DOCUMENT RELEASE AND CHANGE FORM

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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

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This document provides the basis for evaluation and review of the hypothetical inadvertent intruder scenario calculations conducted as part of the Waste Management Area A-AX performance assessment modeling.

This calculation report is being referenced by the preliminary Waste Management A-AX Performance Assessment (PA), which will be provided to Ecology later this year. In preparation for providing the preliminary PA to Ecology, the documents that support the PA are also be cleared for public release. The analysis was completed in April 2019, but finalization of the document was put on hold until DOE's Low-Level Waste Disposal Facility Federal Review Group (LFRG) reviewed the PA. That review completed last month so finalization of this report is now moving forward.

Safety statement for photographic images: There are no photographic images in this document.

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Revision 0

WMA A-AX Performance Assessment Hypothetical Inadvertent Intruder Dose Calculation

Prepared by:

D.J. Watson
Washington River Protection Solutions, LLC

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Office of River Protection

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ENVIRONMENTAL MODEL CALCULATION COVER PAGE

SECTION 1: COMPLETED BY RESPONSIBLE MANAGER OR DESIGNEE

Rev. 0
RELEASE/ISSUE

Project: Waste Management Area A-AX Performance Assessment

Date: 01/30/2019

Calculation Title and Description: WMA A-AX Performance Assessment Hypothetical Inadvertent Intruder Dose Calculation

SECTION 2: COMPLETED BY PREPARER

Calculation No.: RPP-CALC-62539 Revision No.: 0

Revision History

Revision No.	Description	Date	ADD ROW Affected Pages
Rev. 0	Initial issue	01/30/2019	

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Software Installation and Checkout Certified:
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CHECKER LOG FOR SYSTEM MODELS

Project and Environmental Model Calculation Specific Information:

Project: Waste Management Area A-AX Performance Assessment

Responsible Manager or Designee, and Position: Bob Hiergesell, Senior Scientist

Originating Group or Department: Closure and Interim Measures | Date: 4/18/2019

Environmental Model Calculation File Report and Revision No.: RPP-CALC-62539, Rev. 0

Environmental Model Calculation File Title: a_ax v1.0_20190228

Check: Environmental Model Calculation File Document Elements

	List where Information is Described *(EMCF Section Number)*	Is the Description Correct and Sufficient?			Checker Signature
		Yes	No	If No, describe deficiency:	
Purpose	1.1	◉	○		
Calculation Approach	3.4 and 6	◉	○		
Assumptions	4.1	◉	○		
Inputs *(reference detailed checklist below as well)*	4.2	◉	○		
Equations used	3.3	◉	○		
Conclusions	7.2	◉	○		
References	8	◉	○		

Check: Controlled Software Use

	List where Information is Described *(EMCF Section Number)*	Is the Criteria Met?			Checker Signature
		Yes	No	If No, describe deficiency:	
Software used in the calculation is appropriate for application	5.1	◉	○		
Software use is approved and properly validated in accordance with approved software management plan	5.2	◉	○		
Software use is properly documented	5.3	◉	○		
Verify data was input correctly to approved software or spreadsheets	Attachments 2 - 7	◉	○		
If a spreadsheet is used, verify inputs/outputs of calculation(s) to ensure accuracy		○	◉	No spreadsheet is used	

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	Yes.		

CHECKER LOG FOR SYSTEM MODELS (Continued)

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	Yes	Yes
Simulation time step control	No. Timestep is not important because no transport simulation.	Not applicable	Not applicable
Simulated chemical list	Yes		
Simulated radionuclides list	Yes		
External model components identified and documented or referenced	Not applicable	Not applicable	Not applicable
External model linkages *(dynamic link libraries, etc.)* checked	Not applicable	Not applicable	Not applicable
If model is probabilistic, stochastic distributions are defined and consistent	Not applicable	Not applicable	Not applicable
Input units are declared and of correct dimensionality	Yes	Yes	Yes
Equations used in the model file are presented in EMCF and consistent	Yes	Yes	Yes

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?	Yes	Yes	Yes	
Inventory: Mass Balance. Is mass balance of inventory maintained in system model calculation(s)?	Not applicable. Model does not involve transport simulation.	Not applicable.	Not applicable.	
				X
				X

EXECUTIVE SUMMARY

This environmental model calculation file provides the basis for evaluation and review of the hypothetical inadvertent intruder scenario calculations conducted as part of the Waste Management Area A-AX performance assessment modeling. The results of the inadvertent intruder calculations support parts of the performance assessment focused on radiological impacts to meet the requirements for a closure authorization under DOE O 435.1, *Radioactive Waste Management* and are used to demonstrate compliance with performance measures. The model calculations are performed using GoldSim©[1] software (GoldSim Contaminant Transport Module User's Guide [GoldSim Technology Group 2014a]; GoldSim Distributed Processing Module User's Guide [GoldSim Technology Group 2014b]; GoldSim Probabilistic Simulation Environment User's Guide [GoldSim Technology Group 2014c]).

This environmental model calculation file identifies the specific model parameters evaluated in the inadvertent intruder analysis, along with descriptions of associated modeling assumptions. The model package report (RPP-RPT-60885, *Model Package Report System Model for the WMA A-AX Performance Assessment*) documents the development of the system model of which the intruder calculations are a part. The model package report includes description and development of the model and base case analysis, along with certain calculations that are necessary to demonstrate the soundness of the model. The model package report also provides the technical basis for specific model parameters and boundary conditions, along with descriptions of modeling assumptions. Those discussions are not repeated in this environmental model calculation file. This document only summarizes key assumptions and inputs that are fully described in the model package report, as required by the documentation requirements associated with the preparation and issue of environmental calculations. Control of all software used to implement the model is directed by the requirements of PRC-PRO-IRM-309, "Controlled Software Management."

Effective doses to an inadvertent intruder are evaluated starting at 100 years after closure for pipelines and 500 years after closure for tanks until the end of the compliance period (1,000 years after closure) for one acute and three chronic exposure scenarios. In the acute scenario, all of the sources in Waste Management Area A-AX produce doses below the 500 mrem performance measure, with the maximum dose potential occurring if intrusion into tank 241-A-105 happens at 500 years post-closure. In the chronic scenarios, potential dose rates are below the 100 mrem/year performance measure for all sources and scenarios except the AX pipelines under the Rural Pasture scenario. In this scenario, the potential for dose rates from a low probability intrusion into the AX pipeline slightly exceeds the performance measure when the intrusion occurs between 100 and 107 years after closure.

[1] GoldSim© simulation software is copyrighted by GoldSim Technology Group LLC of Issaquah, Washington (see http://www.goldsim.com).

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LIST OF TERMS, ACRONYMS, AND ABBREVIATIONS

AMS	American Meteorological Society
BBI	Best-Basis Inventory
CHPRC	CH2M HILL Plateau Remediation Company
DCAL	Dose and Risk Calculation
DOE	U.S. Department of Energy
EMCF	Environmental Model Calculation File
EMMA	Environmental Model Management Archive
EPA	U.S. Environmental Protection Agency
HTWOS	Hanford Tank Waste Operations Simulator
IMBA	Integrated Modules for Bioassay Assessment
MATLAB	matrix laboratory (software)
MPR	Model Package Report
PA	Performance Assessment
PUREX	Plutonium Uranium Extraction (Plant)
RESRAD	RESidual RADioactive
SST	Single-Shell Tank
STOMP	Subsurface Transport Over Multiple Phases
WMA	Waste Management Area
WRPS	Washington River Protection Solutions, LLC

1.0 PURPOSE

The purpose of this environmental model calculation file (EMCF) is to document the calculations evaluating the dose to a hypothetical inadvertent intruder into tanks or pipelines at Waste Management Area (WMA) A-AX after closure for conducting preliminary WMA A-AX performance assessment (PA). The closure date for the calculations is assumed to be January 1, 2050 (RPP-RPT-60101, *Model Package Report Flow and Contaminant Transport Numerical Model Used in WMA A-AX Performance Assessment and RCRA Closure Analysis*) and radionuclide inventories are decay corrected to this closure date. Because closed and grouted tanks represent robust intruder barriers preventing intrusion for at least 500 years (NUREG-1854, *NRC Staff Guidance for Activities Related to U.S. Department of Energy Waste Determinations – Draft Final Report for Interim Use*), the intrusion calculation for tanks is conducted beginning at 500 years post-closure. Wastes at shallow depths without significant intrusion barriers (i.e., pipelines) have the intrusion calculation beginning at the end of institutional control (NUREG-1854), which is 100 years post-closure.

This EMCF documents the assumptions and methodology for calculating the doses to hypothetical inadvertent intruders under different exposure scenarios. Its primary goal is to determine the maximum dose to an intruder, and the year that it occurs, for each tank and pipeline waste source at WMA A-AX. These calculations are performed for one acute exposure scenario (Well Driller) and three chronic exposure scenarios (Suburban Garden, Commercial Farm, and Rural Pasture) as described in RPP-ENV-58813, *Exposure Scenarios for Risk and Performance Assessments in Tank Farms at the Hanford Site, Washington*.

1.1 OBJECTIVE

The objective of the modeling described in this EMCF is to evaluate the dose from exposure in hypothetical scenarios of inadvertent intrusion into closed tanks and pipes at WMA A-AX. These dose calculations are performed using a system model of WMA A-AX, implemented using GoldSim©[2] software (GoldSim Contaminant Transport Module User's Guide [GoldSim Technology Group 2014a]; GoldSim Distributed Processing Module User's Guide [GoldSim Technology Group 2014b]; GoldSim Probabilistic Simulation Environment User's Guide [GoldSim Technology Group 2014c]). The system model is developed to support parts of the PA focused on radiological impacts to meet the requirements for a closure authorization under DOE O 435.1, *Radioactive Waste Management*.

1.2 SUPPORTING DOCUMENTS

The calculations described in this EMCF use conceptual models and mathematical models that are appropriate for the intended use as documented in a series of data package reports, model package reports (MPRs), other environmental calculation reports, and/or other technical literature.

[2] GoldSim© simulation software is copyrighted by GoldSim Technology Group LLC of Issaquah, Washington (see http://www.goldsim.com).

1.2.1 Data Package Reports

Data package reports are reports that are developed for use in the environmental model. Data package reports supporting this calculation support mathematical model selection, key assumptions and parameterization.

The data package reports that support this calculation are:

RPP-ENV-58813, Rev.1	*Exposure Scenarios for Risk and Performance Assessments in Tank Farms at the Hanford Site, Washington*
RPP-RPT-58293, Rev. 2	*Hanford 241-A and 241-AX Farm Tank and Ancillary Equipment Residual Waste Inventory Estimates*
RPP-RPT-58693, preliminary draft	*Engineered System Data Package for Waste Management Area A-AX*

1.2.2 Model Package Reports

Model package reports are reports that describe the conceptual and mathematical models used in the calculation. The model package report supporting this calculation supports model implementation and is:

RPP-RPT-60885, Rev. 0	*Model Package Report System Model for the WMA A-AX Performance Assessment*

1.2.3 Other Environmental Model Calculation Files

The EMCFs supporting this calculation support parameterization and are:

RPP-CALC-62319	*Residual Waste Source Inventory Term for the Waste Management Area A-AX Performance Assessment Inventory Case 1*
RPP-CALC-61254	*Inadvertent Intruder Dose Calculation Update for the Integrated Disposal Facility Performance Assessment* (provides multiplication factors for dose conversion factors to correct for the effects of short-lived progeny at the time of consumption [RPP-RPT-60885]).

1.2.4 Other Technical Reports

DOE/RL-2016-67	*Hanford Site Groundwater Monitoring Report for 2016* (provides site-specific depth to groundwater).

1.3 DOCUMENT STRUCTURE

The structure of this EMCF follows the required structure of an EMCF.

- Section 2.0 provides supplemental background for the calculation.
- Section 3.0 describes calculation methodology.
- Section 4.0 describes the assumptions and inputs.
- Section 5.0 describes the computational software.
- Section 6.0 describes the output(s) from the environmental model.
- Section 7.0 provides the calculation results and conclusions.
- Section 8.0 is a list of references cited in this calculation report.

Attachment 1 contains the software installation and checkout forms for the GoldSim© simulation software.

Attachment 2 contains the tank residual inventories used in the model for the inadvertent intruder calculations.

Attachment 3 contains the parameter inputs used for each inadvertent intruder scenario calculated in this document.

Attachment 4 contains the dose conversion factors used in the model for the inadvertent intruder calculations.

Attachment 5 contains the bioconcentration factors entered in the model for the inadvertent intruder calculations.

Attachment 6 contains the radionuclide-specific shielding factors entered in the model for the inadvertent intruder calculations.

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2.0 BACKGROUND

Details of the development of the system model used in the calculations described in this EMCF are provided in RPP-RPT-60885, *Model Package Report System Model for the WMA A-AX Performance Assessment*.

2.1 HISTORY

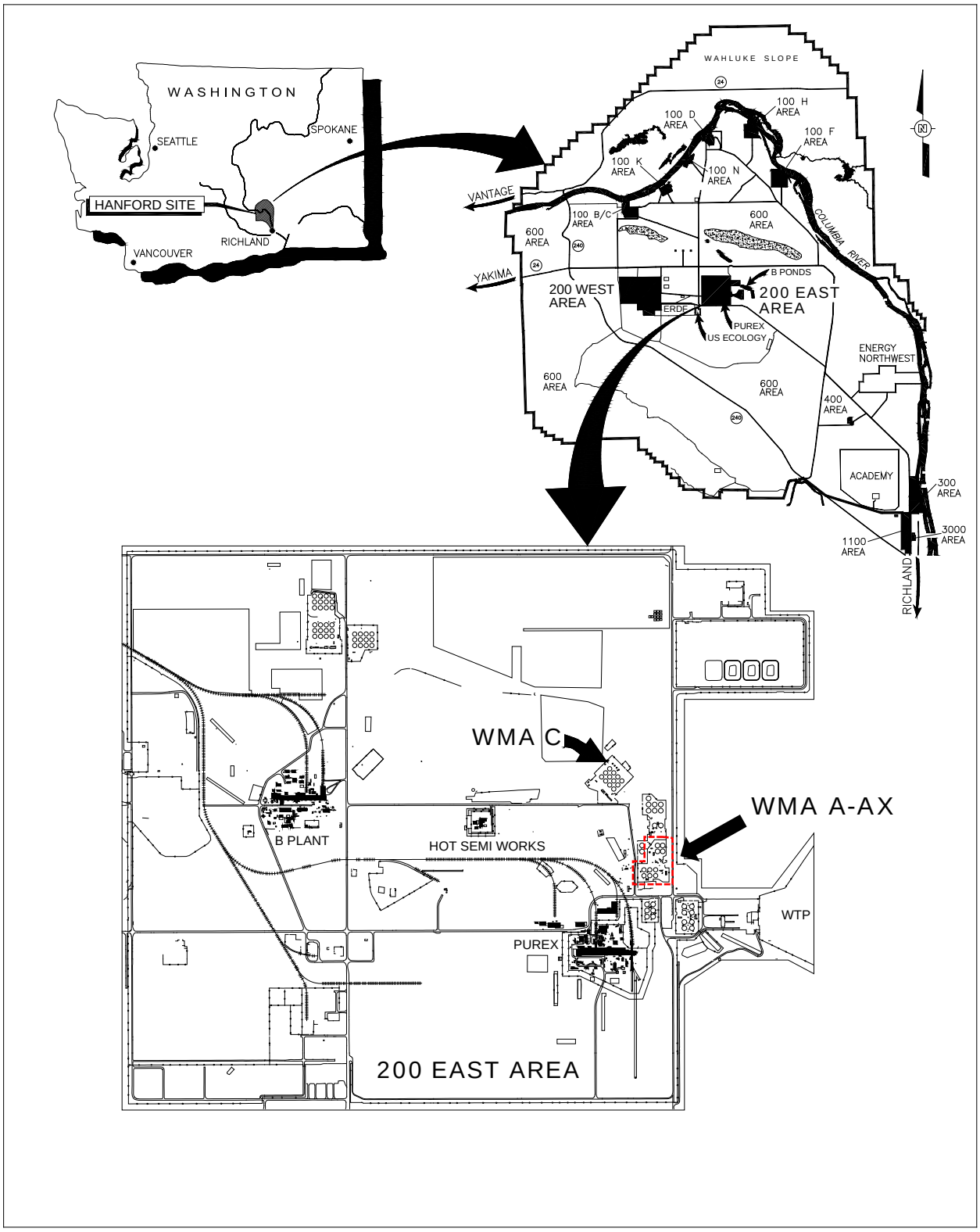
WMA A-AX comprises the 241-A and 241-AX Tank Farms and is located within the 200 East Area of the Central Plateau of the Hanford Site. The 241-A Tank Farm (A Farm) and 241-AX Tank Farm (AX Farm) were constructed between 1953 and 1955 and between 1963 and 1965, respectively. The WMA A-AX tank farms are surrounded by several other double-shell tank farms within the A Complex, and Single-Shell Tank (SST) Farm 241-C (C Farm) is located nearby to the northwest (Figure 2-1). WMA A-AX includes catch tanks, diversion boxes, valve pits, pipelines, French drains and unplanned release sites. Numerous liquid discharge facilities used at various times (cribs, trenches, ditches, septic systems, etc.) surround the WMA.

The tanks in both A Farm and AX Farm were designed for the storage of boiling waste generated from irradiated fuel reprocessing at the 202-A Plutonium Uranium Extraction (PUREX) Plant. A Farm contains six 75-ft diameter nominally 1,000,000-gal capacity SSTs that consist of a carbon steel liner inside a concrete tank. AX Farm contains four such SSTs of a later design. A Farm and AX Farm were placed in service in 1955 and 1965, respectively, and both were used to store and transfer waste until mid-1980.

Figure 2-2 illustrates the closure concept for WMA A-AX following tank waste retrieval. Surface facilities will be removed and retrieved SSTs and accessible ancillary equipment with significant void spaces will be filled with grout. Waste transfer pipelines are also expected to be left in place. An engineered surface cover system will be placed over the tank farm and will be monitored using existing wells.

In brief, as of 2018, plans for the future closure of A Farm and AX Farm call for retrieval of wastes remaining in the SSTs (mostly sludge and saltcake solids) to the maximum extent practicable, grouting the residual wastes and interior volume of the SSTs, and construction of a surficial barrier over the tank farms. The PA uses numerical models to evaluate the potential dose to an inadvertent intruder at any specific point in time after institutional control is lost (for pipelines) and tank structure is no longer a significant barrier to intrusion (for tanks).

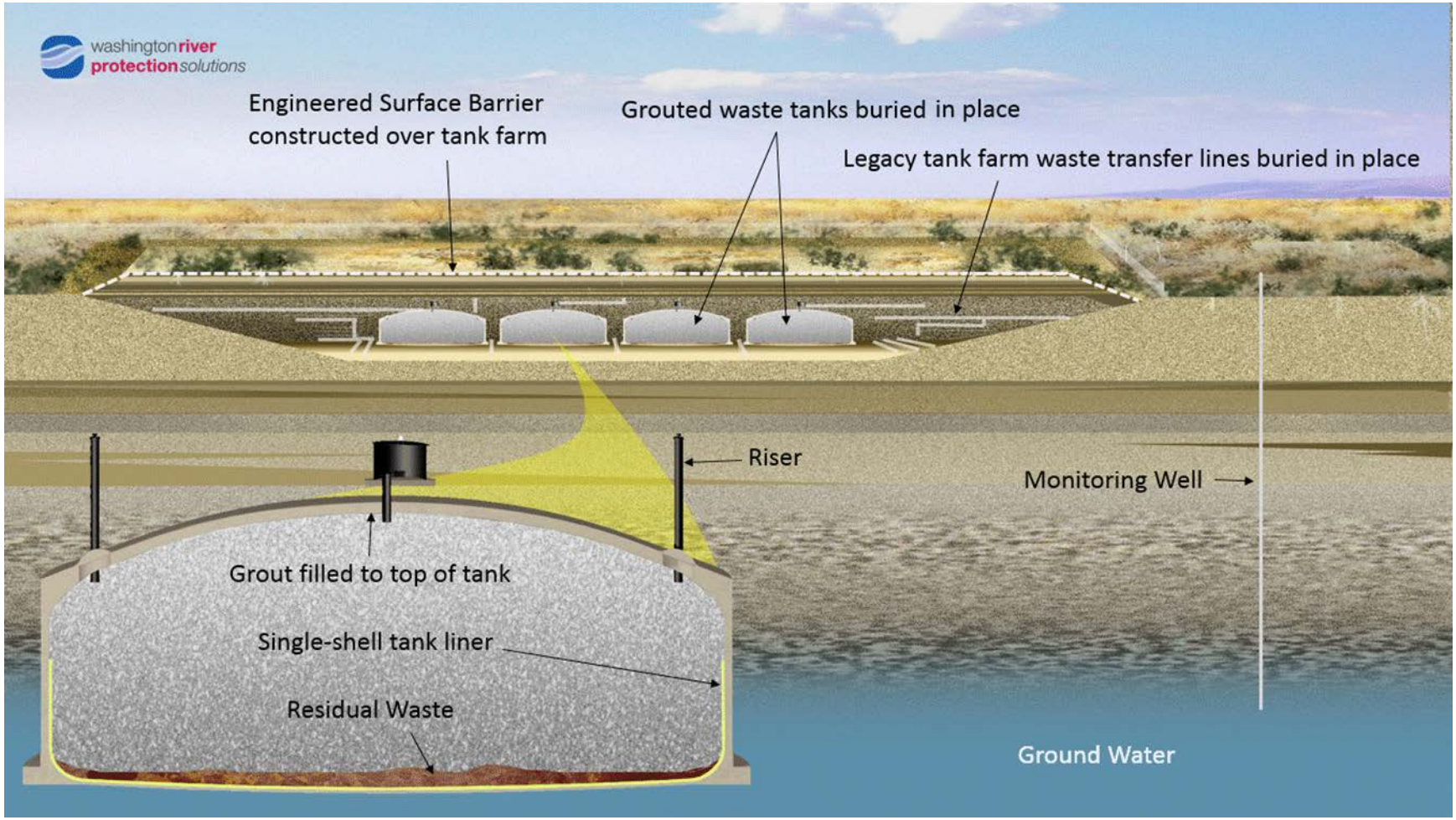
Figure 2-1. Location of Waste Management Area A-AX in Relation to Hanford Site.



H:\CHG\241-C TF\2E-WMA-C1A

PUREX = Plutonium Uranium Extraction (Plant) WMA = Waste Management Area WTP = Waste Treatment Plant

Figure 2-2. Conceptual Model of Closure of Waste Management Area A-AX.



2.2 JUSTIFICATION OF METHODOLOGY

While calculating intruder doses over time from a radionuclide without progeny can be done using a spreadsheet application, the calculation complexity increases as the number of radionuclides and waste sources increase. This can substantially increase the potential for data entry or calculation error. Radionuclides with progeny require the use of Bateman equations, further complicating the calculation. The RT module in the GoldSim© simulation software is a tool that can specifically and easily evaluate decay and ingrowth of radionuclides. The GoldSim Contaminant Transport Module User's Guide (GoldSim Technology Group 2014a) states:

> *The RT Module allows decay chains (daughter products) to be simulated (one species can be specified to transform into one or more others). To support modeling of radioactive decay chains, the RT Module also allows you to link to an extensive database of radionuclide decay data (based on a standard reference provided by the Inte[r]national Commission for Radiation Protection). … The data is based on the International Commission for Radiation Protection (ICRP)'s Publication 107. The feature allows you to view over 1300 radionuclides (along with their corresponding stable elements) and to selectively include some of these radionuclides in your simulation.*

Furthermore, GoldSim© is designed to calculate decay and ingrowth, as well as other parameters, within modules allowing each waste source to be represented by a discrete element within the model.

Using a tool specifically developed to support radionuclide fate and transport calculations facilitates the verification of the calculations and enhances reproducibility and transparency. Furthermore, by using the embedded database of radionuclide properties, there is less chance that a data entry error affecting the radionuclide decay chain calculations can occur.

3.0 METHODOLOGY

The system-level model is implemented using GoldSim© software (GoldSim Technology Group 2014a, 2014b, 2014c]). The detailed methodology for various calculations performed with the system-level model is discussed in RPP-RPT-60885.

3.1 SELECTION OF TECHNICAL STAFF

The responsible manager or a selected delegate is responsible for selecting the technical staff that develops the conceptual and mathematical approach, performs and documents the calculations, checks the work, and reviews the calculation for technical accuracy and completeness.

- For the calculations described in this EMCF, the Washington River Protection Solutions, LLC (WRPS) technical lead, as delegated by the responsible manager, has selected the technical staff.

- Additionally, for the calculations described in this EMCF, the INTERA, Inc. modeling team lead, as delegated by the responsible manager, has selected additional technical staff.

3.1.1 Originators

The originators or preparers of the environmental model calculation develop the methodology; gain early concurrence with the senior reviewers; identify project conditions, assumptions, and inputs; and prepares the calculation and associated calculation report.

David J. (DJ) Watson (Washington River Protection Solutions), Scientist

MS 2009, Environmental Science, Washington State University
BS 1996, Geology, Washington State University

DJ Watson has over 16 years of human health risk assessment and PA experience. He has over 13 years of environmental modeling experience, including: subsurface contaminant transport using STOMP©[3], pflotran[4], and TOUGH2[5]; air dispersion with AERMOD[6]; internal and external

[3] Subsurface Transport Over Multiple Phases (STOMP)© is copyrighted by Battelle Memorial Institute, 1996.
[4] PFLOTRAN is open-source software and can be redistributed and/or modified under the terms of the GNU Lesser General Public License as published by the Free Software Foundation.
[5] TOUGH2 software was developed by Lawrence Berkeley National Laboratory, University of California, Berkeley, California with support from the Office of Science, Office of Basic Energy Sciences, Materials Sciences and Engineering Division of the U.S. Department of Energy.
[6] AERMOD atmospheric dispersion modeling system was developed by the AERMIC (American Meteorological Society [AMS]/U.S. Environmental Protection Agency [EPA] Regulatory Model Improvement Committee), a collaborative working group of scientists from the AMS and the EPA.

radiological dosimetry using IMBA®[7], DCAL[8], OLINDA[9], and RESRAD[10]; and system modeling using GoldSim©. He has worked in the areas of underground tank waste retrieval and tank closure, radiation dosimetry of both internally-deposited radionuclides and external exposure, nuclear fuel fabrication and transport, and geologic carbon dioxide (CO_2) sequestration. His work has supported the U.S. Department of Energy (DOE), U.S. Nuclear Regulatory Commission, International Atomic Energy Agency, Joint Global Change Research Institute and other industrial and research organizations.

3.1.2 Checkers

The checker reviews the environmental model calculation to verify that it is clearly developed and that the calculation was performed as described and without error. Checking includes ensuring that all the inputs are consistent with the original referenced material. The checker documents the review of the calculation on an appropriate Checker Log.

Wei Zhou (INTERA, Inc.) Senior Engineer

PhD 1992, Nuclear Engineering, University of California at Berkeley
MS, 1986, Mechanical Engineering, San Jose State University
BS, 1982, Mechanical Engineering, Beijing University of Technology

Wei Zhou has more than 30 years of experience in the areas of performance and safety assessment of near-surface and deep geological radioactive waste repositories, risk assessments for organic wastes including dense and light non-aqueous phase liquids and volatile organic compounds, and the geological sequestration of CO_2. She has provided technical support in these areas to industrial, governmental, and international organizations such as the Electric Power Research Institute, International Atomic Energy Agency, Nuclear Energy Institute, Korean Hydro and Nuclear Power, Canadian Petroleum Technology Research Institute, U.S. Environmental Protection Agency, DOE, Swedish Nuclear Inspectorate, Japan Atomic Energy Agency, Taiwan Institute of Nuclear Energy Research, International Energy Agency, Nuclear Energy Agency, and the Commission for European Communities. She specializes in modeling and simulation of radionuclide transport, coupled heat and mass transfer in fractured media, as well as multiphase and multi-component transport systems using public or commercial

[7] Integrated Modules for Bioassay Assessment (IMBA)® is a registered trademark of Public Health England, London, United Kingdom; IMBA Expert™ DOE-Edition is a trademark of ACJ & Associates, Richland, Washington and U.K. Health Protection Agency, Oxfordshire, United Kingdom.

[8] DCAL (Dose and Risk Calculation) software was developed by the Dosimetry Research Group (now the Biosystems Modeling Team in the Advanced Biomedical Science and Technology Group) at Oak Ridge National Laboratory under the sponsorship of the U.S. Environmental Protection Agency.

[9] OLINDA code was written by Michael Stabin, PhD, CHP, Department of Radiology and Radiological Sciences, Vanderbilt University, Nashville, Tennessee.

[10] The RESRAD (RESidual RADioactive) family of codes is developed at Argonne National Laboratory, Lemont, Illinois, managed by UChicago Argonne, LLC, for the U.S. Department of Energy's Office of Science.

codes including TOUGH2, TOUGHREACT[11], STOMP©, ECLIPSE suite codes[12], MATLAB®[13], and GoldSim©. Her expertise also includes developing customized software using FORTRAN and C++. She has completed all reading assignments that are procedurally required to perform environmental fate and transport calculations.

Wei was the lead checker for this work and reviewed the GoldSim© model, verifying that inputs in the model matched the source documents, the model was implemented correctly for the intended purpose, and the outputs were exported correctly.

3.1.3 Senior Reviewers

Kearn Patrick (Pat) Lee (Orano Federal Services) Advisory Engineer
MCE, 1996, Civil and Environmental Engineering, University of Delaware
BChE, 1993, Chemical Engineering, University of Delaware

Pat Lee has over 18 years of modeling experience using the GoldSim© RT Module to perform PAs for DOE. He was a lead analyst on the high-level waste PA for Yucca Mountain from 2001 to 2010 and has been the technical lead for the Integrated Disposal Facility PA since 2015. He has presented models he developed for the Yucca Mountain Project at several GoldSim© user's conferences and he also developed Yucca Mountain Project training modules to provide an overview of the Yucca Mountain high-level waste PA model. He has checked several other models for the WMA A-AX PA.

3.2 CONCEPTUAL MODEL

The conceptual model is described in detail in Section 3.5 of RPP-RPT-60885.

3.3 MATHEMATICAL MODEL

The equations used in the model are described in detail in Section 4.5 of RPP-RPT-60885.

3.4 CALCULATION PROCEDURE

The calculation procedure is described in detail in Section 4.5.3 of RPP-RPT-60885.

[11] TOUGHREACT software was developed by Lawrence Berkeley National Laboratory, University of California, Berkeley, California with support from the Office of Science, Office of Geothermal Technologies of the U.S. Department of Energy.
[12] ECLIPSE is a suite of reservoir simulator software developed by GeoQuest, an operating unit of Schlumberger Oilfield Services, Houston, Texas.
[13] MATLAB® (matrix laboratory) is a registered trademark of The MathWorks, Inc., Natick, Massachusetts.

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4.0 ASSUMPTIONS AND INPUTS

RPP-RPT-60885 lists key assumptions and inputs for the inadvertent intruder calculations. Inventory-related assumptions are detailed in RPP-CALC-62319. Pipeline inventories assumptions are discussed in RPP-RPT-58293. Inadvertent intruder scenario assumptions are detailed in RPP-ENV-58813.

4.1 KEY ASSUMPTIONS

General assumptions related to inadvertent intruder scenarios used in the model are detailed in RPP-RPT-60885, and are as follows.

- The landfill closure of WMA A-AX is assumed to occur at year 2050.
- It is assumed that institutional control and societal memory is retained for the first 100 years after the year of closure.
- WMA A-AX tanks (except for 241-A-104 and 241-A-105) are assumed to be retrieved and filled with grout.
- Pipelines in WMA A-AX are not grouted and are 5% full of waste, evenly distributed throughout the pipeline.
- The dose calculations are based on the residual radionuclide inventory after retrieval in WMA A-AX (considering radioactive decay and ingrowth), but ignoring any depletion due to transport of radionuclides from the waste site.

The estimated volume of waste in pipelines is uncertain. An effort was made to provide a conservative estimate (RPP-RPT-58293). Limited pipeline investigations in other tank farms have indicated that the lines should be flushed. While none of the WMA A-AX pipelines are known to be plugged, the possibility of a plug exists. There is also the possibility that some of the lines in WMA A-AX may not be well flushed. Overall, a 5% estimate is believed to be high; pipelines studied in 241-SY Tank Farm showed no discernable waste and about 4% of the pipe volume contained waste in 15- to 18-in. vitrified clay pipes between the 231-Z building and Z ditches (RPP-RPT-58293).

Assumptions about the residual waste form are detailed in RPP-RPT-60885, while inventory-related assumptions are detailed in RPP-CALC-62319. Residual waste assumptions used in the model are:

- Due to the lack of characterization data on WMA A-AX residual waste, most of the residual waste characteristics are assumed to be the same as WMA C residual waste
- The unretrieved wastes are assumed to be distributed uniformly throughout the bottom area of the waste source

- Residual waste volumes for all tanks, except 241-A-104 and 241-A-105, are assumed to be 360 ft^3

- Residual waste volumes for tanks 241-A-104 and 241-A-105 are those found in the current Best-Basis Inventory (BBI)

- Current BBI concentrations are used for tank inventory estimates due to lack of specific retrieval information

- Pipeline inventories are developed using the Hanford Tank Waste Operations Simulator (HTWOS) (RPP-RPT-58293) because flushed pipelines are assumed to have similar residual concentrations as retrieved tanks.

Since HTWOS is a model, its results are uncertain. Retrieval data reports (RDR) from C Farm retrievals compared post-retrieval waste sample results with HTWOS results for each tank. In general, HTWOS was not a good predictor for sorbing radionuclides' (e.g., ^{90}Sr, ^{137}Cs) post-retrieval concentrations, with ^{90}Sr concentration estimates ranging from a little over 10 times greater than post-retrieval sample concentrations (tank 241-C-203 [RPP-RPT-26475, *Retrieval Data Report for Single-Shell Tank 241-C-203*]) to 10 times less (tank 241-C-204 [RPP-RPT-34062, *Retrieval Data Report for Single-Shell Tank 241-C-204*]). Because of this uncertainty, pipeline intruder calculations are also performed with inventories developed by taking the average BBI concentration of each radionuclide in all tanks in each farm and multiplying them by the pipeline volume (RPP-RPT-58293).

A linear correlation between inventory and dose was confirmed in RPP-CALC-61254, *Inadvertent Intruder Dose Calculation Update for the Integrated Disposal Facility Performance Assessment*, which eliminates the need to explicitly evaluate inventory uncertainty because dose results can be directly scaled to inventory changes. This correlation is confirmed in Section 7.1.3. Providing results for intruder calculations using both BBI- and HTWOS-based inventories provides a range of possible doses, given the absence of post-retrieval waste sample results.

Assumptions specific to inadvertent intruder scenarios are detailed in RPP-ENV-58813, and are:

- Pipelines do not represent a significant intrusion barrier, and consequently the intrusion calculation is conducted beginning at 100 years after closure (end of institutional control period)

- Tanks and infill grout represent very significant and robust barriers to intrusion, and therefore the intrusion calculation is conducted beginning at 500 years

- 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 acute well driller dose is calculated by assuming that the cuttings are uniformly spread across the drill pad and are not diluted by mixing with clean soil

- For the acute Well Driller exposure scenario, the driller is assumed to drill through the residual waste and all the way to the water table

- Radionuclide concentration in water for chronic inadvertent intruder dose calculations is assumed to be zero

- In the chronic scenarios (commercial farm worker, resident with a rural pasture, resident with a suburban garden), contaminated drill cuttings are assumed to be spread evenly over the receptor's land to a tillage depth of 15cm

- For calculating dose from external exposure, the thickness and lateral extent of the contaminated layer is assumed to be infinite as a conservatism when applied to exposures from relatively small contamination sources (like a drill core).

4.2 INPUTS

Inputs for this calculation include residual waste inventories, inadvertent intruder scenario parameters, dose conversion factors and bioconcentration factors. Table 4-1 lists the inputs, their sources and the attachments to this document that list their values.

Table 4-1. Inputs Used in the Inadvertent Intruder Model.

Input	Reference	Attachment
Inventory	RPP-CALC-62319, *Residual Waste Source Inventory Term for the Waste Management Area A-AX Performance Assessment Inventory Case 1* (tank inventories); RPP-RPT-58293, *Hanford 241-A and 241-AX Farm Tank and Ancillary Equipment Residual Waste Inventory Estimates* (pipeline inventories).	2
Inadvertent Intruder Scenario Parameters	RPP-ENV-58813, *Exposure Scenarios for Risk and Performance Assessments in Tank Farms at the Hanford Site, Washington*	3
Dose Conversion Factors	RPP-ENV-58813, *Exposure Scenarios for Risk and Performance Assessments in Tank Farms at the Hanford Site, Washington*	4
Dose Conversion Factor Multipliers	RPP-CALC-61254, *Inadvertent Intruder Dose Calculation Update for the Integrated Disposal Facility Performance Assessment*	4
Bioconcentration Factors	RPP-ENV-58813, *Exposure Scenarios for Risk and Performance Assessments in Tank Farms at the Hanford Site, Washington*	5
Radionuclide-Specific Shielding Factors	RPP-ENV-58813, *Exposure Scenarios for Risk and Performance Assessments in Tank Farms at the Hanford Site, Washington*	6

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5.0 SOFTWARE APPLICATIONS

The software used to perform this calculation are approved, managed, and used in compliance with the CH2M HILL Plateau Remediation Company (CHPRC) requirements of PRC-PRO-IRM-309, "Controlled Software Management."

5.1 SOFTWARE IDENTIFICATION

Software is registered on the Hanford Information System Inventory and is identified as approved for use. The identification for the software package used in the calculation is as follows:

- GoldSim© Pro
- Version 12.0
- Hanford Information System Inventory Identification Number: 2461
- Workstation type and property number: Dell™ Optiplex™[14] 7040 (WF34039).

5.2 SOFTWARE QUALITY ASSURANCE

All calculations are performed using GoldSim© Pro simulator software, version 12.0. GoldSim© Pro simulator is approved for use by CHPRC at the Hanford Site in accordance with the requirements of PRC-PRO-IRM-309. WRPS recognizes CHPRC's role as Hanford Site environmental modeling integrator (TFC-PLN-155, "General Project Plan for Environmental Modeling") and accepts CHPRC's qualification of GoldSim© Pro. The installed GoldSim© Pro simulator software was tested in accordance with the procedure per CHPRC-00175, *GoldSim Pro Software Management Plan*, Rev. 3, using CHPRC-00224, *GoldSim Pro Software Test Plan*, Rev. 2.

5.3 SOFTWARE INSTALLATION AND CHECKOUT

The software installation and checkout form for GoldSim© is provided in Attachment 1 to this EMCF.

5.4 STATEMENT OF VALID SOFTWARE APPLICATION

The following verifies that GoldSim© is a valid software application and was applied in this EMCF 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 contamination mass transport in

[14] Dell™ and Optiplex™ are trademarks of Dell Inc., Round Rock, Texas.

subsurface environment, and perform human health dose and risk assessment for the Hanford Site.

- GoldSim© Pro as it is used in this EMCF has been implemented within the range of its limitations.

6.0 CALCULATION

The calculations are performed with GoldSim© using the named a_ax v1.0_20190408_Intruder.gsm model file. This model file is reviewed and checked and will be archived in Environmental Model Management Archive (EMMA) along with this EMCF and other supporting files.

6.1 DESCRIPTION OF MODEL CHANGES

This model uses the model described in RPP-RPT-60885 as its basis. This model file was created from the version-controlled "a_ax v1.0_20190408_Intruder.gsm" model file by utilizing the "scenario" feature in GoldSim© to add BBI-based pipeline inventories and evaluate their impacts on the intruder doses.

The two scenarios contained in the model file are:

- "BBI," which is the same as the reference case model except for the **Initial_Rad_Inventory** element (located in \Inventory\Initial_Rad_Inventory) which has BBI derived inventories for all radionuclides in the **A_Pipelines** and **AX_Pipelines** columns of the matrix

- "HTWOS," which is the same as the reference case model; the **Initial_Rad_Inventory** element contains HTWOS derived inventories for all radionuclides in the **A_Pipelines** and **AX_Pipelines** columns of the matrix.

6.1.1 Model Configuration Control

All inputs and outputs for the development of the WMA A-AX PA GoldSim©-based system model are archived to the CHPRC EMMA to maintain and preserve models, input and select output files under configuration management. Inputs include the input files used in the GoldSim© simulations and the input parameters. Basis information (that information collected to form the basis for model input parameterization) is also stored in the EMMA for traceability purposes.

6.1.2 Model Checking

The WMA A-AX GoldSim© system model is checked using the procedure found in Section 4.2.2 of TFC-ESHQ-ENV_FS-C-05, "Preparation and Issuance of Model Package Reports and Environmental Model Calculation Files." The model checker was provided with:

- the versioned copy of the GoldSim© model file ("a_ax v1.0_Intruder.gsm")
- A copy of the model package report (RPP-RPT-60885)
- A draft copy of this EMCF.

The checker made comments and all comments were resolved as indicated by a signed checker's log.

6.2 DESCRIPTION OF CALCULATED OUTPUT

The output of these calculations is a series of data matrices. There is one matrix for each exposure scenario with a row index of waste source (tank or ancillary equipment) name and a column index of dose rate (in mrem/year) for chronic exposure scenarios or dose (in mrem) for the acute exposure scenario. A peak dose or dose rate during the compliance period is calculated for each waste source in each exposure scenario and stored as an extrema.

Each exposure scenario also has a chart plotting the time-series of dose or dose rate for each waste source by year of intrusion for the length of the compliance period.

There is a model container for each waste source, which contains an output data matrix for each exposure scenario. The row index for these matrices is radionuclide, and the column index is dose rate (in mrem/year) for chronic exposure scenarios or dose (in mrem) for the acute exposure scenario. A peak dose or dose rate during the compliance period is calculated for each radionuclide in each exposure scenario and stored as an extrema.

Each exposure scenario in a waste source's result container also has a chart plotting the time-series of dose or dose rate for each radionuclide by year of intrusion for the length of the compliance period.

Graphic displays show the effective dose starting at 100 years after closure for intrusion into a pipeline source and 500 years after closure for the other sources that have substantial barriers to intrusion. For the purpose of analysis the total intruder dose and doses from major radionuclide contributors from intrusion into the pipeline contributing the highest dose or dose rate at 100 years after closure and the tank contributing the highest dose or dose rate at 500 years after closure are presented separately for each exposure scenario.

Tables show the total effective dose from intrusion into each source, as well as the relative fraction of pathway contributions to the total effective dose, for each exposure scenario from intrusion into the source providing the maximum effective dose at both 100 years after closure and 500 years after closure.

7.0 RESULTS AND CONCLUSIONS

This section presents the results of the inadvertent intruder dose calculations for each of the four inadvertent intrusion scenarios. Effective doses for all waste sources are displayed graphically with the relevant performance measure for comparison.

7.1 RESULTS

Effective doses to an inadvertent intruder were evaluated starting at 100 years after closure for pipelines and 500 years after closure for tanks until the end of the compliance period (1,000 years after closure). The relative contribution to the effective dose of individual radionuclides in the residual waste varies over the compliance period because of different inventories and half-lives. The total effective dose, however, decreases over the compliance period, with the highest dose occurring at the time of intrusion. Table 7-1 summarizes the calculated effective doses for each intrusion scenario of all of the waste sources considered in WMA A-AX. Tank 241-A-105 produces the highest effective dose for the Acute Well Driller and the Chronic Commercial Farm scenarios, while the AX pipeline produces the highest dose for the Chronic Rural Pasture and Chronic Suburban Garden scenarios.

Table 7-1. Peak Effective Dose for the Inadvertent Intruder Scenarios for All Residual Waste Sources.

Source	Well Driller Acute Dose (mrem)	Commercial Farm Chronic Dose Rate (mrem/yr)	Rural Pasture Chronic Dose Rate (mrem/yr)	Suburban Garden Chronic Dose Rate (mrem/yr)
241-A-101	1.66E-01	3.27E-04	1.00E-01	1.07E-01
241-A-102	2.15E+00	3.49E-03	3.17E-01	5.79E-01
241-A-103	1.98E-01	3.68E-04	8.69E-02	1.02E-01
241-A-104	5.67E+01	9.03E-02	7.34E+00	1.39E+01
241-A-105	**1.06E+02**	**1.73E-01**	1.34E+01	2.55E+01
241-A-106	4.82E+00	7.67E-03	6.40E-01	1.24E+00
241-AX-101	1.55E-01	3.07E-04	9.34E-02	1.00E-01
241-AX-102	5.25E+00	8.73E-03	6.16E-01	1.23E+00
241-AX-103	5.82E-01	9.97E-04	1.33E-01	1.90E-01
241-AX-104	1.43E+01	2.31E-02	2.15E+00	3.66E+00
A Pipeline (HTWOS)	3.74E+00	2.83E-03	6.63E+01	3.10E+01
AX Pipeline (HTWOS)	5.72E+00	4.67E-03	**1.16E+02**	**5.42E+01**
A Pipeline (BBI)	4.95E+00	4.17E-03	3.28E+01	1.55E+01
AX Pipeline (BBI)	8.57E+00	7.41E-03	7.29E+01	3.42E+01

BBI = Best-Basis Inventory HTWOS = Hanford Tank Waste Operations Simulator

Note: Peak dose occurs at 500 years for all sources except for pipeline, which occurs at 100 years after closure.
The peak dose for each scenario is shown in **bold**.

BBI-based post-retrieval inventories for radionuclides in the AX pipelines are about an order of magnitude lower than those in the HTWOS-based post-retrieval inventories except for ^{14}C, ^{243}Cm, ^{244}Cm, ^{137}Cs, ^{3}H, ^{129}I, ^{210}Pb, ^{226}Ra, ^{79}Se, ^{126}Sn, ^{99}Tc, ^{229}Th, and ^{230}Th, which are all about 4 orders of magnitude higher.

While this analysis assumes WMA A-AX closure in 2050, the surrounding Hanford site will continue to operate beyond 2050 as other tank farms are retrieved and closed and tank waste treatment continues at the Waste Treatment Plant (WTP). The River Protection Project System Plan (ORP 11242, Rev. 8), anticipates closing the last double-shell tank (DST) farm in 2068, and the Hanford Site cannot be closed before then. A number of other actions in the Central Plateau associated with records of decisions related to the decommissioning and decontamination of existing facilities, remediation of past-practice wastes sites, and mitigation of existing contaminated groundwater using pump-and treat systems may also result in further delays in the actual date of site closure from an operational perspective. Therefore, it is reasonable to expect institutional control and societal memory of the Hanford Site to be retained until at least 2168. If intrusion into WMA A-AX pipelines were to occur at that time, the potential dose would be substantially lower because of the rapid decay of the primary contributors to pipeline doses, ^{90}Sr and ^{137}Cs, both of which have an approximately 30-year half-life.

Table 7-2 presents the relative importance of each pathway for each intruder scenario for the AX pipeline (the source term contributing the highest dose at 100 years after closure) using the HTWOS-based inventory while Table 7-3 presents the same using the BBI-based inventory. Table 7-4 presents the relative importance of each pathway for each intruder scenario for tank 241-A-105 (the source term contributing the highest dose at 500 years after closure).

Table 7-2. Relative Fraction of Pathway Contributions to the Inadvertent Intruder Dose from AX Pipeline at 100 Years After Closure (Hanford Tank Waste Operations Simulator-based inventory).

Scenario	Pathways				
	External Exposure	Soil Inhalation	Soil Ingestion	Milk Ingestion	Vegetable Ingestion
Well Driller	0.31	**0.38**	0.31	x	x
Rural Pasture	<0.01	<0.01	<0.01	**1.00**	x
Suburban Garden	<0.01	<0.01	<0.01	x	**0.99**
Commercial Farm	0.32	0.06	**0.62**	x	x

x = pathway not considered

Pathway contributing the most is shown in **bold** for each scenario.

Table 7-3. Relative Fraction of Pathway Contributions to the Inadvertent Intruder Dose from AX Pipeline at 100 Years After Closure (Best-Basis Inventory-based inventory).

Scenario	Pathways				
	External Exposure	Soil Inhalation	Soil Ingestion	Milk Ingestion	Vegetable Ingestion
Well Driller	**0.79**	0.09	0.12	x	x
Rural Pasture	0.01	<0.01	<0.01	**0.98**	x
Suburban Garden	0.03	<0.01	<0.01	x	**0.97**
Commercial Farm	**0.76**	0.01	0.22	x	x

x = pathway not considered

Pathway contributing the most is shown in **bold** for each scenario.

Table 7-4. Relative Fraction of Pathway Contributions to the Inadvertent Intruder Dose from Tank 241-A-105 at 500 Years After Closure.

Scenario	Pathways				
	External Exposure	Soil Inhalation	Soil Ingestion	Milk Ingestion	Vegetable Ingestion
Well Driller	0.04	**0.81**	0.15	x	x
Rural Pasture	0.10	0.30	**0.44**	0.17	x
Suburban Garden	0.03	0.09	0.18	x	**0.71**
Commercial Farm	0.08	0.27	**0.65**	x	x

x = pathway not considered

Pathway contributing the most is shown in **bold** for each scenario.

7.1.1 Acute Exposure Dose

Figure 7-1 presents the acute effective doses to a hypothetical well driller produced by each of the WMA A-AX waste sources at the year of intrusion for the length of the compliance period. The earliest assumed intrusion for tanks is 500 years after closure and 100 years after closure for pipelines.

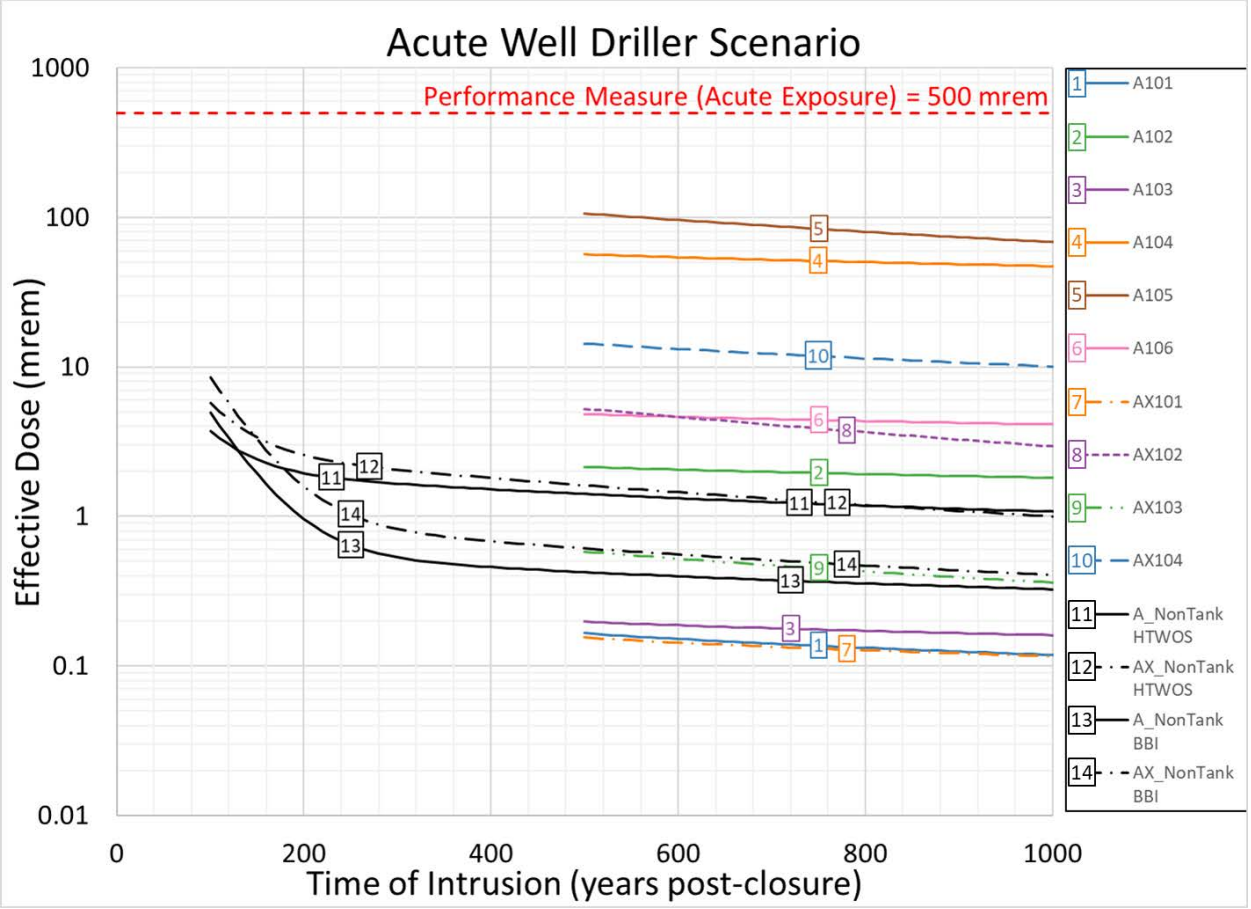
All of the sources in WMA A-AX produce doses below the 500 mrem performance measure, with intrusion into tank 241-A-105 at 500 years post-closure producing the highest dose (106.4 mrem). In the following figures, the plotted values represent the dose received by the well driller if the intrusion occurs at the given year after closure.

Figure 7-2 shows the total acute effective dose to the well driller from the source providing the greatest intruder dose at 100 years post-closure, the AX pipeline with HTWOS-based inventory estimates, along with the major dose-contributing radionuclides. Even with BBI-based inventory estimates, the AX pipeline provides the greatest intruder dose at 100 years post-closure, as is shown in Figure 7-3. Figure 7-4 shows the results for tank 241-A-105, the source providing the maximum intruder dose at 500 years post-closure.

With HTWOS-based inventory at the time of highest dose rate for the AX pipeline, the major dose-contributing radionuclides are ^{90}Sr (3.1 mrem), ^{241}Am (2.1 mrem), and ^{239}Pu (0.4 mrem) which together account for 98% of the total effective dose of 5.7 mrem to the well driller.

With BBI-based inventory at the time of highest dose rate for the AX pipeline, the major dose-contributing radionuclides are ^{137}Cs (5.7 mrem), ^{90}Sr (1.9 mrem), ^{241}Am (0.7 mrem), ^{239}Pu (0.2 mrem) and ^{240}Pu (0.05 mrem) which together account for over 99% of the total effective dose of 8.6 mrem to the well driller.

Figure 7-1. Effective Dose for the Well Driller Acute Exposure Scenario.

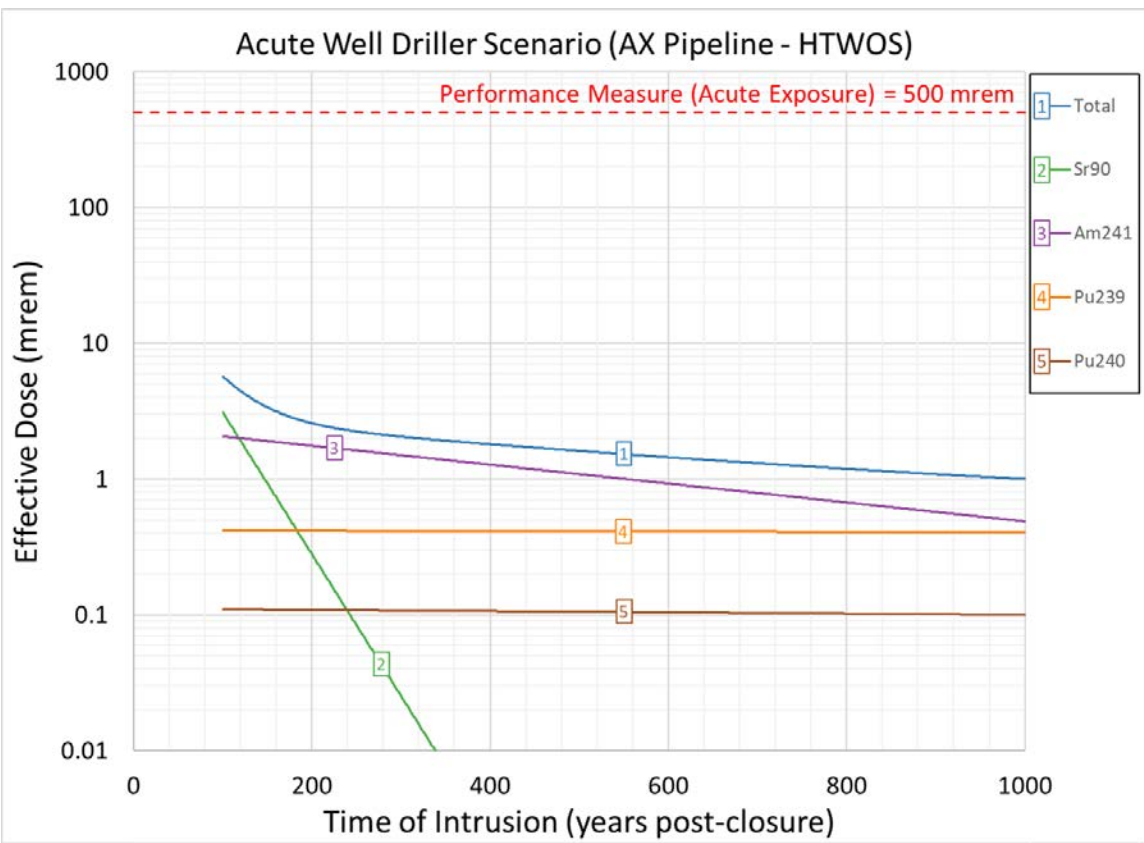


At the time of highest dose rate for tank 241-A-105, the major dose-contributing radionuclides are ^{241}Am (67.0 mrem), ^{239}Pu (31.5 mrem) and ^{240}Pu (7.4 mrem), which together account for 99% of the total effective dose of 106.4 mrem to the well driller.

Figure 7-5 shows the contribution of each exposure pathway to the overall dose to the well driller from AX pipeline intrusion, using HTWOS-based inventories. The highest dose of the compliance time period occurs if the intrusion happens at 100 years post-closure, and potential dose steadily declines as the intrusion time occurs farther in the future. Regardless the time of intrusion, soil inhalation contributes the largest fraction of the total dose to the well driller, followed by soil ingestion and external exposure.

Figure 7-6 shows the contribution of each exposure pathway to the overall dose to the well driller from intrusion into the AX pipeline, using BBI-based inventories. As with the HTWOS-based inventories the highest dose occurs if intrusion occurs at 100 years post-closure, and dose potential decreases with time. Unlike the HTWOS-based inventory, the primary contributing pathway at 100 years is external exposure, followed by soil ingestion, and soil inhalation. The larger ^{137}Cs inventory in the BBI causes external exposure to dominate the total acute well driller dose. Because of the short half-life of ^{137}Cs, the contribution of external exposure quickly decreases for about the first 200 years after closure, after which soil inhalation becomes the top contributor, driven by ^{241}Am and ^{239}Pu. At about 300 years after closure the contribution from soil ingestion is overtaken by the contribution from soil ingestion, which at that time is driven by ^{241}Am and ^{239}Pu.

Figure 7-2. Effective Dose for the Well Driller Acute Exposure Scenario from AX Pipeline (Hanford Tank Waste Operations Simulator-based inventory).



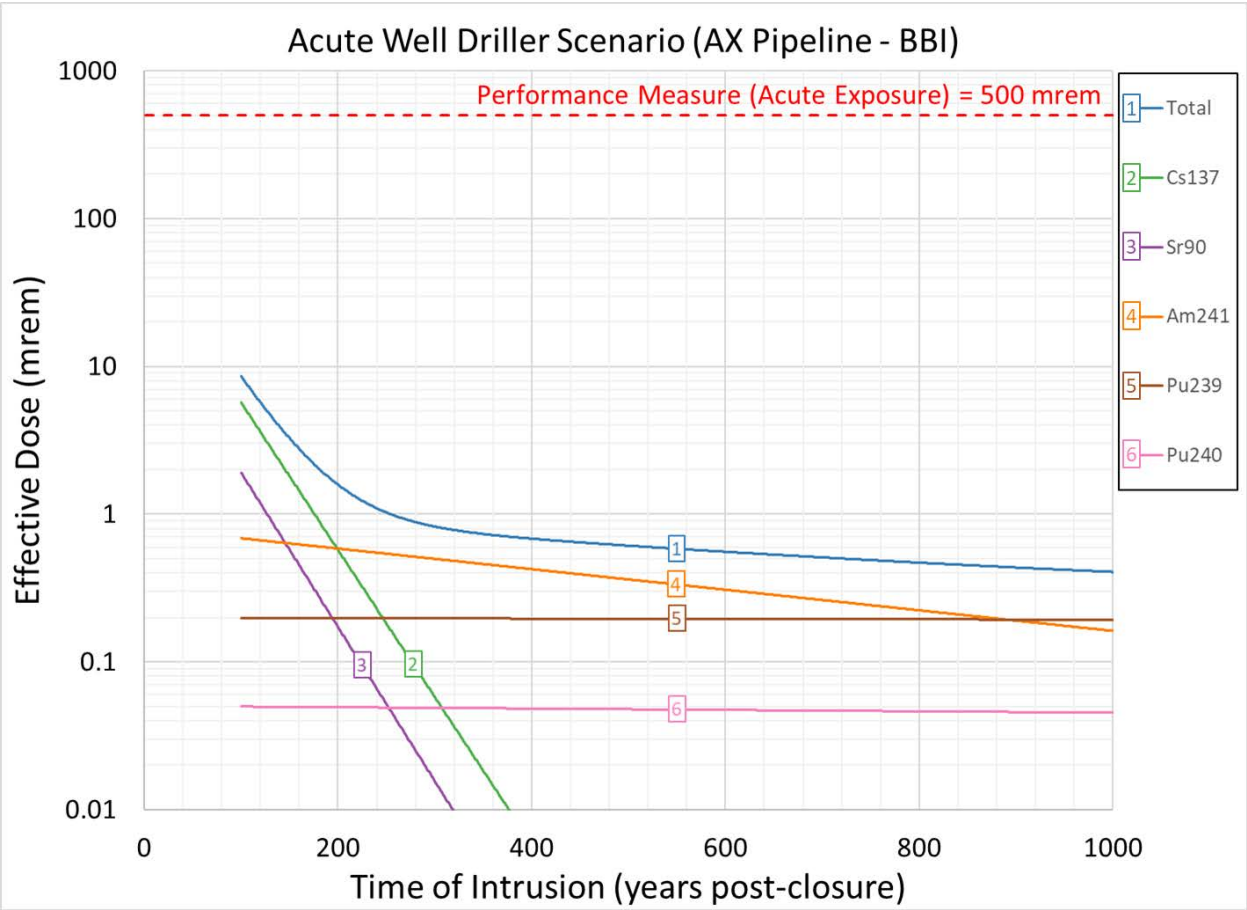
HTWOS = Hanford Tank Waste Operations Simulator

Figure 7-7 shows the contribution of each exposure pathway to the overall dose to the well driller from intrusion into tank 241-A-105. As with the pipeline, the earlier the intrusion, the higher the dose, with the highest dose of the compliance time-period occurring at 500 years post-closure. Like the pipeline intrusion, soil inhalation contributes the largest fraction of the total dose, followed by soil ingestion and external exposure, regardless of the time of intrusion.

7.1.2 Chronic Exposure Dose

Three chronic exposure scenarios evaluate the long-term exposure of three different receptors from previously-exhumed drill cuttings that have been uniformly spread and tilled onto three different land areas or target fields. The three different target fields include the following: a rural pasture, a suburban garden, and a commercial farm (RPP-RPT-60885). In the following figures, the plotted values represent the dose received by the inadvertent intruder if the intrusion occurs at the given year after closure and is left unmitigated in subsequent years.

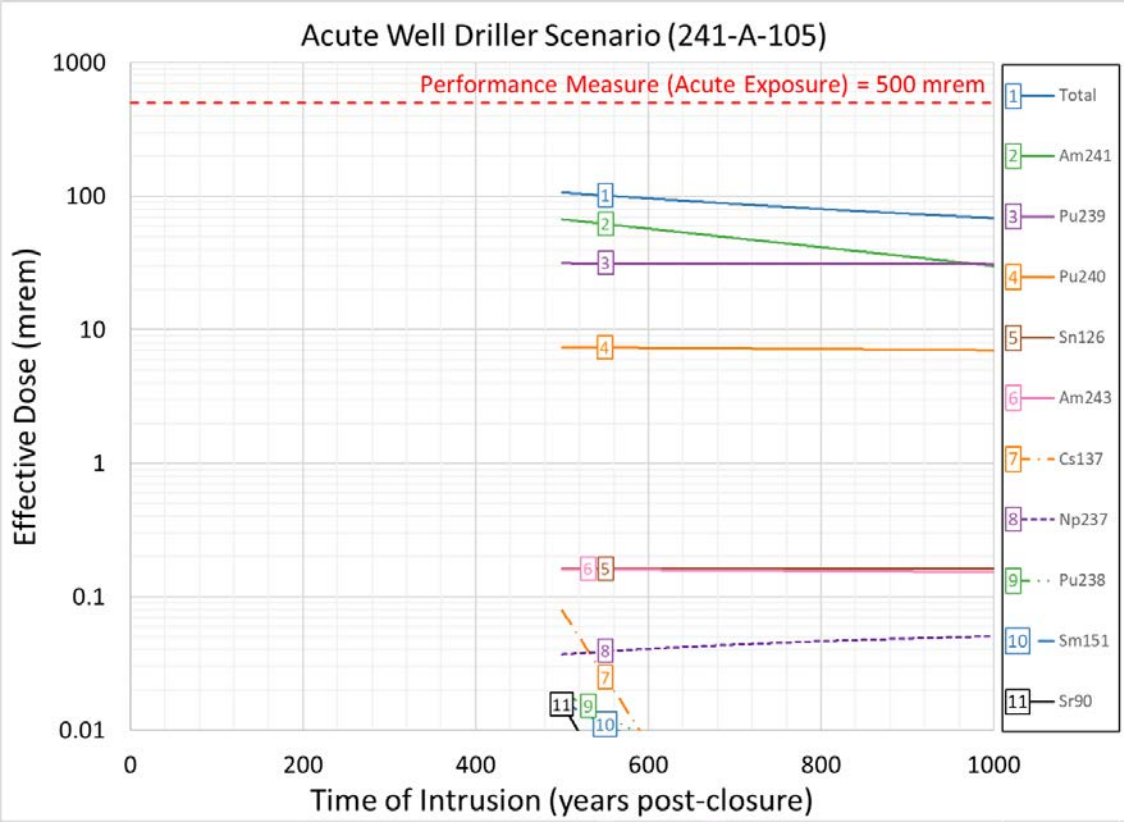
Figure 7-3. Effective Dose for the Well Driller Acute Exposure Scenario from AX Pipeline (Best-Basis Inventory-based inventory).



BBI = Best-Basis Inventory

7.1.2.1 Rural Pasture Scenario. Figure 7-8 presents the chronic effective dose rates to a hypothetical adult receptor who uses the target field as a residence, with a pasture used to raise dairy cows. The results are presented for each of the WMA A-AX waste sources for the duration of the compliance period. The earliest assumed intrusion for tanks is 500 years after closure and 100 years after closure for pipelines. All of the sources in WMA A-AX produce dose rates below the 100 mrem/yr performance measure, except for the AX pipeline with HTWOS-based inventory, which exceeds the performance measure for six years after intrusion (assumed at 100 years post-closure) with a maximum dose rate of 116.3 mrem/yr. This means that in order to receive a dose greater than the performance measure, the intrusion needs to occur between 100 and 107 years after closure. Furthermore, while this analysis assumes the occurrence of an intrusion event, there is no regard for its likelihood, nor the likelihood of intersecting waste. The probability of intersecting waste could be evaluated in principle by using the ratio of the total AX Farm pipeline area to the area of WMA A-AX. In this case, there are 7.9 miles of pipes in AX Farm with a diameter of 3 inches (RPP-RPT-60885) which equals an area of 972.5 m^2. The ratio of that to the WMA A-AX area of 28,553.8 m^2 (Hanford Maps [HMAPS], Queried 12/12/2018, [Query, Advanced Measurement, Polygon], [URL REDACTED] is 0.03. This means there is a low probability of actually intersecting a pipeline if the drilling location is randomly chosen within the WMA boundaries. As discussed in Section 4.1, studies in 241-SY Tank Farm found about 4% of the pipe volume contained waste. Dose scales linearly with inventory, so if 4% pipe volume is filled with waste, instead of the conservatively assumed 5%, the resulting dose would be 20% less as well. A 20% reduction in dose would be about 93 mrem/yr—if the intrusion occurred at 100 years post-closure—which is under the 100 mrem/yr performance measure.

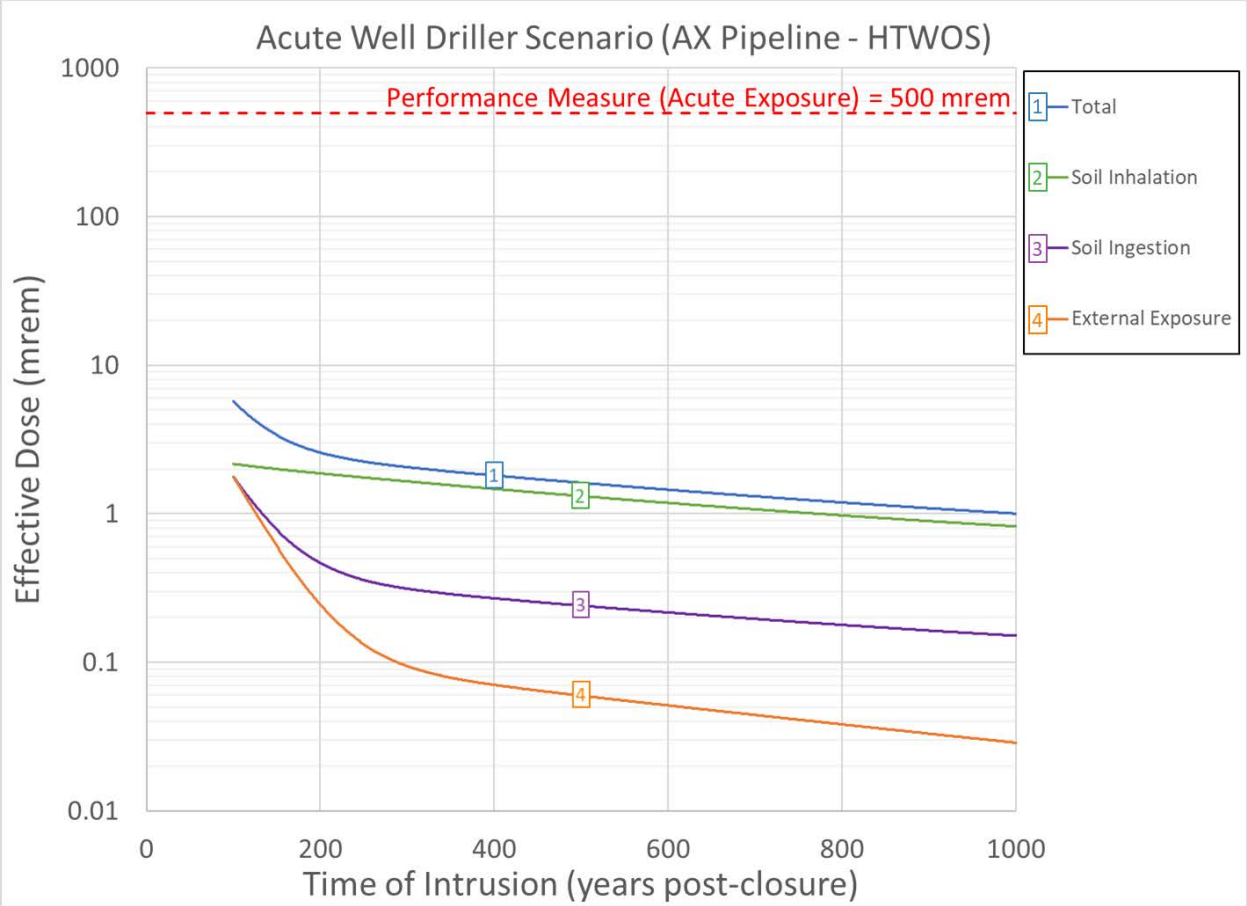
Figure 7-4. Effective Dose for the Well Driller Acute Exposure Scenario from Tank 241-A-105.



When using BBI-based inventory, the AX pipelines are still the highest contributing source if intrusion occurs 100 years post-closure, but the dose is below the 100 mrem/yr performance measure, at 73 mrem/yr.

Figure 7-9 presents the total chronic effective dose rate to the rural pasture resident from the AX pipeline using HTWOS-based inventory (the source providing the maximum dose rate at 100 years post-closure), along with the major dose rate-contributing radionuclides. Figure 7-10 shows the effective dose rate to the rural pasture resident from the AX pipeline using BBI-based inventory. Figure 7-11 shows the results for tank 241-A-105, which produces the maximum intruder dose rate at 500 years post-closure. In these cases, the highest dose rate of the compliance period occurs at the earliest credible intrusion time, and subsequently decreases as radioactive decay reduces the activity in the residual waste.

Figure 7-5. Effective Dose for the Well Driller Acute Exposure Scenario from AX Pipeline with Pathway Contributions (Hanford Tank Waste Operations Simulator-based inventory).

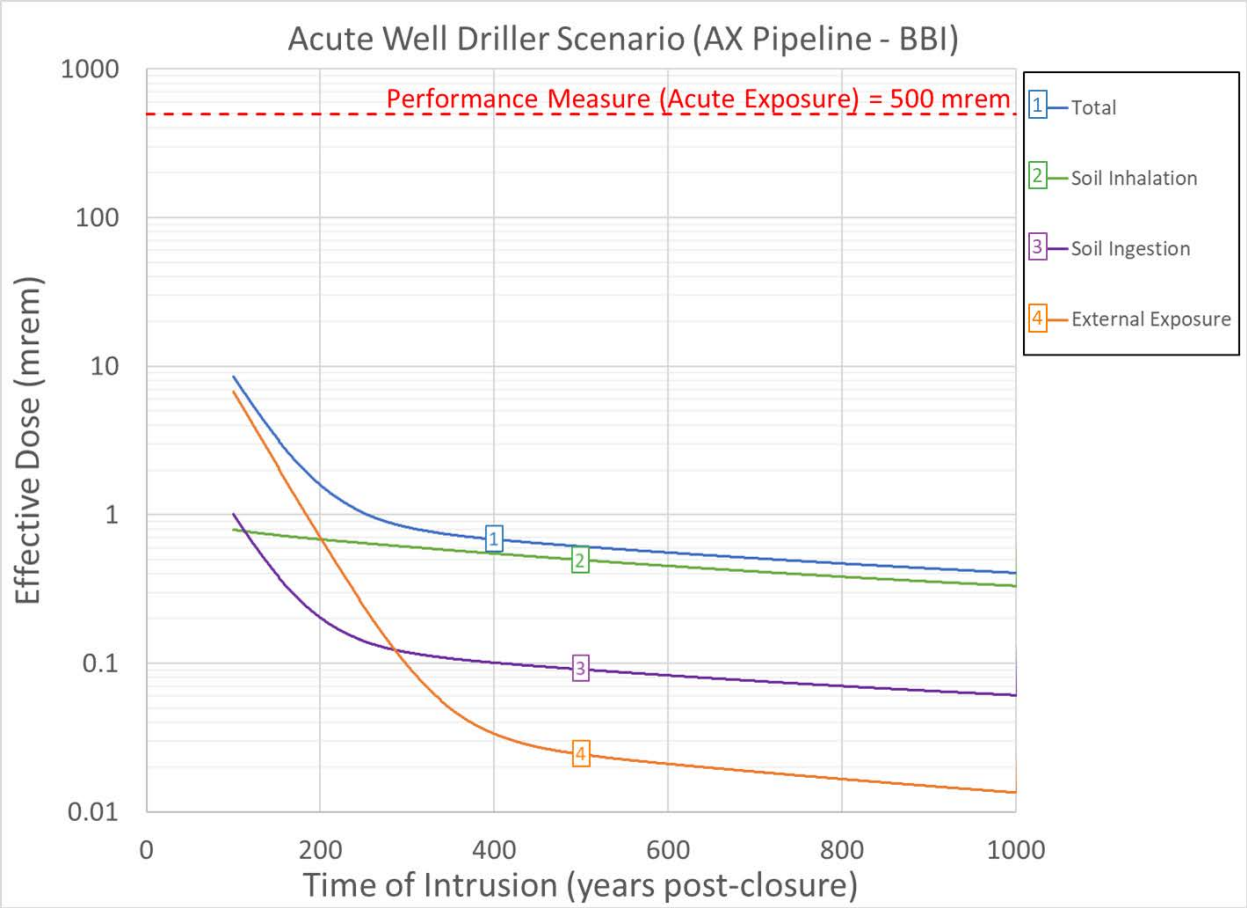


HTWOS = Hanford Tank Waste Operations Simulator

At the time of highest dose rate for the AX pipeline using the HTWOS-based inventory, the major dose rate-contributing radionuclide is ^{90}Sr (116.0 mrem/yr), which contributes over 99% of the total effective dose rate of 116.3 mrem/yr to the rural pasture resident. Americium-241 (0.08 mrem/yr), and ^{239}Pu (0.01 mrem/yr) are the next two highest contributors to the total effective dose rate.

At the time of highest dose rate for the AX pipeline using the BBI-based inventory, the major dose-rate contributing radionuclide is ^{90}Sr (71.6 mrem/yr), which contributes over 98% of the total effective dose rate of 72.9 mrem/yr to the rural pasture resident. Cesium-137 (1.2 mrem/yr) and ^{241}Am (0.03 mrem/yr) are the next two highest contributors to the total effective dose rate.

Figure 7-6. Effective Dose for the Well Driller Acute Exposure Scenario from AX Pipeline with Pathway Contributions (Best-Basis Inventory-based inventory).



BBI = Best-Basis Inventory

At time of highest dose rate for tank 241-A-105, the major dose rate-contributing radionuclides are ^{241}Am (7.3 mrem/yr), ^{239}Pu (3.0 mrem/yr), ^{90}Sr (1.6 mrem/yr), ^{240}Pu (0.7 mrem/yr) and ^{99}Tc (0.5 mrem/yr), which together account for 98% of the total effective dose rate of 13.4 mrem/yr to the rural pasture resident.

Figure 7-12 shows the dose contributions of exposure pathways to the overall dose to the resident in the Rural Pasture scenario from the AX pipeline, using the HTWOS-based inventory. The highest dose of the compliance time period is received if the intrusion occurs at 100 years post-closure and decreases rapidly if the intrusion occurs farther in the future. At the time of maximum dose from intrusion, the dominant exposure pathway is milk ingestion because of high levels of ^{90}Sr in the dairy cow's milk. The potential dose from this pathway decreases rapidly because of the short half-life of ^{90}Sr (28.8 years) so that if intrusion occurs after about 475 years post-closure, the dominant pathways will be soil ingestion and soil inhalation.

Figure 7-7. Effective Dose for the Well Driller Acute Exposure Scenario from Tank 241-A-105 with Pathway Contributions.

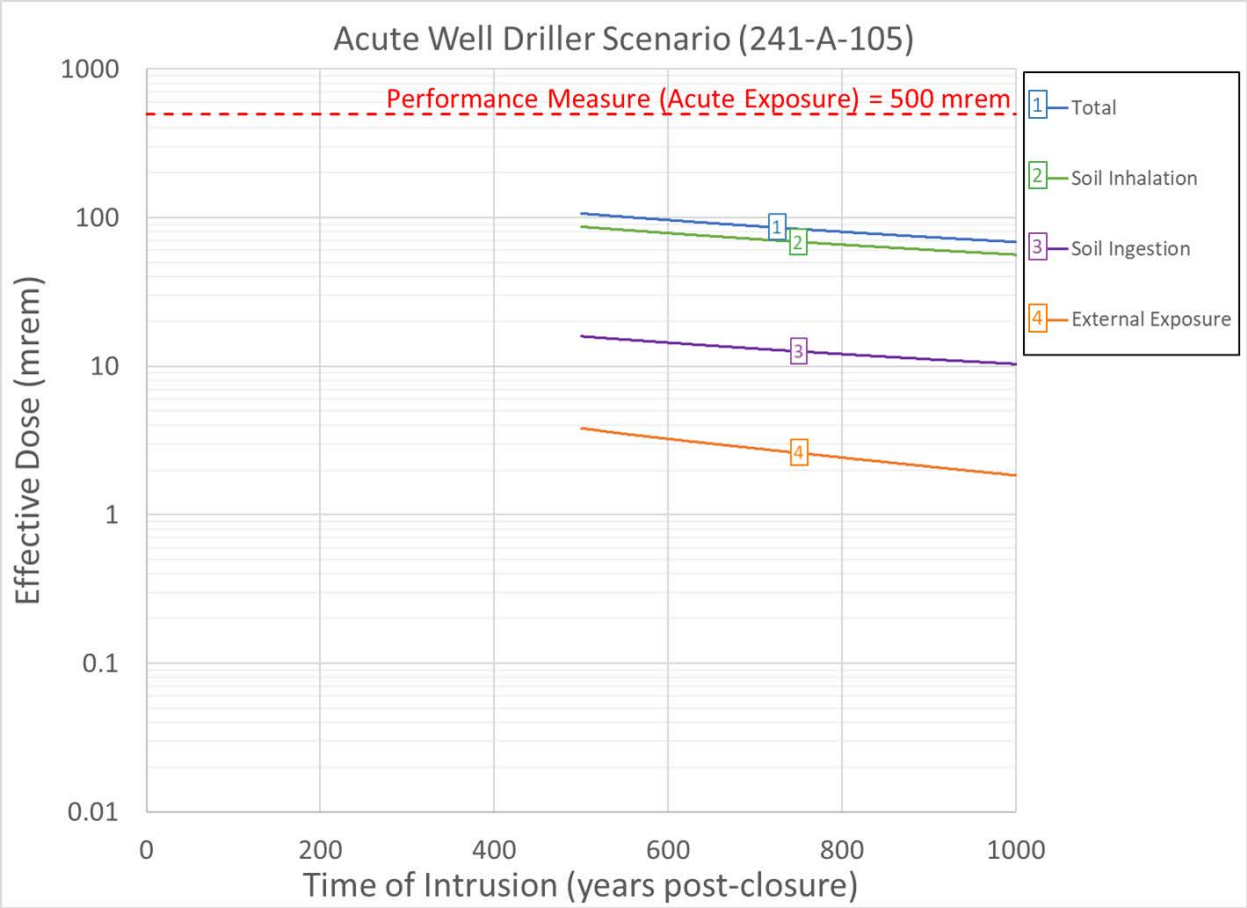
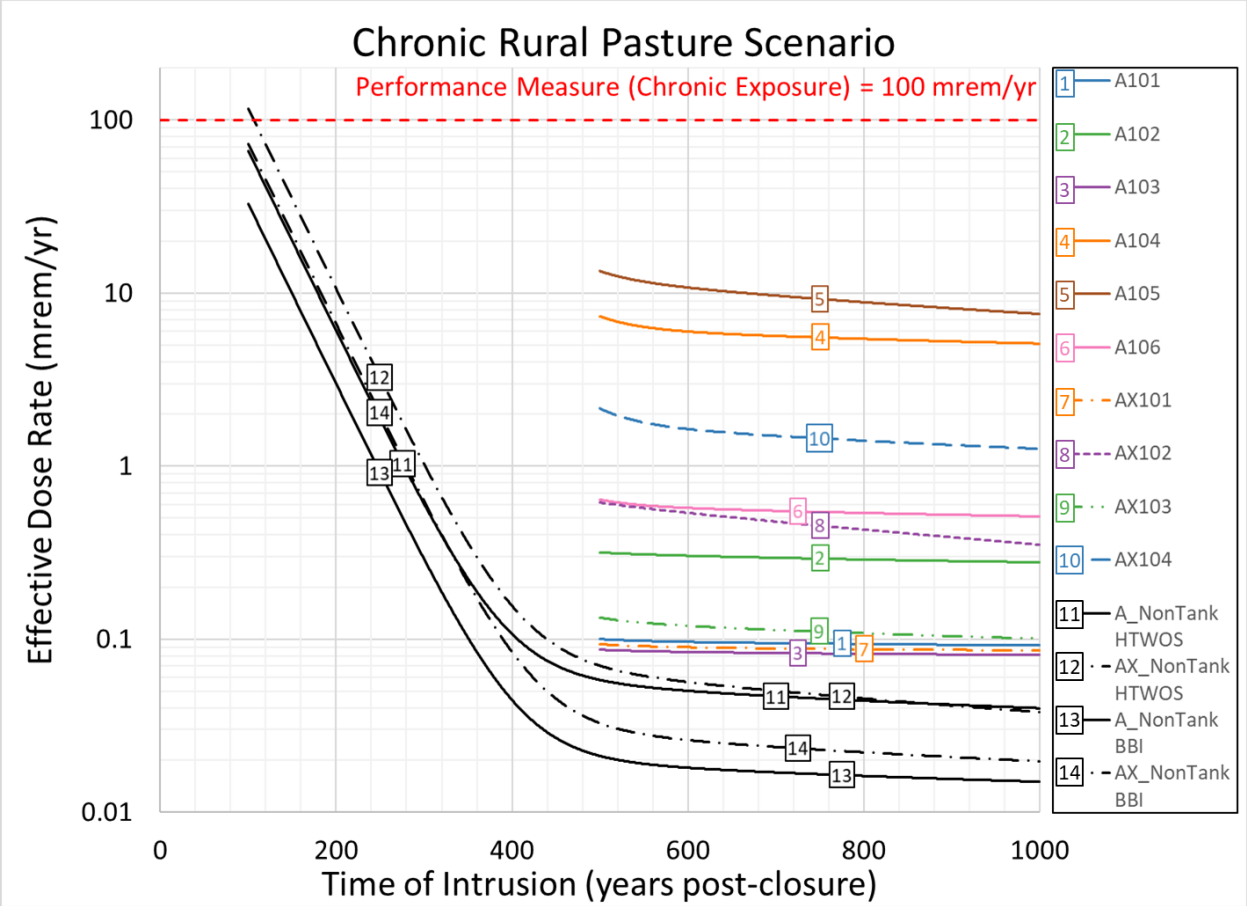


Figure 7-13 shows the dose contributions of exposure pathways to the overall dose to the resident in the Rural Pasture scenario from the AX pipeline, using BBI-based inventory. As with the HTWOS-based inventory, the highest dose occurs if intrusion is at 100 years post-closure and milk ingestion is the dominant pathway, due to ^{90}Sr. Unlike the HTWOS-based inventory, external exposure is the next highest contributor to overall dose because of an increased inventory of ^{137}Cs. External exposure dose potential decreases rapidly with time because of the short ^{137}Cs half-life until about 300 years when the soil ingestion contribution overtakes the external exposure contribution, at which time ^{241}Am is the primary contributing radionuclide to dose from soil ingestion. Soil ingestion becomes the primary contributor to overall dose if intrusion occurs approximately 500 years post-closure or later because rapid ^{90}Sr decay causes potential milk ingestion dose to be lower than that from soil ingestion by this time.

Figure 7-14 shows the dose contributions of exposure pathways to the overall dose to the resident in the Rural Pasture scenario from tank 241-A-105. Like the AX pipeline, the earlier the intrusion time, the higher the dose, with the highest possible dose of the compliance time period occurring at 500 years post-closure. Unlike the AX pipeline, the soil ingestion and soil inhalation pathways contribute more dose than the milk ingestion pathway because ^{90}Sr has decayed enough by 500 years post-closure to be a lower contributor to overall dose.

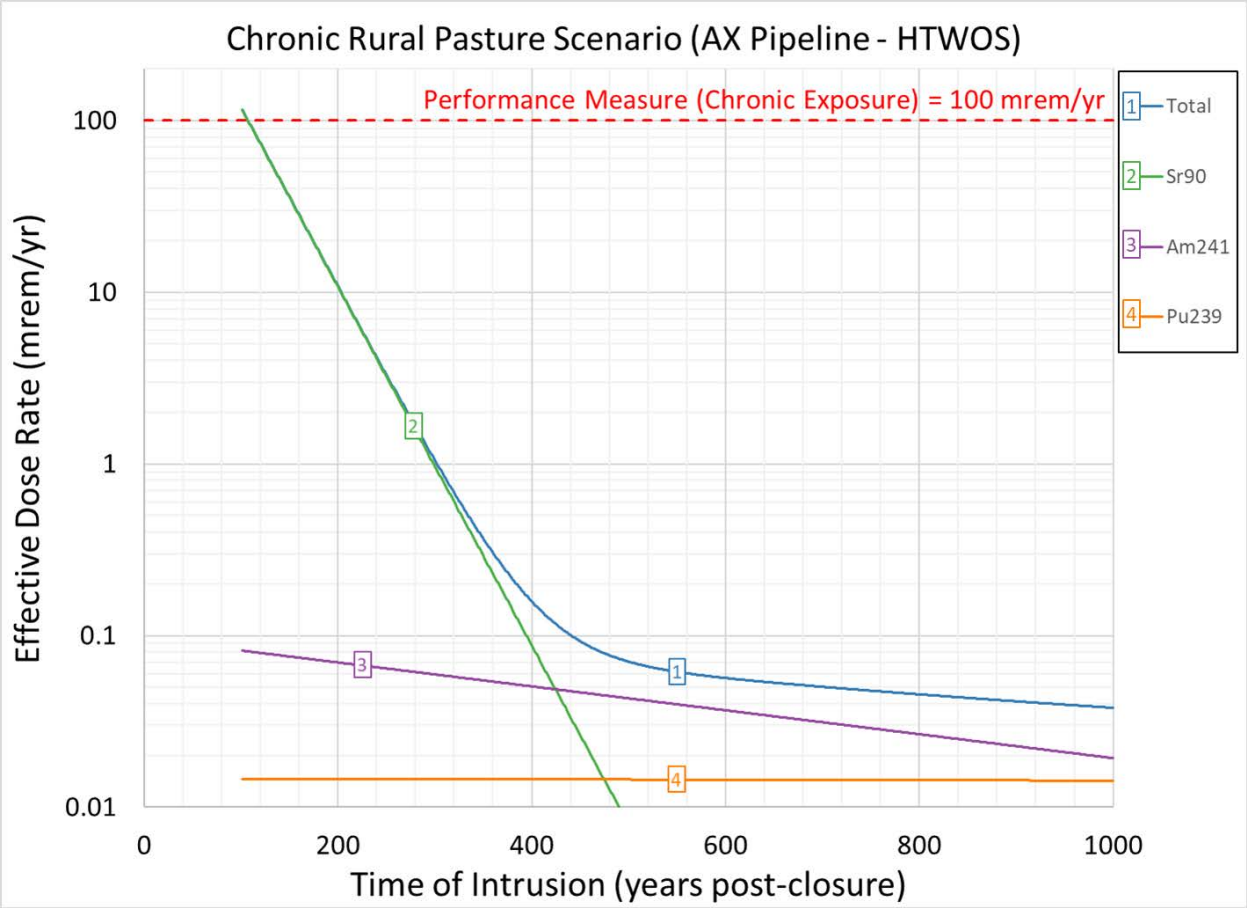
Figure 7-8. Effective Dose Rate for the Rural Pasture Chronic Exposure Scenario.



7.1.2.2 Suburban Garden Scenario. The chronic effective dose rate to a hypothetical adult receptor who uses the target field as a home construction lot with a garden is shown in Figure 7-15. The results are presented for each of the WMA A-AX waste sources over time. The earliest assumed intrusion for tanks is 500 years after closure and 100 years after closure for pipelines. All of the sources in WMA A-AX produce dose rates below the 100 mrem/yr performance measure, with the maximum dose rate of the compliance period (54.2 mrem/yr) occurring at 100 years post-closure from the AX pipeline using the HTWOS-based inventory.

Figure 7-16 presents the total chronic effective dose rate to the suburban gardener resident from the AX pipeline using the HTWOS-based inventory, which provides the maximum dose rate at 100 years post-closure, along with the major dose rate-contributing radionuclides. Figure 7-17 presents the total chronic effective dose rate to the suburban gardener resident from the AX pipeline using the BBI-based inventory along with the primary dose rate-contributing radionuclides. Figure 7-18 presents the results for tank 241-A-105, which produces the maximum intruder dose rate at 500 years post-closure. In all cases, the highest dose rate of the compliance period occurs at the earliest credible intrusion time, and subsequently decreases as radioactive decay reduces the activity in the residual waste.

Figure 7-9. Effective Dose Rate for the Rural Pasture Chronic Exposure Scenario from AX Pipeline (Hanford Tank Waste Operations Simulator-based inventory).



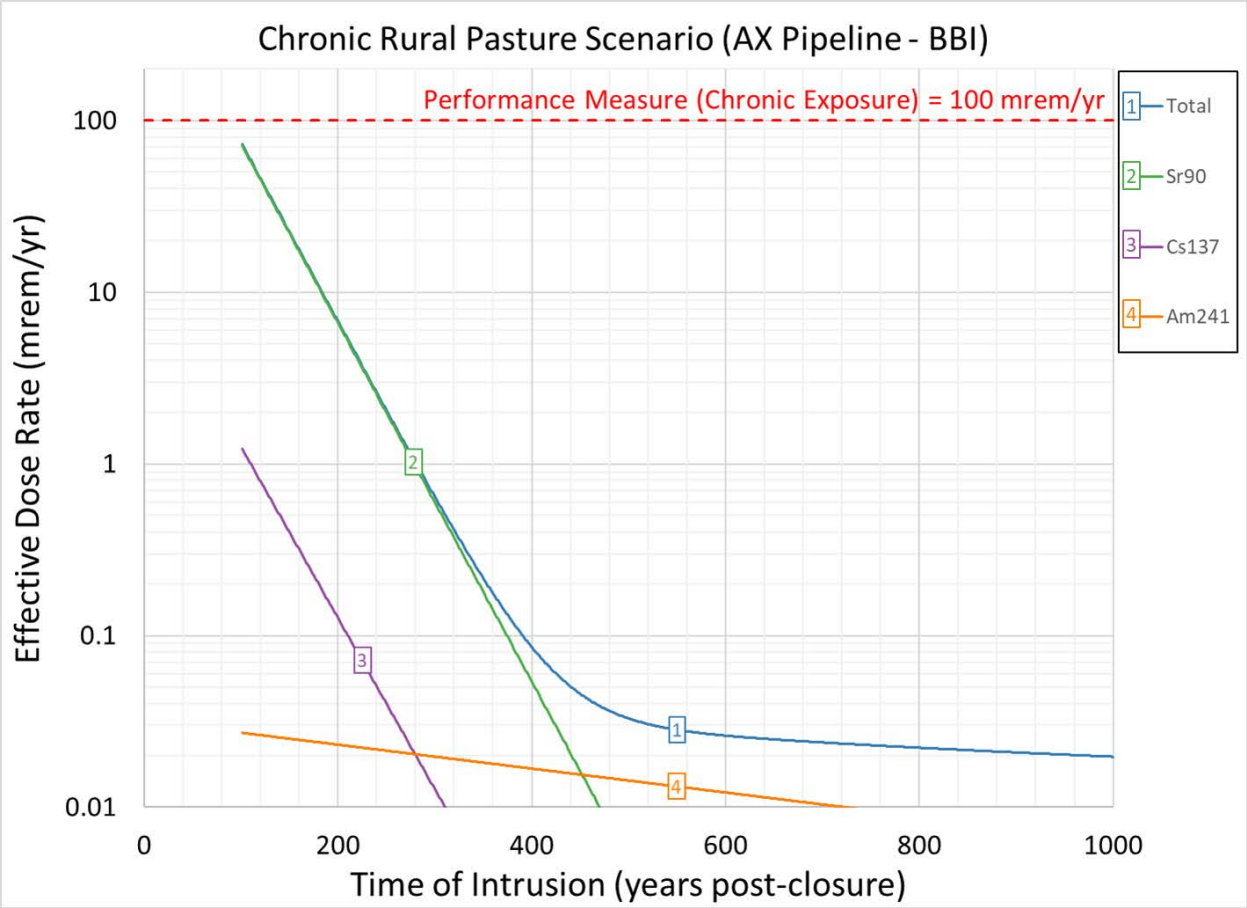
HTWOS = Hanford Tank Waste Operations Simulator

At the time of highest dose rate for the AX pipeline using the HTWOS-based inventory, the major dose rate-contributing radionuclides are ^{90}Sr (53.8 mrem/yr), ^{241}Am (0.3 mrem/yr), ^{239}Pu (0.1 mrem/yr) and ^{240}Pu (<0.1 mrem/yr), which together account for over 99% of the 54.2 mrem/yr total effective dose rate.

When using the BBI-based inventory for the AX pipeline at the time of highest dose rate, the major dose rate-contributing radionuclides are ^{90}Sr (33.2 mrem/yr), ^{137}Cs (0.9 mrem/yr), and ^{241}Am (0.09 mrem/yr), which together account for over 99% of the 34.2 mrem/yr total effective dose rate.

At the time of highest dose rate for tank 241-A-105, the major dose rate-contributing radionuclides are ^{241}Am (15.3 mrem/yr), ^{239}Pu (7.4 mrem/yr), ^{240}Pu (1.7 mrem/yr), ^{99}Tc (0.5 mrem/yr), and ^{90}Sr (0.5 mrem/yr), which together account for over 99% of the 25.5 mrem/yr total effective dose rate.

Figure 7-10. Effective Dose Rate for the Rural Pasture Chronic Exposure Scenario from AX Pipeline (Best-Basis Inventory-based inventory).



BBI = Best-Basis Inventory

Figure 7-19 shows the contribution of exposure pathways to overall dose from the AX pipeline using the HTWOS-based inventory to an inadvertent intruder under the Suburban Garden scenario. The highest dose of the compliance time-period is obtained when intrusion occurs at 100 years post-closure and progressively decreases over time. The contribution of vegetable ingestion dominates the overall dose regardless of the time of intrusion.

Figure 7-20 shows the contribution of exposure pathways to overall dose from the AX pipeline using the BBI-based inventory to an inadvertent intruder under the Suburban Garden scenario. As with the HTWOS-based inventory, the highest dose is received when intrusion occurs at 100 years post-closure, with potential dose decreasing farther out in time. Also, like the HTWOS-based inventory, the total dose is dominated by the contribution of vegetable ingestion throughout the simulation time-frame. Unlike the HTWOS-based inventory, the external exposure pathway is the next highest contributor to total dose at 100 years post-closure. This is because there is more ^{137}Cs in the BBI-based inventory, which is the primary radionuclide contributing to external exposure. Because of the short half-life of ^{137}Cs, the contribution of external exposure drops below that of the soil ingestion pathway at approximately 300 years post-closure.

Figure 7-11. Effective Dose Rate for the Rural Pasture Chronic Exposure Scenario from Tank 241-A-105.

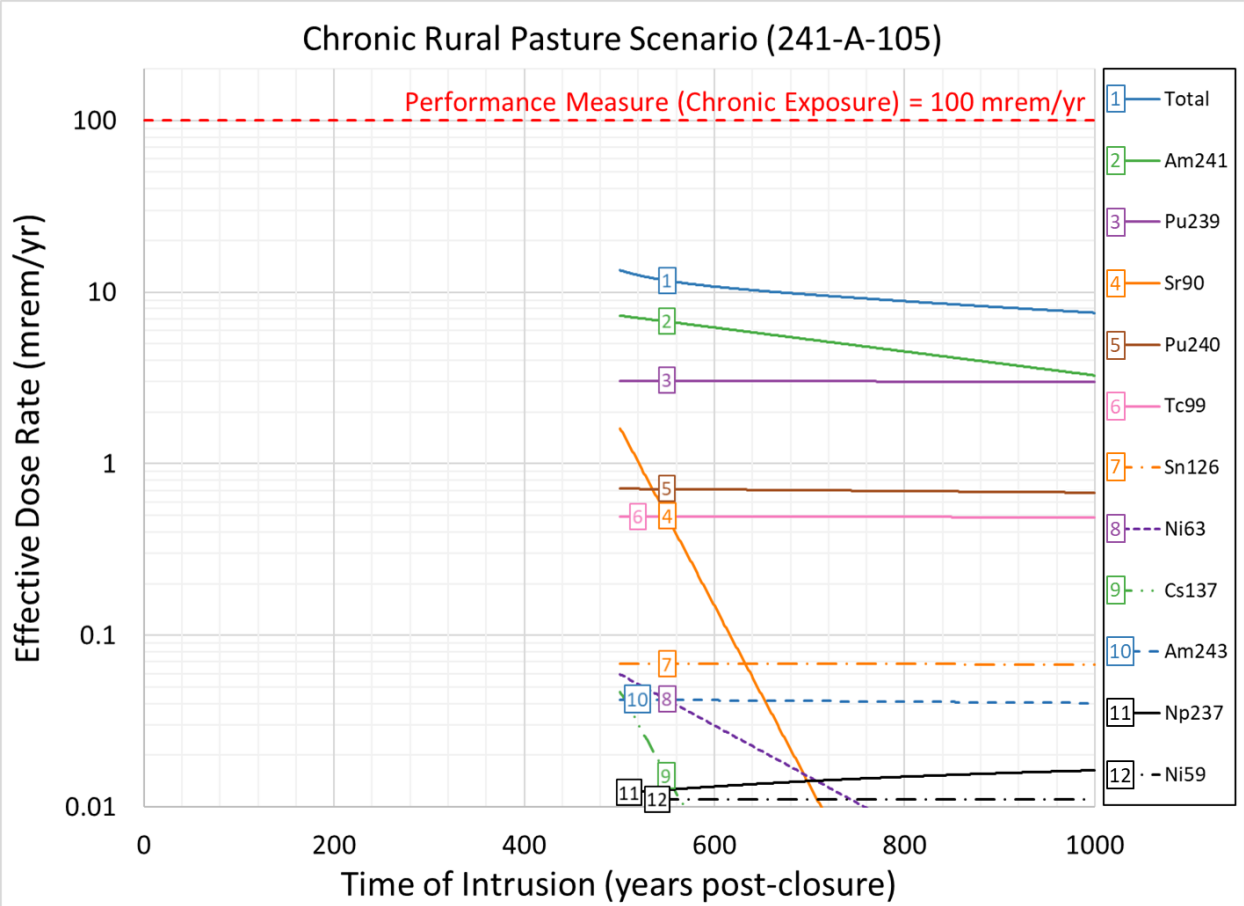


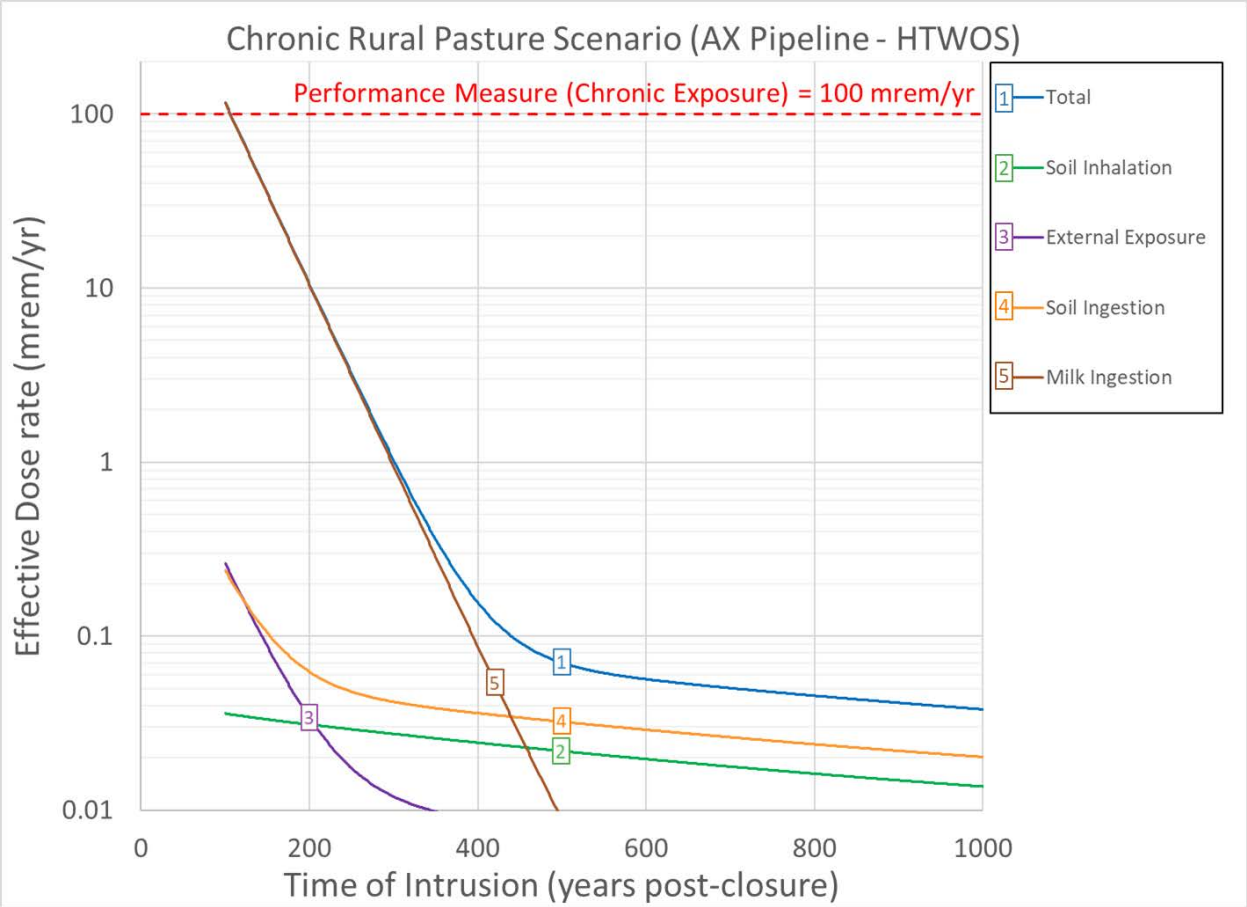
Figure 7-21 shows the contribution of exposure pathways to overall dose from tank 241-A-105 to an inadvertent intruder under the Suburban Garden scenario. As with the AX pipeline, the later in time the intrusion occurs, the lower the dose, with the highest dose of the compliance period occurring at 500 years post-closure. The vegetable ingestion pathway dominates the overall dose regardless of the time of intrusion.

7.1.2.3 Commercial Farm Scenario. The chronic effective dose rates to a hypothetical adult receptor who works in the target field as a commercial farm are presented in Figure 7-22. The results are presented for each of the WMA A-AX waste sources over time. The earliest assumed intrusion for tanks is 500 years after closure and 100 years after closure for pipelines. All of the sources in WMA A-AX produce dose rates below the 100 mrem/yr performance measure with a maximum dose rate of 0.17 mrem/year at 500 years after closure.

Figure 7-23 presents the total chronic effective dose rate to the commercial farmer from the AX pipeline using the HTWOS-based inventory, which provides the maximum dose rate at 100 years post-closure, along with the major dose rate-contributing radionuclides. Figure 7-24 shows the total chronic effective dose rate to the commercial farmer from the AX pipeline using the BBI-based inventory, along with major dose rate-contributing radionuclides. Figure 7-25

presents the results for tank 241-A-105, which produces the maximum intruder dose rate at 500 years post-closure. In both cases, the highest dose rate of the compliance period occurs at the earliest credible intrusion time, and subsequently decreases as radioactive decay reduces the activity in the residual waste.

Figure 7-12. Effective Dose Rate for the Rural Pasture Chronic Exposure Scenario from AX Pipeline with Exposure Pathway Contributions (Hanford Tank Waste Operations Simulator-based inventory).

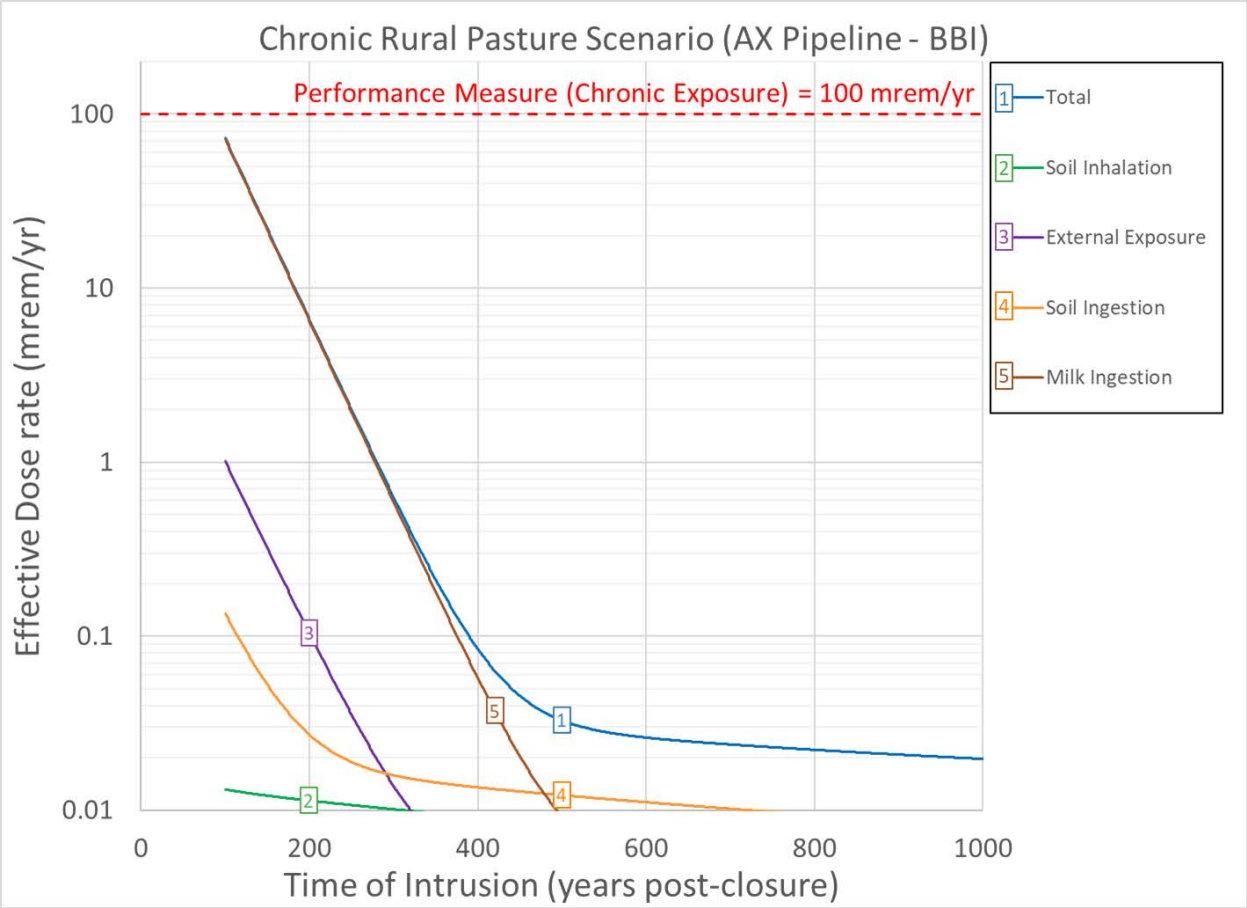


HTWOS = Hanford Tank Waste Operations Simulator

At the time of highest dose rate for the AX pipeline using the HTWOS-based inventory, the major dose rate-contributing radionuclides are ^{90}Sr (0.0037 mrem/yr), ^{241}Am (0.00079 mrem/yr), ^{239}Pu (0.00015 mrem/yr), and ^{240}Pu (0.00004 mrem/yr), which together account for over 99% of the 0.0047 mrem/yr total effective dose rate.

Using the BBI-based inventory at the time of highest dose rate for the AX pipeline, the major dose rate-contributing radionuclides are ^{137}Cs (0.005 mrem/yr), ^{90}Sr (0.002 mrem/yr), and ^{241}Am (0.0002 mrem/yr), which together account for about 99% of the 0.0074 mrem/yr total effective dose rate.

Figure 7-13. Effective Dose Rate for the Rural Pasture Chronic Exposure Scenario from AX Pipeline with Exposure Pathway Contributions (Best-Basis Inventory-based inventory).



BBI = Best-Basis Inventory

At the time of highest dose rate for tank 241-A-105, the major dose rate-contributing radionuclides are ^{241}Am (0.11 mrem/yr), ^{239}Pu (0.05 mrem/yr), and ^{240}Pu (0.01 mrem/yr), which together account for over 99% of the 0.17 mrem/yr total effective dose rate.

Figure 7-26 shows the contribution of exposure pathways to overall dose to an inadvertent intruder under the Commercial Farm scenario from the AX pipeline using the HTWOS-based inventory. The highest dose of the compliance time-period is received when intrusion occurs at 100 years post-closure and progressively decreases over time. Soil ingestion accounts for the highest contribution of overall dose regardless of intrusion time. If intrusion occurs between 100 years post-closure and just before 200 years post-closure, external exposure is the next highest contributing pathway, but decreases quickly as the presence of short-lived radionuclides diminishes.

Figure 7-27 shows the contribution of exposure pathways to overall dose to an inadvertent intruder under the Commercial Farm scenario from the AX pipeline using the BBI-based inventory. As with the HTWOS-based inventory, the highest dose is obtained if intrusion occurs at 100 years post-closure, with dose potential decreasing with time. Unlike the HTWOS-based

inventory, the external exposure pathway provides the majority of the dose at 100 years post-closure. This is because the BBI-based inventory has more ^{137}Cs. Because of the short half-life of ^{137}Cs, the potential dose rate from external exposure decreases rapidly until it is less than the dose rate from the soil ingestion pathway at about 250 years post-closure.

Figure 7-14. Effective Dose Rate for the Rural Pasture Chronic Exposure Scenario from Tank 241-A-105 with Exposure Pathway Contributions.

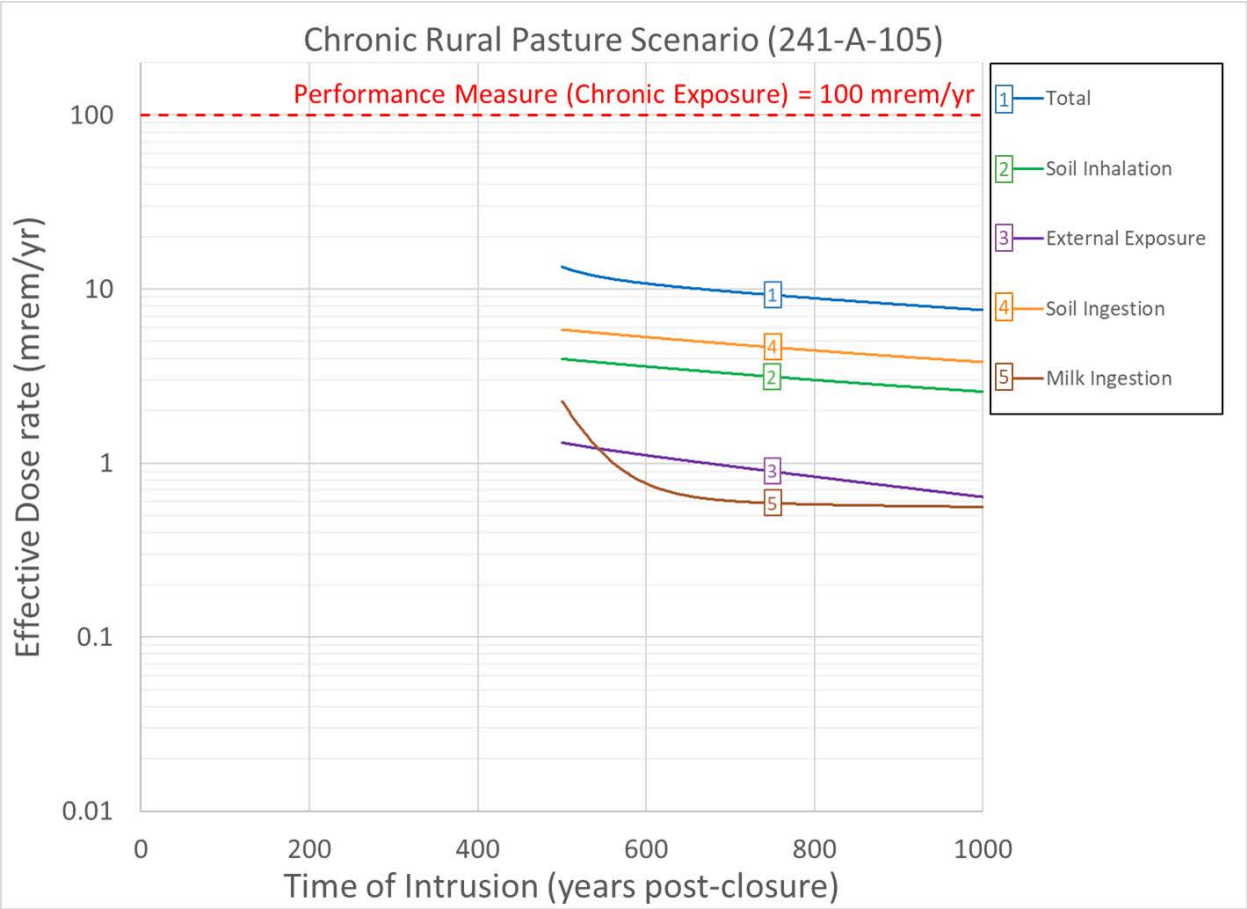


Figure 7-28 shows the contribution of exposure pathways to overall dose from tank 241-A-105 to an inadvertent intruder under the Commercial Farm scenario. As with AX pipeline waste, the highest dose of the compliance time-period is received at 500 years post-closure and potential dose decreases the farther in the future intrusion occurs. The soil ingestion pathway accounts for most of the overall dose, followed by soil inhalation and external exposure.

7.1.3 Inventory Sensitivity

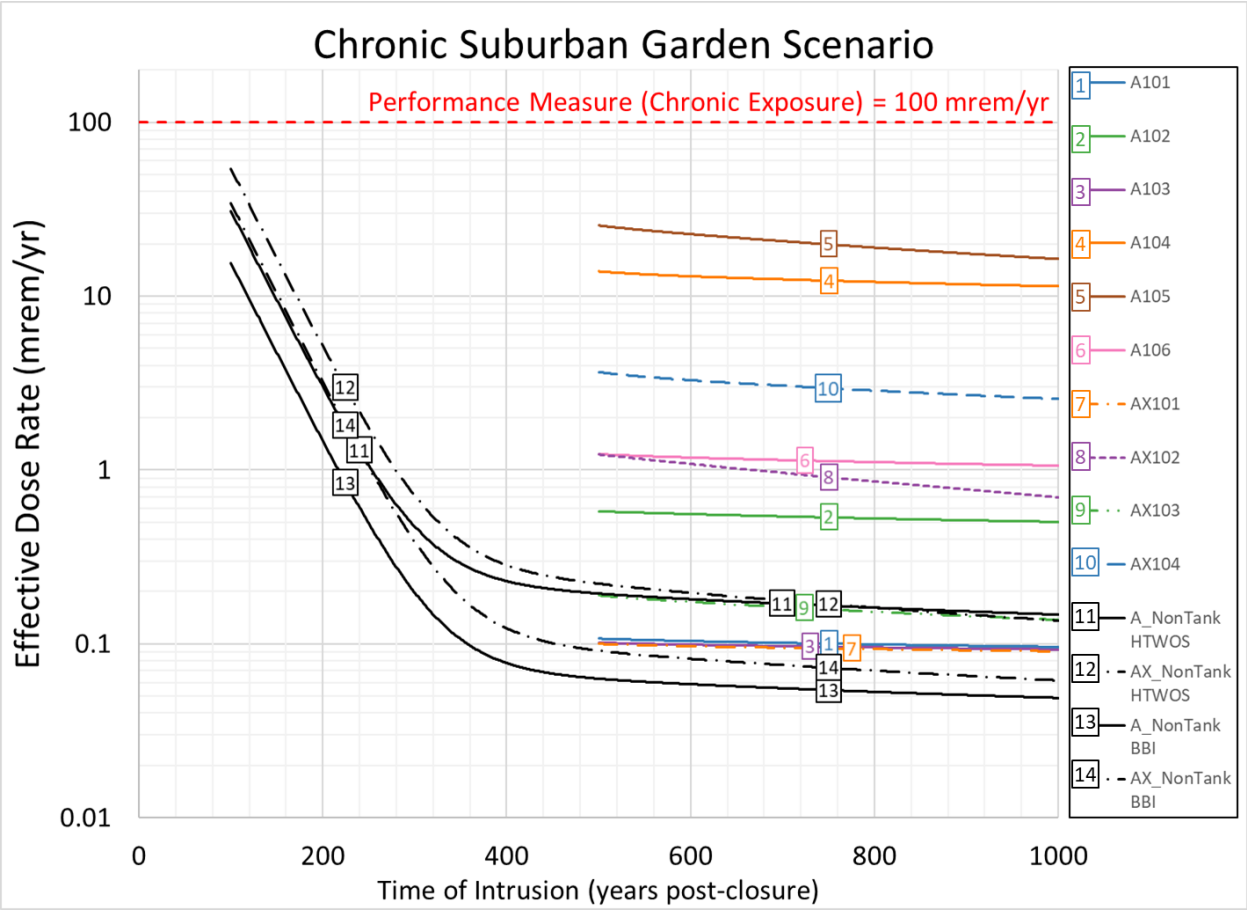
A linear correlation between inventory and dose was shown in RPP-CALC-61254. This correlation is confirmed through a separate analysis which demonstrates how changes to the inventory affect the dose. The highest contributing pathway for each exposure scenario was re-run with each radionuclide in the AX pipeline inventory increased by factors of two, five, and ten. The differences in resulting doses are summarized in Table 7-5. Each time the model was

run with an increase in the inventory, the corresponding dose increased by the same factor. This is the expected result because all of the dose equations in Section 4.5 of RPP-RPT-60885 are of the general form:

$$Dose = Concentration \times Dose\ factors \tag{7-1}$$

Where dose factors are a combination of exposure time, dose conversion factors, shielding factors, and other parameters. This linear correlation between inventory and dose eliminates the need to explicitly evaluate inventory uncertainty because dose results can be directly scaled to inventory changes.

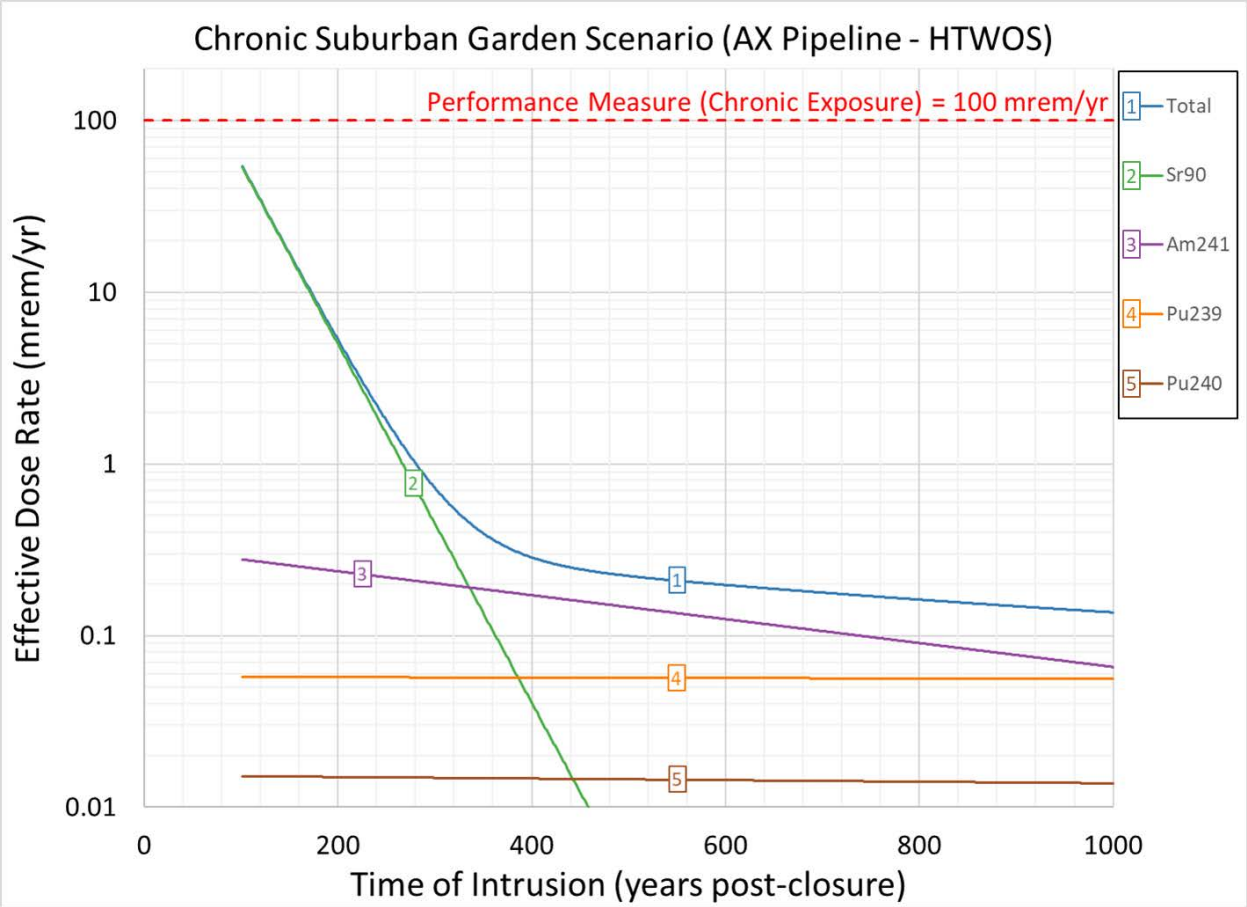
Figure 7-15. Effective Dose Rate for the Suburban Garden Chronic Exposure Scenario.



7.2 CONCLUSIONS

Effective doses for the acute Well Driller inadvertent intruder scenario and effective dose rates for the chronic Rural Pasture, Suburban Garden and Commercial Farm inadvertent intruder scenarios were calculated using the WMA A-AX system model developed in GoldSim©. Intrusion into the source areas was assumed to occur at 100 years post-closure for the pipelines and 500 years post-closure for tanks.

Figure 7-16. Effective Dose Rate for the Suburban Garden Chronic Exposure Scenario from AX Pipeline (Hanford Tank Waste Operations Simulator-based inventory).



HTWOS = Hanford Tank Waste Operations Simulator

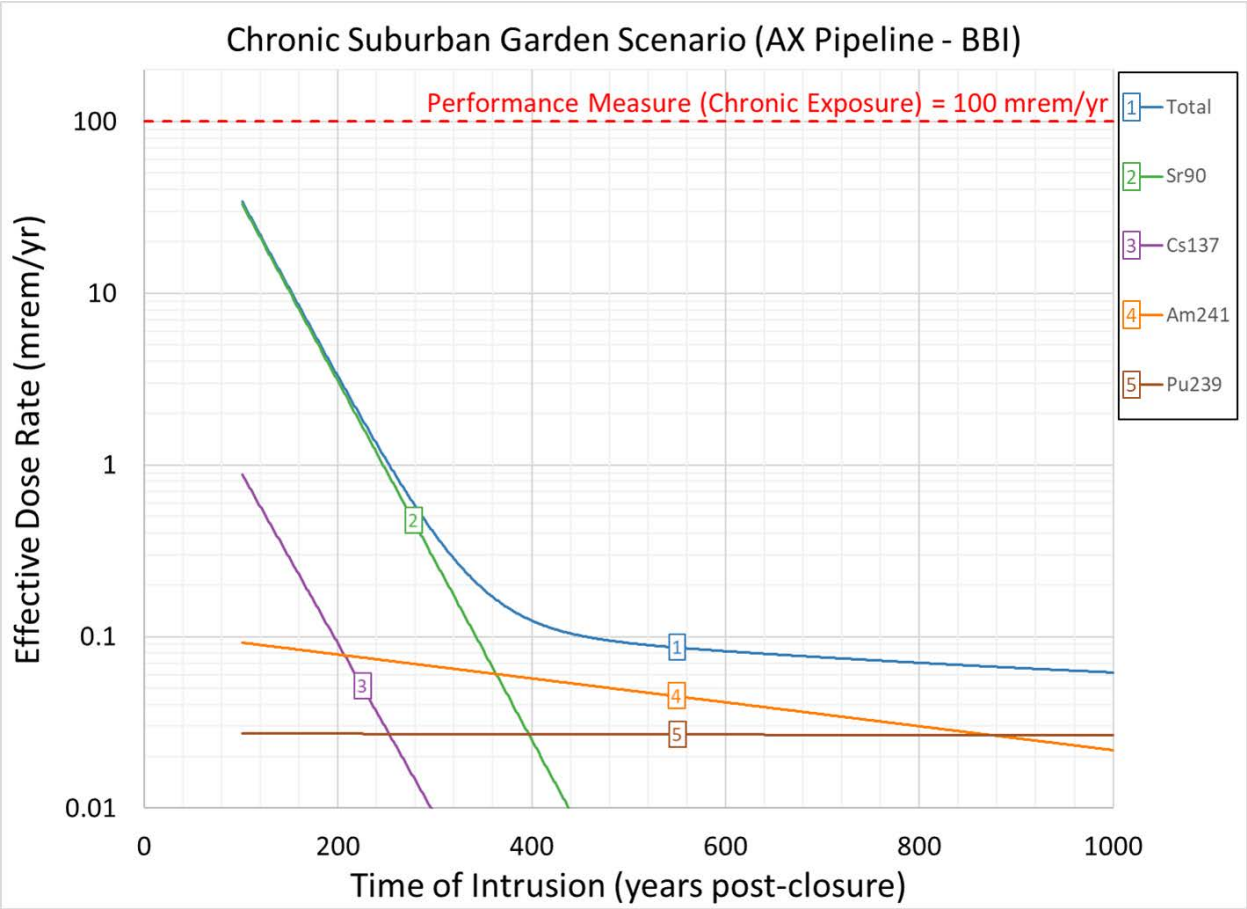
Inadvertent intrusion into tank 241-A-105 provides the highest acute dose in the Well Driller scenario (106.4 mrem) as well as the highest dose rate in the Commercial Farm scenario (0.17 mrem/yr). Intrusion into the AX pipeline provides the highest dose rates in the Rural Pasture (116.3 mrem/yr) and Suburban Garden (54.2 mrem/yr) scenarios.

Except for the intrusion into the AX pipeline (using the HTWOS-based inventory) in the Rural Pasture scenario, intrusions into all waste sources in all scenarios are under the performance measures of 500 mrem for acute doses and 100 mrem/yr for chronic dose rates. The AX pipeline in the Rural Pasture scenario, using the HTWOS-based inventory, provides 116.3 mrem/yr peak dose rate at 100 years post-closure, but quickly declines under the 100 mrem/yr performance measure within 7 years, driven by ^{90}Sr decay.

Using the HTWOS-based inventory, and with intrusion into the AX pipeline at 100 years, ^{90}Sr contributes the most dose in all scenarios. Americium-241 and ^{239}Pu contribute the second and third highest doses in all scenarios. Plutonium-240 contributes the fourth highest dose in all scenarios except for Rural Pasture, where ^{63}Ni is the fourth highest dose contributor. Strontium-90, ^{241}Am and ^{239}Pu account for over 98% of the total dose in all scenarios. The

inadvertent intruder analysis does not account for the likelihood of intrusion, nor does it account for the likelihood of intersecting a pipeline. For the purposes of analysis, the intrusion into the WMA is assumed to occur; however, the likelihood of actually intersecting a pipeline is low if one uses the ratio of total pipe area to total WMA area.

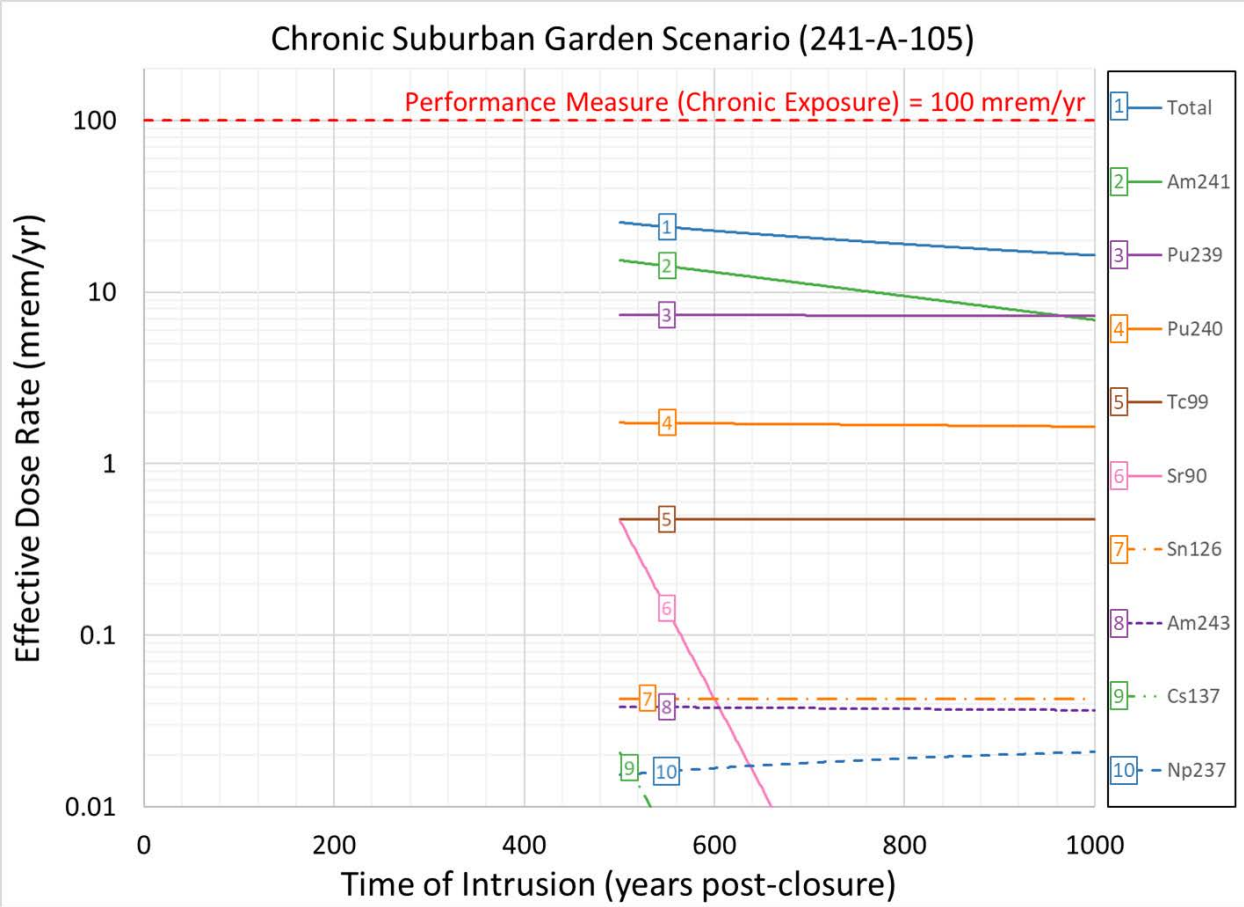
Figure 7-17. Effective Dose Rate for the Suburban Garden Chronic Exposure Scenario from AX Pipeline (Best-Basis Inventory-based inventory).



BBI = Best-Basis Inventory

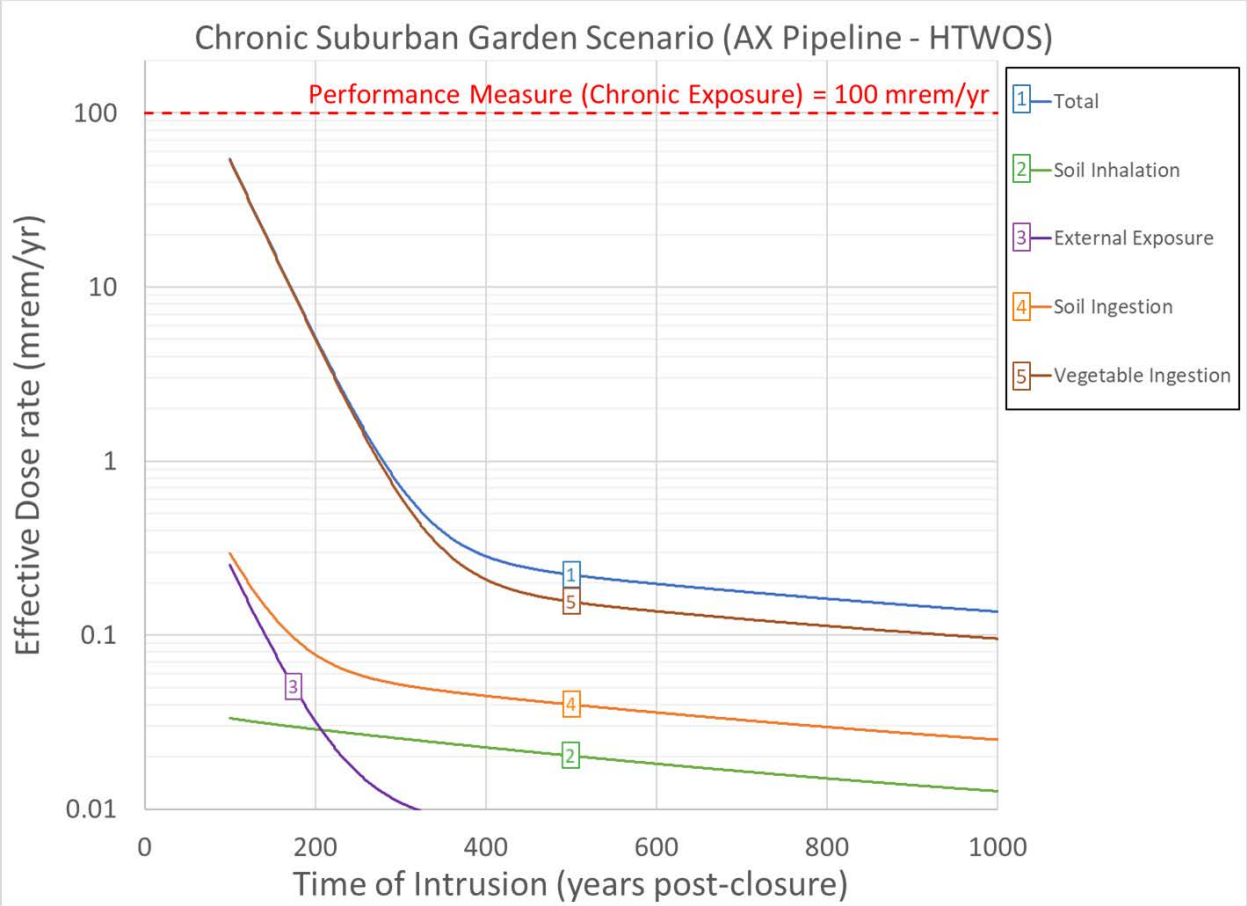
Using the BBI-based inventory, and with intrusion into the AX pipeline at 100 years, ^{137}Cs contributes the most dose in the Well Driller and Commercial Farm scenarios, while ^{90}Sr contributes the most dose in the Rural Pasture and Suburban Garden scenarios. Cesium-137 becomes a higher contributor in all scenarios because the BBI-based inventory of ^{137}Cs in the AX pipelines is about four orders of magnitude higher than that of the HTWOS-based inventory. Strontium-90 is still the primary dose-contributing radionuclide in the Rural Pasture and Suburban Garden scenarios only because the ingestion of ^{90}Sr in vegetables and dairy products produces far more dose than ingestion of the same amount of ^{137}Cs, which is reflected in a higher dose conversion factor for ingestion of ^{90}Sr. In all scenarios, ^{241}Am and ^{239}Pu contribute the 3rd and 4th highest doses. Taken together, ^{137}Cs, ^{90}Sr, ^{241}Am and ^{239}Pu account for over 99% of the dose in every scenario. As with the HTWOS-based inventory analysis, intrusion into the WMA is assumed to occur, but the likelihood of intersecting a pipeline is low.

Figure 7-18. Effective Dose Rate for the Suburban Garden Chronic Exposure Scenario from Tank 241-A-105.



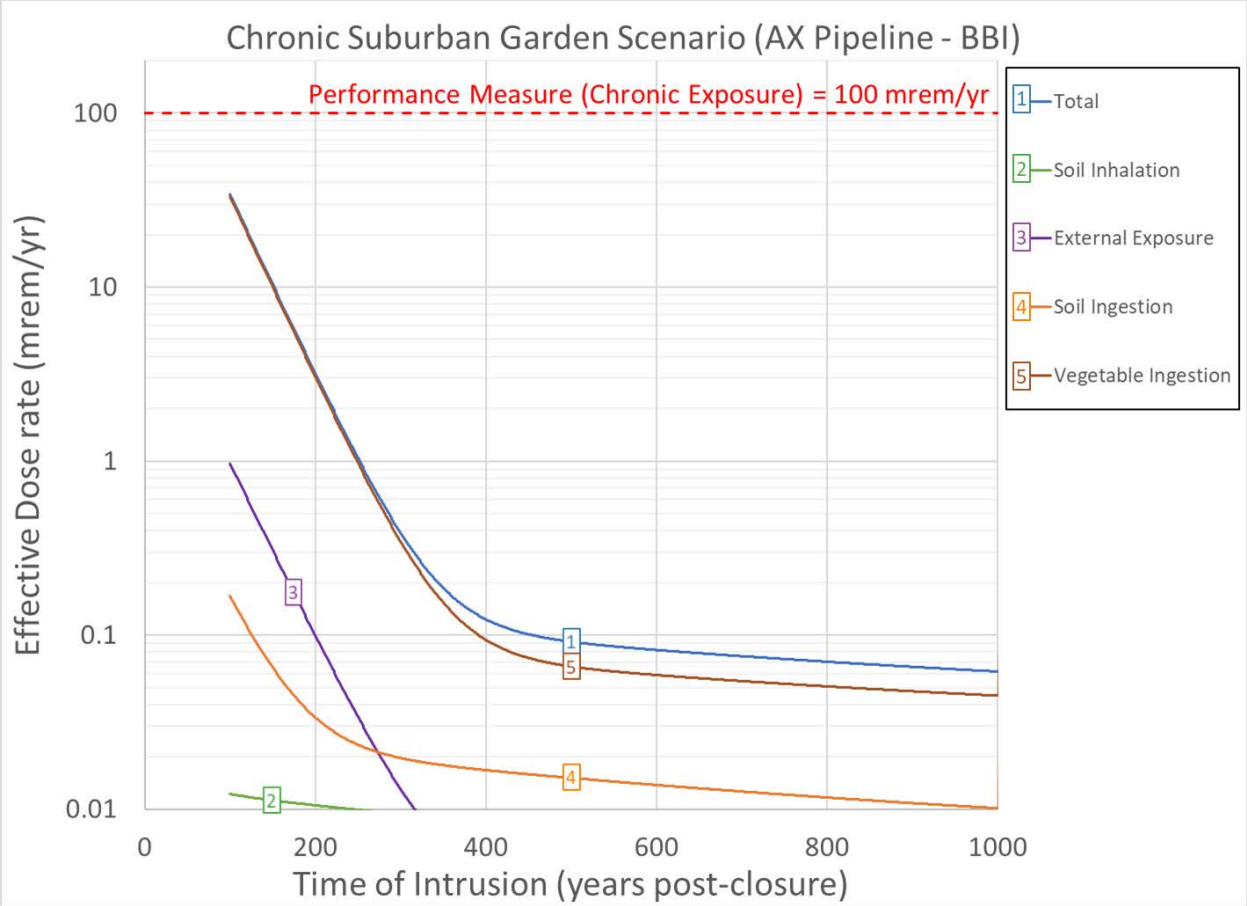
With intrusion into tank 241-A-105 at 500 years, the top two dose contributors in all scenarios are ^{241}Am and ^{239}Pu. The third highest dose contributor is ^{240}Pu for all scenarios except Rural Pasture, where it is replaced by ^{90}Sr. The fourth highest dose contributor for the Well Driller and Commercial Farm scenarios is ^{126}Sn, while for the Suburban Garden scenario it is ^{99}Tc and for the Rural Pasture scenario it is ^{240}Pu. Americium-241 and ^{239}Pu account for more than 89% of the total dose in all scenarios except for Rural Pasture, where they account for 77% of the total dose.

Figure 7-19. Effective Dose Rate for the Suburban Garden Chronic Exposure Scenario from AX Pipeline with Exposure Pathway Contributions (Hanford Tank Waste Operations Simulator-based inventory).



HTWOS = Hanford Tank Waste Operations Simulator

Figure 7-20. Effective Dose Rate for the Suburban Garden Chronic Exposure Scenario from AX Pipeline with Exposure Pathway Contributions (Best-Basis Inventory-based inventory).



BBI = Best-Basis Inventory

Figure 7-21. Effective Dose Rate for the Suburban Garden Chronic Exposure Scenario from Tank 241-A-105 with Exposure Pathway Contributions.

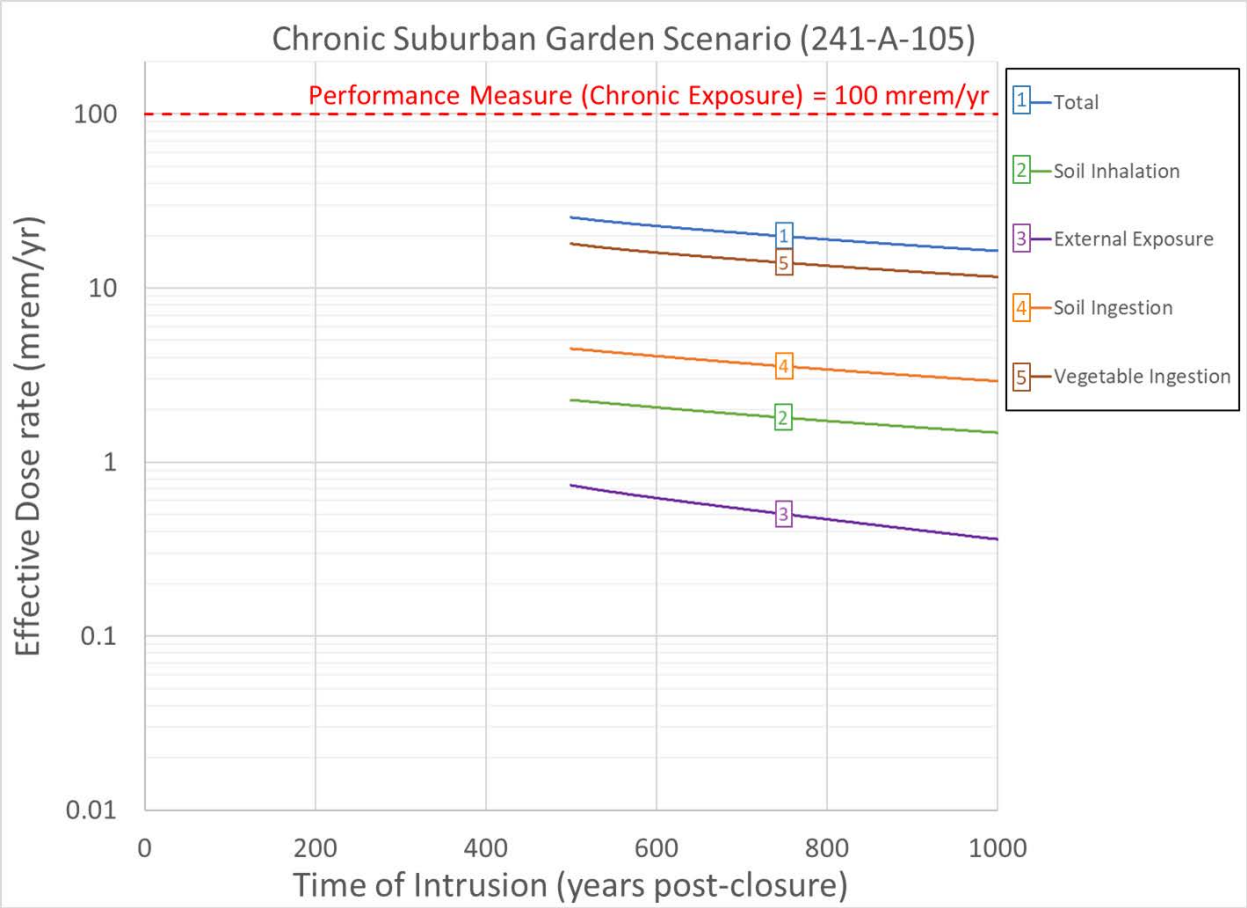


Figure 7-22. Effective Dose Rate for the Commercial Farm Chronic Exposure Scenario.

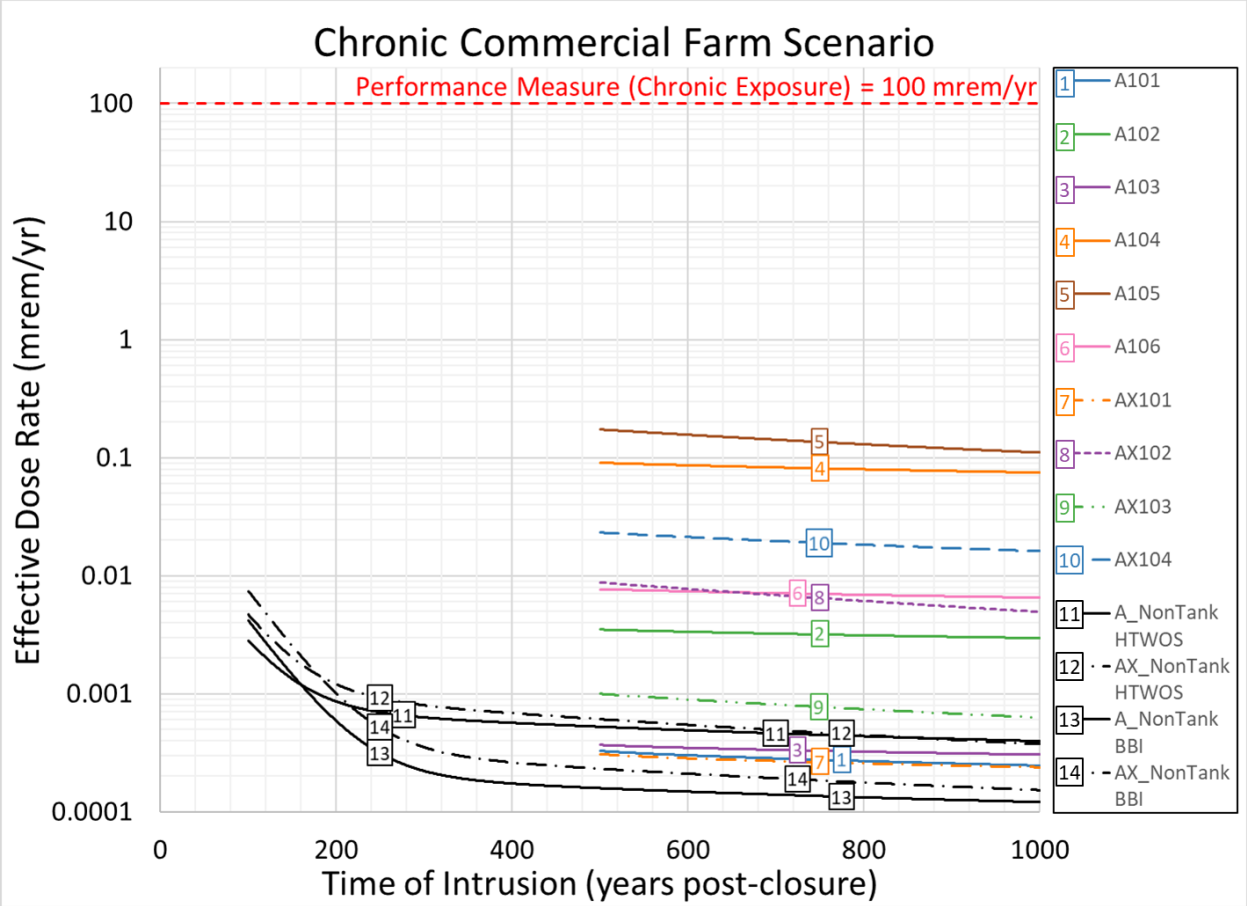
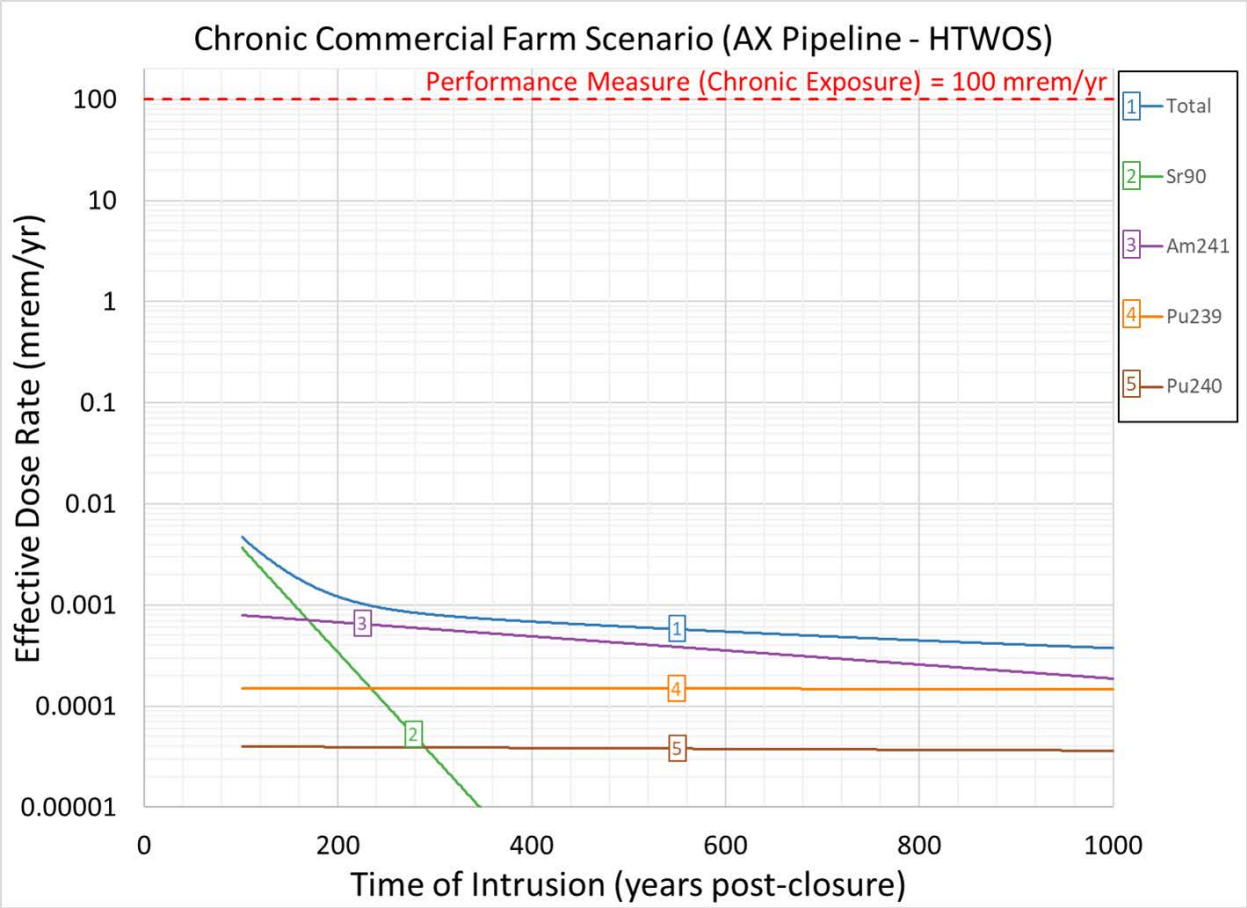
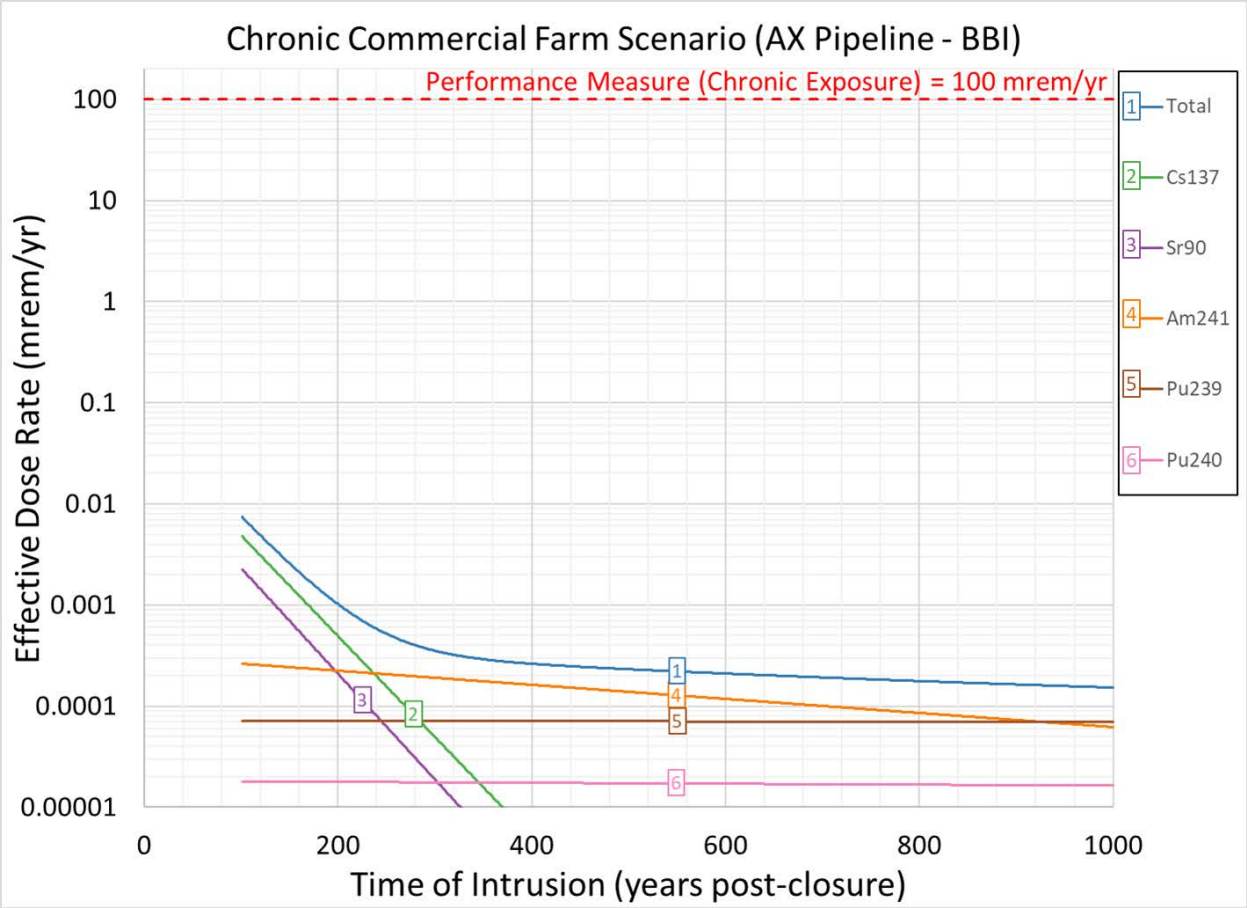


Figure 7-23. Effective Dose Rate for the Commercial Farm Chronic Exposure Scenario from AX Pipeline (Hanford Tank Waste Operations Simulator-based inventory).



HTWOS = Hanford Tank Waste Operations Simulator

Figure 7-24. Effective Dose Rate for the Commercial Farm Chronic Exposure Scenario from AX Pipeline (Best-Basis Inventory-based inventory).



BBI = Best-Basis Inventory

Figure 7-25. Effective Dose Rate for the Commercial Farm Chronic Exposure Scenario from Tank 241-A-105.

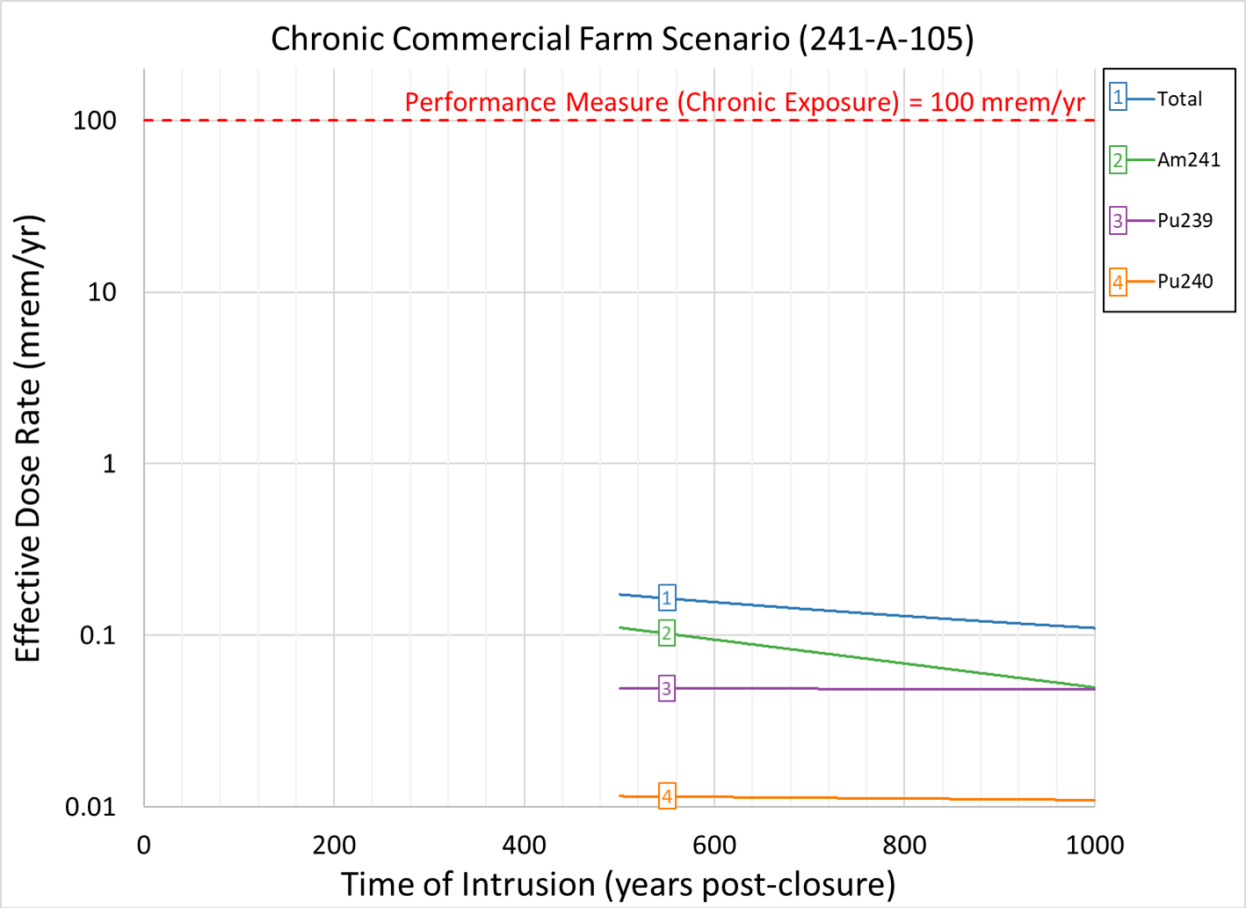
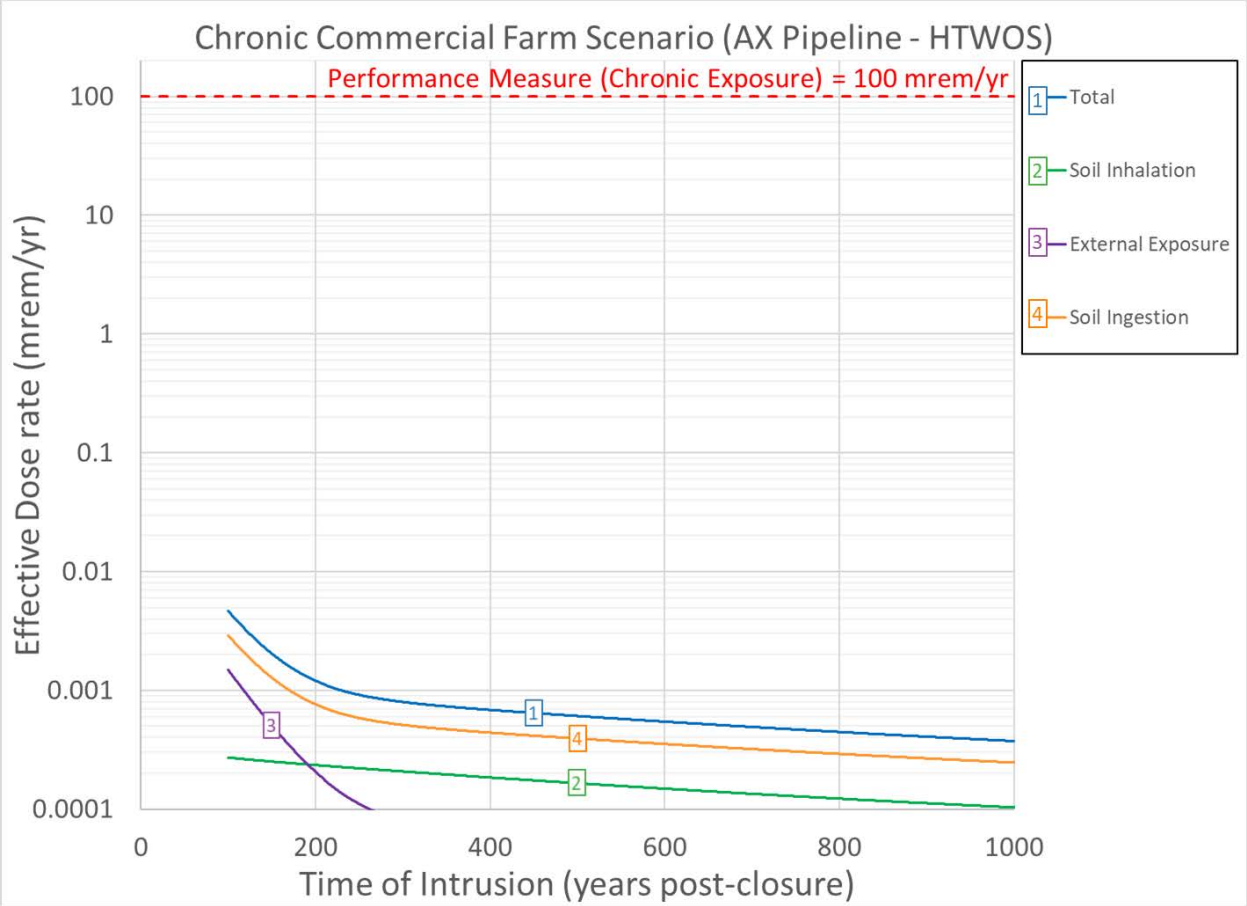


Figure 7-26. Effective Dose Rate for the Commercial Farm Chronic Exposure Scenario from AX Pipeline with Exposure Pathway Contributions (Hanford Tank Waste Operations Simulator-based inventory).



HTWOS = Hanford Tank Waste Operations Simulator

Figure 7-27. Effective Dose Rate for the Commercial Farm Chronic Exposure Scenario from AX Pipeline with Exposure Pathway Contributions (Best-Basis Inventory-based inventory).

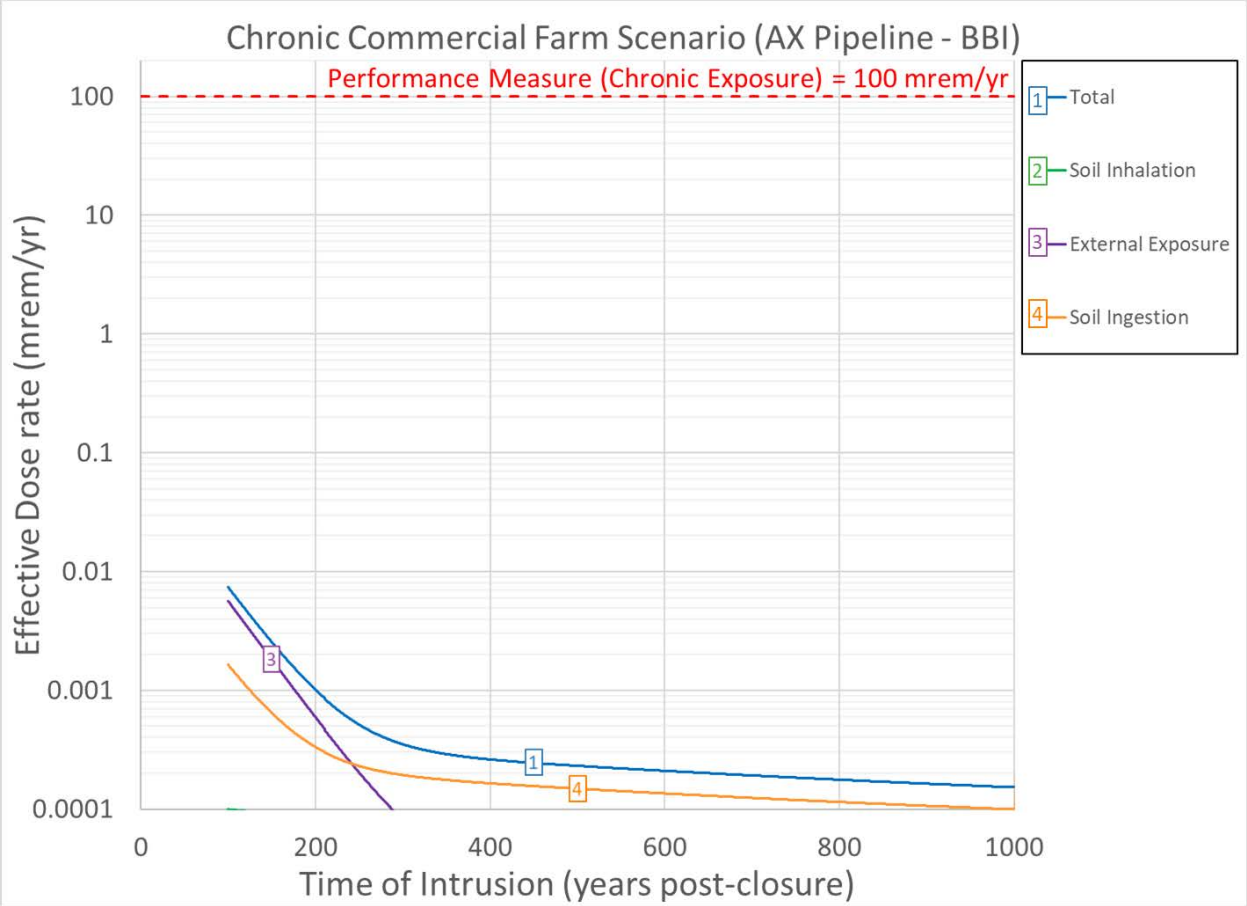


Figure 7-28. Effective Dose Rate for the Commercial Farm Chronic Exposure Scenario from Tank 241-A-105 with Exposure Pathway Contributions.

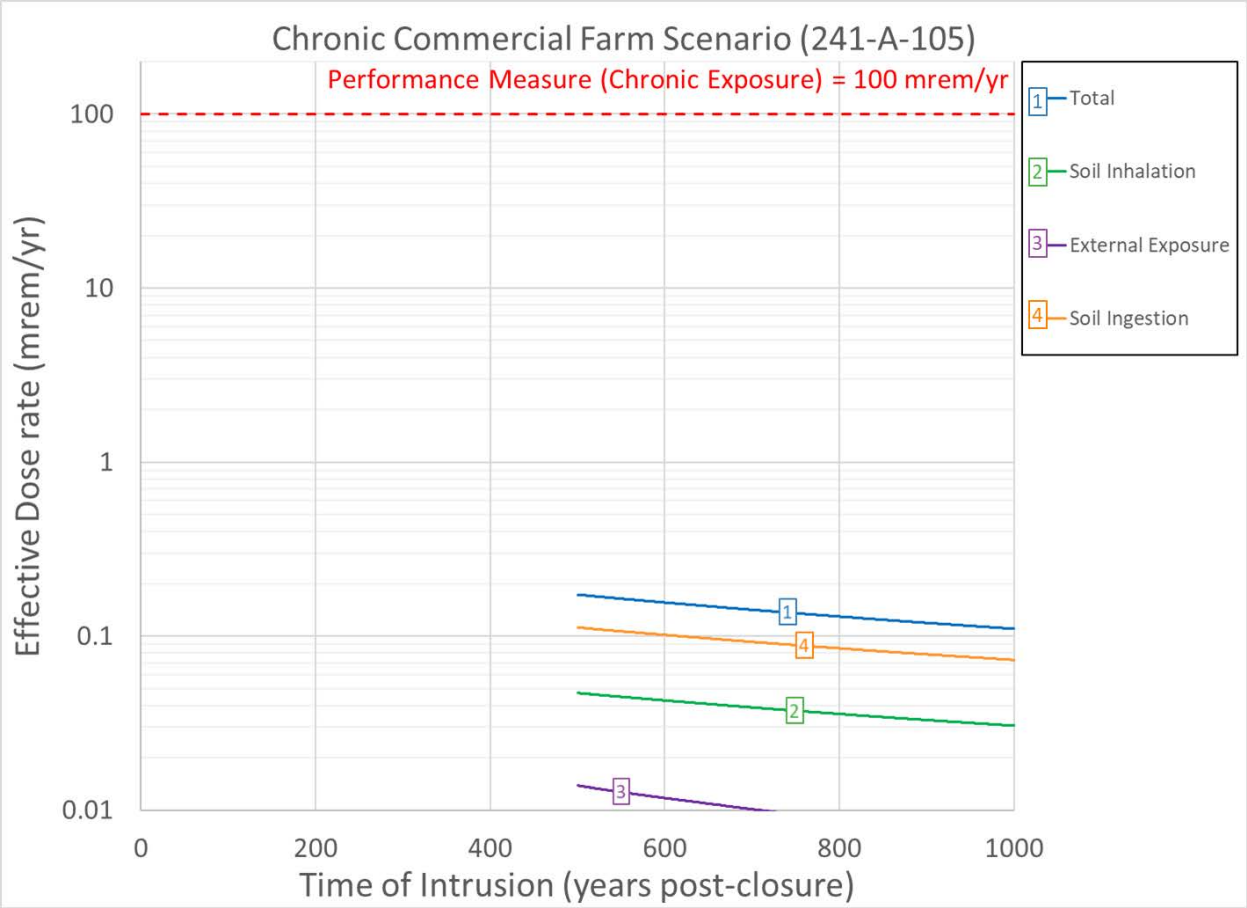


Table 7-5. Effect of Inventory Changes on Top Contributing Pathways at the Year of Maximum Possible Dose.

	Base (mrem/yr)	2× (mrem/yr)	2×/ Base	5× (mrem/yr)	5×/ Base	10× (mrem/yr)	10×/ Base
AX Pipelines – Hanford Tank Waste Operations Simulator-based inventory (100 years post-closure)							
Chronic Rural Pasture, Milk Ingestion Dose	115.7	231.5	2	580	5	1,157.00	10
Chronic Suburban Garden, Vegetable Ingestion Dose	53.7	107.3	2	269.2	5	536.6	10
Chronic Commercial Farm, Soil Ingestion	0.0029	0.0058	2	0.015	5	0.029	10
Acute Well Driller, Soil Inhalation	2.16	4.32	2	10.81	5	21.62	10
Tank 241-A-105 (500 years post-closure)							
Chronic Rural Pasture, Soil Ingestion Dose	5.84	11.68	2	29.27	5	58.41	10
Chronic Suburban Garden, Vegetable Ingestion Dose	17.99	35.96	2	90.12	5	179.9	10
Chronic Commercial Farm, Soil Ingestion	0.11	0.22	2	0.56	5	1.12	10
Acute Well Driller, Soil Inhalation	86.7	173.3	2	434.4	5	867	10

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ATTACHMENT 1

SOFTWARE INSTALLATION AND CHECKOUT FORMS

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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 Transport Software Version No.: 12.0

EXECUTABLE INFORMATION:

2. Executable Name (include path):

[redacted]\GoldSim.exe

3. Executable Size (bytes): 2,836 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):

WF34039

7. Operating System (include version number):

Windows 10 Enterprise, Version 1709, OS Build 16299.785

8. Open Problem Report? (●) No ( ) Yes PR/CR No.

TEST CASE INFORMATION:

9. Directory/Path:

[redacted]\FirstModel.gsm

10. Procedure(s):

CHPRC-00224 Section 3.3

11. Libraries:

Radionuclide 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 those provided in section 3.3. The results match the example

16. Test Performed By: David J. Watson

17. Test Results: (●) Satisfactory, Accepted for Use ( ) Unsatisfactory

18. Disposition (include HISI update): Accepted & HISI authorized user listing added. -WEN

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CHPRC SOFTWARE INSTALLATION AND CHECKOUT FORM (continued)

1. Software Name: GoldSim Pro w/Radionuclide Transport Software Version No.: 12.0

Prepared By:

19. WILLIAM NICHOLS (Affiliate) Digitally signed by WILLIAM NICHOLS (Affiliate) Date: 2018.11.29 14:33:22 -08'00'

Software Owner (Signature)	Print	Date

20. Test Personnel:

Sign	Print	Date
	David J. Watson	29November2018

Approved By:

21. Not required per CHPRC-00175, Rev. 3, Section 12.3

Software SME (Signature)	Print	Date

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ATTACHMENT 2

TANK RESIDUAL WASTE CHARACTERISTICS

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Table Att-2-1. Residual Inventories Used in Waste Management Area A-AX Inadvertent Intruder Scenario Calculations (Ci)*. (1 of 2 sheets)

Radionuclide	Tanks ("241-" prefix omitted)										Pipelines			
	A-101	A-102	A-103	A-104	A-105	A-106	AX-101	AX-102	AX-103	AX-104	A (HTWOS)	AX (HTWOS)	A (BBI)	AX (BBI)
Ac-227	6.42E-04	6.17E-04	4.68E-04	2.68E-05	1.46E-05	1.60E-04	5.92E-04	4.39E-04	4.68E-04	2.30E-06	1.26E-03	1.02E-03	1.02E-04	1.07E-04
Am-241	3.50E+00	2.41E+01	2.67E+00	6.82E+02	2.95E+03	4.91E+01	2.82E+00	1.82E+02	1.72E+01	3.26E+02	6.96E+01	1.13E+02	2.00E+01	3.75E+01
Am-243	2.08E-03	1.38E-02	1.56E-03	3.57E-01	1.67E+00	1.15E-01	1.83E-03	1.76E-01	9.83E-03	1.83E-01	3.91E-02	9.02E-02	1.58E-02	2.64E-02
C-14	6.43E-02	1.72E-02	3.18E-02	3.24E-01	2.75E-01	1.39E-02	5.71E-02	5.96E-03	4.35E-02	3.87E-02	4.14E-07	2.82E-07	9.86E-03	1.03E-02
Cd-113m	7.87E-02	6.71E-02	5.06E-02	2.18E-01	3.12E-01	3.22E-02	7.08E-02	6.08E-02	5.55E-02	4.39E-02	1.20E-01	7.18E-02	1.49E-02	1.64E-02
Cm-243	5.68E-05	3.14E-04	3.84E-05	7.21E-03	5.28E-02	3.68E-03	5.52E-05	9.39E-03	3.06E-04	5.78E-03	4.39E-09	1.26E-08	4.72E-04	1.10E-03
Cm-244	6.63E-04	3.72E-03	4.49E-04	8.40E-02	6.06E-01	4.37E-02	6.59E-04	1.13E-01	3.54E-03	6.66E-02	5.13E-08	1.50E-07	5.51E-03	1.31E-02
Co-60	9.94E-04	3.91E-03	4.17E-04	2.75E-01	4.03E-01	7.04E-03	7.65E-04	2.16E-02	4.20E-03	1.27E-01	1.30E-02	2.45E-02	3.89E-03	1.09E-02
Cs-137	1.03E+03	1.02E+03	6.87E+02	1.89E+04	3.73E+04	1.06E+03	1.14E+03	7.70E+02	1.01E+03	6.28E+03	1.33E-02	8.68E-03	4.64E+02	6.55E+02
Eu-152	7.42E-03	8.34E-03	4.00E-03	7.71E-01	6.63E+00	2.39E-01	4.31E-03	1.80E-01	3.92E-02	9.33E-01	1.75E-01	1.91E-01	4.47E-02	8.22E-02
Eu-154	1.38E-01	1.56E-01	7.46E-02	2.78E+01	7.05E+01	4.39E+00	7.71E-02	1.71E+00	1.19E+00	7.81E+00	2.13E+00	2.31E+00	7.00E-01	7.67E-01
Eu-155	3.02E-03	3.45E-03	1.61E-03	3.10E-01	5.97E-01	9.54E-02	1.53E-03	3.77E-02	1.68E-02	1.99E-01	3.22E-02	4.61E-02	9.78E-03	1.81E-02
H-3	1.45E-02	1.14E-02	8.52E-03	1.13E-01	6.96E-02	8.63E-03	1.29E-02	1.26E-02	9.86E-03	9.84E-03	1.37E-07	7.52E-08	3.26E-03	3.21E-03
I-129	2.29E-03	1.34E-03	3.35E-04	6.36E-03	9.47E-04	1.33E-03	2.12E-03	1.52E-03	1.71E-03	1.34E-04	4.10E-05	1.11E-08	3.27E-04	3.90E-04
Nb-93m	3.80E-01	3.70E-01	2.77E-01	2.25E+00	2.87E+00	1.90E-01	3.49E-01	2.72E-01	2.92E-01	4.04E-01	1.03E+00	8.08E-01	9.03E-02	9.37E-02
Ni-59	1.39E-01	1.22E-01	8.18E-02	8.62E+00	7.20E+00	2.60E-01	1.18E-01	1.54E-01	1.28E-01	1.01E+00	5.89E-01	3.99E-01	1.12E-01	1.01E-01
Ni-63	9.41E+00	8.30E+00	5.57E+00	5.83E+02	4.93E+02	1.76E+01	8.03E+00	1.05E+01	8.72E+00	6.96E+01	4.00E+01	2.72E+01	7.60E+00	6.89E+00
Np-237	1.33E-02	1.05E-02	7.79E-03	5.82E-02	7.62E-02	6.12E-03	1.17E-02	2.70E-02	1.46E-03	9.73E-03	2.84E-02	2.48E-02	2.68E-03	3.55E-03
Pa-231	8.11E-04	7.81E-04	5.91E-04	3.89E-05	1.57E-05	2.02E-04	7.49E-04	5.55E-04	5.92E-04	2.85E-06	1.90E-03	1.55E-03	1.29E-04	1.35E-04
Pb-210	5.33E-07	8.69E-07	3.39E-07	2.46E-06	1.45E-06	1.88E-07	4.36E-07	4.39E-07	3.83E-07	2.58E-07	0.00E+00	0.00E+00	1.24E-07	1.08E-07
Pu-238	2.52E-02	6.49E-01	4.70E-02	1.39E+01	1.88E+01	1.57E+00	2.59E-02	9.60E-01	8.03E-02	3.27E+00	8.91E-01	7.15E-01	2.80E-01	3.08E-01
Pu-239	7.85E-01	2.22E+01	1.58E+00	5.96E+02	5.56E+02	5.30E+01	8.84E-01	1.37E+01	2.34E+00	9.79E+01	3.24E+01	1.72E+01	9.91E+00	8.16E+00
Pu-240	1.88E-01	5.16E+00	3.69E-01	1.31E+02	1.36E+02	1.23E+01	2.04E-01	4.38E+00	5.89E-01	2.39E+01	7.43E+00	4.58E+00	2.28E+00	2.07E+00
Pu-241	1.58E-01	4.38E+00	3.13E-01	7.93E+01	1.14E+02	9.80E+00	1.66E-01	7.06E+00	4.79E-01	2.01E+01	5.75E+00	5.08E+00	1.71E+00	1.98E+00
Pu-242	1.39E-05	3.87E-04	2.76E-05	6.55E-03	9.91E-03	8.53E-04	1.45E-05	6.76E-04	4.17E-05	1.75E-03	4.93E-04	4.57E-04	1.47E-04	1.76E-04
Ra-226	7.42E-07	1.89E-06	5.33E-07	5.49E-06	2.19E-06	3.05E-07	6.71E-07	6.69E-07	5.32E-07	4.61E-07	5.53E-12	3.53E-12	2.28E-07	1.66E-07
Ra-228	1.08E-06	1.03E-06	7.83E-07	1.63E-06	1.90E-11	2.90E-07	9.94E-07	1.07E-04	3.09E-06	3.37E-12	2.52E-06	4.08E-05	1.82E-07	7.93E-06
Rn-222	7.42E-07	1.89E-06	5.33E-07	5.49E-06	2.19E-06	3.05E-07	6.71E-07	6.69E-07	5.32E-07	4.61E-07	5.53E-12	3.53E-12	2.28E-07	1.66E-07
Se-79	1.46E-02	1.36E-02	1.03E-02	8.89E-02	1.13E-01	6.80E-03	1.33E-02	3.20E-03	1.11E-02	1.60E-02	1.37E-07	7.16E-08	3.41E-03	3.10E-03
Sm-151	1.31E+02	2.18E+02	7.76E+01	2.70E+04	5.60E+04	6.30E+03	1.62E+02	2.41E+03	3.77E+02	7.90E+03	3.37E+03	2.11E+03	7.44E+02	7.72E+02

Table Att-2-2. Residual Inventories Used in Waste Management Area A-AX Inadvertent Intruder Scenario Calculations (Ci)*. (2 of 2 sheets)

Radionuclide	Tanks ("241-" prefix omitted)										Pipelines			
	A-101	A-102	A-103	A-104	A-105	A-106	AX-101	AX-102	AX-103	AX-104	A (HTWOS)	AX (HTWOS)	A (BBI)	AX (BBI)
Sn-126	3.73E-02	4.44E-02	3.34E-02	1.79E-01	2.29E-01	1.50E-02	3.56E-02	9.74E-02	3.19E-02	3.22E-02	3.67E-07	2.71E-07	8.98E-03	1.40E-02
Sr-90	3.93E+02	1.73E+03	3.17E+02	6.67E+05	9.54E+05	2.91E+04	5.47E+02	6.86E+03	3.72E+03	2.47E+05	1.95E+04	2.97E+04	9.42E+03	1.83E+04
Tc-99	2.25E+00	2.51E+00	1.82E+00	1.24E+01	1.58E+01	3.27E+00	2.09E+00	5.68E-01	1.78E+00	7.48E+00	2.86E-05	1.37E-05	6.67E-01	8.47E-01
Th-229	1.03E-04	3.11E-03	1.19E-04	6.32E-04	2.70E-08	2.78E-05	4.77E-05	3.82E-04	9.38E-06	1.31E-08	0.00E+00	0.00E+00	1.85E-04	3.12E-05
Th-230	3.09E-06	1.11E-04	4.28E-06	3.38E-04	9.21E-07	3.96E-06	2.70E-06	1.22E-05	1.74E-06	1.37E-05	0.00E+00	0.00E+00	8.58E-06	2.15E-06
Th-232	1.08E-06	1.03E-06	7.83E-07	1.63E-06	1.91E-11	2.90E-07	9.94E-07	1.07E-04	3.09E-06	3.59E-12	2.56E-06	4.15E-05	1.82E-07	7.93E-06
U-232	2.62E-04	9.70E-03	3.72E-04	1.94E-03	4.19E-08	8.68E-05	1.49E-04	9.82E-04	1.71E-04	9.81E-07	4.43E-03	6.89E-04	5.74E-04	9.26E-05
U-233	2.59E-02	9.57E-01	3.65E-02	1.94E-01	9.05E-06	8.51E-03	1.46E-02	9.65E-02	2.31E-03	4.09E-06	4.33E-01	5.75E-02	5.66E-02	8.07E-03
U-234	4.67E-03	1.67E-01	6.47E-03	5.12E-01	2.95E-03	6.11E-03	4.08E-03	1.84E-02	2.64E-03	2.09E-02	8.31E-02	1.58E-02	1.30E-02	3.28E-03
U-235	1.90E-04	6.78E-03	2.62E-04	2.15E-02	5.56E-05	2.49E-04	1.68E-04	7.45E-04	6.97E-05	8.64E-04	3.38E-03	6.23E-04	5.31E-04	1.31E-04
U-236	1.22E-04	4.40E-03	1.70E-04	1.23E-02	1.61E-04	1.66E-04	1.07E-04	5.17E-04	9.36E-05	5.53E-04	2.16E-03	4.40E-04	3.35E-04	9.04E-05
U-238	4.20E-03	1.51E-01	5.81E-03	5.07E-01	8.57E-04	5.71E-03	3.77E-03	1.62E-02	1.63E-03	2.01E-02	7.54E-02	1.39E-02	1.20E-02	2.97E-03
Zr-93	3.98E-01	3.86E-01	2.89E-01	2.35E+00	3.00E+00	1.99E-01	3.65E-01	2.85E-01	3.06E-01	4.23E-01	1.04E+00	8.14E-01	9.44E-02	9.80E-02

*Inventories decay corrected to January 1, 2050.

BBI = Best-Basis Inventory

HTWOS = Hanford Tank Waste Operations Simulator

Table Att-2-3. Residual Waste Parameters Used in Waste Management Area A-AX Inadvertent Intruder Scenario Calculations.

Source	Residual Waste Volume (L)[a]	Cross-sectional Area (m^2)[b]	Thickness (m)[c]
A101	1.02E+04	4.10E+02	2.48E-02
A102	1.02E+04	4.10E+02	2.48E-02
A103	1.02E+04	4.10E+02	2.48E-02
A104	9.30E+04	4.10E+02	2.27E-01
A105	1.39E+05	4.10E+02	3.39E-01
A106	1.02E+04	4.10E+02	2.48E-02
AX101	1.02E+04	4.10E+02	2.48E-02
AX102	1.02E+04	4.10E+02	2.48E-02
AX103	1.02E+04	4.10E+02	2.48E-02
AX104	1.02E+04	4.10E+02	2.48E-02
A Pipelines	3.30E+03	1.12E+03	2.96E-03
AX Pipelines	2.90E+03	9.69E+02	2.99E-03

[a]Tank residual waste volumes from RPP-CALC-62319, *Residual Waste Source Inventory Term for the Waste Management Area A-AX Performance Assessment Inventory Case 1*, Table 4-5. Pipeline residual waste volumes from RPP-RPT-58293, *Hanford 241-A and 241-AX Farm Tank and Ancillary Equipment Residual Waste Inventory Estimates*, Table ES-2.

[b]Tank and pipeline cross-sectional area calculated from data in RPP-RPT-58293, *Hanford 241-A and 241-AX Farm Tank and Ancillary Equipment Residual Waste Inventory Estimates*.

[c]Waste thickness calculated using equations in RPP-RPT-60885, *Model Package Report System Model for the WMA A-AX Performance Assessment*.

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ATTACHMENT 3

INADVERTENT INTRUDER SCENARIO PARAMETER INPUTS

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Table Att-3-4. Inadvertent Intruder Scenario Parameters Used for Calculating Doses to Inadvertent Intruders at Waste Management Area A-AX. (4 sheets)

Parameter	Notation	Value	Unit	GoldSim Parameter Name
Common to All Intruder Scenarios[a]				
Soil dry bulk density for soil layers below the waste management area	ρ_{sl}, ρ_s	1.67[b]	g/cm^3	Cuttings_Bulk_Density
Soil dry bulk density in the pasture	ρ_p	2.05	g/cm^3	TargetField_Bulk_Density
Bulk density of residual waste	ρ_{ws}	2.05	g/cm^3	Waste_Bulk_Density
Time of intrusion	T	100 (pipes), 500 (tanks)	years (post-closure)	Intrusion_Time
Depth to groundwater	Z_{gw}	8,700[c]	cm	Groundwater_Depth
Acute Well Driller Intruder Scenario[d]				
Area of the well	A_{well}	1,379.51	cm^2	Well_Area_WD
Diameter of the well	D_{well}	41.91	cm	Well_Diameter_WD
Soil ingestion rate – well driller	$IR_{s,wd}$	100	mg/day	Soil_Ingestion_Rate_WD
Exposure frequency – well driller	EF_{wd}	5	days/yr	Exposure_Frequency_WD
Enrichment factor	E_f	4	unitless	Enrichment_Factor_WD
Outdoor inhalation rate – well driller	$INH_{out,wd}$	12,775	m^3/yr	Outdoor_Inhalation_Rate_WD
Mass loading factor	M	6.66E-05	g/m^3	Mass_Loading_Fact_WD
Fraction of time spent outdoors	$t_{out,wd}$	0.0046	unitless	Outdoor_Time_Fraction_WD
Chronic Rural Pasture Intruder Scenario[e]				
Area of the well	A_{well}	558.6	cm^2	Well_Area_RP
Diameter of the well	D_{well}	26.67	cm	Well_Diameter_RP
Area of rural pasture	A_{rp}	5.00E+07	cm^2	Target_Field_Area_RP
Tilled depth of rural pasture	Z_{rp}	15	cm	Tilled_Depth_RP
Soil ingestion rate – resident	$IR_{s,rp}$	100	mg/day	Soil_Ingestion_Rate_RP

Table Att-3-4. Inadvertent Intruder Scenario Parameters Used for Calculating Doses to Inadvertent Intruders at Waste Management Area A-AX. (4 sheets)

Parameter	Notation	Value	Unit	GoldSim Parameter Name
Exposure frequency – resident	EF_{rp}	350	days/yr	Exposure_Frequency_RP
Milk ingestion rate	IR_m	155.96	L/yr	Milk_Ingestion_Rate_RP
Fraction of locally-produced dairy products that are consumed	F_a	1	unitless	Fraction_Of_Dairy_Consumed_RP
Water ingestion rate for dairy cattle	$IR_{w,d}$	92	L/day	Cattle_Water_Ingestion_Rate_RP
Soil ingestion rate for dairy cattle	$IR_{s,d}$	0.41	kg/day	Cattle_Soil_Ingestion_Rate_RP
Fodder ingestion rate for dairy cattle	$IR_{fodder,d}$	16.9	kg/day	Cattle_Fodder_Ingestion_Rate_RP
Pasture-soil bioconcentration factor through uptake	B_p	Table Att-5-1	(pCi/kg dry weight of crop)/ (pCi/kg dry weight of soil)	BCF_Uptake_FodderSoil
Pasture-soil bioconcentration factor from resuspension processes	B'_p	0.1	(pCi/kg dry weight of crop)/ (pCi/kg dry weight of soil)	Resuspension_FodderSoil_BCF_RP
Enrichment factor	E_f	0.7	unitless	Enrichment_Factor_RP
Indoor inhalation rate – resident	$INH_{in,r}$	7,300	m^3/yr	Indoor_Inhalation_Rate_RP
Mass loading factor	M	6.66E-05	g/m^3	Mass_Loading_Factor_RP
Fraction of time spent indoors – rural pasture	$ti_{n,rp}$	0.656	unitless	Indoor_Time_Fraction_RP
Outdoor inhalation rate – rural pasture	INH_{out_rp}	9,125	m^3/yr	Outdoor_Inhalation_Rate_RP
Fraction of time spent outdoors – rural pasture	t_{out}	0.16	unitless	Outdoor_Time_Fraction_RP
Ratio of radionuclide concentrations in indoor versus outdoor air	I/O	0.3	unitless	Indoor_Outdoor_Ratio_IN
Chronic Suburban Garden Intruder Scenario[f]				
Diameter of the well	D_{well}	16.51	cm	Well_Diameter_SG
Area of the well	A_{well}	214.08	cm^2	Well_Area_SG
Area of home construction lot (target field)	A_{tf}	25,000,000	cm^2	Target_Field_Area_SG
Tilled depth of garden	Z_g	15	cm	Tilled_Depth_SG

Table Att-3-4. Inadvertent Intruder Scenario Parameters Used for Calculating Doses to Inadvertent Intruders at Waste Management Area A-AX. (4 sheets)

Parameter	Notation	Value	Unit	GoldSim Parameter Name
Soil ingestion rate – suburban garden	$IR_{s,sg}$	100	mg/day	Soil_Ingestion_Rate_SG
Exposure frequency – resident	EF_{sg}	350	day/yr	Exposure_Frequency_SG
Crop (fruit and vegetables) ingestion rate	I_{rc}	106.51	kg/yr	Veg_Ingestion_Rate_SG
Crop-soil bioconcentration factor from uptake	B_v	Table Att-5-1	(pCi/kg fresh wt crop)/ (pCi/kg dry wt soil)	BCF_Uptake_VegSoil
Crop-soil bioconcentration factor from resuspension/soil adhesion	B'_v	0.004	(pCi/kg fresh wt crop)/ (pCi/kg dry wt soil)	Resuspension_VegSoil_BCF_SG
Fraction of locally-produced crop (fruit and vegetables) that are consumed	F_v	0.25	unitless	Fraction_Of_Veg_Consumed_SG
Enrichment factor	E_f	0.7	unitless	Enrichment_Factor_SG
Indoor inhalation rate – suburban garden	$INH_{in,sg}$	7,300	m^3/yr	Indoor_Inhalation_Rate_SG
Mass loading factor	M	6.66E-05	g/m^3	Mass_Loading_Factor_SG
Fraction of time spent indoors – suburban garden	$t_{in,sg}$	0.656	unitless	Indoor_Time_Fraction_SG
Outdoor inhalation rate – suburban garden	$INH_{out,sg}$	9,125	m^3/yr	Outdoor_Inhalation_Rate_SG
Fraction of time spent outdoors	$t_{out,sg}$	0.08	unitless	Outdoor_Time_Fraction_SG
Ratio of radionuclide concentrations in indoor versus outdoor air	I/O	0.3	unitless	Indoor_Outdoor_Ratio_IN
Chronic Commercial Farm Intruder Scenario[g]				
Area of the well	A_{well}	1,379.51	cm^2	Well_Diameter_CF
Diameter of the well	D_{well}	41.91	cm	Well_Area_CF
Area of commercial farm	A_{cf}	6.48E+09	cm^2	Target_Field_Area_CF
Tilled depth of commercial farm	Z_{cf}	15	cm	Tilled_Depth_CF
Soil ingestion rate – commercial farmer	$IR_{s,cf}$	100	mg/day	Soil_Ingestion_Rate_CF
Exposure frequency – commercial farmer	EF_{cf}	350	days/yr	Exposure_Frequency_CF

Table Att-3-4. Inadvertent Intruder Scenario Parameters Used for Calculating Doses to Inadvertent Intruders at Waste Management Area A-AX. (4 sheets)

Parameter	Notation	Value	Unit	GoldSim Parameter Name
Enrichment factor	E_f	0.7	unitless	Enrichment_Factor_CF
Indoor inhalation rate – commercial farmer	$INH_{in,cf}$	7,300	m^3/yr	Indoor_Inhalation_Rate_CF
Mass loading factor	M	6.66E-05	g/m^3	Mass_Loading_Factor_CF
Fraction of time spent indoors – commercial farmer	$t_{in,cf}$	0	unitless	Indoor_Time_Fraction_CF
Outdoor inhalation rate – commercial farmer	$INH_{out,cf}$	10,950	m^3/yr	Outdoor_Inhalation_Rate_CF
Fraction of time spent outdoors – commercial farmer	$t_{out,cf}$	0.164	unitless	Outdoor_Time_Fraction_CF
Ratio of radionuclide concentrations in indoor versus outdoor air	I/O	0.3	unitless	Indoor_Outdoor_Ratio_IN

[a]RPP-ENV-58813, *Exposure Scenarios for Risk and Performance Assessments in Tank Farms at the Hanford Site, Washington*, Table R-2.

[b]RPP-RPT-60101, Draft B, *Model Package Report Flow and Contaminant Transport Numerical Model Used in WMA A-AX Performance Assessment and RCRA Closure Analysis*, Table B-8.

[c]DOE/RL-2016-67, *Hanford Site Groundwater Monitoring Report for 2016*.

[d]RPP-ENV-58813, *Exposure Scenarios for Risk and Performance Assessments in Tank Farms at the Hanford Site, Washington*, Table R-3.

[e]RPP-ENV-58813, *Exposure Scenarios for Risk and Performance Assessments in Tank Farms at the Hanford Site, Washington*, Table R-4.

[f]RPP-ENV-58813, *Exposure Scenarios for Risk and Performance Assessments in Tank Farms at the Hanford Site, Washington*, Table R-5.

[g]RPP-ENV-58813, *Exposure Scenarios for Risk and Performance Assessments in Tank Farms at the Hanford Site, Washington*, Table R-6.

ATTACHMENT 4

DOSE CONVERSION FACTORS

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Table Att-4-1. Dose Conversion Factors Used for Calculating Doses to Inadvertent Intruders at Waste Management Area A-AX. (2 sheets)

Radionuclide	Inhalation (mrem/pCi)	Ingestion (mrem/pCi)	External Exposure Groundwater Pathway (mrem/yr)/(pCi/g)	External Exposure Air Pathway (mrem/yr)/(pCi/m^2)
Ac-227	5.96E-01	1.45E-03	1.57E+00	4.52E-05
Am-241	1.56E-01	8.81E-04	3.41E-02	3.21E-06
Am-243	1.54E-01	8.73E-04	6.98E-01	2.53E-05
C-14	8.21E-06	2.34E-06	1.05E-05	1.88E-09
Cd-113m	4.33E-04	9.51E-05	5.06E-04	3.07E-08
Cm-243	1.20E-01	6.66E-04	4.55E-01	1.46E-05
Cm-244	1.01E-01	5.59E-04	9.83E-05	1.03E-07
Co-60	4.14E-05	2.03E-05	1.27E+01	2.74E-04
Cs-137	1.70E-05	4.92E-05	2.66E+00	6.46E-05
Eu-152	3.67E-04	6.44E-06	5.47E+00	1.28E-04
Eu-154	4.26E-04	9.66E-06	5.99E+00	1.39E-04
Eu-155	5.11E-05	1.67E-06	1.42E-01	6.89E-06
H-3	1.97E-07	7.77E-08	0.00E+00	0.00E+00
I-129	1.50E-04	4.48E-04	1.01E-02	3.01E-06
Nb-93m	2.26E-06	6.59E-07	8.12E-05	1.10E-07
Ni-59	5.48E-07	2.95E-07	0.00E+00	0.00E+00
Ni-63	2.01E-06	7.33E-07	0.00E+00	0.00E+00
Np-237	8.51E-02	4.63E-04	8.57E-01	2.61E-05
Pa-231	8.77E-01	2.07E-03	1.49E-01	4.75E-06
Pb-210	4.48E-03	3.77E-03	4.76E-03	4.13E-07
Pu-238	1.72E-01	9.73E-04	1.18E-04	9.79E-08
Pu-239	1.86E-01	1.07E-03	2.30E-04	4.29E-08
Pu-240	1.86E-01	1.07E-03	1.14E-04	9.38E-08
Pu-241	3.31E-03	1.93E-05	4.61E-06	2.25E-10
Pu-242	1.77E-01	1.01E-03	9.99E-05	7.79E-08
Ra-226	1.41E-02	1.68E-03	2.48E-02	1.94E-04
Ra-228	1.14E-02	5.92E-03	1.26E+01	2.73E-04
Rn-222	0.00E+00	0.00E+00	8.70E+00	0.00E+00
Se-79	6.22E-06	1.73E-05	1.45E-05	2.42E-09
Sm-151	3.64E-05	5.00E-07	7.68E-07	5.88E-10
Sn-126	6.14E-04	2.36E-05	9.25E+00	2.29E-04
Sr-90	1.45E-04	1.33E-04	1.92E-02	6.55E-07
Tc-99	1.64E-05	3.33E-06	9.80E-05	9.11E-09
Th-229	2.79E-01	2.25E-03	1.24E+00	3.70E-05

Table Att-4-1. Dose Conversion Factors Used for Calculating Doses to Inadvertent Intruders at Waste Management Area A-AX. (2 sheets)

Radionuclide	Inhalation (mrem/pCi)	Ingestion (mrem/pCi)	External Exposure Groundwater Pathway (mrem/yr)/(pCi/g)	External Exposure Air Pathway (mrem/yr)/(pCi/m^2)
Th-230	5.44E-02	9.36E-04	9.43E-04	8.76E-08
Th-232	9.47E-02	1.03E-03	4.07E-04	6.44E-08
U-232	3.19E-02	1.49E-03	7.96E+00	1.64E-04
U-233	1.44E-02	2.23E-04	1.09E-03	8.36E-08
U-234	1.41E-02	2.15E-04	3.13E-04	8.74E-08
U-235	1.25E-02	2.03E-04	5.91E-01	1.94E-05
U-236	1.29E-02	2.02E-04	1.68E-04	7.59E-08
U-238	1.16E-02	1.94E-04	8.89E-02	2.82E-06
Zr-93	3.34E-05	3.70E-06	0.00E+00	0.00E+00

Source: RPP-ENV-58813, *Exposure Scenarios for Risk and Performance Assessments in Tank Farms at the Hanford Site, Washington*, Table N-1.

Table Att-4-2. Dose Conversion Factor Multipliers Used for Calculating Doses to Inadvertent Intruders at Waste Management Area A-AX.

Radionuclide	Inhalation Multiplier (unitless)	Ingestion Multiplier (unitless)
Ac-227	1.118	1.595
Am-243	1.00	1.005
Np-237	1.00	1.011
Pb-210	4.268	2.728
Ra-226	1.009	1.001
Ra-228	23.33	1.242
Sn-126	1.003	1.087
Sr-90	1.043	1.1
Th-229	1.213	1.468
U-232	6.541	1.649
U-235	1.00	1.008
U-238	1.003	1.089

Source: RPP-CALC-61254, Rev. 2, *Inadvertent Intruder Dose Calculation Update for the Integrated Disposal Facility Performance Assessment*.

ATTACHMENT 5

BIOCONENTRATION FACTORS

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Table Att-5-1. Bioconcentration Factors Used for Calculating Inadvertent Intruder Doses at Waste Management Area A-AX. (2 sheets)

Radionuclide	Fodder and Grass (B_p) (pCi/kg fresh wgt of fodder)/ (pCi/kg dry wgt of soil)	Vegetables, Fruit and Grain (B_v) (pCi/kg fresh wgt of crop)/ (pCi/kg dry wgt of soil)	Milk (BCF_{milk}) day/L
Ac-227	4.00E-03	1.00E-03	2.00E-06
Am-241	4.00E-03	1.00E-03	2.00E-06
Am-243	4.00E-03	1.00E-03	2.00E-06
C-14	7.00E-01	7.00E-01	1.05E-02
Cd-113m	1.00E+00	5.00E-01	2.00E-03
Cm-243	4.00E-03	1.00E-03	2.00E-06
Cm-244	4.00E-03	1.00E-03	2.00E-06
Co-60	2.00E+00	8.00E-02	2.00E-03
Cs-137	2.00E-01	4.00E-02	1.00E-02
Eu-152	5.00E-02	2.00E-03	6.00E-05
Eu-154	5.00E-02	2.00E-03	6.00E-05
Eu-155	5.00E-02	2.00E-03	6.00E-05
H-3	2.86E+01	2.86E+01	3.36E+01
I-129	1.00E-01	2.00E-02	1.00E-02
Nb-93m	1.00E-01	1.00E-02	2.00E-06
Ni-59	1.00E+00	5.00E-02	2.00E-02
Ni-63	1.00E+00	5.00E-02	2.00E-02
Np-237	1.00E-01	2.00E-02	1.00E-05
Pa-231	5.00E-02	1.00E-02	5.00E-06
Pb-210	9.00E-02	4.00E-03	3.00E-04
Pu-238	1.00E-03	1.00E-03	1.00E-06
Pu-239	1.00E-03	1.00E-03	1.00E-06
Pu-240	1.00E-03	1.00E-03	1.00E-06
Pu-241	1.00E-03	1.00E-03	1.00E-06
Pu-242	1.00E-03	1.00E-03	1.00E-06
Ra-226	2.00E-01	4.00E-02	1.00E-03
Ra-228	2.00E-01	4.00E-02	1.00E-03
Rn-222	0.00E+00	0.00E+00	0.00E+00
Se-79	5.00E-01	1.00E-01	1.00E-02

Table Att-5-1. Bioconcentration Factors Used for Calculating Inadvertent Intruder Doses at Waste Management Area A-AX. (2 sheets)

Radionuclide	Fodder and Grass (B_p) (pCi/kg fresh wgt of fodder)/ (pCi/kg dry wgt of soil)	Vegetables, Fruit and Grain (B_v) (pCi/kg fresh wgt of crop)/ (pCi/kg dry wgt of soil)	Milk (BCF_{milk}) day/L
Sm-151	5.00E-02	2.00E-03	6.00E-05
Sn-126	1.00E+00	3.00E-01	1.00E-03
Sr-90	4.00E+00	3.00E-01	2.00E-03
Tc-99	4.00E+01	5.00E+00	1.00E-03
Th-229	1.00E-03	1.00E-03	5.00E-06
Th-230	1.00E-03	1.00E-03	5.00E-06
Th-232	1.00E-03	1.00E-03	5.00E-06
U-232	1.00E-01	2.00E-03	4.00E-04
U-233	1.00E-01	2.00E-03	4.00E-04
U-234	1.00E-01	2.00E-03	4.00E-04
U-235	1.00E-01	2.00E-03	4.00E-04
U-236	1.00E-01	2.00E-03	4.00E-04
U-238	1.00E-01	2.00E-03	4.00E-04
Zr-93	5.00E-03	1.00E-03	6.00E-07

Source: RPP-ENV-58813, *Exposure Scenarios for Risk and Performance Assessments in Tank Farms at the Hanford Site, Washington*, Table N-3.

ATTACHMENT 6

RADIONUCLIDE-SPECIFIC SHIELDING FACTORS

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Table Att-6-1. Radionuclide-Specific Shielding Factors Used in Calculating Inadvertent Intruder Doses at Waste Management Area A-AX.

Radionuclide	Shielding Factor (ε) (unitless)	Radionuclide	Shielding Factor (ε) (unitless)
Ac-227	0.4	Pu-240	0.1
Am-241	0.2	Pu-241	0.4
Am-243	0.3	Pu-242	0.1
C-14	0.4	Ra-226	0.4
Cd-113m	0.3	Ra-228	0.4
Cm-243	0.4	Rn-222	0.4
Cm-244	0.1	Se-79	0.1
Co-60	0.4	Sm-151	0.1
Cs-137	0.3	Sn-126	0.3
Eu-152	0.4	Sr-90	0.3
Eu-154	0.4	Tc-99	0.2
Eu-155	0.3	Th-229	0.4
H-3	0.4	Th-230	0.3
I-129	0.1	Th-232	0.2
Nb-93m	0.1	U-232	0.3
Ni-59	0.4	U-233	0.4
Ni-63	0.4	U-234	0.2
Np-237	0.3	U-235	0.4
Pa-231	0.4	U-236	0.1
Pb-210	0.1	U-238	0.1
Pu-238	0.1	Zr-93	0.4
Pu-239	0.3	—	—

Source: RPP-ENV-58813, *Exposure Scenarios for Risk and Performance Assessments in Tank Farms at the Hanford Site, Washington*, Table N-4.

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