DOCUMENT RELEASE AND CHANGE FORM

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

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Release Stamp

DATE: Jul 16,2020 HANFORD RELEASE

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WMA A-AX Performance Assessment Groundwater Pathway Dose Calculation

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Checker	Childress, Ryan D	*Childress, Ryan D*	07/07/2020
Document Control Approval	Alvarez, Efren	*Alvarez, Efren*	07/16/2020
Originator	Lee, Kearn (Pat)	*Lee, Kearn (Pat)*	07/07/2020
Quality Assurance	Lungu, Cris C	*Lungu, Cris C*	06/08/2020
Responsible Engineer	Lee, Kearn (Pat)	*Lee, Kearn (Pat)*	07/07/2020
Responsible Manager	Rutland, Paul L	*Rutland, Paul L*	07/08/2020

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Document Number	Rev.	Title
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RPP-CALC-63247	00	WMA A-AX Performance Assessment Sensitivity Analysis
RPP-ENV-61497	00	Preliminary Performance Assessment of Waste Management Area A-AX, Hanford Site, Washington
RPP-ENV-62206	00	Analysis of Post-Closure Groundwater Impacts from Hazardous Chemicals in Residual Wastes in Tanks and Ancillary Equipment at Waste Management Area A-AX at the Hanford Site, Southeast Washington
RPP-RPT-60885	00	Model Package Report System Model for the WMA A-AX Performance Assessment

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Lee, Kearn (Pat)	CLOSURE & INTERIM MEASURES
Rutland, Paul L	CLOSURE & INTERIM MEASURES
Singleton, Kristin M	CLOSURE & INTERIM MEASURES
Watson, David (Dj) J	CLOSURE & INTERIM MEASURES

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- ☐ Internet ☐ Visual Aid ☐ Software
- ☐ Full Paper ☑ Report ☐ Other

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Trademark/Copyright "Right to Use" Information or Permission Documentation	Yes	NA
	☐	☑

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DOE – ORP Public Affairs/Communications	☒	☐	Levardi, Yvonne & Tyree, Geoff - workflow data attached
Other: DOE OCC	☒	☐	Zelen, Ben J - IDMS workflow data attached
Other: DOE ORP SME	☒	☐	Lobos, Rodrigo A - IDMS workflow data attached

Comments Required for WRPS-Indicate Purpose of Document:

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 June 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 in April so finalization of this report is now moving forward.

APPROVED
By Lynn M. Ayers at 10:07 am, Jun 24, 2020

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WMA A-AX Performance Assessment Groundwater Pathway Dose Calculation

Prepared by:

N. Hasan
W. Zhou
INTERA, Inc.

Prepared for:
Washington River Protection Solutions, LLC

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ENVIRONMENTAL MODEL CALCULATION COVER PAGE

Section 1: Completed by Responsible Manager

RELEASE/ISSUE

Project: Waste Management Area A-AX Performance Assessment

Date: 05/29/2019

Calculation Title & Description: WMA A-AX PERFORMANCE ASSESSMENT GROUNDWATER PATHWAY DOSE CALCULATION

Section 2: Completed by Preparer

Calculation No.: RPP-CALC-62538 Revision No.: ~~Draft~~ Rev. 0 KPL 6/24/2020

Revision History

Revision No.	Description	Date	Affected Pages

Section 3: Completed by Responsible Manager

Document Control

1. Is document intended to be controlled within SmartPlant? ☒ Yes ☐ No
2. Does document contain scientific and technical information intended for public use? X| Yes ~~☒ No~~ KPL 6/24/2020
3. Does document contain controlled-use information? ☐ Yes ☒ No

Section 4: Training and Software Installation Approval (Completed Prior to Performing Calculation)

Modeler-Required Training Completed:

Ghada Saad/Training Coordinator (INTERA) — Training Coordinator (Name/Position) — Ghada Saad — Signature — 5.29.2019 — Date

Software Installation and Checkout Certified:

William Nichols/Principal Engineer (INTERA) — Integration Lead (Name/Position) — Signature — 29 MAY 2019 — Date

Section 5: Document Review & Approval

Nazmul Hasan/Hydrologist (INTERA) — Preparer (Name/Position) — Signature — 05/29/2019 — Date

Ryan Childress/Scientist (WRPS) — Checker (Name/Position) — Signature — 5/29/2019 — Date

Matt Kozak/Principal Engineer (INTERA) — Senior Reviewer (Name/Position) — Signature — 5/29/2019 — Date

Bob Hiergesell/Sr.Scientist (WRPS) — Responsible Manager (Name/Position) — Signature — 5/29/2019 — Date

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CHECKER LOG FOR SYSTEM MODELS

Project and Environmental Model Calculation Specific Information:

Project: WMA A-AX System Model to support FY19 preliminary PA

Responsible Manager or Designee, and Position: Robert Hiergesell

Originating Group or Department: Closure and Interim Measures | Date: 5/16/2019

Environmental Model Calculation File Report and Revision No.: RPP-CALC-62538, DRAFT A

Environmental Model Calculation File Title: WMA A-AX Performance Assessment Groundwater Pathway Dose

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	1.0	◉	○		
Calculation Approach	3.0	◉	○		
Assumptions	4.0	◉	○		
Inputs *(reference detailed checklist below as well)*	4.0	◉	○		
Equations used	3.3	◉	○		
Conclusions	7.2	◉	○		
References	8.0	◉	○		

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	5.4	◉	○		
Software use is approved and properly validated in accordance with approved software management plan	5.2	◉	○		
Software use is properly documented	5.1	◉	○		
Verify data was input correctly to approved software or spreadsheets	7.1	◉	○		
If a spreadsheet is used, verify inputs/outputs of calculation(s) to ensure accuracy	7.1. There was a discrepancy between Figure 23 which was generated in Excel and the GoldSim result element GW_peakdose_time_tanks. The excel formula works slightly differently than GoldSim, but they are both accepted methods and	◉	○		

CHECKER LOG FOR SYSTEM MODELS (Continued)

	List where Information is Described *(EMCF Section Number)*	Is the Criteria Met? Yes	No	If No, describe deficiency:	Checker Signature
	the differences are insignificant.				

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	None	

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	Yes	Yes	Yes
Simulated chemical list	Yes	Yes	Yes
Simulated radionuclides list	Yes	Yes	Yes
External model components identified and documented or referenced	NA	NA	NA
External model linkages *(dynamic link libraries, etc.)* checked	NA	NA	NA
If model is probabilistic, stochastic distributions are defined and consistent	NA	NA	NA
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?	NA, Inventory is the same as a_ax v1.0_20190408.gsm, which were checked for the MPR (RPP-RPT-60885).	NA, Inventory is the same as a_ax v1.0_20190408.gsm, which were checked for the MPR (RPP-RPT-60885).	NA, Inventory is the same as a_ax v1.0_20190408.gsm, which were checked for the MPR (RPP-RPT-60885).
Inventory: Mass Balance. Is mass balance of inventory maintained in system model calculation(s)?	Yes	Yes	Yes

CHECKER LOG FOR SYSTEM MODELS (Continued)			
Model Parameter Type	(1) Input Documented in EMCF?	(2) Values checked against parameter source?	(3) Input in EMCF matches model input file(s)?

EXECUTIVE SUMMARY

The purpose of this environmental model calculation file is to assess the performance of the residual waste grouted in the tanks and remaining in the pipelines/ancillary equipment in the 241-A and 241-AX Tank Farms of Waste Management Area A-AX after the tank farms are closed. In particular, the report details the Base Case results of the system model developed to simulate radionuclide release into, and subsequent transport through, the groundwater pathway. The Base Case calculation used the best-estimate or nominal parameter values covering the performance of the system including the waste (primarily residual waste inventories and uranium solubility), engineered barriers (primarily grout K_ds and effective diffusivity), and natural barriers (primarily recharge rate and K_d in the VZ, and Darcy velocity and K_d in the SZ).

Specifically, the calculation results presented in this report include key radionuclide (^{99}Tc, ^{129}I, and ^{238}U) release rates from the residual waste inside the tanks and the pipelines/ancillary equipment into the VZ underneath the tank farms. These radionuclides are important dose contributors and/or represent different transport characteristics. The report also presented the groundwater concentrations of these radionuclides at 100 m from the fence line that are important to understand the transport processes. The presented results also include annual doses at 241-A and 241-AX Tank Farms, which illustrated important dose-contributing sources (tanks or pipelines), radionuclides, and exposure pathways. The calculation duration starts from the closure to 10,000 years beyond including the first 1,000-year compliance period.

The results show that the key sources are the tanks 241-A-104 and 241-A-105 from 241-A Tank Farm. The key dose-contributing radionuclides within 10,000 years are ^{99}Tc, ^{79}Se, and ^{129}I. Most importantly, the results indicate that both 241-A and 241-AX Tank Farms meet the performance objectives with a substantial margin. There is essentially no dose within the 1,000-year performance period. Within 10,000 years, the peak annual doses are 0.3 mrem/year for the 241-A Tank Farm and 0.05 mrem/year for the 241-AX Tank Farm 100-m regulatory boundaries.

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LIST OF TERMS, ACRONYMS, AND ABBREVIATIONS

CHPRC	CH2M HILL Plateau Remediation Company
COPC	contaminant of potential concern
DOE	U.S. Department of Energy
EMCF	Environmental Model Calculation File
EMMA	Environmental Model Management Archive
FEPs	features, events, and processes
FFTF	Fast Flux Test Facility
IAEA	International Atomic Energy Agency
MCL	maximum contaminant level
MPR	Model Package Report
PA	Performance Assessment
POC	point of calculation
PUREX	Plutonium Uranium Extraction (Plant)
RCRA	*Resource Conservation and Recovery Act of 1976*
RT	Radionuclide Transport (module)
SDWA	*Safe Drinking Water Act of 1974*
SST	Single-Shell Tank
SZ	Saturated Zone
TEDE	total effective dose equivalent
VZ	Vadose Zone
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 Base Case calculations of deterministic groundwater concentrations and doses to support the performance assessment (PA) of the residual waste in the underground tanks and pipelines in Waste Management Area (WMA) A-AX. WMA A-AX comprises the 241-A and 241-AX Tank Farms and is located within in the 200 East Area of the Central Plateau of the Hanford Site. Plans for the future closure of the 241-A and 241-AX Tank Farms call for retrieval of wastes remaining in the tanks to the maximum extent practicable, grouting the residual wastes and interior volume of the tanks, and construction of a surficial barrier over the tank farms.

In accordance with DOE O 435.1, *Radioactive Waste Management*, radioactive waste shall be managed and disposed in a manner that is protective of worker and public health and safety, and the environment. DOE O 435.1 requires a site-specific radiological PA that includes calculations of potential releases and subsequent doses to members of the public for a period of 1,000 years after closure of a low-level waste disposal facility. Washington River Protection Solutions, LLC (WRPS) and INTERA Inc. are performing the calculations supporting the PA for WMA A-AX.

The radioactive contaminants of potential concern (COPCs) are assumed to be released into the vadose zone (VZ) after a period of institutional control. This is followed by subsequent transport in the saturated zone (SZ) once the COPCs reach the water table. Quantitative assessment of the impact of the released COPCs to the individual at the receptor location for at least 1,000 years is required to demonstrate compliance with DOE O 435.1. The receptor location is defined at 100 m away from the farm fence along the groundwater flow direction in the SZ.

1.1 OBJECTIVE

The major objective of this EMCF is to present the results of a deterministic assessment of the groundwater pathway annual doses caused by COPCs that may be released from the tanks and pipelines/ancillary equipment at WMA A-AX. 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 documents. The integration of the calculation models, also called the "system model" for WMA A-AX, is implemented 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]).

The case presented in this EMCF uses the nominal parameter values, and serves as the Base Case for WMA A-AX PA calculations. The required inputs are provided by other EMCFs and their associated MPRs supporting the WMA A-AX PA listed in Sections 1.2 through 1.5.

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

1.2 DATA PACKAGE REPORTS

Data package reports are reported in the MPR (see Section 1.3).

1.3 MODEL PACKAGE REPORTS

The MPR supporting this calculation supports model implementation and is:

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

1.4 OTHER ENVIRONMENTAL MODEL CALCULATION FILES

The environmental model calculation files supporting this calculation include:

RPP-CALC-62319	*Residual Waste Source Inventory Term for the Waste Management Area A-AX Performance Assessment Inventory Case 1*

1.5 OTHER TECHNICAL REPORTS

RPP-RPT-60101	*Model Package Report Flow and Contaminant Transport Numerical Model Used in WMA A-AX Performance Assessment and RCRA Closure Analysis*

1.6 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 presents 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.

2.0 BACKGROUND

This section summarizes relevant information on the WMA A-AX performance objectives, waste characteristics, processes and system model developed to characterize the release and transport processes of the contaminants and dose assessment for the groundwater pathway representative person exposure scenario. Details of the development of the system model used in the calculations described in this EMCF are provided in RPP-RPT-60885.

2.1 PERFORMANCE OBJECTIVES

Dose assessments from exposure to both groundwater and atmospheric pathways and measurements of radon flux are required to meet the objectives of the PA. DOE M 435.1-1, *Radioactive Waste Management Manual*, Chapter VI – Low-Level Waste Requirements, prescribes numerous requirements and the performance objectives for the low-level waste disposal facility. Two performance objectives for the PA shall include calculations of potential doses to representative future members of the public due to potential releases from the facility for a 1,000-year period after closure, as listed below.

- Dose to representative members of the public shall not exceed 25 mrem in a year total effective dose equivalent (TEDE) from all exposure pathways, excluding the dose from radon and its progeny in air.

- Dose to representative members of the public via the air pathway shall not exceed 10 mrem in a year TEDE, excluding the dose from radon and its progeny. A separate objective set for radon requires that the ^{222}Rn flux emanating at the surface from waste sources shall not exceed 20 pCi $m^{-2}s^{-1}$.

Two additional performance objectives are related to inadvertent intrusion: the maximum 100 mrem (1 mSv) and 500 mrem/yr (5 mSv) TEDE for chronic and acute exposure scenarios, respectively. The inadvertent intruder model and calculations used to evaluate the DOE M 435.1-1 performance measure are presented in a separate EMCF, RPP-CALC-62539, *WMA A-AX Performance Assessment Hypothetical Inadvertent Intruder Dose Calculation*.

To meet these performance objectives, the performance assessment of WMA A-AX models COPC transport along the groundwater pathway and the atmospheric pathway. However, the atmospheric pathway modeling results indicated that under the extremely conservative conditions, the dose from air pathway is insignificant (RPP-CALC-63180, *Calculation of Inhalation Doses from H-3, C-14 and I-129 Originating from Waste Management Area A-AX*) compared to the dose from groundwater pathway. Hence, the groundwater pathway dose can be considered as the all-pathway dose (groundwater pathway + air pathway). This EMCF describes the dose calculation for the WMA A-AX performance assessment of the groundwater pathway.

2.2 HISTORY

WMA A-AX comprises the 241-A and 241-AX Tank Farms and is located in 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.

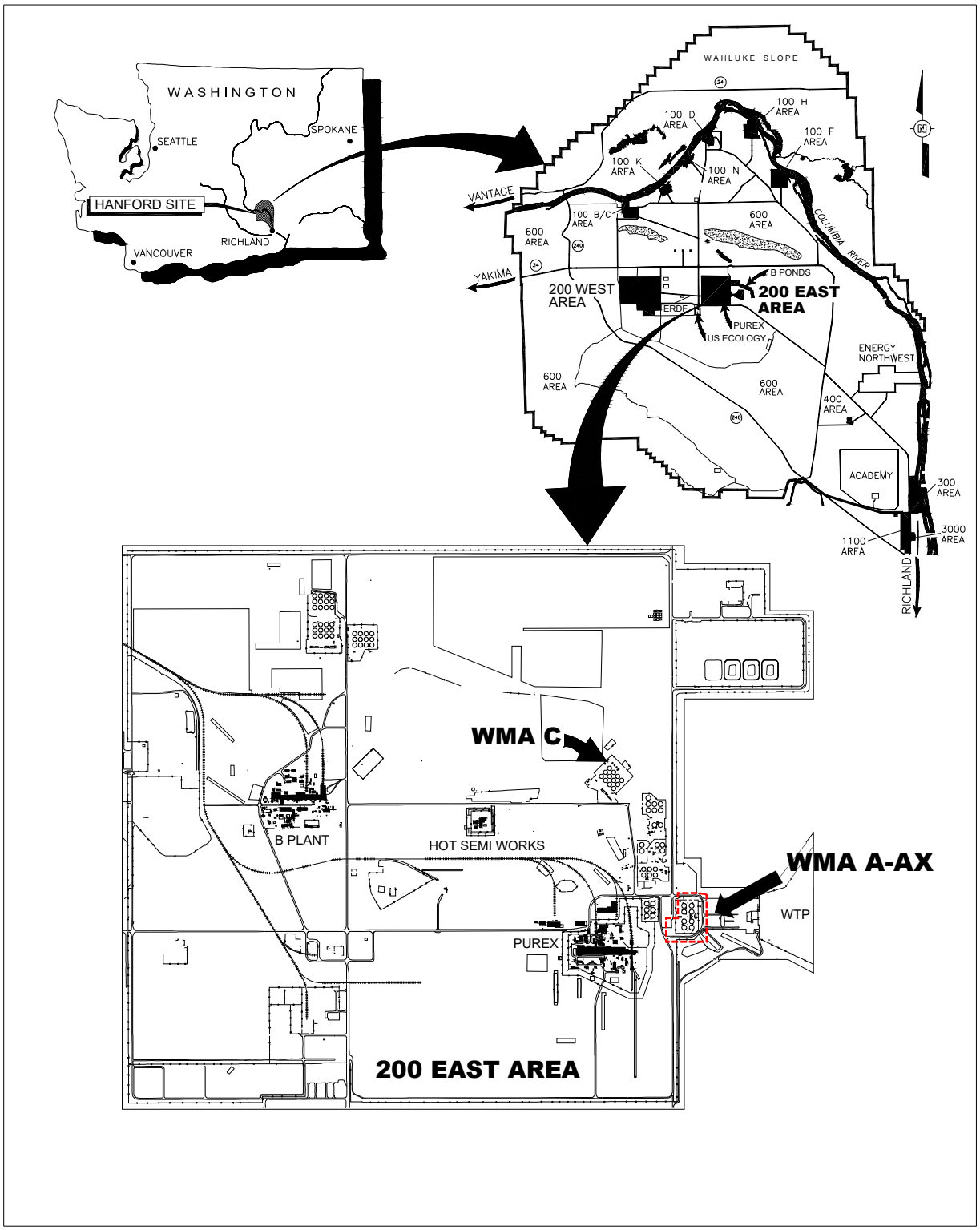
Figure 2-2 illustrates the closure concept for WMA A-AX following tank waste retrieval. Surface facilities will be removed and retrieved SSTs and accessible ancillary equipment with significant void spaces will be filled with grout. Waste transfer pipelines are also expected to be left in place. An engineered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

2.3 JUSTIFICATION OF METHODOLOGY

The establishment of groundwater pathway system model was described in RPP-RPT-60885.

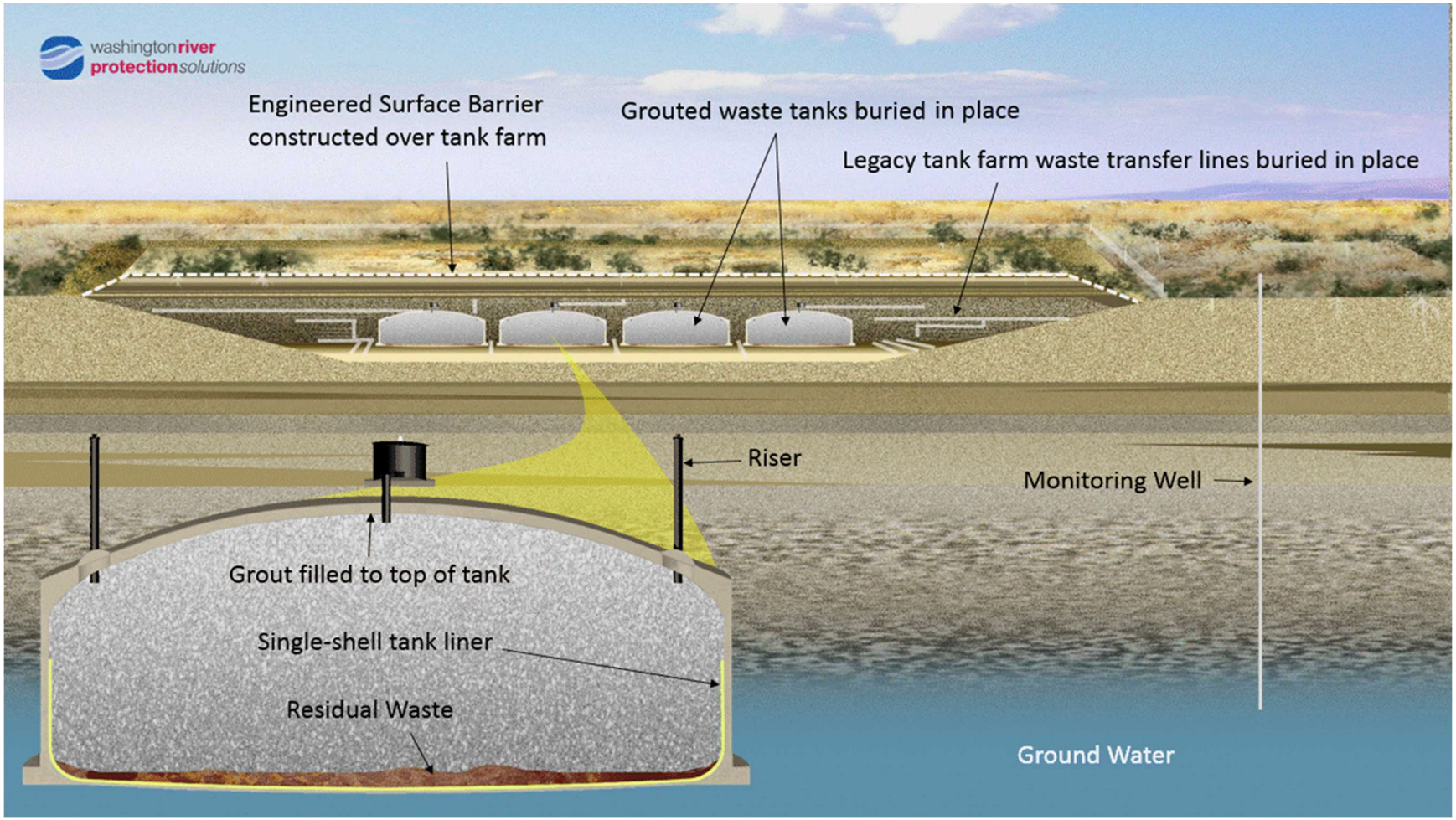
The model includes releases from the tanks (six tanks in A Farm and four in AX Farm) and pipeline and ancillary equipment in the two farms. Distribution of the released COPCs in the VZ depends on the inventory, the liner system, transport of the contaminants through the VZ, transport in the SZ to a point of compliance (or point of calculation [POC]) for DOE O 435.1 (100 m downgradient from the facility boundary) and for subsequent doses to humans from the potential use of the contaminated water at the POC. The system model was developed by abstracting process modelling results, capturing key features, events, and processes (FEPs) related to barriers' safety functions, while maintaining computational efficiency so that sensitivity and uncertainty analysis can be performed in an efficient manner.

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



FFTF = Fast Flux Test Facility PUREX = Plutonium Uranium Extraction (Plant) WMA = Waste Management Area

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



The results obtained from the system model related to the groundwater pathway include (a) the COPC concentration in the SZ at the 100-m buffer boundary that can be compared to the *Safe Drinking Water Act of 1974* (SDWA)'s maximum contaminant level (MCL) and (b) the dose to the receptor from using water withdrawn from the SZ at the 100-m buffer boundary that can be compared to the 25-mrem/yr limit for the all-pathways performance objective. Details of the development of the system model are provided in RPP-RPT-60885.

The system model for the WMA A-AX PA was developed by connecting the subsystem PA models of WMA A-AX using the GoldSim© computer code. The Radionuclide Transport (RT) module in the GoldSim© simulation software is a tool that can specifically and easily evaluate decay and ingrowth of radionuclides. The GoldSim© user manual (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 simulate transport of COPCs accompanied with decay/ingrowth, solubility-limit, and sorption within modules allowing each waste source to be represented by a discrete element within the model.

Using a tool specifically developed to support COPC 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.

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3.0 METHODOLOGY

The system-level model has been implemented using GoldSim© software (GoldSim Technology Group 2014a, GoldSim Technology Group 2014b, GoldSim Technology Group 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 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 develops the methodology, gains early concurrence with the senior reviewers, identifies project conditions, assumptions, and inputs, and prepares the calculation and associated calculation report.

Nazmul Hassan, INTERA, Inc.
Hydrologist, PE
M.S., 2008, Environmental Engineering, Washington State University
B.S., 2007, Civil Engineering, Bangladesh University of Engineering & Technology

Mr. Hasan is a hydrologist with 11 years of experience in numerical modeling of groundwater in the saturated and unsaturated zones, model calibration, groundwater management, geostatistics analysis, and programming in and application of multiple languages and codes including

FORTRAN, MODFLOW[2], MT3DMS[3], MODPATH[4], PEST[5], STOMP[6], ArcGIS[7], GoldSim©, Groundwater Vistas[8], RETC[9], R[10], and TecPlot®[11].

Wei Zhou, INTERA, Inc.
Senior Engineer
Ph.D., 1992, Nuclear Engineering, University of California at Berkeley
M.S., 1986, Mechanical Engineering, San Jose State University
B.S., 1982, Mechanical Engineering, Beijing University of Technology

Wei Zhou has 31 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 carbon dioxide (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 (IAEA), Nuclear Energy Institute, Korean Hydro and Nuclear Power, Canadian Petroleum Technology Research Institute, U.S. Environmental Protection Agency, U.S. Department of Energy (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 codes including TOUGH2[12], TOUGHREACT[13], STOMP, ECLIPSE[14] suite codes, MATLAB[15], and GoldSim©.

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[2] MODFLOW software has been developed and distributed by the U.S. Geological Survey, Washington, D.C.

[3] MT3DMS© model software is copyrighted by The University of Alabama, Tuscaloosa, Alabama.

[4] MODPATH software has been developed and distributed by the U.S. Geological Survey, Washington, D.C.

[5] PEST (Parameter ESTimation) is an open-source, freely-available software tool currently distributed by S. S. Papadopoulos & Associates, Inc., Bethesda, Maryland.

[6] Subsurface Transport Over Multiple Phases (STOMP) is developed and distributed by Battelle Memorial Institute.

[7] ArcGIS® is a registered trademark of Environmental Systems Research Institute, Inc., Redlands, California.

[8] Groundwater Vistas is a product of Environmental Simulations, Inc., Leesport, Pennsylvania.

[9] RETC (RETention Curve) was developed by the U.S. Department of Agriculture, Agricultural Research Service for the U.S. Environmental Protection Agency Office of Research and Development, Washington, D.C.

[10] R is a programming language and free software environment created by Ross Ihaka and Robert Gentleman at the University of Auckland, New Zealand.

[11] Tecplot® is a registered trademark of Tecplot, Inc., 3535 Factoria Blvd. SE, Bellevue, Washington.

[12] 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.

[13] 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.

[14] ECLIPSE is a suite of reservoir simulator software developed by GeoQuest, an operating unit of Schlumberger Oilfield Services, Houston, Texas.

[15] MATLAB® (matrix laboratory) is a registered trademark of The MathWorks, Inc., Natick, Massachusetts.

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.

Ryan Childress, Washington River Protection Solutions, Scientist
M.S., 2019, Environmental Science, Washington State University
B.S., 2015, Environmental Science, Washington State University

Ryan Childress has six years of experience working at the Hanford Site for DOE as well as their contractors. Ryan has worked on developing many regulatory documents including Data Quality Objectives, Sampling and Analysis Plans, *Resource Conservation and Recovery Act of 1976* (RCRA) Facility Investigations, EMCFs, MPRs, and 435.1 PAs.

3.1.3 Senior Reviewers

Matthew W. Kozak, INTERA, Inc.
Ph.D., 1988, Chemical Engineering, University of Washington
B.S., 1981, Chemical Engineering, Cleveland State University

Dr. Kozak has more than 30 years of experience in the areas of performance assessment of near-surface and geological radioactive waste repositories, regulatory development, dose assessment for residual contamination of soils and buildings, toxic materials risk assessment, and mixed waste issues. He is the author of over 100 publications on these topics. He has supported national programs in the U.S. and countries in Europe, Asia, and Africa to site, develop, construct, and analyze facilities for disposal of radioactive waste.

He has participated in a number of international research programs, including IAEA's Coordinated Research Program on Improvement of Safety Assessment Methodologies, and its successor programs: Application of Safety Assessment Methodologies, Practical Illustration and Use of the Safety Case Concept in the Management of Near-Surface Disposal, and most recently Modelling and Data for Radiological Impact Assessments.

He is a principle investigator for the WMA A-AX PA.

3.2 CONCEPTUAL MODEL

The conceptual model is described in detail in Sections 3.2 and 3.3 of RPP-RPT-60885.

3.3 MATHEMATICAL MODEL

The equations used to calculate groundwater pathway annual doses are described in detail in Section 4.6 of RPP-RPT-60885.

3.4 CALCULATION PROCEDURE

The calculation of the groundwater pathway doses used the system model file a_ax v1.0_20190408.gsm. The simulation duration is from the closure to 10,000 years beyond.

Table 3-1 lists radionuclides simulated in the system. Although this EMCF reports the transport and doses of radionuclides, some chemical COPCs are also simulated and listed in Table 3-2. The timesteps are the same as a_ax v1.0_20190408.gsm, i.e., 1 year from the closure to 1,000 years and 10 years thereafter.

Table 3-1. List of Simulated Radionuclides.

Actinium-227	Cesium-137	Nickel-59	Plutonium-242	Technetium-99	Uranium-236
Americium-241	Europium-152	Nickel-63	Radium-226	Thorium-229	Uranium-238
Americium-243	Europium-154	Neptunium-237	Radium-228	Thorium-230	Zirconium-93
Carbon-14	Europium-155	Protactinium-231	Radon-222	Thorium-232	
Cadmium-113m	Hydrogen-3	Plutonium-238	Samarium-151	Uranium-232	
Curium-243	Iodine-129	Plutonium-239	Selenium-79	Uranium-233	
Curium-244	Lead-210	Plutonium-240	Tin-126	Uranium-234	
Cobalt-60	Niobium-93m	Plutonium-241	Strontium-90	Uranium-235	

Table 3-2. List of Simulated Chemicals.

Aluminum	Iron	Nitrate
Boron	Lead	Selenium
Chromium	Mercury	Strontium
Cobalt	Manganese	Tin
Cyanide	Nickel	Tributyl phosphate
Fluorine	Nitrite	

4.0 ASSUMPTIONS AND INPUTS

RPP-RPT-60885 lists key assumptions and inputs for the groundwater pathway calculations presented in this EMCF. Inventory related assumptions are detailed in RPP-CALC-62319, *Residual Waste Source Inventory Term for the Waste Management Area A-AX Performance Assessment Inventory Case 1*.

4.1 KEY ASSUMPTIONS

General assumptions related to groundwater pathway performance objectives assessed in the model are detailed in RPP-RPT-60885. This EMCF inherits all relevant assumptions presented in RPP-RPT-60885.

4.2 INPUTS

Inputs for this calculation include residual waste inventories, tank and pipeline area dimensions, transport and physical parameters, geochemical parameters, VZ and SZ flow field parameters, and exposure parameters. Table 4-1 lists the inputs, their sources and the attachments to this document that list their values.

Table 4-1. List of Source Documents for Input Parameters.

Input	Reference
Inventory and waste dimension parameters	RPP-CALC-62319, *Residual Waste Source Inventory Term for the Waste Management Area A-AX Performance Assessment Inventory Case 1*; RPP-RPT-60885, *Model Package Report System Model for the WMA A-AX Performance Assessment*.
Transport and physical parameters	RPP-RPT-60885, *Model Package Report System Model for the WMA A-AX Performance Assessment*.
Geochemical parameters	RPP-RPT-60885, *Model Package Report System Model for the WMA A-AX Performance Assessment*.
Vadose zone and saturated zone flow field parameters	RPP-RPT-60885, *Model Package Report System Model for the WMA A-AX Performance Assessment*.
Exposure parameters	RPP-RPT-60885, *Model Package Report System Model for the WMA A-AX Performance Assessment*.

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5.0 SOFTWARE APPLICATIONS

The software used to perform this calculation is 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: Lenovo Yoga 900-131SK2 Signature Edition, SN PFOGS02H.

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*, Revision 3, using CHPRC-00224, *GoldSim© Pro Software Test Plan*, Revision 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 validates 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 as well as contamination mass transport in subsurface environment and to 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 "a_ax v1.0_20190408.gsm" model file (RPP-RPT-60885) with added elements for conducting mass balance calculations and capturing results presented in this EMCF.

A full description of the construction and model parameters is presented in RPP-RPT-60885.

6.1 DESCRIPTION OF MODEL CHANGES

There are no model changes from the "a_ax v1.0_20190408.gsm" model file except for several mass balance and result elements created in the model to conduct mass balance calculations and to capture simulation results for presentation in this EMCF. The model is renamed as "a_ax v1.0_20190408_EMCF-62538.gsm" file.

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 Environmental Model Management Archive (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 controlled copy of the GoldSim© model file ("a_ax v1.0_20190408_EMCF-62538.gsm")
- A copy of the MPR (RPP-RPT-60885)
- A 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

All the radionuclides listed in Table 3-1 and chemicals listed in Table 3-2 were simulated in the model but only the results for major dose contributors are presented in this EMCF.

The output of these calculations is a series of data matrices with time-after-closure as the independent variable. The dependent variables include

- Release rates into VZ from tanks and pipeline areas for key COPCs (^{99}Tc, ^{129}I, and ^{238}U),
- Key radionuclide (^{99}Tc, ^{129}I, and ^{238}U) concentrations at the 100-m POC location from tanks and pipeline areas and total concentrations for A Farm and AX Farm, respectively,
- Annual doses from all exposure pathways and total doses for key COPCs, and
- Total annual dose contributed from major radioactive COPCs and from all exposure pathways.

Although ^{238}U is not as mobile as ^{99}Tc and ^{129}I, it is subjected to solubility limit and hence depicts different release and transport characteristics compared to ^{99}Tc and ^{129}I.

Each of the above categories of the results are presented in a series of time-history plots for up to 10,000 years after closure. Whenever applicable, the performance objectives are presented in the plots as a reference for the relevant results.

7.0 RESULTS AND CONCLUSIONS

This section presents the results of the calculations for each of the result categories described in Section 6.2.

7.1 RESULTS

In this section, the VZ release rates, concentrations at the POC (i.e., 100 m from the fence line along the SZ groundwater flow direction), and dose histories for ^{99}Tc, ^{129}I, and ^{238}U will be presented.

7.1.1 Release Rates to Vadose Zone

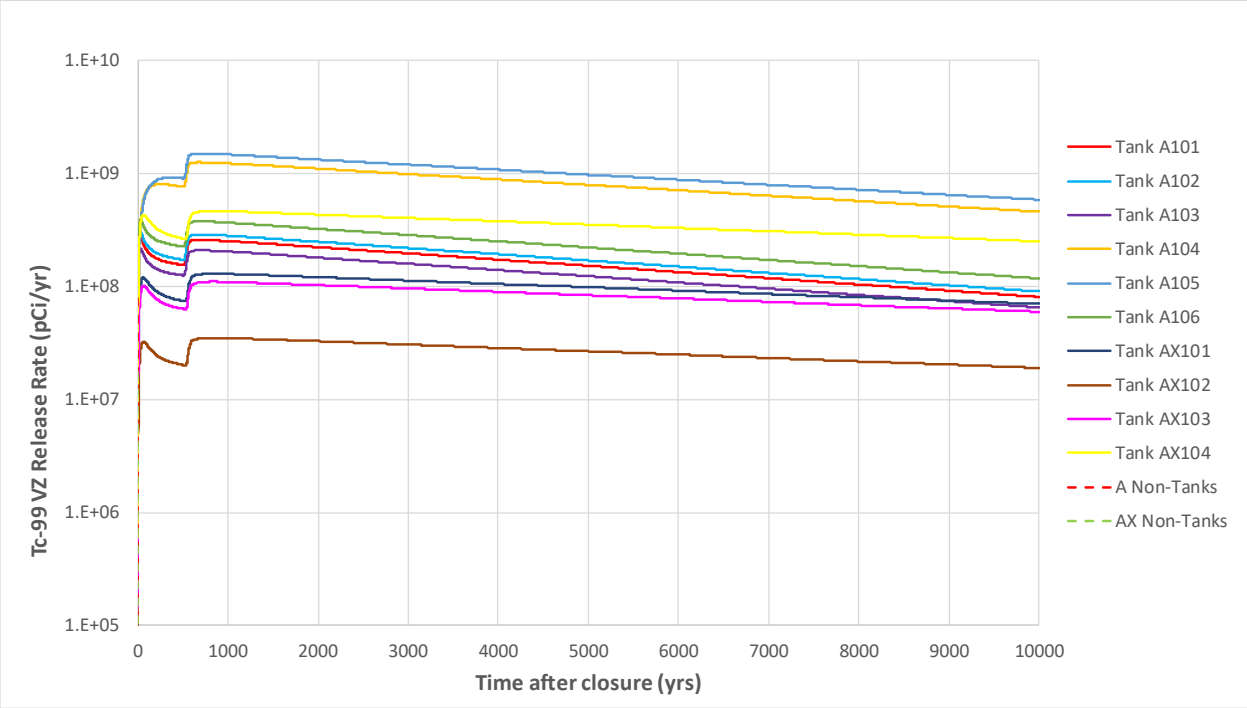
This section presents and discusses release rates to the VZ for selected radionuclides. To help the results be more understandable, some input parameters are also presented.

7.1.1.1 Technetium-99. Technetium-99 release rates into the VZ from various tanks and the pipeline/ancillary equipment for A Farm and AX Farm are shown in Figure 7-1a for linear time scale and Figure 7-1b for logarithmic time scale. Initially, the release rates from all tanks are slow, during the period when the tanks are covered by a surface barrier. The release rate increases after 500 years when the surface barrier is assumed to degrade and the recharge rate increases from 0.5 mm/yr to the ambient rate of 3.5 mm/yr, raising the vertical Darcy velocities and moisture contents in the VZ below the tank farms. The increased VZ transport decreases concentrations in the near field (below the waste source), hence raising diffusive release rates from the waste source. The highest release rates are produced by tank 241-A-105 (A-105) and tank 241-A-104 (A-104).

Unlike tanks A-105 and A-104, other tanks show two peaks of VZ release rates: the earlier peaks occur decades after closure while the later peaks occur a few hundreds of years after the 500-year surface barrier failure when the VZ recharge rate increases to 3.5 mm/yr (see Figure 7-1b). This difference is caused by differences in inventories, as shown in Figure 7-2 (also shown in Table 7-1). Tanks with relatively low inventories cannot sustain the release rates like tanks A-105 and A-104 that have relatively higher inventories, so the inventory becomes depleted during the initial period. Once VZ recharge rate and moisture content increase, the diffusive release rates from all tanks increase as a result of decreased VZ concentrations.

For all tanks, release of ^{99}Tc continues throughout the 10,000-year time period, due to sorption of technetium in the grouted tank base. Although technetium's K_d is small (1 mL/g – see Table 7-2) compared with iodine (3 mL/g) and uranium (2,000 mL/g) and the grouted bases are thin (8 inches and 17.5 inches for A Farm and AX Farm, respectively), sorption effectively delays release and lowers the peak release rates.

Figure 7-1a. Waste Management Area A-AX Technetium-99 Release Rates to Vadose Zone (linear time scale).



VZ = vadose zone

Figure 7-1b. Waste Management Area A-AX Technetium-99 Release Rates to Vadose Zone (logarithmic time scale).

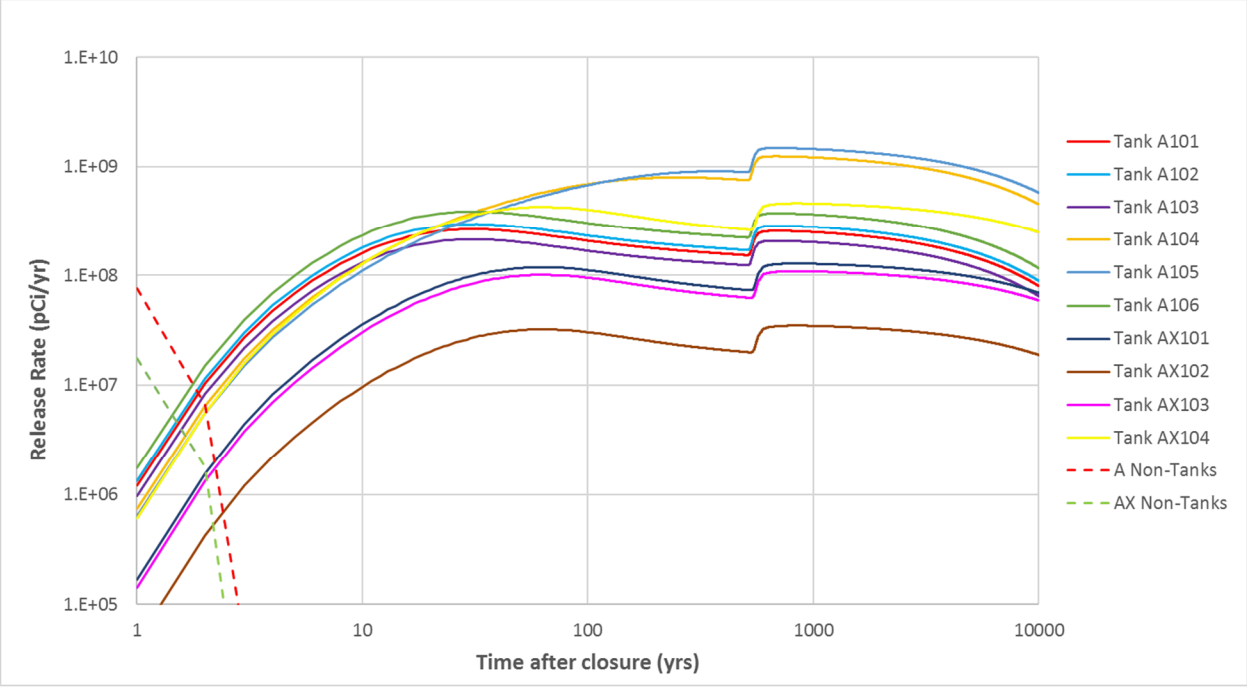
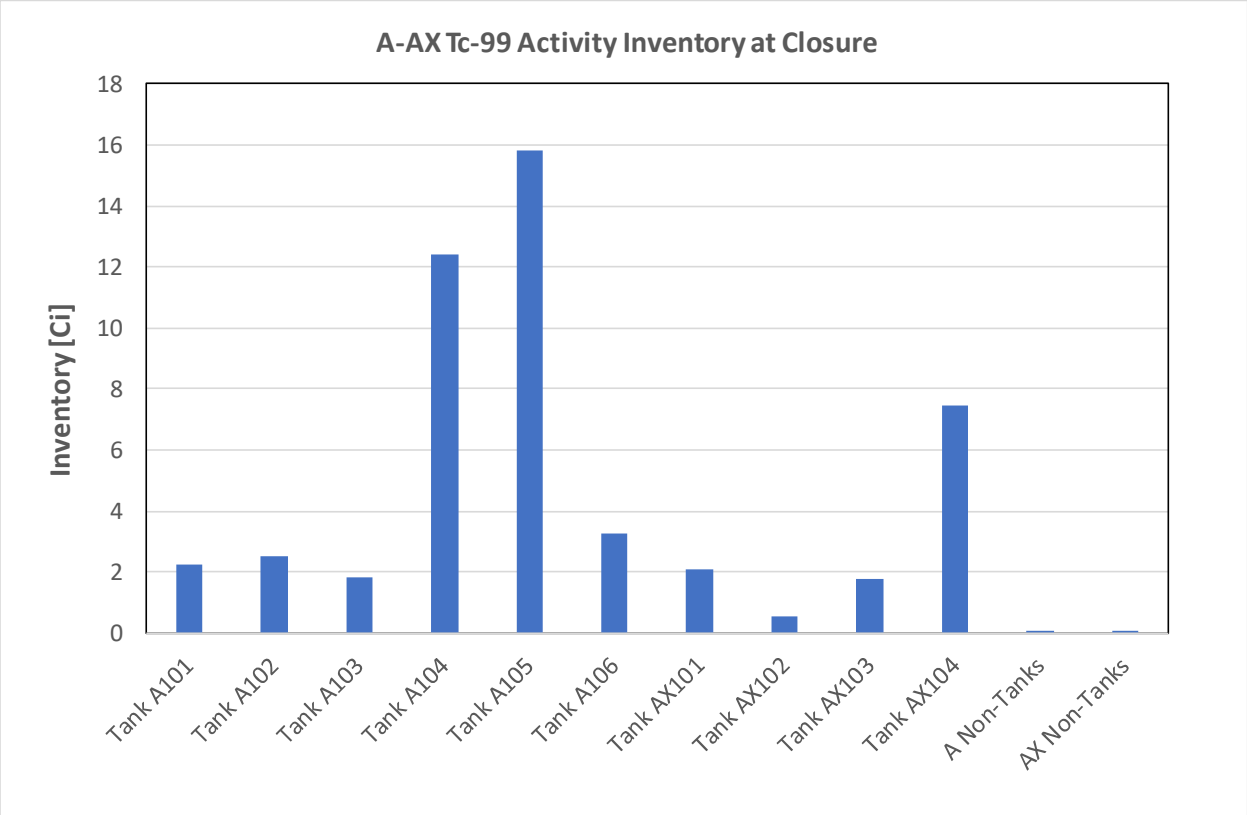


Figure 7-2. Residual Technetium-99 Activities at Closure in Waste Management Area A-AX Tanks and Pipelines/Ancillary Equipment.



The release rates from the pipelines/ancillary equipment areas are different from those of the tanks. Under the base case assumptions, the grout infill above the residual waste zone within each tank is assumed to be intact, minimizing water movement into the residual waste zone. Releases from residual waste are therefore by diffusion only. Sorption (Table 7-2) in the cementitious tank base mat further retards release of ^{99}Tc to the VZ below. Unlike the tanks, there is no comparable grouted barrier above the pipelines and ancillary equipment. The release from the waste is by both advection and diffusion, with advection being the dominant mechanism. Furthermore, the absence of a comparable grout base below the pipelines means there is no delay of release from the pipelines/ancillary equipment. As a result, ^{99}Tc is rapidly released at very early times from the pipeline and ancillary areas of A Farm and AX Farm, as indicated by the dashed lines in Figure 7-1b.

7.1.1.2 Iodine-129. Iodine-129 release rates into the VZ from various tanks and the pipeline/ancillary equipment for A Farm and AX Farm are shown in Figure 7-3a for linear time scale and Figure 7-3b for logarithmic time scale. The initial residual waste activities are shown in Figure 7-4 and Table 7-1. Near-field K_d values for iodine are shown in Table 7-2.

Table 7-1. Waste Management Area A-AX Residual Waste Inventories for Selected Radionuclides at Closure.

	Technetium-99	Iodine-129	Uranium-238
Tank 241-A-101	2.25E+00	2.29E-03	4.20E-03
Tank 241-A-102	2.51E+00	1.34E-03	1.51E-01
Tank 241-A-103	1.82E+00	3.35E-04	5.81E-03
Tank 241-A-104	1.24E+01	6.36E-03	5.07E-01
Tank 241-A-105	1.58E+01	9.47E-04	8.57E-04
Tank 241-A-106	3.27E+00	1.33E-03	5.71E-03
Tank 241-AX-101	2.09E+00	2.12E-03	3.77E-03
Tank 241-AX-102	5.68E-01	1.52E-03	1.62E-02
Tank 241-AX-103	1.78E+00	1.71E-03	1.63E-03
Tank 241-AX-104	7.48E+00	1.34E-04	2.01E-02
241-A Tank Farm Non-Tanks	8.36E-05	1.20E-04	2.21E-01
241-AX Tank Farm Non-Tanks	1.94E-05	1.56E-08	1.97E-02

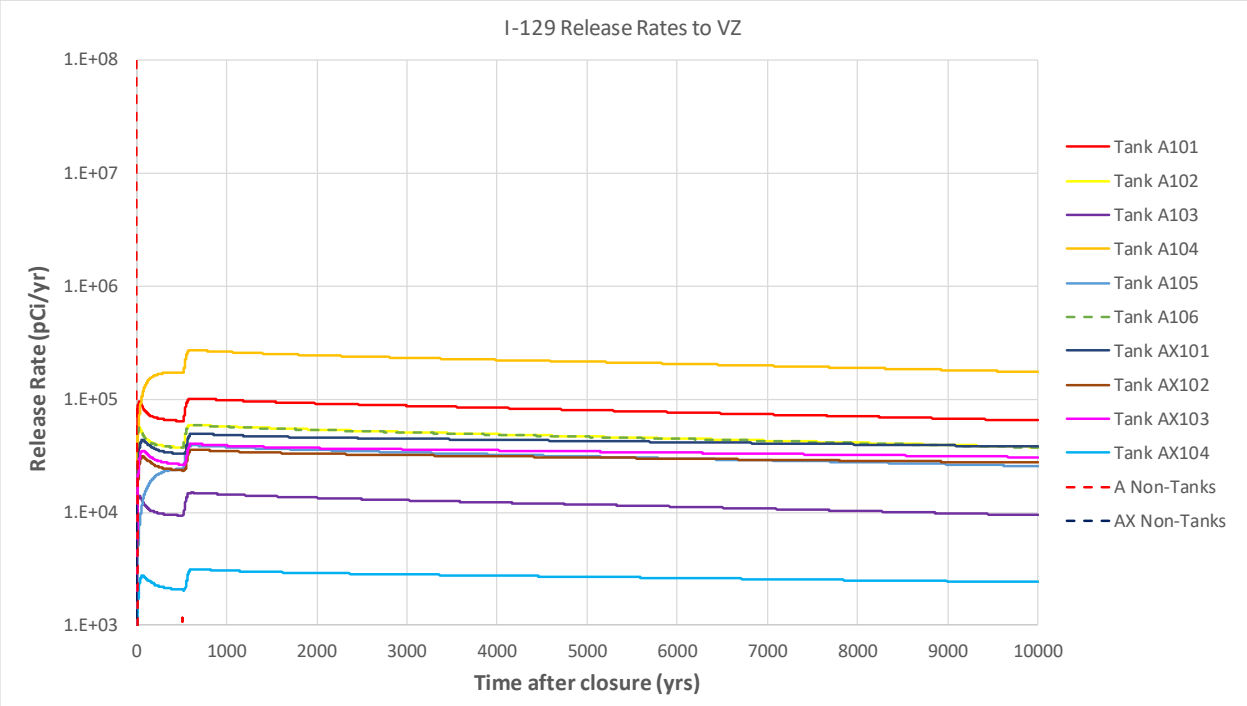
Table 7-2. Near-field K_d (mL/g) Values for Selected Radionuclides.

	Grout	H1	H2	Soil (below pipelines)
Technetium	1	0	0	0
Iodine	3	0.19	0.19	0.084
Uranium	2,000	0.57	0.57	0.252

Descriptions of ^{99}Tc release behavior in the previous section also apply to ^{129}I release behavior. Release from pipeline sources are advection dominated, and the peak releases are higher than the release from tanks. The highest ^{129}I release rate to the VZ is from A Farm pipelines/ancillary equipment; this happens less than a year after closure and declines rapidly in the years immediately after that (Figure 7-3b). Initially, flow rates are high (due to 100 mm/yr recharge in the operation period), then flow rates decline due to the presence of intact surface barrier (0.5 mm/yr recharge rate). When the surface barrier fails, the flow rates increase and become steady in response to the long-term recharge rate of 3.5 mm/yr. Due to the initially high flow rates, most of the waste from pipeline sources is released very quickly, and waste migrates to the "Soil_Below_Pipearea" cell and sorbs into the soil. When flow rates start to decline, backward diffusion from the "Soil_Below_Pipearea" cell dominates over the release from the residual wastes, and release rates become negative (very small rates). Later, when flow rates increase again, infiltrating water flushes the waste from the "Soil_Below_Pipearea" cell, reducing backward diffusion and increasing the release rate to positive values again (the tiny bump in the A Farm pipeline release rate in Figure 7-3b). Although the initial ^{129}I activity in A Farm pipeline

area is less than most tanks (Figure 7-4 and Table 7-1), the difference in initial ^{129}I activities between the tanks and A Farm pipeline areas is about one order of magnitude, whilst for ^{99}Tc, the difference is more than five orders of magnitude (Table 7-1). The advective-diffusive release and proportionately higher inventory (in comparison to ^{99}Tc) result in a higher A Farm pipeline ^{129}I release rate to VZ than other WMA A-AX tank sources.

Figure 7-3a. Waste Management Area A-AX Iodine-129 Release Rates to Vadose Zone (linear time scale).

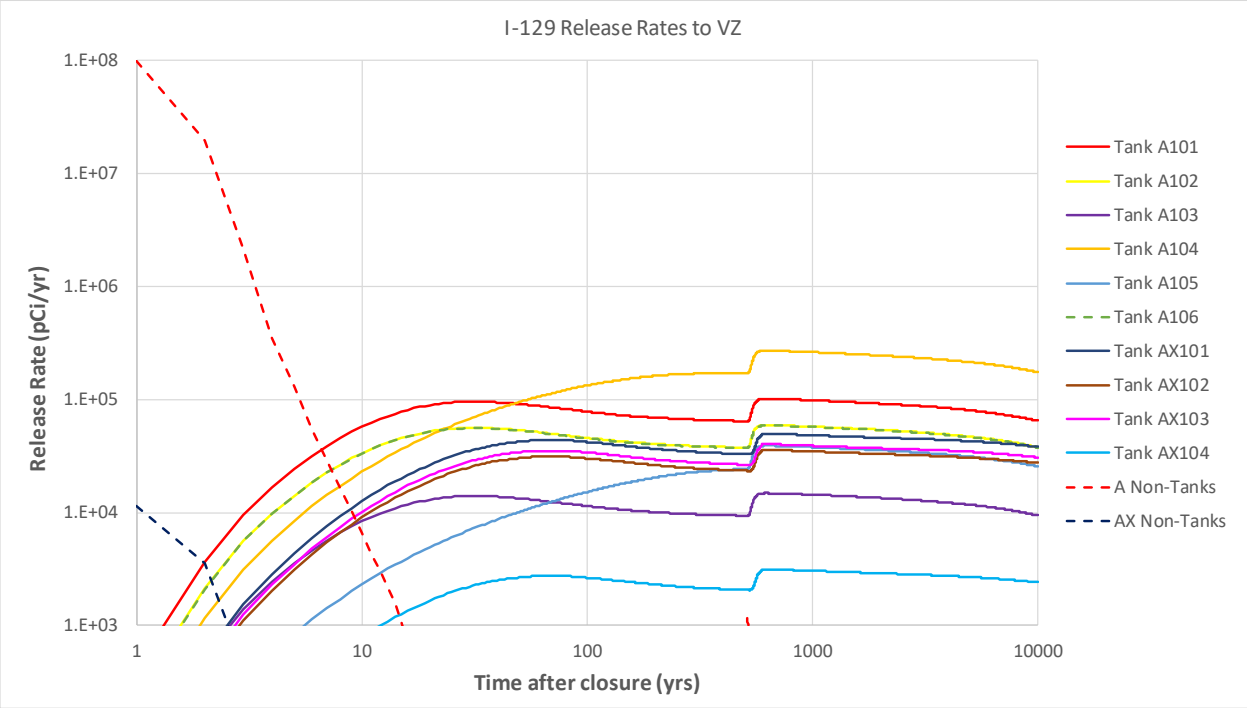


Sorption of iodine in the cementitious tank base mat is higher than in the soil below the pipelines, which contributes to the higher release rate from the pipelines compared to tanks, as illustrated in Table 7-2. The stronger sorption effect in the cementitious tank bases results in slower release rates from the tanks and the retention of most ^{129}I within the near field, as compared to the pipeline areas where transport is more rapid owing to weaker sorption.

The initial inventories of ^{129}I for tanks 241-A-102 (A-102) and 241-A-106 (A-106) are almost the same, leading to their indistinguishable release curves shown in Figure 7-5. This will also cause identical concentrations for the two tanks, to be presented later.

7.1.1.3 Uranium-238. Uranium-238 release rates into the VZ from various tanks and the pipeline/ancillary equipment for WMA A-AX are shown in Figure 7-5a for linear time scale and Figure 7-5b for logarithmic time scale. The initial residual ^{238}U activities are shown in Table 7-1. Uranium sorption coefficients in the near field can be found in Table 7-2.

Figure 7-3b. Waste Management Area A-AX Iodine-129 Release Rates to Vadose Zone (logarithmic time scale).



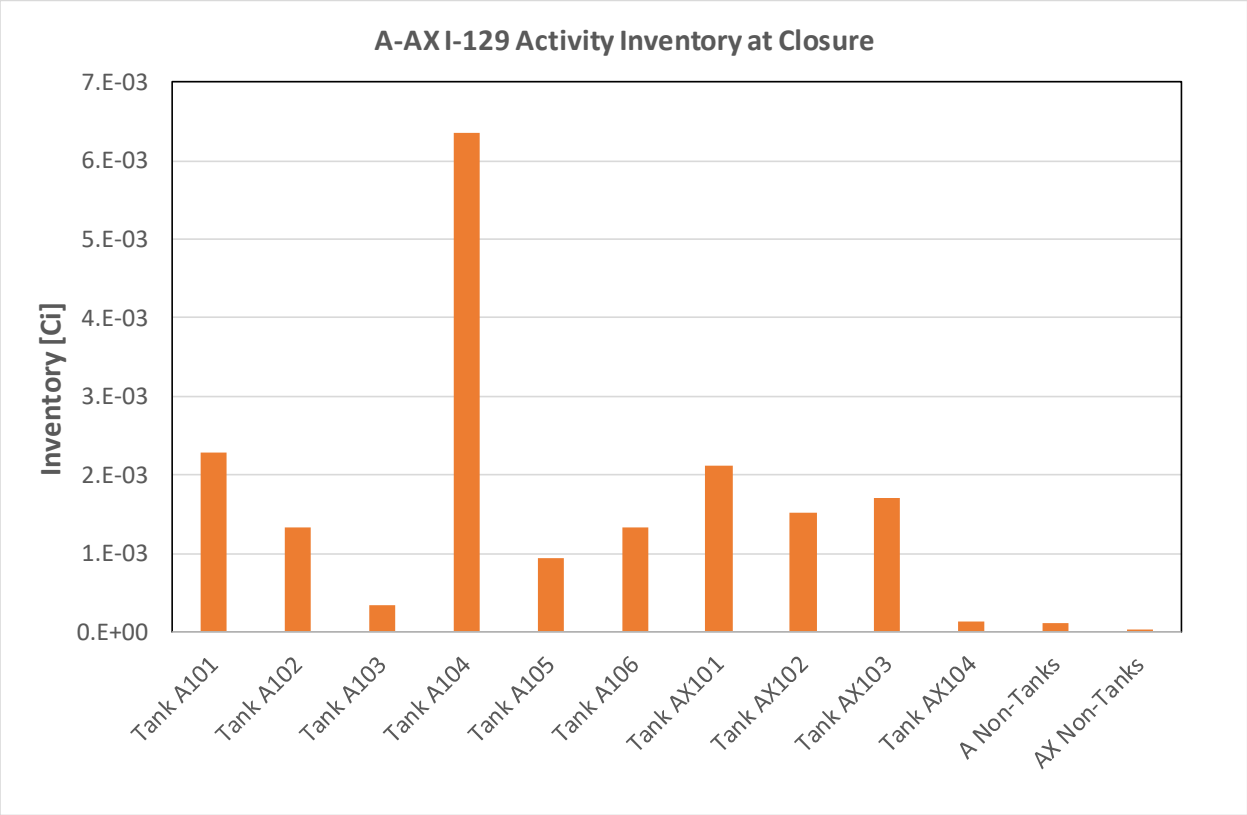
Residual ^{238}U release rates from the tanks to VZ are influenced by both sorption and solubility limitation. The model assumes that uranium solubility in the tank residual wastes equals 1×10^{-4} M before 1,000 years when the porewater in the residual wastes is not affected by the presence of the grout and uranium solubility is the same as that at ambient conditions, including VZ and SZ. After 1,000 years when the grout is assumed to slowly leach, modifying the grout chemistry, uranium solubility in the residual waste is assumed to decrease to 1×10^{-6} M. Releases from pipeline areas and chemical conditions in the VZ/SZ are not affected by the grout conditions.

Referring to Figure 7-5a, for the tanks, ^{238}U release rates gradually increase until 1,000 years. Release rates of the A Farm tanks are identical, except tank A-105, because the transport conditions, or properties, of the VZ in vicinity of the waste, are identical.

Tank A-105 residual wastes have a large volume and relatively low mass (Table 7-1); consequently, its release curve initially overlaps to the rest of A Farm tanks and then, at about 300 years, its release curve is lower than the other A Farm tanks.

The release curves of all AX Farm tanks are identical because their residual aqueous concentrations are all equal to the solubility limit and the VZ concentration variations are the same. The AX Farm release curves, however, are lower than A Farm because of different VZ transport conditions (primarily Darcy velocities and moisture contents).

Figure 7-4. Residual Iodine-129 Activities at Closure in Waste Management Area A-AX Tanks and Pipelines/Ancillary Equipment.



While tank release curves are controlled by solubility in the residual waste and sorption in cementitious tank base mats (Table 7-2), the release curves in the pipeline areas are controlled by advection with lower sorption, giving rise to high release rates at very early times as shown in Figure 7-5b. The release rates rapidly decline as the inventory is depleted. The release rate gradually declines as it moves from the soil below the pipeline area within the source. The sorption of uranium in this soil zone (see Table 7-2 for soil K_ds) is responsible for the release "tails" shown in Figure 7-5b. It can be seen that the "tail" begins at approximately 900 years for A Farm, and approximately 700 years for AX Farm, pipeline areas, respectively.

After 1,000 years, the tank release curves reach a plateau due to solubility decrease, resulting in large amounts of uranium precipitated within the residual waste. From 1,000 years and beyond, the release from the tanks is controlled by the solubility limit. Precipitated uranium in residual wastes combined with uranium retained in the grouted bases by strong sorption (Table 7-2) provides a constant source for release for over 10,000 years.

Figure 7-5a. Waste Management Area A-AX Uranium-238 Release Rates to Vadose Zone (linear time scale).

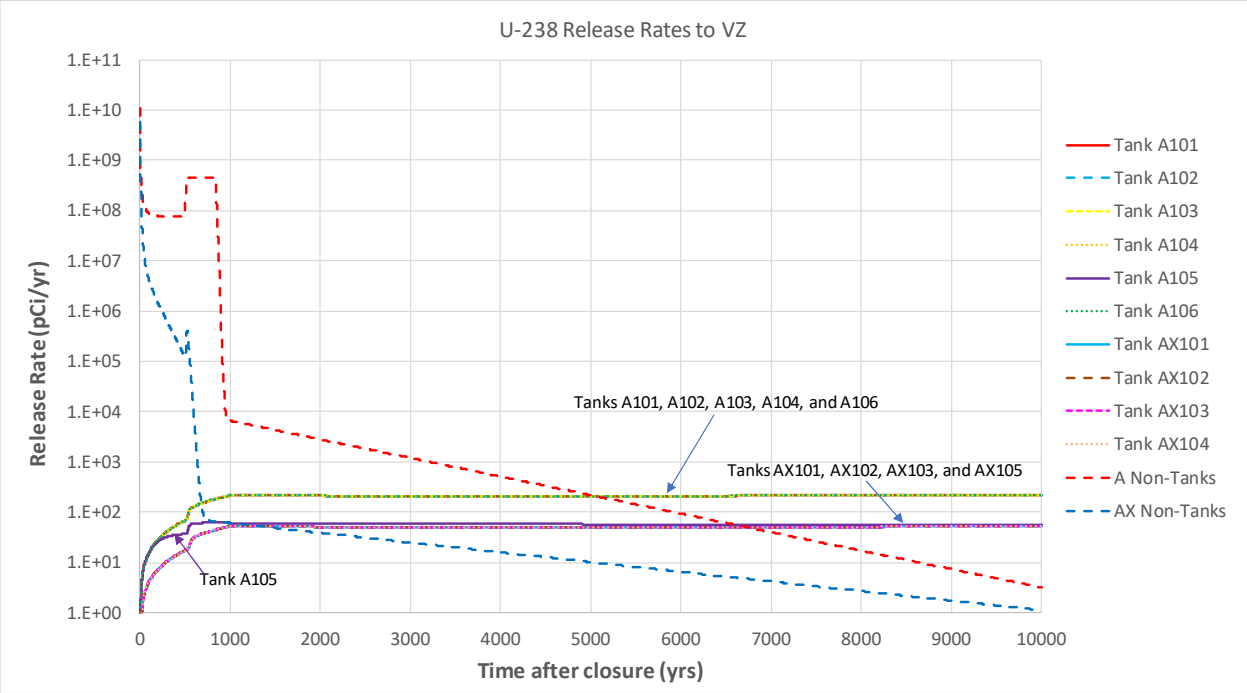
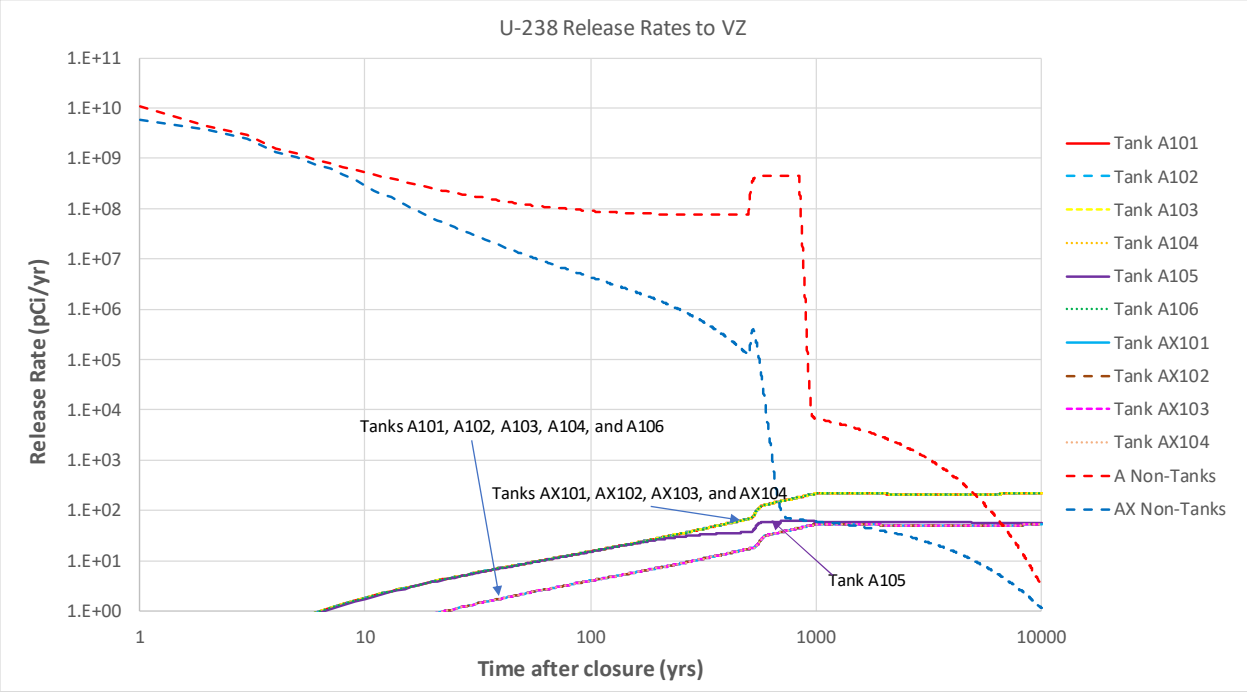


Figure 7-5b. Waste Management Area A-AX Uranium-238 Release Rates to Vadose Zone (logarithmic time scale).

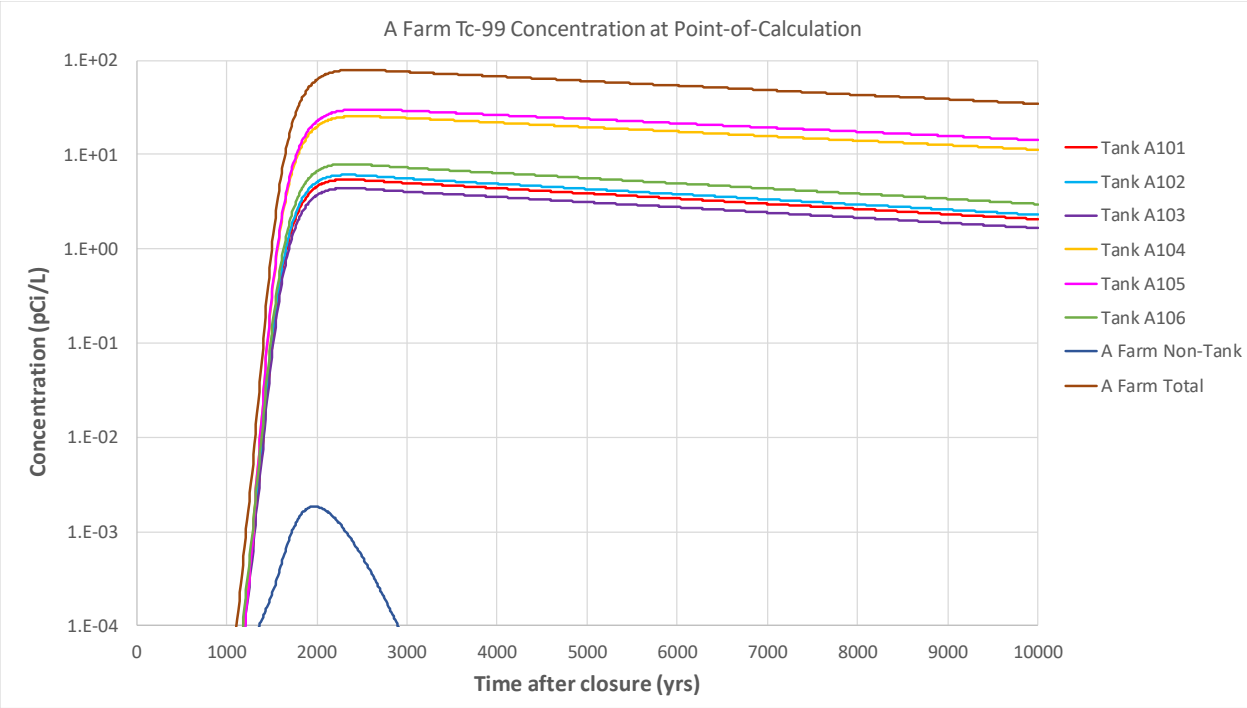


7.1.2 Concentrations

This section presents the groundwater concentration results at the 100-m regulatory boundary from A Farm and AX Farm. For each farm, the concentrations for ^{99}Tc, ^{129}I, and ^{238}U will be presented. The total concentration for each farm and each radionuclide will also be presented.

7.1.2.1 Technetium-99. Figures 7-6 and 7-7 show ^{99}Tc concentrations in A Farm and AX Farm, respectively. In A Farm, the primary contributors to the total concentration are tanks A-105 and A-104, consistent with the release rates (Figure 7-1). In AX Farm, the primary contributor to total concentration is tank 241-AX-104 (AX-104). The peak total concentrations and peak times for the two farms are summarized in Table 7-3.

Figure 7-6. Technetium-99 Groundwater Concentrations at 100 meters from the 241-A Tank Farm Fence Line.



7.1.2.2 Iodine-129. Groundwater concentrations of ^{129}I at the 100-m POC for A Farm and AX Farm are illustrated in Figures 7-8 and 7-9, respectively. In A Farm, the earliest contributors to total concentration are the pipeline release and tank A-104 at later times. Compared to ^{99}Tc, there is a significant delay in ^{129}I transport from the source to the 100-m regulatory boundary because of its higher sorption of ^{129}I, both in the cementitious tank material and within the different hydrostratigraphic units. The first arrival of ^{129}I in groundwater at the 100-m location adjacent to both A Farm and AX Farm occurs at approximately 4,600 years after tank closure. Table 7-4 lists VZ/SZ hydrostratigraphic unit K_d values associated with technetium, iodine, and uranium. The times of peak total VZ release rate and peak total concentration are summarized in Table 7-5.

Figure 7-7. Technetium-99 Groundwater Concentrations at 100 meters from the 241-AX Tank Farm Fence Line.

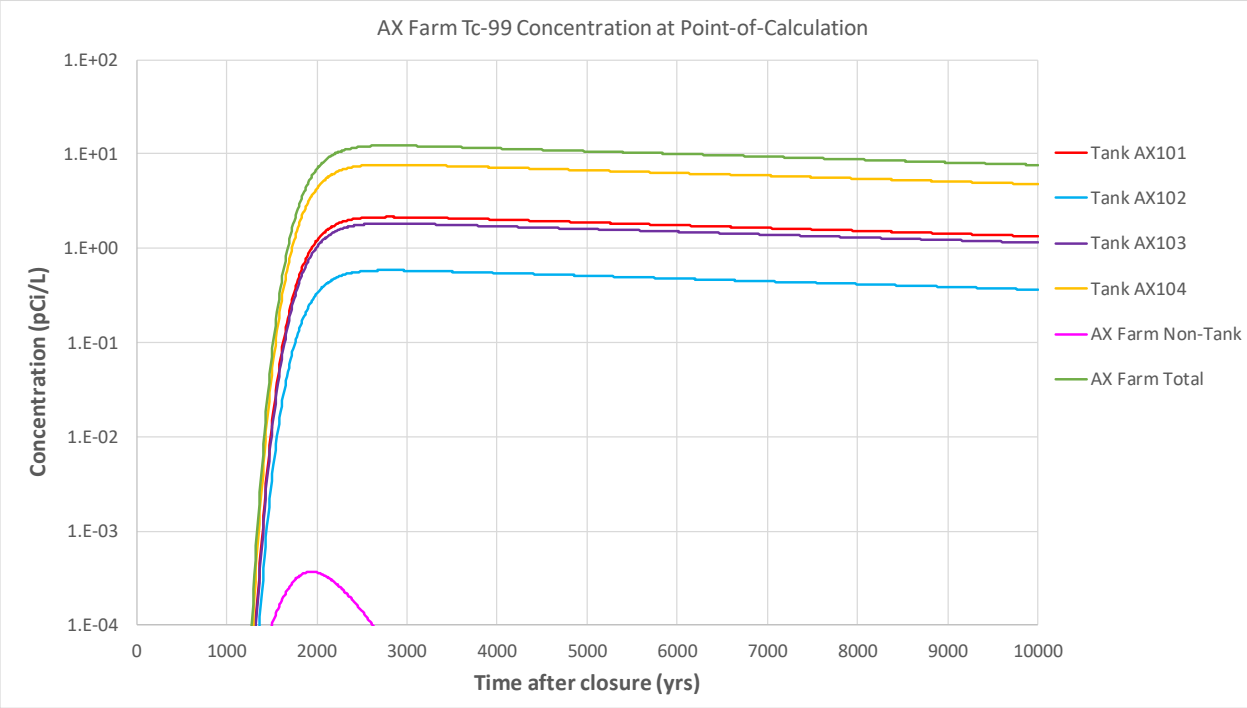


Table 7-3. Peak Total Concentration for Technetium-99 and Peak Times.

	241-A Tank Farm	241-AX Tank Farm
Peak concentration (pCi/L)	79.4	12.3
Peak times (years)	2,450	2,770

Table 7-5 summarizes peak total groundwater concentrations and the times of occurrence of each peak for the two farms. It shows that there is significant delay in ^{129}I arrival at the 100-m boundary. Recall that the maximum VZ release rate is associated with the pipeline area inventories, as explained in detail in Section 7.1.1.2. The majority of the ^{129}I mass, however, comes from the tanks, and this mass is more slowly released into the VZ. In addition to delay and dilution, VZ/SZ sorption (Table 7-5) further retards ^{129}I migration. In short, slow release, delay, dilution, and retardation all contribute to the late occurrence of peak total concentrations of ^{129}I.

Figure 7-8. Iodine-129 Concentration at 100 meters from the 241-A Tank Farm Fence Line.

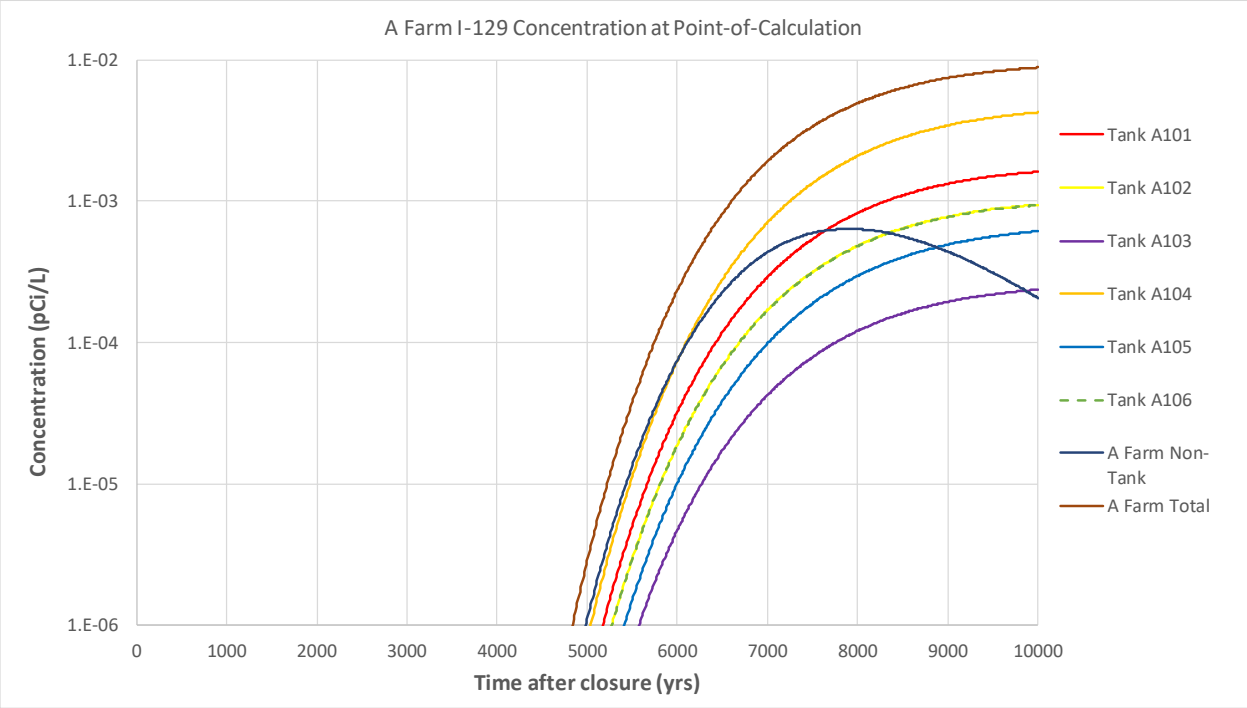


Figure 7-9. Iodine-129 Concentration at 100 meters from the 241-AX Tank Farm Fence Line.

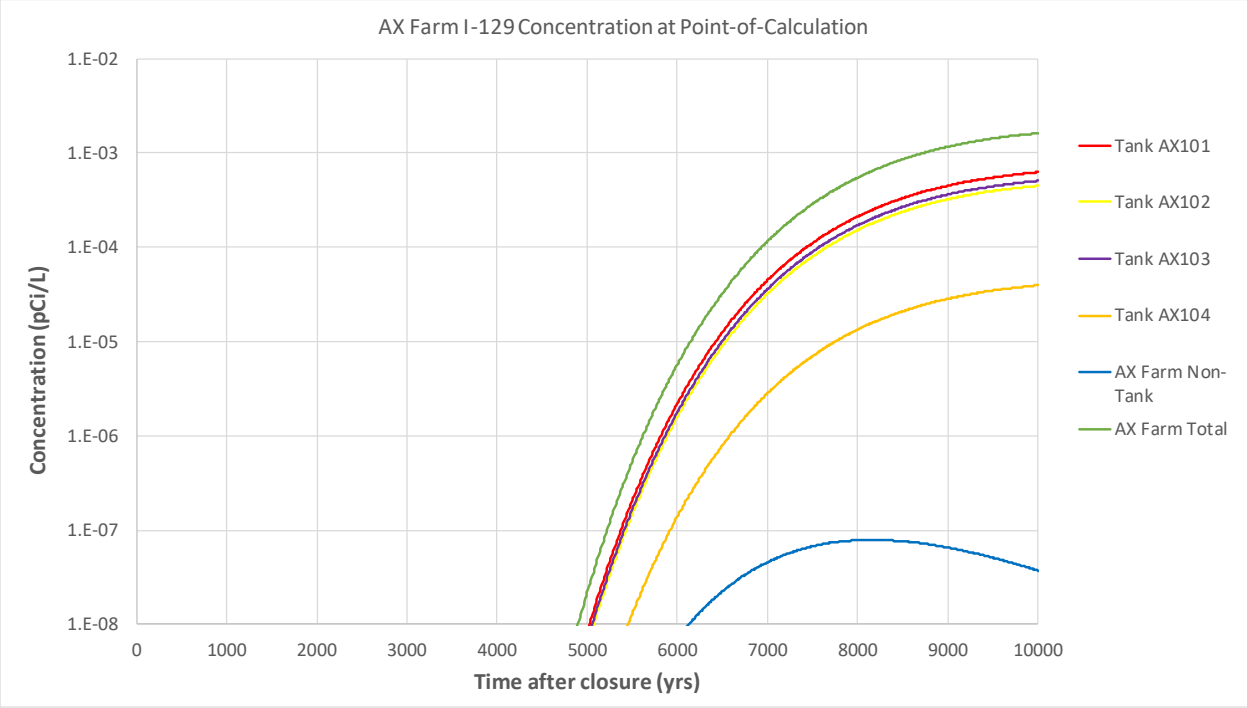


Table 7-4. K_d (mL/g) Values in Vadose Zone and Saturated Zone Units.

	H1 and H2	H3	CCUz	CCUg and SZ
Technetium	0	0	0	0
Iodine	0.19	0.068	0.2	0.068
Uranium	0.57	0.204	0.6	0.204

Table 7-5. Peak Iodine-129 Total Concentration and Peak Times.

	241-A Tank Farm	241-AX Tank Farm
Peak total concentrations (pCi/L)	8.8E-3	1.62E-3
Peak times (years)	10,000	10,000

7.1.2.3 Uranium-238. Groundwater concentrations of ^{238}U at the 100-m POC for A Farm and AX Farm are illustrated in Figures 7-10 and 7-11, respectively. The total groundwater concentrations are controlled by the pipeline sources because of the absence of solubility and sorption controls in the pipelines, and are reflected in the significantly earlier arrival of ^{238}U attributed to pipeline sources compared to the ^{238}U attributed to tank sources. Sorption in the VZ and SZ (Table 7-5) delays the uranium to the extent that the concentrations in both farms are still increasing by 10,000 years. The solubility limit in the source region plays a key role in reducing concentrations of ^{238}U released from tank sources.

7.1.3 Doses

This section will present the groundwater pathway dose results including annual doses contributed by different sources, by different analytes from the key sources, and by different exposure pathways from the key analytes released from the key sources. At the end of the section, peak doses and peak-dose times of each source will be summarized.

7.1.3.1 241-A Tank Farm Results.

7.1.3.1.1 Total and Individual Tank Doses. The contribution to annual doses from individual A Farm sources as well as the A Farm total dose are shown in Figure 7-12. The primary contributing sources to total dose are tanks A-105 and A-104. The behavior over time of all A Farm tanks has the same general pattern as that of ^{99}Tc concentrations shown in Figure 7-6. This is because ^{99}Tc dominates the total dose. This observation can be verified by plotting histories of the annual doses of different analytes. This will be discussed in Section 7.1.3.1.2. The total dose peaks between 2,000 and 3,000 years and is driven by releases of ^{99}Tc from the tank sources. With reference to the non-tank sources illustrated in Figure 7-12, the earlier peak is attributed to ^{99}Tc while the later, broader peak is attributed to ^{129}I.

Figure 7-10. Uranium-238 Concentration at 100 meters from the 241-A Tank Farm Fence Line.

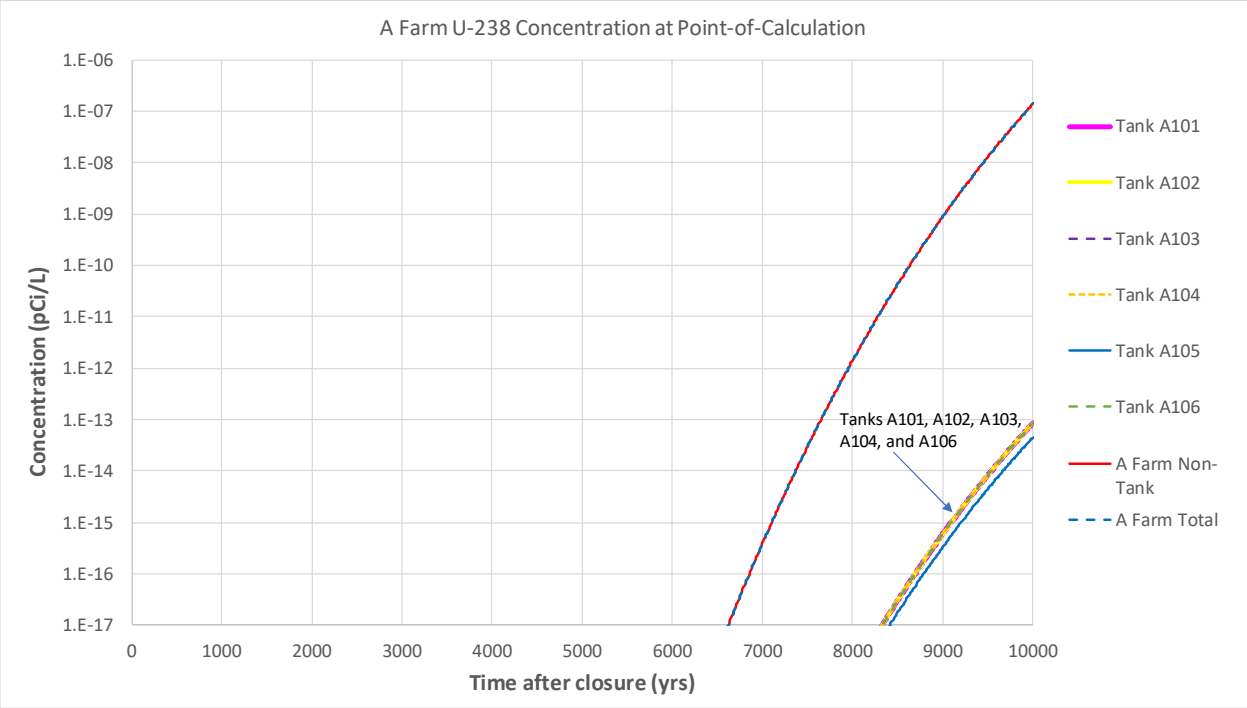


Figure 7-11. Uranium-238 Concentration at 100 meters from the 241-AX Tank Farm Fence Line.

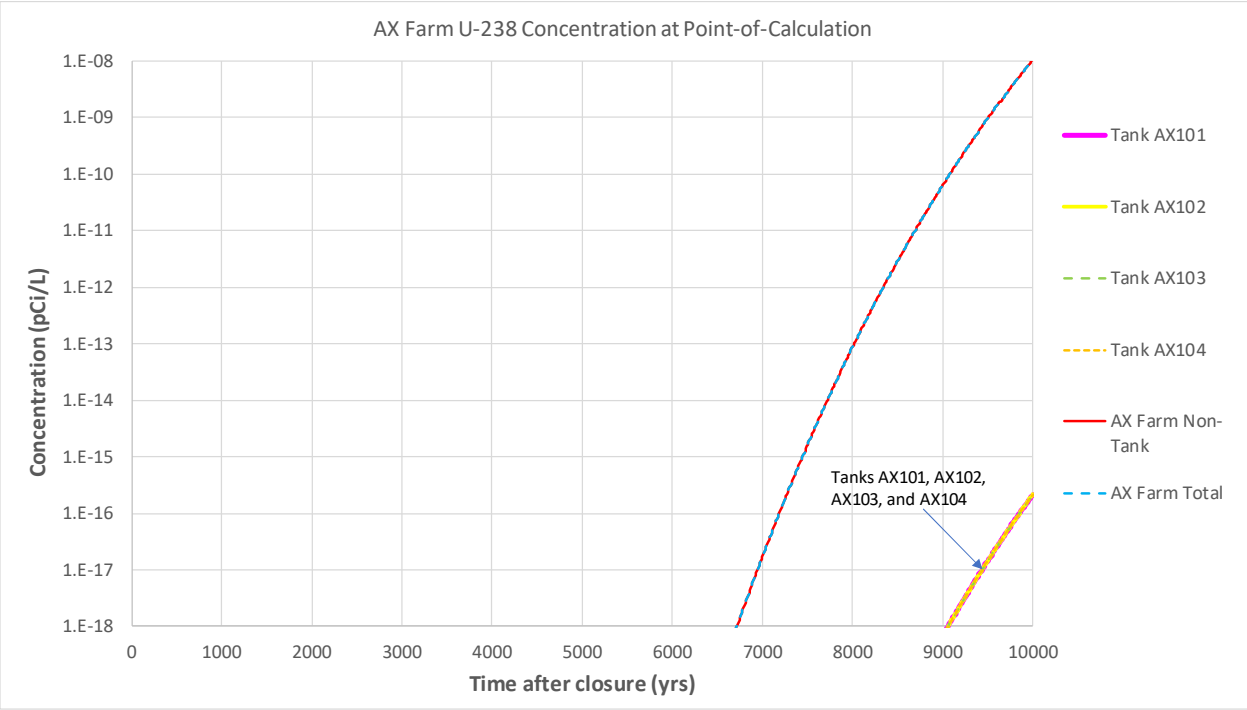
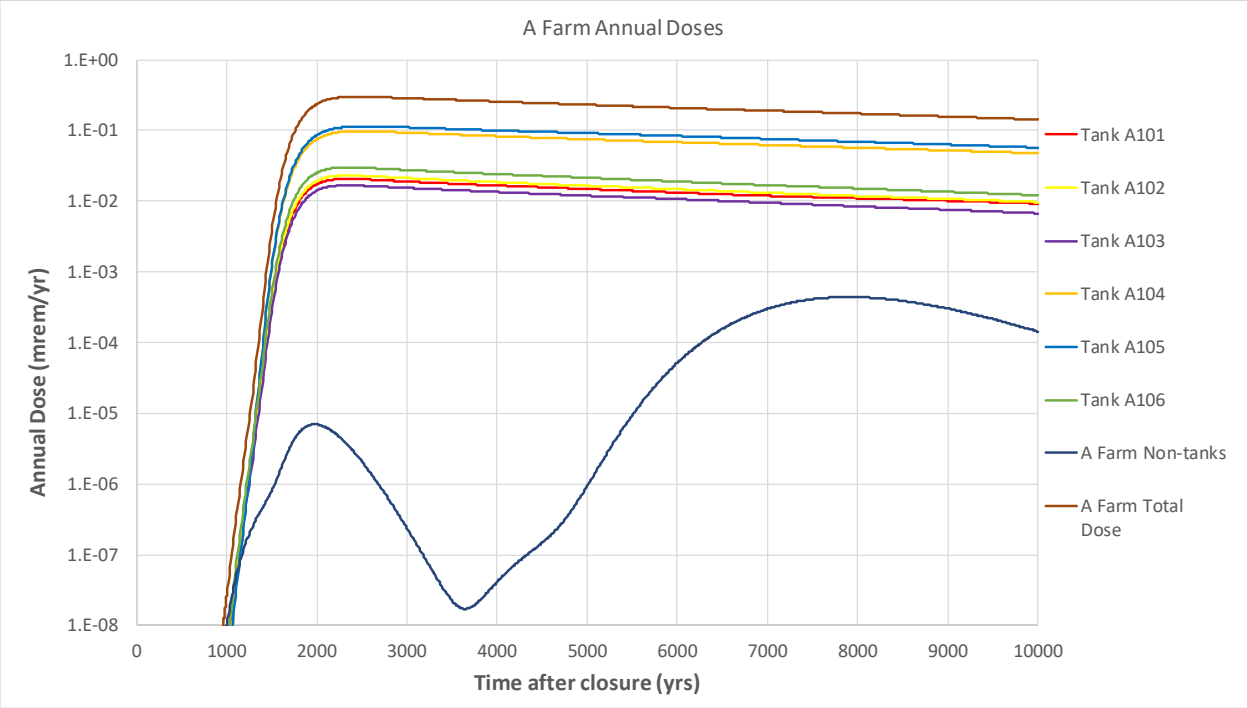


Figure 7-12. Annual Doses from the Different Sources and the Total Annual Dose of 241-A Tank Farm.



7.1.3.1.2 Dose by Analytes. The A Farm total annual doses attributed to the 10 top dose-contributing radionuclides are illustrated in Figure 7-13. As has been indicated earlier, ^{99}Tc is the top contributor followed by ^{79}Se and ^{129}I. Doses of all other analytes are significantly lower. The total dose line in this figure is coincident with the dose line attributed to ^{99}Tc. The contributions to dose from ^{79}Se and ^{129}I are more than an order of magnitude less than the contribution from ^{99}Tc over the 10,000-year period of evaluation.

Figure 7-14 displays the total dose and dose histories of releases from tank A-105, the tank with the highest dose. Only the top 10 dose contributor results are plotted. However, the figure only shows the results of ^{99}Tc, ^{79}Se, ^{129}I, and ^{126}Sn. Doses of other radionuclides are less than 1×10^{-11} mrem/yr and are not shown. This means that tank A-105 is not the main dose source for the uranium isotopes shown in Figure 7-13. Instead, the pipeline/ancillary equipment is the main dose source for uranium isotopes as shown in Figure 7-5 and the next figure.

Figure 7-15 displays histories of the total dose, ^{99}Tc, ^{129}I, ^{79}Se, and uranium isotope doses in the A Farm pipeline area. It verifies that the early peak of the pipeline dose is produced by ^{99}Tc and the later one is by ^{129}I. Iodine-129 migrates slower than ^{99}Tc due to sorption and hence reaches its peak dose at later time than ^{99}Tc. The ^{79}Se dose occurs at an intermediate time between the ^{99}Tc and ^{129}I peaks. Doses from uranium isotopes occur much later, and have not reached their peak within 10,000 years.

Figure 7-13. 241-A Tank Farm Total Annual Doses by Analytes.

Figure 7-14. Tank 241-A-105 Annual Doses by Analytes.

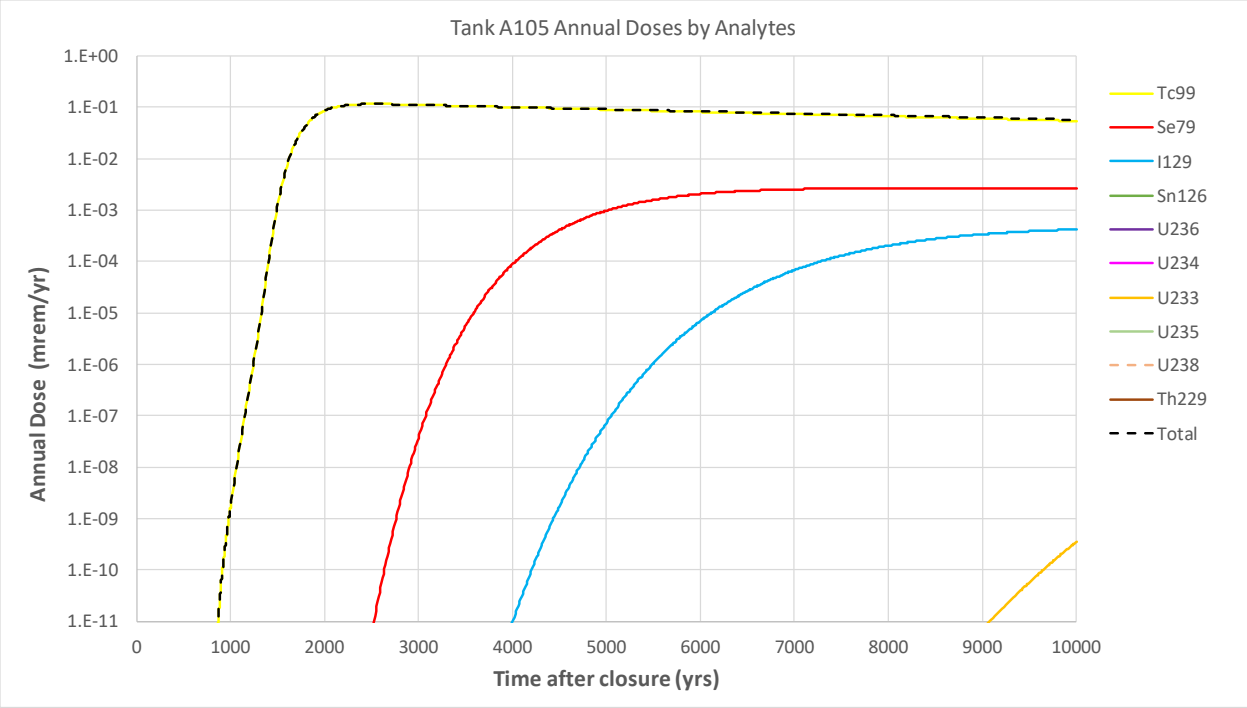
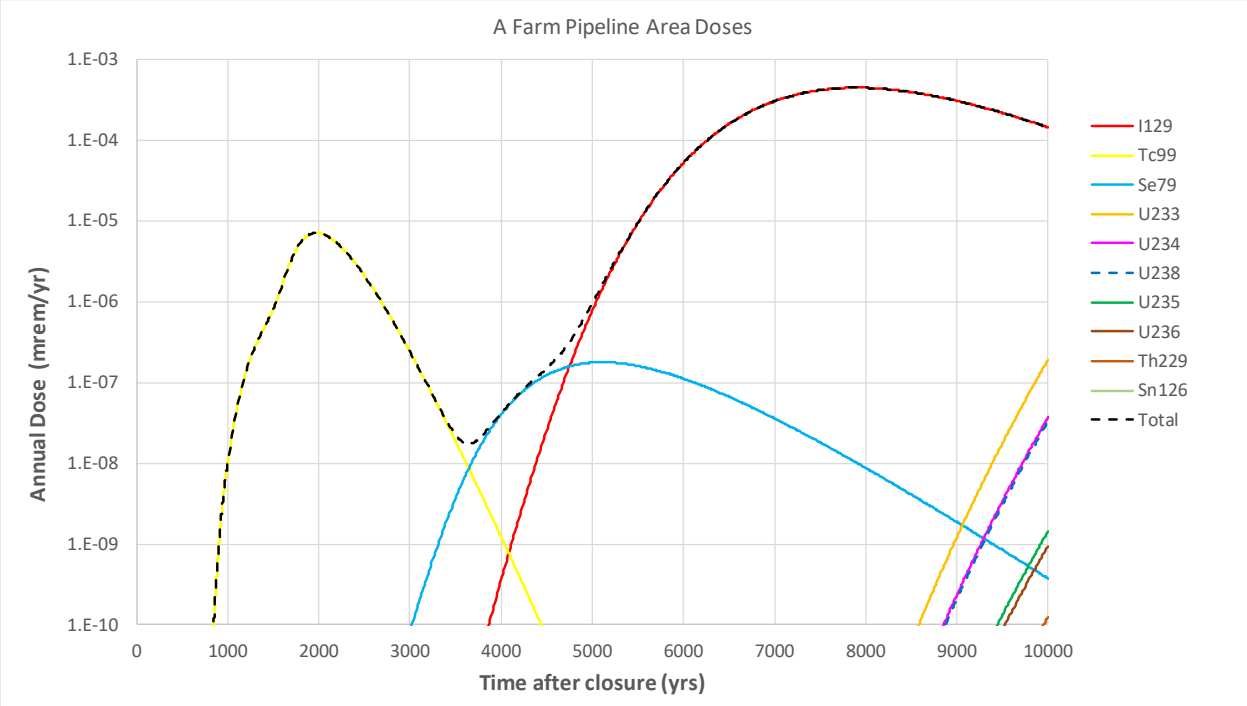


Figure 7-15. 241-A Tank Farm Pipeline Area Doses by Analytes.



7.1.3.2 241-AX Tank Farm Results.

7.1.3.2.1 Total and Individual Tank Doses. Annual doses at the 100-m regulatory boundary from different AX Farm sources are shown in Figure 7-16. The total annual dose from all contributing AX Farm sources is also shown. The primary dose-contributing source is tank AX-104. The change in dose over time for all AX Farm tanks has the same pattern as that of ^{99}Tc concentrations shown in Figure 7-7, since ^{99}Tc is the dominating contributor to the total dose. The AX Farm pipelines are the highest early doses, as a result of their faster release, but the peak dose from pipeline/ancillary equipment is insignificant compared to the peak does from tanks.

7.1.3.2.2 Doses by Analytes. Figure 7-17 displays dose histories of different radionuclides released from AX Farm. Only the top 10 dose contributor results are plotted. Only the results of ^{99}Tc, ^{79}Se, ^{129}I, ^{233}U, ^{234}U, ^{238}U, ^{235}U and ^{236}U can be observed in the plotted scale. Doses of other radionuclides are lower than 1×10^{-11} mrem/yr.

Figure 7-18 displays the total dose and dose histories of different radionuclides released from tank AX-104, the tank with the highest dose for AX Farm. Only the dose results of ^{99}Tc, ^{79}Se, and ^{129}I can be seen. Doses of all other analytes from tank AX-104 are significantly lower.

Figure 7-19 shows the total dose and doses of ^{99}Tc, ^{129}I, ^{79}Se, and uranium isotopes released from the AX Farm pipeline area. The total dose is controlled by ^{99}Tc at early times, by ^{79}Se during 4,000 to 6,000 years, and by ^{129}I after 6,000 years. Doses from uranium isotopes occur much later and have not yet peaked within 10,000 years.

Figure 7-16. Annual Doses from the Different Sources and the Total Annual Dose of 241-AX Tank Farm.

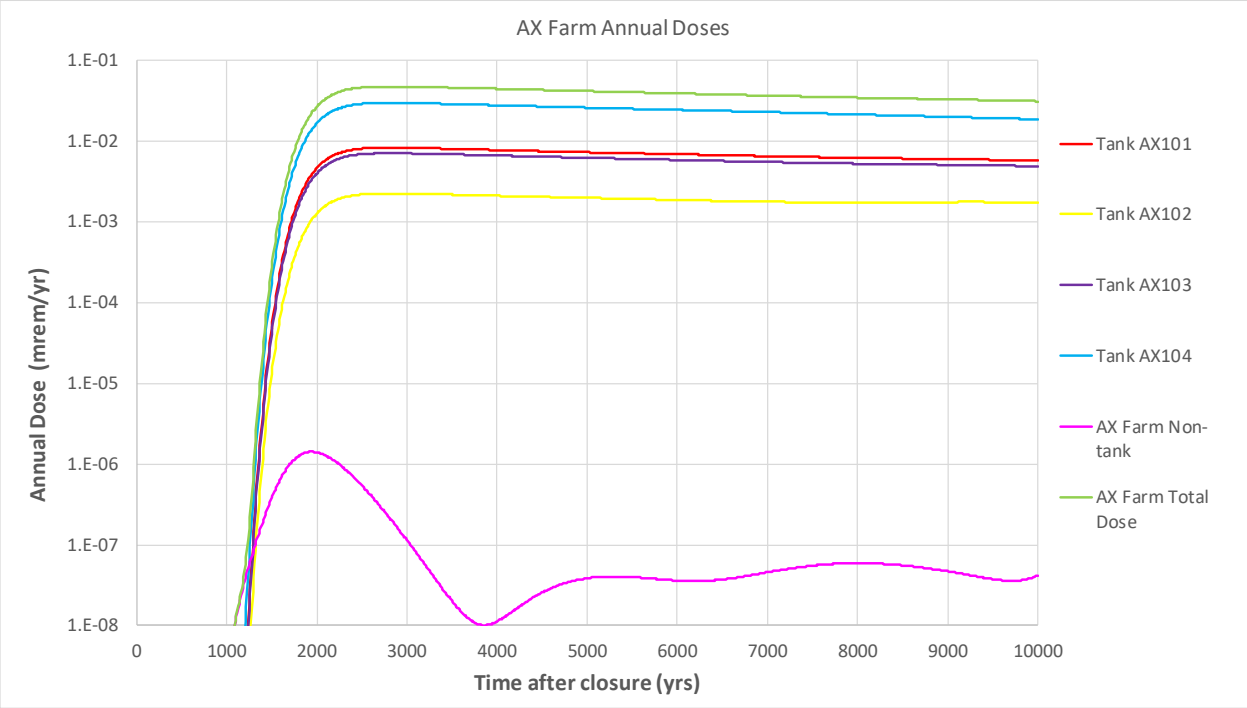


Figure 7-17. 241-AX Tank Farm Total Annual Doses by Analytes.

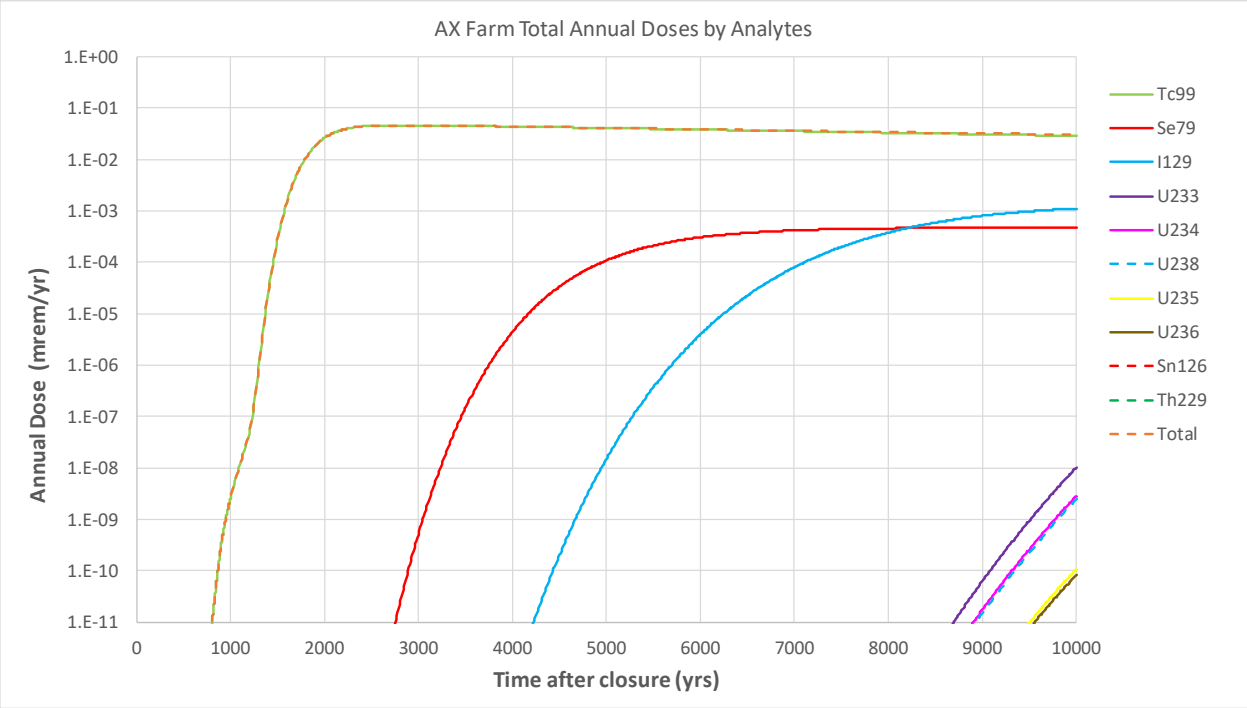


Figure 7-18. Tank 241-AX-104 Annual Doses by Analytes.

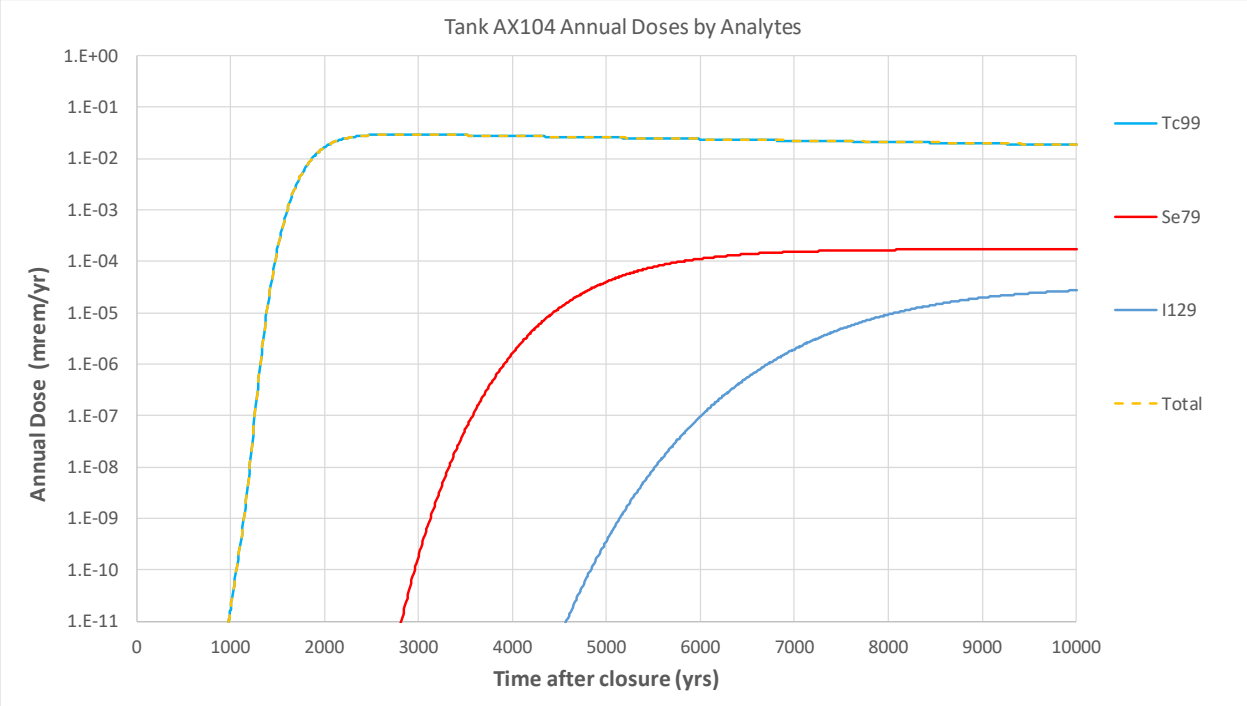
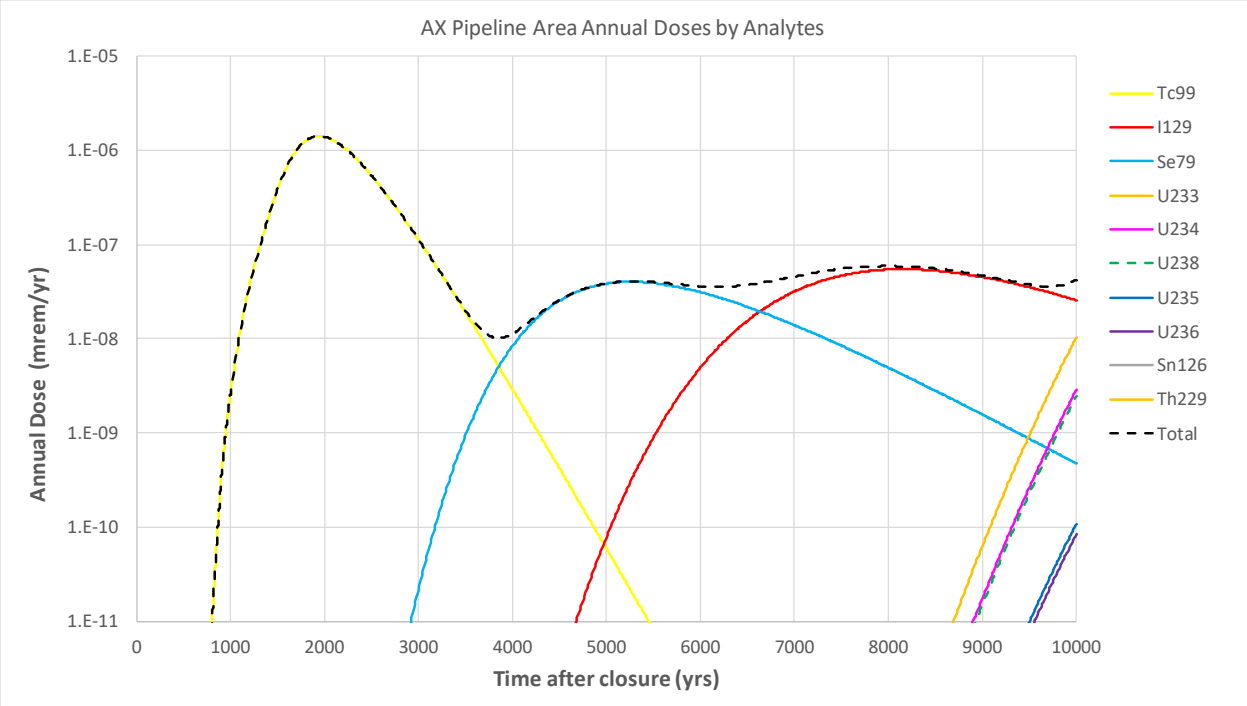


Figure 7-19. 241-AX Tank Farm Pipeline Area Annual Doses by Analytes.



7.1.3.3 Doses by Exposure Pathways. As demonstrated in the previous sections, the total dose is dominated by tank A-105 in A Farm and by tank AX-104 in AX Farm. For both tanks, the total dose is controlled by ^{99}Tc. The total dose of a radionuclide is the sum of doses of all exposure pathways; the doses by pathways of ^{99}Tc and ^{129}I released from tank A-105 are plotted in Figures 7-20 and 7-21.

Figure 7-20. Tank 241-A-105 Technetium-99 Doses by Exposure Pathways.

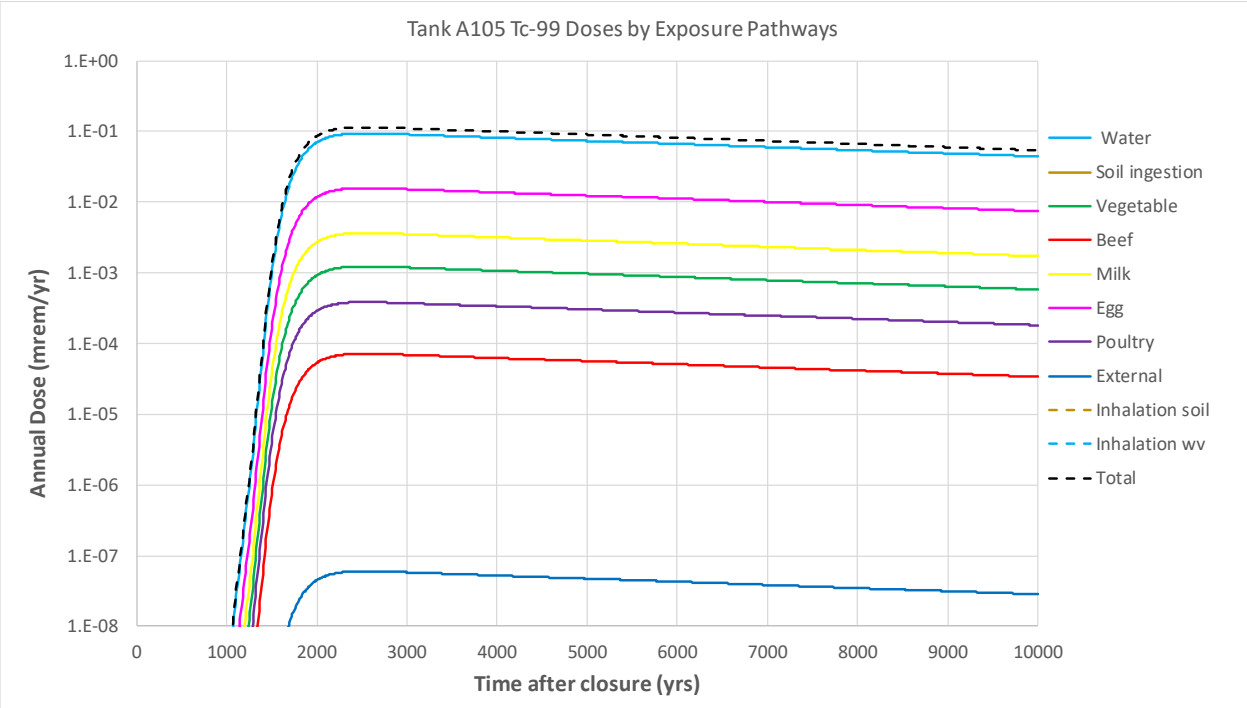
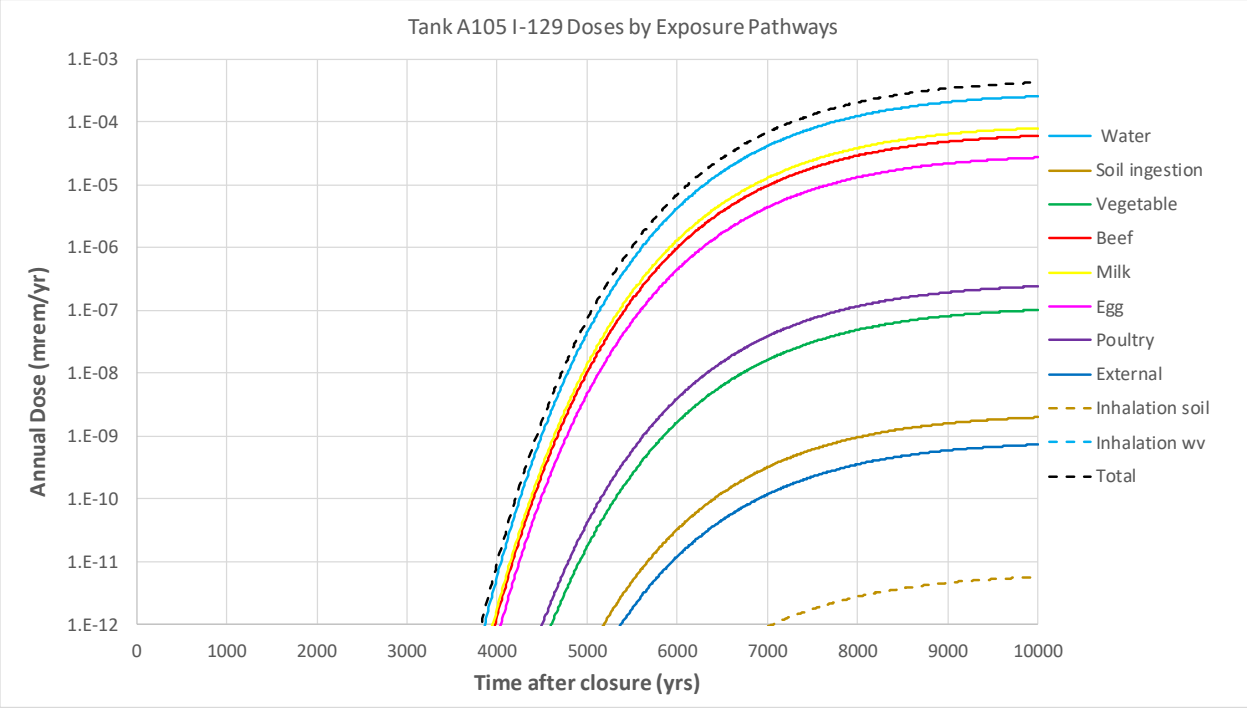


Figure 7-20 illustrates that the total ^{99}Tc dose is dominated by drinking water. Consumption of eggs, milk, and vegetables contribute substantially lower fractions of the total dose. Technetium-99 is not sorbed in soil and hence presents no dose in inadvertent ingestion of soil and inhalation of soil dust. Technetium-99 is not volatile, which means no dose from inhalation of water vapor for ^{99}Tc.

As illustrated in Figure 7-21, for ^{129}I, drinking water is the most important pathway, followed by consumption of milk, beef, and egg. There is a non-zero but trivial dose due to inadvertent ingestion of soil particles. There is no dose due to inhalation of water vapor because dissolved ^{129}I in water is not considered as volatile.

Figure 7-21. Tank 241-A-105 Iodine-129 Doses by Exposure Pathways.



7.1.3.4 Summary of Peak Dose Results. The peak doses and times of occurrence of the peak dose are displayed Figures 7-22 and 7-23. The peak dose downstream of A Farm is 0.3 mrem/yr, nearly two orders of magnitude lower than the performance objective (25 mrem/yr). At AX Farm, the peak dose is about 0.05 mrem/yr, nearly three orders of magnitude lower than the performance objective. All peak doses occur between 2,000 and 3,000 years except for the A Farm pipelines, where the peak dose is observed to occur at 7,900 years. For the A Farm pipelines, the peak dose is caused by ^{129}I (Figure 7-15) and is insignificant compared to other sources.

7.2 CONCLUSIONS

The Base Case calculation of the WMA A-AX system model was developed using nominal parameter values. The results indicate that both A Farm and AX Farm meet the performance objectives with a substantial margin. There is essentially no dose within the 1,000-year performance period. Within 10,000 years, the peak annual doses are 0.3 mrem/yr for the A Farm and 0.05 mrem/yr for the AX Farm 100-m regulatory boundaries.

Figure 7-22. Peak Dose Results.

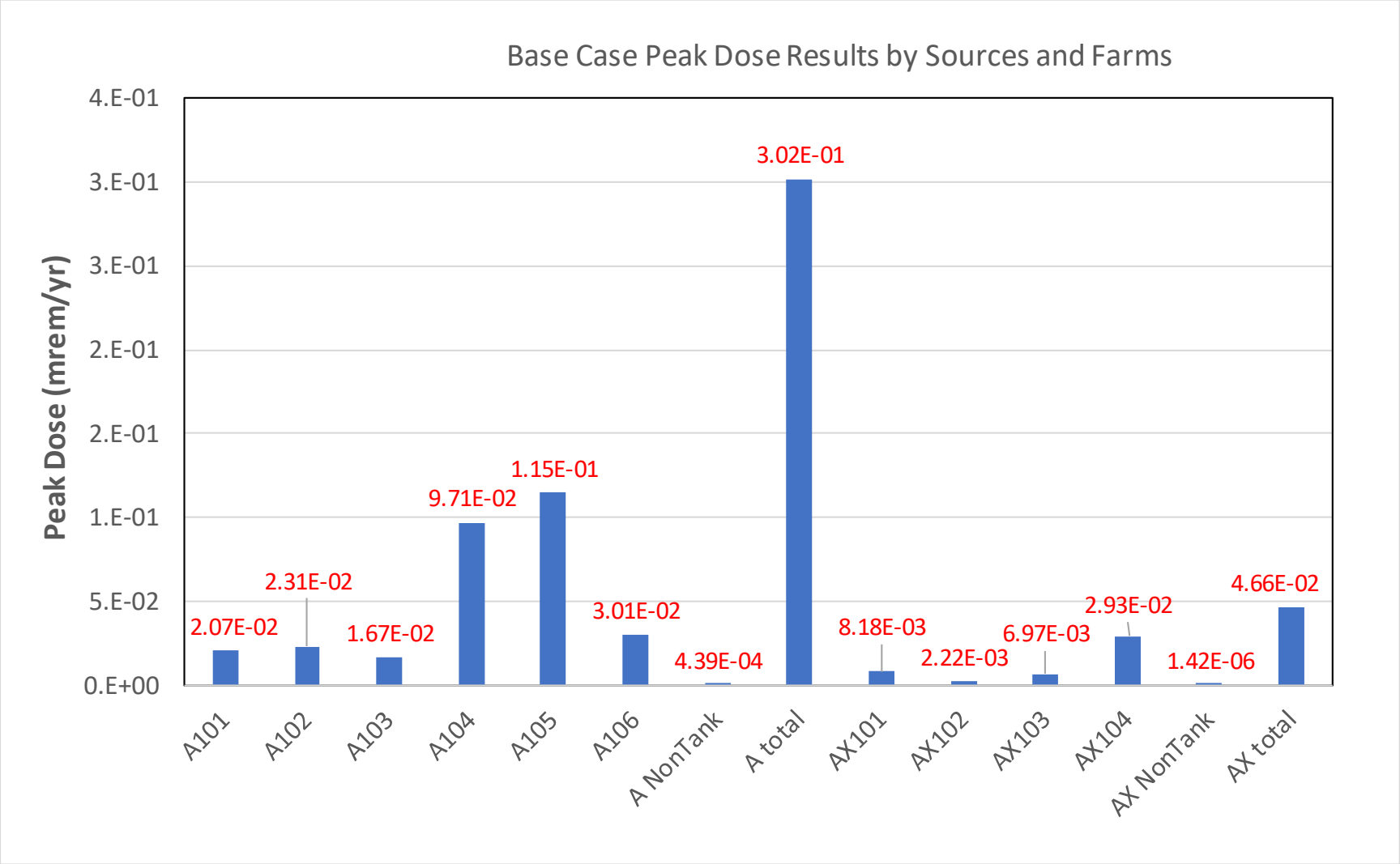
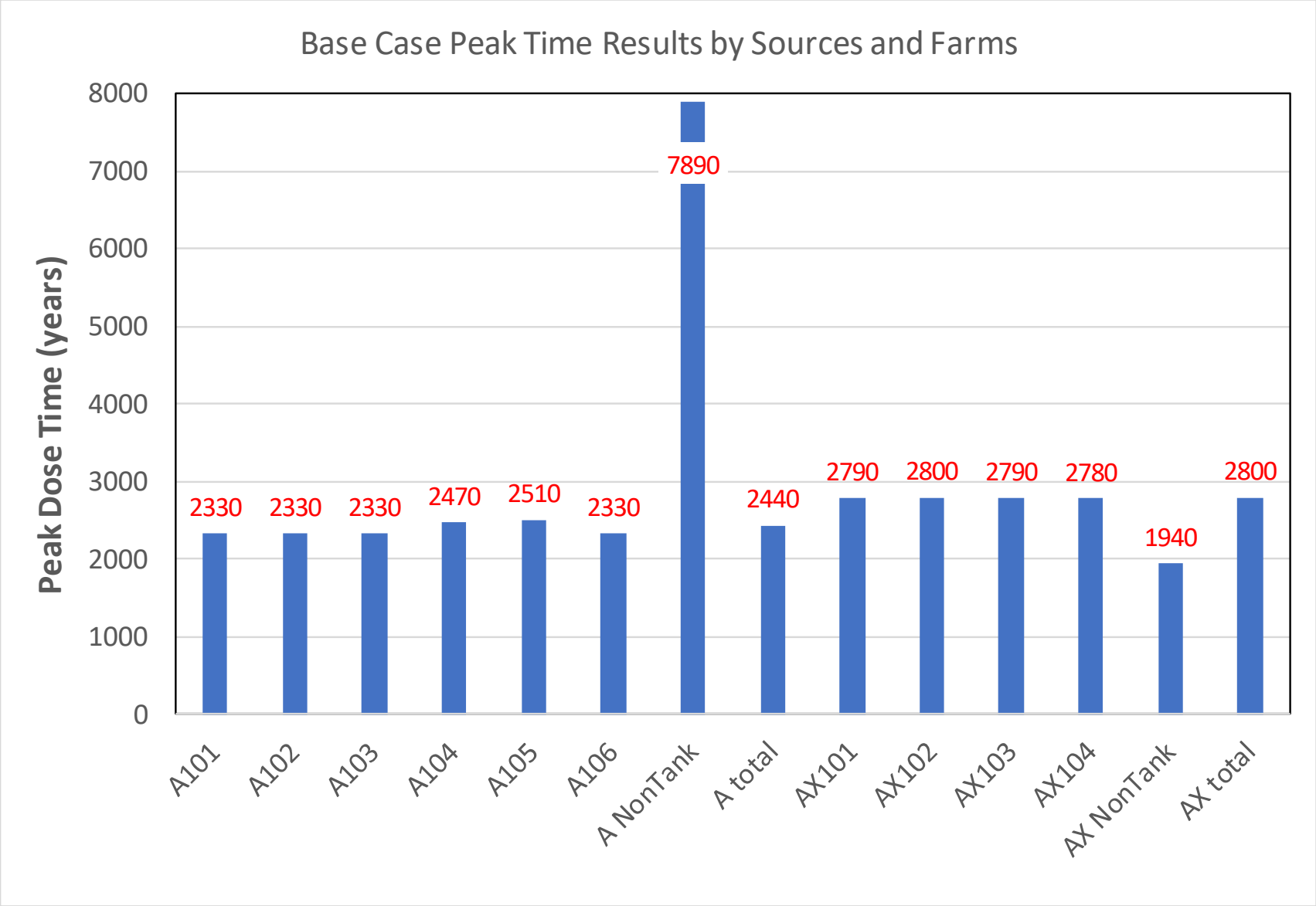


Figure 7-23. Peak Dose Time Results.



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Safe Drinking Water Act of 1974, 42 USC 300, et seq.

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TFC-PLN-155, "General Project Plan for Environmental Modeling", Washington River Protection Solutions, LLC, Richland, Washington.

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 Software Version No.: 12.0

EXECUTABLE INFORMATION:

2. Executable Name [redacted] GoldSim.exe
3. Executable Size (bytes): 2,836 kB

COMPILATION INFORMATION:

4. Hardware System (i.e., property number or ID):
   Compiled by vendor
5. Operating System (include version number):
   Windows 10

INSTALLATION AND CHECKOUT INFORMATION:

6. Hardware System (i.e., property number or ID):
   Lenovo YOGA 900-131SK2 Signature Edition SN: PFOGS02H
7. Operating System (include version number):
   Window 10
8. Open Problem Report? (●) No ( ) Yes PR/CR No.

TEST CASE INFORMATION:

[redacted]

10. Procedure(s):
    per CHPRC-00224 Rev 1, GoldSim Pro Software Test Plan
11. Libraries:
    N/A
12. Input Files:
    FirstModel.gsm
13. Output Files:
    FirstModel.gsm
14. Test Cases:
    GS-ITC-1
15. Test Case Results:
    Match expected results as presented in CHPRC-00224, GoldSim Pro Software Test Plan
16. Test Performed By: Wei Zhou
17. Test Results: (●) Satisfactory, Accepted for Use ( ) Unsatisfactory
18. Disposition (include HISI update): ADDED TO HISI ENTRY [signature]

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CHPRC SOFTWARE INSTALLATION AND CHECKOUT FORM (continued)

1. Software Name: GoldSim Pro Software Version No.: 12.0

Prepared By:

19. _____ Software Owner (Signature) | WE Nichols Print | 12 APR 2018 Date

20. Test Personnel:

_____ Sign | Wei Zhou Print | 4/12/2018 Date

_____ Sign | _____ Print | _____ Date

_____ Sign | _____ Print | _____ Date

Approved By:

21. _____ Software SME (Signature) | N/R per SMP Print | _____ Date