DOCUMENT RELEASE AND CHANGE FORM

Prepared For the U.S. Department of Energy, Assistant Secretary for Environmental Management
By Washington River Protection Solutions, LLC., PO Box 850, Richland, WA 99352
Contractor For U.S. Department of Energy, Office of River Protection, under Contract DE-AC27-08RV14800

Release Stamp

DATE: Dec 03,2019 HANFORD RELEASE

1. **Doc No:** RPP-CALC-61254 **Rev.** 03

2. **Title:**
Inadvertent Intruder Dose Calculation Update for the Integrated Disposal Facility Performance Assessment

3. **Project Number:** ☐N/A
T2C24

4. **Design Verification Required:**
☐Yes ☒No

5. **USQ Number:** ☒ N/A
RPP-27195

6. **PrHA Number** **Rev.** ☒ N/A

Clearance Review Restriction Type:
public

7. **Approvals**

Title	**Name**	**Signature**	**Date**
Clearance Review	Harrison, Sarah E	*Harrison, Sarah E*	12/03/2019
Checker	Watson, David (Dj) J	*Watson, David (Dj) J*	11/26/2019
Document Control Approval	Alvarez, Efren	*Alvarez, Efren*	12/03/2019
Originator	Lee, Kearn (Pat)	*Lee, Kearn (Pat)*	11/26/2019
Quality Assurance	Lungu, Cris C	*Lungu, Cris C*	11/13/2019
Responsible Engineer	Lee, Kearn (Pat)	*Lee, Kearn (Pat)*	11/26/2019
Responsible Manager	Rutland, Paul L	*Rutland, Paul L*	11/26/2019

8. **Description of Change and Justification**

Rev 0 - Initial Issue
Rev 1 - Include disposal limit concentration calculations
Rev 2 - Revise to combine all SSW terms and limit intruder protections to 100 years after closure. Update disposal limit calculations. Remove inventory variation cases.
Rev 2A - Editorial changes only.

9. **TBDs or Holds** ☒N/A

10. **Related Structures, Systems, and Components**

a. **Related Building/Facilities** ☒N/A	b. **Related Systems** ☒N/A	c. **Related Equipment ID Nos. (EIN)** ☒N/A

11. **Impacted Documents – Engineering** ☒N/A

Document Number	**Rev.**	**Title**

12. **Impacted Documents (Outside SPF):**

N/A

13. **Related Documents** ☐N/A

Document Number	**Rev.**	**Title**
RPP-CALC-61015	00	Inadvertent Intruder Dose Calculation for the Integrated Disposal Facility Performance Assessment

14. **Distribution**

Name	**Organization**
Bergeron, Marcel P	CLOSURE & INTERIM MEASURES
Childress, Ryan D	CLOSURE & INTERIM MEASURES
Hiergesell, Bob A	CLOSURE & INTERIM MEASURES
Lee, Kearn (Pat)	CLOSURE & INTERIM MEASURES
Lungu, Cris C	PROCUREMENT QA
Rutland, Paul L	CLOSURE & INTERIM MEASURES
Singleton, Kristin M	CLOSURE & INTERIM MEASURES
Watson, David (Dj) J	CLOSURE & INTERIM MEASURES

INFORMATION CLEARANCE REVIEW AND RELEASE APPROVAL

Part I: Background Information

Title: Inadvertent Intruder Dose Calculation Update for the Integrated Disposal Facility Performance Assessment	Information Category: ☐ Abstract ☐ Journal Article ☐ Summary ☐ Internet ☐ Visual Aid ☐ Software ☐ Full Paper ☑ Report ☐ Other
Publish to OSTI? ☐ Yes ☑ No	
Trademark/Copyright "Right to Use" Information or Permission Documentation	Yes ☐ NA ☑
Document Number: RPP-CALC-61254 Revision 3	Date: November 2019
Author: Lee, Kearn (Pat)	

Part II: External/Public Presentation Information

Conference Name: NA

Sponsoring Organization(s): DOE-ORP

Date of Conference: NA | Conference Location: NA

Will Material be Handed Out? ☐ Yes ☑ No | Will Information be Published? ☐ Yes ☑ No | *(If Yes, attach copy of Conference format instructions/guidance.)*

Part III: WRPS Document Originator Checklist

Description	*Yes*	*N/A*	*Print/Sign/Date*
Information Product meets requirements in TFC-BSM-AD-C-01?	☑	☐	Kearn Patrick Lee IDMS data file att. 11/21/2019
Document Release Criteria in TFC-ENG-DESIGN-C-25 completed? (Attach checklist)	☐	☑	
If product contains pictures, safety review completed?	☐	☑	

Part IV: WRPS Internal Review

Function	*Organization*	*Date*	*Print Name/Signature/Date*
Subject Matter Expert	WRPS	11/20/2019	Lee, Kearn (Pat) IDMS data file att.
Responsible Manager	WRPS	11/12/2019	Rutland, Paul L IDMS data file att.
Other:			

Part V: IRM Clearance Services Review

Description	*Yes*	*No*	*Print Name/Signature*
Document Contains Classified Information?	☐	☒	If Answer is "Yes," ADC Approval Required Print Name/Signature/Date
Document Contains Information Restricted by DOE Operational Security Guidelines?	☐	☒	Reviewer Signature: Print Name/Signature/Date
Document is Subject to Release Restrictions? *If the answer is "Yes," please mark category at right and describe limitation or responsible organization below:*	☐	☒	Document contains: ☐ Applied Technology ☐ Protected CRADA ☐ Personal/Private ☐ Export Controlled ☐ Proprietary ☐ Procurement – Sensitive ☐ Patentable Info. ☐ OUO ☐ Predecisional Info. ☐ UCNI ☐ Restricted by Operational Security Guidelines ☐ Other (Specify)
Additional Comments from Information Clearance Specialist Review?	☐	☒	Information Clearance Specialist Approval APPROVED By Sarah Harrison at 12:55 pm, Dec 03, 2019 Print Name/Signature/Date

When IRM Clearance Review is Complete – Return to WRPS Originator for Final Signature Routing (Part VI)

INFORMATION CLEARANCE REVIEW AND RELEASE APPROVAL

Part VI: Final Review and Approvals

Description	Approved for Release		Print Name/Signature
	Yes	N/A	
WRPS External Affairs	☒	☐	IDMS data file att. McKenna, Mark
WRPS Office of Chief Counsel	☒	☐	IDMS data file att. Cherry, Stephen B
DOE – ORP Public Affairs/Communications	☒	☐	IDMS data file att. Levardi, Yvonne M/ Tyree, Geoff T
Other: ORP SME	☒	☐	IDMS data file att. Pyles, Gary L
Other: DOE OCC	☒	☐	IDMS data file att. Zelen, Benjamin J

Comments Required for WRPS-Indicate Purpose of Document:

The document is currently in the document release workflow in SmartPlant. This calculation report has been through checking, technical editing, and senior review. A public release clearance is requested as part of the document release workflow. Rev 2A was just cleared for public release on 10/29/19. Since that time, DOE recommended all Hanford Site PAs assume institutional controls will be in place site wide until 2278. This EMCF revision updates the calculations in Section 6.2 that only assumed institutional controls were in place until 2151.

APPROVED
By Sarah Harrison at 12:55 pm, Dec 03, 2019

Approved for Public Release; Further Dissemination Unlimited

Information Release Station

Was/Is Information Product Approved for Release? ☒ Yes ☐ No

If Yes, what is the Level of Releaser? ☑ Public/Unrestricted ☐ Other (Specify) ____________

Date Information Product Stamped/Marked for Release: 12/03/2019

Was/Is Information Product Transferred to OSTI? ☐ Yes ☒ No

Forward Copies of Completed Form to WRPS Originator

- <workflow name="(JDA) Normal - RPP-CALC-61254 Rev3_DoseCalcIDF PA" id="252340510">
- <task name="Clearance Process" id="0" date-initiated="20191112T1133" performer="Janis D Aardal" performer-id="267960" username="h0090683">
<comments>Due Monday November 25, 2019 - COB Please approve the Rev 3 Inadvertent Intruder Dose Calculation Update for the Integrated Disposal Facility Performance Assessment, by Pat Lee for public release. Thank you, Janis Aardal Information Clearance</comments>
</task>
<task name="Add XML" id="1" date-done="20191112T1134" />
<task name="Manager Approval" id="41" date-due="20191115T1133" date-done="20191112T1152" performer="Paul L Rutland" performer-id="140633218" username="h4494439" disposition="Approve" authentication="true" />
- <task name="Document Reviewer3" id="52" date-due="20191115T1152" date-done="20191112T1508" performer="Gary L Pyles" performer-id="147601648" username="h6400308" disposition="Public Release" authentication="true">
<comments>No Comments</comments>
</task>
<task name="Document Reviewer1" id="54" date-due="20191115T1152" date-done="20191114T0720" performer="Mark McKenna" performer-id="182697281" username="h1903617" disposition="Public Release" authentication="true" />
<task name="Document Reviewer2" id="53" date-due="20191115T1152" date-done="20191120T0821" performer="Stephen B Cherry" performer-id="1382719" username="h0374767" disposition="Public Release" authentication="true" />
<task name="Doc Owner Clearance Review" id="13" date-due="20191121T0821" date-done="20191120T0830" performer="Kearn P Lee" performer-id="148796764" username="h8500694" disposition="Send On" authentication="true" />
<task name="Milestone 1" id="24" date-done="20191120T0830" />
<task name="ORP Document Reviewer1" id="57" date-due="20191122T0830" date-done="20191120T0950" performer="Benjamin J Zelen" performer-id="141965018" username="h1214744" disposition="Public Release" authentication="true" />
- <task name="ORP Document Reviewer2" id="58" date-due="20191122T0830" date-done="20191121T1017" performer="Yvonne M Levardi" performer-id="185346745" username="h7131303" disposition="Public Release" authentication="true">
<comments>no comments</comments>
</task>
<task name="ORP Document Reviewer3" id="59" date-due="20191122T0830" date-done="20191121T1504" performer="Geoff T Tyree" performer-id="6158846" username="h0068565" disposition="Public Release" authentication="true" />
<task name="Doc Owner Reviews ORP Comments" id="61" date-due="20191122T1504" date-done="20191121T1540" performer="Kearn P Lee" performer-id="148796764" username="h8500694" disposition="Send On" authentication="true" />
<task name="Milestone 2" id="62" date-done="20191121T1540" />
<task name="Verify Doc Consistency" id="4" date-due="20191122T1540" date-done="20191203T1042" performer="Janis D Aardal" performer-id="267960" username="h0090683" disposition="Cleared" authentication="true" />
</workflow>

9, Rev. 3

Inadvertent Intruder Dose Calculation Update for the Integrated Disposal Facility Performance Assessment

D.J. Watson, Glenn Taylor (retired), Washington River Protection Solutions, LLC

K. Patrick Lee, Orano Federal Services, LLC
Richland, WA 99352
U.S. Department of Energy Contract DE-AC27-08RV14800

EDT/ECN:	N/A	UC:	N/A
Cost Center:	2FL00	Charge Code:	203284
B&R Code:	NA	Total Pages:	139

Key Words: Integrated Disposal Facility, performance assessment, inadvertent intruder, exposure scenario, dose calculation, dose conversion factors, GoldSim

Abstract: This environmental model calculation report documents the assumptions, equations, and methods used to perform the inadvertant intruder radiological dose calculations for the 2017 Integrated Disposal Facility Performance Assessment. The inadvertent intruder dose is based on a stylized scenario that involves a loss of instituional controls and subsequent loss of memory of the disposal facility. A well-driller drills through the waste to install a groundwater well. The well-driller is exposed as the drill cuttings are brought to the surface. Subsequent exposures to indiviudals occur as the cuttings are spread over a specific area and an individual lives or works on the area for one year. This calculation replicates a previously released calculation to utilize alternative simulation software. Revision 3 re-evaluates disposal limits for different intruder protection durations..

APPROVED
By Sarah Harrison at 4:13 pm, Dec 03, 2019

DATE: Dec 04, 2019 HANFORD RELEASE

Release Approval Date Release Stamp

Approved For Public Release

ENVIRONMENTAL MODEL CALCULATION COVER PAGE

SECTION 1: COMPLETED BY RESPONSIBLE MANAGER OR DESIGNEE

3
RELEASE/ISSUE

Project: T2C24 2017 IDF PA

Date: 11/4/2019

Calculation Title and Description: Inadvertent Intruder Dose Calculation Update for the Integrated Disposal Facility Performance Assessment

SECTION 2: COMPLETED BY PREPARER

Calculation No.: RPP-CALC-61254 Revision No.: 3

Revision History ADD ROW

Revision No.	Description	Date	Affected Pages	
0	Initial Issue	5/22/2017	New	
1	Minor rror correction	9/11/2017	All	D
2	Address external review comments	3/29/2018	All	D
3	Evaluate additional intruder protection durations	11/04/2019	Section 6.2	D

SECTION 3: COMPLETED BY RESPONSIBLE MANAGER OR DESIGNEE

Document Control

1. Is document intended to be controlled within SmartPlant? ☒ Yes ☐ No
2. Does document contain scientific and technical information intended for public use? ☐ Yes ☒ No
3. Does document contain controlled-use information? ☐ Yes ☒ No

SECTION 4: TRAINING AND SOFTWARE INSTALLATION APPROVAL *(COMPLETED PRIOR TO PERFORMING CALCULATION)*

Modeler-Required Training Completed:
Training Coordinator:

Kearn Patrick Lee	Technical Lead	[signature]	11/4/2019
Print First and Last Name	*Position*	*Signature*	*Date*

Software Installation and Checkout Certified:
Integration Lead:

Will Nichols	Software Owner	Not applicable	see Att 1
Print First and Last Name	*Position*	*Signature*	*Date*

ENVIRONMENTAL MODEL CALCULATION COVER PAGE (Continued)

SECTION 5: DOCUMENT REVIEW AND APPROVAL

	Print First and Last Name	Position	Signature	Date
Preparer:	Kearn Patrick Lee	Technical Lead	[signature]	11/4/19
Checker:	DJ Watson	Scientist	[signature]	11/11/19
Senior Reviewer:	See attachment 1	Not Applicable	Not Applicable	see Att 1
Responsible Manager or Designee:	Paul Rutland	Manager	[signature]	11/11/19

Executive Summary

The Hanford Integrated Disposal Facility (IDF) is a near-surface disposal facility for vitrified low-activity tank waste and solid secondary waste (SSW). DOE Order 435.1, *Radioactive Waste Management*, and DOE Manual 435.1-1, *Radioactive Waste Management Manual*, prescribe numerous post-closure requirements that a low-level waste (LLW) disposal facility must satisfy to obtain permission to operate. For some of these requirements, relevant exposure scenarios must be developed and evaluated in a performance assessment (PA) analysis to demonstrate compliance with the requirements. The purpose of this environmental model calculation file (EMCF) is to document the analysis of an inadvertent intrusion into radioactive waste containers disposed of at the IDF. A stylized inadvertent intruder scenario and exposure calculation is evaluated to support the development of waste acceptance criteria for the IDF. Doses to a member of the public in the future are calculated for four inadvertent intruder scenarios, represented by one acute exposure scenario and three chronic exposure scenarios. The calculated doses are compared to DOE performance measures for a chronic exposure, 100 mrem (1 mSv) in a year, and for an acute exposure, 500 mrem (5 mSv). The calculated total effective dose equivalent (TEDE) excludes radon.

The acute exposure scenario evaluates the dose received during the intrusion event from well drilling and subsequent exposure to residual waste in the drill cuttings; exposure is evaluated over a short time period. The chronic exposure scenarios evaluate the post-intrusion dose received from spreading the drill cuttings over a specific area, after which an individual lives or works on that area. Dose to a future member of the public is calculated using site-specific exposure scenarios including both site-specific and general parameters for calculating exposure.

Inadvertent intruder dose is calculated after facility closure and after an assumed period during which institutional controls and intruder protections prevent an inadvertent intrusion into the disposal facility. For the calculations, institutional controls are assumed to be lost as early as 100 years after the expected closure of the facility (2051) but also evaluate peak doses assuming an institutional control period until a recommended sitewide closure date in 2278. The dose calculations assume a single intrusion can occur at any year between 100 years after closure and 1,000 years after closure to evaluate the peak dose resulting from an intrusion during the compliance period specified in DOE O 435.1. Intruder protections are used to further restrict the 100-year to 1,000-year dose results to times in the future when intrusions could actually occur (i.e. after a temporary lapse in institutional controls). After the loss of institutional controls and failure of additional intruder protections, it is assumed that the engineered features of the facility (surface cover, waste container, and waste forms) provide no further intrusion protection. Once intruder protections fail, it is assumed that there is no recognition of non-native material being exhumed from the subsurface that would cause subsequent investigative measures to mitigate the exposure to exhumed waste from the disposal facility.

Using the waste stream inventories that are expected to be disposed of in the IDF, the peak dose to the well driller was 9.3 mrem if an intrusion occurred 100 years after closure and 6.0 mrem if it occurred after 2278. Because of radionuclide decay of the dominant dose contributors, the dose decreases when longer durations of intruder protections are assumed. Both values are well below the acute dose performance measure (500 mrem). For the earliest simulated intrusion time (100 years after closure), ^{137}Cs in solid secondary waste is the dominant dose contributor to the

well driller. For longer durations of credited intruder protections, ^{126}Sn, ^{241}Am, and ^{239}Pu in vitrified waste are the primary dose contributors to the well driller.

The chronic dose scenario considers a future resident that resides and raises livestock in the area contaminated by the drill cuttings. Similar to the well driller scenario, the peak dose decreases when longer durations of intruder protections are assumed. The peak dose in this scenario was 43 mrem/yr if an intrusion occurred 100 years after closure and 14 mrem/yr if it occurred in 2278. Both values are below the chronic dose performance measure (100 mrem/yr). For the earliest simulated intrusion time (100 years after closure), ^{90}Sr and ^{99}Tc in vitrified waste are the dominant dose contributors. For longer durations of credited intruder protections, ^{90}Sr dose is lower, but ^{99}Tc and ^{90}Sr in vitrified waste are still the primary dose contributors; ^{126}Sn, ^{241}Am, and ^{239}Pu in vitrified waste are smaller dose contributors to the resident.

The intruder calculations were also used to calculate the concentrations in the waste that could be disposed of in the IDF without exceeding the inadvertent intruder performance measures. This calculation is independent of the waste form. These concentration limits can be used to specify waste acceptance criteria. The concentration limits for short-lived radionuclides increase when longer periods of intruder protections can be credited. Concentration limits for long-lived radionuclides are not sensitive to the assumed duration of intruder protections. Table ES-1 shows the calculated disposal limits for two intruder protection periods.

Table ES-1. Disposal Limits (Ci/m^3) Based on Peak Dose Following an Inadvertent Intrusion at the End of Intruder Protections in 2151 and 2278.

Radio-nuclide	2151*	2278*	Radio-nuclide	2151*	2278*	Radio-nuclide	2151*	2278*
Ac227	23.6	1,320	**Ni59**	18.3	18.3	**Sn126**	0.0945	0.0945
Am241	3.0	3.67	**Ni63**	18.0	43.4	**Sr90**	2.26	47.6
Am243	1.07	1.08	**Np237**	0.740	0.740	**Tc99**	0.906	0.906
C14	6.05	6.15	**Pa231**	0.211	0.211	**Th229**	0.414	0.419
Cd113m	186	92,200	**Pb210**	8.63	448	**Th230**	0.467	0.467
Cm243	29.9	480	**Pu238**	6.40	17.4	**Th232**	0.0267	0.0267
Cm244	327	771	**Pu239**	2.11	2.11	**U232**	0.333	1.19
Co60	1.15E+06	1.61E+09	**Pu240**	2.13	2.16	**U233**	2.52	2.52
Cs137	4.57	83.9	**Pu241**	87.2	107	**U234**	5.04	5.04
Eu152	103	65,900	**Pu242**	2.21	2.21	**U235**	0.967	0.967
Eu154	4.07E+03	1.03E+08	**Ra226**	0.216	0.228	**U236**	5.62	5.62
Eu155	7.44E+08	1.75E+09	**Ra228**	1.36E+05	1.87E+11	**U238**	4.03	4.03
H3	2.30	2,780	**Rn222**	1.83E+04	9.51E+05	**Zr93**	462	462
I129	0.120	0.120	**Se79**	1.12	1.12	--	--	--
Nb93m	3.83E+05	8.73E+07	**Sm151**	1.12E+04	2.97E+04	--	--	--

* Column heading refers to the calendar year when there is a lapse in intruder protections and an intrusion into the waste can occur.

TABLE OF CONTENTS

APPENDIX/ATTACHMENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF TERMS

AgM	silver mordenite
CEM	Conceptual exposure model
CERCLA	*Comprehensive Environmental Response, Compensation, and Liability Act of 1980*
CHPRC	CH2M Hill Plateau Remediation Company
COPC	contaminant(s) of potential concern
DOE	The United States Department of Energy
DCF	dose conversion factor
EMCF	Environmental model calculation file
ETF	Effluent Treatment Facility
FFTF	Fast Flux Test Facility
FV	final value
GAC	granular activated carbon
HEPA	high-efficiency particulate arrestance (filter)
HISI	Hanford Information Systems Inventory
ICRP	International Commission for Radiation Protection
IDF	Integrated Disposal Facility
IIDM	Inadvertent Intruder Dose Model
ILAW	immobilized low-activity waste
IX	ion exchange
LAW	low-activity waste
LSW	Liquid secondary waste
LLW	low-level waste
MLLW	mixed low-level waste
OD	other solid secondary waste debris
PA	performance assessment
SSW	solid secondary waste
TEDE	total effective dose equivalent
TH	time histories
WM	waste management
WTP	Waste Treatment and Immobilization Plant

[THIS PAGE INTENTIONALLY LEFT BLANK]

1.0 PURPOSE

The Hanford Integrated Disposal Facility (IDF) is a near-surface disposal facility for vitrified low-activity tank waste and solid secondary waste (SSW). DOE Order 435.1, *Radioactive Waste Management*, and DOE Manual 435.1-1, *Radioactive Waste Management Manual*, prescribe numerous post-closure requirements that a low-level waste (LLW) disposal facility must satisfy to obtain permission to operate. For some of these requirements, relevant exposure scenarios must be developed and evaluated in a performance assessment (PA) analysis to demonstrate compliance with the requirements. The purpose of this environmental model calculation file (EMCF) is to document the analysis of an inadvertent intrusion into radioactive waste containers disposed of at the IDF. The analysis is performed in accordance with DOE requirements to perform an inadvertent intruder analysis. A stylized inadvertent intruder scenario and exposure calculation is evaluated to support the development of waste acceptance criteria for the IDF. The conceptual and mathematical models for the exposure are identical to those described in RPP-CALC-61015, *Inadvertent Intruder Dose Calculation for the Integrated Disposal Facility Performance Assessment*. The calculations described in RPP-CALC-61015 were performed using Microsoft Excel®[1] and were performed for a hypothetical inventory. The calculations performed in this EMCF are performed in GoldSim®[2] and use projected waste stream inventories. Doses to a member of the public in the future are calculated for four inadvertent intruder scenarios, represented by one acute exposure scenario and three chronic exposure scenarios. The calculated doses are compared to DOE performance measures for a chronic exposure, 100 mrem (1 mSv) in a year, and for an acute exposure, 500 mrem (5 mSv). The calculated total effective dose equivalent (TEDE) excludes radon.

The acute exposure scenario evaluates the dose received during the intrusion event from well drilling and subsequent exposure to residual waste in the drill cuttings; exposure is evaluated over a short time period. The chronic exposure scenarios evaluate the post-intrusion dose received from spreading the drill cuttings over a specific area, after which an individual lives or works on that area.

Inadvertent intruder dose is calculated after facility closure and after an assumed period during which institutional controls prevent an inadvertent intrusion into the disposal facility. Institutional controls are assumed to be lost as soon as 100 years after the expected closure of the facility (2051) but also include longer duration of institutional control out to a recommended sitewide closure date in 2278. The dose calculations are performed between 100 years after closure and 1,000 years after closure to evaluate the peak dose resulting from an intrusion during the compliance period specified in DOE O 435.1. DOE O 435.1 allows institutional controls to be effective in deterring intrusion for at least 100 years following closure. After the loss of institutional controls and failure of additional intruder protections, it is assumed that the engineered features of the facility (surface cover, waste container, and waste forms) provide no further intrusion protection. Once intruder protections fail, it is assumed that there is no recognition of non-native material being exhumed from the subsurface that would cause subsequent investigative measures to mitigate the exposure to exhumed waste from the IDF.

---

[1] Microsoft® Excel is a registered trademark of the Microsoft Corporation, Redmond, Washington.

[2] GoldSim® is a registered trademark of the GoldSim Technology Group, LLC, Issaquah, Washington.

[THIS PAGE INTENTIONALLY LEFT BLANK]

2.0 BACKGROUND

This section summarizes relevant information on the IDF PA performance measures for an inadvertent intrusion, contaminant sources, release and transport mechanisms, and conceptual exposure models (CEMs) for the hypothetical inadvertent intruder scenarios. More detailed discussion can be found in the supporting data package, RPP-ENV-58813, *Exposure Scenarios for Risk and Performance Assessments in Tank Farms at the Hanford Site, Washington*.

2.1 PERFORMANCE OBJECTIVES

DOE O 435.1 and DOE M 435.1-1 prescribe numerous post-closure requirements that a LLW disposal facility must satisfy to obtain authorization to operate. For some of these requirements, relevant exposure scenarios must be constructed and evaluated in a PA analysis to demonstrate compliance with the requirements. DOE M 435.1-1 provides requirements that must be addressed by exposure scenario analysis. The assessment of a hypothetical person assumed to inadvertently intrude for a temporary period into the facility is used to establish disposal limits on radionuclide concentrations.

For performance measures relevant to inadvertent intruders, the initial point of compliance is the point of intrusion into the disposal facility after the assumed loss of active institutional controls. For the inadvertent intruder, the applicable performance measures are 100 mrem (1 mSv) in a year and 500 mrem (5 mSv) TEDE for chronic and acute exposure scenarios, respectively.

2.2 CONTAMINANT SOURCES

The IDF is planning to receive mixed low-level waste (MLLW) and LLW generated by the Hanford Waste Treatment and Immobilization Plant (WTP) as a result of the vitrification process. Those waste streams include:

- immobilized low-activity waste (ILAW) glass
- ILAW glass melters
- solid secondary waste (SSW)
- Effluent Treatment Facility (ETF)-treated liquid secondary waste (LSW).

Additional waste streams would be generated that are not a result of the WTP process. These waste streams would also be disposed of at the IDF and include:

- Fast Flux Test Facility (FFTF) decommissioning waste
- secondary waste management LLW and MLLW
- onsite Non-*Comprehensive Environmental Response, Compensation, and Liability Act of 1980* (CERCLA) non-tank LLW and MLLW.

For PA models that evaluate the mobility of radionuclides from different waste streams, the SSW from the WTP is discretized into different waste streams to specifically evaluate waste streams that may release radionuclides at different rates due to the specific unit operations involved in the treatment mission. The inventory used in the PA models was developed in RPP-CALC-62058, *Waste Stream Inventory Calculations for the Integrated Disposal Facility Performance Assessment* with the intent of modeling the release behavior of different waste streams separately. The contaminant sources that are included in the PA models, including the inadvertent intruder model discussed in this EMCF, include:

- ILAW glass
- ILAW glass melters
- WTP SSW
  - Solidified WTP SSW ion exchange (IX) resins
  - Compacted and encapsulated WTP SSW high-efficiency particulate arrestance (HEPA) filters
  - Solidified WTP SSW carbon adsorption media (GAC)
  - Solidified WTP SSW silver mordenite (AgM)
  - Compacted and encapsulated WTP SSW other debris (OD)
- Solidified ETF LSW
- Compacted and encapsulated FFTF SSW
- Compacted and encapsulated waste management (WM) SSW
- Compacted and encapsulated Non-CERCLA waste.

However, in the inadvertent intruder scenario waste form release processes are not modeled; instead, waste is transported to the accessible environment because of the intrusion. Therefore, the release behavior from different SSW waste streams is not relevant to the calculations and all SSW waste streams (i.e., WTP SSW, compacted and encapsulated FFTF SSW, compacted and encapsulated WM SSW, and compacted and encapsulated Non-CERCLA waste) are assumed to be co-located with an equal opportunity to intrude into any waste package. To implement this condition, the average concentration in the SSW is used in the inadvertent intruder dose assessment. To be consistent with the transport of waste through the natural system in the other IDF PA models, the inadvertent intruder dose calculations assume that ILAW glass is co-located with ILAW melters, that ETF-LSW is disposed of in a separate area of the IDF, and that all SSW is disposed of together, but segregated from the ILAW glass and ETF-LSW. Thus, the inadvertent intruder model simulates an intrusion into three separate waste streams, ILAW glass, ETF-LSW, and SSW.

The treatment of all SSW as a combined, averaged waste stream differs from earlier revisions of this evaluation. The change reflects the intended operational method that does not currently plan to segregate SSW waste from different sources and removes the previous pessimistic assumption that the worst waste streams would all be disposed of above one another. This last condition is a very low probability condition given that total SSW makes up less than 5% of the waste volume planned for disposal in the IDF.

Forty-three radionuclides are addressed in the inadvertent intruder analysis. The screening of radionuclides was limited to the list of radionuclides included in the tank waste inventory database and the long-lived decay products of those radionuclides. Additional information regarding the radionuclides and associated inventory is provided in Section 3.2.2 of this EMCF.

2.3 RELEASE AND TRANSPORT MECHANISMS AND CONCEPTUAL EXPOSURE MODELS

In the intruder scenarios, institutional controls and societal memory are credited for delaying an inadvertent intrusion into the facility for at least 100 years after the facility is closed. In accordance with DOE guidance in "*Recommendations for Institutional Control Time Period for Conducting DOE Order 435.1 Performance Assessments at the Hanford Site*" (Hamel et al. 2019), it is assumed that the Hanford Site will be under institutional control until at least 2278. Therefore, intruder protections are assumed until 2278. For this analysis, facility closure is assumed to be 2051, which is the original end date of the waste treatment mission. No additional engineered features of the IDF (e.g., engineered surface barrier with bio-intrusion barriers, robust stainless steel waste containers, or robust vitrified waste forms) are credited for extending intruder protections beyond the loss of institutional controls. After a loss of institutional controls and societal memory a well is installed through the IDF to the depth of the water table for the supply of water. As the well is drilled through the IDF, waste is intercepted and brought to the ground surface in the form of drill cuttings. At the time of the intrusion it is assumed that the exhumed waste is not recognizable as non-native materials, and would not be distinguishable from the sand, silts, and gravels of the Hanford formation in the vicinity of the IDF. This is a pessimistic assumption that a driller would not recognize a difference in drilling rates when the drill bit encounters a robust waste form or a robust waste container. It is also pessimistic to assume that corrosion and impacts from a drill bit using conventional drilling techniques for the area would cause the waste to be indistinguishable from sand, silt, or gravel.

Two types of exposure scenarios are considered to estimate dose to the hypothetical intruder and other members of the public: (1) acute scenarios and (2) chronic scenarios. One of two acute scenario evaluates the dose received from well drilling and subsequent exposure to residual waste in the drill cuttings; exposure is evaluated over a short time period (40 hours over a five-day period of time). A second acute scenario considered an excavation into the facility to build a home with a basement over the facility. This scenario was excluded from further consideration because the depth of the disposed of waste (more than 5 meters below the top of the IDF surface barrier) exceeds typical basement excavation depths; therefore, it is expected that a drilling scenario would result in a greater dose to a member of the public in the future following an inadvertent intrusion into the IDF. The chronic dose is evaluated using the well-drilling scenario. The dose to the member of the public in the future is received from spreading the drill cuttings with exhumed waste over a specific area while living and/or working on that area for one year before recognizing that the area may be contaminated.

These acute and chronic exposure scenarios are evaluated in this EMCF, and brief descriptions of each scenario are provided in Table 2-1. A discussion of each scenario, including a description of the input parameters used for the each scenario, is briefly covered. More detailed discussions of the scenarios and parameters used in these scenarios can be found in Appendices N, O, and R of RPP-ENV-58813.

Table 2-1. Descriptions of the Inadvertent Intruder Scenarios Evaluated in the Integrated Disposal Facility Performance Assessment.

Scenario	Description
Acute Exposure: Well Driller	Dose is the result of drilling through the Integrated Disposal Facility. Exposure routes include external exposure, inhalation of soil particulates, and incidental soil ingestion. Exposure occurs during the drilling operation while in contact with the drill cuttings. Resulting dose does not depend on the borehole diameter.
Acute Exposure: Basement Intrusion	Dose is considered highly unlikely due to the thickness of the closure cap. A basement excavation would not disturb the waste. No further discussion of this scenario is included.
Chronic Exposure: Rural Pasture	Dose is the result of drilling a well that serves a rural pasture. Contaminated drill cuttings are mixed with the soil over the pasture area. Exposure routes include external exposure, inhalation of soil particulates, incidental soil ingestion, and milk consumption.
Chronic Exposure: Suburban Garden	Dose is the result of drilling a well that serves a suburban garden. Contaminated drill cuttings are mixed with the soil over the area where a residence and a garden are constructed. Exposure routes include external exposure, inhalation of soil particulates, incidental soil ingestion, and fruit and vegetable consumption.
Chronic Exposure: Commercial Farm	Dose is the result of drilling a well that serves a commercial farm. Contaminated drill cuttings are mixed with the soil over the commercial farm area. Exposure routes are external exposure, inhalation of soil particulates, and incidental soil ingestion.

Reference: RPP-ENV-58813, *Exposure Scenarios for Risk and Performance Assessments in Tank Farms at the Hanford Site, Washington*.

2.3.1 Acute Well Driller Scenario

The acute well driller scenario evaluates the short-term exposure of a well driller to drill cuttings that are exhumed from a well that is installed to the depth of the water table for the supply of water. The well is installed after an assumed loss of intruder protections. As the well is drilled through the IDF waste forms, the driller will be exposed to the radiation dose from waste exhumed with the drill cuttings. The well driller is assumed to be exposed to drill cuttings for a total of five days (8 hours per day for a total of 40 hours). The dose is calculated assuming that the cuttings are uniformly spread across the drill pad, and the pad is small enough that concentrations are not diluted by mixing with clean soil. A more detailed description of the scenario is documented in Appendix R, Section R.2 of RPP-ENV-58813 (see Figure 2-1). Because the depth to the waste under the surface barrier exceeds 5 meters, radiological exposure to contaminated drill cuttings in a well driller scenario is expected to have a greater dose than exposure to gaseous emissions that would be shielded by more than 5 feet of soil during an excavation scenario.

Dose coefficients for this scenario are derived assuming that the well driller is exposed to contaminated soil represented as an infinite surface in length, width, and depth, and the concentration in this surface is equal to the concentration in the drill cuttings. This assumption will overestimate the dose to the well driller.

The size of the water well is consistent with the usage assumptions for each chronic exposure scenario evaluated. After the appropriately-sized well is installed, the contaminated cuttings are assumed to be spread out onto the ground surface. The representative area contaminated by spreading out the cuttings and working the cuttings into the soil is specific to each chronic exposure scenario evaluated.

2.3.2 Chronic Rural Pasture Scenario

The chronic rural pasture scenario is also based on the well driller scenario (Section 2.3.1). This exposure scenario considers an individual that uses a target field contaminated by the waste in the drill cuttings. The target field is used as a residence with a dairy cow pasture for milk production. In this scenario it is assumed that the well diameter is 26.67 cm (10.5 in.) and that the drill cuttings are spread over a pasture area of 5,000 m^2. This scenario represents an individual that resides and has a pasture on the target field area. A more detailed description of the scenario is documented in Appendix R, Section R.3 of RPP-ENV-58813 (see Figure 2-2).

Dose coefficients for this scenario are derived assuming that a member of the public is exposed to contaminated soil represented as an infinite surface in length, width, and depth, and the concentration in this surface is equal to the concentration in the drill cuttings spread out over the pasture area and then tilled to the depth of 15 cm. This assumption of exposure to an infinite surface will overestimate the dose to the rural pasture resident.

2.3.3 Chronic Suburban Garden Scenario

The chronic suburban garden scenario is also based on the well driller scenario (Section 2.3.1). This exposure scenario considers an individual that uses a target field contaminated by the waste in the drill cuttings. The target field is used as a residence with a garden. In this scenario, it is assumed that the well diameter is 16.51 cm (6.5 in.), that the well is drilled prior to the construction of the house and garden, and that the drill cuttings are spread over the 2,500-m^2 lot. The size of the home garden is 100 m^2. This size of the garden has been estimated as reasonable to provide 25% of the daily vegetable diet for a family of four living in the home. A more detailed description of the scenario is documented in Appendix R, Section R.3 of RPP-ENV-58813 (see Figure 2-3).

Similar to the Rural Pasture Scenario, the dose coefficients for this scenario assume exposure to contaminated soil represented as an infinite surface in length, width, and depth. The concentration in this surface is equal to the concentration in the drill cuttings spread out over the garden area and then tilled to the depth of 15 cm. This assumption of exposure to an infinite surface will overestimate the dose to the suburban garden resident.

2.3.4 Chronic Commercial Farm Scenario

The chronic commercial farm worker scenario is also based on the well driller scenario (Section 2.3.1). This exposure scenario considers an individual that uses a target field contaminated by the waste in the drill cuttings. The target field is used as a commercial farm. In this scenario, it is assumed that the well diameter is 41.91 cm (16.5 in.) and that the drill cuttings are spread over a farm area of 647,000 m^2 (160 acres) for growing food crops. This scenario considers an individual that works on the commercial farm and tends to the crops but does not consume what is produced. A more detailed description of the scenario is documented in Appendix R, Section R.3 of RPP-ENV-58813 (see Figure 2-4).

Similar to the Rural Pasture Scenario, the dose coefficients for this scenario assume exposure to contaminated soil represented as an infinite surface in length, width, and depth. The concentration in this surface is equal to the concentration in the drill cuttings spread out over the farmed area and then tilled to the depth of 15 cm. This assumption of exposure to an infinite surface will overestimate the dose to the commercial farm worker.

Figure 2-1. Well Driller Conceptual Exposure Model.

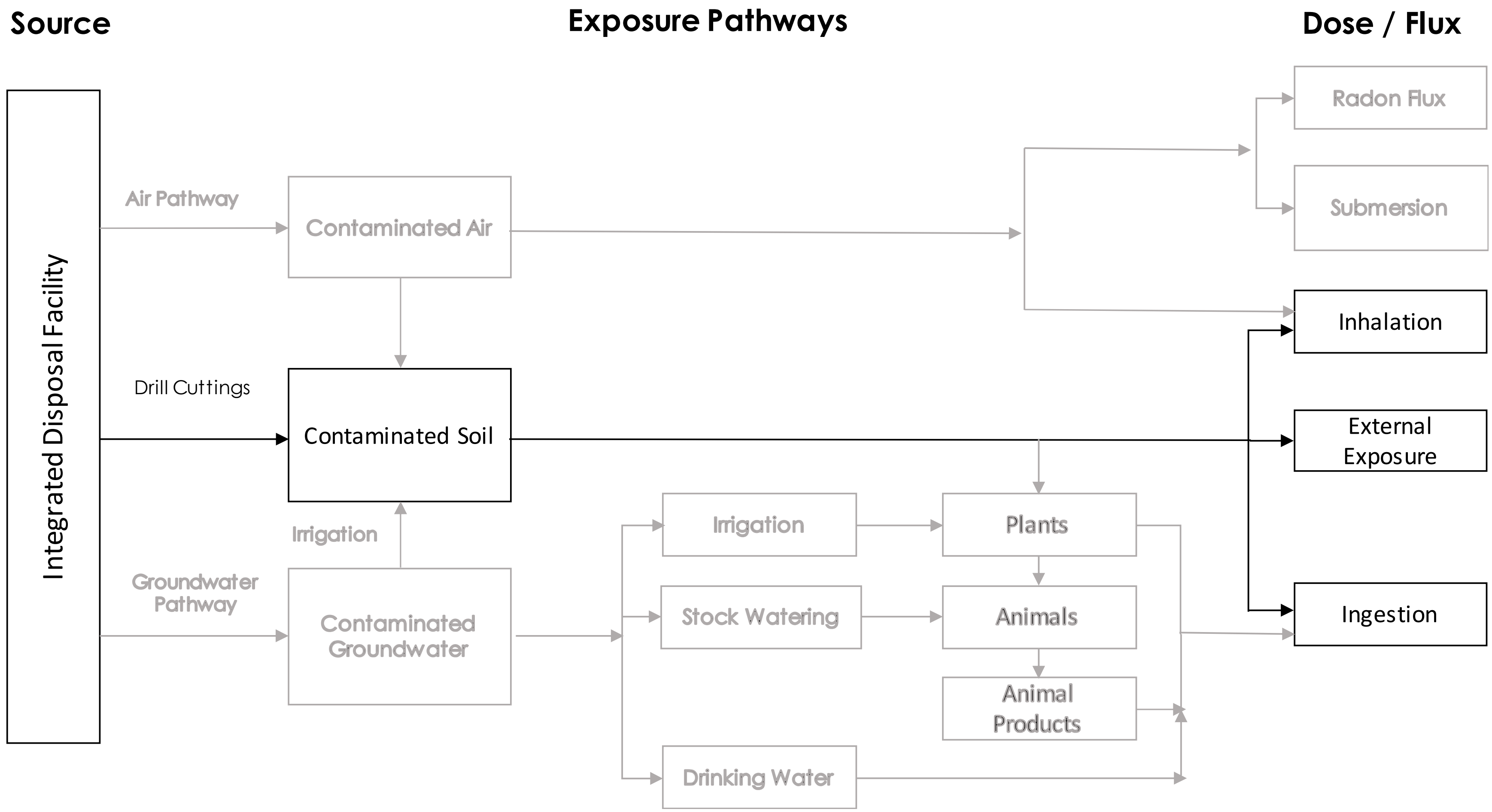


Figure 2-2. Rural Pasture Conceptual Exposure Model.

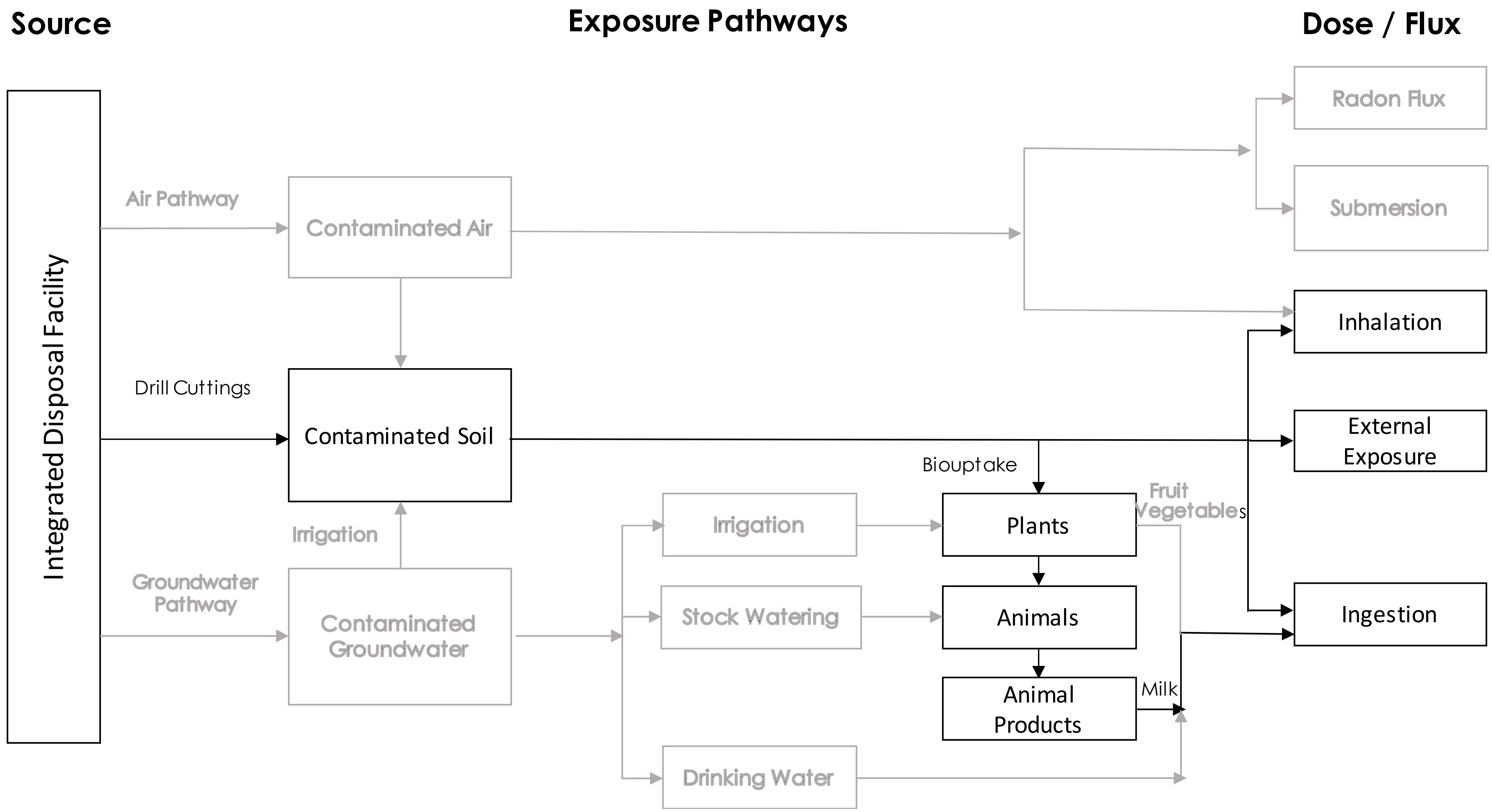


Figure 2-3. Suburban Garden Conceptual Exposure Model.

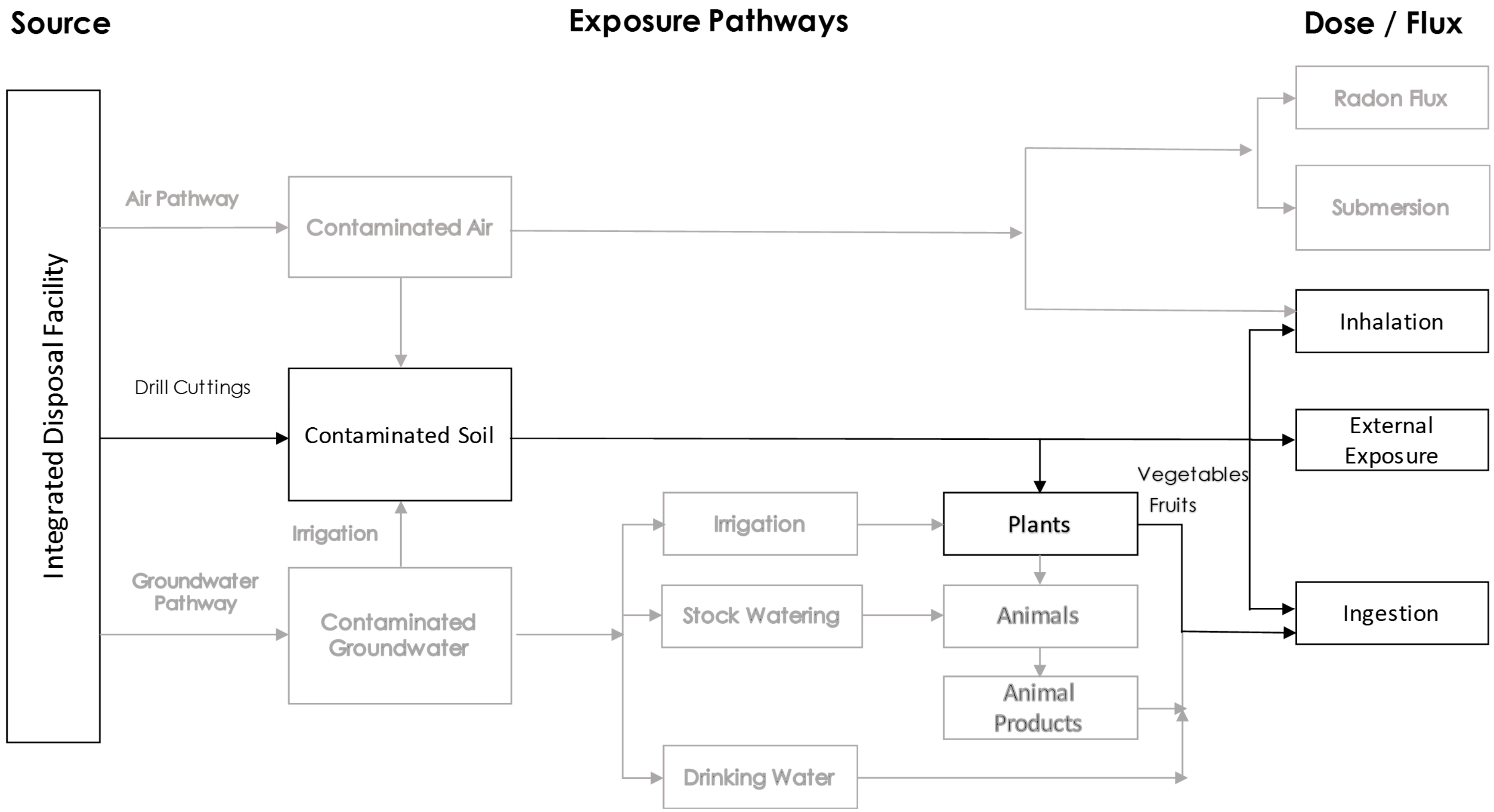
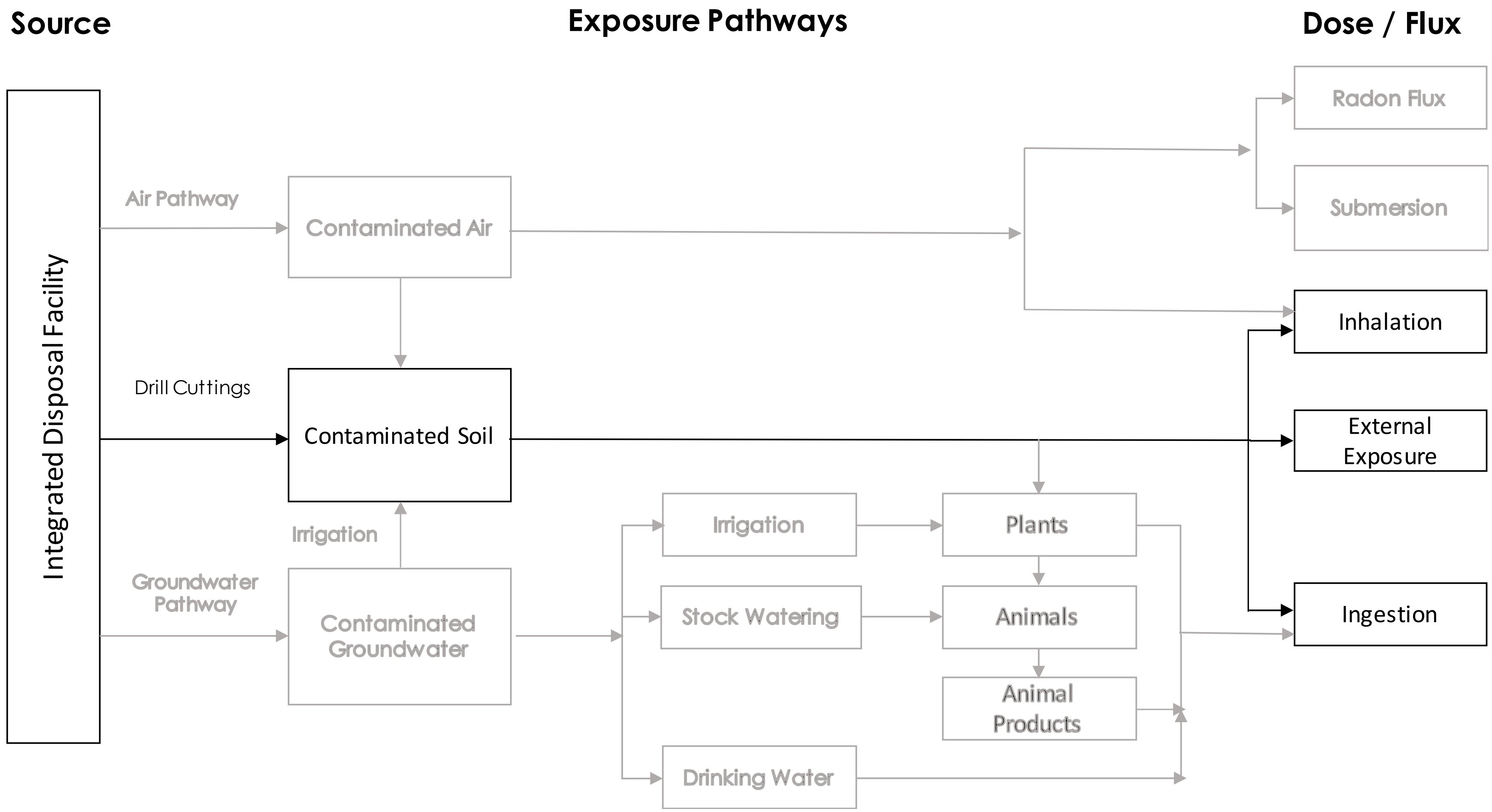


Figure 2-4. Commercial Farm Conceptual Exposure Model.



3.0 METHODOLOGY

The inadvertent intruder analysis methodology is documented in the following section. This EMCF will discuss the implementation of the methodology in the GoldSim programming environment. A detailed description of the scenarios and their pathways, including the equations used to compute concentrations and exposures, can be found in Appendices O and R of RPP-ENV-58813. The equations are reproduced here for clarity, but the basis for the equations is not repeated in this report. Parameter values used in the calculations are from Appendices N, O, and R of RPP-ENV-58813.

Readers who are unfamiliar with the GoldSim programming environment may find it useful to review Attachment 2, which describes the types of model objects (e.g., containers, data elements, stochastic elements, function elements, media elements, cell pathway elements, species element, ordinal sets for vectors and matrices) discussed in the text.

TEXT CONVENTION: Model element names are presented in bold face italics for clarity and may be abbreviated using squares brackets ("[ ]") to signify a convention for elements with a similar name. For example, ***Kd_[COPC]*** would represent a group of model elements with values that represent the soil-water partition coefficient for different contaminants of potential concern (COPC).

3.1 INADVERTENT INTRUDER DOSE MODEL OVERVIEW

The Inadvertent Intruder Dose Model (IIDM) (see Figure 3-1) used in this calculation is essentially the model discussed in RPP-CALC-61015 with the inclusion of additional detailed source terms to simulate different SSW waste streams and additional inventories. The IIDM's source is treated as waste-stream specific; that is, doses are calculated as though the driller penetrated a single waste stream (ILAW glass, ETF-LSW, or SSW). This single waste stream treatment allows the evaluation of maximum concentration limits for each waste stream type without factoring in probabilities for intersecting different waste streams. See Table 3-1 for a description of the sources and how the sources compare between the two reports.

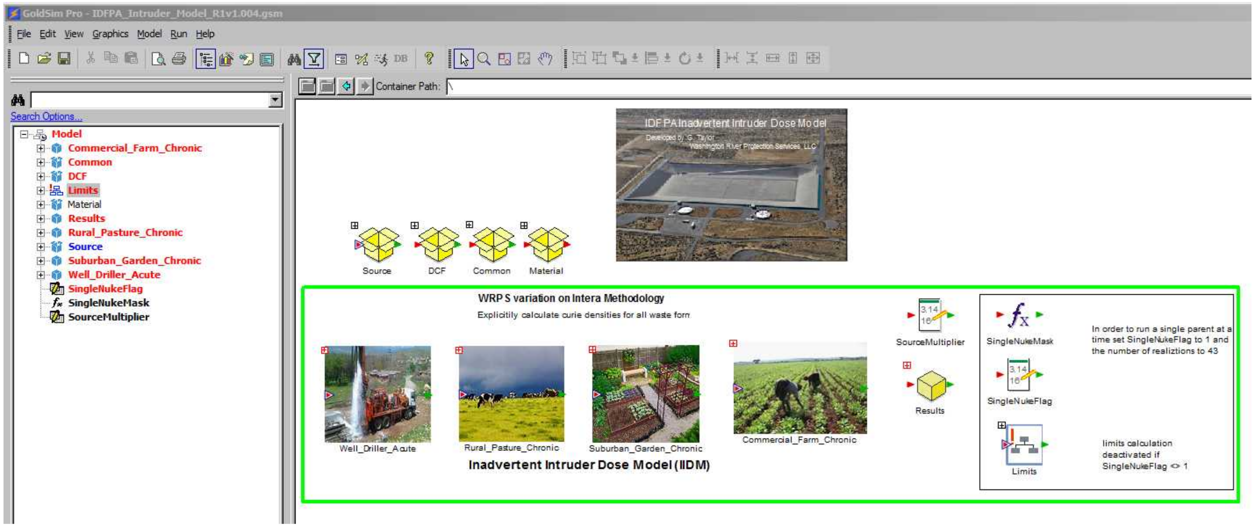
The IIDM performs a dynamic (i.e., time-dependent) calculation. The time dependency allows for the radionuclide decay and subsequent ingrowth of modeled radionuclides. The IIDM explicitly calculates the inventories of each waste stream for each radionuclide at each time step, including decay product ingrowth. The GoldSim software uses user-provided input and/or an extensive built-in database of radionuclide decay data based on "ICRP Publication 107: Nuclear Decay Data for Dosimetric Calculations" (International Commission for Radiation Protection [ICRP] 2008). The doses are then calculated for each time step after an assumed loss of intruder protections and the peak dose during the evaluation period is compared to the specified performance metrics.

Table 3-1. Modeled Waste Streams.

Implementation	Model Source	Waste Stream
RPP-CALC-61015, "*Inadvertent Intruder Dose Calculation for the Integrated Disposal Facility Performance Assessment*"	Immobilized low-activity waste (ILAW)	ILAW Glass
	Solid secondary waste (SSW)	WTP GAC
		WTP IX resin
		WTP Silver mordanite
		WTP SSW other
		LAW melters
		WM SSW
		FFTF SSW
		Non-CERCLA SSW
		ETF SSW
RPP-CALC-61254, *Inadvertent Intruder Dose Calculation Update for the Integrated Disposal Facility Performance Assessment* (Inadvertent Intruder Dose Model)	ILAW_Glass	ILAW glass
	LAW_melters	
	WTP_SSW_IX	SSW
	WTP_SSW_HEPA	
	WTP_SSW_GAC	
	WTP_SSW_AG	
	WTP_SSW_other	
	WM_SSW	
	FFTF_SSW	
	nonCERCLA	
	ETF_SSW	ETF SSW

CERCLA = *Comprehensive Environmental Response, Compensation, and Liability Act of 1980*
ETF = Effluent Treatment Facility
FFTF = Fast Flux Test Facility
GAC = granular activated carbon
HEPA = high-efficiency particulate arrestance (filter)
IX = ion exchange
WTP = Waste Treatment and Immobilization Plant

Figure 3-1. Top-Level View Inadvertent Intruder Dose Model.



3.2 MODEL IMPLEMENTATION

The following sections describe the structure and calculations performed in the IIDM. The discussion of the implementation is documented at the container level.

> **TEXT CONVENTION:** The discussion uses GoldSim vernacular to describe model details. Readers that are not familiar with this vernacular can refer to Attachment 2 as a guide, but Attachment 2 is not intended to be a tutorial for an inexperienced GoldSim user.

3.2.1 Common Containers

There are four implementation containers, ***Material***, ***DCF***, ***Source***, and ***Common***, which contain information that is common to all exposure scenarios.

Material defines the reference fluid (***Water***) and COPC set (***Species***) with decay parameters from ICRP Publication 107. See Table 3-2 for a listing of the GoldSim species along with decay information for the radioactive species. The list of COPCs tracked in the IIDM only includes radioactive isotopes for comparison to dose-based performance measures. The list of the tracked COPCs and their decay data is found in the ***Species*** element. The ***Species*** element defines an ordinal set for all COPCs tracked in the model. The ordinal set is an ordered listing for use in defining vectors and matrices.

DCF contains the inhalation, ingestion, and external exposure dose conversion factors (DCFs) along with radionuclide-specific shielding factors used in the analyses. Soil external exposure DCFs include short-lived progeny (RPP-ENV-58813). Air inhalation and water ingestion DCFs from RPP-ENV-58813 are updated to include short-lived progeny. This update is described in Appendix B. NOTE: There is some ambiguity as to whether or not water ingestion and air inhalation DCFs include progeny in secular equilibrium with the radionuclide at the time of exposure; there is no ambiguity as to whether or not these DCFs include the effects of progeny after internal ingestion. A pessimistic approach is assumed that increases the DCFs for internal exposure routes to account for short-lived decay products.

Common contains the input definitions for data and stochastic elements common to all exposure scenarios. All input parameters that may have uncertainty are defined using stochastic elements in GoldSim. If a scenario-specific value is required it is defined in the scenario's ***Parameters_[ii]*** container, where ***[ii]*** denotes an abbreviation used for each exposure scenario listed in Table 2-1. These scenario-specific containers of parameters are defined within each scenarios calculation container, which are shown in Figure 3-1 as ***Well_Driller_Acute***, ***Rural_Pasture_Chronic***, ***Suburban_Garden_Chronic***, and ***Commercial_Farm_Chronic***.

Table 3-2. Inadvertent Intruder Dose Model Species List. (2 sheets)

Species ID	Isotope	Atomic Weight	Half-life	Radioactive	Daughter1	Stoichiometry1	Daughter2	Stoichiometry2
Ac227	Y	227.028	21.772 yr	Y	--	--	--	--
Am241	Y	241.057	432.2 yr	Y	Np237	1	--	--
Am243	Y	243.061	7,370 yr	Y	Pu239	1	--	--
C14	Y	14.0032	5,700 yr	Y	--	--	--	--
Cd113m	Y	112.904	14.1 yr	Y	--	--	--	--
Cm243	Y	243.061	29.1 yr	Y	Pu239	0.9976	Am243	0.0024
Cm244	Y	244.063	18.1 yr	Y	Pu240	1	--	--
Co60	Y	59.9338	5.2713 yr	Y	--	--	--	--
Cs137	Y	136.907	30.167 yr	Y	--	--	--	--
Eu152	Y	151.922	13.537 yr	Y	--	--	--	--
Eu154	Y	153.923	8.593 yr	Y	--	--	--	--
Eu155	Y	154.923	4.7611 yr	Y	--	--	--	--
H3	Y	3.01605	12.32 yr	Y	--	--	--	--
I129	Y	128.905	1.57E+07 yr	Y	--	--	--	--
Nb93m	Y	92.9064	16.13 yr	Y	--	--	--	--
Ni59	Y	58.9343	1.01E+05 yr	Y	--	--	--	--
Ni63	Y	62.9297	100.1 yr	Y	--	--	--	--
Np237	Y	237.048	2.144E+06 yr	Y	U233	1	--	--
Pa231	Y	231.036	32,760 yr	Y	Ac227	1	--	--
Pb210	Y	209.984	22.2 yr	Y	--	--	--	--
Pu238	Y	238.05	87.7 yr	Y	U234	1	--	--
Pu239	Y	239.052	24,110 yr	Y	U235	1	--	--
Pu240	Y	240.054	6,564 yr	Y	U236	1	--	--

Table 3-2. Inadvertent Intruder Dose Model Species List. (2 sheets)

Species ID	Isotope	Atomic Weight	Half-life	Radioactive	Daughter1	Stoichiometry1	Daughter2	Stoichiometry2
Pu241	Y	241.057	14.35 yr	Y	Am241	0.99998	Np237	2.45E-05
Pu242	Y	242.059	3.75E+05 yr	Y	U238	1	--	--
Ra226	Y	226.025	1,600 yr	Y	--	--	--	--
Ra228	Y	228.031	5.75 yr	Y	--	--	--	--
Rn222	Y	222.018	3.8235 day	Y	Pb210	0.9998	--	--
Se79	Y	78.9185	2.95E+05 yr	Y	--	--	--	--
Sm151	Y	150.92	90 yr	Y	--	--	--	--
Sn126	Y	125.908	2.3E+05 yr	Y	--	--	--	--
Sr90	Y	89.9077	28.79 yr	Y	--	--	--	--
Tc99	Y	98.9063	2.111E+05 yr	Y	--	--	--	--
Th229	Y	229.032	7,340 yr	Y	--	--	--	--
Th230	Y	230.033	75,380 yr	Y	Ra226	1	--	--
Th232	Y	232.038	1.405E+10 yr	Y	Ra228	1	--	--
U232	Y	232.037	68.9 yr	Y	--	--	--	--
U233	Y	233.04	1.592E+05 yr	Y	Th229	1	--	--
U234	Y	234.041	2.455E+05 yr	Y	Th230	1	--	--
U235	Y	235.044	7.04E+08 yr	Y	Pa231	1	--	--
U236	Y	236.046	2.342E+07 yr	Y	Th232	1	--	--
U238	Y	238.051	4.468E+09 yr	Y	U234	1	--	--
Zr93	Y	92.9065	1.53E+06 yr	Y	Nb93m	0.975	--	--

NOTE: -- means that a first and/or second decay chain product is not included in the GoldSim© model. (GoldSim© simulation software is copyrighted by GoldSim Technology Group LLC of Issaquah, Washington [see http://www.goldsim.com]).

3.2.2 Source Container

The inventory of COPCs inside each waste container intersected by the inadvertent intrusion is calculated in the ***Source*** container. The initial inventory for the nominal inventory case, ***StreamInventories***, was developed in RPP-CALC-62058. In RPP-CALC-62058, the inventory was decayed to a common decay date associated with the anticipated date of first receipt (2021), ***StreamInventories_2021***, and also an assumed time for the lapse in intruder protections, ***StreamInventories_2151***. Waste stream inventories using the WTP flow sheet split fractions (RPP-CALC-62058 Table 7-1 and Table 7-7) are the initial inventories used in the IIDM. The option to use an inventory after IDF closure and 100 years of credited intruder protections (i.e., the 2151 inventory) is implemented by setting the value of ***StreamInventoryYear*** to 2151; otherwise the 2021 data is used. The initial inventory is developed from the radionuclide inventory values presented in the inventory data package, RPP-ENV-58562, *Inventory Data Package for the Integrated Disposal Facility Performance Assessment*. The GoldSim elements used to compute the inventory are grouped into separate containers for input (***Model_Input_Inventory***) and output (***Model_Calcs_Inventory***). The calculations use the tabulated input from RPP-CALC-62058 and subsequently decay the inventory through time and calculate the waste concentrations used in the stylized inadvertent intruder analysis. The start time for the model clock (i.e., ETime = 0 years) is aligned with the initial inventory decay date. The intruder model will calculate the dose from an intrusion in every year after the date associated with the initial inventory; however, dose results are only reported for dates after an assumed loss in intruder protections.

3.2.2.1 Initial Inventory. The Inventory Submodel of the IIDM determines initial inventories for several different waste sources, including the ILAW glass inventory, the ILAW glass melter inventory, the WTP SSW and LSW inventories, and other waste management inventory. The source information is extracted from tables in RPP-CALC-62058.

RPP-CALC-62058 develops initial inventories (in grams) for six inventory cases, but only the Case 7 radionuclide inventory with the WTP flow sheet split fractions (i.e., RPP-CALC-62058 Table 7-1) is used in the IIDM. This inventory case is the inventory case used to assess compliance with DOE M 435.1-1 all pathways dose performance objectives. An option to use this same inventory decayed to 2151 is also provided but would yield the same results included in this calculation for all times after credited intruder protections. The 2021 inventory is used to help identify waste disposal limits. The initial inventories for WTP-derived waste streams are included in columns 1 through 7 of ***StreamInventories_2021***. Column 1 contains the total initial inventory associated with ILAW glass and disposed ILAW glass melters. This inventory is represented by the ILAW glass waste stream in the IIDM. Column 2 contains the total initial inventory associated with solidified ETF-LSW. This inventory is represented by the ETF-LSW waste stream in the IIDM. Columns 3 through 7 contain the total initial inventory associated with the key WTP waste streams (AgM, GAC, IX, HEPA, and OD, respectively). Column 8 contains the total initial inventory associated with the non-CERCLA waste streams destined for IDF. Column 9 contains the total initial inventory associated with the SWM waste streams destined for IDF. Column 10 contains the total initial inventory associated with the FFTF decommissioning waste destined for IDF. The initial inventory of each radionuclide in columns 3 through 10 is summed to get the inventory represented by the SSW waste stream in the IIDM.

This summation is performed by ***SSW_Inv_Sum***. ***StreamInventories_2151*** contain the same data structure as the 2021 inventory table but the values have been decayed for an additional 130 years to account for a 30-year operational period plus 100 years of institutional controls. A selector element, ***StreamInventories***, is used with user specified settings, to apply the 2021 or 2151 inventory values in the dose calculations. There is no reported uncertainty for the inventory estimate. However, the inadvertent intruder dose will be shown to be proportional to the concentration of the waste, so that the effect of uncertainty in inventory and waste volume can be evaluated directly from changes that directly affect the concentration.

Other inventory cases from RPP-CALC-62058 can be modeled in the IIDM by adding in additional inventory tables and switches in ***StreamInventories*** to select the values from the new tables.

3.2.2.2 Time Dependent Inventory. One of the capabilities of the GoldSim software coupled with the Radionuclide Transport module is that GoldSim internally accounts for radionuclide decay and progeny ingrowth. As the IIDM model steps through time, calculations are internally performed by the GoldSim software to adjust the initial inventory to account for radionuclide decay and decay product ingrowth for all decay chains specified using the ***Species*** element. The cell pathway element is a specialized GoldSim element of the Radionuclide Transport module that applies the decay chain calculations.

The input to the decay calculations are the half-lives of the different radionuclides and specification of parent-progeny decay chain relationships. Decay chains and half-lives are specified in the ***Species*** element. In order to propagate radionuclide decay, the initial inventory of each waste stream is entered as separate inventories to a set of cell pathway elements (see Figure 3-2). Each cell pathway element (***SSW***, ***ILAW***, and ***ETF***) is assigned an initial inventory from Section 3.2.2.1. These elements are used to simply compute the changes to the initial inventory over time accounting for radionuclide decay and progeny ingrowth. In the IIDM, the initial inventory is added to each cell pathway using a discrete event element (***SSW_DC***, ***ILAW_DC***, and ***ETF_DC***) that adds the initial inventory to an appropriate cell pathway with an activation trigger set to trigger at the beginning of the model simulation. The time-dependent inventory in each cell pathway element can be accessed by referencing the elements “Mass In Pathway” output result (see Figure 3-3). An average package concentration (***Conc_SSW***, ***Conc_ILAW***, and ***Conc_ETF)*** can be computed by dividing the time-dependent inventory by the total waste volume of the applicable waste stream (see Section 3.2.2.3).

In an alternate run configuration to calculate concentration limits for disposal, the initial inventory is limited to a single radionuclide to totalize the dose from a parents and its progeny. Zeroing out all the initial inventory for all but one radionuclide is performed by ***SingleNukeScript*** and ***SingleNukeSelector***. The implementation assigns the total inventory for one radionuclide at a time based on a realization index, each of the 43 radionuclides included in the species list is modeled in 43 runs of the model.

3.2.2.3 Initial, As-Disposed Waste Volumes. In addition to the total waste inventory of radionuclides, the Inventory Submodel also models the waste volumes. In some cases the waste volumes presented in the inventory data package are as-disposed of volumes, in others the as-disposed of volumes must be calculated from as-generated volumes. Volume changes are calculated by applying volume adjustment factors to account for volume decreases due to compaction or volume increases due to the addition of solidifying materials. The Inventory Submodel computes the as-disposed of waste volumes to generate the COPC concentrations in the different waste streams.

Figure 3-2. Inventory Submodel Source Term Elements for the Different Waste Streams and Illustration of Specified Inventory for ILAW_Glass.

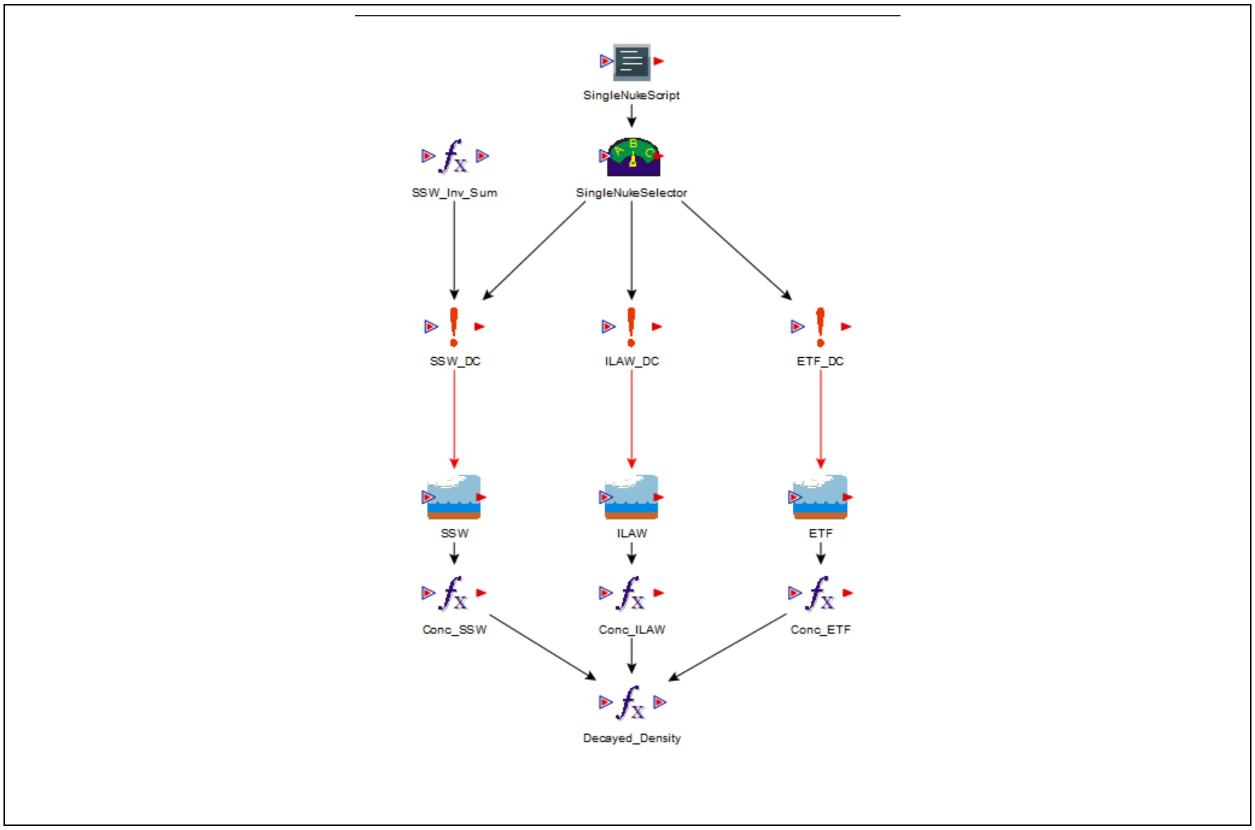
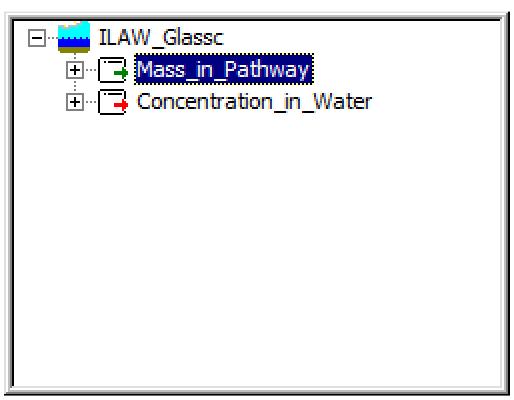


Figure 3-3. Determining the Mass in the Source Term Cell Pathway.



3.2.2.3.1 Waste Treatment and Immobilization Plant Immobilized Low-Activity Waste Glass Waste Volumes. Table 8-1 in RPP-ENV-58562 provides the deterministic estimate for the volume (m^3) of ILAW glass produced at the WTP in the different inventory modeling cases In the inadvertent intruder analysis, the applied volume for ILAW glass (***ILAW_glass_volume***) is equated to the volume of ILAW glass for inventory case 7, (i.e., 278,797 m^3). There is no reported uncertainty for this estimate. However, the inadvertent intruder dose will be shown to be proportional to the waste concentration in a waste container, so that the effect of inventory and volume uncertainty can be evaluated directly from changes that directly affect the concentration.

3.2.2.3.2 Waste Treatment and Immobilization Plant Immobilized Low-Activity Waste Melter Volumes. Table 8-3 in RPP-ENV-58562 provides the deterministic estimate for the volume (m^3) of ILAW melters that will be removed during the waste treatment mission. There is no reported uncertainty for these estimates. The melter volume is not used in the IIDM. The inventory associated with residual glass on the melters is included in the ILAW glass inventory without increasing the waste volume.

3.2.2.3.3 Waste Treatment and Immobilization Plant Solid Secondary Waste Volumes. Table 8-2 in RPP-ENV-58562 provides the deterministic estimate for the volume (m^3) of SSW that is expected to be produced at the WTP. The volume produced is waste stream-specific (e.g., ***WTP_SSW_volume_HEPA***, ***WTP_SSW_volume_other***, ***WTP_SSW_Volume_IX_Resin***, ***WTP_SSW_volume_GAC***, and ***WTP_SSW_volume_Ag_mord***). There is no reported uncertainty for these estimates. However, the inadvertent intruder dose will be shown to be proportional to the waste concentration, so that the effect of uncertainty in inventory and volume can be evaluated directly from changes that directly affect the concentration. The reported values for SSW volumes are as-produced estimates, not as-disposed of estimates. Sections 8.3 and 8.4 of RPP-ENV-58562 provide multipliers to convert the as-produced volume estimates to as-disposed of volume estimates.

For HEPA filters, the inventory data package says that compactible debris could be compacted using a compaction ratio of 2 to 10 (RPP-ENV-58562, Section 8.3.1) and Section 8.4 of RPP-ENV-58562 says for HEPA filters a compaction ratio of 10:1 should be applied. A triangular distribution (***WTP_SSW_volume_compact_HEPA_1***) is selected with a minimum of 2, a maximum of 10, and a most likely value of 10. The larger value creates the smallest waste volume, which leads to the highest waste concentrations in each waste container. For deterministic simulations, a value of 10 is used (***HEPA_Compact_datum***). A selector switch, ***WTP_SSW_volume_Compact_HEPA***, chooses between the sampled value from the triangular distribution if a probabilistic analysis is performed and the fixed value if a deterministic value is desired. The selection is based on the setting of configuration element **SingleNukeFlag** (1 = uses the datum value, <>1 uses the stochastic value). NOTE: GoldSim has the capability to specify a deterministic value when a deterministic run is performed using the Simulation Settings menu; the datum value is used to override the value sampled from the uncertainty distribution when it is preferred to run a multiple realization run but not sample the compaction ratio for the HEPA waste stream. The volume of SSW HEPA filters encapsulated by grout is equated to the as-produced volume estimate divided by the sampled compaction ratio by model element ***Disposed_Vol_WTP_SSW_HEPA***.

For other debris SSW, the inventory data package says that compactible debris could be compacted using a compaction ratio of 2 to 10 (RPP-ENV-58562, Section 8.3.1) and Section 8.4 of RPP-ENV-58562 says the average should be about 5:1. A triangular distribution (***WTP_SSW_volume_compact_other_1***) is selected with a minimum of 2, a maximum of 10, and a most likely value of 3 to yield a distribution with a mean value of 5. For deterministic simulations, a value of 5 is used (***Other_Compact_datum***). A selector switch, ***WTP_SSW_volume_compact_other***, chooses between the sampled value from the triangular distribution if a probabilistic analysis is performed and the fixed value if a deterministic value is desired. The selection is based on the setting of configuration element ***SingleNukeFlag*** (1 = uses the datum value, <>1 uses the stochastic value). NOTE: Similar to the implementation for the HEPA waste stream, the datum value is used to override the value sampled from the uncertainty distribution when it is preferred to run a multiple realization run but not sample the compaction ratio for the other debris waste stream. The disposed volume of other debris SSW encapsulated by grout is equated to the as-produced volume estimate divided by the sampled compaction ratio by model element ***Disposed_Vol_WTP_SSW_other***.

The as-generated volumes of the non-debris waste streams (IX resin, spent carbon adsorber bed media, and silver mordenite) from the WTP from RPP-ENV-58562 Rev 03 Table 8-2 are included in the inadvertent intruder analysis via ***WTP_SSW_Volume_IX_Resin***, ***WTP_SSW_volume_GAC***, and ***WTP_SSW_volume_Ag_mord***, respectively. For these non-debris waste streams, the expectation is that the waste will be solidified in grout, which will increase the volume, not reduce it as was the case for debris SSW. Section 8.4 of RPP-ENV-58562 says for non-debris the waste volume is expected to increase by a factor of 1.5 to 3. A triangular distribution (***WTP_SSW_volume_mult_nondebris_1***) is selected with a minimum of 1.5, a maximum of 3, and a most likely value of 1.5 to match the recommended value to be applied to all non-debris SSW. For deterministic simulations, a value of 1.5 is used (***Nondebris_Volume_Mult_datum***). The same value, whether sampled or deterministic, is applied to the all non-debris waste streams. The smaller multiplier creates the smallest waste volume, which leads to the highest waste concentrations for consideration in the stylized intruder analysis. A selector switch, ***WTP_SSW_volume_mult_nondebris***, chooses between the sampled value from the triangular distribution if a probabilistic analysis is performed and the fixed value if a deterministic value is desired. The selection is based on the setting of configuration element ***SingleNukeFlag*** (1 = uses the datum value, <>1 uses the stochastic value). NOTE: Similar to the implementation for the HEPA waste stream, the datum value is used to override the value sampled from the uncertainty distribution when it is preferred to run a multiple realization run but not sample the compaction ratio for the non-debris waste streams. The waste volume of non-debris SSW solidified in grout is equated to the as-produced volume estimate multiplied by the sampled expansion factor. For solidified carbon adsorber bed media, this calculation is performed by model element ***Disposed_Vol_WTP_SSW_GAC***. For solidified ion exchange resin, this calculation is performed by model element ***Disposed_Vol_WTP_SSW_IX_Resin***. For solidified silver mordenite, this calculation is performed by model element ***Disposed_Vol_WTP_SSW_Ag_mord***.

The total volume of WTP SSW disposed of in the IDF is the sum of the different SSW sources and is computed by ***Disposed_Vol_SSW***, which also includes the volume of other (non-WTP) debris waste streams.

3.2.2.3.4 Effluent Treatment Facility-Secondary Liquid Waste Solid Secondary Waste Volumes. Table 8-4 in RPP-ENV-58562 provides the deterministic estimate for the volume (m^3) of SSW that will be produced as a result of treating the WTP-secondary liquid waste at the ETF in the different modeling cases. In the inadvertent intruder analysis, the applied volume for ETF-LSW (***ETF_LSW_volume***) is equated to the volume of solidified liquid secondary waste for inventory case 7 (i.e., 18,900 m^3). The included value is the waste volume after the ETF product is solidified in grout. There is no reported uncertainty for this estimate. However, the inadvertent intruder dose will be shown to be proportional to the waste concentration, so that the effect of uncertainty in inventory and volume can be evaluated directly from changes that directly affect the waste concentration.

3.2.2.3.5 Other Waste Volumes. Section 8 in RPP-ENV-58562 also provides an estimate for the volume of other solid waste that will disposed of in the IDF. Estimates of waste volumes for secondary waste management SSW (combined LLW and MLLW), secondary waste from the decommissioning of the Fast Flux Test Facility, and secondary waste from the non-CERCLA, non-tank waste sources on-site (combined LLW and MLLW) are included in the inventory data package. These inventories have no reported uncertainty. The volume of as-generated secondary waste management SSW (***SSW_volume_WM***) is taken from Table 8-5 in RPP-ENV-58562. The disposed of volume for FFTF decommissioning waste (***SSW_volume_FFTF***) is taken from Table 8-6 in RPP-ENV-58562. The volume of as-generated secondary waste from the non-CERCLA, non-tank waste sources on-site (***SSW_volume_NonCERCLA***) is taken from Table 8-7 in RPP-ENV-58562. The disposed of volume of these three other waste streams is calculated using applicable compaction factors by model elements ***Disposed_Vol_WM_SSW***, ***Disposed_Vol_FFTF_SSW***, and ***Disposed_Vol_NonCERCLA_SSW***, respectively. The total waste volume of SSW is the sum of the volumes of the different SSW sources and is computed by ***Disposed_Vol_SSW***, which also includes the volume of WTP SSW. There is no reported uncertainty for these estimates. However, the inadvertent intruder dose will be shown to be proportional to the waste concentration, so that the effect of uncertainty in inventory and volume can be evaluated directly from changes that directly affect the waste concentration.

3.2.2.4 Miscellaneous Elements. In order to use the IIDM to compute concentration limits for disposal, the total dose impact from the initial inventory must be calculated. For radionuclides in a decay chain, the total dose impact from the initial inventory must include the dose from the radionuclide and all progeny that are produced from the initial inventory. When progeny are initially present in the inventory, separation of the dose impacts from initially present progeny and dose impacts from decay product growth becomes difficult. The IIDM includes the capability to efficiently evaluate the total dose impact by simulating a single radionuclide in the initial inventory (i.e., the inventory of any previous parents and all progeny in the decay chain are zeroed out). The total dose impact from the initially-present radionuclide is the total dose calculated in the model and is due to the initially-present radionuclide and any progeny that are also tracked in the IIDM (or included in the dose conversion factor).

The GoldSim script ***SingleNukeScript*** implements the functionality to zero out the initial inventory of any previous parents and any progeny in the decay chain. The functionality uses the multiple realization capability of GoldSim to assign an initial inventory to one of the 43 radionuclides included in the model. NOTE: This is an instance where using the multiple realization capability of GoldSim with deterministic values instead of values that are sampled from uncertainty distributions is necessary.

In the first realization the script assigns a unit multiplier (1×) to the initial inventory of the first species in the species list and a zero multiplier (0×) to the initial inventory of the all other species in the species list. This effectively zeroes out the initial inventory of all radionuclides except the first radionuclide in the species list. However, because the IIDM simulates decay chains, decay products of the initially-present radionuclide will also be included in the total dose calculation for the initially-present radionuclide. Therefore, the total dose calculated by the IIDM in the first simulated realization is solely attributed to the initial inventory of the first radionuclide in the species list and includes the dose from any progeny produced by radionuclide decay of the initial inventory. In the second realization the script assigns a unit multiplier (1×) to the initial inventory of the second species in the species list and a zero multiplier (0×) to the initial inventory of the all other species in the species list. In the third realization the script assigns a unit multiplier (1×) to the initial inventory of the third species in the species list and a zero multiplier (0×) to the initial inventory of the all other species in the species list. This continues until the last species in the list has been simulated without any other initial inventory. Since there are 43 radionuclides in the species list, this special case must be run for 43 realizations with the proper simulation case flags set (***SingleNukeFlag*** = 1 and number of "Monte Carlo" realizations equal to 43). The developed "mask" is applied by ***SingleNukeSelector*** based on configuration settings (***SingleNukeFlag*** = 1) and applied to the initial ILAW glass, ETF-LSW, and total SSW inventories by model elements ***ILAW_DC***, ***ETF_DC*** ¸ and ***SSW_DC, respectively***.

3.2.2.5 Concentrations of Waste Disposed of in the Integrated Disposal Facility. Having combined radionuclide inventories for the different waste sources, the concentration of a typical waste source is determined by dividing the combined inventory by the combined volume of waste disposed of in the IDF for those sources.

The average concentration in the ILAW glass associated with the initial inventory included in ***StreamInventories*** and subsequently decayed to the current simulation time is determined by ***Conc_ILAW***, as described in Section 3.2.2.2. Similarly, the bulk average concentration in waste containers of encapsulated debris together with solidified non-debris SSW is determined by ***Conc_SSW***. The average concentration in the solidified ETF-LSW is determined by ***Conc_ETF***.

In the post-closure intruder analysis, the volume of the disposed-of waste does not change with time; the concentration in the waste after accounting for decay and ingrowth according to the specified half-lives and decay chains can be computed by dividing the decayed inventory (i.e., the mass in the different cell pathway elements in the model [see Figure 3-3] by the initial volume of waste disposed of in the IDF. These calculations are performed in the Inventory Submodel.

3.2.2.6 Submodel Output. The output of the Inventory Submodel is a series of final value (FV) and time history (TH) result elements that report the concentration in the different waste streams at the end of the reporting period (FV) or as a function of time (TH). The outputs account for uncertainty in the waste volumes when a probabilistic treatment of the volume compaction and expansion factors is performed. The calculations also account for radionuclide decay and decay product ingrowth. The output is intended to represent the calculation of any waste package intercepted by an inadvertent intrusion into the disposal facility. Table 3-3 provides the list of outputs that are determined in the model.

The decayed density, a concentration accounting for radionuclide decay and ingrowth, is needed for the dose calculations. All decayed waste stream concentrations (densities) are collected by a single matrix element, ***Decayed_Density***, as a single point of reference for the conversion to dose.

Table 3-3. Submodel Elements Performing Inventory Concentration Calculations.

Element Name	Waste Stream Type	Output Time
Conc_ILAW	Average ILAW glass	Simulation time (Simulation time 0 yr is equivalent to calendar year 2021). The equivalent start time is tracked by model element ***StreamInventory_Year***.
Conc_SSW	Average encapsulated debris and non-debris SSW (all sources)	
Conc_ETF	Average ETF SSW	

ETF = Effluent Treatment Facility
ILAW = immobilized low-activity waste
SSW = solid secondary waste

3.2.3 Well Driller Acute Dose Pathway

The conceptual model and equations used for the acute well driller scenario are described in Appendix R, Section R.2 of RPP-ENV-58813.

Figure 3-4 illustrates the general format for the GoldSim implementation of the well driller scenario. In the GoldSim implementation, the calculations for this scenario are done using elements that are based on the ordinal set “Vols.” The “Vols” ordinal set accounts for the three different waste sources listed in Table 3-3. Each element using the “Vols” ordinal set is effectively computing each equation at least three times using the inputs that are appropriate for each waste source type. For elements that are matrices by the “Species” ordinal set and “Vols” ordinal set, the element is effectively performing the calculation 129 times, once for each radionuclide (43) and each waste source (3) combination.

In this implementation, the IIDM simultaneously calculates doses to the well driller assuming that the waste has been segregated according to three waste sources: ILAW glass, ETF-LSW, and SSW. This calculation assumes that these three sources are not placed over one another in the IDF and that different SSW waste streams are not strategically segregated. It is also assumed that the intrusion occurs with the maximum potential impact (i.e., the intrusion intercepts the center of the facility where waste is disposed of in four lifts instead of near the sides where fewer lifts of waste could occur). Using these assumptions, an intrusion into the segregated ILAW would intrude into four ILAW glass waste containers (one in each lift); an intrusion into the segregated ETF-LSW would intrude into eight ETF-LSW waste containers (two stacked drums or B-25 boxes in each lift); and an intrusion into the segregated SSW would intrude into eight SSW waste containers (two stacked drums or B-25 boxes in each lift). Each SSW waste container is filled with a bulk average concentration of radionuclides in the SSW. For other disposal configurations, the dose from a single ILAW glass waste container is one-fourth the dose from the ILAW glass case, and the dose from a single ETF-LSW waste container or a single SSW waste container is one-eighth the dose of the ETF-LSW case dose or SSW case dose, respectively. These dose alternatives for different waste package interceptions can be applied to the acute and chronic exposure scenarios. With the most predominant disposal volume being the ILAW glass, it is most probable that a hypothetical intrusion would impact four ILAW glass waste containers.

The pathway-specific parameters for the well driller scenario are contained in ***Parameters_WD*** (Figure 3-5).

Figure 3-4. \Well_Driller_Acute Container.

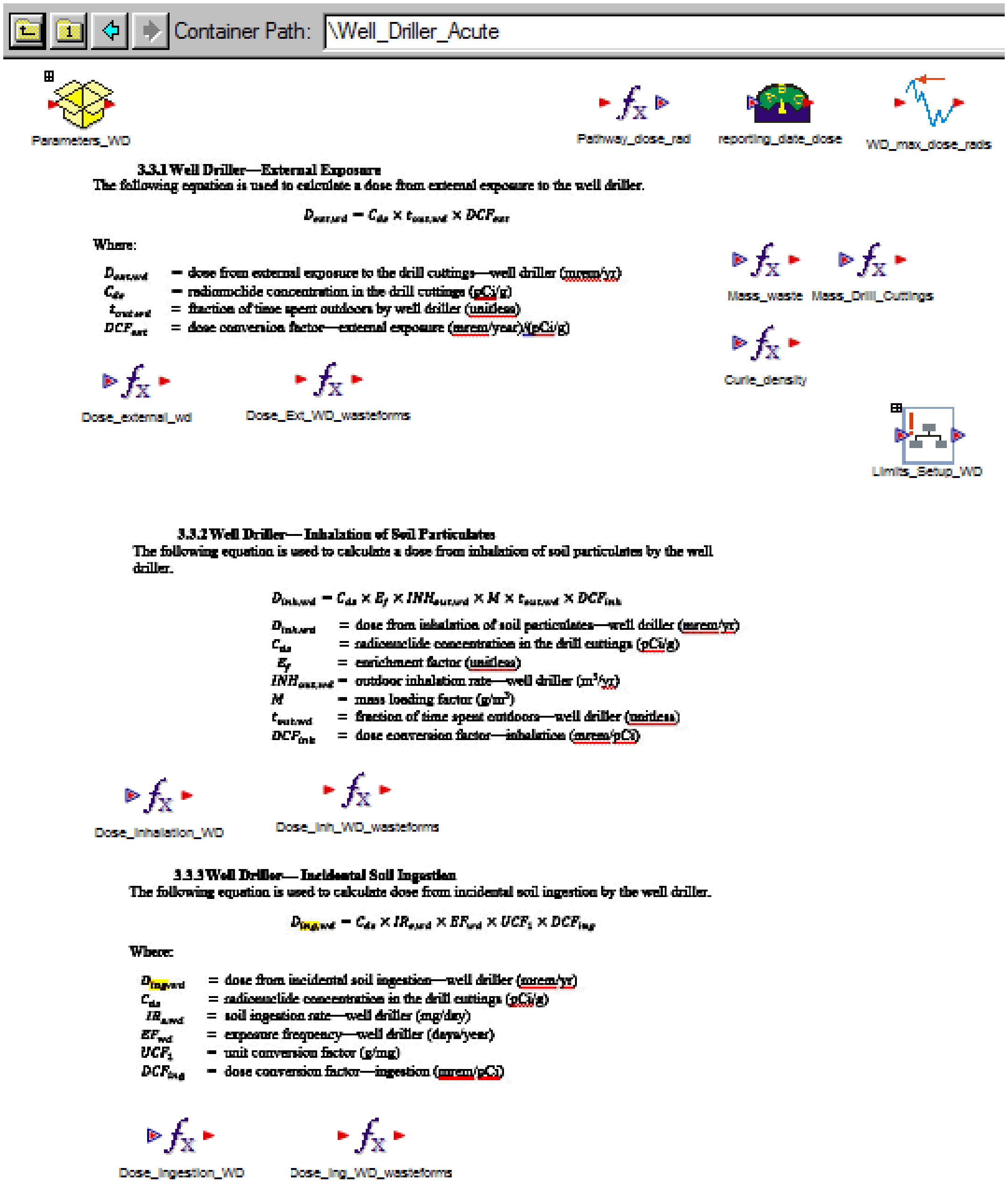
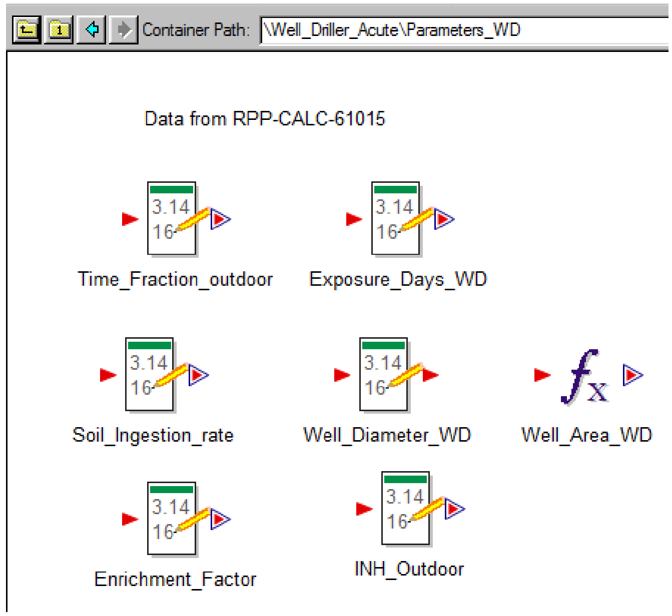


Figure 3-5. Well Driller Pathway Specific Parameters.



3.2.3.1 Concentration in Drill Cuttings. The volume of waste and soil brought to the surface during the installation of the groundwater well is calculated assuming a circular borehole with diameter equal to ***Well_Diameter_WD*** and total depth equal to ***ZGW***, the depth to groundwater. The volume of waste intercepted by this borehole is maximized by assuming that the well completely intercepts waste along the total depth of the waste (***ZWaste***). For ILAW glass waste packages, the length is the height of four ILAW glass waste containers reduced by 10% to neglect the volume that is filled with an inert material, ***xZWaste***. It is also assumed that the drill bit fully penetrates the waste container within the cross-sectional area of waste. No distinction is made by container type for the length of intercepted waste; the value assumed in the model (9.2 meters, including filler volume) is for the ILAW glass waste packages placed above each other in the four lifts. The ILAW glass containers stand taller than a pair of stacked drums or B-25 boxes so that the assumption of a 8.3-meter waste length (9.2-m less 10%) overestimates the amount of waste brought to the surface in the drill cuttings for sources in stacked drums or B-25 boxes. Overestimating the amount of waste brought to the surface will also overestimate the dose to the driller by an equivalent proportion. The mass of each COPC in the waste brought to the surface is equal to the product of the volume of waste brought to the surface and the volume concentration of each COPC in the intercepted waste (Equation 1).

$$M_i = V_{WASTE} C_i = A_{WELL} h_{WASTE} C_i = \pi \left(\frac{D_{WELL}}{2}\right)^2 h_{WASTE} C_i \tag{1}$$

Where:

M_i = mass of each COPC brought to the surface
D_{WELL} = well diameter
V_{WASTE} = volume of waste brought to the surface
h_{WASTE} = height of waste intercepted by bore hole

C_i = concentration of each COPC in the waste brought to the surface
A_{WELL} = area of borehole drilled to groundwater.

By difference, the volume of the non-waste materials (the soil below the IDF, the backfill, and the engineered materials of the surface barrier and liner system) brought to the surface is equal to the volume of the borehole less the volume of waste intercepted by the borehole. The mass of non-waste material brought to the surface is equal to the product of the volume brought to the surface and the density of the material brought to the surface (Equation 2). It is assumed that the density of the non-waste materials are equal.

$$\begin{aligned} M_{CUTTINGS} &= V_{WASTE}\rho_{WASTE} + V_{SOIL}\rho_{SOIL} \\ &= V_{WASTE}\rho_{WASTE} + (V_{WELL} - V_{WASTE})\rho_{SOIL} \\ &= A_{WELL}h_{WASTE}\rho_{WASTE} + (A_{WELL}h_{WELL} - A_{WELL}h_{WASTE})\rho_{SOIL} \\ &= \pi\left(\frac{D_{WELL}}{2}\right)^2 [h_{WASTE}\rho_{WASTE} + (h_{WELL} - h_{WASTE})\rho_{SOIL}] \end{aligned} \tag{2}$$

Where:

$M_{CUTTINGS}$ = total mass of the drill cuttings brought to the surface
ρ_{SOIL} = bulk density of non-waste material (i.e., soil, backfill) brought to the surface
ρ_{WASTE} = density of waste brought to the surface
V_{SOIL} = volume of non-waste material brought to the surface
h_{WELL} = total depth of well
V_{WELL} = volume of borehole drilled to groundwater.

Assuming that the soil and waste are homogenously mixed when the material is brought to the surface, the concentration of each COPC in the drill cuttings is equal to the mass of each COPC in the waste brought to the surface divided by the mass of material brought to the surface. For dose calculations, the concentration can be expressed in curies by multiplying the concentration by the specific activity of each radioactive COPC.

$$C_{ds,i} = \frac{M_i S_{A,i}}{M_{CUTTINGS}} \tag{3}$$

Where:

$C_{ds,i}$ = curie concentration of each radioactive COPC in the material brought to the surface (pCi/g)
$S_{A,i}$ = specific activity of each radioactive COPC brought to the surface

In the GoldSim implementation the following model elements implement the terms in Equations 1, 2, and 3. Intermediate calculations may not be computed directly by the model.

M_i	***Mass_Waste***	A_{WELL}	***Well_Area_WD***
h_{WASTE}	***xZWaste***	D_{WELL}	***Well_Diameter_WD***
C_i	***Decayed_Density***		

ρ_{WASTE}	***Waste_BD***	h_{WELL}	***ZGW*** (groundwater depth)
ρ_{SOIL}	***Soil_Bulk_Density***	$C_{ds,i}$	***curie_density***
$S_{A,i}$	***sa_rads***		

3.2.3.2 Well Driller—External Exposure. The following equation from Appendix R, Section R.2.4 in RPP-ENV-58813 is used to calculate the acute dose from each radionuclide, i, due to external exposure to the well driller. The total acute dose can be computed by summing the dose contributions of the individual radionuclides. NOTE: the total acute dose is in units of mrem for the 40-hour exposure period, but the GoldSim model outputs dose in mrem/yr because the dose conversion factors are specified in those units for the chronic exposure scenarios.

$$D_{ext,wd,i} = C_{ds,i} \times t_{out,wd} \times DCF_{ext,i}$$
$$D_{ext,wd} = \sum D_{ext,wd,i} \tag{4}$$

Where:

$D_{ext,wd,i}$ = radionuclide dose from external exposure to the drill cuttings—well driller (mrem)
$C_{ds,i}$ = radionuclide concentration in the drill cuttings (pCi/g)
$t_{out,wd}$ = fraction of time spent outdoors by well driller (unitless)
$DCF_{ext,i}$ = radionuclide dose conversion factor—external exposure (mrem/year)/(pCi/g)
$D_{ext,wd}$ = total dose from external exposure to the drill cuttings—well driller (mrem).

In the GoldSim implementation the following model elements implement the new terms in Equation 4.

$D_{ext,wd,i}$	***Dose_external_wd***	$DCF_{ext,i}$	***DCF_ExternalExposure***
$t_{out,wd}$	***Time_Fraction_outdoor***	$D_{ext,wd}$	***Dose_Ext_WD_wasteforms***

3.2.3.3 Well Driller—Inhalation of Soil Particulates. The following equation from Appendix R, Section R.2.3 in RPP-ENV-58813 is used to calculate a dose from each radionuclide, i, from inhalation of soil particulates by the well driller. The total dose can be computed by summing the dose contributions of the individual radionuclides.

$$D_{inh,wd,i} = C_{ds,i} \times E_f \times INH_{out,wd,i} \times M \times t_{out,wd} \times DCF_{inh,i}$$
$$D_{inh,wd} = \sum D_{inh,wd,i} \tag{5}$$

Where:

$D_{inh,wd,i}$ = radionuclide dose from inhalation of soil particulates—well driller (mrem)
E_f = enrichment factor (unitless)
$INH_{out,wd}$ = outdoor inhalation rate—well driller (m^3/yr)
M = mass loading factor (g/m^3)

$DCF_{inh,i}$ = radionuclide dose conversion factor—inhalation (mrem/pCi)
$D_{inh,wd,i}$ = total acute dose from inhalation of soil particulates—well driller (mrem).

In the GoldSim implementation the following model elements implement the new terms in Equation 5. $DCF_{inh,i}$ includes an additional factor, ***Air_inhalation_dcf_mult***, to account for the contribution of progeny to the inhalation dose (see Appendix B).

$D_{inh,wd,i}$	***Dose_Inhalation_WD***	$INH_{out,wd}$	***INH_outdoor***
E_f	***Enrichment_Factor***	M	***M***
$DCF_{inh,i}$	***DCF_Inhalation***	$D_{inh,wd}$	***Dose_Inh_WD_wasteforms***

3.2.3.4 Well Driller—Incidental Soil Ingestion. The following equation from Appendix R, Section R.2.2 in RPP-ENV-58813 is used to calculate an acute dose from each radionuclide, i, from incidental soil ingestion by the well driller. The total dose can be computed by summing the dose contributions of the individual radionuclides. Note that unit conversion factors referred to in the source document are applied automatically by GoldSim to keep units consistent with reporting units; therefore, these factors are not required in the GoldSim implementation.

$$D_{ing,wd,i} = C_{ds,i} \times IR_{s,wd} \times EF_{wd} \times DCF_{ing,i}$$
$$D_{ing,wd} = \sum D_{ing,wd,i} \qquad (6)$$

Where:

$D_{ing,wd,i}$ = radionuclide dose from incidental soil ingestion—well driller (mrem/yr)
$IR_{s,wd}$ = soil ingestion rate—well driller (mg/day)
EF_{wd} = exposure frequency—well driller (days/year)
$DCF_{ing,i}$ = radionuclide dose conversion factor—ingestion (mrem/pCi)
$D_{ing,wd}$ = total dose from incidental soil ingestion—well driller (mrem/yr).

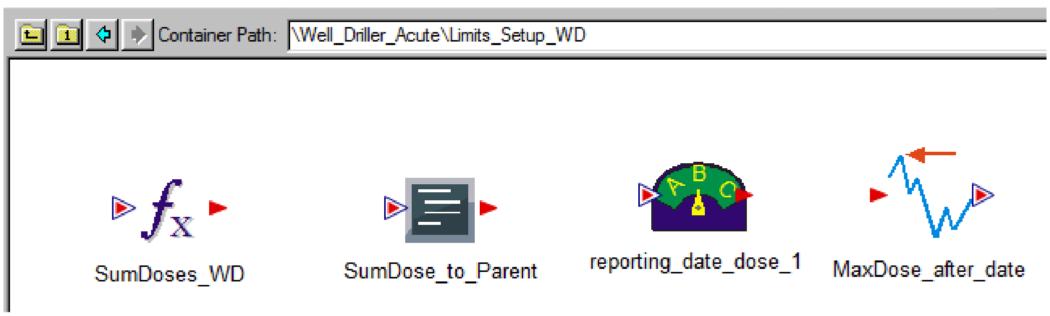
In the GoldSim implementation the following model elements implement the new terms in Equation 6. $DCF_{ing,i}$ includes an additional factor, ***Water_ingestion_dcf_mult***, to account for the contribution of progeny to the ingestion dose (see Appendix B).

$D_{ing,wd,i}$	***Dose_ingestion_WD***	$IR_{s,wd}$	***Soil_ingestion_rate***
EF_{wd}	***Exposure_Days_WD***	$DCF_{ing,i}$	***DCF_Ingestion***
$D_{ing,wd}$	***Dose_Ing_WD_wasteforms***		

The total acute dose to the well driller is the sum of the doses from all radionuclides in the three exposure pathways (***Pathway_Dose_rad*** in Figure 3-4). For an initial inventory decay date in 2021, the dose is calculated from the start of the simulation, which includes 30 years of operational time. The dose output is zeroed out until 2151, which includes a minimum duration of institutional controls (100 years) without any additional credit for intruder protections. Doses for other periods of intruder protections can be calculated using the 2021 inventory and specifying an alternative intruder protection period in ***Start_reporting_year***. Credited intruder protections mitigate the possibly of an intrusion into the facility during this time, so ***reporting_date_dose*** zeroes out the dose prior to a possible intrusion without recognition. ***WD_max_Dose_rads*** is used to record the peak dose from each radionuclide between the dose reporting start date and the end of the simulation.

3.2.3.5 Well Driller—Limits Setup. This container is the same for all exposure scenarios and will only be discussed for the well driller scenario. The total dose for all radionuclides is calculated for each waste stream in ***SumDoses_WD*** (see Figure 3-6). The total dose is the sum of the doses from all radionuclides and all exposure pathways (e.g., external, inhalation, and ingestion). ***SumDoses_WD*** performs the dose summation separately for ILAW glass, ETF-LSW, and SSW. For the other exposure scenarios, there is an equivalent calculation by an element with a name similar to ***SumDoses_WD***, but uses an appropriate suffix for that scenario. The other three elements in Figure 3-6 are used for the limits calculations and are discussed in Section 3.3.

Figure 3-6. GoldSim Summation Element Example.



3.2.4 Rural Pasture Chronic Dose Pathway

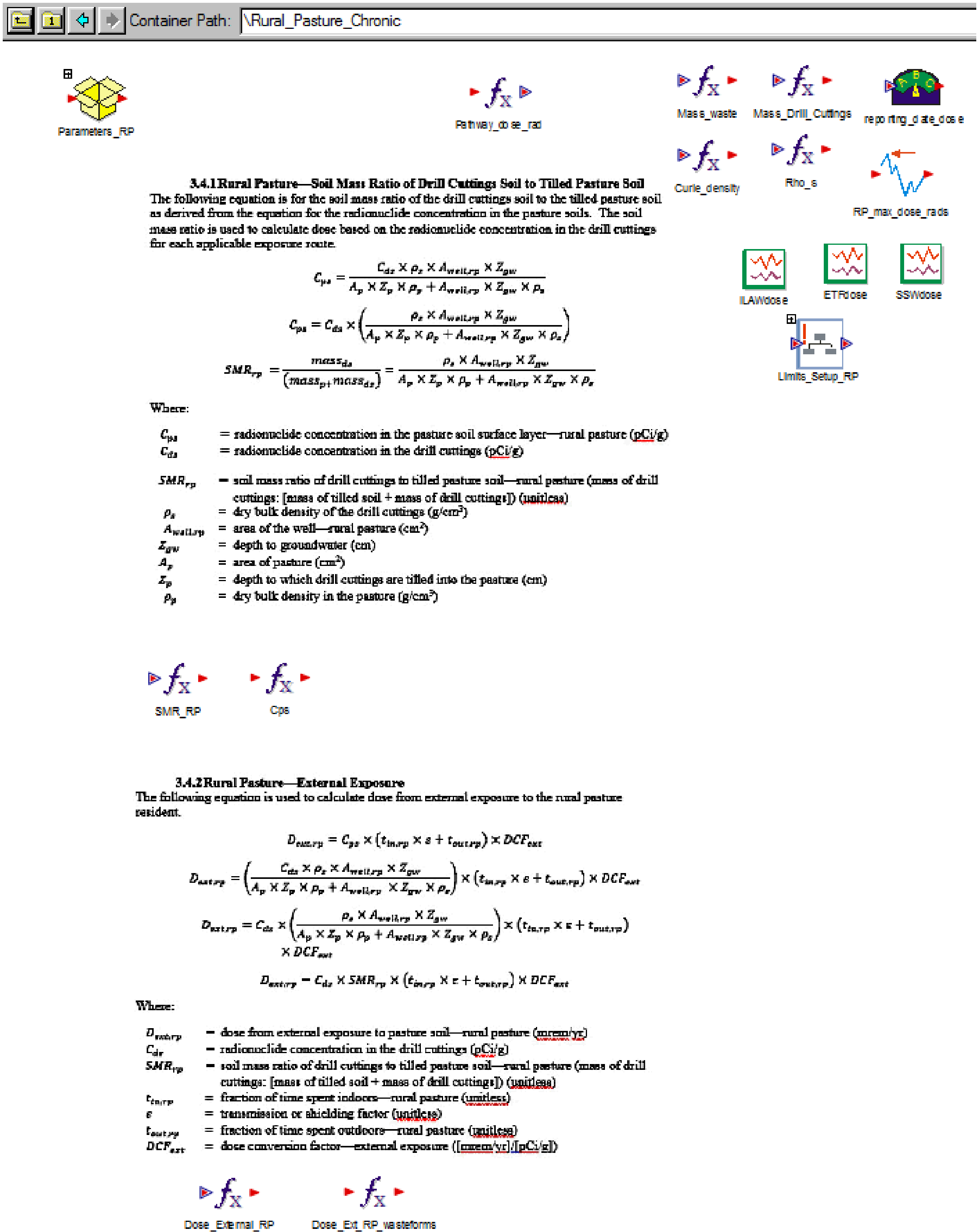
The conceptual model and equations used for the chronic rural pasture resident scenario are described in Appendix R, Sections R.3.1 and R.3.3 of RPP-ENV-58813.

The ***Rural_Pasture_Chronic*** (Figure 3-7) container follows the same format discussed in the preceding section. An additional sub-container, ***Milk_Concentration_RP*** (Figure 3-8), has been added to compute radionuclide concentrations in milk. The rural pasture chronic dose pathway includes external, ingestion, inhalation, and milk ingestion pathways.

Similar to the implementation for the well driller scenario, the calculations for the rural pasture scenario are performed using the ordinal set "Vols" so that many of the elements included in the IIDM evaluate multiple equations simultaneously.

The pathway-specific parameters are contained in ***Parameters_RP*** (Figure 3-9).

Figure 3-7. Rural_Pasture_Chronic Container. (1 of 2 sheets)



3.4.1 Rural Pasture—Soil Mass Ratio of Drill Cuttings Soil to Tilled Pasture Soil

The following equation is for the soil mass ratio of the drill cuttings soil to the tilled pasture soil as derived from the equation for the radionuclide concentration in the pasture soils. The soil mass ratio is used to calculate dose based on the radionuclide concentration in the drill cuttings for each applicable exposure route.

$$C_{ps} = \frac{C_{ds} \times \rho_s \times A_{well,rp} \times Z_{gw}}{A_p \times Z_p \times \rho_p + A_{well,rp} \times Z_{gw} \times \rho_s}$$

$$C_{ps} = C_{ds} \times \left(\frac{\rho_s \times A_{well,rp} \times Z_{gw}}{A_p \times Z_p \times \rho_p + A_{well,rp} \times Z_{gw} \times \rho_s} \right)$$

$$SMR_{rp} = \frac{mass_{ds}}{(mass_{p+}mass_{ds})} = \frac{\rho_s \times A_{well,rp} \times Z_{gw}}{A_p \times Z_p \times \rho_p + A_{well,rp} \times Z_{gw} \times \rho_s}$$

Where:

C_{ps} = radionuclide concentration in the pasture soil surface layer—rural pasture (pCi/g)
C_{ds} = radionuclide concentration in the drill cuttings (pCi/g)

SMR_{rp} = soil mass ratio of drill cuttings to tilled pasture soil—rural pasture (mass of drill cuttings: [mass of tilled soil + mass of drill cuttings]) (unitless)
ρ_s = dry bulk density of the drill cuttings (g/cm^3)
$A_{well,rp}$ = area of the well—rural pasture (cm^2)
Z_{gw} = depth to groundwater (cm)
A_p = area of pasture (cm^2)
Z_p = depth to which drill cuttings are tilled into the pasture (cm)
ρ_p = dry bulk density in the pasture (g/cm^3)

3.4.2 Rural Pasture—External Exposure

The following equation is used to calculate dose from external exposure to the rural pasture resident.

$$D_{ext,rp} = C_{ps} \times (t_{in,rp} \times \varepsilon + t_{out,rp}) \times DCF_{ext}$$

$$D_{ext,rp} = \left(\frac{C_{ds} \times \rho_s \times A_{well,rp} \times Z_{gw}}{A_p \times Z_p \times \rho_p + A_{well,rp} \times Z_{gw} \times \rho_s} \right) \times (t_{in,rp} \times \varepsilon + t_{out,rp}) \times DCF_{ext}$$

$$D_{ext,rp} = C_{ds} \times \left(\frac{\rho_s \times A_{well,rp} \times Z_{gw}}{A_p \times Z_p \times \rho_p + A_{well,rp} \times Z_{gw} \times \rho_s} \right) \times (t_{in,rp} \times \varepsilon + t_{out,rp}) \times DCF_{ext}$$

$$D_{ext,rp} = C_{ds} \times SMR_{rp} \times (t_{in,rp} \times \varepsilon + t_{out,rp}) \times DCF_{ext}$$

Where:

$D_{ext,rp}$ = dose from external exposure to pasture soil—rural pasture (mrem/yr)
C_{ds} = radionuclide concentration in the drill cuttings (pCi/g)
SMR_{rp} = soil mass ratio of drill cuttings to tilled pasture soil—rural pasture (mass of drill cuttings: [mass of tilled soil + mass of drill cuttings]) (unitless)
$t_{in,rp}$ = fraction of time spent indoors—rural pasture (unitless)
ε = transmission or shielding factor (unitless)
$t_{out,rp}$ = fraction of time spent outdoors—rural pasture (unitless)
DCF_{ext} = dose conversion factor—external exposure ([mrem/yr]/[pCi/g])

Figure 3-7. Rural_Pasture_Chronic_1 Container. (2 of 2 sheets)

3.4.3 Rural Pasture—Inhalation of Soil Particulates

The following equation is used to calculate dose from the inhalation of soil particulates by the rural pasture resident.

$$D_{inh,rp} = C_{ps} \times E_f \times M \times \left(INH_{in,rp} \times t_{in,rp} \times \left(\frac{I}{O}\right) + INH_{out,rp} \times t_{out,rp}\right) \times DCF_{inh}$$

$$D_{inh,rp} = \left(\frac{C_{ds} \times \rho_s \times A_{well,rp} \times Z_{gw}}{A_p \times Z_p \times \rho_p + A_{well,rp} \times Z_{gw} \times \rho_s}\right) \times E_f \times M \times \left(INH_{in,rp} \times t_{in,rp} \times \left(\frac{I}{O}\right) + INH_{out,rp} \times t_{out,rp}\right) \times DCF_{inh}$$

$$D_{inh,rp} = C_{ds} \times \left(\frac{\rho_s \times A_{well,rp} \times Z_{gw}}{A_p \times Z_p \times \rho_p + A_{well,rp} \times Z_{gw} \times \rho_s}\right) \times E_f \times M \times \left(INH_{in,rp} \times t_{in,rp} \times \left(\frac{I}{O}\right) + INH_{out,rp} \times t_{out,rp}\right) \times DCF_{inh}$$

$$D_{inh,rp} = C_{ds} \times SMR_{rp} \times E_f \times M \times \left(INH_{in,rp} \times t_{in,rp} \times \left(\frac{I}{O}\right) + INH_{out,rp} \times t_{out,rp}\right) \times DCF_{inh}$$

$D_{inh,rp}$ = dose from inhalation of soil particulates—rural pasture (mrem/yr)
C_{ds} = radionuclide concentration in the drill cuttings (pCi/g)
SMR_{rp} = soil mass ratio of drill cuttings to tilled pasture soil—rural pasture (mass of drill cuttings: [mass of tilled soil + mass of drill cuttings]) (unitless)
E_f = enrichment factor (unitless)
M = mass loading factor (unitless)
$INH_{in,rp}$ = indoor inhalation rate—rural pasture (m^3/yr)
$t_{in,rp}$ = fraction of time spent indoors—rural pasture (unitless)
$\frac{I}{O}$ = ratio of radionuclide concentrations in indoor and outdoor air (unitless)
$INH_{out,rp}$ = outdoor inhalation rate—rural pasture (m^3/yr)
$t_{out,rp}$ = fraction of time spent outdoors—rural pasture (unitless)
DCF_{inh} = dose conversion factor—inhalation (mrem/pCi)

Dose_Inhalation_RP   Dose_Inh_RP_wasteforms

3.4.4 Rural Pasture— Incidental Soil Ingestion

The following equation is used to calculate dose from incidental soil ingestion by the rural pasture resident.

$$D_{ing,rp} = C_{ps} \times IR_{s,rp} \times EF_{rp} \times UCF_1 \times DCF_{ing}$$

$$D_{ing,rp} = \left[\frac{C_{ds} \times \rho_s \times A_{well,rp} \times Z_{gw}}{A_p \times Z_p \times \rho_p + A_{well,rp} \times Z_{gw} \times \rho_s}\right] \times IR_{s,rp} \times EF_{rp} \times UCF_1 \times DCF_{ing}$$

$$D_{ing,rp} = C_{ds} \times \left[\frac{\rho_s \times A_{well,rp} \times Z_{gw}}{A_p \times Z_p \times \rho_p + A_{well,rp} \times Z_{gw} \times \rho_s}\right] \times IR_{s,rp} \times EF_{rp} \times UCF_1 \times DCF_{ing}$$

$$D_{ing,rp} = C_{ds} \times SMR_{rp} \times IR_{s,rp} \times EF_{rp} \times UCF_1 \times DCF_{ing}$$

Where:

$D_{ing,rp}$ = dose from incidental soil ingestion—rural pasture (mrem/yr)
C_{ds} = radionuclide concentration in the drill cuttings (pCi/g)
SMR_{rp} = soil mass ratio of drill cuttings to tilled pasture soil—rural pasture (mass of drill cuttings: [mass of tilled soil + mass of drill cuttings]) (unitless)
$IR_{s,rp}$ = soil ingestion rate (mg/day)
EF_{rp} = exposure frequency—rural pasture (days/yr)
DCF_{ing} = dose conversion factor—ingestion (mrem/pCi)

Dose_Ingestion_RP   Dose_Ing_RP_wasteforms

3.4.6 Rural Pasture— Milk Ingestion

The following equation is used to calculate dose from the ingestion of milk by the rural pasture resident.

$$D_{m,rp} = C_m \times IR_m \times F_a \times DCF_{ing}$$

Milk_Concentration_RP

Where:

$D_{m,rp}$ = dose from milk consumption—rural pasture (mrem/yr)
C_m = radionuclide concentration in milk at any given time (pCi/L)
IR_m = milk ingestion rate—rural pasture (L/yr)
F_a = fraction of locally produced milk consumed (unitless)
DCF_{ing} = dose conversion factor—ingestion (mrem/pCi)

Dose_Milk_RP   Dose_Milk_RP_wasteforms

Figure 3-8. Milk_Concentration_RP Container.

Container Path: \Rural_Pasture_Chronic\Milk_Concentration_RP

3.4.5 Rural Pasture—Radionuclide Concentration in Milk

The following equation calculates the radionuclide concentration in milk and is used to derive a dose for consumption of milk by the rural pasture resident.

Concentration in Fodder

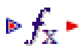
$$C_{fodder} = C_{ps} \times \left(B_p + B_p'\right)$$

$$C_{fodder} = \left(\frac{C_{ds} \times \rho_s \times A_{well,rp} \times Z_{gw}}{A_p \times Z_p \times \rho_p + A_{well,rp} \times Z_{gw} \times \rho_s}\right) \times \left(B_p + B_p'\right)$$

$$C_{fodder} = C_{ds} \times \left(\frac{\rho_s \times A_{well,rp} \times Z_{gw}}{A_p \times Z_p \times \rho_p + A_{well,rp} \times Z_{gw} \times \rho_s}\right) \times \left(B_p + B_p'\right)$$

$$C_{fodder} = C_{ds} \times SMR_{rp} \times \left(B_p + B_p'\right)$$

C_{fodder} = radionuclide concentration in livestock fodder (at any given time)—rural pasture (pCi/g)
C_{ds} = radionuclide concentration in the drill cuttings (pCi/g)
SMR_{rp} = soil mass ratio of drill cuttings to tilled pasture soil—rural pasture (mass of drill cuttings: [mass of tilled soil + mass of drill cuttings]) (unitless)
B_p = pasture-soil bioconcentration factor through uptake ([pCi/kg-dry weight of fodder]/[pCi/kg-dry weight of soil])
B_p' = pasture-soil bioconcentration factor for resuspension effects ([pCi/kg-dry weight of fodder]/[pCi/kg-dry weight of soil])



Concentration in Milk

$$C_m = \left[\left(C_{fodder} \times IR_{fodder,d} \times UCF_2\right) + \left(C_{ps} \times IR_{s,d} \times UCF_2\right)\right] \times BCF_{milk}$$

$$C_m = \left[\left(C_{fodder} \times IR_{fodder,d} \times UCF_2\right) + \left(\left(\frac{C_{ds} \times \rho_s \times A_{well,rp} \times Z_{gw}}{A_p \times Z_p \times \rho_p + A_{well,rp} \times Z_{gw} \times \rho_s}\right) \times IR_{s,d} \times UCF_2\right)\right] \times BCF_{milk}$$

$$C_m = \left[\left(C_{fodder} \times IR_{fodder,d} \times UCF_2\right) + \left(C_{ds} \times \left(\frac{\rho_s \times A_{well,rp} \times Z_{gw}}{A_p \times Z_p \times \rho_p + A_{well,rp} \times Z_{gw} \times \rho_s}\right) \times IR_{s,d} \times UCF_2\right)\right] \times BCF_{milk}$$

$$C_m = \left[\left(C_{fodder} \times IR_{fodder,d} \times UCF_2\right) + \left(C_{ds} \times SMR_{rp} \times IR_{s,d} \times UCF_2\right)\right] \times BCF_{milk}$$

C_m = radionuclide concentration in milk (at any given time)—rural pasture (pCi/L)
C_{fodder} = radionuclide concentration in livestock fodder (at any given time)—rural pasture (pCi/g)
$IR_{fodder,d}$ = ingestion rate of fodder by dairy cattle (kg/day)
UCF_2 = unit conversion factor (g/kg)
C_{ds} = radionuclide concentration in the drill cuttings (pCi/g)
SMR_{rp} = soil mass ratio of drill cuttings to tilled pasture soil—rural pasture (mass of drill cuttings: [mass of tilled soil + mass of drill cuttings]) (unitless)
$IR_{s,d}$ = ingestion rate of soil by dairy cattle (kg/day)
BCF_{milk} = bioconcentration factor of radionuclides in milk (day/L)

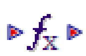
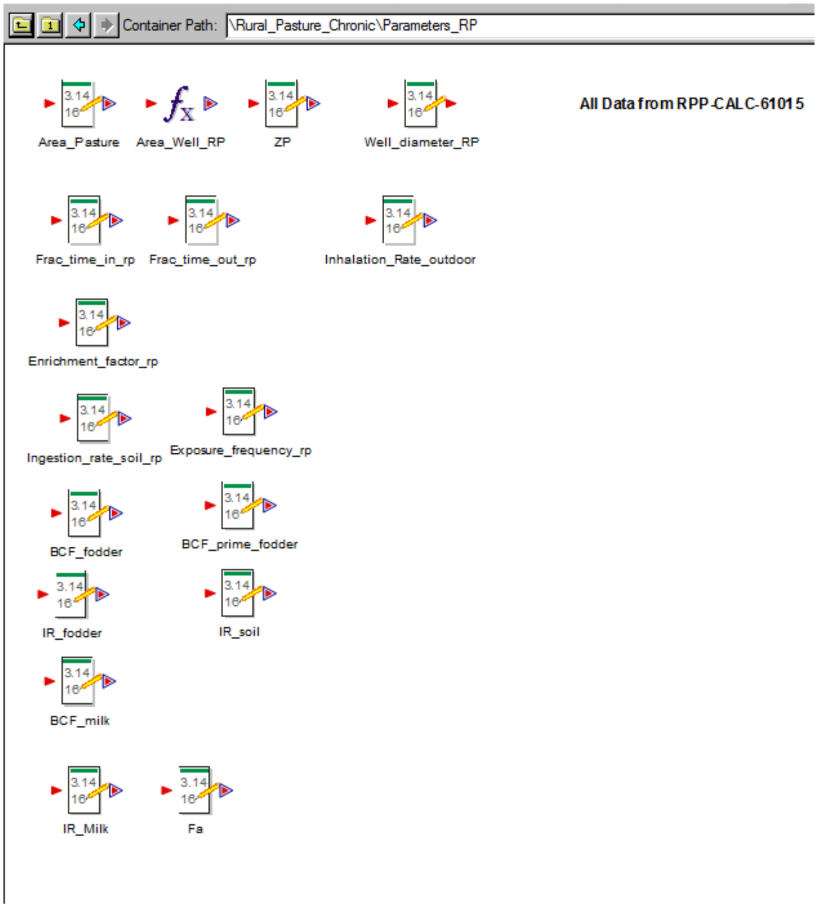


Figure 3-9. Rural Pasture Pathway Specific Parameters.



3.2.4.1 Rural Pasture—Concentration in the Tilled Pasture Soil. The following equation is based on the discussion in Appendix R, Section R.3.3 in RPP-ENV-58813 that is used to calculate the soil mass ratio of the drill cuttings to the tilled pasture soil. The soil mass ratio is used to calculate dose based on the radionuclide concentration in the drill cuttings for each applicable exposure route. The use of a soil mass ratio factor allows for the retention of the radionuclide concentration in the drill cuttings (C_{ds}) as a direct input to the dose calculation equations.

The radionuclide concentration in the scenario-specific soils layer (i.e., C_{ps} for the rural pasture scenario shown below) is derived by a mass ratio (the mass of the intercepted waste brought to the surface divided by the total mass brought to the surface) and is equivalent to the soil mass ratio multiplied by the radionuclide concentration in the drill cuttings. The derivation of the soil mass ratio is shown below. The soil mass ratio is effectively a dilution factor that accounts for the conceptual model that the exhumed waste is homogenously tilled into the fixed volume of the target field.

$$SMR_{rp} = \frac{M_{CUTTINGS}}{M_{PASTURE} + M_{CUTTINGS}} \qquad (7)$$

$$SMR_{rp} = \frac{M_{CUTTINGS}}{A_p \times Z_p \times \rho_p + M_{CUTTINGS}}$$

$$C_{ps,i} = C_{ds,i} \times SMR_{rp} \quad (8)$$

Where:

$C_{ps,i}$ = radionuclide concentration in the pasture soil surface layer—rural pasture (pCi/g)
SMR_{rp} = soil mass ratio of drill cuttings to tilled pasture soil—rural pasture (unitless)
$M_{PASTURE}$ = mass of soil in the pasture impacted by drill cuttings (g)
A_p = area of pasture (cm^2)
Z_p = depth to which drill cuttings are tilled into the pasture (cm)
ρ_p = dry bulk density in the pasture (g/cm^3)
$M_{CUTTINGS}$ is calculated using Equation 2.

In the GoldSim implementation the following model elements implement the new terms in Equations 7 and 8.

SMR_{rp}	***SMR_RP***	ρ_p	***Soil_Bulk_Density***
A_p	***Area_Pasture***	$C_{ps,i}$	***Cps***
Z_p	***Zp***		

3.2.4.2 Rural Pasture—External Exposure. The following equation from Appendix R, Section R.3.3.4 in RPP-ENV-58813 is used to calculate dose from external exposure to the rural pasture resident. The total dose from this pathway is the sum of the radionuclide dose contributions, i.

$$D_{ext,rp,i} = C_{ps,i} \times \left(t_{in,rp} \times \varepsilon_i + t_{out,rp}\right) \times DCF_{ext,i}$$
$$D_{ext,rp} = \sum D_{ext,rp,i} \quad (9)$$

Where:

$D_{ext,rp,i}$ = radionuclide dose from external exposure to pasture soil—rural pasture (mrem/yr)
$t_{in,rp}$ = fraction of time spent indoors—rural pasture (unitless)
ε_i = radionuclide transmission or shielding factor (unitless)
$t_{out,rp}$ = fraction of time spent outdoors—rural pasture (unitless)
$D_{ext,rp}$ = total dose from external exposure to pasture soil—rural pasture (mrem/yr).

In the GoldSim implementation the following model elements implement the new terms in Equation 9.

$D_{ext,rp,i}$	***Dose_External_RP***	$t_{out,rp}$	***Frac_time_out_rp***

$t_{in,rp}$	***Frac_time_in_rp***	$D_{ext,rp}$	***Dose_Ext_RP_Total***
ε_i	***Shielding_Factor***		

3.2.4.3 Rural Pasture—Inhalation of Soil Particulates. The following equation from Appendix R, Section R.3.3.3 in RPP-ENV-58813 is used to calculate dose from the inhalation of soil particulates by the rural pasture resident. The total dose from this exposure pathway is the sum of the dose contributions from the radionuclides, i.

$$D_{inh,rp,i} = C_{ps,i} \times E_f \times M \times \left(INH_{in,rp} \times t_{in,rp} \times \left(\frac{I}{O}\right) + INH_{out,rp} \times t_{out,rp}\right) \times DCF_{inh,i}$$
$$D_{inh,rp} = \sum D_{inh,rp,i} \qquad (10)$$

Where:

$D_{inh,rp,i}$ = radionuclide dose from inhalation of soil particulates—rural pasture (mrem/yr)
$INH_{in,rp}$ = indoor inhalation rate—rural pasture (m^3/yr)
$\frac{I}{O}$ = ratio of radionuclide concentrations in indoor and outdoor air (unitless)
$INH_{out,rp}$ = outdoor inhalation rate—rural pasture (m^3/yr).

In the GoldSim implementation the following model elements implement the new terms in Equation 10. $DCF_{inh,i}$ includes an additional factor, ***Air_inhalation_dcf_mult***, to account for the contribution of progeny to the inhalation dose (see Appendix B).

$D_{inh,rp,i}$	***Dose_Inhalation_RP***	$INH_{out,rp}$	***Inhalation_Rate_outdoor***
$INH_{in,rp}$	***Inhalation_Rate_indoor***	$D_{inh,rp}$	***Dose_Inhalation_RP_Total***
$\frac{I}{O}$	***I_over_O***		

3.2.4.4 Rural Pasture—Incidental Soil Ingestion. The following equation from Appendix R, Section R.3.3.1 in RPP-ENV-58813 is used to calculate dose from incidental soil ingestion by the rural pasture resident. The total dose from this pathway is the sum of the dose contributions from the radionuclides, i.

$$D_{ing,rp,i} = C_{ps,i} \times IR_{s,rp} \times EF_{rp} \times DCF_{ing,i}$$
$$D_{ing,rp} = \sum D_{ing,rp,i} \qquad (11)$$

Where:

$D_{ing,rp,i}$ = radionuclide dose from incidental soil ingestion—rural pasture (mrem/yr)
$IR_{s,rp}$ = soil ingestion rate (mg/day)
EF_{rp} = exposure frequency—rural pasture (days/yr)
$D_{ing,rp}$ = total dose from incidental soil ingestion—rural pasture (mrem/yr).

In the GoldSim implementation the following model elements implement the new terms in Equation 11. $DCF_{ing,i}$ includes an additional factor, ***Water_ingestion_dcf_mult***, to account for the contribution of progeny to the ingestion dose (see Appendix B).

$D_{ing,rp,i}$	***Dose_Ingestion_RP***	EF_{rp}	***Exposure_Frequency_rp***
$IR_{s,rp}$	***Ingestion_rate_soil_rp***	$D_{ing,rp}$	***Dose_Ingestion_RP_Total***

3.2.4.5 Rural Pasture—Radionuclide Concentration in Milk. The following equations from Appendix R, Section R.3.3.2 in RPP-ENV-58813 are used to derive a dose for consumption of milk by the rural pasture resident. Consumption of contaminated water by the dairy cow(s) is not included.

Concentration in Fodder

$$C_{fodder,i} = C_{ps,i} \times \left(B_{p,i} + B'_p\right) \tag{12}$$

Where:

$C_{fodder,i}$ = radionuclide concentration in livestock fodder—rural pasture (pCi/g)
$B_{p,i}$ = radionuclide pasture-soil bioconcentration factor through uptake ([pCi/kg-dry weight of fodder]/[pCi/kg-dry weight of soil])
B'_p = pasture-soil bioconcentration factor for resuspension-soil-soil adhesion effects ([pCi/kg-dry weight of fodder]/[pCi/kg-dry weight of soil]).

Concentration in Milk

$$C_{m,i} = \left[\left(C_{fodder,i} \times IR_{fodder,d}\right) + \left(C_{ps,i} \times IR_{s,d}\right)\right] \times BCF_{milk,i} \tag{13}$$

Where:

$C_{m,i}$ = radionuclide concentration in milk—rural pasture (pCi/L)
$IR_{fodder,d}$ = ingestion rate of fodder by dairy cattle (kg/day)
$IR_{s,d}$ = ingestion rate of soil by dairy cattle (kg/day)
$BCF_{milk,i}$ = radionuclide bioconcentration factor in milk (day/L).

In the GoldSim implementation the following model elements implement the new terms in Equations 12 and 13.

$C_{fodder,i}$	***Cfodder***	$IR_{fodder,d}$	***IR_fodder***
$B_{p,i}$	***BCF_fodder***	$IR_{s,d}$	***IR_soil***
B'_p	***BCF_prime_fodder***	$BCF_{milk,i}$	***BCF_milk***
$C_{m,i}$	***Cmilk***		

3.2.4.6 Rural Pasture—Milk Ingestion. The following equation from Appendix R, Section R.3.3.2 in RPP-ENV-58813 is used to calculate dose to the rural pasture resident from the ingestion of milk from livestock that reside and graze in the contaminated area. The total dose from this pathway is the sum of the dose contributions from the radionuclides, i.

$$D_{m,rp,i} = C_{m,i} \times IR_m \times F_a \times DCF_{ing,i}$$
$$D_{m,rp} = \sum D_{m,rp,i} \tag{14}$$

Where:

$D_{m,rp,i}$ = radionuclide dose from milk consumption—rural pasture (mrem/yr)
IR_m = milk ingestion rate—rural pasture (L/yr)
F_a = fraction of locally produced milk consumed (unitless)
$D_{m,rp}$ = total dose from milk consumption—rural pasture (mrem/yr).

In the GoldSim implementation the following model elements implement the new terms in Equation 14. $DCF_{ing,i}$ includes an additional factor, ***Water_ingestion_dcf_mult***, to account for the contribution of progeny to the ingestion dose (see Appendix B).

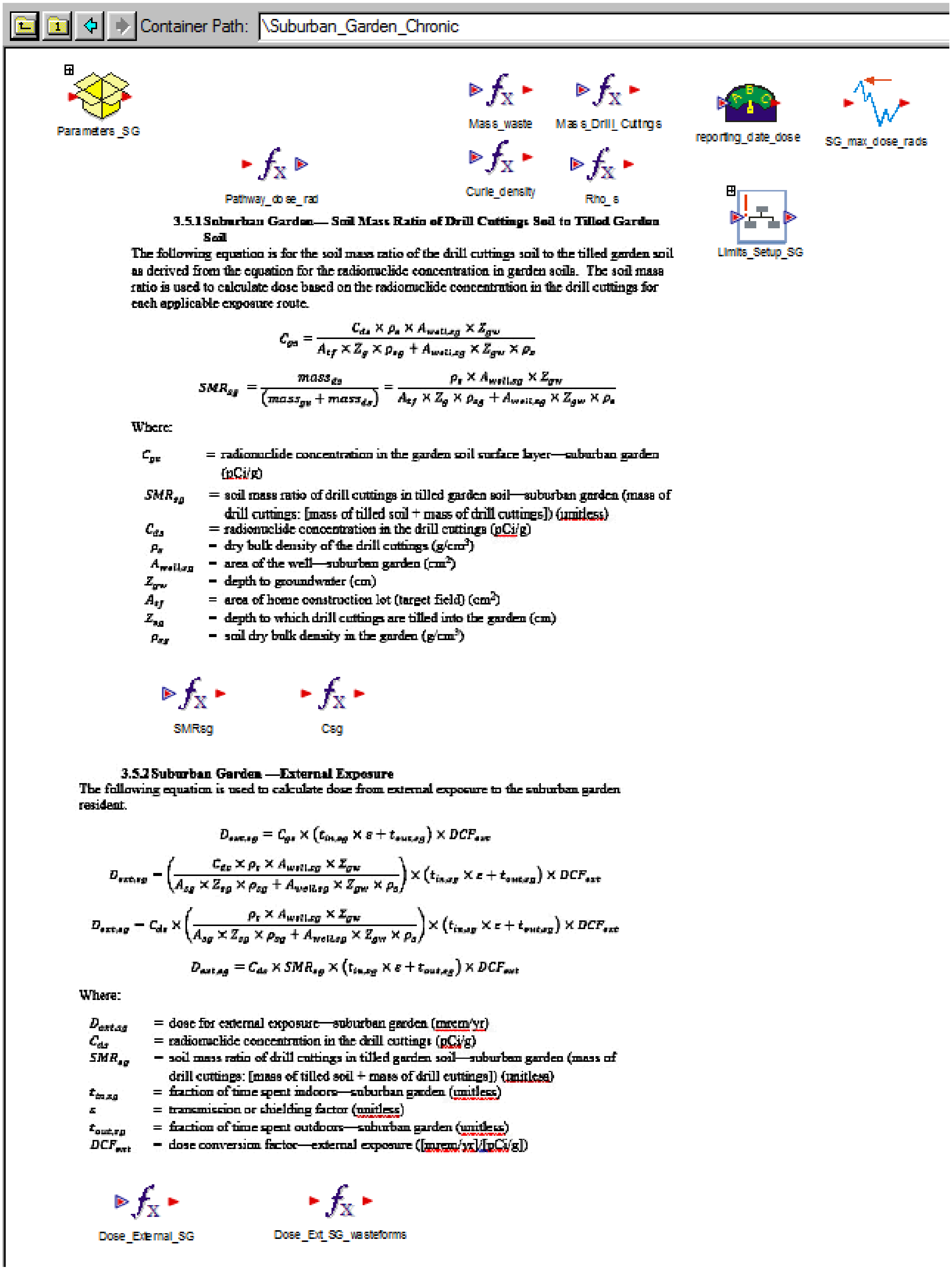
$D_{m,rp,i}$	***Dose_Milk_RP***	F_a	***Fa***
IR_m	***IR_Milk***	$D_{m,rp}$	***Dose_Milk_RP_Total***

3.2.4.7 Rural Pasture—Total Dose from All Pathways. The term of interest for the dose to the resident with a rural pasture impacted by the inadvertent intrusion is the total chronic dose from all pathways (external, ingestion, inhalation, and milk ingestion). The total chronic dose from each radionuclide is the sum of the pathway doses and is determined by model element ***Pathway_dose_rad***, which is analogous to the element with the same name discussed in Section 3.2.3.5 and shown in Figure 3-7. The summation provides the radionuclide doses assuming a single waste source (ILAW glass, ETF-LSW, or SSW) is penetrated by the borehole, but the dose is separately and simultaneously computed for each radionuclide and waste source. Credited intruder protections (e.g., institutional controls) mitigate the possibly of an intrusion into the facility so ***reporting_date_dose*** zeroes out the dose prior to a possible intrusion occurrence without subsequent recognition to mitigate the impact. ***RP_max_dose_rads*** is used to record the peak dose from each radionuclide whenever it occurs after the dose reporting period begins up until the end of the simulated time period. The dose reporting period is determined by model element ***Start_reporting_year***. The value of ***Start_reporting_year*** is entered by the user and must account for any pre-closure period plus any credited time for intruder protections.

3.2.5 Suburban Garden Chronic Dose Pathway

The conceptual model and equations used for the chronic suburban garden resident scenario are described in Appendix R, Sections R.3.1 and R.3.4 of RPP-ENV-58813. The suburban garden chronic dose pathway is shown in Figure 3-10. This pathway includes external, inhalation of soil particles, incidental soil ingestion, and, consumption of homegrown crops.

Figure 3-10. Suburban_Garden_Chronic Container. (1 of 2 sheets)



3.5.1 Suburban Garden— Soil Mass Ratio of Drill Cuttings Soil to Tilled Garden Soil

The following equation is for the soil mass ratio of the drill cuttings soil to the tilled garden soil as derived from the equation for the radionuclide concentration in garden soils. The soil mass ratio is used to calculate dose based on the radionuclide concentration in the drill cuttings for each applicable exposure route.

$$C_{gs} = \frac{C_{ds} \times \rho_s \times A_{well,sg} \times Z_{gw}}{A_{tf} \times Z_g \times \rho_{sg} + A_{well,sg} \times Z_{gw} \times \rho_s}$$

$$SMR_{sg} = \frac{mass_{ds}}{(mass_{gs} + mass_{ds})} = \frac{\rho_s \times A_{well,sg} \times Z_{gw}}{A_{tf} \times Z_g \times \rho_{sg} + A_{well,sg} \times Z_{gw} \times \rho_s}$$

Where:

C_{gs} = radionuclide concentration in the garden soil surface layer—suburban garden (pCi/g)
SMR_{sg} = soil mass ratio of drill cuttings in tilled garden soil—suburban garden (mass of drill cuttings: [mass of tilled soil + mass of drill cuttings]) (unitless)
C_{ds} = radionuclide concentration in the drill cuttings (pCi/g)
ρ_s = dry bulk density of the drill cuttings (g/cm^3)
$A_{well,sg}$ = area of the well—suburban garden (cm^2)
Z_{gw} = depth to groundwater (cm)
A_{tf} = area of home construction lot (target field) (cm^2)
Z_{sg} = depth to which drill cuttings are tilled into the garden (cm)
ρ_{sg} = soil dry bulk density in the garden (g/cm^3)

3.5.2 Suburban Garden —External Exposure

The following equation is used to calculate dose from external exposure to the suburban garden resident.

$$D_{ext,sg} = C_{gs} \times (t_{in,sg} \times \varepsilon + t_{out,sg}) \times DCF_{ext}$$

$$D_{ext,sg} = \left(\frac{C_{ds} \times \rho_s \times A_{well,sg} \times Z_{gw}}{A_{sg} \times Z_{sg} \times \rho_{sg} + A_{well,sg} \times Z_{gw} \times \rho_s}\right) \times (t_{in,sg} \times \varepsilon + t_{out,sg}) \times DCF_{ext}$$

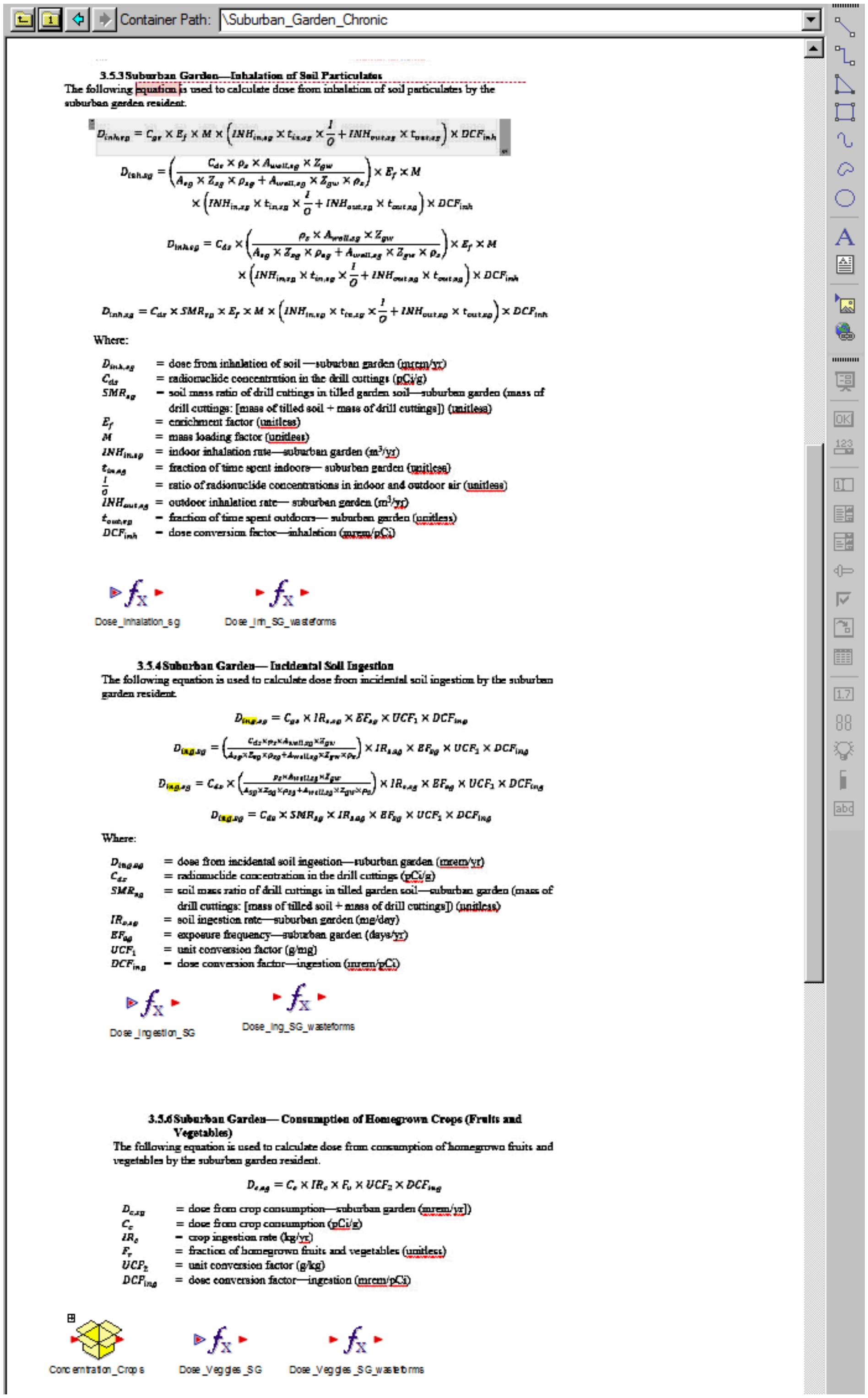
$$D_{ext,sg} = C_{ds} \times \left(\frac{\rho_s \times A_{well,sg} \times Z_{gw}}{A_{sg} \times Z_{sg} \times \rho_{sg} + A_{well,sg} \times Z_{gw} \times \rho_s}\right) \times (t_{in,sg} \times \varepsilon + t_{out,sg}) \times DCF_{ext}$$

$$D_{ext,sg} = C_{ds} \times SMR_{sg} \times (t_{in,sg} \times \varepsilon + t_{out,sg}) \times DCF_{ext}$$

Where:

$D_{ext,sg}$ = dose for external exposure—suburban garden (mrem/yr)
C_{ds} = radionuclide concentration in the drill cuttings (pCi/g)
SMR_{sg} = soil mass ratio of drill cuttings in tilled garden soil—suburban garden (mass of drill cuttings: [mass of tilled soil + mass of drill cuttings]) (unitless)
$t_{in,sg}$ = fraction of time spent indoors—suburban garden (unitless)
ε = transmission or shielding factor (unitless)
$t_{out,sg}$ = fraction of time spent outdoors—suburban garden (unitless)
DCF_{ext} = dose conversion factor—external exposure ([mrem/yr]/[pCi/g])

Figure 3-10. Suburban_Garden_Chronic Container. (2 of 2 sheets)



3.5.3 Suburban Garden—Inhalation of Soil Particulates

The following equation is used to calculate dose from inhalation of soil particulates by the suburban garden resident.

$$D_{inh,sg} = C_{gr} \times E_f \times M \times \left(INH_{in,sg} \times t_{in,sg} \times \frac{I}{O} + INH_{out,sg} \times t_{out,sg}\right) \times DCF_{inh}$$

$$D_{inh,sg} = \left(\frac{C_{ds} \times \rho_s \times A_{well,sg} \times Z_{gw}}{A_{sg} \times Z_{sg} \times \rho_{sg} + A_{well,sg} \times Z_{gw} \times \rho_s}\right) \times E_f \times M \times \left(INH_{in,sg} \times t_{in,sg} \times \frac{I}{O} + INH_{out,sg} \times t_{out,sg}\right) \times DCF_{inh}$$

$$D_{inh,sg} = C_{ds} \times \left(\frac{\rho_s \times A_{well,sg} \times Z_{gw}}{A_{sg} \times Z_{sg} \times \rho_{sg} + A_{well,sg} \times Z_{gw} \times \rho_s}\right) \times E_f \times M \times \left(INH_{in,sg} \times t_{in,sg} \times \frac{I}{O} + INH_{out,sg} \times t_{out,sg}\right) \times DCF_{inh}$$

$$D_{inh,sg} = C_{ds} \times SMR_{sg} \times E_f \times M \times \left(INH_{in,sg} \times t_{in,sg} \times \frac{I}{O} + INH_{out,sg} \times t_{out,sg}\right) \times DCF_{inh}$$

Where:

$D_{inh,sg}$ = dose from inhalation of soil —suburban garden (mrem/yr)
C_{ds} = radionuclide concentration in the drill cuttings (pCi/g)
SMR_{sg} = soil mass ratio of drill cuttings in tilled garden soil—suburban garden (mass of drill cuttings: [mass of tilled soil + mass of drill cuttings]) (unitless)
E_f = enrichment factor (unitless)
M = mass loading factor (unitless)
$INH_{in,sg}$ = indoor inhalation rate—suburban garden (m^3/yr)
$t_{in,sg}$ = fraction of time spent indoors— suburban garden (unitless)
$\frac{I}{O}$ = ratio of radionuclide concentrations in indoor and outdoor air (unitless)
$INH_{out,sg}$ = outdoor inhalation rate— suburban garden (m^3/yr)
$t_{out,sg}$ = fraction of time spent outdoors— suburban garden (unitless)
DCF_{inh} = dose conversion factor—inhalation (mrem/pCi)

3.5.4 Suburban Garden— Incidental Soil Ingestion

The following equation is used to calculate dose from incidental soil ingestion by the suburban garden resident.

$$D_{ing,sg} = C_{gs} \times IR_{s,sg} \times EF_{sg} \times UCF_1 \times DCF_{ing}$$

$$D_{ing,sg} = \left(\frac{C_{ds} \times \rho_s \times A_{well,sg} \times Z_{gw}}{A_{sg} \times Z_{sg} \times \rho_{sg} + A_{well,sg} \times Z_{gw} \times \rho_s}\right) \times IR_{s,sg} \times EF_{sg} \times UCF_1 \times DCF_{ing}$$

$$D_{ing,sg} = C_{ds} \times \left(\frac{\rho_s \times A_{well,sg} \times Z_{gw}}{A_{sg} \times Z_{sg} \times \rho_{sg} + A_{well,sg} \times Z_{gw} \times \rho_s}\right) \times IR_{s,sg} \times EF_{sg} \times UCF_1 \times DCF_{ing}$$

$$D_{ing,sg} = C_{ds} \times SMR_{sg} \times IR_{s,sg} \times EF_{sg} \times UCF_1 \times DCF_{ing}$$

Where:

$D_{ing,sg}$ = dose from incidental soil ingestion—suburban garden (mrem/yr)
C_{ds} = radionuclide concentration in the drill cuttings (pCi/g)
SMR_{sg} = soil mass ratio of drill cuttings in tilled garden soil—suburban garden (mass of drill cuttings: [mass of tilled soil + mass of drill cuttings]) (unitless)
$IR_{s,sg}$ = soil ingestion rate—suburban garden (mg/day)
EF_{sg} = exposure frequency—suburban garden (days/yr)
UCF_1 = unit conversion factor (g/mg)
DCF_{ing} = dose conversion factor—ingestion (mrem/pCi)

3.5.6 Suburban Garden— Consumption of Homegrown Crops (Fruits and Vegetables)

The following equation is used to calculate dose from consumption of homegrown fruits and vegetables by the suburban garden resident.

$$D_{c,sg} = C_c \times IR_c \times F_v \times UCF_2 \times DCF_{ing}$$

$D_{c,sg}$ = dose from crop consumption—suburban garden (mrem/yr])
C_c = dose from crop consumption (pCi/g)
IR_c = crop ingestion rate (kg/yr)
F_v = fraction of homegrown fruits and vegetables (unitless)
UCF_2 = unit conversion factor (g/kg)
DCF_{ing} = dose conversion factor—ingestion (mrem/pCi)

3.2.5.1 Suburban Garden—Soil Mass Ratio of Drill Cuttings Soil to Tilled Garden Soil. The following equations for the soil mass ratio of the drill cuttings to the tilled garden soil and resulting concentration in the tilled surface soil are analogous to the equations used in the rural pasture scenario (see Section 3.2.4.1). The soil mass ratio is used to calculate dose based on the radionuclide concentration in the drill cuttings for each applicable exposure route. The use of a soil mass ratio factor allows for the retention of the radionuclide concentration in the drill cuttings (C_{ds}) as a direct input to the dose calculation equations.

The radionuclide concentration in the scenario-specific soils layer (i.e., C_{sg} for the suburban garden scenario shown below) is equivalent to the soil mass ratio multiplied by the radionuclide concentration in the drill cuttings. The derivation of the soil mass ratio from a mass balance is analogous to the derivation in Section 3.2.4.1 and is shown below.

$$SMR_{sg} = \frac{M_{CUTTINGS}}{M_{GARDEN} + M_{CUTTINGS}}$$

$$SMR_{sg} = \frac{M_{CUTTINGS}}{A_{tf} \times Z_{sg} \times \rho_{sg} + M_{CUTTINGS}} \quad (15)$$

$$C_{sg,i} = C_{ds,i} \times SMR_{sg} \quad (16)$$

Where:

$C_{sg,i}$ = radionuclide concentration in the garden soil surface layer—suburban garden (pCi/g)
SMR_{sg} = soil mass ratio of drill cuttings in tilled garden soil—suburban garden (mass of drill cuttings: [mass of tilled soil + mass of drill cuttings]) (unitless)
M_{GARDEN} = mass of soil in the garden impacted by drill cuttings (g)
A_{tf} = area of suburban garden lot (target field) (cm^2)
Z_{sg} = depth to which drill cuttings are tilled into the garden (cm)
ρ_{sg} = soil dry bulk density in the garden (g/cm^3)
$M_{CUTTINGS}$ is calculated using Equation 2.

In the GoldSim implementation the following model elements implement the terms in Equations 15 and 16.

$C_{sg,i}$	***Csg***	Z_{sg}	***Zg***
SMR_{sg}	***SMRsg***	ρ_{sg}	***Soil_Bulk_Density***
A_{tf}	***Area_Home_lot***		

3.2.5.2 Suburban Garden—External Exposure. The following equation from Appendix R, Section R.3.4.4 in RPP-ENV-58813 is used to calculate dose from external exposure to the suburban garden resident. The total dose from this pathway is the sum of the dose contributions from the radionuclides, i.

$$D_{ext,sg,i} = C_{sg,i} \times \left(t_{in,sg} \times \varepsilon + t_{out,sg}\right) \times DCF_{ext,i} \quad (17)$$

$$D_{ext,sg} = \sum D_{ext,sg,i}$$

Where:

$D_{ext,sg,i}$	=	radionuclide dose for external exposure—suburban garden (mrem/yr)
$t_{in,sg}$	=	fraction of time spent indoors—suburban garden (unitless)
$t_{out,sg}$	=	fraction of time spent outdoors—suburban garden (unitless)
$D_{ext,sg}$	=	total dose for external exposure—suburban garden (mrem/yr).

In the GoldSim implementation the following model elements implement the new terms in Equation 17.

$D_{ext,sg,i}$	***Dose_External_SG***	$t_{out,sg}$	***Frac_time_out_sg***
$t_{in,sg}$	***Frac_time_in_sg***	$D_{ext,sg}$	***Dose_Ext_SG_wasteforms***

3.2.5.3 Suburban Garden—Inhalation of Soil Particulates. The following equation from Appendix R, Section R.3.4.3 in RPP-ENV-58813 is used to calculate dose from inhalation of soil particulates by the suburban garden resident. The total dose from this pathway is the sum of the dose contributions from the radionuclides, i.

$$D_{inh,sg,i} = C_{sg,i} \times E_f \times M \times \left(INH_{in,sg} \times t_{in,sg} \times \frac{I}{O} + INH_{out,sg} \times t_{out,sg} \right) \times DCF_{inh,i} \tag{18}$$

$$D_{inh,sg} = \sum D_{inh,sg,i}$$

Where:

$D_{inh,sg,i}$	=	radionuclide dose from inhalation of soil—suburban garden (mrem/yr)
$INH_{in,sg}$	=	indoor inhalation rate—suburban garden (m^3/yr)
$INH_{out,sg}$	=	outdoor inhalation rate—suburban garden (m^3/yr)
$D_{inh,sg}$	=	total dose from inhalation of soil—suburban garden (mrem/yr).

In the GoldSim implementation the following model elements implement the new terms in Equation 18. $DCF_{inh,i}$ includes an additional factor, ***Air_inhalation_dcf_mult***, to account for the contribution of progeny to the inhalation dose (see Appendix B).

$D_{inh,sg,i}$	***Dose_Inhalation_sg***	$INH_{out,sg}$	***IR_out_sg***
E_f	***Enrichment_Factor_sg***	$D_{inh,sg}$	***Dose_Inh_SG_wasteforms***
$INH_{in,sg}$	***Inhalation_rate_indoor***		

3.2.5.4 Suburban Garden—Incidental Soil Ingestion. The following equation from Appendix R, Section R.3.4.1 in RPP-ENV-58813 is used to calculate dose from incidental soil ingestion by the suburban garden resident. The total dose from this pathway is the sum of the dose contributions from the radionuclides, i.

$$D_{ing,sg,i} = C_{sg,i} \times IR_{s,sg} \times EF_{sg} \times DCF_{ing,i}$$
$$D_{ing,sg} = \sum D_{ing,sg,i} \qquad (19)$$

Where:

$D_{ing,sg,i}$ = radionuclide dose from incidental soil ingestion—suburban garden (mrem/yr)
$IR_{s,sg}$ = soil ingestion rate—suburban garden (mg/day)
EF_{sg} = exposure frequency—suburban garden (days/yr)
$D_{ing,sg}$ = total dose from incidental soil ingestion—suburban garden (mrem/yr).

In the GoldSim implementation the following model elements implement the new terms in Equation 19. $DCF_{ing,i}$ includes an additional factor, ***Water_ingestion_dcf_mult***, to account for the contribution of progeny to the ingestion dose (see Appendix B).

$D_{ing,sg,i}$	***Dose_Ingestion_SG***	$IR_{s,sg}$	***IR_soil_sg***
EF_{sg}	***Exposure_Frequency_sg***	$D_{ing,sg}$	***Dose_Ing_SG_wasteforms***

3.2.5.5 Suburban Garden—Radionuclide Concentration in Crops (Fruits and Vegetables). The following equation from Appendix R, Section R.3.4.2 in RPP-ENV-58813 is used to calculate the radionuclide concentration in crops (fruits and vegetables) and is used to derive dose for the consumption of crops by the suburban garden resident.

$$C_{c,i} = C_{sg,i} \times (B_{v,i} + B_v') \qquad (20)$$

Where:

$C_{c,i}$ = radionuclide concentration in crop (pCi/g)
$B_{v,i}$ = crop-soil bioconcentration factor through uptake ([pCi/kg-fresh weight of crop]/[pCi/kg-dry weight of soil])
B_v' = crop-soil bioconcentration factor representing all resuspension-soil adhesion processes ([pCi/kg-fresh weight of crop]/[pCi/kg-dry weight of soil]).

In the GoldSim implementation the following model elements implement the new terms in Equation 20.

$C_{c,i}$	***Ccrops***	B_v'	***BCF_prime_sg***
$B_{v,i}$	***BCF_sg***		

3.2.5.6 Suburban Garden—Consumption of Homegrown Crops (Fruits and Vegetables). The following equation from Appendix R, Section R.3.4.1 in RPP-ENV-58813 is used to calculate dose from consumption of homegrown fruits and vegetables by the suburban garden resident. The total dose from this pathway is the sum of the dose contributions from the radionuclides, i.

$$D_{c,sg,i} = C_{c,i} \times IR_c \times F_v \times DCF_{ing,i}$$
$$D_{c,sg} = \sum D_{c,sg,i} \tag{21}$$

Where:

$D_{c,sg,i}$ = radionuclide dose from crop consumption—suburban garden (mrem/yr)
IR_c = crop ingestion rate (kg/yr)
F_v = fraction of homegrown fruits and vegetables (unitless)
$D_{c,sg}$ = total dose from crop consumption—suburban garden (mrem/yr).

In the GoldSim implementation the following model elements implement the new terms in Equation 21. $DCF_{ing,i}$ includes an additional factor, ***Water_ingestion_dcf_mult***, to account for the contribution of progeny to the ingestion dose (see Appendix B).

$D_{c,sg,i}$	***Dose_Veggies_SG***	F_v	***Fv***
IR_c	***IR_veggies***	$D_{c,sg}$	***Dose_Veggies_SG_wasteforms***

3.2.5.7 Suburban Garden—Total Dose from All Pathways. The term of interest for the dose to the resident with a suburban garden impacted by the inadvertent intrusion in the IIDM is the total chronic dose from all pathways (external, ingestion, inhalation, and crop ingestion). The total chronic dose from each radionuclide is the sum of the pathway doses and is determined by model element ***Pathway_dose_rad***, which is analogous to the element with the same name discussed in Section 3.2.3.5. The summation provides the radionuclide doses assuming a single waste stream is penetrated by the borehole, but the dose is separately and simultaneously computed for each radionuclide and waste source (ILAW glass, ETF-LSW, and SSW). Credited intruder protections (e.g., institutional controls) mitigate the possibly of an intrusion into the facility so ***reporting_date_dose*** zeroes out the dose prior to a possible intrusion occurrence without subsequent recognition to mitigate the impact. ***SG_max_dose_rads*** is used to record the peak dose from each radionuclide whenever it occurs after the dose reporting period begins up until the end of the simulated time period. The dose reporting period is determined by model element ***Start_reporting_year***. The value of ***Start_reporting_year*** is entered by the user and must account any pre-closure period plus any credited time for intruder protections.

3.2.6 Commercial Farm Chronic Dose Pathway

The conceptual model and equations used for the chronic commercial farm worker scenario are described in Appendix R, Sections R.3.1 and R.3.5 of RPP-ENV-58813.

The commercial farm dose pathway includes external exposure, inhalation of soil particles, and ingestion of soil particles as shown in Figure 3-11.

Figure 3-11. Commercial Farm Container. (1 of 2 sheets)

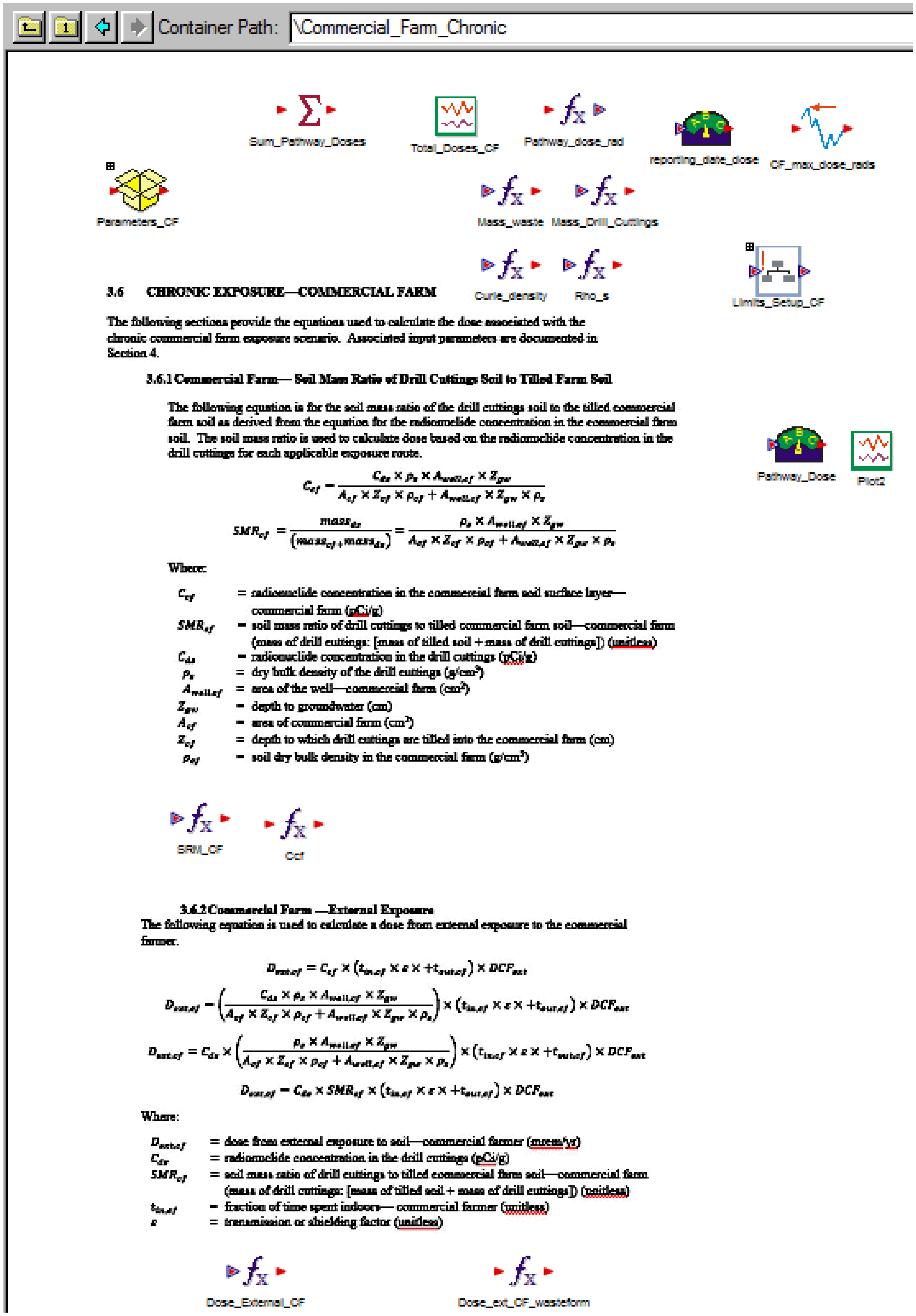
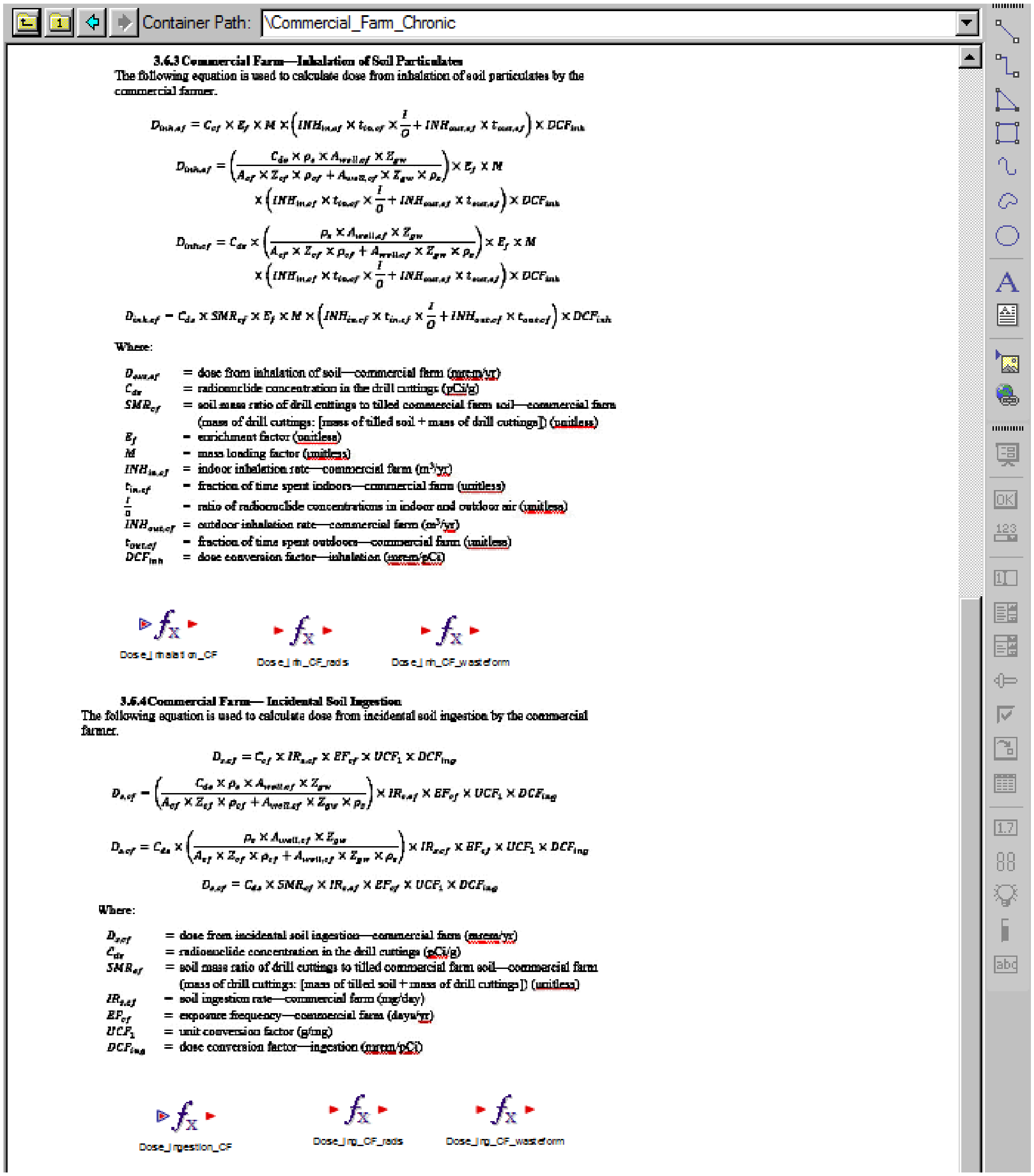


Figure 3-11. Commercial Farm Container. (2 of 2 sheets)



Container Path: \Commercial_Farm_Chronic

3.6.3 Commercial Farm—Inhalation of Soil Particulates

The following equation is used to calculate dose from inhalation of soil particulates by the commercial farmer.

$$D_{inh,cf} = C_{cf} \times E_f \times M \times \left(INH_{in,cf} \times t_{in,cf} \times \frac{I}{O} + INH_{out,cf} \times t_{out,cf} \right) \times DCF_{inh}$$

$$D_{inh,cf} = \left(\frac{C_{dr} \times \rho_s \times A_{well,cf} \times Z_{gw}}{A_{cf} \times Z_{cf} \times \rho_{cf} + A_{well,cf} \times Z_{gw} \times \rho_s} \right) \times E_f \times M \times \left(INH_{in,cf} \times t_{in,cf} \times \frac{I}{O} + INH_{out,cf} \times t_{out,cf} \right) \times DCF_{inh}$$

$$D_{inh,cf} = C_{dr} \times \left(\frac{\rho_s \times A_{well,cf} \times Z_{gw}}{A_{cf} \times Z_{cf} \times \rho_{cf} + A_{well,cf} \times Z_{gw} \times \rho_s} \right) \times E_f \times M \times \left(INH_{in,cf} \times t_{in,cf} \times \frac{I}{O} + INH_{out,cf} \times t_{out,cf} \right) \times DCF_{inh}$$

$$D_{inh,cf} = C_{ds} \times SMR_{cf} \times E_f \times M \times \left(INH_{in,cf} \times t_{in,cf} \times \frac{I}{O} + INH_{out,cf} \times t_{out,cf} \right) \times DCF_{inh}$$

Where:

- $D_{out,cf}$ = dose from inhalation of soil—commercial farm (mrem/yr)
- C_{dr} = radionuclide concentration in the drill cuttings (pCi/g)
- SMR_{cf} = soil mass ratio of drill cuttings to tilled commercial farm soil—commercial farm (mass of drill cuttings: [mass of tilled soil + mass of drill cuttings]) (unitless)
- E_f = enrichment factor (unitless)
- M = mass loading factor (unitless)
- $INH_{in,cf}$ = indoor inhalation rate—commercial farm (m^3/yr)
- $t_{in,cf}$ = fraction of time spent indoors—commercial farm (unitless)
- $\frac{I}{O}$ = ratio of radionuclide concentrations in indoor and outdoor air (unitless)
- $INH_{out,cf}$ = outdoor inhalation rate—commercial farm (m^3/yr)
- $t_{out,cf}$ = fraction of time spent outdoors—commercial farm (unitless)
- DCF_{inh} = dose conversion factor—inhalation (mrem/pCi)

Dose_Inhalation_CF Dose_Inh_CF_rads Dose_Inh_CF_wasteform

3.6.4 Commercial Farm— Incidental Soil Ingestion

The following equation is used to calculate dose from incidental soil ingestion by the commercial farmer.

$$D_{s,cf} = C_{cf} \times IR_{s,cf} \times EF_{cf} \times UCF_1 \times DCF_{ing}$$

$$D_{s,cf} = \left(\frac{C_{ds} \times \rho_s \times A_{well,cf} \times Z_{gw}}{A_{cf} \times Z_{cf} \times \rho_{cf} + A_{well,cf} \times Z_{gw} \times \rho_s} \right) \times IR_{s,cf} \times EF_{cf} \times UCF_1 \times DCF_{ing}$$

$$D_{s,cf} = C_{ds} \times \left(\frac{\rho_s \times A_{well,cf} \times Z_{gw}}{A_{cf} \times Z_{cf} \times \rho_{cf} + A_{well,cf} \times Z_{gw} \times \rho_s} \right) \times IR_{s,cf} \times EF_{cf} \times UCF_1 \times DCF_{ing}$$

$$D_{s,cf} = C_{ds} \times SMR_{cf} \times IR_{s,cf} \times EF_{cf} \times UCF_1 \times DCF_{ing}$$

Where:

- $D_{s,cf}$ = dose from incidental soil ingestion—commercial farm (mrem/yr)
- C_{dr} = radionuclide concentration in the drill cuttings (pCi/g)
- SMR_{cf} = soil mass ratio of drill cuttings to tilled commercial farm soil—commercial farm (mass of drill cuttings: [mass of tilled soil + mass of drill cuttings]) (unitless)
- $IR_{s,cf}$ = soil ingestion rate—commercial farm (mg/day)
- EF_{cf} = exposure frequency—commercial farm (days/yr)
- UCF_1 = unit conversion factor (g/mg)
- DCF_{ing} = dose conversion factor—ingestion (mrem/pCi)

Dose_Ingestion_CF Dose_Ing_CF_rads Dose_Ing_CF_wasteform

3.2.6.1 Commercial Farm—Soil Mass Ratio of Drill Cuttings Soil to Tilled Farm Soil. The following equations for the soil mass ratio of the drill cuttings to the tilled soil and resulting concentration in the tilled surface soil of the commercial farm are analogous to the equations used in the rural pasture scenario (see Section 3.2.4.1). The soil mass ratio is used to calculate dose based on the radionuclide concentration in the drill cuttings for each applicable exposure route. The use of a soil mass ratio factor allows for the retention of the radionuclide concentration in the drill cuttings (C_{ds}) as a direct input to the dose calculation equations.

The radionuclide concentration in the scenario-specific soils layer (i.e., C_{cf} for the commercial farm scenario shown below) is equivalent to the soil mass ratio multiplied by the radionuclide concentration in the drill cuttings.

$$SMR_{cf} = \frac{M_{CUTTINGS}}{M_{COMMERCIAL} + M_{CUTTINGS}}$$

$$SMR_{cf} = \frac{M_{CUTTINGS}}{A_{cf} \times Z_{cf} \times \rho_{cf} + M_{CUTTINGS}} \quad (22)$$

$$C_{cf,i} = C_{ds,i} \times SMR_{cf} \quad (23)$$

Where:

$C_{cf,i}$ = radionuclide concentration in the commercial farm soil surface layer—commercial farm (pCi/g)
SMR_{cf} = soil mass ratio of drill cuttings to tilled commercial farm soil—commercial farm (mass of drill cuttings: [mass of tilled soil + mass of drill cuttings]) (unitless)
$M_{COMMERCIAL}$ = mass of the soils impacted by drill cuttings (g)
A_{cf} = area of commercial farm (cm^2)
Z_{cf} = depth to which drill cuttings are tilled into the commercial farm (cm)
ρ_{cf} = soil dry bulk density in the commercial farm (g/cm^3)
$M_{CUTTINGS}$ is calculated using Equation 2.

In the GoldSim implementation the following model elements implement the new terms in Equations 22 and 23.

$C_{cf,i}$	***Ccf***	Z_{cf}	***Zcf***
SMR_{cf}	***SRM_CF***	ρ_{cf}	***Soil_Bulk_Density***
A_{cf}	***Area_CF***		

3.2.6.2 Commercial Farm—External Exposure. The following equation from Appendix R, Section R.3.5.3 in RPP-ENV-58813 is used to calculate dose from external exposure to the commercial farm worker. The total dose from this pathway is the sum of the dose contributions from the radionuclides, i.

$$D_{ext,cf,i} = C_{cf,i} \times (t_{in,cf} \times \varepsilon \times +t_{out,cf}) \times DCF_{ext}$$
$$D_{ext,cf} = \sum D_{ext,cf,i} \quad (24)$$

Where:

$D_{ext,cf,i}$ = radionuclide dose from external exposure to soil—commercial farm (mrem/yr)
$t_{in,cf}$ = fraction of time spent indoors—commercial farmer (unitless)
$t_{out,cf}$ = fraction of time spent outdoors—commercial farmer (unitless)
$D_{ext,cf}$ = total dose from external exposure to soil—commercial farm (mrem/yr).

In the GoldSim implementation the following model elements implement the new terms in Equation 24.

$D_{ext,cf,i}$	***Dose_External_CF***	$t_{out,cf}$	***Frac_time_out_cf***
$t_{in,cf}$	***Frac_time_in_cf***	$D_{ext,cf}$	***Dose_ext_CF_wasteform***

3.2.6.3 Commercial Farm—Inhalation of Soil Particulates. The following equation from Appendix R, Section R.3.5.2 in RPP-ENV-58813 is used to calculate dose from inhalation of soil particulates by the commercial farm worker. The total dose from this pathway is the sum of the dose contributions from the radionuclides, i.

$$D_{inh,cf,i} = C_{cf,i} \times E_f \times M \times \left(INH_{in,cf} \times t_{in,cf} \times \frac{I}{O} + INH_{out,cf} \times t_{out,cf}\right) \times DCF_{inh,i}$$
$$D_{inh,cf} = \sum D_{inh,cf,i} \quad (25)$$

Where:

$D_{inh,cf,i}$ = radionuclide dose from inhalation of soil—commercial farm (mrem/yr)
$INH_{in,cf}$ = indoor inhalation rate—commercial farm (m^3/yr)
$INH_{out,cf}$ = outdoor inhalation rate—commercial farm (m^3/yr)
$D_{inh,cf}$ = total dose from inhalation of soil—commercial farm (mrem/yr).

In the GoldSim implementation the following model elements implement the new terms in Equation 25. $DCF_{inh,i}$ includes an additional factor, ***Air_inhalation_dcf_mult***, to account for the contribution of progeny to the inhalation dose (see Appendix B).

$D_{inh,cf,i}$	***Dose_Inhalation_CF***	$INH_{out,cf}$	***Inhalation_Rate_out_cf***
$INH_{in,cf}$	***Inhalation_Rate_indoor***	$D_{inh,cf}$	***Dose_inh_CF_wasteform***

3.2.6.4 Commercial Farm—Incidental Soil Ingestion. The following equation from Appendix R, Section R.3.5.1 in RPP-ENV-58813 is used to calculate dose from incidental soil ingestion by the commercial farm worker. The total dose from this pathway is the sum of the dose contributions from the radionuclides, i.

$$D_{s,cf,i} = C_{cf,i} \times IR_{s,cf} \times EF_{cf} \times DCF_{ing,i}$$
$$D_{s,cf} = \sum D_{s,cf,i} \quad (26)$$

Where:

$D_{s,cf,i}$ = radionuclide dose from incidental soil ingestion—commercial farm (mrem/yr)
$IR_{s,cf}$ = soil ingestion rate—commercial farm (mg/day)
EF_{cf} = exposure frequency—commercial farm (days/yr)
$D_{s,cf}$ = total dose from incidental soil ingestion—commercial farm (mrem/yr).

In the GoldSim implementation the following model elements implement the new terms in Equation 26. $DCF_{ing,i}$ includes an additional factor, ***Water_ingestion_dcf_mult***, to account for the contribution of progeny to the ingestion dose (see Appendix B).

$D_{s,cf,i}$	***Dose_Ingestion_CF***	EF_{cf}	***Exposure_Days_CF***
$IR_{s,cf}$	***IR_soil_cf***	$D_{s,cf}$	***Dose_ing_CF_wasteform***

3.2.6.5 Commercial Farmer—Total Dose from All Pathways. The term of interest for the dose to the commercial farm worker impacted by the inadvertent intrusion is the total dose from all pathways (external, ingestion, and inhalation). The total chronic dose from each radionuclide is the sum of the pathway doses and is determined by model element ***Pathway_dose_rad***, which is analogous to the element with the same name discussed in Section 3.2.3.5 and shown in Figure 3-7. The summation provides the radionuclide doses assuming a single waste source (ILAW glass, ETF-LSW, or SSW) is penetrated by the borehole, but the dose is separately and simultaneously computed for each radionuclide and waste source. Credited intruder protections (e.g., institutional controls) mitigate the possibly of an intrusion into the facility, so ***reporting_date_dose*** zeroes out the dose prior to a possible intrusion occurrence without subsequent recognition. ***CF_max_dose_rads*** is used to record the peak dose from each radionuclide whenever it occurs after the dose reporting period begins up until the end of the simulated time period. The dose reporting period is determined by model element ***Start_reporting_year***. The value of ***Start_reporting_year*** is entered by the user and must account any pre-closure period plus any credited time for intruder protections.

3.3 WASTE ACCEPTANCE CRITERIA CONCENTRATION LIMITS

Revision 0 of this calculation report demonstrated that the dose to the inadvertent intruder scales proportionally with inventory for radionuclides that do not have simulated decay chains (e.g., ^{3}H, ^{14}C, ^{90}Sr, ^{99}Tc, ^{129}I, and ^{137}Cs), if the inventory is doubled, the dose to the intruder doubles. Using this inventory-dose relationship, the inventory can be scaled to determine the inventory that results in a specific dose result. If the targeted dose result is equated to a performance metric, the calculation returns the inventory that results in a dose to the intruder that equals the performance metric. This relationship is illustrated in Equation 27.

$$I_{LIMIT} = \frac{D_{LIMIT}}{\sum_{j=1}^{n} Dose_j} * I \tag{27}$$

Where:

I_{LIMIT} = disposal limit (Ci) (per radionuclide)
D_{LIMIT}t = performance measure (500 mrem acute, 100 mrem/year chronic)
$Dose_j$ = peak of the combined dose from each j^{th} pathway in a dose scenario (for *n* pathways)
I = radionuclide inventory at time of waste receipt (Ci).

The calculation uses the waste stream concentration at the time of first receipt (assumed to be 2021) and calculates the dose from a simulated intrusion from that inventory. The dose from the simulated intrusion is the peak dose from the initial inventory of each radionuclide plus the dose from the progeny of the initially present inventory (see Section 3.2.2.4). The peak dose can occur anytime between the time of intrusion and the DOE time of compliance (1,000 years after closure). The time of intrusion includes any pre-closure time (i.e., the duration between the initial inventory decay date and the IDF closure date) and the duration of credited intruder protections after the IDF closure date. For many radionuclides, the peak dose occurs at the earliest time of the intrusion, but for others, decay products may result in a radionuclide-specific total dose that is greater than the dose that would be received at the time of the intrusion. This potential is accounted for in the calculated limits. The ratio of the scenario performance measure to the calculated peak dose is used to scale the waste concentration to a concentration that would yield a dose equal to the performance measure.

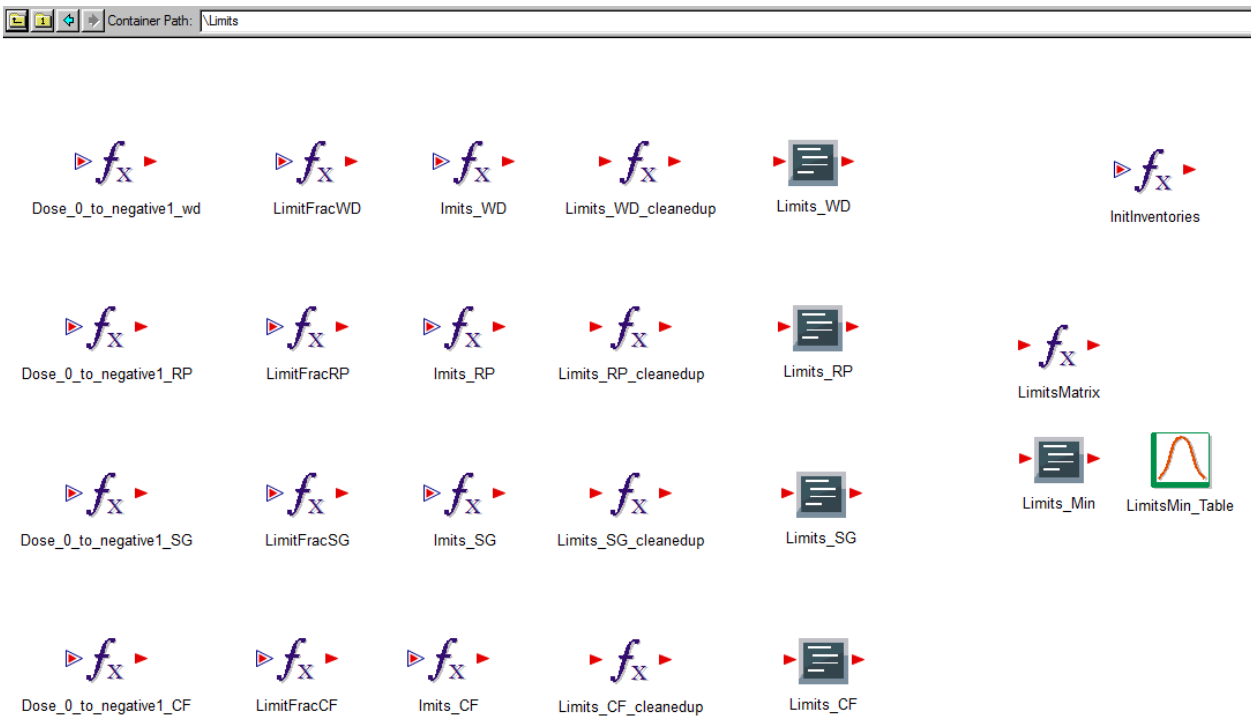
Because the volumes of the different waste streams are fixed within the model, the inventories are converted to concentrations by dividing each side in Equation 27 by the volume of the applicable waste source (ILAW glass, ETF-LSW, or SSW).

The concentration limit calculation is embedded into the GoldSim model (see Figure 3-12) and is performed only once at the end of the simulation. Model elements with names similar to ***Dose_0_to_negative1_xx***[3] are error traps that convert zero dose values to a negative one dose value so that a divide-by-zero error can be avoided. Each exposure scenario is represented by a function element defined as a vector by species. Model element ***LimitFracXX*** calculates the fraction of the disposal limit for each radionuclide. For each radionuclide, ***lmits_XX*** calculates the disposal concentration (Ci/m^3) that yields a dose equal to the dose target. ***Limits_XX_cleanedup*** performs some additional formatting of the calculated results to zero out limits for radionuclides with very low dose values. These calculations are simultaneously

[3] Note in this discussion "xx" and "XX" are used in the names of model elements that perform analogous calculations for different exposure scenarios. These elements are located within the submodel for each exposure scenario and are distinguished from one another in the model by a suffix that identifies the exposure scenario (e.g., XX is a surrogate for WD in the well driller scenario and RP in the rural pasture scenario).

performed for each waste source; ***Limits_WD*** picks the lowest concentration that results in the targeted dose result from the three different waste streams (which only vary slightly because of the different waste stream densities). Model element ***limitsmatrix*** gathers the results for the dose limiting concentrations for the four different exposure scenarios into a matrix and ***Limits_Min*** finds the smallest positive non-zero value in each row (radionuclide) of the matrix. Model element ***LimitsMin_Table*** displays the limits determined by ***Limits_Min***.

Figure 3-12. Implementation of Disposal Limits Calculation.



Several conditions must be met in order to run the limits calculation. In the black box on the right side of Figure 3-13 the data element ***SingleNukeFlag*** must be set to "1". This invokes special logic so that only a single parent at a time is run. In addition, as seen in Figure 3-14, a probabilistic simulation must be selected with the number of realization being set to "43". The logic runs each realization for a single radionuclide, incrementing through the species list.

Figure 3-13. Limits Calculation Flag.

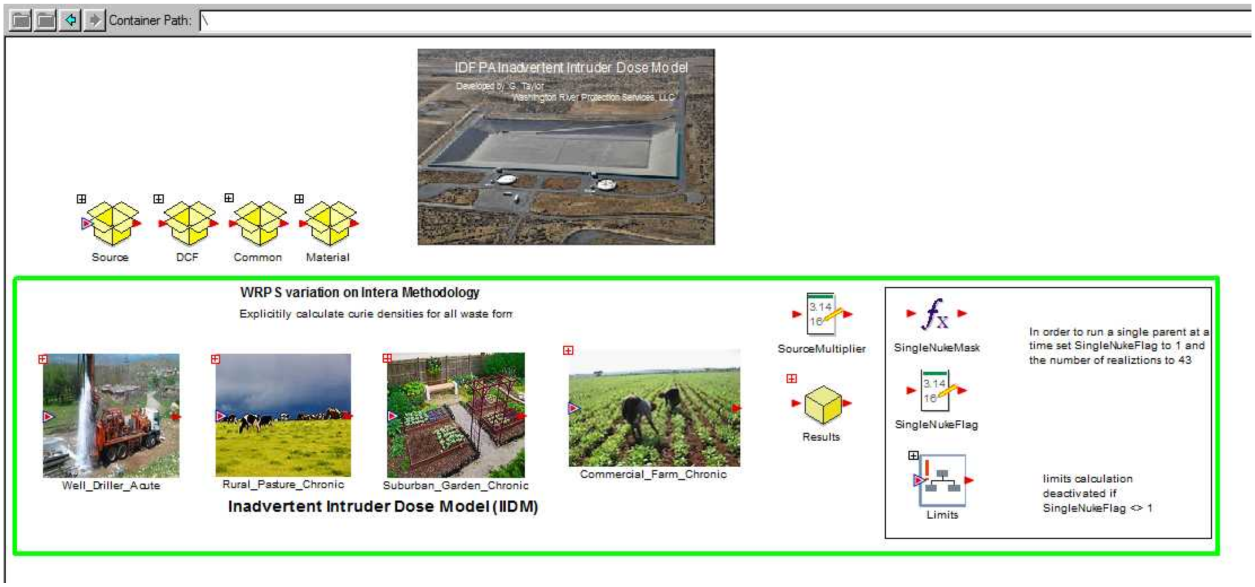
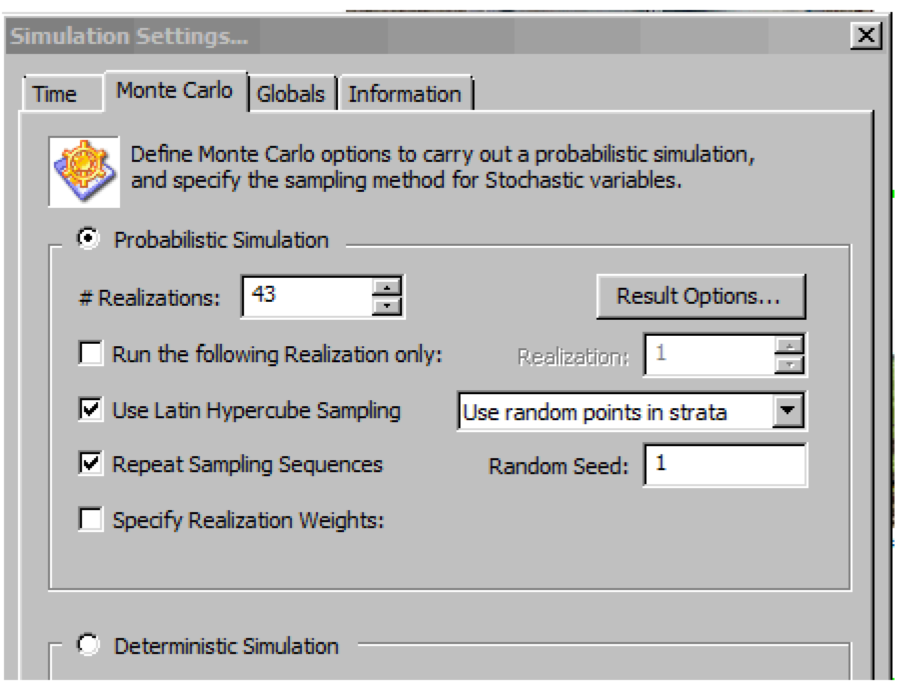


Figure 3-14. Limits Calculation Run.



The actual disposal limits are calculated in ***Limits*** (Figure 3-13). Limits for each radionuclide are calculated for each exposure scenario. Each row of Figure 3-15 represents an exposure scenario.

Dose_0_to_negative1_XX sets any zero dose to "-1" so a divide-by-zero does not occur:

```
if(Well_Driller_Acute.MaxDose_after_date <= matrix(1.0e-20
mREM/yr),matrix( -1
mREM/yr),Well_Driller_Acute.MaxDose_after_date)
```

LimitFracXX computes the fraction of dose limit on a specific volume basis:

```
(matrix(Dose_Limit_Acute)/Dose_0_to_negative1
_wd)/Disposed_Volumes
```

lmits_XX calculates the limit for each radionuclide assuming a linear relationship between dose and inventory (Equation 27). It is multiplied by species specific activity to convert the limits to an activity basis (Ci/m^3) rather than a mass basis (g/m^3):

```
LimitFracWD * InitInventories * Species.Specific_Activity
```

Limits_XX_cleanup turns the negative numbers back to "0" to improve aesthetics:

```
if(lmits_WD <=matrix(1e-20 Ci/m3),matrix( 0 Ci/m3), lmits_WD)
```

The above four GoldSim variables create a matrix of radionuclide-by-waste stream.

Limits_XX picks the minimum, positive, non-zero value for each row creating a vector by radionuclides for each exposure pathway:

Script

	Statement List
1	Define: tmp = 1e25 Ci/m3
2	DO irow = 1, 43, 1
3	DO icol = 1, 3, 1
4	IF (Limits_WD_cleanedup[~irow,~icol] > 0 Ci/m3) THEN
5	IF (Limits_WD_cleanedup[~irow, ~icol] < ~tmp) THEN
6	tmp = Limits_WD_cleanedup[~irow, ~icol]
7	END IF
8	Result[~irow] = ~tmp
9	END IF
10	END DO
11	END DO

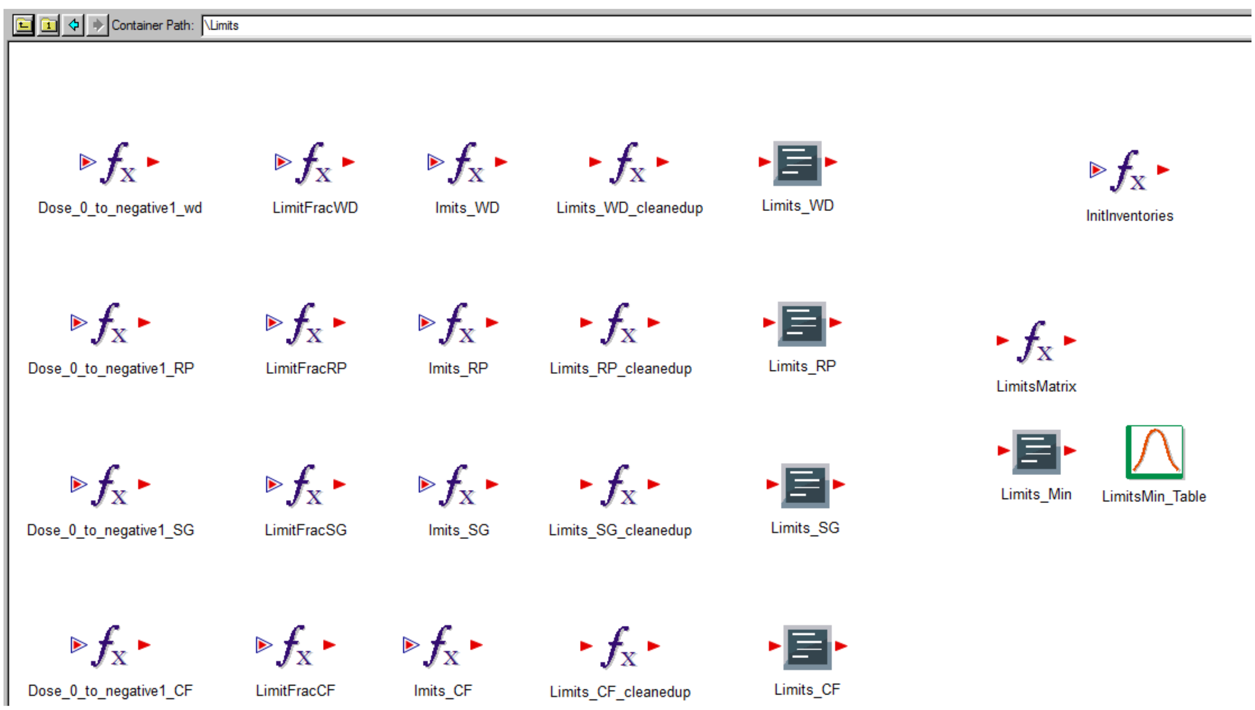
LimitsMatrix gathers the four vectors from the above step and puts them in matrix form:

```
matrix(Limits_WD,Limits_RP, Limits_SG, Limits_CF)
```

Finally, ***Limits_Min*** selects the lowest non-zero limit:

```
Define: tmp = 1e25 Ci/m3
DO irow = 1, 43, 1
  DO icol = 1, 4, 1
    IF (LimitsMatrix[~irow, ~icol] > 0 Ci/m3) THEN
      IF (LimitsMatrix[~irow, ~icol] < ~tmp) THEN
        tmp = LimitsMatrix[~irow,~icol]
      END IF
      Result[~irow] = ~tmp
    END IF
  END DO
END DO
```

Figure 3-15. Limits Calculation.



[THIS PAGE INTENTIONALLY LEFT BLANK]

4.0 ASSUMPTIONS AND INPUTS

4.1 INTEGRATED DISPOSAL FACILITY RADIONUCLIDE INVENTORIES

The basis for the radionuclide inventory used to evaluate dose to an inadvertent intruder is RPP-ENV-58562, *Inventory Data Package for the Integrated Disposal Facility Performance Assessment*, Revision 3. The inventory used is allocated to different waste streams and decayed to a common decay date in RPP-CALC-62058.

For the purposes of establishing waste acceptance criteria on waste source concentration limits, it is assumed that the intrusion fully penetrates four lifts of similar waste stacked above one another. This assumption allows for the maximum dose consequence from individual waste sources (i.e., ILAW glass, ETF-LSW, or SSW) to be evaluated and can be used to set concentration limits for the waste sources. This assumption is consistent with all pathways dose modeling that treated SSWs as being comingled in the facility so that the intrusion intercepts SSW with average concentrations rather than waste stream-specific concentrations. There is no expectation that only like waste sources will be disposed of above similar wastes in lower lifts as the facility is filled.

For other disposal configurations, a dose could be approximated as the sum of the doses from individual package types. The dose from a single ILAW glass waste container is one-fourth the dose from the ILAW glass source, and the dose from a single ETF-LSW waste container or a single SSW waste container is one-eighth the dose of the ETF-LSW source dose or SSW source dose, respectively. These dose alternatives for different waste package interceptions can be applied to the acute and chronic exposure scenarios. With the most predominant disposal volume being the ILAW glass, it is most probable that a hypothetical intrusion would occur into four ILAW glass waste containers.

4.2 OTHER DATA

Other data and assumptions used in the IIDM can be found in RPP-CALC-61015 and the sources mentioned in Section 3.0 and will not be reproduced in this document. When necessary, any parameter deviations from those included in RPP-CALC-61015 are identified in the model file where the parameters are defined. An example of this is shown in Figure 4-1 where applicable values from a recently reported data package are used to replace default place holder values in the source calculation.

The source of the dose conversion factors is RPP-ENV-58813 Rev 1. The dose conversion factors for the external pathways listed in RPP-ENV-58813 Table N-2 incorporate the dose from short-lived progeny in the decay chains. The dose coefficients for air inhalation and water ingestion in RPP-ENV-58813 Rev 1 Table N-1 include the dose of all progeny produced in the body after consumption. It is ambiguous as to whether or not short-lived progeny in equilibrium at the time of consumption are included in those DCFs. Treatment at different sites has made different determinations on this point. The pessimistic approach adopted in this calculation is to assume that the effects of progeny present at the time of exposure are not included in the DCF and to perform a calculation to determine a dose multiplier that accounts for the short-lived progeny at the time of consumption (see Appendix B). In the event that this assumption is incorrect, the derived doses using these dose multipliers will overestimate the calculated dose due to a future intrusion. In addition, derived disposal limits calculated using those calculated doses will be underestimated, resulting in waste concentration limits that are more restrictive than necessary to meet specific performance metrics.

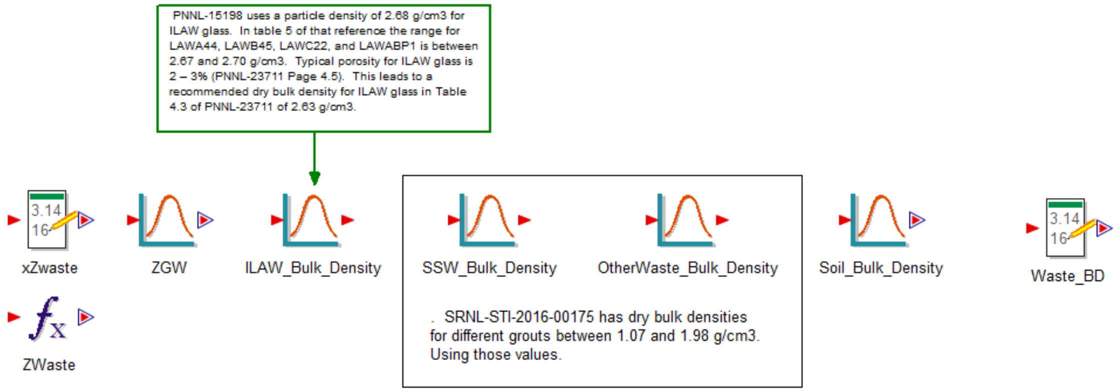
4.3 ASSUMPTIONS

To be consistent with site-specific guidance for developing consistency for all performance assessments conducted for the Hanford Site, institutional controls are assumed to provide intruder protections until calendar year 2278 (Hamel et al. 2019). DOE maintains its policy that controls over site activities will be maintained as long as necessary. Therefore, although placement of waste into "300-year high integrity containers" or crediting the robustness of the vitrified waste form and/or stainless steel waste containers could be pursued, DOE has directed its contractors to assume institutional controls will be maintained at the Hanford Site until 2278. After the period of intruder protections, it is assumed that a well driller does not initiate investigative activities after encountering non-native materials from the surface barrier, liner system, or solidified waste forms. However, because of the flexibility of using a dynamic simulator, doses can be calculated and reported after any intruder protection period. For the purposes of this report, dose results are reported assuming a minimum of 100 years of institutional controls. Additionally, disposal limits are calculated for multiple durations of intruder protections, the longest extending out until calendar year 2278.

It is also assumed that the only inventory depletion mechanism before and after the intrusion is radionuclide decay. The loss of ^{3}H, ^{14}C, and other radionuclides that could escape to the atmosphere prior to the intrusion is neglected. This assumption is contrary to modeling performed for the atmospheric pathway, which allows ^{3}H release from waste containers that are not expected to be air tight. This assumption is a pessimistic assumption that results in an evaluation that simulates a greater dose impact to a member of the public following an inadvertent intrusion into the waste and leads to lower disposal concentration limits.

Ultimately the dose in the evaluated scenarios is dependent on the amount of activity brought to the surface. Waste acceptance criteria concentration limits based on the dose measure are dependent on the time of the intrusion, and only slightly affected by the waste stream types because of the different densities of the waste materials.

Figure 4-1. Example of Updated Input Parameter Identifcation in the GoldSim Model File.



GoldSim© is copyrighted by the GoldSim Technology Group, Issaquah, Washington.

[THIS PAGE INTENTIONALLY LEFT BLANK]

5.0 SOFTWARE APPLICATIONS

All calculations in this EMCF revision and in previous revisions of this environmental calculation were performed using GoldSim Pro Version 11.1.5.

GoldSim Pro Version 11.1.5 use at the Hanford Site is managed and controlled such that the computational needs filled by use of GoldSim Pro (and any associated utility codes) and the specific roles and responsibilities for management and the modeling staff and subcontractors have been identified and traced.

GoldSim Pro Version 11.1.5 was registered in the Hanford Information Systems Inventory (HISI) under identification number 2461. At the time of this EMCF revision, the latest version of GoldSim registered in HISI was version 12. There was no deficiency reported on version 11.1.5, so it was used for the latest revision to this EMCF. The simulation software is qualified for use and controlled by CH2M Hill Plateau Remediation Company (CHPRC). The HISI registration information lists the documents associated with software grading (it is graded as Level C Safety Software), minimum system requirements, software functional requirements, software management, software testing, and software installation plans. The HISI database also contains information on approved installations and user training. The software was installed and used on computers using the Microsoft® Windows®[4] operating system. The computers have property numbers WF34039 and WF40244. The software installation and checkout forms for GoldSim Pro are provided in Attachment 1 to this EMCF.

Software development of GoldSim Pro meets AMSE NQA-1-2008, *Quality Assurance Requirements for Nuclear Facility Applications* with NQA-1a-2009 Addenda software requirements, as well as the requirements specified under DOE O 414.1D, *Quaility Assurance* for Safety Software. The applicable software quality assurance documents are:

- CHPRC-00180, *GoldSim® Pro Functional Requirements Document*
- CHPRC-00175, *GoldSim® Pro Software Management Plan*
- CHPRC-00256, *GoldSim® Pro Functional Requirements Traceability Matrix Version 11.1.5*
- CHPRC-00224, *GoldSim® Pro Software Test Plan*
- CHPRC-00262, *GoldSim® Pro Acceptance Test Report Version 11.1.5*.

Attachment 1 also documents the selection of technical staff for this EMCF. Responsibilities for management and the modeling staff include the following:

- modeler training,
- source code installation and testing,
- preserving the software and verification test results,
- validation and verification that the GoldSim Pro quality assurance documentation demonstrate that GoldSim Pro meets identified modeling needs and purposes,

[4] Microsoft® and Windows® are registered trademarks of Microsoft Corporation in the U.S. and other countries.

- reporting and documenting any software errors (none were encountered during the development of the IDF PA),
- management of the GoldSim Pro input files, and
- contingency and disaster recovery (which was not encountered during the development of the IDF PA).

GoldSim Pro is a valid software application and was applied in this report within its range of intended uses for which it was tested and approved. GoldSim Pro was utilized for DOE to assist in performing simulation of radioactive mass conservation including decay and ingrowth and to perform human health dose and risk assessment for the Hanford Site.

Acceptance and installation tests of the GoldSim Pro simulation software demonstrate that it is appropriate for its intended uses for the IDF PA and that it has been successfully installed on the computing systems used to conduct IDF PA modeling.

Comparison to runs performed using the basis document performed with spreadsheet software were performed prior to finalizing the model to ensure the GoldSim implementation provided equivalent results. Comparison results are included in Appendix A to this EMCF.

6.0 CALCULATION, RESULTS, AND CONCLUSIONS

This section presents the results of the IIDM. The results presented below are deterministic (Section 6.1) and probabilistic (Section 6.3) results. Deterministic results assume the most expected inventory (Case 07 from RPP-ENV-58562 Rev 03) and recommended parameter values for each waste stream (ILAW glass, SSW, or ETF-LSW). The doses presented are not additive across waste streams because the calculations assume that the intrusion penetrates the facility and intercepts four lifts containing only one waste type (ILAW glass, ETF-LSW, or SSW).

6.1 DOSE RESULTS – INADVERTENT INTRUDER DOSE MODEL

The radionuclide inventory from the GoldSim model at calendar year 2021 is output from the model from ***StreamInventories***. The mass is converted to a concentration, in kg/m^3, by dividing by the volume of each waste stream. The volumes are calculated in the model by applying applicable volume multipliers to the as-generated waste volume (see Section 3.2.2.3). The volumes range from 11,435 m^3 for SSW to 278,797 m^3 for ILAW glass.

Table 6-1, Table 6-2, Table 6-3, and Table 6-4 show a summary of the calculated doses following an inadvertent intrusion into the IDF after 30 years of disposal operations and at least 100 years of intruder protections.

Table 6-1 provides the calculated total pathway doses for each exposure scenario following an intrusion into four lifts of each source (ILAW glass, ETF-LSW, or SSW) with the Case 07 inventory. The total dose results are doses after an assumed duration of intruder protections (100 years assuming closure in 2051, 100 years assuming closure in 2064, 150 years assuming closure in 2051, and 227 years assuming closure in 2051 to align with DOE guidance for a sitewide institutional control date). Using the projected inventories developed for the PA, the doses are below DOE performance measures after assuming 100 years of intruder protections.

Table 6-2 provides a more detailed breakdown of the calculated doses for each pathway. The tabulated values are provided for the well driller scenario for comparison to the acute dose performance measure (500 mrem) and the rural pasture scenario for comparison to the chronic dose performance measure (100 mrem/yr). The rural pasture scenario is used for the chronic scenario because the total dose result is higher in the rural pasture scenario than it is in either the suburban garden scenario or the commercial farm worker scenario. The pathway dose results shown in Table 6-2 are doses after an assumed duration of intruder protections for 100 years (assuming closure in 2051) and for 227 years to align with DOE guidance for a sitewide institutional control date of 2278. For the well driller, the dose from external exposure and inhalation exposure from ILAW glass sources are similar; external exposure is the dominant pathway for ETF-LSW and SSW sources. For the rural pasture scenario, the dose from milk ingestion is the dominant pathway for all three waste sources at early times but transitions to the external pathway after short-lived fission products decay.

Table 6-3 and Table 6-4 tabulate the peak dose for each radionuclide for an intrusion that could occur any time after calendar years 2151 and 2278, respectively. For radionuclides that are not a decay product of a parent that is included in the initial inventory, the peak dose occurs at the time of the earliest possible intrusion (2151). For radionuclides with inventories that increase over time because of radionuclide decay, the peak dose from the initial inventory of its parent may occur for intrusions that occur at later times; however, as indicated by Table 6-1, the total dose occurs at the earliest intrusion time. Also, even though the model is a dynamic model that begins calculations at 2021, the doses presented below are limited to the peak at a time that is at least 100 years after closure (2051). Table 6-3 confirms that the greatest dose in calendar year 2151 is attributable to short-lived radionuclides, ^{90}Sr, ^{137}Cs, and ^{3}H. Due to decay, the dose after 227 years of credited intruder protections (i.e., calendar year 2278) will be dominated by long-lived radionuclides such as ^{99}Tc, ^{126}Sn, and ^{239}Pu (Table 6-4).

Figure 6-1 through Figure 6-4 show dose histories for each exposure scenario. The time axis represents a simulated time of an intrusion, not a recurring dose to an individual. These are time-dependent plots beginning at 130 years after the simulation start time, or 2151 in calendar years. By 2551, all the relatively short-lived radionuclides have decayed to the point where they produce doses less than 0.1 mrem/yr. As seen in the figures, the dose for many of the waste streams containing short-lived radionuclides are highest immediately following the loss of institutional controls. As the short-lived radionuclides decay, the dose from an intrusion at a later time decreases until it is dominated by the dose from longer-lived radionuclides. Without other removal mechanisms simulated in the model, the dose from the longer-lived radionuclides decreases because of radionuclide decay. The longer-lived radionuclides have long enough half-lives that the slopes of the lines appears flat. No doses are reported for the period of institutional control (years 0-130 in the simulated duration which starts at calendar year 2021).

For the well driller scenario the calculated peak dose from intersecting four lifts of a single waste stream occurs at the earliest assumed exposure time, 100 years post-closure, and decreases until the end of the simulation (Figure 6-1). The waste stream with the highest consequence is SSW Table 6-1. The dose consequence from the well driller intruding into four lifts of SSW is 9.28 mrem, which is below the performance measure of 500 mrem for acute exposures. This evaluation does not take into account for additional intruder protections, such as the packaging or waste form robustness, and is still below the performance measures for all modeled waste streams at and after the time of institutional controls.

For the commercial farm worker scenario the calculated peak dose from intersecting four lifts of a single waste stream occurs at the earliest assumed exposure time, 100 years post-closure, and decreases until the end of the simulation. The waste stream with the highest consequence is SSW (0.056 mrem/yr). The dose consequence to the commercial farm worker is below the performance objective of 100 mrem/yr for chronic exposures.

For the rural pasture scenario the calculated dose from intersecting four lifts of a single waste stream at the end of the 100-yr institutional control period is the highest of the four exposure scenarios. Like the other scenarios, the peak dose occurs at the earliest assumed exposure time, 100 years post-closure, and decreases until the end of the simulation. The waste stream with the highest dose consequence is ILAW glass. The dose consequence to the rural pasture resident following an intrusion into four lifts of ILAW glass is 43.3 mrem/yr. The dose consequence to the rural pasture resident is below the performance measure of 100 mrem/yr for chronic exposures.

For the suburban garden scenario the calculated peak dose from intersecting four lifts of a single waste stream occurs at the earliest assumed exposure time, 100 years post-closure, and decreases until the end of the simulation. The waste stream with the highest consequence is ILAW glass. The dose consequence to the suburban gardener at the end of the institutional control period is 8.96 mrem/yr. The dose consequence to the suburban garden resident is below the performance measure of 100 mrem/yr for chronic exposures.

Table 6-1. Dose by Waste Stream and Exposure Scenario Following an Intrusion Event.

Waste Stream	**Year of Intrusion**	**Well Driller (mrem)**	**Rural Pasture (mrem/yr)**	**Suburban Garden (mrem/yr)**	**Commercial Farm (mrem/yr)**
ILAW_Glass	2151	7.1	43	22	0.030
	2164	6.8	35	19	0.028
	2201	6.4	22	15	0.026
	2278	6.0	14	13	0.024
ETF_LSW	2151	0.13	0.29	0.11	0.00082
	2164	0.13	0.24	0.10	0.00082
	2201	0.13	0.17	0.079	0.00081
	2278	0.13	0.12	0.066	0.00081
SSW_Tot	2151	9.3	23	6.8	0.056
	2164	6.9	16	5.1	0.042
	2201	3.1	6.8	2.4	0.018
	2278	0.72	2.0	0.70	0.0037

ETF = Effluent Treatment Facility
LSW = liquid solid waste
ILAW = immobilized low-activity waste
SSW = solid secondary waste

Table 6-2. Detailed Waste Stream Doses.

Scenario	Acute dose values are in mrem. Chronic dose values are in mrem/yr				
	Year of Intrusion	**Exposure Pathway**	**ILAW Glass**	**ETF LSW**	**SSW Total**
Well Driller (acute)	2151	External	2.8	0.13	9.0
		Ingestion	0.72	0.00060	0.082
		Inhalation	3.5	0.00022	0.18
	2278	External	2.2	0.13	0.50
		Ingestion	0.60	0.00017	0.044
		Inhalation	3.2	0.00016	0.18
Rural Pasture (chronic)	2151	External	2.0	0.092	6.2
		Ingestion	0.46	0.00037	0.051
		Inhalation	0.28	1.7E-05	0.014
		Milk	41	0.20	17
	2278	External	1.5	0.091	0.35
		Ingestion	0.38	0.00010	0.027
		Inhalation	0.25	1.2E-05	0.014
		Milk	12	0.032	1.6

ETF = Effluent Treatment Facility
ILAW = immobilized low-activity waste
LSW = liquid solid waste
SSW = solid secondary waste

Table 6-3. Peak Radionuclide Dose Results Following an Inadvertent Intrusion in Calendar Year 2151. (2 sheets)

COPC	Well Driller (mrem)			Rural Pasture (mrem/yr)			Suburban Garden (mrem/yr)			Commercial Farmer (mrem/yr)		
	ILAW Glass	ETF LSW	SSW_Tot	ILAW Glass	ETF LSW	SSW_Tot	ILAW_Glass	ETF LSW	SSW_Tot	ILAW Glass	ETF LSW	SSW_Tot
Ac227	3.2E-04	2.2E-05	8.1E-03	1.3E-04	8.6E-06	3.2E-03	1.2E-04	7.7E-06	2.9E-03	1.2E-06	7.8E-08	2.9E-05
Am241	1.9E+00	9.5E-05	7.9E-05	3.6E-01	1.7E-05	1.4E-05	7.5E-01	3.6E-05	3.0E-05	5.4E-03	2.6E-07	2.2E-07
Am243	2.3E-03	1.2E-07	1.4E-08	1.0E-03	5.5E-08	6.3E-09	9.4E-04	5.0E-08	5.8E-09	1.0E-05	5.5E-10	6.4E-11
C14	0.0E+00	8.7E-06	3.4E-06	0.0E+00	3.1E-03	1.2E-03	0.0E+00	1.9E-03	7.5E-04	0.0E+00	9.3E-08	3.6E-08
Cd113m	2.1E-05	1.2E-06	1.3E-09	1.9E-03	1.1E-04	1.1E-07	3.2E-03	1.8E-04	1.9E-07	2.3E-07	1.3E-08	1.3E-11
Cm243	2.4E-04	1.3E-05	3.0E-07	1.2E-04	6.3E-06	1.4E-07	1.1E-04	5.7E-06	1.3E-07	1.0E-06	5.7E-08	1.3E-09
Cm244	2.9E-04	1.6E-05	2.7E-08	4.8E-05	2.6E-06	4.3E-09	1.1E-04	5.9E-06	1.0E-08	7.6E-07	4.1E-08	7.0E-11
Co60	1.2E-14	8.6E-14	2.8E-14	1.0E-14	7.3E-14	2.4E-14	5.5E-15	3.9E-14	1.3E-14	7.4E-17	5.2E-16	1.7E-16
Cs137	6.0E-01	5.8E-04	9.0E+00	6.1E-01	5.8E-04	9.0E+00	2.7E-01	2.5E-04	3.9E+00	3.8E-03	3.5E-06	5.5E-02
Eu152	1.9E-10	1.5E-14	3.7E-11	1.6E-10	1.2E-14	3.0E-11	9.4E-11	7.2E-15	1.8E-11	1.2E-12	9.1E-17	2.2E-13
Eu154	3.3E-11	1.2E-13	3.8E-11	2.7E-11	9.6E-14	3.1E-11	1.6E-11	5.5E-14	1.8E-11	2.0E-13	7.2E-16	2.3E-13
Eu155	1.2E-16	1.3E-19	5.3E-17	8.2E-17	9.0E-20	3.6E-17	4.2E-17	4.7E-20	1.9E-17	7.2E-19	8.0E-22	3.2E-19
H3	0.0E+00	6.2E-11	1.1E-07	0.0E+00	2.6E-03	4.4E+00	0.0E+00	5.6E-07	9.5E-04	0.0E+00	6.9E-13	1.2E-09
I129	5.6E-04	3.3E-05	1.0E-02	5.0E-02	2.8E-03	8.9E-01	4.3E-03	2.5E-04	7.7E-02	6.2E-06	3.5E-07	1.1E-04
Nb93m	7.2E-11	1.8E-11	6.2E-10	3.7E-11	9.2E-12	3.2E-10	1.9E-10	4.5E-11	1.6E-09	6.2E-13	1.5E-13	5.2E-12
Ni59	9.8E-07	3.8E-08	2.0E-10	9.9E-04	3.8E-05	2.0E-07	1.9E-05	7.2E-07	3.9E-09	1.1E-08	4.3E-10	2.3E-12
Ni63	8.3E-05	3.2E-06	1.7E-08	8.2E-02	3.1E-03	1.7E-05	1.6E-03	5.9E-05	3.2E-07	9.4E-07	3.6E-08	1.9E-10
Np237	1.3E-02	7.7E-07	1.3E-04	7.0E-03	4.2E-07	6.8E-05	9.0E-03	5.4E-07	8.7E-05	6.6E-05	3.9E-09	6.4E-07
Pa231	5.2E-05	6.7E-07	6.7E-03	7.9E-06	9.9E-08	1.0E-03	2.3E-05	2.9E-07	2.9E-03	1.0E-07	1.3E-09	1.3E-05
Pb210	3.7E-08	1.1E-08	3.5E-11	1.3E-07	3.7E-08	1.2E-10	1.2E-07	3.3E-08	1.1E-10	4.2E-10	1.2E-10	3.9E-13
Pu238	2.9E-02	4.8E-06	3.5E-05	4.8E-03	7.7E-07	5.7E-06	1.2E-02	1.9E-06	1.4E-05	7.8E-05	1.3E-08	9.2E-08
Pu239	1.9E+00	4.0E-05	1.0E-01	3.2E-01	6.5E-06	1.7E-02	7.6E-01	1.6E-05	4.1E-02	5.1E-03	1.0E-07	2.7E-04
Pu240	4.0E-01	2.7E-05	1.0E-01	6.6E-02	4.4E-06	1.7E-02	1.6E-01	1.1E-05	4.1E-02	1.1E-03	7.1E-08	2.7E-04
Pu241	5.9E-05	1.2E-09	1.8E-10	9.8E-06	1.9E-10	2.9E-11	2.3E-05	4.4E-10	6.7E-11	1.6E-07	3.1E-12	4.7E-13
Pu242	3.0E-05	2.1E-06	8.9E-11	4.9E-06	3.4E-07	1.4E-11	1.2E-05	8.2E-07	3.5E-11	8.0E-08	5.5E-09	2.3E-13
Ra226	3.1E-05	4.4E-07	1.8E-04	3.6E-04	5.0E-06	2.1E-03	3.7E-04	5.2E-06	2.2E-03	2.9E-07	4.1E-09	1.7E-06

Table 6-3. Peak Radionuclide Dose Results Following an Inadvertent Intrusion in Calendar Year 2151. (2 sheets)

COPC	Well Driller (mrem)			Rural Pasture (mrem/yr)			Suburban Garden (mrem/yr)			Commercial Farmer (mrem/yr)		
	ILAW Glass	ETF LSW	SSW_Tot	ILAW Glass	ETF LSW	SSW_Tot	ILAW_Glass	ETF LSW	SSW_Tot	ILAW Glass	ETF LSW	SSW_Tot
Ra228	7.4E-08	2.7E-08	1.2E-09	1.2E-07	4.4E-08	2.0E-09	9.2E-08	3.3E-08	1.7E-09	4.6E-10	1.7E-10	7.5E-12
Rn222	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Se79	1.5E-04	4.7E-05	1.5E-07	4.5E-02	1.4E-02	4.2E-05	5.9E-03	1.8E-03	5.5E-06	1.9E-06	5.5E-07	1.7E-09
Sm151	7.6E-09	8.8E-12	2.3E-09	3.0E-09	3.5E-12	9.1E-10	6.4E-09	7.3E-12	1.9E-09	3.3E-11	3.8E-14	9.9E-12
Sn126	2.0E+00	1.3E-01	2.5E-03	1.5E+00	9.3E-02	1.8E-03	9.3E-01	5.9E-02	1.1E-03	1.3E-02	8.1E-04	1.5E-05
Sr90	1.7E-01	9.8E-04	4.9E-02	3.0E+01	1.7E-01	8.4E+00	8.4E+00	4.7E-02	2.4E+00	1.5E-03	8.4E-06	4.2E-04
Tc99	7.8E-03	1.0E-06	1.6E-04	1.0E+01	1.3E-03	2.1E-01	1.0E+01	1.3E-03	2.0E-01	7.6E-05	9.8E-09	1.5E-06
Th229	9.7E-03	2.8E-07	1.7E-02	4.8E-03	1.3E-07	8.3E-03	5.4E-03	1.5E-07	9.4E-03	4.7E-05	1.3E-09	8.1E-05
Th230	4.5E-05	6.3E-07	2.6E-04	1.3E-05	1.8E-07	7.4E-05	3.8E-05	5.3E-07	2.2E-04	2.2E-07	3.0E-09	1.3E-06
Th232	4.7E-11	6.3E-14	3.8E-11	1.1E-11	1.4E-14	8.4E-12	3.0E-11	3.9E-14	2.3E-11	1.8E-13	2.4E-16	1.4E-13
U232	1.7E-04	5.4E-09	6.9E-10	1.4E-04	4.2E-09	5.3E-10	7.9E-05	2.4E-09	3.1E-10	1.0E-06	3.2E-11	4.0E-12
U233	4.4E-04	1.3E-08	7.8E-04	7.3E-04	2.1E-08	1.3E-03	4.0E-04	1.2E-08	7.0E-04	2.0E-06	5.9E-11	3.6E-06
U234	1.3E-04	1.8E-06	7.5E-04	2.1E-04	2.9E-06	1.2E-03	1.2E-04	1.6E-06	6.7E-04	5.8E-07	8.1E-09	3.4E-06
U235	6.0E-05	6.8E-07	6.9E-03	5.5E-05	6.2E-07	6.2E-03	3.4E-05	3.8E-07	3.8E-03	3.6E-07	4.1E-09	4.1E-05
U236	1.0E-05	2.0E-08	1.7E-06	1.7E-05	3.3E-08	2.8E-06	9.5E-06	1.8E-08	1.6E-06	4.8E-08	9.0E-11	7.8E-09
U238	2.3E-04	3.6E-06	1.6E-03	2.4E-04	3.6E-06	1.6E-03	1.3E-04	2.0E-06	8.6E-04	1.3E-06	2.0E-08	8.9E-06
Zr93	2.4E-10	9.4E-13	2.0E-09	1.2E-10	4.7E-13	1.0E-09	4.3E-10	1.7E-12	3.6E-09	2.3E-12	8.9E-15	1.9E-11

Shaded cells have peak dose values exceeding 1 mrem (acute) or 1 mrem/yr (chronic)
ETF = Effluent Treatment Facility
ILAW = immobilized low-activity waste
LSW = Liquid solid waste
SS = solid secondary waste
WTP = Waste Treatment and Immobilization Plant
COPC = contaminants of potential concern

Table 6-4. Peak Radionuclide Dose Results Following an Inadvertent Intrusion in Calendar Year 2278. (2 sheets)

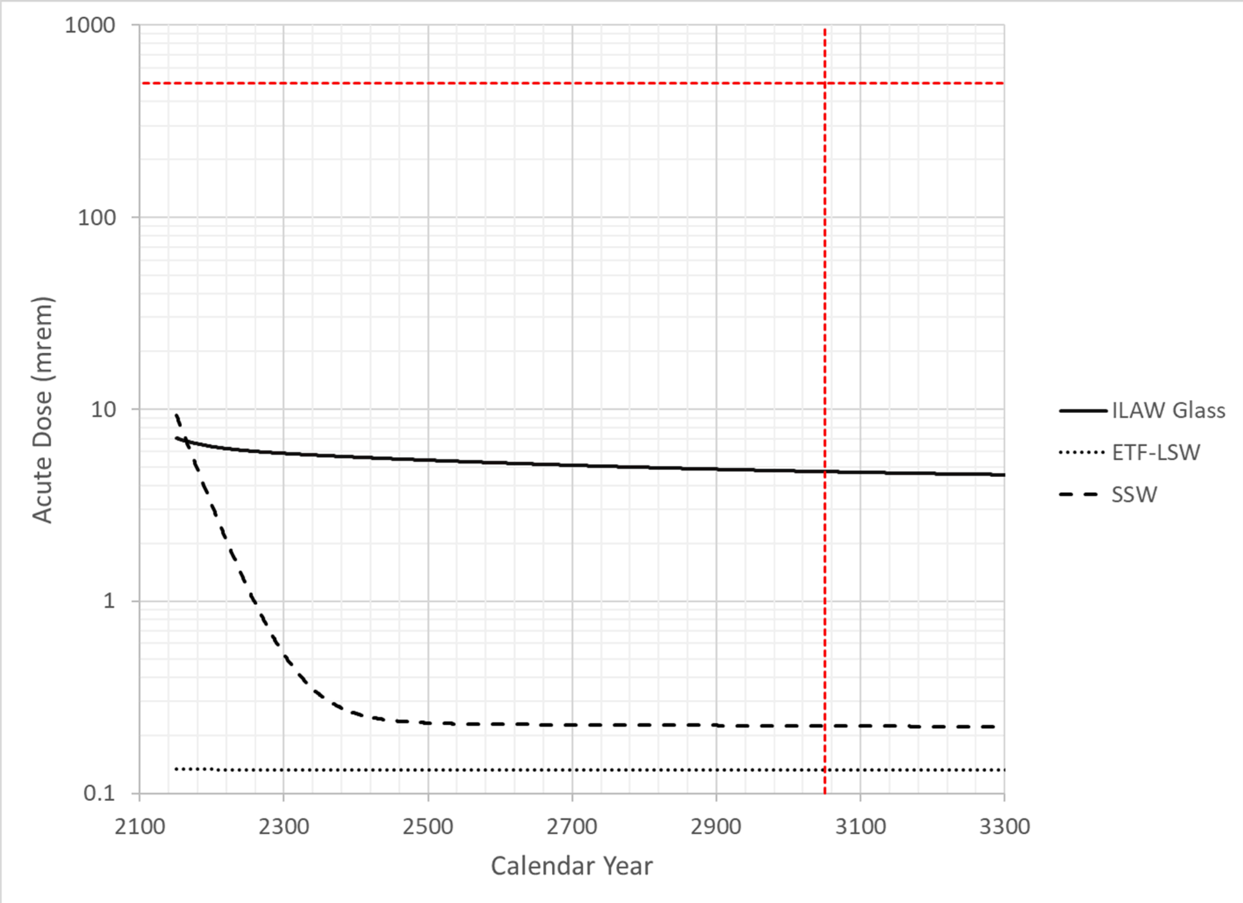
COPC	Well Driller (mrem)			Rural Pasture (mrem/yr)			Suburban Garden (mrem/yr)			Commercial Farmer (mrem/yr)		
	ILAW Glass	ETF LSW	SSW_Tot	ILAW Glass	ETF LSW	SSW_Tot	ILAW_Glass	ETF LSW	SSW_Tot	ILAW Glass	ETF LSW	SSW_Tot
Ac227	6.3E-05	8.1E-07	8.1E-03	2.6E-05	3.2E-07	3.2E-03	2.3E-05	2.9E-07	2.9E-03	2.3E-07	2.9E-09	2.9E-05
Am241	1.6E+00	7.8E-05	6.4E-05	2.9E-01	1.4E-05	1.2E-05	6.1E-01	3.0E-05	2.5E-05	4.4E-03	2.2E-07	1.8E-07
Am243	2.3E-03	1.2E-07	1.4E-08	1.0E-03	5.4E-08	6.3E-09	9.3E-04	4.9E-08	5.7E-09	1.0E-05	5.5E-10	6.3E-11
C14	0.0E+00	8.6E-06	3.3E-06	0.0E+00	3.0E-03	1.2E-03	0.0E+00	1.9E-03	7.4E-04	0.0E+00	9.2E-08	3.6E-08
Cd113m	4.3E-08	2.5E-09	2.6E-12	3.9E-06	2.2E-07	2.3E-10	6.5E-06	3.6E-07	3.8E-10	4.6E-10	2.5E-11	2.7E-14
Cm243	1.2E-05	6.5E-07	1.5E-08	5.7E-06	3.1E-07	7.1E-09	5.2E-06	2.8E-07	6.4E-09	5.1E-08	2.8E-09	6.3E-11
Cm244	2.3E-06	1.3E-07	2.1E-10	3.8E-07	2.0E-08	3.4E-11	8.6E-07	4.7E-08	7.9E-11	6.0E-09	3.3E-10	5.5E-13
Co60	7.2E-19	1.1E-17	2.0E-17	6.3E-19	9.7E-18	1.7E-17	3.8E-19	5.8E-18	1.0E-17	4.5E-21	6.9E-20	1.2E-19
Cs137	3.3E-02	3.2E-05	4.9E-01	3.3E-02	3.1E-05	4.9E-01	1.5E-02	1.4E-05	2.1E-01	2.1E-04	1.9E-07	3.0E-03
Eu152	3.0E-13	2.3E-17	5.8E-14	2.5E-13	1.9E-17	4.7E-14	1.5E-13	1.1E-17	2.8E-14	1.9E-15	1.4E-19	3.5E-16
Eu154	1.3E-15	4.6E-18	1.5E-15	1.1E-15	3.8E-18	1.2E-15	6.2E-16	2.2E-18	7.1E-16	8.1E-18	2.8E-20	9.2E-18
Eu155	1.5E-24	0.0E+00	6.8E-25	1.1E-24	0.0E+00	4.7E-25	5.5E-25	0.0E+00	2.5E-25	0.0E+00	0.0E+00	0.0E+00
H3	0.0E+00	5.1E-14	8.7E-11	0.0E+00	2.1E-06	3.6E-03	0.0E+00	4.7E-10	7.9E-07	0.0E+00	5.7E-16	9.7E-13
I129	5.6E-04	3.3E-05	1.0E-02	5.0E-02	2.8E-03	8.9E-01	4.3E-03	2.5E-04	7.7E-02	6.2E-06	3.5E-07	1.1E-04
Nb93m	7.2E-11	3.6E-13	6.2E-10	3.7E-11	1.8E-13	3.1E-10	1.9E-10	9.3E-13	1.6E-09	6.2E-13	3.0E-15	5.2E-12
Ni59	9.8E-07	3.8E-08	2.0E-10	9.9E-04	3.8E-05	2.0E-07	1.9E-05	7.2E-07	3.9E-09	1.1E-08	4.3E-10	2.3E-12
Ni63	3.4E-05	1.3E-06	7.2E-09	3.4E-02	1.3E-03	7.0E-06	6.5E-04	2.4E-05	1.3E-07	3.9E-07	1.5E-08	8.0E-11
Np237	1.3E-02	7.7E-07	1.3E-04	7.0E-03	4.2E-07	6.8E-05	9.0E-03	5.4E-07	8.7E-05	6.6E-05	3.9E-09	6.4E-07
Pa231	5.2E-05	6.7E-07	6.7E-03	7.9E-06	9.9E-08	1.0E-03	2.3E-05	2.9E-07	2.9E-03	1.0E-07	1.3E-09	1.3E-05
Pb210	7.1E-10	2.1E-10	6.7E-13	2.5E-09	7.1E-10	2.3E-12	2.2E-09	6.4E-10	2.1E-12	8.1E-12	2.3E-12	7.6E-15
Pu238	1.1E-02	1.8E-06	1.3E-05	1.8E-03	2.8E-07	2.1E-06	4.3E-03	6.8E-07	5.0E-06	2.9E-05	4.6E-09	3.4E-08
Pu239	1.9E+00	4.0E-05	1.0E-01	3.1E-01	6.5E-06	1.7E-02	7.6E-01	1.6E-05	4.1E-02	5.1E-03	1.0E-07	2.7E-04
Pu240	3.9E-01	2.7E-05	1.0E-01	6.5E-02	4.3E-06	1.7E-02	1.6E-01	1.0E-05	4.0E-02	1.1E-03	7.0E-08	2.7E-04
Pu241	1.3E-07	2.6E-12	4.0E-13	2.2E-08	4.3E-13	6.5E-14	5.1E-08	9.9E-13	1.5E-13	3.6E-10	6.9E-15	1.0E-15
Pu242	3.0E-05	2.1E-06	8.9E-11	4.9E-06	3.4E-07	1.4E-11	1.2E-05	8.2E-07	3.5E-11	8.0E-08	5.5E-09	2.3E-13
Ra226	3.1E-05	4.4E-07	1.8E-04	3.6E-04	5.0E-06	2.1E-03	3.7E-04	5.2E-06	2.2E-03	2.9E-07	4.1E-09	1.7E-06

Table 6-4. Peak Radionuclide Dose Results Following an Inadvertent Intrusion in Calendar Year 2278. (2 sheets)

COPC	Well Driller (mrem)			Rural Pasture (mrem/yr)			Suburban Garden (mrem/yr)			Commercial Farmer (mrem/yr)		
	ILAW Glass	ETF LSW	SSW_Tot	ILAW Glass	ETF LSW	SSW_Tot	ILAW_Glass	ETF LSW	SSW_Tot	ILAW Glass	ETF LSW	SSW_Tot
Ra228	1.6E-09	2.1E-12	1.2E-09	2.6E-09	3.3E-12	2.0E-09	2.2E-09	2.8E-12	1.7E-09	9.7E-12	1.3E-14	7.5E-12
Rn222	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Se79	1.5E-04	4.7E-05	1.5E-07	4.5E-02	1.4E-02	4.2E-05	5.9E-03	1.8E-03	5.5E-06	1.9E-06	5.5E-07	1.7E-09
Sm151	2.8E-09	3.3E-12	8.7E-10	1.1E-09	1.3E-12	3.4E-10	2.4E-09	2.8E-12	7.2E-10	1.2E-11	1.4E-14	3.7E-12
Sn126	2.0E+00	1.3E-01	2.5E-03	1.5E+00	9.3E-02	1.8E-03	9.3E-01	5.9E-02	1.1E-03	1.3E-02	8.1E-04	1.5E-05
Sr90	8.0E-03	4.6E-05	2.3E-03	1.4E+00	8.0E-03	4.0E-01	4.0E-01	2.2E-03	1.1E-01	7.0E-05	4.0E-07	2.0E-05
Tc99	7.8E-03	1.0E-06	1.6E-04	1.0E+01	1.3E-03	2.1E-01	1.0E+01	1.3E-03	2.0E-01	7.6E-05	9.8E-09	1.5E-06
Th229	9.7E-03	2.8E-07	1.7E-02	4.8E-03	1.3E-07	8.3E-03	5.4E-03	1.5E-07	9.4E-03	4.7E-05	1.3E-09	8.1E-05
Th230	4.5E-05	6.3E-07	2.6E-04	1.3E-05	1.8E-07	7.4E-05	3.8E-05	5.3E-07	2.2E-04	2.2E-07	3.0E-09	1.3E-06
Th232	4.7E-11	6.3E-14	3.8E-11	1.1E-11	1.4E-14	8.4E-12	3.0E-11	3.9E-14	2.3E-11	1.8E-13	2.4E-16	1.4E-13
U232	4.8E-05	1.5E-09	1.9E-10	3.8E-05	1.2E-09	1.5E-10	2.2E-05	6.7E-10	8.6E-11	2.9E-07	8.9E-12	1.1E-12
U233	4.4E-04	1.3E-08	7.8E-04	7.3E-04	2.1E-08	1.3E-03	4.0E-04	1.2E-08	7.0E-04	2.0E-06	5.9E-11	3.6E-06
U234	1.3E-04	1.8E-06	7.5E-04	2.1E-04	2.9E-06	1.2E-03	1.2E-04	1.6E-06	6.7E-04	5.8E-07	8.1E-09	3.4E-06
U235	6.0E-05	6.8E-07	6.9E-03	5.5E-05	6.2E-07	6.2E-03	3.4E-05	3.8E-07	3.8E-03	3.6E-07	4.1E-09	4.1E-05
U236	1.0E-05	2.0E-08	1.7E-06	1.7E-05	3.3E-08	2.8E-06	9.5E-06	1.8E-08	1.6E-06	4.8E-08	9.0E-11	7.8E-09
U238	2.3E-04	3.6E-06	1.6E-03	2.4E-04	3.6E-06	1.6E-03	1.3E-04	2.0E-06	8.6E-04	1.3E-06	2.0E-08	8.9E-06
Zr93	2.4E-10	9.4E-13	2.0E-09	1.2E-10	4.7E-13	1.0E-09	4.3E-10	1.7E-12	3.6E-09	2.3E-12	8.9E-15	1.9E-11

Shaded cells have peak dose values exceeding 1 mrem (acute) or 1 mrem/yr (chronic)
ETF = Effluent Treatment Facility
ILAW = immobilized low-activity waste
LSW = Liquid solid waste
SS = solid secondary waste
WTP = Waste Treatment and Immobilization Plant
COPC = contaminants of potential concern

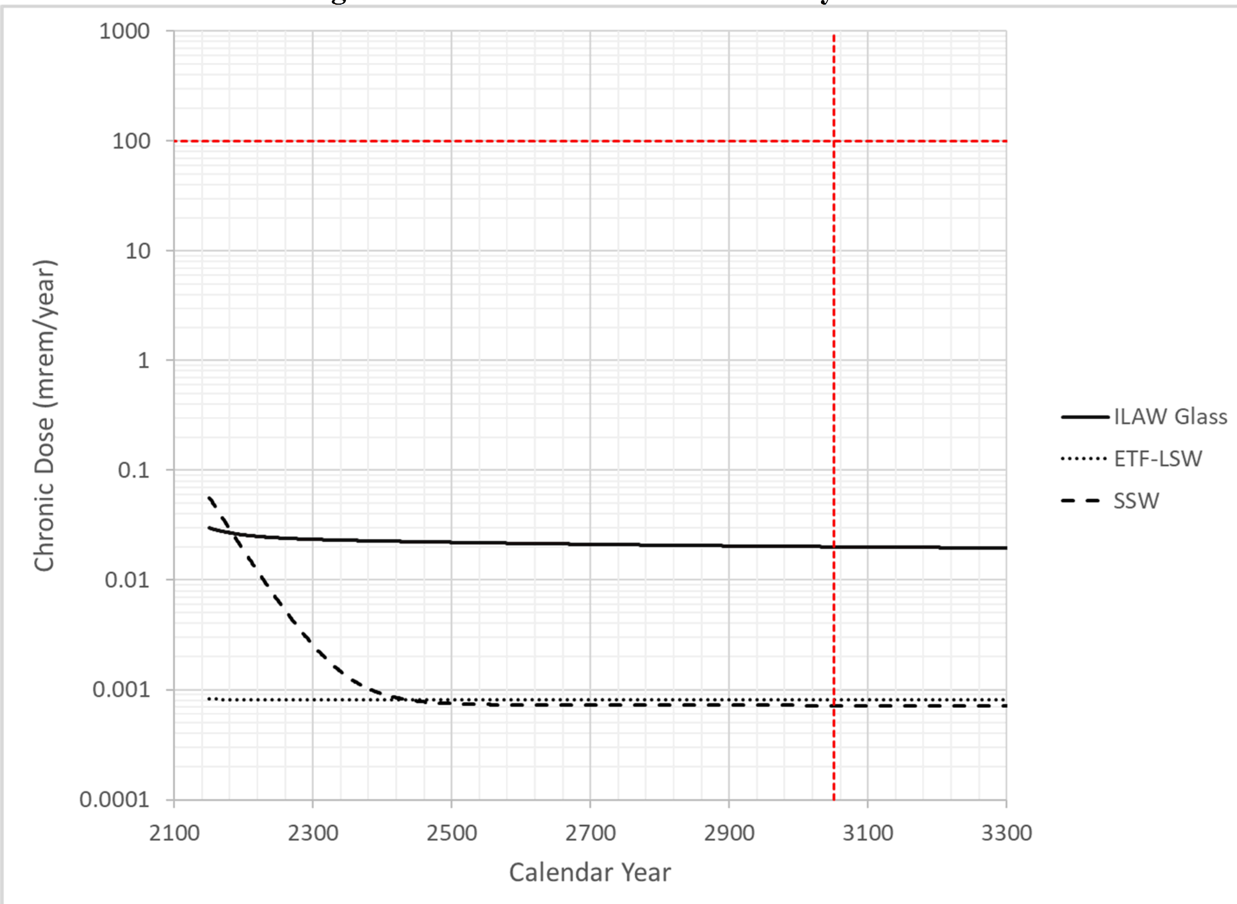
Figure 6-1. Well Driller Acute Dose (mrem) by Source.



NOTE: The plotted dose is received over a 40-hour period. The DOE performance measure (500 mrem) and time of compliance (1,000 years after closure) are shown as red dashed lines.

ETF	= Effluent Treatment Facility	LSW	= liquid solid waste
ILAW	= immobilized low-activity waste	SSW	= solid secondary waste

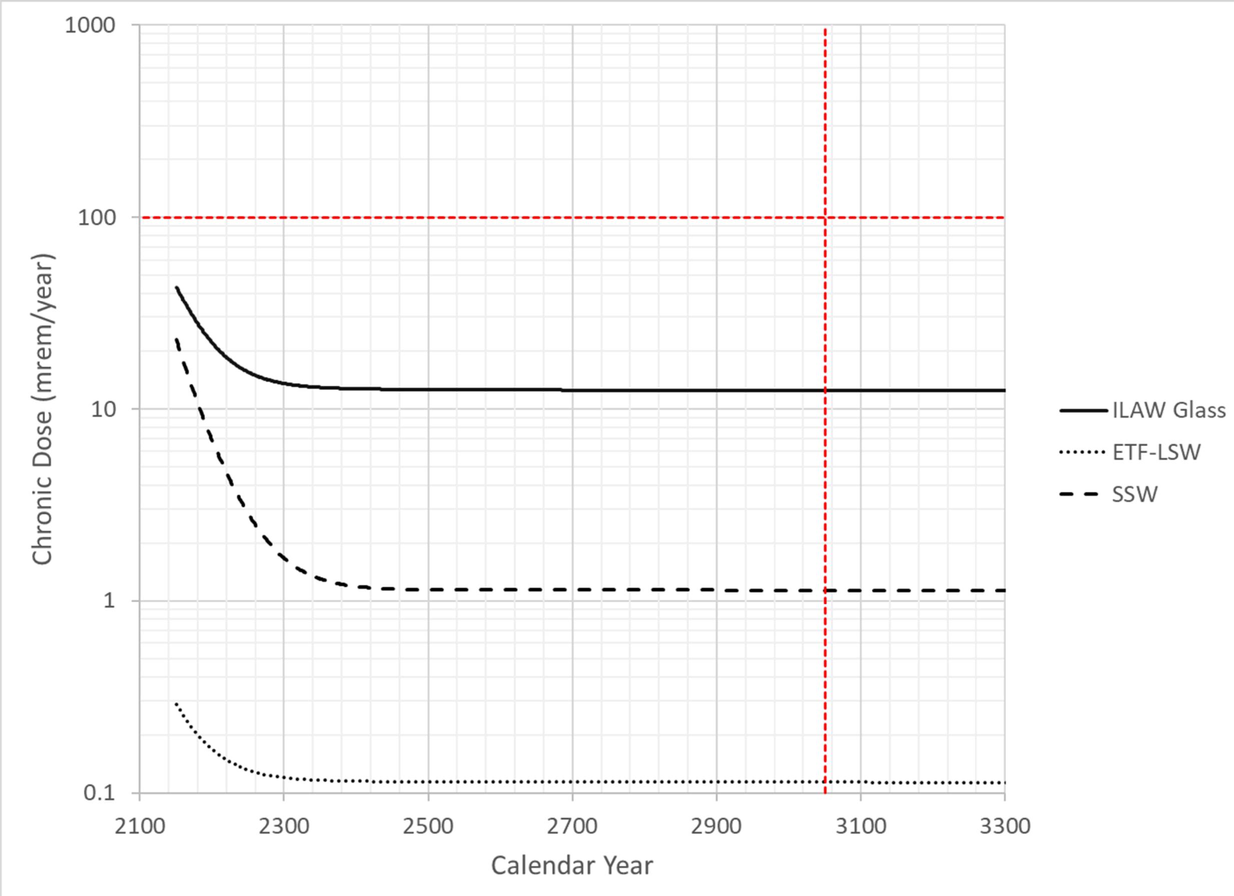
Figure 6-2. Commercial Farm Dose by Source.



ETF	=	Effluent Treatment Facility	LSW	=	liquid solid waste
ILAW	=	immobilized low-activity waste	SSW	=	solid secondary waste

The DOE performance measure (100 mrem/yr) and time of compliance (1,000 years after closure) are shown as red dashed lines.

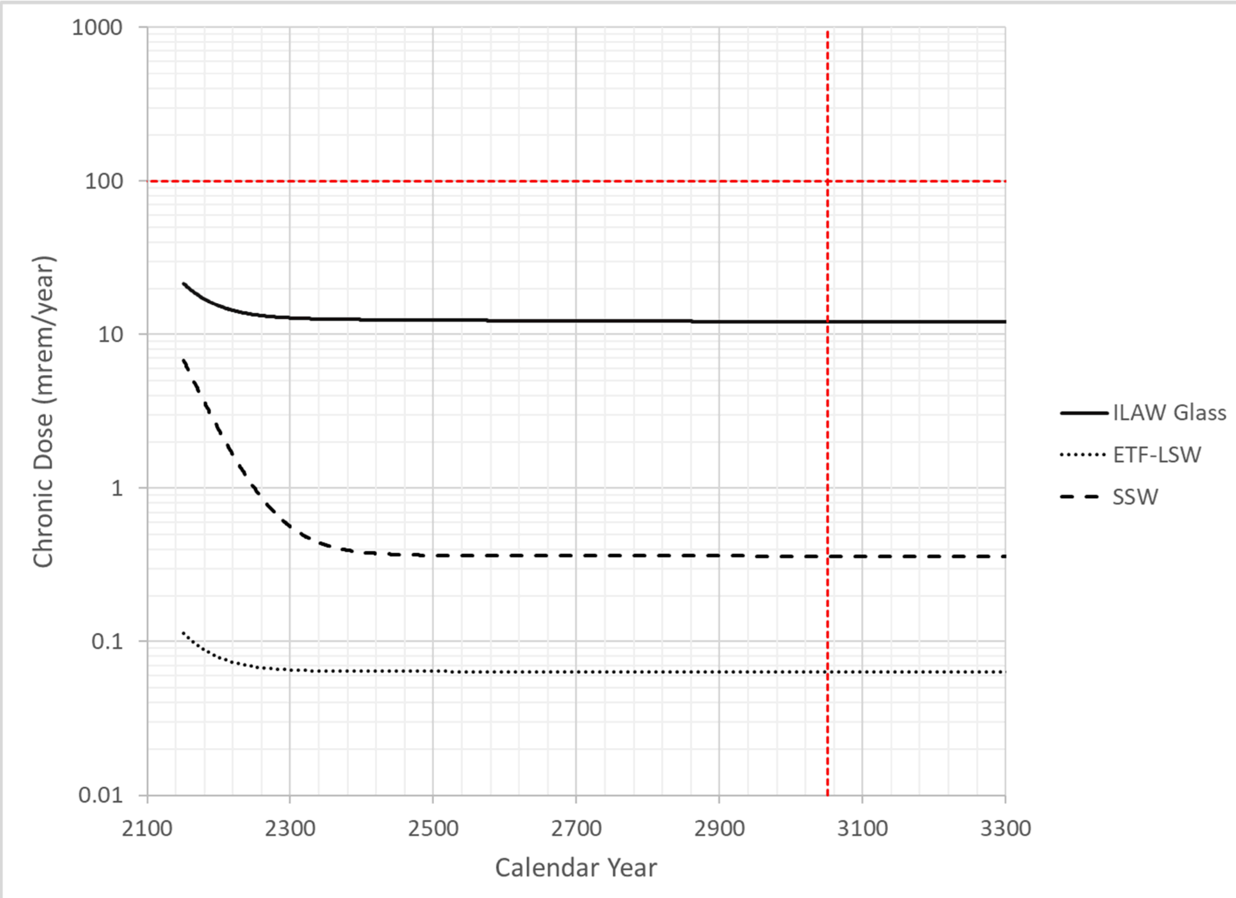
Figure 6-3. Rural Pasture Dose by Source.



ETF = Effluent Treatment Facility
ILAW = immobilized low-activity waste
LSW = liquid solid waste
SSW = solid secondary waste

The DOE performance measure (100 mrem/yr) and time of compliance (1,000 years after closure) are shown as red dashed lines.

Figure 6-4. Suburban Garden by Source.



ETF	= Effluent Treatment Facility	LSW	= liquid solid waste
ILAW	= immobilized low-activity waste	SSW	= solid secondary waste

The DOE performance measure (100 mrem/yr) and time of compliance (1,000 years after closure) are shown as red dashed lines.

6.2 DISPOSAL LIMITS CALCULATION

Disposal limits calculations were performed using the methodology described in Section 3.3. The results of the calculation are shown for all radionuclides in Table 6-5. The calculation uses the waste stream concentration at the time first receipt (assumed to be 2021) and the peak dose following an intrusion into waste packages containing that inventory. The time of intrusion is varied between 100 years after closure (2151) and calendar year 2278, the sitewide institutional control date recommended by DOE (Hamel et al. 2019). Different dates are provided for information to illustrate how the disposal limits vary with different lengths of credited intruder protections. Based on DOE guidance, it is recommended that the waste acceptance criteria for the IDF be based on the disposal limits derived using the sitewide institutional control date (2278).

The calculation is performed separately for each radionuclide in the initial inventory. Furthermore, the calculation is performed such that the peak dose from the initial inventory includes the dose from the undecayed inventory of the parent radionuclide and the undecayed inventory of any progeny of the parent's initial inventory in the waste containers at the time of the intrusion. The ratio of the scenario performance measure to the calculated dose is used to scale the waste concentration to a concentration that would yield a dose equal to the performance measure. For radionuclides that are decay products, the peak dose may occur for events that occur later in time; this consequence is included in the dynamic analysis that effectively simulates events at 1 year intervals between 100 and 1000 years after closure. Peak dose consequences after the DOE time of compliance, 1,000 years after IDF closure, are not considered in the disposal limit calculation.

Table 6-5 provides the disposal limits for radionuclides contributing to the dose from an inadvertent intrusion event. The list includes short-lived radionuclides that impact the dose at early times and longer-lived radionuclides that drive the dose at later event times. Using ^{90}Sr as an example, the disposal limit based on an intrusion occurring in 2151, 100 years after closure, is 2.3 Ci $^{90}Sr/m^3$. If the average concentration in four ILAW glass containers or eight ETF-LSW or SSW waste containers that were placed above one another in the IDF was equal to 2.3 Ci/m^3, then the intruder dose from ^{90}Sr would equal the performance measure based on the most restrictive scenario. If any other radionuclides were present in the intercepted waste packages with an average ^{90}Sr concentration equal to the disposal limit, the dose would exceed the performance measure by an amount equal to the dose from the other radionuclides. Table 6-5 shows that intruder protections until at least 2242 are necessary to protect a member of the public in the future in the unlikely event that all ILAW glass was produced with an average ^{90}Sr concentration equal to the WTP specification limit of 20 Ci $^{90}Sr/m^3$. Current flow sheet estimates from Table C-7 in RPP-RPT-57991, *One System River Protection Project Integrated Flowsheet* suggest an average concentration closer to 4.3 Ci $^{90}Sr/m^3$, which would require intruder protections until at least 2180. The duration of intruder protections that need to be credited will depend on the average concentrations in the products that are disposed of in the IDF, which will be better understood once production begins.

The values in the table reflect the limit for the average waste package concentration in a vertical column of waste packages regardless of waste stream. In other words, the average of four ILAW glass waste packages placed above one another must be below the disposal limits. Similarly the average of eight SSW or eight ETF-LSW waste packages placed above one another must also be below the disposal limits. For the long-lived species, the concentration limit is not sensitive to the event time (i.e., the duration of intruder protections). However, for short-lived radionuclides, the limit is very sensitive to the duration of credited intruder protections. Crediting longer periods of intruder protections could be used to increase disposal limits for short-lived radionuclides.

Based on the calculated disposal limits assuming intruder protections end in 2151 and projected inventory used in the PA (which does not include the revised estimate for ^{90}Sr in Table C-7 of RPP-RPT-57991), the planned waste to be disposed in the IDF is approximately 67.5% of the total activity limit (see Table 6-6) based on limits set for 2151. The radionuclides that contribute the most towards the limits are ^{90}Sr (38.4% of disposal limit), ^{99}Tc (10.7% of disposal limit, almost entirely in ILAW glass), ^{137}Cs (9.6% of disposal limit), ^{3}H (4.4% of disposal limit), ^{126}Sn (1.6% of disposal limit), and ^{129}I (0.9% of disposal limit).

When the average ILAW glass concentration for ^{90}Sr is increased by a factor of 6.5 from 0.67 Ci/m^3 to 4.3 Ci/m^3, and the inventory for the other radionuclides is kept the same, the sum of fractions assuming intruder protections end in 2151 exceeds 1. When the sitewide institutional control date is applied to this inventory, the sum of fractions is 0.249 and is predominantly due to ^{99}Tc and ^{90}Sr, which are each about 10% of the calculated disposal limits (see Table 6-7).

Table 6-5. Disposal Limits (Ci/m^3) Based on Peak Dose Following an Inadvertent Intrusion at the End of Intruder Protections (2 sheets).

Radionuclide	End of Intruder Protections (Calendar Year)						
	2151	2176	2201	2226	2242	2251	2278
Ac227	23.6	52	115	254	422	561	1,320
Am241	3.0	3.11	3.24	3.37	3.46	3.51	3.67
Am243	1.07	1.07	1.08	1.08	1.08	1.08	1.08
C14	6.05	6.07	6.09	6.11	6.12	6.13	6.15
Cd113m	186	632	2,140	7,270	15,900	24,700	92,200
Cm243	29.9	53.8	96.4	171	243	291	480
Cm244	327	506	643	719	745	755	771
Co60	1.15E+06	2.92E+07	7.42E+08	1.61E+09	1.61E+09	1.61E+09	1.61E+09
Cs137	4.57	8.11	14.4	25.5	36.8	45.2	83.9
Eu152	103	367	1,310	4,670	10,600	16,700	65,900
Eu154	4.07E+03	3.00E+04	2.21E+05	1.62E+06	5.83E+06	1.20E+07	1.03E+08
Eu155	7.44E+08	1.75E+09	1.75E+09	1.75E+09	1.75E+09	1.75E+09	1.75E+09
H3	2.30	9.30	37.6	152	372	614	2,780
I129	0.120	0.120	0.120	0.120	0.120	0.120	0.120
Nb93m	3.83E+05	1.12E+06	3.25E+06	9.46E+06	1.87E+07	2.75E+07	8.73E+07
Ni59	18.3	18.3	18.3	18.3	18.3	18.3	18.3
Ni63	18.0	21.5	25.5	30.3	33.9	36.0	43.4
Np237	0.740	0.740	0.740	0.740	0.740	0.740	0.740
Pa231	0.211	0.211	0.211	0.211	0.211	0.211	0.211
Pb210	8.63	18.8	40.9	89.0	146	194	448
Pu238	6.40	7.80	9.50	11.6	13.1	14.1	17.4
Pu239	2.11	2.11	2.11	2.11	2.11	2.11	2.11

Table 6-5. Disposal Limits (Ci/m^3) Based on Peak Dose Following an Inadvertent Intrusion at the End of Intruder Protections (2 sheets).

Radionuclide	End of Intruder Protections (Calendar Year)						
	2151	**2176**	**2201**	**2226**	**2242**	**2251**	**2278**
Pu240	2.13	2.13	2.14	2.14	2.15	2.15	2.16
Pu241	87.2	90.7	94.4	98.2	101	102	107
Pu242	2.21	2.21	2.21	2.21	2.21	2.21	2.21
Ra226	0.216	0.218	0.221	0.223	0.225	0.226	0.228
Ra228	1.36E+05	2.65E+06	5.16E+07	1.00E+09	6.72E+09	1.96E+10	1.87E+11
Rn222	1.83E+04	3.98E+04	8.67E+04	1.89E+05	3.10E+05	4.10E+05	9.51E+05
Se79	1.12	1.12	1.12	1.12	1.12	1.12	1.12
Sm151	1.12E+04	1.35E+04	1.64E+04	1.99E+04	2.25E+04	2.41E+04	2.97E+04
Sn126	0.0945	0.0945	0.0945	0.0945	0.0945	0.0945	0.0945
Sr90	2.26	4.12	7.50	13.7	20.1	24.9	47.6
Tc99	0.906	0.906	0.906	0.906	0.906	0.906	0.906
Th229	0.414	0.415	0.416	0.417	0.418	0.418	0.419
Th230	0.467	0.467	0.467	0.467	0.467	0.467	0.467
Th232	0.0267	0.0267	0.0267	0.0267	0.0267	0.0267	0.0267
U232	0.333	0.428	0.55	0.707	0.831	0.909	1.19
U233	2.52	2.52	2.52	2.52	2.52	2.52	2.52
U234	5.04	5.04	5.04	5.04	5.04	5.04	5.04
U235	0.967	0.967	0.967	0.967	0.967	0.967	0.967
U236	5.62	5.62	5.62	5.62	5.62	5.62	5.62
U238	4.03	4.03	4.03	4.03	4.03	4.03	4.03
Zr93	462	462	462	462	462	462	462

NOTE: The number of digits displayed in the table is reduced from the values calculated in the model file. The values have been rounded from the source model file to only show three significant figures.

Table 6-6. Sum of Fractions Based on Projected Inventory and Calculated Disposal Limits Assuming Intruder Protections End in 2151. (2 sheets)

Radionuclide	Initial Inventory (Ci)			Concentration Limit (Ci/m^3)	Disposal Limit (Ci)[a]			Fraction of Limit[b]		
	ILAW Glass	ETF LSW	SSW Total		ILAW Glass	ETF LSW	SSW Total	ILAW Glass	ETF LSW	SSW Total
Ac227	8.61E+00	3.85E-02	8.21E-05	23.6	6.58E+06	4.46E+05	2.70E+05	1.31E-06	8.63E-08	3.04E-10
Am241	6.11E+03	2.05E-02	1.03E-02	3.0	8.34E+05	5.65E+04	3.42E+04	7.33E-03	3.63E-07	3.01E-07
Am243	3.09E+00	1.08E-05	7.72E-07	1.07	2.98E+05	2.02E+04	1.22E+04	1.04E-05	5.34E-10	6.31E-11
C14	0.00E+00	3.51E+00	8.25E-01	6.05	1.69E+06	1.14E+05	6.92E+04	0.00E+00	3.07E-05	1.19E-05
Cd113m	1.75E+03	6.56E+00	4.22E-03	186	5.19E+07	3.52E+06	2.13E+06	3.37E-05	1.87E-06	1.98E-09
Cm243	9.81E+00	3.60E-02	4.96E-04	29.9	8.34E+06	5.65E+05	3.42E+05	1.18E-06	6.37E-08	1.45E-09
Cm244	1.79E+02	6.57E-01	6.69E-04	327	9.12E+07	6.18E+06	3.74E+06	1.96E-06	1.06E-07	1.79E-10
Co60	3.30E-05	1.58E-05	3.12E-06	1.15E+06	3.21E+11	2.17E+10	1.32E+10	1.03E-16	7.27E-16	2.37E-16
Cs137	7.83E+03	4.98E-01	4.68E+03	4.57	1.27E+06	8.64E+04	5.23E+04	6.15E-03	5.77E-06	8.96E-02
Eu152	4.56E-05	2.38E-10	3.55E-07	103	2.87E+07	1.95E+06	1.18E+06	1.59E-12	1.22E-16	3.01E-13
Eu154	3.11E-04	7.41E-08	1.45E-05	4.07E+03	1.13E+09	7.69E+07	4.65E+07	2.74E-13	9.63E-16	3.12E-13
Eu155	1.70E-04	1.27E-08	3.10E-06	7.44E+08	2.07E+14	1.41E+13	8.51E+12	8.20E-19	9.03E-22	3.64E-19
H3	0.00E+00	1.13E+00	1.16E+03	2.30	6.41E+05	4.35E+04	2.63E+04	0.00E+00	2.60E-05	4.41E-02
I129	1.66E+01	6.41E-02	1.21E+01	0.120	3.35E+04	2.27E+03	1.37E+03	4.96E-04	2.83E-05	8.82E-03
Nb93m	6.63E-04	3.34E-03	7.23E-04	3.83E+05	1.07E+11	7.24E+09	4.38E+09	6.21E-15	4.61E-13	1.65E-13
Ni59	5.05E+01	1.30E-01	4.23E-04	18.3	5.10E+06	3.46E+05	2.09E+05	9.90E-06	3.76E-07	2.02E-09
Ni63	4.13E+03	1.06E+01	3.47E-02	18.0	5.02E+06	3.40E+05	2.06E+05	8.23E-04	3.12E-05	1.69E-07
Np237	1.73E+01	7.10E-05	7.39E-03	0.740	2.06E+05	1.40E+04	8.46E+03	8.39E-05	5.08E-09	8.73E-07
Pa231	3.36E-05	3.34E-08	3.12E-04	0.211	5.88E+04	3.99E+03	2.41E+03	5.71E-10	8.38E-12	1.29E-07
Pb210	3.07E-03	6.00E-05	1.17E-07	8.63	2.41E+06	1.63E+05	9.87E+04	1.28E-09	3.68E-10	1.19E-12
Pu238	2.09E+02	2.26E-03	1.01E-02	6.40	1.78E+06	1.21E+05	7.32E+04	1.17E-04	1.87E-08	1.38E-07
Pu239	4.48E+03	6.19E-03	9.88E+00	2.11	5.88E+05	3.99E+04	2.41E+04	7.62E-03	1.55E-07	4.09E-04
Pu240	9.46E+02	2.45E-03	9.88E+00	2.13	5.94E+05	4.03E+04	2.44E+04	1.59E-03	6.09E-08	4.06E-04
Pu241	3.97E+03	5.19E-03	4.76E-04	87.2	2.43E+07	1.65E+06	9.97E+05	1.63E-04	3.15E-09	4.77E-10
Pu242	7.37E-02	3.41E-04	8.82E-09	2.21	6.16E+05	4.18E+04	2.53E+04	1.20E-07	8.16E-09	3.49E-13
Ra226	9.19E-03	1.80E-04	6.21E-07	0.216	6.02E+04	4.08E+03	2.47E+03	1.53E-07	4.41E-08	2.51E-10

Table 6-6. Sum of Fractions Based on Projected Inventory and Calculated Disposal Limits Assuming Intruder Protections End in 2151. (2 sheets)

Radionuclide	Initial Inventory (Ci)			Concentration Limit (Ci/m^3)	Disposal Limit (Ci)[a]			Fraction of Limit[b]		
	ILAW Glass	ETF LSW	SSW Total		ILAW Glass	ETF LSW	SSW Total	ILAW Glass	ETF LSW	SSW Total
Ra228	4.55E+01	1.13E+00	1.73E-04	1.36E+05	3.79E+10	2.57E+09	1.56E+09	1.20E-09	4.40E-10	1.11E-13
Rn222	9.18E-03	1.80E-04	6.20E-07	1.83E+04	5.10E+09	3.46E+08	2.09E+08	1.80E-12	5.20E-13	2.96E-15
Se79	1.41E+02	2.86E+00	5.41E-03	1.12	3.12E+05	2.12E+04	1.28E+04	4.52E-04	1.35E-04	4.22E-07
Sm151	2.02E-01	1.56E-05	2.48E-03	1.12E+04	3.12E+09	2.12E+08	1.28E+08	6.47E-11	7.37E-14	1.94E-11
Sn126	3.88E+02	1.67E+00	1.92E-02	0.0945	2.63E+04	1.79E+03	1.08E+03	1.47E-02	9.35E-04	1.78E-05
Sr90	1.88E+05	7.21E+01	2.18E+03	2.26	6.30E+05	4.27E+04	2.58E+04	2.98E-01	1.69E-03	8.44E-02
Tc99	2.64E+04	2.29E-01	2.13E+01	0.906	2.53E+05	1.71E+04	1.04E+04	1.05E-01	1.34E-05	2.06E-03
Th229	1.22E-02	2.19E-08	1.39E-03	0.414	1.15E+05	7.82E+03	4.73E+03	1.06E-07	2.80E-12	2.94E-07
Th230	3.61E-04	3.46E-07	1.36E-04	0.467	1.30E+05	8.83E+03	5.34E+03	2.77E-09	3.92E-11	2.55E-08
Th232	9.45E-08	2.17E-14	5.56E-09	0.0267	7.44E+03	5.05E+02	3.05E+02	1.27E-11	4.30E-17	1.82E-11
U232	1.25E-01	2.62E-07	2.01E-08	0.333	9.28E+04	6.29E+03	3.81E+03	1.35E-06	4.16E-11	5.28E-12
U233	9.93E+00	1.77E-05	7.37E-01	2.52	7.03E+05	4.76E+04	2.88E+04	1.41E-05	3.72E-10	2.56E-05
U234	3.02E+00	2.89E-03	7.35E-01	5.04	1.41E+06	9.53E+04	5.76E+04	2.15E-06	3.03E-08	1.28E-05
U235	1.22E-01	1.21E-04	7.38E-01	0.967	2.70E+05	1.83E+04	1.11E+04	4.53E-07	6.62E-09	6.67E-05
U236	9.57E-02	3.38E-05	5.87E-06	5.62	1.57E+06	1.06E+05	6.43E+04	6.11E-08	3.18E-10	9.13E-11
U238	2.71E+00	2.78E-03	7.37E-01	4.03	1.12E+06	7.62E+04	4.61E+04	2.41E-06	3.65E-08	1.60E-05
Zr93	8.05E-04	2.10E-07	2.77E-04	462	1.29E+08	8.73E+06	5.28E+06	6.25E-12	2.41E-14	5.24E-11
								Sum of Fractions		0.675

[a] Calculated disposal limits = Concentration Limit × As-Disposed Volume. Limits for waste stream activity assume an as-disposed volume and would vary for other volume estimates. The as-disposed volume of ILAW glass used for the activity limit is 278,797 m^3. The as-disposed volume of ETF-LSW used for the activity limit is 18,900 m^3. The as-disposed volume of SSW used for the activity limit is 11,435 m^3.

[b] Fraction of Limit = Initial Inventory / Disposal Limit

ILAW = immobilized low-activity waste
SSW = solid secondary waste
ETF = Effluent Treatment Facility
LSW = Liquid solid waste

Table 6-7. Sum of Fractions Based on Projected Inventory and Calculated Disposal Limits Assuming Intruder Protections End in 2278. (2 sheets)

Radionuclide	Initial Inventory (Ci)			Concentration Limit (Ci/m^3)	Disposal Limit (Ci)[a]			Fraction of Limit[b]		
	ILAW Glass	ETF LSW	SSW Total		ILAW Glass	ETF LSW	SSW Total	ILAW Glass	ETF LSW	SSW Total
Ac227	8.61E+00	3.85E-02	8.21E-05	1,320	3.68E+08	2.49E+07	1.51E+07	2.34E-08	1.54E-09	5.44E-12
Am241	6.11E+03	2.05E-02	1.03E-02	3.67	1.02E+06	6.94E+04	4.20E+04	5.97E-03	2.96E-07	2.45E-07
Am243	3.09E+00	1.08E-05	7.72E-07	1.08	3.01E+05	2.04E+04	1.23E+04	1.03E-05	5.29E-10	6.25E-11
C14	0.00E+00	3.51E+00	8.25E-01	6.15	1.71E+06	1.16E+05	7.03E+04	0.00E+00	3.02E-05	1.17E-05
Cd113m	1.75E+03	6.56E+00	4.22E-03	92,200	2.57E+10	1.74E+09	1.05E+09	6.81E-08	3.76E-09	4.00E-12
Cm243	9.81E+00	3.60E-02	4.96E-04	480	1.34E+08	9.07E+06	5.49E+06	7.33E-08	3.97E-09	9.04E-11
Cm244	1.79E+02	6.57E-01	6.69E-04	771	2.15E+08	1.46E+07	8.82E+06	8.33E-07	4.51E-08	7.59E-11
Co60	3.30E-05	1.58E-05	3.12E-06	1.61E+09	4.49E+14	3.04E+13	1.84E+13	7.35E-20	5.19E-19	1.69E-19
Cs137	7.83E+03	4.98E-01	4.68E+03	83.9	2.34E+07	1.59E+06	9.59E+05	3.35E-04	3.14E-07	4.88E-03
Eu152	4.56E-05	2.38E-10	3.55E-07	65,900	1.84E+10	1.25E+09	7.54E+08	2.48E-15	1.91E-19	4.71E-16
Eu154	3.11E-04	7.41E-08	1.45E-05	1.03E+08	2.87E+13	1.95E+12	1.18E+12	1.08E-17	3.81E-20	1.23E-17
Eu155	1.70E-04	1.27E-08	3.10E-06	1.75E+09	4.88E+14	3.31E+13	2.00E+13	3.48E-19	3.84E-22	1.55E-19
H3	0.00E+00	1.13E+00	1.16E+03	2,780	7.75E+08	5.25E+07	3.18E+07	0.00E+00	2.15E-08	3.65E-05
I129	1.66E+01	6.41E-02	1.21E+01	0.12	3.35E+04	2.27E+03	1.37E+03	4.96E-04	2.83E-05	8.82E-03
Nb93m	6.63E-04	3.34E-03	7.23E-04	8.73E+07	2.43E+13	1.65E+12	9.98E+11	2.72E-17	2.02E-15	7.24E-16
Ni59	5.05E+01	1.30E-01	4.23E-04	18.3	5.10E+06	3.46E+05	2.09E+05	9.90E-06	3.76E-07	2.02E-09
Ni63	4.13E+03	1.06E+01	3.47E-02	43.4	1.21E+07	8.20E+05	4.96E+05	3.41E-04	1.29E-05	6.99E-08
Np237	1.73E+01	7.10E-05	7.39E-03	0.74	2.06E+05	1.40E+04	8.46E+03	8.39E-05	5.08E-09	8.73E-07
Pa231	3.36E-05	3.34E-08	3.12E-04	0.211	5.88E+04	3.99E+03	2.41E+03	5.71E-10	8.38E-12	1.29E-07
Pb210	3.07E-03	6.00E-05	1.17E-07	448	1.25E+08	8.47E+06	5.12E+06	2.46E-11	7.09E-12	2.28E-14
Pu238	2.09E+02	2.26E-03	1.01E-02	17.4	4.85E+06	3.29E+05	1.99E+05	4.31E-05	6.87E-09	5.08E-08
Pu239	4.48E+03	6.19E-03	9.88E+00	2.11	5.88E+05	3.99E+04	2.41E+04	7.62E-03	1.55E-07	4.09E-04
Pu240	9.46E+02	2.45E-03	9.88E+00	2.16	6.02E+05	4.08E+04	2.47E+04	1.57E-03	6.00E-08	4.00E-04
Pu241	3.97E+03	5.19E-03	4.76E-04	107	2.98E+07	2.02E+06	1.22E+06	1.33E-04	2.57E-09	3.89E-10
Pu242	7.37E-02	3.41E-04	8.82E-09	2.21	6.16E+05	4.18E+04	2.53E+04	1.20E-07	8.16E-09	3.49E-13
Ra226	9.19E-03	1.80E-04	6.21E-07	0.228	6.36E+04	4.31E+03	2.61E+03	1.45E-07	4.18E-08	2.38E-10

Table 6-7. Sum of Fractions Based on Projected Inventory and Calculated Disposal Limits Assuming Intruder Protections End in 2278. (2 sheets)

Radionuclide	Initial Inventory (Ci)			Concentration Limit (Ci/m^3)	Disposal Limit (Ci)[a]			Fraction of Limit[b]		
	ILAW Glass	ETF LSW	SSW Total		ILAW Glass	ETF LSW	SSW Total	ILAW Glass	ETF LSW	SSW Total
Ra228	4.55E+01	1.13E+00	1.73E-04	1.87E+11	5.21E+16	3.53E+15	2.14E+15	8.73E-16	3.20E-16	8.09E-20
Rn222	9.18E-03	1.80E-04	6.20E-07	9.51E+05	2.65E+11	1.80E+10	1.09E+10	3.46E-14	1.00E-14	5.70E-17
Se79	1.41E+02	2.86E+00	5.41E-03	1.12	3.12E+05	2.12E+04	1.28E+04	4.52E-04	1.35E-04	4.22E-07
Sm151	2.02E-01	1.56E-05	2.48E-03	2.97E+04	8.28E+09	5.61E+08	3.40E+08	2.44E-11	2.78E-14	7.30E-12
Sn126	3.88E+02	1.67E+00	1.92E-02	0.0945	2.63E+04	1.79E+03	1.08E+03	1.47E-02	9.35E-04	1.78E-05
Sr90 [c]	1.22E+06	7.21E+01	2.18E+03	47.6	1.33E+07	9.00E+05	5.44E+05	9.19E-02	8.01E-05	4.01E-03
Tc99	2.64E+04	2.29E-01	2.13E+01	0.906	2.53E+05	1.71E+04	1.04E+04	1.05E-01	1.34E-05	2.06E-03
Th229	1.22E-02	2.19E-08	1.39E-03	0.419	1.17E+05	7.92E+03	4.79E+03	1.04E-07	2.77E-12	2.90E-07
Th230	3.61E-04	3.46E-07	1.36E-04	0.467	1.30E+05	8.83E+03	5.34E+03	2.77E-09	3.92E-11	2.55E-08
Th232	9.45E-08	2.17E-14	5.56E-09	0.0267	7.44E+03	5.05E+02	3.05E+02	1.27E-11	4.30E-17	1.82E-11
U232	1.25E-01	2.62E-07	2.01E-08	1.19	3.32E+05	2.25E+04	1.36E+04	3.77E-07	1.16E-11	1.48E-12
U233	9.93E+00	1.77E-05	7.37E-01	2.52	7.03E+05	4.76E+04	2.88E+04	1.41E-05	3.72E-10	2.56E-05
U234	3.02E+00	2.89E-03	7.35E-01	5.04	1.41E+06	9.53E+04	5.76E+04	2.15E-06	3.03E-08	1.28E-05
U235	1.22E-01	1.21E-04	7.38E-01	0.967	2.70E+05	1.83E+04	1.11E+04	4.53E-07	6.62E-09	6.67E-05
U236	9.57E-02	3.38E-05	5.87E-06	5.62	1.57E+06	1.06E+05	6.43E+04	6.11E-08	3.18E-10	9.13E-11
U238	2.71E+00	2.78E-03	7.37E-01	4.03	1.12E+06	7.62E+04	4.61E+04	2.41E-06	3.65E-08	1.60E-05
Zr93	8.05E-04	2.10E-07	2.77E-04	462	1.29E+08	8.73E+06	5.28E+06	6.25E-12	2.41E-14	5.24E-11
								Sum of Fractions		0.250

[a] Calculated disposal limits = Concentration Limit × As-Disposed Volume. Limits for waste stream activity assume an as-disposed volume and would vary for other volume estimates. The as-disposed volume of ILAW glass used for the activity limit is 278,797 m^3. The as-disposed volume of ETF-LSW used for the activity limit is 18,900 m^3. The as-disposed volume of SSW used for the activity limit is 11,435 m^3.

[b] Fraction of Limit = Initial Inventory / Disposal Limit

[c] Sr-90 inventory in ILAW glass is increased by 6.5× to be consistent with average concentration reported in RPP-RPT-57991 Rev 3 Table C-7.

ILAW = immobilized low-activity waste
SSW = solid secondary waste
ETF = Effluent Treatment Facility
LSW = Liquid solid waste

6.3 SENSITIVITY ANALYSIS

Sensitivity analyses were performed for all dose pathways. Sensitivity results are reported for only the Rural Pasture pathway because it is the exposure scenario that comes closest to the performance metric. The non-source stochastic variables in the model are defined in Table 6-8.

The uncertainty range for ***ILAW_Bulk_Density*** is derived from information in PNNL-15198, *Waste Form Release Calculations for the 2005 Integrated Disposal Facility Performance Assessment*, which uses a particle density of 2.68 g/cm^3 for ILAW glass. In Table 5 of that reference the range for LAWA44, LAWB45, LAWC22, and LAWABP1 is between 2.67 and 2.70 g/cm^3. Typical porosity for ILAW glass is 2 to 3% (PNNL-23711, *Physical, Hydraulic, and Transport Properties of Sediments and Engineered Materials Associated with Hanford Immobilized Low-Activity Waste*, page 4.5). This leads to a recommended dry bulk density for ILAW glass in Table 4.3 of PNNL-23711 of 2.63 g/cm^3.

The uncertainty range for ***ZGW*** uses the current depth to groundwater below the IDF (119.5 m) and applies an uncertainty multiplier to decrease the depth to groundwater by up to 15%. Decreasing the depth to groundwater decreases the mass of soil exhumed when the water well is installed, which increases the concentration of waste in the drill cuttings. Higher concentrations of waste in the drill cuttings increase the dose consequences.

The uncertainty range for ***SSW_Bulk_Density*** and ***OtherWaste_Bulk_Density*** are derived from the range of values reported for different grouts in the SSW data package (SRNL-STI-2016-00175, *Solid Secondary Waste Data Package Supporting Hanford Integrated Disposal Facility Performance Assessment*).

The uncertainty range for ***Soil_Bulk_Density*** values are derived from Table 7 in RPP-20621, *Far-Field Hydrology Data Package for the Integrated Disposal Facility Performance Assessment*, which has bulk density for sandy sediments between 1.52 and 1.98 g/cm^3 and 2.06 and 2.38 g/cm^3 for gravelly sediments.

Source term uncertainties are discussed in Section 3.2.2.

No uncertainty was included for the probability of intercepting waste, the well diameter, or the exposure factors, including the area contaminated by the drilling cuttings in each scenario. Additional uncertainty surrounding the duration of intruder protections is evaluated using sensitivity studies described in Section 6.2.

6.3.1 Rural Pasture Dose Pathway Sensitivity Analysis

Table 6-1 shows the main dose contributors to this pathway are SSW and ILAW glass. The doses come primarily from ^{99}Tc and ^{90}Sr (see Table 6-3). Table 6-9 shows that the greatest effect on the uncertainty in the rural pasture dose result is attributed to the uncertainty in the soil bulk density, which affects the radionuclide density as it is distributed after drilling. Figure 6-5 shows dose uncertainty for the ILAW glass waste stream for the milk dose from the Rural Pasture pathway. Its 95% value is about 50 mrem/yr, well below the 100 mrem/yr limit.

Table 6-8. Non-Source Stochastic Variables.

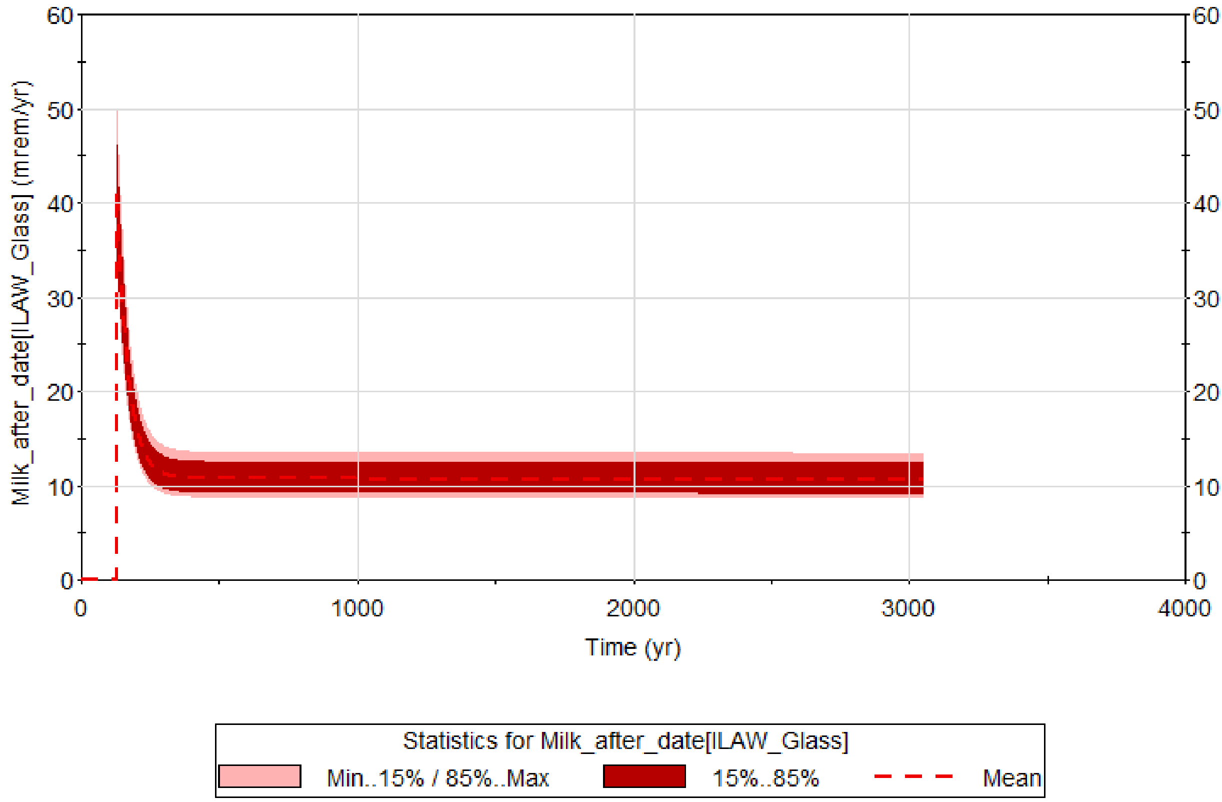
	Distribution Type	Lower Limit	Most Likely	Upper Limit
ILAW_Bulk_Density	Triangular	2.59 g/cm^3	2.63 g/cm^3	2.65 g/cm^3
ZGW (groundwater depth)	Triangular	101.5 m	119.5 m	119.5 m
SSW_Bulk_Density	Uniform	1.07 g/cm^3	—	1.98 g/cm^3
OtherWaste_Bulk_Density	Uniform	1.07 g/cm^3	—	1.98 g/cm^3
Soil_Bulk_Density	Uniform	1.52 g/cm^3	—	2.38 g/cm^3

ILAW = immobilized low-activity waste

Table 6-9. Sensitivity Table.

Result	Importance Measure	Correlation Coefficient	Regression Coefficient	Partial Coefficient
Soil_Bulk_Density	0.878	-0.993	-1.000	-0.993
WTP_SSW_volume_compact_other	0.101	0.263	-0.017	-0.136
WTP_SSW_volume_compact_HEPA	0.077	-0.053	0.014	0.121
WTP_SSW_volume_mult_nondebris	0.059	0.171	-0.002	-0.015
ILAW_Bulk_Density	0.049	-0.022	0.008	0.072
ZGW	0.038	-0.078	0.008	0.068
SSW_Bulk_Density	0.000	-0.054	-0.013	-0.113

Figure 6-5. Immobilized Low Activity Waste Glass Milk Dose Uncertainty.



6.3.2 Inventory Sensitivity Analysis

In order to develop waste acceptance criteria based on the inadvertent intruder scenario, a correlation between the inventory disposed in the facility and the resulting dose consequence is used. The inventory used in the inadvertent intruder analysis is the Case 7 inventory with WTP split fractions at the assumed time of first receipt (2021). In the inventory sensitivity cases, the IIDM was modified to multiply the initial disposed inventory by a scalar between 0.1 and 10. The IIDM was exercised to calculate the total dose. As can be seen in Table 6-10, the milk pathway dose for the rural pasture scenario is a linear function of the inventory multiplier. This makes sense since the suite of equations that are implemented in the model ultimately can be reduced to correlate dose directly to waste concentration. The linear correlation between inventory and dose allows for the scaling that was used in the concentration limits calculation.

Examination of the dose equations (Equations 1 to 26) reveals that all of the equations that calculate dose, as opposed to dose coefficients, are all of the form:

$$\text{Dose} = \text{Waste Concentration} \times \text{Dose Factors} \quad (28)$$

Equation 28 and its summation over all exposure pathways is a linear equation in terms of waste concentration.

The linear correlation between inventory and dose eliminates the need to explicitly evaluate inventory uncertainty because dose results can be directly scaled to inventory changes. Using the linear correlation between inventory and dose, the relationship can be used to calculate concentrations that, when scaled, result in matching the performance measures for the acute or chronic scenarios.

One assumption that could lead to a non-linearity in this analysis is the assumption that the density of the waste intersected by the drilling operation not does change with increased waste loading. With this assumption, the concentration in the tilled soil is directly proportional (i.e., linear) to the waste concentration leading to the proportional change in dose.

Table 6-10. Effect of Inventory Changes on Milk Pathway Dose at Year 3051 for the Rural Pasture.

Waste Stream	Base (mrem/yr)	2x (mrem/yr)	2x/Base	5x (mrem/yr)	5x/Base	10x (mrem/yr)	10x/Base
ILAW_Glass	10.5	21.1	2.0	52.7	5.0	105.4	10.0
ETF_LSW	0.023	0.045	2.0	0.11	4.8	0.23	10.0
SSW	1.09	2.18	2.0	5.45	5.0	10.9	10.0

7.0 REFERENCES

ASME NQA-1, 2008, *Quality Assurance Requirements for Nuclear Facility Applications*, American National Standards Institute/American Society of Mechanical Engineers, New York, New York.

ASME NQA-1a, 2009, *Addenda to Quality Assurance Requirements for Nuclear Facility Applications*, American National Standards Institute/American Society of Mechanical Engineers, New York, New York.

CHPRC-00175, 2015, GoldSim® Pro Software Management Plan, Rev. 2, CH2M HILL Plateau Remediation Company, Richland, Washington.

CHPRC-00180, 2015, GoldSim® Pro Functional Requirements Document, Rev. 1, CH2M HILL Plateau Remediation Company, Richland, Washington.

CHPRC-00224, 2015, GoldSim® Pro Software Test Plan, Rev. 1, INTERA, Inc., Richland, Washington.

CHPRC-00256, 2016, GoldSim® Pro Functional Requirements Traceability Matrix Version 11.1.5, Rev. 4, CH2M HILL Plateau Remediation Company, Richland, Washington.

CHPRC-00262, 2016, GoldSim® Pro Acceptance Test Report Version 11.1.5, Rev. 4, INTERA, Inc., Richland, Washington.

Comprehensive Environmental Response, Compensation, and Liability Act of 1980, 42 USC 9622, et seq.

DOE M 435.1-1, 2007, *Radioactive Waste Management Manual*, U.S. Department of Energy, Washington, D.C.

DOE O 435.1, 2001, *Radioactive Waste Management*, U.S. Department of Energy, Washington, D.C.

DOE O 414.1D, 2013, *Quality Assurance*, U.S. Department of Energy, Washington, D.C.

Hamel, W.F., R. G. Hastings, M. G. Cline, 2019, *Recommendations for Institutional Control Time Period for Conducting DOE Order 435.1 Performance Assessments at the Hanford Site*, U.S. Department of Energy Richland Operations Office and U.S. Department of Energy Office of River Protections, Richland, Washington.

ICRP, 2008, ICRP Publication 107: Nuclear Decay Data for Dosimetric Calculations, *Annals of the ICRP*, International Commission on Radiation Protection, Vol. 38, No. 3, pp. 7–96.

PNNL-15198, 2005, *Waste Form Release Calculations for the 2005 Integrated Disposal Facility Performance Assessment*, Pacific Northwest National Laboratory, Richland, Washington.

PNNL-23711, 2015, *Physical, Hydraulic, and Transport Properties of Sediments and Engineered Materials Associated with Hanford Immobilized Low-Activity Waste*, RPT-IGTP-004, Rev. 0, Pacific Northwest National Laboratory, Richland, Washington.

RPP-20621, 2004, *Far-Field Hydrology Data Package for the Integrated Disposal Facility Performance Assessment*, Rev. 0, CH2M HILL Hanford Group, Inc., Richland, Washington.

RPP-CALC-61015, 2017, *Inadvertent Intruder Dose Calculation for the Integrated Disposal Facility Performance Assessment*, Rev. 0, INTERA, Inc. prepared for Washington River Protection Solutions, LLC, Richland, Washington.

RPP-CALC-62058, 2018, *Waste Stream Inventory Calculations for the Integrated Disposal Facility Performance Assessment*, Rev. 0, Washington River Protection Solutions, LLC, Richland, Washington.

RPP-ENV-58562, 2016, *Inventory Data Package for the Integrated Disposal Facility Performance Assessment*, Rev. 3, Washington River Protection Solutions, LLC, Richland, Washington.

RPP-ENV-58813, 2016, *Exposure Scenarios for Risk and Performance Assessments in Tank Farms at the Hanford Site, Washington*, Rev. 1, Washington River Protection Solutions, LLC, Richland, Washington.

RPP-RPT-57991, 2019, *One System River Protection Project Integrated Flowsheet*, Rev. 3, Washington River Protection Solutions, LLC, Richland, Washington.

SRNL-STI-2016-00175, 2016, *Solid Secondary Waste Data Package Supporting Hanford Integrated Disposal Facility Performance Assessment*, Rev. 0, Savannah River National Laboratory, Aiken, South Carolina.

APPENDIX A

COMPARISON OF IIDM TO RPP-CALC-61015

LIST OF TABLES

APPENDIX A
COMPARISON OF IIDM TO RPP-CALC-61015

The original inadvertent intruder dose evaluation was performed using a spreadsheet calculation, which is documented in RPP-CALC-61015, *Inadvertent Intruder Dose Calculation for the Integrated Disposal Facility Performance Assessment*. This appendix compares the results of the spreadsheet calculation with the Inadvertent Intruder Dose Model (IIDM) to ensure that the IIDM was implemented correctly. Slight differences in the results are most probably due to: the spreadsheets intentional neglect of ingrowth of some daughters, small differences in some decay constants, and rounding. Modifications were made to the IIDM's source term so that the dose equations were supplied with the same radionuclide concentrations as in RPP-CALC-61015.

Table A-1 and Table A-2 show comparisons for Immobilized Low-Activity Waste Glass and Solid Secondary Waste, respectively, at the end of institutional controls (Year 2151) and after an additional 400 years (Year 2551). The results compare quite well and indicate that the exposure models in two independent calculations produce almost identical results. Coupled with the element-by-element check performed on this model, this gives an assurance that the exposure pathways are correctly implemented in the IIDM.

Table A-3 provides further assurance of the correctness of IIDM's implementation of the exposure paths by demonstrating that each exposure path's contribution to the total scenario dose match closely with RPP-CALC-61015's reported results. Only one case is presented as the only difference between cases is the source term and the previous two tables show that the comparison of different source terms provides similar results.

REFERENCE

RPP-CALC-61015, 2017, *Inadvertent Intruder Dose Calculation for the Integrated Disposal Facility Performance Assessment*, Rev. 0, INTERA, Inc. prepared for Washington River Protection Solutions, LLC, Richland, Washington.

[THIS PAGE INTENTIONALLY LEFT BLANK]

Table A-1. Results Comparison Inadvertent Intruder Dose Model and RPP-CALC-61015 for Immobilized Low-Activity Waste Glass.

	Decayed to 2151				Decayed to 2551			
	Acute (mrem)	Chronic (mrem/year)			Acute (mrem)	Chronic (mrem/year)		
	Well Driller Scenario	Rural Pasture Scenario	Suburban Garden Scenario	Commercial Farm Scenario	Well Driller Scenario	Rural Pasture Scenario	Suburban Garden Scenario	Commercial Farm Scenario
RPP-CALC-61015	8.83	49.4	21.4	0.03	6.67	15.2	12.8	0.02
Inadvertent Intruder Dose Model	8.77	49.35	21.4	0.03	6.63	15.15	12.7	0.02

Reference: RPP-CALC-61015, *Inadvertent Intruder Dose Calculation for the Integrated Disposal Facility Performance Assessment*.

Table A-2. Results Comparison Inadvertent Intruder Dose Model and RPP-CALC-61015 for Solid Secondary Waste.

	Decayed to 2151				Decayed to 2551			
	Acute (mrem)	Chronic (mrem/year)			Acute (mrem)	Chronic (mrem/year)		
	Well Driller Scenario	Rural Pasture Scenario	Suburban Garden Scenario	Commercial Farm Scenario	Well Driller Scenario	Rural Pasture Scenario	Suburban Garden Scenario	Commercial Farm Scenario
RPP-CALC-61015	4.81	11.1	2.9	2.5E-2	0.17	0.66	0.18	7.4E-4
Inadvertent Intruder Dose Model	4.76	11.1	2.9	2.5E-2	0.16	0.66	0.18	7.4E-4

Reference: RPP-CALC-61015, *Inadvertent Intruder Dose Calculation for the Integrated Disposal Facility Performance Assessment*.

Table A-3. Comparison of Exposure Routes Immobilized Low-Activity Waste Glass at Year 2151.

Scenario	Model	External	Inhalation	Soil Ingestion	Milk	Veggies
Well Driller	RPP-CALC-61015	3.54	4.39	0.89	not applicable	not applicable
	Inadvertent Intruder Dose Model	3.52	4.36	0.89	not applicable	not applicable
Rural Pasture	RPP-CALC-61015	2.05	0.28	0.47	49.4	not applicable
	Inadvertent Intruder Dose Model	2.04	0.28	0.45	46.6	not applicable
Suburban Garden	RPP-CALC-61015	1.2	0.16	0.36	not applicable	19.7
	Inadvertent Intruder Dose Model	1.2	0.16	0.36	not applicable	19.7
Commercial Farm	RPP-CALC-61015	1.82E-2	3.38E-3	9.00E-3	not applicable	not applicable
	Inadvertent Intruder Dose Model	1.82E-2	3.38E-3	9.00E-3	not applicable	not applicable

Reference: RPP-CALC-61015, *Inadvertent Intruder Dose Calculation for the Integrated Disposal Facility Performance Assessment*.

APPENDIX B

DOSE CONVERSION FACTOR ANALYSIS

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

APPENDIX B
DOSE CONVERSION FACTOR ANALYSIS

The Inadvertent Intruder dose model includes dose from several exposure pathways including: air inhalation, water ingestion, and external exposure to contaminated soil. Dose may also accumulate in crops and livestock grown in and around an area contaminated by the spreading of contaminated drill cuttings onto the ground surface.

The source of the dose conversion factors (DCFs) is RPP-ENV-58813, *Exposure Scenarios for Risk and Performance Assessments in Tank Farms at the Hanford Site, Washington*, Rev 1. The dose conversion factors for the external pathways listed in RPP-ENV-58813 Table N-2 incorporate the dose from short-lived progeny in the decay chains. The dose coefficients for air inhalation and water ingestion in RPP-ENV-58813 Rev 1 Table N-1 include the dose of all progeny produced in the body after consumption. It is ambiguous as to whether or not short-lived progeny in equilibrium at the time of consumption are included in those DCFs. Treatment at different sites has made different determinations on this point. The pessimistic approach adopted in this calculation is to assume that the effects of short-lived progeny that are not part of the IIDM model but would be present at the time of exposure because of radionuclide decay are not included in the DCF. Therefore, a supplemental calculation is needed to determine a dose multiplier that accounts for these short-lived progeny at the time of consumption. In the event that this assumption is incorrect, the derived doses using these dose multipliers will overestimate the calculated dose due to a future intrusion. In addition, derived concentration limits calculated using those calculated doses will be underestimated, resulting in waste concentration limits that are more restrictive than necessary to meet specific performance metrics.

B.1 CALCULATION APPROACH

GoldSim v11.1.5 (see Section 5.0) was used for this calculation. Initially all radionuclides included in the inadvertent intruder dose model (Table 3-2) were added to the species vector using the database of radionuclides included with the GoldSim Radionuclide Transport module. Then the database was used to add in all progeny of the radionuclides included in the initial list. Then air inhalation and water ingestion dose conversion factors from DOE-STD-1196-2011, *Derived Concentration Technical Standard* Tables A-1 and A-2 were added to the model. For air inhalation, the recommended absorption type from DOE-STD-1196-2011 Table 4 was used; if there was no recommendation, the value resulting in the greatest dose was applied. The initial inventory in the model was applied to yield a unit concentration (1 Ci/m^3) of each parent radionuclide, with no additional inventory of any progeny. GoldSim was used to simulate the decay and ingrowth of progeny and calculate concentrations of each in the unit volume as a function of time. The GoldSim calculation accounts for decay chain branching. The resulting concentrations were multiplied by the dose conversion factors to calculate radionuclide doses from the initial parent and its progeny. A dose multiplication factor was created by dividing the total dose (dose from parent plus progeny) by the dose from just the parent radionuclide. The peak value was used as a dose multiplier on the parent to account for the dose that would be attributable to the progeny.

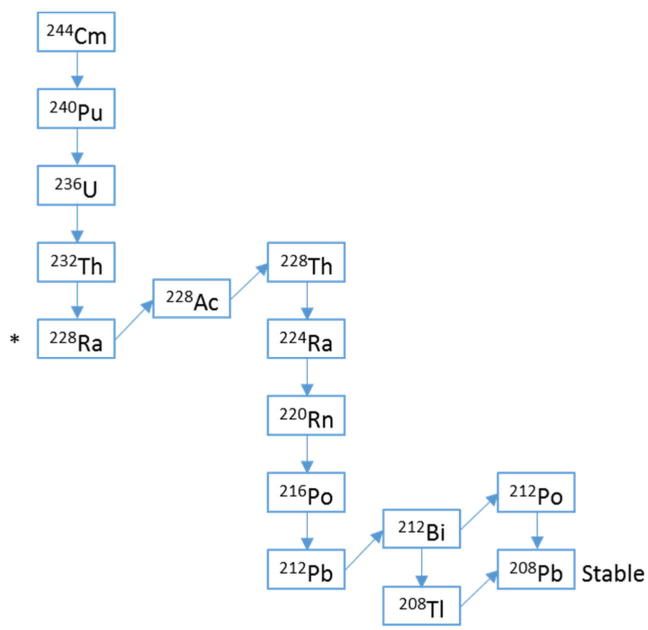
B.2 DECAY CHAINS

Dynamic calculations of decay chains for radionuclide decay and ingrowth can provide the updated inventories at any simulated time. Decay and ingrowth calculations are performed internally by the Radionuclide Transport module, which is a licensed option in the model software, GoldSim (see Section 5.0). RPP-ENV-58562, *Inventory Data Package for the Integrated Disposal Facility Performance Assessment,* identifies the 43 radionuclides that would be disposed of in the IDF. The 43 radionuclides include multiple members of decay chains, which are described in more detail below.

B.2.1 Curium-244

Curium-244 is the radionuclide with the largest atomic mass in the list of radionuclides included in RPP-ENV-58562. According to the database derived from “ICRP Publication 107: Nuclear Decay Data for Dosimetric Calculations” (ICRP 2008), ^{244}Cm has 13 daughter products that have a half-life between 0 years and 1×10^{12} years, before decaying to stable element lead (see Figure B-1). The end of the decay chain simulated in the GoldSim system model is ^{228}Ra. Radionuclides in the decay chain after ^{228}Ra have half-lives between fractions of a second up to 1.9 years and have been screened out for transport simulations. Excluding the shorter-lived radionuclides is consistent with the inventory data package (RPP-ENV-56582), which does not provide an inventory estimate for the subsequent members of the decay chain and is also consistent with the exposure scenario data package (RPP-ENV-58813), which rolls up the external exposure and air immersion dose conversion factors for the shorter-lived radionuclides into ^{228}Ra (RPP-ENV-58813 Table N-2).

Figure B-1. Curium-244 Decay Chain.

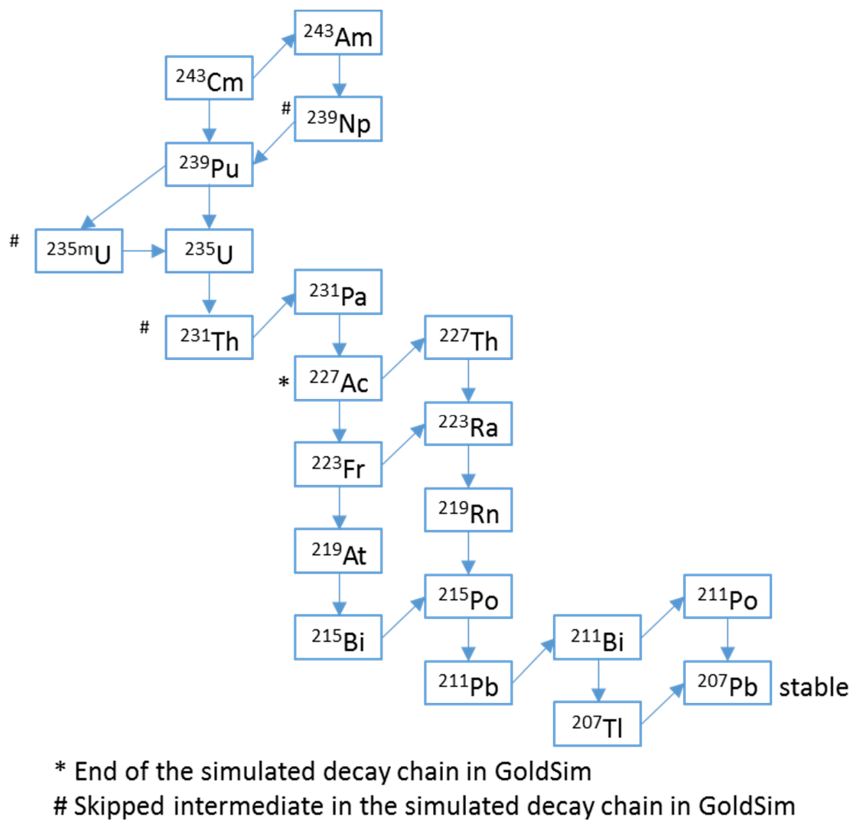


* End of the simulated decay chain in GoldSim

B.2.2 Curium-243

Curium-243 is the radionuclide with the second largest atomic mass in the list of radionuclides included in RPP-ENV-58562. According to the database derived from ICRP Publication 107, ^{243}Cm has 19 daughter products that have a half-life between 0 years and 1×10^{12} years, before decaying to stable element lead (see Figure B-2). The end of the decay chain simulated in the GoldSim system model is ^{227}Ac but the model excludes some intermediate daughter products with short half-lives. Radionuclides in the decay chain after ^{227}Ac have half-lives between fractions of a second up to 11.4 days and have been screened out for transport simulations. Excluding the shorter-lived radionuclides is consistent with the inventory data package (RPP-ENV-56582), which does not provide an inventory estimate for the subsequent members of the decay chain and is also consistent with the exposure scenario data package (RPP-ENV-58813), which rolls up the external exposure and air immersion dose conversion factors for the shorter-lived radionuclides into ^{227}Ac (RPP-ENV-58813 Table N-2).

Figure B-2. Curium-243 Decay Chain.

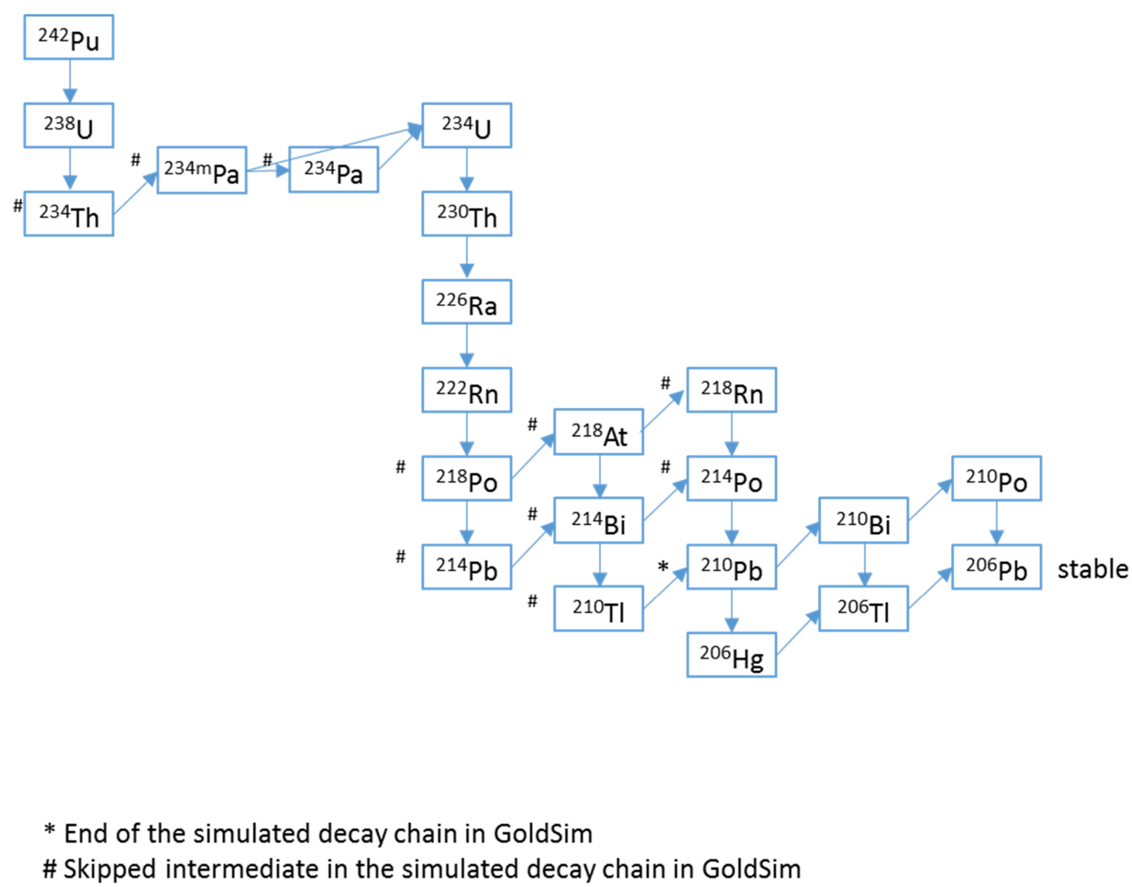


B.2.3 Plutonium-242

Plutonium-242 is the radionuclide with the next largest atomic mass in the list of radionuclides included in RPP-ENV-58562 that is not also a daughter product of another radionuclide in the inventory list. According to the database derived from ICRP Publication 107, ^{242}Pu has

20 daughter products that have a half-life between 0 years and 1×10^{12} years, before decaying to stable element lead (see Figure B-3). The end of the decay chain simulated in the GoldSim system model is ^{210}Pb, but the model excludes some intermediate daughter products with short half-lives. Radionuclides in the decay chain after ^{210}Pb have half-lives between a few seconds and up to 5 days and have been screened out for transport simulations. Excluding the shorter-lived radionuclides is consistent with the inventory data package (RPP-ENV-56582), which does not provide an inventory estimate for the intermediate short-lived radionuclides and subsequent members of the decay chain beyond ^{210}Pb. Truncating the simulated decay chain at ^{210}Pb is also consistent with the exposure scenario data package (RPP-ENV-58813), which rolls up the external exposure and air immersion dose conversion factors for the shorter-lived radionuclides into ^{210}Pb (RPP-ENV-58813 Table N-2). Note that in RPP-ENV-58813 the dose conversion factor for ^{226}Ra includes the dose contributions for the short-lived radionuclides between ^{226}Ra and ^{210}Pb.

Figure B-3. Plutonium-242 Decay Chain.

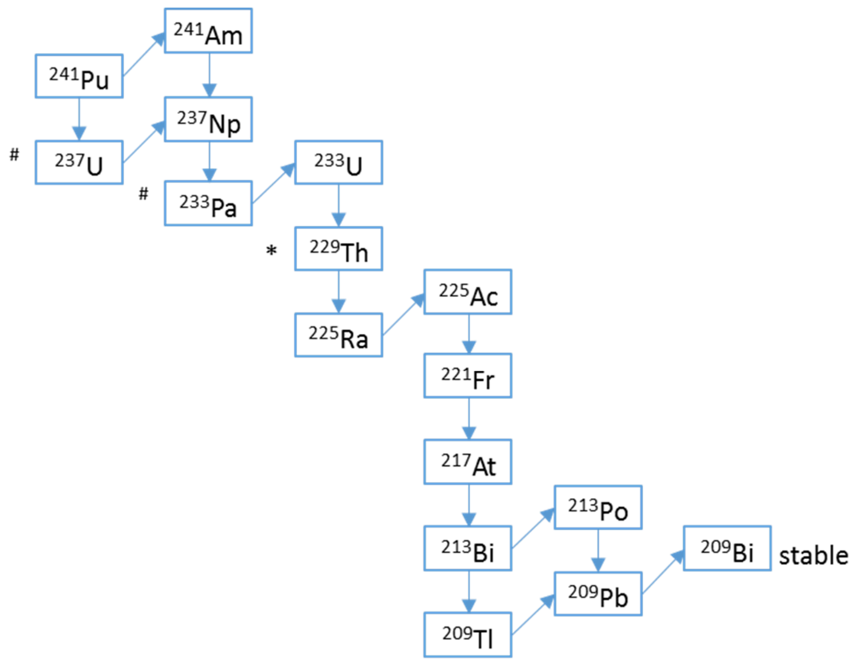


B.2.4 Plutonium-241

Plutonium-241 is the radionuclide with the next largest atomic mass in the list of radionuclides included in RPP-ENV-58562 that is not also a daughter product of another radionuclide in the inventory list. According to the database derived from ICRP Publication 107, ^{241}Pu has

14 daughter products that have a half-life between 0 years and 1×10^{12} years, before decaying to stable element bismuth (see Figure B-4). The end of the decay chain simulated in the GoldSim system model is ^{229}Th, but excludes some intermediate daughter products with short half-lives. Radionuclides in the decay chain after ^{229}Th have half-lives between fractions of a second and up to 14.9 days and have been screened out for transport simulations. Excluding the shorter-lived radionuclides is consistent with the inventory data package (RPP-ENV-56582), which does not provide an inventory estimate for the intermediate short-lived radionuclides and subsequent members of the decay chain beyond ^{229}Th. Truncating the simulated decay chain at ^{229}Th is also consistent with the exposure scenario data package (RPP-ENV-58813), which rolls up the external exposure and air immersion dose conversion factors for the shorter-lived radionuclides into ^{229}Th (RPP-ENV-58813 Table N-2).

Figure B-4. Plutonium-241 Decay Chain.



* End of the simulated decay chain in GoldSim

\# Skipped intermediate in the simulated decay chain in GoldSim

B.2.5 Other Radionuclide Considerations

The initial inventory in RPP-ENV-58562 also includes two additional radionuclides that are decayed to daughters tracked in the GoldSim system model, ^{238}Pu and ^{93}Zr.

^{238}Pu decays into ^{234}U, which is then decayed according to the chain illustrated in Figure B-3.

^{93}Zr decays into ^{93m}Nb, which subsequently decays to stable niobium.

^{113m}Cd decays into ^{113}Cd, but ^{113}Cd has a half-life greater than 1×10^{12} years and is not included in the transport model. ^{113}Cd decays to stable indium.

^{137}Cs decays into ^{137m}Ba, but ^{137m}Ba has a half-life that is less than 2 years and is not included in the transport model. The initial ^{137m}Ba inventory in RPP-ENV-58562 is neglected for all closure calculations. The exposure scenario data package (RPP-ENV-58813) rolls up the external exposure and air immersion dose conversion factors for ^{137m}Ba into ^{137}Cs (RPP-ENV-58813 Table N-2). ^{137m}Ba decays to stable barium.

^{152}Eu decays into ^{152}Gd, ^{148}Sm, and ^{144}Nd, but the primary daughter ^{152}Gd has a half-life that is greater than 1×10^{14} years so it and its decay products are not included in the transport model. These decay chains decay to stable samarium or cerium, depending on decay path.

^{126}Sn decays into ^{126}Sb and ^{126m}Sb, but both of these radionuclides have half-lives that are less than 2 years and are not included in the transport model. The exposure scenario data package (RPP-ENV-58813) rolls up the external exposure and air immersion dose conversion factors for ^{126}Sb and ^{126m}Sb into ^{126}Sn (RPP-ENV-58813 Table N-2). ^{126}Sb decays to stable tellurium.

^{90}Sr decays into ^{90}Y, but ^{90}Y has a half-life that is less than 1 day and is not included in the transport model. The initial ^{90}Y inventory in RPP-ENV-58562 is neglected for all closure calculations. The exposure scenario data package (RPP-ENV-58813) rolls up the external exposure and air immersion dose conversion factors for ^{90}Y into ^{90}Sr (RPP-ENV-58813 Table N-2). ^{90}Y decays to stable zirconium.

^{232}U decays to ^{228}Th, which decays as illustrated in Figure B-1. Similar to ^{228}Ra, the daughter products in the decay chain after ^{232}U have very short half-lives and have been screened out for transport simulations. The exposure scenario data package (RPP-ENV-58813) rolls up the external exposure and air immersion dose conversion factors for ^{232}U decay products into ^{232}U (RPP-ENV-58813 Table N-2).

Radionuclides that are included in the GoldSim system model that decay to stable elements are: ^{14}C, ^{60}Co, ^{154}Eu, ^{155}Eu, ^{3}H, ^{129}I, ^{59}Ni, ^{63}Ni, ^{79}Se, ^{151}Sm, and ^{99}Tc.

RPP-ENV-58562 provides initial inventories for ^{106}Ru, ^{125}Sb, and ^{134}Cs. The half-life of ^{106}Ru and its decay products (^{106}Rh) are less than 1 year and ^{106}Ru and ^{106}Rh have been screened out for transport calculations. The half-life of ^{125}Sb and its decay product (^{125m}Te) are less than

3 years and ^{25}Sb and ^{125m}Te have been screened out for transport calculations. The half-life of ^{134}Cs is less than 3 years and ^{134}Cs has been screened out for transport calculations.

B.3 RESULTS

The analysis of the decay chains indicated that may of the radionuclides in the initial list of radionuclides did not need dose conversion factors that included the dose from short-lived progeny. Radionuclides that did not require a dose conversion factor were eliminated from the computation because:

- The radionuclide decayed to a stable element
- The radionuclide decayed to a radioactive element with a half-life that exceeds 1E12 years
- The radionuclide's next progeny was also simulated in the initial inventory and therefore was already included in the dose calculation.

In addition, some calculations only considered a subset of the decay chain. Figures B-1 through B-4 identify when an intermediate decay product (indicated with a #) were included in the dose of a parent radionuclide. Intermediate decay products are decay products of a parent radionuclide but are short-lived themselves but decay into a radionuclide that is also included in the original inventory list.

The analysis of water ingestion and air inhalation dose coefficients to include decay products was performed for ^{227}Ac, ^{243}Am, ^{137}Cs, ^{237}Np, ^{210}Pb, ^{239}Pu, ^{241}Pu, ^{228}Ra, ^{222}Rn, (^{226}Ra), ^{126}Sn, ^{90}Sr, ^{229}Th, ^{232}U, ^{235}U and ^{238}U. Note the analysis does not exclude the dose from ^{222}Rn and its progeny in air; however, the dose conversion factors for ^{222}Rn are all zero, so the dose multiplier to account for progeny of ^{222}Rn is applied to ^{226}Ra.

The results of the analysis are shown in Table B-1. To calculate the air inhalation and water ingestion doses from these radionuclides the consumed concentration should be multiplied by the parent DCF for the applicable pathway and then also be multiplied by the appropriate value from Table B-1 to include the effects of progeny.

Table B-1. Dose Conversion Factor Multipliers for Radionuclides with Short-Lived Progeny that are Not Included in the Dose Calculation.

Species ID	*Atomic Mass*	*Half-life*	*Air Inhalation*	*Water Ingestion*
Ac227	227.028	21.772 yr	1.118	1.595
Am243	243.061	7370 yr	1	1.005
Cs137	136.907	30.167 yr	1	1
Np237	237.048	2.144e+006 yr	1	1.011
Pb210	209.984	22.2 yr	4.268	2.728
Pu239	239.052	24110 yr	1	1
Pu241	241.057	14.35 yr	1	1
Ra228	228.031	5.75 yr	23.33	1.242
Ra226	226.025	1600 yr	1.009	1.001
Sn126	125.908	2.3e+005 yr	1.003	1.087
Sr90	89.9077	28.79 yr	1.043	1.1
Th229	229.032	7340 yr	1.213	1.468
U232	232.037	68.9 yr	6.541	1.649
U235	235.044	7.04e+008 yr	1	1.008
U238	238.051	4.468e+009 yr	1.003	1.089

B.4 REFERENCES

DOE-STD-1196-2011, 2011, *Derived Concentration Technical Standard*, U.S. Department of Energy, Washington, D.C.

ICRP, 2008, "ICRP Publication 107: Nuclear Decay Data for Dosimetric Calculations," *Annals of the ICRP*, International Commission on Radiation Protection, Vol. 38, No. 3, pp. 7–96.

RPP-ENV-58562, 2016, *Inventory Data Package for the Integrated Disposal Facility Performance Assessment*, Rev. 3, Washington River Protection Solutions, LLC, Richland, Washington.

RPP-ENV-58813, 2016, *Exposure Scenarios for Risk and Performance Assessments in Tank Farms at the Hanford Site, Washington*, Rev. 1, Washington River Protection Solutions, LLC, Richland, Washington.

1.0 SELECTION OF TECHNICAL STAFF

The selection of the technical staff for revision 2 and 3 are discussed. Revision 3 is a computational update to extend the duration of intruder protections beyond the 100 year institutional control period evaluated in Revisions 1 and 2. The methology for the update in Revision 3 is unchanged from Revision 2.

1.1 Technical Staff for Revisions 1 and 2

1.1.1 Originator

Glenn Taylor was the originator for revisions 1 and 2. At the time of those revisions, Glenn had more than years of engineering experience, the last 12 of which was in a Performance Assessment group performing work related to this calculation. Glenn's extensive experience in developing and reviewing GoldSim (and other software) models and applying statistical methods to evaluate model results made him an ideal choice for this role on those EMCFs. He was selected to be the originator of the original revision and the update. As originator, Glenn did require special software (GoldSim Pro version 11.1.5) to be installed onto his machine and this was done according to the user requirements set forth by the software owner (see Attachment 1, Section 2).

Glenn retired prior to Revision 3, but the methodology and models used in Revision 3 are unchanged from Revision 2, only parameter values are modified.

1.1.2 Checker

Pat Lee was the lead checker for revisions 1 and 2. At the time of those revisions, Pat had 18 years of GoldSim model building experience for conducting performance assessment. Pat Lee directed some of the technical changes based on review comments received during external reviews of the PA. He was the lead coordinator of that review and therefore had the specific knowledge to direct the technical changes that are included in those revisions.

1.1.3 Senior Reviewer

The calculations and approach for revisions 1 and 2 were developed in a separate EMCF (RPP-CALC-61015) and this EMCF implements those calculations in other modeling frameworks. The originator, checker, and senior reviewer of RPP-CALC-61015 approved the conceptual and mathematical models implemented in RPP-CALC-61015. Since the conceptual and numerical models applied in RPP-CALC-61254 are equivalent to those in RPP-CALC-61015, a separate senior review was not performed. Instead, a numerical comparison demonstrating that the two reports are numerically equivalent is performed. Therefore, there is no specific Senior Reviewer to oversee that the calculation methodology was developed consistently with a prescribed conceptual model. That review was already performed for RPP-CALC-61015. The checker, who is also an experienced performance assessment modeler and technical reviewer, confirmed that the methodology approved by the Senior Review for RPP-CALC-61015 is implemented correctly in RPP-CALC-61254.

1.2 Technical Staff for Revision 3

1.2.1 Originator

The conceptual and numerical models used to develop revision 3 are unchanged from the Revision 2. Revision 3 performs minor editorial updates and a revision to calculations performed in Section 6.2. The revised calculations change input values for the duration of intruder protections credited in the model and outputs the results with the revised input conditions. No new calculation methodology is invoked. Therefore, pat Lee, who is involved in Revisions 2 and 3 as a checker of the work, performed the updated calculations.

Pat Lee has 19 years of performance assessment modeling experience for high-level and low-activity waste. Based on his work supporting the performance assessment for the high-level waste disposal facility at Yucca Mountain and the performance assessment for the Hanford Integrated Disposal Facility, he was asked to be part of an international peer review team for a low-level waste disposal facility seeking a license to construct a disposal facility in Canada.

1.2.2 Checker

Revision 3 documents additional results in Section 6.2. Specifically, calculations for reporting disposal limits were re-run with different assumed durations of intruder protections. There is no revision to the calculations reported in Section 6.1 or 6.3. Extending the duration of intruder protections requires no changes to the conceptual or mathematical models and limited changes to model input values. Checking for Revision 3 confirms that the input parameter values are changed correctly and that the revised results are documented correctly.

1.2.3 Senior Reviewer

The calculations and approach for revisions 1, 2 and 3 were developed in a separate EMCF (RPP-CALC-61015) and this EMCF implements those calculations in other modeling frameworks. For revision 3, the only new calculations that are performed require parameter changes to the duration of credited intruder protections. This revision does not require a change to the conceptual or mathematical models. The checker, who is also an experienced performance assessment modeler and technical reviewer, confirmed that the methodology approved by the Senior Review for RPP-CALC-61015 is implemented correctly in RPP-CALC-61254.

2.0 Checker Log(s)

2.1 Revision 2 Checker Logs

Checker Logs for Revision 2 apply to the implementation of the conceptual and mathematical models discussed in Revision 2 and 3 of this calculation report. In revision 3, only Section 6.2 results are updated between Revision 2 and revision 3. Therefore, checker logs for Revision 2 are maintained with this revision.

2.2 Revision 3 Checker Logs

Revision 3 updates the calculations reported in Section 6.2 with extra results. The conceptual and mathematical models are unchanged from Revision 2. The checker confirmed that the updated analyses varied the parameters necessary to perform the updated calculation and confirmed that no additional changes to the model were necessary or performed.

RPP-CALC-61254, Rev. 3 – Attachment I

CHECKER LOG FOR SYSTEM MODELS

Project and Environmental Model Calculation Specific Information:

Project: T2C24 (2017 IDF PA)

Responsible Manager or Designee, and Position: Paul Rutland, Manager

Originating Group or Department: Closure and Interim Measures | Date: 3/29/2018

Environmental Model Calculation File Report and Revision No.: RPP-CALC-61254 Rev 2

Environmental Model Calculation File Title: Inadvertent Intruder Dose Calculation Update for the Int

Check: Environmental Model Calculation File Document Elements

	List where Information is Described *(EMCF Section Number)*	Is the Description Correct and Sufficient? Yes	No	If No, describe deficiency:	Checker Signature
Purpose	section 1.0	☒	○		[signature]
Calculation Approach	section 3.0	☒	○		[signature]
Assumptions	section 4.0	☒	○		[signature]
Inputs *(reference detailed checklist below as well)*	Goldsim file section 4.0	☒	○		[signature]
Equations used	section 3.0	☒	○		[signature]
Conclusions	section 6.0 (minimal)	☒	○		[signature]
References	section 7.0	☒	○		[signature]

Check: Controlled Software Use

	List where Information is Described *(EMCF Section Number)*	Is the Criteria Met? Yes	No	If No, describe deficiency:	Checker Signature
Software used in the calculation is appropriate for application	Section 5.0	◉	○		[signature]
Software use is approved and properly validated in accordance with approved software management plan	Section 5.0	◉	○		[signature]
Software use is properly documented	Section 5.0	◉	○		[signature]
Verify data was input correctly to approved software or spreadsheets	Throughout document and in IDFPA_Intruder_Model R2v2.000.gsm	◉	○		[signature]
If a spreadsheet is used, verify inputs/outputs of calculation(s) to ensure accuracy	Not applicable, not a spreadsheet.	○	☒	Not applicable, not a spreadsheet.	[signature]

Check: Perform Calculation to Verify Free of Errors

	Describe how calculation was performed	List any discrepancies encountered *(If none, enter "None")*	Checker Signature
Perform the environmental model calculation as described to verify it is free of errors	100% review of the model and source input verification.	All discrepancies were communicated to originator and addressed to checker satisfaction.	[signature]

Page 1 of 3 A-6007-210 (REV 2)

RPP-CALC-61254, Rev. 3 – Attachment I

CHECKER LOG FOR SYSTEM MODELS (Continued)			
Model Parameter Type	(1) Input Documented in EMCF?	(2) Values checked against parameter source?	(3) Input in EMCF matches model input file(s)?
Check: Process Model Parameterization *(Specify Values and Units in Each Column)*			
Model Parameter Type	(1) Input Documented in EMCF?	(2) Values checked against parameter source?	(3) Input in EMCF matches model input file(s)?
Simulation duration	Yes, 1030 years	Yes, DOE O 435.1	Yes
Simulation time step control	Yes, in model file	Not applicable, user specification	Not specifically documented in EMCF, nor does it need to be.
Simulated chemical list	Not applicable, no chemicals simulated	Not applicable, no chemicals simulated	Not applicable, no chemicals simulated
Simulated radionuclides list	Yes, Table 3-2	Derived from software database	Yes
External model components identified and documented or referenced	Not applicable, no external model components	Not applicable, no external model components	Not applicable, no external model components
External model linkages *(dynamic link libraries, etc.)* checked	Not applicable, no external model linkages	Not applicable, no external model linkages	Not applicable, no external model linkages
If model is probabilistic, stochastic distributions are defined and consistent	Yes, Section 3.2 and Table 6-6, also documented in model file comments	Yes. Cited sources are reasonable.	Yes. Documented values are verified.
Input units are declared and of correct dimensionality	Yes, GoldSim enforces dimensional consistency	Input units checked against sources and verified	Documented units verified
Equations used in the model file are presented in EMCF and consistent	Yes, Section 3.2 documents equations used, model file also includes similar documentation	Implemented equations are derived from mass balance and also RPP-ENV-58813 Rev 1.	Yes. Verified equations in model match text.
Check: Further Checks *(Record additional checks performed and results)*			
Model Parameter Type	(1) Input Documented in EMCF?	(2) Values checked against parameter source?	(3) Input in EMCF matches model input file(s)?
Inventory: Radiological Decay Correction. Does the inventory *(source term)* include radionuclides, and if so, is it decay-corrected to the appropriate date for inclusion as a source?	Radionuclide decay of initial inventory to common dates is addressed in source, RPP-CALC-62058.	Confirmed against Tables 7-1 and 7-7 in RPP-CALC-62058.	Confirmed against Tables 7-1 and 7-7 in RPP-CALC-62058.

[signature] 4/4/18

RPP-CALC-61254, Rev. 3 – Attachment I

CHECKER LOG FOR SYSTEM MODELS (Continued)

Model Parameter Type	(1) Input Documented in EMCF?	(2) Values checked against parameter source?	(3) Input in EMCF matches model input file(s)?
Mass balance	The implementation for decaying radionuclide inventory would result in a model mass balance. Radionuclide decay is handled by the Radionuclide Transport module with no subsequent transport out of the cell pathway performing the decay calculations. There is no transport between other components and no scaling of inventory to alter the balance of mass in the system.	Not applicable.	Not applicable.
Model revisions	The GoldSim model was checked in its entirety. All previous errors identified in the model were corrected and all new changes to the previously checked model were reviewed. A few iterations were necessary to correct any issues identified by the checker / senior reviewer.	Not applicable.	Not applicable.

[signature] 4/4/18

Page 3 of 3 A-6007-210 (REV 2)

RPP-CALC-61254, Rev. 3 – Attachment I

CHECKER LOG FOR SYSTEM MODELS

Project and Environmental Model Calculation Specific Information:

Project: T2C24 (2017 IDF PA)

Responsible Manager or Designee, and Position: Paul Rutland, Manager

Originating Group or Department: Closure and Interim Measures | Date: 11/06/2019

Environmental Model Calculation File Report and Revision No.: RPP-CALC-61254, Rev 3

Environmental Model Calculation File Title: Inadvertent Intruder Dose Calculation Update for the ...

Check: Environmental Model Calculation File Document Elements

	List where Information is Described *(EMCF Section Number)*	Is the Description Correct and Sufficient? Yes	No	If No, describe deficiency:	Checker Signature
Purpose	1.0 Purpose	◉	○		[signature]
Calculation Approach	3.0 Methodology	◉	○		[signature]
Assumptions	4.0 Assumptions and inputs	◉	○		[signature]
Inputs *(reference detailed checklist below as well)*	4.0 Assumptions and inputs, GoldSim File	◉	○		[signature]
Equations used	3.0 Methodology	◉	○		[signature]
Conclusions	6.0 Calculation, Results and Conclusions	◉	○		[signature]
References	7.0 References	◉	○		[signature]

Check: Controlled Software Use

	List where Information is Described *(EMCF Section Number)*	Is the Criteria Met? Yes	No	If No, describe deficiency:	Checker Signature
Software used in the calculation is appropriate for application	5.0 Software applications	◉	○		[signature]
Software use is approved and properly validated in accordance with approved software management plan	5.0 Software applications, Attachment 1	◉	○		[signature]
Software use is properly documented	3.0 Methodology, Attachment 1	◉	○		[signature]
Verify data was input correctly to approved software or spreadsheets	4.0 Assumptions and Inputs	◉	○		[signature]
If a spreadsheet is used, verify inputs/outputs of calculation(s) to ensure accuracy	N/A not a spreadsheet	○	◉	N/A not a spreadsheet	[signature]

Check: Perform Calculation to Verify Free of Errors

	Describe how calculation was performed	List any discrepancies encountered *(If none, enter "None")*	Checker Signature
Perform the environmental model calculation as described to verify it is free of errors	Ran the system model and compared outputs with results	None	[signature]

RPP-CALC-61254, Rev. 3 – Attachment I

CHECKER LOG FOR SYSTEM MODELS (Continued)			
	Describe how calculation was performed	List any discrepancies encountered *(If none, enter "None")*	Checker Signature
	presented in document. Only new tables and figures were checked as the figures and tables present in Rev. 2 had already been verified and remained unchanged.		

Check: Process Model Parameterization *(Specify Values and Units in Each Column)*

Model Parameter Type	(1) Input Documented in EMCF?	(2) Values checked against parameter source?	(3) Input in EMCF matches model input file(s)?
Simulation duration	No. Simulation duration is long enough to capture the intrusion times discussed in the EMCF	yes	yes. Simulation duration is long enough to capture the intrusion times discussed in the EMCF
Simulation time step control	N/A, User specification	N/A, User specification	N/A, User specification
Simulated chemical list	N/A, no chemicals simulated	N/A, no chemicals simulated	N/A, no chemicals simulated
Simulated radionuclides list	Yes, Table 3-2	Derived from GoldSim database	yes
External model components identified and documented or referenced	N/A, no external components	N/A, no external components	N/A, no external components
External model linkages *(dynamic link libraries, etc.)* checked	N/A, no external linkages	N/A, no external linkages	N/A, no external linkages
If model is probabilistic, stochastic distributions are defined and consistent	Not checked; unchanged from Rev.2, which was already verified.	Not checked; unchanged from Rev.2, which was already verified.	Not checked; unchanged from Rev.2, which was already verified.
Input units are declared and of correct dimensionality	Yes. GoldSim enforces dimensional consistency	Input units checked against sources and verified	Documented units verified
Equations used in the model file are presented in EMCF and consistent	Not checked; unchanged from Rev.2, which was already verified.	Not checked; unchanged from Rev.2, which was already verified.	Not checked; unchanged from Rev.2, which was already verified.

Check: Further Checks *(Record additional checks performed and results)*

Model Parameter Type	(1) Input Documented in EMCF?	(2) Values checked against parameter source?	(3) Input in EMCF matches model input file(s)?
Inventory: Radiological Decay Correction. Does the inventory *(source term)* include radionuclides, and if so, is it	Not checked; unchanged from Rev.2, which was already verified.	Not checked; unchanged from Rev.2, which was already verified.	Not checked; unchanged from Rev.2, which was already verified.

CHECKER LOG FOR SYSTEM MODELS (Continued)			
Model Parameter Type	(1) Input Documented in EMCF?	(2) Values checked against parameter source?	(3) Input in EMCF matches model input file(s)?
decay-corrected to the appropriate date for inclusion as a source?			
Inventory: Mass Balance. Is mass balance of inventory maintained in system model calculation(s)?	Not checked; unchanged from Rev.2, which was already verified.	Not checked; unchanged from Rev.2, which was already verified.	Not checked; unchanged from Rev.2, which was already verified.

3.0 Software Installation and Checkout Forms

CHPRC SOFTWARE INSTALLATION AND CHECKOUT FORM

Software Owner Instructions:
Complete Fields 1-13, then run test cases in Field 14. Compare test case results listed in Field 15 to corresponding Test Report outputs. If results are the same, sign and date Field 19. If not, resolve differences and repeat above steps.

Software Subject Matter Expert Instructions:
Assign test personnel. Approve the installation of the code by signing and dating Field 21, then maintain form as part of the software support documentation.

GENERAL INFORMATION:

1. Software Name: Goldsim Software Version No.: 11.1.5

EXECUTABLE INFORMATION:

2. Executable Name (include path):
   Directory Path Intentionally Obscured \GoldSim.exe
3. Executable Size (bytes): 3138 KB

COMPILATION INFORMATION:

4. Hardware System (i.e., property number or ID):
   vendor compiled
5. Operating System (include version number):

INSTALLATION AND CHECKOUT INFORMATION:

6. Hardware System (i.e., property number or ID):
   wf34039
7. Operating System (include version number):
   Windows 7 Enterprise SP1
8. Open Problem Report? (●) No ( ) Yes PR/CR No.

TEST CASE INFORMATION:

9. Directory/Path:
   Directory Path Intentionally Obscured \FirstModel.gsm
10. Procedure(s):
    in accordance with CHPRC-00224
11. Libraries:
    na
12. Input Files:
    na
13. Output Files:
    na
14. Test Cases:
    GS-ITC-1
15. Test Case Results:
    matched expectations
16. Test Performed By: Glenn Taylor
17. Test Results: (●) Satisfactory, Accepted for Use ( ) Unsatisfactory
18. Disposition (include HISI update):

Page 1 of 2 A-6005-149 (REV 0)

CHPRC SOFTWARE INSTALLATION AND CHECKOUT FORM (continued)

1. Software Name: Goldsim Software Version No.: 11.1.5

Prepared By:

19. ______ Software Owner (Signature) ______ Print ______ Date

20. Test Personnel:

Glenn Taylor

Digitally signed by Glenn Taylor
DN: cn=Glenn Taylor, o=Tank Operations Contractor, ou=Closure and Interim Measures, email=glenn_a_taylor@rl.gov, c=US
Date: 2016.08.22 08:20:48 -07'00'

Sign ______ Print ______ Date

Sign ______ Print ______ Date

Sign ______ Print ______ Date

Approved By:

21. ______ Software SME (Signature) ______ Print ______ Date

 A-6005-149 (REV 0)

CHPRC SOFTWARE INSTALLATION AND CHECKOUT FORM

Software Owner Instructions:
Complete Fields 1-13, then run test cases in Field 14. Compare test case results listed in Field 15 to corresponding Test Report outputs. If results are the same, sign and date Field 19. If not, resolve differences and repeat above steps.

Software Subject Matter Expert Instructions:
Assign test personnel. Approve the installation of the code by signing and dating Field 21, then maintain form as part of the software support documentation.

GENERAL INFORMATION:

1. Software Name: GoldSim Pro w/ Radionuclide Tranport Software Version No.: 11.1.5

EXECUTABLE INFORMATION:

2. Executable Name (include path):
[redacted]GoldSim.exe
3. Executable Size (bytes): 3,138 KB

COMPILATION INFORMATION:

4. Hardware System (i.e., property number or ID):
Not Applicable (Commercial installer)
5. Operating System (include version number):
Not Applicable (Commercial installer)

INSTALLATION AND CHECKOUT INFORMATION:

6. Hardware System (i.e., property number or ID):
WF40244
7. Operating System (include version number):
Windows 10 Enterprise Version 1709 (Build 16299.492)
8. Open Problem Report? ◉ No ◯ Yes PR/CR No. N/A

TEST CASE INFORMATION:

9. Directory/Path:
[redacted]FirstModel.gsm
10. Procedure(s):
CHPRC-00224 Section 3.3
11. Libraries:
Radionulcide Transport Module
12. Input Files:
Not Applicable
13. Output Files:
Not Applicable
14. Test Cases:
GS-ITC-1
15. Test Case Results:
Results visually compared to expected volume output in the test case description.
16. Test Performed By: Kearn Patrick Lee
17. Test Results: ◉ Satisfactory, Accepted for Use ◯ Unsatisfactory
18. Disposition (include HISI update):
Not applicable

RPP-CALC-61254, Rev. 3 – Attachment I

CHPRC SOFTWARE INSTALLATION AND CHECKOUT FORM (continued)		
1. Software Name: GoldSim Pro w/ Radionuclide Tranport		Software Version No.: 11.1.5
Prepared By:		
19. WILLIAM NICHOLS (Affiliate) Digitally signed by WILLIAM NICHOLS (Affiliate) Date: 2018.06.19 16:36:03 -07'00' Software Owner (Signature)	William E. Nichols Print	 Date
20. Test Personnel: [signature] Sign	Kearn Patrick Lee Print	6/19/18 Date
  Sign	 Print	 Date
  Sign	 Print	 Date
Approved By:		
21. Software SME (Signature)	 Print	 Date

Page 2 of 2 A-6005-149 (REV 0)

[THIS PAGE INTENTIONALLY LEFT BLANK]

ATTACHMENT 2

GOLDSIM VERNACULAR

The following table gives a brief description of the GoldSim modeling elements in the IIDM. Unless otherwise noted, all GoldSim elements listed in the table can exist in either scalar, vector, or matrix form. Note that any icon's default depiction can be replaced with an icon of the user's choice.

Common Terms

Realization – a single instance of a model run.

Deterministic – that which can be described by a single value.

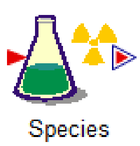
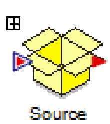
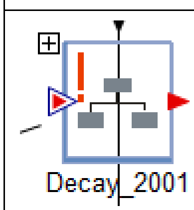
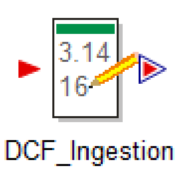
Stochastic – that which is defined by a distribution rather than a specific, single value.

Probabilistic Simulation – a multiple realization simulation utilizing stochastic variables.

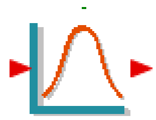
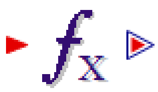
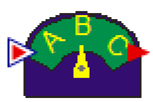
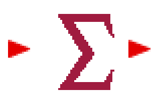
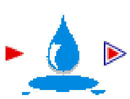
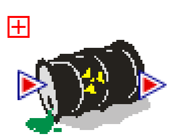
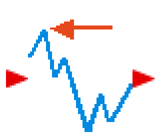
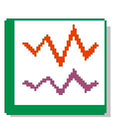
Deterministic Simulation – a single realization using a single, predetermined value for a parameter.

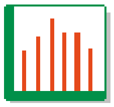
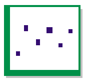
Monte Carlo method – a computational algorithm that relies on repeated random sampling.

Sensitivity Analysis – a statistical method used by probabilistic simulations to determine the affect and ranking stochastic variables have on the selected dependent variable. Sometimes referred to as an importance analysis.

Icon	Element Type	Function	Comments
	Species	Defines radioactive and chemical species along with appropriate properties.	Only exists as a vector element.
 	Container	A Container is similar to a directory in that it can contain sub-elements.	
	Conditional Container	A Container which is not active until specified conditions are met.	
	Data	Used primarily to define static data. At times is used as a matrix in which each matrix element contains an expression.	

RPP-CALC-61254, Rev. 3 – Attachment II

Icon	Element Type	Function	Comments
 ILAW_Bulk_Density	Stochastic	Defines a deterministic value for deterministic runs and a distribution with appropriate parameters for a Monte Carlo simulation.	
 ZWaste	Function	Defines a mathematical expression.	
 Inventory melter rad	Selector	Provides an If, Then, Else construct.	Could be done as a Function Element, but its use is clearer.
 Sum1	Summation	Provides the ability to sum a string of elements.	Could be done as a Function Element, but its use is clearer.
 Water	Fluid	Defines fluid (water in this case) properties used for concentrations calculations.	
 Cell1	Cell Pathway	Calculates species decay and concentrations.	
 NonCERCLA_SSW	Source	Contains Cell Pathways.	
 Inventory_conc_2051	Extrema	Records either the maximum or minimum value of a parameter.	
 Total_Doses_WD	Time History Result	Displays selected results in either graphical or tabular form.	

Icon	Element Type	Function	Comments
 I129_values	Array Result	Displays the selected result for an array as either a table or a bar chart at a selected time.	
 Multivariate 1	Multivariate	Displays selected results with stochastic parameters as a table. Performs sensitivity analysis.	