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EXECUTIVE SUMMARY

This model package report documents the development of a system-level model for the Waste Management Area A-AX Performance Assessment. Instead of performing calculations using specialized process-level models for each part of the subsystem, a single model is developed for computationally efficient evaluation of the total system through coupling of processes at various scales that are relevant for evaluating the long-term performance and for comparison to the performance objectives. This report documents the development, testing and validation of the model that will be utilized in this capacity. Some of the important submodels/processes that are included within the system model calculation architecture are: (a) waste form degradation and release from various residual inventory-containing sources at closure (tanks and ancillary equipment), (b) flow and transport of contaminants through the vadose zone and saturated zone using an abstraction approach, (c) air-pathway transport of volatile contaminants, (d) calculation of effective dose and risk from exposure of radionuclides and chemicals at the point of compliance for various exposure scenarios, (e) calculation of acute and chronic dose to the inadvertent intruder, and (f) radon flux calculation from residual waste. This report describes the system-level model architecture and software; however, calculations performed using this model will be documented in separate calculation reports.

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TERMS

1-D	one dimensional
3-D	three-dimensional
ALC	air lift circulator
BBI	Best-Basis Inventory
CAD	computer-aided design
CCU	Cold Creek unit
CCUg	Cold Creek gravel
CCUz	Cold Creek silt
CDF	cumulative distribution function
CHPRC	CH2M HILL Plateau Remediation Company
COPC	constituent of potential concern
CPGWM	Central Plateau Groundwater Model
DCF	dose conversion factor
DOE	U.S. Department of Energy
EHM	equivalent homogeneous medium
EMMA	Environmental Model Management Archive
eSTOMP	extreme-scale Subsurface Transport Over Multiple Phases
FEP	Feature, event, or process
FFTF	Fast Flux Test Facility
H1	Hanford formation unit 1
H2	Hanford formation unit 2
H3	Hanford formation unit 3

HI	hydrogen iodide
HISI	Hanford Information Systems Inventory
HSU	hydrostratigraphic unit
HTWOS	Hanford Tank Waste Operations Simulator
MPR	model package report
PA	performance assessment
PUREX	Plutonium Uranium Extraction (Plant)
RCRA	*Resource Conservation and Recovery Act of 1976*
RSD	relative standard deviation
SD	standard deviation
SST	single-shell tank
STOMP	Subsurface Transport Over Multiple Phases
TEDE	total effective dose equivalent
TH	tritiated dihydrogen
TOH	tritiated water
TWINS	Tank Waste Information Network System
WMA	Waste Management Area

1.0 INTRODUCTION

A performance assessment (PA) of Single-Shell Tank (SST) Waste Management Area (WMA) A-AX located at the U.S. Department of Energy (DOE)'s Hanford Site in southeastern Washington is being conducted to satisfy the requirements of the *Hanford Federal Facility Agreement and Consent Order* (Ecology et al. 1989), as well as other Federal requirements and State-approved closure plans and permits. The WMA A-AX PA assesses the fate, transport, and impacts of radionuclides and hazardous chemicals within residual wastes left in tanks and ancillary equipment and facilities in their assumed closed configuration and the subsequent potential doses to humans in the future.

The PA has been structured around the complementary use of process-level and system-level models. Process-level models are those that represent a detailed phenomenological representation of processes of concern in the PA. Process models typically only represent one or a few of the components of the PA, such as groundwater flow and transport, and must be integrated with other modeling elements to perform PA calculations. System-level models are those that are abstracted from the process models, retaining the essential features of the process model, while allowing integration of all aspects of the PA in a single modeling framework. System-level models are often characterized by coarser numerical discretization, lower dimensionality, or other similar simplifications compared to the process-level model.

The system-level model has been developed to assess the long-term performance of WMA A-AX following closure. It has been constructed in order to evaluate the impact of relevant features, processes, and events to the release of contaminants from the residual waste, their transport through the geosphere, and eventual dose to humans at the point of compliance.

The system-level model integrates several necessary computational components that allow it to not only mimic the process-level model of the groundwater release pathway, but also to perform several other calculations required for a PA. Calculations performed within the WMA A-AX system-level model include: (a) waste form degradation and release from various residual inventory-containing sources at closure (tanks and ancillary equipment), (b) flow and transport of contaminants through the vadose zone and saturated zone using abstracted information from the Subsurface Transport Over Multiple Phases (STOMP)[1] process model, (c) effective dose and risk from exposure to radionuclides and chemicals at the point of compliance for various exposure scenarios, (d) acute and chronic doses to the inadvertent intruder, and (e) radon flux from the facility. Transport of contaminants through an air pathway was considered for implementation in the system model, but the consequences were found to be insignificant. This pathway was therefore screened from further consideration, and was not implemented in the system model. This report therefore only provides a brief summary of the arguments for screening the pathway, which are provided in detail in RPP-CALC-63180, *Calculation of inhalation doses from H-3, C-14 and I-129 originating from Waste Management Area A-AX*.

The system-level model has been developed to complement the more detailed process-level models of the groundwater system. The use of these complementary modeling approaches supports the credibility of both by allowing results to be compared.

[1] Subsurface Transport Over Multiple Phases (STOMP) is copyrighted by Battelle Memorial Institute, 1996.

One of the major benefits of using a system-level model is that all of the component-level models are integrated into a common modeling framework. The use of a common framework fosters consistency in modeling approaches and ensures that interfaces between the components are implemented in an internally consistent manner. The result is a single model used to evaluate the long-term performance of the total system.

One of the principal uses of the system-level model is to evaluate the uncertainty in the performance of the WMA A-AX system. The computational burden associated with process-level models means that probabilistic uncertainty analyses are generally impractical.

The system-level model has been developed in the GoldSim©[2] software, which has been developed with the capability to perform probabilistic uncertainty analyses in a computationally efficient fashion. Developing abstractions from the detailed process-level model and implementing the abstractions in the system-level model with the GoldSim© software allows efficient evaluations of parameter and conceptual model uncertainty in an integrated model so that the total impacts and significance of uncertainties can be quantified.

1.1 NEED

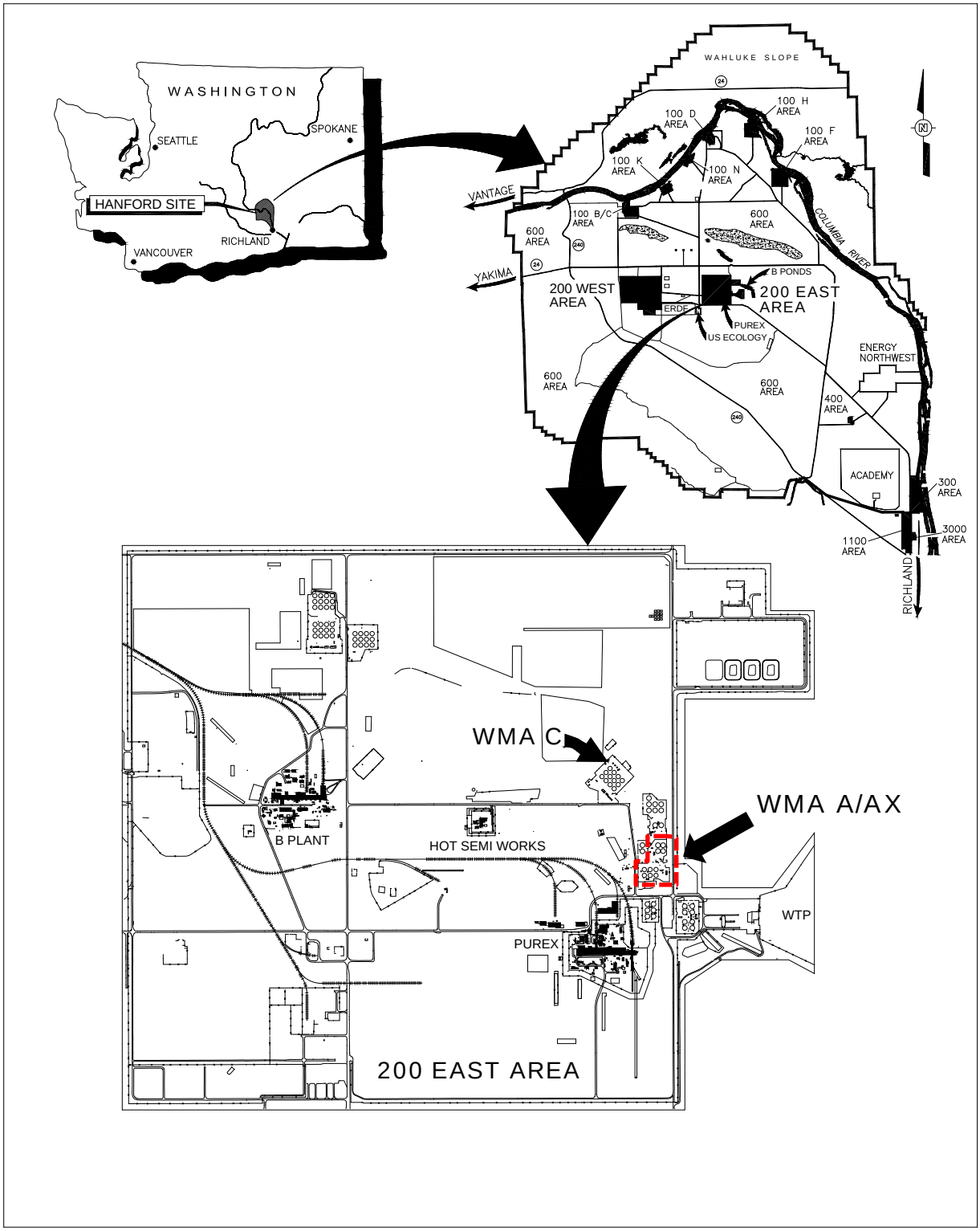
System-level modeling is needed to evaluate the long-term impacts from slow release of contaminants from the residual inventories at closure. The time scale of analysis is up to 10,000 years and the model needs to consider the combined effects of contaminants in the aquifer from various source terms leading to eventual exposure to a Reference Person. In addition, a probabilistic analysis is appropriate to evaluate the impact of parameter uncertainty in estimating dose for the PA, which requires a system model.

1.2 BACKGROUND

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. 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 SST Farm 241-C (C Farm) is located nearby to the northwest (Figure 1-1). WMA A-AX includes catch tanks, diversion boxes, valve pits, pipelines, French drains and unplanned release sites. Numerous liquid discharge facilities used nearby at various times (cribs, trenches, ditches, septic systems, etc.) surround the WMA.

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

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



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

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, after which transfers ceased.

Figure 1-2 illustrates the closure concept for WMA A-AX following tank waste retrieval. Surface facilities will be removed while both 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 and filled with grout. An engineered surface cover system, also called a surface barrier, will be placed over each tank farm and will be monitored using existing wells.

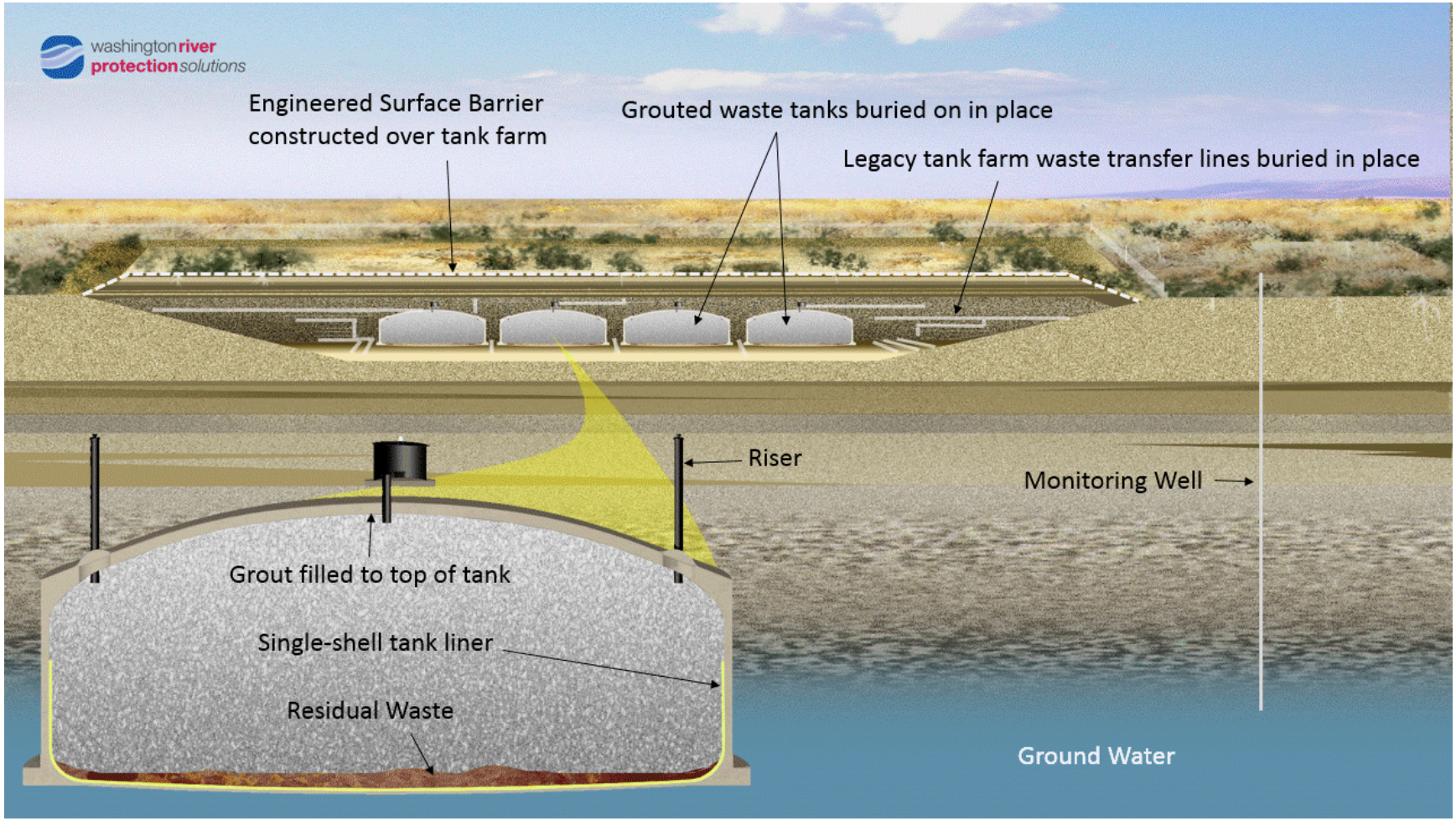
In brief, as of 2018, plans for the future closure of A Farm and AX Farm call for retrieving the wastes remaining in the SSTs (mostly sludge and saltcake solids) to the maximum extent practicable, grouting the residual wastes and interior volume of the SSTs, and constructing a surface barrier over the tank farms. The PA uses numerical models to evaluate the ability of the closed WMA to meet dose-based performance objectives associated with release and migration of radioactive contaminants. The performance objectives require reasonable assurance of compliance for 1,000 years, with analyses to 10,000 years needed for sensitivity and uncertainty analyses.

1.3 DOCUMENT ORGANIZATION

This model package report (MPR) is organized into the following sections:

- Section 2 presents the model development objectives
- Section 3 presents the conceptualization of the various components (groundwater pathway, air pathway, exposure scenarios, etc.) of the WMA A-AX system
- Section 4 describes the model implementation details
- Section 5 discusses the plans for sensitivity and uncertainty analyses using this system-level model
- Section 6 identifies the limitations of the model, and the applicability of the results
- Section 7 discusses the use of the GoldSim© software to conduct the analysis, and the configuration management of the model inputs and outputs including the software used
- Section 8 presents recommendations regarding the future development of the model
- Section 9 provides the references cited in this document.

Figure 1-2. Conceptual Model of Closure of Waste Management Area A-AX.



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2.0 MODEL OBJECTIVES

DOE O 435.1, *Radioactive Waste Management* dictates that the DOE radioactive waste management activities shall protect the public from exposure to radiation from radioactive materials, protect the environment, and comply with applicable Federal, State, and local laws and regulations, as well as any applicable Executive Orders and other DOE directives. The PA provides calculations, including various modeling activities, to assess whether there is reasonable assurance that the facility will provide the necessary levels of protection. DOE M 435.1-1, *Radioactive Waste Management Manual* identifies specific performance objectives, as well as other performance-related factors that need to be considered in the PA.

The objective of developing a system model is to provide one of the modeling tools that will be used to evaluate the various prescribed performance objectives identified in DOE M 435.1-1, namely the dose to humans from groundwater and air contamination (all-pathways 25 mrem/yr limit and a 10 mrem/yr atmospheric release limit), radon flux (20 pCi/m^2/s limit) and inadvertent intrusion (500 mrem acute dose limit and 100 mrem/yr chronic dose limit). The system model also evaluates impacts to groundwater resources from dangerous chemicals released from tanks and ancillary equipment. One of the primary goals of the system model is to evaluate the uncertainty in calculated human dose at the point of compliance due to uncertainty in input parameters and in recognition of environmental processes that are inherently uncertain. Uncertainty analysis is undertaken to understand which uncertain factors (parameters or processes) exert the greatest influence on the model results. The objective of the uncertainty analysis is to support the determination that there is a reasonable expectation of meeting the performance objectives.

The major pathways for contamination entering the environment are the groundwater pathway, the air pathway, and a hypothetical inadvertent intruder pathway (through drill cuttings brought to the surface). Figure 2-1 shows the various pathways of possible exposure evaluated in the PA.

As mentioned in Section 1.0, the modeling approach to support the PA is being conducted using complementary models, including both deterministic and probabilistic approaches for simulating contaminant releases to groundwater (see Figure 2-2). Since a variety of mass transport and exposure scenario calculations are needed to support the PA, the methodology conducts some calculations using a process-level model while other calculations are conducted using the system-level model.

A three-dimensional (3-D) process-level flow and contaminant transport model has been developed using STOMP and the multi-processor-capable extreme-scale STOMP (eSTOMP) simulator to evaluate the contaminant transport through the vadose zone and saturated zone and to calculate the groundwater concentration at the receptor location. All other calculations that are needed to satisfy the requirements of the PA are undertaken using the system-level model. The system-level model developed using GoldSim© is used for:

- Source term modeling to evaluate release from residual waste within the grouted tanks and ancillary equipment and to provide input to the 3-D process model developed using STOMP/eSTOMP code

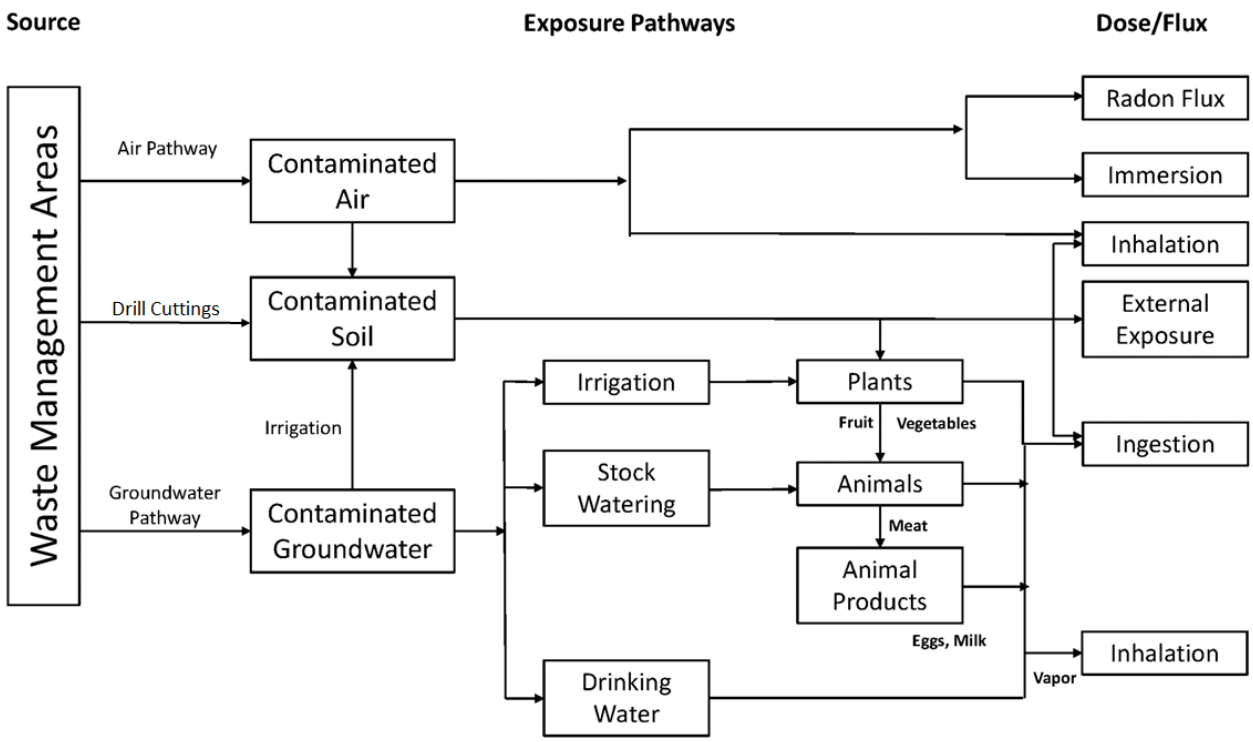
- Modeling transport of contaminants through the vadose zone and saturated zone using flow fields abstracted from the 3-D process model

- Modeling transport of volatile contaminants along the air pathway including calculation of radon flux at the surface of WMA A-AX

- Calculating radiological dose and risk through implementation of exposure scenarios

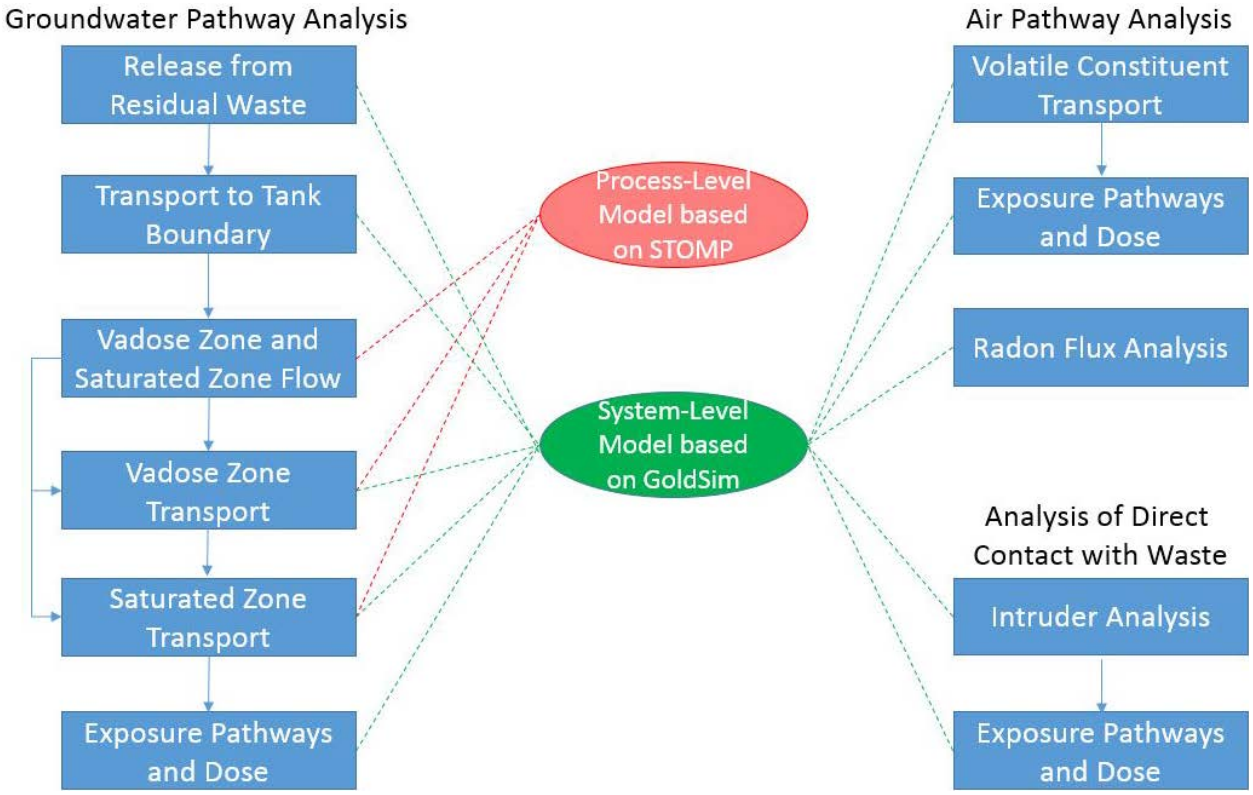
- Inadvertent intruder analysis.

Figure 2-1. Overview of the Analysis of Performance for the Waste Management Area A-AX Performance Assessment.



The description of the 3-D flow and contaminant transport model developed using STOMP is presented in a separate document (RPP-RPT-60101, *Model Package Report Flow and Contaminant Transport Numerical Model used in WMA A-AX Performance Assessment and RCRA Closure Analysis*). The current report discusses the system-level model that is implemented using GoldSim©.

Figure 2-2. Complementary Use of Subsurface Transport Over Multiple Phases (STOMP) and GoldSim© in the Evaluation of Parts of the Performance Assessment.



GoldSim© simulation software is copyrighted by GoldSim Technology Group LLC of Issaquah, Washington (see http://www.goldsim.com).
Subsurface Transport Over Multiple Phases (STOMP) has been developed and distributed by Battelle Memorial Institute.

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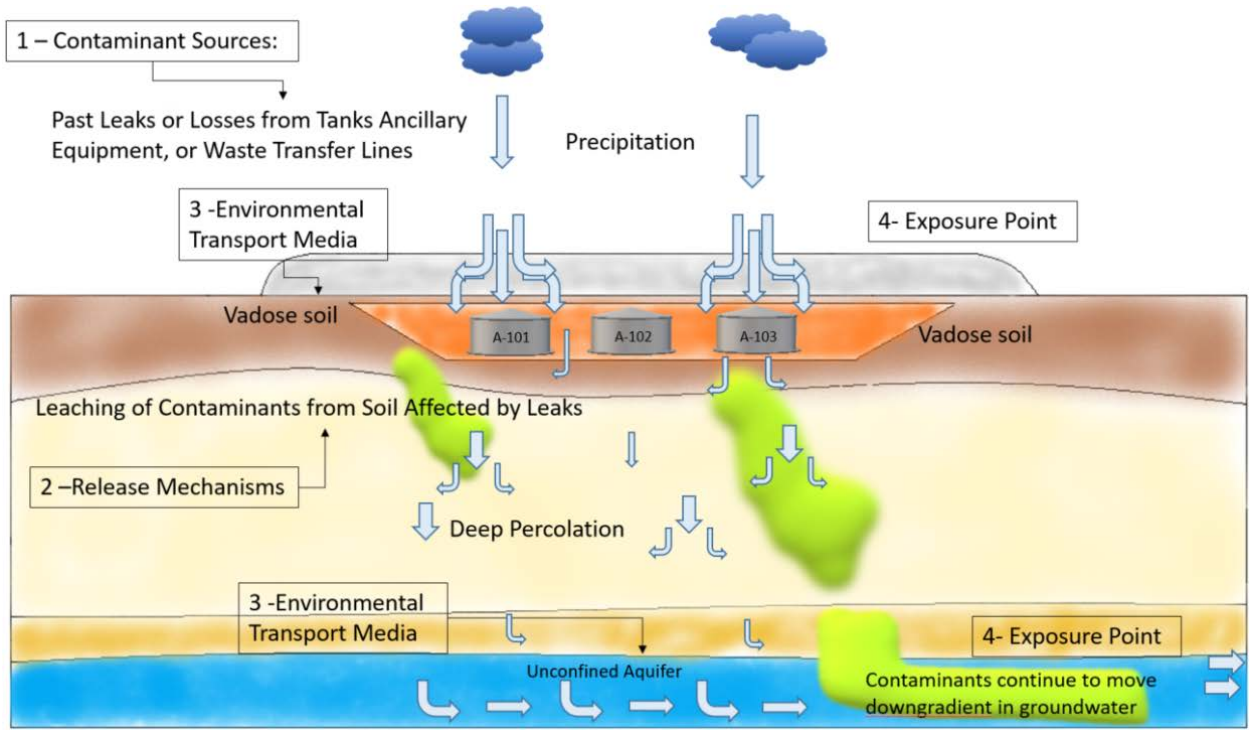
3.0 MODEL CONCEPTUALIZATION

This section describes the modeling methodology for the determination of the WMA A-AX residual waste impacts using the system model. This methodology uses conceptual models that are based on the physical system and expected contaminant migration pathways.

Figure 3-1 provides a schematic representation of both WMA A-AX as it will exist at closure and the contaminant migration pathways evaluated in this modeling effort. It is emphasized that the PA documented here focuses solely on the consequences of releases from residual wastes in the post-closure period. Past leaks and losses shown in Figure 3-1 are considered only from the perspective of how they may affect soils in ways that pertain to the migration of residual wastes. Specific consideration of the consequences of past leaks is subject to different regulatory requirements, and the modeling to address those requirements is being undertaken in a separate effort.

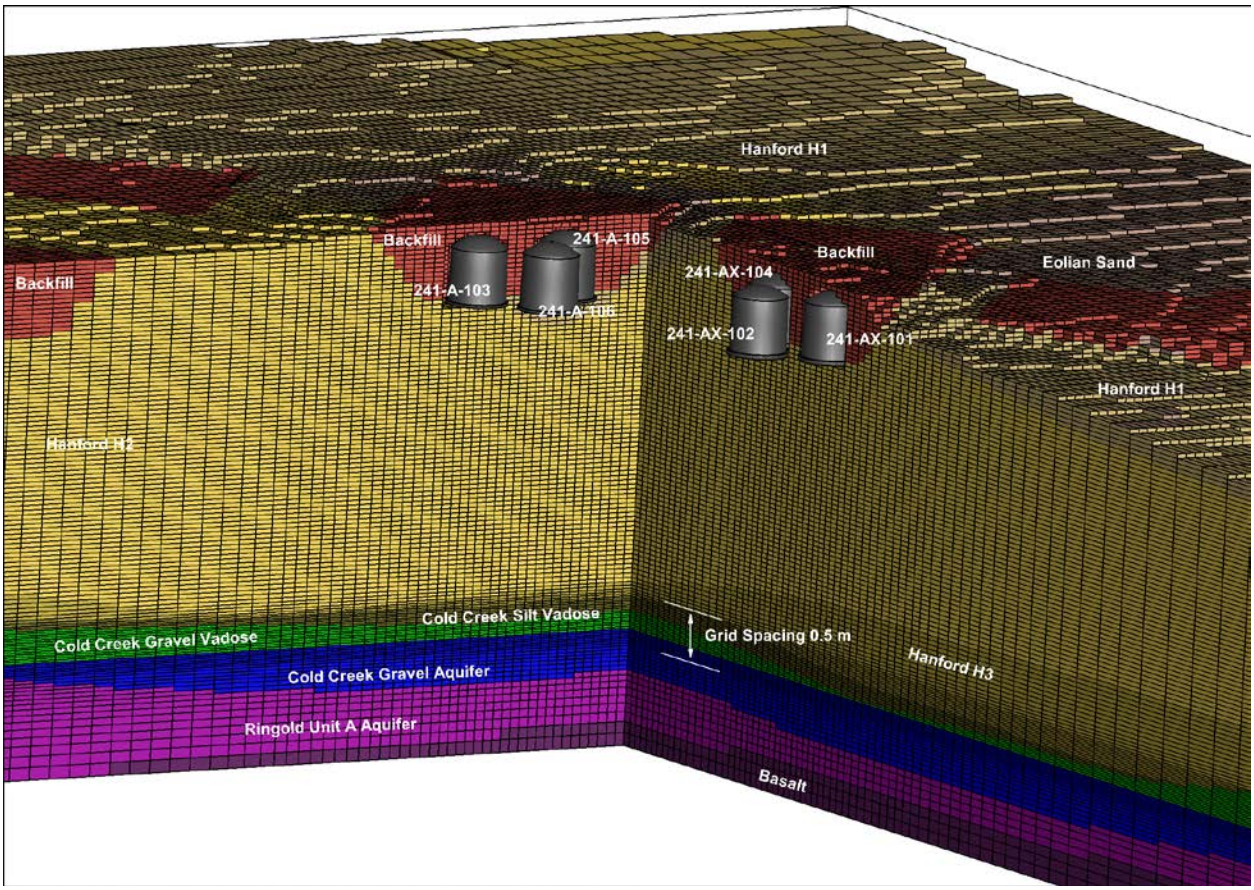
Figure 3-1 Schematic Conceptual Representation of Waste Management Area A-AX and Various Pathways.



WMA A-AX is composed of both man-made and natural components. The man-made components of the system that influence contaminant migration include a closure surface barrier, the WMA A-AX tanks and ancillary equipment, and the distribution of waste in those components. The natural components of the system that influence contaminant migration are a number of mostly horizontal stratigraphic layers within the vadose zone and an underlying stratigraphic layer that is part of the unconfined aquifer. Figure 3-2 illustrates the stratigraphy for the WMA A-AX site. The site has a thick vadose zone above the water table within the

undifferentiated Hanford formation and Cold Creek gravels and a predominantly northwest to southeast groundwater flow.

Figure 3-2. Conceptual Model of the Waste Management Area A-AX Site Showing Stratigraphy.

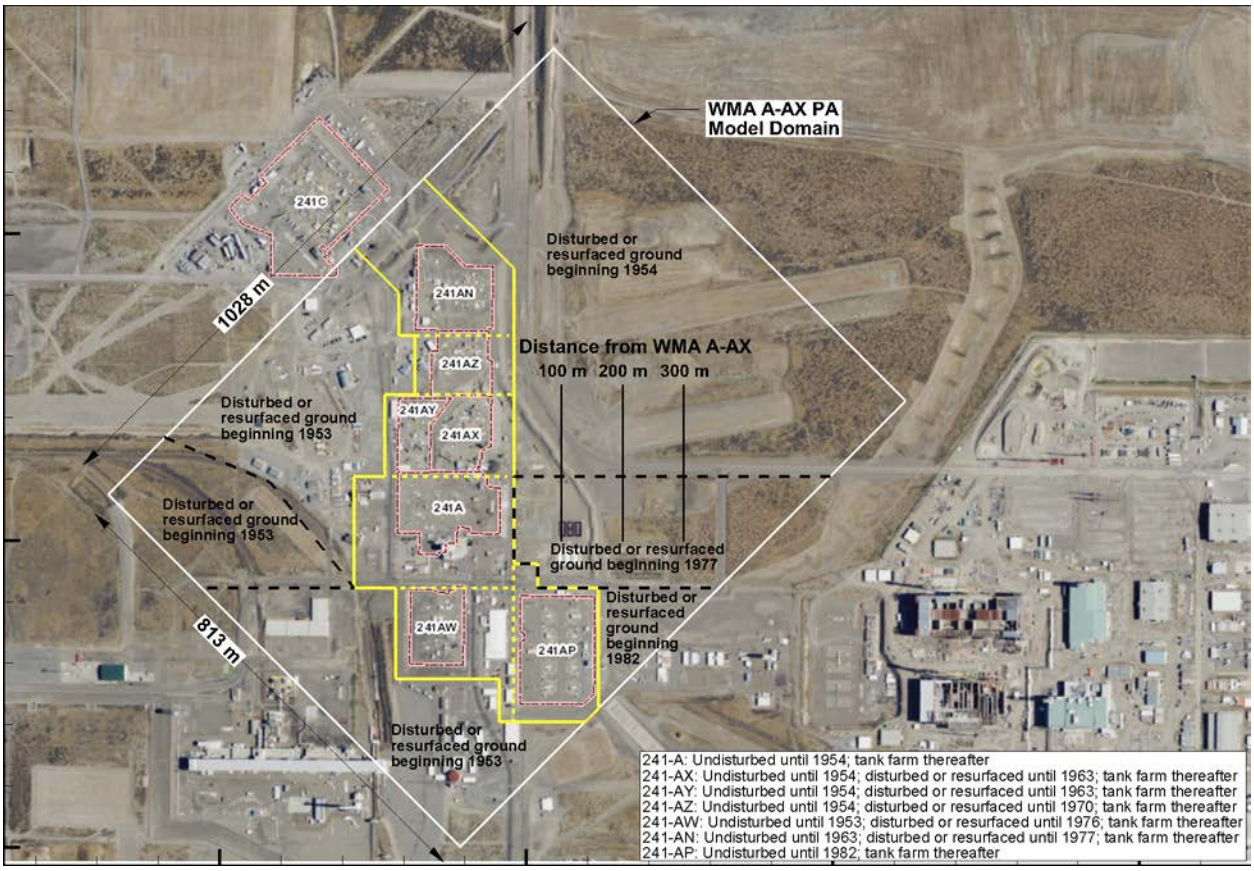


H1 = Hanford formation unit 1 H2 = Hanford formation unit 2 H3 = Hanford formation unit 3

Figure 3-3 shows an aerial view of WMA A-AX, and the current surrounding disturbed, undisturbed, and resurfaced areas. These areas will be replaced as part of the closure process by the surface barrier.

For performing contaminant transport calculations using the system model, an abstraction approach is undertaken, where the flow field based on the results from the 3-D model developed using STOMP is used in the system model. Detailed representations of the geological system and hydraulic properties are implemented in the 3-D model developed using STOMP, so that effects of relevant features and processes on water flow and radionuclide transport in groundwater can be evaluated. However, the model for evaluating flow requires significant computational time, limiting its ability to fully address parameter uncertainties at the system level. The abstraction approach assures that the flow field in both models is consistent for a specific set of input parameters for flow, differing only in the discretization and dimensionality of the two models.

Figure 3-3. Aerial View of Waste Management Area A-AX Showing Surface Features and the Surrounding Area.



WMA = Waste Management Area

3.1 FEATURES, EVENTS, AND PROCESSES

The landfill closure of WMA A-AX is assumed to occur at year 2050, at which time the tanks are assumed to be filled with grout and covered with a final closure cover. It is assumed that institutional control and societal memory is retained for the first 100 years after the year of closure. The point of analysis for all-pathways and groundwater protection analyses is at the location of highest concentration located outside of a 100-m buffer zone surrounding the WMA A-AX facility boundary. In order to ensure consistency in the analyses, hazardous chemicals are also evaluated at this point.

Several key safety functions and related features, events, or processes (FEPs) characterize the conceptual models for release and transport of radionuclides in WMA A-AX for the post-closure period. For the system-level model calculations, the following FEPs are included:

- The process of waste form degradation and release of contaminants from the grouted tanks and ancillary equipment to the outside of the tank

- Contaminant transport through the natural environment
- Transport of volatiles through the air pathway
- Calculation of radiological dose and risk to the receptor (a Representative Individual)
- Evaluation of radiological doses in an inadvertent intruder scenario
- Account for decay and in-growth of daughter isotopes.

Input parameter uncertainty is considered along with alternative representation of these FEPs as expressions of model uncertainty.

The conceptual models and relevant parameters for fate and transport modeling have been developed for the following three time periods:

- Operations period, representing tank farm construction, current, and immediate future conditions of the tank farm (1945 to 2050)
- Closure and post-closure period during the assumed design life of the intact surface barrier (2050 to 2550), when the tanks become grouted and radionuclides begin to diffuse out of the grout
- Post-closure period beyond assumed design life of the surface barrier (2550 to 3050), when the performance of the surface barrier is assumed to degrade.

A 1,000-year post-closure period is considered in the WMA A-AX PA for evaluating compliance with DOE O 435.1 performance objectives; a 10,000-year post-closure period is considered for the purpose of evaluating uncertainty in the results.

3.2 SOURCE TERM AND ENGINEERED FEATURES

The processes associated with the release of contaminants into the pore waters of the material in the tank and ancillary equipment, and their migration from the residual waste matrix through the surrounding engineered barriers, are denoted as the “source term” in PA modeling. Separate source terms are considered for each of the 10 tanks (6 A Farm Tanks and 4 AX Farm tanks) and 2 pipeline sources (1 for A Farm pipelines and 1 for AX Farm), resulting in 12 separate source terms. The inventory used for the source term model is obtained from RPP-RPT-58293, *Hanford 241-A and 241-AX Farm Tank and Ancillary Equipment Residual Waste Inventory Estimates*, Rev. 2 (in process).

The objective of this section is to present the conceptual description of the processes implemented for modeling the release of constituents of potential concern (COPCs) from the waste and transport through near-field to the edge of the tanks and pipelines. Much of the discussion below is excerpted from Chapter 6 of the WMA C PA (RPP-ENV-58782, *Performance Assessment of Waste Management Area C, Hanford Site, Washington*). Because of

the lack of characterization data for WMA A-AX residual wastes, the following discussion relies primarily on the extensive testing and analyses done for WMA C residual wastes. This is necessary as of 2019 because, unlike the WMA C PA, the initial WMA A-AX PA is deliberately being completed before any tanks in the WMA have been retrieved; thus, characterization of tank-specific residuals will not be possible until future updates to the PA.

There are differences between the wastes historically stored at WMA A-AX versus those at WMA C and in the retrieval technologies to be deployed, each of which may lead to different chemical compositions or physical properties in WMA A-AX residuals than those of the WMA C residuals for which data are available. WMA C residuals were sampled from the hard heel of sludge phases remaining after sluicing with a supernate solution and multiple rinses. Phases of wastes stored in WMA A-AX SSTs pending retrieval are reported in monthly updates to HNF-EP-0182, *Waste Tank Summary Report for Month Ending January 31, 2019*, in some cases include significant amounts of saltcake in varying proportions to sludge. The first retrieval technology to be deployed for the AX Farm SSTs is sluicing using hot water, and cold water may also be used (RPP-RPT-58932, *241-AX-101 Tank Waste Retrieval Work Plan* through RPP-RPT-58935, *241-AX-104 Tank Waste Retrieval Work Plan*); retrieval technologies have not been selected for A Farm as of 2019. It is expected that water sluicing will preferentially remove the most soluble waste constituents in each phase, leaving the least soluble contaminants in any residual phases; it is further expected that water will dissolve and preferentially remove most saltcake, whereas relatively insoluble sludge is more likely to dominate the material remaining in any residual phases of wastes that may escape being physically sluiced and pumped out of the tanks. The anticipated preferential removal of saltcake and dominance of sludge in WMA A-AX residuals supports the proposition that WMA C residuals are adequately similar for purposes of modeling contaminant release behaviors in the initial WMA A-AX PA. Use of water rather than supernate for sluicing may achieve greater dissolution of some contaminants from either sludge or saltcake due to a higher chemical concentration gradient, in which case assuming contaminant releases similar to those from WMA C residuals may potentially overestimate the availability of some soluble contaminants which may be released from WMA A-AX residuals.

Both mineral phase solubility-limited and matrix degradation rate-limited processes are considered for release of contaminants from the waste. These conceptual models were developed based on observations made for WMA C through multi-year leaching tests and identification of mineral phases with the assumption that these are valid for WMA A-AX. The following release models are considered based on empirical evidence:

- solubility-controlled releases of uranium, and
- dissolved concentration limits for chromium.

The engineered features that are considered in the source term calculations are the tank structure, pipeline area,[1] infill grout material, and the emplaced surface barrier at closure. The modified *Resource Conservation and Recovery Act of 1976* (RCRA) barrier reduces the net infiltration that percolates to the buried tank structures and ancillary equipment. The infill grout material provides both structural stability to the tank configuration, and also a relatively impermeable

[1] Individual pipelines are not treated as separate sources. Instead, the inventory associated with the pipeline source term is distributed uniformly over the two areas associated with the pipelines of A Farm and AX Farm.

barrier to flow leading to flow diversion around the tank, as long as the grout is not physically degraded. The infill grout material also controls the chemical conditions of the pore water that contacts the residual waste through mineral phase dissolution and precipitation (e.g., dissolution of portlandite and precipitation of calcite).

The source term processes considered in the post-closure period include releases of contaminants from residual waste and their transport to the underlying vadose zone via either diffusion or advection. Key processes expected to affect release of contaminants from tank residuals include:

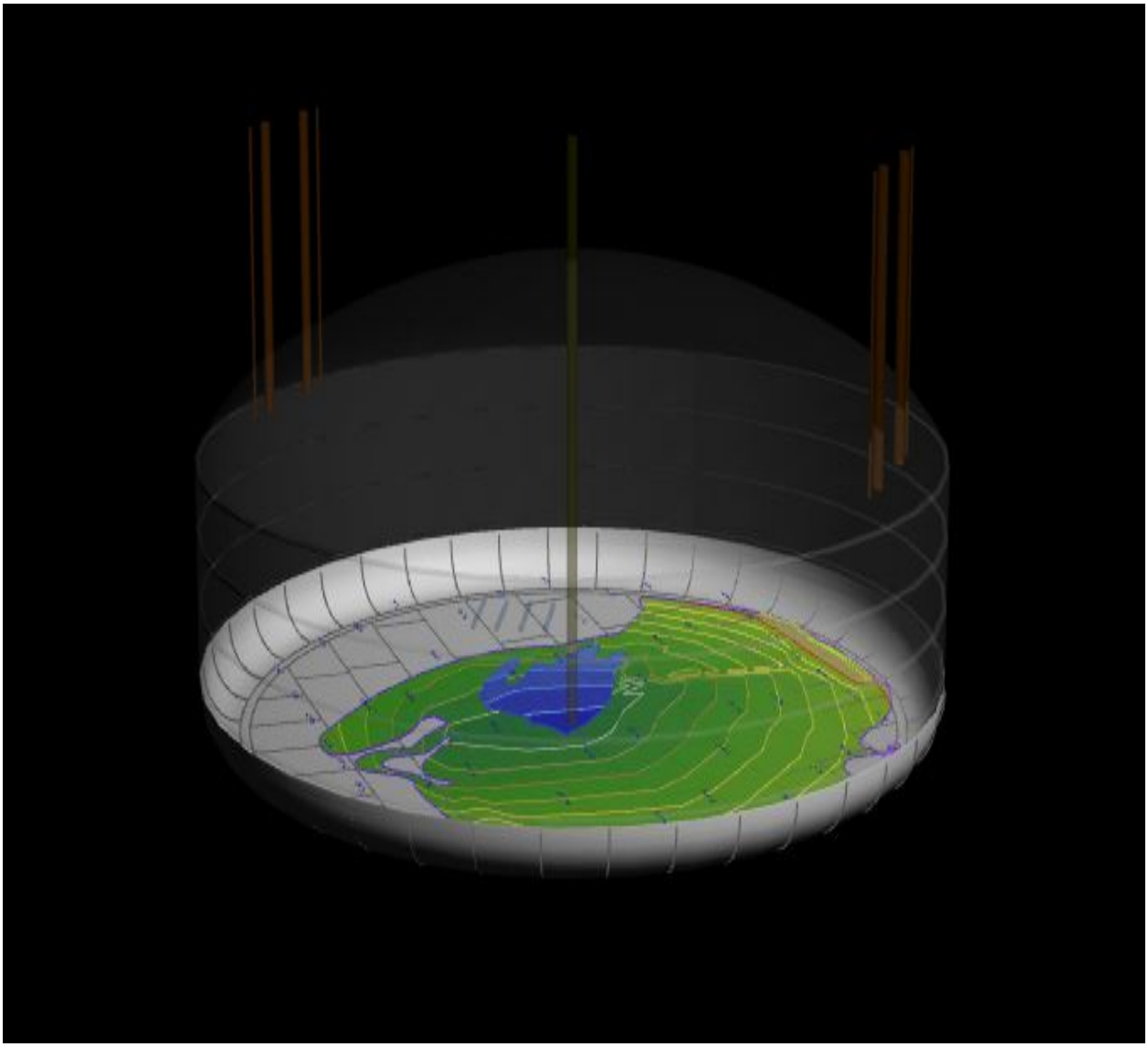
- Leaching of contaminants from the tank waste residual layer into the pore water associated with the tank residuals
- Diffusive transport of contaminants through the tank wall grout and concrete layer, along the tortuous continuous connections, to vadose zone soil outside the tank
- Ongoing chemical and physical degradation of the tank wall concrete and grout layer
- Ongoing dissolution and degradation of emplaced grout in the tank leading to eventual formation of cracks
- Advective flow of water potentially influencing the source term once a sufficient number of cracks form in the engineered barriers.

In addition to these key processes, it is important to note that the impact of the steel liner inside the concrete tank in terms of delaying the release of contaminants from the waste zone is ignored. In actuality, no release can occur until the steel liner corrodes; hence, this key assumption is regarded as a measure of conservatism.

The distribution of residual waste volume within the retrieved tanks at WMA C was estimated by a variety of techniques involving video observations and camera/computer-aided design (CAD) modeling (e.g., RPP-CALC-54266, *Post-Hard Heel Retrieval Camera/CAD Modeling System Waste Volume Estimate for Tank 241-C-108*). One such result is presented in Figure 3-4. Spatial distributions of residual waste volumes were estimated for the tank dish bottom, tank walls and stiffener rings, and in-tank equipment for the retrieved tanks, and are summarized in RPP-RPT-42323, *Hanford C-Farm Tank and Ancillary Equipment Residual Waste Inventory Estimates*. The estimates indicate that the majority of residual waste is located in the tank dish bottom (>80% for the 100-series tanks and >50% for the 200-series tanks), with minor amounts associated with the in-tank equipment. WMA A-AX is anticipated to have a similar distribution of residual waste, post-closure.

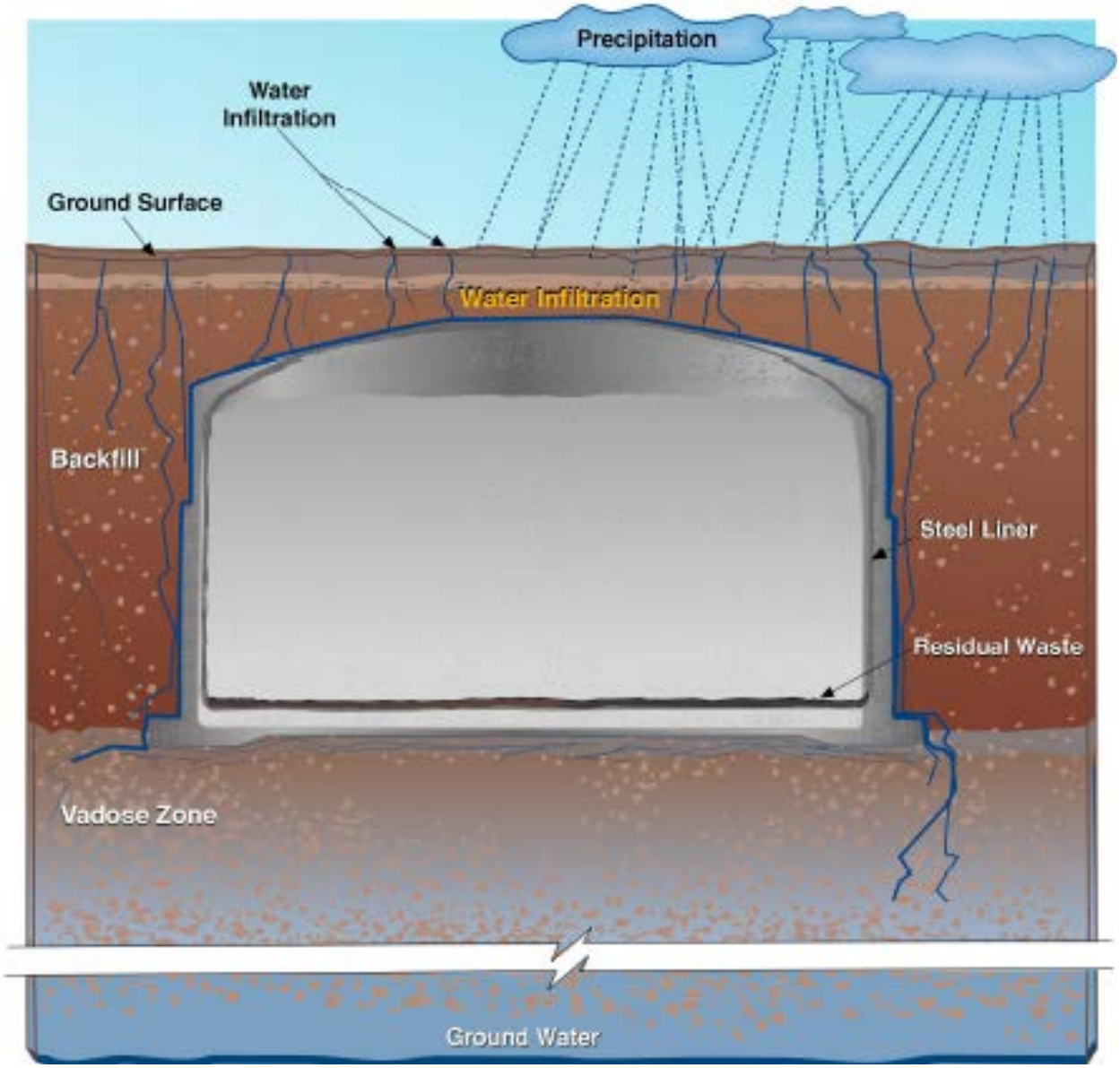
For the purpose of developing a source release model for tanks, the residual waste volume is conceptualized to be present as a thin layer at the base of the tank (Figure 3-5). The estimated residual waste volume is assumed to be spread across the circular tank dish bottom area. The residual waste is conceptualized to be sludge-like, with a texture similar to a hardened paleosol. It is assumed to be fully saturated with a porosity of 40% based on evaluation of sludge waste phase from the WMA C retrieved tanks (RPP-ENV-58782).

Figure 3-4. Computer-Aided Modeling Results Showing Distribution of Residual Waste for a Retrieved Tank.



The closure concept is to fill the tanks with grout, providing a very low permeability environment in the tank. While the grout is intact, it will divert water that infiltrates through the surface barrier. Therefore, the transport mechanism for release of contaminants from the residual tank waste to the underlying vadose zone is primarily diffusive while the grout is intact. The dissolved concentration of contaminants in the residual waste pore volume is controlled by the waste characteristics, such as waste form degradation and dissolution of solubility-controlling mineral phases. The presence of continuous water connections is assumed across the grout and concrete layers for the diffusive transport to occur in the aqueous phase.

Figure 3-5. Conceptual Model of Tank after Site Closure.



The source release model for the pipelines is quite different from the one for tanks. Instead of modeling discrete source terms, two separate source areas (one for A Farm and one for AX Farm) reflecting the approximate areal distribution of the waste transfer pipelines are considered. These are the assessed areas of the tank farms where pipelines are generally present. The estimated residual inventory is uniformly spread over these areas. Unlike tanks, the pipelines are assumed not to be filled with grout at closure, and due to limited information on the condition of the pipeline material, no credit is taken for the structural integrity of the pipeline. Therefore, both advective and diffusive releases are considered from the pipelines. More details related to the source conceptualization are discussed below.

3.2.1 241-A and 241-AX Tank Sources

Details of all engineered features of A Farm and AX Farm are presented in RPP-RPT-58693, *Engineered System Data Package for Waste Management Area A-AX*. Only the relevant engineered features for source term modeling for residual wastes are presented here.

The A Farm contains six 100-series tanks and AX Farm contains four 100-series tanks. The 100-series tanks are 23 m (75 ft) in diameter, have a 9-m (30-ft) operating depth, and have a nominal capacity of 3,785,000 L (1,000,000 gal) each. The tanks were designed to receive boiling waste from the PUREX process and have several unique design features, including: air lift circulators (ALCs) for cooling the boiling wastes, underground vessel ventilation headers to remove condensate and volatiles, laterals 10 ft beneath the tank for leak detection (A Farm only), and leak detection pits (AX Farm only).

Figure 3-6 shows a schematic of a typical A Farm SST, and Figure 3-7 gives dimensions of the A Farm SSTs' concrete shells and steel liners. Figure 3-8 gives the dimensions of a typical AX Farm SST's concrete shells and steel liners. Design requirements for the tanks are summarized in RPP-10435, *Single-Shell Tank System Integrity Assessment Report*, Appendix A. Each tank consists of a concrete shell with a steel plate lining having an inside diameter of 75 ft and an internal height of 32 ft 4 in. (A Farm) or 32 ft 6 in. (AX Farm) from the tank bottom to the top of the steel liner (H-2-55911, "Waste Storage Tanks Composite Section PUREX Waste Disposal Facility" and H-2-44562, "Structural Waste Storage Tanks Composite Section & Details").

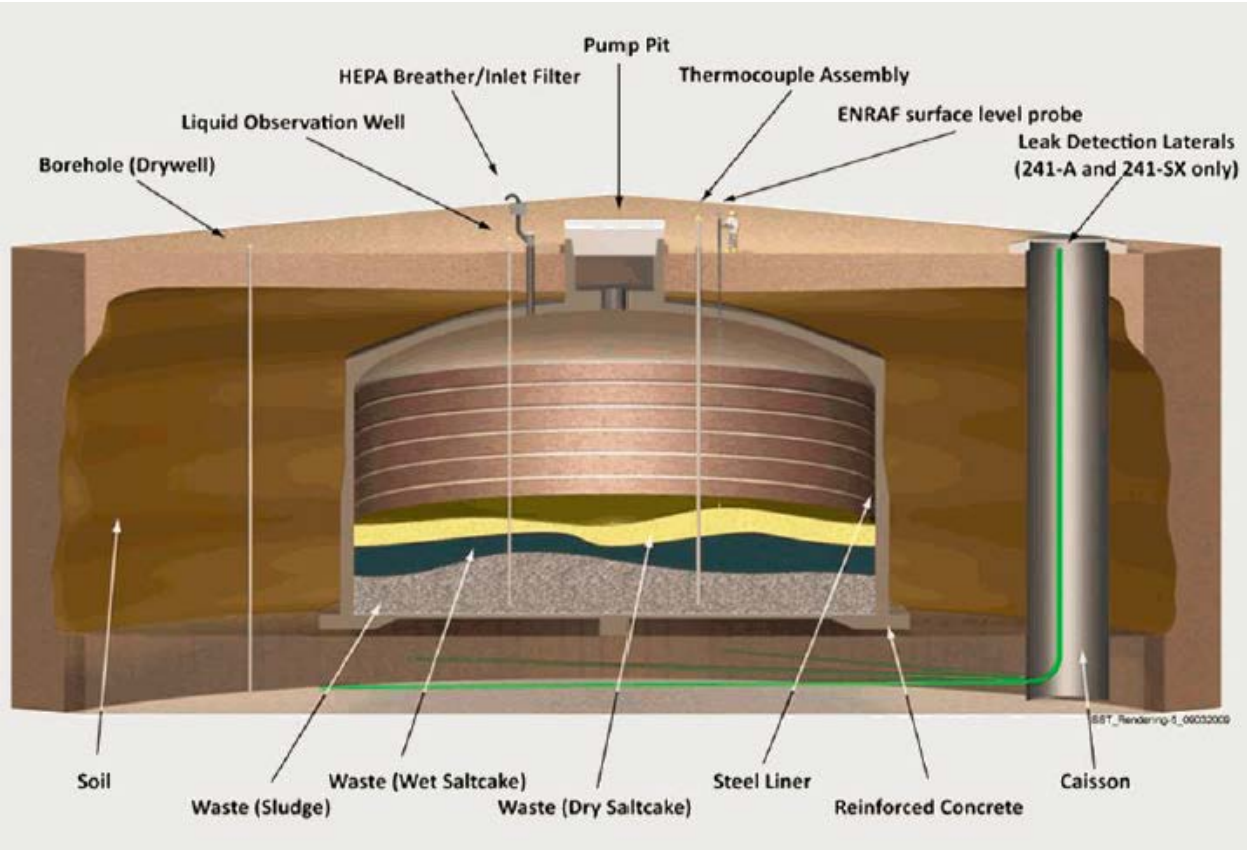
The tanks are buried underground with ~6 to 7.5 ft of backfill over the crest of the dome to provide radiation shielding for operating personnel. The SSTs were constructed in place with 0.375-in.-thick carbon steel (ASTM A283-52T or ASTM A285-52T in A Farm and ASTM A201 Grade A in AX Farm) lining the bottom and the sides of a reinforced-concrete shell (RPP-10435 Table A.6). Although the carbon steel liner was designed to hold the waste in place and act as a barrier to the transport of contaminants, recent studies related to characterization of the corrosion behavior of the carbon steel liner (WHC-EP-0772, *Characterization of the Corrosion Behavior of the Carbon Steel Liner in Hanford Site Single-Shell Tanks*) determined several likely corrosion processes within the tank environment that could lead to degradation of steel. Some of the likely corrosion processes are pitting and crevice corrosion, stress corrosion cracking, general corrosion, and galvanic cell corrosion. These are discussed in more detail in RPP-RPT-46879, *Corrosion and Structural Degradation within Engineered System in Waste Management Area C*. These processes lead to uncertainties regarding the state of the carbon steel liner; consequently, no credit is taken in the source term release model for its presence.

The A Farm and AX Farm tanks have flat bottoms; the tank steel bottoms intersect the sidewalls orthogonally, unlike the dished bottoms of earlier-designed tank farms. The tanks are equipped with saltwell pump pits located on top of the tanks to provide access to the tank, pumps, and monitoring equipment.

The A Farm SSTs were built by installing a reinforced-concrete base that is at least 6 in. thick. Three layers of asphalt-impregnated waterproofing cotton fabric was then applied to the concrete

base. After the waterproofing was applied, 2 in. of grout were laid on top of it with the steel liner being fabricated on top of the grout. The AX Farm SSTs were similar in construction to the A Farm SSTs but featured a thicker base construction with a network of drain slots for leak detection. The AX Farm SST bases had a minimum of 18 in. of reinforced concrete overlying 2 in. of grout, except where the concrete thickness was reduced 2.5 in. by the drain slots (Figure 3-9).

Figure 3-6. 241-A Farm and 241-SX Farm Single-Shell Tank Configuration.



HEPA = high-efficiency particulate air (filter)

Source: HNF-EP-0182, *Waste Tank Summary Report for Month Ending January 31, 2019*, Rev. 373.

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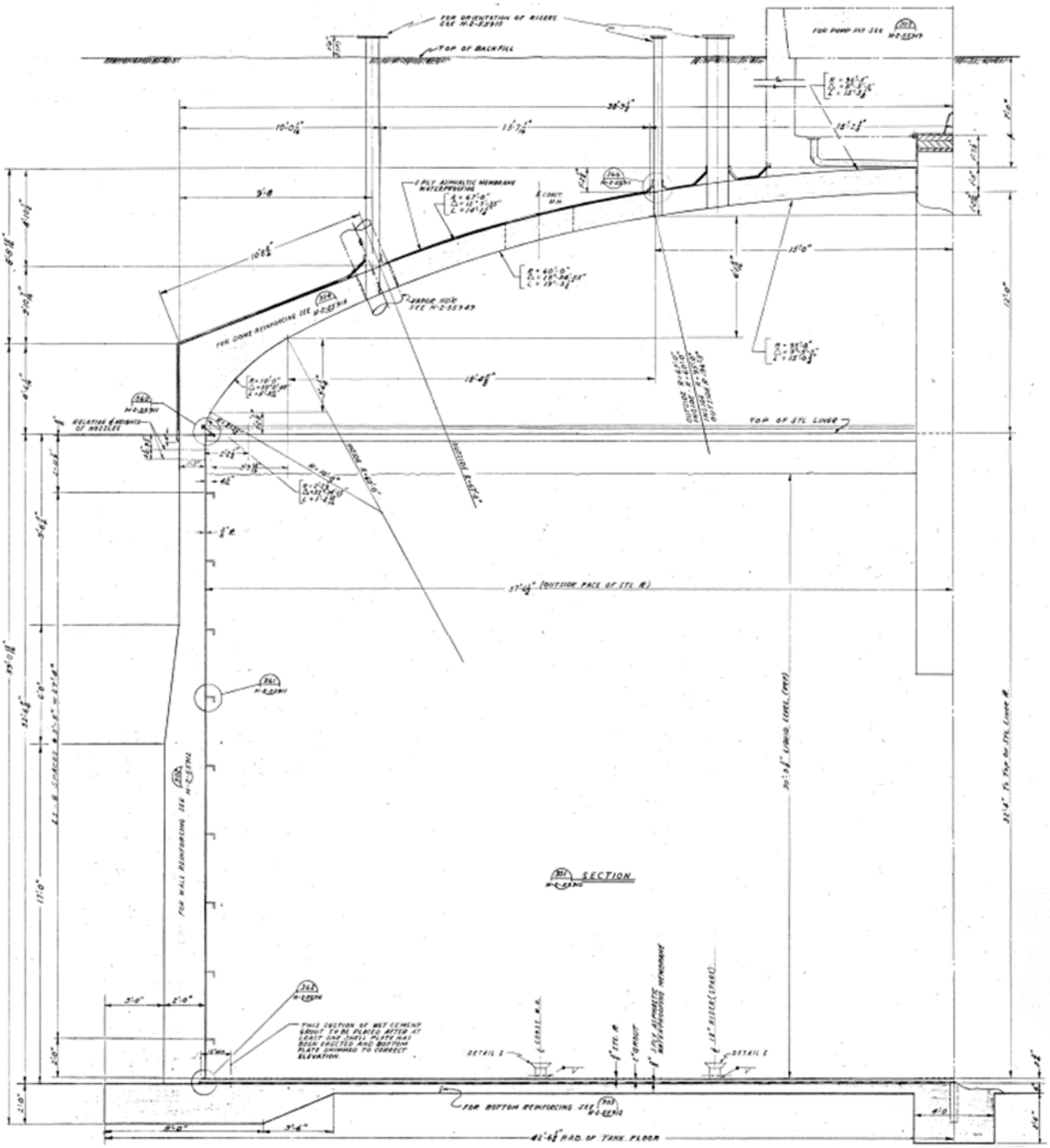
The residual waste layer is conceptualized to overlie the grout layer that is underlain by a base slab concrete layer. The source term model represents the shortest possible vertical diffusive transport path length from residual waste layer to outside of the tank, which is the combined thickness of grout and base slab concrete layer. The diffusive area is taken to be the base area of the tank.

Once the contaminants diffuse through the base of the tank they are treated as advective dispersive transport. For advective transport the flow rate is equated to the flow rates abstracted from the STOMP process model for WMA A-AX. In this leg, the aqueous concentration of

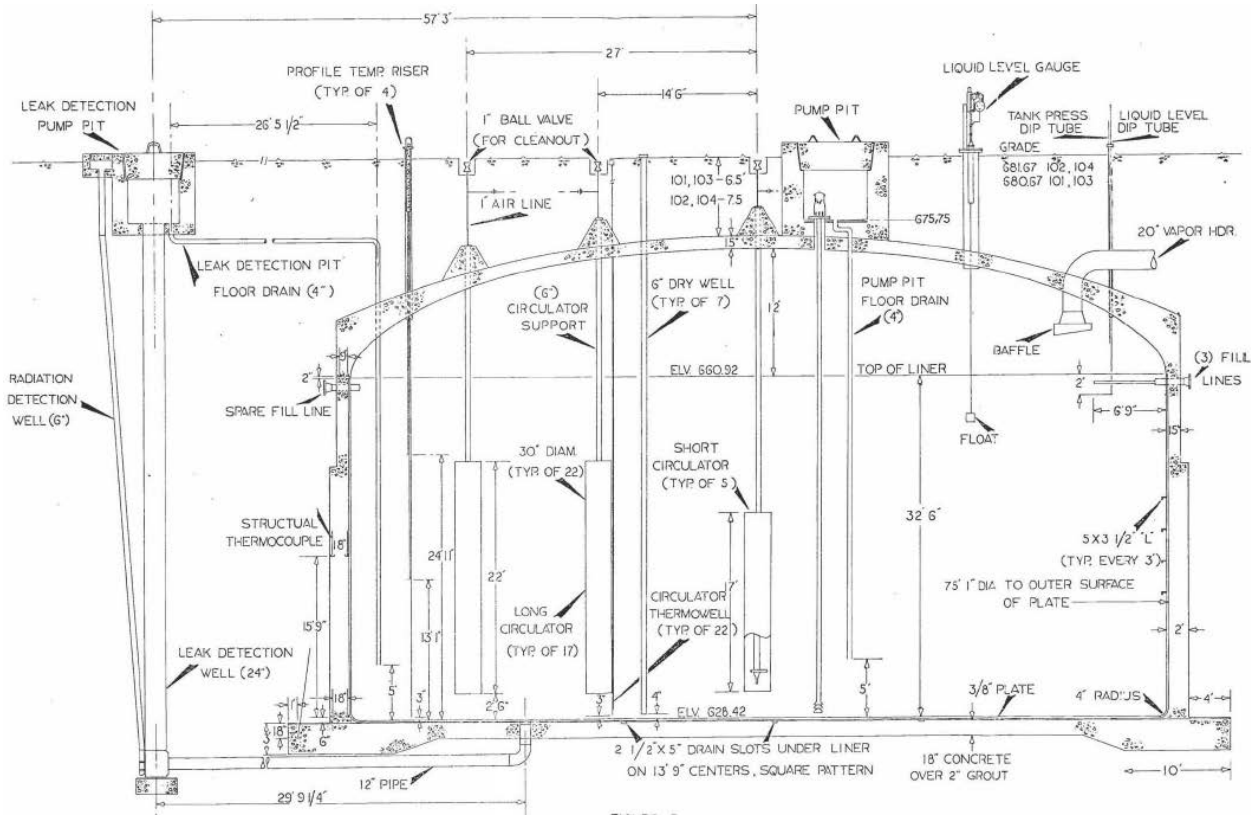
contaminants provide the upgradient boundary condition. The downstream boundary condition is a zero concentration applied at the water table.

Figure 3-7. 241-A Farm Tank Composite.



Source: H-2-55911, "Waste Storage Tanks Composite Section PUREX Waste Disposal Facility," Rev. 1.

Figure 3-8. 241-AX Farm Tank Composite.



Source: RL-SEP-9, *PUREX 241-AX Tank Farm and Waste Routing System Information Manual*.

3.2.2 Pipeline Sources

An extensive network of transfer lines connects the various components of the tank farms. The transfer lines were designed to convey wastes. The piping network conveyed a variety of process wastes, typically in a slurry form. Some lines were installed for specific purposes (e.g., drain lines, saltwell lines), while others were used for general transfers between facilities in the 200 Areas. RPP-15043, *Single-Shell Tank System Description* identified at least 121 pipelines (9.1 miles ± 3 miles) in A Farm and 119 pipelines (7.93 miles ± 2.3 miles) in AX Farm. The identities of these pipelines and the facilities they connect are given in Table 1-1 of RPP-RPT-58293.

The residual inventory for pipeline source is based on the residual volume calculations provided in RPP-RPT-58293 (based on 90% retrieval of catch tanks and vaults and 5% volume in the pipelines) and based on average Hanford Tank Waste Operations Simulator (HTWOS) concentration. The volume estimates provided in RPP-RPT-58293 for the pipelines, diversion boxes, catch tanks, and pits are combined due to limited information on spatial distribution. The inventory estimates at closure (January 1, 2050) are very small for pipelines (RPP-CALC-62319, *Residual Waste Source Inventory Term for the Waste Management Area A-AX Performance Assessment Inventory Case 1*) in comparison to residual waste in the tanks. Due to the small

inventory and lack of adequate information, the following simplifying assumptions are made for the pipeline source conceptual model.

- The waste residual releases are assumed to occur uniformly throughout two specific areas (Figure 3-10) associated with A Farm and AX Farm pipelines. The A Farm pipeline area represents approximately 11,032 m^2, with approximately 6,640 m^2 in the AX Farm pipeline area.

- The residual inventory is conceptualized to be uniformly distributed with the bulk soil (backfill).

- The average thickness of the residual waste is assumed to be 3 in. based on the predominant pipeline diameter present in A Farm and AX Farm.

- The pipelines will not be grouted, and residual waste will be available for release to the surrounding environment due to advection (caused by infiltration water) and diffusion processes.

- While the grout is assumed to remain intact for the length of the simulation, it is assumed that steel components have degraded or will degrade rapidly and will not provide a long-term barrier to flow. No credit is taken for any geochemical safety function served by the presence of steel or its corrosion products.

Figure 3-9. 241-AX Farm Tank Base Drain Slot Arrangement.

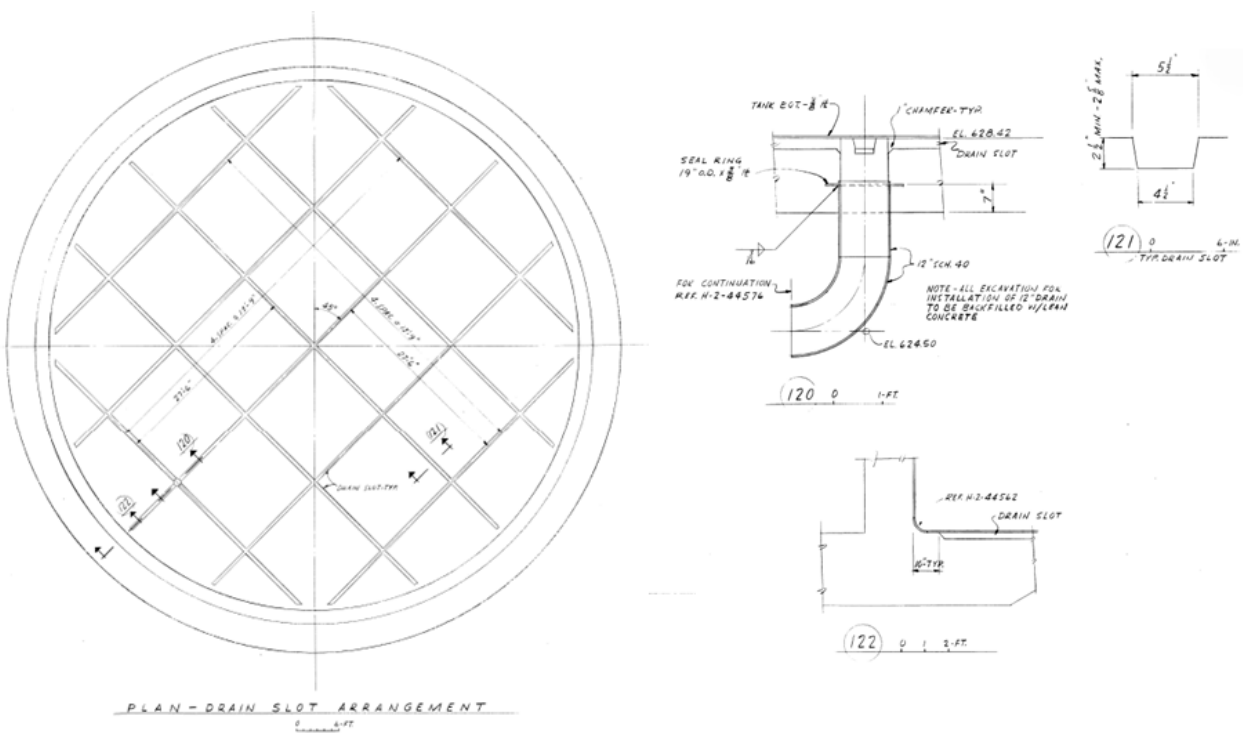
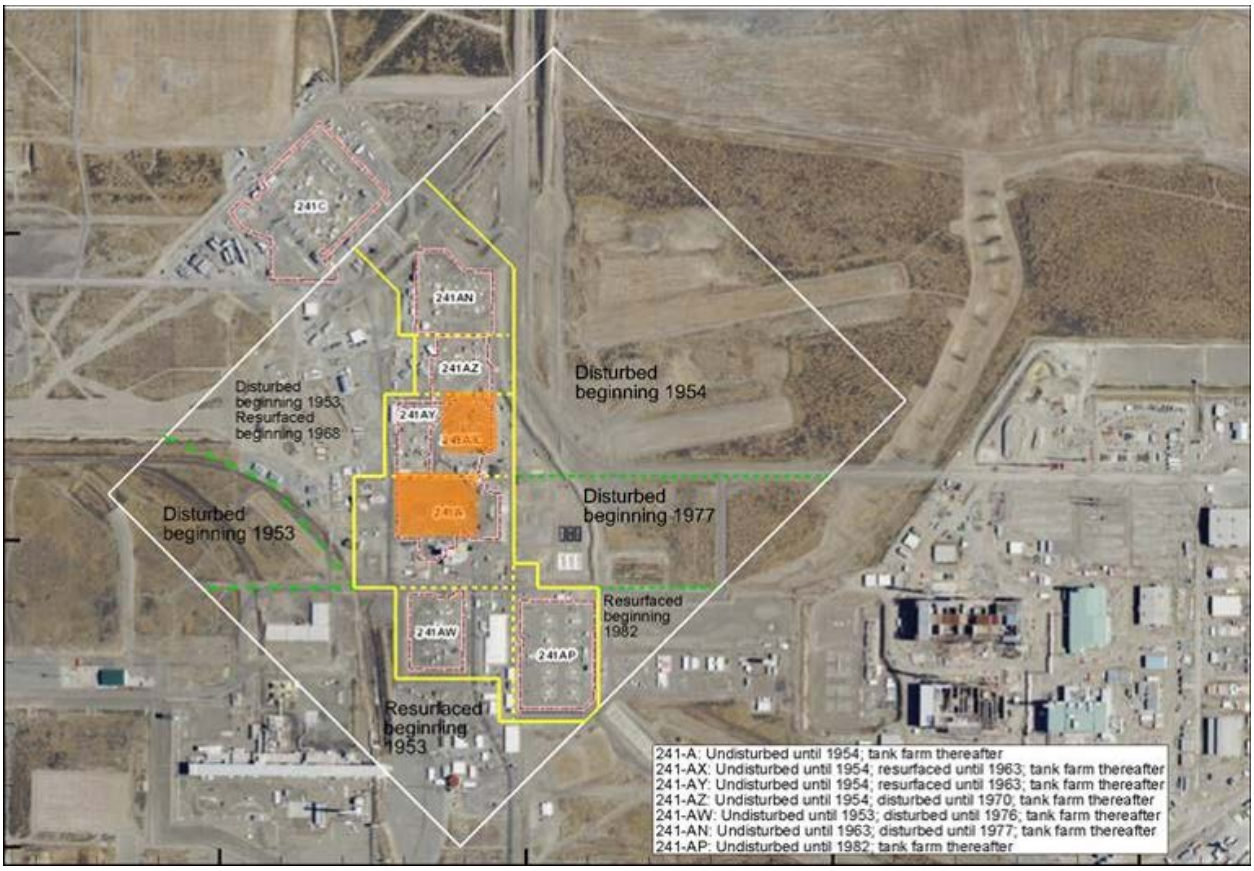


Figure 3-10. Approximate Area (orange shaded area) Associated with 241-A and 241-AX Tank Farm Pipeline Source.



3.3 CONCEPTUALIZATION OF TRANSPORT ALONG GROUNDWATER PATHWAY

This section presents the conceptual description of the release of radionuclides from the closed waste sources, subsequent transport through the thick vadose zone to the water table, and lateral transport through the aquifer to a hypothetical well located 100 m downgradient as implemented in the system model.

The transport of radionuclides to the groundwater is a complicated process that depends on data and assumptions relevant to the following physical systems: (1) engineered features of WMA A-AX (Section 3.2), (2) surface features of WMA A-AX (Figure 3-3), (3) the vadose zone beneath WMA A-AX, and (4) the saturated zone (groundwater) beneath WMA A-AX. Key features and processes expected to affect transport of contaminants through the groundwater pathway include:

- Release of contaminants from tank residuals and pipelines
- Chemical character of the released waste (e.g., salinity, pH, etc.)
- Infiltration rate

- Thickness of the vadose zone
- Hydrostratigraphic unit composition
- Lateral aquifer distance from tanks to point of compliance.

Radionuclide release from the grouted tanks is modeled as diffusive transport through the tank wall grout and concrete base layer because, as described in Section 3.2, the residual waste layer is overlain by a stabilizing grout layer that acts as a barrier to infiltrating water. Pipeline releases are modeled as advective transport because, as discussed in Section 3.2.2, the pipelines will not be grouted and any residual waste can be carried by infiltration water to the surrounding environment. Key processes affecting contaminant release from the WMA A-AX waste forms are detailed in Section 3.2.

Once contaminants enter the vadose zone, the low recharge (infiltration rate) controlled by the surface barrier system, the thickness of the vadose zone between the base of the tanks and the unconfined aquifer, and soil-contaminant interaction prevent all but the least-reactive contaminants from reaching the unconfined aquifer for thousands of years.

The vadose zone underlying WMA A-AX consists of heterogeneous layers of sedimentary units that vary in thickness at different locations. WMA A-AX lies within the Hanford formation unit 1 (H1) in the vadose zone, although construction of the farms replaced the H1 unit with backfill. From top to bottom, the hydrostratigraphic units (HSUs) overlying the basalt beneath WMA A-AX are as follows:

- Backfill (A Farm, gravel-dominated; AX Farm, sand-dominated)

- Hanford formation unit 1 (H1) (sand-dominated) (Note this layer is only in A Farm)

- Hanford formation unit 2 (H2) (sand-dominated)

- Hanford formation unit 3 (H3) (gravel-dominated) (Note that this unit is often referred to as undifferentiated Hanford H3, Cold Creek, and Ringold gravel in the vicinity of WMA A-AX)

- Cold Creek gravel (CCUg) (gravel-dominated)

- Cold Creek silt (CCUz) (silt-dominated).

Conceptually, and for the purpose of simplification, these layers have been combined into equivalent homogeneous medium (EHM) units with macroscopic flow properties. The porous media continuum assumption (an extended form of Darcy's Law for vadose zone applications) and the soil relative permeability/saturation/capillary pressure relations provide the basis for vadose zone flow and transport modeling. In the model domain, the hydraulic properties describing fluid transport characteristics associated with each geologic layer are approximated by average up-scaled values.

As waste moves downward through the vadose zone, chemical reactions between the waste and surrounding sediment may cause some constituents to adsorb onto sediment, thus limiting their mobility. The degree of mobility for individual contaminants is measured by a soil adsorption coefficient (K_d); the less mobile the contaminant, the higher the K_d value. Geochemistry conceptual models involving linear K_d isotherms and developed for the Hanford Site include consideration of the dominant sediment textures, the percentage of gravel, the mineral character of the natural sediments, the chemical character of the released waste, and the extent of interaction between waste releases and the natural sediments (DOE/RL-2011-50, *Regulatory Basis and Implementation of a Graded Approach to Evaluation of Groundwater Protection*; PNNL-17154, *Geochemical Characterization Data Package for the Vadose Zone in the Single-Shell Tank Waste Management Areas at the Hanford Site*). Representative and bounding distribution coefficients (K_d values) recommended for vadose zone modeling are based on extensive laboratory studies, testing, and measurements of adsorption and desorption coefficients under saturated and unsaturated conditions involving Hanford Site-specific sediments, contaminants, and conditions (PNNL-13037, *Geochemical Data Package for the 2005 Hanford Integrated Disposal Facility Performance Assessment*; PNNL-13895, *Hanford Contaminant Distribution Coefficient Database and Users Guide*; PNNL-16663, *Geochemical Processes Data Package for the Vadose Zone in the Single-Shell Tank Waste Management Areas at the Hanford Site*; and PNNL-17154). The distribution coefficient (K_d) conceptual model describing contaminant partitioning holds that for a given volume of sediment, the surface area with reactive mineral phases, organic carbon, or both is less for coarse-textured sediments than for fine-textured sediments (PNNL-13895). Therefore, coarse-textured sediments typically exhibit weaker sorption characteristics than fine-textured sediments, which leads to lower K_d values for HSUs representing coarse-textured sediments than for HSUs representing fine-textured sediments. In most cases, empirical K_d values are determined using sediment samples sieved finer than 2 mm in size (PNNL-13895). Corrections for gravel-size and larger sediments physically excluded by sampling and laboratory techniques are necessary to make the K_d values measured for the fine fraction applicable to a particular HSU.

The saturated zone (aquifer) beneath WMA A-AX affects calculated doses, because as recharge containing contaminants enters the aquifer, the leachate mixes with groundwater and becomes more dilute. This dilution in concentration lowers the exposure point concentration and subsequent dose to a receptor.

3.4 CONCEPTUALIZTION OF TRANSPORT ALONG ATMOSPHERIC PATHWAY

Gases or vapors that are released from the residual waste can potentially diffuse upward through the infill grout, the tank shell or ancillary equipment structure, and the closure barrier to the ground surface, where they can subsequently be transported downwind through the atmosphere to a receptor location. Key processes expected to affect the transport of contaminants through the atmospheric pathway include:

- The partitioning of the COPCs between the solid and liquid phases
- The subsequent partitioning between the liquid and gas phases
- Degree of grout degradation

- Distance through the grout between the waste and the tank dome
- Thickness of overlying soils and surface barrier
- Adsorption of contaminants to sediment
- Distance from tank farm to receptor location.

The release of gases and vapors depends on the partitioning of the COPCs between the solid and liquid phases and the subsequent partitioning between the liquid and gas phases. The partitioning between the solid and liquid phases is defined by the partition coefficient, K_d. The partitioning between the liquid and gas phases is defined by the Henry's Law constant.

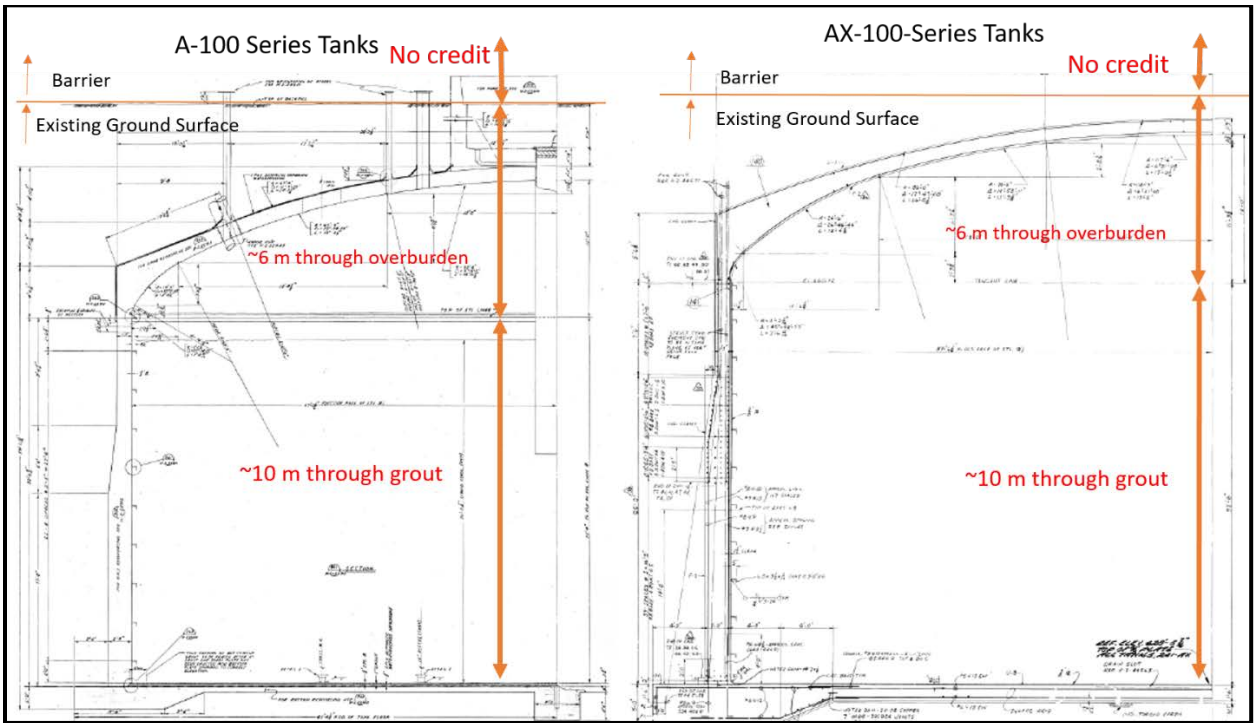
Once the contaminant has partitioned into the gas phase, the principal mechanism by which contaminants migrate through the subsurface is gaseous diffusion along the air-filled pore spaces in the infill grout, backfill sediments, and materials in the surface barrier. The effective diffusion coefficient for each gas is a function of its chemical properties and the pressure, temperature, and gas phase tortuosity of the pore space. Adsorption of COPCs to infill grout is assumed to be at equilibrium, whereas sorption to backfill sediments is ignored for the atmospheric pathway. Atmospheric dispersion acts on COPCs between the point of release to the atmosphere and the point of potential exposure.

It should be emphasized that releases of gases from an SST would be very restricted while the grout monolith remains intact. Section 7 of RPP-RPT-58693 reviewed information available for estimating mechanisms and timing of degradation for the concrete SST shells and infill grout considered in the WMA A-AX PA, which leads to an expectation that "it is highly unlikely for the tank degradation to occur within the modeled time period of 10,000 years."

Figure 3-11 illustrates the conceptual model for upward diffusive gas phase transport in the SSTs and the conservatism of assumptions applied to represent that process in a one-dimensional (1-D) mathematical model. The diffusive area is the base area of each source term, e.g., the area of each SST floor within the liner walls. The diffusive length chosen is the minimum thickness over which gas-phase diffusion is likely to occur through the tortuous air-filled pore volume (defined by the air content). Whereas the grout monolith would fill the entire tank space from the thin residual waste layer anticipated at the tank floor up to the tank dome, only the first 10 m (from the residual layer to just above the height of the fill lines) is modeled as grout. Another 6 m including infill grout in the domespace, the dome concrete, and backfill sediments is modeled as comprising only backfill (overburden). No credit is taken for the small remaining distance to the ground surface nor for any delay of upward gas phase transport to the atmosphere by the future surface barrier.

The air content of the overburden is the difference between the backfill porosity and moisture content, which varies as a function of time. The air content of the infill grout for the purpose of diffusive release calculations is fixed over time, even though chemical transformation of initial grout material will likely cause porosity reduction over time due to increased volume of newly-formed mineral phases.

Figure 3-11. Conceptualization of Air Pathway Diffusive Release from the Tank to the Surface.



References:
H-2-44562, "Structural Waste Storage Tanks Composite Section & Details, 241-AX PUREX Waste Tank Farm," Rev. 4.
H-2-55911, "Waste Storage Tanks Composite Section PUREX Waste Disposal Facility," Rev. 1.

3.4.1 Potentially Gaseous Radionuclides

Of the radionuclides contained in residual inventory at closure, three could potentially originate as gas, and need to be considered as potential contributors to doses associated with the atmospheric pathway:[2]

- Carbon-14
- Hydrogen-3 (tritium)
- Iodine-129.

The chemical form in which these contaminants are released is important to an evaluation of their subsequent behavior in the environment, and in the exposure pathways that need to be considered in the dose assessment. The mechanisms by which these contaminants may be released into gaseous form are not fully understood, leading to a degree of uncertainty in their

[2] The dose performance objective in DOE O 435.1 excludes the contribution from radon. The analysis of the radon pathway is discussed in Section 3.4.2.

assessment as gaseous contaminants. It is considered that the most likely chemical forms in which these contaminants may be released are

- Carbon-14 as either CO_2 or CH_4,
- Tritium (T) as either tritiated dihydrogen (TH) gas or tritiated water (TOH) vapor, and
- Iodine-129 as either I_2 or hydrogen iodide (HI).

The chemical forms CH_4, TH, and I_2 are generally the more stable forms of the three contaminants in environmental conditions, and can be expected to be less reactive and less likely to be redeposited on the ground surface after release, and less likely to interact with components of the food chain.

A Reference Person may be exposed to airborne contaminants through the following mechanism and steps.

- A radionuclide is released from the residual waste in a gaseous form.

- The radionuclide diffuses through the subsurface to the ground surface.

- The radionuclide is released into the air above the WMA, and transported in air to a potential point of exposure.

- A Representative Person at that location may be exposed though inhalation of the contaminant. Evaluation of additional potential exposures is dependent on the chemical form of the contaminant.

- When ^{3}H exists in the air column as water vapor and ^{14}C as CO_2, these radionuclides may partition directly into plants, as these forms are part of the life cycle of the plants. If they exist as H_2 and CH_4, they may not be absorbed.

- For other radionuclides, the radionuclide in the air phase may be redeposited on the ground by dry or wet depositions if it is in a chemical and physical form that is subject to these processes. In general, this means it must be sorbed onto a solid particulate suspended in air or dissolved in an aqueous aerosol suspended in air. Such processes are likely to be small for the stable forms of the contaminants of concern. For these forms, both dry and wet deposition is likely to be negligible.

These steps in the exposure pathway show that ingestion pathways associated with airborne releases from tanks may only occur under very specialized circumstances, and the need to consider them is dependent on the chemical form of the radionuclide. For ingestion pathways to be relevant, the radionuclide must be in a chemical form that is conducive to its deposition on the ground or its uptake in plants. The complexity of the chemistry associated with airborne releases means that the likely chemical form of released radionuclides is uncertain, and that uncertainty leads to uncertainty whether ingestion pathways will occur. For instance, if ^{129}I is released as gaseous iodine (I_2), redeposition of the gas to the ground surface will not occur, and associated ingestion pathways will not occur. However, if ^{129}I is aqueous HI, or is transformed in the

subsurface to an organic iodine species, the potential exists that it could be taken up in water droplets and redeposited, with potential subsequent contamination of the ground surface. In this case, the potential for ingestion pathways is relevant, and should be considered.

These uncertainties prompted a screening calculation (RPP-CALC-63180) to estimate the dose to a receptor inhaling these radionuclides at the site boundary. The calculation assumed that the entire inventory of ^{3}H, ^{14}C and ^{129}I 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 concentration of these radionuclides at the receptor's location was estimated using a method drawing on previous work on atmospheric dispersion for the Central Plateau in which the annual sector-average atmospheric dispersion coefficients (χ/Q) were estimated for ground level and 60-m releases for the 100-N, 200, 300 and 400 Areas at Hanford [PNNL-6415, *Hanford Site National Environmental Policy Act (NEPA) Characterization*, Rev. 18]. These dispersion coefficients are based on meteorological data collected from 1983 through 2006. The dispersion coefficient chosen for the calculation corresponds to 12 km, which is the shortest distance between WMA A-AX and the site boundary.

The concentration of gaseous COPCs at the receptor location was calculated by (PNNL-6415):

$$\chi = \frac{\chi}{Q'} \times Q \tag{3-1}$$

Where:

χ = Air concentration (Ci/m^3)
$\frac{\chi}{Q'}$ = factor – concentration at receptor location per unit release from source (1.3×10^{-7} s/m^3 [PNNL-6415, Rev. 18])
Q = Emission rate (Ci/s).

The resulting concentration in air was used to calculate the inhalation dose to receptor using the following equation:

$$D_{inh,i} = C_{air,i} \times (INH_{in} \times t_{in} + INH_{out} \times t_{out}) \times DCF_{inh,i} \tag{3-2}$$

Where:

$D_{inh,i}$ = Dose of radionuclide i in air (mrem)
$C_{air,\,i}$ = Concentration of radionuclide i in air (pCi/m^3)
INH_{in} = Indoor inhalation rate (m^3/yr)
t_{in} = Fraction of time spent indoors (unitless)
INH_{out} = Outdoor inhalation rate (m^3/yr)
t_{out} = Fraction of time spent outdoors (unitless)
$DCF_{inh,i}$ = Dose conversion factor of radionuclide i (mrem/pCi).

The dose to the receptor from all radionuclides from all sources at WMA A-AX was calculated to be 2.75×10^{-4} mrem for the year, which is several orders of magnitude lower than the performance objective of 10 mrem/yr. For this reason, the atmospheric pathway was not considered further in the system model.

3.4.2 Radon

The dose performance objective in DOE O 435.1 excludes the contribution from radon. Releases of radon are instead subject to a prescribed radon flux limit at the ground surface of 20 pCi/m^2/s. Therefore, the radon pathway needs to address only the production of radon gas in the waste, and its transport to the ground surface.

Radon-222 (half-life 3.82 days) is produced from the alpha decay of ^{226}Ra (half-life 1,600 years) in the waste. Radium-226 may be present in some residual wastes, and is also produced from decay of ^{230}Th, which means it is part of the decay chains including ^{238}U (half-life of 4.47×10^9 years), ^{234}U (half-life of 2.45×10^5 years), ^{238}Pu (half-life of 87.7 years), and ^{230}Th (half-life of 7.54×10^4 years). The amount of ^{226}Ra associated with the waste is therefore the sum of the initial inventory, and the ingrowth from all precursors in the U-series decay chain.

During the decay by alpha recoil, the produced ^{222}Rn atom (initially in the solid phase) has the potential to end up in either the solid, liquid, or gas phase, with the amount in gas available for further diffusion to the ground surface. The fraction of ^{222}Rn in the gas phase over the total ^{222}Rn produced at any time is called the emanation coefficient, which is typically determined empirically for a given material. The emanation coefficient is highly variable from one material to another and depends on a variety of specific features of the contaminated material, including the distribution of radium within the material particles, grain size and pore size distributions, and moisture content of the contaminated material ("A comprehensive review of radon emanation measurements for mineral, rock, soil, mill tailing and fly ash" [Sakoda et al. 2011]).

Emanation coefficients have not been measured for the WMA A-AX residual waste forms. For the purposes of this assessment, all radon produced is conservatively assumed to be available for gaseous transport (an emanation factor of unity).

Once the radon is produced and released from the waste form, it is assumed to be transported by diffusion upward through the backfill and surface barrier layers to the surface.

3.5 CONCEPTUALIZATION OF INADVERTENT INTRUDER SCENARIO

The inadvertent intruder scenario considers the hypothetical situation where residual waste is disturbed and brought to the surface in the course of drilling a drinking water well and the subsequent dispersal of drill cuttings on the surface. Well drilling is considered to be the most plausible intrusion scenario because it is the only activity that reaches the depth of disposal. A basement scenario is excluded from further analysis because the depth of disposal exceeds regional basement depths.

Inadvertent intruder dose is calculated at times consistent with regulatory guidance contained in NUREG-1854, *NRC Staff Guidance for Activities Related to U.S. Department of Energy Waste Determinations – Draft Final Report for Interim Use*. NUREG-1854 notes that it is inappropriate to strictly apply the waste classification system in Title 10, *Code of Federal Regulations*, Part 61, "Licensing Requirements for Land Disposal of Radioactive Waste" (10 CFR 61), § 61.55, Waste classification (10 CFR 61.55) to tank farm residual wastes, because the underlying assumptions used in developing the generic waste classification system in 10 CFR 61.55 differ from the site-specific considerations at DOE tank farms. Nevertheless, NUREG-1854 further describes appropriate approaches for evaluating the conditions at DOE tank farms using the logic applied to the development of 10 CFR 61.55. They note that the depth to the waste and the use of robust intruder barriers are the determining conditions for the type and timing of intruder scenarios. A robust intruder barrier is defined as one that will prevent intrusion into the waste for 500 years.

NUREG-1854 concludes that for wastes at relatively shallow depths without robust intrusion barriers, it is appropriate to carry out the intrusion calculation at the end of institutional control: 100 years. For deeper wastes when robust intruder barriers exist, it is appropriate to assume that intrusion is prevented for at least 500 years, and therefore the intrusion calculation should be carried out at 500 years. For WMA A-AX, these principles are applied by assuming that pipelines do not represent a significant intrusion barrier, and consequently the intrusion calculation is conducted beginning at 100 years after closure (end of institutional control period). By contrast, the tanks and infill grout represent very significant and robust barriers to intrusion, and therefore the intrusion calculation is conducted beginning at 500 years.

These principles are consistent with prior DOE and NRC approaches to evaluating inadvertent intrusion. DOE O 435.1 allows institutional controls to be effective in deterring intrusion for at least 100 years following closure.

Since tanks will be fully grouted at closure and the residual waste layer is conceptualized to be present near the base of the tank, the tanks represent a significant mechanical barrier to drilling. Therefore, it is not considered likely that the residual tank waste would be disturbed from well-drilling activities. It is more likely that the residual waste in waste transfer pipelines will be intruded because of the absence of a mechanical barrier to drilling compared to drilling through the Hanford unit sediments. Waste transfer pipelines will be flushed and will not be filled with grout at closure. Since the pipelines are not known to be plugged they are assumed to be 5% full of waste for this analysis (RPP-RPT-58293).

Intruder scenarios are evaluated for each of the 12 waste sources (ten 100-series tanks and two pipeline sources). The dose calculations are based on the emplaced radionuclide inventory in WMA A-AX (considering radioactive decay and ingrowth), but ignoring any depletion due to transport of radionuclides from the waste site. The inventory used for the intruder dose calculation is from RPP-RPT-58293. For all inadvertent intruder scenarios, the emplaced wastes are assumed to be distributed uniformly throughout the bottom area of the waste source.

The methodology used to assess exposure to an inadvertent intruder at WMA A-AX is based on the volume of residual waste and drill cuttings exhumed during drilling and assumptions based

on what is done with that material afterwards. Both acute and chronic inadvertent intruder scenarios are evaluated for WMA A-AX. The acute scenario evaluates the dose received during the intrusion event from well drilling and subsequent exposure to residual waste in the drill cuttings; exposure is evaluated over a short time period. Chronic scenarios evaluate the post-intrusion dose received from spreading the drill cuttings over a specific area, after which an individual lives or works on that area. One acute exposure scenario and three chronic exposure scenarios are specified.

3.5.1 Acute Exposure Scenario

A single acute exposure scenario evaluates the short-term exposure of a well driller to drill cuttings that are exhumed from a well that is installed to the depth of the water table for the supply of water. As the well is drilled through the WMA A-AX waste residuals, the driller will be exposed to the radiation dose from the drill cuttings. The well driller is assumed to be exposed to drill cuttings for a total of five days (8 hours per day for a total of 40 hours). The dose is calculated by assuming that the cuttings are uniformly spread across the drill pad and are not diluted by mixing with clean soil. As discussed above, the timing of the intrusion event is assumed to be 100 years for pipelines and 500 years for more highly stabilized wastes with robust intrusion barriers.

Exposure pathways evaluated for the well driller scenario are incidental soil ingestion, inhalation of soil particulates, and direct external exposure as illustrated in Figure 3-12.

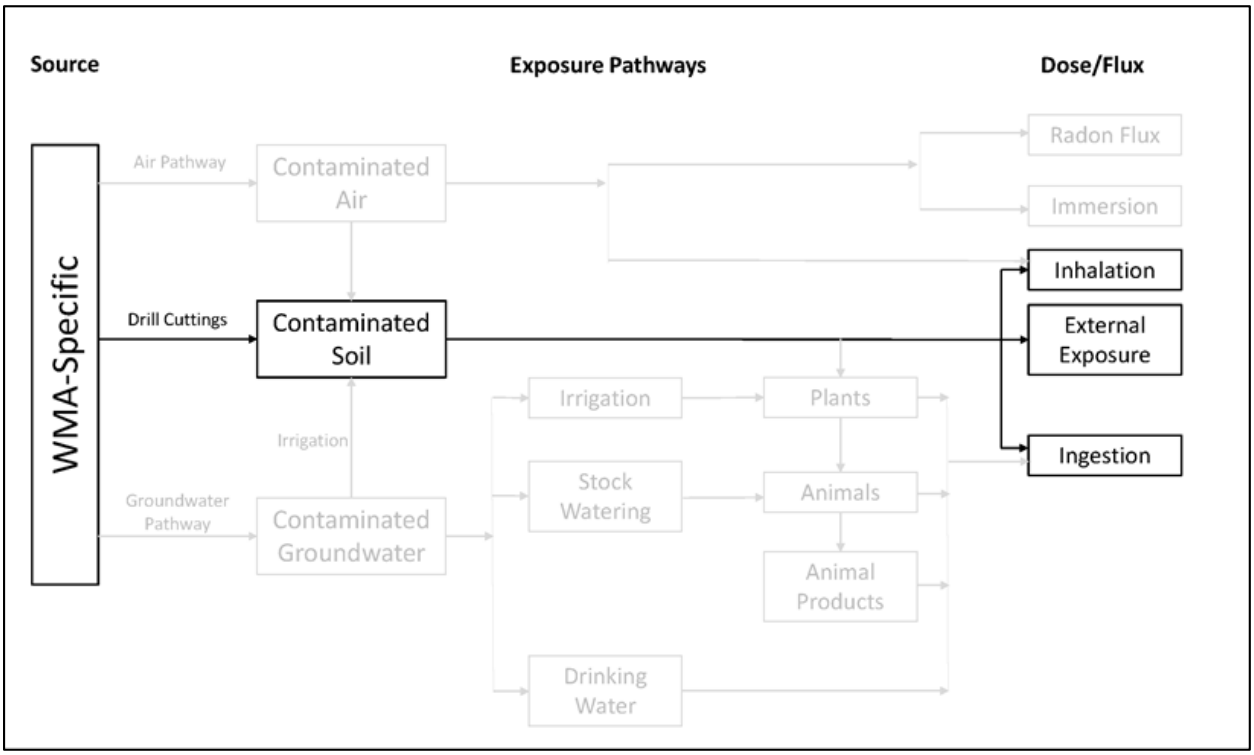
3.5.2 Chronic Exposure Scenarios

Three chronic hypothetical inadvertent intruder exposure scenarios are evaluated for the WMA A-AX PA which are representative of lifestyles in and around the Hanford Site. These scenarios evaluate the long-term exposure of three different receptors from previously-exhumed drill cuttings that have been uniformly spread and tilled onto three different land areas or target fields. The three different target fields include the following: a rural pasture, a suburban garden, and a commercial farm. Radionuclide concentrations in the target field are dependent on the diameter of the well that is drilled to support the scenario, the area of the target field over which the drill cuttings are spread, and the depth to which the drill cuttings are tilled into the soil. In the chronic scenarios, the exposed individual does not drill or add the cuttings to the soil but simply lives or works on the land where the cuttings have been spread and tilled into the soil.

3.5.2.1 Rural Pasture Scenario

The rural pasture scenario evaluates the long-term exposure to an individual who uses the target field as a residence, with a pasture used for milk production from dairy cows. The pasture is used to raise dairy cattle that eat fodder grown from the pasture, and the resident subsequently drinks the pasture cows' milk. In addition to exposure from milk consumption, the resident is exposed by incidental soil ingestion, inhalation of the soil particulates, and external exposure as illustrated in Figure 3-13.

Figure 3-12. Exposure Pathways Considered in the Inadvertent Intruder Acute Well Driller Scenario.



WMA = Waste Management Area

3.5.2.2 Suburban Garden Scenario

The suburban garden scenario evaluates the long-term exposure to an individual who uses the target field as a home construction lot with a garden. The garden is used to grow fruits and vegetables and the resident subsequently eats them. In addition to exposure from fruit and vegetable consumption, the resident is exposed by incidental soil ingestion, inhalation of the soil particulates, and external exposure as illustrated in Figure 3-14.

3.5.2.3 Commercial Farm Scenario

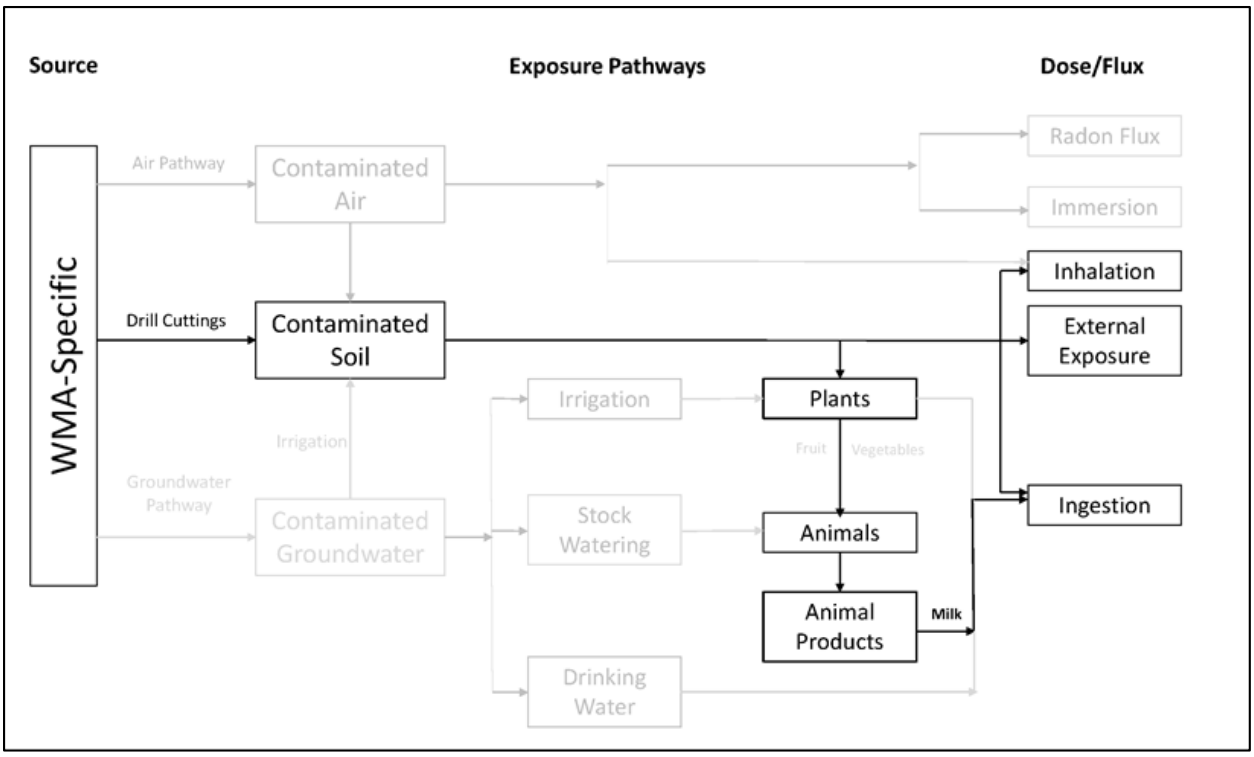
The commercial farm scenario evaluates the long-term exposure to an individual who uses the target field as a commercial farm. This scenario represents an individual who works on the commercial farm, and grows and tends to the crops but does not consume what is produced. The commercial farm worker is exposed by incidental soil ingestion, inhalation of soil particulates, and external exposure as illustrated in Figure 3-15.

3.6 CONCEPTUALIZATION OF EXPOSURE MODEL

To meet the DOE O 435.1 requirements, an all-pathways farmer scenario is implemented to calculate the annual total effective dose equivalent (TEDE) for comparison to the performance objective of 25 mrem/yr, which is the performance objective from all exposure pathways,

excluding the dose from radon and progeny in air. This scenario includes exposure via both groundwater and air transport pathways. For the compliance determinations, dose from these two pathways will be summed and compared to the all-pathways performance objective even though the maximum plume concentrations 100 m from the facility fence line (i.e., the point of compliance) may be at different locations.

Figure 3-13. Exposure Pathways Considered for the Inadvertent Intruder Chronic Rural Pasture Exposure Scenario.



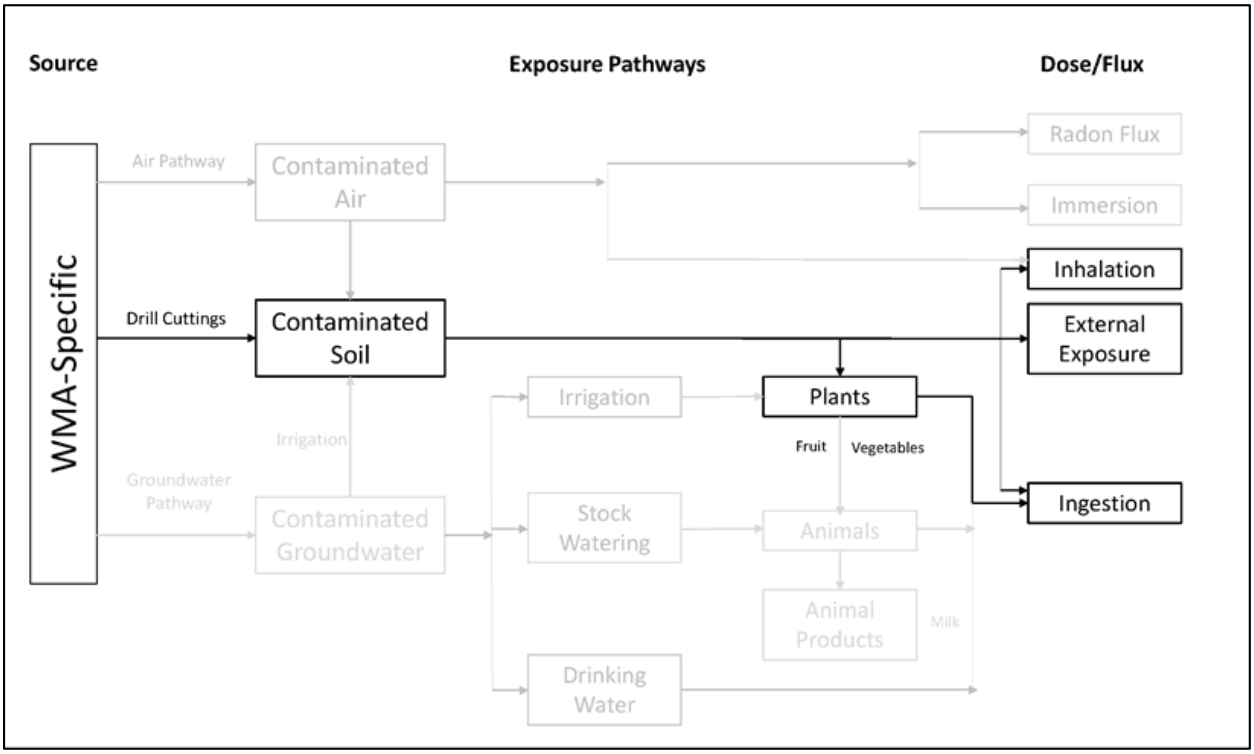
WMA = Waste Management Area

The groundwater pathway dose is based on simulated transport through the groundwater and exposure at an assumed point of contact. The receptor is assumed to reside on a farm located 100 m downgradient from the facility fence line. The receptor withdraws contaminated water from a well located at the 100-m boundary. The receptor is an adult who is assumed to use the water to drink, irrigate crops, and water livestock. The receptor is assumed to receive dose from the following exposure routes:

- Ingestion of water
- Ingestion of garden vegetables grown on the farm
- Ingestion of beef raised on the farm
- Ingestion of milk from cows raised on fodder grown on the farm
- Ingestion of eggs from poultry fed with fodder grown on the farm
- Ingestion of poultry fed with fodder grown on the farm
- Incidental ingestion of contaminated soil
- Inhalation of contaminated soil (dust) in the air

- Inhalation of water vapor
- External exposure to radiation.

Figure 3-14. Exposure Pathways Considered in the Inadvertent Intruder Chronic Suburban Garden Exposure Scenario.

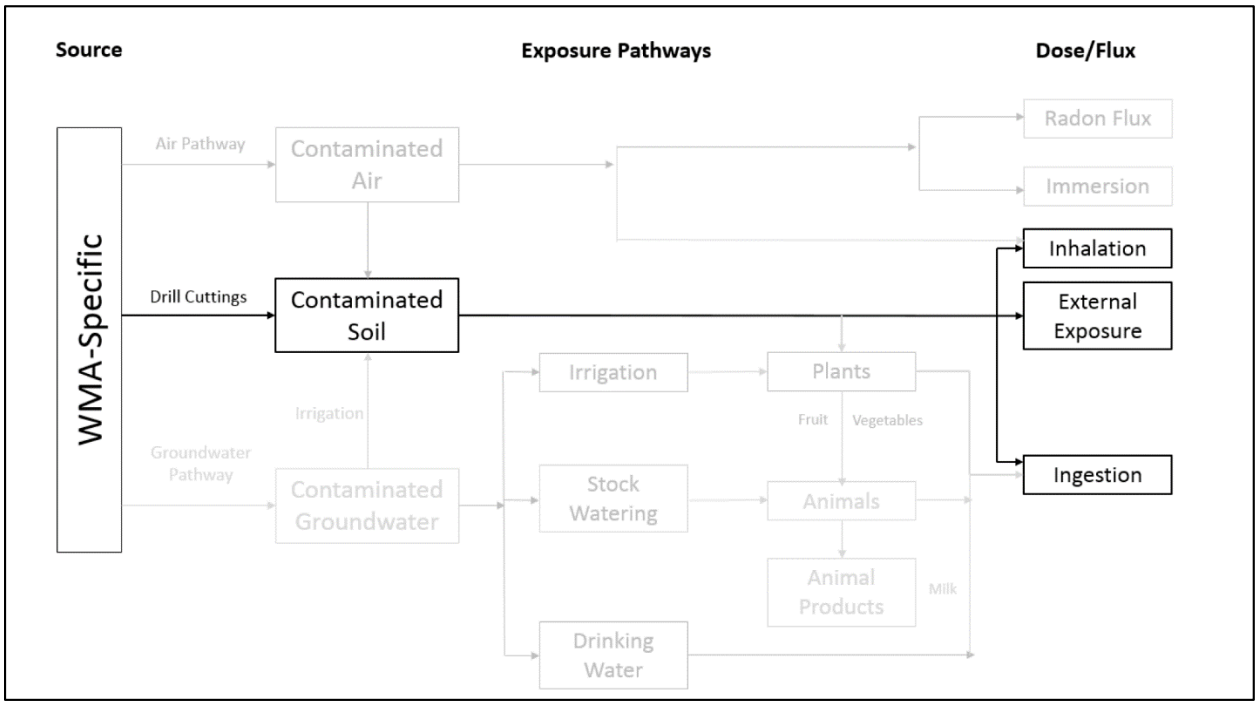


WMA = Waste Management Area

The air pathway dose is based on simulated transport vertically from the waste to the surface of the facility and subsequent transport in air to assumed point of contact. For the atmospheric transport pathway, the following nine exposure routes are considered for the receptor residing 100 m (328 ft) downgradient of the facility fence line:

- Air submersion
- Inhalation of gaseous radionuclides
- External exposure to contaminated soil
- Incidental ingestion of contaminated soil
- Consumption of crops grown on the farm
- Ingestion of beef raised on the farm
- Ingestion of milk from cows raised on fodder grown on the farm
- Ingestion of eggs from poultry fed with fodder grown on the farm
- Ingestion of poultry fed with fodder grown on the farm.

Figure 3-15. Exposure Pathways Considered for the Inadvertent Intruder Chronic Commercial Farm Exposure Scenario.



WMA = Waste Management Area

For each transport pathway, the dose is initially calculated per unit concentration of radionuclides. This will allow the dose associated with any model-predicted concentration to be determined by multiplying the modeled concentration (in pCi/L or pCi/m^3) by the corresponding unit dose factor (in mrem/yr per pCi/L or mrem/yr per pCi/m^3).

Exposure routes and related assumptions are discussed in detail in RPP-ENV-58813, *Exposure Scenarios for Risk and Performance Assessments in Tank Farms at the Hanford Site, Washington*.

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4.0 MODEL IMPLEMENTATION

4.1 SOFTWARE

GoldSim© Pro Version 12.0 use at the Hanford Site is managed and controlled such that the computational needs filled by use of GoldSim© Pro (and any associated utility codes) and the specific roles and responsibilities for management and the modeling staff and subcontractors have been identified and traced.

Software development of GoldSim© Pro meets ASME NQA-1-2008, *Quality Assurance Requirements for Nuclear Facility Applications* with NQA-1a-2009, *Addenda to Quality Assurance Requirements for Nuclear Facility Applications* software requirements, as well as the requirements specified under DOE O 414.1D, *Quality Assurance* for Safety Software. GoldSim© Pro Version 12 is registered in the Hanford Information Systems Inventory (HISI) under identification number 2461. The simulation software is qualified for use and controlled by CH2M HILL Plateau Remediation Company (CHPRC). The HISI registration information lists the documents associated with software grading (it is graded as Level C Safety Software), minimum system requirements, software functional requirements, software management, software testing, and software installation plans. The HISI database also contains information on approved installations and user training. The applicable software quality assurance documents are:

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

Responsibilities for management and the modeling staff include the following:

- modeler training,
- source code installation and testing,
- preserving the software and verification test results,
- validation and verification that the GoldSim© Pro quality assurance documentation demonstrate that GoldSim© Pro meets identified modeling needs and purposes,
- reporting and documenting any software errors (none were encountered during the development of the WMA A-AX PA),
- management of the GoldSim© Pro input files, and
- contingency and disaster recovery.

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

Acceptance and installation tests of the GoldSim© Pro simulation software demonstrate that it is appropriate for its intended uses for the WMA A-AX PA and that it has been successfully installed on the computing systems used to conduct WMA A-AX PA modeling. The software installation and checkout form for GoldSim© Pro is provided in Attachment B to this MPR.

Comparison to runs performed using the STOMP software for confidence-building purposes are described in this MPR, but the STOMP calculations are not described in this MPR because the STOMP models are described by other MPRs and their companion calculation documents.

4.2 SOURCE TERM IMPLEMENTATION

The conceptual model of the source term comprises two primary steps:[1]

1. Release from the waste form, assumed to be residual waste mingled with grout on the bottom of the tank, and

2. Diffusion of the dissolved contaminants across the base mat to the underlying vadose zone.

This conceptual model (described more fully in Section 3.2) is implemented using the GoldSim© simulation software, with the Radionuclide Transport module for simulating radioactive decay and ingrowth. This section reports the GoldSim© model structure, implementation of source term and parameters used in source term implementation.

4.2.1 GoldSim© Implementation of Source Term

Observations of retrieved tanks show that the residual waste is primarily distributed on the tank bottoms (Figure 3-4). Consequently, the residual waste is conceptualized to be distributed in a uniform layer at the base of the tank. The residual waste layer is underlain by a grout layer, which is itself underlain by a concrete base mat. Over the residual waste layer is stabilizing grout, which is covered by airspace within the tank dome (Figure 3-5). Table 4-1 lists the different components of the tanks source term and the values associated with them. Figure 4-1 illustrates how the source term is set up in GoldSim©.

[1] This conceptual model is the primary one, documented in this report. In the full PA, sensitivity analyses are used to explore alternative conceptual models, including advection through the base mat.

Table 4-1. Components of Tanks Source Term and Associated Values Used in the System Model.

	241-A Farm Tanks	241-AX Farm Tanks	GoldSim© Element Name
Stabilizing grout and air (m)	10	10	Tank
Residual waste (m^3)[a]	10.19	10.19	Residual_Waste_Vol_Source
Grout layer (in.)	2	2	Grout_Base
Concrete base slab layer (in.)	6	15.5[b]	

[a]These values represent retrieved tanks. Tanks 241-A-104 and 241-A-105 are assumed to be un-retrieved, and have residual waste volumes of 93 and 139 m^3, respectively.

[b]In the case of 241-AX Tank Farm, the underlying slab concrete layer is 0.45 m (18 in.). For conservatively accounting for presence of the drain slots in 241-AX Farm tanks, the underlying slab concrete layer thickness was assumed to be 15.5 in. (18 in. minus 2.5 in.).

The GoldSim© **Tank** element contains the physical properties for the grout (**Grout_Material** and **Grout_Air**), air (**Air**) and water (**Water**) media contained in the tank. The **Grout_Material** and **Grout_Air** elements contain relevant partitioning coefficients. The **Residual_Waste_Container** contains a **Residual_Waste** mixing cell, a **Water** reference fluid and a lookup table of the solubilities of residual waste chemical components in water.

As long as tank wall integrity is maintained and the infill grout is not physically degraded, the primary contaminant transport process will be diffusive. The shortest diffusive pathway for release to the near-field environment is through the base of the tank. The diffusive area is taken to be the base area of the tank. The aqueous concentration of contaminants in the residual waste provide the upstream boundary concentration for diffusive transport with a zero-concentration boundary being applied in the far field (at the receptor).

Non-tank sources (i.e., pipelines) differ only in that the **Tank**, **Residual_Waste_Container**, and **Grout_Base** elements are replaced by an advectively-controlled **Residual_Waste** mixing cell. The volumes used in the model for non-tank sources are listed in table Table 4-2.

Table 4-2. Ancillary Equipment Volumes Used in the WMA A-AX System Model

	Volume (L)	GoldSim© Element Name
A Farm Ancillary Equipment	6357	Res_Waste_Vol_Source
A Farm Pipelines	3300	Res_Waste_Vol_Source
A Farm Ancillary (Combined)[a]	9657	Res_Waste_Vol_Tank
AX Farm Ancillary Equipment	1203	Res_Waste_Vol_Source
AX Farm Pipelines	2900	Res_Waste_Vol_Source
AX Farm Ancillary (Combined)	4103	Res_Waste_Vol_Tank

[a]Ancillary Equipment and Pipelines are combined for groundwater transport calculations. Only pipelines are used in intruder calculations

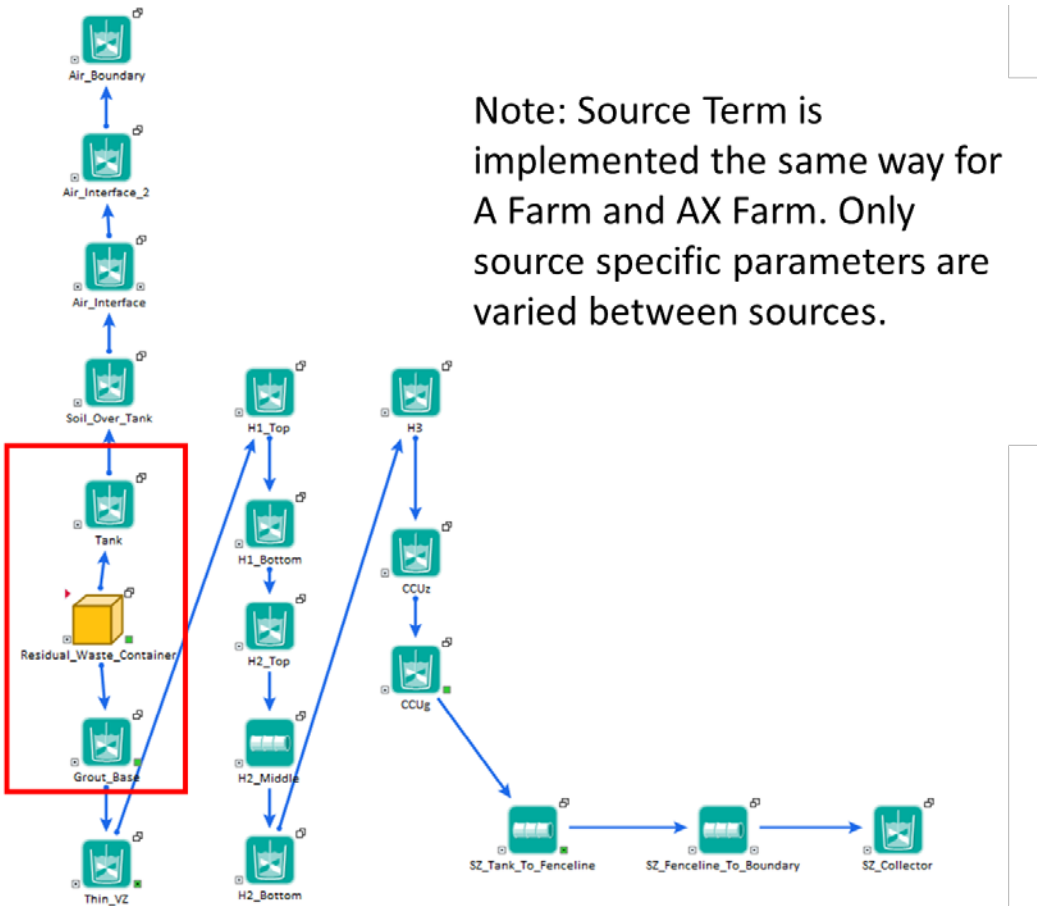
Source: RPP-CALC-62319, *"Residual Waste Source Inventory for the Waste Management Area A-AX Performance Assessment Inventory Case 1"*, Table 4-6

4.2.2 Waste Form Release Mechanisms

As mentioned in Section 3.2, 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 those of WMA C residual waste. Waste form degradation and release mechanisms of WMA C tank residual waste were evaluated experimentally for ^{99}Tc, uranium, and chromium. These experiments were conducted under static and under slowly-flowing conditions as described in "Single-pass flow-through test elucidation of weathering behavior and evaluation of contaminant release models for Hanford tank residual radioactive waste" (Cantrell et al. 2013) and "Thermodynamic Model for Uranium Release from Hanford Site Tank Residual Waste" (Cantrell et al. 2011). Based on the results of the experiments and detailed evaluations, the following conditions are applied to uranium:

- Apply a solubility limit of 1×10^{-4} M for 1,000 years (equivalent to a reaction progress of 0.2) based on the assumption that amorphous uranium mineral phases such as $Na_2U_2O_7$(am) control the solubility.

Figure 4-1. Transport Abstraction Model for A Series Tanks.



Note: Elements used in the source term are indicated in red outline.

- After 1,000 years, apply the solubility limit of 1×10^{-6} M, assuming $CaUO_4$ as the solubility-controlling mineral phase under $Ca(OH)_2$ saturated conditions (infill grout saturated and intact-tank conditions).

- If and when the tank is assumed to be degraded such that flow rates are fast enough not to equilibrate with the infill grout material and are $CaCO_3$ saturated (vadose zone water), then apply a solubility limit of 1×10^{-4} M for 1,000 years. Beyond this time, apply solubility limit of 2×10^{-5} M based on the long-term uranium concentrations assuming minimal influence of $Ca(OH)_2$ water (Cantrell et al. 2011).

For chromium, a constant high dissolved concentration limit of 2,000 µg/L is imposed. This value is at the high end of observed values in tank 241-C-202 leachate (Cantrell et al. 2013). All other analytes evaluated in the WMA A-AX PA, including ^{99}Tc, are assumed to be instantly and completely available in solution for immediate diffusive release within the tank residual waste volume. This assumption tends to maximize release rates compared to alternative assumptions.

4.2.3 Diffusion Coefficients

The effective diffusion coefficient of mobile contaminants (such as ^{99}Tc) through the combined grout and concrete base mat is considered a key parameter that controls the diffusive flux. Over the past decade, several experiments have been conducted to determine the effective diffusion coefficient through concrete for relatively mobile contaminants under unsaturated conditions. The results of various experiments are presented in PNNL-23841, *Radionuclide Migration through Sediment and Concrete: 16 Years of Investigations*. Of particular interest are the sediment-concrete half-cell experiments conducted in Year 2008 (for a period of 351 days) with ^{99}Tc and stable iodine. The concentration profiles developed in the concrete are analyzed by fitting the analytical solution to Fick's second law, with the assumption of zero concentration downstream boundary condition, and deriving a bulk diffusion coefficient for the media. This bulk diffusion coefficient implicitly incorporates the effects of porosity and tortuosity due to diffusion that primarily occurs along the water films in the concrete. For the purpose of modeling mass transport along the water (liquid) phase the effective diffusion coefficient in the water phase is needed (instead of bulk diffusion coefficient), which can be derived by multiplying bulk diffusion coefficient with the moisture content. Since the moisture content of the base mat concrete and grout material is not known and would likely change with time due to slow but steady physical and chemical degradation, the effective diffusion coefficient is chosen conservatively to be the same as the measured bulk diffusion coefficient for the purpose of source-term modeling. In other words, the reduction due to multiplying with moisture content is not applied for calculating the diffusive flux. Note that the effective diffusion coefficient incorporates the effects of tortuosity resulting from transport along water films in the porous media.

According to PNNL-23841, the calculated effective diffusion coefficients of ^{99}Tc derived from the experimental results range from 6.6×10^{-9} cm^2/s to 1.6×10^{-7} cm^2/s, with a median value of about 3×10^{-8} cm^2/s. No particular measurable trend exists to indicate whether the effective diffusion coefficient varies with moisture content of the sediment. The highest ^{99}Tc diffusivities were predominantly observed in the non-carbonated concrete cores contacting spiked sediments. A clear effect from the addition of iron was not observed. In general, the increased carbonation reduced diffusion coefficients. For the purpose of the PA base case calculations, a best-estimate value of 3×10^{-8} cm^2/s is chosen for the effective diffusion coefficient in concrete. Effective diffusion coefficient is a physical property, which is not dependent on species-specific solubility and/or sorption (SRNL-STI-2016-00175, *Solid Secondary Waste Data Package Supporting Hanford Integrated Disposal Facility Performance Assessment*). This value is applied to all species diffusing through the concrete. Data from experiments on 100 cement paste and mortar specimens involving the leaching of nitrate, nitrite, tritium and chloride resulted in a geometric mean effective diffusion coefficient of 3×10^{-8} cm^2/s (SRNL-STI-2016-00175) and provides a good basis for the value selected for this model. The effects of sorption onto the concrete are constituent-specific so that different constituents will diffuse through the concrete at different rates.

4.2.4 Sorption of Contaminants to Grout and Concrete

A linear sorption isotherm (using a K_d approach) is used to represent sorption within the grout and concrete layer for various contaminants as they undergo diffusive (and advective) transport through the tank. Development of a sophisticated sorption model depends on the availability of complete sets of experimental data, including measurement of isotherm, and dependence on solid-to-liquid ratio under conditions that are applicable to the near-field environment. It is noted that presently the vast majority of sorption values on cementitious material are still results from single-point measurements, and information on uptake mechanisms and uptake controlling phases in cement systems are lacking to a large extent (NAGRA NTB 02-20, *Cementitious Near-Field Sorption Data Base for Performance Assessment of an ILW Repository in Opalinus Clay*). The macroscopic studies would have to be complemented by studies performed on a molecular level to discern uptake processes. Due to these limitations, the available sorption databases typically rely on expert judgment in selecting realistic and defensible sorption values. As a result, a simple linear sorption isotherm approach based on empirical information that is commensurate with the level of knowledge is applicable.

As described below, selections for values of K_d have been made based on review of past reports that are focused on developing internally-consistent sorption databases for cementitious near-field material (hardened cement paste) based on composition of cement porewaters and stage of cement degradation.

- Because the closed tanks are in the unsaturated zone, conditions are expected to be moderately oxidizing. When data are available to differentiate between oxidizing and reducing conditions, oxidizing conditions are assumed. This approach leads to selecting lower K_d values in the model.

- Composition of the cementitious material (grout or concrete) may have different chemical compositions, and therefore differ in contaminant uptake mechanisms and cement phases. Due to lack of information, the differences in sorption between various types of cements and concretes are ignored here.

- The selected K_d values are based on the assumption of $Ca(OH)_2$-saturated waters contacting the waste, and therefore represent the so-called stage II of the chemical degradation of cementitious material. In this stage, chemical composition of the alkali-depleted cement pore water is controlled by the solubility of portlandite. The impact on K_d values during evolution of chemical conditions from stage I (higher alkali content and pH) to stage II is expected to be minor and incorporated within the uncertainty range.

- The reviews of SKB Rapport R-05-75, *Assessment of uncertainty intervals for sorption coefficients, SFR-1 uppföljning av SAFE* and NIROND-TR 2008-23 E, *Review of sorption values for the cementitious near field of a near surface radioactive waste disposal facility, Project near surface disposal of category A waste at Dessel* are more recent, and represent critical reviews and independent data from NAGRA NTB 02-20 and PSI Bericht Nr. 95-06, *Sorption Databases for the Cementitious Near-Field of a L/ILW*

Repository for Performance Assessment. Where appropriate values are available from these more recent references, they are preferred to the older ones.

- When literature values are absent from these references, a value of zero has been assigned to the analyte. At this stage of the PA, no attempt has been made to draw chemical equivalences between similar analytes to justify nonzero K_d values. As necessary, the chemical equivalences suggested by SKB Rapport R-05-75 may be used to update K_d values.

- When there was significant disagreement between literature sources, the more conservative (lower) K_d value was chosen but a range of K_ds are addressed in the uncertainty analysis. This occurs, for instance, in a preference for NAGRA NTB 02-20 data for oxidizing conditions, compared to values from more recent references. In assessments of the Central Plateau, this tends to be a conservative assumption because of the long transport times.

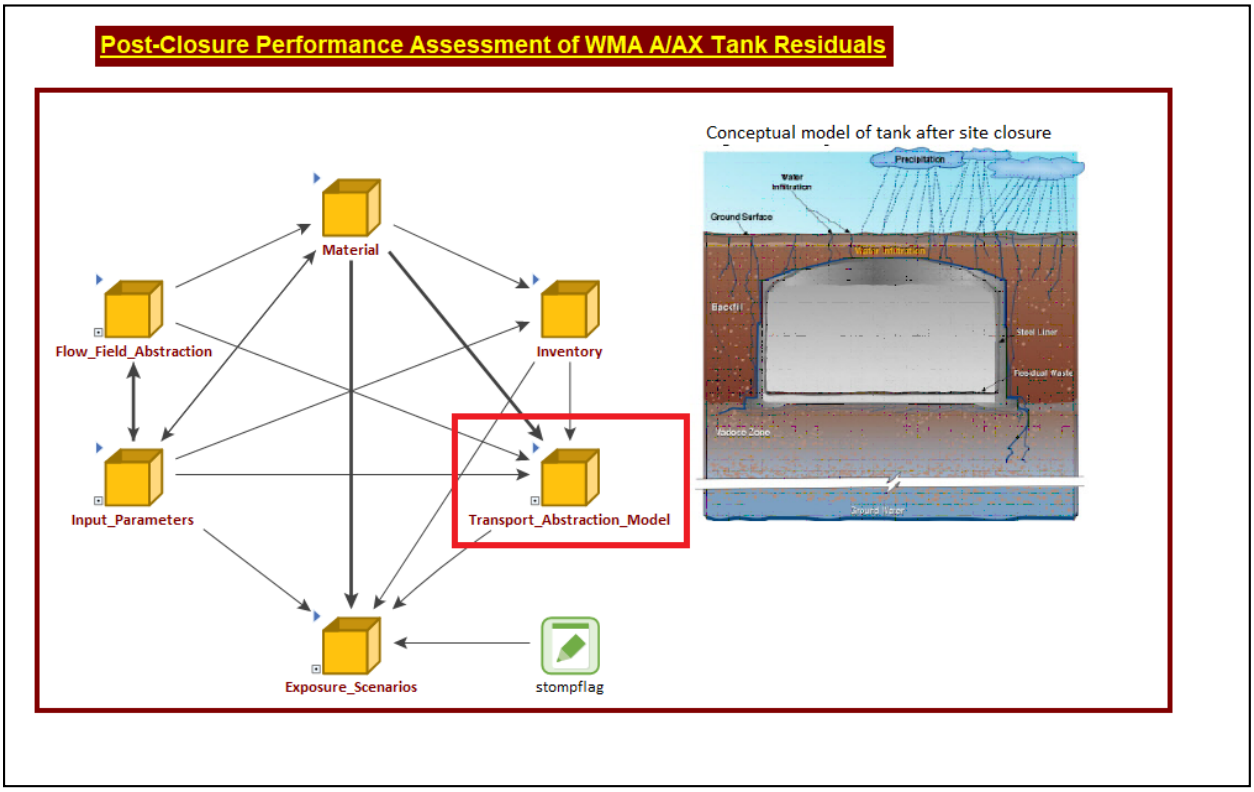
Appendix C presents the entire list of grout/concrete K_d values in terms of best estimate and the uncertainty range that are derived from relevant published literature for chemical conditions that are likely to exist within the grout/concrete layer within the tanks.

4.3 IMPLEMENTATION OF GROUNDWATER TRANSPORT PATHWAY

The groundwater pathway transport calculation includes release of radionuclides from the different sources, transport through the thick vadose zone to the water table, and then transport through the aquifer to a hypothetical well located 100 m downgradient. In the system-level model, releases from the source term models (Section 3.3) are coupled directly to the natural system transport models. The natural system transport models in the system-level model implemented in GoldSim© are 1-D abstractions of the 3-D process-level models implemented in STOMP. Figure 4-2 shows the location of the vadose zone transport module within the GoldSim© model.

The GoldSim© software is not used to calculate flow in partially-saturated media; it requires that the transport elements be provided the moisture content and Darcy flow rate. The flow field for the vadose zone and saturated zone is derived from the 3-D STOMP model, and abstracted to provide a 1-D representation of the flow in key locations as input to the process-level analysis. Figure 4-3 shows the location of the abstracted flow field container within the GoldSim© model. Transport using the abstracted flow field will be compared between the system-level and process-level model results to ensure that the two produce comparable results. The general structure of the system-level vadose zone and saturated zone transport model implementation is shown in Figure 4-4.

Figure 4-2. Root Level of the Waste Management Area A-AX System Model.



Note: Containers used in the vadose zone transport calculations are indicated with red outline.

WMA = Waste Management Area

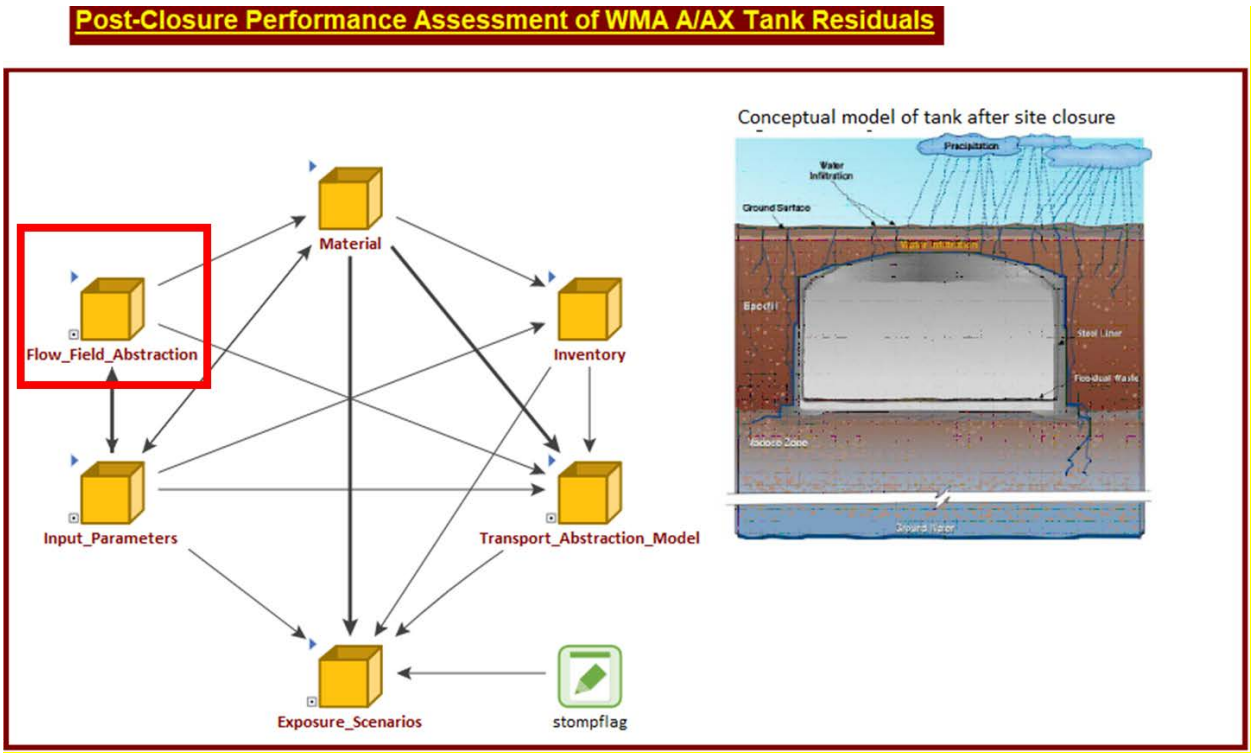
4.3.1 System-Level Model Discretization and Flow Field Abstraction

First, the approximate thicknesses of the HSUs were extracted from the STOMP-based model under each of the tanks. As discussed in Chapter 3, residual waste was assumed to be uniformly distributed in the base of the tank. Each tank base area occupies certain nodes (I, J) in the STOMP model. The thicknesses of HSUs based on average of all the nodes occupied by a tank are extracted from the STOMP model. Table 4-3 presents the average thickness of each HSU under each of the tanks in A Farm and AX Farm; the average thickness for each HSU for each tank farm is also presented. Figure 4-5 presents the average thickness of each HSU by farm graphically.

Figure 4-5 shows that the H1 gravelly sand unit is absent underneath AX Farm tanks and the H3 gravelly unit is thicker below AX Farm tanks than below A Farm tanks. Table 4-3 shows that the average thickness of the HSUs beneath all of the tanks in A Farm is very similar to tank 241-A-102 (A-102). Table 4-3 also shows that the average thickness of the HSUs beneath all of the tanks in AX Farm is very similar to tank 241-AX-101 (AX-101). Based on this information, one representative column (based on HSU thicknesses below tank A-102) was selected for A Farm and another representative column (based on HSU thicknesses below tank AX-101) was selected for AX Farm in the system model. Four vertical 1-D transport networks were implemented in the GoldSim© model to simulate the transport through the vadose

zone. Two columns represent transport below A Series tanks (Figure 4-6) and AX Series tanks (Figure 4-7), while the other two columns represent transport below non-tank sources at A Farm (Figure 4-8) and at AX Farm (Figure 4-9). The GoldSim© cloning method is used in the model to replicate the vadose zone transport model for each waste source. Only source specific parameters (source release rates, source width, source area, aquifer width) were varied between sources. Figure 4-10 shows the cloned containers within the **Transport_Abstraction_Model** container of the GoldSim© model.

Figure 4-3. Root Level of the Waste Management Area A-AX System Model.



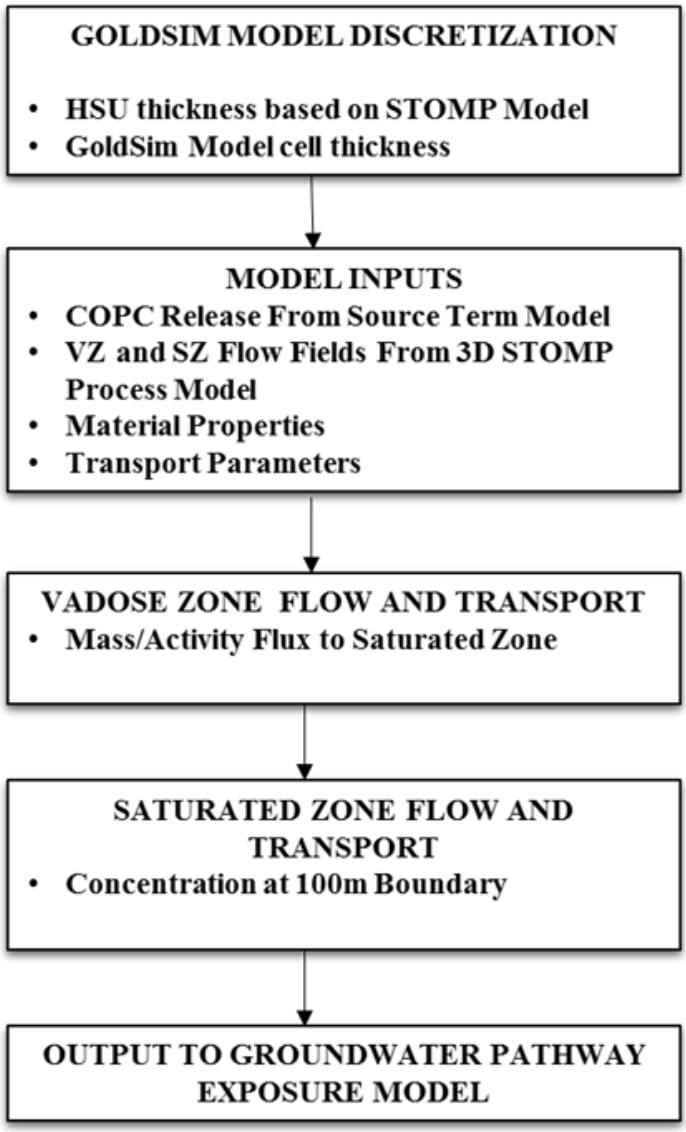
Note: Container used for the vadose zone flow field are indicated with red outline.

WMA = Waste Management Area

The vadose zone flow-field abstractions were performed separately for A Farm and AX Farm. The flow field (Vertical Darcy flow rate and moisture content) was extracted from STOMP model simulation for each of the vertical layers below tank A-102 and tank AX-101. The flow fields for all the nodes (I, J) were extracted from STOMP model results; both arithmetic mean and geometric mean of the flow fields were calculated (for a certain layer, all the I, J nodes occupied by the tank were averaged). The system model user has the flexibility to use either arithmetic mean or geometric mean of the flow field. For the pipeline, the flow field was calculated based on all the nodes occupied by the area assumed for A Farm pipeline and AX Farm pipeline. Figure 4-11 shows the contents of the **Flow_Field_Abstraction** container of the GoldSim© model. Within that container are separate flow fields for the A Farm tanks (GoldSim© container **Flow_Field_A100_Tanks**, Figure 4-12), the AX Farm tanks (GoldSim© container **Flow_Field_AX100_Tanks**, Figure 4-13), the A Farm pipelines (GoldSim© container

Flow_Field_Pipeline_A, Figure 4-14), and the AX Farm pipelines (GoldSim© container **Flow_Field_Pipeline_AX**, Figure 4-15).

Figure 4-4. General Structure of System-Level Groundwater Pathway Transport Model in GoldSim.



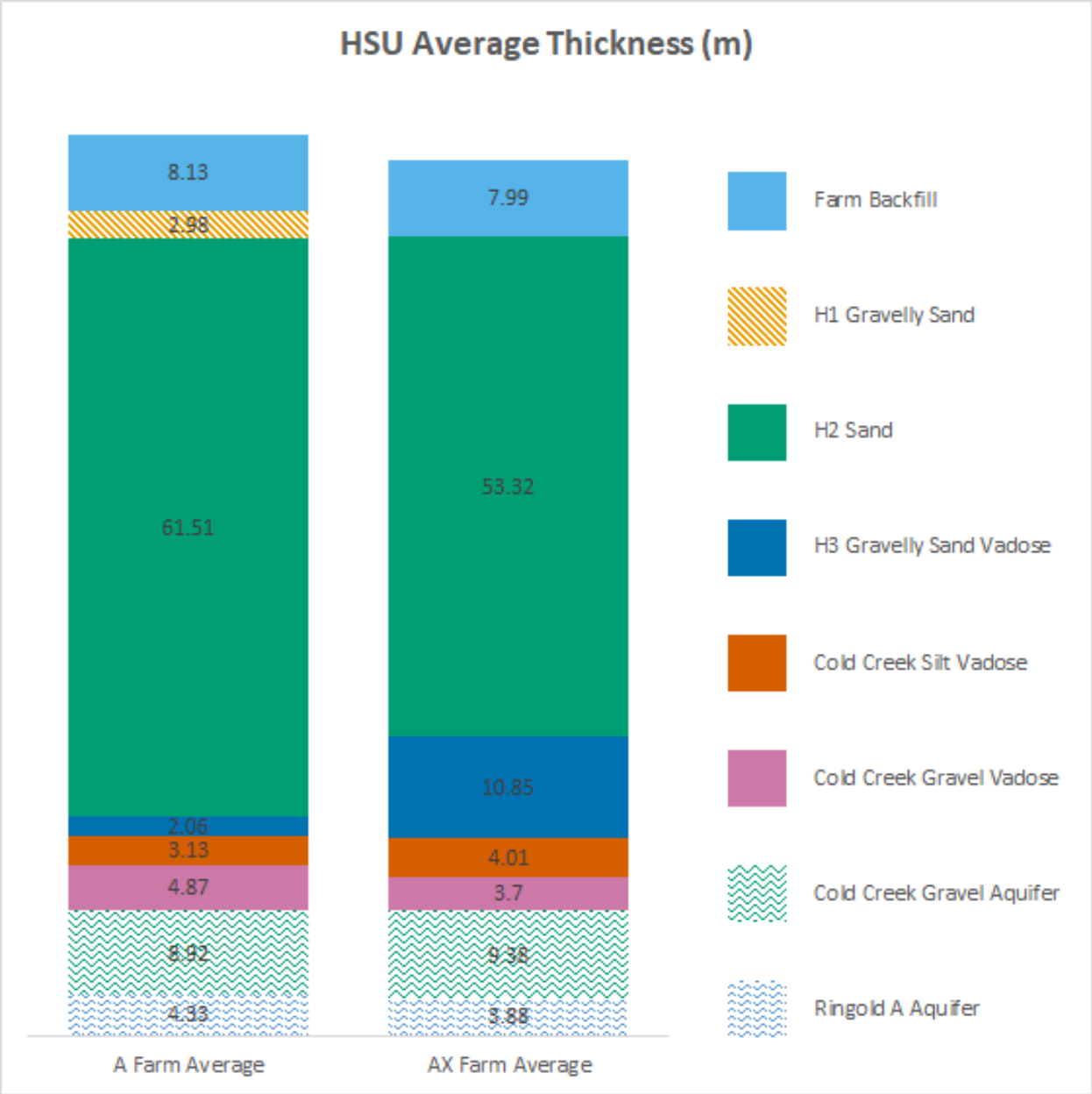
3D = three-dimensional HSU = hydrostratigraphic unit VZ = vadose zone
COPC = constituent of potential concern SZ = saturated zone

GoldSim© simulation software is copyrighted by GoldSim Technology Group LLC of Issaquah, Washington (see http://www.goldsim.com).
Subsurface Transport Over Multiple Phases (STOMP) has been developed and distributed by Battelle Memorial Institute.

Table 4-3. Hydrostratigraphic Unit Thickness (in meters) below each Tank in 241-A and 241-AX Farms.

Hydrostratigraphic Unit	Tank 241-A-						241-A Farm Average	Tank 241-AX-				241-AX Farm Average
	101	**102**	**103**	**104**	**105**	**106**		**101**	**102**	**103**	**104**	
Ringold A Aquifer	3.94	3.70	4.47	5.02	4.50	4.36	**4.33**	3.25	3.28	4.43	4.53	**3.88**
Cold Creek Gravel Aquifer	9.31	9.55	8.78	8.23	8.75	8.89	**8.92**	10.00	9.97	8.82	8.72	**9.38**
Cold Creek Gravel Vadose	4.68	4.90	4.79	5.04	4.96	4.85	**4.87**	2.94	3.83	3.75	4.26	**3.70**
Cold Creek Silt Vadose	2.60	3.01	3.38	2.82	3.36	3.63	**3.13**	3.88	3.75	4.13	4.29	**4.01**
Hanford Formation Unit 3 Gravelly Sand Vadose	0.96	1.38	1.84	1.85	2.70	3.65	**2.06**	12.65	12.89	8.63	9.22	**10.85**
Hanford Formation Unit 2 Sand	63.54	61.82	63.83	60.87	57.53	61.46	**61.51**	52.39	51.39	55.39	54.11	**53.32**
Hanford Formation Unit 1 Gravelly Sand	2.88	3.30	1.00	3.93	5.31	1.43	**2.98**	—	—	—	—	**—**
Farm Backfill	8.81	8.28	7.92	7.94	7.92	7.92	**8.13**	7.94	7.89	7.92	8.19	**7.99**

Figure 4-5. Average Hydrostratigraphic Unit Thickness (in meters) in 241-A and 241-AX Tank Farms.

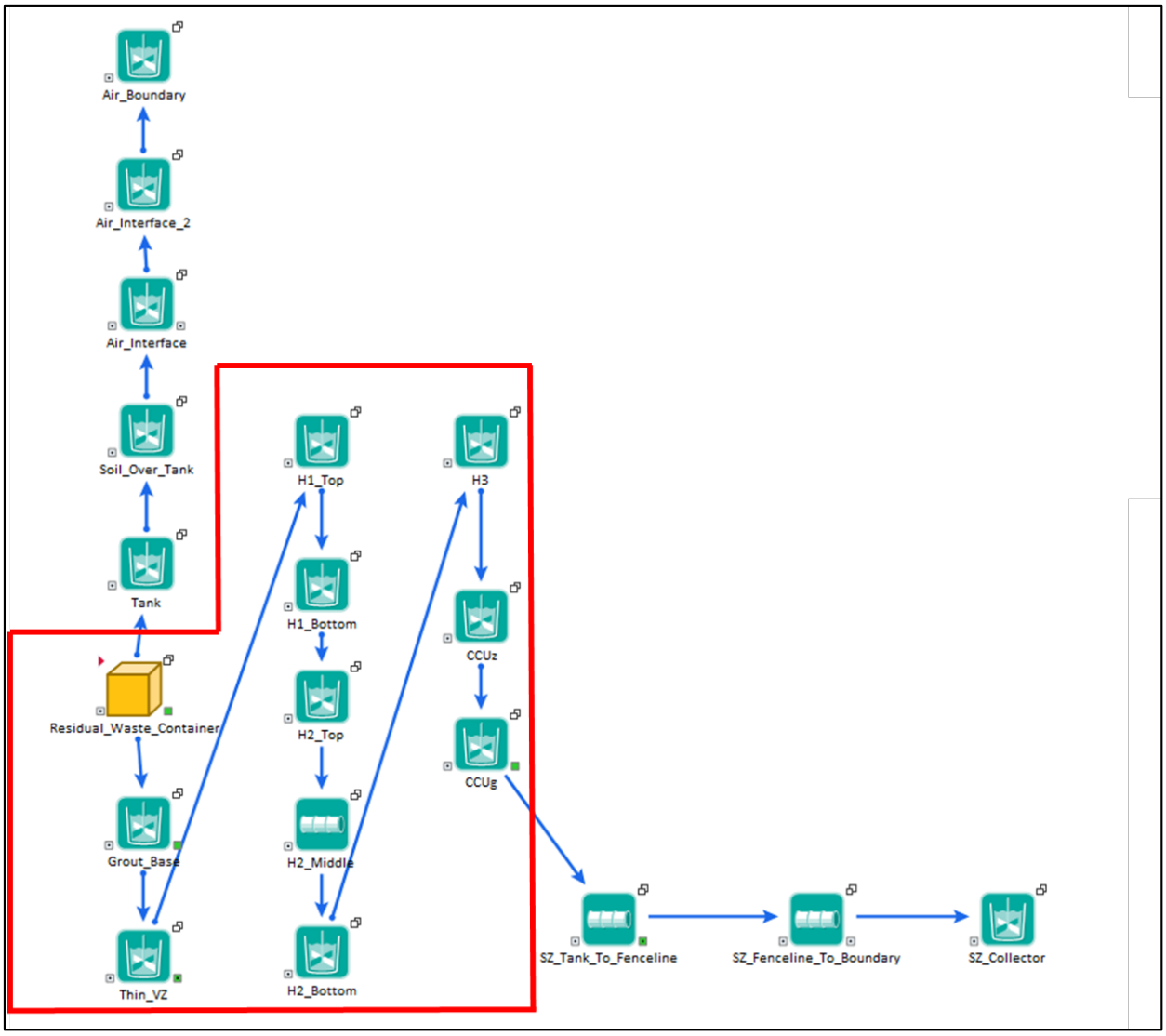


H1 = Hanford formation unit 1 HSU = hydrostratigraphic unit
H2 = Hanford formation unit 2 H3 = Hanford formation unit 3

For the saturated zone, the Darcy flow rate is extracted from STOMP model results. Figure 4-16 shows the Darcy flow rate contour (resultant of X direction and Y direction velocity) from an example STOMP simulation. The contact of highly conductive Cold Creek unit (CCU) Gravel with low conductivity Ringold units in the saturated zone model domain causes a non-uniform groundwater velocity distribution in the aquifer. Based on Figure 4-16, an average Darcy flow rate of 45 m/yr can be applied for A Farm saturated zone transport calculation and

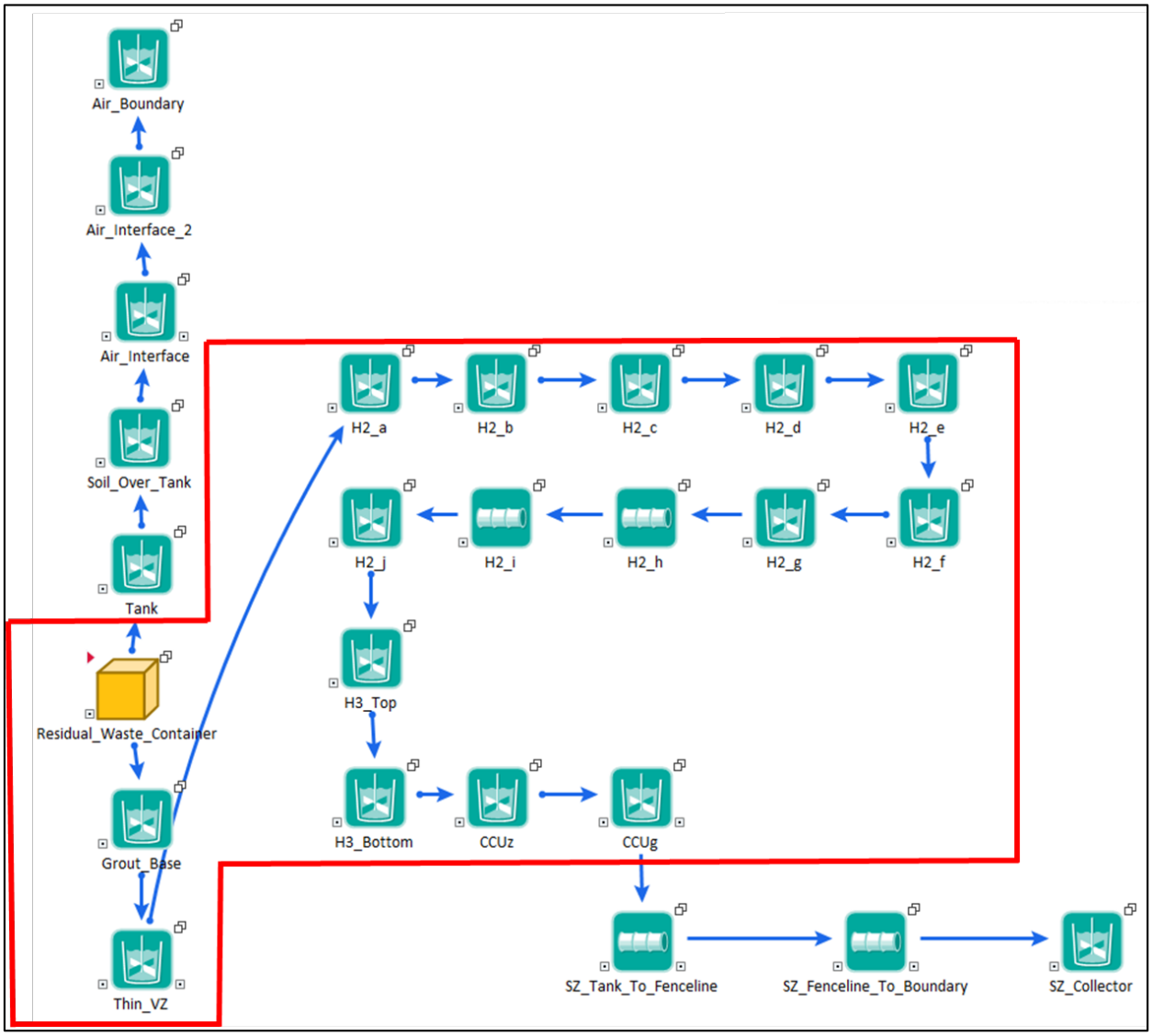
average Darcy flow rate of 55 m/yr can be applied for AX Farm saturated zone transport calculation.

Figure 4-6. Transport Abstraction Model for A Series Tanks.



Note: Elements used in the vadose zone transport are indicated in red outline.

Figure 4-7. Transport Abstraction Model for AX Series Tanks.



Note: Elements used in the vadose zone transport are indicated in red outline.

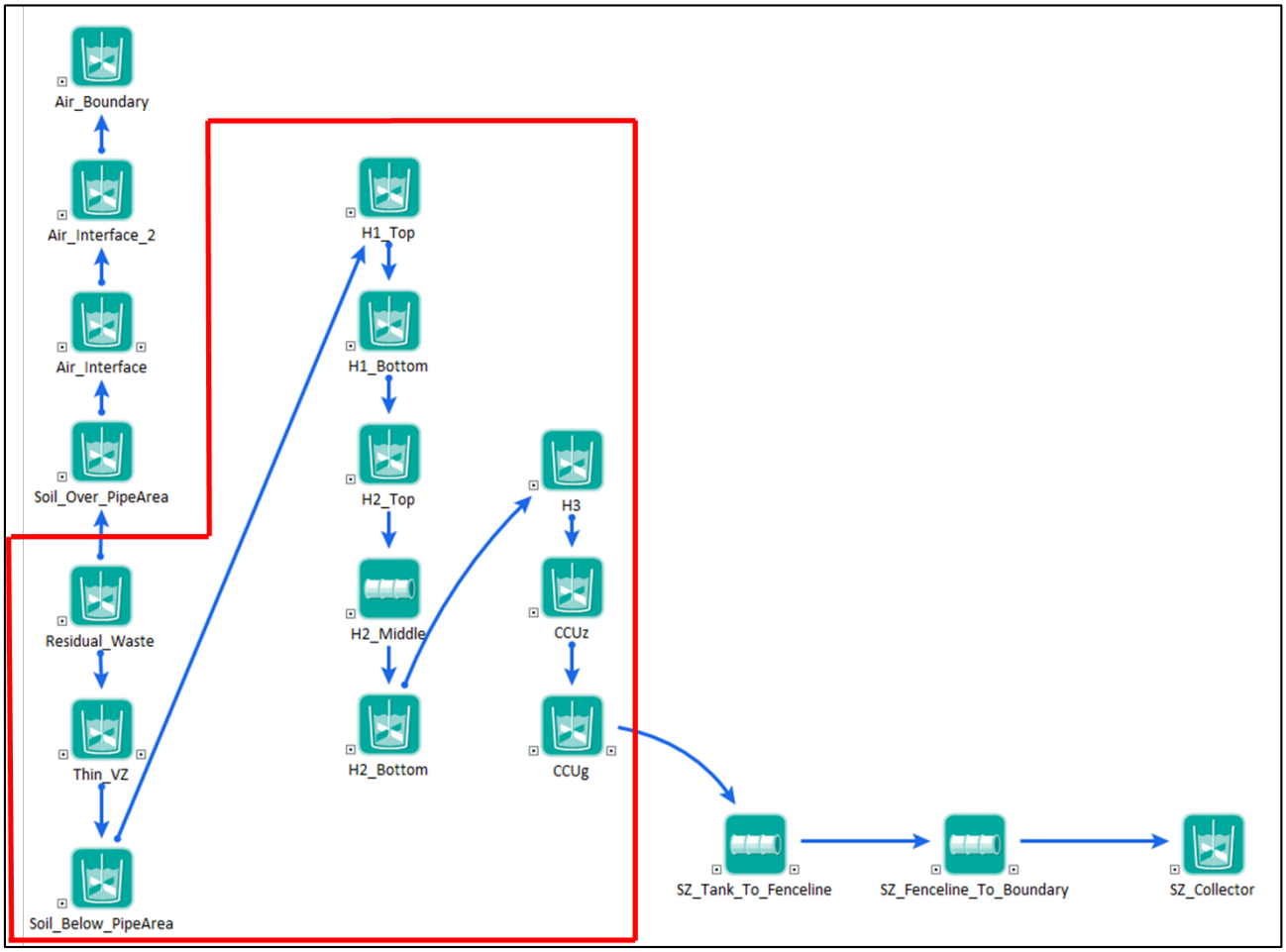
4.3.2 Distribution Coefficient (K_d) Estimates for Waste Management Area A-AX Hydrostratigraphic Units

PNNL-17154 provides recommendations for K_d values applicable to the waste and sediments present at WMA A-AX based on the broader Hanford Site database. K_d values presented in PNNL-17154 include values for sorption of key radiological and non-radiological contaminants to sand-size and silt-size sediments[6] where waste-sediment interactions are considered to have had no impact, intermediate impact, or high impact on sorption processes. The key

[6] PNNL-17154 also provides values for "carbonate-dominated sediments" at WMA A-AX. Although carbonate minerals appear to exist in much of the vadose zone at WMA A-AX, none of the HSUs are interpreted in RPP-RPT-60171, *Model Package Report: Geologic Framework Model used in WMA A AX Performance Assessment and RCRA Closure Analysis* to be carbonate dominated.

characteristics relevant to sorption of the WMA A-AX wastes are high salinity and alkaline pH, which are expected for past releases of waste liquids and to a lesser degree for future releases from solid waste residuals leached into natural porewater by alkaline grout pore fluids (PNNL-17154, RPP-RPT-58693). As conceived in PNNL-17154 for WMAs with tank waste releases, the high impact zone is assumed to have elevated salinity and pH, whereas the intermediate impact zone is assumed to have pH largely neutralized by reaction with the natural sediments, but the salinity remains elevated. For the analysis of future releases from waste residuals, it is assumed that the majority of the vadose zone and saturated zone below each release is characterized by intermediate impact. Intermediate impact represents zones where reactions between the natural sediment and the waste releases have largely neutralized the acidic or basic nature of the wastes likely to cause changes in the K_d values. Overall, the assumption of intermediate impact throughout the transport pathway leads to similar or faster contaminant transport than assuming that the impacted sediments give way to an unimpacted zone at some distance from the releases.

Figure 4-8. Transport Abstraction Model for A Series NonTanks.

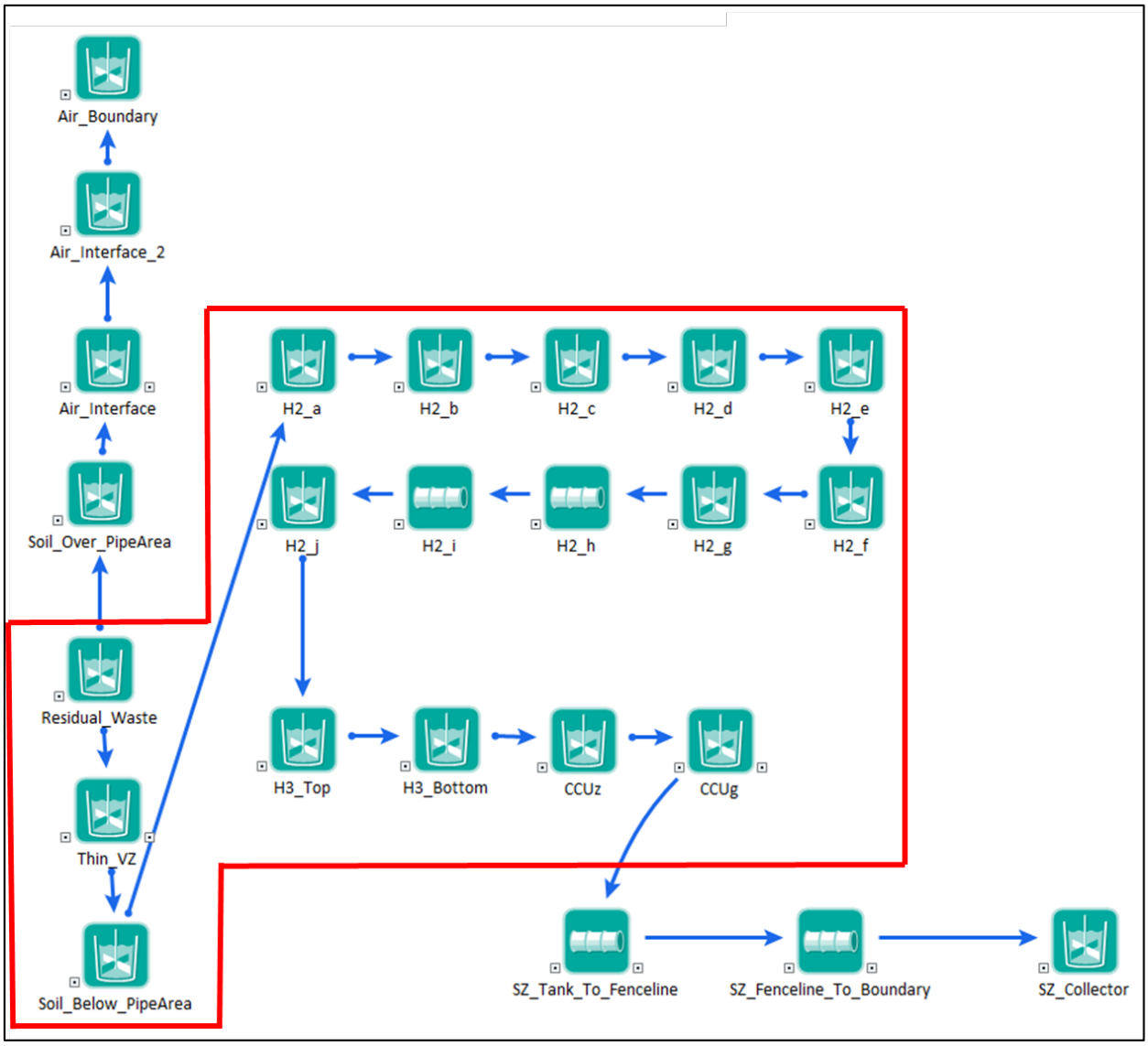


Note: Elements used in the vadose zone transport are indicated in red outline.

WMA A-AX has a silt-dominated HSU of significant areal extent below the footprint of the SSTs, i.e., the CCUz unit of the Cold Creek Formation (RPP-RPT-60171, *Model Package*

Report: Geologic Framework Model used in WMA A AX Performance Assessment and RCRA Closure Analysis). As previously stated, PNNL-17154 provides recommended K_d values for silt-sized sediments with varying degrees of chemical impact. Radiological and non-radiological contaminants with no data for silt default to the sand values, which are generally expected to underestimate sorption on silt. Values for ^{99}Tc and uranium sorption on silt likewise default to the sand values with the intention of conservatism, given the existing uncertainty in how to interpret empirical data from other facilities and sites.

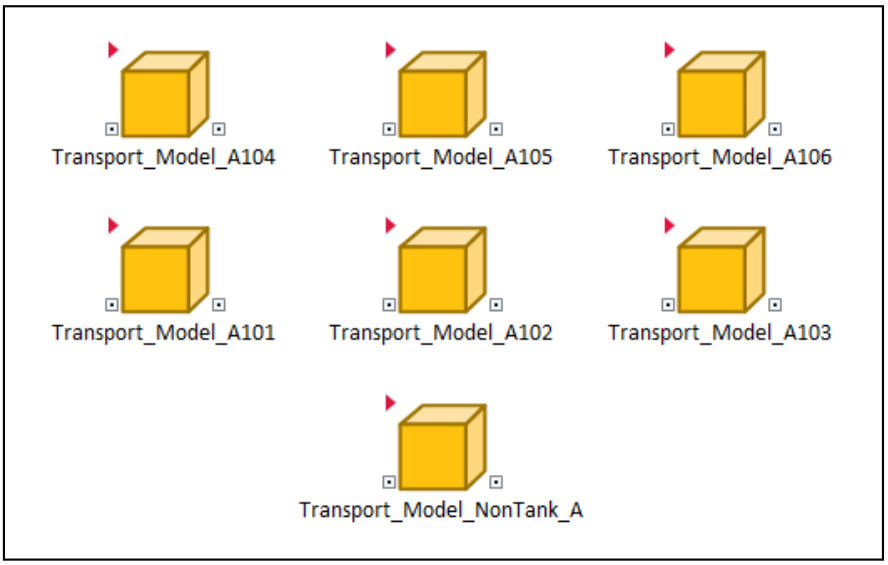
Figure 4-9. Transport Abstraction Model for AX Series NonTanks.



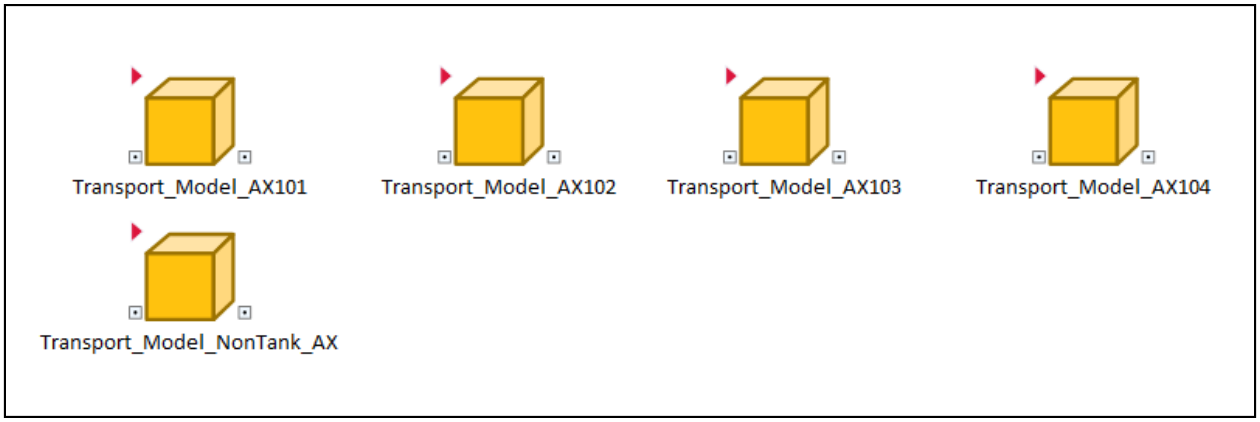
Note: Elements used in the vadose zone transport are indicated in red outline.

Appendix C contains the complete list of both sand and silt K_d values with their references, including the minimum and maximum values applicable to the uncertainty analysis distribution, used in the WMA A-AX system model.

Figure 4-10. Transport Model Containers for the a) A Series Tanks and NonTanks, and b) AX Series Tanks and NonTanks.

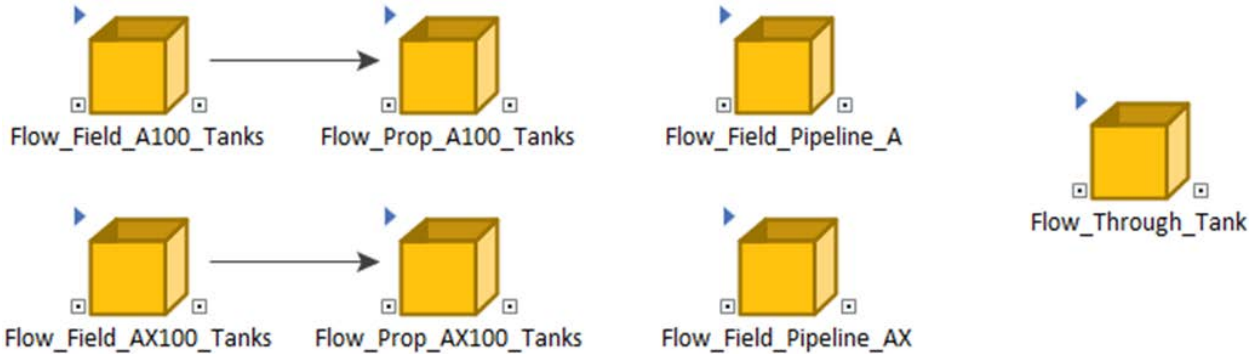


a.



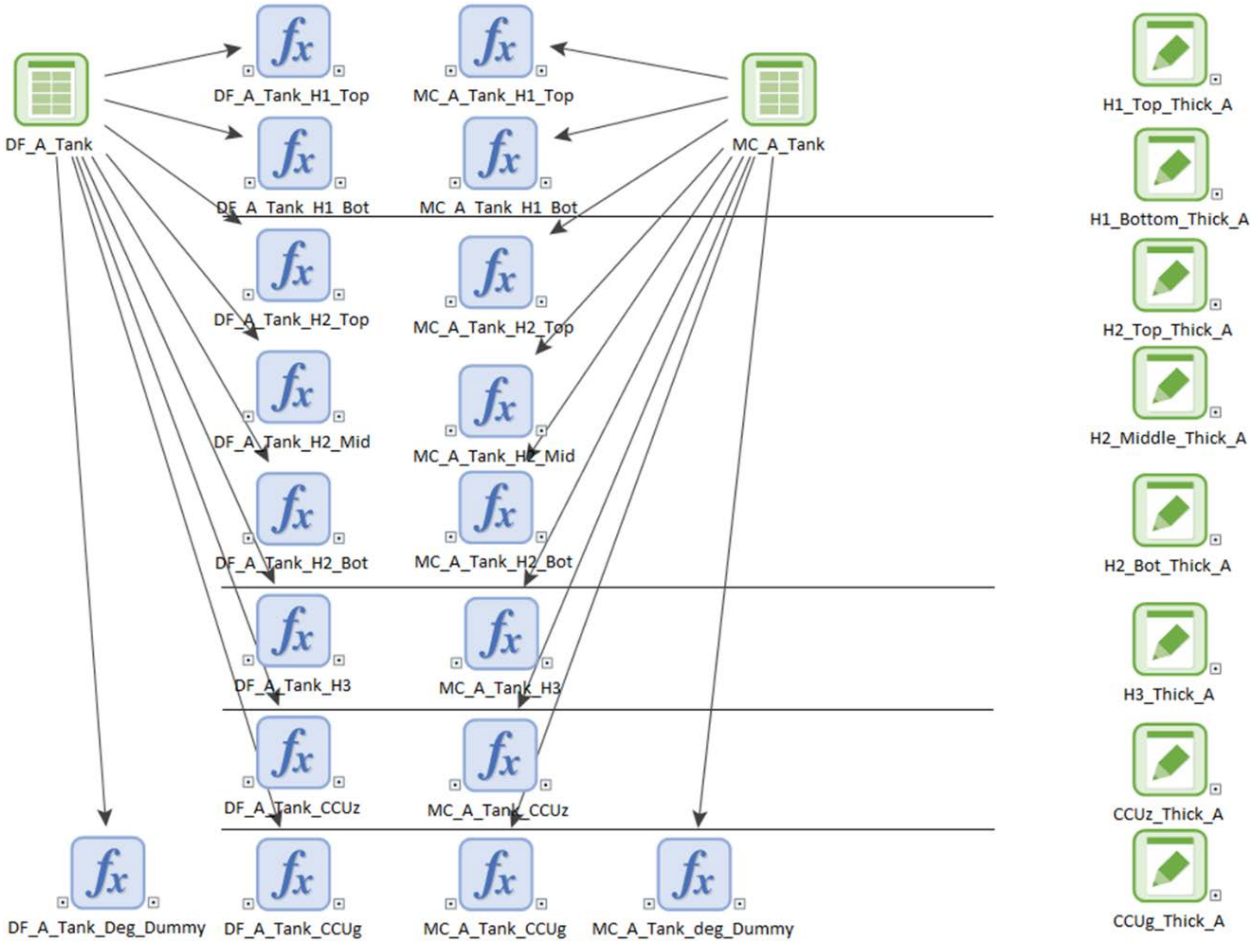
b.

Figure 4-11. Contents of the Flow_Field_Abstraction Container of the GoldSim© Model.



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

Figure 4-12. Implementation of the 241-A Farm Tank Flow Field in GoldSim©.



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

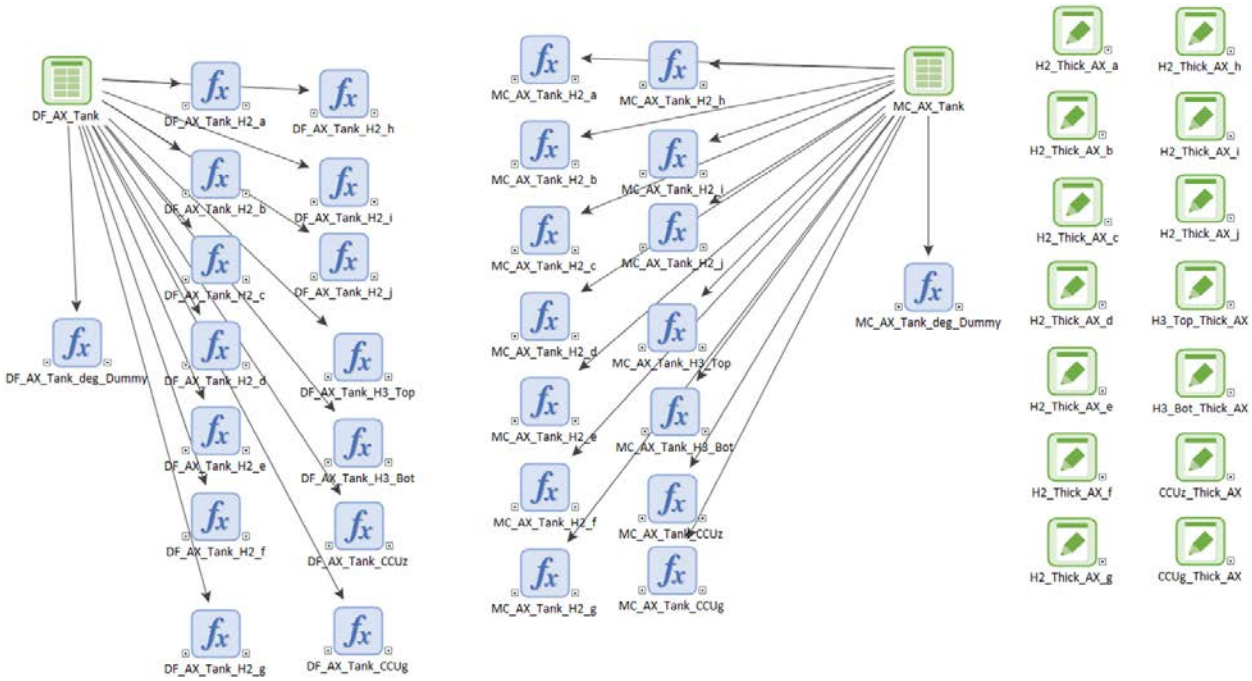
4.3.3 Vadose Zone Transport Model Implementation

The representative hydrostratigraphic columns for the A Farm and AX Farm tanks are compared against the vertical discretization chosen for the system-level model. Also presented is the vertical discretization implemented in the STOMP-based model. For the system-level model, finer discretization was chosen at shallow depths with coarser discretization at deeper depths. However, near the HSU contacts, finer discretization was used to produce improved numerical results near the interface. Coarser discretization was allowable in the deeper portion of the vadose zone (e.g., CCUg) because the flow field was not found to change appreciably with depth.

For A Farm, the STOMP-based model nodes were used as the basis to assign representative values of moisture content and Darcy flow rate for the grid cells in the system model. For example, the H1 Gravelly Sand unit in the representative column for A Farm tanks has a total thickness in STOMP of 3.3 m and in the system model, this unit is divided into two grid cells of 1.5 m each. The flow field (moisture content and Darcy flow rate) extracted from STOMP

model node 104 is applied in the first cell of the unit in the system-level abstraction model, and STOMP model node 103 is applied to the second cell of this unit in the system model. The H2 Sand unit is the thickest HSU in the vertical profile. It is discretized into a 4-m grid cell at the top and an 8.25-m grid cell at the bottom. The middle 50 m is discretized into 100 grid cells, each being 0.5 m in length to match the 0.25-m longitudinal dispersivity (RPP-RPT-60101) applied within the H2 Sand unit (the numerical dispersivity in the GoldSim© cell is calculated to be equal to half the cell length). The top and bottom grid cells for the H2 Sand unit are assigned the flow field extracted from STOMP nodes 102 and 44, respectively, while the middle 50-m length is represented by the flow field from STOMP node 69. A single flow field over the 50-m length is used, since the flow field varies little for the corresponding STOMP nodes at depth. The H3 Gravel is discretized into a 1.5-m grid cell, and assigned the flow field STOMP node 37. CCU Silt is discretized into a 3-m grid cell, and assigned the flow field STOMP node 33. CCUg is discretized into a 5-m grid cell, and assigned the flow field STOMP node 24. Figure 4-6 shows the GoldSim© implementation of the hydrostratigraphic column for A Farm tanks, while Figure 4-8 shows the hydrostratigraphic column for A Farm pipelines. Figure 4-12 and Figure 4-14 illustrate the flow field implementation in GoldSim© for the A Farm tanks and pipelines, respectively. The details of the A Farm grid discretization are presented in Table 4-4.

Figure 4-13. Implementation of the 241-AX Farm Tank Flow Field in GoldSim©.



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

The discretization for AX Farm tanks is shown in Table 4-5. The H2 Sand unit is the uppermost HSU and the thickest HSU in the vertical profile. It is discretized into five grid cells ($H2_a$ through $H2_e$) of 1-m thickness and two grid cells ($H2_f$ through $H2_g$) of 2-m thickness, with the 1-m grid cells at the top. The flow field (moisture content and Darcy flow rate) extracted from STOMP model nodes 102, 101, 100, 99, 98, 96, and 94 are applied to the top seven grid cells of

this unit. The middle ($H2_h$) 10 m is discretized into 40 grid cells, each being 0.25 m in length, and is represented by STOMP node 89. The following middle ($H2_i$) 32 m is discretized into 100 grid cells, each being 0.32 m in length, and is represented by STOMP node 67. The bottom of the H2 Sand unit is discretized into a 1-m ($H2_j$) grid cell, assigned the flow field STOMP node 51. The H3 Gravel unit total thickness is 13 m and is divided into two grid cells of 1 m for the top and 12 m for the bottom thickness. The flow field (moisture content and Darcy flow rate) extracted from STOMP model node 50 is applied in the first cell of the unit in the system-level abstraction model, and STOMP model node 43 is applied to the second cell of this unit in the system model. CCUz is discretized into a 4-m grid cell, and assigned the flow field STOMP node 29. CCUg is discretized into a 3-m grid cell, and assigned the flow field STOMP node 23. Figure 4-7 shows the GoldSim© implementation of the hydrostratigraphic column for AX Farm tanks, while Figure 4-9 shows the hydrostratigraphic column for AX Farm pipelines. Figure 4-13 and Figure 4-15 illustrate the flow field implementation in GoldSim© for the AX Farm tanks and pipelines, respectively.

Figure 4-14. Implementation of the 241-A Tank Farm Pipelines Flow Field in GoldSim©.

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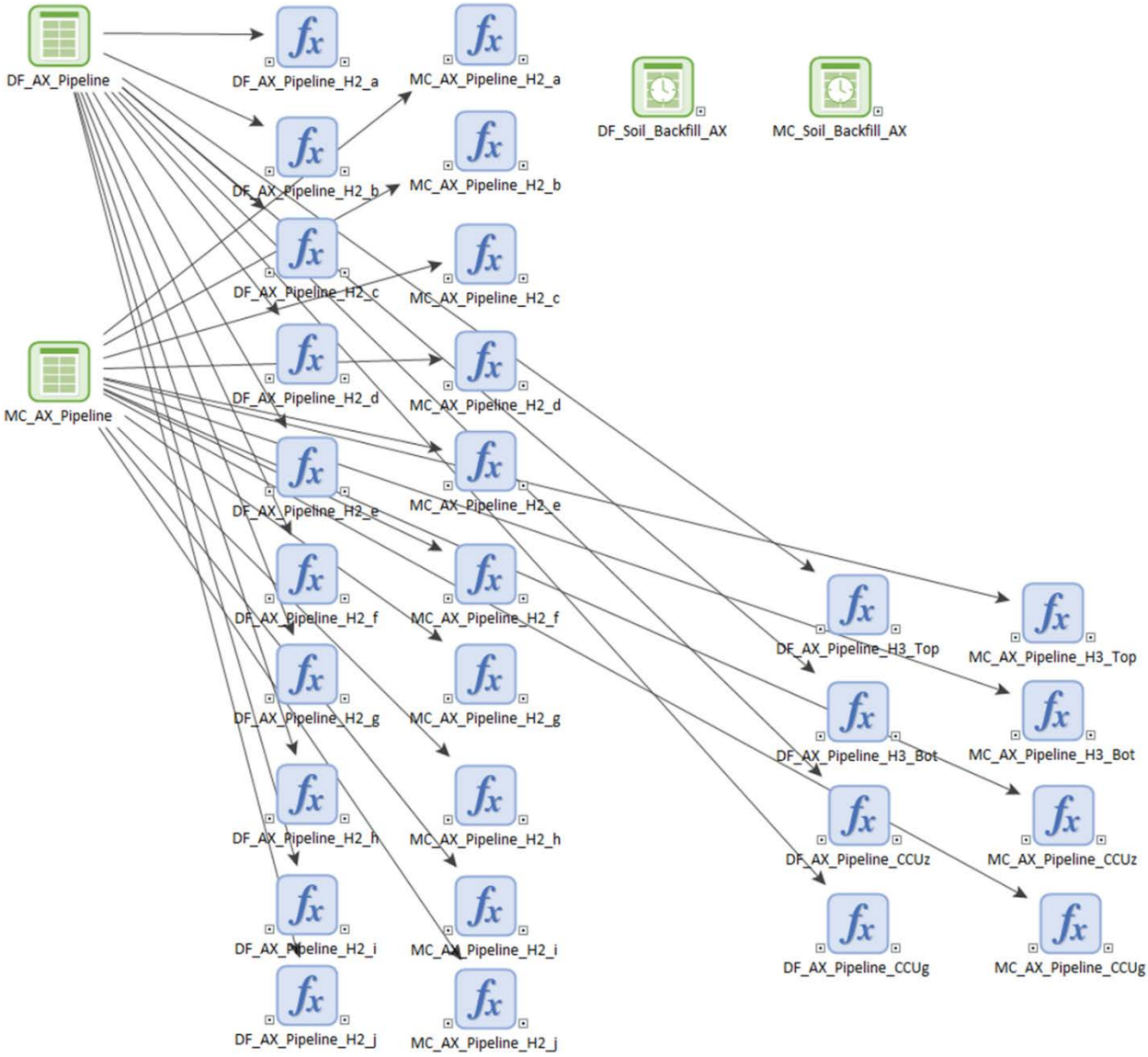
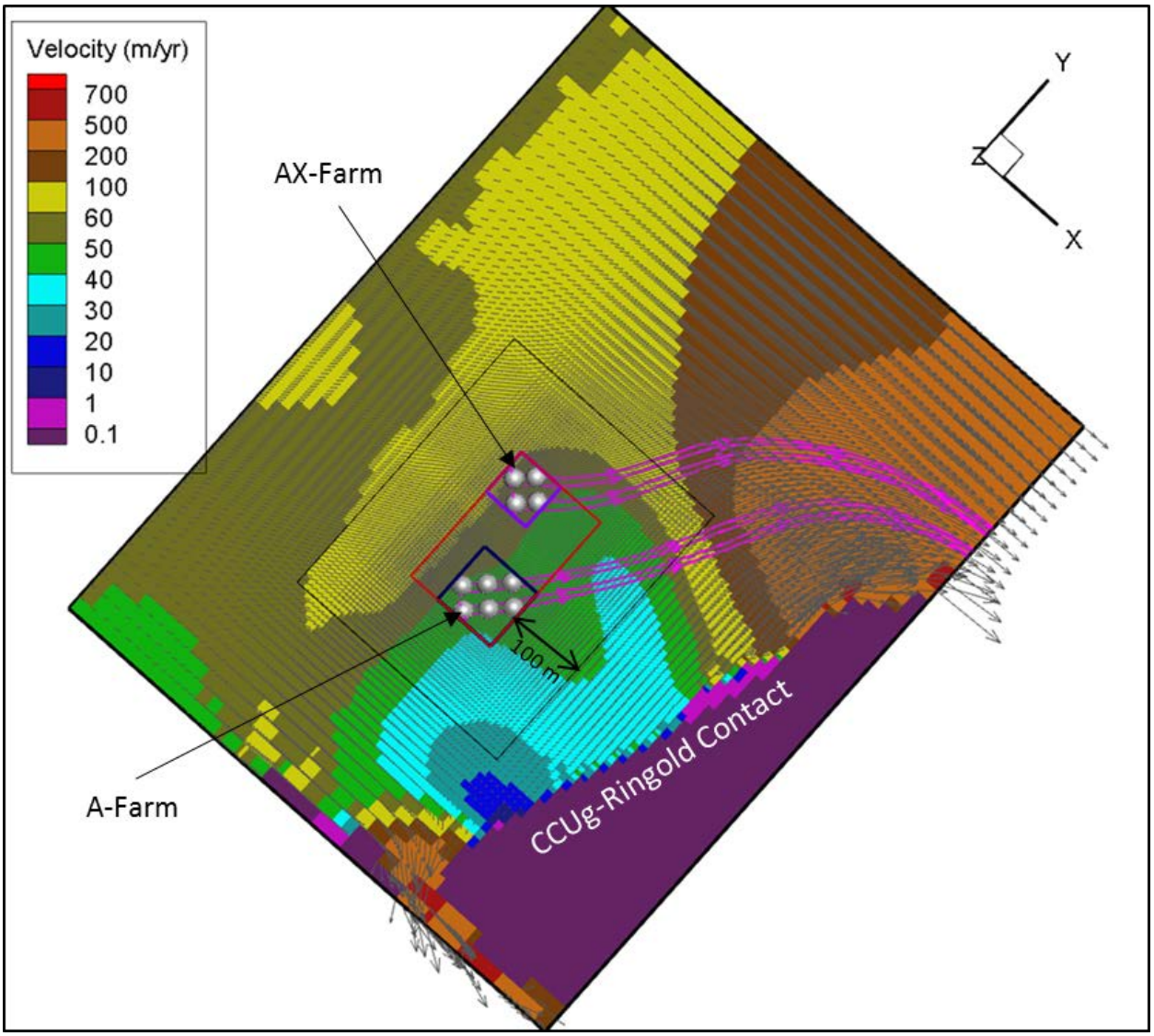
Figure 4-15. Implementation of the 241-AX Tank Farm Pipelines Flow Field in GoldSim©.



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

Appendix D contains the moisture content and Darcy flow rate outputs from the STOMP process model for the nodes listed in Table 4-4 and Table 4-5 used in the GoldSim© system model. From closure to about 500 years post-closure, the moisture content and Darcy flow rate decrease as the recharge rate decreases from 100 mm/yr to 0.50 mm/yr because of the emplacement of the surface barrier. As the surface barrier is assumed to be degraded 500 years after closure, the recharge rate transitions from a barrier rate of 0.5 mm/yr to a natural background rate of 3.5 mm/yr, and reaches steady state by year 3000. The STOMP nodes 33 and 29, used to set the CCUz flow fields in A Farm and AX Farm, respectively, show high moisture content.

Figure 4-16. Saturated Zone Darcy Flow Rate Contour of an Example STOMP Model Simulation.



Subsurface Transport Over Multiple Phases (STOMP) has been developed and distributed by Battelle Memorial Institute.

CCUg = Cold Creek unit gravel

The flow field applied to the pipeline releases is calculated separately for A Farm and AX Farm. Vertical Darcy flow rates and volumetric moisture contents from the STOMP nodes that fall within the pipeline source area, but outside the tank footprint, are averaged to calculate the pipeline flow field. The representative hydrostratigraphic columns for the A Farm tanks and the AX Farm tanks are applied to the two pipeline source areas. Advective flow occurs though the pipelines for all time periods. The hydraulic effect of the presence of buried pipelines in the vadose zone are not modeled explicitly, and the areas occupied by the pipelines are modeled with hydraulic properties of soil backfill material.

Table 4-4. 241-A Tank Farm Vertical Grid Discretization and Flow Field for the System-Level Model.

Hydrostratigraphic Unit	GoldSim© Element Name(s)	Thickness (meters)	Number of Cells	Associated GoldSim© Flow Field Data Elements			STOMP Node Used for Flow Field
				Thickness	Darcy Flow Rate	Moisture Content	
H1 Gravelly Sand	H1_Top	1.5	1	H1_Top_Thick_A	DF_A_Tank_H1_Top	MC_A_Tank_H1_Top	104
	H1_Bottom	1.5	1	H1_Bottom_Thick_A	DF_A_Tank_H1_Bot	MC_A_Tank_H1_Bot	103
H2 Sand	H2_Top	4	1	H2_Top_Thick_A	DF_A_Tank_H2_Top	MC_A_Tank_H2_Top	102
	H2_Middle	50	100	H2_Middle_Thick_A	DF_A_Tank_H2_Mid	MC_A_Tank_H2_Mid	69
	H2_Bot	8.25	1	H2_Bot_Thick_A	DF_A_Tank_H2_Bot	MC_A_Tank_H2_Bot	44
H3 Gravel	H3	1.5	1	H3_Thick_A	DF_A_Tank_H3	MC_A_Tank_H3	37
Cold Creek Silt	CCUz	3	1	CCUz_Thick_A	DF_A_Tank_CCUz	MC_A_Tank_CCUz	33
Cold Creek Gravel	CCUg	5	1	CCUg_Thick_A	DF_A_Tank_CCUg	MC_A_Tank_CCUg	24
Saturated Zone	SZ_Tank_To_Fenceline, SZ_Fenceline_to_Boundary, SZ_Collector	13.25	Aquifer Pathway	Avg_Sat_Thickness	—	—	—

H1 = Hanford formation unit 1 H2 = Hanford formation unit 2 H3 = Hanford formation unit 3

Table 4-5. 241-AX Tank Farm Vertical Grid Discretization and Flow Field for the System-Level Model.

Hydrostratigraphic Unit	GoldSim© Element Name(s)	Thickness (meters)	Number of Cells	Associated GoldSim© Flow Field Data Elements			STOMP Node Used for Flow Field
				Thickness	Darcy Flow Rate	Moisture Content	
H2 Sand	H2_a	1	1	H2_Thick_AX_a	DF_AX_Tank_H2_a	MC_AX_Tank_H2_a	102
	H2_b	1	1	H2_Thick_AX_b	DF_AX_Tank_H2_b	MC_AX_Tank_H2_b	101
	H2_c	1	1	H2_Thick_AX_c	DF_AX_Tank_H2_c	MC_AX_Tank_H2_c	100
	H2_d	1	1	H2_Thick_AX_d	DF_AX_Tank_H2_d	MC_AX_Tank_H2_d	99
	H2_e	1	1	H2_Thick_AX_e	DF_AX_Tank_H2_e	MC_AX_Tank_H2_e	98
	H2_f	1	1	H2_Thick_AX_f	DF_AX_Tank_H2_f	MC_AX_Tank_H2_f	96
	H2_g	1	1	H2_Thick_AX_g	DF_AX_Tank_H2_g	MC_AX_Tank_H2_g	94
	H2_h	10	40	H2_Thick_AX_h	DF_AX_Tank_H2_h	MC_AX_Tank_H2_h	89
	H2_i	32	100	H2_Thick_AX_i	DF_AX_Tank_H2_i	MC_AX_Tank_H2_i	67
	H2_j	1	1	H2_Thick_AX_j	DF_AX_Tank_H2_j	MC_AX_Tank_H2_j	51
H3 Gravel	H3_Top	1	1	H3_Top_Thick_AX	DF_AX_Tank_H3_Top	MC_AX_Tank_H3_Top	50
	H3_Bot	12	1	H3_Bot_Thick_AX	DF_AX_Tank_H3_Bot	MC_AX_Tank_H3_Bot	43
Cold Creek Silt	CCUz	4	1	CCUz_Thick_AX	DF_AX_Tank_CCUz	MC_AX_Tank_CCUz	29
Cold Creek Gravel	CCUg	3	1	CCUg_Thick_AX	DF_AX_Tank_CCUg	MC_AX_Tank_CCUg	23
Saturated Zone	SZ_Tank_To_Fenceline, SZ_Fenceline_to_Boundary, SZ_Collector	13.25	Aquifer Pathway	—	—	—	—

H1 = Hanford formation unit 1 H2 = Hanford formation unit 2 H3 = Hanford formation unit 3

Within the 200 Areas, unlike the sand-dominated (H2) sediments, both H1 and H3 sediments typically are comprised of a significant gravel fraction and considered as "gravel-dominated." However, sediment data indicate that the Hanford H1 unit at WMA A-AX is similar to the sand-dominated H2 unit with respect to gravel content. The average gravel contents for H1 and H2 units are about 16% and 14% (by weight), respectively. Because of this similarity, the WMA A-AX H1 unit is assigned the hydraulic properties of the Hanford H2 unit (RPP-RPT-60101).

Although tank farm backfill is usually gravel-dominated (like the A Farm backfill comprised of 58% gravel, by weight), the AX Farm backfill unit gravel content (>2-mm size fraction) is only 7% (by weight), and the particle size distribution is similar to H2 sand (RPP-RPT-60101).

Properties of the hydrostratigraphic units in the WMA A-AX system model, including gravel content, porosity and effective bulk density, are outlined in Table 4-6.

These layers have been represented as EHM units with macroscopic flow properties. The porous media continuum assumption (an extended form of Darcy's Law for vadose zone applications) and the soil relative permeability/saturation/capillary pressure relations provide the basis for vadose zone flow and transport modeling. The hydraulic properties describing fluid flow and transport characteristics associated with each geologic unit are thus represented by average upscaled (effective) parameters.

4.3.4 Saturated Zone Transport Model Implementation

The purpose of the system-level far-field transport model is to represent the 3-D STOMP vadose zone and saturated zone flow and transport model (RPP-RPT-60101) in a way that is amenable to efficient calculations for sensitivity and uncertainty analyses. In order to efficiently implement the 3-D transport behavior in a 1-D model, first a detailed understanding of the 3-D process model is necessary. The details of 3-D STOMP vadose zone and saturated zone flow and transport model features are provided in RPP-RPT-60101. Some of the essential features that form the basis for the implementation of the 1-D transport model are presented below.

4.3.4.1 Points of Calculation in Three-Dimensional Process Model

To calculate the highest groundwater concentration, the WMA A-AX process model evaluates the average concentration in the aquifer within a series of nine aquifer segments oriented parallel to the WMA A-AX fence line (Figure 4-17). Concentrations calculated in the nine aquifer segments are intended to be comparable to concentrations that would be measured by sampling a monitoring well at those locations. The points of calculation are aligned such that the centerline of the plume in groundwater resulting from all of the sources intersects the set of segments near their center. The segments alternate in orientation in the x- and y-directions in a zigzag pattern because the model grid is rotated 45 degrees from the azimuth. The model grid is intended to align parallel to the direction of incoming flow; however, the flow direction in the aquifer includes some curvature in the vicinity of WMA A-AX, so the points of calculation needed to be adjusted accordingly.

Table 4-6. Vadose Zone Properties Used in the Waste Management Area A-AX System Model.

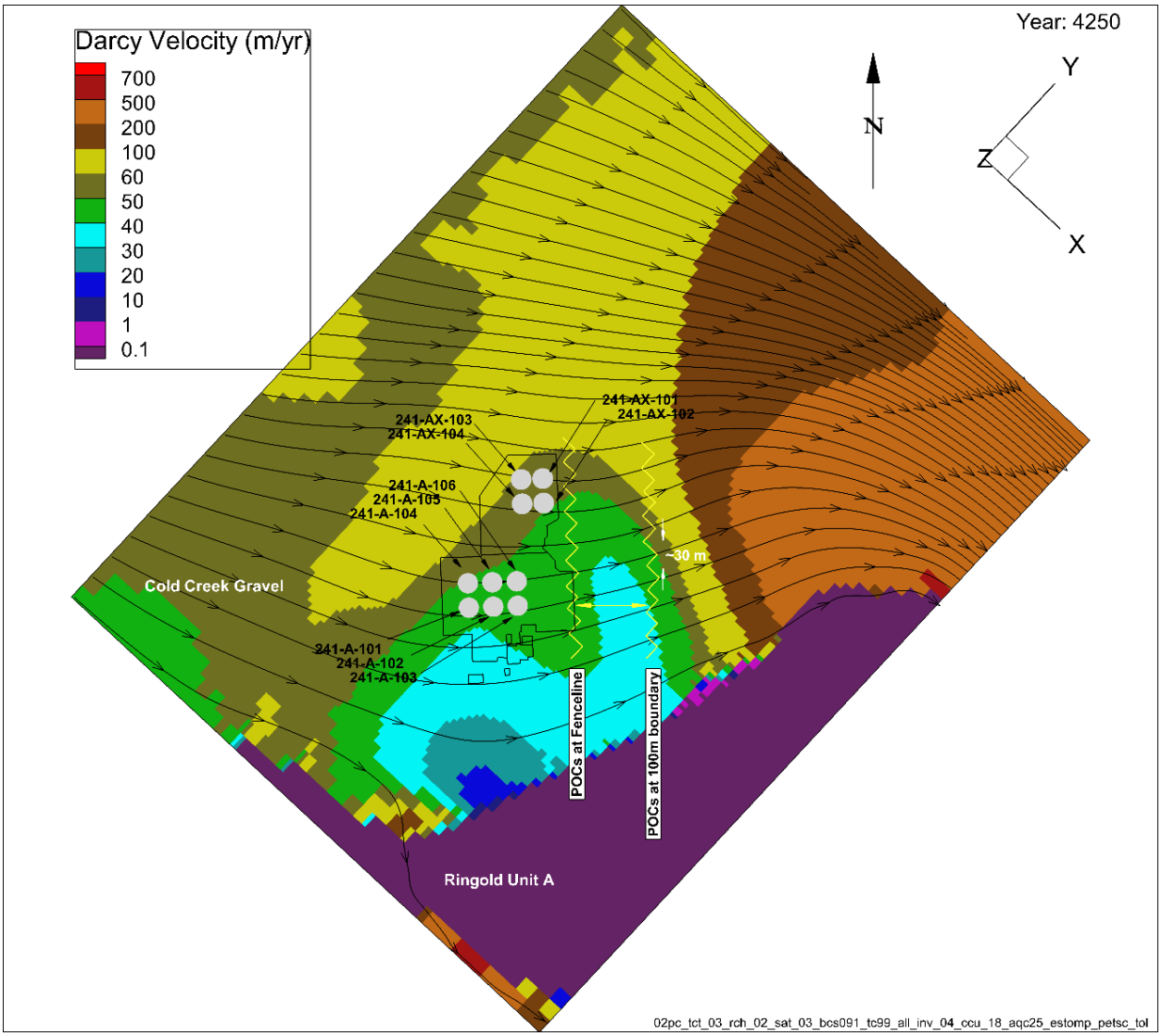
Hydrostratigraphic Unit		Gravel Content (% weight)		Porosity (θ_s) (cm^3/cm^3)		Effective Bulk Density (ρ_b) (g/cm^3)	
		Value Used[a]	GoldSim© Parameter Name	Value Used[b]	GoldSim© Parameter Name	Value Used[c]	GoldSim© Parameter Name
Backfill	241-A Tank Farm	58	Gravel_Content_Backfill_A	0.174	Soil_Porosity_A	2.15	Soil_Bulk_Density_A
	241-AX Tank Farm	7	Gravel_Content_Backfill_AX	0.384	Soil_Porosity_AX	1.67	Soil_Bulk_Density_AX
Hanford Formation Unit 1 (H1)		5	Gravel_Content_H1	0.384	H1_Porosity	1.67	H1_Bulk_Density
Hanford Formation Unit 2 (H2)		5	Gravel_Content_H2	0.384	H2_Porosity	1.67	H2_Bulk_Density
Hanford Formation Unit 3 (H3)		66	Gravel_Content_H3	0.174	H3_Porosity	2.15	H3_Bulk_Density
Cold Creek Unit gravel (CCUg)		66	Gravel_Content_CCUg	0.174	CCUg_Porosity	2.15	CCUg_Bulk_Density
Cold Creek Unit silt (CCUz)		0	Gravel_Content_CCUz	0.433	CCUz_Porosity	1.6	CCUz_Bulk_Density

[a]RPP-RPT-60101, *Model Package Report Flow and Contaminant Transport Numerical Model used in WMA A-AX Performance Assessment and RCRA Closure Analysis*, Table 3-2.

[b]RPP-RPT-60101, Table 3-2.

[c]RPP-RPT-60101, Table B-8.

Figure 4-17. Points of Calculation and Flow Velocity Distribution in Waste Management Area A-AX Three-Dimensional Process Model.



POCs = Points of Calculation

4.3.4.2 Saturated Zone Flow Field in the Three-Dimensional Process Model

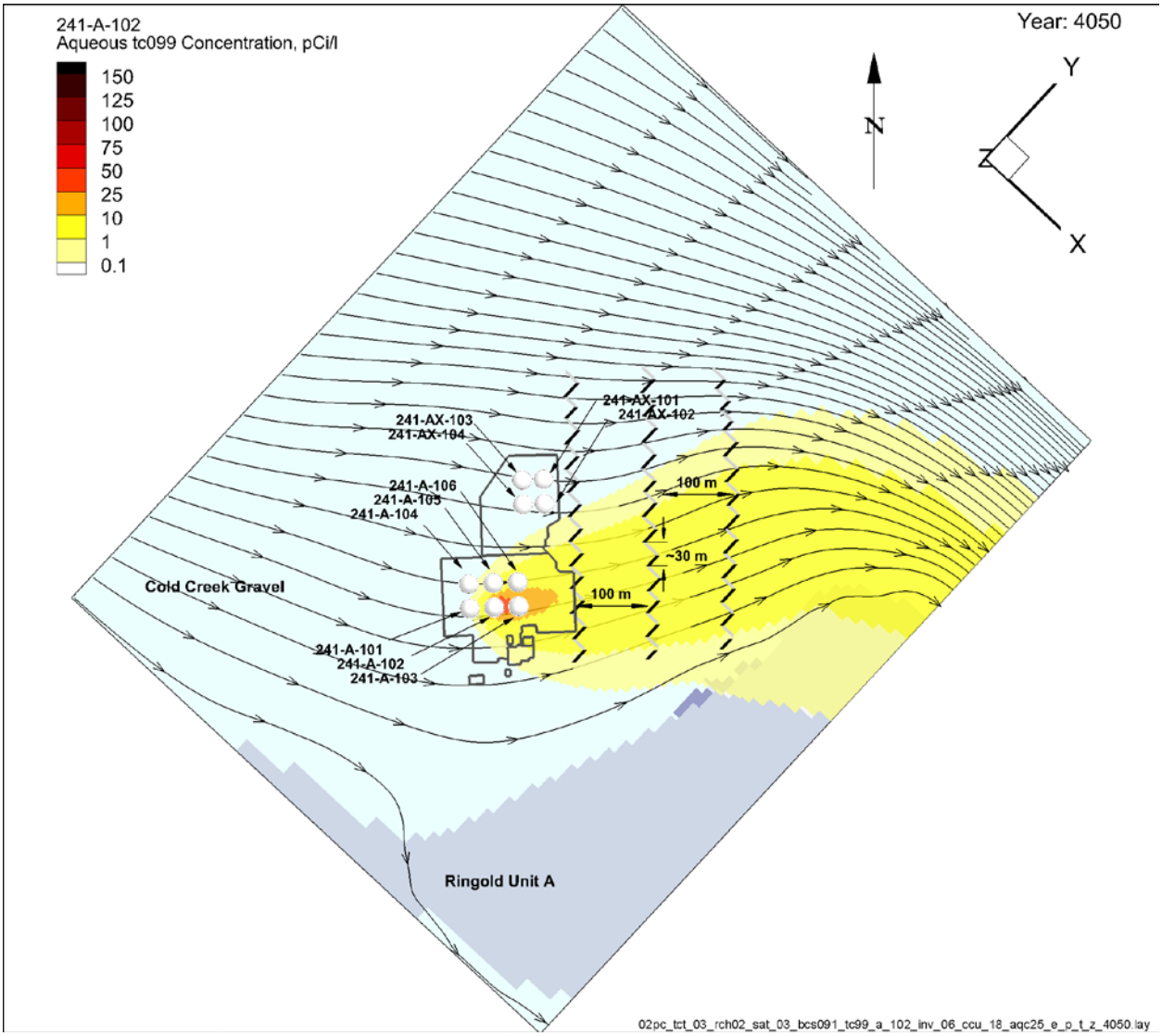
The contact of highly-conductive CCUg gravel and low-conductive Ringold formation unit A (Rwia) in the saturated zone model domain causes a heterogeneous groundwater velocity distribution in the aquifer. In the best-estimate case, the process-level models apply 18,200 m/day hydraulic conductivity for the CCUg gravel and 1 m/day for the Rwia formation (RPP-CALC-63164, *WMA A-AX Performance Assessment Contaminant Fate and Transport Process Model to Evaluate Impacts to Groundwater*). The less-conductive Rwia formation, which appears at the water table in the south corner and along part of the southeast side, acts as a hydraulic barrier and causes the flow to change to a northeasterly direction. Figure 4-17 shows the flow velocity distribution at the water table obtained from STOMP simulations. Velocity

vectors indicate the direction of flow; contour lines indicate the flow velocity. The average flow velocity below A Farm is about 45 m/yr and about 55 m/yr below AX Farm (Figure 4-17).

4.3.4.3 Spreading of the Plume in the Aquifer

Figure 4-18 shows the ^{99}Tc plume at the water table resulting from tank A-102. The flow field is nonuniform over the scale of the model domain, but is not highly variable over the 100-m scale of interest in the PA.

Figure 4-18. Technetium-99 Plume at Water Table Resulting from Residual Waste Release from Tank 241-A-102.

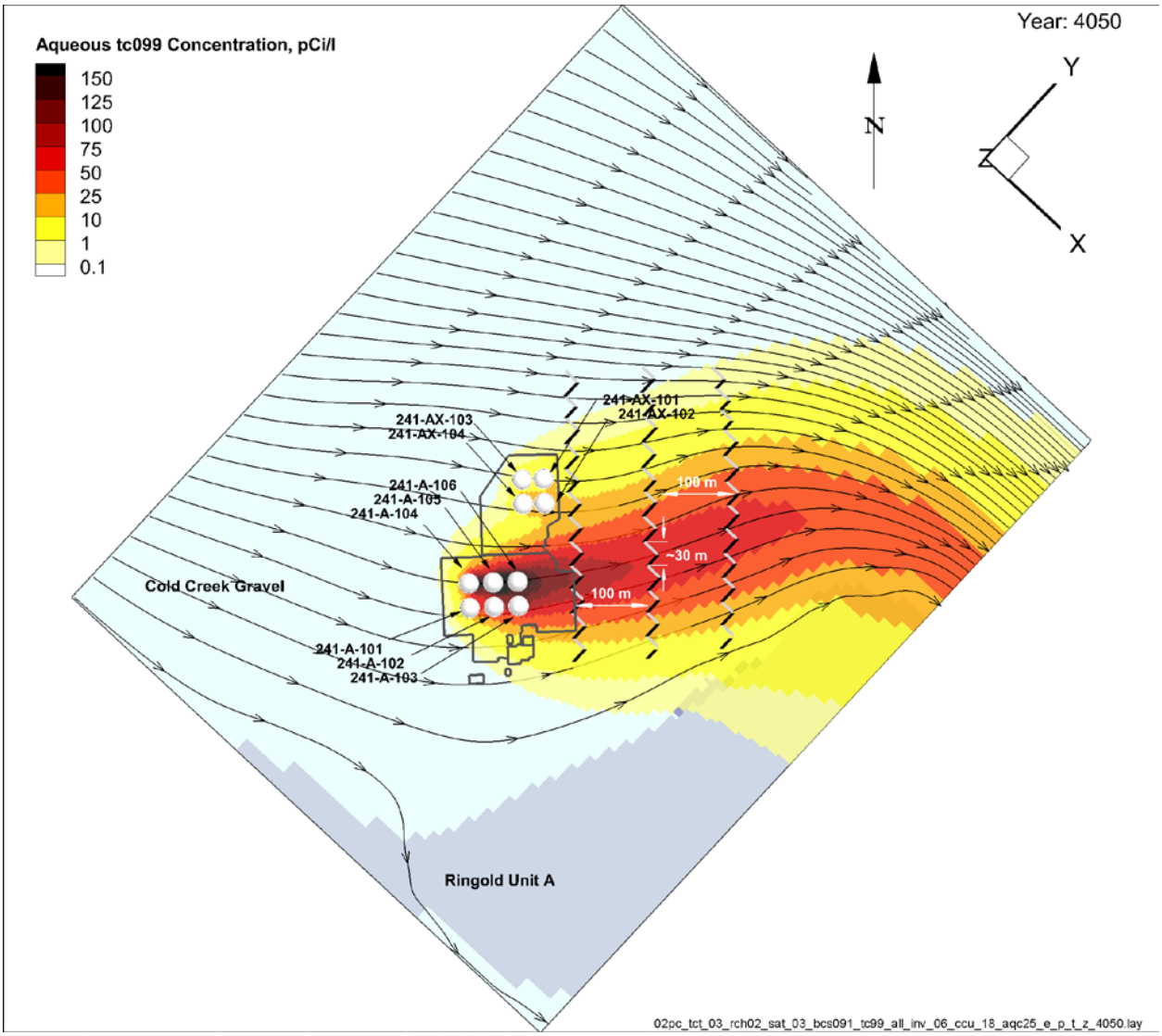


4.3.4.4 Commingling of Different Sources in the Aquifer

Figure 4-19 shows the ^{99}Tc plume at the water table resulted from combining all the sources (10 tank sources and 2 non-tank sources). This combined plume is based on the latest Best-Basis

Inventory (BBI) tank residual inventory (RPP-RPT-58293, Rev. 2). As shown in Figure 4-19, the maximum concentration at the fence line and the 100-m boundary is dominated by A Farm tanks. The contribution from AX Farm is negligible by comparison.

Figure 4-19. Technetium-99 Plume at Water Table Resulting from Waste Release from All Sources.



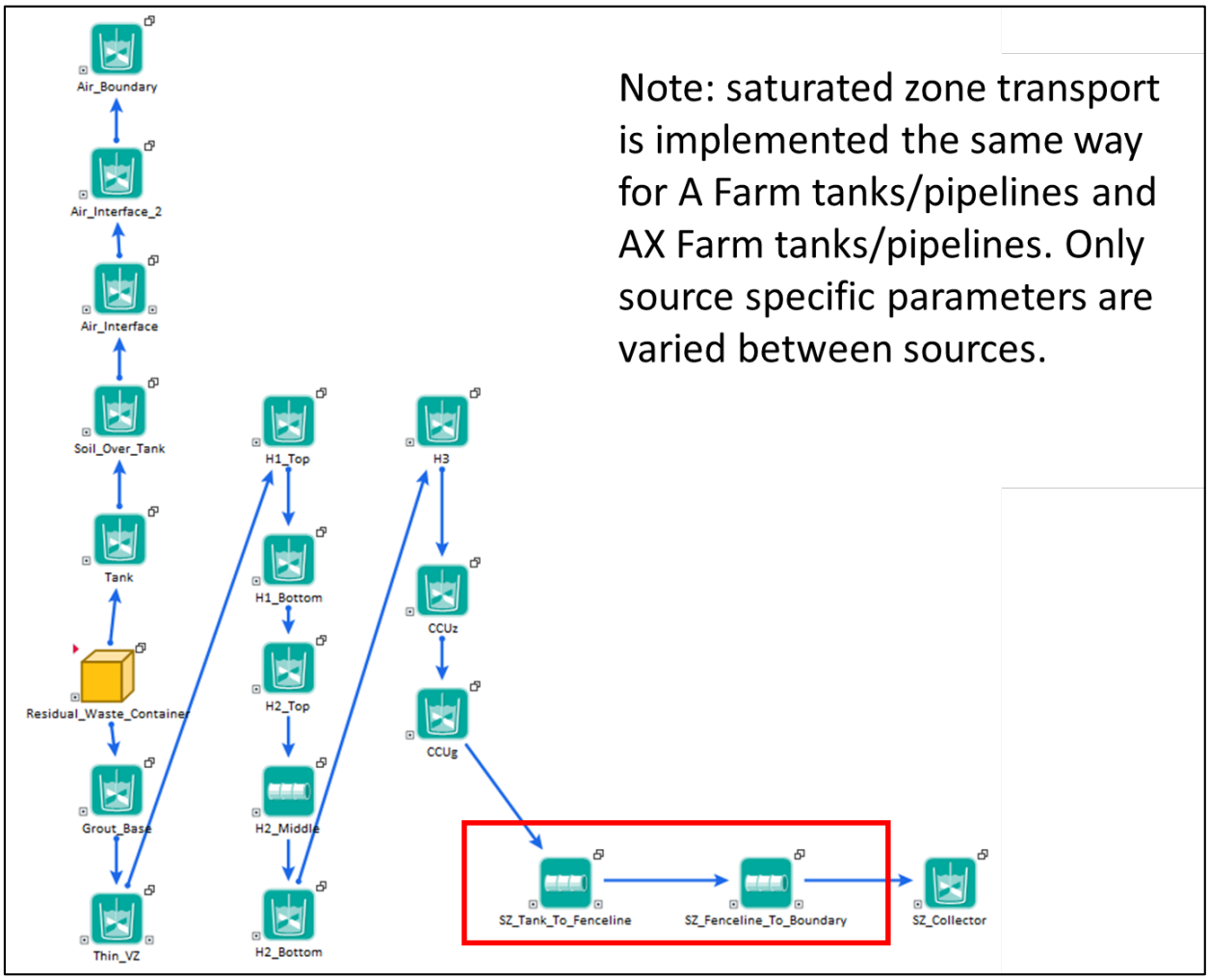
4.3.5 Saturated Zone Transport Model Implementation in the System Model

Based on the above features of the process model, the saturated zone has been modelled as a 1-D transport pathway oriented along the primary flow direction using the aquifer pathway capability in GoldSim©. Modelling a 3-D transport process with a simplified 1-D model is quite challenging. The lateral spreading that is not represented in a 1-D model is accounted for in a simplified manner. The mass flux from the vadose zone for each source term is transported to the aquifer. This mass flux from the vadose zone to the saturated zone acts as an upgradient

boundary condition for the contaminant transport in the aquifer. Evaluation of the process model results (RPP-RPT-60101) shows that the vertical mass transport in the vadose zone stays within the footprint of the source area, indicating insignificant lateral dispersion in the vadose zone.

Two aquifer elements were used for the saturated zone transport in the system model (Figure 4-20). The first aquifer element (GoldSim© element "SZ_Tank_To_Fenceline") takes the mass flux from the vadose zone and transports it to the fence line. The length of this aquifer element varies for different sources and is determined by the approximate distance from the source entry point in the aquifer to the fence line along the flow path. Table 4-7 presents these distances for various sources. As an example, the length of the first aquifer pathway for tank A-102 is ~105 m, as compared with ~44 m for tank AX-101. For the pipeline source areas, the aquifer pathway is assumed to begin at the center of the A Farm area and the AX Farm area to account for some vadose zone contribution occurring earlier.

Figure 4-20. Transport Abstraction Model for A Series Tanks.



Note: Elements used in the saturated zone transport are indicated in red outline.

The second aquifer element (GoldSim© element SZ_Fenceline_To_Boundary) is 100 m long and transports the mass from fence line to 100-m boundary. Each of these aquifer elements is divided into 100 cells (maximum allowed in GoldSim©) to reduce the numerical dispersion in the finite-difference cell network. A longitudinal dispersivity of 10.5 m was assigned in each aquifer element. This value is consistent with the STOMP 3-D process model (RPP-RPT-60101). The cross-sectional area of the 1-D GoldSim© aquifer is calculated from the average aquifer thickness of 13.25 m and an aquifer width equal to the width of the source. The mass loading into the first leg of the aquifer pathway from the vadose zone occurs over the length of the source parallel to the flow path. The volumetric flow rate through the aquifer is calculated by multiplying the flow velocity abstracted from the STOMP model with the aquifer cross-sectional area. Since the 1-D model does not allow the contaminant mass to spread out laterally and flow remains constant in the entire pathway, a dimensional adjustment factor was used in the aquifer model. This dimensional adjustment factor modifies the outflow rate of the aquifer to account for the lateral spreading and flow heterogeneties in the 3-D process model. This is a simplified way of accounting for the differences in the heterogeneities and lateral spreading in the 3-D and 1-D models.

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Table 4-7. Source to Fence Line Approximate Distance for Different Sources*.

Source	Source to the Fence Line Distance along the Flow Path (meters)
Tank 241-A-101	137.0
Tank 241-A-102	105.5
Tank 241-A-103	76.4
Tank 241-A-104	140.2
Tank 241-A-105	108.6
Tank 241-A-106	78.1
A-NonTank	105.5
Tank 241-AX-101	44.0
Tank 241-AX-102	44.7
Tank 241-AX-103	68.8
Tank 241-AX-104	71.1
AX-NonTank	44.7

*GoldSim© element name: **Distance_Tank_To_Fenceline**.

Since lateral dispersion and flow velocity changes with distance along the flow path, the effective dimensional adjustment factor was different in the two aquifer elements in the pathway. Since the fence line is closer to AX Farm (Figure 4-17), the effective value of dimensional adjustment factor in the first aquifer element in AX Farm tanks is less than the value used for A Farm tanks.

Non-tank (pipeline + ancillary equipment) sources are distributed in a much larger area than the tank sources. As a result, the effect of lateral spreading expected to be insignificant and no dimensional factor was needed for the non-tank sources. For the tanks, a dimensional adjustment factor was obtained for the second aquifer pathway element by fitting the concentration at 100 m calculated by the 1-D system model to the concentration at 100 m calculated by the 3-D process model.

The GoldSim© cloning method is used in the model to replicate the saturated zone transport model for each waste source. Only source-specific parameters (source zone length, aquifer length, aquifer area, infill medium) were varied between sources.

4.3.6 Comparison to the Waste Management Area A-AX Process Model (STOMP)

In order to provide confidence that the system-level implementation of transport through the natural system beneath WMA A-AX is representative of the process-level simulations, GoldSim© vadose zone-saturated zone model results were compared with STOMP model results (RPP-CALC-63164).

Mass fluxes of ^{99}Tc and ^{129}I were calculated using the source term model for all sources in WMA A-AX using GoldSim©. These fluxes are displayed in Figure 4-21 and Figure 4-22. These fluxes were applied as boundary conditions to both the STOMP and GoldSim© models. Three key results were compared for these two analytes and for five sources (tank A-102, tank AX-101, tank 241-A-105 [A-105], A Farm non-tank and AX Farm non-tank sources). The three key results are (a) contaminant mass flux at the water table, (b) concentration at the fence line, and (c) concentration at the 100-m boundary. The results are presented in Figure 4-23 to Figure 4-33. For the tanks sources, the 1-D system model breakthrough time and peak concentrations matched well with the 3-D process model results.

For the non-tank sources, results are in reasonable agreement between the models. The concentration for non-tank sources is much smaller than the tank sources because of the small inventory in the non-tank sources. As a result, the non-tank sources are not significant contributors to the overall dose from all sources, and minor differences between the models are tolerable.

As identified in Figure 4-19, the plume from A Farm sources does not interact with the plume from AX Farm sources. The maximum concentrations at the fence line and the 100-m boundary occur at the centerline of A Farm sources. Based on this understanding, the concentrations for the 1-D model were calculated by adding the contributions from all sources in A Farm. That is, in the system model, no contribution was added from the AX Farm sources, since these have been shown above to add negligible contributions to the peak concentrations from WMA A-AX. These concentrations were then compared to the combined concentration calculated using the 3-D process model (all sources from A Farm and AX Farm). The comparisons at the fence line and the 100-m boundary are shown in Figure 4-33. The system model results match very well with the 3-D process model results.

Figure 4-21: Tc-99 Flux to Vadose Zone by Source

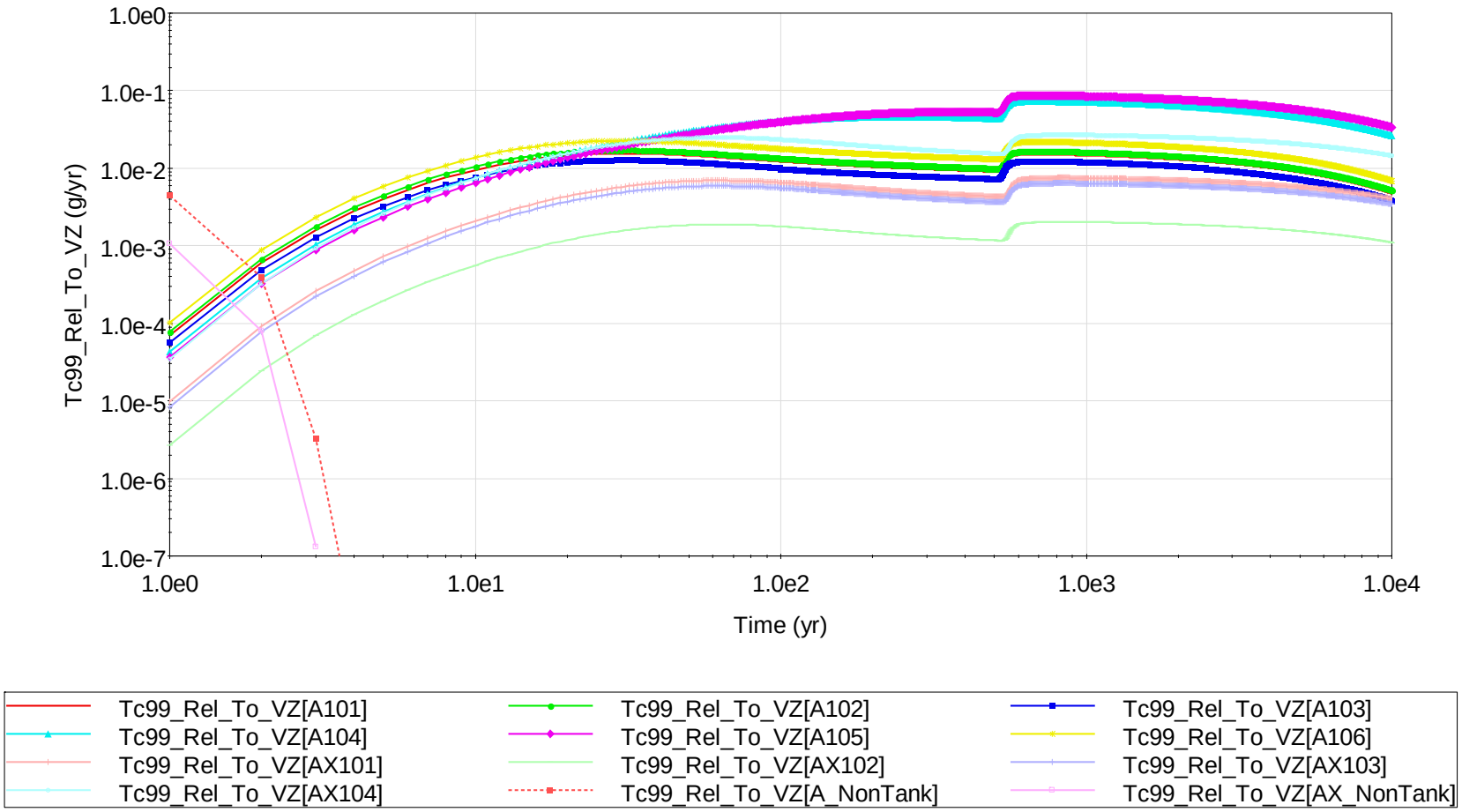


Figure 4-22: I-129 Flux to Vadose Zone by Source

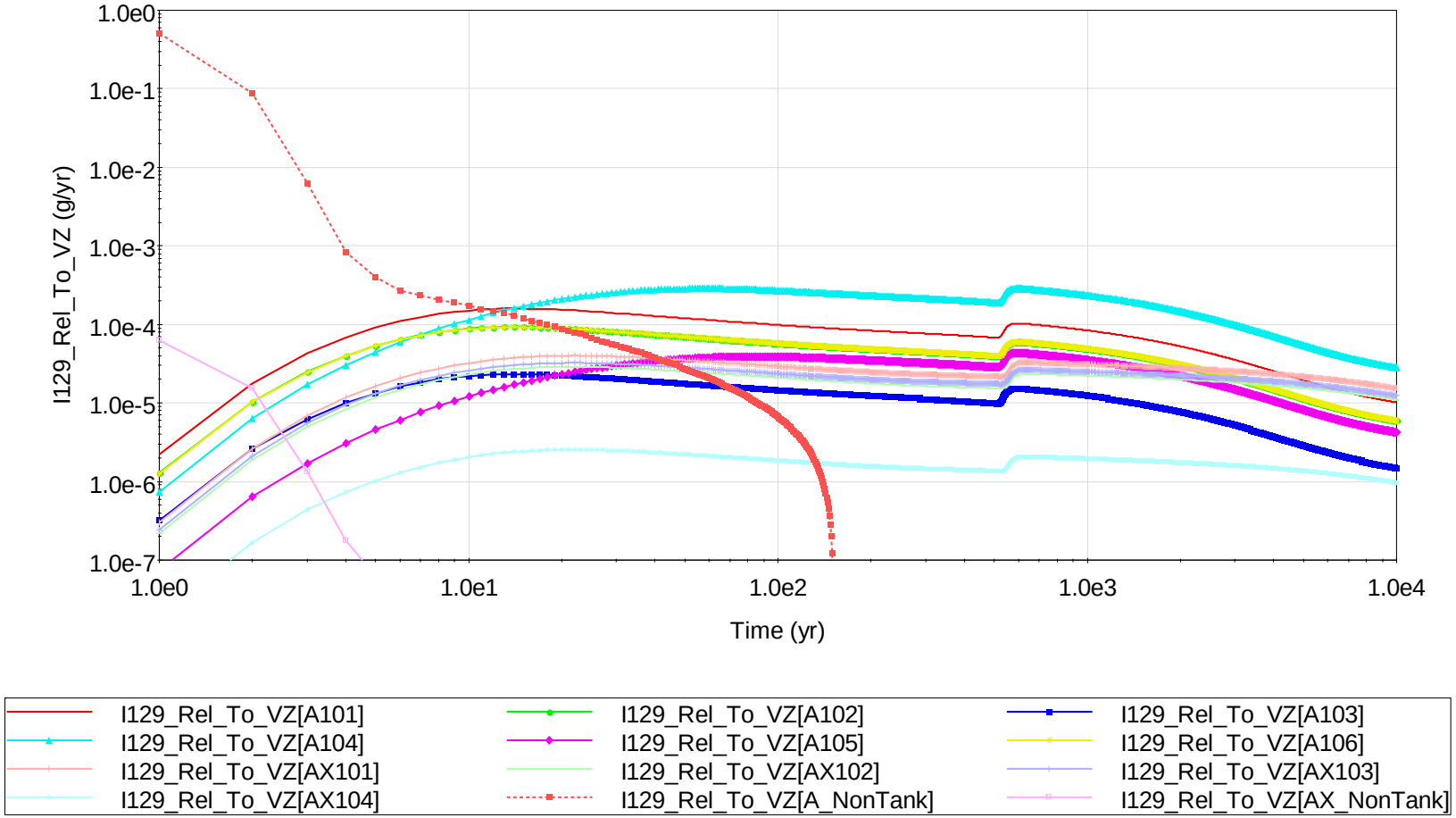
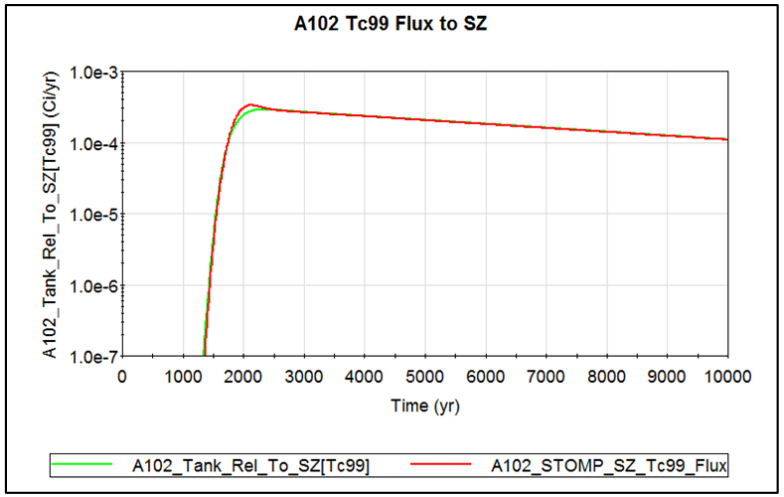


Figure 4-23. Comparison between Three-Dimensional Process Model (STOMP) and One-Dimensional System Model (GoldSim©) for Technetium-99 Release from Tank 241-A-102 (a) Mass Flux Arriving at the Water Table and (b) Concentration at Fence Line (c) Concentration at 100 meters.



(a) Mass flux at the water table

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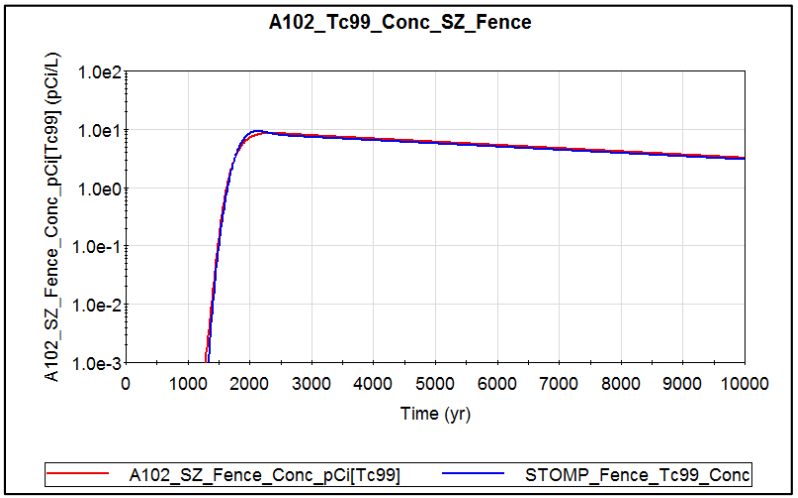
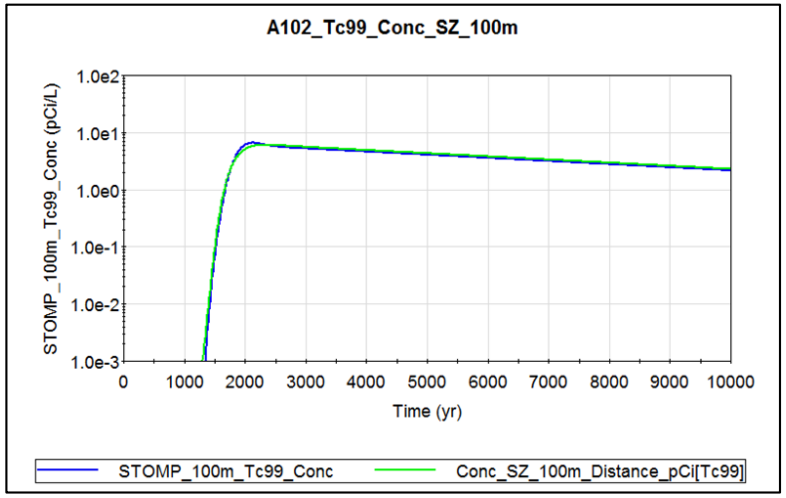
Subsurface Transport Over Multiple Phases (STOMP) has been developed and distributed by Battelle Memorial Institute.

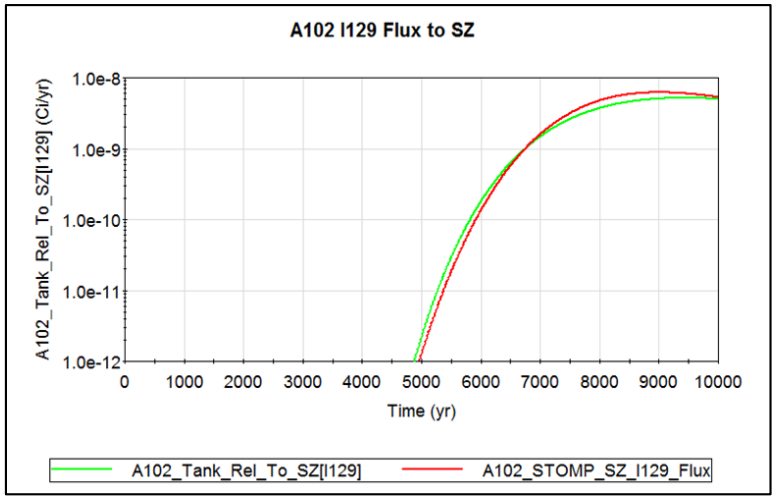


(b) Concentration at fence line



(c) Concentration at 100-m boundary

Figure 4-24. Comparison between Three-Dimensional Process Model (STOMP) and One-Dimensional System Model (GoldSim©) for Iodine-129 Release from Tank 241-A-102 (a) Mass Flux Arriving at the Water Table and (b) Concentration at Fence Line (c) Concentration at 100 meters.



(a) Mass flux at the water table

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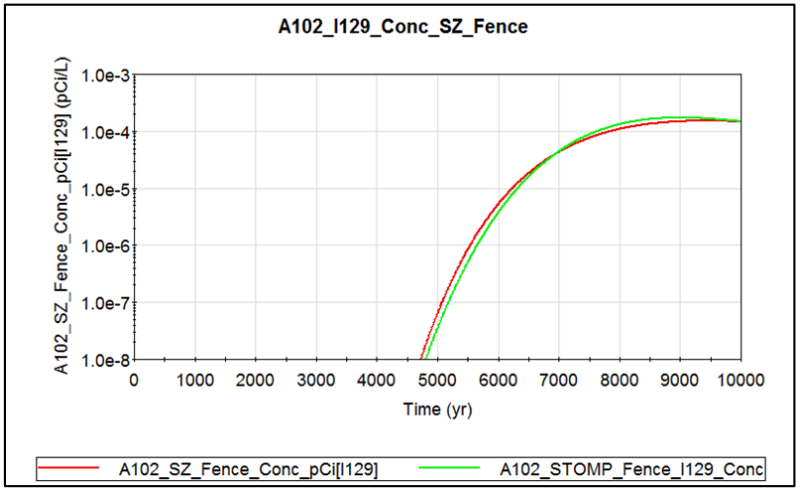
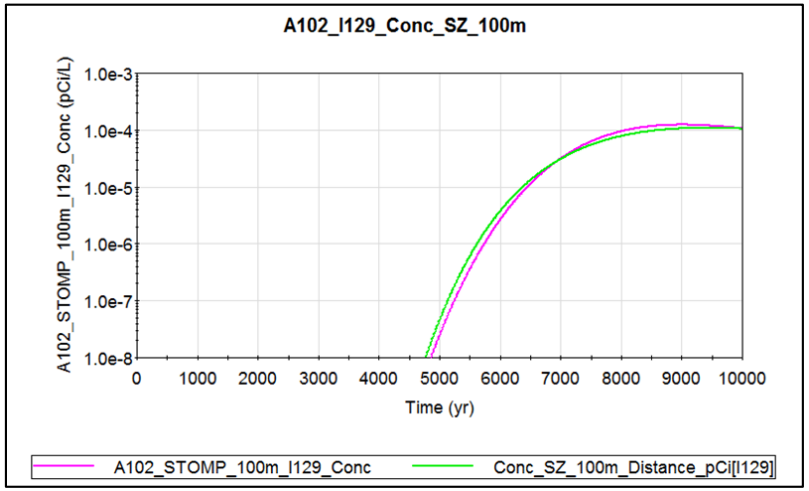
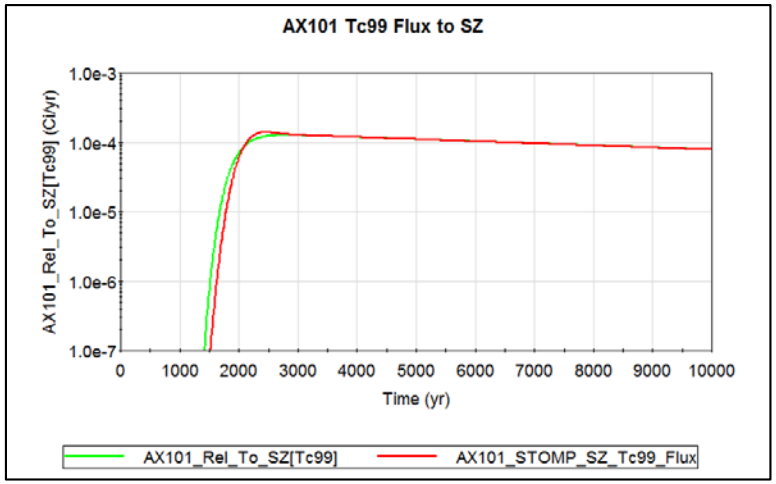


(b) Concentration at fence line



(c) Concentration at 100-m boundary

Figure 4-25. Comparison between Three-Dimensional Process Model (STOMP) and One-Dimensional System Model (GoldSim©) for Technetium-99 Release from Tank 241-AX-101 (a) Mass Flux Arriving at the Water Table and (b) Concentration at Fence Line (c) Concentration at 100 meters.



(a) Mass flux at the water table

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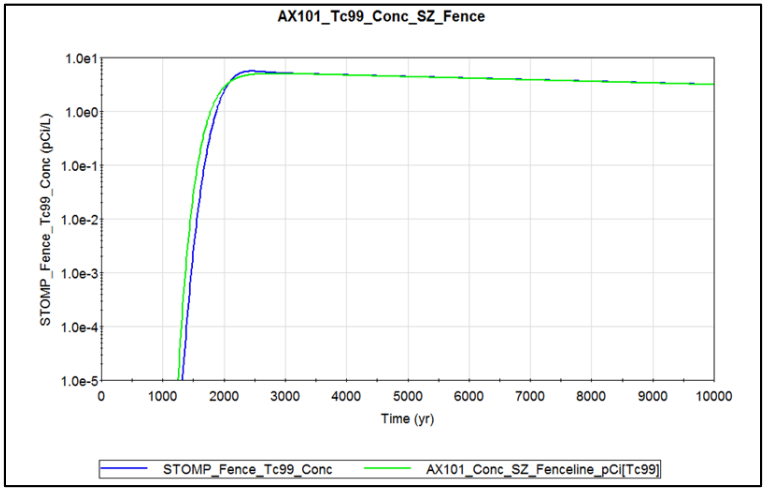
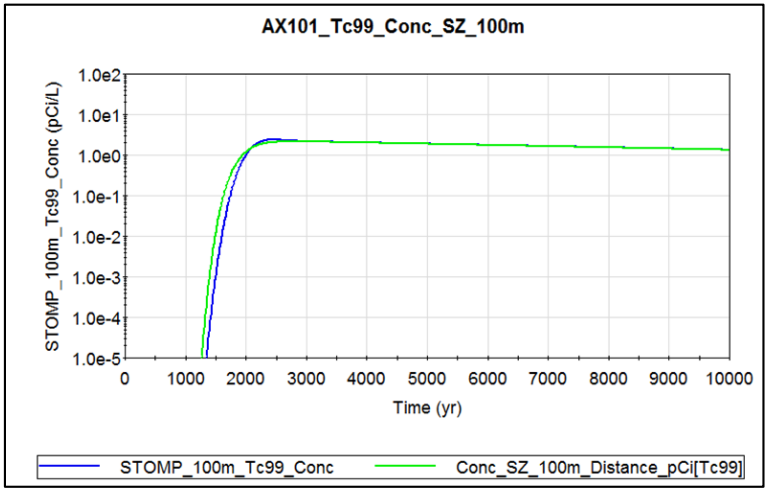
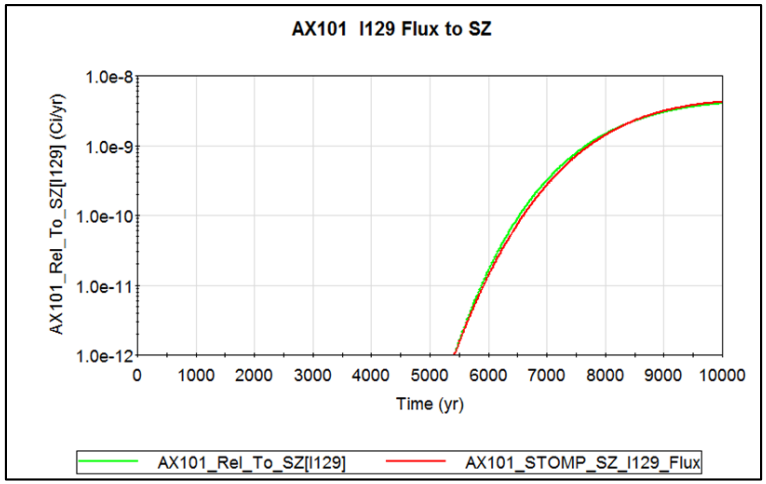


(b) Concentration at fence line



(c) Concentration at 100-m boundary

Figure 4-26. Comparison between Three-Dimensional Process Model (STOMP) and One-Dimensional System Model (GoldSim©) for Iodine-129 Release from Tank A-105 (a) Mass Flux Arriving at the Water Table and (b) Concentration at Fence Line (c) Concentration at 100 meters.



(a) Mass flux at the water table

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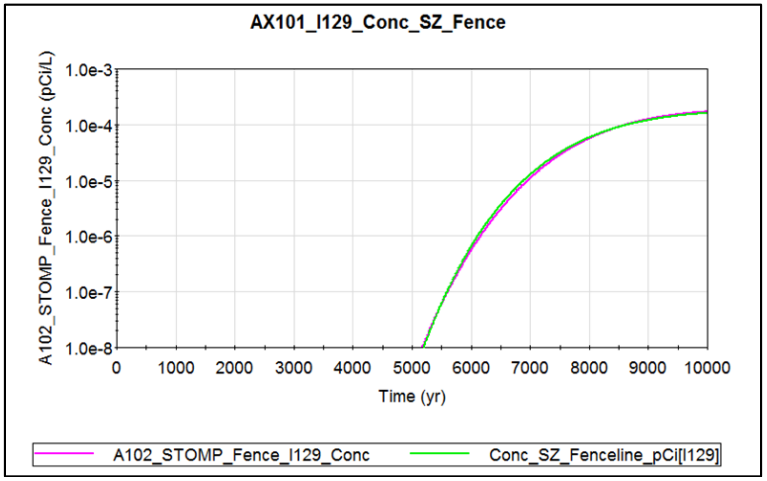
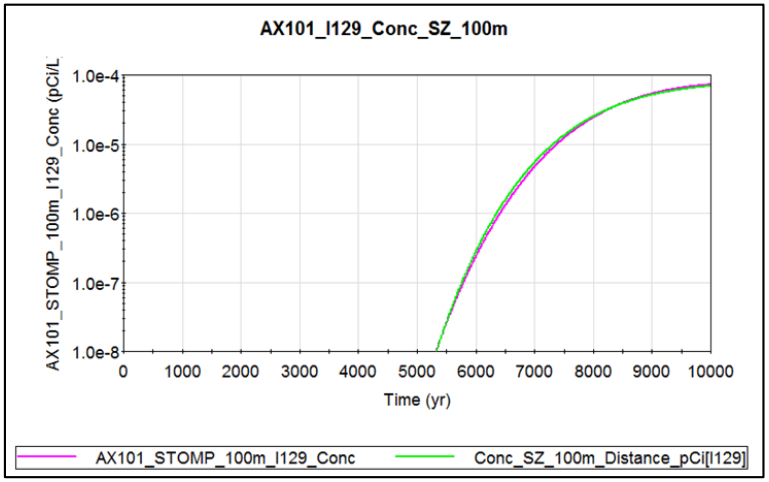
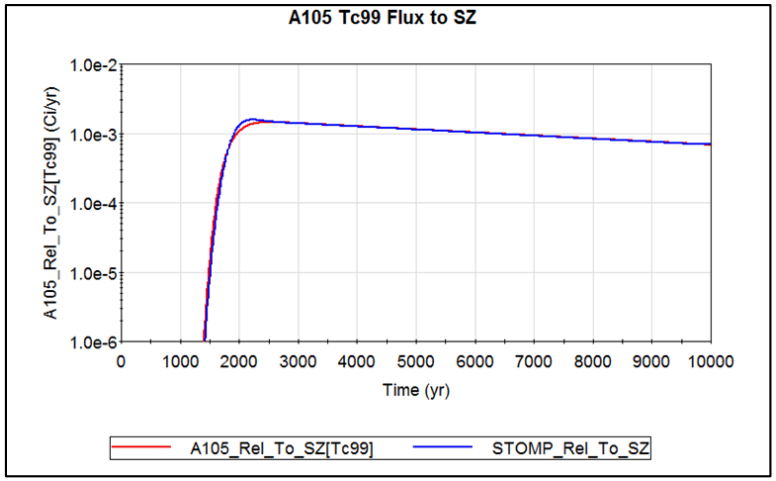


(b) Concentration at fence line



(c) Concentration at 100-m boundary

Figure 4-27. Comparison between Three-Dimensional Process Model (STOMP) and One-Dimensional System Model (GoldSim©) for Technetium-99 Release from Tank 241-A-105 (a) Mass Flux Arriving at the Water Table and (b) Concentration at Fence Line (c) Concentration at 100 meters.



(a) Mass flux at the water table

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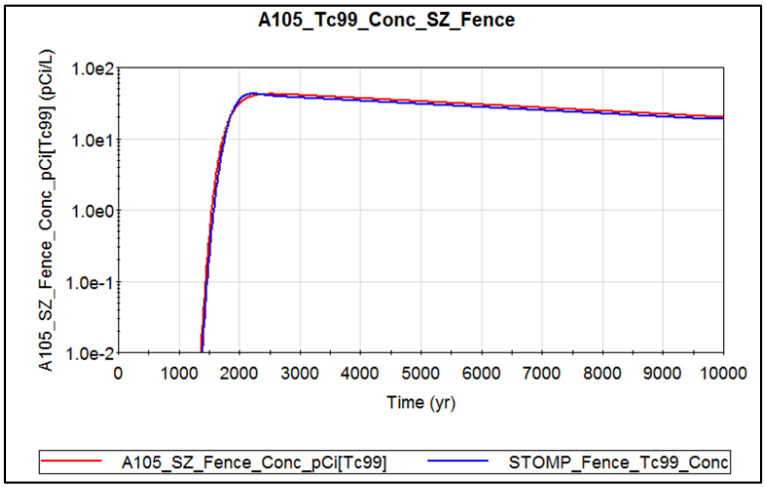
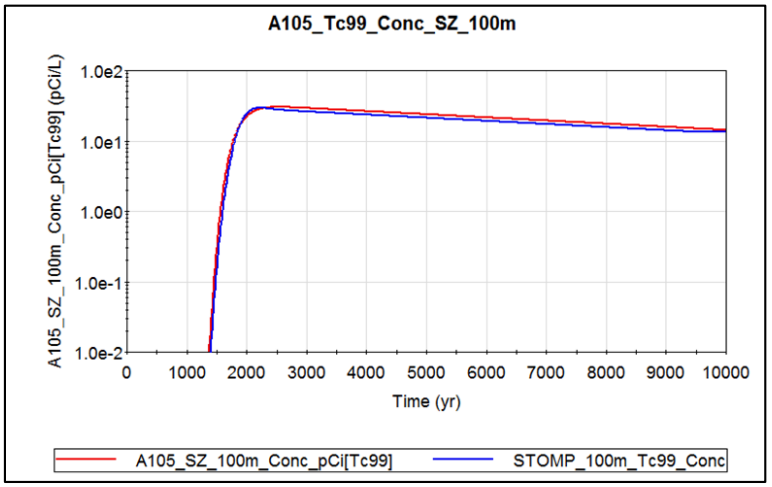
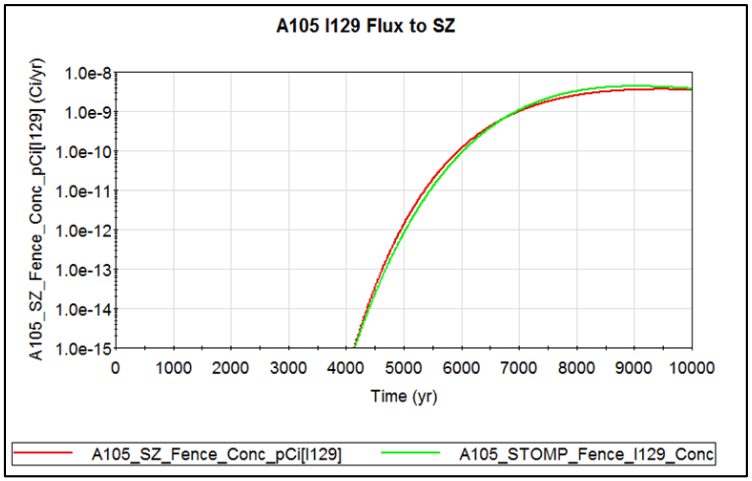


(b) Concentration at fence line



(c) Concentration at 100-m boundary

Figure 4-28. Comparison between Three-Dimensional Process Model (STOMP) and One-Dimensional System Model (GoldSim©) for Iodine-129 Release from Tank 241-A-105 (a) Mass Flux Arriving at the Water Table and (b) Concentration at Fence Line (c) Concentration at 100 meters.



(a) Mass flux at the water table

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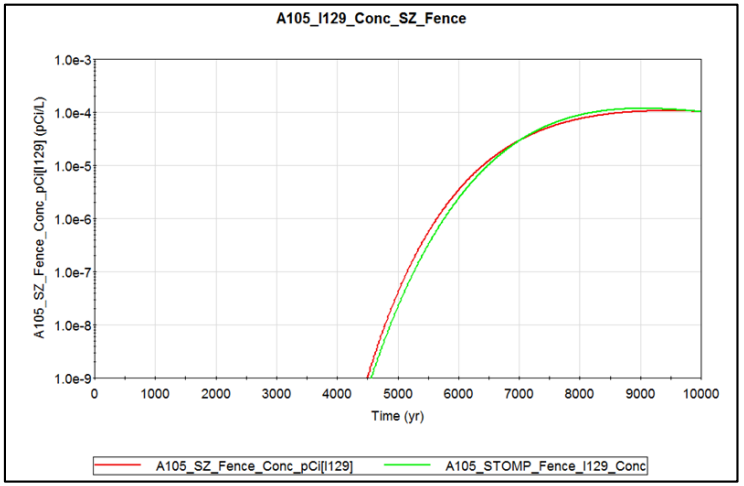
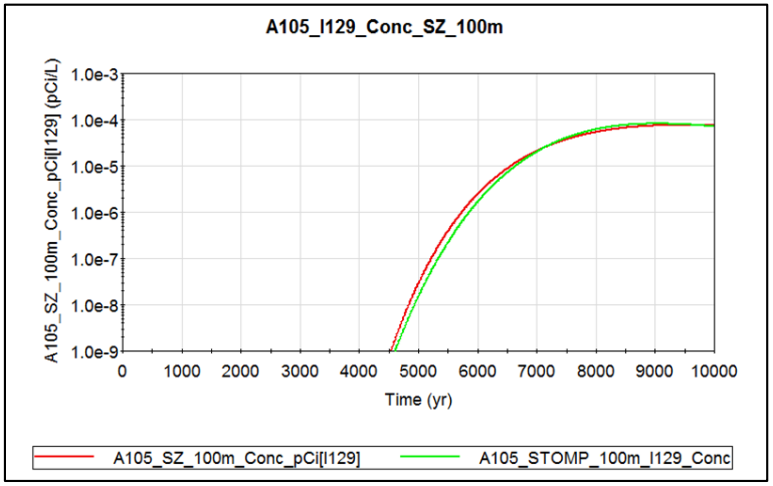
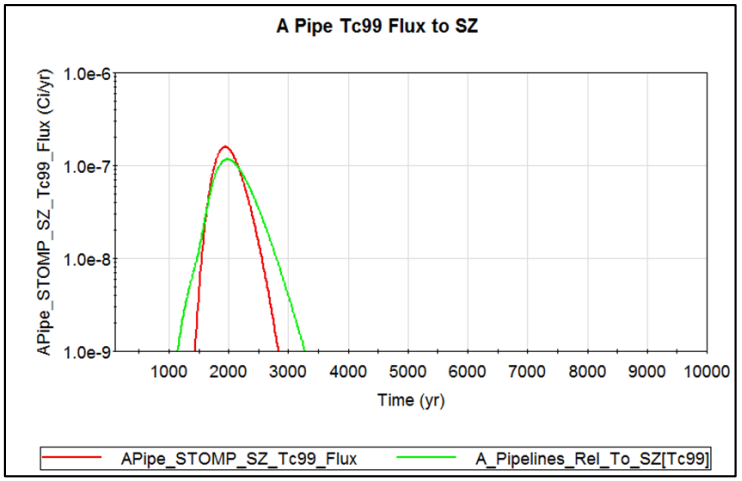


(b) Concentration at fence line



(c) Concentration at 100-m boundary

Figure 4-29. Comparison between Three-Dimensional Process Model (STOMP) and One-Dimensional System Model (GoldSim©) for Technetium-99 Release from 241-A Tank Farm Non-Tank Sources (a) Mass Flux Arriving at the Water Table and (b) Concentration at Fence Line (c) Concentration at 100 meters.



(a) Mass flux at the water table

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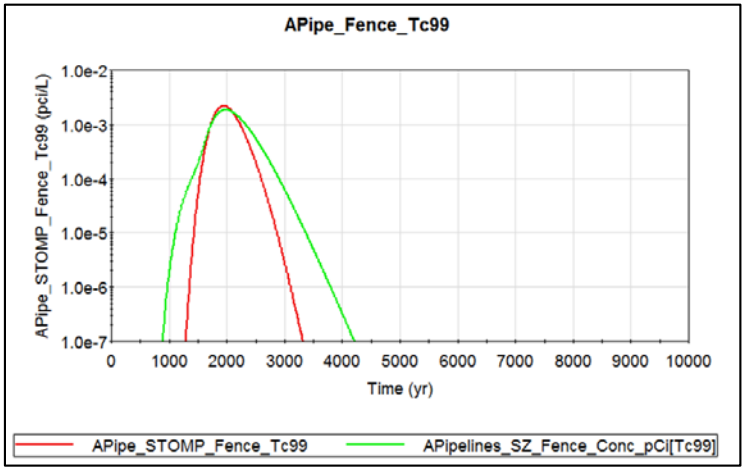
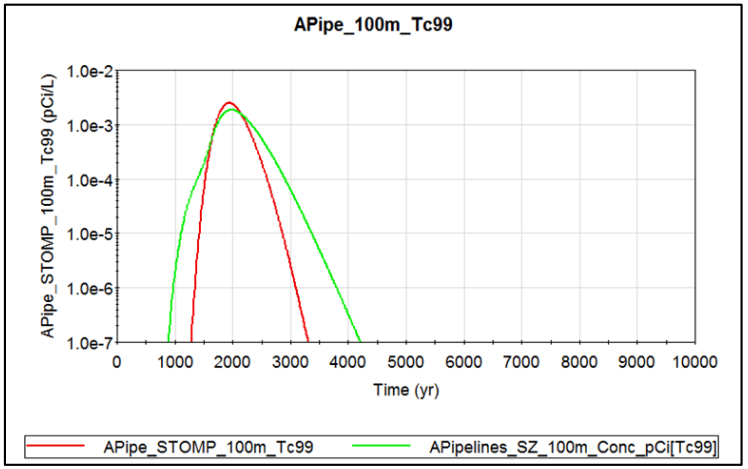
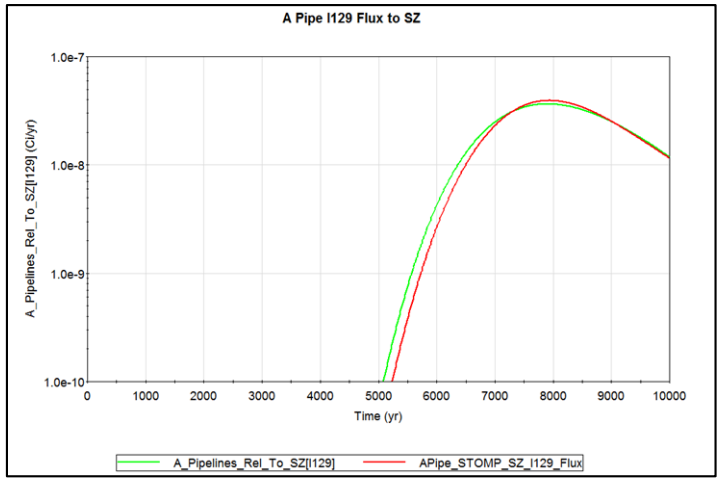


(b) Concentration at fence line



(c) Concentration at 100-m boundary

Figure 4-30. Comparison between Three-Dimensional Process Model (STOMP) and One-Dimensional System Model (GoldSim©) for Iodine-129 Release from 241-A Tank Farm Non-Tank Sources (a) Mass Flux Arriving at the Water Table and (b) Concentration at Fence Line (c) Concentration at 100 meters.



(a) Mass flux at the water table

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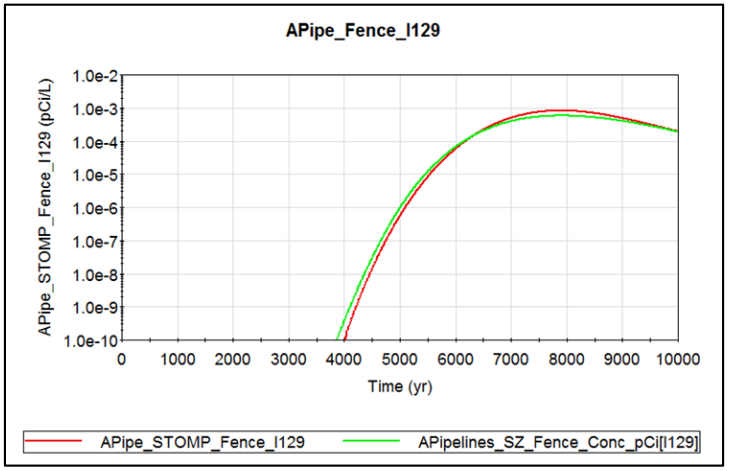
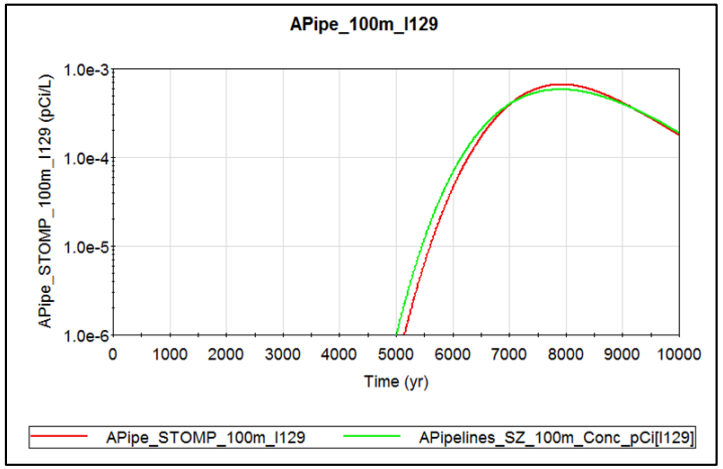
Subsurface Transport Over Multiple Phases (STOMP) has been developed and distributed by Battelle Memorial Institute.

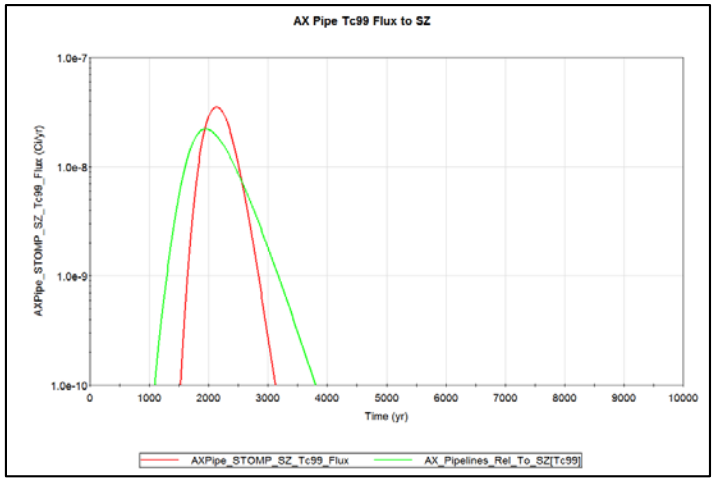


(b) Concentration at fence line



(c) Concentration at 100-m boundary

Figure 4-31. Comparison between Three-Dimensional Process Model (STOMP) and One-Dimensional System Model (GoldSim©) for Technetium-99 Release from 241-AX Tank Farm Non-Tank Sources (a) Mass Flux Arriving at the Water Table and (b) Concentration at Fence Line (c) Concentration at 100 meters.



(a) Mass flux at the water table

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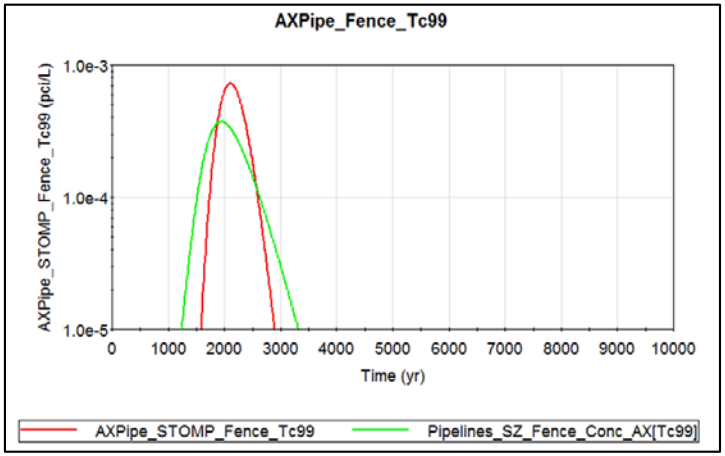
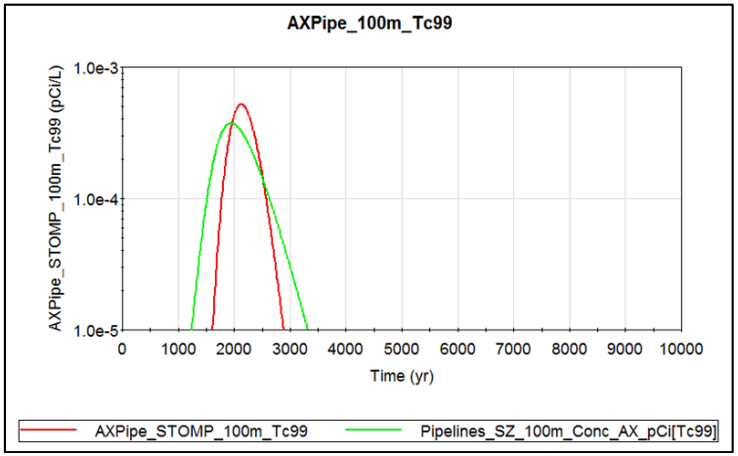
Subsurface Transport Over Multiple Phases (STOMP) has been developed and distributed by Battelle Memorial Institute.

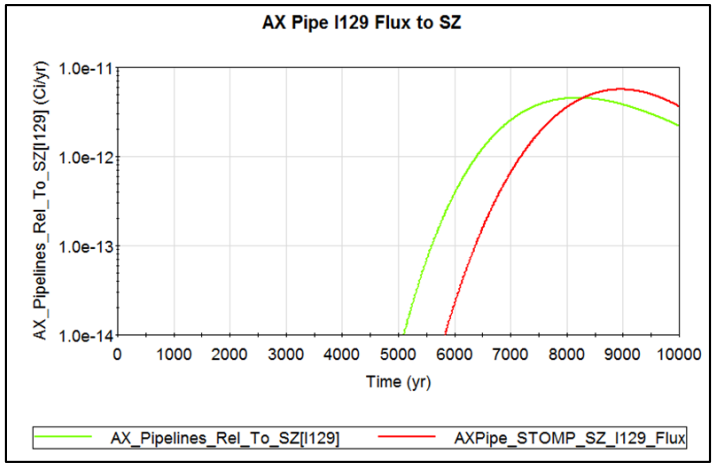


(b) Concentration at fence line



(c) Concentration at 100-m boundary

Figure 4-32. Comparison between Three-Dimensional Process Model (STOMP) and One-Dimensional System Model (GoldSim©) for Iodine-129 Release from 241-AX Tank Farm Non-Tank (a) Mass Flux Arriving at the Water Table and (b) Concentration at Fence Line (c) Concentration at 100 meters.



(a) Mass flux at the water table

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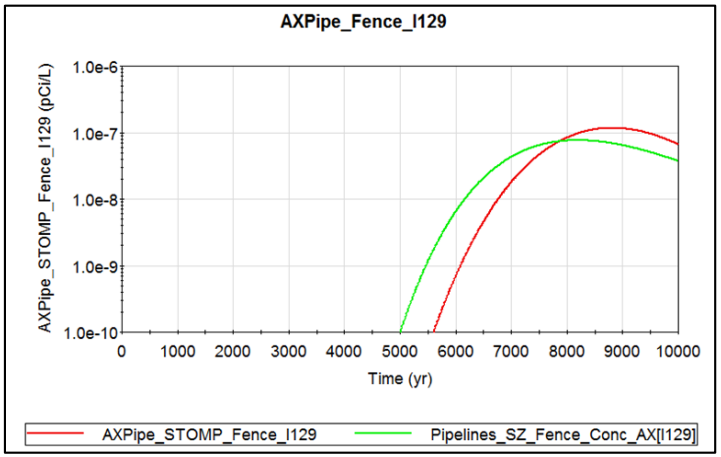
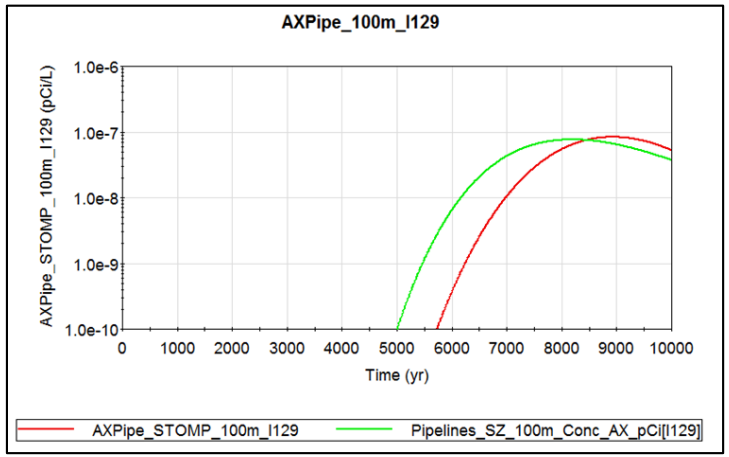
Subsurface Transport Over Multiple Phases (STOMP) has been developed and distributed by Battelle Memorial Institute.

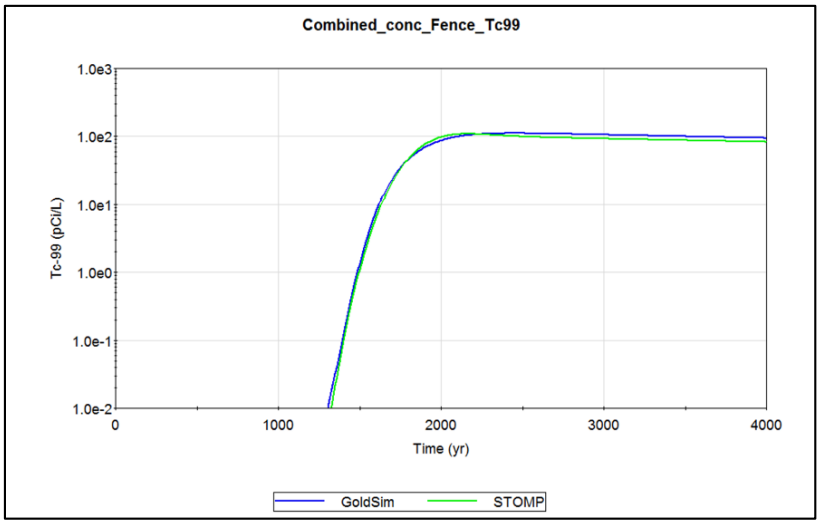


(b) Concentration at fence line

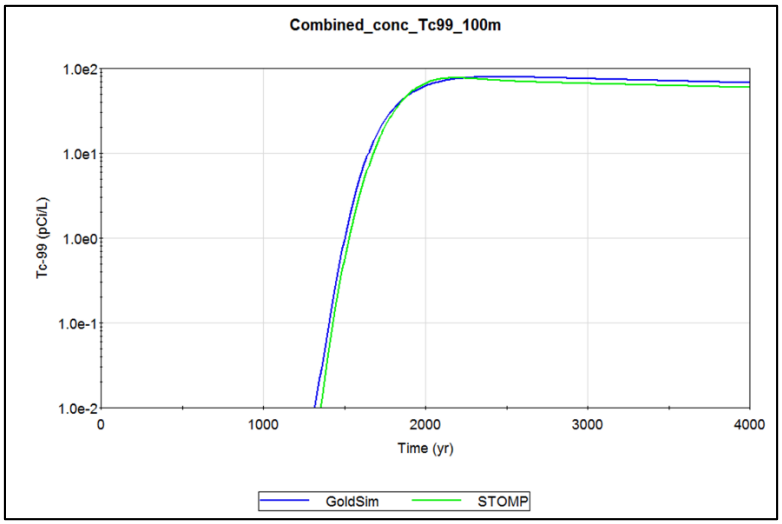


(c) Concentration at 100-m boundary

Figure 4-33. Comparison between Three-Dimensional Process Model (STOMP) and One-Dimensional System Model (GoldSim©) for the Combined Effect of Different Sources at Maximum Concentration Location (a) Technetium-99 Concentration at Fence Line (b) Technetium-99 Concentration at 100 meters.



(a) ^{99}Tc Concentration at fence line



(b) ^{99}Tc Concentration at 100-m boundary

GoldSim© simulation software is copyrighted by GoldSim Technology Group LLC of Issaquah, Washington (see http://www.goldsim.com).
Subsurface Transport Over Multiple Phases (STOMP) has been developed and distributed by Battelle Memorial Institute.

4.4 IMPLEMENTATION OF ATMOSPHERIC TRANSPORT PATHWAY

4.4.1 Atmospheric Transport Calculation

As discussed in Section 3.4, four radionuclides contained in residual inventory at closure could potentially originate as gas:

- Carbon-14 as CO_2 gas
- Hydrogen-3 (tritium) as H_2 gas
- Iodine-129 as I_2 gas
- Radon-222 as Rn gas.

A screening calculation (RPP-CALC-63180) showed that the inhalation dose to a receptor at the site boundary from ^{14}C, ^{3}H and ^{129}I from all WMA A-AX sources would be orders of magnitude lower than the performance objective. Therefore the atmospheric transport of those three radionuclides is not included in the system model. Atmospheric transport of ^{222}Rn is retained, however, to demonstrate compliance with DOE O 435.1 surface radon flux performance objectives. Radon fluxes are calculated for comparison to the performance objective of 20 pCi/m^2/s at the ground surface for each source.

Gaseous releases are controlled by the partitioning of the radionuclides among:

- the solid fraction of the porous medium (sorbed fraction),
- aqueous dissolved fraction (grout/water partitioning) – represented by the K_d equilibrium coefficient,
- the gaseous fraction (air/water partitioning) – represented by Henry's law constant (K_h).

For ^{222}Rn, Henry's law constant is 9.30×10^{-3} mol atm^{-1}L^{-1} (*Compilation of Henry's Law Constants for Inorganic and Organic Species of Potential Importance in Environmental Chemistry*, Version 3 [Sander 1999]) and the calculated gas-to-aqueous dimensionless Henry's constant at 20°C is 4.47.

The upward diffusive flux of ^{222}Rn is calculated from each source term to the surface. A zero-concentration boundary condition at the presumed land surface (the top of soil fill above the closed tanks) is imposed to calculate the gaseous flux. This is conceptually equivalent to having a large enough wind speed above WMA A-AX such that the air parcel is renewed constantly, thereby maximizing the diffusive gradient.

- For all sources except pipelines, while the infill grout is intact, upward gaseous diffusion of volatile contaminants is modeled from the residual waste layer towards the atmosphere. Upward diffusive gas phase transport through the tanks is modeled along a 16-m-long pathway towards the land surface. This pathway is split into a lower 10-m thickness composed of infill grout material, followed by another 6-m thickness of

soil overburden. For the pipeline source area, the diffusive length is the pipeline diameter (0.076 m [3 in.]) and the 6-m thickness of the soil overburden.

- 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. For the purpose of performing the air pathway calculations, this additional thickness is ignored.

- Radionuclide vapor diffusion is assumed to only migrate vertically upward from the source zone. Lateral boundaries of this flow path are no-flow boundaries in the calculations, resulting in a larger mass flux at the land surface than what actually will occur. Thus, this assumption builds in a further measure of conservatism into the calculation.

- 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 porosity and saturation of the infill grout are fixed over time in the diffusive release calculations. This is a conservative assumption, as studies have indicated that chemical transformation of initial grout minerals will likely cause porosity reduction over time due to increased molar volume of the newly-formed mineral phases.

4.4.2 Mathematical Modeling of Subsurface Vapor Diffusional Releases

The equations representing the conceptual model are implemented using GoldSim©. Diffusion pathways are modeled using a series of cells representing components in the source term that constitutes a mass transfer resistance network. GoldSim© solves diffusive mass transfer equations numerically based on a user-established discretized system. Diffusive mass transfer in 1-D is given by Equation 4-1.

$$R_d \frac{\partial(\theta_a C)}{\partial t} = D_{ef} \frac{\partial^2 C}{\partial x^2} \tag{4-1}$$

Where:

C = the air concentration (kg/m^3) in the pore network of a given gas at the distance x (m) from the waste layer and time t(s) from assumed closure at WMA A-AX

D_{ef} = the effective diffusion coefficient of a given gas through the tortuous air pathway of the porous medium (m^2/s)

R_d = the retardation coefficient of a given gas due to partitioning among different phases (air, water and solids) of the porous medium (Equation 4-2; calculated by GoldSim©)

θ_a = the air content (or air-filled porosity) of the porous medium (for soil, calculated by $(\phi - \theta_w)^2$, where ϕ is total porosity (measured) and θ_w is water content.

The retardation coefficient (R_d) in Equation 4-1 is calculated by:

$$R_d = 1 + \frac{\rho K_d}{\theta} \tag{4-2}$$

Where:

ρ = bulk density of the porous medium (g/cm^3)
K_d = partitioning coefficient of the porous medium (mL/g)
θ = porosity of the porous medium (unitless).

The diffusion coefficient for each gas component through the tortuous air pathway of the porous medium is calculated as follows:

$$D_{ef} = D_0 \tau \tag{4-3}$$

Where:

D_{ef} = the effective diffusion coefficient through the tortuous air pathway of the porous medium for a given gas (m^2/s)
D_0 = the binary diffusion coefficient of the gas of concern in air (m^2/s)
τ = the tortuosity of the porous medium for air pathway.

An effective zero concentration boundary condition is imposed above WMA A-AX to maximize the diffusive flux of gases. The diffusive area varies by the source geometry.

The radon flux from each source in the model is estimated by dividing the ^{222}Rn release rate by its source area.

4.4.3 Diffusion Coefficient and Gas Tortuosity

The binary diffusion coefficient of radon in air at 20°C and 1 atmosphere of pressure is 0.11 cm^2 s^{-1} (Radon and Its Decay Products in Indoor Air [Nazaroff and Nero 1988]).

"Simulating the Gas Diffusion Coefficient in Macropore Network Images: Influence of Soil Pore Morphology" (Liu et al. 2006) compiled data sets and presented the experimentally-determined gas tortuosity (ratio of the effective diffusion coefficient in soil [$\boldsymbol{D_{ef}}$] to that in free air [$\boldsymbol{D_0}$]) as a function of the air-filled porosity (air content) for various soil types. It also provided the best fit lines and bounding estimates based on models presented by "Transport in porous media" (Millington and Quirk 1960) and "Permeability of Porous Solids" (Millington and Quirk 1961).

Gas tortuosity in the infill grout material is calculated using the following equation (Millington and Quirk 1961):

$$\tau = \frac{\theta_a^2}{\Phi^{2/3}} \tag{4-4}$$

Where:

τ = tortuosity

θ_a = air content (or air-filled porosity) of the porous medium; fixed value of 6% (WSRC-TR-2005-00195)
Φ = fitted total porosity; set equal to 0.8 for best fit (Liu et al. 2006).

The tortuosity of the backfill material (soil overburden) is calculated by:

$$\tau = \frac{(\phi - \theta_w)^2}{\Phi^{2/3}} \tag{4-5}$$

Where:

τ = tortuosity
ϕ = total porosity (measured)
θ_w = water content of the porous medium; varies as a function of time
Φ = fitted total porosity; set equal to 0.8 for best fit (Liu et al. 2006).

The infill grout is the solid surface within the tank, while the pipelines are not assumed to be grouted. The K_d value for ^{222}Rn is set to zero because it is a noble gas and unreactive with its surroundings.

Sorption on the backfill could be considered, but is conservatively ignored since it is typically much smaller than on the grout.

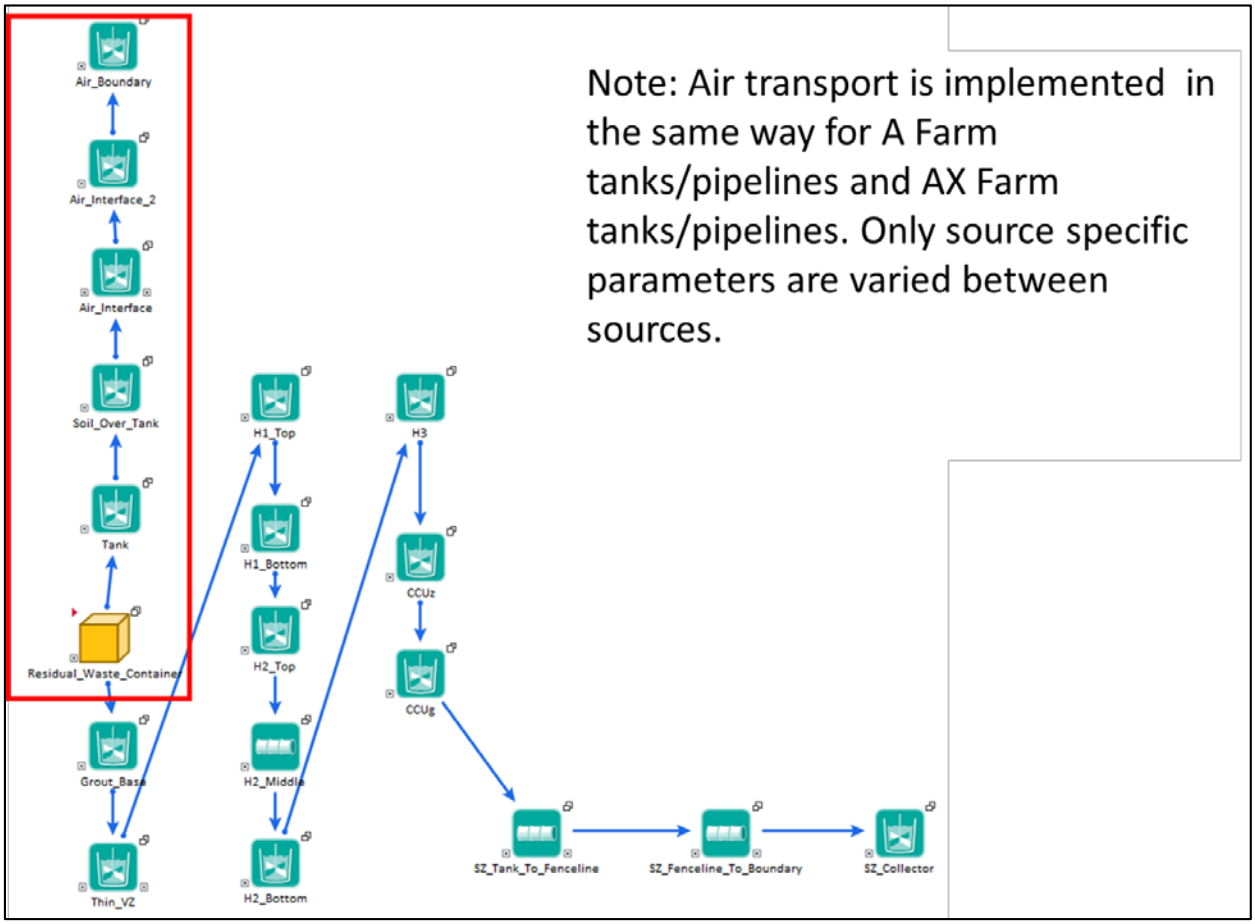
4.4.4 GoldSim© Implementation of Atmospheric Transport Pathway

Figure 4-34 highlights the GoldSim© cell pathway network for the vadose zone. The air transport in these figures begins from the Residual_Waste cell, and diffuses upwards through the Tank, Soil_Over_Tank, Air_Interface, Air_Interface_2, and Air_Boundary cells using the equations described in this section, with the physical properties described in Section 4.3.

4.4.5 Radon Flux Analysis

The radon flux analysis is a very simple calculation that uses the release rates of ^{222}Rn for each source (g/yr) from the **Transport_Abstraction** container, which are calculated using the atmospheric transport pathway described in Sections 3.4 and 4.4. These fluxes from the ground surface are first multiplied by the specific activity of ^{222}Rn (Ci/g) and then divided by **Base_Area_Tank**, which is a vector of areas (m^2) for each source in the model. The result is the radon flux from each source in the model ($pCi/m^2/s$), which is needed to compare to the performance objective of <20 $pCi/m^2/s$ of radon as defined by DOE-STD-5002-2017, *Disposal Authorization Statement and Tank Closure Documentation*.

Figure 4-34. Transport Abstraction Model for A Series Tanks.



Note: Elements used in the air transport are indicated in red outline.

4.5 IMPLEMENTATION OF INADVERTENT INTRUDER SCENARIO

A hypothetical inadvertent intruder analysis is undertaken to meet the requirements of DOE O 435.1. Guidance for the inadvertent intruder analysis comes from DOE G 435.1, *Implementation Guide for Use with DOE M 435.1-1, Radioactive Waste Management Manual*, which states the following:

> "Although DOE is committed to retaining control of land containing residual radioactive material, such as disposed low-level waste, it is nonetheless appropriate to consider the impacts of potential inadvertent intrusion. Intrusion should be considered as an accident scenario which could occur during lapses of institutional controls. It is a hypothetical situation assumed simply to provide a basis for determining the acceptability of waste for near-surface disposal and may be used for establishing concentrations of radioactive material in a near-surface disposal facility."

Two types of exposure scenarios are considered to estimate dose to the hypothetical intruder: (1) acute scenarios and (2) chronic scenarios. Acute scenarios evaluate the dose received from well drilling and subsequent exposure to residual waste in the drill cuttings; exposure is evaluated over a short time period. Chronic scenarios evaluate the dose received from spreading the drill cuttings over the surface followed by living and/or working on that area. One acute exposure scenario and three chronic exposure scenarios are evaluated in the system model and brief descriptions of each scenario are provided in Table 4-8. The equations are presented in the following sections and additional details, including input parameters, are provided in RPP-ENV-58813.

Table 4-8. Descriptions of the Inadvertent Intruder Scenarios Evaluated in the Waste Management Area A-AX Performance Assessment.

Scenario	Description
Acute Exposure: Well Driller	Dose is the result of drilling through Waste Management Area A-AX. Exposure pathways include external exposure, inhalation of soil particulates, and incidental soil ingestion. Exposure occurs during the drilling operation while in contact with the drill cuttings. Exposure does not depend on the borehole diameter.
Chronic Exposure: Rural Pasture	Dose is the result of drilling a well that serves a rural pasture. Contaminated drill cuttings are mixed with the soil over the pasture area. Exposure pathways include external exposure, inhalation of soil particulates, incidental soil ingestion, and milk consumption.
Chronic Exposure: Suburban Garden	Dose is the result of drilling a well that serves a suburban garden. Contaminated drill cuttings are mixed with the soil over the area where a residence and a garden are constructed. Exposure pathways include external exposure, inhalation of soil particulates, incidental soil ingestion, and fruit and vegetable consumption.
Chronic Exposure: Commercial Farm	Dose is the result of drilling a well that serves a commercial farm. Contaminated drill cuttings are mixed with the soil over the commercial farm area. Exposure pathways are external exposure, inhalation of soil particulates, and incidental soil ingestion.

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

Intruder scenarios are evaluated for each of the 12 waste sources (10 tanks, A Farm pipelines and AX Farm pipelines). The calculations are performed using the same model setup that is described in Section 4.2. The only difference is that contaminant transport and release is not allowed out of the tanks or ancillary equipment. The residual inventory for radionuclides undergoes decay and ingrowth and the radionuclide concentration is calculated at the time of the intrusion.

Dose conversion factors (DCFs) used in the intruder dose calculations come from RPP-ENV-58813. It is unclear whether the ingestion and inhalation DCFs include short-lived progeny in equilibrium at the time of consumption (RPP-CALC-61254, *Inadvertent Intruder Dose Calculation Update for the Integrated Disposal Facility Performance Assessment*). To compensate for this, a conservative approach assuming that the effects of progeny present at the time of exposure are not included in the DCF is used. This approach uses dose multipliers determined in RPP-CALC-61254 to account for short-lived progeny at the time of consumption. If this assumption is incorrect, the derived doses will be overestimated, resulting in waste

concentration limits that are more restrictive than necessary to meet performance metric. Where DCFs are mentioned in the following sections, it is assumed they are corrected for the effects of short-lived progeny at the time of consumption.

4.5.1 Acute Well Driller Exposure Scenario

The single acute exposure scenario evaluates the short-term exposure of a well driller to drill cuttings that are exhumed from a well that is installed to the depth of the water table for the supply of water. As the well is drilled through the WMA A-AX waste residuals, the driller will be exposed to the radiation dose from the drill cuttings. The well driller is assumed to be exposed to drill cuttings for a total of five days (8 hours per day for a total of 40 hours). The dose is calculated by assuming that the cuttings are uniformly spread across the drill pad and are not diluted by mixing with clean soil. As discussed in Section 3.5, the timing of the intrusion event is assumed to be 100 years for pipelines and 500 years for more highly-stabilized wastes with robust intrusion barriers.

The borehole diameter is not a factor in determining dose for this scenario because the radionuclide concentrations in the drill cuttings are independent of the size of the borehole, and because the cuttings are assumed to be distributed over the drill pad with no mixing with clean soil. Conceptually, the driller is assumed to be exposed to the drill core mixed with drilling mud in a pile adjacent to the drill rig, spread over a relatively small area, and not mixed with other soil materials. However, the equations used in this analysis represent an exposure situation with widespread contamination, so there is enough contaminated material to provide continuous exposure of the Representative Individual regardless of their activities. For instance, for the purpose of calculating dose from external exposure, the thickness and lateral extent of the contaminated layer is assumed to be infinite. This approach to calculating exposures contains embedded conservatism when applied to exposures from a relatively small contamination source like a drill core.

4.5.1.1 Acute Well Driller Scenario – Radionuclide Concentration in Drill Cuttings

For the acute well driller exposure scenario, the driller is assumed to drill through the residual waste and all the way to the water table. Radionuclide concentrations in the drill cuttings are calculated as shown in Equations 4-6 through 4-8 (RPP-ENV-58813).

$$A_{well} = \pi \times \left(\frac{d_{well}}{2}\right)^2 \tag{4-6}$$

$$C_{i,j,ds} = \frac{C_{i,j,ws} \times A_{well} \times Z_{j,ws} \times \rho_{ws}}{A_{well} \times Z_{j,ws} \times \rho_{ws} + A_{well} \times (Z_{gw} - Z_{j,ws}) \times \rho_{sl}} = \frac{C_{i,j,ws} \times Z_{j,ws} \times \rho_{ws}}{Z_{ws} \times \rho_{ws} + (Z_{gw} - Z_{j,ws}) \times \rho_{sl}} \tag{4-7}$$

Because the bulk densities of residual waste and soil are very similar, the equations are simplified by assuming that $\rho_{ws} = \rho_{sl}$. As a result, the above equation simplifies to:

$$C_{i,j,ds} = \frac{C_{i,j,ws} \times Z_{j,ws}}{Z_{gw}} \tag{4-8}$$

Where:

A_{well} = area of well (cm^2)
d_{well} = diameter of well (cm)
$C_{i,j,ds}$ = concentration of radionuclide *i* from waste source *j* in drill cuttings (pCi/g)
$C_{i,j,ws}$ = concentration of radionuclide *i* from waste source *j* in the residual tank waste (pCi/g), varies as a function of time due to radioactive decay and ingrowth – Equation 4-9
$Z_{j,ws}$ = thickness of waste in waste source *j* intercepted by borehole (cm)
ρ_{ws} = residual tank waste bulk density (g/cm^3)
Z_{gw} = depth to groundwater (cm)
ρ_{sl} = soil dry bulk density for soil layers below WMA A-AX (g/cm^3).

The minimum depth to groundwater is approximately 87 m assuming a long-term groundwater elevation of approximately 119.5 m amsl, a ground surface elevation between 202 m and 211 m amsl (RPP-RPT-58693 Section 3.1), and a minimum surface barrier depth of 5 m.

The concentration of radionuclide *i* from waste source *j* in the residual tank waste is calculated by:

$$C_{i,j,ws} = \frac{I_{i,j,ws}}{(V_{j,ws} \times \rho_{j,ws})} \tag{4-9}$$

Where:

$C_{i,j,ws}$ = concentration of radionuclide *i* from waste source *j* in the residual tank waste (pCi/g)
$I_{i,jws}$ = inventory of radionuclide *i* in waste source *j* (pCi)
$V_{j,ws}$ = volume of residual waste in waste source *j* (cm^3)
$\rho_{j,ws}$ = density of residual waste in waste source *j* (g/cm^3).

The thickness of the waste in waste source *j* ($Z_{j,ws}$)is calculated by:

$$Z_{j,ws} = \frac{V_{j,ws}}{A_{j,ws}} \tag{4-10}$$

Where:

$Z_{j,ws}$ = thickness of waste in waste source *j* intercepted by borehole (cm)
$V_{j,ws}$ = volume of residual waste in waste source *j* (cm^3)
$A_{j,ws}$ = area of the base of waste source *j* (cm^2).

The following sections provide the equations used to calculate dose for this scenario.

4.5.1.2 Acute Well Driller Scenario – Incidental Soil Ingestion

The following equation is used to calculate dose to the well driller resulting from incidental ingestion of soil (RPP-ENV-58813):

$$D_{i,j,s} = C_{i,j,ds} \times IR_{s,wd} \times EF_{wd} \times UCF \times DCF_{i,ing} \quad (4\text{-}11)$$

Where:

$D_{i,j,s}$ = dose from radionuclide *i* in waste source *j* resulting from incidental soil ingestion (mrem/yr)
$C_{i,j,ds}$ = concentration of radionuclide *i* from waste source *j* in drill cuttings (pCi/g) – calculated using Equation 4-8
$IR_{s,wd}$ = soil ingestion rate – well driller (mg/day)
EF_{wd} = exposure frequency – well driller (days/yr)
UCF = unit conversion factor (g/mg) (note: GoldSim© automatically converts units, so this term is not used in the model)
$DCF_{i,ing}$ = ingestion dose conversion factor for radionuclide *i* (mrem/pCi).

4.5.1.3 Acute Well Driller Scenario – Inhalation of Soil Particulates

The following equation is used to calculate dose to the well driller resulting from inhalation of soil particulates (RPP-ENV-58813):

$$D_{i,j,inh} = C_{i,j,ds} \times E_f \times INH_{out,wd} \times M \times t_{out,wd} \times DCF_{i,inh} \quad (4\text{-}12)$$

Where:

$D_{i,j,inh}$ = dose from radionuclide *i* in waste source *j* resulting from inhalation of soil (mrem/yr)
$C_{i,j,ds}$ = radionuclide concentration of radionuclide *i* from waste source *j* in drill cuttings (pCi/g) – calculated using Equation 4-8
E_f = enrichment factor (unitless)
$INH_{out,wd}$ = outdoor inhalation rate – well driller (m^3/yr)
M = mass loading factor (g/m^3)
$t_{out,wd}$ = fraction of time spent outdoors – well driller (unitless)
$DCF_{i,inh}$ = inhalation dose conversion factor for radionuclide *i* (mrem/pCi).

4.5.1.4 Acute Well Driller Scenario – External Exposure

The following equation is used to calculate dose to the well driller resulting from external exposure (RPP-ENV-58813):

$$D_{i,j,ext} = C_{i,j,ds} \times t_{out,wd} \times DCF_{i,ext} \quad (4\text{-}13)$$

Where:

$D_{i,j,ext}$ = dose from radionuclide i in waste source j resulting from external exposure to drill cuttings (mrem/yr)
$C_{i,j,ds}$ = radionuclide concentration of radionuclide i from waste source j in drill cuttings (pCi/g) – calculated using Equation 4-8
$t_{out,wd}$ = fraction of time spent outdoors by well driller (unitless)
$DCF_{i,ext}$ = external exposure dose conversion factor for radionuclide i (mrem/yr)/(pCi/g).

4.5.1.5 Acute Well Driller Scenario – Total Dose

The following equation is used to calculate the total dose to the well driller for each radionuclide in each waste source:

$$D_{i,j,wd} = D_{i,j,s} + D_{i,j,inh} + D_{i,j,ext} \tag{4-14}$$

Where:

$D_{i,j,wd}$ = total dose from radionuclide i in waste source j (mrem/yr)
$D_{i,j,s}$ = dose from radionuclide i in waste source j resulting from incidental soil ingestion (mrem/yr) – calculated using Equation 4-11
$D_{i,j,inh}$ = dose from radionuclide i in waste source j resulting from inhalation of soil (mrem/yr) – calculated using Equation 4-12
$D_{i,j,ext}$ = dose from radionuclide i in waste source j resulting from external exposure to drill cuttings (mrem/yr) – calculated using Equation 4-13.

The following equation is used to calculate the total dose to the well driller for each waste source:

$$D_{j,wd} = \sum_i D_{i,j,wd} \tag{4-15}$$

Where:

$D_{j,wd}$ = total dose from waste source j (mrem/yr)
$D_{i,j,wd}$ = total dose from radionuclide i in waste source j (mrem/yr) – calculated using Equation 4-14.

4.5.2 Chronic Exposure Scenarios

These scenarios evaluate the long-term exposure of three different receptors from previously-exhumed drill cuttings that have been uniformly spread and tilled onto three different land areas or target fields. The three different target fields include the following: a rural pasture, a suburban garden, and a commercial farm. Radionuclide concentrations in the target field are dependent on the diameter of the well that is drilled to support the scenario, the area of the target field over which the drill cuttings are spread, and the depth to which the drill cuttings are tilled into the soil. While a 16.5-cm (6.5-in.) well diameter is commonly used in the State of Washington, it is not considered representative for the target fields in each scenario (RPP-ENV-58813). The rural pasture scenario uses a 26.67-cm (10.5-in) diameter well, since rural pasture irrigation requires a larger pump than that used for domestic purposes

(RPP-ENV-58813). The commercial farm would also require a higher flow rate than a domestic well, and would therefore need a larger well diameter. This analysis uses a diameter of 41.91 cm (16.5 in.) for the commercial farm scenario (RPP-ENV-58813). A suburban garden would use a domestic well for irrigation, therefore a diameter of 16.5 cm (6.5 in.) is used (RPP-ENV-58813). It is assumed that the cuttings from drilling the water well in each scenario are those spread and tilled into the soil. Therefore, the activity distributed over the target field varies by scenario. In the chronic scenarios, the exposed individual does not drill or add the cuttings to the soil but simply lives or works on the land where the cuttings have been spread and tilled into the soil.

4.5.2.1 Radionuclide Concentrations in Drill Cuttings

The following equation is used to calculate the total radionuclide activity in the drill cuttings for the chronic scenarios (RPP-ENV-58813):

$$S_{i,j,A} = T_{i,j,A} \times \left(\frac{A_{well}}{A_{j,source_term}}\right) \tag{4-16}$$

Where:

$S_{i,j,A}$ = activity of radionuclide *i* from waste source *j* in soil from drill cuttings (pCi) at any given time

$T_{i,j,A}$ = residual activity of radionuclide *i* in the tank waste of waste source *j* (pCi), varies with time due to radioactive decay and ingrowth

A_{well} = area of the well (cm^2)

$A_{j,source_term}$ = area over which the residual waste is spread at base of the tank *j* (cm^2) – Equation 4-17.

The area over which the residual waste is spread at base of tank *j* is calculated by:

$$A_{j,source_term} = \pi \left(\frac{d_j}{2}\right)^2 \tag{4-17}$$

Where:

$A_{j,source_term}$ = area over which the residual waste is spread at base of tank *j* (cm^2)

d_j = diameter of tank *j* (cm)

π = 3.14159…

For the pipeline source term, which runs horizontally in the subsurface, the activity in the drill cuttings is based on the contaminated pipeline area that is interrogated by the borehole. The approach here differs from the one used to calculate the groundwater pathway, described in Section 3.2.2, where residual waste is distributed uniformly throughout two specific areas associated with A Farm and AX Farm pipeline areas. If this assumption were used, the borehole would exhume a circular area of waste the size of the borehole, and the ratio of borehole area to total pipeline area (the last term of Equation 4-16) would be unrealistically small. This, in turn, would underestimate the activity exhumed by the borehole, and by extension the dose to the receptor. Conceptually, the pipeline width is 3 in. and the diameter of the borehole is between

6.5 and 16.5 in. (depending on the scenario). Therefore, the area of the pipeline that is intercepted by the borehole is less than the borehole's area and A_{well} needs to be modified to only include the area in which the waste is contained to avoid overestimating the activity in the drill cuttings. In this case, the term A_{well} in Equation 4-16 and all of Equation 4-17 need to be modified. A_{well} is modified by:

$$A_{well} = d_{well} \times d_{pipe} \tag{4-18}$$

Where:

A_{well} = area of the waste within the well area (cm^2)
d_{well} = diameter of the well (cm)
d_{pipe} = diameter of the pipeline (cm).

Note that the borehole diameter varies based on the chronic scenario being evaluated.

For pipelines, Equation 4-17 becomes:

$$A_{pipes} = w_{pipes} \times l_{pipes} \tag{4-19}$$

Where:

A_{pipes} = area over which the residual waste is spread in the pipelines (cm^2)
w_{pipes} = width (diameter) of pipelines (cm)
l_{pipes} = length of pipelines (cm).

4.5.2.2 Radionuclide Concentrations in Pasture Soil

The following equation is used to calculate the radionuclide concentration in pasture soil for the chronic scenarios (RPP-ENV-58813):

$$C_{i,j,ps} = \frac{S_{i,j,A}}{A_p \times Z_p \times \rho_p + A_{well} \times Z_{gw} \times \rho_s} \tag{4-20}$$

Where:

$C_{i,j,ps}$ = radionuclide concentration of radionuclide *i* from waste source *j* in pasture soil (pCi/g) at any given time
$S_{i,j,A}$ = radionuclide activity from radionuclide *i* from waste source *j* in soil from drill cuttings (pCi) at any given time
A_p = area of the target field (cm^2)
Z_p = depth the drill cuttings are tilled into the pasture (cm)
ρ_p = soil dry bulk density in the pasture (g/cm^3)
A_{well} = area of the well (cm^2)
Z_{gw} = depth to groundwater (cm)
ρ_s = dry bulk density of the drill cuttings (g/cm^3).

The minimum depth to groundwater is approximately 87 m assuming a long-term groundwater elevation of approximately 119.5 m amsl, a ground surface elevation between 202 m and 211 m amsl (RPP-RPT-58693 Section 3.1), and a minimum surface barrier depth of 5 m.

4.5.2.3 Chronic Rural Pasture Exposure Scenario

The rural pasture scenario evaluates the long-term exposure to an individual who uses the target field as a residence, with a pasture used for milk production from dairy cows.

4.5.2.3.1 Chronic Rural Pasture Scenario – Incidental Soil Ingestion. The following equation is used to calculate dose to the rural pasture resident resulting from incidental ingestion of pasture soil (RPP-ENV-58813):

$$D_{i,j,s} = C_{i,j,ps} \times IR_{s,rp} \times EF_{rp} \times UCF \times DCF_{i,ing} \quad (4\text{-}21)$$

Where:

$D_{i,j,s}$ = dose from radionuclide i in waste source j resulting from incidental soil ingestion (mrem/yr)
$C_{i,j,ps}$ = concentration of radionuclide i from waste source j in pasture soil (pCi/g) at any given time – calculated using Equation 4-20
$IR_{s.rp}$ = soil ingestion rate – rural pasture (mg/day)
EF_{rp} = exposure frequency – rural pasture (days/yr)
UCF = unit conversion factor (g/mg) (note: GoldSim© automatically converts units, so this term is not used in the model)
$DCF_{i,ing}$ = ingestion dose conversion factor for radionuclide i (mrem/pCi).

4.5.2.3.2 Chronic Rural Pasture Scenario – Consumption of Milk. The following equations are used to calculate the concentration of contaminant in livestock fodder, the concentration of contaminant in milk, and the dose from consumption of milk (RPP-ENV-58813).

The equation used to calculate the concentration of contaminant in livestock fodder is given by:

$$C_{i,j,fodder} = C_{i,j,ps} \times (B_{i,p} + B'_{i,p}) \quad (4\text{-}22)$$

Where:

$C_{i,j,fodder}$ = concentration of radionuclide i from waste source j in livestock fodder (pCi/g) at any given time
$C_{i,j,ps}$ = concentration of radionuclide i from waste source j in the pasture soil (pCi/g) at any given time – calculated using Equation 4-20
$B_{i,p}$ = pasture-soil bioconcentration factor through uptake for radionuclide i $\left(\frac{\left(\frac{pCi}{kg\ dry\ weight\ of\ fodder}\right)}{\left(\frac{pCi}{kg\ dry\ weight\ of\ soil}\right)}\right)$

$B'_{i,p}$ = pasture-soil bioconcentration factor for resuspension effects for radionuclide i $\left(\frac{\left(\frac{pCi}{kg\ dry\ weight\ of\ fodder}\right)}{\left(\frac{pCi}{kg\ dry\ weight\ of\ soil}\right)}\right)$.

The following equation is used to calculate the concentration of contaminant in milk resulting from consumption of contaminated water (if any), contaminated fodder, and contaminated soil by the dairy animal:

$$C_{i,j,m} = \left(C_{i,j,w} \times IR_{w,d} + C_{i,j,fodder} \times IR_{fodder,d} \times UCF + C_{i,j,ps} \times IR_{s,d} \times UCF\right) \times BCF_{i,milk} \quad (4\text{-}23)$$

Where:

$C_{i,j,m}$ = concentration of radionuclide i from waste source j in milk (pCi/L) at any given time

$C_{i,j,w}$ = concentration of radionuclide i from waste source j in water (pCi/L) at any given time (assumed zero for the intruder scenario)

$IR_{w,d}$ = ingestion rate of water by dairy cattle (L/day)

$C_{i,j,fodder}$ = concentration of radionuclide i from waste source j in livestock fodder (pCi/g) at any given time – calculated using Equation 4-22

$IR_{fodder,d}$ = ingestion rate of fodder by dairy cattle (kg/day)

UCF = unit conversion factor (g/kg) (note: GoldSim© automatically converts units, so this term is not used in the model)

$C_{i,j,ps}$ = concentration of radionuclide i from waste source j in the pasture soil (pCi/g) at any given time – calculated using Equation 4-20

$IR_{s,d}$ = ingestion rate of soil by dairy cattle (kg/day)

$BCF_{i,milk}$ = bioconcentration factor of radionuclide i in milk (day/L).

The equation used to calculate the dose from ingestion of milk is given by:

$$D_{i,j,m} = C_{i,j,m} \times IR_m \times F_a \times DCF_{i,ing} \quad (4\text{-}24)$$

Where:

$D_{i,j,m}$ = dose from radionuclide i from waste source j resulting from ingestion of milk (mrem/yr)

$C_{i,j,m}$ = concentration of radionuclide i from waste source j in milk (pCi/L) at any given time – calculated using Equation 4-23

IR_m = milk ingestion rate (L/yr)

F_a = fraction of locally-produced milk that is consumed (unitless)

$DCF_{i,ing}$ = ingestion dose conversion factor for radionuclide i (mrem/pCi).

4.5.2.3.3 Chronic Rural Pasture Scenario – Inhalation of Soil Particulates. The following equation is used to calculate dose to the rural pasture resident resulting from inhalation of dust particulates (RPP-ENV-58813):

$$D_{i,j,inh} = C_{i,j,ps} \times E_f \times M \times \left(INH_{in,rp} \times t_{in,rp} \times \left(\frac{I}{O}\right) + INH_{out,rp} \times t_{out,rp}\right) \times DCF_{i,inh} \quad (4\text{-}25)$$

Where:

$D_{i,j,inh}$ = dose from radionuclide *i* from waste source *j* resulting from inhalation of soil
$C_{i,j,ps}$ = concentration of radionuclide *i* from waste source *j* in the pasture soil surface layer (pCi/g) – calculated using Equation 4-20
E_f = enrichment factor (unitless)
M = mass loading factor (g/m^3)
$INH_{in,rp}$ = indoor inhalation rate – rural pasture (m^3/yr)
$t_{in,rp}$ = fraction of time spent indoors – rural pasture (unitless)
$\frac{I}{O}$ = ratio of radionuclide concentrations in indoor and outdoor air (unitless)
$INH_{out,rp}$ = outdoor inhalation rate – rural pasture (m^3/yr)
$t_{out,rp}$ = fraction of time spent outdoors – rural pasture (unitless)
$DCF_{i,inh}$ = inhalation dose conversion factor for radionuclide *i* (mrem/pCi).

4.5.2.3.4 Chronic Rural Pasture Scenario – External Exposure. The following equation is used to calculate dose to the rural pasture resident resulting from external exposure (RPP-ENV-58813):

$$D_{i,j,ext} = C_{i,j,ps} \times \left(t_{in,rp} \times \varepsilon + t_{out,rp}\right) \times DCF_{i,ext} \quad (4\text{-}26)$$

Where:

$D_{i,j,ext}$ = dose from radionuclide *i* from waste source *j* resulting from external exposure to pasture soil (mrem/yr)
$C_{i,j,ps}$ = concentration of radionuclide *i* from waste source *j* in the pasture soil (pCi/g) at any given time
$t_{in,rp}$ = fraction of time spent indoors – rural pasture (unitless)
ε = transmission or shielding factor (unitless)
$t_{out,rp}$ = fraction of time spent outdoors – rural pasture (unitless)
$DCF_{i,ext}$ = external exposure dose conversion factor for radionuclide *i* (mrem/yr)/(pCi/g).

4.5.2.3.5 Chronic Rural Pasture Scenario – Total Dose. The following equation is used to calculate the total dose to the resident with a rural pasture for each radionuclide in each waste source:

$$D_{i,j,rp} = D_{i,j,s} + D_{i,j,m} + D_{i,j,inh} + D_{i,j,ext} \quad (4\text{-}27)$$

Where:

$D_{i,j,rp}$ = total dose from radionuclide *i* in waste source *j* (mrem/yr)
$D_{i,j,s}$ = dose from radionuclide *i* in waste source *j* resulting from incidental soil ingestion (mrem/yr) – calculated using Equation 4-21

$D_{i,j,m}$ = dose from radionuclide *i* in waste source *j* resulting from ingestion of milk (mrem/yr) – calculated using Equation 4-24
$D_{i,j,inh}$ = dose from radionuclide *i* in waste source *j* resulting from inhalation of soil (mrem/yr) – calculated using Equation 4-25
$D_{i,j,ext}$ = dose from radionuclide *i* in waste source *j* resulting from external exposure to drill cuttings (mrem/yr) – calculated using Equation 4-26.

The following equation is used to calculate the total dose to the resident with a rural pasture for each waste source:

$$D_{j,rp} = \sum_i D_{i,j,rp} \tag{4-28}$$

Where:

$D_{j,rp}$ = total dose from waste source *j* (mrem/yr)
$D_{i,j,rp}$ = total dose from radionuclide *i* in waste source *j* (mrem/yr) – calculated using Equation 4-27.

4.5.2.4 Chronic Suburban Garden Exposure Scenario

The suburban garden scenario evaluates the long-term exposure to an individual who uses the target field as a home construction lot with a garden.

4.5.2.4.1 Chronic Suburban Garden Scenario – Incidental Soil Ingestion. The following equation is used to calculate dose to the suburban garden resident resulting from incidental ingestion of garden soil (RPP-ENV-58813):

$$D_{i,j,s} = C_{i,j,gs} \times IR_{s,sg} \times EF_{sg} \times UCF \times DCF_{i,ing} \tag{4-29}$$

Where:

$D_{i,j,s}$ = dose from radionuclide *i* in waste source *j* resulting from incidental soil ingestion (mrem/yr)
$C_{i,j,gs}$ = concentration of radionuclide *i* in waste source *j* in garden soil (pCi/g) – calculated using Equation 4-20
$IR_{s,sg}$ = soil ingestion rate – suburban garden (mg/day)
EF_{sg} = exposure frequency – resident (days/yr)
UCF = unit conversion factor (g/mg) (note: GoldSim© automatically converts units, so this term is not used in the model)
$DCF_{i,ing}$ = ingestion dose conversion factor for radionuclide *i* (mrem/pCi).

4.5.2.4.2 Chronic Suburban Garden Scenario – Consumption of Homegrown Crops (Fruits and Vegetables). The following equations are used to calculate the concentration of contaminant in the crop (homegrown fruits and vegetables) and the dose from consumption of the crop. The following equation is used to calculate the concentration of contaminant in the crop (RPP-ENV-58813):

$$C_{i,j,c} = C_{i,j,gs} \times \left(B_{i,v} + B'_{i,v}\right) \quad (4\text{-}30)$$

Where:

$C_{i,j,c}$ = concentration of radionuclide *i* from waste source *j* in crop (pCi/g)
$C_{i,j,gs}$ = concentration in garden soil (pCi/g) – calculated using Equation 4-20
$B_{i,v}$ = crop-soil bioconcentration factor through uptake for radionuclide *i* $\left(\frac{\left(\frac{pCi}{kg\ fresh\ weight\ of\ crop}\right)}{\left(\frac{pCi}{kg\ dry\ weight\ of\ soil}\right)}\right)$
$B'_{i,v}$ = crop-soil bioconcentration factor representing all resuspension-soil adhesion processes for radionuclide *i* $\left(\frac{\left(\frac{pCi}{kg\ fresh\ weight\ of\ crop}\right)}{\left(\frac{pCi}{kg\ dry\ weight\ of\ soil}\right)}\right)$.

The following equation is used to calculate dose resulting from consumption of homegrown fruits and vegetables (RPP-ENV-58813):

$$D_{i,j,c} = C_{i,j,c} \times IR_c \times F_v \times UCF \times DCF_{i,ing} \quad (4\text{-}31)$$

Where:

$D_{i,j,c}$ = dose from radionuclide *i* from waste source *j* resulting from consumption of crops (homegrown fruits and vegetables) (mrem/yr)
$C_{i,j,c}$ = concentration of radionuclide *i* from waste source *j* in crop (pCi/g)
IR_c = crop ingestion rate (kg/yr)
F_v = fraction of homegrown fruits and vegetables consumed (unitless)
UCF = unit conversion factor (g/kg) (note: GoldSim© automatically converts units, so this term is not used in the model)
$DCF_{i,ing}$ = ingestion dose conversion factor for radionuclide *i* (mrem/pCi).

4.5.2.4.3 Chronic Suburban Garden Scenario – Inhalation of Soil Particulates. The following equation is used to calculate dose to the suburban garden resident resulting from inhalation of dust particulates (RPP-ENV-58813):

$$D_{i,j,inh} = C_{i,j,gs} \times E_f \times M \times \left(INH_{in,sg} \times t_{in,sg} \times \frac{I}{O} + INH_{out,sg} \times t_{out,sg}\right) \times DCF_{i,inh} \quad (4\text{-}32)$$

Where:

$D_{i,j,inh}$ = dose from radionuclide *i* from waste source *j* resulting from inhalation of soil (mrem/yr)
$C_{i,j,gs}$ = concentration of radionuclide *i* from waste source *j* in garden soil (pCi/g) – calculated using Equation 4-20
E_f = enrichment factor (unitless)
M = mass loading factor (g/m^3)
$INH_{in,sg}$ = indoor inhalation rate – suburban garden (m^3/yr)

$t_{in,sg}$ = fraction of time spent indoors – suburban garden (unitless)
$\frac{I}{O}$ = ratio of radionuclide concentrations in indoor and outdoor air (unitless)
$INH_{out,sg}$ = outdoor inhalation rate –suburban garden (m^3/yr)
$t_{out,sg}$ = fraction of time spent outdoors – suburban garden (unitless)
$DCF_{i,inh}$ = inhalation dose conversion factor for radionuclide *i* (mrem/pCi).

4.5.2.4.4 Chronic Suburban Garden Scenario – External Exposure. The following equation is used to calculate dose to the suburban garden resident resulting from external exposure (RPP-ENV-58813):

$$D_{i,j,ext} = C_{i,j,gs} \times \left(t_{in,sg} \times \varepsilon + t_{out,sg}\right) \times DCF_{i,ext} \quad (4\text{-}33)$$

Where:

$D_{i,j,ext}$ = dose from radionuclide *i* from waste source *j* resulting from external exposure (mrem/yr)
$C_{i,j,gs}$ = concentration of radionuclide *i* from waste source *j* in garden soil (pCi/g) – calculated using Equation 4-20
$t_{in,sg}$ = fraction of time spent indoors – suburban garden (unitless)
ε = transmission or shielding factor
$t_{out,sg}$ = fraction of time spent outdoors – suburban garden (unitless)
$DCF_{i,ext}$ = external exposure dose conversion factor for radionuclide *i* (mrem/yr)/(pCi/g).

4.5.2.4.5 Chronic Suburban Garden Scenario – Total Dose. The following equation is used to calculate the total dose to the resident with a rural pasture for each radionuclide in each waste source:

$$D_{i,j,sg} = D_{i,j,s} + D_{i,j,c} + D_{i,j,inh} + D_{i,j,ext} \quad (4\text{-}34)$$

Where:

$D_{i,j,sg}$ = total dose from radionuclide *i* in waste source *j* (mrem/yr)
$D_{i,j,s}$ = dose from radionuclide *i* in waste source *j* resulting from incidental soil ingestion (mrem/yr) – calculated using Equation 4-29
$D_{i,j,c}$ = dose from radionuclide *i* in waste source *j* resulting from ingestion of milk (mrem/yr) – calculated using Equation 4-31
$D_{i,j,inh}$ = dose from radionuclide *i* in waste source *j* resulting from inhalation of soil (mrem/yr) – calculated using Equation 4-32
$D_{i,j,ext}$ = dose from radionuclide *i* in waste source *j* resulting from external exposure to drill cuttings (mrem/yr) – calculated using Equation 4-33.

The following equation is used to calculate the total dose to the resident with a rural pasture for each waste source:

$$D_{j,sg} = \sum_i D_{i,j,sg} \quad (4\text{-}35)$$

Where:

$D_{j,sg}$ = total dose from waste source *j* (mrem/yr)
$D_{i,j,sg}$ = total dose from radionuclide *i* in waste source *j* (mrem/yr) – calculated using Equation 4-34.

4.5.2.5 Chronic Commercial Farm Exposure Scenario

The commercial farm scenario evaluates the long-term exposure to an individual who uses the target field as a commercial farm.

4.5.2.5.1 Chronic Commercial Farm Scenario – Incidental Soil Ingestion. The following equation is used to calculate dose to the commercial farmer resulting from incidental ingestion of soil (RPP-ENV-58813):

$$D_{i,j,s} = C_{i,j,ps} \times IR_{s,cf} \times EF_{cf} \times UCF \times DCF_{i,ing} \quad (4\text{-}36)$$

Where:

$D_{i,j,s}$ = dose from radionuclide *i* in waste source *j* resulting from incidental soil ingestion (mrem/yr)
$C_{i,j,ps}$ = concentration of radionuclide *i* in waste source *j* in the commercial farm soil (pCi/g) – calculated using Equation 4-20
$IR_{s,cf}$ = soil ingestion rate – commercial farmer (mg/day)
EF_{cf} = exposure frequency – commercial farmer (days/yr)
UCF = unit conversion factor (g/mg) (note: GoldSim© automatically converts units, so this term is not used in the model)
$DCF_{i,ing}$ = ingestion dose conversion factor for radionuclide *i* (mrem/pCi).

4.5.2.5.2 Chronic Commercial Farm Scenario – Inhalation of Soil Particulates. The following equation is used to calculate dose to the commercial farmer resulting from inhalation of dust particulates (RPP-ENV-58813):

$$D_{i,j,inh} = C_{i,j,ps} \times E_f \times M \times \left(INH_{in,cf} \times t_{in,cf} \times \frac{I}{O} + INH_{out,cf} \times t_{out,cf}\right) \times DCF_{i,inh} \quad (4\text{-}37)$$

Where:

$D_{i,j,inh}$ = dose from radionuclide *i* from waste source *j* resulting from inhalation of soil (mrem/yr)
$C_{i,j,ps}$ = concentration of radionuclide *i* from waste source *j* in commercial farm soil (pCi/g) – calculated using Equation 4-20
E_f = enrichment factor (unitless)
M = mass loading factor (g/m^3)
$INH_{in,cf}$ = indoor inhalation rate – commercial farmer (m^3/yr)
$t_{in,cf}$ = fraction of time spent indoors – assumed to be zero for commercial farmer
$\frac{I}{O}$ = ratio of radionuclide concentrations in indoor and outdoor air (unitless)

$INH_{out,cf}$ = outdoor inhalation rate – commercial farmer (m^3/yr)
$t_{out,cf}$ = fraction of time spent outdoors – commercial farmer (unitless)
$DCF_{i,inh}$ = inhalation dose conversion factor for radionuclide *i* (mrem/pCi).

4.5.2.5.3 Chronic Commercial Farm Scenario – External Exposure. The following equation is used to calculate dose to the resident resulting from external exposure (RPP-ENV-58813):

$$D_{i,j,ext} = C_{i,j,cf} \times \left(t_{in,cf} \times \varepsilon + t_{out,cf}\right) \times DCF_{i,ext} \quad (4\text{-}38)$$

Where:

$D_{i,j,ext}$ = dose from radionuclide *i* from waste source *j* resulting from external exposure
$C_{i,j,cf}$ = concentration of radionuclide *i* from waste source *j* in commercial farm soil (pCi/g) – calculated using Equation 4-20
$t_{in,cf}$ = fraction of time spent indoors – assumed to be zero for commercial farmer
ε = transmission or shielding factor for radionuclide *i*
$t_{out,cf}$ = fraction of time spent outdoors – commercial farmer (unitless)
$DCF_{i,ext}$ = external exposure dose conversion factor for radionuclide *i* (mrem/yr)/(pCi/g).

4.5.2.5.4 Chronic Commercial Farm Scenario – Total Dose. The following equation is used to calculate the total dose to the resident with a rural pasture for each radionuclide in each waste source:

$$D_{i,j,cf} = D_{i,j,s} + D_{i,j,inh} + D_{i,j,ext} \quad (4\text{-}39)$$

Where:

$D_{i,j,cf}$ = total dose from radionuclide *i* in waste source *j* (mrem/yr)
$D_{i,j,s}$ = dose from radionuclide *i* in waste source *j* resulting from incidental soil ingestion (mrem/yr) – calculated using Equation 4-36
$D_{i,j,inh}$ = dose from radionuclide *i* in waste source *j* resulting from inhalation of soil (mrem/yr) – calculated using Equation 4-37
$D_{i,j,ext}$ = dose from radionuclide *i* in waste source *j* resulting from external exposure to drill cuttings (mrem/yr) – calculated using Equation 4-38

The following equation is used to calculate the total dose to the resident with a rural pasture for each waste source:

$$D_{j,cf} = \sum_i D_{i,j,cf} \quad (4\text{-}40)$$

Where:

$D_{j,cf}$ = total dose from waste source *j* (mrem/yr)
$D_{i,j,cf}$ = total dose from radionuclide *i* in waste source *j* (mrem/yr) – calculated using Equation 4-39.

4.5.3 GoldSim© Implementation of Intruder Scenario and Description of Intruder Submodel

The WMA A-AX PA Inadvertent Intruder submodel is part of the WMA A-AX system model which was constructed in GoldSim© Version 12.0. The calculations utilize the internal decay and ingrowth computational functionality included in the Radionuclide Transport module. The purpose of the submodel is to calculate doses over time arising from inadvertent intrusion into the waste sources at the closed WMA A-AX.

RPP-CALC-62319 is the source of inventory values used in the model. The tank inventories are based on the BBI and the pipeline inventories are obtained from the HTWOS, with both being decay corrected to the assumed closure year of 2050.

The source of intruder scenario parameters is RPP-ENV-58813.

This section describes how the WMA A-AX PA Inadvertent Intruder submodel was constructed, including how data from RPP-CALC-62319 and RPP-ENV-58813 were incorporated into the calculations.

The intruder dose calculations and intruder scenario parameters are all contained within the **DOE_Exposure_Scenarios** container, which itself is contained within the **Exposure_Scenarios** container of the WMA A-AX system model. Other containers at the root level of the system model that are used by the intruder calculations are **Inventory** and **Material**. Figure 4-35 shows the root level of the WMA A-AX system model and highlights the containers used in the intruder calculations.

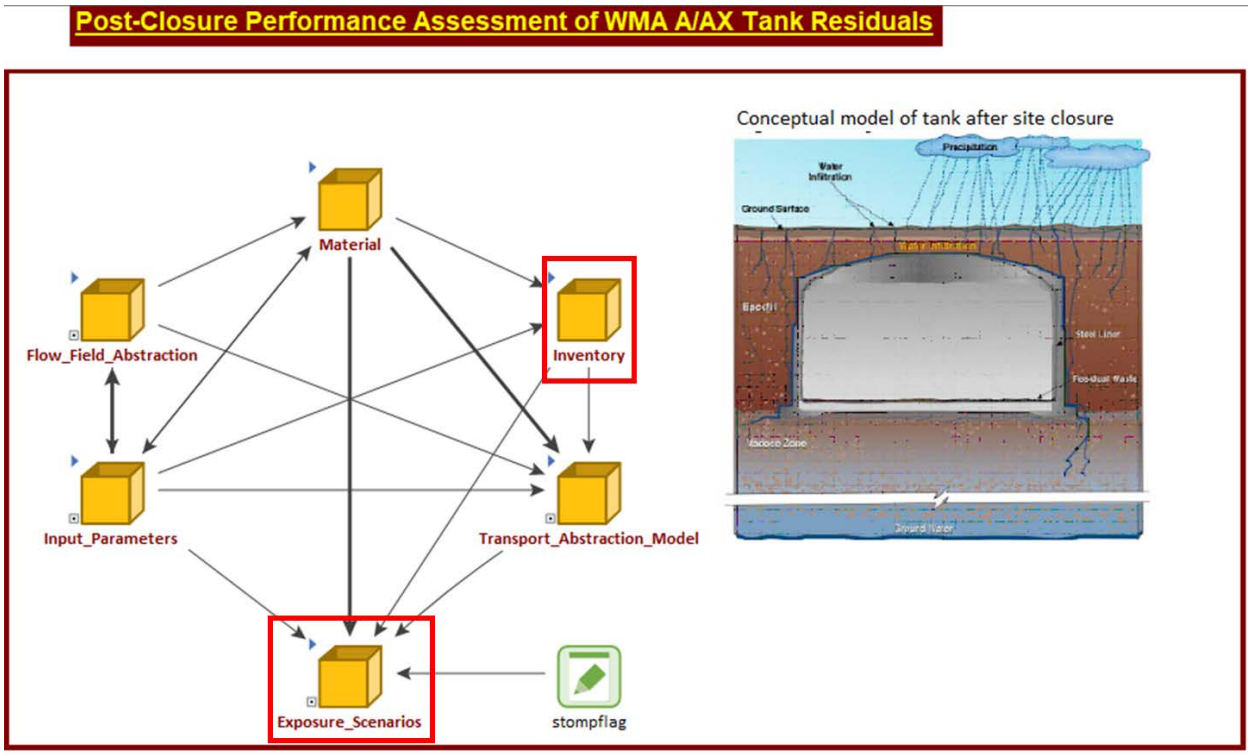
The list of radionuclides and dangerous chemicals that are included in the WMA A-AX system model are defined within the **Material** container (Figure 4-36). The list of COPCs is developed from the internal database of radionuclides included with the Radionuclide Transport module of GoldSim© and is supplemented with additional COPCs that are included in RPP-CALC-62319 but not included in the internal database. Dangerous chemicals are not used in the intruder calculations. The initial inventories at the closure date of 2050 are contained in the **Inventory** module (Figure 4-37) and are listed in RPP-CALC-62319.

The containers within the **DOE_Exposure_Scenarios** module (contained within the **Exposure_Scenarios** module shown in Figure 4-35) are shown in Figure 4-38. **Intruder_Parameters** (Figure 4-39) contains all of the parameters exclusive to the Inadvertent Intruder calculations which are defined in Sections 4.5.1 and 4.5.2. **DCF** (Figure 4-40) contains radionuclide-specific DCFs needed to calculate doses from exposure to any radionuclide in the intruder scenarios. The DCFs are defined in RPP-ENV-58813. **Intruder_Dose_Calc** (Figure 4-41) has a container for the intruder calculations (**Intruder_Calculations**) and for the decayed inventory used in those calculations (**Intruder_Inventory**).

4.5.3.1 Input Definitions

4.5.3.1.1 Material Container. The **Material** container (Figure 4-36) holds two specialized elements of the Radionuclide Transport module, the Species element and the Water element. All other elements contained in **Material** are not used by the Intruder Calculations. Default values for the Water element are applied. The list of COPCs included in the Species element is derived from RPP-CALC-62319. When available, the species list was created using the built-in database of COPCs and augmented with additional chemicals that were not included in the database. The radionuclide properties, including decay chain structure, embedded in the GoldSim© Radionuclide Transport module are based on "ICRP[1] Publication 107: Nuclear Decay Data for Dosimetric Calculations" (ICRP 2008).

Figure 4-35. Root Level of the Waste Management Area A-AX System Model.



Note: Containers used in the intruder calculations are indicated with red outline boxes.

WMA = Waste Management Area

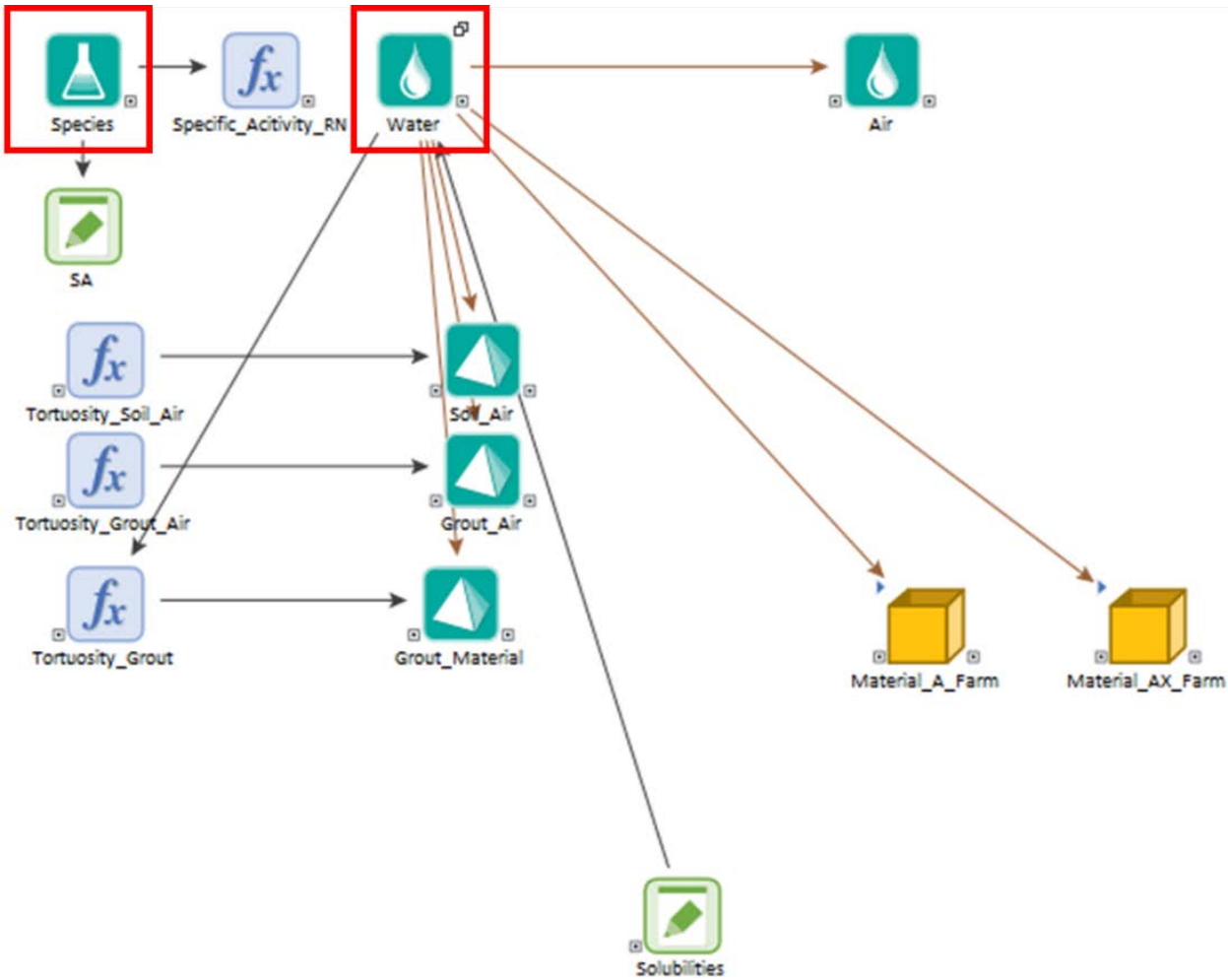
Once the list of COPCs with known starting inventories was established, the built-in database of radionuclides was used to show and include all daughter products of the previously-included radionuclide species, including the stable element at the end of the decay chain. The list of included daughter products was limited to radionuclides with a half-life greater than 2 years and below 1×10^{12} years. The resulting list of COPCs included 60 species, both radionuclides and

[1] ICRP is the International Commission on Radiological Protection.

dangerous chemicals. Dangerous chemicals are not evaluated in the intruder scenario, so the list of COPCs used contains 43 radionuclides.

4.5.3.1.2 Inventory Container. The **Inventory** container holds the elements used to define the initial radioactive and dangerous chemical inventory in all the waste sources of WMA A-AX (Figure 4-37). The **Initial_Chem_Inventory** and **Initial_Rad_Inventory** elements are populated with data from RPP-CALC-62319 and are combined in the **Initial_Inventory** expression element, which also converts the activities of the radionuclides to mass using specific activities from GoldSim©'s built-in database of radionuclides. **Initial_Inventory** is the only element used in the Intruder calculations.

Figure 4-36. Material Container of the Waste Management Area A-AX System Model.



Note: Elements used in the intruder calculations are indicated with red outline boxes.

4.5.3.1.3 Intruder_Parameters Container. Intruder_Parameters (Figure 4-39) holds the parameters exclusive to the intruder calculations as defined in Sections 4.5.1 and 4.5.2 and the values for these parameters are found in Appendix R of RPP-ENV-58813. The containers found in **Intruder_Parameters** are as follows.

- **Intruder_Scenario_Common:** Parameters used in all intruder scenarios. Contains data elements of scalar values found in Table R-2 of RPP-ENV-58813 as well as data elements of scalar values defining the time of intrusion (100 years for pipes, 500 years for tanks) and selectors for including pipes or tanks in the intruder calculations for a given year.

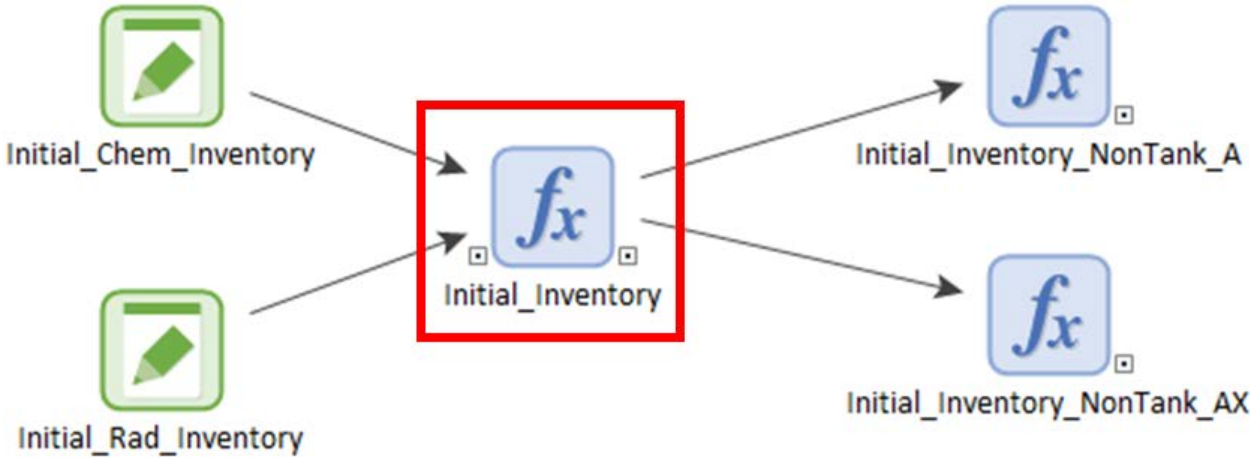
- **WellDriller_Parameters:** Parameters used only in the Acute Well Driller scenario. Holds only data elements of scalar values found in Table R-3 of RPP-ENV-58813.

- **RuralPasture_Parameters:** Parameters used only in the Chronic Rural Pasture scenario. Holds data elements of scalar values found in Table R-4 of RPP-ENV-58813, along with an expression element to look up the area of a waste source and an expression element creating a vector of type "Rads" for the bioconcentration factor from resuspension processes.

- **SuburbanGarden_Parameters:** Parameters used only in the Chronic Suburban Garden scenario. Holds data elements of scalar values found in Table R-5 of RPP-ENV-58813, along with an expression element calculating the area of waste intercepted by the borehole for each waste source and an expression element creating a vector of type "Rads" for the bioconcentration factor from resuspension processes.

- **Commercial Farm_Parameters:** Parameters used only in the Chronic Commercial Farm scenario. Holds data elements of scalar values found in Table R-6 of RPP-ENV-58813, along with an expression element calculating the area of waste intercepted by the borehole for each waste source.

Figure 4-37. Inventory Container of the Waste Management Area A-AX System Model.



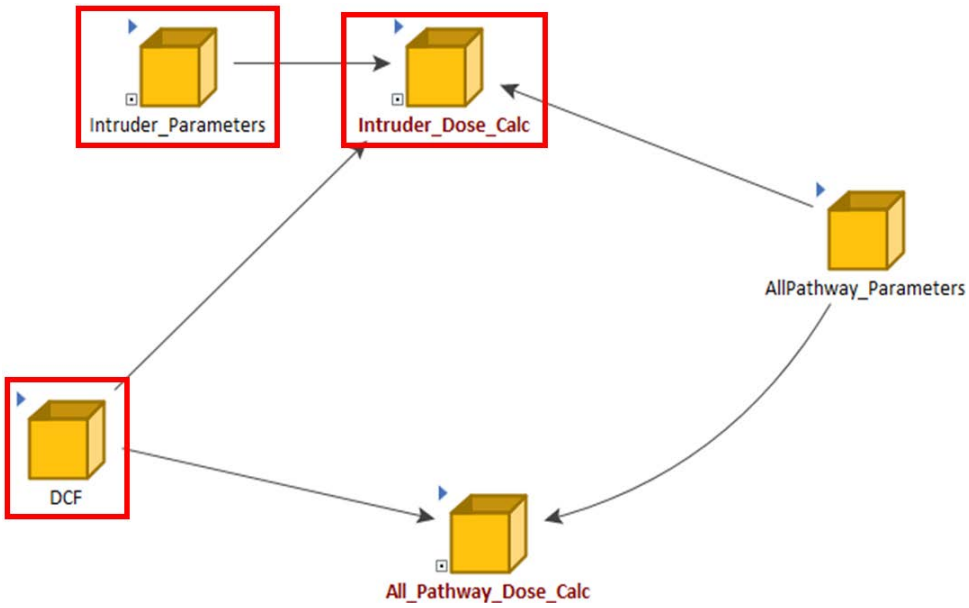
Note: Elements used in the intruder calculations are indicated with red outline boxes.

4.5.3.1.4 DCF Container. DCF (Figure 4-40) holds scalar data elements of the dose conversion factors found in Appendix N of RPP-ENV-58813. **DCF** has two data elements, **Air_Inhalation_DCF_mult** and **Water_Ingestion_DCF_mult** that contain multipliers derived in RPP-CALC-61254 to account for dose obtained from ingrown

progeny. Two expression elements, **DCF_Inhalation** and **DCF_Ingestion**, multiply the DCFs by the multipliers to calculate a new DCF used by the intruder calculations.

4.5.3.1.5 Intruder_Inventory Container. Intruder_Inventory (Figure 4-42) contains one cell pathway and one data element for every waste source in WMA A-AX. The cell pathway decays the radionuclide inventories from the **Inventory** container during every timestep of the simulation. The GoldSim© cell pathway element is a specialized element of the Radionuclide Transport module that is capable of applying and tracking radionuclide decay for individual radionuclides and decay chains. No special coding is needed to simulate decay chains as long as the Species element defines the half-life of each radionuclide, the decay chain order, and decay chain stoichiometry. In the inventory submodel, the radionuclide half-life, decay chain order, and decay chain stoichiometry are derived from the internal database provided with the Radionuclide Transport module.

Figure 4-38. DOE_Exposure_Scenarios Container of the Waste Management Area A-AX System Model.



Note: Elements used in the intruder calculations are indicated with red outline boxes.

The cell pathway outputs to a data element, which converts the mass of each radionuclide to activity using specific activities from GoldSim©'s built in radionuclide database. An expression element (**Residual_Inventories**) combines the values in each data element into a matrix of "Rads, Tanks" for use in the rest of the intruder calculations.

4.5.3.1.6 Intruder_Waste_Characteristics Container. Intruder_Waste_Characteristics (Figure 4-43) holds a vector of type "Rads" (**GW_Conc_Intruder**) with the concentration of radionuclides in groundwater used in the rural pasture scenario calculations, a vector of type "Tanks" with the thickness of residual wastes in each waste source, an expression element (**Residual_Waste**) creating a matrix of type

"Rads, Tanks" that holds the concentration of each radionuclide in each waste source, and an expression element (**Res_Waste_Mass**) creating a vector of type "Tanks" holding the mass of residual waste in each waste source.

Figure 4-39. Intruder_Parameters Container of the Waste Management Area A-AX System Model.

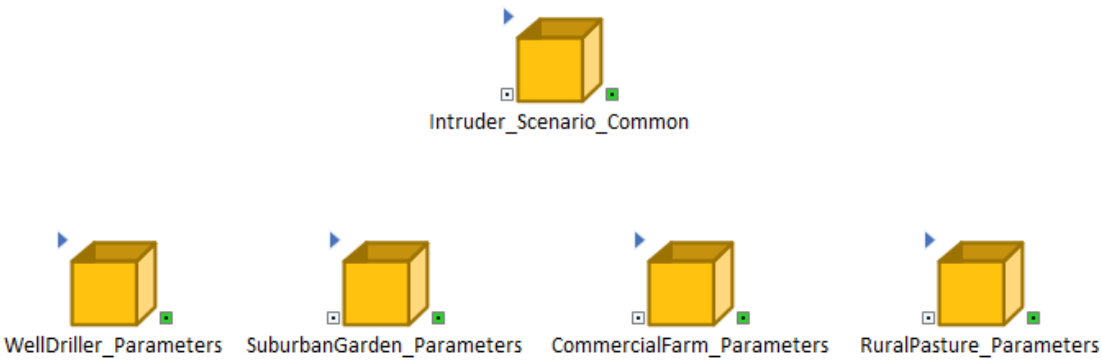
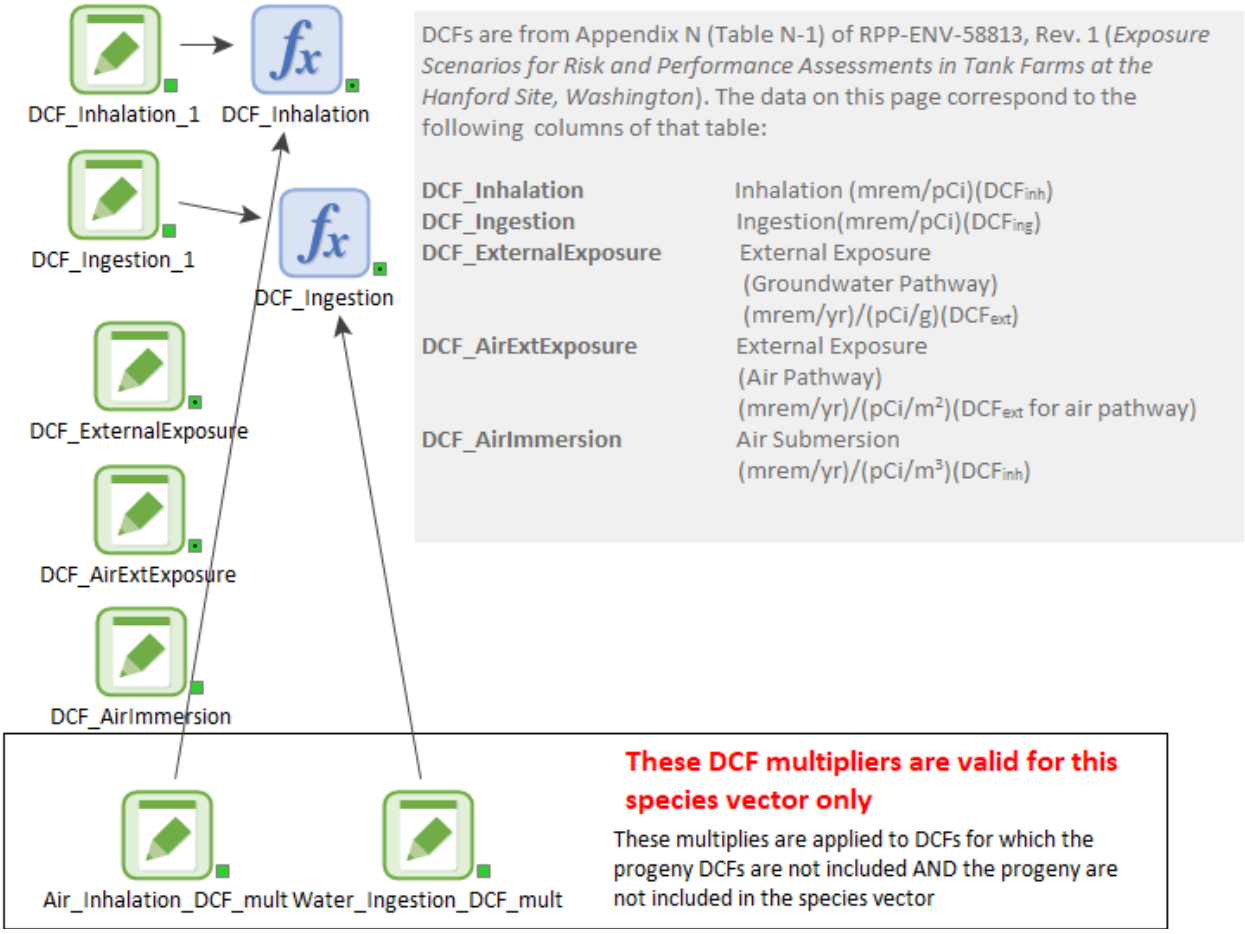
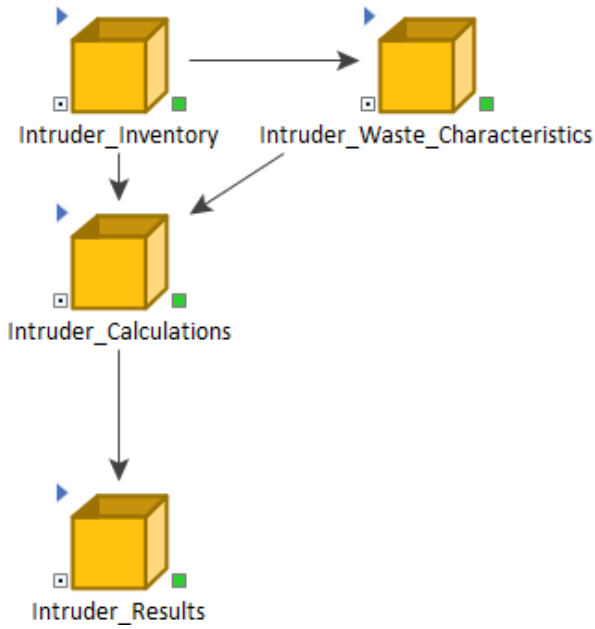


Figure 4-40. Dose Conversion Factor Container of the Waste Management Area A-AX System Model.



DCF = Dose conversion factor

Figure 4-41. Intruder_Dose_Calc Container of the Waste Management Area A-AX System Model.



4.5.3.2 Calculations

4.5.3.2.1 Intruder_Calculations Container. Intruder dose calculations for each scenario and pathway are in this container (Figure 4-44). All of the dose calculations in this container use the **Intrusion_time** vector which has a conditional activity criterion of Etime >= 100 years for pipes and Etime >= 500 years for tanks. This means that if the simulation time is less than the threshold year, the dose will be multiplied by 0 and if it is greater, then it will be multiplied by 1. This prevents reporting doses prior to the assumed intrusion year. Each scenario is self contained, so **Intruder_Calculations** holds the containers **Acute_Exp_Well_Driller**, **Chronic_Exp_Commercial_Farm**, **Chronic_Exp_Rural_Pasture**, and **Chronic_Exp_Suburban_Garden**.

4.5.3.2.2 Acute_Exp_Well_Driller Container. The calculations performed in **Acute_Exp_Well_Driller** (Figure 4-45) estimate the dose to the inadvertent intruder in the Acute Well Driller scenario. The inputs to the calculation are **Residual_Waste**, **Waste_Thickness**, **Waste_Bulk_Density**, **Cuttings_Bulk_Density**, and **Groundwater_Depth**. The **DrillingSoil_Conc_WD** expression element calculates the radionuclide concentration in the drill cuttings produced during drilling. **Soil_Ingestion_Dose_WD**, **Inhalation_Dose_WD**, and **External_Exposure_Dose_WD** are expression elements calculating the dose to the intruder from the radionuclides in drill cuttings through incidental soil ingestion, inhalation of soil particulates and external exposure, respectively. The **WellDriller_Sum** expression element calculates a total dose to the intruder by summing the pathway doses.

Figure 4-42. Intruder_Inventory Container of the Waste Management Area A-AX System Model.

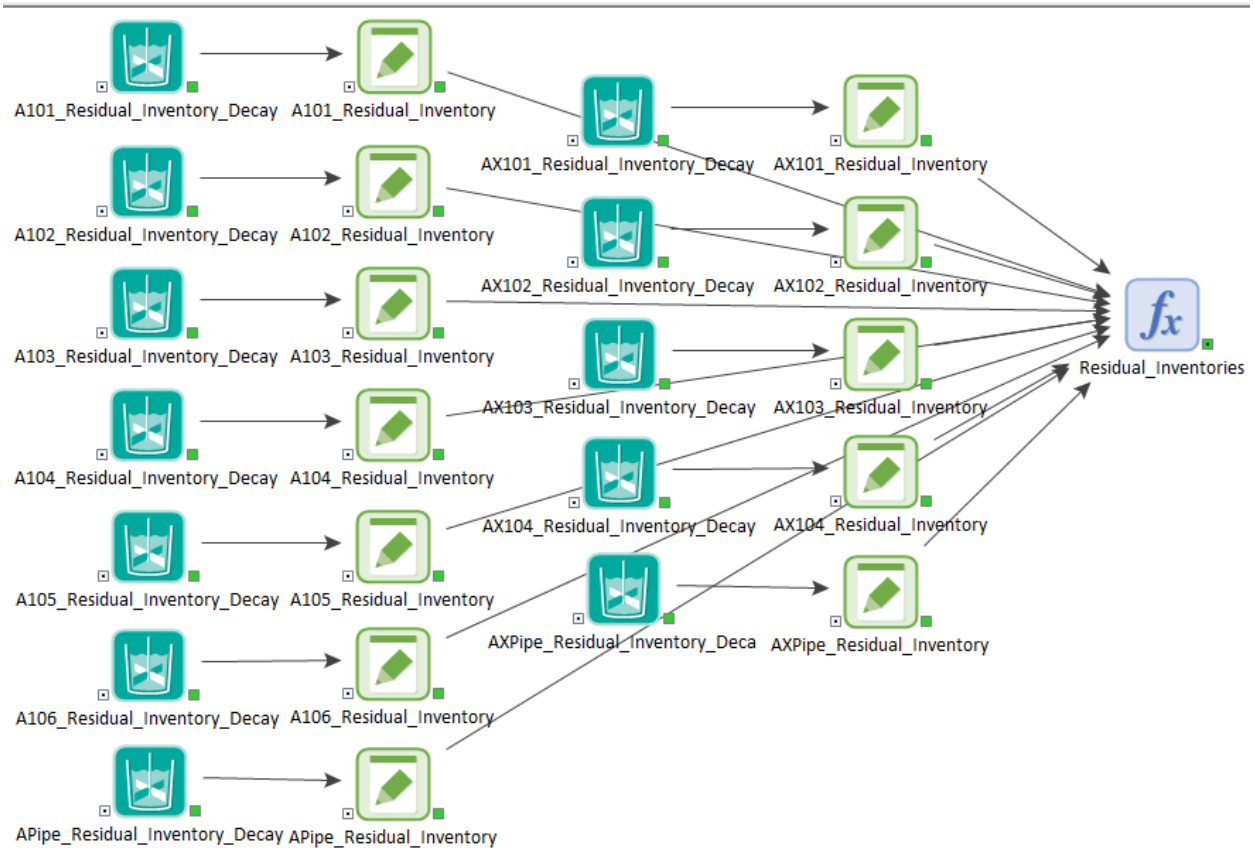
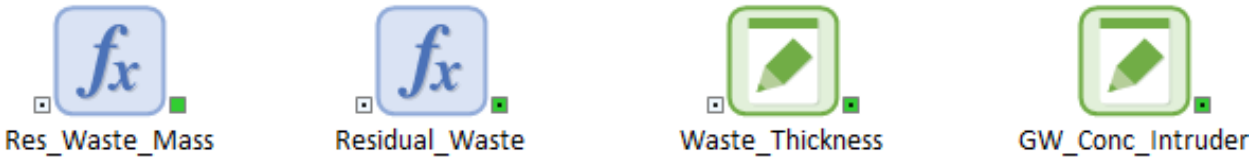


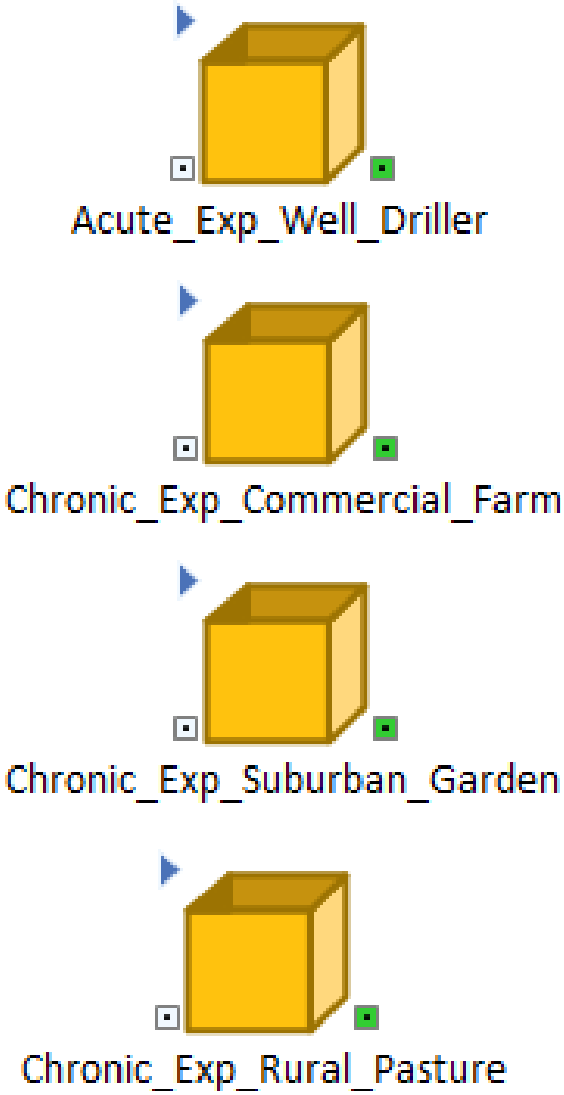
Figure 4-43. Intruder_Waste_Characteristics Container of the Waste Management Area A-AX System Model.



4.5.3.2.3 Chronic_Exp_Commercial_Farm Container. The calculations performed in **Chronic_Exp_Commercial_Farm** (Figure 4-46) estimate the dose to the inadvertent intruder in the Commercial Farm scenario over time. The inputs to the calculation are **Residual_Inventories**, **Intercepted_Waste_Area_CF**, and **Intruder_CrossSectional_Area**. The **Cuttings_Activity_CF** expression element calculates the activity of each radionuclide exhumed through drilling. The **Soil_Conc_CF** expression element takes the activities of radionuclides in cuttings and calculates their concentration in the commercial farm soil. **Soil_Ingestion_Dose_CF**, **Inhalation_Dose_CF**, and **External_Exposure_Dose_CF** are expression elements

calculating the dose to the intruder from the radionuclides in pasture soil through incidental soil ingestion, inhalation of soil particulates and external exposure, respectively. The **Commercial_Farm_Sum** expression element calculates a total dose to the intruder by summing the pathway doses.

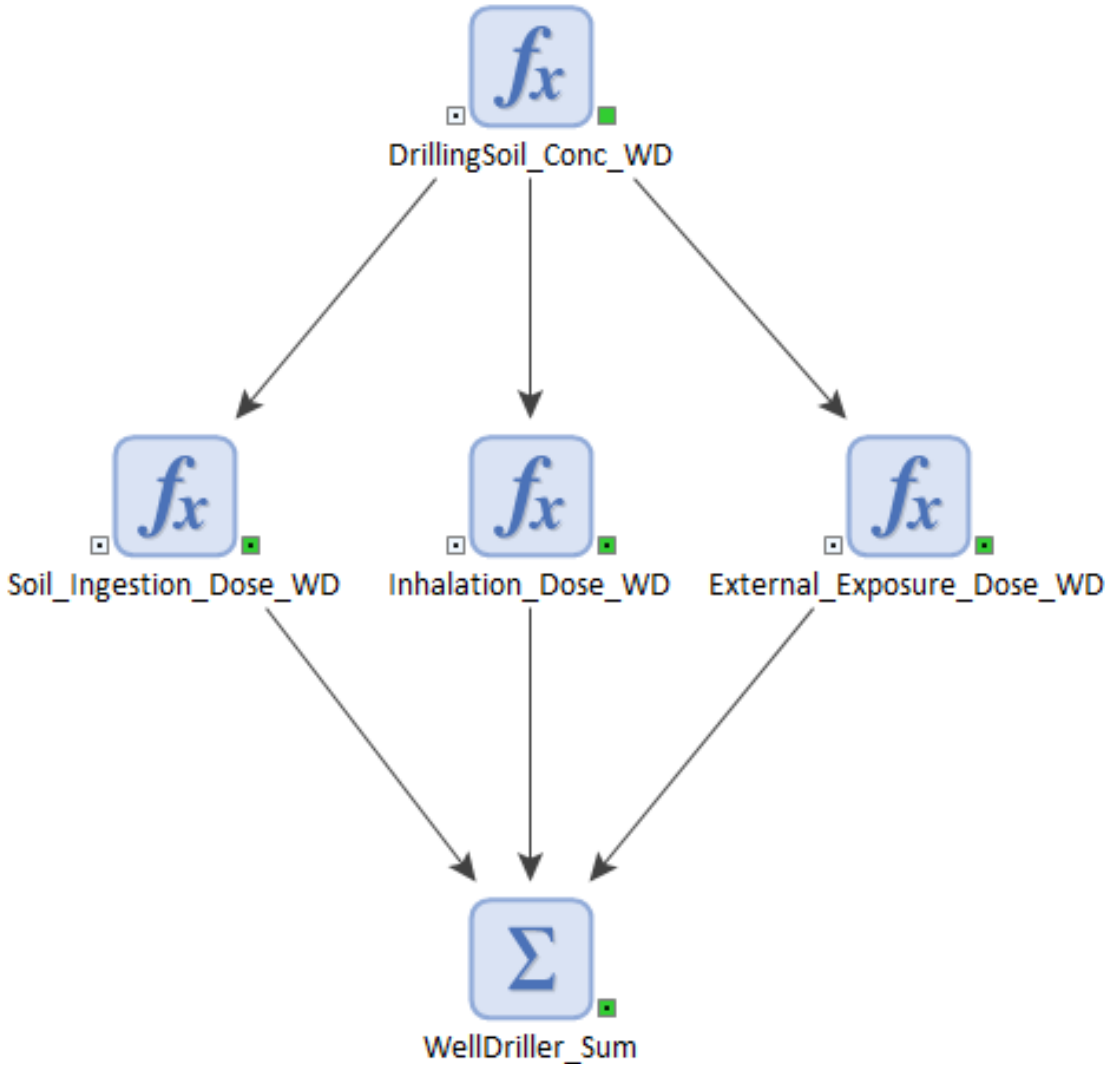
Figure 4-44. Intruder_Calculations Container of the Waste Management Area A-AX System Model.



4.5.3.2.4 Chronic_Exp_Rural_Pasture Container. The calculations performed in **Chronic_Exp_Rural_Pasture** (Figure 4-47) estimate the dose to the inadvertent intruder in the Rural Pasture scenario over time. The inputs to the calculation are **Residual_Inventories**, **Intercepted_Waste_Area_RP** and **Intruder_CrossSectional_Area**. The **Cuttings_Activity_RP** expression element calculates the activity of each radionuclide exhumed through drilling. The **Soil_Conc_RP** expression element takes the activities of radionuclides in cuttings and calculates their concentration in the rural pasture soil. **Fodder_Conc_RP** calculates

the radionuclide concentration in livestock fodder obtained through uptake of radionuclides from the soil (**Soil_Conc_RP**). **Milk_Conc_RP** calculates the radionuclide concentration in milk from a cow exposed to contaminated soil (**Soil_Conc_RP**) and contaminated fodder (**Fodder_Conc_RP**). **Milk_Ingestion_Dose_RP** calculates the dose to the inadvertent intruder from consuming the contaminated milk (**Milk_Conc_RP**). **Soil_Ingestion_Dose_RP**, **Inhalation_Dose_RP**, and **External_Exposure_Dose_RP** are expression elements calculating the dose to the intruder from the radionuclides in pasture soil through incidental soil ingestion, inhalation of soil particulates and external exposure, respectively. The **RuralPasture_Sum** expression element calculates a total dose to the intruder by summing the pathway doses.

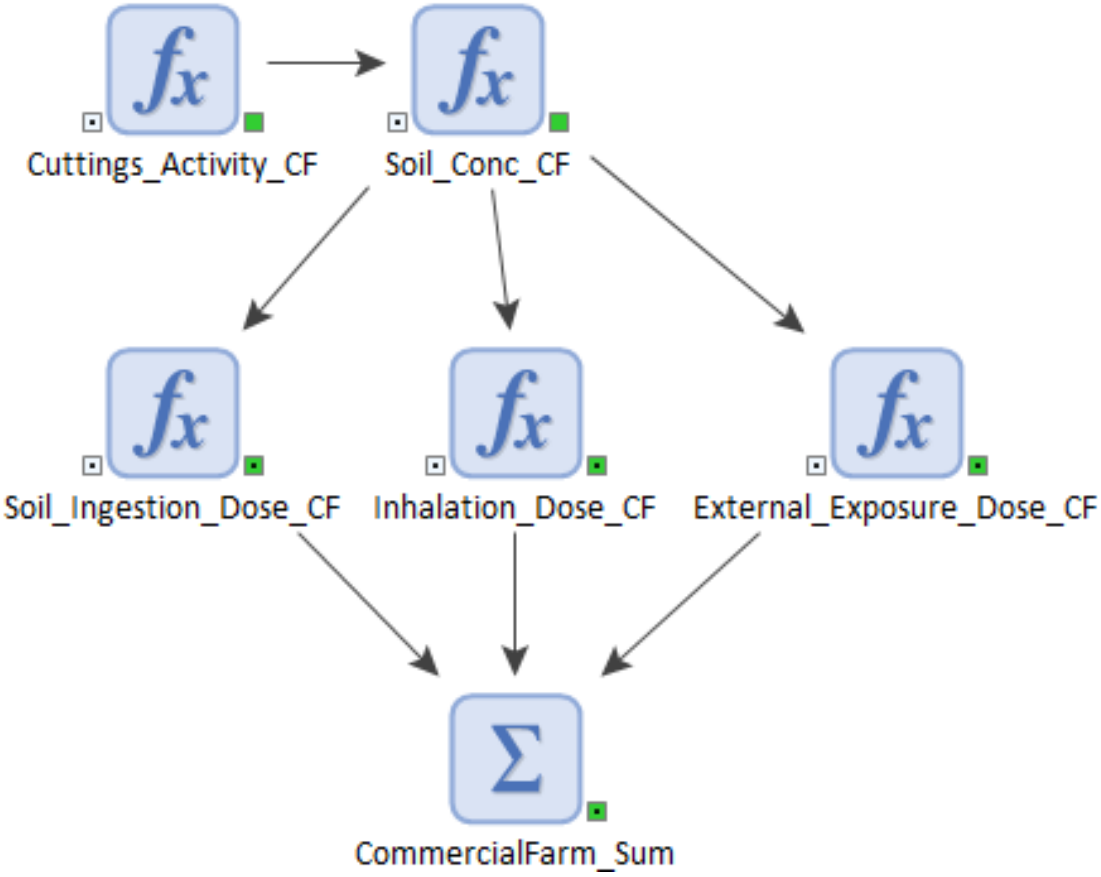
Figure 4-45. Acute_Exp_Well_Driller Container of the Waste Management Area A-AX System Model.



4.5.3.2.5 Chronic_Exp_Suburban_Garden Container. The calculations performed in **Chronic_Exp_Suburban_Garden** (Figure 4-48) estimate the dose to the inadvertent

intruder in the Suburban Garden scenario over time. The inputs to the calculation are **Residual_Inventories**, **Intercepted_Waste_Area_SG** and **Intruder_CrossSectional_Area**. The **Cuttings_Activity_SG** expression element calculates the activity of each radionuclide exhumed through drilling. The **Soil_Conc_SG** expression element takes the activities of radionuclides in cuttings and calculates their concentration in the rural pasture soil. **Veg_Conc_SG** calculates the radionuclide concentration in garden vegetables obtained through uptake of radionuclides from the soil (**Soil_Conc_SG**). **Veg_Ingestion_Dose_RP** calculates the dose to the inadvertent intruder from consuming the contaminated vegetables (**Milk_Conc_SG**). **Soil_Ingestion_Dose_SG**, **Inhalation_Dose_SG**, and **External_Exposure_Dose_SG** are expression elements calculating the dose to the intruder from the radionuclides in pasture soil through incidental soil ingestion, inhalation of soil particulates and external exposure, respectively. The **SuburbanGarden_Sum** expression element calculates a total dose to the intruder by summing the pathway doses.

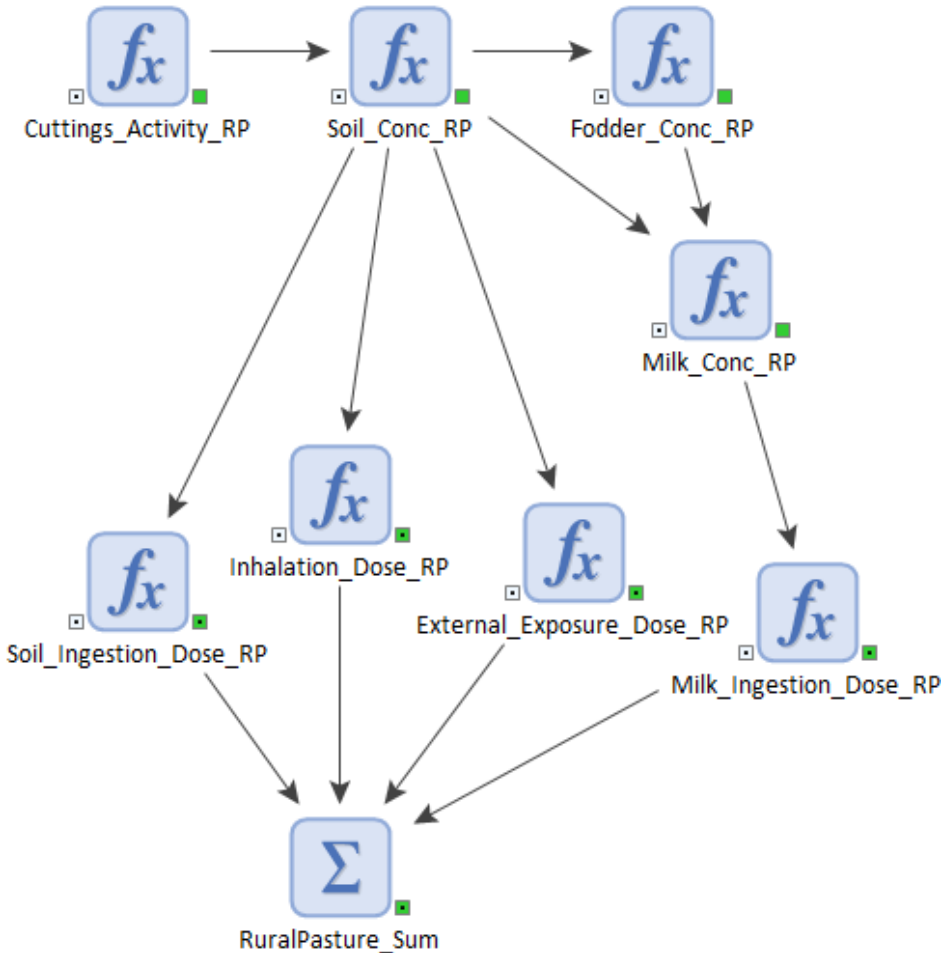
Figure 4-46. Chronic_Exp_Commercial_Farm Container of the Waste Management Area A-AX System Model.



4.5.3.3 Output: Intruder_Results Container

The elements in the **Intruder_Results** container (Figure 4-49) format the results of the calculations performed in this submodel. The results are formatted for export to WMA A-AX PA-related documents.

Figure 4-47. Chronic_Exp_Rural_Pasture Container of the Waste Management Area A-AX System Model.



Each intrusion scenario has a data element, an extrema element and a chart element. Additionally, there is a data element and an extrema element that combine the results by scenario and waste source.

- **WellDriller_Dose_ByTank**: a data element which holds the total well driller dose by waste source over time.

- **WellDriller_Max**: an extrema element calculating the maximum well driller dose by waste source.

- **WD_Dose_ByTank_cht**: a chart element displaying the well driller dose for each waste source over time.

- **CommercialFarm_Dose_ByTank**: a data element which holds the total commercial farm dose by waste source over time.

- **CommercialFarm_Max**: an extrema element calculating the maximum commercial farm dose by waste source.

- **CF_Dose_ByTank_cht**: a chart element displaying the commercial farm dose for each waste source over time.

- **RuralPasture_Dose_ByTank**: a data element which holds the total rural pasture dose by waste source over time.

- **RuralPasture_Max**: an extrema element calculating the maximum rural pasture dose by waste source.

- **RP_Dose_ByTank_cht**: a chart element displaying the rural pasture dose for each waste source over time.

- **SuburbanGarden_Dose_ByTank**: a data element which holds the total suburban garden dose by waste source over time.

- **SuburbanGarden_Max**: an extrema element calculating the maximum suburban garden dose by waste source.

- **SG_Dose_ByTank_cht**: a chart element displaying the suburban garden dose for each waste source over time.

- **Scenario_Doses_by_Tank**: a data element containing a matrix of "Tank, DoseScenarios" showing the dose by scenario and waste source. This element has a time history.

- **Scenario_Doses_Max**: a data element containing a matrix of "Tank, DoseScenarios" showing the maximum dose by scenario and waste source.

The **Intruder_Results** container also holds one container per tank, which has the doses by scenario, by analyte. Each tank's container is formatted the same and the contents of **A101_ByAnalyte** (Figure 4-50) are listed here as an example.

- **TankNum**: a scalar containing the row number of the tank for lookup purposes.

- **WD_By_Analyte**: a data element which holds the total well driller dose by analyte for the selected waste source over time.

- **WD_By_Analyte_Max**: an extrema element calculating the maximum well driller dose for the selected waste source by analyte.

- **WD_By_Analyte_cht**: a chart element displaying the well driller dose for each analyte in the selected waste source over time.

- **CF_By_Analyte**: a data element which holds the total commercial farm dose by analyte for the selected waste source over time.

- **CF_By_Analyte_Max**: an extrema element calculating the maximum commercial farm dose for the selected waste source by analyte.

- **CF_By_Analyte_cht**: a chart element displaying the commercial farm dose for each analyte in the selected waste source over time.

- **RP_By_Analyte**: a data element which holds the total rural pasture dose by analyte for the selected waste source over time.

- **RP_By_Analyte_Max**: an extrema element calculating the maximum rural pature dose for the selected waste source by analyte.

- **RP_By_Analyte_cht**: a chart element displaying the rural pasture dose for each analyte in the selected waste source over time.

- **SG_By_Analyte**: a data element which holds the total suburban garden dose by analyte for the selected waste source over time.

- **SG_By_Analyte_Max**: an extrema element calculating the maximum suburban garden dose for the selected waste source by analyte.

- **SG_By_Analyte_cht**: a chart element displaying the suburban garden dose for each analyte in the selected waste source over time.

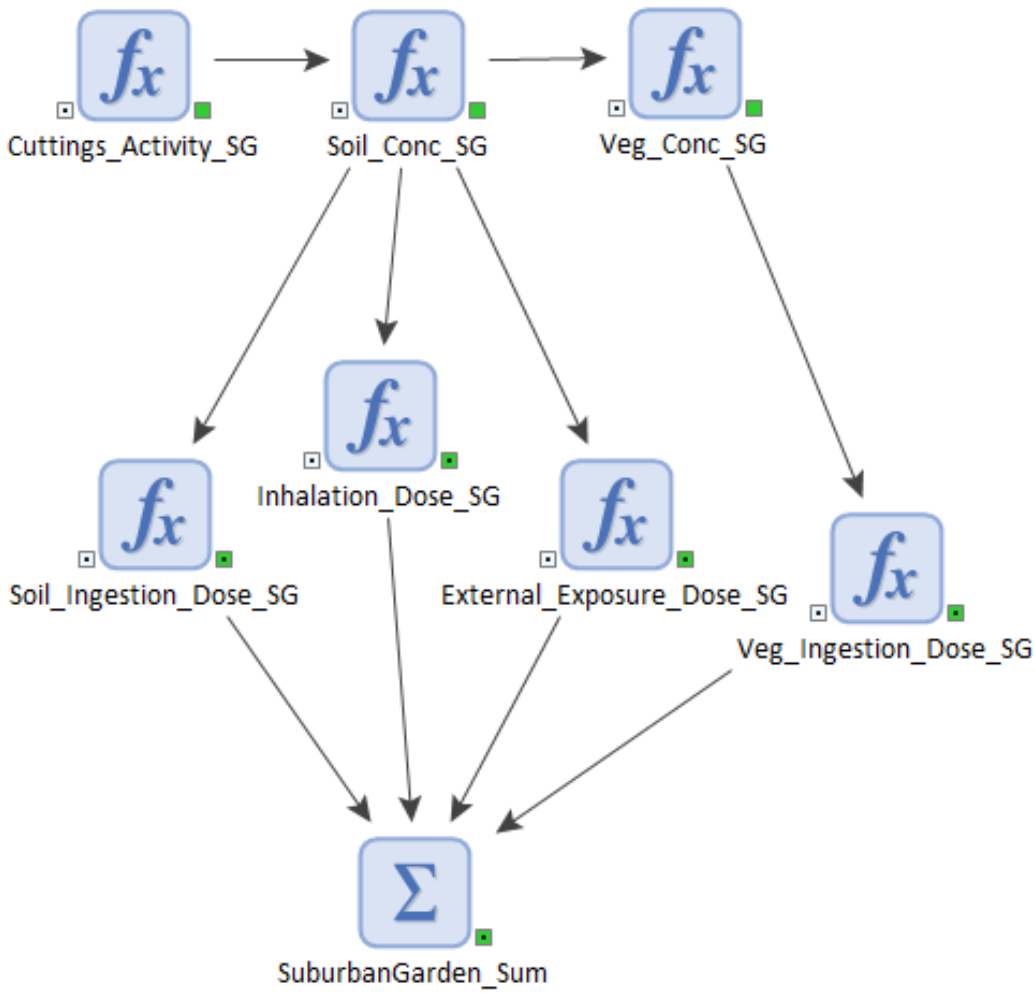
- **Relative_Fraction_of_Pathways**: an expression element calculating the relative fraction of each pathway in each scenario.

4.6 IMPLEMENTATION OF EXPOSURE AND DOSE MODELING

To support the WMA A-AX compliance determinations, an All-Pathways Representative Person exposure scenario is implemented using GoldSim© Pro simulator software as a component of the larger WMA A-AX system model. This scenario includes exposure via both groundwater and air transport pathways. For the compliance determinations, dose from each pathway will be compared to their respective performance objectives. The dose from both pathways will also be summed and compared to the all-pathways performance objective.

The source of groundwater contamination for the All-Pathways Representative Person scenario is the portion of the WMA A-AX inventory transported by groundwater to a hypothetical well location located 100 m downgradient from the facility, and drawn through the well by the Representative Person. The exposed individual is assumed to use the water to drink, shower, irrigate crops, and water livestock. The contaminated water is the only source of exposure; dose from exposure to contaminated air was calculated separately and has been screened out (RPP-CALC-63180).

Figure 4-48. Chronic_Exp_Suburban_Garden Container of the Waste Management Area A-AX System Model.



4.6.1 Equations Used to Calculate Media Concentrations for the All-Pathways Representative Person Scenario

4.6.1.1 Radionuclide Concentrations in Soil

When contaminated water is applied to soil, the contaminants are held in the soil by two mechanisms: sorption onto soil particles and dissolved contaminants held in the water

content in the soil. The concentration of a radionuclide sorbed on the soil particles is given by the following equation (RPP-ENV-58813):

$$C_s = C_w \times K_d \times UCF \tag{4-41}$$

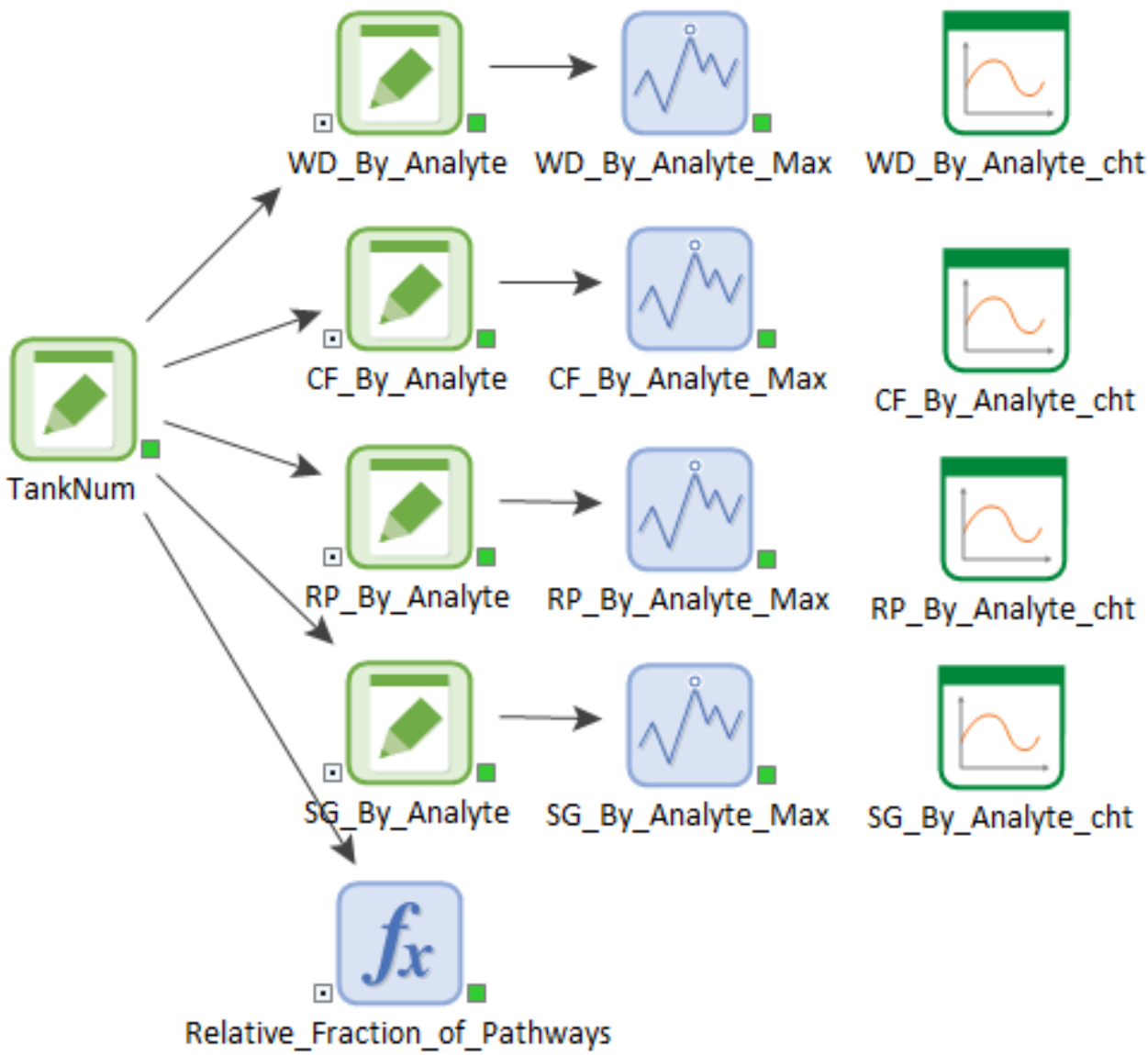
Where:

C_s = radionuclide concentration in soil (pCi/g)
C_w = radionuclide concentration in irrigation water (pCi/L)
K_d = soil-water partition coefficient for the given soil type and radionuclide (mL/g)
UCF = unit conversion factor (L/mL) (note: GoldSim© automatically converts units, so this term is not used in the model).

Figure 4-49. Intruder_Results Container of the Waste Management Area A-AX System Model.

This equation assumes that the irrigation water is in rapid equilibrium with the surface soil layer, which tends to overestimate the concentration in soil, in some cases significantly. To reduce this conservatism, it would be necessary to model application of contaminated water on the ground and calculate radionuclide concentration profiles in the top layer of soil.

Figure 4-50. A101_ByAnalyte Container of the Waste Management Area A-AX System Model.



Total radionuclide concentration in the soil (i.e., sorbed plus dissolved plus vapor) is given by the following equation (RPP-ENV-58813):

$$C_{stot} = C_w \times \left(K_d + \frac{\theta_w + \theta_a \times H}{\rho_s}\right) \times UCF \approx C_w \times \left(K_d + \frac{\theta_w}{\rho_s}\right) \times UCF \qquad (4\text{-}42)$$

Where:

C_{stot} = total radionuclide concentration in surface soil layer (pCi/g)
C_w = radionuclide concentration in irrigation water (pCi/L)
K_d = soil-water partition coefficient for the given soil type and radionuclide (mL/g)
θ_w = soil volumetric water content (mL water/cm^3 soil)
θ_a = air-filled soil porosity (mL air/cm^3 soil)
H = Henry's Law constant (dimensionless)
ρ_s = soil dry bulk density (g/cm^3)
UCF = unit conversion factor (L/mL) (note: GoldSim© automatically converts units, so this term is not used in the model).

The volatile radionuclide inventory in the contaminated water used for irrigation is likely to be negligibly small, so $\theta_a \times H$ can be ignored. These equations are used whenever C_s and C_{stot} are used in the equations for the All-Pathways Representative Person scenario.

4.6.1.2 Radionuclide Concentrations in Homegrown Crops

Crops grown in contaminated soil may be consumed by people. The equation below determines the amount of contaminant that is transferred from the soil to the crop by root uptake and deposition processes. The concentration of a radionuclide in the crop is given by the following equation (RPP-ENV-58813):

$$C_c = C_{stot} \times (B_v + B'_v) \tag{4-43}$$

Where:

C_c = radionuclide concentration in homegrown crops (pCi/g)
C_{stot} = total radionuclide concentration in surface soil layer (pCi/g) (Equation 4-42)
B_v = crop-soil bioconcentration factor through root uptake $\left(\frac{\left(\frac{pCi}{kg\ fresh\ weight\ of\ crop}\right)}{\left(\frac{pCi}{kg\ dry\ weight\ of\ soil}\right)}\right)$
B'_v = crop-soil bioconcentration factor representing all resuspension-soil adhesion processes $\left(\frac{\left(\frac{pCi}{kg\ fresh\ weight\ of\ crop}\right)}{\left(\frac{pCi}{kg\ dry\ weight\ of\ soil}\right)}\right)$.

4.6.1.3 Radionuclide Concentrations in Animal Fodder

Fodder grown in contaminated soil may be used to feed livestock animals. The equation below determines the amount of contaminant that is transferred from the soil to fodder by root uptake and deposition processes. The concentration of a radionuclide in animal fodder is given by the following equation (RPP-ENV-58813):

$$C_{fodder} = C_{stot} \times (B_p + B'_p) \tag{4-44}$$

Where:

C_{fodder} = radionuclide concentration in livestock fodder (pCi/g)
C_{stot} = total radionuclide concentration in surface soil layer (pCi/g) (Equation 4-42)
B_p = pasture-soil bioconcentration factor through uptake $\left(\frac{\left(\frac{pCi}{kg\ dry\ weight\ of\ fodder}\right)}{\left(\frac{pCi}{kg\ dry\ weight\ of\ soil}\right)}\right)$
B'_p = pasture-soil bioconcentration factor representing all resuspension-soil adhesion processes $\left(\frac{\left(\frac{pCi}{kg\ dry\ weight\ of\ fodder}\right)}{\left(\frac{pCi}{kg\ dry\ weight\ of\ soil}\right)}\right)$.

Note that C_{fodder} refers generically to all livestock animal feed. This equation is used whenever C_{fodder} is used in the equations for calculating radionuclide concentrations in meat and animal products (beef, milk, eggs, and poultry) for the All-Pathways Representative Person scenario.

4.6.1.4 Radionuclide Concentrations in Farm-Raised Beef

The concentration of a radionuclide that is transferred to beef from the consumption of contaminated water, contaminated fodder, and contaminated soil is given by the following equation (RPP-ENV-58813):

$$C_b = \left(C_w \times IR_{w,b} + C_{fodder} \times IR_{fodder,b} \times UCF + C_{stot} \times IR_{s,b} \times UCF\right) \times BCF_{beef} \qquad (4\text{-}45)$$

Where:

C_b = radionuclide concentration in beef (pCi/kg)
C_w = radionuclide concentration in water (pCi/L)
$IR_{w,b}$ = ingestion rate of water for beef (L/day)
C_{fodder} = radionuclide concentration in fodder (pCi/g) (Equation 4-44)
$IR_{fodder,b}$ = ingestion rate of fodder for beef (kg/day)
C_{stot} = total radionuclide concentration in surface soil layer (pCi/g) (Equation 4-42)
$IR_{s,b}$ = ingestion rate of soil for beef (kg/day)
BCF_{beef} = bioconcentration factor of radionuclides in beef (day/kg)
UCF = unit conversion factor (g/kg) (note: GoldSim© automatically converts units, so this term is not used in the model).

4.6.1.5 Radionuclide Concentrations in Milk

The concentration of a radionuclide that is transferred to milk from the consumption of contaminated water, contaminated fodder, and contaminated soil by dairy cattle is given by the following equation (RPP-ENV-58813):

$$C_m = \left(C_w \times IR_{w,d} + C_{fodder} \times IR_{fodder,d} \times UCF + C_{stot} \times IR_{s,d} \times UCF\right) \times BCF_{milk} \qquad (4\text{-}46)$$

Where:

C_m = radionuclide concentration in milk (pCi/L)

C_w = radionuclide concentration in water (pCi/L)
$IR_{w,d}$ = ingestion rate of water by dairy cattle (L/day)
C_{fodder} = radionuclide concentration in fodder (pCi/g) (Equation 4-44)
$IR_{fodder,d}$ = ingestion rate of fodder by dairy cattle (kg/day)
C_{stot} = total radionuclide concentration in surface soil layer (pCi/g) (Equation 4-42)
$IR_{s,d}$ = ingestion rate of soil by dairy cattle (kg/day)
BCF_{milk} = bioconcentration factor of radionuclides in milk (day/L)
UCF = unit conversion factor (g/kg) (note: GoldSim© automatically converts units, so this term is not used in the model).

4.6.1.6 Radionuclide Concentrations in Eggs

The concentration of a radionuclide that is transferred to eggs from the consumption of contaminated water, contaminated fodder, and contaminated soil by poultry is given by the following equation (RPP-ENV-58813):

$$C_e = \left(C_w \times IR_{w,p} + C_{fodder} \times IR_{fodder,p} \times UCF + C_{stot} \times IR_{s,p} \times UCF\right) \times BCF_{egg} \qquad (4\text{-}47)$$

Where:

C_e = radionuclide concentration in eggs (pCi/kg)
C_w = radionuclide concentration in water (pCi/L)
$IR_{w,p}$ = ingestion rate of water by poultry (L/day)
C_{fodder} = radionuclide concentration in fodder (pCi/g) (Equation 4-44)
$IR_{fodder,p}$ = ingestion rate of fodder by poultry (kg/day)
C_{stot} = total radionuclide concentration in surface soil layer (pCi/g) (Equation 4-42)
$IR_{s,p}$ = ingestion rate of soil by poultry (kg/day)
BCF_{egg} = bioconcentration factor of radionuclides in eggs (day/kg)
UCF = unit conversion factor (g/kg) (note: GoldSim© automatically converts units, so this term is not used in the model).

4.6.1.7 Radionuclide Concentrations in Poultry

The concentration of a radionuclide that is transferred to poultry from the consumption of contaminated water, contaminated fodder, and contaminated soil is given by the following equation (RPP-ENV-58813):

$$C_p = \left(C_w \times IR_{w,p} + C_{fodder} \times IR_{fodder,p} \times UCF + C_{stot} \times IR_{s,p} \times UCF\right) \times BCF_{poultry} \qquad (4\text{-}48)$$

Where:

C_p = radionuclide concentration in poultry (pCi/kg)
C_w = radionuclide concentration in water (pCi/L)
$IR_{w,p}$ = ingestion rate of water by poultry (L/day)
C_{fodder} = radionuclide concentration in fodder (pCi/g) (Equation 4-44)
$IR_{fodder,p}$ = ingestion rate of fodder by poultry (kg/day)
C_{stot} = total radionuclide concentration in surface soil layer (pCi/g) (Equation 4-42)

$IR_{s,p}$ = ingestion rate of soil by poultry (kg/day)
$BCF_{poultry}$ = bioconcentration factor of radionuclides in poultry (day/kg)
UCF = unit conversion factor (g/kg) (note: GoldSim© automatically converts units, so this term is not used in the model).

4.6.2 Equations Used to Calculate Dose for the All-Pathways Representative Person Scenario

4.6.2.1 Dose from Ingestion of Water

The following equation is used to calculate dose from ingestion of water (RPP-ENV-58813):

$$D_w = C_w \times IR_w \times EF \times DCF_{ing} \tag{4-49}$$

Where:

D_w = dose from drinking contaminated water (mrem/yr)
C_w = radionuclide concentration in water (pCi/L)
IR_w = water ingestion rate (L/day)
EF = exposure frequency (days/yr)
DCF_{ing} = ingestion dose conversion factor (mrem/pCi).

4.6.2.2 Dose from Inhalation of Water Vapor

The following equation (RPP-ENV-58813) is used to calculate dose from inhalation of water vapor from showering or other household activities. Dose is only calculated for ^{14}C, ^{3}H, and ^{226}Ra, which are assumed to volatilize during household water use (EPA Home | OLEM | Superfund | Superfund Risk Assessment | Risk Assessment Home | Human Health Risk Assessment Tools and Databases, Queried 12/05/2018, [Preliminary Remediation Goals for Radionuclides (PRG) | PRG User's Guide], http://epa-prgs.ornl.gov/radionuclides/prg_guide.html, Section 4.1.4).

$$D_{inh,w} = C_w \times INH_w \times EF \times K \times DCF_{inh} \tag{4-50}$$

Where:

$D_{inh,w}$ = dose from inhalation of water vapor (mrem/yr)
C_w = radionuclide concentration in water (pCi/L)
INH_w = inhalation rate of water vapor (m^3/day)
EF = exposure frequency (days/yr)
K = Andelman volatilization factor (L/m^3)
DCF_{inh} = inhalation dose conversion factor (mrem/pCi).

Equation 4-50 does not account for dermal absorption of tritiated water vapor and could therefore lead to an underestimation of dose for ^{3}H. With a half-life of 12 years, ^{3}H released from WMA A-AX will likely decay to negligible levels before reaching the saturated zone and

100-m downgradient compliance boundary in the aquifer. The potential for a significant underestimation of dose for ^3H is therefore considered to be small.

4.6.2.3 Dose from Consumption of Homegrown Crops (Fruits and Vegetables)

The following equation is used to calculate dose from consumption of homegrown crops (fruits and vegetables) (RPP-ENV-58813):

$$D_c = C_c \times IR_c \times F_v \times UCF \times DCF_{ing} \tag{4-51}$$

Where:

D_c = dose from crop consumption (mrem/yr)
C_c = radionuclide concentration in crop (pCi/g) (Equation 4-43)
IR_c = crop ingestion rate (kg/yr)
F_v = fraction of homegrown crops consumed (unitless)
UCF = unit conversion factor (g/kg) (note: GoldSim© automatically converts units, so this term is not used in the model)
DCF_{ing} = ingestion dose conversion factor (mrem/pCi).

4.6.2.4 Dose from Consumption of Farm-Raised Beef

The following equation is used to calculate dose from consumption of farm-raised beef (RPP-ENV-58813):

$$D_b = C_b \times IR_b \times F_a \times DCF_{ing} \tag{4-52}$$

Where:

D_b = dose from beef consumption (mrem/yr)
C_b = radionuclide concentration in beef (pCi/kg) (Equation 4-45)
IR_b = beef ingestion rate (kg/yr)
F_a = fraction of farm-raised beef consumed (unitless)
DCF_{ing} = ingestion dose conversion factor (mrem/pCi).

4.6.2.5 Dose from Consumption of Milk

The following equation is used to calculate dose from consumption of milk (RPP-ENV-58813):

$$D_m = C_m \times IR_m \times F_a \times DCF_{ing} \tag{4-53}$$

Where:

D_m = dose from milk consumption (mrem/yr)
C_m = radionuclide concentration in milk (pCi/L) (Equation 4-46)
IR_m = milk ingestion rate (L/yr)
F_a = fraction of locally-produced milk consumed (unitless)
DCF_{ing} = ingestion dose conversion factor (mrem/pCi).

4.6.2.6 Dose from Consumption of Eggs

The following equation is used to calculate dose from consumption of eggs (RPP-ENV-58813):

$$D_e = C_e \times IR_e \times F_a \times DCF_{ing} \tag{4-54}$$

Where:

D_e = dose from consumption of eggs (mrem/yr)
C_e = radionuclide concentration in eggs (pCi/kg) (Equation 4-47)
IR_e = egg ingestion rate (kg/yr)
F_a = fraction of locally-produced eggs consumed (unitless)
DCF_{ing} = ingestion dose conversion factor (mrem/pCi).

4.6.2.7 Dose from Consumption of Poultry

The following equation is used to calculate dose from consumption of poultry (RPP-ENV-58813):

$$D_p = C_p \times IR_p \times F_a \times DCF_{ing} \tag{4-55}$$

Where:

D_p = dose from poultry consumption (mrem/yr)
C_p = radionuclide concentration in poultry (pCi/kg) (Equation 4-48)
IR_p = poultry ingestion rate (kg/yr)
F_a = fraction of locally-produced poultry consumed (unitless)
DCF_{ing} = ingestion dose conversion factor (mrem/pCi).

4.6.2.8 Dose from Incidental Ingestion of Soil

The following equation is used to calculate dose from incidental ingestion of soil (RPP-ENV-58813):

$$D_s = C_s \times IR_s \times EF \times UCF \times DCF_{ing} \tag{4-56}$$

Where:

D_s = dose from incidental ingestion of soil (mrem/yr)
C_s = radionuclide concentration in soil (pCi/kg) (Equation 4-41)
IR_s = soil ingestion rate (mg/day)
EF = exposure frequency (days/yr)
UCF = unit conversion factor (g/mg) (note: GoldSim© automatically converts units, so this term is not used in the model)
DCF_{ing} = ingestion dose conversion factor (mrem/pCi).

Note that use of the sorbed radionuclide soil concentration (C_s) in this equation assumes ingestion of dry soil.

4.6.2.9 Dose from Inhalation of Soil Particulates

The following equation is used to calculate dose from inhalation of soil particulates. This equation assumes the concentration and mass loading factor are the same indoors and outdoors (RPP-ENV-58813):

$$D_{inh} = C_s \times E_f \times M \times (INH_{in} \times t_{in} \times (\frac{I}{O}) + INH_{out} \times t_{out}) \times DCF_{inh} \qquad (4\text{-}57)$$

Where:

D_{inh} = dose from inhalation of soil particulates (mrem/yr)
C_s = radionuclide concentration in soil (pCi/g) (Equation 4-41)
E_f = enrichment factor (unitless)
M = mass loading factor (g/m^3)
INH_{in} = indoor inhalation rate (m^3/yr)
t_{in} = fraction of time spent indoors (unitless)
$\frac{I}{O}$ = ratio of radionuclide concentrations in indoor and outdoor air (unitless)
INH_{out} = outdoor inhalation rate (m^3/yr)
t_{out} = fraction of time spent outdoors (unitless)
DCF_{inh} = inhalation dose conversion factor (mrem/pCi).

4.6.2.10 Dose from External Exposure to Soil

The following equation is used to calculate dose from external exposure to soil (RPP-ENV-58813):

$$D_{ext} = C_{stot} \times (t_{in} \times \epsilon + t_{out}) \times DCF_{ext} \qquad (4\text{-}58)$$

Where:

D_{ext} = dose from external exposure to soil (mrem/yr)
C_{stot} = total radionuclide concentration in soil (pCi/g) (Equation 4-42)
t_{in} = fraction of time spent indoors (unitless)
ϵ = transmission or shielding factor (unitless)
t_{out} = fraction of time spent outdoors (unitless)
DCF_{ext} = external exposure dose conversion factor ([mrem/yr]/[pCi/g]).

4.6.2.11 Total Effective Dose for All-Pathways Representative Person Scenario

The following equation is used to calculate the groundwater pathway total effective dose for each radionuclide from all exposure routes summed (RPP-ENV-58813):

$$D_{total} = \sum_j^M \sum_i^N D_{ij} \qquad (4\text{-}59)$$

Where:

D_{total} = total effective dose from all groundwater pathway exposure routes (mrem/yr)
$D_{i,j}$ = radionuclide dose for the ith groundwater pathway exposure route (mrem/yr) for radionuclide j
N = number of exposure routes (i)
M = number of radionuclides (j).

4.6.3 GoldSim© Implementation of Exposure and Dose Modeling

The WMA A-AX PA dose calculation submodel is part of the WMA A-AX system model that was constructed in GoldSim© Version 12.0. Sections 4.6.1 and 4.6.2 describe the mathematical equations used to calculate dose, and this section describes how those equations are implemented in the GoldSim© software. The purpose of the submodel is to calculate doses over time using an All-Pathways Representative Person exposure scenario. For WMA A-AX, the All-Pathways exposure scenario will only include dose from the groundwater pathway, as the air pathway has been screened out per RPP-CALC-63180.

The models used for these calculations comprise a set of algebraic equations taking account of a variety of exposure pathways. Such equations take a large number of parameters to express complex physical, chemical and biological processes. The equations and parameters for the All-Pathways scenario are established in regulatory guidance from a number of sources, and have been compiled in RPP-ENV-58813.

4.6.3.1 Groundwater Dose Analysis

The GoldSim© elements that calculate dose for the groundwater pathway are within the **GW_Conc_Dose** container, which reside in the **Exposure_Scenarios** container at the root level of the model. Containers at the root level of the system model that are used by the **GW_Conc_Dose** container are **Material**, **Input_Parameters**, and **Transport_Abstraction_Model** (Figure 4-51).

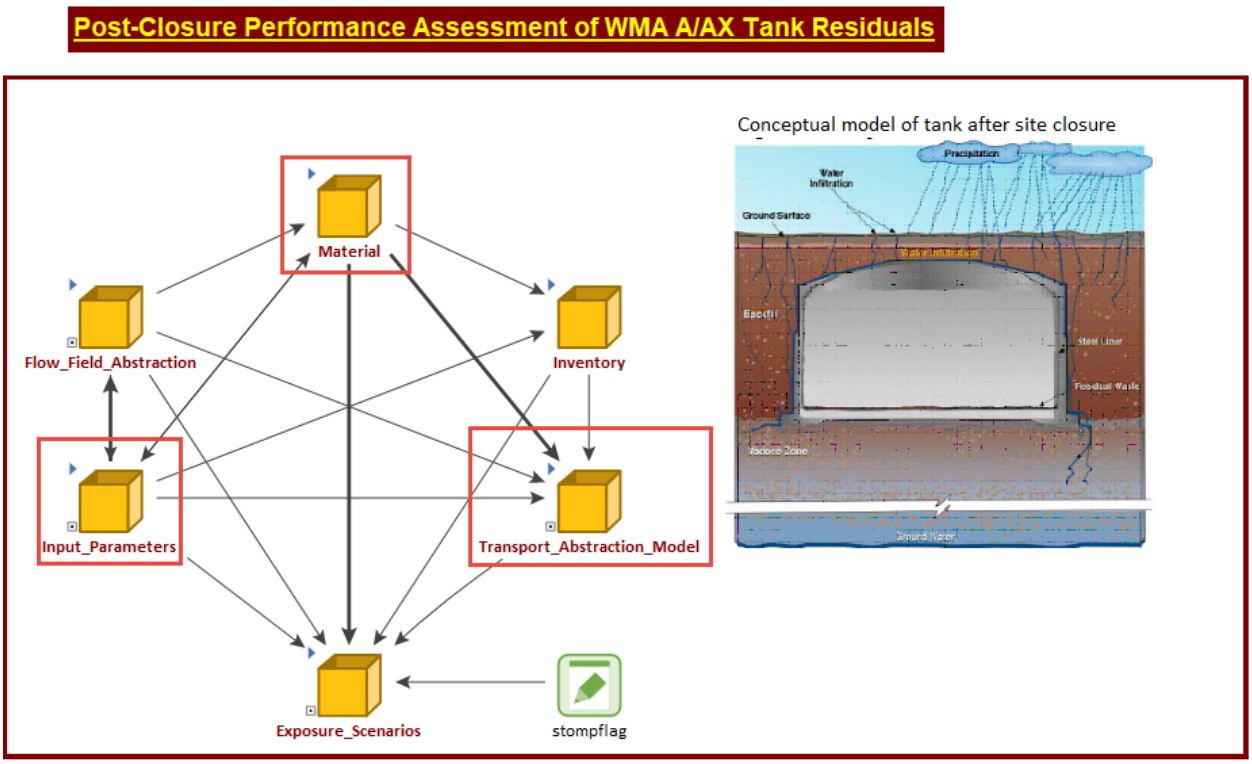
4.6.3.2 Inputs

The input to the **GW_Conc_Dose** container from the **Transport_Abstraction_Model** is the most important, and that is the concentration of each radionuclide (pCi/L) in groundwater at the point of compliance (100 m downstream), for each source.

The inputs to the **GW_Conc_Dose** container from the **Material** container are highlighted in Figure 4-52. This includes the list of radionuclides and chemicals included in the **Species** element, the specific activity of each radionuclide in the species vector, and the reference fluid properties in the **Water** element. Partitioning coefficients and density of **H1_Top_VZ_Material_A** element (Figure 4-53), which are listed in Appendix C, are also needed for dose calculations, and these reside within the **Material_A_Farm** container. These values are used to simulate partitioning coefficients for soil used to farm fodder and crops for the All-Pathways scenario for both A Farm and AX Farm, and are used in Equations 4-41 and 4-42.

There are also input parameters to **GW_Conc_Dose** from within the **DOE_Exposure_Scenarios** container itself (Figure 4-54). All of these parameters come from appendices in RPP-ENV-58813; Appendix N (Scenario-independent parameters for performance assessment scenarios), Appendix O (Equations and input parameters used to calculate media-specific concentrations), or Appendix P (Exposure assumptions and equations used to calculate dose for the All-Pathways Representative Person). The **DCF** container (Figure 4-55) contains parameters from Appendix N that are used in dose calculations. The **AllPathway_Parameters** (Figure 4-56) include parameters from Appendices O and P used in dose calculations.

Figure 4-51. Root Level of the Waste Management Area A-AX System Model.



Note: Containers used in dose calculations are indicated with red outline boxes.

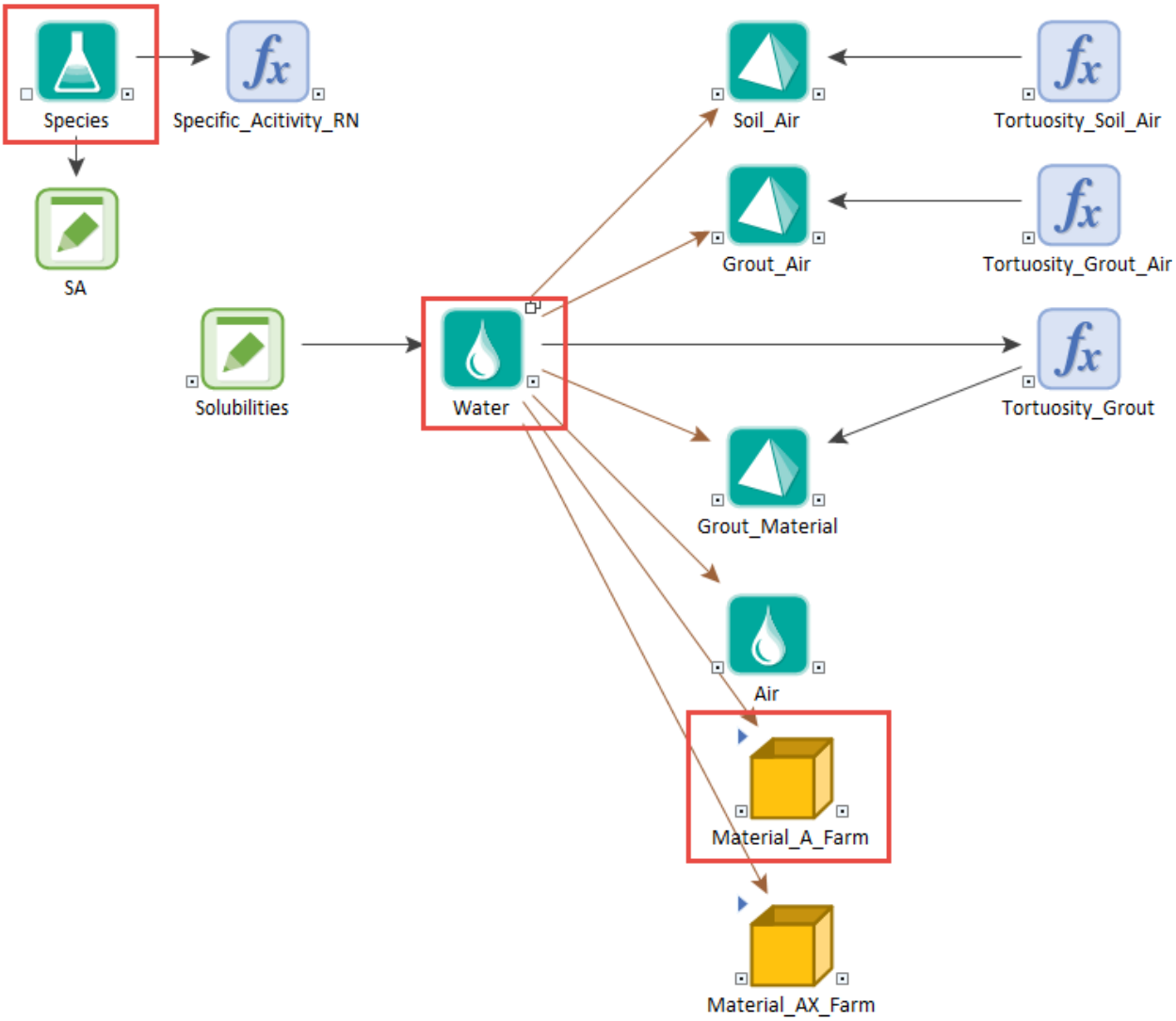
WMA = Waste Management Area

4.6.3.3 Calculations

Within the **GW_Conc_Dose** container (Figure 4-57), the concentration of each radionuclide (pCi/L) in groundwater at the point of compliance (100 m downstream) for each source from the **Transport_Abstraction** container is fed into the **Media_Concentrations_AP** container as well as directly into two of the ten dose pathway calculations (**DrinkWater_Ingestion_Dose_AP**) and (**Inhalation_Dose_WV_AP),** which are described in Sections 4.6.2.1 and 4.6.2.2, respectively. As noted in section 4.6.2.2, dose from inhalation of water vapor is only calculated for ^{14}C, ^{3}H and ^{226}Ra, which is accomplished by multiplying the GoldSim© calculated groundwater concentrations by the **DCF_inhal_factor** element, which is a vector of radionuclides and corresponding factors (either 1 or 0). The inhalation factor for ^{14}C, ^{3}H and ^{226}Ra are set to one, with all other radionuclides set to zero, effectively eliminating all but the

desired radionuclides from subsequent inhalation dose equations. The **Media_Concentrations_AP** (Figure 4-58) container calculates all media concentration equations described in Section 4.6.1. These media concentrations feed into the eight remaining dose pathway calculations described in Sections 4.6.2.3 through 4.6.2.11.

Figure 4-52. Contents of the Material Container.



Note: Elements that are used in dose calculations are indicated with red outline boxes.

Figure 4-53. Partitioning Coefficients from H1_Top_VZ_Material_A within the Material_A_Farm Container.

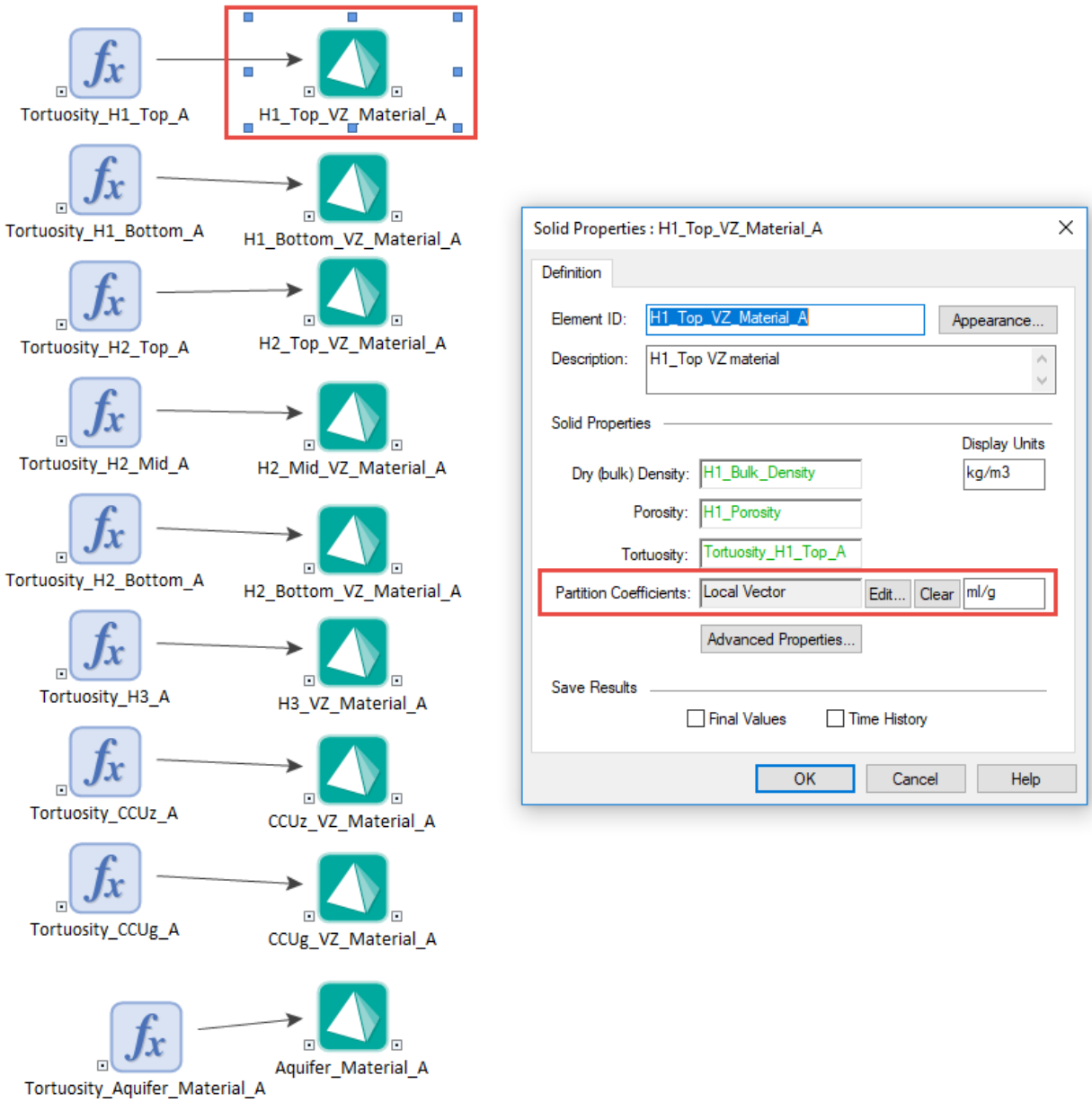
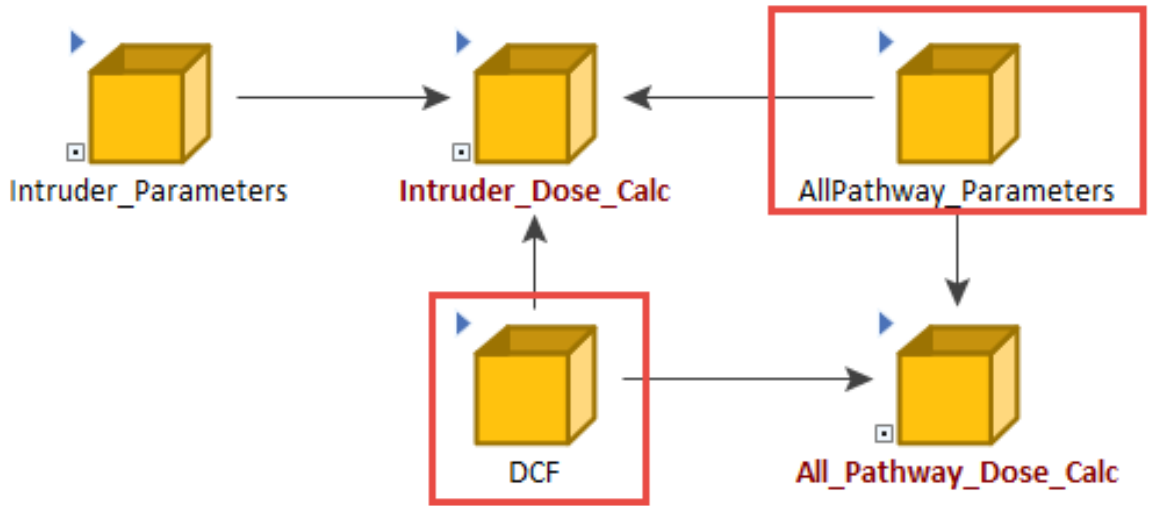
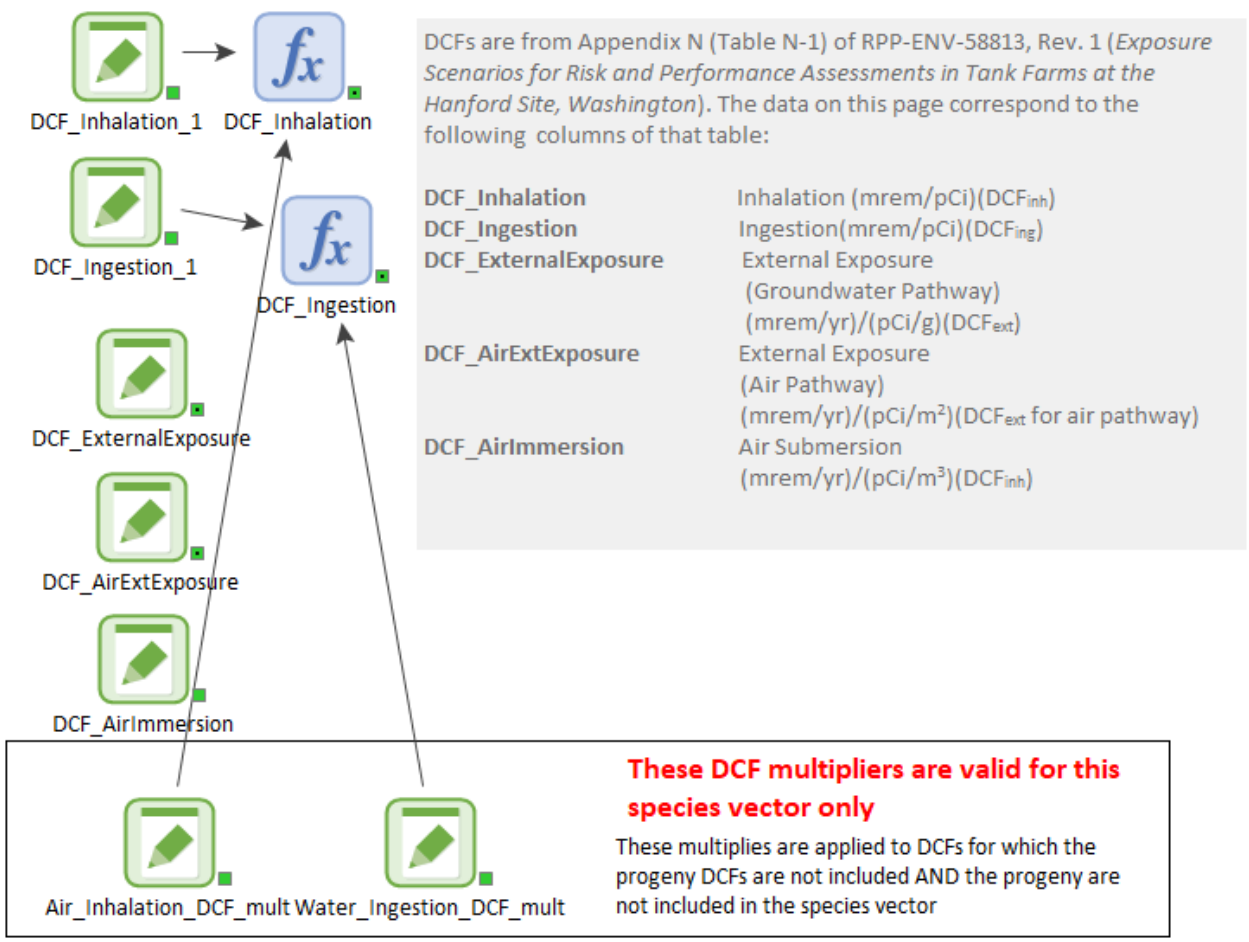


Figure 4-54. DOE_Exposure_Scenarios Container.



Note: Elements used in dose calculations are indicated with red outline boxes.

Figure 4-55. Dose Conversion Factor Container.



DCF = dose conversion factor

Figure 4-56. AllPathway_Parameters Container.

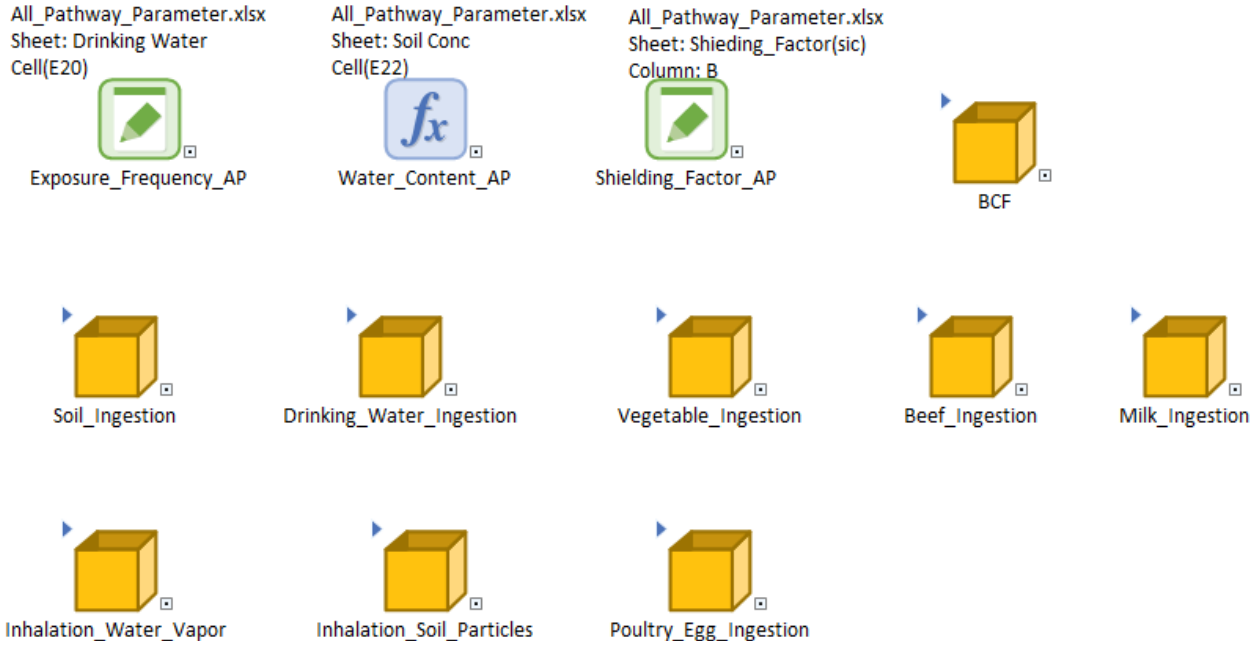


Figure 4-57. Calculation of Dose from Groundwater Concentration.

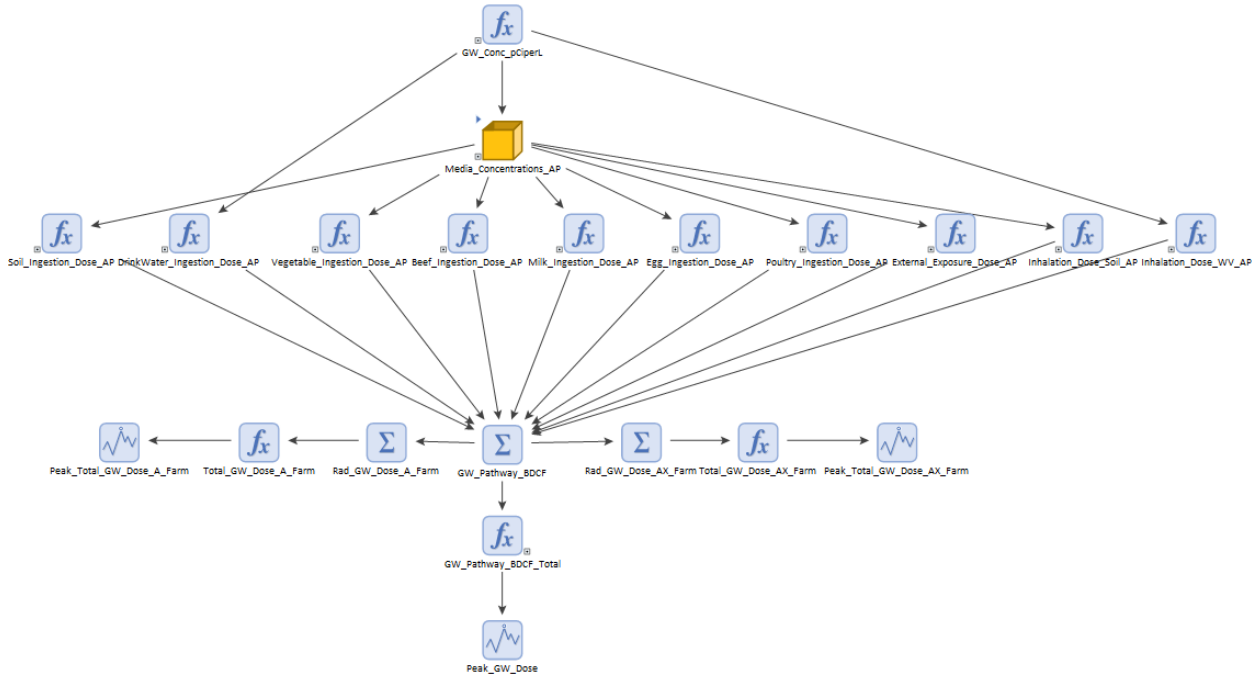
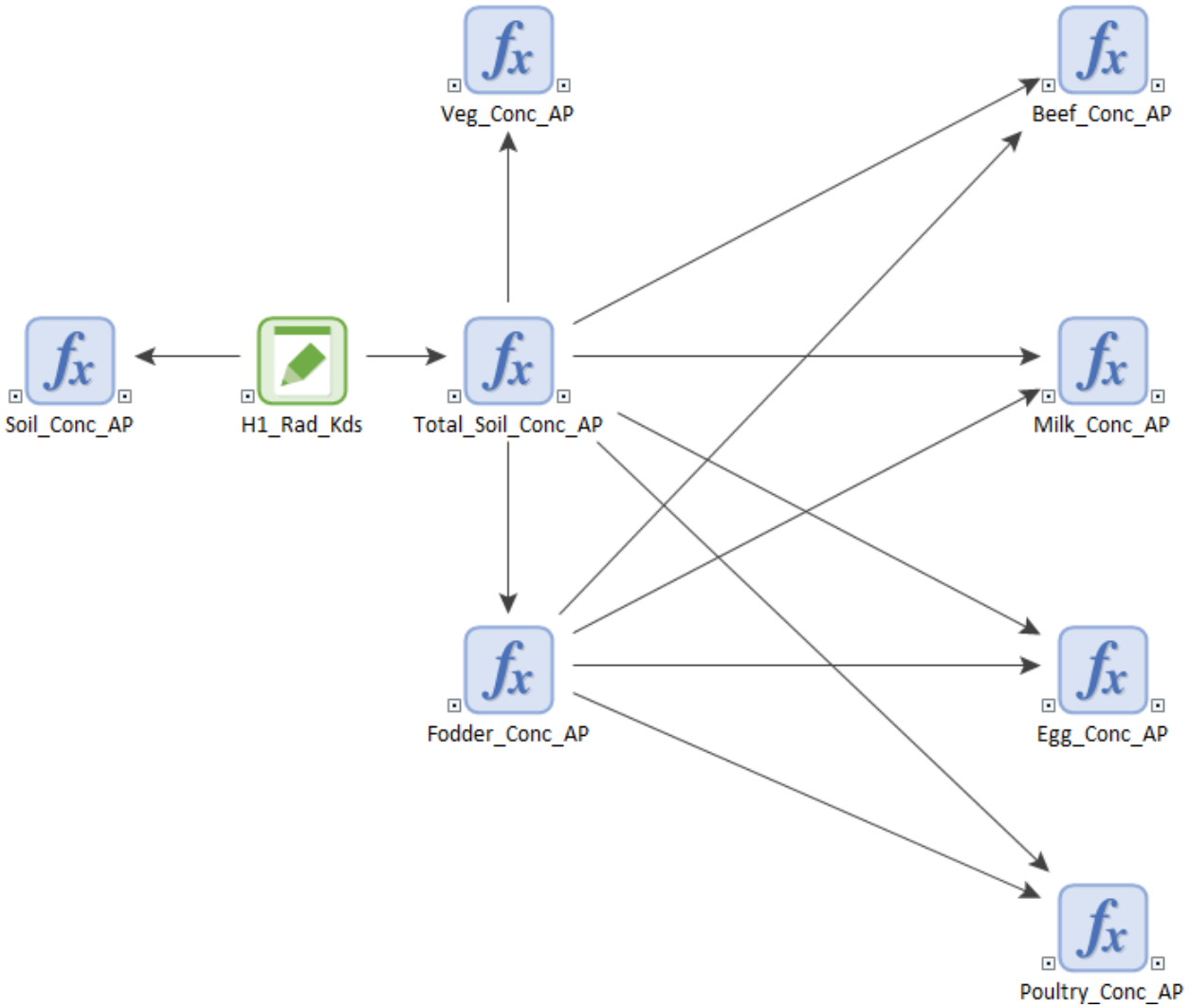


Figure 4-58. Calculation of Media Concentrations Used to Calculate Dose from Groundwater Concentration.



5.0 DISCUSSION OF UNCERTAINTY

Projections of environmental processes are inherently uncertain. Assessment of uncertainty in model results arising from assumptions and parameter values is necessary to support the determination that there is reasonable expectation of meeting the performance objectives. The objective of the uncertainty analysis is to estimate the plausible range of radionuclide dose that results from selecting parameter values within their uncertainty ranges. When a sufficient number of parameter combinations is evaluated over their plausible range, the calculated range of potential radionuclide dose can be used to quantify the uncertainty in the dose estimates. This analysis supports the demonstration of meeting the requirements of DOE M 435.1-1.

RPP-ENV-61482, *Input Parameter Uncertainties for the Performance Assessment of Waste Management Area A-AX Residual Wastes* provides the starting point for developing parameter uncertainty in the WMA A-AX system model. These uncertainty distributions may be refined to be more specific to WMA A-AX conditions in future work as new data become available.

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6.0 MODEL LIMITATIONS

The system model described in the report is developed specifically to evaluate the long-term impact of releases to the biosphere from residual waste in WMA A-AX tanks and ancillary equipment. The system model is developed for the site-specific conditions at WMA A-AX and should not be used for other tank farms without performing necessary adjustments/modification.

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7.0 MODEL CONFIGURATION MANAGEMENT

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.

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8.0 MODEL RECOMMENDATIONS

None at this time.

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APPENDIX A

KEY ASSUMPTIONS IN THE SYSTEM MODEL

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LIST OF TERMS

Abbreviations and Acronyms

BBI	Best-Basis Inventory
CCU	Cold Creek unit
CCUg	Cold Creek unit gravels
DOE	U.S. Department of Energy
HFFACO	Hanford Federal Facility Agreement and Consent Order
HSU	hydrostratigraphic unit
HTWOS	Hanford Tank Waste Operations Simulator
RCRA	Resource Conservation and Recovery Act of 1976
SST	single-shell tank
WMA	Waste Management Area

APPENDIX A

KEY ASSUMPTIONS IN THE SYSTEM MODEL

In this Appendix, a set of key assumptions used in the nominal case of the Waste Management Area (WMA) A-AX system model are listed.

FEATURES, EVENTS AND PROCESSES

- The landfill closure of WMA A-AX occurs in 2050, consistent with planning assumptions in the Tank Closure and Waste Management Environmental Impact Statement (DOE/EIS-0391, 2012, *Final Tank Closure and Waste Management Environmental Impact Statement for the Hanford Site, Richland, Washington*).

- The results of the modeling are not significantly affected by alternative assumptions about closure timing.

- The Central Plateau has been designated Industrial-Exclusive for the indefinite future, based on several Records of Decision [64 FR 61615, "Record of Decision: Hanford Comprehensive Land-Use Plan Environmental Impact Statement (HCP EIS)"; 73 FR 55824, "Amended Record of Decision for the Hanford Comprehensive Land-Use Plan Environmental Impact Statement"]. This area, which includes the 200 East and 200 West Areas, includes WMA A-AX. There is no stated intention to release the Central Plateau from this designation or from U.S. Department of Energy (DOE) control at any time in the future.

- The engineered cover for WMA A-AX is not yet designed but is assumed to be similar to the Modified *Resource Conservation and Recovery Act of 1976* (RCRA) Subtitle C Barrier that limits infiltration through the waste primarily by evapotranspiration processes (i.e., surface barrier) based on the work done for the Hanford Prototype barrier (DOE/RL-2016-37, *Prototype Hanford Barrier 1994 to 2015*). These processes are not modeled directly, but those processes have been studied through field measurements, tracer studies, and numerical models to estimate net infiltration (PNNL-14744, *Recharge Data Package for the 2005 Integrated Disposal Facility Performance Assessment*; PNNL-14960, *200-BP-1 Prototype Hanford Barrier Annual Monitoring Report for Fiscal Year 2004*; "Multiple-Year Water Balance of Soil Covers in a Semiarid Setting" [Fayer and Gee 2006]). Instead, the recommended net infiltration rates from those reports are applied to the area under the engineered cover and are varied spatially and temporally as appropriate according to the estimated or assumed time-dependent performance of a surface barrier.

- The modified RCRA Subtitle C barrier functions according to its design specifications for 500 years.

- A vegetation cover representative of natural conditions is assumed over the whole domain during the pre-operations period.

- During the construction and operations period, the following covers are assumed:

  - The undisturbed zone around the facility characterized by a native vegetation cover

  - The disturbed zone around the facility that has scant deep-rooted vegetation but extensive grass cover, combined with the resurfaced zone around the facility that has no vegetation cover

  - The tank farm zone where gravel backfill is kept free of vegetation.

- During the early post-closure period, the following covers are assumed:

  - The zone beneath the extent of the A Complex surface barrier that is designed to minimize infiltration of meteoric waters

  - The disturbed/resurfaced zone, outside the surface barrier, characterized by an artificially-introduced vegetation cover attempting to reclaim the surface with native vegetation species.

A.1 SOURCE TERM AND ENGINEERED FEATURES

A.1.1 Tank Source Conceptual Model

- WMA A-AX tanks (except for 241-A-104 [A-104] and 241-A-105 [A-105]) are assumed to be retrieved.

- WMA A-AX tanks are assumed to be filled with grout.

- The lower-bound estimate for the residual volume of waste remaining at closure is 10 kL (360 ft^3). This is the threshold goal for 100-series Single-Shell Tanks (SST) specified in the *Hanford Federal Facility Agreement and Consent Order* (HFFACO) (Ecology et al. 1989). The lower-bound estimate is assumed as a “best estimate” for the volume of residual waste for all SSTs except tanks A-104 and A-105.

- Due to the lack of characterization data on WMA A-AX residual waste, most of the residual waste characteristics are assumed to be same as for the WMA C residual waste.

- The unretrieved wastes are distributed uniformly throughout the bottom area of the waste source.

- Current Best-Basis Inventory (BBI) concentrations are used for tank inventory estimates due to lack of specific retrieval information.

- The grout remains intact for the length of the simulation.

- Steel components have degraded or will degrade rapidly and will not provide a long-term barrier to flow. No credit is taken for any geochemical safety function served by the presence of steel or its corrosion products.

- For conservatively accounting for presence of the drain slots in 241-AX Tank Farm (AX Farm) tanks, the underlying slab concrete layer thickness is assumed to be 15.5 in. (18 in. minus 2.5 in.).

A.1.2 Pipeline Source Conceptual Model

- The pipelines will not be grouted, and residual waste will be available for release to the surrounding environment due to advection (caused by infiltration water) and diffusion processes.

- The average thickness of the residual waste is 3 in. based on the predominant pipeline diameter present in 241-A Tank Farm (A Farm) and AX Farm.

- In pipelines and ancillary equipment, the residual waste is distributed in a homogeneous layer across WMA A-AX at the depth and area of the pipelines. The A Farm pipeline area represents approximately 11,032 m^2, with approximately 6,640 m^2 in the AX Farm pipeline area.

- Although some of the ancillary equipment may be grouted consistent with 78 FR 75913, it is assumed for the purpose of the analysis that none of the ancillary equipment is grouted, and the presence of pipeline walls and encasements is ignored, such that releases from ancillary equipment are primarily controlled by advection.

- The pipeline residual inventory is uniformly distributed with the bulk soil (backfill).

A.1.2.1 Grout

- The tanks are filled with grout according to the basic assumptions outlined for landfill closure in DOE/EIS-0391 (2012). The specific formulation of the grout has not yet been established, but consistent with DOE/EIS-0391 (2012), it is assumed the fill material for the tanks will be similar to the cold-cap grout formulation developed by the U.S. Army Corps of Engineers for the Hanford Grout Vault Program. This type of grout is assumed to behave chemically like ordinary cementitious material. It has been assumed that the grout formulation does not provide any specific or unusual chemical conditions, such as reducing conditions.

- The chemical effect of the grout is represented by contaminant-specific distributions of distribution coefficients (K_d), which have been developed from international literature on sorption of radionuclides on cementitious materials. These values are generally consistent with, or lower than, comparable values used for the facility-specific grout at

the Savannah River F and H tank farm performance assessments [WSRC-STI-2007-00369, *Hydraulic and Physical Properties of Tank Grouts and Base Mat Surrogate Concrete for FTF Closure* and WSRC-STI-2007-00607, *Chemical Degradation Assessment of Cementitious Materials for the HLW Tank Closure Project (U)*].

- Because the closed tanks are in the unsaturated zone, conditions are expected to be moderately oxidizing. When data are available to differentiate between oxidizing and reducing conditions, oxidizing conditions are assumed. This approach leads to selecting lower K_d values in the model.

- The selected K_d values are based on the assumption of $Ca(OH)_2$-saturated waters contacting the waste.

- Once the grout is cured, limited physical damage is expected since the tank structure is below ground and will be protected by lithostatic (overburden) pressure.

- Degradation due to freezing and thawing is not likely to be significant, due to depth of the tanks and ancillary equipment being below the freeze zone (deeper than 0.61 m [24 in.]).

- The geochemical conditions in the Hanford vadose zone are favorable for preventing concrete degradation. The Hanford soil pore waters are alkaline and are at or near saturation with calcite; therefore, any meaningful decalcification (acid attack) is unlikely.

- Grout is likely to provide a significant barrier to infiltrating water, thus limiting any water flow through the tank and thereby restricting the release from the residual waste to be diffusion-controlled.

- The presence of continuous water connections is assumed across the grout and concrete layers for the diffusive transport to occur in the aqueous phase.

A.1.2.2 Inventory

- No additional sample data has been obtained or waste transfers have occurred from the A Farm or AX Farm SSTs since October 1, 2016. Hence, these estimates are assumed to have remained unchanged through July 1, 2018.

- The upper-bound volume estimate and "best" volume estimate for tanks A-104 and A-105 is the pre-retrieval waste volume estimate. This estimate is highly unlikely for most of the SSTs because it assumes little or no retrieval of waste will occur. While retrieval methods and designs are selected with the intent to achieve the threshold goal or better, it is unknown how much of the existing waste will be retrieved. Consequently, "no retrieval" is the only defensible technical basis for a bounding estimate. No retrieval is a best estimate for tanks A-104 and A-105, because these tanks leaked from near the tank bottom and tank A-105 has a bulged bottom liner with waste predicted to be under

the liner. Retrieval methods for these tanks are being investigated, but retrieval without releasing additional waste to the soil will be difficult for both of these tanks and "no retrieval" could be a preferred alternative for closure.

- The Hanford Tank Waste Operations Simulator (HTWOS) model results were assumed to provide a minimum composition estimate for residual waste in the A Farm and AX Farm SSTs and best estimate for all of the SSTs except A-104 and A-105. This is because HTWOS assumes that soluble constituents are mobilized during the retrieval process and largely removed when waste is retrieved to the threshold goal. The HTWOS assumptions are located in HNF-SD-WM-SP-012, *Tank Farm Contractor Operation and Utilization Plan*.

- The BBI described in RPP-7625, *Guidelines for Updating Best-Basis Inventory* provides an upper-bound composition estimate for the residual waste in A Farm and AX Farm SSTs and is the best estimate for the residual waste composition in tanks A-104 and A-105. The BBI estimates the composition of waste currently in the tank. The BBI is conservative because, as shown for 241-C Tank Farm SSTs (RPP-RPT-42323, *Hanford C-Farm Tank and Ancillary Equipment Residual waste Inventory Estimates*), the composition of soluble constituents (e.g., ^{99}Tc) is expected to be reduced significantly after retrieval.

- The best estimate for residual waste concentrations in ancillary equipment in WMA A-AX is assumed to be represented by the average HTWOS concentration for waste residuals in the A Farm SSTs for ancillary equipment in A Farm and the average HTWOS concentration for the AX Farm SSTs for ancillary equipment in AX Farm. This simplifying assumption is made because:

    - Little analytical data is available for waste in ancillary equipment and the little radionuclide data available indicates that the radioactivity in the ancillary equipment is lower compared to radioactivity in the SSTs

    - Ancillary equipment was flushed, mobilizing soluble constituents similar to retrieval

    - Ancillary equipment received waste to or from many of the SSTs in a farm

    - Process history of waste types and volumes received by different ancillary equipment has not been developed and estimates would be highly uncertain.

- Waste in the catch tanks and 244-AR vault will be retrieved prior to closure (no specific goals or limits have been established for these facilities). Retrieval of 90% of the waste was assumed for these facilities. The upper-bound estimate is the pre-retrieval volume.

- Waste was or will be flushed from pits and diversion boxes and the primary residual waste remaining at closure will be limited to waste adsorbed to concrete surfaces with

waste penetration to a depth of 0.04 cm (0.0157 in.) (RPP-15043, *Single-Shell Tank System Description*).

- On average, waste transfer pipelines are 5% full of waste. RPP-RPT-58293, *Hanford 241-A and 241-AX Farm Tank and Ancillary Equipment Residual Waste Inventory Estimates* notes that cascade lines and plugged lines may contain more waste, but make up only a small fraction of the pipeline volume and would not change the rounded volume estimate. In addition, the length of pipelines estimated for RPP-RPT-58293 is biased high as it includes half the distance of pipelines extending beyond the WMA A-AX fence line. Overall, a 5% estimate is believed to be high.

- Progeny radionuclides with a half-life of less than two years are assumed to be in secular equilibrium with their parent, which allows a reduction in the number of species tracked but still accounts for the radiological effects of the progeny.

A.1.2.3 Release and Transport

- Radionuclide and chemical release mechanisms from the sources are assumed to occur by one of two mechanisms: (a) the entire inventory of the residual waste is assumed to be instantly available for release and transport out of the tanks, or (b) for uranium, a semi-empirical release function is applied based on leach tests performed on residual waste from WMA C.

- Saltcake waste will be preferentially dissolved during retrieval such that residual waste will have physical properties similar to sludge, but preferential retrieval of relatively soluble constituents is ignored in the base case SST inventories.

- Release from one WMA A-AX solute source and migration are independent of other solute transport and source terms in the mode.

- Release of radionuclides contained within the grouted residual waste in SSTs is controlled by the process of diffusion, and remains diffusive with no advection occurring through the tank during the simulated time period of 10,000 years.

- The impact of the varying size and shapes of waste material within the grouted tanks and ancillary equipment is ignored.

- Moisture flow within the grouted tanks and ancillary equipment is negligible.

- The drain slots in the concrete base of each AX Farm SST and the 12-in. pipe connecting the drain slots to a leak detection well will be sufficiently grouted as part of the closure process to prevent advective releases.

- Releases from ancillary equipment are combined into a single, uniformly-distributed release from an area surrounding the SSTs in each tank farm.

- Transport of contamination from the tanks is assumed to be primarily controlled by diffusion from the grouted tanks through the base mat below the tank.

A.1.2.4 Uranium Solubility

- Amphorous uranium mineral phases such as $Na_2U_2O_7$(am) control the solubility (at closure), with a solubility limit of 1×10^{-4} M.

- $CaUO_4$ is the solubility-controlling mineral phase under $Ca(OH)_2$ saturated conditions in the infill grout (1,000 years post-closure), resulting in a solubility limit of 1×10^{-6} M.

- Flow rates are fast enough to prevent equilibrium with the infill grout material and that the infiltrating water has properties similar to vadose zone pore water (saturated in $CaCO_3$) (when tank degrades), yielding a solubility limit of 1×10^{-4} M.

- Infiltrating water is saturated with $Ca(OH)_2$ (1,000 years after tank degrades), resulting in a solubility limit of 2×10^{-5} M.

A.1.3 Groundwater Transport

- The impact of the closure barrier on moisture flow is approximated by an assumed recharge rate into the facility.

- The design life of the cover is 500 years in the nominal case, following which the infiltration through the cover returns to the site-wide average infiltration rate for undisturbed soil.

- In the nominal case, the land use and land cover, including the barrier, remain shrub steppe indefinitely after closure.

- Impacts resulting from plausible climate change that may occur during the evaluation period do not adversely impact the performance of the surface or vadose zone as a barrier.

- Net infiltration through the thick, heterogeneous vadose zone in the 200 Areas dampens the effect of discrete events, and therefore episodic precipitation events can be replaced by an average annual recharge rate.

- The porous media continuum assumption (an extended form of Darcy's Law for vadose zone applications) and the soil relative permeability/saturation/capillary pressure relations provide the basis for vadose zone flow and transport modeling.

- The vadose zone is modeled as an aqueous-gas porous media system where flow and transport through the gas phase are assumed to be negligible.

- The hydrostratigraphy of the vadose zone is adequately represented by the delineation of equivalent homogeneous units for evaluating bulk (or mean) flow and contaminant transport.

- Vadose zone hydraulic property values upscaled from small- and micro-scale (sample) measurements apply to the field scale for the equivalent homogeneous units.

- The inclusion of moisture-dependent anisotropy functions allows the homogeneous hydrostratigraphic units (HSUs) to adequately approximate the effects of heterogeneity.

- Hydraulic property heterogeneity is assumed to be insignificant within geologic units. Hence, each geologic unit within the vadose zone is assigned upscaled, effective hydraulic properties.

- The linear isotherm (constant K_d model) captures the effective geochemical behavior of radionuclides along the subsurface transport pathway, and K_d values representative of intermediate impacts of waste releases on sediment sorption characteristics are sufficient for the analysis.

- The groundwater pathway calculations treat the entire space within the concrete shell as inactive space (unavailable for pore water flow) as long as the grout monolith remains intact.

- Features such as clastic dikes, sills, and tectonic structures that can allow water and contaminants to bypass vadose zone continuum fate and transport processes are not consequential to the analysis.

- Impacts resulting from plausible climate change that may occur during the evaluation period do not adversely impact the performance of the surface or vadose zone as a barrier.

- The mass flux from the vadose zone for each source term is transported to the aquifer assuming the vertical mass transport in the vadose zone stays within the footprint of the source area, ignoring any lateral dispersion.

- For the pipeline source areas, the aquifer pathway begins at the center of the A Farm area and the AX Farm area to account for some vadose zone contribution occurring earlier.

- For the pipeline sources, the source loading from the vadose zone to the aquifer is assumed to occur over the length of the pipeline source area along the flow path.

- The average aquifer pathway concentrations at the 100 m downgradient boundary are calculated for each source separately, by assuming that the mass within the defined one-dimensional aquifer stream tube configuration is diluted to account for dispersion using a dimensional adjustment factor derived to match process model simulations that account for dispersion.

- Post-closure groundwater flow beneath WMA A-AX is northwest to southeast. The justification for this assumption is found in RPP-RPT-60101, *Model Package Report Flow and Contaminant Transport Numerical Model Used in WMA A-AX Performance Assessment and RCRA Closure Analysis*. Groundwater flow parameters have been derived from the Central Plateau groundwater model (CP-47631, *Model Package Report: Central Plateau Groundwater Model Version 6.3.3*).

- The majority of groundwater flow below WMA A-AX is through the paleochannel region where gravels attributed to the Cold Creek Unit gravels (CCUg) unit have been reworked to much higher permeability than the Ringold Formation units below and downgradient of the CCUg.

- The parameterization for saturated media in the portion of the aquifer ~100 m surrounding WMA A-AX that is achieved via a large-scale multi-well pumping test elsewhere in the CCUg and a field-scale calibrated groundwater model is effective and appropriate for the scale of the calculations.

- The point of calculation used in the calculation of the groundwater concentrations corresponds to the location 100 m (328 ft) downgradient from the facility per DOE O 435.1, *Radioactive Waste Management*. For the purpose of calculating groundwater concentrations for comparison with groundwater protection requirements, it is necessary to identify the peak location in space at which the concentration occurs.

A.1.4 Atmospheric Transport

- 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.

- Residual wastes are assumed to have emanation properties comparable to soils.

- 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 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 will occur.

- Once volatile radionuclides reach the ground surface, a simplified Gaussian plume model with uniform velocity and atmospheric conditions is assumed for the air transport analysis.

A.1.5 Inadvertent Intruder

- The landfill closure of WMA A-AX occurs at year 2050.

- Institutional control and societal memory are retained for 100 years after the year of closure, based on the standard DOE O 435.1 requirement for inadvertent human intrusion.

- The only credible intrusion event is a drilling event. Both depth of disposal and the existence of concrete and grout intrusion barriers limit credible intrusion scenarios.

- Although results are provided for intrusion into individual SSTs, the most credible intrusion event is assumed to be into the ancillary equipment rather than a tank. This type of event is more credible than a tank intrusion, since the tank dome and grout form a substantial intruder protection barrier.

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

- The dose calculations are based on the residual radionuclide inventory after retrieval in WMA A-AX (considering radioactive decay and ingrowth), but ignoring any depletion due to transport of radionuclides from the waste site.

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

- Pipelines in WMA A-AX are not grouted and are 5% full of waste, evenly distributed throughout the pipeline.

- Acute exposures are limited to a well driller that is exposed to waste exhumed by the drill bit during the drilling.

- The acute exposure to the driller is calculated using representative local assumptions about the duration of the drilling; the well driller is assumed to be exposed to drill cuttings for a total of five days (8 hours per day for a total of 40 hours).

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

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

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

- Chronic post-intrusion exposures are calculated for several alternative exposure scenarios. In these scenarios, waste exhumed by the intrusion event is assumed to be mixed with a surface soil layer. In each scenario, the volume of soil in this layer represents the minimum area consistent with the assumed activities of the scenario. For instance, the residential garden scenario mixes the contamination in an area of a garden sufficient to grow vegetables, whereas the rural pasture scenario mixes the contamination in an area sufficient for cattle grazing. The effect of this assumption is that different post-intrusion chronic scenarios have different soil concentrations, and the relative importance of the scenarios is strongly dependent on the assumed area of contamination.

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

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

A.1.6 Exposure and Dose Modeling

A.1.6.1 All-Pathways

- Assumptions used in the exposure scenarios to define input parameter values are based on appropriate regulatory guidance as detailed in RPP-ENV-58813, *Exposure Scenarios for Risk and Performance Assessments in Tank Farms at the Hanford Site, Washington*. These values represent conservative inputs to the exposure scenario calculations characteristic of a highly exposed individual.

- Age- and gender-weighted intake rates are generally developed for a Representative Person in accordance with the recommendations described in DOE-STD-1196-2011, *Derived Concentration Technical Standard*. The 95th percentile intake rates were obtained from EPA/600/R-090/052F, *Exposure Factors Handbook: 2011 Edition, National Center for Environmental Assessment*, based on available information. Even though mean intake rates were available, the 95th percentile values from the underlying distribution were chosen conservatively to maximize the likely exposure. Typically, the 95th percentile intake rates weighted by age and gender are calculated (Appendix P of RPP-ENV-58813). The exceptions to this approach were the indoor inhalation rate (taken directly from a reference source) and the soil ingestion rates (where simple age weighting is performed for children and adults).

- At the end of the institutional control period, there will be no institutional constraints on where the receptor may reside, so a distance of 100 m from the WMA A-AX fence line is assumed.

- For the sake of adding exposures from groundwater and air pathways, the location of the peak dose from groundwater and from air are the same.

- The single-family farmer resides 100 m from the facility fence line and draws contaminated water from a well located 100 m from the facility fence line in the downgradient direction in the center of the saturated zone plume.

- The receptor receives dose from the following exposure routes:

    - Ingestion of water
    - Ingestion of garden vegetables grown on the farm
    - Ingestion of beef raised on the farm
    - Ingestion of milk from cows raised on fodder grown on the farm
    - Ingestion of eggs from poultry fed with fodder grown on the farm
    - Ingestion of poultry fed with fodder grown on the farm
    - Incidental ingestion of contaminated soil
    - Inhalation of contaminated soil (dust) in the air
    - Inhalation of water vapor
    - External exposure to radiation.

- The exposed individual uses the contaminated water to drink, shower, irrigate crops, and water livestock.

- Radionuclides concentration in soil calculation assumes that the irrigation water is in rapid equilibrium with the surface soil layer, which tends to overestimate the concentration in soil, in some cases significantly.

A.1.6.2 Air Pathway

- The following nine exposure routes are considered for the receptor residing 100 m downgradient of the facility fence line:

    - Air submersion
    - Inhalation of gaseous radionuclides
    - External exposure to contaminated soil
    - Incidental ingestion of contaminated soil
    - Consumption of crops grown on the farm
    - Ingestion of beef raised on the farm
    - Ingestion of milk from cows raised on fodder grown on the farm
    - Ingestion of eggs from poultry fed with fodder grown on the farm
    - Ingestion of poultry fed with fodder grown on the farm.

- Receptor is located at the closest location of an offsite receptor in the direction of the prevailing wind, about 20 km to the east southeast.

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APPENDIX B

PARAMETERS AND VALUES USED IN THE WASTE MANAGEMENT AREA A-AX SYSTEM MODEL

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APPENDIX B

PARAMETERS AND VALUES USED IN THE WASTE MANAGEMENT AREA A-AX SYSTEM MODEL

This appendix compiles the parameters in the Waste Management Area (WMA) A-AX system model, as called out in the text, and the values used for those parameters. Excluded are parameters that have already been presented in tables in the document. System model parameters that are subject to change (e.g., tank residual inventories) are not included here, but would be incorporated into the relevant Environmental Model Calculation Files.

Table B-1 contains single parameters (i.e., not tables of values) used in the WMA A-AX system model arranged by document section.

Table B-2 through Table B-6 are inadvertent intruder analysis-related parameters and values. Single parameters and the values used in the model are in Table B-2. Intruder Scenario-related dose conversion factors are in Table B-3, and related multipliers are in Table B-4. Table B-5 contains bioconcentration factors used in the inadvertent intruder analysis and Table B-6 contains radionuclide-specific shielding factors.

Table B-7 contains parameters and values used for the atmospheric pathway analysis.

Table B-1. Parameters Used in the Waste Management Area A-AX System Model. (3 sheets)

Parameter	Value	Units	GoldSim© Element Name	Reference
Section 3.2				
Bulk density of concrete base slab layer	2.41	g/cm^3	Grout_Bulk_Density	RPP-RPT-50934
Bulk density of intact grout	1.8	g/cm^3	Grout_Bulk_Density_Intact	WSRC-STI-2007-00369
Diameter of tanks (241-A Tank Farm)	75	ft	Diameter_A_Series_Tank	RPP-RPT-58693
Diameter of tanks (241-AX Tank Farm)	75	ft	Diameter_AX_Series_Tank	RPP-RPT-58693
Pipeline diameter	3	in	Pipe_Diameter	RPP-RPT-58293
Porosity in degraded tank	0.384	—[a]	Porosity_Deg_Tank	—
Porosity of concrete base slab layer	0.11	—	Grout_Concrete_Porosity	RPP-RPT-58693
Porosity of intact grout	0.269	—	Porosity_Intact_Tank_Grout	RPP-RPT-58693
Porosity of residual waste	0.4	—	Waste_Porosity	RPP-ENV-58782
Saturation of an intact tank	1	—	Saturation_Intact_Tank	RPP-RPT-58693
Saturation of concrete base slab layer	1	—	Grout_Concrete_Base_Sat	RPP-RPT-58693
Waste Saturation	1	—	Waste_Sat	RPP-RPT-58693
Section 3.5				
Earliest possible intrusion time into pipes	100	yr	Pipes_Intrusion_Time	RPP-ENV-58813
Earliest possible intrusion time into tanks	500	yr	Tanks_Intrusion_Time	RPP-ENV-58813
Surface barrier failure time	500	yr	Surface_Barrier_Failure_Time	RPP-ENV-58813
Section 4.2				
Chromium dissolved concentration limit	2,000	µg/L	Solubilities	Cantrell, et al. 2013
Effective diffusion coefficient in concrete	3E-8	cm^2/s	Grout_Diff_Coeff_Best	RPP-RPT-58693
Release rate of remaining fraction of Tc-99 (after instantaneous release)	6E-4	1/day	Tc99_WF_Deg_Rate_Best	RPP-RPT-58693

Table B-1. Parameters Used in the Waste Management Area A-AX System Model. (3 sheets)

Parameter	Value	Units	GoldSim© Element Name	Reference
Instant release fraction of ^{99}Tc from residual waste	1	—	Tc99_Instant_Rel_Frac_Best	RPP-RPT-58693
Uranium solubility limit (first 1,000 years)	1E-4	M	Solubilities	Cantrell, et al. 2013; Cantrell, et al. 2011
Uranium solubility limit (rest of simulation; intact tank)	1E-6	M	Solubilities	Cantrell, et al. 2013; Cantrell, et al. 2011
Uranium solubility limit (rest of simulation, degraded tank)	2E-5	M	Solubilities	Cantrell, et al. 2013; Cantrell, et al. 2011
Section 4.3				
Darcy flow rate (241-A Tank Farm)	45	m/yr	DF_Afarm	Section 4.3.1
Darcy flow rate (241-AX Tank Farm)	55	m/yr	DF_Axfarm	Section 4.3.1
H2 Sand unit dispersivity	0.25	m	H2_Dispersivity_Best	RPP-RPT-60101
Hydraulic conductivity for the CCUg gravel	18,200	m/day	K_Sat_SZ_Mode	RPP-RPT-60101
Hydraulic gradient in saturated zone	5E-6	m/m	SZ_Hyd_Gradient	RPP-RPT-60101
Longitudinal dispersivity in aquifer	10.5	m	SZ_Long_Disp_Best	RPP-RPT-60101
Saturated zone dispersivity	10.5	m	SZ_Dispersivity_Best	RPP-RPT-60101
Saturated zone hydraulic conductivity	18,200	m/day	SZ_Hyd_Cond	RPP-RPT-60101
Saturated zone porosity	0.25	—	SZ_Porosity	RPP-RPT-60101
Section 4.4				
Air content within the infill grout	0.06	—	Air_Content_Grouted_Tank	WSRC-TR-2005-00195
Binary diffusion coefficient of radon	0.11	cm^2s^{-1}	Rel_Air_Diff_Coeff	Nazaroff and Nero 1988
Diffusion length in tank	10	m	Tank_Diff_Length	Section 4.4.1
Gas-to-aqueous Henry's constant for ^{222}Rn	4.47	—	Kh_Gas_To_Aqueous	Calculated
Recharge rate (surface barrier – 0-500 years post-closure)	0.5	mm/yr	Base_Case_Recharge_Early_PC	RPP-RPT-60101

Table B-1. Parameters Used in the Waste Management Area A-AX System Model. (3 sheets)

Parameter	Value	Units	GoldSim© Element Name	Reference
Recharge rate (degraded surface barrier – 500+ years post-closure)	3.5	mm/yr	Base_Case_Recharge_Late_PC	RPP-RPT-60101
Backfill over tank waste	6	m	Soil_Thick	RPP-RPT-58693
Thickness of Soil above pipelines	6	m	Soil_Above_Pipe_Thick	RPP-RPT-58693

[a]Unitless.

[b]Including infill grout in the domespace, the dome concrete, and backfill sediments.

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WSRC-STI-2007-00369, 2007, *Hydraulic and Physical Properties of Tank Grouts and Base Mat Surrogate Concrete for FTF Closure*, Rev. 0, Savannah River National Laboratory, Aiken, South Carolina.

Table B-2. Inadvertent Intruder Scenario Parameters Used for Calculating Doses to Inadvertent Intruders at Waste Management Area A-AX. (4 sheets)

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

Table B-2. Inadvertent Intruder Scenario Parameters Used for Calculating Doses to Inadvertent Intruders at Waste Management Area A-AX. (4 sheets)

Parameter	Notation	Value	Unit	GoldSim Parameter Name
Tilled depth of rural pasture	Z_{rp}	15	cm	Tilled_Depth_RP
Soil ingestion rate – resident	$IR_{s,rp}$	100	mg/day	Soil_Ingestion_Rate_RP
Exposure frequency – resident	EF_{rp}	350	days/yr	Exposure_Frequency_RP
Milk ingestion rate	IR_m	155.96	L/yr	Milk_Ingestion_Rate_RP
Fraction of locally-produced dairy products that are consumed	F_a	1	unitless	Fraction_Of_Dairy_Consumed_RP
Water ingestion rate for dairy cattle	$IR_{w,d}$	92	L/day	Cattle_Water_Ingestion_Rate_RP
Soil ingestion rate for dairy cattle	$IR_{s,d}$	0.41	kg/day	Cattle_Soil_Ingestion_Rate_RP
Fodder ingestion rate for dairy cattle	$IR_{fodder,d}$	16.9	kg/day	Cattle_Fodder_Ingest_Rate_RP
Pasture-soil bioconcentration factor through uptake	B_p	Table B-5	(pCi/kg dry weight of crop)/ (pCi/kg dry weight of soil)	BCF_Uptake_FodderSoil
Pasture-soil bioconcentration factor from resuspension processes	B'_p	0.1	(pCi/kg dry weight of crop)/ (pCi/kg dry weight of soil)	Resuspension_FodderSoil_BCF_RP
Enrichment factor	E_f	0.7	unitless	Enrichment_Factor_RP
Indoor inhalation rate – resident	$INH_{in,r}$	7,300	m^3/yr	Indoor_Inhalation_Rate_RP
Mass loading factor	M	6.66E-05	g/m^3	Mass_Loading_Factor_RP
Fraction of time spent indoors – rural pasture	$ti_{n,rp}$	0.656	unitless	Indoor_Time_Fraction_RP
Outdoor inhalation rate – rural pasture	INH_{out_rp}	9,125	m^3/yr	Outdoor_Inhalation_Rate_RP
Fraction of time spent outdoors – rural pasture	t_{out}	0.16	unitless	Outdoor_Time_Fraction_RP
Ratio of radionuclide concentrations in indoor versus outdoor air	I/O	0.3	unitless	Indoor_Outdoor_Ratio_IN

Table B-2. Inadvertent Intruder Scenario Parameters Used for Calculating Doses to Inadvertent Intruders at Waste Management Area A-AX. (4 sheets)

Parameter	Notation	Value	Unit	GoldSim Parameter Name
Chronic Suburban Garden Intruder Scenario[f]				
Diameter of the well	D_{well}	16.51	cm	Well_Diameter_SG
Area of the well	A_{well}	214.08	cm^2	Well_Area_SG
Area of home construction lot (target field)	A_{tf}	25,000,000	cm^2	Target_Field_Area_SG
Tilled depth of garden	Z_g	15	cm	Tilled_Depth_SG
Soil ingestion rate – suburban garden	$IR_{s,sg}$	100	mg/day	Soil_Ingestion_Rate_SG
Exposure frequency – resident	EF_{sg}	350	day/yr	Exposure_Frequency_SG
Crop (fruit and vegetables) ingestion rate	I_{rc}	106.51	kg/yr	Veg_Ingestion_Rate_SG
Crop-soil bioconcentration factor from uptake	B_v	Table B-5	(pCi/kg fresh wt crop)/ (pCi/kg dry wt soil)	BCF_Uptake_VegSoil
Crop-soil bioconcentration factor from resuspension/soil adhesion	B'_v	0.004	(pCi/kg fresh wt crop)/ (pCi/kg dry wt soil)	Resuspension_VegSoil_BCF_SG
Fraction of locally-produced crop (fruit and vegetables) that is consumed	F_v	0.25	unitless	Fraction_Of_Veg_Consumed_SG
Enrichment factor	E_f	0.7	unitless	Enrichment_Factor_SG
Indoor inhalation rate – suburban garden	$INH_{in,sg}$	7,300	m^3/yr	Indoor_Inhalation_Rate_SG
Mass loading factor	M	6.66E-05	g/m^3	Mass_Loading_Factor_SG
Fraction of time spent indoors – suburban garden	$t_{in,sg}$	0.656	unitless	Indoor_Time_Fraction_SG
Outdoor inhalation rate – suburban garden	$INH_{out,sg}$	9,125	m^3/yr	Outdoor_Inhalation_Rate_SG
Fraction of time spent outdoors	$t_{out,sg}$	0.08	unitless	Outdoor_Time_Fraction_SG
Ratio of radionuclide concentrations in indoor versus outdoor air	I/O	0.3	unitless	Indoor_Outdoor_Ratio_IN

Table B-2. Inadvertent Intruder Scenario Parameters Used for Calculating Doses to Inadvertent Intruders at Waste Management Area A-AX. (4 sheets)

Parameter	Notation	Value	Unit	GoldSim Parameter Name
Chronic Commercial Farm Intruder Scenario[g]				
Area of the well	A_{well}	1,379.51	cm^2	Well_Diameter_CF
Diameter of the well	D_{well}	41.91	cm	Well_Area_CF
Area of commercial farm	A_{cf}	6.48E+09	cm^2	Target_Field_Area_CF
Tilled depth of commercial farm	Z_{cf}	15	cm	Tilled_Depth_CF
Soil ingestion rate – commercial farmer	$IR_{s,cf}$	100	mg/day	Soil_Ingestion_Rate_CF
Exposure frequency – commercial farmer	EF_{cf}	350	days/yr	Exposure_Frequency_CF
Enrichment factor	E_f	0.7	unitless	Enrichment_Factor_CF
Indoor inhalation rate – commercial farmer	$INH_{in,cf}$	7,300	m^3/yr	Indoor_Inhalation_Rate_CF
Mass loading factor	M	6.66E-05	g/m^3	Mass_Loading_Factor_CF
Fraction of time spent indoors – commercial farmer	$t_{in,cf}$	0	unitless	Indoor_Time_Fraction_CF
Outdoor inhalation rate – commercial farmer	$INH_{out,cf}$	10,950	m^3/yr	Outdoor_Inhalation_Rate_CF
Fraction of time spent outdoors – commercial farmer	$t_{out,cf}$	0.164	unitless	Outdoor_Time_Fraction_CF
Ratio of radionuclide concentrations in indoor versus outdoor air	I/O	0.3	unitless	Indoor_Outdoor_Ratio_IN

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

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

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

[d]RPP-ENV-58813, Table R-3.

[e]RPP-ENV-58813, Table R-4.

[f]RPP-ENV-58813, Table R-5.

[g]RPP-ENV-58813, Table R-6.

Table B-3. Dose Conversion Factors Used for Calculating Doses to Inadvertent Intruders at Waste Management Area A-AX[a]. (2 sheets)

Radionuclide	Inhalation[b] (mrem/pCi)	Ingestion[c] (mrem/pCi)	External Exposure Groundwater Pathway[d] (mrem/yr)/(pCi/g)
Ac-227	5.96E-01	1.45E-03	1.57E+00
Am-241	1.56E-01	8.81E-04	3.41E-02
Am-243	1.54E-01	8.73E-04	6.98E-01
C-14	8.21E-06	2.34E-06	1.05E-05
Cd-113m	4.33E-04	9.51E-05	5.06E-04
Cm-243	1.20E-01	6.66E-04	4.55E-01
Cm-244	1.01E-01	5.59E-04	9.83E-05
Co-60	4.14E-05	2.03E-05	1.27E+01
Cs-137	1.70E-05	4.92E-05	2.66E+00
Eu-152	3.67E-04	6.44E-06	5.47E+00
Eu-154	4.26E-04	9.66E-06	5.99E+00
Eu-155	5.11E-05	1.67E-06	1.42E-01
H-3	1.97E-07	7.77E-08	0.00E+00
I-129	1.50E-04	4.48E-04	1.01E-02
Nb-93m	2.26E-06	6.59E-07	8.12E-05
Ni-59	5.48E-07	2.95E-07	0.00E+00
Ni-63	2.01E-06	7.33E-07	0.00E+00
Np-237	8.51E-02	4.63E-04	8.57E-01
Pa-231	8.77E-01	2.07E-03	1.49E-01
Pb-210	4.48E-03	3.77E-03	4.76E-03
Pu-238	1.72E-01	9.73E-04	1.18E-04
Pu-239	1.86E-01	1.07E-03	2.30E-04
Pu-240	1.86E-01	1.07E-03	1.14E-04
Pu-241	3.31E-03	1.93E-05	4.61E-06
Pu-242	1.77E-01	1.01E-03	9.99E-05
Ra-226	1.41E-02	1.68E-03	2.48E-02
Ra-228	1.14E-02	5.92E-03	1.26E+01
Rn-222	0.00E+00	0.00E+00	8.70E+00
Se-79	6.22E-06	1.73E-05	1.45E-05

Table B-3. Dose Conversion Factors Used for Calculating Doses to Inadvertent Intruders at Waste Management Area A-AX[a]. (2 sheets)

Radionuclide	Inhalation[b] (mrem/pCi)	Ingestion[c] (mrem/pCi)	External Exposure Groundwater Pathway[d] (mrem/yr)/(pCi/g)
Sm-151	3.64E-05	5.00E-07	7.68E-07
Sn-126	6.14E-04	2.36E-05	9.25E+00
Sr-90	1.45E-04	1.33E-04	1.92E-02
Tc-99	1.64E-05	3.33E-06	9.80E-05
Th-229	2.79E-01	2.25E-03	1.24E+00
Th-230	5.44E-02	9.36E-04	9.43E-04
Th-232	9.47E-02	1.03E-03	4.07E-04
U-232	3.19E-02	1.49E-03	7.96E+00
U-233	1.44E-02	2.23E-04	1.09E-03
U-234	1.41E-02	2.15E-04	3.13E-04
U-235	1.25E-02	2.03E-04	5.91E-01
U-236	1.29E-02	2.02E-04	1.68E-04
U-238	1.16E-02	1.94E-04	8.89E-02
Zr-93	3.34E-05	3.70E-06	0.00E+00

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

[b]GoldSim© element name: DCF_Inhalation_1.

[c]GoldSim© element name: DCF_Ingestion_1.

[d]GoldSim© element name: DCF_ExternalExoposure.

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Table B-4. Dose Conversion Factor Multipliers Used for Calculating Doses to Inadvertent Intruders at Waste Management Area A-AX[a].

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

[a]RPP-CALC-61254, *Inadvertent Intruder Dose Calculation Update for the Integrated Disposal Facility Performance Assessment.*

[b]GoldSim© element name: Air_Inhalation_DCF_mult.

[c]GoldSim© element name: Water_Ingestion_DCF_mult.

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

Table B-5. Bioconcentration Factors Used for Calculating Inadvertent Intruder Doses at Waste Management Area A-AX[a]. (2 sheets)

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

Table B-5. Bioconcentration Factors Used for Calculating Inadvertent Intruder Doses at Waste Management Area A-AX[a]. (2 sheets)

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

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

[b]GoldSim© element name: BCF_Uptake_FodderSoil.

[c]GoldSim© element name: BCF_Uptake_VegSoil.

[d]GoldSim© element name: BCF_milk.

[e] NCRP Report No. 129, *Recommended Screening Limits for Contaminated Surface Soil and Review of Factors Relevant to Site-Specific Studies*

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Table B-6. Radionuclide-Specific Shielding Factors Used in Calculating Inadvertent Intruder Doses at Waste Management Area A-AX[a].

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

[a]RPP-ENV-58813, *Exposure Scenarios for Risk and Performance Assessments in Tank Farms at the Hanford Site, Washington*, Table N-4.
[b]GoldSim© element name: Shielding_Factor_AP.

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Table B-7. 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	2.41	g/cm^3	Grout_Bulk_Density	RPP-RPT-58693, Table 5-4
Partitioning coefficient	K_d	0	mL/g	Grout_Air.Partition Coefficients	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 (A Farm)	ρ	2.15	g/cm^3	Soil_Bulk_Density_A	RPP-RPT-60101, Table B-8
Bulk density (AX Farm)	ρ	1.67	g/cm^3	Soil_Bulk_Density_AX	RPP-RPT-60101, Table B-8
Gas Tortuosity in Grout[b]					
The 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
Total porosity (soil) – 241-AX Tank Farm	ϕ	0.384	unitless	Soil_Porosity_AX	RPP-RPT-60101, Table 3-2

Table B-7. Parameters Used for Calculating Radon Flux at Waste Management Area A-AX. (2 sheets)

Parameter	Notation	Value	Unit	GoldSim© Parameter Name	Reference
Fitted total porosity	Φ	0.8	unitless	Not applicable[c]	RPP-RPT-60885, Section 4.4.3

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

[b]RPP-RPT-60885, 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, Equation 4-5.

References:
RPP-CALC-63164, *WMA A-AX Performance Assessment Contaminant Fate and Transport Process Model to Evaluate Impacts to Groundwater*.
RPP-RPT-58693, *Engineered System Data Package for Waste Management Area A-AX*.
RPP-RPT-60101, *Model Package Report Flow and Contaminant Transport Numerical Model used in WMA A-AX Performance Assessment and RCRA Closure Analysis*.

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Subsurface Transport Over Multiple Phases (STOMP) has been developed and distributed by Battelle Memorial Institute.

Table B-8. Parameters Used for Calculating All Pathways Dose at Waste Management Area A-AX.

Parameter	Notation	Value	Unit	GoldSim© Parameter Name	Reference
Enrichment factor	E_f	0.7	unitless	Enrichment_Factor_AP	RPP-ENV-58813, Table P-2
Exposure frequency	EF	350	days/yr	Exposure_Frequency_AP	RPP-ENV-58813, Table P-2
Soil moisture content	θw	0.06	unitless	Water_Content_AP	RPP-ENV-58813, Section O.9.1
Fraction of locally-produced animal products (beef, dairy, poultry, eggs) that is consumed	F_a	1	unitless	Animal_Fraction_AP	RPP-ENV-58813, Table P-2
Fraction of locally-produced crops (fruits and vegetables) that are consumed	F_v	0.25	unitless	Veg_Fraction_AP	RPP-ENV-58813, Table P-2
Ratio of radionuclide concentrations in indoor versus outdoor air	I/O	0.3	unitless	Indoor_Outdoor_Ratio	RPP-ENV-58813, Table P-2
Inhalation rate – indoors	INH_{in}	7300	m^3/yr	Indoor_Inhalation_Rate_AP	RPP-ENV-58813, Table P-2
Inhalation rate – outdoors	INH_{out}	12775	m^3/yr	Outdoor_Inhalation_Rate_AP	RPP-ENV-58813, Table P-2
Inhalation rate – water vapor	INH_w	20	m^3/day	InhalationRate_WV	RPP-ENV-58813, Table P-2
Bioconcentration factor from resuspension/soil adhesion for fodder	B'_p	0.1	(pCi/kg dry weight of fodder)/ (pCi/kg dry weight of soil)	Resuspension_FodderSoil_BCF_AP	RPP-ENV-58813, Table O-2
Crop-soil bioconcentration factor from all resuspension/soil adhesion processes	B'_v	0.004	(pCi/kg dry weight of crop)/ (pCi/kg dry weight of soil)	Resuspension_VegSoil_BCF_AP	RPP-ENV-58813, Table O-2
Beef ingestion rate	IR_b	101.9	kg/yr	Beef_Ingestion_Rate_AP	RPP-ENV-58813, Table P-2
Crop ingestion rate (includes fruits and vegetables)	IR_c	272.3	kg/yr	Veg_Ingestion_Rate_AP	RPP-ENV-58813, Table P-1
Egg ingestion rate	IR_e	40.5	kg/yr	Egg_Ingestion_Rate_AP	RPP-ENV-58813, Table P-2
Fodder ingestion rate for beef	$IR_{fodder,b}$	11.77	kg/day	Beef_Ingestion_Rate_AP	RPP-ENV-58813, Table O-2
Fodder ingestion rate for dairy cattle	$IR_{fodder,d}$	16.9	kg/day	Milk_Fodder_Ingestion_Rate_AP	RPP-ENV-58813, Table O-2
Fodder ingestion rate for poultry	$IR_{fodder,p}$	0.2	kg/day	Poultry_Fodder_Ingest_Rate_AP	RPP-ENV-58813, Table O-2
Milk ingestion rate	IR_m	311.3	L/yr	Milk_Ingestion_Rate_AP	RPP-ENV-58813, Table P-2
Poultry ingestion rate	IR_p	99.4	kg/yr	Poultry_Ingestion_Rate_AP	RPP-ENV-58813, Table P-1
Soil ingestion rate	IR_s	108.6	mg/day	Soil_Ingestion_Rate_AP	RPP-ENV-58813, Table P-1
Soil ingestion rate for beef	$IR_{s,b}$	0.39	kg/day	Beef_Soil_Ingestion_Rate_AP	RPP-ENV-58813, Table O-2
Soil ingestion rate for dairy cattle	$IR_{s,d}$	0.41	kg/day	Milk_Soil_Ingestion_Rate_AP	RPP-ENV-58813, Table O-2
Soil ingestion rate for poultry	$IR_{s,p}$	0.022	kg/day	Poultry_Soil_Ingest_Rate_AP	RPP-ENV-58813, Table O-2
Drinking water ingestion rate	IR_w	2.66	L/day	Water_Ingestion_Rate_AP	RPP-ENV-58813, Table P-1
Water ingestion rate for beef	$IR_{w,b}$	53	L/day	Beef_Water_Ingestion_Rate_AP	RPP-ENV-58813, Table O-2
Water ingestion rate for dairy cattle	$IR_{w,d}$	92	L/day	Milk_Water_Ingestion_Rate_AP	RPP-ENV-58813, Table O-2
Water ingestion rate for poultry	$IR_{w,p}$	1	L/day	Poultry_Water_Ingest_Rate_AP	RPP-ENV-58813, Table O-2
Andelman Volatilization Factor	K	0.5	L/m^3	Volatilization_factor	RPP-ENV-58813, Table P-2
Mass loading factor	M	6.66E-5	g/m^3	Mass_Loading_Factor_AP	RPP-ENV-58813, Table P-2
Fraction of time spent indoors	t_{in}	0.4	Unitless	Indoor_Time_Fraction_AP	RPP-ENV-58813, Table P-2
Fraction of time spent outdoors	t_{out}	0.486	Unitless	Outdoor_Time_Fraction_AP	RPP-ENV-58813, Table P-2

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

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Table B-9. Bioconcentration Factors Used for Calculating All Pathway Doses at Waste Management Area A-AX.[ab] (2 sheets)

Radionuclide	Beef (BCF_{beef})[c] (day/kg)	Poultry ($BCF_{poultry}$)[d] (day/kg)	Egg (BCF_{egg})[e] (day/kg)
Ac-227	2.00E-05	4.00E-03	2.00E-03
Am-241	5.00E-05	6.00E-03	9.00E-03
Am-243	5.00E-05	6.00E-03	9.00E-03
C-14	4.89E-02	4.16E+00	3.12E+00
Cd-113m	1.00E-03	1.70E+00	1.00E-01
Cm-243	2.00E-05	4.00E-03	2.00E-03
Cm-244	2.00E-05	4.00E-03	2.00E-03
Co-60	3.00E-02	9.70E-01	3.30E-02
Cs-137	5.00E-02	2.70E+00	4.00E-01
Eu-152	2.00E-03	4.00E-03	7.00E-03
Eu-154	2.00E-03	4.00E-03	7.00E-03
Eu-155	2.00E-03	4.00E-03	7.00E-03
H-3	3.36E+01	3.36E+01	3.36E+01
I-129	4.00E-02	8.70E-03	2.40E+00
Nb-93m	1.00E-06	3.00E-04	1.00E-03
Ni-59	5.00E-03	1.00E-03	1.00E-01
Ni-63	5.00E-03	1.00E-03	1.00E-01
Np-237	1.00E-03	4.00E-03	2.00E-03
Pa-231	5.00E-06	4.00E-03	2.00E-03
Pb-210	8.00E-04[f]	2.00E-01[g]	8.00E-01[g]
Pu-238	1.00E-04	3.00E-03	8.00E-03
Pu-239	1.00E-04	3.00E-03	8.00E-03
Pu-240	1.00E-04	3.00E-03	8.00E-03
Pu-241	1.00E-04	3.00E-03	8.00E-03
Pu-242	1.00E-04	3.00E-03	8.00E-03
Ra-226	1.00E-03	3.00E-02	2.00E-05
Ra-228	1.00E-03	3.00E-02	2.00E-05
Rn-222	0.00+00	0.00+00	0.00+00
Se-79	1.00E-01	9.70E+00	1.60E+01

Table B-9. Bioconcentration Factors Used for Calculating All Pathway Doses at Waste Management Area A-AX.[ab] (2 sheets)

Radionuclide	Beef (BCF_{beef})[c] (day/kg)	Poultry ($BCF_{poultry}$)[d] (day/kg)	Egg (BCF_{egg})[e] (day/kg)
Sm-151	2.00E-03	4.00E-03	7.00E-03
Sn-126	1.00E-02	2.00E-01	8.00E-01
Sr-90	1.00E-02	2.00E-02	3.50E-01
Tc-99	1.00E-04	3.00E-02	3.00E+00
Th-229	1.00E-04	4.00E-03	2.00E-03
Th-230	1.00E-04	4.00E-03	2.00E-03
Th-232	1.00E-04	4.00E-03	2.00E-03
U-232	8.00E-04	1.20E+00	9.90E-01
U-233	8.00E-04	1.20E+00	9.90E-01
U-234	8.00E-04	1.20E+00	9.90E-01
U-235	8.00E-04	1.20E+00	9.90E-01
U-236	8.00E-04	1.20E+00	9.90E-01
U-238	8.00E-04	1.20E+00	9.90E-01
Zr-93	1.00E-06	6.00E-05	2.00E-04

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

[b]Fodder and Grass (B_p), Vegetables, Fruit and Grain (B_v) and Milk (BCF_{milk}) bioconcentration values are contained in Table B-5.

[c]GoldSim© element name: BCF_Beef.

[d]GoldSim© element name: BCF_Poultry.

[e]GoldSim© element name: BCF_egg.

[f]NCRP Report No. 129, *Recommended Screening Limits for Contaminated Surface Soil and Review of Factors Relevant to Site-Specific Studies*

[g]NUREG/CR-5512, *Residual Radioactive Contamination from Decommissioning: Technical Basis for Translating Contamination Levels to Annual Total Effective Dose Equivalent*

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APPENDIX C

K_d ESTIMATES USED IN THE WASTE MANAGEMENT AREA A-AX PERFORMANCE ASSESSMENT MODELS

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LIST OF TERMS

Abbreviations and Acronyms

CLARC	Cleanup Levels and Risk Calculation
PNNL	Pacific Northwest National Laboratory
WMA	Waste Management Area

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APPENDIX C

K_d ESTIMATES USED IN THE WASTE MANAGEMENT AREA A-AX PERFORMANCE ASSESSMENT MODELS

Table C-**1** gives the complete list of sand K_d values used in the Waste Management Area (WMA) A-AX system model with their references. Table C-2 gives the complete list of silt K_d values used in the WMA A-AX system model with their references. Table C-3 gives the complete list of grout and concrete K_d values used in the WMA A-AX system model with their references. All three tables include the minimum and maximum values applicable to the uncertainty analysis distribution.

Table C-1. K_d Value Estimates (mL/g) for Sand in the Waste Management Area A-AX Performance Assessment Models. (2 sheets)

Contaminant	Most Likely[a]	Minimum[b]	Maximum[c]	Basis
Ac	350	100	1,500	PNNL-16663 Table C.5
Al	1,500	1,500	1,500	RPP-RPT-46088
Am	600	200	2,000	PNNL-17154 Table A.4
B	3	3	3	RPP-RPT-46088
C-14	1	0	100	PNNL-17154 Table A.4
Cd	6.7	6.7	6.7	CLARC
Cm	350	100	1,500	PNNL-16663 Table C.5
CN	0	0	0	RPP-RPT-46088
Co	0	0	10	PNNL-17154 Table A.4
Cr(VI)	0	0	3	PNNL-17154 Table A.4
Cs	100	10	1,000	PNNL-17154 Table A.4
Eu	10	3	100	PNNL-17154 Table A.4
F	0	0	1	PNNL-17154 Table A.4
Fe	25	25	25	RPP-RPT-46088
H-3	0	0	0	PNNL-17154 Table A.4
Hg	52	52	100	CLARC; RPP-ENV-58782 Table 8-6
I	0.2	0	2	PNNL-17154 Table A.4
Mn	65	65	65	RPP-RPT-46088
Nb	0	0	0.1	PNNL-16663 Table C.5
Ni	3	1	20	PNNL-17154 Table A.4

Table C-1. K_d Value Estimates (mL/g) for Sand in the Waste Management Area A-AX Performance Assessment Models. (2 sheets)

Contaminant	Most Likely[a]	Minimum[b]	Maximum[c]	Basis
NO_2	0	0	0.1	PNNL-17154 Table A.4
NO_3	0	0	0.1	PNNL-17154 Table A.4
Np	10	2	30	PNNL-17154 Table A.4
Pa	10	2	30	Assume analogue to Np
Pb	10	3	100	PNNL-17154 Table A.4
Pu	600	200	2,000	PNNL-17154 Table A.4
Ra	10	5	20	PNNL-17154 Table A.4
Rn	0	0	0	No relevant information; RPP-ENV-58782 Table 8-6
Se	0.1	0	3	PNNL-17154 Table A.4
Sm	10	3	100	RPP-ENV-58782 Table 8-6
Sn	0.5	0	20	PNNL-17154 Table A.4
Sr	10	5	20	PNNL-17154 Table A.4
Tri-butyl Phosphate	1.89	1.89	1.89	RPP-RPT-46088
Tc	0	0	0.1	PNNL-16663 Table C.5
Th	300	40	500	PNNL-16663 Table C.5
U	0.6	0.2	2	RPP-RPT-46088
Zr	300	40	500	PNNL-16663 Table C.5

[a]GoldSim© element name: Kd_Sand_Best.

[b]GoldSim© element name: Kd_Sand_Min.

[c]GoldSim© element name: Kd_Sand_Max.

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RPP-RPT-46088, *Flow and Transport in the Natural System at Waste Management Area C*.

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Table C-2. K_d Value Estimates (mL/g) for Silt in the Waste Management Area A-AX Performance Assessment Models. (2 sheets)

Contaminant	Most Likely[a]	Minimum[b]	Maximum[c]	Basis
Ac	350	100	1,500	Assumes sand fraction values apply
Al	1,500	1,500	1,500	Assumes sand fraction values apply
Am	600	200	2,000	PNNL-17154 Table A.5
B	3	3	3	Assumes sand fraction values apply
C-14	1	0	100	PNNL-17154 Table A.5
Cd	6.7	6.7	6.7	Assumes sand fraction values apply
Cm	350	100	1,500	Assumes sand fraction values apply
CN	0	0	0	Assumes sand fraction values apply
Co	0	0	30	PNNL-17154 Table A.5
Cr(VI)	0	0	10	PNNL-17154 Table A.5
Cs	100	30	3,000	PNNL-17154 Table A.5
Eu	30	10	300	PNNL-17154 Table A.5
F	0.05	0	1	PNNL-17154 Table A.5
Fe	25	25	25	Assumes sand fraction values apply
^3H	0	0	0	Assumes sand fraction values apply
Hg	52	52	100	Assumes sand fraction values apply
I	0.2	0	2	PNNL-17154 Table A.5
Mn	65	65	65	Assumes sand fraction values apply
Nb	0	0	0.1	Assumes sand fraction values apply
Ni	10	3	60	PNNL-17154 Table A.5
NO_2	0	0	0.1	PNNL-17154 Table A.5
NO_3	0	0	0.1	PNNL-17154 Table A.5
Np	10	2	50	PNNL-17154 Table A.5
Pa	10	2	50	Assume analogue to Np
Pb	30	10	300	PNNL-17154 Table A.5
Pu	600	200	2,000	PNNL-17154 Table A.5
Ra	10	5	60	PNNL-17154 Table A.5
Rn	0	0	0	Assumes sand fraction values apply
Se	0.3	0	10	PNNL-17154 Table A.5
Sm	10	3	100	Assumes sand fraction values apply

Table C-2. K_d Value Estimates (mL/g) for Silt in the Waste Management Area A-AX Performance Assessment Models. (2 sheets)

Contaminant	Most Likely[a]	Minimum[b]	Maximum[c]	Basis
Sn	1.5	0	60	PNNL-17154 Table A.5
Sr	10	5	60	PNNL-17154 Table A.5
Tri-butyl Phosphate	1.89	1.89	1.89	Assumes sand fraction values apply
Tc	0	0	0.1	Assumes sand fraction values apply
Th	300	40	500	Assumes sand fraction values apply
U	0.6	0.2	2	Assumes sand fraction values apply
Zr	300	40	500	Assumes sand fraction values apply

[a]GoldSim© element name: Kd_Silt_Best.
[b]GoldSim© element name: Kd_Silt_Min.
[c]GoldSim© element name: Kd_Silt_Max.

Reference: PNNL-17154, *Geochemical Characterization Data Package for the Vadose Zone in the Single-Shell Tank Waste Management Areas at the Hanford Site*.

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Table C-3. K_d Values (mL/g) for Grout/Concrete Used for Waste Management Area A-AX Performance Assessment. (2 sheets)

Element	Minimum[a]	Best[bc]	Maximum[d]	Basis
Ac	30,300	100,000	330,000	NAGRA NTB 02-20
Al	0	0	0	No relevant information
Am	200	1,000	5,000	SKB R-05-75
B	0	0	0	No relevant information
C	10	200	4,000	SKB R-05-75
Cd	2	40	800	SKB R-05-75
Cm	200	1,000	5,000	SKB R-05-75
CN	0	0	0	No relevant information
Co	4	40	400	SKB R-05-75
Cr	0	0	0	No relevant information
Cs	0.1	1	10	SKB R-05-75
Eu	1,000	5,000	25,000	SKB R-05-75
F	0	0	0	No relevant information
Fe	0	0	0	No relevant information
H	0.0714	0.1	0.14	NAGRA NTB 02-20
Hg	0	0	0	No relevant information
I	0.3	3	30	SKB R-05-75
Mn	0	0	0	No relevant information
Nb	100	500	25,000	SKB R-05-75
Ni	8	40	200	SKB R-05-75
NO2	0	0	0	No relevant information
NO3	0	0	0	No relevant information
Np	71.4	100	140	NAGRA NTB 02-20
Pa	71.4	100	140	NAGRA NTB 02-20
Pb	360	500	710	NAGRA NTB 02-20
Pu	71.4	100	140	NAGRA NTB 02-20
Ra	5	50	500	SKB R-05-75
Rn	0	0	0	No relevant information
Se	0.1	6	400	SKB R-05-75
Sm	1,000	5,000	25,000	SKB R-05-75

Table C-3. K_d Values (mL/g) for Grout/Concrete Used for Waste Management Area A-AX Performance Assessment. (2 sheets)

Element	Minimum[a]	Best[bc]	Maximum[d]	Basis
Sn	25	500	10,000	SKB R-05-75
Sr	0.5	1	50	SKB R-05-75
TBP	0	0	0	No relevant information
Tc	0.714	1	1.4	NAGRA NTB 02-20
Th	1,000	30,000	1,000,000	NIROND-TR 2008-23 E
U	1,430	2,000	2,800	NAGRA NTB 02-20
Zr	3,030	10,000	33,000	NAGRA NTB 02-20

[a]GoldSim© element name: Kd_Grout_Min.

[b]The best estimate value is used for deterministic calculations.

[c]GoldSim© element name: Kd_Grout_Best.

[d]GoldSim© element name: Kd_Grout_Max.

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

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APPENDIX D

STOMP PROCESS MODEL OUTPUTS USED IN THE WASTE MANAGEMENT AREA A-AX SYSTEM MODEL GROUNDWATER PATHWAY IMPLEMENTATION

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LIST OF TERMS

Abbreviations and Acronyms

STOMP	Subsurface Transport Over Multiple Phases
PNNL	Pacific Northwest National Laboratory
WMA	Waste Management Area

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APPENDIX D

STOMP PROCESS MODEL OUTPUTS USED IN THE WASTE MANAGEMENT AREA A-AX SYSTEM MODEL GROUNDWATER PATHWAY IMPLEMENTATION

Table D-1 contains the Darcy flow rate output over time for selected STOMP[1] nodes representing different vertical locations under the intact tank 241-A-102. Table D-2 presents the moisture content for the same STOMP nodes. This flow field is applied to model the transport underneath the 241-A Farm tanks. The representative flow fields for 241-A Farm Non-Tank sources are presented in Table D-3 and Table D-4. The representative flow field underneath an intact 241-AX Farm tank is presented in Table D-5 and Table D-6. The representative flow fields for 241-AX Farm Non-Tank sources are presented in Table D-7 and Table D-8.

Table D-1. Representative Flow Field Applied Under Tank 241-A-102: Darcy Flow Rate. (2 sheets)

Year	Node_24	Node_33	Node_37	Node_44	Node_69	Node_102	Node_103	Node_104
0	97.4628	96.6832	97.4298	97.6094	94.5930	34.7454	23.2439	8.3607
0.001	97.4628	96.6832	97.4298	97.6094	94.5930	34.7454	23.2439	8.3607
0.5	97.4625	96.6832	97.4298	97.6094	94.5930	34.6152	23.1135	8.3016
1	97.4627	96.6832	97.4298	97.6094	94.5930	32.6155	21.5209	7.6677
3	97.4627	96.6827	97.4289	97.6068	93.9709	19.6513	12.8139	4.5453
5	97.3856	96.5144	97.1784	97.1331	85.8730	13.0933	8.6108	3.0783
7	96.1814	94.5250	94.6032	93.4048	71.7514	9.6895	6.4279	2.3144
10	88.5314	84.7434	83.4495	80.3657	53.3500	6.9266	4.6447	1.6868
15	68.2917	63.3961	61.3364	57.8648	35.1865	4.6802	3.1805	1.1672
20	52.0605	47.7847	45.9003	43.0348	25.5384	3.5337	2.4253	0.8970
25	41.0074	37.5005	35.9020	33.5944	19.7785	2.8416	1.9659	0.7316
30	33.3833	30.5040	29.1519	27.2640	16.0113	2.3802	1.6577	0.6201
40	23.7728	21.7684	20.7713	19.4299	11.4128	1.8017	1.2686	0.4785
50	18.1192	16.6550	15.8867	14.8724	8.7575	1.4575	1.0356	0.3933
70	11.9334	11.0618	10.5598	9.9053	5.8706	1.0740	0.7744	0.2973
100	7.6212	7.1438	6.8353	6.4317	3.8513	0.8032	0.5893	0.2290
130	5.4747	5.1771	4.9653	4.6861	2.8354	0.6709	0.4989	0.1957
160	4.2171	4.0152	3.8593	3.6525	2.2339	0.5972	0.4488	0.1772
200	3.1912	3.0598	2.9481	2.8000	1.7391	0.5425	0.4118	0.1636
250	2.4214	2.3367	2.2569	2.1527	1.3664	0.5073	0.3883	0.1551
300	1.9380	1.8792	1.8187	1.7419	1.1336	0.4896	0.3765	0.1508
400	1.3762	1.3436	1.3044	1.2600	0.8709	0.4751	0.3670	0.1474

[1] Subsurface Transport Over Multiple Phases (STOMP)© is copyrighted by Battelle Memorial Institute, 1996.

Table D-1. Representative Flow Field Applied Under Tank 241-A-102: Darcy Flow Rate. (2 sheets)

Year	Node_24	Node_33	Node_37	Node_44	Node_69	Node_102	Node_103	Node_104
500	1.0715	1.0511	1.0231	0.9972	0.7408	0.4707	0.3641	0.1464
500.5	1.0704	1.0500	1.0221	0.9962	0.7403	0.4707	0.3641	0.1464
501	1.0692	1.0489	1.0210	0.9952	0.7398	0.4706	0.3641	0.1464
502	1.0669	1.0467	1.0189	0.9933	0.7389	0.4706	0.3641	0.1464
503	1.0647	1.0445	1.0168	0.9913	0.7380	0.4706	0.3641	0.1464
505	1.0601	1.0401	1.0126	0.9874	0.7363	0.4706	0.3641	0.1464
507	1.0557	1.0358	1.0084	0.9836	0.7345	0.4705	0.3641	0.1464
510	1.0490	1.0294	1.0023	0.9779	0.7319	0.4707	0.3644	0.1466
515	1.0382	1.0190	0.9923	0.9686	0.7277	0.4742	0.3699	0.1497
520	1.0277	1.0089	0.9825	0.9595	0.7237	0.4918	0.3928	0.1616
525	1.0175	0.9990	0.9731	0.9507	0.7198	0.5430	0.4512	0.1901
530	1.0075	0.9894	0.9638	0.9421	0.7160	0.6509	0.5606	0.2402
540	0.9882	0.9709	0.9460	0.9256	0.7088	1.0604	0.9095	0.3845
550	0.9699	0.9532	0.9290	0.9098	0.7021	1.5680	1.2698	0.5178
570	0.9359	0.9205	0.8975	0.8807	0.6901	2.1776	1.6457	0.6455
600	0.8908	0.8769	0.8556	0.8421	0.6756	2.3966	1.7715	0.6865
630	0.8518	0.8393	0.8194	0.8090	0.6926	2.4301	1.7903	0.6926
660	0.8180	0.8067	0.7882	0.7805	1.2860	2.4352	1.7932	0.6935
700	0.7801	0.7703	0.7534	0.7511	3.3501	2.4360	1.7936	0.6936
800	2.1146	2.4734	2.7887	3.4261	3.8612	2.4360	1.7937	0.6937
900	3.7355	3.7292	3.7243	3.8156	3.8623	2.4360	1.7937	0.6937
1,000	3.7413	3.7327	3.7264	3.8164	3.8623	2.4360	1.7937	0.6937
1,200	3.7413	3.7327	3.7264	3.8164	3.8623	2.4360	1.7937	0.6937
1,400	3.7413	3.7327	3.7264	3.8164	3.8623	2.4360	1.7937	0.6937
1,600	3.7413	3.7327	3.7264	3.8164	3.8623	2.4360	1.7937	0.6937
1,800	3.7413	3.7327	3.7264	3.8164	3.8623	2.4360	1.7937	0.6937
2,000	3.7413	3.7327	3.7264	3.8164	3.8623	2.4360	1.7937	0.6937
2,200	3.7413	3.7327	3.7264	3.8164	3.8623	2.4360	1.7937	0.6937
2,400	3.7413	3.7327	3.7264	3.8164	3.8623	2.4360	1.7937	0.6937
2,600	3.7413	3.7327	3.7264	3.8164	3.8623	2.4360	1.7937	0.6937
2,800	3.7413	3.7327	3.7264	3.8164	3.8623	2.4360	1.7937	0.6937
3,000	3.7413	3.7327	3.7264	3.8164	3.8623	2.4360	1.7937	0.6937
10,000	3.7413	3.7327	3.7264	3.8164	3.8623	2.4360	1.7937	0.6937

Table D-2. Representative Flow Field Applied Under Tank 241-A-102: Moisture Content. (2 sheets)

Year	Node_24	Node_33	Node_37	Node_44	Node_69	Node_102	Node_103	Node_104
0	0.0851	0.2544	0.0946	0.1042	0.1038	0.0935	0.0907	0.0861
0.001	0.0851	0.2544	0.0946	0.1042	0.1038	0.0935	0.0907	0.0861
0.5	0.0851	0.2544	0.0946	0.1042	0.1038	0.0935	0.0907	0.0860
1	0.0851	0.2544	0.0946	0.1042	0.1038	0.0929	0.0900	0.0852
3	0.0851	0.2544	0.0946	0.1042	0.1037	0.0873	0.0845	0.0802
5	0.0851	0.2543	0.0945	0.1041	0.1025	0.0830	0.0805	0.0767
7	0.0850	0.2539	0.0943	0.1036	0.1001	0.0801	0.0778	0.0743
10	0.0845	0.2510	0.0933	0.1016	0.0963	0.0769	0.0749	0.0718
15	0.0831	0.2431	0.0908	0.0972	0.0912	0.0735	0.0717	0.0690
20	0.0818	0.2354	0.0884	0.0935	0.0876	0.0711	0.0695	0.0671
25	0.0807	0.2290	0.0864	0.0906	0.0848	0.0694	0.0679	0.0657
30	0.0799	0.2237	0.0847	0.0882	0.0826	0.0681	0.0667	0.0646
40	0.0788	0.2156	0.0820	0.0845	0.0793	0.0660	0.0648	0.0629
50	0.0781	0.2097	0.0799	0.0817	0.0768	0.0646	0.0634	0.0617
70	0.0773	0.2016	0.0769	0.0778	0.0733	0.0625	0.0615	0.0600
100	0.0766	0.1944	0.0738	0.0739	0.0699	0.0606	0.0598	0.0585
130	0.0763	0.1901	0.0717	0.0712	0.0676	0.0595	0.0587	0.0575
160	0.0761	0.1872	0.0701	0.0692	0.0659	0.0587	0.0581	0.0569
200	0.0759	0.1846	0.0684	0.0672	0.0642	0.0581	0.0575	0.0565
250	0.0757	0.1825	0.0669	0.0653	0.0626	0.0576	0.0571	0.0561
300	0.0757	0.1811	0.0658	0.0638	0.0614	0.0573	0.0569	0.0559
400	0.0756	0.1794	0.0642	0.0617	0.0598	0.0571	0.0567	0.0558
500	0.0755	0.1784	0.0631	0.0602	0.0588	0.0571	0.0566	0.0557
500.5	0.0755	0.1784	0.0631	0.0602	0.0588	0.0570	0.0566	0.0557
501	0.0755	0.1784	0.0631	0.0602	0.0588	0.0570	0.0566	0.0557
502	0.0755	0.1784	0.0631	0.0602	0.0588	0.0570	0.0566	0.0557
503	0.0755	0.1784	0.0631	0.0602	0.0588	0.0570	0.0566	0.0557
505	0.0755	0.1784	0.0630	0.0602	0.0588	0.0570	0.0566	0.0557
507	0.0755	0.1784	0.0630	0.0601	0.0588	0.0570	0.0566	0.0557
510	0.0755	0.1783	0.0630	0.0601	0.0587	0.0570	0.0566	0.0557

Table D-2. Representative Flow Field Applied Under Tank 241-A-102: Moisture Content. (2 sheets)

Year	Node_24	Node_33	Node_37	Node_44	Node_69	Node_102	Node_103	Node_104
515	0.0755	0.1783	0.0629	0.0600	0.0587	0.0571	0.0566	0.0558
520	0.0755	0.1783	0.0629	0.0600	0.0587	0.0571	0.0568	0.0560
525	0.0755	0.1782	0.0629	0.0599	0.0586	0.0574	0.0572	0.0565
530	0.0755	0.1782	0.0628	0.0599	0.0586	0.0580	0.0580	0.0574
540	0.0755	0.1781	0.0627	0.0598	0.0585	0.0602	0.0605	0.0599
550	0.0755	0.1781	0.0627	0.0597	0.0585	0.0630	0.0630	0.0621
570	0.0755	0.1780	0.0625	0.0595	0.0584	0.0662	0.0656	0.0641
600	0.0755	0.1778	0.0623	0.0592	0.0582	0.0674	0.0665	0.0647
630	0.0755	0.1777	0.0622	0.0590	0.0583	0.0675	0.0666	0.0648
660	0.0755	0.1776	0.0620	0.0587	0.0606	0.0676	0.0666	0.0649
700	0.0755	0.1774	0.0618	0.0585	0.0681	0.0676	0.0666	0.0649
800	0.0757	0.1821	0.0677	0.0682	0.0697	0.0676	0.0666	0.0649
900	0.0760	0.1862	0.0697	0.0694	0.0697	0.0676	0.0666	0.0649
1,000	0.0760	0.1862	0.0697	0.0694	0.0697	0.0676	0.0666	0.0649
1,200	0.0760	0.1862	0.0697	0.0694	0.0697	0.0676	0.0666	0.0649
1,400	0.0760	0.1862	0.0697	0.0694	0.0697	0.0676	0.0666	0.0649
1,600	0.0760	0.1862	0.0697	0.0694	0.0697	0.0676	0.0666	0.0649
1,800	0.0760	0.1862	0.0697	0.0694	0.0697	0.0676	0.0666	0.0649
2,000	0.0760	0.1862	0.0697	0.0694	0.0697	0.0676	0.0666	0.0649
2,200	0.0760	0.1862	0.0697	0.0694	0.0697	0.0676	0.0666	0.0649
2,400	0.0760	0.1862	0.0697	0.0694	0.0697	0.0676	0.0666	0.0649
2,600	0.0760	0.1862	0.0697	0.0694	0.0697	0.0676	0.0666	0.0649
2,800	0.0760	0.1862	0.0697	0.0694	0.0697	0.0676	0.0666	0.0649
3,000	0.0760	0.1862	0.0697	0.0694	0.0697	0.0676	0.0666	0.0649
10,000	0.0760	0.1862	0.0697	0.0694	0.0697	0.0676	0.0666	0.0649

Table D-3. Representative Flow Field Applied Under Tank A-NonTank: Darcy Flow Rate. (2 sheets)

Year	Node_24	Node_33	Node_37	Node_44	Node_69	Node_102	Node_103	Node_104
0	101.3869	101.1809	101.7267	101.9486	104.1009	117.8048	117.4258	111.1733
0.001	101.3869	101.1809	101.7267	101.9486	104.1009	117.8048	117.4258	111.1733
0.5	101.3866	101.1808	101.7267	101.9486	104.1009	117.2260	116.5237	109.9140
1	101.3868	101.1809	101.7267	101.9486	104.1009	109.4393	106.9305	99.0397
3	101.3868	101.1804	101.7259	101.9463	103.4856	60.3597	56.8288	50.9322
5	101.3139	101.0239	101.4862	101.5132	95.1337	37.2021	34.8803	31.2031
7	100.1534	99.1216	98.9804	97.9544	79.9240	26.0505	24.4391	21.9043
10	92.5351	89.3658	87.7703	84.8705	59.5176	17.5529	16.5030	14.8429
15	71.6821	67.1961	64.7982	61.3542	39.1001	11.0980	10.4718	9.4663
20	54.6592	50.6501	48.4884	45.5723	28.2395	8.0032	7.5753	6.8766
25	43.0115	39.6915	37.8760	35.4858	21.7741	6.2177	5.9017	5.3767
30	34.9731	32.2312	30.7084	28.7242	17.5607	5.0685	4.8232	4.4084
40	24.8584	22.9338	21.8264	20.3810	12.4450	3.6825	3.5210	3.2369
50	18.9321	17.5165	16.6731	15.5550	9.5127	2.8908	2.7763	2.5656
70	12.4870	11.6325	11.0909	10.3369	6.3495	2.0381	1.9736	1.8406
100	8.0123	7.5322	7.2054	6.7105	4.1468	1.4500	1.4200	1.3398
130	5.7710	5.4636	5.2434	4.8822	3.0357	1.1636	1.1510	1.0967
160	4.4448	4.2315	4.0729	3.7930	2.3760	1.0030	1.0008	0.9614
200	3.3550	3.2126	3.1029	2.8915	1.8335	0.8819	0.8882	0.8605
250	2.5356	2.4412	2.3667	2.2084	1.4275	0.8031	0.8156	0.7959
300	2.0241	1.9568	1.9030	1.7789	1.1776	0.7631	0.7791	0.7638
400	1.4406	1.4008	1.3693	1.2864	0.9035	0.7311	0.7503	0.7387
500	1.1356	1.1085	1.0880	1.0285	0.7740	0.7220	0.7422	0.7318
500.5	1.1345	1.1074	1.0869	1.0275	0.7735	0.7220	0.7422	0.7317
501	1.1334	1.1063	1.0859	1.0266	0.7731	0.7220	0.7422	0.7317
502	1.1311	1.1042	1.0838	1.0247	0.7722	0.7219	0.7422	0.7317
503	1.1289	1.1020	1.0818	1.0228	0.7713	0.7219	0.7421	0.7317
505	1.1245	1.0978	1.0777	1.0191	0.7696	0.7218	0.7421	0.7317
507	1.1201	1.0936	1.0736	1.0154	0.7679	0.7218	0.7422	0.7322
510	1.1136	1.0874	1.0677	1.0100	0.7654	0.7225	0.7442	0.7364

Table D-3. Representative Flow Field Applied Under Tank A-NonTank: Darcy Flow Rate. (2 sheets)

Year	Node_24	Node_33	Node_37	Node_44	Node_69	Node_102	Node_103	Node_104
515	1.1031	1.0773	1.0579	1.0011	0.7614	0.7320	0.7638	0.7692
520	1.0929	1.0674	1.0484	0.9925	0.7575	0.7695	0.8276	0.8592
525	1.0830	1.0579	1.0392	0.9841	0.7537	0.8585	0.9588	1.0229
530	1.0733	1.0486	1.0303	0.9760	0.7501	1.0158	1.1639	1.2563
540	1.0547	1.0307	1.0131	0.9603	0.7433	1.5122	1.7316	1.8488
550	1.0371	1.0138	0.9968	0.9455	0.7370	2.1275	2.3728	2.4826
570	1.0046	0.9826	0.9667	0.9183	0.7256	3.2908	3.5182	3.5593
600	0.9619	0.9415	0.9271	0.8826	0.7121	4.2219	4.3423	4.2503
630	0.9254	0.9064	0.8934	0.8524	0.7223	4.4157	4.4983	4.3701
660	0.8942	0.8765	0.8646	0.8267	1.0971	4.4423	4.5190	4.3856
700	0.8601	0.8438	0.8336	0.8017	2.9985	4.4459	4.5217	4.3876
800	2.0841	2.3653	2.6746	3.1895	3.7673	4.4461	4.5219	4.3877
900	3.6497	3.6363	3.6449	3.6470	3.7688	4.4461	4.5219	4.3877
1,000	3.6562	3.6403	3.6472	3.6479	3.7688	4.4461	4.5219	4.3877
1,200	3.6562	3.6404	3.6472	3.6479	3.7688	4.4461	4.5219	4.3877
1,400	3.6562	3.6404	3.6472	3.6479	3.7688	4.4461	4.5219	4.3877
1,600	3.6562	3.6404	3.6472	3.6479	3.7688	4.4461	4.5219	4.3877
1,800	3.6562	3.6404	3.6472	3.6479	3.7688	4.4461	4.5219	4.3877
2,000	3.6562	3.6404	3.6472	3.6479	3.7688	4.4461	4.5219	4.3877
2,200	3.6562	3.6404	3.6472	3.6479	3.7688	4.4461	4.5219	4.3877
2,400	3.6562	3.6404	3.6472	3.6479	3.7688	4.4461	4.5219	4.3877
2,600	3.6562	3.6404	3.6472	3.6479	3.7688	4.4461	4.5219	4.3877
2,800	3.6562	3.6404	3.6472	3.6479	3.7688	4.4461	4.5219	4.3877
3,000	3.6562	3.6404	3.6472	3.6479	3.7688	4.4461	4.5219	4.3877
10,000	3.6562	3.6404	3.6472	3.6479	3.7688	4.4461	4.5219	4.3877

Table D-4. Representative Flow Field Applied Under Tank A-NonTank: Moisture Content. (2 sheets)

Year	Node_24	Node_33	Node_37	Node_44	Node_69	Node_102	Node_103	Node_104
0	0.0854	0.2484	0.1130	0.1017	0.1051	0.1069	0.1069	0.1069
0.001	0.0854	0.2484	0.1130	0.1017	0.1051	0.1069	0.1069	0.1069
0.5	0.0854	0.2484	0.1130	0.1017	0.1051	0.1068	0.1069	0.1067
1	0.0854	0.2484	0.1130	0.1017	0.1051	0.1060	0.1058	0.1054
3	0.0854	0.2484	0.1130	0.1017	0.1050	0.0983	0.0976	0.0968
5	0.0854	0.2484	0.1129	0.1016	0.1039	0.0923	0.0916	0.0909
7	0.0853	0.2480	0.1126	0.1011	0.1016	0.0882	0.0875	0.0868
10	0.0848	0.2453	0.1112	0.0993	0.0977	0.0839	0.0833	0.0827
15	0.0834	0.2376	0.1076	0.0951	0.0925	0.0794	0.0788	0.0783
20	0.0820	0.2300	0.1041	0.0915	0.0887	0.0763	0.0759	0.0754
25	0.0809	0.2236	0.1013	0.0887	0.0858	0.0741	0.0737	0.0733
30	0.0801	0.2183	0.0989	0.0863	0.0835	0.0724	0.0720	0.0716
40	0.0790	0.2101	0.0952	0.0827	0.0801	0.0698	0.0695	0.0692
50	0.0782	0.2041	0.0924	0.0800	0.0776	0.0680	0.0677	0.0674
70	0.0773	0.1959	0.0884	0.0762	0.0740	0.0654	0.0652	0.0650
100	0.0767	0.1886	0.0844	0.0725	0.0705	0.0631	0.0629	0.0628
130	0.0763	0.1841	0.0817	0.0699	0.0681	0.0616	0.0615	0.0614
160	0.0761	0.1811	0.0797	0.0680	0.0663	0.0606	0.0606	0.0605
200	0.0759	0.1783	0.0777	0.0660	0.0645	0.0598	0.0597	0.0598
250	0.0758	0.1760	0.0758	0.0642	0.0629	0.0591	0.0592	0.0592
300	0.0757	0.1745	0.0744	0.0627	0.0616	0.0588	0.0588	0.0590
400	0.0756	0.1726	0.0724	0.0607	0.0600	0.0584	0.0586	0.0587
500	0.0755	0.1715	0.0712	0.0594	0.0591	0.0583	0.0585	0.0586
500.5	0.0755	0.1715	0.0712	0.0594	0.0591	0.0583	0.0585	0.0586
501	0.0755	0.1715	0.0712	0.0594	0.0591	0.0583	0.0585	0.0586
502	0.0755	0.1715	0.0712	0.0594	0.0591	0.0583	0.0585	0.0586
503	0.0755	0.1715	0.0712	0.0594	0.0590	0.0583	0.0585	0.0586
505	0.0755	0.1715	0.0711	0.0594	0.0590	0.0583	0.0585	0.0586
507	0.0755	0.1715	0.0711	0.0593	0.0590	0.0583	0.0585	0.0586
510	0.0755	0.1715	0.0711	0.0593	0.0590	0.0583	0.0585	0.0586

Table D-4. Representative Flow Field Applied Under Tank A-NonTank: Moisture Content. (2 sheets)

Year	Node_24	Node_33	Node_37	Node_44	Node_69	Node_102	Node_103	Node_104
515	0.0755	0.1714	0.0710	0.0593	0.0590	0.0584	0.0585	0.0588
520	0.0755	0.1714	0.0710	0.0592	0.0589	0.0585	0.0588	0.0591
525	0.0755	0.1713	0.0710	0.0592	0.0589	0.0588	0.0593	0.0599
530	0.0755	0.1713	0.0709	0.0591	0.0589	0.0595	0.0601	0.0610
540	0.0755	0.1712	0.0708	0.0590	0.0588	0.0615	0.0625	0.0635
550	0.0755	0.1712	0.0707	0.0589	0.0588	0.0639	0.0648	0.0657
570	0.0755	0.1711	0.0706	0.0588	0.0587	0.0676	0.0682	0.0687
600	0.0755	0.1709	0.0704	0.0585	0.0586	0.0700	0.0703	0.0705
630	0.0755	0.1708	0.0702	0.0584	0.0585	0.0705	0.0707	0.0709
660	0.0755	0.1707	0.0700	0.0582	0.0601	0.0706	0.0708	0.0709
700	0.0755	0.1705	0.0699	0.0580	0.0671	0.0706	0.0708	0.0709
800	0.0757	0.1751	0.0760	0.0662	0.0695	0.0706	0.0708	0.0709
900	0.0760	0.1792	0.0787	0.0675	0.0695	0.0706	0.0708	0.0709
1,000	0.0760	0.1792	0.0787	0.0675	0.0695	0.0706	0.0708	0.0709
1,200	0.0760	0.1792	0.0787	0.0675	0.0695	0.0706	0.0708	0.0709
1,400	0.0760	0.1792	0.0787	0.0675	0.0695	0.0706	0.0708	0.0709
1,600	0.0760	0.1792	0.0787	0.0675	0.0695	0.0706	0.0708	0.0709
1,800	0.0760	0.1792	0.0787	0.0675	0.0695	0.0706	0.0708	0.0709
2,000	0.0760	0.1792	0.0787	0.0675	0.0695	0.0706	0.0708	0.0709
2,200	0.0760	0.1792	0.0787	0.0675	0.0695	0.0706	0.0708	0.0709
2,400	0.0760	0.1792	0.0787	0.0675	0.0695	0.0706	0.0708	0.0709
2,600	0.0760	0.1792	0.0787	0.0675	0.0695	0.0706	0.0708	0.0709
2,800	0.0760	0.1792	0.0787	0.0675	0.0695	0.0706	0.0708	0.0709
3,000	0.0760	0.1792	0.0787	0.0675	0.0695	0.0706	0.0708	0.0709
10,000	0.0760	0.1792	0.0787	0.0675	0.0695	0.0706	0.0708	0.0709

Table D-5. Representative Flow Field Applied Under Tank 241-AX-101: Darcy Flow Rate. (sheet 1 of 2)

Year	Node_23	Node_29	Node_43	Node_50	Node_51	Node_67	Node_89	Node_94	Node_96	Node_98	Node_99	Node_100	Node_101	Node_102
0	96.30502	95.39021	94.12168	92.59994	92.48	89.44181	74.19691	63.45837	56.46408	46.52013	39.86144	31.58025	21.10318	7.5864
0.001	96.30502	95.39021	94.12168	92.59994	92.4795	89.44181	74.19691	63.45837	56.46408	46.52013	39.86144	31.58025	21.10318	7.5864
0.5	96.3034	95.38985	94.12168	92.59994	92.4795	89.44181	74.1969	63.4582	56.46348	46.51847	39.85897	31.57699	21.09971	7.584777
1	96.30418	95.38995	94.12168	92.59994	92.4795	89.44181	74.188	63.3898	56.33233	46.30402	39.60898	31.31459	20.87497	7.491244
3	96.30483	95.38995	94.12046	92.59671	92.47548	89.28897	67.73946	53.41551	45.58476	35.92293	30.1154	23.37886	15.35706	5.466388
5	96.24335	95.28032	93.82404	92.08133	91.89408	85.29941	52.06986	38.67774	32.38656	25.18383	21.03864	16.32288	10.75386	3.842604
7	95.2062	93.77579	91.04076	88.27913	87.82881	74.89328	39.5107	28.77015	23.98723	18.64172	15.60151	12.14991	8.052924	2.892806
10	88.136	85.29957	79.77798	75.52802	74.7478	57.7947	27.78829	20.08941	16.75476	13.07113	10.98372	8.605859	5.752409	2.081001
15	68.36196	64.80688	58.3362	54.00351	53.2341	38.71658	17.86264	12.93054	10.822	8.503205	7.187446	5.677892	3.837214	1.40065
20	52.08888	49.07537	43.59129	39.94344	39.32939	28.11513	12.86604	9.34909	7.851419	6.205329	5.268931	4.18819	2.853871	1.048695
25	40.94038	38.54914	34.08464	31.03797	30.55034	21.71654	9.93027	7.242868	6.100415	4.844355	4.12813	3.297488	2.261643	0.835474
30	33.26117	31.35929	27.68605	25.09558	24.69931	17.52634	8.024609	5.87254	4.95859	3.953233	3.378745	2.709772	1.868559	0.693273
40	23.63777	22.387	19.77703	17.7992	17.51978	12.43456	5.715491	4.206265	3.566274	2.861533	2.457365	1.983588	1.379673	0.51547
50	18.04808	17.17347	15.20384	13.60755	13.39698	9.526536	4.395447	3.249477	2.764212	2.229396	1.921748	1.559157	1.091865	0.41018
70	12.03501	11.53967	10.26673	9.112325	8.976661	6.411515	2.976427	2.216473	1.895605	1.541479	1.336693	1.093127	0.773589	0.293056
100	7.849949	7.583981	6.792898	5.97711	5.892498	4.229979	1.981446	1.490485	1.283871	1.055117	0.921681	0.760883	0.545003	0.208405
130	5.695684	5.530675	4.981677	4.354421	4.294253	3.096174	1.469386	1.11847	0.970966	0.806678	0.709693	0.590999	0.427791	0.164869
160	4.393539	4.282265	3.875486	3.368918	3.322884	2.40872	1.164802	0.899398	0.78771	0.662119	0.586769	0.492802	0.360192	0.139782
200	3.314833	3.24284	2.950589	2.550097	2.515769	1.841133	0.920674	0.726757	0.644677	0.550615	0.492587	0.418085	0.309084	0.120889
250	2.507036	2.460637	2.251807	1.936531	1.911393	1.421436	0.748997	0.608927	0.548697	0.477334	0.431421	0.370164	0.276705	0.109013
300	2.010037	1.97744	1.818837	1.559895	1.540942	1.169179	0.653084	0.545963	0.498655	0.440236	0.400963	0.346713	0.261128	0.103366
400	1.460813	1.441376	1.337117	1.145982	1.134984	0.902272	0.564641	0.492185	0.457554	0.411087	0.3776	0.329163	0.24975	0.099307
500	1.188128	1.174266	1.096738	0.942783	0.936637	0.78071	0.533881	0.475653	0.44563	0.403145	0.371441	0.324689	0.246943	0.098328
500.5	1.187144	1.173301	1.095872	0.942058	0.935931	0.7803	0.533794	0.475609	0.4456	0.403126	0.371426	0.324679	0.246937	0.098326
501	1.186163	1.17234	1.095009	0.941334	0.935228	0.779891	0.533708	0.475566	0.44557	0.403106	0.371411	0.324668	0.24693	0.098323
502	1.184213	1.170429	1.09329	0.939897	0.933828	0.779078	0.533537	0.47548	0.44551	0.403068	0.371381	0.324647	0.246917	0.098319
503	1.182275	1.168528	1.091584	0.938468	0.932438	0.778271	0.533368	0.475396	0.445451	0.40303	0.371352	0.324626	0.246905	0.098314
505	1.178438	1.164764	1.088204	0.935638	0.929685	0.776676	0.533035	0.47523	0.445335	0.402955	0.371296	0.324586	0.24688	0.098306
507	1.174649	1.16105	1.084866	0.932846	0.926968	0.775106	0.532711	0.475068	0.445222	0.402882	0.37124	0.324546	0.246855	0.098297
510	1.169056	1.155563	1.079938	0.928725	0.922959	0.772797	0.532237	0.474833	0.445058	0.402777	0.37116	0.324489	0.24682	0.098285
515	1.159966	1.146649	1.071928	0.922034	0.916452	0.769066	0.531482	0.47446	0.444799	0.402612	0.371035	0.324403	0.246771	0.09827

Table D-5. Representative Flow Field Applied Under Tank 241-AX-101: Darcy Flow Rate. (sheet 1 of 2)

Year	Node_23	Node_29	Node_43	Node_50	Node_51	Node_67	Node_89	Node_94	Node_96	Node_98	Node_99	Node_100	Node_101	Node_102
520	1.151158	1.138007	1.064169	0.915557	0.910155	0.765478	0.53077	0.474111	0.444559	0.402469	0.370943	0.324368	0.246796	0.098295
525	1.14262	1.129629	1.056648	0.909286	0.90406	0.762028	0.530097	0.473788	0.444359	0.402429	0.371032	0.324637	0.247241	0.098549
530	1.134342	1.121506	1.049361	0.903213	0.898161	0.758709	0.529464	0.473523	0.444299	0.402824	0.371875	0.326121	0.249288	0.099649
540	1.118505	1.105968	1.035425	0.891623	0.886905	0.752435	0.52834	0.47372	0.446307	0.409955	0.384054	0.345001	0.27286	0.111745
550	1.103582	1.091324	1.022305	0.880731	0.876334	0.746619	0.527724	0.47903	0.463045	0.457089	0.456903	0.445176	0.381676	0.163626
570	1.076257	1.064508	0.99831	0.860877	0.857086	0.736239	0.54041	0.629294	0.7958	1.030086	1.112497	1.102827	0.910443	0.375471
600	1.040852	1.029759	0.967304	0.835365	0.832396	0.723653	1.029777	1.935479	2.14718	2.130615	2.002492	1.752183	1.30577	0.50824
630	1.011191	1.000648	0.941448	0.814291	0.81207	0.7197	2.443857	2.688964	2.598271	2.365019	2.160163	1.8504	1.358182	0.524393
660	0.986667	0.976599	0.920433	0.797917	0.796642	0.796497	2.944727	2.812214	2.660786	2.393856	2.178639	1.861411	1.363826	0.526082
700	0.966048	0.956801	0.908816	0.802302	0.807942	1.924894	3.02759	2.828895	2.668839	2.397413	2.180871	1.862714	1.36448	0.526275
800	2.332423	2.414369	2.877	2.978381	3.027043	3.242228	3.033312	2.82995	2.669334	2.397627	2.181003	1.86279	1.364518	0.526286
900	3.474986	3.455183	3.404521	3.189229	3.197709	3.245374	3.033316	2.829952	2.669335	2.397627	2.181003	1.86279	1.364518	0.526286
1,000	3.478989	3.458503	3.405758	3.189621	3.19801	3.245377	3.033316	2.829952	2.669335	2.397627	2.181003	1.86279	1.364518	0.526286
1,200	3.478994	3.458507	3.405761	3.189622	3.198011	3.245377	3.033316	2.829952	2.669335	2.397627	2.181003	1.86279	1.364518	0.526286
1,400	3.478994	3.458507	3.405761	3.189622	3.198011	3.245377	3.033316	2.829952	2.669335	2.397627	2.181003	1.86279	1.364518	0.526286
1,600	3.478994	3.458507	3.405761	3.189622	3.198011	3.245377	3.033316	2.829952	2.669335	2.397627	2.181003	1.86279	1.364518	0.526286
1,800	3.478994	3.458507	3.405761	3.189622	3.198011	3.245377	3.033316	2.829952	2.669335	2.397627	2.181003	1.86279	1.364518	0.526286
2,000	3.478994	3.458507	3.405761	3.189622	3.198011	3.245377	3.033316	2.829952	2.669335	2.397627	2.181003	1.86279	1.364518	0.526286
2,200	3.478994	3.458507	3.405761	3.189622	3.198011	3.245377	3.033316	2.829952	2.669335	2.397627	2.181003	1.86279	1.364518	0.526286
2,400	3.478994	3.458507	3.405761	3.189622	3.198011	3.245377	3.033316	2.829952	2.669335	2.397627	2.181003	1.86279	1.364518	0.526286
2,600	3.478994	3.458507	3.405761	3.189622	3.198011	3.245377	3.033316	2.829952	2.669335	2.397627	2.181003	1.86279	1.364518	0.526286
2,800	3.478994	3.458507	3.405761	3.189622	3.198011	3.245377	3.033316	2.829952	2.669335	2.397627	2.181003	1.86279	1.364518	0.526286
3,000	3.478994	3.458507	3.405761	3.189622	3.198011	3.245377	3.033316	2.829952	2.669335	2.397627	2.181003	1.86279	1.364518	0.526286
10,000	3.478994	3.458507	3.405761	3.189622	3.198011	3.245377	3.033316	2.829952	2.669335	2.397627	2.181003	1.86279	1.364518	0.526286

Table D-6. Representative Flow Field Applied Under Tank 241-AX-101: Moisture Content. (sheet 1 of 2)

Year	Node_23	Node_29	Node_43	Node_50	Node_51	Node_67	Node_89	Node_94	Node_96	Node_98	Node_99	Node_100	Node_101	Node_102
0	0.086768	0.256965	0.082355	0.088356	0.096308	0.102981	0.100621	0.098832	0.097593	0.095697	0.094313	0.092423	0.089662	0.085071
0.001	0.086768	0.256965	0.082355	0.088356	0.096308	0.102981	0.100621	0.098832	0.097593	0.095697	0.094313	0.092423	0.089662	0.085071
0.5	0.086768	0.256965	0.082355	0.088356	0.096308	0.102981	0.100621	0.098832	0.097593	0.095696	0.094312	0.092422	0.089661	0.08507
1	0.086768	0.256965	0.082355	0.088356	0.096308	0.102981	0.10062	0.098821	0.09757	0.095652	0.094252	0.092343	0.089561	0.084953
3	0.086768	0.256965	0.082355	0.088355	0.096308	0.102961	0.099538	0.096806	0.095106	0.092754	0.091174	0.089141	0.086333	0.081908
5	0.086765	0.256942	0.082331	0.0883	0.096232	0.102381	0.096263	0.092919	0.091079	0.0887	0.087171	0.085253	0.082662	0.078644
7	0.08671	0.256586	0.082094	0.087865	0.095655	0.100677	0.092904	0.089486	0.08769	0.085425	0.083993	0.082215	0.079832	0.076154
10	0.086325	0.2543	0.081036	0.08622	0.093549	0.097313	0.088821	0.085539	0.083858	0.081773	0.08047	0.078862	0.076718	0.073418
15	0.085149	0.247519	0.078562	0.08273	0.089194	0.092357	0.084039	0.081031	0.079516	0.077657	0.076506	0.075094	0.073217	0.070335
20	0.084056	0.240957	0.076341	0.07971	0.085478	0.088641	0.080731	0.07794	0.076546	0.074845	0.073797	0.072517	0.07082	0.068215
25	0.083225	0.235657	0.074534	0.077279	0.082512	0.085796	0.07826	0.075637	0.074333	0.07275	0.071778	0.070594	0.069027	0.066626
30	0.082605	0.231464	0.07306	0.0753	0.080111	0.083537	0.076316	0.073825	0.072593	0.071102	0.070189	0.069079	0.067613	0.065368
40	0.081763	0.225338	0.070779	0.072234	0.076416	0.080103	0.073377	0.071088	0.069963	0.068609	0.067784	0.066784	0.065467	0.063454
50	0.081233	0.221169	0.069088	0.069952	0.073683	0.077588	0.071229	0.069086	0.068039	0.066784	0.066023	0.065102	0.063892	0.062044
70	0.080625	0.215975	0.066715	0.06673	0.06985	0.074075	0.068231	0.066293	0.065355	0.064238	0.063564	0.062752	0.061689	0.060066
100	0.080175	0.211772	0.064413	0.063586	0.066136	0.07066	0.065328	0.063596	0.062768	0.06179	0.061204	0.060499	0.059576	0.058165
130	0.079933	0.209362	0.062815	0.061395	0.063557	0.068268	0.063326	0.061756	0.061014	0.060142	0.059621	0.058994	0.058171	0.056902
160	0.079783	0.207806	0.061604	0.059727	0.061597	0.066442	0.06184	0.060412	0.059744	0.058963	0.058495	0.057932	0.057186	0.056022
200	0.079657	0.206452	0.060372	0.058021	0.059596	0.064579	0.060388	0.059131	0.05855	0.057873	0.057465	0.056969	0.056303	0.05524
250	0.079562	0.205395	0.059234	0.05644	0.057746	0.062868	0.059148	0.05808	0.057592	0.05702	0.056672	0.056239	0.055644	0.054663
300	0.079502	0.204724	0.058394	0.055269	0.056378	0.061624	0.058334	0.057427	0.057013	0.056522	0.056216	0.055828	0.055279	0.05435
400	0.079436	0.203963	0.057272	0.053705	0.054553	0.060029	0.057459	0.056784	0.056467	0.056074	0.055816	0.055476	0.054975	0.054094
500	0.079403	0.203578	0.056603	0.052777	0.053471	0.059157	0.057109	0.056557	0.056286	0.055934	0.055695	0.055373	0.054888	0.054022
500.5	0.079403	0.203576	0.0566	0.052773	0.053467	0.059154	0.057108	0.056556	0.056285	0.055933	0.055695	0.055373	0.054888	0.054022
501	0.079403	0.203575	0.056598	0.052769	0.053463	0.059151	0.057107	0.056556	0.056285	0.055933	0.055694	0.055373	0.054888	0.054022
502	0.079403	0.203572	0.056593	0.052762	0.053455	0.059145	0.057104	0.056555	0.056284	0.055932	0.055694	0.055372	0.054888	0.054022
503	0.079403	0.203569	0.056587	0.052755	0.053446	0.059139	0.057102	0.056553	0.056283	0.055932	0.055693	0.055372	0.054887	0.054021
505	0.079402	0.203564	0.056577	0.052741	0.05343	0.059126	0.057098	0.056551	0.056281	0.05593	0.055692	0.055371	0.054886	0.054021
507	0.079402	0.203559	0.056567	0.052727	0.053414	0.059114	0.057094	0.056549	0.056279	0.055929	0.055691	0.05537	0.054886	0.05402
510	0.079401	0.203551	0.056552	0.052707	0.05339	0.059096	0.057089	0.056545	0.056277	0.055927	0.055689	0.055368	0.054884	0.054019
515	0.0794	0.203538	0.056528	0.052673	0.053351	0.059067	0.057079	0.05654	0.056272	0.055924	0.055687	0.055366	0.054883	0.054018

Table D-6. Representative Flow Field Applied Under Tank 241-AX-101: Moisture Content. (sheet 1 of 2)

Year	Node_23	Node_29	Node_43	Node_50	Node_51	Node_67	Node_89	Node_94	Node_96	Node_98	Node_99	Node_100	Node_101	Node_102
520	0.079399	0.203525	0.056505	0.052641	0.053313	0.059039	0.057071	0.056534	0.056268	0.055921	0.055684	0.055364	0.054881	0.054017
525	0.079398	0.203513	0.056482	0.052609	0.053277	0.059012	0.057062	0.05653	0.056265	0.055918	0.055683	0.055364	0.054883	0.054022
530	0.079397	0.203501	0.056459	0.052578	0.053241	0.058985	0.057055	0.056525	0.056262	0.055918	0.055685	0.055371	0.054898	0.054047
540	0.079395	0.203478	0.056416	0.052519	0.053172	0.058935	0.05704	0.05652	0.056267	0.05595	0.055747	0.055484	0.055091	0.054337
550	0.079393	0.203457	0.056375	0.052462	0.053106	0.058888	0.057029	0.05654	0.056343	0.056191	0.056155	0.056137	0.056053	0.055568
570	0.07939	0.203418	0.056299	0.052358	0.052986	0.058804	0.057076	0.057261	0.058019	0.05933	0.06003	0.060574	0.060729	0.060032
600	0.079385	0.203367	0.056199	0.052221	0.052827	0.058698	0.059369	0.063449	0.064672	0.065239	0.065224	0.064943	0.064255	0.062756
630	0.079382	0.203325	0.056114	0.052105	0.052693	0.058643	0.065476	0.066872	0.066863	0.066527	0.066186	0.06565	0.064766	0.063118
660	0.079379	0.20329	0.056043	0.052011	0.052586	0.058985	0.067548	0.067441	0.067177	0.066694	0.066306	0.065735	0.064826	0.063159
700	0.079376	0.20326	0.055993	0.051983	0.052585	0.063589	0.067895	0.06752	0.067219	0.066716	0.066321	0.065746	0.064833	0.063164
800	0.079542	0.205208	0.059888	0.058506	0.060472	0.068345	0.06792	0.067526	0.067222	0.066717	0.066322	0.065746	0.064833	0.063165
900	0.079676	0.206683	0.060889	0.059188	0.0611	0.068357	0.06792	0.067526	0.067222	0.066717	0.066322	0.065746	0.064833	0.063165
1,000	0.079676	0.206688	0.060892	0.059189	0.061102	0.068357	0.06792	0.067526	0.067222	0.066717	0.066322	0.065746	0.064833	0.063165
1,200	0.079676	0.206688	0.060892	0.059189	0.061102	0.068357	0.06792	0.067526	0.067222	0.066717	0.066322	0.065746	0.064833	0.063165
1,400	0.079676	0.206688	0.060892	0.059189	0.061102	0.068357	0.06792	0.067526	0.067222	0.066717	0.066322	0.065746	0.064833	0.063165
1,600	0.079676	0.206688	0.060892	0.059189	0.061102	0.068357	0.06792	0.067526	0.067222	0.066717	0.066322	0.065746	0.064833	0.063165
1,800	0.079676	0.206688	0.060892	0.059189	0.061102	0.068357	0.06792	0.067526	0.067222	0.066717	0.066322	0.065746	0.064833	0.063165
2,000	0.079676	0.206688	0.060892	0.059189	0.061102	0.068357	0.06792	0.067526	0.067222	0.066717	0.066322	0.065746	0.064833	0.063165
2,200	0.079676	0.206688	0.060892	0.059189	0.061102	0.068357	0.06792	0.067526	0.067222	0.066717	0.066322	0.065746	0.064833	0.063165
2,400	0.079676	0.206688	0.060892	0.059189	0.061102	0.068357	0.06792	0.067526	0.067222	0.066717	0.066322	0.065746	0.064833	0.063165
2,600	0.079676	0.206688	0.060892	0.059189	0.061102	0.068357	0.06792	0.067526	0.067222	0.066717	0.066322	0.065746	0.064833	0.063165
2,800	0.079676	0.206688	0.060892	0.059189	0.061102	0.068357	0.06792	0.067526	0.067222	0.066717	0.066322	0.065746	0.064833	0.063165
3,000	0.079676	0.206688	0.060892	0.059189	0.061102	0.068357	0.06792	0.067526	0.067222	0.066717	0.066322	0.065746	0.064833	0.063165
10,000	0.079676	0.206688	0.060892	0.059189	0.061102	0.068357	0.06792	0.067526	0.067222	0.066717	0.066322	0.065746	0.064833	0.063165

Table D-7. Representative Flow Field Applied Under AX Non_Tanks: Darcy Flow Rate. (sheet 1 of 2)

Year	Node_23	Node_29	Node_43	Node_50	Node_51	Node_67	Node_89	Node_94	Node_96	Node_98	Node_99	Node_100	Node_101	Node_102
0	98.93657	98.8455	99.3565	99.35759	99.43143	100.8186	106.7132	110.2302	112.1719	114.4202	115.5426	116.391	116.125	109.4107
0.001	98.93656	98.8455	99.3565	99.35759	99.43143	100.8186	106.7132	110.2302	112.1719	114.4202	115.5426	116.391	116.125	109.4107
0.5	98.93553	98.84526	99.3565	99.35759	99.43143	100.8186	106.7132	110.2297	112.17	114.4132	115.5296	116.3675	116.084	109.3461
1	98.93606	98.84534	99.3565	99.35759	99.43143	100.8186	106.6968	110.0666	111.7944	113.602	114.3709	114.7504	113.899	106.6422
3	98.9364	98.84528	99.35513	99.3532	99.42607	100.6051	94.93184	87.74509	83.94045	79.66901	77.3454	74.79455	71.60255	64.82385
5	98.87311	98.74199	99.0225	98.70219	98.69023	95.33561	69.14617	59.05254	54.86633	50.72021	48.6786	46.61645	44.30373	39.93979
7	97.80698	97.29088	95.94045	94.14323	93.80404	82.43982	50.50635	41.89286	38.5376	35.32506	33.79088	32.28581	30.66396	27.68063
10	90.532	88.84217	83.67882	79.67922	78.93393	62.48396	34.31871	27.99782	25.60922	23.36463	22.31455	21.30831	20.26105	18.35152
15	70.17288	67.77511	60.76362	56.37022	55.59592	41.2365	21.38989	17.28241	15.75304	14.33258	13.67898	13.067	12.45431	11.33869
20	53.45098	51.37137	45.21947	41.52854	40.89763	29.74599	15.14542	12.18762	11.09175	10.07944	9.618062	9.192707	8.779149	8.025927
25	42.02288	40.36088	35.27714	32.23258	31.72327	22.90382	11.56764	9.28745	8.444501	7.668405	7.31703	6.996864	6.693034	6.139703
30	34.16576	32.83805	28.62181	26.06777	25.64806	18.46106	9.286462	7.445153	6.765205	6.140638	5.859294	5.605345	5.369327	4.939696
40	24.33782	23.46165	20.43769	18.53553	18.2322	13.10298	6.570151	5.258493	4.774589	4.331566	4.133532	3.95744	3.799481	3.512285
50	18.63074	18.01663	15.72476	14.22051	13.98687	10.05731	5.038126	4.028809	3.656698	3.316937	3.166002	3.033402	2.917989	2.708186
70	12.43892	12.08987	10.61067	9.557348	9.400918	6.765191	3.385029	2.706522	2.457105	2.230722	2.131341	2.045897	1.975431	1.846139
100	8.040258	7.855514	6.951298	6.234543	6.132893	4.408422	2.206896	1.770651	1.611731	1.469324	1.408179	1.357504	1.319253	1.245214
130	5.776216	5.664827	5.049004	4.513388	4.439567	3.190175	1.610363	1.30283	1.192207	1.094802	1.05423	1.022268	1.001067	0.954407
160	4.427386	4.354547	3.905878	3.482918	3.425824	2.466774	1.26594	1.036687	0.955492	0.885595	0.857656	0.837227	0.826479	0.795545
200	3.324542	3.279307	2.963349	2.636915	2.593896	1.879653	0.996043	0.831966	0.77531	0.728428	0.711112	0.700435	0.698525	0.679977
250	2.506246	2.478557	2.25788	2.0072	1.975174	1.450179	0.808127	0.693345	0.655261	0.625823	0.616583	0.613353	0.618192	0.608337
300	2.005135	1.986654	1.822606	1.621093	1.59627	1.192506	0.702359	0.618371	0.59179	0.573069	0.56876	0.570063	0.578984	0.573971
400	1.45122	1.441183	1.337702	1.194425	1.178382	0.916804	0.60216	0.552209	0.537813	0.530082	0.530696	0.536449	0.549307	0.548574
500	1.173438	1.1668	1.093018	0.981635	0.970644	0.787705	0.565756	0.530876	0.521362	0.517759	0.520132	0.527428	0.541609	0.542192
500.5	1.172427	1.165801	1.092129	0.980868	0.969896	0.787261	0.565651	0.530818	0.521319	0.517728	0.520106	0.527406	0.54159	0.542177
501	1.17142	1.164805	1.091243	0.980103	0.969151	0.786819	0.565546	0.530761	0.521277	0.517697	0.52008	0.527384	0.541572	0.542162
502	1.169416	1.162824	1.089479	0.978581	0.967669	0.785941	0.565339	0.530648	0.521192	0.517635	0.520028	0.527341	0.541536	0.542132
503	1.167424	1.160855	1.087725	0.977069	0.966196	0.785068	0.565135	0.530537	0.521109	0.517575	0.519977	0.527298	0.5415	0.542103
505	1.163479	1.156954	1.084251	0.974073	0.963278	0.783344	0.564733	0.530318	0.520945	0.517457	0.519878	0.527214	0.54143	0.542046
507	1.159583	1.153102	1.08082	0.971115	0.960397	0.781644	0.564339	0.530104	0.520786	0.517341	0.51978	0.527133	0.541362	0.541991
510	1.153828	1.147411	1.075751	0.966747	0.956144	0.779142	0.563765	0.529793	0.520554	0.517174	0.51964	0.527016	0.541267	0.541921
515	1.144472	1.138157	1.067509	0.95965	0.949234	0.775095	0.56285	0.529301	0.520189	0.516917	0.519434	0.52687	0.541208	0.542018

Table D-7. Representative Flow Field Applied Under AX Non_Tanks: Darcy Flow Rate. (sheet 1 of 2)

Year	Node_23	Node_29	Node_43	Node_50	Node_51	Node_67	Node_89	Node_94	Node_96	Node_98	Node_99	Node_100	Node_101	Node_102
520	1.135396	1.12918	1.059514	0.952771	0.942539	0.771197	0.561984	0.528841	0.519862	0.516747	0.51939	0.527042	0.54179	0.543329
525	1.126591	1.12047	1.051758	0.946105	0.936052	0.767441	0.561166	0.528438	0.519657	0.516944	0.520022	0.528479	0.544741	0.548739
530	1.118046	1.112017	1.044234	0.939643	0.929766	0.763823	0.560401	0.528181	0.519837	0.518292	0.522699	0.533592	0.554269	0.564891
540	1.101678	1.095824	1.029829	0.92729	0.917753	0.756968	0.559126	0.529192	0.52425	0.532662	0.548286	0.578964	0.633103	0.687906
550	1.086225	1.080534	1.016238	0.915658	0.906448	0.750594	0.558819	0.537791	0.548823	0.602884	0.665681	0.770434	0.931638	1.101477
570	1.057849	1.052455	0.99131	0.894389	0.885794	0.739173	0.57565	0.697283	0.919612	1.362616	1.676503	2.03969	2.427033	2.680372
600	1.020904	1.015892	0.958933	0.866922	0.859162	0.725502	1.01964	2.190863	2.696985	3.11853	3.305771	3.488329	3.664265	3.66486
630	0.989784	0.985092	0.931811	0.844196	0.837211	0.723059	2.607561	3.231504	3.378027	3.522171	3.607859	3.711081	3.826195	3.777547
660	0.964078	0.959688	0.910094	0.827283	0.821307	0.795748	3.250259	3.402507	3.470324	3.570028	3.641823	3.734961	3.842803	3.788645
700	0.943409	0.939834	0.901575	0.8382	0.838349	1.819761	3.35241	3.424411	3.481588	3.575632	3.645722	3.737647	3.844633	3.789842
800	2.061471	2.131463	2.791943	3.096544	3.141724	3.329293	3.358941	3.425709	3.482237	3.575946	3.645937	3.737794	3.844731	3.789905
900	3.44855	3.447336	3.424942	3.323055	3.322937	3.332442	3.358946	3.42571	3.482238	3.575947	3.645937	3.737794	3.844731	3.789905
1,000	3.45389	3.45204	3.426172	3.323403	3.323205	3.332445	3.358946	3.42571	3.482238	3.575947	3.645937	3.737794	3.844731	3.789905
1,200	3.453897	3.452046	3.426174	3.323403	3.323206	3.332445	3.358946	3.42571	3.482238	3.575947	3.645937	3.737794	3.844731	3.789905
1,400	3.453897	3.452046	3.426174	3.323403	3.323206	3.332445	3.358946	3.42571	3.482238	3.575947	3.645937	3.737794	3.844731	3.789905
1,600	3.453897	3.452046	3.426174	3.323403	3.323206	3.332445	3.358946	3.42571	3.482238	3.575947	3.645937	3.737794	3.844731	3.789905
1,800	3.453897	3.452046	3.426174	3.323403	3.323206	3.332445	3.358946	3.42571	3.482238	3.575947	3.645937	3.737794	3.844731	3.789905
2,000	3.453897	3.452046	3.426174	3.323403	3.323206	3.332445	3.358946	3.42571	3.482238	3.575947	3.645937	3.737794	3.844731	3.789905
2,200	3.453897	3.452046	3.426174	3.323403	3.323206	3.332445	3.358946	3.42571	3.482238	3.575947	3.645937	3.737794	3.844731	3.789905
2,400	3.453897	3.452046	3.426174	3.323403	3.323206	3.332445	3.358946	3.42571	3.482238	3.575947	3.645937	3.737794	3.844731	3.789905
2,600	3.453897	3.452046	3.426174	3.323403	3.323206	3.332445	3.358946	3.42571	3.482238	3.575947	3.645937	3.737794	3.844731	3.789905
2,800	3.453897	3.452046	3.426174	3.323403	3.323206	3.332445	3.358946	3.42571	3.482238	3.575947	3.645937	3.737794	3.844731	3.789905
3,000	3.453897	3.452046	3.426174	3.323403	3.323206	3.332445	3.358946	3.42571	3.482238	3.575947	3.645937	3.737794	3.844731	3.789905
10,000	3.453897	3.452046	3.426174	3.323403	3.323206	3.332445	3.358946	3.42571	3.482238	3.575947	3.645937	3.737794	3.844731	3.789905

Table D-8. Representative Flow Field Applied Under AX Non_Tanks: Moisture Content. (sheet 1 of 2)

Year	Node 23	Node 29	Node 43	Node 50	Node 51	Node 67	Node 89	Node 94	Node 96	Node 98	Node 99	Node 100	Node 101	Node 102
0	0.086906	0.251543	0.083227	0.0946	0.097282	0.104623	0.105396	0.105834	0.106074	0.106356	0.106508	0.106655	0.106763	0.106705
0.001	0.086906	0.251543	0.083227	0.0946	0.097282	0.104623	0.105396	0.105834	0.106074	0.106356	0.106508	0.106655	0.106763	0.106705
0.5	0.086907	0.251543	0.083227	0.0946	0.097282	0.104623	0.105396	0.105834	0.106073	0.106355	0.106507	0.106653	0.106759	0.1067
1	0.086907	0.251543	0.083227	0.0946	0.097282	0.104623	0.105394	0.105819	0.106038	0.106278	0.106396	0.106496	0.106542	0.106406
3	0.086907	0.251543	0.083227	0.094599	0.097282	0.104598	0.103917	0.102916	0.102347	0.101678	0.101305	0.100901	0.100447	0.099847
5	0.086904	0.25152	0.083202	0.09453	0.097198	0.103901	0.09975	0.097763	0.096849	0.09588	0.095379	0.094868	0.094336	0.093709
7	0.086848	0.251165	0.082953	0.094001	0.096595	0.10196	0.095745	0.093505	0.092523	0.091508	0.090994	0.09048	0.089958	0.089372
10	0.086457	0.248815	0.081861	0.092088	0.094501	0.098304	0.091084	0.088809	0.087834	0.086838	0.08634	0.085848	0.08536	0.084834
15	0.085263	0.241612	0.079343	0.088176	0.090323	0.093097	0.085797	0.08362	0.082695	0.081755	0.081289	0.080834	0.080393	0.079938
20	0.084153	0.234436	0.077108	0.084858	0.086821	0.089262	0.082217	0.080142	0.079262	0.078371	0.077931	0.077503	0.077094	0.076687
25	0.083309	0.228514	0.075304	0.082215	0.084043	0.086354	0.079579	0.07759	0.076747	0.075894	0.075473	0.075066	0.074681	0.074308
30	0.082681	0.22375	0.073839	0.080076	0.081802	0.084059	0.077525	0.075608	0.074795	0.073973	0.073568	0.073178	0.072811	0.072464
40	0.081827	0.216665	0.071583	0.076782	0.078359	0.080597	0.074458	0.072654	0.071888	0.071115	0.070734	0.070369	0.07003	0.069719
50	0.081291	0.211743	0.069916	0.074341	0.075812	0.078074	0.072237	0.070519	0.06979	0.069053	0.068691	0.068345	0.068026	0.067742
70	0.08067	0.205433	0.067557	0.070874	0.072202	0.074522	0.069113	0.067523	0.066849	0.06617	0.065838	0.065523	0.065236	0.064992
100	0.080198	0.2001	0.065204	0.067416	0.068602	0.070976	0.066001	0.064558	0.063952	0.063346	0.063053	0.062778	0.062535	0.06234
130	0.079944	0.196982	0.063547	0.064985	0.066067	0.068481	0.063857	0.062544	0.062	0.061463	0.061208	0.060973	0.060772	0.060625
160	0.079789	0.194972	0.062294	0.063143	0.064143	0.066602	0.062295	0.061105	0.06062	0.060149	0.05993	0.059733	0.059573	0.05947
200	0.07966	0.193229	0.061022	0.061268	0.062182	0.064709	0.060795	0.059758	0.059346	0.058957	0.058783	0.058632	0.058522	0.058472
250	0.079563	0.19187	0.059848	0.059526	0.06036	0.062987	0.059526	0.05866	0.058329	0.058029	0.057902	0.057801	0.057742	0.057745
300	0.079503	0.191007	0.058977	0.058227	0.059	0.061738	0.058686	0.057969	0.057706	0.057478	0.057389	0.057326	0.057306	0.057348
400	0.079436	0.190022	0.057802	0.056461	0.057151	0.060118	0.057761	0.057267	0.057098	0.056965	0.056922	0.056906	0.05693	0.057015
500	0.079403	0.189517	0.057087	0.055378	0.05602	0.059207	0.057372	0.057007	0.056885	0.056796	0.056774	0.056776	0.056819	0.05692
500.5	0.079403	0.189515	0.057084	0.055373	0.056015	0.059203	0.057371	0.057006	0.056884	0.056796	0.056773	0.056776	0.056819	0.056919
501	0.079403	0.189513	0.057082	0.055369	0.056011	0.0592	0.057369	0.057005	0.056884	0.056795	0.056773	0.056776	0.056818	0.056919
502	0.079403	0.189509	0.057076	0.055361	0.056002	0.059193	0.057367	0.057004	0.056883	0.056794	0.056772	0.056775	0.056818	0.056919
503	0.079403	0.189506	0.057071	0.055352	0.055993	0.059187	0.057365	0.057002	0.056882	0.056793	0.056771	0.056775	0.056817	0.056918
505	0.079402	0.189499	0.05706	0.055336	0.055976	0.059173	0.05736	0.056999	0.056879	0.056792	0.05677	0.056773	0.056816	0.056917
507	0.079402	0.189491	0.057049	0.055319	0.055959	0.05916	0.057356	0.056997	0.056877	0.05679	0.056768	0.056772	0.056815	0.056917
510	0.079401	0.189481	0.057033	0.055295	0.055933	0.059141	0.057349	0.056993	0.056874	0.056787	0.056766	0.05677	0.056814	0.056915
515	0.0794	0.189464	0.057006	0.055255	0.055891	0.05911	0.057339	0.056986	0.056869	0.056784	0.056763	0.056767	0.056811	0.056914

Table D-8. Representative Flow Field Applied Under AX Non_Tanks: Moisture Content. (sheet 1 of 2)

Year	Node 23	Node 29	Node 43	Node 50	Node 51	Node 67	Node 89	Node 94	Node 96	Node 98	Node 99	Node 100	Node 101	Node 102
520	0.079399	0.189447	0.056981	0.055216	0.055851	0.05908	0.057329	0.05698	0.056864	0.05678	0.05676	0.056766	0.056812	0.056918
525	0.079398	0.189431	0.056956	0.055178	0.055811	0.059051	0.057319	0.056974	0.05686	0.056779	0.056761	0.05677	0.056822	0.056939
530	0.079397	0.189415	0.056931	0.055141	0.055773	0.059022	0.05731	0.05697	0.056858	0.056782	0.056771	0.05679	0.056861	0.05701
540	0.079395	0.189385	0.056884	0.05507	0.055698	0.058968	0.057294	0.056968	0.056874	0.056844	0.056881	0.056985	0.057199	0.057577
550	0.079393	0.189357	0.056839	0.055002	0.055628	0.058918	0.057284	0.057005	0.056986	0.057159	0.057401	0.05782	0.05848	0.059415
570	0.07939	0.189305	0.056756	0.054876	0.055496	0.058826	0.057357	0.057759	0.058666	0.060403	0.061566	0.062849	0.064172	0.065451
600	0.079385	0.189237	0.056645	0.054708	0.055322	0.058711	0.05942	0.063903	0.06573	0.067146	0.067709	0.068205	0.068659	0.069079
630	0.079381	0.18918	0.05655	0.054566	0.055175	0.058664	0.065699	0.067929	0.06837	0.068717	0.068887	0.069073	0.069289	0.069529
660	0.079378	0.189133	0.056472	0.054452	0.055058	0.059021	0.068162	0.068603	0.06874	0.068912	0.069027	0.069172	0.069358	0.069577
700	0.079376	0.189097	0.056426	0.054436	0.05507	0.063151	0.068558	0.068691	0.068787	0.068936	0.069044	0.069184	0.069366	0.069582
800	0.079519	0.191144	0.0603	0.061877	0.06309	0.068535	0.068584	0.068697	0.068789	0.068937	0.069044	0.069184	0.069366	0.069582
900	0.079674	0.193448	0.06155	0.062638	0.063727	0.068546	0.068584	0.068697	0.068789	0.068937	0.069044	0.069184	0.069366	0.069582
1,000	0.079674	0.193457	0.061553	0.062639	0.063728	0.068546	0.068584	0.068697	0.068789	0.068937	0.069044	0.069184	0.069366	0.069582
1,200	0.079674	0.193457	0.061553	0.062639	0.063728	0.068546	0.068584	0.068697	0.068789	0.068937	0.069044	0.069184	0.069366	0.069582
1,400	0.079674	0.193457	0.061553	0.062639	0.063728	0.068546	0.068584	0.068697	0.068789	0.068937	0.069044	0.069184	0.069366	0.069582
1,600	0.079674	0.193457	0.061553	0.062639	0.063728	0.068546	0.068584	0.068697	0.068789	0.068937	0.069044	0.069184	0.069366	0.069582
1,800	0.079674	0.193457	0.061553	0.062639	0.063728	0.068546	0.068584	0.068697	0.068789	0.068937	0.069044	0.069184	0.069366	0.069582
2,000	0.079674	0.193457	0.061553	0.062639	0.063728	0.068546	0.068584	0.068697	0.068789	0.068937	0.069044	0.069184	0.069366	0.069582
2,200	0.079674	0.193457	0.061553	0.062639	0.063728	0.068546	0.068584	0.068697	0.068789	0.068937	0.069044	0.069184	0.069366	0.069582
2,400	0.079674	0.193457	0.061553	0.062639	0.063728	0.068546	0.068584	0.068697	0.068789	0.068937	0.069044	0.069184	0.069366	0.069582
2,600	0.079674	0.193457	0.061553	0.062639	0.063728	0.068546	0.068584	0.068697	0.068789	0.068937	0.069044	0.069184	0.069366	0.069582
2,800	0.079674	0.193457	0.061553	0.062639	0.063728	0.068546	0.068584	0.068697	0.068789	0.068937	0.069044	0.069184	0.069366	0.069582
3,000	0.079674	0.193457	0.061553	0.062639	0.063728	0.068546	0.068584	0.068697	0.068789	0.068937	0.069044	0.069184	0.069366	0.069582
10,000	0.079674	0.193457	0.061553	0.062639	0.063728	0.068546	0.068584	0.068697	0.068789	0.068937	0.069044	0.069184	0.069366	0.069582

APPENDIX E

SUPPLEMENTAL INFORMATION

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APPENDIX E

Supplemental Information

This Appendix contains supplemental information including the checker log, statement of need, and list of authors and support staff.

E.1 CHECKER LOG

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: 4/10/2019

Environmental Model Calculation File Report and Revision No.: RPP-RPT-60885, Rev. 0

Environmental Model Calculation File Title: Model Package Report System Model for the A-AX PA

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 2	◉	○		
Calculation Approach		○	◉	not relevant	
Assumptions	App. A	◉	○		
Inputs *(reference detailed checklist below as well)*	App. B, C, and D.	◉	○		
Equations used	Section 4	◉	○		
Conclusions		○	◉	not relevant	
References	Section 9	◉	○		

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 4.1	◉	○		
Software use is approved and properly validated in accordance with approved software management plan	Section 4.1	◉	○		
Software use is properly documented	Section 4.1	◉	○		
Verify data was input correctly to approved software or spreadsheets	For parameter values listed in the main text and appendices B through D.	◉	○		
If a spreadsheet is used, verify inputs/outputs of calculation(s) to ensure accuracy		○	◉	N/A (not applicable)	

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	N/A	N/A	

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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	N/A	N/A	N/A
Simulation time step control	N/A	N/A	N/A
Simulated chemical list	N/A	N/A	N/A
Simulated radionuclides list	N/A	N/A	N/A
External model components identified and documented or referenced	N/A	N/A	N/A
External model linkages *(dynamic link libraries, etc.)* checked	N/A	N/A	N/A
If model is probabilistic, stochastic distributions are defined and consistent	N/A	N/A	N/A
Input units are declared and of correct dimensionality	N/A	N/A	N/A
Equations used in the model file are presented in EMCF and consistent	N/A	N/A	N/A
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?	The inventory contains radionuclides that are decay-corrected to the appropriate date for inclusion as a source.	N/A. Inventory data is provided in EMCF 62319.	N/A
Inventory: Mass Balance. Is mass balance of inventory maintained in system model calculation(s)?	Mass balance is performed with decay/ ingrowth up to 10,000 yrs of simulated period and no errors were found.	N/A	N/A

E.2 SUPPORTING INFORMATION

This section contains supportin information for the WMA A-AX Model Package Report (RPP-RPT-60885) *System Model for the WMA A-AX Performance Assessment*. It includes an identification of need, and a list of authors and support staff with their qualifications.

E.2.1 IDENTIFICATION OF NEED FOR RPP-RPT-60885

This Model Package Report (MPR) documents the development of system-level model for the WMA A-AX Performance Assessment (PA). The WMA A-AX system model complements the more detailed process-level model of the groundwater system beneath WMA A-AX. Also, the system-level model integrates several necessary computational components that allow it to not only mimic the fully 3D process-level model of the groundwater release pathway (see RPP-RPT-60101), but also to perform several other calculations required for a PA. The calculations performed within the WMA A-AX system model include: (a) waste form degradation and release from various residual inventory-sources at closure (tanks and ancillary equipment), (b) flow and transport of contaminants through the vadose zone and saturated zone using abstracted information from the process model, (c) effective dose and risk from exposure to radionuclides and chemicals at the point of compliance for various exposure scenarios, (d) acute and chronic doses to the inadvertent intruder, (e) radon flux from the facility.

System-level modeling is needed to evaluate the long-term impacts from slow release of contaminants from the residual inventories at closure. The time scale of analysis is up to 10,000 years and the model needs to consider the combined effects of contaminants in the aquifer from various source terms leading to eventual exposure to a Reference Person. In addition, a probabilistic analysis is appropriate to evaluate the impact of parameter uncertainty in estimating dose for the PA, which requires a system model.

E.2.2 IDENTIFICATION OF MPR DOCUMENT ORIGINATORS, CHECKER, AND SUBJECT MATTER EXPERT (SME)/SENIOR REVIEWER (SR)

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

M. Sci., 2009, Environmental Science, Washington State University
B. Sci., 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 , pflotran , and TOUGH2 ; air dispersion with AERMOD ; internal and external radiological dosimetry using IMBA® , DCAL , OLINDA , and RESRAD ; 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 (CO2) sequestration. His work has supported the U.S. Department of Energy (DOE), U.S. Nuclear Regulatory

Commission, International Atomic Energy Agency, Joint Global Change Research Institute and other industrial and research organizations.

Ryan D. Childress, WRPS

M.S., 2019, Environmental Science, Washington State University
B.S., 2015, Environmental Science, Washington State University

Ryan Childress has 6 years of experience working at the Hanford site for the Department of Energy as well as their contractors. Ryan has worked on developing many regulatory documents including Data Quality Objectives (DQO's), Sampling and Analysis Plans (SAP's), RCRA Facility Investigations (RFI's), Environmental Model Calculation Files (EMCF's), Model Package Reports (MPR's), 435.1 Performance Assessments (PA's).

Kristin M. Singleton, WRPS

B.S., Cellular and Molecular Biology, University of Nevada, Reno

Ms. Singleton has nine years of experience performing extensive risk assessments across the Hanford Site Tank Farms and River Corridor. She has experience developing risk-based remediation goals in compliance with Federal and State regulations and interpreting modeling results for hazardous waste facilities and contaminated sites.

Glenn A. Taylor, WRPS
Nuclear Engineer/Scientist

M.Sci., University of Texas, Austin TX.
B.Sci., University of Louisville, Louisville, KY.

Mr. Taylor has more than 20 years of engineering experience, the last 12 of which has been in a Performance Assessment group conducting various required analyses, predominantly developing and applying system level models using GoldSim software.. His extensive experience in developing and reviewing GoldSim (and other software) models and applying statistical methods to evaluate model results is particularly relevant to the initial construction of the WMA A-AX System Model.

Pat Lee, Orano, Inc.
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© Radionuclide Transport Module to conduct 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 (IDF) 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 completed all reading assignments that are procedurally required to perform environmental fate and transport calculations. He has developed and checked several other models for the IDF PA. He is also familiar with the statistical techniques used to evaluate parameter importance in Monte Carlo analyses.

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 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, MT3DMS, MODPATH, PEST, STOMP, ArcGIS, GoldSim, Groundwater Vistas, RETC, R, and TecPlot.

Sunil Mehta, INTERA, Inc.

Ph.D., Earth Sciences (Hydrogeology specialization), University of Kentucky
M.S., Geosciences, University of Louisiana at Monroe
M.Sc., Geology, University of Poona, India
B.Sc., Chemistry, Zoology, and Geology, University of Jodhpur, India

Dr. Sunil Mehta has more than 18 years of experience related to groundwater flow and transport modeling, reactive transport modeling, total system performance assessment, uncertainty analysis, geophysical logging, and well testing. He has worked on projects involving geologic isolation of radioactive wastes, environmental restoration activities, and water resources exploration and evaluation. Dr. Mehta has over 10 years of experience in designing, developing, and applying probabilistic tools to assess the long-term performance of radioactive waste storage and disposal facilities. He has performed reactive transport modeling and groundwater flow modeling to study behavior of contaminants such as uranium and hexavalent chromium in periodically rewetted zones influenced by aquifer-river interactions.

Checker:

Wei Zhou, INTERA, Inc.
Senior Nuclear Engineer

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

Wei Zhou has 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 (CO2). She has provided technical support in these areas to industrial, governmental, and international organizations such as the Electric Power Research Institute (EPRI), International Atomic Energy Agency (IAEA), Nuclear Energy Institute (NEI), Korean Hydro and Nuclear Power, Canadian Petroleum Technology Research Institute, U.S. Environmental Protection Agency (EPA), U.S. Department of Energy (DOE), Swedish Nuclear Inspectorate (SSM), Japan Atomic Energy Agency (JAEA), Taiwan Institute of Nuclear Energy Research (INER), International Energy Agency (IEA), Nuclear Energy Agency (NEA), and the Commission for European Communities (CEC). 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, TOUGHREACT, STOMP, ECLIPSE suite codes, MATLAB, and GoldSim. Her expertise also includes developing customized software using FORTRAN and C++.

Subject Matter Expert/Senior Reviewer:

Matthew Kozak, INTERA, Inc.
Principal Engineer; Ph.D.

Ph.D., 1988, Chemical Engineering, University of Washington
B.S., 1981, Chemical Engineering, Cleveland State University

Matthew “Matt” Kozak is a principal engineer with experience in the areas of safety assessment of both 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 recognized nationally and internationally for his expertise in conducting safety assessments of waste disposal facilities and contaminated sites and 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 International Atomic Energy Agency’s (IAEA) Coordinated Research Program on Improvement of Safety Assessment Methodologies (ISAM) and its successor programs: Application of Safety Assessment Methodologies (ASAM), Practical Illustration and Use of the Safety Case Concept in the

Management of Near-Surface Disposal (PRISM), and most recently Modelling and Data for Radiological Impact Assessments (MODARIA). In the U.S., Dr. Kozak has led projects to support agencies and organizations such as the U.S. Environmental Protection Agency (EPA), Electric Power Research Institute (EPRI), the U.S. Department of Energy (DOE), and the Nuclear Regulatory Commission (NRC) on a wide variety of radioactive waste disposal and contamination issues involving low- and high-level wastes. He has also provided technical input on the establishment of regulations for radioactive wastes, and for residual contamination produced as a result of decommissioning activities. Dr. Kozak is the former chair of Scientific Committee 87-3 for the National Council on Radiation Protection (NCRP) on safety assessment of radioactive waste disposal facilities, and a past member of NCRP Umbrella Scientific Committee 87 on Radioactive and Mixed Waste. Dr. Kozak was a member of the National Research Council Committee on Cesium Processing Alternatives for High-Level Waste at the Savannah River Site. He was also on the IAEA's International Peer Review Team for the Australian National Repository for low and intermediate level waste at Woomera, South Australia.

Responsible WRPS Technical Project Lead:

Robert A. Hiergesell, WRPS
Technical Lead WMA A-AX Performance Assessment

M.Sci., Hydrogeology from Univ. of Nebraska-Lincoln.
B.Sci., Geology at Virginia Polytechnic Institute, Blacksburg, Va.

Mr. Hiergesell has over thirty years of experience in the areas of groundwater monitoring, subsurface flow and transport simulation, environmental remediation and performance assessment for low-level radioactive waste disposal. Prior to joining WRPS, he was employed at the DOE Savannah River National Laboratory where he was the lead technical investigator for numerous environmental restoration and waste management projects.

Robert A. Hiergesell

Robert A. Hiergesell

11/5/2019

Date