DOCUMENT RELEASE AND CHANGE FORM

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DATE: Jul 01, 2020 HANFORD RELEASE

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WMA A-AX Performance Assessment Radon and Atmospheric Pathway Dose Calculation

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Document Control Approval	Alvarez, Efren	*Alvarez, Efren*	07/01/2020
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Quality Assurance	Lungu, Cris C	*Lungu, Cris C*	06/13/2019
Responsible Manager	Rutland, Paul L	*Rutland, Paul L*	08/15/2019

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

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Comments Required for WRPS-Indicate Purpose of Document:

This document provides the basis for evaluation and review of the atmospheric pathway and radon flux calculations conducted as part of the WMA A-AX performance assessment (PA) 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 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 last month so finalization of this report is now moving forward.

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RPP-CALC-62540
Revision 0

WMA A-AX Performance Assessment Radon and Atmospheric Pathway 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: 04/18/2019

Calculation Title and Description: WMA A-AX Performance Assessment Radon and Atmospheric Pathway Dose Calculation

SECTION 2: COMPLETED BY PREPARER

Calculation No.: RPP-CALC-62540 Revision No.: 0

Revision History

Revision No.	Description	Date	ADD ROW Affected Pages
Rev. 0	Initial issue	04/18/2019	D

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Training Coordinator:

Print First and Last Name	Position	Signature	Date
Marcel P. Bergeron	Principal Scientist		4/29/2019

Software Installation and Checkout Certified:

Integration Lead:

Print First and Last Name	Position	Signature	Date
WIlliam E. Nichols	CHPRC Modeling Team Ldr	WILLIAM NICHOLS (Affiliate) Digitally signed by WILLIAM NICHOLS (Affiliate) Date: 2019.04.29 11:14:11 -07'00'	

SECTION 5: DOCUMENT REVIEW AND APPROVAL

Preparer:

Print First and Last Name	Position	Signature	Date
David J. Watson	Scientist		4/29/2019

Checker:

Print First and Last Name	Position	Signature	Date
K. Pat Lee	Senior Scientist		5/29/19

Senior Reviewer:

Print First and Last Name	Position	Signature	Date
Matt Kozak	Principal Engineer		5-7-19

Responsible Manager or Designee:

Print First and Last Name	Position	Signature	Date
Bob Hiergesell	Senior Scientist		5/29/19

CHECKER LOG FOR SYSTEM MODELS

Project and Environmental Model Calculation Specific Information:

Project: WMA A/AX Performance Assessment

Responsible Manager or Designee, and Position: Bob Hiergesell

Originating Group or Department: Closure and Interim Measures | Date: 5/20/2019

Environmental Model Calculation File Report and Revision No.: RPP-CALC-62540 Rev. 0

Environmental Model Calculation File Title: WMA A-AX PA Radon and Atmospheric Pathway Dose Calc

Check: Environmental Model Calculation File Document Elements

	List where Information is Described *(EMCF Section Number)*	Is the Description Correct and Sufficient? Yes	No	If No, describe deficiency:	Checker Signature
Purpose	Section 1.0	◉	○		
Calculation Approach	Section 3.0	◉	○		
Assumptions	Section 4.1	◉	○		
Inputs *(reference detailed checklist below as well)*	Section 4.2	◉	○		
Equations used	Section 3.0	◉	○		
Conclusions	Section 7.2	◉	○		
References	Section 8.0	◉	○		

Check: Controlled Software Use

	List where Information is Described *(EMCF Section Number)*	Is the Criteria Met? Yes	No	If No, describe deficiency:	Checker Signature
Software used in the calculation is appropriate for application	Section 5.0	◉	○		
Software use is approved and properly validated in accordance with approved software management plan	Section 5.0 Attachment 1	◉	○		
Software use is properly documented	Section 5.0	◉	○		
Verify data was input correctly to approved software or spreadsheets	Model inspection	◉	○		
If a spreadsheet is used, verify inputs/outputs of calculation(s) to ensure accuracy	NA, spreadsheet only for plotting graphics.	◉	○		

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	Replication from starting file, different approach, same result.	None	

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	Y, throughout	Yes	Yes
Simulation time step control	No - same as MPR	Yes	Yes
Simulated chemical list	No - radionuclide analysis only	Not Applicable	Not Applicable
Simulated radionuclides list	Y, throughout	Yes	Yes
External model components identified and documented or referenced	Not Applicable - no external components not previously developed by MPR	Not Applicable	Not Applicable
External model linkages *(dynamic link libraries, etc.)* checked	Not Applicable - no external linkages to model file	Not Applicable	Not Applicable
If model is probabilistic, stochastic distributions are defined and consistent	Not Applicable - deterministic with sensitivity	Not Applicable	Not Applicable
Input units are declared and of correct dimensionality	Yes same as MPR unless changed for this analysis	Yes (changes only)	Yes (changes only)
Equations used in the model file are presented in EMCF and consistent	Not Applicable - this documentation is in MPR	Not Applicable	Not Applicable

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?	Inventory basis reviewed, confirmed no changes to MPR for main case.	Yes - initial inventories checked against sources	Yes - checked for all decay chains that include radon-222.
Inventory: Mass Balance. Is mass balance of inventory maintained in system model calculation(s)?	Inventory basis reviewed, confirmed no changes to model structure that impact mass balance review performed for MPR.	Mass balance confirmed in MPR. No mass balance analysis was performed for this sensitivity case because the changes made could not introduce mass balance losses or gains.	Not applicable
Independent verification of approach using alternative method to preclude downward flux yeilded same result.	Not Applicable	Not Applicable	Not Applicable

EXECUTIVE SUMMARY

This environmental model calculation file provides the basis for evaluation and review of the radon flux calculations conducted as part of the Waste Management Area A-AX performance assessment modeling. The results of the radon flux 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 objectives. 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]).

A screening calculation was performed (RPP-CALC-63180, *Calculation of Inhalation Doses from H-3, C-14 and I-129 Originating from Waste Management Area A-AX*) to estimate the dose to a receptor at the site boundary inhaling gaseous ^{3}H, ^{14}C and ^{129}I (the only volatile radionuclides considered for air pathway dose calculations). Despite the conservatism of the release assumptions of the calculation, the results showed that the dose to the receptor was several orders of magnitude lower than the performance objectives and are thus not considered in this environmental model calculation file. As a result of that screening calculation, the only remaining analysis of gaseous radionuclides needed in the performance assessment is the radon flux analysis, which is documented in this report.

This environmental model calculation file identifies the specific model parameters evaluated in the radon flux 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 radon flux 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."

The radon flux at the surface of Waste Management Area A-AX was calculated for each tank and the ancillary equipment (pipelines and other ancillary structures) in the facility from time of facility closure to 10,000 years post-closure. Sensitivity cases using alternate inventories were also evaluated. The 241-A Tank Farm ancillary equipment has the highest radon flux, both within the compliance period of 1,000 years and for the entire simulation duration. The peak radon flux from the 241-A Tank Farm ancillary equipment at 1,000 years post-closure is

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

1.8×10^{-3} pCi/m^2/sec and at 10,000 years post-closure is 7.3×10^{-2} pCi/m^2/sec. The tank with the highest radon flux at the surface is 241-A-102, with peak fluxes of 1.0×10^{-4} pCi/m^2/sec at the end of the compliance period and 3.5×10^{-3} pCi/m^2/sec at the end of the simulation. The highest flux among all the inventories evaluated is 8.1×10^{-2} pCi/m^2/sec from the 241-A Tank Farm ancillary equipment at 10,000 years post-closure using an inventory based on current, unretrieved Best Basis Inventory for tanks and ancillary equipment. Despite several conservative assumptions in the calculations, the peak flux at the facility surface remains substantially below the performance objective of 20 pCi/m^2/sec through the entire simulation.

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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
IAEA	International Atomic Energy Agency
ICRP	International Commission for Radiation Protection
MATLAB	matrix laboratory (software)
MPR	Model Package Report
PA	Performance Assessment
PUREX	Plutonium Uranium Extraction (Plant)
RESRAD	RESidual RADioactive
RT	Radionuclide Transport (module)
SST	Single-Shell Tank
STOMP	Subsurface Transport Over Multiple Phases
WMA	Waste Management Area
WRPS	Washington River Protection Solutions, LLC
WTP	Waste Treatment Plant

1.0 PURPOSE

The purpose of this environmental model calculation file (EMCF) is to document the radon flux calculations performed to support the Waste Management Area (WMA) A-AX performance assessment (PA). As described in RPP-RPT-60885, *Model Package Report System Model for the WMA A-AX Performance Assessment*, a screening calculation was performed (RPP-CALC-63180, *Calculation of Inhalation Doses from H-3, C-14 and I-129 Originating from Waste Management Area A-AX*) to estimate the dose to a receptor at the site boundary inhaling gaseous ^{3}H, ^{14}C and ^{129}I (the only volatile radionuclides considered for air pathway dose calculations). The calculation assumed the entire inventory from all sources in WMA A-AX was released from the ground surface over one year and available for atmospheric transport to the receptor, who was exposed over the course of the year. The results of the calculation showed that the dose to the receptor was several orders of magnitude lower than the performance measure and are thus not considered in this EMCF.

As a result of the screening calculation, this EMCF is limited to documenting the assumptions and methodology for calculating the radon flux at the facility surface with the year at which the maximum flux occurs. These calculations are performed as described in RPP-RPT-60885. 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.

1.1 OBJECTIVE

The objective of this EMCF is to present the results of deterministic assessments of radon flux from closed tanks and pipes at WMA A-AX. These flux 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-RPT-58293	*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	*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-63180	*Calculation of Inhalation Doses from H-3, C-14 and I-129 Originating from Waste Management Area A-AX*

1.2.4 Other Technical Reports

No other technical reports were used in the calculations.

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 radon flux calculations.

Attachment 3 contains the various parameters used in the radon flux calculations, their values, and the value sources.

1

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3

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.

2.1 HISTORY

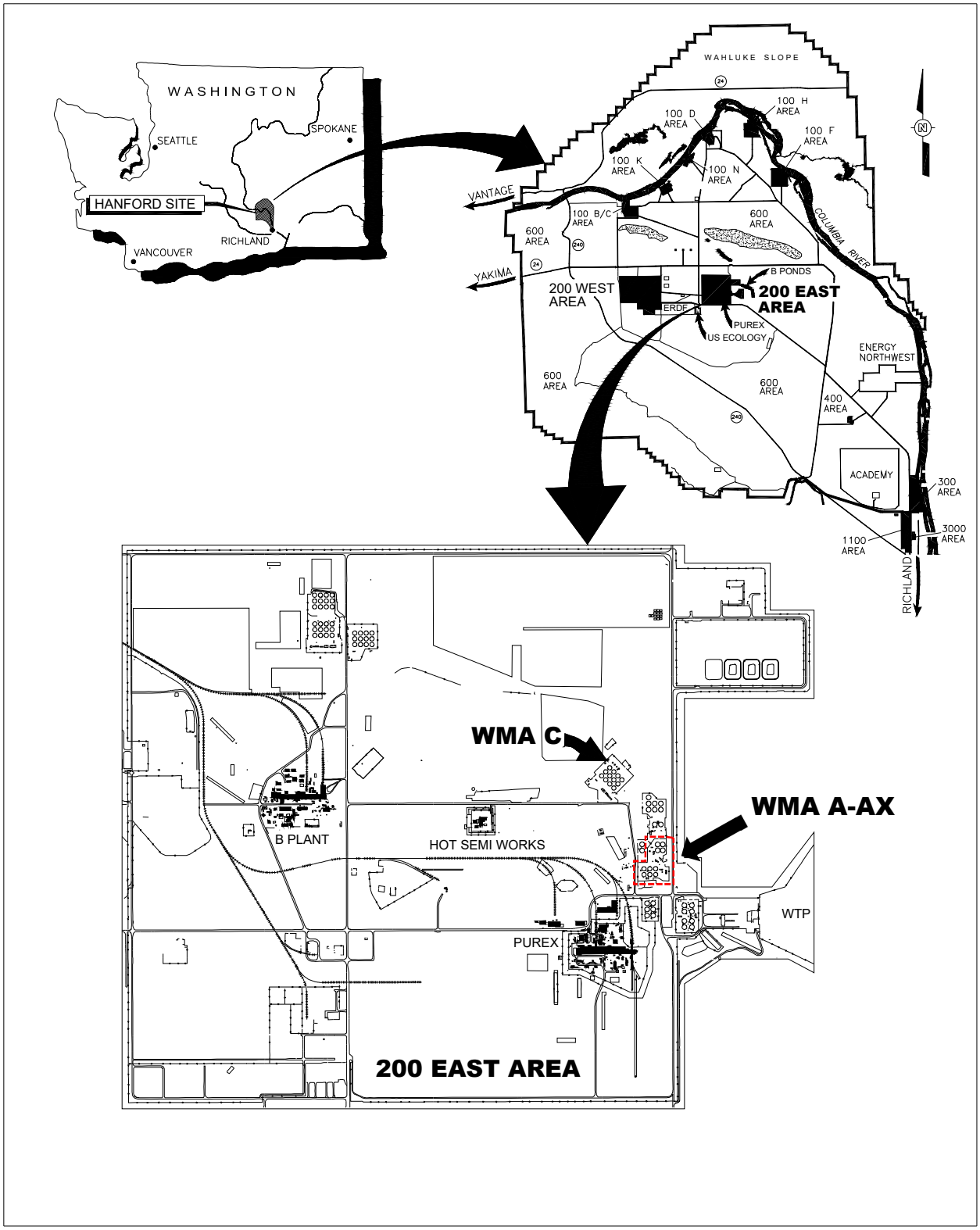
WMA A-AX comprises the 241-A and 241-AX Tank Farms and is located within the 200 East Area of the Central Plateau of the Hanford Site. The 241-A Tank Farm (A Farm) and 241-AX Tank Farm (AX Farm) were constructed between 1953 and 1955 and between 1963 and 1965, respectively. The WMA A-AX tank farms are 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 impacts to the groundwater from WMA A-AX sources 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 radon flux at the surface of the WMA A-AX facility from every source at any time from closure to 10,000 years post-closure.

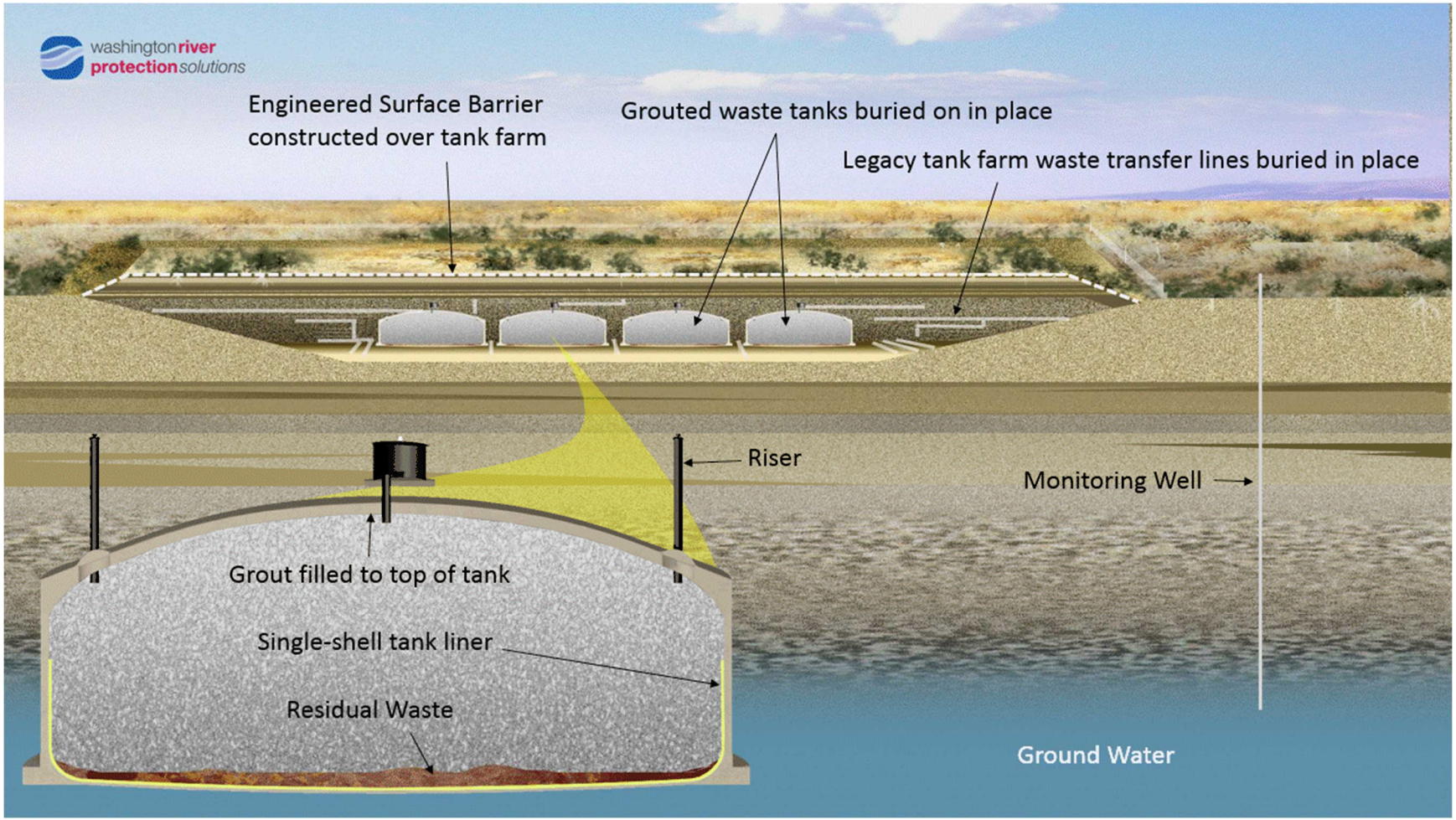
Figure 2-1. Location of Waste Management Area A-AX in Relation to Hanford Site.



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

Calculating radon flux over time from a closed facility is done using the GoldSim© Radionuclide Transport (RT) module because it allows calculation of both the decay and ingrowth of radionuclides and diffusion of gaseous radionuclides through different media (e.g., grout and soil backfill). The decay of uranium series radionuclides that produce ^{222}Rn are easily evaluated in the RT module in the GoldSim© simulation software. 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 allow each waste source to be represented by a discrete element within the model. GoldSim© is also designed to calculate diffusion through various media.

Using a tool specifically developed to support both diffusion and 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 of a data entry error affecting the radionuclide decay chain calculations.

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 prepare the calculation and associated calculation report.

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

M.S., 2009, Environmental Science, Washington State University
B.S., 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

[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.

external 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 (IAEA), 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.

Kearn Patrick (Pat) Lee (Orano Federal Services) Advisory Engineer
M.C.E., 1996, Civil and Environmental Engineering, University of Delaware
B.Ch.E., 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 developed and checked several models for the Hanford Site Integrated Disposal Facility PA. He has checked several other models for the WMA A-AX PA.

3.1.3 Senior Reviewer

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 27 years of experience in the areas of performance assessment of near-surface and geological radioactive waste repositories, regulatory development, dose

[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.

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 the 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 Section 3.4 of RPP-RPT-60885.

3.3 MATHEMATICAL MODEL

The equations used in the model are described in detail in Section 4.4 of RPP-RPT-60885.

3.4 CALCULATION PROCEDURE

The calculation procedure is described in detail in Section 4.4.4 of RPP-RPT-60885.

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4.0 ASSUMPTIONS AND INPUTS

RPP-RPT-60885 lists key assumptions and inputs for the radon flux calculations. Inventory-related assumptions are detailed in RPP-CALC-62319.

4.1 KEY ASSUMPTIONS

General assumptions related to radon flux calculation 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.
- WMA A-AX tanks are assumed to be filled with grout.
- Pipelines in WMA A-AX are not grouted and are 5% full of waste, evenly distributed throughout the pipeline.
- The 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.

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), and represent the current inventory in those tanks without further retrieval
- 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.

Assumptions specific to the calculation of radon generation and emanation include the following.

- All radon produced is conservatively assumed to be available for gaseous transport (an emanation factor of unity).

- The porosity and saturation of the infill grout are assumed to be fixed over time in the diffusive release calculations.

- For all grouted facilities, the air content within the infill grout is assumed to be 6% based on characterization information for possible Hanford grout formulations (WSRC-TR-2005-00195, *Summary of Grout Development and Testing for Single Shell Tank Closure at Hanford*).

- The air pathway calculations for a tank assume a 10-m thickness of the infill grout, which does not take credit for additional thickness in the dome space.

- Radionuclide vapor only diffuses vertically upward from the source zone. Lateral boundaries of this transport path are no-flux boundaries in the calculations, resulting in a larger mass flux at the land surface than what actually could occur.

- A surface barrier that will be emplaced at closure over the tank farm will provide additional depth to the waste and therefore greater diffusive length. This additional thickness is ignored.

4.2 INPUTS

Inputs for this calculation include residual waste inventories, and various parameters for calculating diffusion of gas through grout and soil. 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 Atmospheric Pathway 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*	2
Atmospheric Transport Parameters	Various; see table for details	3

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: Dell™ Optiplex™[11] 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 used by DOE to assist in performing simulation of radioactive mass conservation (including decay and ingrowth) and contamination mass transport in

[11] 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_radon.gsm" model file. This model file is reviewed and checked and will be archived in the Environmental Model Management Archive (EMMA) along with this EMCF and other supporting files.

6.1 DESCRIPTION OF MODEL CHANGES

This model file was created from the version-controlled "a_ax v1.0_20190408.gsm" model file described in RPP-RPT-60885, by decoupling liquid phase transport from the air pathway for each waste source element in the **Transport_A_Series_Tanks** and **Transport_AX_Series_Tanks** containers in the model. This was accomplished by deleting the **Residual_Waste** to **Grout_Base** outflow and diffusive flux in each **Residual_Waste** element in the model.

Sensitivity of the model to differences in inventory was examined by creating an additional model file from the "a_ax v1.0_20190408_radon.gsm" file and adding two different inventories using the GoldSim© Scenario Manager. The two added inventories were those created for RPP-CALC-63247, *WMA A-AX Performance Assessment Sensitivity Analysis*, cases INV1 (No action inventory based on current BBI volumes and inventory for tanks and ancillary equipment) and INV2 (Ancillary equipment estimate. Base case post-retrieval inventory and volumes for tanks. Average BBI composition and post-retrieval volumes for ancillary equipment).

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 files 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_20190408_radon.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 chart plotting the time-series of radon flux at the surface of the WMA for each waste source by year for the length of the compliance period.

7.0 RESULTS AND CONCLUSIONS

This section presents the results of the radon flux calculations for each of the waste sources at WMA A-AX. For purposes of comparison, the performance objective for ^{222}Rn is 20 $pCi/m^2/sec$ at the facility surface, as specified in DOE M 435.1-1, *Radioactive Waste Management Manual*.

7.1 RESULTS

Releases of radon from the WMA A-AX facility were evaluated and compared to the 20 $pCi/m^2/sec$ radon flux performance objective in DOE M 435.1-1. The inventory of ^{226}Ra (the parent of ^{222}Rn) in WMA A-AX residual waste is small, and initial radon fluxes are very low compared to the performance objectives. Ingrowth of ^{222}Rn from decay of the ^{238}U and ^{238}Pu decay chains lead to increasing radon fluxes at longer times. However, the fluxes remain many orders of magnitude below the performance objective at all times. The source of the peak flux at the facility, regardless of inventory used (e.g., base case, INV1 or INV2) is the A Farm ancillary equipment. Table 7-1 presents the peak radon flux from the A Farm ancillary equipment and corresponding total curies of inventory.

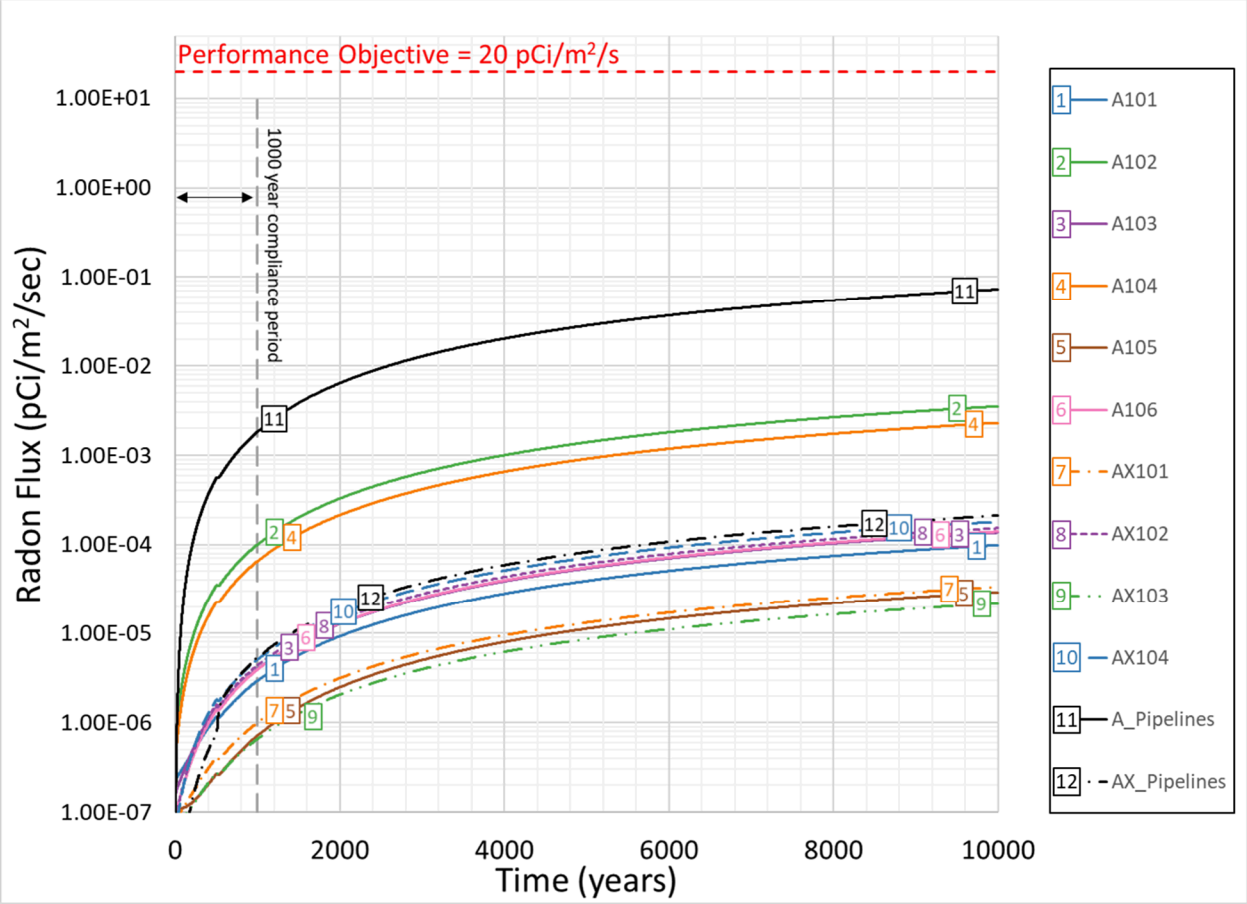
Table 7-1. Summary of Peak Radon Flux Analyses from 241-A Tank Farm Ancillary Equipment and Corresponding Inventories.

		Base Case	INV1	INV2
241-A Tank Farm Ancillary Equipment Inventory (Curies)	^{222}Rn	1.6×10^{-11}	4.6×10^{-6}	6.7×10^{-7}
	^{226}Ra	1.6×10^{-11}	4.6×10^{-6}	6.7×10^{-7}
	^{230}Th	0.0×10^{0}	1.7×10^{-4}	2.5×10^{-5}
	^{234}U	2.4×10^{-1}	2.6×10^{-1}	3.8×10^{-2}
	^{238}Pu	2.6×10^{0}	5.6×10^{0}	8.2×10^{-1}
	^{238}U	2.2×10^{-1}	2.4×10^{-1}	3.5×10^{-2}
Compliance Period (<1,000 years)	Peak Flux ($pCi/m^2/sec$)	1.8×10^{-3}	2.3×10^{-3}	3.3×10^{-4}
	Time of peak (years after closure)	1,000	1,000	1,000
Sensitivity/Uncertainty Period (1,000 – 10,000 years)	Peak Flux ($pCi/m^2/sec$)	7.3×10^{-2}	8.1×10^{-2}	1.2×10^{-2}
	Time of peak (years after closure)	10,000	10,000	10,000

The radon flux at the surface of the WMA A-AX facility is calculated for each source separately. The time histories from these sources are presented in Figure 7-1. The relative magnitudes of the fluxes are the result of the initial residual inventory of ^{226}Ra and the amount of uranium inventory that decays to form ^{226}Ra and then to ^{222}Rn. The radon flux increases with time resulting from decay chain ingrowth. The peak flux of 7.3×10^{-2} $pCi/m^2/sec$ in the base case results from the A Farm ancillary equipment at the end of the sensitivity/uncertainty analysis time period. This value is substantially lower than the 20 $pCi/m^2/sec$ performance objective. While the A Farm tanks have a higher inventory of ^{226}Rn and uranium-series radionuclides than

the A Farm ancillary equipment, the tanks have a lower radon flux at the surface throughout the simulation. This is because the radon generated by the residual waste layer in the ancillary equipment only has to diffuse through 6 meters of backfill, while the radon generated by the residual waste layer in the tanks diffuses through 10 meters of grout in addition to 6 meters of backfill. Thus, much of the ^{222}Rn decays before reaching the surface because of the longer transport time through the grout layer. Among the tanks, tank 241-A-102 has the highest radon flux at the facility surface (1.0×10^{-4} pCi/m^2/sec peak in the compliance period and 3.5×10^{-3} pCi/m^2/sec at the end of the simulation). The tank with the second highest peak flux, tank 241-A-104, has a higher inventory of ^{226}Ra and uranium-series radionuclides than tank 241-A-102 (Figure 7-1). Since tank 241-A-104 is assumed to be unretrieved before grouting, it has a higher residual volume compared to tank 241-A-102, resulting in lower concentration (and flux) of radon.

Figure 7-1. Radon Flux at the Surface of Waste Management Area A-AX.



For the analysis of radon flux, releases of all other contaminants from the residual waste are set to zero, so the inventory of ^{226}Ra is allowed to build up in the residual layer. This is a significant conservatism at long times, since uranium migrating downward through the groundwater pathway would decrease the later peaks. Despite this conservatism, even at 10,000 years the peak radon flux is several orders of magnitude below the performance objective. The peak radon flux for the 1,000-year compliance period in the base case is 1.8×10^{-3} pCi/m^2/sec. The overall

peak radon flux for any inventory is 8.10×10^{-2} pCi/m^2/sec at 10,000 years post-closure from the A Farm ancillary equipment using the INV1 inventory, which is based on current, unretrieved BBI volumes and inventory for tanks and ancillary equipment. This result demonstrates that even with inventory uncertainties, the peak radon flux at the facility during the analysis period remains well below the performance objective.

7.2 CONCLUSIONS

The radon flux at the surface of WMA A-AX was calculated for each tank and for the ancillary equipment (equipment and pipelines) in the facility from time of facility closure to 10,000 years post-closure. The A Farm ancillary equipment has the highest radon flux, within both the compliance period of 1,000 years and the entire simulation duration. The peak radon flux from the A Farm ancillary equipment at 1,000 years post-closure is 1.8×10^{-3} pCi/m^2/sec and at 10,000 years post-closure is 7.3×10^{-2} pCi/m^2/sec. The tank with the highest radon flux at the surface is tank 241-A-102, with peak fluxes of 1.0×10^{-4} pCi/m^2/sec at the end of the compliance period and 3.5×10^{-3} pCi/m^2/sec at the end of the simulation. Despite several conservative assumptions in the calculations, the peak flux at the facility surface remains substantially below the performance objective of 20 pCi/m^2/sec through the entire simulation.

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WSRC-TR-2005-00195, 2005, *Summary of Grout Development and Testing for Single Shell Tank Closure at Hanford*, Rev. 0, Savannah River National Laboratory, Aiken, South Carolina.

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):

   C:\Program Files (x86)\GTG\GoldSim 12.0\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:

   C:\Program Files (x86)\GTG\GoldSim 12.0\General Examples\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

ATTACHMENT 2

TANK RESIDUAL WASTE CHARACTERISTICS

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Table Att-2-1. Residual Inventories Used in Waste Management Area A-AX Atmospheric Pathway Scenario Calculations (Curies)*.

Radio-nuclide	Tanks ("241-" prefix omitted)										Ancillary Equipment and Pipelines	
	A-101	A-102	A-103	A-104	A-105	A-106	AX-101	AX-102	AX-103	AX-104	A	AX
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	2.61E-00	1.01E+00
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	1.62E-11	5.00E-12
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	1.62E-11	5.00E-12
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
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	2.43E-01	2.24E-02
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	2.21E-01	1.97E-02

*Inventories decay corrected to January 1, 2050.

Table Att-2-2. Residual Waste Parameters Used in Waste Management Area A-AX Radon Flux Calculations.

Source	Residual Waste Volume (L)[a]	Cross-sectional Area (m^2)[b]
Tank 241-A-101	1.02E+04	4.10E+02
Tank 241-A-102	1.02E+04	4.10E+02
Tank 241-A-103	1.02E+04	4.10E+02
Tank 241-A-104	9.30E+04	4.10E+02
Tank 241-A-105	1.39E+05	4.10E+02
Tank 241-A-106	1.02E+04	4.10E+02
Tank 241-AX-101	1.02E+04	4.10E+02
Tank 241-AX-102	1.02E+04	4.10E+02
Tank 241-AX-103	1.02E+04	4.10E+02
Tank 241-AX-104	1.02E+04	4.10E+02
241-A Tank Farm Ancillary Equipment and Pipelines	9.66E+03	1.10E+04
241-AX Tank Farm Ancillary Equipment and Pipelines	4.10E+03	6.64E+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-1.

[b]Tank 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*. Pipeline cross-sectional area from RPP-RPT-60101, *Model Package Report Flow and Contaminant Transport Numerical Model Used in WMA A-AX Performance Assessment and RCRA Closure Analysis*, Draft B, Section 3.1.3.

ATTACHMENT 3

ATMOSPHERIC PATHWAY PARAMETER INPUTS

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Table Att-3-1. Parameters Used for Calculating Radon Flux at Waste Management Area A-AX. (2 sheets)

Parameter	Notation	Value	Unit	GoldSim© Parameter Name	Reference
General Inputs					
Henry's constant	K_h	4.47	unitless	Kh_gas_to_Aqueous	RPP-RPT-60885, Section 4.4.1
Binary diffusion coefficient (radon)	D_0	0.11	$cm^2\ s^{-1}$	Rel_air_Diff_coeff	RPP-RPT-60885, Section 4.4.3
Grout Diffusion Inputs[a]					
Diffusion length (tanks)	x	10	m	tank_Diff_Length	RPP-RPT-60885, Section 4.4.1
Diffusion length (pipelines)	x	3	in	Pipe_Diameter	RPP-RPT-60885, Section 4.4.1
Air content (air-filled porosity)	θ_a	6	%	Air_content_tank	RPP-RPT-60885, Section 4.4.1
Bulk density	ρ	1.8	g/cm^3	Grout_Bulk_Density_Intact	RPP-RPT-60885, Table B-1
Partitioning coefficient	K_d	0	mL/g	Grout_Kd	RPP-RPT-60885, Section 4.4.3
Soil Diffusion Inputs[a]					
Diffusion length	x	6	m	Soil_Thick (tanks), Soil_Above_Pipe_Thick (Pipelines)	RPP-RPT-60885, Section 4.4.1
Bulk density in 241-A Tank Farm	ρ	2.15	g/cm^3	Soil_Bulk_Density_A	RPP-RPT-60885, Table 4-5
Bulk density in 241-AX Tank Farm	ρ	1.67	g/cm^3	Soil_Bulk_Density_AX	RPP-RPT-60885, Table 4-5
Gas Tortuosity in Grout[b]					
Air content (or air-filled porosity)	θa	6	%	Air_content_tank	RPP-RPT-60885, Section 4.4.1
Fitted total porosity	Φ	0.8	unitless	Not applicable[c]	RPP-RPT-60885, Section 4.4.3
Gas Tortuosity in Soil[d]					
The water content (or water-filled porosity)	θ_w	varies	unitless	MC_Soil_Backfill_A, MC_Soil_Backfill_AX	Obtained from STOMP© simulations (RPP-CALC-63164)
Total Porosity (Soil) – 241-A Tank Farm	ϕ	0.174	unitless	Soil_Porosity_A	RPP-RPT-60101, Table 3-2

Table Att-3-1. Parameters Used for Calculating Radon Flux at Waste Management Area A-AX. (2 sheets)

Parameter	Notation	Value	Unit	GoldSim© Parameter Name	Reference
Total Porosity (Soil) – 241-AX Tank Farm	ϕ	0.384	unitless	Soil_Porosity_AX	RPP-RPT-60101, Table 3-2
Fitted total porosity	Φ	0.8	unitless	Not applicable[e]	RPP-RPT-60885, Section 4.4.3

[a]RPP-RPT-60885, Rev. 0, *Model Package Report System Model for the WMA A-AX Performance Assessment*, Equation 4-1.

[b]RPP-RPT-60885, Rev. 0, *Model Package Report System Model for the WMA A-AX Performance Assessment*, Equation 4-4.

[c]Number is entered directly into the equation defining gas tortuosity in the infill grout (GoldSim© parameter name: Grout_Air_Tortuosity_Best).

[d]RPP-RPT-60885, Rev. 0, *Model Package Report System Model for the WMA A-AX Performance Assessment*, Equation 4-5.

[e]Number is entered directly into the equation defining gas tortuosity in the soil (GoldSim© parameter name: Soil_Air_Tortuosity_Best).

References:
RPP-CALC-63164, *WMA A-AX Performance Assessment Contaminant Fate and Transport Model to Evaluate Impacts to Groundwater*.
RPP-RPT-60101, *Model Package Report Flow and Contaminant Transport Numerical Model Used in WMA A-AX Performance Assessment and RCRA Closure Analysis*.