUT	7/12/2005	03:01p	725,438
12i	lanav01i.inp	6/26/2005	01:27p	46,130
12i	LANAV01I.OUT	7/12/2005	03:12p	734,227
13i	lasen01i.inp	7/7/2005	07:50a	44,835
13i	LASEN01I.OUT	7/12/2005	03:24p	735,932
14i	lasen02i.inp	6/29/2005	04:45p	44,832
14i	LASEN02I.OUT	7/12/2005	03:35p	735,848
15i	lasen03i.inp	7/15/2005	08:47a	44,810
15i	LASEN03I.OUT	7/15/2005	09:00a	735,890
16i	lasen04i.inp	7/12/2005	04:22p	44,795
16i	LASEN04I.OUT	7/12/2005	05:41p	735,759
17i	Lasen05i.inp	7/18/2005	07:54a	44,887
17i	LASEN05I.OUT	7/18/2005	09:24a	736,526
18i	Lahepa1i.inp	7/18/2005	07:59a	44,825
18i	LAHEPA1I.OUT	7/18/2005	08:17a	729,881

Table F-1. Listing of MACCS2 ICRP-72 Computer Input and Output Files (Continued)

ICRP-72 Run No.	MACCS2 Input and Output File Name	Date	Time	File Size (B)
All i's	YMP1999.INP	07/31/2003	02:27 PM	166,602
All i's	YMPCH1i.INP	06/26/2005	06:49 AM	11,141
3i, 5i, 7i, and 8i thru 12i	YMPEAi.INP	07/12/2005	12:54 PM	12,358
1i, 2i, 4i, 6i, 13i, thru 16i	YMPEA1i.INP	07/12/2005	12:53 PM	12,101
1i,2i and 4i thru 16i	YMPSIT.INP	07/17/2003	8:39 AM	7,564
3i	YSITE8.INP	05/07/2001	8:27 AM	7,564
All i's	YUCICRPD.BIN	03/16/2004	10:18 AM	1,337,623
All i's	YMPICRPD.INP	03/16/2005	9:40 AM	676,863

ATTACHMENT G – COMPARISON OF ICRP-72 AND FGR-11 DOSE CONVERSION FACTORS

This Attachment G provides a summary table comparing general public inhalation and ingestion dose conversion factors including implicit daughter contributions from FGR-11 (Eckerman, 1988 [DIRS 101069]) as tabulated in the MACCS2 dose conversion factor input file YMPD825.inp (see Table C-1) and from ICRP-72 (BSC 2005h [DIRS 174424]). The ratios of ICRP-72-to-FGR-11 dose conversion factors for inhalation and ingestion are provided. Ratios greater than 1.0 are bolded and identify ICRP-72 dose factors that are higher, all others are lower.

Table G-1. Ratio of ICRP-72-to-FGR-11 Dose Conversion Factors

		ICRP-72 DCFs		FGR-11 DCFs		Ratio (ICRP-72 / FGR-11) DCFs	
		A	B	C	D	A/C	B/D
		INHALED CHRONIC (Sv/Bq)	INGESTION (Sv/Bq)	INHALED CHRONIC (Sv/Bq)	INGESTION (Sv/Bq)	INHALED CHRONIC	INGESTION
1	Ac-225						
	GONADS	6.40E-10	7.90E-10	5.20E-09	1.36E-09	1.23E-01	5.81E-01
	BREAST	7.80E-11	2.20E-11	4.66E-11	2.73E-11	1.67E+00	8.06E-01
	LUNGS	7.10E-05	2.30E-11	1.79E-05	3.98E-12	3.97E+00	5.78E+00
	RED MARR	4.20E-09	4.00E-09	3.63E-08	7.99E-09	1.16E-01	5.01E-01
	BONE SUR	5.20E-08	4.90E-08	4.53E-07	9.94E-08	1.15E-01	4.93E-01
	THYROID	4.50E-11	2.00E-11	2.64E-11	5.49E-13	1.70E+00	3.64E+01
	REMAINDER	3.00E-09	3.90E-10	6.14E-08	8.57E-08	4.89E-02	4.55E-03
	EFFECTIVE	8.50E-06	2.40E-08	2.19E-06	3.00E-08	3.88E+00	8.00E-01
	SKIN(FGR)	3.40E-11	2.80E-11	0.00E+00	0.00E+00	n/a	n/a
2	Ac-227						
	GONADS	8.40E-06	4.20E-07	3.56E-05	8.31E-07	2.36E-01	5.05E-01
	BREAST	7.50E-09	8.37E-11	1.06E-08	1.73E-10	7.07E-01	4.84E-01
	LUNGS	4.10E-04	1.52E-10	1.54E-03	2.52E-10	2.66E-01	6.02E-01
	RED MARR	5.50E-05	2.70E-06	2.33E-04	5.40E-06	2.36E-01	5.00E-01
	BONE SUR	6.90E-04	3.40E-05	2.91E-03	6.73E-05	2.37E-01	5.05E-01
	THYROID	3.61E-09	7.37E-11	6.49E-09	1.08E-10	5.56E-01	6.86E-01
	REMAINDER	9.40E-08	1.08E-10	1.34E-04	3.08E-06	7.02E-04	3.50E-05
	EFFECTIVE	7.20E-05	1.10E-06	3.49E-04	3.80E-06	2.06E-01	2.89E-01
	SKIN(FGR)	2.41E-09	7.27E-11	0.00E+00	0.00E+00	n/a	n/a
3	Ac-228						
	GONADS	1.90E-10	1.70E-10	6.84E-10	1.79E-10	2.78E-01	9.50E-01
	BREAST	1.20E-11	4.30E-12	1.28E-11	2.31E-11	9.38E-01	1.86E-01
	LUNGS	1.30E-07	6.40E-12	2.53E-07	7.34E-12	5.14E-01	8.72E-01
	RED MARR	1.20E-09	1.50E-10	4.76E-09	2.75E-10	2.52E-01	5.45E-01
	BONE SUR	1.50E-08	1.50E-09	5.93E-08	3.01E-09	2.53E-01	4.98E-01
	THYROID	8.00E-12	6.90E-13	7.79E-12	9.39E-13	1.03E+00	7.35E-01
	REMAINDER	3.50E-11	4.30E-11	3.36E-09	1.38E-09	1.04E-02	3.12E-02
	EFFECTIVE	1.60E-08	4.30E-10	3.39E-08	5.85E-10	4.72E-01	7.35E-01
	SKIN(FGR)	5.40E-12	8.50E-12	0.00E+00	0.00E+00	n/a	n/a

Table G-1. Ratio of ICRP-72-to-FGR-11 Dose Conversion Factors

		ICRP-72 DCFs		FGR-11 DCFs		Ratio (ICRP-72 / FGR-11) DCFs	
		A	B	C	D	A/C	B/D
		INHALED CHRONIC (Sv/Bq)	INGESTION (Sv/Bq)	INHALED CHRONIC (Sv/Bq)	INGESTION (Sv/Bq)	INHALED CHRONIC	INGESTION
4	AI-28						
	GONADS	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a
	BREAST	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a
	LUNGS	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a
	RED MARR	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a
	BONE SUR	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a
	THYROID	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a
	REMAINDER	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a
	EFFECTIVE	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a
	SKIN(FGR)	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a
5	Am-241						
	GONADS	3.30E-05	1.80E-07	3.25E-05	2.70E-07	1.02E+00	6.67E-01
	BREAST	2.90E-06	1.50E-08	2.67E-09	2.62E-11	1.09E+03	5.73E+02
	LUNGS	3.70E-05	1.50E-08	1.84E-05	3.36E-11	2.01E+00	4.46E+02
	RED MARR	5.80E-05	3.10E-07	1.74E-04	1.45E-06	3.33E-01	2.14E-01
	BONE SUR	1.70E-03	9.00E-06	2.17E-03	1.81E-05	7.83E-01	4.97E-01
	THYROID	2.90E-06	1.50E-08	1.60E-09	1.32E-11	1.81E+03	1.14E+03
	REMAINDER	2.90E-06	1.60E-08	7.82E-05	6.66E-07	3.71E-02	2.40E-02
	EFFECTIVE	4.20E-05	2.00E-07	1.20E-04	9.84E-07	3.50E-01	2.03E-01
	SKIN(FGR)	2.90E-06	1.50E-08	0.00E+00	0.00E+00	n/a	n/a
6	Am-242						
	GONADS	1.70E-09	2.00E-11	1.94E-09	2.74E-11	8.76E-01	7.30E-01
	BREAST	1.20E-10	8.30E-13	2.94E-12	9.38E-13	4.08E+01	8.85E-01
	LUNGS	1.20E-07	8.90E-13	5.20E-08	1.58E-13	2.31E+00	5.63E+00
	RED MARR	6.30E-09	4.60E-11	1.32E-08	1.24E-10	4.77E-01	3.71E-01
	BONE SUR	9.20E-08	6.30E-10	1.65E-07	1.52E-09	5.58E-01	4.14E-01
	THYROID	1.20E-10	7.80E-13	2.52E-12	2.61E-14	4.76E+01	2.99E+01
	REMAINDER	1.40E-10	1.10E-11	8.54E-09	1.05E-09	1.64E-02	1.05E-02
	EFFECTIVE	1.70E-08	3.00E-10	1.58E-08	3.81E-10	1.08E+00	7.87E-01
	SKIN(FGR)	1.20E-10	1.00E-12	0.00E+00	0.00E+00	n/a	n/a
7	Am-242m						
	GONADS	3.20E-05	1.70E-07	3.21E-05	2.66E-07	9.97E-01	6.39E-01
	BREAST	2.90E-06	1.50E-08	1.38E-09	1.22E-11	2.10E+03	1.23E+03
	LUNGS	8.80E-06	1.50E-08	4.20E-06	1.65E-11	2.10E+00	9.09E+02
	RED MARR	5.50E-05	2.90E-07	1.69E-04	1.41E-06	3.25E-01	2.06E-01
	BONE SUR	1.70E-03	8.80E-06	2.12E-03	1.76E-05	8.02E-01	5.00E-01
	THYROID	2.90E-06	1.50E-08	5.64E-10	3.77E-12	5.14E+03	3.98E+03
	REMAINDER	2.90E-06	1.50E-08	7.48E-05	6.20E-07	3.88E-02	2.42E-02
	EFFECTIVE	3.70E-05	1.90E-07	1.15E-04	9.50E-07	3.22E-01	2.00E-01
	SKIN(FGR)	2.90E-06	1.50E-08	0.00E+00	0.00E+00	n/a	n/a

Table G-1. Ratio of ICRP-72-to-FGR-11 Dose Conversion Factors

		ICRP-72 DCFs		FGR-11 DCFs		Ratio (ICRP-72 / FGR-11) DCFs	
		A	B	C	D	A/C	B/D
		INHALED CHRONIC (Sv/Bq)	INGESTION (Sv/Bq)	INHALED CHRONIC (Sv/Bq)	INGESTION (Sv/Bq)	INHALED CHRONIC	INGESTION
8	Am-243						
	GONADS	3.30E-05	1.70E-07	3.26E-05	2.71E-07	1.01E+00	6.27E-01
	BREAST	2.90E-06	1.50E-08	1.52E-08	1.41E-10	1.91E+02	1.06E+02
	LUNGS	3.50E-05	1.50E-08	1.78E-05	1.95E-10	1.97E+00	7.69E+01
	RED MARR	5.70E-05	3.00E-07	1.73E-04	1.44E-06	3.29E-01	2.08E-01
	BONE SUR	1.70E-03	9.00E-06	2.17E-03	1.80E-05	7.83E-01	5.00E-01
	THYROID	2.90E-06	1.50E-08	8.29E-09	6.80E-11	3.50E+02	2.21E+02
	REMAINDER	3.00E-06	1.60E-08	7.74E-05	6.61E-07	3.88E-02	2.42E-02
	EFFECTIVE	4.10E-05	2.00E-07	1.19E-04	9.79E-07	3.45E-01	2.04E-01
	SKIN(FGR)	2.90E-06	1.50E-08	0.00E+00	0.00E+00	n/a	n/a
9	Ar-41						
	GONADS	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a
	BREAST	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a
	LUNGS	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a
	RED MARR	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a
	BONE SUR	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a
	THYROID	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a
	REMAINDER	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a
	EFFECTIVE	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a
	SKIN(FGR)	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a
10	At-217						
	GONADS	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a
	BREAST	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a
	LUNGS	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a
	RED MARR	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a
	BONE SUR	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a
	THYROID	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a
	REMAINDER	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a
	EFFECTIVE	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a
	SKIN(FGR)	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a
11	Ba-137m						
	GONADS	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a
	BREAST	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a
	LUNGS	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a
	RED MARR	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a
	BONE SUR	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a
	THYROID	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a
	REMAINDER	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a
	EFFECTIVE	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a
	SKIN(FGR)	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a

Table G-1. Ratio of ICRP-72-to-FGR-11 Dose Conversion Factors

		ICRP-72 DCFs		FGR-11 DCFs		Ratio (ICRP-72 / FGR-11) DCFs	
		A	B	C	D	A/C	B/D
		INHALED CHRONIC (Sv/Bq)	INGESTION (Sv/Bq)	INHALED CHRONIC (Sv/Bq)	INGESTION (Sv/Bq)	INHALED CHRONIC	INGESTION
12	Bi-210						
	GONADS	4.70E-11	2.00E-11	6.47E-11	1.97E-11	7.26E-01	1.02E+00
	BREAST	4.70E-11	2.00E-11	6.47E-11	1.97E-11	7.26E-01	1.02E+00
	LUNGS	7.70E-07	2.00E-11	4.26E-07	1.97E-11	1.81E+00	1.02E+00
	RED MARR	4.70E-11	2.00E-11	6.47E-11	1.97E-11	7.26E-01	1.02E+00
	BONE SUR	4.70E-11	2.00E-11	6.47E-11	1.97E-11	7.26E-01	1.02E+00
	THYROID	4.70E-11	2.00E-11	6.47E-11	1.97E-11	7.26E-01	1.02E+00
	REMAINDER	2.50E-10	1.00E-10	5.66E-09	5.72E-09	4.42E-02	1.75E-02
	EFFECTIVE	9.30E-08	1.30E-09	5.29E-08	1.73E-09	1.76E+00	7.51E-01
	SKIN(FGR)	4.70E-11	2.00E-11	0.00E+00	0.00E+00	n/a	n/a
13	Bi-213						
	GONADS	1.60E-11	6.60E-12	3.80E-11	6.17E-12	4.21E-01	1.07E+00
	BREAST	1.60E-11	4.50E-12	3.80E-11	4.73E-12	4.21E-01	9.51E-01
	LUNGS	1.70E-07	4.60E-12	3.16E-08	4.56E-12	5.38E+00	1.01E+00
	RED MARR	1.60E-11	4.90E-12	3.81E-11	4.89E-12	4.20E-01	1.00E+00
	BONE SUR	1.60E-11	4.60E-12	3.80E-11	4.45E-12	4.21E-01	1.03E+00
	THYROID	1.60E-11	4.30E-12	3.80E-11	4.20E-12	4.21E-01	1.02E+00
	REMAINDER	1.80E-07	2.60E-11	1.14E-09	6.38E-10	1.58E+02	4.08E-02
	EFFECTIVE	3.00E-08	2.00E-10	4.16E-09	1.95E-10	7.21E+00	1.03E+00
	SKIN(FGR)	1.60E-11	4.50E-12	0.00E+00	0.00E+00	n/a	n/a
14	C-14						
	GONADS	6.20E-12	5.70E-10	6.36E-12	5.64E-10	9.75E-01	1.01E+00
	BREAST	6.20E-12	5.70E-10	6.36E-12	5.64E-10	9.75E-01	1.01E+00
	LUNGS	6.20E-12	5.70E-10	6.36E-12	5.64E-10	9.75E-01	1.01E+00
	RED MARR	6.20E-12	5.70E-10	6.36E-12	5.64E-10	9.75E-01	1.01E+00
	BONE SUR	6.20E-12	5.70E-10	6.36E-12	5.64E-10	9.75E-01	1.01E+00
	THYROID	6.20E-12	5.70E-10	6.36E-12	5.64E-10	9.75E-01	1.01E+00
	REMAINDER	6.20E-12	5.70E-10	6.36E-12	5.64E-10	9.75E-01	1.01E+00
	EFFECTIVE	6.20E-12	5.80E-10	6.36E-12	5.64E-10	9.75E-01	1.03E+00
	SKIN(FGR)	6.20E-12	5.70E-10	0.00E+00	0.00E+00	n/a	n/a
15	Cd-113m						
	GONADS	1.80E-09	3.50E-09	4.72E-09	3.44E-09	3.81E-01	1.02E+00
	BREAST	1.80E-09	3.50E-09	4.72E-09	3.44E-09	3.81E-01	1.02E+00
	LUNGS	1.70E-07	3.50E-09	4.09E-07	3.44E-09	4.16E-01	1.02E+00
	RED MARR	1.80E-09	3.50E-09	4.72E-09	3.44E-09	3.81E-01	1.02E+00
	BONE SUR	1.80E-09	3.50E-09	4.72E-09	3.44E-09	3.81E-01	1.02E+00
	THYROID	1.80E-09	3.50E-09	4.72E-09	3.44E-09	3.81E-01	1.02E+00
	REMAINDER	1.40E-07	2.80E-07	1.86E-07	1.37E-07	7.53E-01	2.04E+00
	EFFECTIVE	3.10E-08	2.30E-08	1.08E-07	4.35E-08	2.87E-01	5.29E-01
	SKIN(FGR)	1.80E-09	3.50E-09	0.00E+00	0.00E+00	n/a	n/a

Table G-1. Ratio of ICRP-72-to-FGR-11 Dose Conversion Factors

		ICRP-72 DCFs		FGR-11 DCFs		Ratio (ICRP-72 / FGR-11) DCFs	
		A	B	C	D	A/C	B/D
		INHALED CHRONIC (Sv/Bq)	INGESTION (Sv/Bq)	INHALED CHRONIC (Sv/Bq)	INGESTION (Sv/Bq)	INHALED CHRONIC	INGESTION
16	Ce-144						
	GONADS	1.80E-09	7.41E-11	2.39E-10	6.99E-11	7.53E+00	1.06E+00
	BREAST	1.80E-09	1.20E-11	3.48E-10	1.22E-11	5.17E+00	9.83E-01
	LUNGS	1.90E-07	1.30E-11	7.91E-07	6.55E-12	2.40E-01	1.99E+00
	RED MARR	2.80E-08	1.90E-10	2.88E-09	8.92E-11	9.72E+00	2.13E+00
	BONE SUR	4.90E-08	3.30E-10	4.72E-09	1.28E-10	1.04E+01	2.58E+00
	THYROID	1.80E-09	1.20E-11	2.92E-10	5.15E-12	6.16E+00	2.33E+00
	REMAINDER	1.91E-09	9.70E-11	1.91E-08	1.89E-08	9.99E-02	5.13E-03
	EFFECTIVE	3.60E-08	5.25E-09	1.01E-07	5.71E-09	3.57E-01	9.19E-01
	SKIN(FGR)	1.70E-09	1.40E-11	0.00E+00	0.00E+00	n/a	n/a
17	Cf-252						
	GONADS	4.10E-06	3.10E-08	1.09E-06	5.39E-08	3.76E+00	5.75E-01
	BREAST	3.80E-08	2.20E-10	6.12E-08	1.49E-09	6.21E-01	1.48E-01
	LUNGS	5.40E-05	4.10E-10	2.99E-04	4.67E-10	1.81E-01	8.78E-01
	RED MARR	4.10E-05	2.40E-07	1.10E-05	4.69E-07	3.73E+00	5.12E-01
	BONE SUR	5.10E-04	2.90E-06	1.37E-04	5.84E-06	3.72E+00	4.97E-01
	THYROID	3.00E-08	1.60E-10	3.20E-08	2.68E-10	9.38E-01	5.97E-01
	REMAINDER	4.60E-08	1.30E-09	2.73E-06	1.58E-07	1.68E-02	8.23E-03
	EFFECTIVE	2.00E-05	9.00E-08	4.24E-05	2.93E-07	4.72E-01	3.07E-01
	SKIN(FGR)	2.60E-08	4.10E-10	0.00E+00	0.00E+00	n/a	n/a
18	Cl-36						
	GONADS	2.70E-10	8.00E-10	5.04E-10	7.99E-10	5.36E-01	1.00E+00
	BREAST	2.70E-10	8.00E-10	5.04E-10	7.99E-10	5.36E-01	1.00E+00
	LUNGS	5.90E-08	8.00E-10	1.33E-09	7.99E-10	4.44E+01	1.00E+00
	RED MARR	2.70E-10	8.00E-10	5.04E-10	7.99E-10	5.36E-01	1.00E+00
	BONE SUR	2.70E-10	8.00E-10	5.04E-10	7.99E-10	5.36E-01	1.00E+00
	THYROID	2.70E-10	8.00E-10	5.04E-10	7.99E-10	5.36E-01	1.00E+00
	REMAINDER	2.70E-10	8.00E-10	5.14E-10	8.61E-10	5.25E-01	9.29E-01
	EFFECTIVE	7.30E-09	9.30E-10	6.06E-10	8.18E-10	1.20E+01	1.14E+00
	SKIN(FGR)	2.70E-10	8.00E-10	0.00E+00	0.00E+00	n/a	n/a
19	Cm-242						
	GONADS	4.80E-07	3.30E-09	5.70E-07	5.20E-09	8.42E-01	6.35E-01
	BREAST	3.50E-08	2.30E-10	9.44E-10	8.95E-12	3.71E+01	2.57E+01
	LUNGS	3.50E-05	2.30E-10	1.55E-05	8.84E-12	2.26E+00	2.60E+01
	RED MARR	1.90E-06	1.30E-08	3.90E-06	3.57E-08	4.87E-01	3.64E-01
	BONE SUR	2.70E-05	1.90E-07	4.87E-05	4.46E-07	5.54E-01	4.26E-01
	THYROID	3.50E-08	2.30E-10	9.41E-10	8.82E-12	3.72E+01	2.61E+01
	REMAINDER	4.20E-08	3.40E-10	2.45E-06	4.02E-08	1.71E-02	8.46E-03
	EFFECTIVE	5.20E-06	1.20E-08	4.67E-06	3.10E-08	1.11E+00	3.87E-01
	SKIN(FGR)	3.50E-08	2.30E-10	0.00E+00	0.00E+00	n/a	n/a

Table G-1. Ratio of ICRP-72-to-FGR-11 Dose Conversion Factors

		ICRP-72 DCFs		FGR-11 DCFs		Ratio (ICRP-72 / FGR-11) DCFs	
		A	B	C	D	A/C	B/D
		INHALED CHRONIC (Sv/Bq)	INGESTION (Sv/Bq)	INHALED CHRONIC (Sv/Bq)	INGESTION (Sv/Bq)	INHALED CHRONIC	INGESTION
20	Cm-243						
	GONADS	2.30E-05	1.20E-07	2.07E-05	1.73E-07	1.11E+00	6.94E-01
	BREAST	1.70E-06	9.30E-09	6.29E-09	6.96E-11	2.70E+02	1.34E+02
	LUNGS	4.00E-05	9.30E-09	1.94E-05	7.73E-11	2.06E+00	1.20E+02
	RED MARR	4.50E-05	2.40E-07	1.18E-04	9.81E-07	3.81E-01	2.45E-01
	BONE SUR	1.20E-03	6.20E-06	1.47E-03	1.23E-05	8.16E-01	5.04E-01
	THYROID	1.70E-06	9.30E-09	3.83E-09	3.15E-11	4.44E+02	2.95E+02
	REMAINDER	1.80E-06	9.70E-09	5.76E-05	4.97E-07	3.13E-02	1.95E-02
	EFFECTIVE	3.10E-05	1.50E-07	8.30E-05	6.79E-07	3.73E-01	2.21E-01
	SKIN(FGR)	1.70E-06	9.30E-09	0.00E+00	0.00E+00	n/a	n/a
21	Cm-244						
	GONADS	1.80E-05	9.80E-08	1.59E-05	1.33E-07	1.13E+00	7.37E-01
	BREAST	1.30E-06	6.90E-09	1.04E-09	8.82E-12	1.25E+03	7.82E+02
	LUNGS	3.90E-05	6.90E-09	1.93E-05	8.81E-12	2.02E+00	7.83E+02
	RED MARR	3.90E-05	2.10E-07	9.38E-05	7.82E-07	4.16E-01	2.69E-01
	BONE SUR	9.20E-04	4.90E-06	1.17E-03	9.77E-06	7.86E-01	5.02E-01
	THYROID	1.30E-06	6.90E-09	1.01E-09	8.44E-12	1.29E+03	8.18E+02
	REMAINDER	1.30E-06	7.20E-09	4.78E-05	4.15E-07	2.72E-02	1.73E-02
	EFFECTIVE	2.70E-05	1.20E-07	6.70E-05	5.45E-07	4.03E-01	2.20E-01
	SKIN(FGR)	1.30E-06	6.90E-09	0.00E+00	0.00E+00	n/a	n/a
22	Cm-245						
	GONADS	3.40E-05	1.80E-07	3.37E-05	2.80E-07	1.01E+00	6.43E-01
	BREAST	3.00E-06	1.60E-08	6.69E-09	6.80E-11	4.48E+02	2.35E+02
	LUNGS	3.60E-05	1.60E-08	1.80E-05	8.34E-11	2.00E+00	1.92E+02
	RED MARR	5.90E-05	3.10E-07	1.79E-04	1.49E-06	3.30E-01	2.08E-01
	BONE SUR	1.70E-03	9.30E-06	2.24E-03	1.86E-05	7.59E-01	5.00E-01
	THYROID	3.00E-06	1.60E-08	3.68E-09	3.02E-11	8.15E+02	5.30E+02
	REMAINDER	3.10E-06	1.60E-08	7.96E-05	6.79E-07	3.89E-02	2.36E-02
	EFFECTIVE	4.20E-05	2.10E-07	1.23E-04	1.01E-06	3.41E-01	2.08E-01
	SKIN(FGR)	3.00E-06	1.60E-08	0.00E+00	0.00E+00	n/a	n/a
23	Cm-246						
	GONADS	3.40E-05	1.80E-07	3.34E-05	2.77E-07	1.02E+00	6.50E-01
	BREAST	3.00E-06	1.60E-08	4.00E-09	3.91E-11	7.50E+02	4.09E+02
	LUNGS	3.60E-05	1.60E-08	1.82E-05	2.67E-11	1.98E+00	5.99E+02
	RED MARR	5.90E-05	3.10E-07	1.78E-04	1.48E-06	3.31E-01	2.09E-01
	BONE SUR	1.70E-03	9.20E-06	2.22E-03	1.85E-05	7.66E-01	4.97E-01
	THYROID	3.00E-06	1.60E-08	2.26E-09	1.87E-11	1.33E+03	8.56E+02
	REMAINDER	3.00E-06	1.60E-08	7.94E-05	6.76E-07	3.78E-02	2.37E-02
	EFFECTIVE	4.20E-05	2.10E-07	1.22E-04	1.00E-06	3.44E-01	2.10E-01
	SKIN(FGR)	3.00E-06	1.60E-08	0.00E+00	0.00E+00	n/a	n/a

Table G-1. Ratio of ICRP-72-to-FGR-11 Dose Conversion Factors

		ICRP-72 DCFs		FGR-11 DCFs		Ratio (ICRP-72 / FGR-11) DCFs	
		A	B	C	D	A/C	B/D
		INHALED CHRONIC (Sv/Bq)	INGESTION (Sv/Bq)	INHALED CHRONIC (Sv/Bq)	INGESTION (Sv/Bq)	INHALED CHRONIC	INGESTION
24	Cm-247						
	GONADS	3.10E-05	1.60E-07	3.07E-05	2.56E-07	1.01E+00	6.25E-01
	BREAST	2.70E-06	1.50E-08	2.23E-08	2.29E-10	1.21E+02	6.55E+01
	LUNGS	3.20E-05	1.50E-08	1.67E-05	2.66E-10	1.92E+00	5.64E+01
	RED MARR	5.40E-05	2.90E-07	1.63E-04	1.36E-06	3.31E-01	2.13E-01
	BONE SUR	1.60E-03	8.50E-06	2.04E-03	1.70E-05	7.84E-01	5.00E-01
	THYROID	2.70E-06	1.50E-08	1.45E-08	1.20E-10	1.86E+02	1.25E+02
	REMAINDER	2.80E-06	1.50E-08	7.30E-05	6.23E-07	3.84E-02	2.41E-02
	EFFECTIVE	3.90E-05	1.90E-07	1.12E-04	9.24E-07	3.48E-01	2.06E-01
	SKIN(FGR)	2.70E-06	1.50E-08	0.00E+00	0.00E+00	n/a	n/a
25	Cm-248						
	GONADS	1.20E-04	6.70E-07	1.21E-04	1.02E-06	9.92E-01	6.57E-01
	BREAST	1.10E-05	5.90E-08	1.07E-06	1.10E-08	1.03E+01	5.36E+00
	LUNGS	7.70E-05	6.20E-08	6.65E-05	6.52E-09	1.16E+00	9.51E+00
	RED MARR	2.20E-04	1.10E-06	6.52E-04	5.42E-06	3.37E-01	2.03E-01
	BONE SUR	6.30E-03	3.40E-05	8.12E-03	6.75E-05	7.76E-01	5.04E-01
	THYROID	1.10E-05	6.00E-08	4.71E-07	3.87E-09	2.34E+01	1.55E+01
	REMAINDER	1.20E-05	6.40E-08	2.89E-04	2.49E-06	4.15E-02	2.57E-02
	EFFECTIVE	1.50E-04	7.70E-07	4.47E-04	3.68E-06	3.36E-01	2.09E-01
	SKIN(FGR)	1.10E-05	6.00E-08	0.00E+00	0.00E+00	n/a	n/a
26	Co-58						
	GONADS	3.20E-10	1.10E-09	6.17E-10	1.04E-09	5.19E-01	1.06E+00
	BREAST	1.30E-09	1.10E-10	9.37E-10	1.79E-10	1.39E+00	6.15E-01
	LUNGS	1.30E-08	1.50E-10	1.60E-08	8.53E-11	8.13E-01	1.76E+00
	RED MARR	7.00E-10	3.10E-10	9.23E-10	2.60E-10	7.58E-01	1.19E+00
	BONE SUR	5.20E-10	2.20E-10	6.93E-10	1.25E-10	7.50E-01	1.76E+00
	THYROID	5.10E-10	1.30E-10	8.72E-10	6.31E-11	5.85E-01	2.06E+00
	REMAINDER	5.30E-10	2.40E-10	1.89E-09	1.58E-09	2.80E-01	1.52E-01
	EFFECTIVE	2.10E-09	7.40E-10	2.94E-09	8.09E-10	7.14E-01	9.15E-01
	SKIN(FGR)	2.90E-10	1.30E-10	0.00E+00	0.00E+00	n/a	n/a
27	Co-60						
	GONADS	2.30E-09	4.30E-09	4.76E-09	3.19E-09	4.83E-01	1.35E+00
	BREAST	2.50E-08	1.30E-09	1.84E-08	1.10E-09	1.36E+00	1.18E+00
	LUNGS	1.80E-07	1.80E-09	3.45E-07	8.77E-10	5.22E-01	2.05E+00
	RED MARR	1.20E-08	2.10E-09	1.72E-08	1.32E-09	6.98E-01	1.59E+00
	BONE SUR	9.30E-09	2.00E-09	1.35E-08	9.39E-10	6.89E-01	2.13E+00
	THYROID	9.80E-09	1.70E-09	1.62E-08	7.88E-10	6.05E-01	2.16E+00
	REMAINDER	9.40E-09	1.90E-09	3.60E-08	4.97E-09	2.61E-01	3.82E-01
	EFFECTIVE	3.10E-08	3.40E-09	5.91E-08	2.77E-09	5.25E-01	1.23E+00
	SKIN(FGR)	5.50E-09	1.30E-09	0.00E+00	0.00E+00	n/a	n/a

Table G-1. Ratio of ICRP-72-to-FGR-11 Dose Conversion Factors

		ICRP-72 DCFs		FGR-11 DCFs		Ratio (ICRP-72 / FGR-11) DCFs	
		A	B	C	D	A/C	B/D
		INHALED CHRONIC (Sv/Bq)	INGESTION (Sv/Bq)	INHALED CHRONIC (Sv/Bq)	INGESTION (Sv/Bq)	INHALED CHRONIC	INGESTION
28	Cs-134						
	GONADS	7.20E-09	2.10E-08	1.30E-08	2.06E-08	5.54E-01	1.02E+00
	BREAST	4.80E-09	1.40E-08	1.08E-08	1.72E-08	4.44E-01	8.14E-01
	LUNGS	6.00E-09	1.70E-08	1.18E-08	1.76E-08	5.08E-01	9.66E-01
	RED MARR	6.30E-09	1.80E-08	1.18E-08	1.87E-08	5.34E-01	9.63E-01
	BONE SUR	6.70E-09	2.00E-08	1.10E-08	1.74E-08	6.09E-01	1.15E+00
	THYROID	6.30E-09	1.80E-08	1.11E-08	1.76E-08	5.68E-01	1.02E+00
	REMAINDER	9.10E-09	1.90E-08	1.39E-08	2.21E-08	6.55E-01	8.60E-01
	EFFECTIVE	6.60E-09	1.90E-08	1.25E-08	1.98E-08	5.28E-01	9.60E-01
	SKIN(FGR)	4.40E-09	1.30E-08	0.00E+00	0.00E+00	n/a	n/a
29	Cs-135						
	GONADS	6.50E-10	1.90E-09	1.20E-09	1.91E-09	5.42E-01	9.95E-01
	BREAST	6.50E-10	1.90E-09	1.20E-09	1.91E-09	5.42E-01	9.95E-01
	LUNGS	6.60E-10	1.90E-09	1.41E-09	1.91E-09	4.68E-01	9.95E-01
	RED MARR	6.50E-10	1.90E-09	1.20E-09	1.91E-09	5.42E-01	9.95E-01
	BONE SUR	6.50E-10	1.90E-09	1.20E-09	1.91E-09	5.42E-01	9.95E-01
	THYROID	6.50E-10	1.90E-09	1.20E-09	1.91E-09	5.42E-01	9.95E-01
	REMAINDER	9.00E-10	1.90E-09	1.20E-09	1.93E-09	7.50E-01	9.84E-01
	EFFECTIVE	6.90E-10	2.00E-09	1.23E-09	1.91E-09	5.61E-01	1.05E+00
	SKIN(FGR)	6.50E-10	1.90E-09	0.00E+00	0.00E+00	n/a	n/a
30	Cs-137						
	GONADS	4.80E-09	1.40E-08	8.76E-09	1.39E-08	5.48E-01	1.01E+00
	BREAST	3.80E-09	1.10E-08	7.84E-09	1.24E-08	4.85E-01	8.87E-01
	LUNGS	4.30E-09	1.30E-08	8.82E-09	1.27E-08	4.88E-01	1.02E+00
	RED MARR	4.40E-09	1.30E-08	8.30E-09	1.32E-08	5.30E-01	9.85E-01
	BONE SUR	4.60E-09	1.40E-08	7.94E-09	1.26E-08	5.79E-01	1.11E+00
	THYROID	4.40E-09	1.30E-08	7.93E-09	1.26E-08	5.55E-01	1.03E+00
	REMAINDER	5.80E-09	1.20E-08	9.12E-09	1.45E-08	6.36E-01	8.28E-01
	EFFECTIVE	4.60E-09	1.30E-08	8.63E-09	1.35E-08	5.33E-01	9.63E-01
	SKIN(FGR)	3.60E-09	1.10E-08	0.00E+00	0.00E+00	n/a	n/a
31	Eu-152						
	GONADS	1.40E-08	1.30E-09	1.31E-08	1.33E-09	1.07E+00	9.77E-01
	BREAST	1.30E-08	7.20E-11	1.74E-08	2.85E-10	7.47E-01	2.53E-01
	LUNGS	6.20E-08	1.40E-10	5.76E-08	2.40E-10	1.08E+00	5.83E-01
	RED MARR	7.00E-08	5.90E-10	7.91E-08	9.19E-10	8.85E-01	6.42E-01
	BONE SUR	1.90E-07	1.10E-09	2.40E-07	2.09E-09	7.92E-01	5.26E-01
	THYROID	8.30E-09	4.30E-11	8.25E-09	6.66E-11	1.01E+00	6.46E-01
	REMAINDER	1.40E-08	2.30E-10	9.99E-08	3.92E-09	1.40E-01	5.87E-02
	EFFECTIVE	4.20E-08	1.40E-09	5.97E-08	1.75E-09	7.04E-01	8.00E-01
	SKIN(FGR)	8.80E-09	9.80E-11	0.00E+00	0.00E+00	n/a	n/a

Table G-1. Ratio of ICRP-72-to-FGR-11 Dose Conversion Factors

		ICRP-72 DCFs		FGR-11 DCFs		Ratio (ICRP-72 / FGR-11) DCFs	
		A	B	C	D	A/C	B/D
		INHALED CHRONIC (Sv/Bq)	INGESTION (Sv/Bq)	INHALED CHRONIC (Sv/Bq)	INGESTION (Sv/Bq)	INHALED CHRONIC	INGESTION
32	Eu-154						
	GONADS	1.20E-08	1.40E-09	1.17E-08	1.37E-09	1.03E+00	1.02E+00
	BREAST	1.20E-08	6.70E-11	1.55E-08	2.79E-10	7.74E-01	2.40E-01
	LUNGS	1.00E-07	1.30E-10	7.92E-08	2.16E-10	1.26E+00	6.02E-01
	RED MARR	9.10E-08	7.20E-10	1.06E-07	1.15E-09	8.58E-01	6.26E-01
	BONE SUR	4.10E-07	2.30E-09	5.23E-07	4.46E-09	7.84E-01	5.16E-01
	THYROID	7.50E-09	3.90E-11	7.14E-09	5.71E-11	1.05E+00	6.83E-01
	REMAINDER	1.20E-08	2.50E-10	1.13E-07	6.32E-09	1.06E-01	3.96E-02
	EFFECTIVE	5.30E-08	2.00E-09	7.73E-08	2.58E-09	6.86E-01	7.75E-01
	SKIN(FGR)	7.80E-09	9.70E-11	0.00E+00	0.00E+00	n/a	n/a
33	Eu-155						
	GONADS	4.90E-10	9.50E-11	3.56E-10	9.83E-11	1.38E+00	9.66E-01
	BREAST	4.20E-10	1.90E-12	6.14E-10	1.44E-11	6.84E-01	1.32E-01
	LUNGS	1.90E-08	5.50E-12	1.19E-08	9.64E-12	1.60E+00	5.71E-01
	RED MARR	1.00E-08	7.00E-11	1.43E-08	1.56E-10	6.99E-01	4.49E-01
	BONE SUR	1.20E-07	6.60E-10	1.52E-07	1.29E-09	7.89E-01	5.12E-01
	THYROID	2.60E-10	1.20E-12	2.40E-10	1.78E-12	1.08E+00	6.74E-01
	REMAINDER	5.00E-10	1.70E-11	1.11E-08	1.09E-09	4.50E-02	1.56E-02
	EFFECTIVE	6.90E-09	3.20E-10	1.12E-08	4.13E-10	6.16E-01	7.75E-01
	SKIN(FGR)	2.30E-10	3.50E-12	0.00E+00	0.00E+00	n/a	n/a
34	Fe-55						
	GONADS	9.50E-11	8.50E-11	1.79E-10	1.07E-10	5.31E-01	7.94E-01
	BREAST	9.50E-11	8.50E-11	1.74E-10	1.04E-10	5.46E-01	8.17E-01
	LUNGS	4.00E-10	8.50E-11	1.06E-09	1.02E-10	3.77E-01	8.33E-01
	RED MARR	1.20E-09	1.10E-09	1.76E-10	1.05E-10	6.82E+00	1.05E+01
	BONE SUR	6.80E-10	6.10E-10	1.75E-10	1.05E-10	3.89E+00	5.81E+00
	THYROID	9.50E-11	8.50E-11	1.85E-10	1.10E-10	5.14E-01	7.73E-01
	REMAINDER	1.40E-09	1.30E-09	4.37E-10	3.00E-10	3.20E+00	4.33E+00
	EFFECTIVE	3.80E-10	3.30E-10	3.61E-10	1.64E-10	1.05E+00	2.01E+00
	SKIN(FGR)	9.50E-11	8.50E-11	0.00E+00	0.00E+00	n/a	n/a
35	Fe-59						
	GONADS	7.40E-10	1.70E-09	1.39E-09	1.66E-09	5.32E-01	1.02E+00
	BREAST	1.10E-09	4.90E-10	1.26E-09	7.37E-10	8.73E-01	6.65E-01
	LUNGS	2.30E-08	6.80E-10	1.38E-08	6.35E-10	1.67E+00	1.07E+00
	RED MARR	1.30E-09	1.50E-09	1.31E-09	8.45E-10	9.92E-01	1.78E+00
	BONE SUR	9.80E-10	1.10E-09	1.11E-09	6.61E-10	8.83E-01	1.66E+00
	THYROID	6.70E-10	5.40E-10	1.17E-09	6.03E-10	5.73E-01	8.96E-01
	REMAINDER	7.20E-10	7.20E-10	2.96E-09	3.56E-09	2.43E-01	2.02E-01
	EFFECTIVE	3.70E-09	1.80E-09	3.30E-09	1.81E-09	1.12E+00	9.94E-01
	SKIN(FGR)	4.60E-10	4.60E-10	0.00E+00	0.00E+00	n/a	n/a

Table G-1. Ratio of ICRP-72-to-FGR-11 Dose Conversion Factors

		ICRP-72 DCFs		FGR-11 DCFs		Ratio (ICRP-72 / FGR-11) DCFs	
		A	B	C	D	A/C	B/D
		INHALED CHRONIC (Sv/Bq)	INGESTION (Sv/Bq)	INHALED CHRONIC (Sv/Bq)	INGESTION (Sv/Bq)	INHALED CHRONIC	INGESTION
36	Fr-221						
	GONADS	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a
	BREAST	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a
	LUNGS	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a
	RED MARR	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a
	BONE SUR	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a
	THYROID	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a
	REMAINDER	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a
	EFFECTIVE	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a
	SKIN(FGR)	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a
37	Fr-223						
	GONADS	7.90E-10	2.30E-09	1.44E-09	2.32E-09	5.49E-01	9.91E-01
	BREAST	7.90E-10	2.30E-09	1.44E-09	2.32E-09	5.49E-01	9.91E-01
	LUNGS	8.50E-10	2.30E-09	3.44E-09	2.32E-09	2.47E-01	9.91E-01
	RED MARR	7.90E-10	2.30E-09	1.44E-09	2.32E-09	5.49E-01	9.91E-01
	BONE SUR	7.90E-10	2.30E-09	1.44E-09	2.32E-09	5.49E-01	9.91E-01
	THYROID	7.90E-10	2.30E-09	1.44E-09	2.32E-09	5.49E-01	9.91E-01
	REMAINDER	2.60E-09	2.30E-09	1.44E-09	2.35E-09	1.81E+00	9.79E-01
	EFFECTIVE	8.90E-10	2.40E-09	1.68E-09	2.33E-09	5.30E-01	1.03E+00
	SKIN(FGR)	7.90E-10	2.30E-09	0.00E+00	0.00E+00	n/a	n/a
38	Gd-152						
	GONADS	3.00E-10	1.60E-12	0.00E+00	0.00E+00	n/a	n/a
	BREAST	3.00E-10	1.60E-12	0.00E+00	0.00E+00	n/a	n/a
	LUNGS	4.30E-06	1.60E-12	7.28E-06	0.00E+00	5.91E-01	n/a
	RED MARR	2.10E-05	1.10E-07	2.63E-05	6.57E-08	7.98E-01	1.67E+00
	BONE SUR	2.60E-04	1.40E-06	3.29E-04	8.21E-07	7.90E-01	1.71E+00
	THYROID	3.00E-10	1.60E-12	0.00E+00	0.00E+00	n/a	n/a
	REMAINDER	1.30E-09	3.20E-11	1.20E-05	3.62E-08	1.08E-04	8.84E-04
	EFFECTIVE	8.00E-06	4.10E-08	1.75E-05	4.34E-08	4.57E-01	9.45E-01
	SKIN(FGR)	3.00E-10	1.60E-12	0.00E+00	0.00E+00	n/a	n/a
39	H-3						
	GONADS	2.70E-11	4.10E-11	1.73E-11	1.73E-11	1.56E+00	2.37E+00
	BREAST	2.70E-11	4.10E-11	1.73E-11	1.73E-11	1.56E+00	2.37E+00
	LUNGS	2.70E-11	4.10E-11	1.73E-11	1.73E-11	1.56E+00	2.37E+00
	RED MARR	2.70E-11	4.10E-11	1.73E-11	1.73E-11	1.56E+00	2.37E+00
	BONE SUR	2.70E-11	4.10E-11	1.73E-11	1.73E-11	1.56E+00	2.37E+00
	THYROID	2.70E-11	4.10E-11	1.73E-11	1.73E-11	1.56E+00	2.37E+00
	REMAINDER	2.70E-11	4.10E-11	1.73E-11	1.73E-11	1.56E+00	2.37E+00
	EFFECTIVE	2.70E-11	4.20E-11	1.73E-11	1.73E-11	1.56E+00	2.43E+00
	SKIN(FGR)	2.70E-11	4.10E-11	0.00E+00	0.00E+00	n/a	n/a

Table G-1. Ratio of ICRP-72-to-FGR-11 Dose Conversion Factors

		ICRP-72 DCFs		FGR-11 DCFs		Ratio (ICRP-72 / FGR-11) DCFs	
		A	B	C	D	A/C	B/D
		INHALED CHRONIC (Sv/Bq)	INGESTION (Sv/Bq)	INHALED CHRONIC (Sv/Bq)	INGESTION (Sv/Bq)	INHALED CHRONIC	INGESTION
40	I-129						
	GONADS	4.30E-11	1.30E-10	8.69E-11	1.38E-10	4.95E-01	9.42E-01
	BREAST	3.90E-11	1.10E-10	2.09E-10	3.31E-10	1.87E-01	3.32E-01
	LUNGS	6.30E-11	1.50E-10	3.14E-10	1.65E-10	2.01E-01	9.09E-01
	RED MARR	4.80E-11	1.40E-10	1.40E-10	2.21E-10	3.43E-01	6.33E-01
	BONE SUR	1.40E-10	4.00E-10	1.38E-10	2.17E-10	1.01E+00	1.84E+00
	THYROID	7.10E-07	2.10E-06	1.56E-06	2.48E-06	4.55E-01	8.47E-01
	REMAINDER	9.70E-11	2.80E-10	1.18E-10	1.99E-10	8.22E-01	1.41E+00
	EFFECTIVE	3.60E-08	1.10E-07	4.69E-08	7.46E-08	7.68E-01	1.47E+00
	SKIN(FGR)	4.80E-11	1.40E-10	0.00E+00	0.00E+00	n/a	n/a
41	K-42						
	GONADS	7.50E-11	2.10E-10	1.08E-10	2.13E-10	6.94E-01	9.86E-01
	BREAST	7.30E-11	2.10E-10	1.06E-10	2.08E-10	6.89E-01	1.01E+00
	LUNGS	1.10E-10	2.10E-10	2.15E-09	2.07E-10	5.12E-02	1.01E+00
	RED MARR	7.40E-11	2.10E-10	1.06E-10	2.08E-10	6.98E-01	1.01E+00
	BONE SUR	7.50E-11	2.10E-10	1.06E-10	2.07E-10	7.08E-01	1.01E+00
	THYROID	7.50E-11	2.10E-10	1.05E-10	2.06E-10	7.14E-01	1.02E+00
	REMAINDER	4.90E-10	2.10E-10	1.57E-10	5.30E-10	3.12E+00	3.96E-01
	EFFECTIVE	1.20E-10	4.30E-10	3.67E-10	3.06E-10	3.27E-01	1.41E+00
	SKIN(FGR)	7.20E-11	2.10E-10	0.00E+00	0.00E+00	n/a	n/a
42	Kr-85						
	GONADS	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a
	BREAST	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a
	LUNGS	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a
	RED MARR	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a
	BONE SUR	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a
	THYROID	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a
	REMAINDER	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a
	EFFECTIVE	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a
	SKIN(FGR)	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a
43	Na-24						
	GONADS	1.10E-10	3.30E-10	1.78E-10	3.43E-10	6.18E-01	9.62E-01
	BREAST	8.40E-11	2.20E-10	1.61E-10	2.71E-10	5.22E-01	8.12E-01
	LUNGS	1.30E-10	2.60E-10	1.25E-09	2.60E-10	1.04E-01	1.00E+00
	RED MARR	1.50E-10	3.90E-10	2.13E-10	3.74E-10	7.04E-01	1.04E+00
	BONE SUR	2.00E-10	5.40E-10	2.58E-10	4.68E-10	7.75E-01	1.15E+00
	THYROID	1.20E-10	2.70E-10	1.53E-10	2.60E-10	7.84E-01	1.04E+00
	REMAINDER	3.00E-09	2.70E-10	2.35E-10	5.31E-10	1.28E+01	5.08E-01
	EFFECTIVE	2.70E-10	4.30E-10	3.27E-10	3.84E-10	8.26E-01	1.12E+00
	SKIN(FGR)	8.10E-11	2.10E-10	0.00E+00	0.00E+00	n/a	n/a

Table G-1. Ratio of ICRP-72-to-FGR-11 Dose Conversion Factors

		ICRP-72 DCFs		FGR-11 DCFs		Ratio (ICRP-72 / FGR-11) DCFs	
		A	B	C	D	A/C	B/D
		INHALED CHRONIC (Sv/Bq)	INGESTION (Sv/Bq)	INHALED CHRONIC (Sv/Bq)	INGESTION (Sv/Bq)	INHALED CHRONIC	INGESTION
44	Nb-93m						
	GONADS	3.50E-11	6.40E-12	1.55E-10	3.34E-11	2.26E-01	1.92E-01
	BREAST	3.50E-11	3.60E-12	4.36E-11	2.57E-12	8.03E-01	1.40E+00
	LUNGS	3.30E-09	3.70E-12	6.45E-08	2.45E-12	5.12E-02	1.51E+00
	RED MARR	1.40E-10	1.40E-11	1.14E-10	2.32E-11	1.23E+00	6.03E-01
	BONE SUR	3.60E-10	3.80E-11	2.84E-10	5.98E-11	1.27E+00	6.35E-01
	THYROID	3.50E-11	3.60E-12	1.14E-11	2.44E-12	3.07E+00	1.48E+00
	REMAINDER	4.30E-11	6.00E-12	3.04E-10	4.25E-10	1.41E-01	1.41E-02
	EFFECTIVE	5.10E-10	1.20E-10	7.90E-09	1.41E-10	6.46E-02	8.51E-01
	SKIN(FGR)	3.40E-11	3.60E-12	0.00E+00	0.00E+00	n/a	n/a
45	Nb-94						
	GONADS	2.30E-09	1.90E-09	4.42E-09	1.80E-09	5.20E-01	1.06E+00
	BREAST	4.40E-09	1.40E-10	2.24E-08	3.47E-10	1.96E-01	4.03E-01
	LUNGS	6.00E-08	2.20E-10	7.48E-07	1.72E-10	8.02E-02	1.28E+00
	RED MARR	4.90E-09	6.40E-10	2.26E-08	7.39E-10	2.17E-01	8.66E-01
	BONE SUR	5.80E-09	6.00E-10	1.97E-08	7.65E-10	2.94E-01	7.84E-01
	THYROID	2.60E-09	1.50E-10	2.22E-08	1.23E-10	1.17E-01	1.22E+00
	REMAINDER	2.90E-09	3.90E-10	4.45E-08	4.30E-09	6.52E-02	9.07E-02
	EFFECTIVE	1.10E-08	1.70E-09	1.12E-07	1.93E-09	9.82E-02	8.81E-01
	SKIN(FGR)	1.80E-09	1.90E-10	0.00E+00	0.00E+00	n/a	n/a
46	Ni-59						
	GONADS	7.80E-11	3.70E-11	1.09E-10	3.83E-11	7.16E-01	9.66E-01
	BREAST	7.80E-11	3.70E-11	1.05E-10	3.58E-11	7.43E-01	1.03E+00
	LUNGS	4.70E-10	3.70E-11	1.20E-09	3.50E-11	3.92E-01	1.06E+00
	RED MARR	7.80E-11	3.70E-11	1.06E-10	3.66E-11	7.36E-01	1.01E+00
	BONE SUR	7.80E-11	3.70E-11	1.05E-10	3.62E-11	7.43E-01	1.02E+00
	THYROID	7.80E-11	3.70E-11	1.14E-10	3.90E-11	6.84E-01	9.49E-01
	REMAINDER	7.80E-11	3.70E-11	1.40E-10	1.03E-10	5.57E-01	3.59E-01
	EFFECTIVE	1.30E-10	6.30E-11	2.48E-10	5.67E-11	5.24E-01	1.11E+00
	SKIN(FGR)	7.80E-11	3.70E-11	0.00E+00	0.00E+00	n/a	n/a
47	Ni-63						
	GONADS	1.90E-10	8.70E-11	2.47E-10	8.50E-11	7.69E-01	1.02E+00
	BREAST	1.90E-10	8.70E-11	2.47E-10	8.50E-11	7.69E-01	1.02E+00
	LUNGS	2.50E-09	8.70E-11	3.07E-09	8.50E-11	8.14E-01	1.02E+00
	RED MARR	1.90E-10	8.70E-11	2.47E-10	8.50E-11	7.69E-01	1.02E+00
	BONE SUR	1.90E-10	8.70E-11	2.47E-10	8.50E-11	7.69E-01	1.02E+00
	THYROID	1.90E-10	8.70E-11	2.47E-10	8.50E-11	7.69E-01	1.02E+00
	REMAINDER	1.90E-10	8.80E-11	3.67E-10	3.20E-10	5.18E-01	2.75E-01
	EFFECTIVE	4.80E-10	1.50E-10	6.22E-10	1.56E-10	7.72E-01	9.62E-01
	SKIN(FGR)	1.90E-10	8.70E-11	0.00E+00	0.00E+00	n/a	n/a

Table G-1. Ratio of ICRP-72-to-FGR-11 Dose Conversion Factors

		ICRP-72 DCFs		FGR-11 DCFs		Ratio (ICRP-72 / FGR-11) DCFs	
		A	B	C	D	A/C	B/D
		INHALED CHRONIC (Sv/Bq)	INGESTION (Sv/Bq)	INHALED CHRONIC (Sv/Bq)	INGESTION (Sv/Bq)	INHALED CHRONIC	INGESTION
48	Np-237						
	GONADS	1.40E-05	7.40E-08	2.96E-05	2.46E-07	4.73E-01	3.01E-01
	BREAST	1.30E-06	7.10E-09	1.69E-08	1.45E-10	7.69E+01	4.90E+01
	LUNGS	2.90E-05	7.10E-09	1.61E-05	1.53E-10	1.80E+00	4.64E+01
	RED MARR	3.90E-05	2.10E-07	2.62E-04	2.18E-06	1.49E-01	9.63E-02
	BONE SUR	1.00E-03	5.40E-06	3.27E-03	2.72E-05	3.06E-01	1.99E-01
	THYROID	1.30E-06	7.10E-09	1.34E-08	1.10E-10	9.70E+01	6.45E+01
	REMAINDER	1.40E-06	7.30E-09	2.34E-05	2.10E-07	5.98E-02	3.48E-02
	EFFECTIVE	2.30E-05	1.10E-07	1.46E-04	1.20E-06	1.58E-01	9.17E-02
	SKIN(FGR)	1.30E-06	7.10E-09	0.00E+00	0.00E+00	n/a	n/a
49	Np-238						
	GONADS	9.80E-10	4.00E-10	1.99E-09	3.89E-10	4.92E-01	1.03E+00
	BREAST	1.20E-10	6.70E-12	4.18E-11	4.81E-11	2.87E+00	1.39E-01
	LUNGS	5.40E-09	9.30E-12	3.47E-09	1.02E-11	1.56E+00	9.12E-01
	RED MARR	2.80E-09	8.60E-11	1.69E-08	2.17E-10	1.66E-01	3.96E-01
	BONE SUR	6.70E-08	3.90E-10	2.10E-07	1.77E-09	3.19E-01	2.20E-01
	THYROID	1.00E-10	1.60E-12	2.45E-11	1.50E-12	4.08E+00	1.07E+00
	REMAINDER	1.20E-10	6.70E-11	2.55E-09	2.97E-09	4.71E-02	2.26E-02
	EFFECTIVE	2.10E-09	9.10E-10	1.00E-08	1.08E-09	2.10E-01	8.43E-01
	SKIN(FGR)	9.80E-11	1.80E-11	0.00E+00	0.00E+00	n/a	n/a
50	Np-239						
	GONADS	3.70E-11	1.50E-10	7.45E-11	1.62E-10	4.97E-01	9.26E-01
	BREAST	1.30E-11	1.10E-12	1.63E-11	1.72E-11	7.98E-01	6.40E-02
	LUNGS	6.30E-09	2.10E-12	2.36E-09	2.40E-12	2.67E+00	8.75E-01
	RED MARR	4.50E-11	2.60E-11	2.08E-10	4.66E-11	2.16E-01	5.58E-01
	BONE SUR	5.10E-10	2.50E-11	2.03E-09	3.59E-11	2.51E-01	6.96E-01
	THYROID	8.20E-12	1.50E-13	7.62E-12	2.07E-13	1.08E+00	7.25E-01
	REMAINDER	1.60E-11	3.30E-11	9.59E-10	2.77E-09	1.67E-02	1.19E-02
	EFFECTIVE	9.30E-10	8.00E-10	6.78E-10	8.82E-10	1.37E+00	9.07E-01
	SKIN(FGR)	5.70E-12	5.00E-12	0.00E+00	0.00E+00	n/a	n/a
51	Np-240m						
	GONADS	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a
	BREAST	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a
	LUNGS	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a
	RED MARR	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a
	BONE SUR	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a
	THYROID	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a
	REMAINDER	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a
	EFFECTIVE	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a
	SKIN(FGR)	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a

Table G-1. Ratio of ICRP-72-to-FGR-11 Dose Conversion Factors

		ICRP-72 DCFs		FGR-11 DCFs		Ratio (ICRP-72 / FGR-11) DCFs	
		A	B	C	D	A/C	B/D
		INHALED CHRONIC (Sv/Bq)	INGESTION (Sv/Bq)	INHALED CHRONIC (Sv/Bq)	INGESTION (Sv/Bq)	INHALED CHRONIC	INGESTION
52	Pa-231						
	GONADS	1.80E-09	1.30E-10	3.06E-09	1.21E-10	5.88E-01	1.07E+00
	BREAST	2.90E-09	2.60E-11	5.65E-09	7.81E-11	5.13E-01	3.33E-01
	LUNGS	1.40E-04	4.70E-11	7.47E-04	6.80E-11	1.87E-01	6.91E-01
	RED MARR	7.00E-05	2.90E-06	2.88E-04	5.78E-06	2.43E-01	5.02E-01
	BONE SUR	8.80E-04	3.60E-05	3.60E-03	7.22E-05	2.44E-01	4.99E-01
	THYROID	1.90E-09	4.00E-11	4.45E-09	6.33E-11	4.27E-01	6.32E-01
	REMAINDER	2.90E-08	1.50E-10	2.12E-07	1.71E-08	1.37E-01	8.77E-03
	EFFECTIVE	3.40E-05	7.10E-07	2.32E-04	2.86E-06	1.47E-01	2.48E-01
	SKIN(FGR)	1.20E-09	3.00E-11	0.00E+00	0.00E+00	n/a	n/a
53	Pa-233						
	GONADS	5.90E-11	2.30E-10	1.29E-10	2.58E-10	4.57E-01	8.91E-01
	BREAST	1.30E-10	2.00E-12	9.20E-11	2.71E-11	1.41E+00	7.38E-02
	LUNGS	3.00E-08	3.40E-12	1.70E-08	3.70E-12	1.76E+00	9.19E-01
	RED MARR	8.60E-11	4.60E-11	1.86E-10	6.89E-11	4.62E-01	6.68E-01
	BONE SUR	2.20E-10	6.60E-11	8.28E-10	1.02E-10	2.66E-01	6.47E-01
	THYROID	5.00E-11	3.40E-13	5.62E-11	4.81E-13	8.90E-01	7.07E-01
	REMAINDER	6.20E-11	4.10E-11	1.48E-09	3.00E-09	4.19E-02	1.37E-02
	EFFECTIVE	3.90E-09	8.70E-10	2.58E-09	9.81E-10	1.51E+00	8.87E-01
	SKIN(FGR)	2.60E-11	8.30E-12	0.00E+00	0.00E+00	n/a	n/a
54	Pa-234						
	GONADS	6.70E-11	3.40E-10	6.13E-11	3.30E-10	1.09E+00	1.03E+00
	BREAST	1.90E-11	8.70E-12	2.19E-11	4.99E-11	8.68E-01	1.74E-01
	LUNGS	1.70E-09	1.30E-11	8.97E-10	1.51E-11	1.90E+00	8.61E-01
	RED MARR	2.50E-11	6.90E-11	2.74E-11	7.86E-11	9.12E-01	8.78E-01
	BONE SUR	1.90E-11	3.20E-11	2.06E-11	2.74E-11	9.22E-01	1.17E+00
	THYROID	1.40E-11	1.30E-12	1.23E-11	1.86E-12	1.14E+00	6.99E-01
	REMAINDER	1.70E-09	7.20E-11	2.98E-10	1.61E-09	5.70E+00	4.47E-02
	EFFECTIVE	4.00E-10	5.10E-10	2.20E-10	5.84E-10	1.82E+00	8.73E-01
	SKIN(FGR)	9.50E-12	1.80E-11	0.00E+00	0.00E+00	n/a	n/a
55	Pa-234m						
	GONADS	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a
	BREAST	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a
	LUNGS	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a
	RED MARR	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a
	BONE SUR	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a
	THYROID	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a
	REMAINDER	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a
	EFFECTIVE	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a
	SKIN(FGR)	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a

Table G-1. Ratio of ICRP-72-to-FGR-11 Dose Conversion Factors

		ICRP-72 DCFs		FGR-11 DCFs		Ratio (ICRP-72 / FGR-11) DCFs	
		A	B	C	D	A/C	B/D
		INHALED CHRONIC (Sv/Bq)	INGESTION (Sv/Bq)	INHALED CHRONIC (Sv/Bq)	INGESTION (Sv/Bq)	INHALED CHRONIC	INGESTION
56	Pb-210						
	GONADS	6.50E-08	8.80E-08	3.18E-07	1.25E-07	2.04E-01	7.04E-01
	BREAST	6.50E-08	8.80E-08	3.18E-07	1.25E-07	2.04E-01	7.04E-01
	LUNGS	5.50E-06	8.80E-08	3.18E-07	1.25E-07	1.73E+01	7.04E-01
	RED MARR	1.60E-06	2.50E-06	3.75E-06	1.48E-06	4.27E-01	1.69E+00
	BONE SUR	1.30E-05	2.30E-05	5.47E-05	2.16E-05	2.38E-01	1.06E+00
	THYROID	6.50E-08	8.80E-08	3.18E-07	1.25E-07	2.04E-01	7.04E-01
	REMAINDER	1.10E-07	1.40E-07	4.69E-06	1.85E-06	2.35E-02	7.57E-02
	EFFECTIVE	1.10E-06	6.90E-07	3.67E-06	1.45E-06	3.00E-01	4.76E-01
	SKIN(FGR)	6.50E-08	8.80E-08	0.00E+00	0.00E+00	n/a	n/a
57	Pb-211						
	GONADS	1.80E-11	1.80E-11	1.63E-10	1.97E-11	1.10E-01	9.14E-01
	BREAST	1.80E-11	1.70E-11	1.63E-10	1.91E-11	1.10E-01	8.90E-01
	LUNGS	9.20E-08	1.70E-11	1.78E-08	1.90E-11	5.17E+00	8.95E-01
	RED MARR	4.10E-11	3.90E-11	2.64E-10	3.07E-11	1.55E-01	1.27E+00
	BONE SUR	2.80E-10	2.70E-10	1.39E-09	1.60E-10	2.01E-01	1.69E+00
	THYROID	1.80E-11	1.70E-11	1.63E-10	1.88E-11	1.10E-01	9.04E-01
	REMAINDER	6.40E-11	2.80E-11	2.51E-10	4.10E-10	2.55E-01	6.83E-02
	EFFECTIVE	1.10E-08	1.80E-10	2.35E-09	1.42E-10	4.68E+00	1.27E+00
	SKIN(FGR)	1.70E-11	1.70E-11	0.00E+00	0.00E+00	n/a	n/a
58	Pd-107						
	GONADS	2.90E-14	1.00E-14	1.05E-13	9.91E-15	2.76E-01	1.01E+00
	BREAST	2.90E-14	1.00E-14	1.05E-13	9.91E-15	2.76E-01	1.01E+00
	LUNGS	4.80E-09	1.00E-14	2.85E-08	9.91E-15	1.68E-01	1.01E+00
	RED MARR	1.60E-13	5.50E-14	5.68E-13	5.36E-14	2.82E-01	1.03E+00
	BONE SUR	4.30E-13	1.50E-13	1.51E-12	1.43E-13	2.85E-01	1.05E+00
	THYROID	2.90E-14	1.00E-14	1.05E-13	9.91E-15	2.76E-01	1.01E+00
	REMAINDER	4.40E-13	6.30E-13	9.71E-11	1.35E-10	4.53E-03	4.67E-03
	EFFECTIVE	5.90E-10	3.70E-11	3.45E-09	4.04E-11	1.71E-01	9.16E-01
	SKIN(FGR)	2.90E-14	1.00E-14	0.00E+00	0.00E+00	n/a	n/a
59	Pm-147						
	GONADS	2.90E-14	8.90E-15	8.25E-15	6.86E-15	3.52E+00	1.30E+00
	BREAST	6.50E-14	2.30E-15	3.60E-14	7.45E-16	1.81E+00	3.09E+00
	LUNGS	3.90E-08	2.50E-15	7.74E-08	1.96E-16	5.04E-01	1.28E+01
	RED MARR	3.90E-10	3.50E-11	1.61E-09	2.09E-11	2.42E-01	1.67E+00
	BONE SUR	4.90E-09	4.30E-10	2.01E-08	2.61E-10	2.44E-01	1.65E+00
	THYROID	3.90E-14	2.30E-15	1.98E-14	3.12E-17	1.97E+00	7.37E+01
	REMAINDER	5.50E-12	3.70E-12	1.56E-09	9.08E-10	3.53E-03	4.07E-03
	EFFECTIVE	4.90E-09	2.60E-10	1.06E-08	2.83E-10	4.62E-01	9.19E-01
	SKIN(FGR)	3.30E-14	2.50E-15	0.00E+00	0.00E+00	n/a	n/a

Table G-1. Ratio of ICRP-72-to-FGR-11 Dose Conversion Factors

		ICRP-72 DCFs		FGR-11 DCFs		Ratio (ICRP-72 / FGR-11) DCFs	
		A	B	C	D	A/C	B/D
		INHALED CHRONIC (Sv/Bq)	INGESTION (Sv/Bq)	INHALED CHRONIC (Sv/Bq)	INGESTION (Sv/Bq)	INHALED CHRONIC	INGESTION
60	Po-210						
	GONADS	4.90E-08	2.80E-07	1.26E-07	8.23E-08	3.89E-01	3.40E+00
	BREAST	4.90E-08	2.80E-07	1.26E-07	8.23E-08	3.89E-01	3.40E+00
	LUNGS	2.60E-05	2.80E-07	1.30E-05	8.23E-08	2.00E+00	3.40E+00
	RED MARR	4.60E-07	2.60E-06	1.26E-07	8.23E-08	3.65E+00	3.16E+01
	BONE SUR	2.80E-07	1.60E-06	1.26E-07	8.23E-08	2.22E+00	1.94E+01
	THYROID	4.90E-08	2.80E-07	1.26E-07	8.23E-08	3.89E-01	3.40E+00
	REMAINDER	8.40E-08	6.50E-06	2.30E-06	1.52E-06	3.65E-02	4.28E+00
	EFFECTIVE	3.30E-06	1.20E-06	2.32E-06	5.14E-07	1.42E+00	2.33E+00
	SKIN(FGR)	4.90E-08	2.80E-07	0.00E+00	0.00E+00	n/a	n/a
61	Po-215						
	GONADS	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a
	BREAST	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a
	LUNGS	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a
	RED MARR	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a
	BONE SUR	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a
	THYROID	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a
	REMAINDER	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a
	EFFECTIVE	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a
	SKIN(FGR)	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a
62	Pr-144						
	GONADS	1.20E-14	8.80E-14	2.41E-15	7.38E-14	4.98E+00	1.19E+00
	BREAST	1.70E-14	1.90E-14	1.05E-14	3.38E-14	1.62E+00	5.62E-01
	LUNGS	5.70E-11	2.70E-14	9.40E-11	3.15E-14	6.06E-01	8.57E-01
	RED MARR	1.60E-14	3.40E-14	1.38E-14	3.22E-14	1.16E+00	1.06E+00
	BONE SUR	1.40E-14	1.80E-14	1.47E-14	1.52E-14	9.52E-01	1.18E+00
	THYROID	1.60E-14	2.70E-15	8.47E-15	3.59E-15	1.89E+00	7.52E-01
	REMAINDER	1.10E-10	2.00E-12	1.40E-12	1.05E-10	7.86E+01	1.90E-02
	EFFECTIVE	1.80E-11	5.00E-11	1.17E-11	3.15E-11	1.54E+00	1.59E+00
	SKIN(FGR)	8.60E-15	1.40E-14	0.00E+00	0.00E+00	n/a	n/a
63	Pr-144m						
	GONADS	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a
	BREAST	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a
	LUNGS	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a
	RED MARR	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a
	BONE SUR	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a
	THYROID	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a
	REMAINDER	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a
	EFFECTIVE	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a
	SKIN(FGR)	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a

Table G-1. Ratio of ICRP-72-to-FGR-11 Dose Conversion Factors

		ICRP-72 DCFs		FGR-11 DCFs		Ratio (ICRP-72 / FGR-11) DCFs	
		A	B	C	D	A/C	B/D
		INHALED CHRONIC (Sv/Bq)	INGESTION (Sv/Bq)	INHALED CHRONIC (Sv/Bq)	INGESTION (Sv/Bq)	INHALED CHRONIC	INGESTION
64	Pu-238						
	GONADS	2.20E-06	9.90E-08	1.04E-05	2.33E-09	2.12E-01	4.25E+01
	BREAST	2.80E-07	1.30E-08	4.40E-10	1.80E-13	6.36E+02	7.22E+04
	LUNGS	9.30E-05	1.30E-08	3.20E-04	8.64E-14	2.91E-01	1.50E+05
	RED MARR	8.30E-06	3.70E-07	5.80E-05	1.27E-08	1.43E-01	2.91E+01
	BONE SUR	1.60E-04	7.40E-06	7.25E-04	1.58E-07	2.21E-01	4.68E+01
	THYROID	2.80E-07	1.30E-08	3.86E-10	7.99E-14	7.25E+02	1.63E+05
	REMAINDER	3.00E-07	1.30E-08	2.74E-05	2.18E-08	1.09E-02	5.96E-01
	EFFECTIVE	1.60E-05	2.30E-07	7.79E-05	1.34E-08	2.05E-01	1.72E+01
	SKIN(FGR)	2.80E-07	1.30E-08	0.00E+00	0.00E+00	n/a	n/a
65	Pu-239						
	GONADS	2.50E-06	1.10E-07	1.20E-05	2.64E-09	2.08E-01	4.17E+01
	BREAST	3.20E-07	1.40E-08	3.99E-10	1.21E-13	8.02E+02	1.16E+05
	LUNGS	8.70E-05	1.40E-08	3.23E-04	7.89E-14	2.69E-01	1.77E+05
	RED MARR	9.10E-06	3.90E-07	6.57E-05	1.41E-08	1.39E-01	2.77E+01
	BONE SUR	1.80E-04	8.20E-06	8.21E-04	1.76E-07	2.19E-01	4.66E+01
	THYROID	3.20E-07	1.40E-08	3.75E-10	7.50E-14	8.53E+02	1.87E+05
	REMAINDER	3.40E-07	1.50E-08	3.02E-05	2.12E-08	1.13E-02	7.08E-01
	EFFECTIVE	1.60E-05	2.50E-07	8.33E-05	1.40E-08	1.92E-01	1.79E+01
	SKIN(FGR)	3.20E-07	1.40E-08	0.00E+00	0.00E+00	n/a	n/a
66	Pu-240						
	GONADS	2.50E-06	1.10E-07	1.20E-05	2.64E-09	2.08E-01	4.17E+01
	BREAST	3.20E-07	1.40E-08	4.33E-10	1.73E-13	7.39E+02	8.09E+04
	LUNGS	8.80E-05	1.40E-08	3.23E-04	8.22E-14	2.72E-01	1.70E+05
	RED MARR	9.10E-06	3.90E-07	6.57E-05	1.41E-08	1.39E-01	2.77E+01
	BONE SUR	1.80E-04	8.20E-06	8.21E-04	1.76E-07	2.19E-01	4.66E+01
	THYROID	3.20E-07	1.40E-08	3.76E-10	7.51E-14	8.51E+02	1.86E+05
	REMAINDER	3.40E-07	1.50E-08	3.02E-05	2.13E-08	1.13E-02	7.04E-01
	EFFECTIVE	1.60E-05	2.50E-07	8.33E-05	1.40E-08	1.92E-01	1.79E+01
	SKIN(FGR)	3.20E-07	1.40E-08	0.00E+00	0.00E+00	n/a	n/a
67	Pu-241						
	GONADS	5.50E-08	2.20E-09	2.76E-07	5.66E-11	1.99E-01	3.89E+01
	BREAST	7.10E-09	3.00E-10	2.14E-11	2.79E-15	3.32E+02	1.08E+05
	LUNGS	4.60E-07	3.00E-10	3.18E-06	4.48E-15	1.45E-01	6.70E+04
	RED MARR	1.80E-07	6.40E-09	1.43E-06	2.78E-10	1.26E-01	2.30E+01
	BONE SUR	4.10E-06	1.60E-07	1.78E-05	3.48E-09	2.30E-01	4.60E+01
	THYROID	7.10E-09	3.00E-10	9.15E-12	1.01E-15	7.76E+02	2.97E+05
	REMAINDER	7.30E-09	3.00E-10	6.02E-07	1.85E-10	1.21E-02	1.62E+00
	EFFECTIVE	1.70E-07	4.80E-09	1.34E-06	2.07E-10	1.27E-01	2.32E+01
	SKIN(FGR)	7.10E-09	3.00E-10	0.00E+00	0.00E+00	n/a	n/a

Table G-1. Ratio of ICRP-72-to-FGR-11 Dose Conversion Factors

		ICRP-72 DCFs		FGR-11 DCFs		Ratio (ICRP-72 / FGR-11) DCFs	
		A	B	C	D	A/C	B/D
		INHALED CHRONIC (Sv/Bq)	INGESTION (Sv/Bq)	INHALED CHRONIC (Sv/Bq)	INGESTION (Sv/Bq)	INHALED CHRONIC	INGESTION
68	Pu-242						
	GONADS	2.40E-06	1.00E-07	1.14E-05	2.51E-09	2.11E-01	3.98E+01
	BREAST	3.00E-07	1.40E-08	4.35E-10	2.54E-13	6.90E+02	5.51E+04
	LUNGS	8.10E-05	1.40E-08	3.07E-04	9.18E-14	2.64E-01	1.53E+05
	RED MARR	8.70E-06	3.70E-07	6.25E-05	1.34E-08	1.39E-01	2.76E+01
	BONE SUR	1.80E-04	7.80E-06	7.81E-04	1.67E-07	2.30E-01	4.67E+01
	THYROID	3.00E-07	1.40E-08	3.71E-10	7.38E-14	8.09E+02	1.90E+05
	REMAINDER	3.20E-07	1.40E-08	2.86E-05	2.02E-08	1.12E-02	6.93E-01
	EFFECTIVE	1.50E-05	2.40E-07	7.92E-05	1.33E-08	1.89E-01	1.80E+01
	SKIN(FGR)	3.00E-07	1.40E-08	0.00E+00	0.00E+00	n/a	n/a
69	Pu-243						
	GONADS	1.10E-12	4.50E-12	1.67E-12	4.56E-12	6.59E-01	9.87E-01
	BREAST	2.20E-13	5.90E-14	2.75E-13	5.93E-13	8.00E-01	9.95E-02
	LUNGS	4.70E-10	1.20E-13	2.27E-10	1.47E-13	2.07E+00	8.16E-01
	RED MARR	9.90E-13	7.70E-13	5.77E-12	1.82E-12	1.72E-01	4.23E-01
	BONE SUR	1.50E-11	1.50E-12	6.53E-11	5.71E-13	2.30E-01	2.63E+00
	THYROID	1.60E-13	7.00E-15	1.13E-13	5.50E-15	1.42E+00	1.27E+00
	REMAINDER	2.60E-10	6.50E-12	4.69E-11	2.96E-10	5.54E+00	2.20E-02
	EFFECTIVE	8.60E-11	8.50E-11	4.44E-11	9.02E-11	1.94E+00	9.42E-01
	SKIN(FGR)	1.10E-13	1.50E-13	0.00E+00	0.00E+00	n/a	n/a
70	Pu-244						
	GONADS	2.30E-06	1.00E-07	1.13E-05	2.94E-09	2.04E-01	3.40E+01
	BREAST	3.10E-07	1.40E-08	2.07E-08	5.36E-11	1.50E+01	2.61E+02
	LUNGS	7.80E-05	1.40E-08	3.03E-04	9.29E-12	2.57E-01	1.51E+03
	RED MARR	8.60E-06	3.70E-07	6.19E-05	1.33E-08	1.39E-01	2.78E+01
	BONE SUR	1.70E-04	7.70E-06	7.69E-04	1.65E-07	2.21E-01	4.67E+01
	THYROID	3.10E-07	1.40E-08	1.27E-08	2.22E-12	2.44E+01	6.31E+03
	REMAINDER	3.30E-07	1.40E-08	2.84E-05	2.84E-08	1.16E-02	4.93E-01
	EFFECTIVE	1.50E-05	2.40E-07	7.82E-05	1.58E-08	1.92E-01	1.52E+01
	SKIN(FGR)	3.00E-07	1.40E-08	0.00E+00	0.00E+00	n/a	n/a
71	Ra-223						
	GONADS	3.30E-09	1.30E-08	3.38E-08	4.26E-08	9.76E-02	3.05E-01
	BREAST	3.50E-09	1.30E-08	3.38E-08	4.23E-08	1.04E-01	3.07E-01
	LUNGS	6.20E-05	1.30E-08	1.66E-05	4.23E-08	3.73E+00	3.07E-01
	RED MARR	7.50E-08	2.80E-07	2.24E-07	2.80E-07	3.35E-01	1.00E+00
	BONE SUR	7.80E-07	2.90E-06	2.34E-06	2.93E-06	3.33E-01	9.90E-01
	THYROID	3.40E-09	1.30E-08	3.38E-08	4.23E-08	1.01E-01	3.07E-01
	REMAINDER	6.20E-09	1.30E-08	6.14E-08	1.10E-07	1.01E-01	1.18E-01
	EFFECTIVE	7.40E-06	1.00E-07	2.12E-06	1.78E-07	3.49E+00	5.62E-01
	SKIN(FGR)	3.40E-09	1.30E-08	0.00E+00	0.00E+00	n/a	n/a

Table G-1. Ratio of ICRP-72-to-FGR-11 Dose Conversion Factors

		ICRP-72 DCFs		FGR-11 DCFs		Ratio (ICRP-72 / FGR-11) DCFs	
		A	B	C	D	A/C	B/D
		INHALED CHRONIC (Sv/Bq)	INGESTION (Sv/Bq)	INHALED CHRONIC (Sv/Bq)	INGESTION (Sv/Bq)	INHALED CHRONIC	INGESTION
72	Ra-224						
	GONADS	2.70E-09	1.10E-08	1.56E-08	2.12E-08	1.73E-01	5.19E-01
	BREAST	2.70E-09	1.10E-08	1.54E-08	2.06E-08	1.75E-01	5.34E-01
	LUNGS	2.50E-05	1.10E-08	6.56E-06	2.05E-08	3.81E+00	5.37E-01
	RED MARR	4.00E-08	1.70E-07	1.13E-07	1.52E-07	3.54E-01	1.12E+00
	BONE SUR	4.10E-07	1.70E-06	1.17E-06	1.59E-06	3.50E-01	1.07E+00
	THYROID	2.60E-09	1.10E-08	1.53E-08	2.05E-08	1.70E-01	5.37E-01
	REMAINDER	4.00E-09	1.10E-08	3.55E-08	7.15E-08	1.13E-01	1.54E-01
	EFFECTIVE	3.00E-06	6.50E-08	8.53E-07	9.89E-08	3.52E+00	6.57E-01
	SKIN(FGR)	2.60E-09	1.10E-08	0.00E+00	0.00E+00	n/a	n/a
73	Ra-225						
	GONADS	1.50E-08	1.30E-08	3.07E-08	3.37E-08	4.89E-01	3.86E-01
	BREAST	6.40E-09	1.10E-08	3.07E-08	3.37E-08	2.08E-01	3.26E-01
	LUNGS	5.20E-05	1.10E-08	1.67E-05	3.37E-08	3.11E+00	3.26E-01
	RED MARR	2.00E-07	3.50E-07	1.58E-07	1.68E-07	1.27E+00	2.08E+00
	BONE SUR	2.20E-06	3.60E-06	1.68E-06	1.78E-06	1.31E+00	2.02E+00
	THYROID	6.30E-09	1.10E-08	3.07E-08	3.37E-08	2.05E-01	3.26E-01
	REMAINDER	8.90E-09	1.20E-08	3.63E-08	4.09E-08	2.45E-01	2.93E-01
	EFFECTIVE	6.30E-06	9.90E-08	2.10E-06	1.04E-07	3.00E+00	9.52E-01
	SKIN(FGR)	6.30E-09	1.10E-08	0.00E+00	0.00E+00	n/a	n/a
74	Ra-226						
	GONADS	2.40E-08	4.10E-08	1.02E-07	9.16E-08	2.35E-01	4.48E-01
	BREAST	2.40E-08	4.00E-08	1.02E-07	9.17E-08	2.35E-01	4.36E-01
	LUNGS	2.80E-05	4.00E-08	1.61E-05	9.16E-08	1.74E+00	4.37E-01
	RED MARR	5.20E-07	8.70E-07	6.64E-07	5.98E-07	7.83E-01	1.45E+00
	BONE SUR	7.40E-06	1.20E-05	7.59E-06	6.83E-06	9.75E-01	1.76E+00
	THYROID	2.40E-08	4.00E-08	1.02E-07	9.15E-08	2.35E-01	4.37E-01
	REMAINDER	2.70E-08	4.00E-08	1.07E-07	1.03E-07	2.52E-01	3.88E-01
	EFFECTIVE	3.50E-06	2.80E-07	2.32E-06	3.58E-07	1.51E+00	7.82E-01
	SKIN(FGR)	2.40E-08	4.00E-08	0.00E+00	0.00E+00	n/a	n/a
75	Ra-228						
	GONADS	5.00E-07	2.10E-07	1.83E-07	1.58E-07	2.73E+00	1.33E+00
	BREAST	2.00E-07	1.50E-07	1.84E-07	1.57E-07	1.09E+00	9.55E-01
	LUNGS	9.70E-06	1.50E-07	7.22E-06	1.57E-07	1.34E+00	9.55E-01
	RED MARR	4.70E-06	2.30E-06	7.38E-07	6.53E-07	6.37E+00	3.52E+00
	BONE SUR	5.60E-05	2.20E-05	6.51E-06	5.82E-06	8.60E+00	3.78E+00
	THYROID	2.00E-07	1.50E-07	1.83E-07	1.57E-07	1.09E+00	9.55E-01
	REMAINDER	2.20E-07	1.50E-07	1.87E-07	1.63E-07	1.18E+00	9.20E-01
	EFFECTIVE	2.60E-06	6.90E-07	1.29E-06	3.88E-07	2.02E+00	1.78E+00
	SKIN(FGR)	2.00E-07	1.50E-07	0.00E+00	0.00E+00	n/a	n/a

Table G-1. Ratio of ICRP-72-to-FGR-11 Dose Conversion Factors

		ICRP-72 DCFs		FGR-11 DCFs		Ratio (ICRP-72 / FGR-11) DCFs	
		A	B	C	D	A/C	B/D
		INHALED CHRONIC (Sv/Bq)	INGESTION (Sv/Bq)	INHALED CHRONIC (Sv/Bq)	INGESTION (Sv/Bq)	INHALED CHRONIC	INGESTION
76	Rh-102						
	GONADS	2.10E-09	3.90E-09	4.09E-09	3.54E-09	5.13E-01	1.10E+00
	BREAST	1.80E-08	9.80E-10	1.40E-08	1.50E-09	1.29E+00	6.53E-01
	LUNGS	9.00E-08	1.30E-09	1.58E-07	1.31E-09	5.70E-01	9.92E-01
	RED MARR	9.40E-09	1.80E-09	1.34E-08	1.83E-09	7.01E-01	9.84E-01
	BONE SUR	7.20E-09	1.70E-09	1.07E-08	1.41E-09	6.73E-01	1.21E+00
	THYROID	7.20E-09	1.40E-09	1.32E-08	1.28E-09	5.45E-01	1.09E+00
	REMAINDER	7.10E-09	1.50E-09	2.66E-08	4.19E-09	2.67E-01	3.58E-01
	EFFECTIVE	1.70E-08	2.60E-09	3.24E-08	2.82E-09	5.25E-01	9.22E-01
	SKIN(FGR)	3.90E-09	9.40E-10	0.00E+00	0.00E+00	n/a	n/a
77	Rh-106						
	GONADS	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a
	BREAST	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a
	LUNGS	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a
	RED MARR	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a
	BONE SUR	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a
	THYROID	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a
	REMAINDER	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a
	EFFECTIVE	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a
	SKIN(FGR)	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a
78	Rn-219						
	GONADS	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a
	BREAST	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a
	LUNGS	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a
	RED MARR	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a
	BONE SUR	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a
	THYROID	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a
	REMAINDER	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a
	EFFECTIVE	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a
	SKIN(FGR)	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a
79	Rn-222						
	GONADS	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a
	BREAST	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a
	LUNGS	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a
	RED MARR	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a
	BONE SUR	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a
	THYROID	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a
	REMAINDER	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a
	EFFECTIVE	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a
	SKIN(FGR)	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a

Table G-1. Ratio of ICRP-72-to-FGR-11 Dose Conversion Factors

		ICRP-72 DCFs		FGR-11 DCFs		Ratio (ICRP-72 / FGR-11) DCFs	
		A	B	C	D	A/C	B/D
		INHALED CHRONIC (Sv/Bq)	INGESTION (Sv/Bq)	INHALED CHRONIC (Sv/Bq)	INGESTION (Sv/Bq)	INHALED CHRONIC	INGESTION
80	Ru-106						
	GONADS	2.70E-09	1.70E-09	1.30E-09	1.64E-09	2.08E+00	1.04E+00
	BREAST	2.90E-09	1.40E-09	1.78E-09	1.44E-09	1.63E+00	9.72E-01
	LUNGS	2.00E-07	1.40E-09	1.04E-06	1.42E-09	1.92E-01	9.86E-01
	RED MARR	2.80E-09	1.50E-09	1.76E-09	1.46E-09	1.59E+00	1.03E+00
	BONE SUR	2.80E-09	1.50E-09	1.61E-09	1.43E-09	1.74E+00	1.05E+00
	THYROID	2.70E-09	1.40E-09	1.72E-09	1.41E-09	1.57E+00	9.93E-01
	REMAINDER	2.80E-09	1.50E-09	1.20E-08	2.11E-08	2.33E-01	7.11E-02
	EFFECTIVE	2.80E-08	7.00E-09	1.29E-07	7.40E-09	2.17E-01	9.46E-01
	SKIN(FGR)	2.60E-09	1.40E-09	0.00E+00	0.00E+00	n/a	n/a
81	Sb-125						
	GONADS	4.60E-10	7.90E-10	3.19E-10	5.24E-10	1.44E+00	1.51E+00
	BREAST	1.00E-09	2.10E-10	2.51E-10	1.00E-10	3.98E+00	2.10E+00
	LUNGS	3.20E-08	2.90E-10	6.38E-10	6.03E-11	5.02E+01	4.81E+00
	RED MARR	1.70E-09	1.50E-09	6.49E-10	2.26E-10	2.62E+00	6.64E+00
	BONE SUR	8.70E-09	9.00E-09	2.73E-09	5.86E-10	3.19E+00	1.54E+01
	THYROID	5.50E-10	2.60E-10	2.28E-10	4.62E-11	2.41E+00	5.63E+00
	REMAINDER	5.90E-10	3.20E-10	7.16E-10	1.86E-09	8.24E-01	1.72E-01
	EFFECTIVE	4.80E-09	1.10E-09	5.75E-10	7.59E-10	8.35E+00	1.45E+00
	SKIN(FGR)	3.50E-10	2.10E-10	0.00E+00	0.00E+00	n/a	n/a
82	Sb-126m						
	GONADS	9.00E-13	6.00E-12	1.19E-12	5.24E-12	7.56E-01	1.15E+00
	BREAST	1.10E-12	1.00E-12	1.33E-12	2.07E-12	8.27E-01	4.83E-01
	LUNGS	4.70E-11	1.60E-12	5.04E-11	1.91E-12	9.33E-01	8.38E-01
	RED MARR	1.10E-12	2.20E-12	1.46E-12	2.18E-12	7.53E-01	1.01E+00
	BONE SUR	9.40E-13	1.20E-12	1.32E-12	1.01E-12	7.12E-01	1.19E+00
	THYROID	9.50E-13	1.40E-13	1.13E-12	1.99E-13	8.41E-01	7.04E-01
	REMAINDER	1.70E-10	3.30E-12	7.92E-12	7.72E-11	2.15E+01	4.27E-02
	EFFECTIVE	1.90E-11	3.60E-11	9.17E-12	2.53E-11	2.07E+00	1.42E+00
	SKIN(FGR)	5.20E-13	8.20E-13	0.00E+00	0.00E+00	n/a	n/a
83	Se-79						
	GONADS	1.10E-09	2.90E-09	5.98E-10	9.06E-10	1.84E+00	3.20E+00
	BREAST	3.80E-10	9.60E-10	5.98E-10	9.06E-10	6.35E-01	1.06E+00
	LUNGS	3.90E-10	9.60E-10	9.81E-09	9.06E-10	3.98E-02	1.06E+00
	RED MARR	3.80E-10	9.60E-10	5.98E-10	9.06E-10	6.35E-01	1.06E+00
	BONE SUR	3.80E-10	9.60E-10	5.98E-10	9.06E-10	6.35E-01	1.06E+00
	THYROID	3.80E-10	9.60E-10	5.98E-10	9.06E-10	6.35E-01	1.06E+00
	REMAINDER	6.60E-09	1.70E-08	3.77E-09	5.73E-09	1.75E+00	2.97E+00
	EFFECTIVE	1.10E-09	2.90E-09	2.66E-09	2.35E-09	4.14E-01	1.23E+00
	SKIN(FGR)	3.80E-10	9.60E-10	0.00E+00	0.00E+00	n/a	n/a

Table G-1. Ratio of ICRP-72-to-FGR-11 Dose Conversion Factors

		ICRP-72 DCFs		FGR-11 DCFs		Ratio (ICRP-72 / FGR-11) DCFs	
		A	B	C	D	A/C	B/D
		INHALED CHRONIC (Sv/Bq)	INGESTION (Sv/Bq)	INHALED CHRONIC (Sv/Bq)	INGESTION (Sv/Bq)	INHALED CHRONIC	INGESTION
84	Si-31						
	GONADS	4.60E-13	1.20E-13	1.20E-12	1.14E-13	3.83E-01	1.05E+00
	BREAST	4.50E-13	7.50E-14	1.20E-12	8.05E-14	3.75E-01	9.32E-01
	LUNGS	3.20E-10	7.60E-14	3.59E-10	7.55E-14	8.91E-01	1.01E+00
	RED MARR	4.50E-13	8.40E-14	1.20E-12	8.33E-14	3.75E-01	1.01E+00
	BONE SUR	4.50E-13	7.80E-14	1.19E-12	7.58E-14	3.78E-01	1.03E+00
	THYROID	4.50E-13	7.30E-14	1.19E-12	7.20E-14	3.78E-01	1.01E+00
	REMAINDER	2.10E-10	3.30E-10	3.79E-11	4.86E-10	5.54E+00	6.79E-01
	EFFECTIVE	7.40E-11	1.60E-10	5.52E-11	1.46E-10	1.34E+00	1.10E+00
	SKIN(FGR)	4.50E-13	7.60E-14	0.00E+00	0.00E+00	n/a	n/a
85	Sm-147						
	GONADS	3.20E-10	1.70E-12	0.00E+00	0.00E+00	n/a	n/a
	BREAST	3.20E-10	1.70E-12	0.00E+00	0.00E+00	n/a	n/a
	LUNGS	4.80E-06	1.70E-12	7.62E-06	0.00E+00	6.30E-01	n/a
	RED MARR	2.20E-05	1.10E-07	2.75E-05	6.87E-08	8.00E-01	1.60E+00
	BONE SUR	2.70E-04	1.40E-06	3.44E-04	8.59E-07	7.85E-01	1.63E+00
	THYROID	3.20E-10	1.70E-12	0.00E+00	0.00E+00	n/a	n/a
	REMAINDER	5.50E-10	2.90E-11	1.89E-05	5.37E-08	2.91E-05	5.40E-04
	EFFECTIVE	9.60E-06	4.90E-08	2.02E-05	5.01E-08	4.75E-01	9.78E-01
	SKIN(FGR)	3.20E-10	1.70E-12	0.00E+00	0.00E+00	n/a	n/a
86	Sm-151						
	GONADS	1.70E-13	1.60E-14	4.03E-14	2.12E-14	4.22E+00	7.55E-01
	BREAST	1.70E-13	8.70E-16	1.49E-13	1.03E-15	1.14E+00	8.45E-01
	LUNGS	3.10E-09	2.00E-15	3.26E-09	6.52E-16	9.51E-01	3.07E+00
	RED MARR	8.70E-09	4.60E-11	1.10E-08	2.76E-11	7.91E-01	1.67E+00
	BONE SUR	1.10E-07	5.70E-10	1.38E-07	3.45E-10	7.97E-01	1.65E+00
	THYROID	1.50E-13	7.80E-16	1.32E-14	3.27E-17	1.14E+01	2.39E+01
	REMAINDER	7.90E-13	1.20E-12	7.51E-09	3.04E-10	1.05E-04	3.95E-03
	EFFECTIVE	4.00E-09	9.80E-11	8.10E-09	1.05E-10	4.94E-01	9.33E-01
	SKIN(FGR)	1.80E-13	9.90E-16	0.00E+00	0.00E+00	n/a	n/a
87	Sn-126						
	GONADS	4.10E-09	2.51E-09	4.95E-09	2.42E-09	8.28E-01	1.04E+00
	BREAST	6.30E-09	4.61E-10	5.39E-09	7.98E-10	1.17E+00	5.78E-01
	LUNGS	1.80E-07	6.32E-10	1.51E-07	6.01E-10	1.19E+00	1.05E+00
	RED MARR	1.40E-08	2.80E-09	1.69E-08	2.72E-09	8.28E-01	1.03E+00
	BONE SUR	2.80E-08	5.40E-09	3.33E-08	5.06E-09	8.41E-01	1.07E+00
	THYROID	4.60E-09	6.20E-10	4.90E-09	5.51E-10	9.39E-01	1.13E+00
	REMAINDER	4.87E-09	8.73E-10	1.20E-08	1.34E-08	4.05E-01	6.53E-02
	EFFECTIVE	2.80E-08	4.74E-09	2.69E-08	5.30E-09	1.04E+00	8.94E-01
	SKIN(FGR)	3.20E-09	5.51E-10	0.00E+00	0.00E+00	n/a	n/a

Table G-1. Ratio of ICRP-72-to-FGR-11 Dose Conversion Factors

		ICRP-72 DCFs		FGR-11 DCFs		Ratio (ICRP-72 / FGR-11) DCFs	
		A	B	C	D	A/C	B/D
		INHALED CHRONIC (Sv/Bq)	INGESTION (Sv/Bq)	INHALED CHRONIC (Sv/Bq)	INGESTION (Sv/Bq)	INHALED CHRONIC	INGESTION
88	Sr-90						
	GONADS	2.80E-10	6.60E-10	2.64E-09	1.51E-09	1.06E-01	4.37E-01
	BREAST	2.80E-10	6.60E-10	2.64E-09	1.51E-09	1.06E-01	4.37E-01
	LUNGS	2.10E-07	6.60E-10	3.73E-09	1.51E-09	5.63E+01	4.37E-01
	RED MARR	7.00E-08	1.80E-07	3.36E-07	1.94E-07	2.08E-01	9.28E-01
	BONE SUR	1.60E-07	4.10E-07	7.27E-07	4.19E-07	2.20E-01	9.79E-01
	THYROID	2.80E-10	6.60E-10	2.64E-09	1.51E-09	1.06E-01	4.37E-01
	REMAINDER	2.90E-10	6.70E-10	3.36E-09	6.14E-09	8.63E-02	1.09E-01
	EFFECTIVE	3.60E-08	2.80E-08	6.47E-08	3.85E-08	5.56E-01	7.27E-01
	SKIN(FGR)	2.80E-10	6.60E-10	0.00E+00	0.00E+00	n/a	n/a
89	Tc-99						
	GONADS	9.20E-12	3.90E-11	3.99E-11	6.04E-11	2.31E-01	6.46E-01
	BREAST	9.20E-12	3.90E-11	3.99E-11	6.04E-11	2.31E-01	6.46E-01
	LUNGS	3.20E-08	3.90E-11	1.67E-08	6.04E-11	1.92E+00	6.46E-01
	RED MARR	9.20E-12	3.90E-11	3.99E-11	6.04E-11	2.31E-01	6.46E-01
	BONE SUR	9.20E-12	3.90E-11	3.99E-11	6.04E-11	2.31E-01	6.46E-01
	THYROID	2.40E-10	1.00E-09	1.07E-09	1.62E-09	2.24E-01	6.17E-01
	REMAINDER	1.20E-11	4.20E-11	6.26E-10	1.02E-09	1.92E-02	4.12E-02
	EFFECTIVE	4.00E-09	6.40E-10	2.25E-09	3.95E-10	1.78E+00	1.62E+00
	SKIN(FGR)	9.20E-12	3.90E-11	0.00E+00	0.00E+00	n/a	n/a
90	Te-125m						
	GONADS	3.70E-11	1.40E-10	7.93E-11	1.27E-10	4.67E-01	1.10E+00
	BREAST	5.00E-11	5.20E-11	7.08E-11	4.64E-11	7.06E-01	1.12E+00
	LUNGS	2.60E-08	6.10E-11	1.04E-08	4.36E-11	2.50E+00	1.40E+00
	RED MARR	4.20E-10	1.70E-09	1.15E-09	1.21E-09	3.65E-01	1.40E+00
	BONE SUR	4.80E-09	2.00E-08	1.18E-08	1.27E-08	4.07E-01	1.57E+00
	THYROID	2.50E-10	1.00E-09	3.87E-11	3.93E-11	6.46E+00	2.54E+01
	REMAINDER	4.20E-11	7.60E-11	6.75E-10	1.40E-09	6.22E-02	5.43E-02
	EFFECTIVE	3.40E-09	8.70E-10	1.97E-09	9.92E-10	1.73E+00	8.77E-01
	SKIN(FGR)	1.70E-11	5.10E-11	0.00E+00	0.00E+00	n/a	n/a
91	Th-227						
	GONADS	5.60E-10	6.80E-10	2.96E-09	2.95E-10	1.89E-01	2.31E+00
	BREAST	3.90E-10	3.10E-10	2.98E-09	1.40E-10	1.31E-01	2.21E+00
	LUNGS	8.70E-05	3.10E-10	3.58E-05	1.25E-10	2.43E+00	2.48E+00
	RED MARR	6.40E-09	7.90E-09	1.30E-07	5.69E-09	4.92E-02	1.39E+00
	BONE SUR	7.40E-08	8.80E-08	1.58E-06	6.84E-08	4.68E-02	1.29E+00
	THYROID	2.90E-10	3.10E-10	2.94E-09	1.23E-10	9.86E-02	2.52E+00
	REMAINDER	3.40E-09	4.30E-10	2.06E-08	2.47E-08	1.65E-01	1.74E-02
	EFFECTIVE	1.00E-05	8.80E-09	4.37E-06	1.03E-08	2.29E+00	8.54E-01
	SKIN(FGR)	2.60E-10	3.20E-10	0.00E+00	0.00E+00	n/a	n/a

Table G-1. Ratio of ICRP-72-to-FGR-11 Dose Conversion Factors

		ICRP-72 DCFs		FGR-11 DCFs		Ratio (ICRP-72 / FGR-11) DCFs	
		A	B	C	D	A/C	B/D
		INHALED CHRONIC (Sv/Bq)	INGESTION (Sv/Bq)	INHALED CHRONIC (Sv/Bq)	INGESTION (Sv/Bq)	INHALED CHRONIC	INGESTION
92	Th-228						
	GONADS	2.00E-07	2.10E-08	2.26E-07	2.53E-09	8.85E-01	8.30E+00
	BREAST	7.40E-08	7.10E-09	2.32E-07	2.33E-09	3.19E-01	3.05E+00
	LUNGS	3.30E-04	7.10E-09	6.91E-04	2.31E-09	4.78E-01	3.07E+00
	RED MARR	1.90E-06	2.00E-07	1.87E-05	1.93E-07	1.02E-01	1.04E+00
	BONE SUR	2.40E-05	2.50E-06	2.29E-04	2.37E-06	1.05E-01	1.05E+00
	THYROID	6.90E-08	7.10E-09	2.30E-07	2.30E-09	3.00E-01	3.09E+00
	REMAINDER	1.30E-07	7.80E-09	6.05E-07	3.86E-08	2.15E-01	2.02E-01
	EFFECTIVE	4.00E-05	7.20E-08	9.23E-05	1.07E-07	4.33E-01	6.73E-01
	SKIN(FGR)	6.80E-08	7.10E-09	0.00E+00	0.00E+00	n/a	n/a
93	Th-229						
	GONADS	4.00E-06	1.80E-07	1.18E-06	4.69E-09	3.39E+00	3.84E+01
	BREAST	1.70E-06	7.60E-08	1.18E-06	4.57E-09	1.44E+00	1.66E+01
	LUNGS	5.00E-04	7.60E-08	1.99E-03	4.56E-09	2.51E-01	1.67E+01
	RED MARR	2.50E-05	1.10E-06	4.60E-04	1.91E-06	5.43E-02	5.76E-01
	BONE SUR	5.10E-04	2.30E-05	5.73E-03	2.38E-05	8.90E-02	9.66E-01
	THYROID	1.70E-06	7.60E-08	1.18E-06	4.55E-09	1.44E+00	1.67E+01
	REMAINDER	1.80E-06	7.90E-08	3.02E-06	2.80E-08	5.96E-01	2.82E+00
	EFFECTIVE	7.10E-05	4.90E-07	4.67E-04	9.54E-07	1.52E-01	5.14E-01
	SKIN(FGR)	1.70E-06	7.60E-08	0.00E+00	0.00E+00	n/a	n/a
94	Th-230						
	GONADS	2.30E-06	1.00E-07	1.72E-07	6.82E-10	1.34E+01	1.47E+02
	BREAST	3.00E-07	1.40E-08	1.72E-07	6.80E-10	1.74E+00	2.06E+01
	LUNGS	7.70E-05	1.40E-08	3.00E-04	6.80E-10	2.57E-01	2.06E+01
	RED MARR	1.00E-05	4.20E-07	6.99E-05	2.89E-07	1.43E-01	1.45E+00
	BONE SUR	2.80E-04	1.20E-05	8.71E-04	3.60E-06	3.21E-01	3.33E+00
	THYROID	3.00E-07	1.40E-08	1.72E-07	6.80E-10	1.74E+00	2.06E+01
	REMAINDER	3.60E-07	1.50E-08	4.48E-07	1.54E-08	8.04E-01	9.74E-01
	EFFECTIVE	1.40E-05	2.10E-07	7.07E-05	1.48E-07	1.98E-01	1.42E+00
	SKIN(FGR)	3.00E-07	1.40E-08	0.00E+00	0.00E+00	n/a	n/a
95	Th-231						
	GONADS	4.30E-12	1.90E-11	6.95E-12	2.08E-11	6.19E-01	9.13E-01
	BREAST	6.90E-13	6.00E-14	1.42E-12	1.44E-12	4.86E-01	4.17E-02
	LUNGS	2.20E-09	1.20E-13	8.75E-10	1.43E-13	2.51E+00	8.39E-01
	RED MARR	2.80E-12	1.80E-12	2.78E-11	5.30E-12	1.01E-01	3.40E-01
	BONE SUR	5.60E-11	5.80E-12	3.15E-10	3.17E-12	1.78E-01	1.83E+00
	THYROID	3.60E-13	2.00E-14	3.09E-13	8.80E-15	1.17E+00	2.27E+00
	REMAINDER	3.40E-12	1.00E-11	3.91E-10	1.19E-09	8.70E-03	8.40E-03
	EFFECTIVE	3.30E-10	3.40E-10	2.37E-10	3.65E-10	1.39E+00	9.32E-01
	SKIN(FGR)	3.00E-13	2.90E-13	0.00E+00	0.00E+00	n/a	n/a

Table G-1. Ratio of ICRP-72-to-FGR-11 Dose Conversion Factors

		ICRP-72 DCFs		FGR-11 DCFs		Ratio (ICRP-72 / FGR-11) DCFs	
		A	B	C	D	A/C	B/D
		INHALED CHRONIC (Sv/Bq)	INGESTION (Sv/Bq)	INHALED CHRONIC (Sv/Bq)	INGESTION (Sv/Bq)	INHALED CHRONIC	INGESTION
96	Th-232						
	GONADS	2.60E-06	1.10E-07	5.98E-07	1.25E-09	4.35E+00	8.80E+01
	BREAST	8.30E-07	3.60E-08	6.14E-07	1.26E-09	1.35E+00	2.86E+01
	LUNGS	1.60E-04	3.60E-08	9.40E-04	1.25E-09	1.70E-01	2.88E+01
	RED MARR	1.20E-05	4.70E-07	4.01E-04	1.48E-06	2.99E-02	3.18E-01
	BONE SUR	2.90E-04	1.20E-05	4.99E-03	1.85E-05	5.81E-02	6.49E-01
	THYROID	8.20E-07	3.60E-08	5.99E-07	1.21E-09	1.37E+00	2.98E+01
	REMAINDER	8.90E-07	3.70E-08	1.51E-06	1.47E-08	5.89E-01	2.52E+00
	EFFECTIVE	2.50E-05	2.30E-07	3.11E-04	7.38E-07	8.04E-02	3.12E-01
	SKIN(FGR)	8.20E-07	3.60E-08	0.00E+00	0.00E+00	n/a	n/a
97	Th-234						
	GONADS	1.10E-11	3.20E-11	2.11E-11	3.12E-11	5.21E-01	1.03E+00
	BREAST	1.60E-11	8.80E-13	1.66E-11	3.57E-12	9.64E-01	2.46E-01
	LUNGS	5.70E-08	1.00E-12	6.39E-08	7.05E-13	8.92E-01	1.42E+00
	RED MARR	4.30E-11	2.90E-11	2.56E-10	1.84E-11	1.68E-01	1.58E+00
	BONE SUR	7.30E-11	4.70E-11	6.29E-10	2.08E-11	1.16E-01	2.26E+00
	THYROID	6.70E-12	6.80E-13	1.27E-11	2.88E-13	5.28E-01	2.36E+00
	REMAINDER	2.20E-11	5.70E-11	5.80E-09	1.23E-08	3.79E-03	4.63E-03
	EFFECTIVE	7.70E-09	3.40E-09	9.47E-09	3.69E-09	8.13E-01	9.21E-01
	SKIN(FGR)	4.10E-12	1.70E-12	0.00E+00	0.00E+00	n/a	n/a
98	U-232						
	GONADS	4.20E-07	1.70E-07	1.69E-08	3.34E-10	2.49E+01	5.09E+02
	BREAST	2.00E-07	1.60E-07	2.66E-08	3.33E-10	7.52E+00	4.80E+02
	LUNGS	3.00E-04	1.60E-07	1.48E-03	3.32E-10	2.03E-01	4.82E+02
	RED MARR	3.30E-06	7.00E-07	4.68E-07	1.68E-08	7.05E+00	4.17E+01
	BONE SUR	4.10E-05	7.20E-06	7.14E-06	2.65E-07	5.74E+00	2.72E+01
	THYROID	2.00E-07	1.60E-07	2.43E-08	3.25E-10	8.23E+00	4.92E+02
	REMAINDER	2.70E-07	1.70E-07	5.86E-07	2.83E-08	4.61E-01	6.01E+00
	EFFECTIVE	3.70E-05	3.30E-07	1.78E-04	1.87E-08	2.08E-01	1.76E+01
	SKIN(FGR)	1.90E-07	1.60E-07	0.00E+00	0.00E+00	n/a	n/a
99	U-233						
	GONADS	1.90E-08	2.90E-08	2.69E-09	1.07E-10	7.06E+00	2.71E+02
	BREAST	1.70E-08	2.80E-08	2.73E-09	1.05E-10	6.23E+00	2.67E+02
	LUNGS	8.00E-05	2.80E-08	3.04E-04	1.05E-10	2.63E-01	2.67E+02
	RED MARR	6.80E-08	8.40E-08	7.39E-08	2.95E-09	9.20E-01	2.85E+01
	BONE SUR	8.00E-07	8.40E-07	1.16E-06	4.62E-08	6.90E-01	1.82E+01
	THYROID	1.70E-08	2.80E-08	2.70E-09	1.05E-10	6.30E+00	2.67E+02
	REMAINDER	3.70E-08	3.10E-08	1.08E-07	1.78E-08	3.43E-01	1.74E+00
	EFFECTIVE	9.60E-06	5.10E-08	3.66E-05	7.15E-09	2.62E-01	7.13E+00
	SKIN(FGR)	1.70E-08	2.80E-08	0.00E+00	0.00E+00	n/a	n/a

Table G-1. Ratio of ICRP-72-to-FGR-11 Dose Conversion Factors

		ICRP-72 DCFs		FGR-11 DCFs		Ratio (ICRP-72 / FGR-11) DCFs	
		A	B	C	D	A/C	B/D
		INHALED CHRONIC (Sv/Bq)	INGESTION (Sv/Bq)	INHALED CHRONIC (Sv/Bq)	INGESTION (Sv/Bq)	INHALED CHRONIC	INGESTION
100	U-234						
	GONADS	1.60E-08	2.80E-08	2.65E-09	1.06E-10	6.04E+00	2.64E+02
	BREAST	1.60E-08	2.70E-08	2.68E-09	1.03E-10	5.97E+00	2.62E+02
	LUNGS	7.80E-05	2.80E-08	2.98E-04	1.03E-10	2.62E-01	2.72E+02
	RED MARR	5.20E-08	8.10E-08	7.22E-08	2.88E-09	7.20E-01	2.81E+01
	BONE SUR	5.00E-07	7.80E-07	1.13E-06	4.52E-08	4.42E-01	1.73E+01
	THYROID	1.60E-08	2.70E-08	2.65E-09	1.03E-10	6.04E+00	2.62E+02
	REMAINDER	3.50E-08	3.00E-08	1.06E-07	1.77E-08	3.30E-01	1.69E+00
	EFFECTIVE	9.40E-06	4.90E-08	3.58E-05	7.06E-09	2.63E-01	6.94E+00
	SKIN(FGR)	1.60E-08	2.70E-08	0.00E+00	0.00E+00	n/a	n/a
101	U-235						
	GONADS	1.50E-08	2.60E-08	2.84E-09	3.34E-10	5.28E+00	7.78E+01
	BREAST	1.80E-08	2.60E-08	5.37E-09	1.21E-10	3.35E+00	2.15E+02
	LUNGS	7.00E-05	2.60E-08	2.76E-04	1.01E-10	2.54E-01	2.57E+02
	RED MARR	5.00E-08	7.60E-08	7.15E-08	2.78E-09	6.99E-01	2.73E+01
	BONE SUR	4.70E-07	7.40E-07	1.05E-06	4.20E-08	4.48E-01	1.76E+01
	THYROID	1.60E-08	2.60E-08	4.11E-09	9.82E-11	3.89E+00	2.65E+02
	REMAINDER	3.40E-08	2.80E-08	1.02E-07	1.84E-08	3.33E-01	1.52E+00
	EFFECTIVE	8.50E-06	4.70E-08	3.32E-05	7.22E-09	2.56E-01	6.51E+00
	SKIN(FGR)	1.60E-08	2.60E-08	0.00E+00	0.00E+00	n/a	n/a
102	U-236						
	GONADS	1.50E-08	2.60E-08	2.51E-09	1.00E-10	5.98E+00	2.60E+02
	BREAST	1.50E-08	2.60E-08	2.54E-09	9.79E-11	5.91E+00	2.66E+02
	LUNGS	7.20E-05	2.60E-08	2.82E-04	9.79E-11	2.55E-01	2.66E+02
	RED MARR	4.90E-08	7.70E-08	6.83E-08	2.73E-09	7.17E-01	2.82E+01
	BONE SUR	4.80E-07	7.40E-07	1.07E-06	4.28E-08	4.49E-01	1.73E+01
	THYROID	1.50E-08	2.60E-08	2.51E-09	9.79E-11	5.98E+00	2.66E+02
	REMAINDER	3.40E-08	2.90E-08	1.00E-07	1.67E-08	3.40E-01	1.74E+00
	EFFECTIVE	8.70E-06	4.70E-08	3.39E-05	6.68E-09	2.57E-01	7.04E+00
	SKIN(FGR)	1.50E-08	2.60E-08	0.00E+00	0.00E+00	n/a	n/a
103	U-237						
	GONADS	3.60E-11	1.60E-10	8.15E-11	1.81E-10	4.42E-01	8.84E-01
	BREAST	2.60E-11	1.70E-12	2.51E-11	1.81E-11	1.04E+00	9.39E-02
	LUNGS	1.40E-08	2.80E-12	4.70E-09	2.17E-12	2.98E+00	1.29E+00
	RED MARR	1.90E-11	3.70E-11	5.23E-11	5.69E-11	3.63E-01	6.50E-01
	BONE SUR	3.20E-11	1.00E-10	6.82E-11	3.39E-11	4.69E-01	2.95E+00
	THYROID	1.10E-11	9.90E-13	1.00E-11	2.31E-13	1.10E+00	4.29E+00
	REMAINDER	2.00E-11	3.30E-11	1.19E-09	2.67E-09	1.68E-02	1.24E-02
	EFFECTIVE	1.90E-09	7.60E-10	9.54E-10	8.57E-10	1.99E+00	8.87E-01
	SKIN(FGR)	6.10E-12	5.60E-12	0.00E+00	0.00E+00	n/a	n/a

Table G-1. Ratio of ICRP-72-to-FGR-11 Dose Conversion Factors

		ICRP-72 DCFs		FGR-11 DCFs		Ratio (ICRP-72 / FGR-11) DCFs	
		A	B	C	D	A/C	B/D
		INHALED CHRONIC (Sv/Bq)	INGESTION (Sv/Bq)	INHALED CHRONIC (Sv/Bq)	INGESTION (Sv/Bq)	INHALED CHRONIC	INGESTION
104	U-238						
	GONADS	1.50E-08	2.50E-08	2.42E-09	1.02E-10	6.20E+00	2.45E+02
	BREAST	1.50E-08	2.40E-08	2.91E-09	9.33E-11	5.15E+00	2.57E+02
	LUNGS	6.70E-05	2.50E-08	2.66E-04	9.22E-11	2.52E-01	2.71E+02
	RED MARR	4.90E-08	7.50E-08	6.88E-08	2.72E-09	7.12E-01	2.76E+01
	BONE SUR	4.60E-07	7.10E-07	1.01E-06	4.04E-08	4.55E-01	1.76E+01
	THYROID	1.50E-08	2.40E-08	2.73E-09	9.20E-11	5.49E+00	2.61E+02
	REMAINDER	3.10E-08	2.70E-08	9.61E-08	1.61E-08	3.23E-01	1.68E+00
	EFFECTIVE	8.00E-06	4.50E-08	3.20E-05	6.42E-09	2.50E-01	7.01E+00
	SKIN(FGR)	1.50E-08	2.40E-08	0.00E+00	0.00E+00	n/a	n/a
105	U-240						
	GONADS	2.50E-11	1.20E-10	3.35E-11	1.24E-10	7.46E-01	9.68E-01
	BREAST	6.70E-12	2.60E-12	8.98E-12	1.60E-11	7.46E-01	1.63E-01
	LUNGS	2.90E-09	3.70E-12	2.43E-09	3.69E-12	1.19E+00	1.00E+00
	RED MARR	8.80E-12	2.70E-11	1.26E-11	2.62E-11	6.98E-01	1.03E+00
	BONE SUR	6.30E-12	2.30E-11	1.49E-11	1.02E-11	4.23E-01	2.25E+00
	THYROID	4.40E-12	8.40E-13	4.15E-12	5.59E-13	1.06E+00	1.50E+00
	REMAINDER	1.60E-11	5.70E-11	1.03E-09	3.88E-09	1.55E-02	1.47E-02
	EFFECTIVE	5.80E-10	1.10E-09	6.13E-10	1.20E-09	9.46E-01	9.17E-01
	SKIN(FGR)	3.10E-12	6.00E-12	0.00E+00	0.00E+00	n/a	n/a
106	Y-90						
	GONADS	4.20E-14	1.40E-14	5.17E-13	1.43E-14	8.12E-02	9.79E-01
	BREAST	4.20E-14	1.30E-14	5.17E-13	1.27E-14	8.12E-02	1.02E+00
	LUNGS	7.80E-09	1.30E-14	9.31E-09	1.26E-14	8.38E-01	1.03E+00
	RED MARR	1.20E-12	3.70E-13	1.52E-11	3.70E-13	7.89E-02	1.00E+00
	BONE SUR	1.20E-12	3.70E-13	1.51E-11	3.67E-13	7.95E-02	1.01E+00
	THYROID	4.20E-14	1.30E-14	5.17E-13	1.26E-14	8.12E-02	1.03E+00
	REMAINDER	1.20E-11	5.30E-11	3.87E-09	9.68E-09	3.10E-03	5.48E-03
	EFFECTIVE	1.50E-09	2.70E-09	2.28E-09	2.91E-09	6.58E-01	9.28E-01
	SKIN(FGR)	4.20E-14	1.30E-14	0.00E+00	0.00E+00	n/a	n/a
107	Zr-93						
	GONADS	4.60E-12	4.80E-13	5.58E-12	9.23E-14	8.24E-01	5.20E+00
	BREAST	7.40E-12	7.70E-13	1.20E-11	1.97E-13	6.17E-01	3.91E+00
	LUNGS	2.90E-09	8.10E-13	3.30E-09	1.15E-13	8.79E-01	7.04E+00
	RED MARR	4.00E-08	4.20E-09	4.49E-08	7.42E-10	8.91E-01	5.66E+00
	BONE SUR	5.00E-07	5.30E-08	5.54E-07	9.14E-09	9.03E-01	5.80E+00
	THYROID	3.70E-12	3.80E-13	4.45E-12	7.31E-14	8.31E-01	5.20E+00
	REMAINDER	1.40E-11	2.50E-12	1.54E-10	2.83E-10	9.09E-02	8.83E-03
	EFFECTIVE	1.00E-08	1.10E-09	2.25E-08	4.48E-10	4.44E-01	2.46E+00
	SKIN(FGR)	1.10E-11	1.10E-12	0.00E+00	0.00E+00	n/a	n/a

Notes:

Column A from BSC 2005h [DIRS 174424], Table F-1

Column B from BSC 2005h [DIRS 174424], Table F-1

Column C from dose conversion factor input file YMPD825.inp (see Table C-1).

Column D from dose conversion factor input file YMPD825.inp (see Table C-1).

ATTACHMENT H – COMPARISON OF ICRP-68 AND FGR-11 DOSE CONVERSION FACTORS

This Attachment H provides a summary table comparing inhalation dose conversion factors from ICRP-68 (see Table H-1) and FGR-11 (see Table H-2) from (BSC 2005a [DIRS 173590]) for the nuclides used in worker dose calculations. The ratios of ICRP-68-to-FGR-11 dose conversion factors for inhalation are provided in Table H-3. Ratios greater than 1.0 are bolded and identify ICRP-68 dose factors that are higher, all others are lower. Only inhalation factors are provided because ingestion does are not calculated for workers.

Table H-1. ICRP-68 Committed Dose Equivalent per Unit Intake (rem/Ci) - Inhalation

ICRP-68 Committed Dose Equivalent per Unit Intake (rem/Ci) – Inhalation ^a								
Nuclide (organ)	Gonad	Breast	Lung	R Marrow	BSurface	Thyroid	Remainder	Effective
H-3	6.70E+01	6.70E+01	6.70E+01	6.70E+01	6.70E+01	6.70E+01	6.70E+01	6.70E+01
C-14	2.40E+01	2.40E+01	2.40E+01	2.40E+01	2.40E+01	2.40E+01	2.40E+01	2.40E+01
Cl-36	1.00E+03	1.00E+03	2.00E+05	1.00E+03	1.00E+03	1.00E+03	1.00E+03	2.60E+04
I-129	3.70E+02	3.70E+02	1.30E+03	4.80E+02	1.40E+03	7.00E+06	9.60E+02	3.60E+05
Cs-134	3.10E+04	2.50E+04	3.10E+04	3.30E+04	3.60E+04	3.30E+04	5.60E+04	3.60E+04
Cs-137	2.20E+04	2.00E+04	2.30E+04	2.30E+04	2.40E+04	2.30E+04	3.50E+04	2.50E+04
Fe-55	9.60E+02	9.60E+02	9.60E+02	1.20E+04	6.70E+03	9.60E+02	1.40E+04	3.40E+03
Co-60	2.50E+03	8.50E+04	6.30E+05	4.40E+04	3.30E+04	3.50E+04	3.30E+04	1.10E+05
Ni-63	6.30E+03	6.30E+03	1.00E+04	6.30E+03	6.30E+03	6.30E+03	1.40E+04	7.40E+03
Sr-90 ^b	1.20E+02	1.20E+02	4.50E+06	3.00E+04	6.70E+04	1.20E+02	3.30E+02	5.60E+05
Ru-106	1.90E+03	5.20E+03	1.90E+06	3.60E+03	3.10E+03	3.10E+03	3.20E+03	2.30E+05
Sb-125	7.40E+02	3.60E+03	1.10E+05	5.90E+03	3.00E+04	1.90E+03	2.00E+03	1.70E+04
Pm-147	1.40E+00	1.40E+00	6.70E+04	2.10E+04	2.70E+05	1.40E+00	1.00E+01	1.70E+04
Sm-151	4.80E-01	5.90E-01	1.00E+04	3.00E+04	3.70E+05	5.20E-01	3.00E+00	1.40E+04
Eu-154	1.10E+04	4.10E+04	3.50E+05	3.20E+05	1.40E+06	2.60E+04	4.40E+04	1.90E+05
Eu-155	3.00E+02	1.50E+03	6.30E+04	3.60E+04	4.10E+05	9.30E+02	1.70E+03	2.40E+04
Pu-238	7.40E+06	9.30E+05	3.10E+08	2.80E+07	5.60E+08	9.30E+05	1.00E+06	5.60E+07
Pu-239	8.50E+06	1.10E+06	2.90E+08	3.10E+07	6.30E+08	1.10E+06	1.20E+06	5.60E+07
Pu-240	8.50E+06	1.10E+06	2.90E+08	3.10E+07	6.30E+08	1.10E+06	1.20E+06	5.60E+07
Am-241	1.10E+08	1.00E+07	1.30E+08	2.00E+08	5.90E+09	1.00E+07	1.00E+07	1.40E+08
Pu-241	1.90E+05	2.40E+04	1.60E+06	6.30E+05	1.40E+07	2.40E+04	2.50E+04	5.90E+05
Am-243	1.10E+08	1.00E+07	1.20E+08	2.00E+08	5.90E+09	1.00E+07	1.00E+07	1.40E+08
Cm-242	1.70E+06	1.20E+05	1.20E+08	6.70E+06	9.60E+07	1.20E+05	1.40E+05	1.80E+07
Cm-243	7.80E+07	5.90E+06	1.30E+08	1.60E+08	4.10E+09	5.90E+06	6.30E+06	1.10E+08
Cm-244	6.30E+07	4.40E+06	1.30E+08	1.30E+08	3.20E+09	4.40E+06	4.40E+06	9.30E+07

Notes: ^a ICRP-68 values from BSC 2005a ([DIRS 173590], Tables II-1d and I-3d)
^b Sr-90 effective dose conversion factor includes Y-90.

Table H-2. FGR-11 Committed Dose Equivalent per Unit Intake (rem/Ci) - Inhalation

FGR-11 Committed Dose Equivalent per Unit Intake (rem/Ci) – Inhalation ^a								
Nuclide	Gonad	Breast	Lung	R Marrow	BSurface	Thyroid	Remainder	Effective
H-3	6.40E+01	6.40E+01	6.40E+01	6.40E+01	6.40E+01	6.40E+01	6.40E+01	6.40E+01
C-14	2.40E+01	2.40E+01	2.40E+01	2.40E+01	2.40E+01	2.40E+01	2.40E+01	2.10E+03
Cl-36	1.90E+03	1.90E+03	1.70E+05	1.90E+03	1.90E+03	1.90E+03	2.00E+03	2.20E+04
I-129	3.20E+02	7.70E+02	1.20E+03	5.20E+02	5.10E+02	5.80E+06	4.40E+02	1.70E+05
Cs-134	4.80E+04	4.00E+04	4.40E+04	4.40E+04	4.10E+04	4.10E+04	5.10E+04	4.60E+04
Cs-137	3.20E+04	2.90E+04	3.30E+04	3.10E+04	2.90E+04	2.90E+04	3.40E+04	3.20E+04
Fe-55	1.90E+03	1.90E+03	3.90E+03	1.90E+03	1.90E+03	2.00E+03	4.50E+03	2.70E+03
Co-60	1.80E+04	6.80E+04	1.30E+06	6.40E+04	5.00E+04	6.00E+04	1.30E+05	2.20E+05
Ni-63	6.30E+03	6.30E+03	1.10E+04	6.30E+03	6.30E+03	6.30E+03	6.30E+03	2.30E+03
Sr-90 ^b	9.80E+03	9.80E+03	1.10E+07	1.20E+06	2.70E+06	9.80E+03	3.60E+04	1.30E+06
Ru-106	4.80E+03	6.60E+03	3.80E+06	6.50E+03	6.00E+03	6.40E+03	4.40E+04	4.80E+05
Sb-125	1.30E+03	1.50E+03	8.00E+04	2.00E+03	3.60E+03	1.20E+03	5.40E+03	1.20E+04
Pm-147	7.00E-02	1.30E-01	2.90E+05	3.00E+04	3.80E+05	7.30E-02	2.20E+04	3.90E+04
Sm-151	1.50E-01	5.50E-01	1.20E+04	4.10E+04	5.10E+05	4.90E-02	2.80E+04	3.00E+04
Eu-154	4.30E+04	5.70E+04	2.90E+05	3.90E+05	1.90E+06	2.60E+04	4.20E+05	2.90E+05
Eu-155	1.30E+03	2.30E+03	4.40E+04	5.30E+04	5.60E+05	8.90E+02	4.10E+04	4.10E+04
Pu-238	3.80E+07	1.60E+03	1.20E+09	2.10E+08	2.70E+09	1.40E+03	1.00E+08	2.90E+08
Pu-239	4.40E+07	1.50E+03	1.20E+09	2.40E+08	3.00E+09	1.40E+03	1.10E+08	3.10E+08
Pu-240	4.40E+07	1.60E+03	1.20E+09	2.40E+08	3.00E+09	1.40E+03	1.10E+08	3.10E+08
Am-241	1.20E+08	9.90E+03	6.80E+07	6.40E+08	8.00E+09	5.90E+03	2.90E+08	4.40E+08
Pu-241	1.00E+06	7.90E+01	1.20E+07	5.30E+06	6.60E+07	3.40E+01	2.20E+06	4.90E+06
Am-243	1.20E+08	5.60E+04	6.60E+07	6.40E+08	8.00E+09	3.10E+04	2.90E+08	4.40E+08
Cm-242	2.10E+06	3.50E+03	5.70E+07	1.40E+07	1.80E+08	3.50E+03	9.10E+06	1.70E+07
Cm-243	7.70E+07	2.30E+04	7.20E+07	4.40E+08	5.40E+09	1.40E+04	2.10E+08	3.10E+08
Cm-244	5.90E+07	3.80E+03	7.10E+07	3.50E+08	4.30E+09	3.70E+03	1.80E+08	2.50E+08

Notes: ^a FGR-11 values from BSC 2005a ([DIRS 173590], Tables II-1b and I-3b)
^b Sr-90 effective dose conversion factor includes Y-90.

Table H-3. Ratio of ICRP-68-to-FGR-11 Committed Dose Equivalent per Unit Intake - Inhalation

Ratio of ICRP-68-to-FGR-11 Committed Dose Equivalent per Unit Intake								
Nuclide	Gonad	Breast	Lung	R Marrow	BSurface	Thyroid	Remainder	Effective
H-3	1.0E+00	1.0E+00	1.0E+00	1.0E+00	1.0E+00	1.0E+00	1.0E+00	1.0E+00
C-14	1.0E+00	1.0E+00	1.0E+00	1.0E+00	1.0E+00	1.0E+00	1.0E+00	1.1E-02
Cl-36	5.3E-01	5.3E-01	1.2E+00	5.3E-01	5.3E-01	5.3E-01	5.0E-01	1.2E+00
I-129	1.2E+00	4.8E-01	1.1E+00	9.2E-01	2.7E+00	1.2E+00	2.2E+00	2.1E+00
Cs-134	6.5E-01	6.3E-01	7.0E-01	7.5E-01	8.8E-01	8.0E-01	1.1E+00	7.8E-01
Cs-137	6.9E-01	6.9E-01	7.0E-01	7.4E-01	8.3E-01	7.9E-01	1.0E+00	7.8E-01
Fe-55	5.1E-01	5.1E-01	2.5E-01	6.3E+00	3.5E+00	4.8E-01	3.1E+00	1.3E+00
Co-60	1.4E-01	1.3E+00	4.8E-01	6.9E-01	6.6E-01	5.8E-01	2.5E-01	5.0E-01
Ni-63	1.0E+00	1.0E+00	9.1E-01	1.0E+00	1.0E+00	1.0E+00	2.2E+00	3.2E+00
Sr-90 *	1.2E-02	1.2E-02	4.1E-01	2.5E-02	2.5E-02	1.2E-02	9.2E-03	4.3E-01
Ru-106	4.0E-01	7.9E-01	5.0E-01	5.5E-01	5.2E-01	4.8E-01	7.3E-02	4.8E-01
Sb-125	5.7E-01	2.4E+00	1.4E+00	3.0E+00	8.3E+00	1.6E+00	3.7E-01	1.4E+00
Pm-147	2.0E+01	1.1E+01	2.3E-01	7.0E-01	7.1E-01	1.9E+01	4.5E-04	4.4E-01
Sm-151	3.2E+00	1.1E+00	8.3E-01	7.3E-01	7.3E-01	1.1E+01	1.1E-04	4.7E-01
Eu-154	2.6E-01	7.2E-01	1.2E+00	8.2E-01	7.4E-01	1.0E+00	1.0E-01	6.6E-01
Eu-155	2.3E-01	6.5E-01	1.4E+00	6.8E-01	7.3E-01	1.0E+00	4.1E-02	5.9E-01
Pu-238	1.9E-01	5.8E+02	2.6E-01	1.3E-01	2.1E-01	6.6E+02	1.0E-02	1.9E-01
Pu-239	1.9E-01	7.3E+02	2.4E-01	1.3E-01	2.1E-01	7.9E+02	1.1E-02	1.8E-01
Pu-240	1.9E-01	6.9E+02	2.4E-01	1.3E-01	2.1E-01	7.9E+02	1.1E-02	1.8E-01
Am-241	9.2E-01	1.0E+03	1.9E+00	3.1E-01	7.4E-01	1.7E+03	3.4E-02	3.2E-01
Pu-241	1.9E-01	3.0E+02	1.3E-01	1.2E-01	2.1E-01	7.1E+02	1.1E-02	1.2E-01
Am-243	9.2E-01	1.8E+02	1.8E+00	3.1E-01	7.4E-01	3.2E+02	3.4E-02	3.2E-01
Cm-242	8.1E-01	3.4E+01	2.1E+00	4.8E-01	5.3E-01	3.4E+01	1.5E-02	1.1E+00
Cm-243	1.0E+00	2.6E+02	1.8E+00	3.6E-01	7.6E-01	4.2E+02	3.0E-02	3.5E-01
Cm-244	1.1E+00	1.2E+03	1.8E+00	3.7E-01	7.4E-01	1.2E+03	2.4E-02	3.7E-01

Notes: Ratio of ICRP68 values from Table H-1 divided by FGR-11 values from Table H-2.